Aviation Rulemaking Advisory Committee

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Fuel Tank Harmonization Working Group

Final Report

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Submitted jointly by

AIA, AECMA, ATA, ALPA, IATA, FAA, JAA, GAMA, API

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Industries
Association

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of Aerospace Industries
AECMA

alpa

Air Transport Association of America

Joint
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Institute

IATA

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FUEL TANK HARMONIZATION WORKING GROUP
FINAL REPORT

Executive Summary

The overall goal of the aviation industry and the regulatory agencies is to enhance aircraft safety in an effective and practical manner. The Fuel Tank Harmonization Working Group has spent the last six months aggressively pursuing means to improve airplane safety by reducing flammability in fuel tanks. The group investigated the history of the commercial fleet to understand the significance of each event involving fuel tank flammability, and to look for underlying causes that would assist our investigation. Thermal analyses of a wide range of airplanes operating in worldwide environmental conditions were used to correlate the historical record with the flammability exposure of fuel tanks, and to evaluate potential solutions.

The industry and the FAA have already taken actions to:

- Identify and correct equipment and installations that have the potential to be an ignition source in a fuel tank through service bulletins and Airworthiness Directives,
- Develop and execute inspection programs to assess the conditions of the fuel systems in the fleet and to develop maintenance programs based on those inspection results,
- Initiate work on a Special Federal Aviation Regulation (SFAR) to review system design and certification, and maintenance practices, with the goal of reducing the probability of ignition sources occurring in fuel tanks,
- Establish the Fuel Tank Harmonization Working Group (FTHWG) to investigate means to reduce or eliminate explosive mixtures in fuel tanks.

This comprehensive effort is attempting to address both ignition sources in the fuel system and exposure to flammable fuel-air mixtures.

The FTHWG studies showed that flammability exposure varies among airplane types and depends on fuel tank location. Some fuel tanks (e.g., wing tanks and some center tanks) already have a low exposure to flammable conditions. Reducing flammability in all fuel tanks to the level of the wing tanks on most airplanes, was seen as a worthwhile goal. A variety of possible means to achieve this goal were evaluated for technical and economic merits.

The following conclusions were reached:

- Techniques to reduce or eliminate heat input to the tanks from nearby heat sources were evaluated. Of these techniques, directed ventilation and relocation of the significant heat sources reduce the exposure to an acceptable level. However, relocation is only feasible for new airplane designs. Directed ventilation for in service aircraft is estimated to have an overall cost for a ten-year period of $3.5 billion.

- To reach the goal by changing fuel properties, a minimum flash point specification of 140°F would be required. A change of this magnitude falls outside of the current experience base and may require engine re-design/re-qualification. The overall fuel manufacturing cost increase for a ten-year period is estimated at $15 billion in the USA and $60 billion for the rest of the world and could result in a significant shortfall of jet fuel.

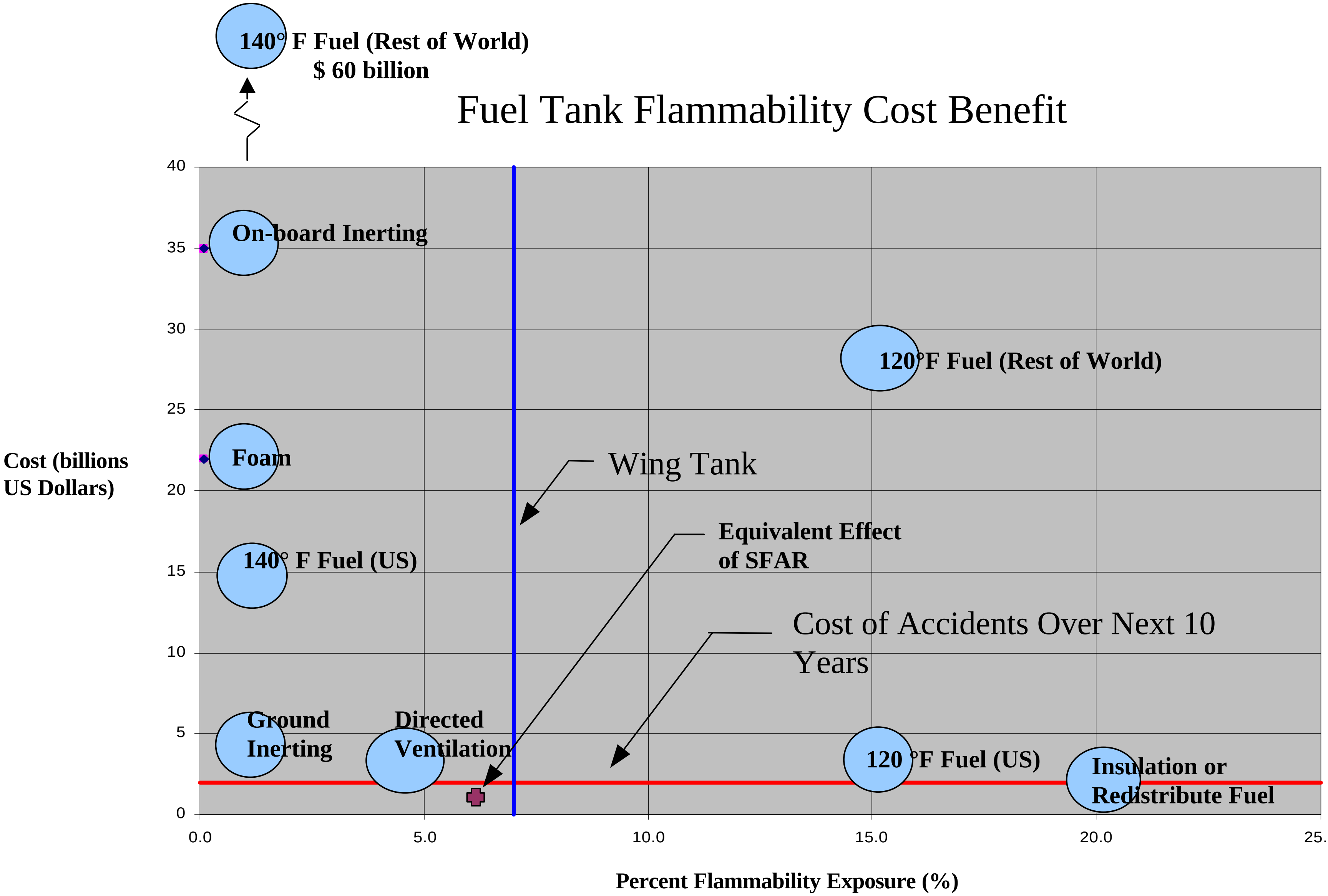
- Techniques such as on board fuel tank inerting or installation of foam in the tanks would also achieve the goal, but at a cost estimated to be at least $20 billion over the next ten years and would be very difficult to retrofit in current airplanes. Ground inerting, wherein specific tanks are made inert prior to flight, at specific airports, is an option that needs future study to determine; (a) the logistical costs of such a system and, (b) if retrofit installation of the distribution system internal to the airplane could be achieved in a cost effective manner.

- The Working Group considered several concepts that were determined to be insufficiently advanced technically at this time, for transport airplane fuel tank use. These included ullage sweeping and explosion suppression systems.

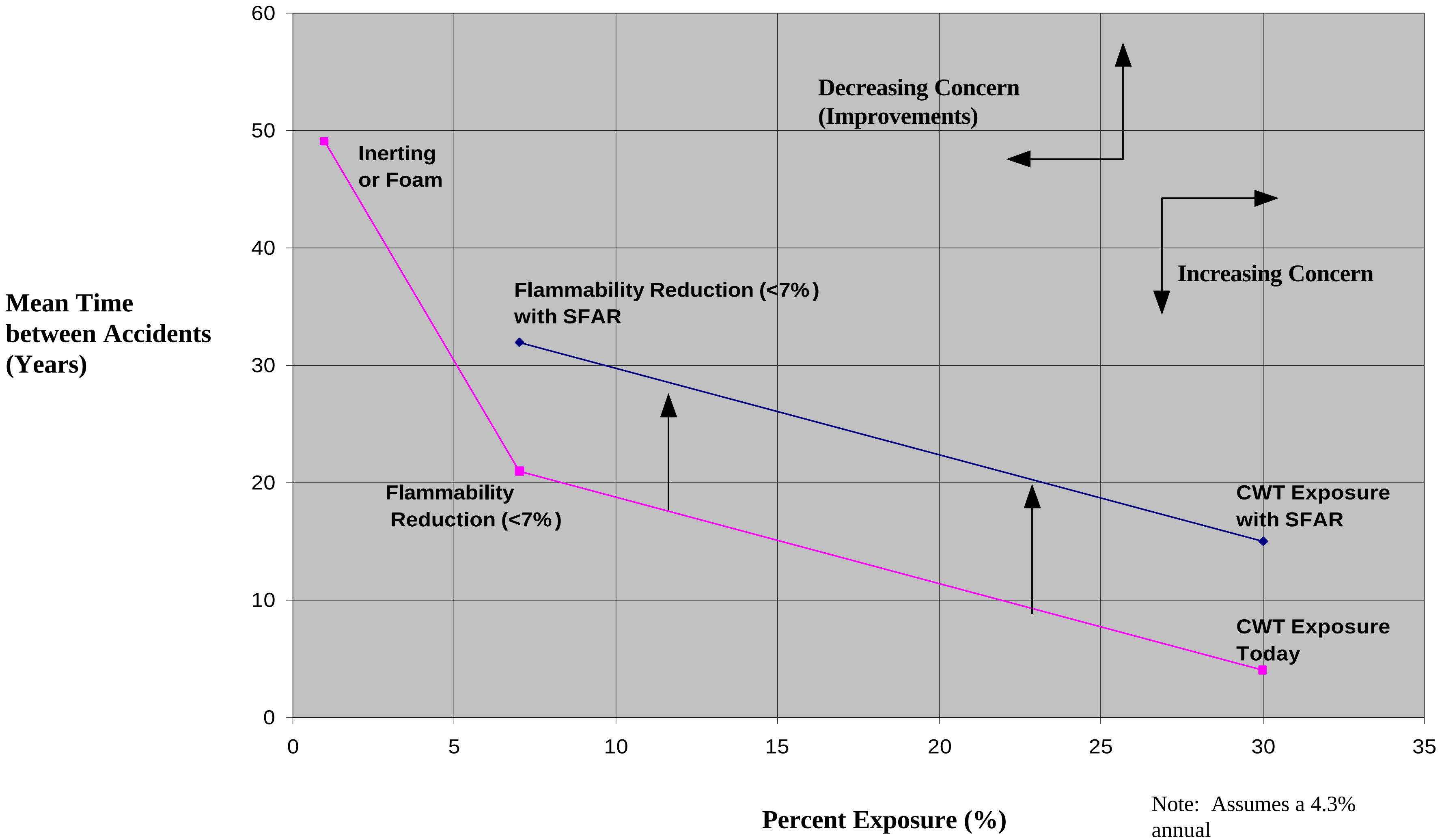
An initial estimate provided by the FAA for the cost of future events is $2 billion over the next ten years, if no changes are made in the fleet. The flammability reduction techniques studied by the group have an economic impact greater than this, and therefore careful consideration must be given to determine which avenue to pursue.

The first chart below depicts the relative costs and flammability exposure benefits of various options studied. The fuel tank inspections, the service bulletins for wiring improvements, and the anticipated SFAR for ignition sources (which the FAA is studying independently of this effort) should reduce the hazard from ignition to a level equivalent to a 6% flammability exposure. The estimated cost for the anticipated SFAR is between $1-2 billion. This is depicted on the chart as a cross to differentiate it from the options studied by the Working Group.

The second chart below depicts the impact on the fuel tank explosion accident frequency predicted for fuel system enhancements in flammability reduction and in ignition source mitigation.


140° F Fuel (Rest of World)
$ 60 billion
Fuel Tank Flammability Cost Benefit
Cost (billions US Dollars)
40
35
30
25
20
15
10
5
0
On-board Inerting
120°F Fuel (Rest of World)
Foam
Wing Tank
Equivalent Effect of SFAR
140° F Fuel (US)
Cost of Accidents Over Next 10 Years
Ground Inerting
Directed Ventilation
120 °F Fuel (US)
Insulation or Redistribute Fuel
0.0
5.0
10.0
15.0
20.0
25.0
Percent Flammability Exposure (%)

Effect of Fuel Tank Enhancements



Note: Assumes a 4.3% annual

The Working Group evaluated potential regulatory actions and concluded that the most effective action would be a revision of FAR 25.981 to address both ignition source prevention and flammable fuel-air mixture exposure in a single regulation, consolidating the major aspects of preventing tank explosions into one rule.

Recommendations

The ARAC Working Group recommends that the FAA/JAA pursue a cost effective approach to enhance fuel tank safety.

The following specific recommendations are made:

1. Adopt the proposed new regulatory action on new aircraft designs.

2. Continue to investigate means to achieve a cost-effective reduction in flammability exposure for the in-service fleet and newly manufactured aircraft.

3. Pursue the studies associated with directed ventilation and ground-based inerting systems to improve their cost effectiveness.

4. If a practical means of achieving a cost effective reduction in flammability exposure can be found for the in service fleet, either at the level specified in the rule or at some intermediate level (recommendations 2 and 3 above), consider application of that solution, in combination with other actions (e.g. SFAR).

5. If a practical means of achieving a cost effective reduction in flammability exposure can be found for newly manufactured aircraft, either at the level specified in the rule or at some intermediate level (recommendations 2 and 3 above), consider application of that solution, in combination with other actions (e.g. SFAR).

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CHAPTER 1 GENERAL CONSIDERATIONS AND PROPOSED RULE

1.1 Introduction

1.1.1 Background

On July 17, 1996 TWA Flight 800, a Boeing model 747-131, exploded in flight shortly after takeoff from Kennedy International Airport in New York. The accident investigation led by the National Transportation Safety Board (NTSB) has not, as of this date, determined the primary cause for the accident. Evidence gathered from the accident site indicates that the center wing tank exploded, but an ignition source has not been identified.

The NTSB sent four recommendations for regulatory changes to the Federal Aviation Administration (FAA) on December 13, 1996. The NTSB had recommended that the FAA require the development and implementation of design or operational changes intended to eliminate, significantly reduce or control explosive fuel-air mixtures in fuel tanks of transport category airplanes.

On April 3, 1997, the FAA issued a public notice soliciting comment on the feasibility of implementing the NTSB recommendations. To support this request, airplane manufacturers and airline operators initiated a comprehensive review of fuel system design and operational practices.

Their report, issued July 30, 1997, concluded that the overall level of safety and reliability of commercial airplane fuel systems was very high and any changes must be carefully studied so that additional risks are not introduced. Net safety benefits must be documented.

The industry further recommended that an international fuel tank group be established to develop aircraft inspection programs to verify the integrity of wiring and grounding straps, the condition of fuel pumps, fuel lines and fittings and the electrical bonding of all equipment, to verify the design and assure that no ignition sources could exist in fuel tanks.

Subsequent to this recommendation, airlines and airframe manufacturers initiated a joint program to examine the condition of aircraft fuel tank wiring and bonding. This program is called Aircraft Fuel System Safety Program (AFSSP) and the group plans to issue a final report by the year 2000. The FAA participates in the leadership of the AFSSP.

Late in 1997, the FAA announced the decision to develop a Special Federal Aviation Regulation (SFAR) with the purpose of reducing the risk of ignition sources in fuel tanks through design reviews and improved maintenance programs.

In December 1997, the FAA/JAA announced the decision to initiate the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group (FTHWG).

1.1.2 Scope

The historical approach to fuel system safety has been to control the risk of ignition sources. All current regulation and commercial aircraft design is based upon this philosophy. The ARAC FTHWG was tasked to recommend new rulemaking to eliminate or significantly reduce the risk of exposure to flammable fuel-air mixtures in fuel tanks.

1.1.3 Charter of the ARAC Fuel Tank Harmonization Working Group

The charter of the ARAC Fuel Tank Harmonization Working Group was:

1. To analyze:
   - The history of the world transport aircraft fleet
   - The safety status of the existing fleet
   - Various means of reducing exposure to flammable fuel vapors
   - Means to eliminate the resultant hazard if ignition does occur
2. To recommend regulatory text for new rulemaking aiming at controlling flammability of fuel vapors in fuel tanks.
3. To assess the cost benefit of those means.
4. To assess the effect of the new rule on other sections of the industry.
5. To follow the rules for ARAC harmonization working groups.
6. To issue a final report within six months after publication of the Terms of Reference (TOR).

1.1.4 Terms of Reference

The National Transportation Safety Board has concluded from the accident investigation that an explosive fuel-air mixture existed in the center wing tank of TWA Flight 800.

The FAA has identified 10 transport airplane hull loss events since 1959, which involved fuel tank explosions. The investigation of TWA Flight 800 and the number of fuel tank explosions which have occurred in service has led the FAA to question the adequacy of transport airplane certification requirements relative to fuel tank design, specifically with respect to environmental considerations and the adequacy of steps to minimize the hazard due to potential ignition sources, both in initial design and over the life of the airplanes.

The FAA further believes that one of the approaches to improve fuel tank explosion safety is the prevention or reduction of the occurrence of a flammable fuel-air mixture in the tanks through some means of inerting, cooling/insulation, modified fuel properties, installation of foam or fire suppression systems.

The task for the ARAC FTHWG was to prepare a report to the FAA/JAA that provides specific recommendations and proposed regulatory text, that will eliminate or significantly reduce the hazards associated with explosive vapors in transport category airplane fuel tanks. Proposed regulatory text should ensure that new type designs, in-production airplanes and the existing fleet of transport airplanes are designed and operated so that during normal operation the presence of an explosive fuel-air mixture in all fuel tanks is eliminated, significantly reduced or controlled to the extent that there could not be a catastrophic event.

The report should include the following:

1. An analysis of the threat of a fuel tank explosion due to internal and external tank ignition sources.

2. An analysis of various means of reducing or eliminating exposure to operation of transport airplane fuel tanks with explosive fuel-air mixtures or eliminating the resultant hazard if ignition does occur.

3. An analysis of the cost/benefit of modified fuel properties that reduce exposure to explosive vapors within fuel tanks. Factors that may enhance the benefits of modified fuels, such as cooling provisions incorporated to reduce fuel tank temperatures, should be considered and cost information for the various options should be developed.

4. Review comments to the April 3, 1997 Federal Register Notice such that validated cost benefit data of a certifiable system is provided for the various options.

5. Recommend objective regulatory actions that will eliminate, significantly reduce or control the hazards associated with explosive fuel-air mixtures in all transport airplane fuel tanks.

In addition to this task, the ARAC FTHWG should support the FAA/JAA in evaluation of application of the proposed regulation to the various types of transport airplanes and any impact on small businesses.

The activity was tasked for a 6-month time limit to complete the tasks.

1.2 Development of the ARAC FTHWG

A public notice was issued in the Federal Register by the FAA on January 23, 1998 surveying industry and regulatory agencies for potential members for this Working Group. Over 75 responses were received. Of those responses, over 45 Task Group members were selected to become part of the FTHWG.

Members were selected based on background, expertise, and affiliation with a variety of industry and regulatory groups. The FAA/JAA wanted to ensure that the regulatory recommendations were developed by a broad-based group of stakeholders who would be impacted by these changes. The FAA/JAA also wanted to access the wide-ranging expertise that industry brings to this subject. ARAC operating procedures were used throughout the process.

The 6-month timeframe specified by the FAA/JAA to complete this analysis was very aggressive and unprecedented. Members selected for the FTHWG had to be available on a nearly full-time basis for the 6-month period.

Due to the extensive amount of work currently taking place throughout industry in harmonizing FAA and JAA regulations, the FAA/JAA also tasked the FTHWG with ensuring that the regulatory recommendations developed were the product of a consensus of the FAA, JAA and industry members.

The FTHWG was co-chaired by representatives of Aerospace Industries Association (AIA) and The European Association of Aerospace Industries (AECMA) and made up of representatives from:

Air Transport Association (ATA)
Air Line Pilots Association (ALPA)
International Air Transport Association (IATA)
Federal Aviation Administration (FAA)
Joint Aviation Authorities (JAA)
General Aviation Manufacturers Association (GAMA)
American Petroleum Institute (API)

1.2.1 FTHWG Organization

The members selected to participate in this project were divided into seven Task Groups. Due to the short time frame of the project, several assignments had to take place concurrently. Each assignment was given to a Task Group, with the entire project being overseen by the nine-member FTHWG. An ‘Organization Chart’ of this arrangement is attached. Much care was taken to balance the Working Group membership so that it represented all aspects of industry and regulatory agencies. Care was also taken to balance each individual Task Group.

1.2.2 Charter and Deliverable of Each Task Group

Several tasks were undertaken simultaneously at the inception of the FTHWG. These tasks fell into five main categories:

1) A review of service history;
2) A thermal analysis to quantify the current fleet exposure to flammable fuel-air mixtures;
3) A detailed analysis of means to reduce exposure to flammable fuel-air mixtures (such as fuel property changes, fuel tank inerting, ullage sweeping, ullage washing, temperature control);
4) A detailed cost/benefit analysis of means to suppress explosions (such as foam);
5) A set of proposed regulatory material.

Task Group charters and objectives are summarized below.

Task Group 1: Service History/Fuel Tank Safety Level Assessment
Prepare a detailed analysis of previous tank explosion events. Carry out a flammability review of the current range of fuel system designs and tank configurations. Develop a safety analysis tool to evaluate the safety impacts of any proposed (design) changes.

Task Group 2: Explosion Suppression
Research the industry for existing technologies and systems specifically designed to actively monitor, detect, react to and suppress an explosion event before the event can produce catastrophic results.

Task Group 3: Fuel Tank Inerting
Provide a feasibility analysis of fuel tank inerting systems. Focus on reducing or eliminating exposure to explosive mixtures for transport airplane operations. Prepare a cost/benefit analysis.

Task Group 4: Foam
Provide a feasibility analysis of foam systems. Also included is an analysis of expanded metal products. Prepare a cost/benefit analysis.

Task Group 5: Fuel Vapor Reduction
Quantify the exposure of fuel tanks to flammable vapor. Analyze means to reduce that exposure. Prepare a cost/benefit analysis for each of the means.

Task Group 6/7: Fuel Properties and Its Effects on Aircraft and Infrastructure
Assess the feasibility of using jet fuel with a higher flash point in the transport airplane fleet as a means of reducing exposure of the fleet to explosive fuel-air mixture. Include an assessment of the impact of modified fuel properties on both the infrastructure and the aircraft and its operations. Include a cost/benefit analysis.

Task Group 8: Evaluation Standards and Proposed Regulatory Action Advisory Group
Provide a common set of definitions to the other Task Groups so there is consistency in the data used by all groups. Define a proposed regulatory action.

1.2.3 Time Schedule

A milestone schedule was developed at the first FTHWG meeting in February 1998. The FTHWG agreed to meet together for a two-day period each month. Task Groups were instructed to meet as often as necessary. The final report was due 23 July 1998.

1.3 Standards Applied

A common set of standards was necessary to achieve consistent results in performing cost benefit studies. To achieve this consistency, Task Group 8 was chartered to provide a common set of definitions to the other Task Groups.

1.3.1 Assumptions Made

A spreadsheet was developed to provide a common source of data to be used by the task groups in order to ensure that the potential methods were evaluated using consistent data and assumptions. Data were included in the spreadsheet for six generic airplane types: small, medium and large transports, regional turbofans, regional turboprops and business jets. The data included summaries for each airplane type, such as fleet size, weights, fuel volumes and flight distributions. Mission profile data such as weight, altitude, Mach number, fuel remaining in each tank and body angle as a function of time was included for each generic airplane type. Temperature profiles ranging from cold to extremely hot were also included in the mission profiles. Performance trades and cost trades were also included to allow the consistent calculation of performance and cost impacts. Details of the standards and assumptions can be found in the Task Group 8 report.

1.4 Service History/ Review of Past Accidents

The service history of the transport airplane fleet (including turbofan and turboprop airplanes) over the last forty years was examined, and information regarding known instances of fuel tank explosion (other than those caused by post-impact crash events) was assembled. The starting point was the table of events contained in the FAA Notice on Fuel Tank Ignition Prevention Measures published in the Federal Register on April 3, 1997. The data sources used were accident and incident reports provided by investigating organizations, regulatory authorities, and original equipment manufacturers' safety-related databases. The level of details reported in the early events was sometimes limited depending on the event location and the type of event (whether it involved an internal or external ignition source).

The attached service history report by Task Group 1 contains a detailed description of each event and the findings of the investigating authority, followed by a description of the mitigating actions taken subsequent to the event. The events have been separated into operational events and refueling and ground maintenance events. They are grouped by cause (lightning, engine separation, refueling, maintenance, etc.), and are then categorized by operational phase, ignition source, type of fuel tank involved, and fuel type. The mitigating actions taken after each event are summarized and any recurring events are identified.

From the analysis, certain patterns emerge:

- Of the 16 fuel tank events examined, 8 involved wing tanks, 8 involved center or fuselage tanks;
- There were 9 operational events and 7 refueling and ground maintenance events.
- There were only 2 explosions due to lightning strike, with 396 million flight hours accumulated since the last event in 1976;
- In the wing tank events, 5 out of 8 involved the use of wide-cut fuel (JP-4/Jet B);
- In the wing tank events, 5 out of 8 occurred in-flight;
- All the wing tank events involved external ignition sources - there were no known wing tank explosions due to internal ignition sources in the 40 years of commercial jet aviation history;
- All the center tank events involved the use of Jet A/Jet A-1 fuel;
- In the center tank events, 6 out of 8 occurred on the ground;

The data suggests that there is a difference in the respective safety levels between wing tanks and center tanks.

All the wing tank events have been due to known, external ignition sources (lightning strikes, over-wing fire, refueling, maintenance error). There were no known internal ignition sources in 520 million hours of commercial transport fleet operation that resulted in a tank explosion. Corrective actions to prevent recurrence of these wing tank events have been in place for many years, and have been demonstrated to be effective.

However, in the two most recent center tank events the ignition sources have not yet been identified. While corrective actions to identify and eliminate potential ignition sources are being put in place, the investigation of flammability reduction is warranted since the efficacy of these actions has yet to be proven.

Over the years, center tanks have accumulated considerably fewer operating hours than wing tanks (for example, a typical twin-engine transport has two wing tanks and one center tank, and therefore accumulates wing tank hours at twice the rate of center tank hours). Since the equipment in wing and center tanks is very similar, i.e. there are similar types and numbers of potential ignition sources, one might expect there to be significantly fewer center tank events than wing tank events. Actually, the numbers of events are equal. This suggests that these tanks have not yet reached the safety level attained by wing tanks, and that action to further reduce the flammability levels in center tanks should be considered.

It might be argued that the reason for this disparity is that components in the wing tanks are more often submerged than those in the center tanks, which empty prior to wing tanks. However, this may be an over-simplification. There are several pieces of electrical equipment inside wing tanks, which routinely operate in the vapor space. The disparity may be the result of the center wing tanks being significantly more flammable than wing tanks. Therefore, altering the flammability level in center tanks equivalent to wing tank levels appears to be a worthwhile target.

The absence of explosions in wing tanks due to lightning strike supports this view. Lightning strikes frequently occur. On average, every aircraft in the world fleet experiences one strike per year. Yet, the data shows that there are only two explosions due to lightning strike in a database spanning 40 years, with the last event occurring 22 years ago. However, both involved the use of wide-cut fuel (JP-4), which has a much higher volatility than kerosene fuel (Jet A/A-1) and whose flammability envelope coincides much more closely with the normal flight ranges of altitude and ambient temperature. The phasing-out of wide-cut fuel from commercial airline use means that for a large proportion of the flight envelope the wing tank ullage is non-flammable.

In the last 20 years (when Jet A/A-1 has been the predominant fuel), there have been five fuel tank explosion events involving center/fuselage tanks, and two wing tank events. The continuing incidence of center tank explosions (all of which involved Jet

A/A-1 fuel) indicates that these tanks have not yet reached the safety level attained by wing tanks, and that action to further reduce the flammability levels in center tanks should be considered.

This study identified and analyzed 16 known instances of fuel tank explosions (other than those following impact with the ground) over the past 40 years of transport aircraft operations worldwide. The following conclusions have been drawn:

- There is a close relationship between the incidence of explosions in wing tanks and the use of wide-cut fuel.
- Wing tanks operating with Jet A/A-1 fuel have demonstrated an acceptable safety record.
- Center tank and fuselage mounted tanks have also shown a low probability of explosions, but there is some evidence that they are more vulnerable to explosion in the presence of ignition sources.
- Apart from the two most recent events, which involved Center Wing Tank with thermal inputs to the tanks, (1990/Manila & 1996/New York), the causes of all the other events have been addressed by actions designed to prevent or minimize their recurrence.
- The Safety Level Performance of wing tanks has been identified as a target for the technologies applied to center wing tanks and their safety level performance.

1.5 Safety/Risk Assessment Methodology

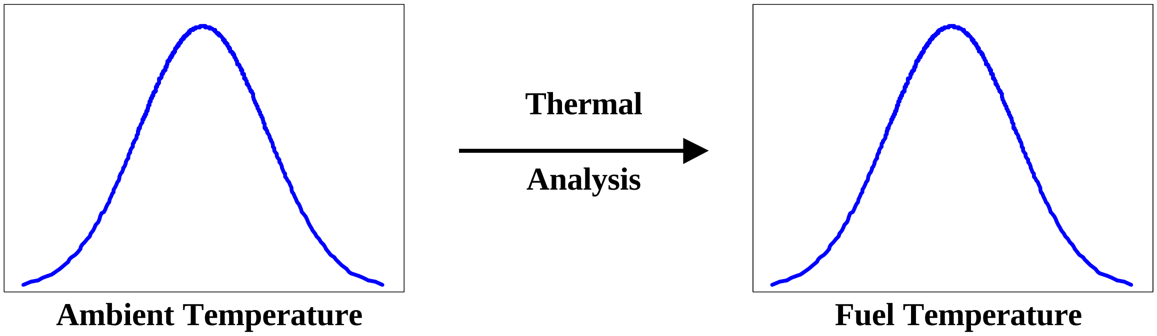
A safety/risk assessment methodology was developed to quantify the current fleet exposure of fuel tanks to flammable fuel vapors, and then to predict the reduction in exposure achievable by implementation of various methods. The additional risks that may be introduced as a result of implementation of a method must be taken into account in the net safety assessment. This methodology was used as the benefit half of the cost/benefit analysis.

1.5.1 Thermal Analysis

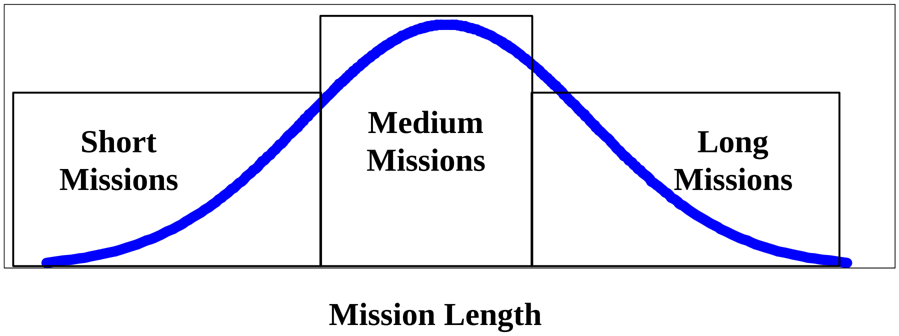
To define the current fleet of fuel tanks, the methodology was to study different fuel tank configurations on airplanes over a wide range of size. Tank configurations analyzed included several wing tanks and several center tanks, some with and some without adjacent heat sources. Representative airplanes from each of the generic size categories were chosen for the analysis (large, medium, and small transports, regional jets and business jets.)

To define the exposure to flammable fuel vapors, the methodology was to quantify the amount of time that the fuel temperature is above the flash point of the fuel over the mission profile. The analysis therefore has three main variables; fuel temperature, mission profile, and flash point.

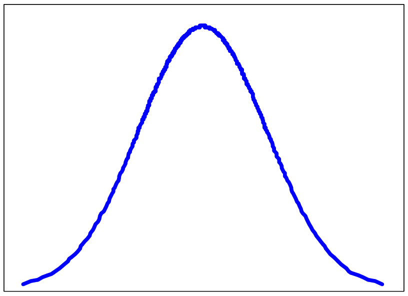
Fuel temperature – In order to quantify the fuel temperature for each fuel tank configuration, thermal analysis of the fuel tank was required, including the affects of adjacent heat sources. Because airplanes operate in a wide range of environments, thermal analysis over a wide range of ambient temperatures was required. Ground and in-flight atmospheric data was used to define the range of ambient temperatures and flight route/frequency data was used to define the probability of a flight encountering a particular ambient condition. From this distribution, representative ambient temperature profiles were chosen as the inputs to the thermal analysis to produce a range of fuel temperature profiles with a defined distribution.



Mission profile – Airplanes operate over a wide range of missions. For each airplane, flight range/frequency data was used to define the distribution of mission lengths. Three mission profiles were chosen to be representative of typical, short, medium and long flights.



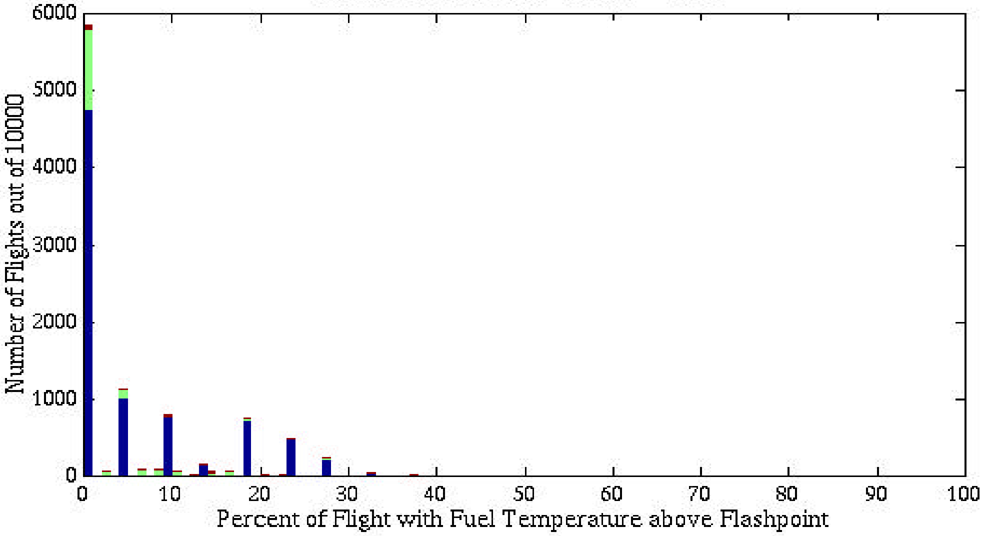
Flash point - To define the flash point of the fuel, the initial assumption was to use the specification limit of 100°F. However, as the objective was to define the exposure of the current fleet of airplanes as they actually operate, it was decided to increase the accuracy of the analysis by using the flash point of the fuel that is loaded onto the airplane. Task Group 6/7 collected data on the current distribution of flash points delivered worldwide and assigned probabilities of a specific mission being fuelled with a fuel at a specific flash point.



Fuel Flash Point

1.5.2 Exposure Analysis

To quantify the fleet exposure, a statistical analysis approach was applied to a statistically significant number (10,000) of randomly selected flights. The flights were then selected to be representative of the fleet using the defined distributions of the three variables. For example, flight one may be a short mission on a cold day with an average flash point fuel, and flight two may be a long mission on an average day with a low flash point fuel, and on and on until 10,000 flights have been defined in this manner. For every one of the 10,000 flights, the time that the fuel temperature was above the flash points was calculated. The results of the exposure analysis are best displayed in the form of a histogram like the example shown below.



Averaging the results for all 10,000 flights provides an average percentage of the flight time that any particular flight could be expected to be exposed to a fuel temperature above the fuel flash point. These fleet average exposure results are given for each airplane size and tank configuration in the table below.

Exposure Analysis Results

Wing Tanks				Center Tanks			
WITHOUT adjacent heat sources				WITHOUT adjacent heat sources		WITH adjacent heat sources	
large	small	regional turbofan	bizjet	small	regional turbofan	large	small
5%				5%		**30%**	

Once the current fleet exposures to fuel tanks with flammable vapors are calculated, the same method of thermal analysis / exposure analysis is used to systematically study methods to reduce the exposure in fuel tanks.

More information on the exposure analysis and thermal analysis can be found in the Task Group 5 report in sections 5.0 and 15.0. Results of the exposure analysis for each of the considered methods can be found in section 2.5 of this report, with more information in the Task Group 5 report.

1.5.3 Safety/Risk Assessment Methodology Conclusions

This safety/risk assessment methodology was developed to quantify the current fleet exposure of fuel tanks to flammable fuel vapors. Quantifying the exposure is a very complex task, so simplifying assumptions had to be made to complete the analysis in the tight time frame available, such as the use of generic airplane fuel tank configurations and typical flight profiles. To ensure confidence in the process, an independent third party audit was conducted by members of the API. The auditors agreed with the process as a valid method to quantify exposures. As discussed in the proposed advisory circular (Task Group 8 report), a simpler method of exposure analysis is currently under development.

1.6 Proposed Rule

The proposed rule was created to serve two purposes, firstly to provide a constant standard for the various task groups to use to develop solutions and to develop internally consistent comparisons, and secondly to provide the draft of a proposed rule to the FAA/JAA if the cost benefit analyses showed such a rule to be of overall benefit.

1.6.1 Methodology

The intent of the proposed rule is to achieve a level of safety that would reduce the probability of another fuel tank explosion event to a low enough level that one would not be expected to occur in the life of a given airplane type. The proposed rule was developed using the history of the fleet from Task Group 1 in conjunction with the analysis of Task Group 5 of the current flammability levels in the fleet today.

This approach was thus to look at the history for factors in explosion events, and then to look at the flammability modeling to see if there were matching factors. The other driver in looking at the proposed rule was to recognize that ignition prevention has been, and will continue to be, the primary protection technique for fuel system explosion prevention.

The group recognized that the FAA was pursuing a plan to address ignition source control through the SFAR process, and that the current rules, while being adequate at a high level, may not be specific enough at a detail level. To address all of these factors the group concluded that the proposed rule should address explosion prevention in one rule, with ignition source control being the first element and flammability control being the second.

The study concluded that fuel tank explosions were the result of unique circumstances at a single point in time, rather than circumstances that generate a continuous or intermittent ignition condition. The reasoning for this conclusion is that the flammability exposure of certain tanks was high (30% of fleet operating time) and therefore if circumstances created long duration ignition conditions, we would expect a far higher number of events than the fleet history shows. Based on this, it was concluded that the presence of an ignition source in any one tank was a very unlikely random event and the recommended way to further reduce the probability of an explosion is to limit the time during which the tank is in a flammable condition. It was concluded that total elimination of flammability is not required in as much as wing tanks operating with relatively low levels of flammability exposure have an excellent safety record.

In addressing the flammability section of the proposed rule, the group considered that total elimination of flammability was not required in as much as wing tanks operating with relatively low levels of flammability exposure have an excellent safety record. With this in mind, the group examined the flammability exposure of various tanks on a wide range of airplane types to determine how to define flammability exposure and how to select a suitable target to use in the rule. The Working Group determined from examination of various airplanes types that the exposure of wing tanks, without additional heat input from sources nearby, was below 6% of fleet operating time, while tanks exposed to heat input were flammable for up to 30% of the fleet operating time. The fleet history suggested that wing tanks with low flammability exposure had an excellent record, and thus a flammability limit that matched the wing tanks of most airplanes was selected for use in the proposed rule.

As noted above, the proposed rule was used to define a set of requirements to size and cost the various systems to satisfy the requirements. The cost benefit analysis provides the data to assess the reasonableness of adopting this rule versus focusing on ignition prevention as the means to reduce events to an acceptable level.

1.6.2 Proposed Rule

In order to enhance fuel system safety, the group recommends to the FAA/JAA the following action:

Create a revised paragraph FAR 25.981 to address fuel tank protection from airplane created threats that could prevent continued safe flight and landing. The proposed revision is as follows:

Section 25.981 Fuel Tank Ignition Prevention

The fuel system must be designed and arranged to prevent the ignition of fuel vapor within the tanks, or mitigate the effects of such an ignition by addressing:

(a) Ignition Sources

(a)1. *Place the current 25.981 requirement here*

(a)2. *Additional requirements in ignition source mitigation as defined by the FAA would be in section (a)2, (a)3, etc. as defined by the SFAR effort underway*

(b) Flammable Vapors

Limiting the development of flammable conditions in the fuel tanks, based on the intended fuel types, to less than 7% of the expected fleet operational time, or

Providing means to mitigate the effects of an ignition of fuel vapors within the fuel tanks such that any damage caused by an ignition will not prevent continued safe flight and landing.

1.6.3 Discussion on the Intent of the Proposed Requirement

The proposed regulatory action provides a single regulation to address ignition prevention, thereby avoiding having several paragraphs which must be linked and interpreted in conjunction with each other. It provides the industry with a requirement that addresses all aspects of fuel tank ignition prevention/mitigation, which can be treated as a comprehensive requirement and addressed as one issue. The existing requirements set forth in sections 25.901, 25.954 and 25.981 are intended to preclude ignition sources from being present in airplane fuel tanks. As proposed, Paragraph (a) maintains these requirements, which have been, are, and should continue to be, the essential primary elements in fuel tank safety. Paragraph (b) provides a requirement to address flammability mitigation as a new layer of protection to the fuel system. The intent of the combined regulation is to prevent an applicant relying solely on ignition prevention or on flammability reduction as the means to protect the fuel system from ignition events.

1.6.4 Proposed Advisory Material

A proposed AC/ACJ 25.981 (b) is included in the Task Group 8 Report. This ACJ sets forth an acceptable method of compliance with the requirements of FAR/JAR 25.981(b). The guidance provided within this AC is harmonized with the FAA and JAA and is intended to provide a method of compliance that has been found acceptable.

CHAPTER 2 POSSIBLE COMPLIANCE METHODS

2.1 Introduction

This chapter summarises the findings of the Task Groups that investigated possible means to comply with the proposed rule.

Where possible, cost to the industry of each means is given.

Detailed reports of each Task Group's work are attached to this report.

2.2 Explosion Suppression

Task Group 2 has performed a search for reference material and documents concerning systems that have been specifically designed to suppress or extinguish an explosion within a fuel tank. This search quickly revealed that a great amount of research had been accomplished in this arena concerning military operations and the need to protect combat aircraft from external threats where fuel ignition could result.

From actual live-firing tests and system performance bench tests, a number of systems have demonstrated positive results in providing fuel tank and dry bay protection from fuel vapor explosions. The applicable technologies center around four separate methods of dispersing the suppressant:

✦ Inert Gas Generators
✦ Gas Generator driven Agent Dispersal
✦ Explosive Expulsion of Low Pressure Agent
✦ Explosive Release of High Pressure Agent

Four companies were contacted, and provided information pertinent to the above suppression methods.

From the review of the data presented by these companies, it is evident that the technology exists and is effective in suppressing the pressure effects of an explosion before those effects can become hazardous to the tank enclosure / structure. However, this technology is not yet fully mature and a significant amount of development is still required to understand to the specific requirements of fuel tank wet-bay protection.

No cost information is provided in this report due to the lack of maturity for fuel tank application.

2.3 Reticulating Foam and Expanded Metal Products

This report provides information on two types of materials available for installation inside aircraft fuel tanks to reduce the risks of aircraft hull losses in case of explosions:

- Reticulated polyether foam.

  This type of material has been used effectively on US military aircraft such as P-3 and C-130.

- Expanded metal products.

  This type of material is not widely used on transport aircraft.

Both have more than one application, and both will require FAA/JAA certification. Some will require extensive qualification tests. When installed inside fuel tanks both materials create their own disadvantages such as weight increase, fuel volume loss, increased pack bay temperatures, structural integrity degradation, Foreign Object Debris (FOD) and maintenance difficulties. Costs associated with using one alternative of each product have been estimated for generic center tanks, with adjacent heat sources. These estimates include total cost, i.e., designs, installations, and operations.

It is estimated that over a ten-year period it would cost the industry over 22 billion dollars to use expanded metal products and over 25 billion dollars to use foam.

The following two tables show the cost breakdowns in $US for the two classes of aircraft. Cost estimate totals are:

Per Aircraft Cost, In service aircraft, (Center Wing Tank only)

Aircraft Size	Foam Nonrecurring	Foam Annual	Exp Metal Nonrecurring	Exp Metal Annual
Large	$390,740	$1,584,121	$848,273	$1,329,017
Medium	$187,427	$653,497	$366,057	$538,951
Small	$64,161	$120,448	$112,605	$88,992

Per Aircraft Cost, Production Aircraft (Center Wing Tank only)

Aircraft Size	Foam Nonrecurring	Foam Annual	Exp Metal Nonrecurring	Exp Metal Annual
Large	$353,884	$1,584,121	$811,416	$1,329,017
Medium	$166,334	$653,497	$344,964	$538,951
Small	$54,636	$120,448	$103,081	$88,992

The findings from this Task Group have shown that foam or expanded metal products can be used effectively to prevent structural failure of fuel tanks as a result of an internal explosion. However, when installed, foam or expanded metal products will reduce aircraft payload and available fuel volume. These reductions are the two most important factors that could result in severe economic impact for operators along with possible health and safety risks, requiring fire prevention, storage and handling of these products in hangars.

2.4 Inerting

The Inerting Task Group studied the technologies offered by the respondents to the FAA's Request for Information. Several technologies for providing inert gas were reviewed including carbon dioxide in gaseous form and as dry ice, nitrogen in gaseous and liquid form, and exhaust gas.

The group analyzed the impacts of carrying an on-board inerting system versus a ground-based system. In addition, the group studied the cost and benefit of inerting the center wing tank only versus inerting all of the aircraft's fuel tanks. Finally, two methods of purging oxygen from the tank were reviewed i.e. "scrubbing" the fuel and "washing" the ullage space above the fuel.

A ground-based system that reduces flammability exposure below the 7% target provides the potential for the least costly (non-recurring cost) inerting system on the aircraft. However, it requires a substantial investment in ground equipment to supply inerting gas, plus the recurring costs of the inerting gas and operation of the equipment. Ground-based ullage washing is effective when considered in combination with the normal changes to fuel temperature during a flight. On average, the exposure to a flammable, non-inert ullage is approximately 1%.

Scrubbing fuel at the airport fuel farm, or on the aircraft during refueling, is the least effective form of tank inerting. The ullage is not inert during taxi, takeoff, and initial climb until inert gas evolves from the fuel. As fuel is consumed from a fuel tank, ambient air flows in to replace it and raises the oxygen concentration. The tank may only be inert for the latter portion of climb and the beginning of cruise. This is highly dependent on the initial fuel load. Clearly, this method provides little added protection to today's design. In addition, this method would provide no added protection for near empty fuel tanks.

On-board systems could provide inert gas throughout the flight and offer zero exposure to a flammable, non-inert ullage. There are several existing methods for providing nitrogen on board an aircraft. It can be stored as a gas in bottles or as a liquid in Dewar bottles, such as on the C-5. Either of these would require replenishment at an airport, which adds to the cost of the airport infrastructure.

An alternative to storing gases or liquids, On-board Inert Gas Generating Systems (OBIGGS) separate nitrogen from engine bleed air. Such systems exist on military aircraft today, notably the C-17 as well as some fighters and helicopters. All of these systems extract a performance penalty from the aircraft. A new aircraft design offers the best opportunity to minimize these penalties. Current production aircraft and the retrofit fleet may incur redesign and operational penalties that make them uneconomical to fly. Operational compromises will almost certainly be required. None of the airplanes analyzed have enough engine bleed air available to supply these systems.

Whichever type of inerting might be used, there are potential hazards to personnel. Gaseous inerting agents present a suffocation hazard and liquid nitrogen presents the additional hazard of freezing trauma to skin and eyes.

Several other on-board systems were reviewed. Exhaust gas from the jet's engines and auxiliary power unit (APU) was deemed infeasible primarily because the exhaust contains too much oxygen. Carbon dioxide in gaseous and solid (dry ice) form was also deemed infeasible. Except for nitrogen systems, none of the systems were mature enough to be considered for installation on commercial aircraft. Nitrogen is the best candidate at this time.

The following table provides a summary of the cost and benefit of each system.

Technology	**Exposure**	**Cost over 10 Years (US Dollars)**
On-board Liquid Nitrogen for All Tanks	< 1%	$35.7B
On-board Gaseous Nitrogen for All Tanks	< 1%	$33.9B
Air Separator Modules for All Tanks	< 1%	$37.3B
Air Separator Modules for the Center Tank	< 1%	$32.6B
Ground-based Ullage Washing with natural Fuel Cooling for Center Tank	1%	$4B with gaseous nitrogen $3B with liquid nitrogen

At this time, nitrogen appears to be the best inerting agent and there are several means of providing it to the aircraft. Ground-based ullage washing in combination with the drop in temperature within the tank reduces exposure to a flammable, non-inerted tank to approximately 1%. This is the most cost effective solution studied, with the cost over a 10 year period estimated at approximately $3 billion.

Present day aircraft do not have enough available engine bleed air, in most cases, to supply an OBIGGS type system. However, OBIGGS systems could be designed into future aircraft.

If a full-time inerting system were required for current production aircraft or retrofit airplanes then liquid or gaseous nitrogen storage could be placed on-board the airplanes. These systems tend to be a little heavier than OBIGGS and require additional airport infrastructure to support them. The overall cost for a 10 year period is similar to OBIGGS.

2.5 Fuel Vapor Reduction

Task Group 5 analyzed the exposure of fuel tanks to flammable vapor and evaluated methods to mitigate the exposure, considering the related impacts: safety, certification, environment, airplane design, operations and cost. Analysis has also been performed to assess the effects of ground inerting and changing the fuel flashpoint in mitigating the exposure to flammable vapors (see reports from Task Group 6/7 and Task Group 3 for the impacts of these modifications). This analysis has been completed for generic airplanes and therefore does not relate to any specific airplane design.

Thermal analysis has shown that all generic fuel tank designs have some exposure to flammable fuel vapor.

- Tanks without adjacent heat sources, independent of location, (wing or fuselage), have equivalent exposure of approximately 5%.
- Tanks with adjacent heat sources have exposure of approximately 30%.

Other factors affecting exposure are:

- Ambient temperature (of which control is not possible)
- Fuel loading (which is discussed further, see option 3)
- Altitude (which is not discussed within this report)

Thirteen methods of mitigating the effects of heat sources adjacent to fuel tanks have been analyzed. Only one eliminates exposure to fuel vapors. This is achieved by disabling the fuel tank and thus has severe operational consequences that can only be evaluated for individual airlines operations, and thus no conclusion is provided within this report.

Five options considered reduce the exposure to flammable fuel vapor, and have been evaluated for the small, medium and large transport airplanes:

1. Insulate the heat source adjacent to fuel tanks
2. Ventilate the space between fuel tanks and adjacent heat sources
3. Redistribute mission fuel into fuel tanks adjacent to heat sources
4. Locate significant heat sources away from fuel tanks.
5. Sweep the ullage of empty fuel tanks.

Options 2 and 4 have been shown to reduce the exposure of fuel tanks with adjacent heat sources to a level similar to fuel tanks without adjacent heat sources. (Option 4 is only applicable to new airplane designs).

Option 5 requires significant further research before a conclusion on its feasibility can be reached.

Table 2.5.1 summarizes the effects and impact of the five options.

Table 2.5.1 Summary of impacts and applicability of the five methods evaluated

Centre Wing Tanks <u>With</u> Adjacent Heat Sources Exposure to Flammable Vapours **30%**					
Fuel Tanks <u>Without</u> Adjacent Heat Sources Exposure to Flammable Vapors **5 %**					
OPTION **IMPACT**	1. Insulate Heat Sources	2. Ventilate (Directed)	3. Redistribute (Fuel)	4. Locate Heat Sources	5. Sweep Ullage
Estimated Exposure to Flammable Vapors after Modification	**20%**	**5%**	**20%**	**5%**	Not quantified
New safety Concerns	minor	none	medium	none	medium
Certification Impact	minor	minor	minor	none	major
Environmental Impact	none	none	none	none	yes
Airplane Impact	minor	medium	minor	major	medium
Operational Impact	minor	minor	major	minor	major
One Time Fleet Costs ($ Million) Small	160	500	4	160	2,000
Medium	50	60	2	50	650
Large	100	300	3	100	1,200
Annual Fleet Costs ($ Million) Small	10	170	7	?	370
Medium	2	20	3	?	80
Large	2	70	14	?	180
10 Year Fleet Costs ($ Million)	**450**	**3,500**	**250**	**?**	**10,000**
Applicability	most	most	most	new designs	most

In addition, the effects of ground inerting and changing the fuel flashpoint were assessed. Either method could reduce the exposure of fuel tanks with adjacent heat sources to a level similar to fuel tanks without adjacent heat sources.

Table 2.5.2 summarizes the effects on exposure of ground inerting, changing the flashpoint, and some potential combinations of modifications. This is not an inclusive list of all feasible combinations due to the time constraints involved in this project.

Table 2.5.2 Summary of the effects of changing the fuel flashpoint, ground inerting and combinations of different modifications.

Modification	**Wing Tanks Without heat sources**	**Center Tanks without heat sources**	**Center Tanks with heat sources**
Current Airplanes	5%	5%	30%
120°F Flashpoint Fuel	**< 1%**	**< 1%**	**10 to 20%**
130°F Flashpoint Fuel	**< 1%**	**< 1%**	**5 to 10%**
140°F Flashpoint Fuel	**< 1%**	**< 1%**	**1 to 5%**
150°F Flashpoint Fuel	**< 1%**	**< 1%**	**1%**
Ground Based Inerting of Fuel Tanks	Not applicable	< 1%	1%
Combinations of Modifications			
Ventilate (Directed) and 120°F Flashpoint Fuel	Not applicable	Not applicable	< 1%
Insulate and 120°F Flashpoint Fuel	Not applicable	Not applicable	5%
Insulate and 130°F Flashpoint Fuel	Not applicable	Not applicable	1%

2.6 Modified Fuel Properties

The purpose of this Task Group report is to evaluate the availability, cost, and risk associated with changing to a high flash point specification jet fuel for commercial aviation.

The Fuels Properties Task Group was charged with assessing the feasibility of using jet fuel with a higher flash point specification in the civil transport airplane fleet than required by current Jet A/Jet A-1 specification, as a means of reducing the exposure of the fleet to flammable/explosive tank vapors.

Raising the minimum flash point specification of jet fuel will result in a combination of changes to other fuel properties, such as viscosity. The magnitude of change is dependent on the magnitude of flash point increase. The engine and APU manufacturers have no experience base for such a modified specification, and are concerned about the risk and potential adverse impact on altitude relight and low temperature operations (especially Extended Twin Operations, ETOPS). Mitigating actions, including hardware modifications, fuel specification revisions, use of additives and revised operational limits, have also been reviewed. Laboratory, rig and/or full-scale engine testing on reference fuels may be required to quantify the impacts depending on the magnitude of change.

Raising the minimum flash point specification could also significantly raise the manufacturing cost and decrease the availability of the modified jet fuel. The reduced availability could have a significant impact on jet fuel price. Again, the higher the flash point, the more severe the effect.

The fuel impacts are most severe outside of the U.S. due to the differences in overseas refinery configurations and product demand. Some countries indicated that a change in flash point specification is not an option to which they would subscribe (Canada, New Zealand, Australia, Japan, United Kingdom, Russia and the Commonwealth of Independent States).

Conclusions of the group are:

An increase in the jet fuel flash point specification will result in shifts of fuel properties. At some increase in the flash point specification, a high flash Jet-A becomes a new fuel, never before used, with properties unlike any other fuel. The predicted fuel specification changes will result in a combination of fuel properties that can fall outside the current experience. The magnitude of property change and potential introduction of new molecules increases with increasing flash point.

Higher flash points could result in significant shortfalls of jet fuel availability and could require at least five years for industry to endeavor to meet jet fuel demand.

Estimated Refinery Shortfall For First 2 Years

Flash Point	**In US**	**Outside US**
120° F	5%	12%
150° F	20%	49%

The API survey results address jet fuel demand at 1998 levels. The survey does not address long-term changes in jet fuel demand, which is projected to grow by 6-15% more than other refined products by 2010. Environmentally driven reformulation of other fuels, (e.g., toward “light” diesel) will further increase demand for the jet fuel portion of the barrel. These pressures are likely to amplify the difficulties predicted for the 1998 level.

Requirements for higher flash point jet fuels could result in United States refinery production cost increasing 1.5-2.2 cents per gallon at 120 degrees and 6-7.5 cents per gallon at 150 degrees (assuming 7% ROI). Based on current U.S. jet demand, this translates into annual costs of $350-520 million at 120 degrees and $1.4-1.7 billion at 150 degrees. Outside the United States, requirements for higher flash point jet fuel will result in refinery production cost increasing 3-15 cents per gallon at 120 degrees and more than 20 cents per gallon at 150 degrees.

Cost Increase

Flash Point	Inside US	Outside US
120° F	1.5 – 2.2 Cents/gallon ($350-520M Annually)	3-15 Cents/gallon
150° F	6 – 7.5 Cents/gallon ($1.4 – 1.7B Annually)	>20 Cents/gallon

The potential for increased production cost and decreased capacity could dramatically impact the market price of jet fuel. Models have been used to calculate the increases in price that could occur for various combinations of capacity reductions and price elasticity. No substitutions for jet fuel were assumed to be available. Based on a price elasticity of 0.2, the annual cost is $4 to $13B.

CHAPTER 3 CONCLUSIONS AND RECOMMENDATIONS

3.1 Overall Conclusions

The study concluded that each fuel tank explosion analyzed was the result of unique circumstances at a single point in time, rather than circumstances that generate a continuous or intermittent ignition condition. The reasoning for this conclusion is that the flammability exposure of certain tanks was high (30% of fleet operating time) and therefore if circumstances created long duration ignition conditions, we would expect a far higher number of events than the fleet history shows. Based on this, it was concluded that the presence of an ignition source in any one tank was a very unlikely random event and the recommended way to further reduce the probability of an explosion is to limit the time during which the tank is in a flammable condition. It was concluded that total elimination of flammability is not required in as much as wing tanks operating with relatively low levels of flammability exposure have an excellent safety record.

A maximum flammability exposure of 7% of expected fleet operational time was selected for use in the proposed rule. This exposure approximates that of wing tanks on most airplanes.

The proposed regulatory action provides the industry with a requirement that addresses all aspects of fuel tank explosion prevention/mitigation, which can be treated as a comprehensive requirement and addressed as one issue. The intent of the combined regulation is to ensure an applicant addresses both ignition prevention and flammability reduction to protect the fuel system.

A range of possible means to achieve this goal was evaluated for technical and economic merits. The following conclusions were reached:

- Explosion suppression technology is not yet fully mature. A significant amount of development is still required to refine the details to meet the specific requirements for fuel tank protection;

- Foam or expanded metal products can be used effectively to prevent structural failure of fuel tanks as a result of an ignition. However, foam or expanded metal products will reduce aircraft payload and available fuel volume. These reductions result in severe economic impact for the industry. There are also health and safety risks associated with storage and handling of these products;

- Nitrogen appears to be the best inerting agent at the present time. Ground-based ullage washing, in combination with the normal changes to fuel temperature during a flight, reduces exposure to approximately 1%. This is the most cost-effective inerting solution studied, with the cost over a 10-year period estimated at approximately $3 billion.

For on-board inert gas generating systems (OBIGGS), most in-service aircraft do not have enough engine bleed air supply. However, future aircraft could be designed to accommodate these systems. Liquid or gaseous nitrogen storage inerting system could be adapted for in-service aircraft. These systems tend to be heavier than OBIGGS and require additional airport infrastructure. The overall cost for a ten-year period is similar to OBIGGS and estimated at approximately $30 billion.

- For fuel vapor reduction, five of the options considered reduce the exposure to flammable fuel vapor. These are:

    - Insulate the heat source adjacent to fuel tanks;
    - Ventilate the space between fuel tanks and adjacent heat sources;
    - Redistribute mission fuel into fuel tanks adjacent to heat sources;
    - Locate significant heat sources away from fuel tanks;
    - Sweep the ullage of empty fuel tanks.

  Only directed ventilation and relocation of the significant heat sources reduce the exposure to an acceptable level. However, relocation is feasible only for new airplane designs. Directed ventilation for in service aircraft is estimated to have an overall cost for a ten-year period of $3.5 billion.

- To reach the goal by changing fuel properties, a minimum flash point specification of 140°F would be required. A change of this magnitude falls outside of the current experience base and may require engine re-design/re-qualification. The overall fuel manufacturing cost increase for a ten year period is estimated at $15 billion in the USA and $60 billion for the rest of the world and could result in a significant shortfall of jet fuel.

Fuel tank explosions represent less than one percent of the accidents that occur in commercial aviation. The FAA has provided an estimate of the cost of future events to be $2 billion over the next ten years, if no fuel systems enhancements were made. The flammability reduction techniques studied by the ARAC Working Group have an economic impact far greater than this.

In addition, the FAA is conducting a thorough review of current design and maintenance practices, which will act to improve the safety of fuel tanks by addressing ignition source mitigation. The group concludes this approach will achieve a significant enhancement in safety.

3.2 Recommendation

The ARAC Working Group recommends that the FAA/JAA pursue a cost effective approach to enhance fuel tank safety.

The following specific recommendations are made:

1. Adopt the proposed new regulatory action on new aircraft designs.

2. Continue to investigate means to achieve a cost-effective reduction in flammability exposure for the in-service fleet and newly manufactured aircraft.

3. Pursue the studies associated with directed ventilation and ground-based inerting systems to improve their cost effectiveness.

4. If a practical means of achieving a cost effective reduction in flammability exposure can be found for the in service fleet, either at the level specified in the rule or at some intermediate level (recommendations 2 and 3 above), consider application of that solution, in combination with other actions (e.g. SFAR).

5. If a practical means of achieving a cost effective reduction in flammability exposure can be found for newly manufactured aircraft, either at the level specified in the rule or at some intermediate level (recommendations 2 and 3 above), consider application of that solution, in combination with other actions (e.g. SFAR).

Recommended Implementation Plan

Proposed Action	**In-Service Aircraft**	**New Production Aircraft**	**New Type Design Aircraft**
Flammability Reduction	Pursue practical means	Pursue practical means	Apply new rule
SFAR	Apply	Apply	Apply
AFSSP	Apply	Does not apply	Does not apply

Note:
The proposed ignition source prevention regulation (FAR/JAR 25.981 (a)), and supporting AC/ACJ, were outside the terms of reference of the ARAC Working Group and no effort was expended on these tasks. However, the group believes that the FAA/JAA should work with a similar group to finalize this action.

REFERENCE MATERIAL

ATTACHMENTS

1) TOR
2) Organizational Chart
3) Task Group 1 - Service History/Fuel Tank Safety Level Assessment Final Report
4) Task Group 2 - Explosion Suppression Final Report
5) Task Group 3 – Fuel Tank Inerting Final Report
6) Task Group 4 – Foam Final Report
7) Task Group 5 – Fuel Vapor Reduction Final Report
8) Task Group 6/7 – Fuel Properties and Its Effects on Aircraft and Infrastructure Final Report
9) Task Group 8 – Evaluation Standards and Proposed Regulatory Action Advisory Group Final Report

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Cold Ambient Temperature Effects on Heated Fuel Tank Vapor Concentrations

Steven M. Summer

July 2000

DOT/FAA/AR-TN99/93

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NOTICE

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15. Supplementary Notes

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16. Abstract

Experiments were conducted within a simulated aircraft center wing fuel tank (CWT) to qualitatively analyze the effects of decreased ambient temperatures, such as might occur at increased altitudes, on the vapor concentrations found in a typical CWT ullage. A small quantity of fuel in the CWT test article was heated to 125°F for two hours, corresponding to a temperature of approximately 10°F above the flashpoint of the fuel. The tests were conducted at sea level (14.7 psia), however, the wall temperature of the tank was cooled to a temperature corresponding to a given altitude. The following real-life scenarios were simulated.

1. BASELINE TEST: The environmental conditioning system (ECS) packs are run for two hours while the aircraft is on the ground. After some time, the packs are turned off, and the aircraft remains on the ground.

2. LOW-ALTITUDE TEST: The aircraft, after running its ECS packs, takes off and climbs to a low altitude, of approximately 9,000 ft, cooling the CWT to approximately 55°F.

3. INTERMEDIATE-ALTITUDE TEST: The aircraft, after running its ECS packs, takes off and climbs to an intermediate altitude of approximately 22,000 ft, cooling the CWT to 15°F.

4. HIGH-ALTITUDE TEST: The aircraft, after running its ECS packs, takes off and climbs to a full altitude of approximately 30,000 ft, cooling the CWT to -20°F.

From these tests, it was determined that the ambient temperature does indeed have a significant effect on the vapor concentrations formed in the fuel tank ullage at small fuel mass loadings. When allowed to cool naturally to the room's ambient temperature (~75°F), the fuel-air ratio decreased at an average rate of 1.07×10^{-5} min^{-1} for the low-altitude test, it decreased at an average rate of 7.50×10^{-5} min, and for intermediate- and high-altitude scenarios, it decreased at an average rate of 1.58×10^{-4} min^{-1} and 2.08×10^{-4} min^{-1}, respectively. Thus, as the ambient temperature is decreased, the rate of decrease in the fuel-air ratio increases.

17. Key Words Flammability, Fuel tank, Jet-A, Fuel	**18. Distribution Statement** This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

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1. INTRODUCTION.

1.1 PURPOSE.

This technical note describes experiments designed to determine and qualitatively analyze the effects of a decrease in the ambient temperature, such as might occur at increased altitude, on the fuel vapor concentrations formed in a heated aircraft fuel tank.

1.2 BACKGROUND.

Although the occurrence of an aircraft fuel tank explosion is quite rare compared with the amount of hours flown, the flammability of the fuel tank vapors is currently a topic of much concern. This interest largely stems from the crash of TWA flight 800 in July of 1996 over East Moriches, NY. Since this accident, a number of research activities have been undertaken, in an attempt to better characterize and understand the flammability characteristics of Jet-A fuel and how the conditions existing within the center wing fuel tank (CWT) affect these characteristics.

1.2.1 The Center Wing Fuel Tank and Environmental Conditioning System.

Passenger aircraft typically use the wing structures as their main fuel tanks, where the fuel is in direct contact with the outside skin. Since larger aircraft (B-737s, B-747s, etc.) have a need for greater quantities of fuel, the structural wing box within the fuselage is also used to store fuel [1]. This fuel tank is referred to as the CWT. In the case of a B-747, this tank is divided into seven bays with a total volume of approximately 2300 ft^3. Figure 1, as taken from reference 2, shows a schematic of the B-747 CWT.

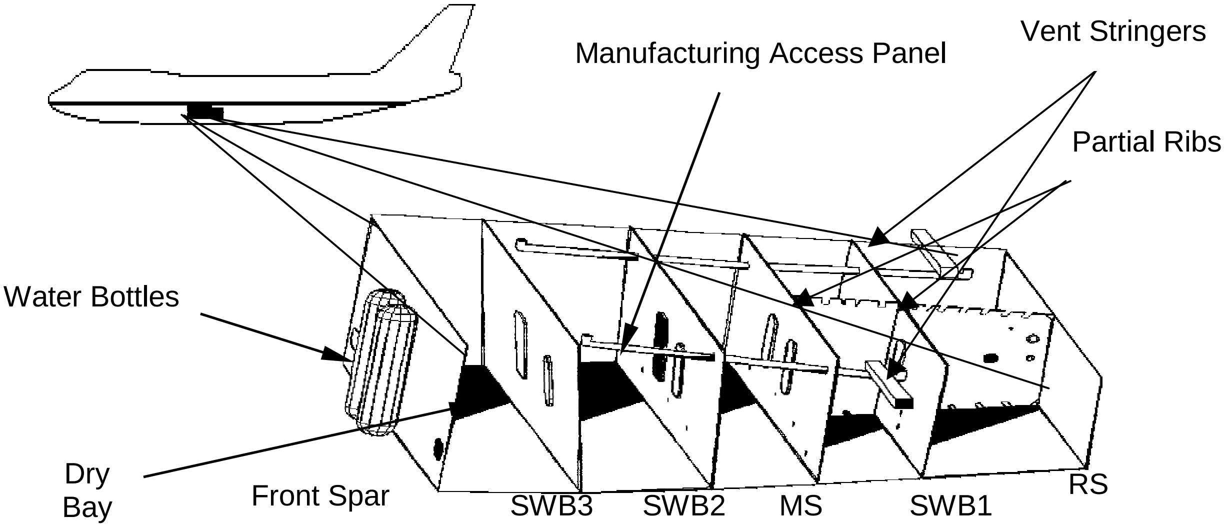

FIGURE 1. SCHEMATIC OF A CENTER WING FUEL TANK

Many of these larger aircraft have environmental conditioning system (ECS) packs located directly under the CWT. Each of these packs "receives regulated bleed air from the engine compressors, removes heat from the bleed air with a primary and a secondary heat exchanger, and exhausts the excess heat beneath the airplane" [3]. The cooled bleed air is then used to pressurize the cabin. Heat transfer from the ECS packs can lead to a significant increase in the fuel temperatures in the CWT.

These packs are used to condition the cabin while the aircraft is on the ground before take off. The increase in fuel temperature, therefore, depends greatly on how long the packs are operating on the ground. The TWA 800 emulation flight data [4] show that the fuel temperature could increase from 80°F to approximately 125°F in 2 1/2 hours of ground time.

This elevation in temperature may create a flammable mixture in the ullage. In fact, the Aviation Rulemaking Advisory Council's (ARAC) Fuel Tank Harmonization Working Group [5] has determined that heated CWTs are at risk of having a potentially flammable mixture in the ullage 30% of the total flight time as compared to only 5% in CWTs without adjacent heat sources.

The potential risk imposed by heated center wing fuel tanks depends on a variety of parameters such as the fuel flash point, mass loading, vapor pressure, and others. Another factor is the impact of a decrease in the ambient temperature such as might occur at increased altitude, on ullage flammability.

The following is a brief discussion of the more important aforementioned parameters affecting the ullage flammability.

1.3 OVERVIEW OF ULLAGE FLAMMABILITY PARAMETERS.

1.3.1 The Fuel Flash Point.

The flash point is an estimate of the minimum temperature, at atmospheric pressure, at which sufficient vapor is released by the fuel to form a flammable fuel-air environment [6]. For Jet-A fuel, the minimum specified allowable flash point is 100°F. While the flash point is a good measure of flammability relative to other fuels, for multicomponent fuels it is difficult to determine a precise relationship between the flash point and the mixture flammability. This stems from the fact that the flash point depends on the vapor concentration, which for multicomponent fuels varies as a function of temperature for the various components of the liquid fuel.

1.3.2 The Fuel Mass Loading.

The fuel mass loading of the tank is defined as the mass of fuel per unit volume of the tank holding it. In other words, for a full tank, the mass loading is equal to the density of the fuel (approximately 800 kg/m^3), for a half-full tank, it is equivalent to half of the density and so on [1]. In the case of TWA 800, the tank had a capacity of 13,200 gallons and only contained 50 gallons of fuel. This corresponds to a fuel mass loading of approximately 3 kg/m^3. The mass loading has a bearing on both the fuel temperature (heat transfer) and ullage vapor concentration.

1.3.3 The Fuel Vapor Pressure.

In a partially filled fuel tank, the hydrocarbon molecules are evaporated into the vapor space above the liquid fuel. If the temperature remains constant and there is no turbulence, this evaporation will continue until the number of fuel molecules leaving the liquid equals the number of molecules returning to the liquid surface. The vapor pressure is defined as the pressure exerted in the ullage (i.e., the vapor space) by the fuel molecules [1]. Therefore, if the vapor pressure at a given temperature is known, through calculations, in principle, one can determine the amount of fuel existing in the ullage at equilibrium, and therefore, the fuel-air ratio. It has also been determined in prior research [7], that a significant decrease in the fuel-air ratio occurs at extremely low mass loadings of approximately 0.08 and 0.15 kg/m^3.

2. DISCUSSION OF TESTS AND RESULTS.

2.1 EXPERIMENTAL SETUP.

The tests discussed in this technical note were conducted in an aluminum tank test article with an internal volume of 88.21 ft^3. This tank was surrounded by a 3″ thick shell on the left, right, and rear walls as shown in figure 2. Carbon dioxide was plumbed into this shell in order to cool the fuel tank walls, simulating lower ambient temperatures at elevated altitudes. On the bottom of the tank, a thermostatically controlled hot plate was located directly beneath the fuel. The tank was instrumented with 11 K-type thermocouples as shown in table 1.

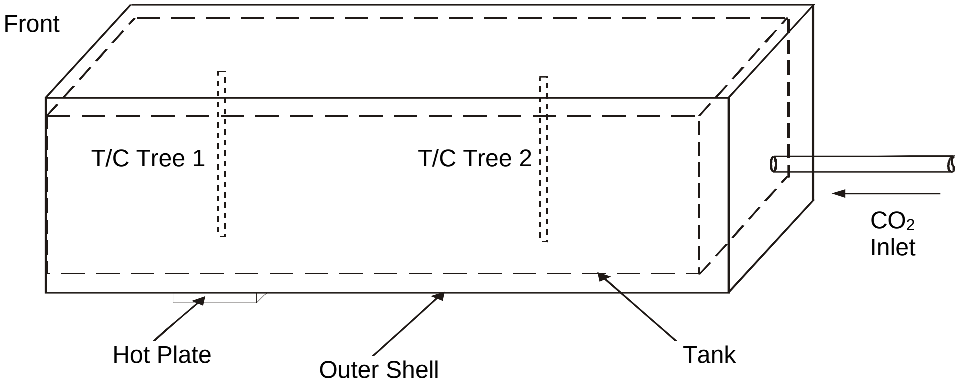

FIGURE 2. EXPERIMENTAL SETUP

TABLE 1. THERMOCOUPLE LOCATIONS

T/C No.	Location Inside Tank	T/C No.	Location Inside Tank
0	T/C Tree 2: Lower	6	Left Ceiling
1	T/C Tree 2: Middle	7	Right Ceiling
2	T/C Tree 2: Upper	8	Right Wall
3	Placed in Fuel	9	Rear Wall
4	T/C Tree 1: Middle	10	Left Wall
5	T/C Tree 1: Upper		

In addition, fuel vapor was collected through two sample lines, one mounted high and the other low, which were easily switched via a three-way electronic ball valve. The fuel vapor concentration was measured with a J.U.M. Model VE7 total hydrocarbon analyzer. Preliminary tests have shown that both ports read the same value, indicating that stratification of the vapor was negligible, and the mixture in the tank could be treated as homogeneous.

The analyzer uses a flame ionization detector burner that was calibrated using a mixture of 4 percent propane in nitrogen. The readings were given in parts per million of propane (ppm C_3H_8) on a scale of 0 to 100,000, corresponding to 0 to 10 volts DC, respectively. These readings were then converted to the more familiar and useful fuel-to-air-mass ratio (kg fuel/kg air) using the following equation:

$$\frac{Mass_{FuelVap}}{Mass_{Air}} = \frac{(ppm\ C_3H_8)(CR)(MW_{FuelVap})}{MW_{Air}}\left(10^{-6}\right)$$

In this formula, the molecular weight of air (MW_{Air}) used was 28.84 g/mol. The carbon ratio (CR) and the fuel vapor's molecular weight ($MW_{FuelVap}$) used were 3/9.58 and 132.4 g/mol, respectively, as determined by Sagebiel in his research for the National Transportation Safety Board [8]. It should be noted, however, that this molecular weight is only an estimate, as Jet-A is an extremely difficult fuel to characterize with properties varying from batch to batch. Therefore, this is not an accurate calculation of the fuel-to-air ratio. Its primary purpose is to approximately locate the mixture within the flammability envelope to determine the *relative* differences in fuel-to-air-mass ratios resulting from heating/cooling the fuel.

2.2 EXPERIMENTAL PROCEDURE.

Experiments were conducted to simulate the following real-life scenarios.

1. BASELINE TEST: The environmental conditioning system (ECS) packs are run for two hours while the aircraft is on the ground. After some time, the packs are turned off and the aircraft remains on the ground.

2. LOW-ALTITUDE TEST: The aircraft, after running its ECS packs, takes off and climbs to a low altitude, of approximately 9,000 ft, cooling the CWT to approximately 55°F.

3. INTERMEDIATE-ALTITUDE TEST: The aircraft, after running its ECS packs, takes off and climbs to an intermediate altitude of approximately 22,000 ft, cooling the CWT to 15°F.

4. HIGH-ALTITUDE TEST: The aircraft, after running its ECS packs, takes off and climbs to a high altitude of approximately 30,000 ft, cooling the CWT to -20°F.

For all tests, 1.5 gallons of fuel was used, corresponding to a mass loading of 1.82 kg/m^3. The fuel was heated and maintained at 125°F, corresponding to approximately 10°F above the fuel's flash point. The total time of heating for all tests was kept constant at 2 hours. After this time passed, the hot plate was turned off and the CO_2 was injected into the fuel tank's shell (with the exception of the baseline test in which no CO_2 was used and the tank was allowed to naturally cool to room ambient temperature).

The amount of CO_2 injected was thermostatically controlled to maintain the three cooled walls at an average temperature corresponding to 30°F above the ambient temperature of the desired altitude. For instance, an altitude of 9,000 ft. corresponds to an ambient temperature of approximately 25°F, so the low-altitude test was performed by maintaining the fuel tank walls at approximately 55°F. It should be noted that the set tank wall temperatures do not simulate an actual aircraft. In fact, in the case of the 747 CWT, the tank wall temperatures are somewhat higher and are location dependent.

The injection of the CO_2 was continued until it was clear that there was a significant decrease in the hydrocarbon count. In the case of the baseline test, the tank was allowed to cool to the room's normal ambient temperature for the maximum amount of time allowed by the data acquisition system.

2.3 EXPERIMENTAL RESULTS.

The results from the experiments are shown in figures 3 through 5. Figures 3 and 4 show plots of the fuel and wall temperature histories, respectively; while figure 5 shows the fuel-air ratio variation with time.

As is seen in figure 3, the wall temperatures rose slightly during the heating of the fuel and then cooled, either naturally or by injection of the CO_2, to the desired ambient temperature. The fuel temperature profiles followed a similar pattern, being held constant at 125°F for the aforementioned 2 hours. After this time, the fuel temperature drops off asymptotically toward the ambient temperature. At small fuel mass loadings, it is evident that the fuel temperature decreased dramatically when subjected to cooler ambient air.

The fuel-air ratio reached a maximum of approximately 0.0145 for all four tests at the end of the 2-hour heating process. After this point, we see a large variation in the fuel-air ratio of the four different cases. For the baseline test with no cooling, it takes a full 6 hours for the fuel-air ratio to decrease to approximately 0.01. On the other hand, when the tank walls are cooled, we see a much more rapid decrease in the fuel-air ratio. When cooled to 55°F, a value of approximately 0.0115 is reached 40 minutes after the start of the cooling process; when cooled to 15°F, a value of 0.005 is reached 60 minutes after; and when cooled to –20°F, a value of 0.002 is reached just 60 minutes into the cooling process.

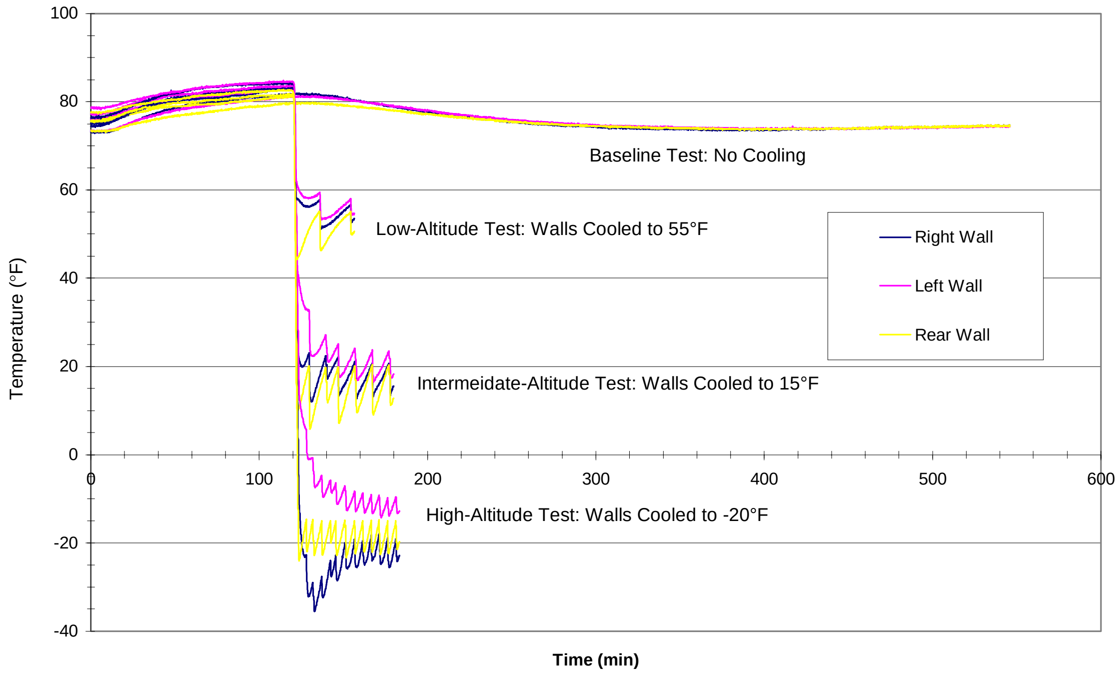

FIGURE 3. TANK WALL TEMPERATURES (°F) AS A FUNCTION OF TIME

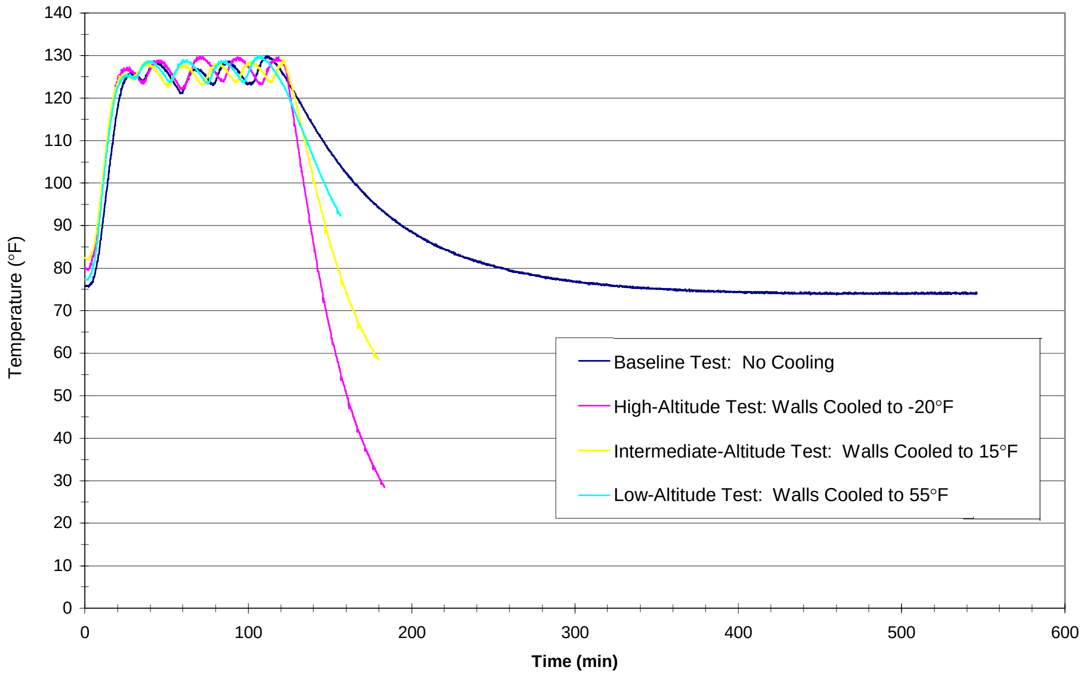

FIGURE 4. FUEL TEMPERATURE (°F) AS A FUNCTION OF TIME

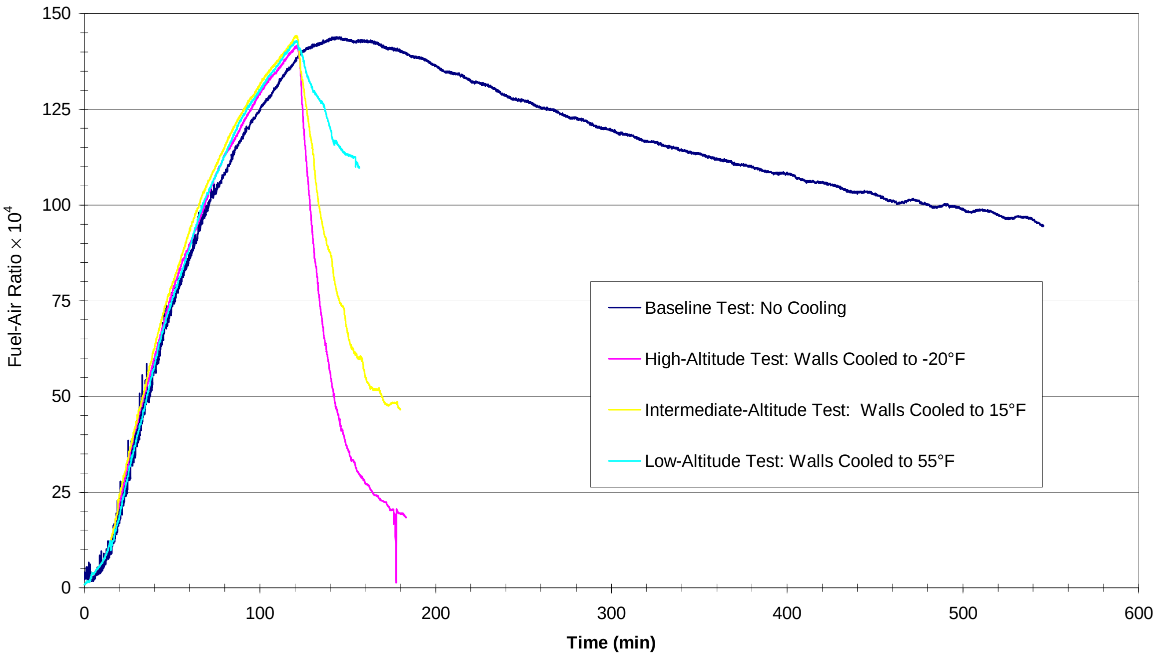

FIGURE 5. FUEL-AIR RATIO AS A FUNCTION OF TIME

2.4 CONCLUSIONS.

Experiments were conducted in a simulated fuel tank to qualitatively determine the effects of a decrease in the ambient temperature, such as might occur at increased altitude, on the fuel vapor concentrations formed in a heated CWT ullage at low fuel mass loadings. From these experiments, it can be concluded that as the ambient temperature is decreased, the fuel-air ratio decreases at an increasing rate. At a fuel mass loading of 1.82 kg/m^3, when allowed to cool naturally to the room's ambient temperature (~75°F), the fuel-air ratio decreased at an average rate of 1.07×10^{-5} min^{-1}; when cooled to 55°F, it decreased at an average rate of 7.50×10^{-5} min^{-1}; and for the cases of 15°F and –20°F, it decreased at an average rate of 1.58×10^{-4} min^{-1} and 2.08×10^{-4} min^{-1}, respectively. Or, at an ambient temperature of -20°F, the rate of decrease of the fuel-air-mass ratio is about 20 times greater than when the fuel is allowed to cool naturally to a standard ambient temperature.

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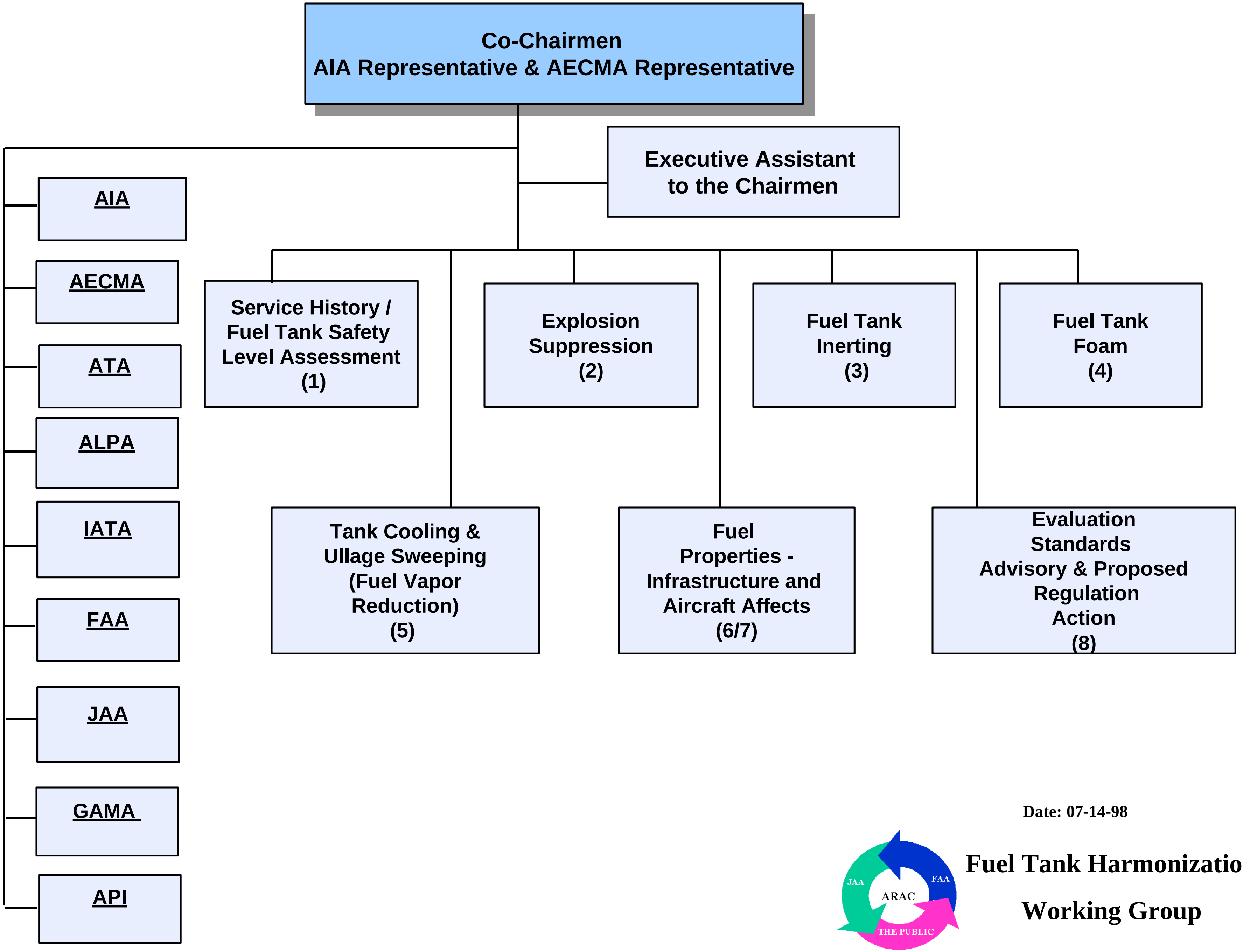
ARAC FTHWG Working Group



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Service History / Fuel Tank Safety Level Assessment (1)

Explosion Suppression (2)

Fuel Tank Inerting (3)

Fuel Tank Foam (4)

Tank Cooling & Ullage Sweeping (Fuel Vapor Reduction) (5)

Fuel Properties - Infrastructure and Aircraft Affects (6/7)

Evaluation Standards Advisory & Proposed Regulation Action (8)

Date: 07-14-98

Fuel Tank Harmonization

Working Group

Aviation Rulemaking
Advisory Committee

Service History/Fuel Tank Safety Level Assessment

Task Group 1

Task Group 1

Service History and Safety Assessment

at 1 July 1998

Summary

Task Group 1 was initially charged with providing "An analysis of the threat of fuel tank explosion due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet, including transport airplanes with heat sources adjacent to or within the fuel tanks."

This was interpreted as a requirement to carry out a detailed analysis of previous tank explosion events, and to carry out a flammability review of the current range of fuel system designs and tank configurations. A further task was then added to prepare a safety analysis to evaluate the safety impacts of any proposed (design) changes recommended by the other groups. Task Group 1 successfully discharged each of these responsibilities, although the detailed flammability review was transferred to (and discharged by) Task Group 5.

Review of Service History

A review of the records of the last 40 years of transport airplane operations worldwide revealed a total of 16 tank explosions relevant to this study. Analysis of these events showed that the fuel tank location was a major factor. In comparing explosion events in integral wing tanks with those located in or adjacent to the fuselage (known as "center tanks"), it was found that the rate of center tank events was considerably higher than one would expect. It was also found that whereas corrective actions to prevent recurrence of the wing tank events were in place, the exact ignition sources in the two most recent center tank events have not been identified, and do not yet have proven remedies.

It was concluded that flammability reduction measures which would reduce the rate of center tank explosions down to the level attained by wing tanks should be investigated.

Safety Assessment

Top-level functional hazard analyses (FHA's) were performed for each option to identify the significant failure conditions these options might bring to the airplane. It was noted that whereas some of the options exhibited relatively benign failure conditions, others had the potential to cause Hazardous or Catastrophic events. However, it was concluded that proper design techniques were available to reduce the frequency of these latter failure conditions to levels consistent with the requirements of FAR/JAR 25.1309. The only exception to this statement was the Explosion Suppression option, where it was not clear that the technology was sufficiently mature to permit identification of all its potential failure modes with confidence.

Contents

1. Introduction

This report describes the work carried out by Task Group 1 to accomplish the tasks outlined below.

The objectives for Task Group 1 were derived from the Terms of Reference for the Fuel Tank Harmonization Working Group (FTHWG), as published in the Federal Register on 23rd January, 1998. Those Terms of Reference included a task to provide:

"An analysis of the threat of fuel tank explosion due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet, including transport airplanes with heat sources adjacent to or within the fuel tanks."

This task was assigned to Group 1, and was further developed at the first Working Group meeting in Washington D.C. into the following three sub-tasks:

(1) Carry out a **detailed analysis of previous tank explosion events**, in order to determine whether any further information could be gained regarding the contributory effects of fuel type, tank location, system design philosophy, environment etc. on the incidence of tank explosions.

The objective was to better identify those circumstances in which there is an increased likelihood of explosion, such that these could be minimized in the future, and also to identify configurations/circumstances where the risk had been shown to be low such that these could be used to guide design practice in the future.

(2) Carry out a **flammability review of the current range of fuel system designs and tank configurations** by first creating a matrix of major types of fuel tank configurations, and then to assess the flammability levels currently existing within a representative selection of those fuel tanks.

However, it became clear during early discussions that members of Task Group 5 (Fuel Vapor Reduction) already possessed the analytical tools to complete this task. It was therefore agreed that Group 1 should compile the **tank configurations matrix** and pass it to task Group 5, which would then carry out flammability analyses.

The objective of this work was to define those configurations most at risk if an ignition source were present, such that these areas received particular attention when considering future rule changes or aircraft modifications.

(3) Prepare a **safety analysis to evaluate the safety impacts of any proposed (design) changes** recommended by the other groups.

The aim was to provide a consistent means of assessing the safety effects of each of the options, and to indicate the level of complexity such systems might require in order to meet any new rules regarding flammability and meet existing rules governing system failure conditions (e.g. JAR/FAR 25.1309).

2. Working Practices

Group 1 comprised four members. Two came from a propulsion design and certification background with aircraft manufacturers. The third member was an airline fleet engineering manager who participated in the TWA800 accident investigation, and the final member came from the propulsion certification office of the FAA.

The group discharged its various tasks through the individual efforts of its members, and held regular reviews of its progress through data exchange, through dedicated task group meetings, and through presentations and reviews of its work in front of the full Working Group on a monthly basis. In addition, because of the relationship and inter-dependence of the tasks of Groups 1, 5 and 8, these teams also held periodic joint meetings to exchange findings and ideas.

3. Review of Service History

The service history of the transport airplane fleet (including turbofan and turboprop airplanes) over the last 40 years was examined, and information regarding known instances of fuel tank explosion (other than those caused by post-impact crash events) was assembled. The starting point was the table of events contained in the FAA Notice on Fuel Tank Ignition Prevention Measures published in the Federal Register on April 3, 1997. The data sources used were accident and incident reports provided by investigating organizations, regulatory authorities, and original equipment manufacturers' safety-related databases. The level of details reported in the early events was sometimes limited dependent on the event location in the world and the type of event (whether it involved an internal or external ignition source).

3.1 Details of previous tank explosions

Appendix A contains a detailed description of each event and the findings of the investigating authority, followed by a description of the mitigating actions taken subsequent to the event to prevent its recurrence.

3.2 Analysis of previous tank explosion events

The 16 tank explosion events are summarized on Tables 1 and 2. They have been separated into Operational Events (i.e. those occurring on an airplane where passenger-carrying flight was intended), and Refuelling & Ground Maintenance Events. They are grouped by cause (Lightning, Engine Separation, Refuelling, Maintenance, etc.), and are then categorized by operational phase, ignition source, type of fuel tank involved, and fuel type. The mitigating actions taken subsequent to each event are summarized, and any recurring events are identified.

Table 3 gives details of the aircraft damage and lives lost due to tank explosions.

Table 1 - Summary of Operational Events

		1963 Lightning Elkton 707	1976 Lightning Madrid 747	1965 UCEF/Eng sep San Francisco 707	1970 Eng Sep Toronto DC-8	1990 Eng Sep New Delhi 747-200	1992 Eng Sep Marseilles 707	1989 Sabotage Bogota 727	1990 Unknown Manila 737-300	1996 Unknown New York 747
Operational Phase	Inflight	•	•	•	•	•	•	•		•
	On Ground Operations								•	
	Ground Maintenance									
	Refuelling									
Ignition Source	Lightning	•	•							
	Overwing Fire - Inflight			•	•	•	•			
	Static Discharge									
	Sabotage							•		
	Unknown								•	•
Tank Type	Main (Wing) = W Center = C	W	W	W	W	W	W	C	C	C
Fuel Type		JP-4 / Jet A	JP-4 / Jet A	Jet A	JP 4	Jet A	Jet A	Jet A	Jet A	Jet A
Mitigating action taken to minimize or prevent recurrence of root cause	Airplane Design Change	• Flow-thru' vent; surge tank suppression	• Improved bonding inside tank	• Redundant control of spar shutoff valve	• Spoiler Lockout Mechanism					• Flame Arrestors on Pump Inlets
	Hardware Inspection Requirements						• Mid-spar attach't repeat inspection		• 12 Service Bulletins	• 12 Service Bulletins
	Ground Support Equipment Change									
	Maintenance Program / Procedures Revised					•			•	•
	Operations Bulletin								•	
	Improved Airport Security							•		•
	None									
	Unknown									
Recurring Event			• Different cause							•

Table 2 - Summary of Refuelling and Ground Maintenance Events

		1970 Refuelling Minneapolis 727	1970 Refuelling Minneapolis 727	1973 Refuelling Toronto DC-8	1989 Refuelling Washington Beechjet 400	1967 Ground Maint. Taiwan 727	1974 Ground Maint. Travis AFB DC-8	1982 Parked Montreal DC-9
Operational Phase	Inflight							
	On Ground Operations							
	Ground Maintenance					●	●	●
	Refuelling	●	●	●	●			
Ignition Source	Lightning							
	Overwing Fire - Inflight							
	Static Discharge	●	●		●	●		
	Sabotage							
	Unknown			●			●	● Suspect dry running boost pump
Tank Type	Wing = W Rear Aux = RA Center = C Fwd Aux = FA	C	C	W	RA	C	W	FA
Fuel Type		Jet A	Jet A	JP-4 / Jet A	Jet A / JP-4	Jet A	JP-4	Jet A
Mitigating action taken to minimize or prevent recurrence of root cause	Airplane Design Change				● Installed conductive foam			
	Hardware Inspection Requirements							
	Ground Support Equipment Change		● “Anti-static” filters introduced					
	Maintenance Program / Procedures Revised			● (probable outcome)		●	●	● (probable outcome)
	Operations Bulletin							
	Improved Airport Security							
	None	●						
	Unknown							
Recurring Event			●					

From Tables 1 and 2, certain patterns and trends emerge:

- There are 8 wing tank events, and 8 involving center or fuselage tanks
- In the wing tank events, 5 out of 8 involved the use of wide-cut fuel (JP-4/Jet B)
- In the wing tank events, 5 out of 8 occurred in flight
- All the wing tank events involved external ignition sources - there are no known wing tank explosions due to internal ignition sources in 520 million hours of flight operations
- There were only 2 explosions due to lightning strike, with 396 million flight hours accumulated since the last event in 1976
- All the center tank events involved the use of Jet A/Jet A-1 fuel
- In the center tank events, 6 out of 8 occurred on the ground
- There are 9 operational events, and 7 refuelling and ground maintenance events

From the data, there appears to be a difference in the respective safety levels of wing tanks and center tanks.

All the wing tank events have been due to known, external ignition sources (lightning strikes, over-wing fire, refuelling, maintenance error) - there are no known internal ignition sources in 520 million hours of commercial transport fleet operation that resulted in a tank explosion. Corrective actions to prevent recurrence of these wing tank events have been in place for many years, and have been demonstrated to be effective.

By contrast however, in the two most recent center tank events the exact ignition sources have not been identified. Whilst corrective actions to identify and eliminate potential ignition sources are now being put in place, the investigation of flammability reduction is warranted since the efficacy of these actions has yet to be proven.

Over the years, center tanks have accumulated considerably fewer operating hours than wing tanks (for example, a B-737 has two wing tanks and one center tank, and therefore accumulates wing tank hours at twice the rate of center tank hours). Since the equipment in wing and center tanks is very similar, i.e. there are similar types and numbers of potential ignition sources, one would expect there to be significantly fewer center tank events than wing tank events. Actually the numbers of events are equal. This indicates that center tanks are significantly more susceptible to explosion than wing tanks.

It might be argued that the reason for this disparity is that components in the wing tanks are more often submerged than those in the center tanks, which often operate almost empty. However, this may be an over-simplification. There are several pieces of equipment inside wing tanks which routinely operate in the vapor space, such as fuel quantity probes and wiring, and partially submerged boost pumps. There is still considerable potential for the existence of ignition sources within the ullage of wing tanks. This being the case, if center tanks are experiencing considerably more explosions than might be expected relative to wing tanks, it must be that center tanks are significantly more flammable than wing tanks. Reducing the flammability in center tanks down to wing tank levels would be a worthwhile goal.

In the last 20 years (when Jet A has been the predominant fuel), there have been five tank explosion events involving center/fuselage tanks, and two wing tank events (which were both exceptional ones - see Appendix A, Event nos. 3 & 4). The continuing incidence of center tank explosions (all of which involved Jet A fuel) indicates that these tanks have not yet reached the safety level attained by wing tanks, and that action to further reduce the flammability levels in center tanks should be considered.

Table 3 summarizes the numbers of fatalities and degree of aircraft damage resulting from all the events. As discussed earlier, the Manila B-737 and New York B-747 events are the only ones for which the corrective actions have not been proven in subsequent airline service. In any cost/benefit analyses performed elsewhere in this study, it is recommended that only those lives lost in these last two events should be counted, since formal or informal cost/benefit analyses have already been performed on the earlier events when the decisions were taken regarding the follow-on actions from those events. A total of 238 lives were lost in the two most recent events.

Table 3 - Aircraft Damage and Fatalities

Operational Events	**No. of Events**	**No. of Fatalities**
Hull loss with fatalities	6	539
Hull loss	2	
Substantial damage	1	
Non-Operational Events		
Hull loss with fatalities	1	1
Hull loss	2	
Substantial damage	4	1
Totals	16	541

3.3 Service History Conclusions

This study identified and analyzed 16 known instances of fuel tank explosions (other than those following impact with the ground) over the last 40 years of transport aircraft operations worldwide. The following conclusions have been drawn:

- There is a close relationship between the incidence of explosions in wing tanks and the use of wide-cut fuel.
- Wing tanks operating with Jet A type fuel have demonstrated an acceptable safety record.
- In comparison, center tanks and fuselage-mounted tanks are more vulnerable to explosion in the presence of ignition sources.
- Apart from the two most recent events (1990/Manila & 1996/New York), the causes of all the other events have been addressed by actions designed to prevent or minimize their recurrence.

It is recommended that action to further reduce the flammability levels in center tanks should be considered.

4. Fuel Tank Configurations

An extensive survey of fuel system and fuel tank configurations was conducted for the commercial transport aircraft fleet. A tabular summary was compiled for 68 different aircraft types or models, including large, medium and small turbofan aircraft, regional jets, business jets and turboprop aircraft. This described the aircraft in terms of size and range, and characterized the wing and tank configurations, the fuel capacity and presence of adjacent heat sources for each aircraft fuel system.

On completion, it was passed to Task Group 5 to facilitate selection of suitable candidate aircraft types on which to perform flammability analyses.

5. Safety Assessment

5.1 Objectives

As stated earlier, the third task assigned to Group 1 was to assess the overall aircraft-level safety implications of carrying out the modifications being investigated by the other Task Groups. Clearly, since some of these modifications involve technologies which are currently not fully mature or proven in a commercial airline environment, rigorous and detailed safety analyses down to component level could not be carried out with confidence. However, the safety assessments described below do allow some useful comparisons to be made regarding the safety impacts of the various options relative to each other. They also provide an indication of the complexity or levels of redundancy which such systems may require in order to meet the certification requirements of FAR 25.901(c) and JAR/FAR 25.1309.

5.2 Analysis Methods

A top-level functional hazard analysis (FHA) was performed for each option. This typically looks at the effects of the system not operating when required, and operating when <u>not</u> required, and identifies the severity of these failure conditions (using the guidance contained in Advisory Circular AC 25.1309-1A).

For each system being analyzed, Group 1 made extensive use of the more detailed knowledge of the individual task group “responsible” for that system.

The following options were the subject of safety assessments:

- Filling the ullage space with inert gas
- Filling the tank with foam
- Purging fuel vapor from the tank
- Raising the flash point of the fuel
- Reducing the heat input into the fuel

Due to the lack of commercial aircraft operational experience with explosion suppression systems, the technology was not considered sufficiently mature or well-understood to merit carrying out an analysis of its safety implications.

5.3 Analyses

For each of the “explosion protection” systems analyzed below, the condition where they failed to operate when required was classified as Minor since loss of the protection system <u>on its own</u> does not significantly reduce airplane safety. Clearly, loss of protection coupled with an ignition source in a flammable atmosphere would be considered a Catastrophic event. This combination of failures is the case which would actually set the required reliability (availability) of the protection system.

5.3.1 Gaseous inerting

The gaseous inerting system is assumed to be one which actively replaces the oxygen component of the air inside the tank(s) such that the resulting fuel vapor/gas mixture is too rich to be flammable. Further, it is assumed that this requires the tank to be closed from the atmosphere to prevent dilution of the inerting agent and re-oxygenation of the ullage.

The gaseous inerting system has the following functions:

(1) To keep the oxygen concentration inside the tank below the level which will support combustion

(2) To keep the tank differential pressure within limits

(3) To prevent leakage of inert gas into the passenger cabin or flight deck

The functional failures are documented below.

Function: (1) To keep the oxygen concentration inside the tank below the level which will support combustion

Functional Failure	**Failure Condition** **Effect on (A) System, (B) Aircraft, (C) Occupants**	**Classification**	**Probability Requirement**	**Safety Design Implications**
Fails to prevent ullage volume becoming flammable	(A) Explosion possible if ignition source present (B) None unless ignition source present (C) None unless ignition source present	Minor	N/A	Loss of protection returns tank to pre-mod condition, i.e. only vulnerable to explosion if flammable atmosphere and ignition source present
Operates inadvertently during tank maintenance	(A) Oxygen concentration inside tank depleted (B) None (C) Asphyxiation of maintenance personnel	Hazardous	1 x 10^{-7} per hour	May require system inhibition interlocks as well as explicit maintenance procedures

Function: (2) To keep the tank differential pressure within limits

Functional Failure	**Failure Condition** **Effect on (A) System, (B) Aircraft, (C) Occupants**	**Classification**	**Probability Requirement**	**Safety Design Implications**
Allows tank differential to exceed maximum positive limits	(A) Wing over-pressure deformation (B) Loss of structural integrity (C) Multiple loss of life	Catastrophic	1 x 10^{-9} per hour	Need dual-redundant vent valves, and an over/under-pressure relief valve
Allows tank differential to exceed maximum negative limits	(A) Wing under-pressure deformation (B) Loss of structural integrity (C) Multiple loss of life	Catastrophic	1 x 10^{-9} per hour	Need dual-redundant vent valves, and an over/under-pressure relief valve

Function: (3) To prevent leakage of inert gas into the passenger cabin or flight deck

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Transfers inert gas into cabin	(A) Possible loss of tank inerting (B) None (unless pilots incapacitated) (C) Incapacitance/death of some occupants before oxygen masks deployed	Hazardous	1 x 10^{-7} per hour	Consider N_2 detector in cabin

5.3.2 Foam

The foam "system" is assumed to comprise multiple small blocks of highly porous material which completely fill the tank interior, with negligible voids. It prevents gross over-pressure or explosion within a tank by limiting the extent of any vapor/air ignition to a small local detonation, preventing it propagating throughout the tank.

The foam "system" has the following functions:

(1) To prevent ignition of the fuel vapor/air mixture from causing a tank explosion

(2) To allow free movement of fuel within the tank and into the fuel delivery system to the engine(s)

The functional failures are documented below.

Function: (1) To prevent ignition of the fuel vapor/air mixture from causing a tank explosion

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Fails to protect against ignition propagating into tank explosion	(A) Explosion possible if ignition source present in flammable atmosphere (B) None unless ignition source present (C) None unless ignition source present	Minor	N/A	Loss of protection returns tank to pre-mod condition, i.e. only vulnerable to explosion if ignition source <u>and</u> flammable atmosphere present

Function: (2) To allow free movement of fuel within the tank and into the fuel delivery system to the engine(s)

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Interruption of fuel flow to the engine(s)	(A) Blockage of fuel supply to engine(s) (B) Possible multiple engine power loss requiring forced landing (C) Serious injury/death of some occupants	Hazardous	1 x 10^{-7} per hour	Life limits for foam. Increased/redesigned filtration and increased frequency of filter inspections
Inability to transfer fuel out of a tank	(A) Fuel trapped within a tank (B) Loss of range requiring diversion (C) None	Major	1 x 10^{-5} per hour	

5.3.3 Ullage sweeping

An ullage sweeping system is one which the fuel vapor is purged from the tank ullage using forced ventilation, making the ullage too lean to be flammable.

The ullage sweeping system has the following functions:

(1) To keep the fuel vapor concentration inside the tank below the level which will support combustion

The functional failures are documented below.

Function: (1) To keep the fuel vapor concentration inside the tank below the level which will support combustion

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Fails to prevent ullage volume becoming flammable	(A) Explosion possible if ignition source present (B) None unless ignition source present (C) None unless ignition source present	Minor	N/A	Loss of protection returns tank to pre-mod condition, i.e. only vulnerable to explosion if flammable atmosphere and ignition source present

5.3.4 High flash-point fuel

This option uses fuel whose flash point has been raised from the current minimum value of 100°F to a significantly higher value (say 120°F). It prevents a fuel tank explosion by maintaining the flash point above the highest temperature attainable inside a fuel tank.

High flash fuel has the following functions:

(1) To prevent formation of a flammable vapor/air mixture within the operating temperature envelope of a fuel tank interior

(2) To provide a fuel suitable for aircraft gas turbine engine operation

The functional failures are documented below.

Function: (1) To prevent formation of a flammable vapor/air mixture within the operating temperature envelope of a fuel tank interior

Functional Failure	**Failure Condition** **Effect on (A) System, (B) Aircraft, (C) Occupants**	**Classification**	**Probability Requirement**	**Safety Design Implications**
Allows formation of a flammable vapor/air mixture inside the tank	(A) Explosion possible if ignition source present (B) None unless ignition source present (C) None unless ignition source present	Minor	N/A	Loss of protection returns tank to pre-mod condition, i.e. only vulnerable to explosion if flammable atmosphere and ignition source present

Function: (2) To provide a fuel suitable for aircraft gas turbine engine operation

Functional Failure	**Failure Condition** **Effect on (A) System, (B) Aircraft, (C) Occupants**	**Classification**	**Probability Requirement**	**Safety Design Implications**
Fuel causes engine malfunction	(A) Flameout (B) Possible multiple engine power loss requiring forced landing (C) Serious injury/death of some occupants	Hazardous	1 x 10^{-7} per hour	Rigorous engine/airframe compatibility testing required, possibly with controlled service introduction & fleet leader program

5.3.5 Heat reduction

This option is intended to minimize the heat added to the fuel once it is onboard the aircraft by insulating, ventilating or otherwise physically separating heat sources from fuel tanks. The intent is to prevent raising the fuel vapor above its flash point.

The heat reduction option has the following functions:

(1) To prevent the fuel vapor inside a tank being raised above its flash point

The functional failures are documented below.

Function: (1) To prevent the fuel vapor inside a tank being raised above its flash point

Functional Failure	**Failure Condition** **Effect on (A) System, (B) Aircraft, (C) Occupants**	**Classification**	**Probability Requirement**	**Safety Design Implications**
Allows fuel temperature to rise above its flash point	(A) Explosion possible if ignition source present (B) None unless ignition source present (C) None unless ignition source present	Minor	N/A	Loss of protection returns tank to pre-mod condition, i.e. only vulnerable to explosion if flammable atmosphere <u>and</u> ignition source present

5.4 Safety Assessments Conclusions

The top-level safety analyses above indicate that some of the options under consideration could exhibit undesirable failure conditions. However, it is considered that all of these systems could be designed with sufficient integrity to meet the requirements of FAR 25.1309 such that the overall safety of a given fleet of airplanes was not compromised. For some of the options, meeting those requirements would require greater system complexity and (possibly) more onerous inspection and maintenance requirements than the options with benign failure conditions. A comparison of the relative merits of these options is therefore primarily an economic consideration, since all of the options could be made equally safe.

Appendix A - Details of previous tank explosions

Appendix A contains a detailed description of each event and the findings of the investigating authority, each followed by a description of the mitigating actions taken subsequent to the event to prevent its recurrence. The 16 events have been grouped initially into broad categories which characterize their circumstances, i.e. engine separation events, lightning strike events, ground maintenance events, refuelling events, "others" and those where the cause remains unknown.

Engine Separation Events

1.	Date:	**28 June 1965**	Flight phase:	**Takeoff climb**
	Aircraft:	**Boeing 707**	Tank type:	**Main reserve tank**
	Location:	**San Francisco**	Fuel type:	**Jet A**

Summary of Event

Approximately 39 seconds after takeoff No.4 engine experienced an uncontained engine failure resulting in separation of the engine from the wing. The loss of the engine resulted in mechanical damage to the wing and a severe fire. The fire triggered a low order explosion in the No.4 reserve tank which resulted in the loss of the lower wing skin, lower stringers, and spar chord flanges. The loss of these components resulted in the loss of wing integrity which allowed the outer wing panel to fail and separate from the wing. The ensuing fire was extinguished by the closing of the main fuel shutoff valve either by the first officer or the flight engineer.

There was evidence of fire on the separated wing section, on the remaining wing around the point of separation, and on the No.4 engine. Fire was observed by ground witnesses, passengers and crew members, and photographed, in color, from the ground and by a passenger. The flight crew was alerted to the fire when an intermittent fire warning was observed while they were going through the engine shutdown procedure following the failure of the No.4 engine. The first officer then actuated the fire selector lever for the No.4 engine and discharged both fire extinguisher bottles to the engine. The fire was observed streaming from the right wing. Fuel was still streaming from the No.4 tank area after landing until the fire department plugged the hole in the bottom of the tank. The area around the fuel spill and the wing stub were foamed as a preventative measure while the passengers were disembarking from the aircraft.

Analysis

A disk failure resulted in an explosive failure of the No.4 engine and its separation from the wing due to high vibration and out of balance oscillation of the rotating parts of the engine. The right outer wing received so much damage to the lower load-bearing skin and associated structure that capability of the wing to sustain in-flight loads were reduced below the loads imposed, and the outer wing panel separated from the wing. Fuel from the engine fuel line was then being pumped directly into the airstream. This fuel was ignited by an undetermined source shortly after the engine separated and resulted in an explosive separation of a portion of the lower wing skin. It is believed that dangling wires from the engine separation sequence ignited the fuel. The fire was sustained by the continued supply of fuel through the engine fuel line until the flight engineer or the first officer shutoff the main fuel supply either by activating the fuel shutoff valve to the closed position or actuating the fire selector handle.

The disintegration of the third stage turbine disk cut the engine in two pieces and threw turbine debris into the wing inboard of the engine pylon. The two engine sections, each supported by only one mount on the strut, began to oscillate and separated from the wing in approximately four seconds. The strut failures were caused by the oscillation, possibly coupled with mechanical damage from flying engine parts. The engine fuel line pulled from the strut closure rib when the engine separated from the wing. Fuel was pumped through this line for an estimated 99 seconds at a rate of approximately 30,000 pounds per hour, until the fuel valve was shut off by the action of either the first officer or the flight engineer. A second fuel source was the fuel line on the forward face of the main spar which had a loosened fitting that leaked and supplied fuel for a fire over the strut center spar between the front spar and the nacelle closure rib. A third possible flammable fluid source was the ruptured slat hydraulic line on the inboard gap cover area.

The source of the ignition cannot be determined, but the possible sources included the engine exhaust, hot turbine parts, or arcing from exposed electrical leads. The latter is the most probable source because there was an appreciable time lapse between observation of the fuel spray and ignition. The fuel sources wetted much of the upper wing surface before ignition occurred.

The fact that No.4 main tank was full of fuel probably prevented more extensive fire damage to that area of the upper wing surface because the fuel acted as a heat sink. The fire in this area reached temps ranging from approximately 870 - 1165°F, based on damage caused to the metal.

The damage to the right outboard wing section top and bottom skin and ribs could only have been caused by an over-pressure in the reserve tank. This is demonstrated particularly by the manner in which the lower skin separated from the aircraft. The entire panel was forced straight down, taking the attaching flanges of both spars with it. This is plainly the result of a low order explosion. The source of ignition for this explosion could not be determined but could have been auto-ignition, burn through, or hot surface ignition from a localized hot spot.

The final separation of the wing followed the explosion in the reserve tank. The wing separation is not believed to have been simultaneous with the explosion. The indications of yaw and vertical oscillation on the flight recorder readout and the location of the wreckage on the ground indicate that the wing section remained on the aircraft approximately 10-11 seconds after the separation of the lower skin panel.

The heat damage to the wing structure was not considered to have been a major factor in the wing failure. Rather, the loss of lower skin panel, stringer, mid spar chord flanges reduced the load carrying capability of the wing below that required to support a 1 “g” condition, thus leading to the failure.

Laboratory tests of the fuel samples taken from the six remaining fuel tanks on the aircraft revealed no significant deviation from the specification established for Jet A turbine engine fuel. It was estimated that the fuel temperature in the tanks at the time of the accident was between 70-80°F. The flammability limit of Jet A fuel was reported by the FAA to be from 90-170°F. Ambient temperature prior to the flight were recorded as 77°F.

Mitigating Actions Taken:

Airplane design change were made to incorporate redundant wiring paths to close spar and engine high pressure valves when the fuel shutoff or fire handle switch is activated. Engine assembly procedures were modified to ensure proper running clearances.

There has been no recurrence of an engine uncontained failure leading to separation of the wing since design changes.

2. Date: **July 1970** Flight phase: **Go-around**
Aircraft: **McDonnell Douglas DC-8** Tank type: **Wing tank**
Location: **Toronto** Fuel type: **JP-4**

Over the threshold of runway 32 at about 60 feet agl, the first officer deployed, instead of arming, the ground spoilers causing a rapid descent until striking the ground. The captain tried to compensate by applying full power and rotating the airplane to initiate a go-around. However, the airplane hit hard at 18 feet per second, number 4 engine separated and number 3 engine partially separated. Somewhere in the sequence of the engine separation from the wing, leaking fuel that may have been ignited by dangling wires causing some explosions. The airplane continued with go-around while trailing fuel and fire. Airplane climbed to 3,100 feet and commenced a turn for a second approach. The right wing separated above the number 3 engine, the airplane rolled over and struck the ground . The airplane crashed 2.5 minutes following touchdown and approximately 8.5 miles from runway 32. The FAA has reported that JP-4 fuel was being used. Ambient conditions were reported as warm and sunny.

Mitigating Action Taken:

As a result of this accident, the FAA issued an airworthiness directive (AD) requiring placard warnings against in-flight deployment of ground spoilers by DC-8 operators. Following a non-fatal accident some three years after this crash, the FAA issued another AD requiring that all aircraft of the type be fitted with spoiler locking mechanisms to prevent such an occurrence.

3. Date: **7 May 1990** Flight phase: **Landing**
Aircraft: **Boeing 747-200** Tank type: **No 1 wing tank**
Location: **New Delhi, India** Fuel type: **Jet A**

A 747-200 operating a flight from London to New Delhi landed at Delhi at 0915 local time. The flight crew reported there were no problems experienced with the No. 1 engine during the London-Delhi flight. Touchdown and engine transition to reverse thrust were reported as normal. Shortly after the engines reached full reverse, all No. 1 engine indications apparently went to zero. The flight crew was not aware of the nature or extent of the problem at this point as there was no engine fire warning. Another 747, which had landed five minutes earlier, advised the 747-200 they had a large fire on the left wing in the area of No. 1 engine. The crew reportedly pulled the No. 1 fire handle and discharged the fire extinguisher. The tower also noted the fire and alerted the aircraft and the airport fire department. The fire department was already aware of the situation and had four fire engines on the scene within two minutes of first noting the fire. The fire was reportedly extinguished within eight minutes of the first report.

All 175 passengers and 20 crew members were evacuated using the five main deck slides on the right side of the aircraft. All five slides deployed normally and were used. There were no reported injuries of anyone on board. The aircraft apparently touched down between one and two thousand feet from approach end of the runway. Weather was clear and dry with little or no wind and the temperature was 35°C. First evidence of the No. 1 engine inlet cowl contacting the runway was at three thousand feet. Spatters of molten aluminium were first noted at above five thousand feet from approach end. The aircraft stopped ten thousand feet from approach end slightly to left of center. The No. 1 engine was in a near vertical position. The engine had rotated around the mid spar attach points with the nose cowl resting on the runway and the exhaust plug and engine tail pipe jammed against the wing lower surface. The No. 1 strut upper link forward attach fuse pin was sheared. Pieces of fractured fuse pin remained in the upper link forward clevis fitting and associated strut attach lug. The aft end of the diagonal brace was detached from its associated fitting on the lower wing skin and the associated fuse pin was completely missing, and could not be found. Failure of these two strut attach points allowed the front of the engine to drop, contacting the runway. All equipment in the No. 1 strut sail boat area was destroyed by impact with strut aft bulkhead, engine exhaust pipe, tail cone and subsequent fire.

The No. 1 engine fuel supply line separated at the wiggins fitting between strut bulkhead and wing front spar. All wire bundles to the engine appeared to have been broken due to tension caused by the strut rotating to a vertical position. All leading edge flaps and leading edge fiberglass panels severely burned inboard and outboard of No. 1 strut. The outboard end of the outboard trailing edge flap was severely burned. The outboard flap track fairing was totally consumed by fire. The inboard end of the outboard aileron was severely burned. The outboard spoilers 1 and 2 and the trailing edge fiberglass panels inboard and outboard of the No. 1 strut was severely burned. The left wing tip was drooping down outboard of the No. 1 strut at about 15 degrees. There was evidence of extreme heating and warping of upper wing skin above the No. 1 strut. The upper wing skin was pulled loose from the forward and aft spar webs outboard of the No. 1 strut. Vent stringers were split open longitudinally. All upper wing skin rivets were pulled through the skin in the area of the surge tank. The lower wing skin was scorched in area of surge tank.

Analysis

In brief summary, the fuel from the ruptured fuel line and hydraulics in the strut were ignited by the hot engine and exhaust, followed by auto ignition of residual fuel in the reserve and surge tanks due to external heating. Fuel supply to the fire was terminated prior to the aircraft coming to rest and flammable wing and subsystem material continued to burn until extinguished by ground personnel.

Following forward strut pin failure and engine dropping nose down:

- Fuel is discharged at approximately 100 gpm into air stream prior to engine spar valve closure due to fuel line separation from front spar coupling. Fuel is washed under and possibly over wing and into leading edge cavity due to both forward speed of aircraft and due to thrust reverser air from engine.
- Due to engine exhaust/tailpipe being rotated up which forced diagonal brace into the hydraulic reservoirs in strut aft fairing, reservoir is crushed and 10 gallon (U.S.) hydraulic fluid is released.
- Fuel and/or hydraulic fluid is ignited on hot engine tail cone/nozzle.
- Hot engine exhaust gases and/or fuel fire heat the lower surface of reserve tank. Reserve tank is empty, but air is heated in excess of fuel AIT (auto ignition temperature). Residual undrainable fuel is approximately one U.S. gallon.
- Heated air or burning fuel vapor reaches surge tank through the reserve tank vent line. Fire initiates in surge tank due to residual fuel vapors and temperature in

excess of AIT for fuel. Hot front spar at surge tank due to leading edge fire could also have been the ignition source.

- Main tank No. 1, because of fuel acting as a heat sink, remains "cool".
- Wing leading edge receives fuel spray or mist due to engine thrust reverser air or free stream air dispersion. Prior to fuel shutoff, during landing roll, fuel attaches to flap torque tubes and interior flap surfaces, and subsequently burns. Resin binding agents in fiberglass honeycomb panels will burn when fed by heat of fuel fire. Fuel was shut off prior to the end of the landing roll as evidenced by soot being confined to aft portions of strut and aft part of core cowl.

Fire damage to aft end of engine is primarily to exterior cowling and exterior surface of nozzle. Inner steel nozzle does not appear fire damaged. This is considered a consequence of external fuel or hydraulic fluid falling or spraying on aft end.

An assessment of the cause of the wing overpressure has been made. This assessment, in conjunction with visual inspection of the damage indicates that an in-tank explosion occurred which destroyed the integrity of the torque box by separating the wing panels and spars from their internal support structure. Further damage occurred after the overpressure due to inertia loads imposed during landing rollout.

The engine separation was found to be due to a maintenance error when re-assembling the components of the strut linkages.

Mitigating Action Taken

Procedural changes were implemented at the specific airline to ensure existing instructions for engine retention hardware installation were properly followed.

4.	Date:	**31 March 1992**	Flight phase:	**Climb**
	Aircraft:	**Boeing 707**	Tank type:	**No 4 wing tank**
	Location:	**Near Marseilles, France**	Fuel type:	**Jet A**

As the aircraft was climbing towards flight level 330, both right engines separated from the wing. The No.3 inboard pylon fitting fractured and subsequently released the engine under power which then impacted the No.4 engine causing it to separate also. The crew succeeded in controlling the aircraft and landed gear and flaps down with the right wing on fire. The aircraft rolled off the runway to the left of centerline and all crew members evacuated the aircraft safely and the firemen extinguished the fire.

The trailing edge of the wing was totally burnt in the area between both engines. The inboard and outboard flaps had completely disappeared, revealing the burnt operating mechanisms. The inboard aileron was severely damaged. Moreover, the examination of the inboard wing box identified the marks of an inner explosion on fuel tank No.4. This explosion seemed to be at the origin of significant deteriorations affecting the wing stiffness. This explosion had caused the displacement of the inner ribs of this tank. The wing stiffness was particularly damaged on the front and aft spars. Thus, it appeared that the right wing was severely damaged first because of a fire and then because of an inner explosion at the fuel tank No.4.

Note: All right wing valves, transfer and shutoff valves operated normally, when tested. The shutoff valves were found in the fully closed position and the transfer valves were found in the open position which matched the cockpit switch positions. The fuel leakage on the leading edge of the wing near engine No.3 could not have been caused by a closing failure of the shutoff valve. Damage (collateral) of the piping following the pylon detachment could be the cause of the leak. The exact location of the leak could not be detected.

During all of the descent at speeds greater than 220 kt, it is probable that the fuel leak carried on without the fuel catching fire, as the conditions for ignition (depression of the upperwing, speed....) were not achieved and the vaporized fuel was not in contact with the electrical short-circuits of the damaged cabling loom located on engine No.3 leading edge. These conditions changed during the last turn as a consequence of the semi-extension of the flaps. The speed reduced (between 220 and 190 kt), the depression on the upper wing decreased and the turbulence increased. Then, it was possible that under the effect of the electric arcs of the short-circuits quoted above, the fuel ignited, as the conditions of the kerosene-air mixture became optimal for burning. The fire was violent as the condition of the upper wing demonstrated, particularly at the trailing edge. This intense fire had destroyed the trailing edge as well as the flaps and left evidence of overheating over the whole of aft part of the right fuselage side. The air traffic controller advised that the right wing was on fire at 08:33:28 hrs and the landing touchdown occurred at 08:35:35 hrs. Consequently, the right wing fire lasted for at least two minutes.

The accident report did not provide a good rationale for the explosion in the No.4 main tank. It is believed that during the intense fire the wing structure may have weakened and fire progressed to the air-fuel mixture in the tank.

Mitigating Action Taken

An airworthiness directive was issued to inspect the pylon/strut mid-spar fittings at 1500 hours or 600 cycles.

Lightning Strike Events

5. Date: **8 December 1963** Flight phase: **Holding**

Aircraft: **Boeing 707** Tank type: **Wing (reserve) tank**

Location: **Elkton, Maryland** Fuel type: **Jet A / JP-4 mix**

The flight was in a holding pattern at 5,000 feet awaiting an instrument approach to Philadelphia airport from Baltimore, when it was struck by lightning. Immediately thereafter, the aircraft was observed to be on fire. A large portion of the left wing separated in flight and the aircraft crashed in flames near Elkton, Maryland. The probable cause was lightning induced ignition of the fuel/air mixture in the No.1 reserve fuel tank with resulting explosive disintegration of the left outer wing and loss of airplane control.

Fuel onboard at the time of the accident was approximately a 68% Jet A / 32% JP-4 by volume mix. It was estimated that fuel temperatures were 42°F in the reserve tank and 46°F in the main tanks. Considering all factors it was concluded the fuel vapors in all tanks were within the flammability limits. Multiple lightning-strike marks were found on the left wing tip. Although much effort was expended, the physical evidence failed to disclose the precise mechanism of ignition which triggered the explosion in the left reserve fuel tank.

Mitigating Action Taken

A fire suppression system was installed on some airplanes which consisted of a light-triggered fire extinguishing system in the wing surge tank. Additionally, some airplanes had a flow-through vent system installed. An FAA Advisory Circular 20-53 was developed to define lightning strike zones.

Since incorporation of the above design changes and practices, there has not been a recurrence of a lightning strike event on the 707/720 model.

6. Date: **9 May 1976** Flight phase: **Approach**

Aircraft: **Boeing 747-IIAF** Tank type: **Wing tank**

Location: **Madrid** Fuel type: **Jet A / JP-4 mix**

The airplane was being operated as a military logistic flight to McGuire AFB with an enroute stop at Madrid, Spain. During descent for the approach at 6,000 feet, the airplane was struck by lightning which resulted in an explosion and separation of the left wing causing loss of control. Prior to the event, the crew requested ATC vectors around severe thunderstorm activity. The fuel onboard was a mixture of 58% JP-4 and 42% Jet A type.

At the time of the accident the weather was cloudy with rain and lightning, but good visibility. At least two witnesses reported seeing lightning strike the airplane. Parts from the left wing, including a section of the left wing tip, were the first found along the flight path wreckage.

Evidence of lightning strike, pitting and localized burn areas typical of lightning attachment were found on the left wing tip and on the vertical fin at the VOR antenna.

The fire centers were located in the wing tip, in the outboard end of No.1 fuel tank, and the outboard end of No.2 fuel tank. These fire centers were independent and not interconnected. There was no pattern to the fire, heat, and soot damage in the reserve tank. In the area of the No.2 tank, the fire, heat, and soot damage pattern on the inner part of the wing indicated that a fuel fire moved inboard behind the rear spar and along the trailing edge. At the wing root, the fire pattern extended fore and aft along the fuselage. The fuel for this fire obviously came from the No.2 tank from which the upper wing skin cover plank was gone.

Findings and Plausible Hypothesis

The aircraft was fueled with a mixture of JP-4 and Jet A fuels. Lightning struck the aircraft an instant before an explosion. The first wreckage on the ground contained a considerable number of parts of the left wing outboard of the No.1 engine. Damage to the wing in the area of the No.1 fuel tank is the result of a low order explosion. The ullage of the No.1 tank contained a flammable mixture of fuel and air. Pressures provided by the ignited fuel were sufficient to cause the damage. Three fires occurred in No.2 tank, No.1 tank, and the wing tip surge tank. The crushing or collapsing of the fuel tube in the No.1 tank required an application of pressure only available from an explosion. The pressure required to detach the stringers and skin from the wing were in the range of typical pressures developed by an explosion. The first deposit of wreckage formed a pattern of light objects downwind and heavy objects upwind, which is not compatible with gusting or turbulent wind conditions but is compatible with an explosion in calm or steady wind conditions. The H.F. antenna and wing tip edge were snapped off the wing by inertial loads developed by an oscillating outer wing. The loosening of the stringer/plank unit from the wing destroyed the aft wing box of the wing. Extreme engine oscillations developed as a result of the wing box damage. The loss of the rear box structure allowed the wing to twist torsionally and to deflect up and down about the rear spar. The first objects along the flight path were units from the inside of No.1 fuel tank. The three fire areas within the left wing contained electrical devices. The highest level of residual magnetic field was along the rear spar aft of the No.1 tank. A motor that operates a fuel valve normally mounted in this position was never found. Damage to the fuel tank access doors could only result from pressure from inside. No structural loads were applied to these doors. The 28Hz oscillations superimposed on the power line were in the area of the third harmonic of the wing oscillations (9Hz) which were attributed to engine fan rub in the early service history of the 747. The inertial damage to the extreme wing tip (H.F. antenna and coupler) could result only if the inboard section of the wing tip was still attached to inner wing. Throttle lever vibration in synchronization with the wing oscillations was observed during previous incidents. The damage to the wing tip cannot be caused by gust loads or aerodynamic loads. They were due to wing oscillations. The wing oscillations were the result of rear box failure. The deformation to rib WS 1168 was caused by pressure loads prior to its departure from the wing along with the jettison fuel line. The flight control difficulty mentioned on the CVR was probably related to the outer wing damage. The crossover vent duct for the forward outboard end of the No.1 tank was severely fire damaged, and the aft end was never recovered.

Fuel Tank Flammability Evaluation Results

Based on these calculations of the fuel and ullage conditions, the fuel/air mixture in portions of the ullage may be such as to permit ignition at the time of a descent through 10,000 feet.

Analysis

Consensus of the highly specialized investigation team was that an explosion occurred at or near the aft outboard corner of the No.1 Tank.

Conclusion from the Accident Report

After analyzing all of the available evidence, it is concluded that the most probable sequence of events which culminated with multiple structural failures and separation of the wing began with an ignition of the fuel vapors in the No.1 fuel tank. The damage to the structure in the area of the tank provided positive indications of an explosion. The possibility that the explosion was a secondary result of an initial structural failure caused by excessive aerodynamic forces developed during high velocity gusts and turbulence cannot be completely dismissed; however, the evidence and the probabilities of an aircraft encountering these unique environmental conditions make this hypothesis less supportable.

Mitigating Action Taken

A design change was incorporated that basically improved bonding (electrical grounding) where plumbing passes through the wing spar to further dissipate the voltage difference.

There has been no recurrence of a lightning strike related explosion to this model airplane or any other fleet airplane since this event in more than 246 million flights.

Ground Maintenance Events

7. Date: **17 September 1967** Flight phase: **Ground maintenance**

Aircraft: **Boeing 727** Tank type: **Center**

Location: **Taiwan** Fuel type: **Jet A**

The airplane was undergoing routine scheduled maintenance of the interior of the left wing tank. Both No.1 (wing) and No.2 (cheek tank) tanks had been drained and were open. Tank No.1 had been purged and No.2 tank was to be purged. A flash fire occurred followed in a few seconds by an explosion which ruptured the integral section comprising the RH end of tank No.2. An 8 ft. by 12 ft. section of upper wing structure was blown off. A small fire flared up in the damaged area which was quickly put out. There were 74 people in the immediate area. 16 persons were injured; five of these received serious injuries.

The precise source of ignition could not be determined. However, the following information was obtained in the ensuing investigation:

An explosion-proof light was illuminating the interior of the electronics compartment and was still functioning after the explosion. There was no evidence to indicate that it had been plugged in coincident with the event. All power was off the airplane, the ground power unit had been shutdown nearly two hours earlier, and the battery had been removed.

The lead man in charge of tank purging stated that purging with portable CO_2 bottles had been completed within tank No.1, and that the CO_2 equipment had been laid down, and that the crew had been instructed to open up the RH access door of tank No.2 before purging that tank. No checks had been made of explosive vapor concentration either internally or externally.

The tank purging procedure used is noted to be contrary to the procedure recommended in the OEM manual. One of the more severely burned mechanics, interviewed later in the hospital, was stated to have corroborated the above. The FAA personnel had come to the conclusion that tank No.2 was being purged through the LH access opening at the time. They based their assumption on the statement that the CO_2 equipment had just been laid down on a work stand, and that the most seriously burned mechanic was standing on a stand near the LH No.2 tank, not No.1.

It was noted that metallic parts in the CO_2 discharge assembly might produce a spark and also that the static electricity discharges from the fiber horn or nozzle on portable CO_2 bottles have been historically a cause of fuel fires.

A mechanic was filing a piece of light gage stainless steel, making a nut retainer, in a wheel well area. Another was making a layout on another piece of metal. The first man, who received burns on exposed skin areas, reported that he felt pain and ran from the area. He did not report noting the origin of the explosion.

The only ground leads specifically identified were connected to the RH landing gear, rather than to the grounding lug provided on a RH gear door, and to the rear fuselage. Whether or not ground leads were attached to the work stands, as recommended by the OEM, was not determined due to confused activities following the explosion. A large crew of workmen were reported to be cleaning (but not polishing i.e., using buffers or polishing compounds) with cans of solvent, brushes and cloths. After the explosion, several of the cans of solvent were noted to be on fire. Electrical outlets were non-explosion proof; however, none was reported as being used, at the time, except for the connection to the light in the electrical compartment.

No precautions had been taken to limit access or post warnings in the area. The FAA considers that any of the 74 men in the area might have created a spark which could have ignited fumes in the area.

Mitigating Action Taken

The CO_2 bottle flow rates were reduce and the discharge nozzles inspected and reworked. There is no known recurrence of this event for these specific causes.

8. Date:	**23 March 1974**	Flight phase:	**Ground maintenance**
Aircraft:	**McDonnell Douglas DC-8**	Tank type:	**Wing**
Location:	**Travis AFB, California**	Fuel type:	**JP-4**

Upon arrival at Travis Air Force Base from a Military Charter flight, a routine maintenance "A" check was being accomplished including maintenance action in response to the flight crew reports of inflight mechanical irregularities that appeared on the previous two flight legs. One of the crew log reports was an inoperative No.1 fuel boost pump.

Access to the boost pump was made through the top of the wing. This was done by removing the No.1 main fuel tank access cover, located behind and slightly outboard of the number 2 engine pylon. Affected circuit breakers for the fuel system had been opened. The tank contained approximately 3,000 pounds of JP-4 fuel. The boost pump was partially submerged in fuel. The total fuel on the aircraft was 25,000 pounds. External power from a ground power unit was connected to the aircraft.

Removal and re-installation of a different boost pump was completed. An operational check of the pump was then attempted and failed. Two of three circuit breakers for the AC three phase pump opened and no boost pressure was noted. It is noteworthy that the same two circuit breakers had opened while enroute on a prior flight leg which resulted in a log book write up "No.1 main boost pump inop". Maintenance replaced the fuel boost pump with the second pump to see if the malfunction could be cleared. Electrical power from an external power unit was reconnected after a "low fuel" warning signal was activated. Inspection of the newly installed fuel boost pump electrical connector was conducted.

At 2008 PDT an explosion occurred in the left wing center section. The upper wing surface between nos. 1 and 2 engines was blown forward and away from the airplane centerline some 250 feet from the airplane. A fire then began which engulfed the entire left wing, fuselage, and inboard right wing. Evidence from the recovered fuel boost pumps and connectors revealed no evidence of burning. The explosion resulted in hull loss, and one fatality.

The investigation also points to an external ground power unit that was supplying power to the aircraft while tank maintenance was being performed. It also mentions a flashlight which one of the mechanics on the wing had in his possession which had a broken "flasher" switch i.e. the switch that allows the user to momentarily activate the light without locking it on or off. Most of the recommendations from everyone involved focused on procedures to prevent another accident. No conclusive evidence of an ignition source was established.

Mitigating Action Taken

The mitigation action taken for this event has yet to be determined.

Refuelling Events

9.

Date:	**3 May 1970**	Flight phase:	**Refuelling**
Aircraft:	**Boeing 727**	Tank type:	**Center**
Location:	**Minneapolis**	Fuel type:	**Jet A**

The airplane was being refuelled using a single-point refuelling system. About 2,000 lbs of fuel had been loaded when a heavy muffled explosion occurred in the No.2 (cheek tank). A puff of gray smoke came from the LH wing tip vent. Fuelling was immediately terminated, all electrical power on the airplane was cut off, the APU was shutdown, and the aircraft was de-fuelled.

No injuries had occurred. No damage was apparent from an external check of the aircraft. The damage was largely confined to the secondary structure within the No.2 tank on the LH side of the airplane. When inspecting the tank, it was found that the structure above the top level of the fuel was heavily soot blackened. The ribs visible from the front spar access hole exhibited heavy deflection and distortion and the stringers were also damaged. Some pulled rivets were noticeable in the LH wing. The formed covers for the fuel boost pump were “hydro-pressed” down over both the RH and LH pumps, but no leaks had developed.

No faults in the electrical systems of the aircraft in and around tank No.2 were found. It is presumed, in the absence of any electrical sources, that ignition resulted from a static discharge within the No.2 tank.

Time of day was 8:28 am. Fuel temperature was 55°F. Flash point of samples was: Tank #1-118°F, Tank #2 - 120°F, Tank #3 - 110°F and the Storage tank from which the fuel was loaded was 127°F.

At the time of the event the following airplane systems were operating; the APU was operating and the LH pack was on to heat the cabin, All navigation lights on. No boost pumps were on.

The duration of the fuelling was approximately 5 minutes with the No.2 tank 31% full.

<u>Mitigating Action Taken</u>

No mitigating action taken since no root cause for an ignition source was found.

10.

Date:	**23 December 1970**	Flight phase:	**Refuelling**
Aircraft:	**Boeing 727**	Tank type:	**Center**
Location:	**Minneapolis**	Fuel type:	**Jet A**

The airplane was being refuelled using under-wing refuelling at the RH wing station. Approximately 3,000 pounds of fuel had been loaded when a muffled explosion was heard. Fuelling was immediately stopped and a minor leak was noticed coming from the area of the inboard boost pump in the LH wing. There was no fire and no injuries to any of the servicing personnel. Over-pressure damage to the aircraft's No.2 fuel tank was extensive but minor in nature.

The aircraft was being readied for its next departure. Besides the refuelling operations, other activity around the aircraft included baggage loading and de-icing operations. Some light snow was being stirred around by a wind that was blowing from the left to the right wing at 18 knots with gusts to 24 knots. The outside ambient temperature was +8°F.

After about 5 minutes of fuelling with kerosene type A (Jet A) , a harsh muffled explosion shook the aircraft with a large white cloud of smoke or vapor issuing from the LH wing root area and continuing for about 30 seconds. The outboard boost pump cavity access door was split in two with half flying across the apron and half still dangling from the opening. Fuel was leaking from the cavity area in a stream about the size of a pencil diameter. The fueller immediately dropped the "dead man" switch and closed both fuelling nozzles. The fire department was then summoned, and they hosed down the area.

Subsequent examination of the aircraft revealed minor exterior physical damage, most noticeable being the blown-off access door, collapsed and fractured number 2 tank LH fuel boost pump cavity housing, and popped rivet heads on the number 2 tank LH upper skin area. Interior physical damage was quite extensive within the number 2 fuel tank. Both the No.1 and No.3 tanks were undamaged. Evidence of soot deposits were found within the left and right hand surge tanks, the number 2 fuel tank, and at each wing tip fuel tank vent scoop area.

The investigation that followed the incident indicated that the probable cause of the explosion was delivery by the ground fuelling system of highly charged fuel into the airplane. However, the investigation was unable to pinpoint the exact source of ignition that triggered the combustion of the fuel vapor. The evidence is very strong, however, that the source of ignition was static discharge internal to the number 2 fuel tank.

Time of day was 6:18 am. Fuel temperature was 31°F. Flash point of samples was: Tank #1-119°F, Tank #2 - 118°F, Tank #3 - 124°F and the Storage tank from which the fuel was loaded was 121°F.

At the time of the event the following airplane systems were operating: APU, all navigation lights on, No.2 tank boost pumps on and all crossfeed valves open.

The duration of the fuelling was approximately 5 minutes with No.2 tank 32% full.

Mitigating Action Taken

The paper element filter separators in the ground refuelling equipment were replaced with filters that did not create electrostatic charging.

The has been no recurrence of a refuelling related event to this model since changes were made.

11. Date: **21 June 1973** Flight phase: **Refuelling**

Aircraft: **McDonnell Douglas DC-8** Tank type: **Wing**

Location: **Toronto** Fuel type: **JP-4 / Jet A mix**

The airplane was at the gate and a ground power unit was connected to the airplane's electrical system when a fuel tank explosion blew off pieces of the right wing top skin and spar structure. Burning fuel rapidly engulfed the right wing. The aircraft was destroyed and two ramp servicing personnel were seriously burned.

The aircraft was being fuelled with Jet B (JP-4), but examination of the left wing tanks revealed a fairly even mix of Jet A-1 and Jet B. Some Jet A-1 was already in the tanks. The ambient temperature was 76°F.

Shortly thereafter an explosion occurred in the right wing. A 20 foot long piece of wing upper skin covering the forward portion of number 3 alternate and number 4 main tank was blown high into the air and landed about 100 feet to the right of the aircraft. Flames erupted from the right wing and burning fuel was sprayed onto a man on a conveyor who leaped off toward the rear of the aircraft. This explosion was followed almost immediately by another which blew a 10 foot long piece of the upper wing skin from the aft section of the number 3 alternate tank to a position forward and to the left of the aircraft. The loss of this skin allowed the right wing to collapse, hinging from the bottom skin. Burning fuel ran from the ruptured number 4 tank and fuel manifold over the leading and trailing edges of the wing. The fueller under the right wing ran toward the front of the aircraft through the fire that now extended to the ground and he was doused with burning fuel. Both the refueller and the cargo handler were seriously burned. No passengers had boarded the aircraft. The nine crew members aboard evacuated through the loading bridge.

The findings of the Canadian Department of Transportation were that the initial explosion occurred in the number 3 alternate tank and that the fuel vapor was ignited in the wing vent system. The source of ignition of fuel vapor in the wing tank vent system could not be definitely determined, but was suspected to have originated outside the aircraft.

Mitigating Action Taken

It is believed that no direct action was taken since it appeared that ignition of the fuel vapor had taken place outside the aircraft adjacent to the vent outlet.

12. Date: **6 June 1989** Flight phase: **Refuelling**

Aircraft: **Beechjet 400** Tank type: **Aux Tank**

Location: **Washington D.C.** Fuel type: **JP-4 / Jet A mix**

The aircraft departed early in the morning from Jackson, Mississippi enroute to New Orleans. Early in the afternoon the airplane returned to Jackson and was refuelled with JP-4. At approximately 4:00 p.m. CST the airplane departed from Jackson enroute to National Airport in Washington, DC After arrival in Washington, the crew spent approximately one hour securing the airplane before departing for the hotel. Line service then began refuelling operations. Operations manager advised that the fuel truck was grounded to the airplane and also to the fuel ramp grounding point. Main wings were topped off first with Jet A fuel. Line personnel then began to service the aft tanks. Prior to service, there was approximately 200 pounds of fuel remaining in the tanks. After pumping five gallons into the aft tank through the aft filler port, line personnel reported hearing a hissing noise followed by a bang. Fuel surged out of the filler opening and covered the line service personnel. At this point, refuelling was terminated and the pilots were contacted. At the time of refuelling there were thunderstorms in the area at the time of refuelling. Shortly after the refuelling operations began, heavy rain began falling in the area of the airport.

Fuel was later noted dripping from the underside of the airplane. After the cabin interior seats were removed to gain access to the aft fuel tank, it was found to be torn loose from all 14 fuselage attach points. The tank had expanded significantly from internal pressure. The forward access panels on the tank were removed for internal viewing. The inside of the tank exhibited very heavy carbon deposits throughout the tank and especially on the upper surface of the horizontal support frames within the tank. These deposits indicate some type of fire or detonation occurred inside the tank.

The investigation concluded the most probable cause was that during refuelling of the interconnected fuselage and auxiliary tanks, an electrostatic discharge occurred which resulted from charged fuel entering the aft auxiliary tank from the fuselage tank. The fuselage mounted tank had a blue foam installed in the tank to protect against rotor burst threats. The foam being used at the time was determined to have low conductivity characteristics and was able to build up an electrostatic charge which subsequently discharged in the aft tank that did not have the protective foam installed.

Mitigating Action Taken

Final action resulted in an airworthiness directive to replace the blue foam with a more conductive foam and install additional bonding and grounding to the subject fuel tank.

Other - Parked in Hanger

13.	Date:	**2 June 1982**	Flight phase:	**Parked**
	Aircraft:	**McDonnell Douglas DC-9**	Tank type:	**Fwd Aux Tank**
	Location:	**Montreal**	Fuel type:	**Jet A-1**

While the airplane was parked in the hangar, it is believed that a fuel boost pump located in the forward auxiliary fuel tank had been left on and overheated, causing an over-pressure in the (de-fuelled) tank, and a subsequent fire which destroyed the aircraft. Structural analysis of the auxiliary tank did not show signs of an “explosion” but did show signs of rapid over-pressure in the tank. The residual fuel in the forward auxiliary fuel tank (estimated at 2.6-3 US gallons) was insufficient for pump priming; therefore there was no motor cooling which resulted in excessive fuel vapor generation within the tank. The exact source of ignition could not be determined during the investigation but out of the four electrically operated components in the auxiliary tank, three could be ruled out as spark producing agents. These are: the fuel quantity probes and the float switch which were not energized and the fuel pressure switch which was found in good condition and its electrical wiring is installed in a metal tube. The fourth item, the transfer pump power supply harness, is the most probable source of sparks. Examination of electrical assemblies on other aircraft indicated burned sockets and pins at the pump connector. The burn marks were the result of arcing. If a faulty connector has a secondary failure at the harness pressure seal, a spark could ignite a critical fuel vapor/air mixture. Considered a serious over-pressure event.

Mitigating Action Taken

No aircraft-related action was taken since this was treated as an industrial accident rather than an event affecting airworthiness.

14. Date:	**11 May 1990**	Flight phase:	**Climb**
Aircraft:	**Boeing 727-100**	Tank type:	**Center tank**
Location:	**Bogota, Colombia**	Fuel type:	**Jet A**

The airplane was climbing through 10,000 feet when an explosion occurred. Investigator reports discovered evidence of a bomb explosion. Close examination of the aircraft structure revealed evidence on the RH side of the passenger cabin between the emergency overwing exits. The evidence indicated the force generated by the blast compromised the structural integrity in this area causing a fuel tank rupture, fire, and inflight structural breakup of the right wing. The local ambient temperature reported at the airport was 52°F.

Cause Unknown

15. Date:	**11 May 1990**	Flight phase:	**Parked / Push Back**
Aircraft:	**Boeing 737-300**	Tank type:	**Center tank**
Location:	**Manila, Philippines**	Fuel type:	**Jet A**

While being pushed back from the gate, the center tank exploded and burned. At the time of the explosion, the engines were not running and the aircraft electrical power and air-conditioning were supplied by the Auxiliary Power Unit (APU). Preliminary evidence indicates that ignition of the fuel-air mixture in the center fuel tanks was the cause of the explosion and subsequent fire. The investigation focused on the center fuel tank, which was determined to be the source of the explosion, and the possibility of an explosive or incendiary device, an external source of ignition or mechanical and/or electrical failure as a source of ignition. The investigation found no evidence of a bomb, an incendiary device, or sabotage. The investigation has yet to reveal the exact ignition source.

At the time of the accident, all the fuel boost pumps were in the “on” position. The center fuel tank had not been filled since 9th March 1990. During the pushback of the airplane the center fuel tank low pressure light illuminated, indicating that the center fuel tank had been emptied of all usable fuel. Laboratory examination of the fuel samples from the airplane and fuel storage tanks indicates that the fuel vapor in the center tank would have had a flash point of between 112 - 117°F. The ambient temperature at the time of the accident was 95°F. The fuel was estimated to be approximately 115°F based on samples of fuel drawn from other similar airplanes following the incident. It was estimated that approximately 90 pounds of fuel was in the center tank.

Of the 114 passengers and six crew members, eight were fatally injured and 30 sustained injuries.

Mitigating Action Taken

Boeing published an all operators bulletin reminding flight crews to not operate the center boost pumps when no usable fuel was available in center tank.

16.

Date:	**17 July 1996**	Flight phase:	**Climb**
Aircraft:	**Boeing 747-100**	Tank type:	**Center tank**
Location:	**New York**	Fuel type:	**Jet A**

The airplane was climbing near 13,800 feet (msl) when an inflight explosion occurred in the center wing fuel tank approximately 13 minutes after takeoff, resulting in loss of structural integrity inflight. The center wing tank was estimated to contain approximately 100 gallons of fuel. Prior to dispatch of the airplane, the air-conditioning air cycle machines, located under the center wing tank, had been operating for up to 2 hours. The center wing tank estimated fuel temperatures was 113-115°F. At the altitude and temperatures of the event, the fuel tank air/vapor mixtures were considered to be flammable. The fuel type was Jet A. There were 230 fatal injuries including the flight crew.

Mitigating Action Taken

A series of service bulletins have been issued against the B-747 series, covering fuel pump electrical installation inspections, addition of a scavenge pump flame arrestor, and inspections and replacements of FQIS wiring and probes.

For the B-737 series (which has a similar fuel system), bulletins covering fuel tank system component and wiring inspections, and flame arrestors in the vent system are being incorporated.

Aviation Rulemaking Advisory Committee

Explosion Suppression

Task Group 2

July 1998 24 June 1998

EXPLOSION SUPPRESSION

ARAC Fuel Tank Harmonization Working Group,
Task Group 2

Terry L. Reddout,	Bombardier Learjet	Chairman
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June 1998

1. Abstract:

HARMONIZATION TERMS OF REFERENCE

TITLE OF INITIATIVE: PREVENTION OF FUEL TANK EXPLOSIONS

Background: The cause of TWA800 747 accident has been attributed to a fuel tank explosion within the center wing fuel tank (CWT). The source of ignition of the explosion is believed to be within the fuel tank, however no conclusive ignition source has been found by accident investigators. The National Transportation Safety Board has concluded from the accident investigation that an explosive mixture of fuel-air vapors existed in the empty CWT of TWA800. The presence of explosive mixtures in the tank is exacerbated by heating of the residual fuel in the tank due to the location of the air conditioning equipment below the CWT.

The FAA has identified 10 transport airplane hull loss events since 1959 which were attributed to fuel tank explosions. The investigation of TWA800 and the number of fuel tank explosions which have occurred in service have led the FAA to question the adequacy of transport airplane certification requirements relative to fuel tank design, specifically with respect to environmental considerations and the adequacy of steps to minimize the hazard due to potential of ignition sources, both in initial design and over the life of the airplanes.

Based on its preliminary study, the FAA believes several approaches to improve fuel tank explosion safety have potential for implementation in the commercial airplane fleet and, therefore, warrant further detailed study. The first is minimization of hazard due to explosive fuel system conditions by mandating certain design and maintenance practices. The second is prevention of the occurrence of a flammable fuel/air mixture in the tanks through some means of inerting, or modified fuel properties such as JP-5. The third means includes mitigation of the hazards of a fuel tank explosion through installation of polyurethane foam or fire suppression systems. The FAA published a notice on April 3, 1997, requesting public comment on the proposed NTSB recommendations. Cost benefit data provided by commenters was inconsistent and in many cases no justification for the data was provided. A significant amount of data has been collected and must be evaluated. The FAA has determined that amendment to the Federal Aviation Regulations concerning fuel tank flammability may be necessary.

The following task should provide the basis for the FAA and JAA to determine what regulatory action should be taken to increase the level of safety of the existing fleet, current production airplanes, and new type designs to address the fuel tank explosion threat.

SPECIFIC TASK:

Prepare a report to the FAA/JAA that provides specific recommendations and proposed regulatory text, that will eliminate or significantly reduce the hazards associated with explosive vapors in transport category airplane fuel tanks. Proposed regulatory text should ensure that new type designs, in-production airplanes and the existing fleet of transport airplanes are designed and operated so that during normal operation (up to maximum certified operating temperatures) the presence of explosive fuel air vapors in all fuel tanks is eliminated, significantly reduced or controlled to the extent that there could not be a catastrophic event. (This task addresses means of reducing explosion hazards by eliminating or controlling explosive vapors. The FAA is also engaged in a separate activity to evaluate whether additional actions should be taken to ensure that ignition sources are not present within the fuel tanks. Therefore, control of ignition sources are not within the scope of this task.) In developing recommendations to the authorities, a report should be generated that includes the following:

1) An analysis of the threat of fuel tank explosion due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet, including transport airplanes with heat sources adjacent to or within the fuel tanks. The SAFER data presented to the FAA in 1978, which includes evaluation of fuel tank safety in both operational and post crash conditions, should be used as a starting point for determining the level of safety.

2) An analysis of various means of reducing or eliminating exposure to operation of transport airplane fuel tanks with explosive fuel air mixtures (e.g., inerting, cooling of lower center tank surfaces,

combination of cooling and modified fuel properties, etc.) or eliminating the resultant hazard if ignition does occur (installation of selective/voided/full tank reticulating foam, explosion suppression systems). Technical discussion of the feasibility, including cost/benefit analysis, of implementing each of the options on a fleet retrofit, current production, and new type design airplanes should be provided.

3) An analysis of the cost/benefit of modified fuel properties that reduce exposure to explosive vapors within fuel tanks. The FAA has asked industry through the American Petroleum Institute to provide pertinent information on fuel properties. The degree of modification to fuel properties necessary to eliminate or significantly reduce exposure to explosive fuel tank ullage spaces in fleet operation must be determined by the group. Factors that may enhance the benefits of modified fuels, such as cooling provisions incorporated to reduce fuel tank temperatures should be considered. Cost information for the various options should be developed, such as engine air/ground starting at low temperatures, maintenance impact, emissions and fuel freeze point, should be analyzed by the group and be provided.

4) Review comments to the April 3, 1997, Federal Register Notice and any additional information such that validated cost benefit data of a certifiable system is provided for the various options proposed by commenters. This information will be used in preparing regulatory action.

   Note: In many cases specific cost data provided in the comments to the notice was competition sensitive, therefore the ARAC group should contact commenters directly and request participation in the group.

5) Recommend objective regulatory actions that will eliminate, significantly reduce or control the hazards associated with explosive fuel air mixtures in all transport airplane fuel tanks to the extent that there could not be a catastrophic event.

In addition to the above tasks, support the FAA in evaluation of application of the proposed regulation to the various types of transport airplanes (turbo-propeller, business jets, large transports, and other turbine-powered aircraft types which may be affected by a change in fuel properties/availability) and any impact on small businesses.

This activity will be tasked for a 6 month time limit to complete the tasks defined above. The FAA will consider the recommendations produced by ARAC and initiate future FAA regulatory action. However, if the group is unable to provide the FAA with proposed regulatory language within this time period the FAA will initiate rulemaking independently. **Participants of the ARAC should be prepared to participate on a full time basis for a 6 month period if necessary.**

PROPOSED HWG ASSIGNMENT: We recommend that this project be managed by a new Fuel Tank Harmonization Working Group (FTHWG), that would report directly to the ARAC Executive Committee.

2. Table of Contents:

3. Introduction:

The assigned efforts of the ARAC Fuel Tank Harmonization Working Group were divided into eight separate tasks, each then assigned to individual Task Groups to conduct the associated investigations and analyses. Each Task Group is staffed by individuals from the various industry, business and professional interests. These assignments are:

Task Group 1:	Service History/Fuel Tank Safety Level Assessment
Task Group 2:	Explosion Suppression
Task Group 3:	Fuel Tank Inerting
Task Group 4:	Fuel Tank Selective/Voided/Full Tank Reticulating Foams
Task Group 5:	Tank cooling/Ullage sweeping
Task Group 6:	Fuel Properties and Its Effect on Aircraft and Its Operation
Task Group 7:	Fuel Properties and Its Effect on Infrastructure
Task Group 8:	Evaluation Standards and Proposed Regulatory Action Advisory Group

For the purposes of identifying the spectrum of aircraft being considered and the characteristics of these aircraft relative to size, operations and environment, a matrix of Standard Aircraft was prepared by Task Group 8 . This matrix is designed to ‘bracket’ the fleet of existing aircraft, with the exception of the smaller transport aircraft, like those at the lower end of the bizjet group, and provide generic representatives upon which the task groups would conduct their analyses. In addition, Task Group 1’s review of the service and incident history, supported by the temperature studies conducted by Task Group 5, identified the environmental differences between wing tanks and center wing tanks (CWT), especially CWTs with external heat sources. It was then proposed and accepted that the specific case of the 747 CWT be included as an additional configuration in each group’s analyses. The Standard Aircraft Matrix is included in Section **10., Other Supporting Data**.

This report documents the activities and findings of Task Group 2, which has the assignment of researching the industry for existing technologies and systems specifically designed to actively monitor, detect, react to and suppress an explosion event before the event can produce catastrophic results, by such means as temperature, structural over-pressure, etc. For the purposes of the Fuel Tank Harmonization Working Group and the assigned reporting, this form of suppression is specifically and distinctly different than fuel tank inerting systems or passive void filling foam systems.

The members of Task Group 2 have performed a search for reference material and documents concerning systems that have been specifically designed to suppress or extinguish an explosion within a fuel tank. This search began with the questions to the Department of Transportation and the Department of Defense, and then to vendors known to be involved with such systems. Through this search and questions of the committee’s membership at large, it was quickly discovered that a great amount of research had been accomplished in this arena concerning military operations and the need to protect combat aircraft from external threats where fuel ignition could result, such as ballistic impacts of High Energy Incendiary (HEI) and Armor Piercing Incendiary (API) projectiles.

From actual live-firing tests and system performance bench tests conducted at the Naval Weapons Center at China Lake, California, and the Flight Dynamics Laboratory at Wright-Patterson Air Force Base, Dayton, Ohio, a number of systems have been identified as having demonstrated positive results in providing fuel tank and dry bay protection from fuel vapor explosions. The applicable technologies center around four separate methods of dispersing the suppressant

- ✦ Inert Gas Generators
- ✦ Gas Generator driven Agent Dispersal
- ✦ Explosive Expulsion of Low Pressure Agent
- ✦ Explosive Release of High Pressure Agent

Research and test information was received from the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS), Air Force Wright Aeronautical Laboratories, Survivability/Vulnerability Information Analysis Center (SURVIAC), and the National Institute of Standards and Technology (NIST). A bibliography of these documents are listed in Section **5., References**.

From these contacts, a list of companies involved in this technology was generated. All of the companies identified were contacted and were provided a questionnaire and invitation for face-to-face discussion meetings with Task Group 2. From those contacts, detailed technical information was received from

- ✦ Kidde Aerospace and Defense (including Graviner and Fenwal Safety Systems),
- ✦ Meggitt Electronics (formerly ARMTEC, Detection Systems) ,
- ✦ Pacific Scientific / HTL,
- ✦ Primex Aerospace Company (including the former Olin Aerospace Co.), and
- ✦ Whittaker Safety Systems.

Of these five, each company with the exception of Meggitt, met with task group members to discuss their particular systems and capabilities.

4. Summary:

4.1. Discussion:

The Kidde Aerospace systems have operational roots in the military. Originally produced by Graviner, the system provided in tank, wet-bay protection using an IR optical sensor, a low vapor pressure suppressant, Pentane, and a small explosive charge to rupture the storage container and throw the suppressant out into the space surrounding the container. This system was placed in service on a number of British military aircraft and has been documented as functioning satisfactorily and being credited with a number of ‘saves’ (suppressant discharges associated with actual ignition threats), though plagued with a large number of ‘false alarms’. These aircraft were phased out of service in the late 1970’s and early 1980’s, and the suppression systems along with them.

In developing this system, a number of suppressants were evaluated and Pentane and Halon 1101 were the two found to be superior suppressants. Halon was rejected due to its high vapor pressure and need for a pressurized container, leaving Pentane as the suppressant of choice for suppression of explosions within an enclosed fuel tank. On the other hand, the post-crash considerations and the likelihood of a fuel tank being ruptured during the crash, leave Pentane as a very undesirable and questionable suppressant.

Pacific Scientific / HTL produce a line of fire extinguishing products, specifically for dry-bays and classically defined fire zones, and a line of explosion suppressors specifically designed to protect the occupied compartments of military armored ground vehicles against an external projectile threat and secondary, internal explosions. The occupied compartment explosion suppression system utilizes a three-frequency optical sensor, a non-microprocessor controller and solenoid opened suppressant bottles, specifically tailored to maintain a survivable atmosphere after discharge.

For the F22 dry-bay protection scheme, Pacific Scientific designed stand-alone sensor-bottle combinations that can react more quickly than their standard extinguishing technology. This system incorporates multiple ‘bottles’, using Halon 1301, to provide appropriate coverage.

None of the Pacific Scientific components or systems have been tested in a wet-bay, and knowingly need a significant amount of additional development and testing to provide adequate protection in this environment. For a complex aircraft fuel system, additional development for alternate, more suitable suppressants, and microprocessor controllers to deal with multiple bottle arrays and variations in ullage volume must be conducted (to minimize any over-pressure hazard).

Primex Aerospace developed a line of solid propellant gas generators, based in the automotive air bag industry, and extending into dry-bay explosion suppression. These systems produce gaseous carbon dioxide, nitrogen and water, which can be used directly as a suppressant, or can

The latter of these systems, as with the others, was developed around the military needs for aircraft protection against the external, incendiary projectile threat. Company and military tests at China

Lake have shown successful ullage protection with response times quick enough to suppress an explosion. Though emersed applications still need to be evaluated and qualified, the technology appears to have a lower sensitivity to variations in ullage volume than a typical Halon suppressant release. Development testing is still necessary to characterize a gas generator system that is compatible with today's aircraft and their requirements.

Whittaker Safety Systems produce a line of fire safety equipment and gas analyzers. In the mid 1980's, they developed, against a military RFP, a dry-bay explosion suppression system based on their fire extinguishing technology, but specifically aimed at the wide area dispersal and quick response needed. Later development of this system utilizes Halon 1301 in a long tube and released by a shaped charge attached to the tube wall axially, and dubbed the linear fire extinguisher, LFE®. A dual-spectrum optical sensor detects fuel ignition and the controller reacts by triggering is a small explosive initiator, mounted outside the fuel bay, which ignites the shaped charge attached to the storage tube.

Testing was successful against the normal range of external threats and was the first system to demonstrate any protection against the 30mm high energy incendiary (HEI) threat.

This system was bid, against Kidde's proposal, for the military P-7A program, as a wet-bay, ullage protection system. Testing has shown this technology to be very effective, with the shortest reaction times of any investigated, but further development is necessary to define a system that is adequately compatible with the closed fuel tank and variations in ullage volume.

4.2. Conclusions:

From the review of the technologies produced by the companies listed above, it is evident that the technology exists and is effective in suppressing the pressure effects of an explosion before those effects can become hazardous to the tank enclosure / structure.

a) Optical sensors have been developed to discriminate between the actual ignition of the hydrocarbon fuel and an extensive number of common and potential light sources.

b) Microprocessor controls have been developed to a level that reliable and explicit decisions can be made within the requisite times. A dedicated controller logic will still be necessary for each specific aircraft installation.

c) Dispersal systems are adequate to provide rapid distribution and suitable concentrations of suppressants.

d) Installations on new aircraft as well as retrofit of existing aircraft appear to be within the capabilities of the technology investigated.

It is evident that this technology is not yet fully mature and a significant amount of development is still required to refine the details to the specific requirements of fuel tank wet-bay protection.

a) Some technologies are out-dated and need to be revisited in light of the current state-of-the-art.

b) Specific design philosophy is needed in each system to adequately address the resulting tank pressures due to the discharge of the suppressant with various liquid levels and ullage volumes (i.e., submerged discharges, excess suppressant release {pressure} and insufficient suppressant release {concentration}).

c) Addition of redundancy, multiple discharges, is needed to meet the potential of recurring ignition.

d) Minimization of in-tank wiring and introduction of potential ignition sources.

e) Alternate suppressants necessary to reduce reliance on Halon 1301.

    1) Alternate suppressants must be compatible with the temperature, altitude and contamination requirements of fuel systems in general.

    2) Alternate suppressants must be compatible with engine components and subsystems.

f) Mature system designs are required to establish

    1) Comparable installation cost and weight estimates.

    2) Appropriate maintenance procedures and intervals.

g) Reliable operation.

    1) Inspections for pressurized containers must be defined and evaluated.

    2) Reliability to perform when commanded must be proven.

    3) Reliability against uncommanded discharges must also be proven.

    4) In depth evaluation of failure modes and hazard assessments.

h) Appropriate ground safety systems and procedures must be developed to protect ground and maintenance personnel during open tank maintenance.

5. References:

5.1. Documentation Received:
The following documents (in alphabetical order) have been received and reviewed:

5.1.1. AFWAL-TR-07-3032, (AFWAL/FIES, WPAFB, OH 45433-6553) Aircraft Dry Bay Test Evaluation, by H.F. Robiadek, Boeing Military Airplane Company, Seattle, WA 98124-2207 for Flight Dynamics Laboratory, Air Force Wright Aeronautics Laboratories, Air force Systems Command, Wright-Patterson AFB 45433-6553, Excerpts.

5.1.2. Graviner Explosion Protection System Installation and Maintenance Manual, excerpts of.

5.1.3. Graviner Report Number 32-001-04, Suppression of Fuel Tank Explosions - An Assessment of Efficacy for McAir, P.E. Moore, N.S. Allen, 18 November 1986.

5.1.4. IMECHE Conference Presentation, on Oct 27-30, 1987, Fire Protection and Survivability, D.N. Ball, Graviner

5.1.5. JTCG/AS-87-T-004, Critical Review of Ullage Code, Dr. N. Albert Moussa, September 1989.

5.1.6. JTCG/AS-87-006, Compartmentalization Aircraft Wing Tank Active Ullage Explosion suppression Tests, Final Report, J. Hardy Tyson, July, 1988.

5.1.7. JTCG/AS-89-T-006, Evaluation of the Linear Fire Extinguisher (LFE); Volume 1: Explosion Suppression and Dry Bay Fire Suppression Ballistic Test Program. John F. Barnes, Sept '89 Prepared for the Joint Logistics Commanders Joint Technical Coordinating Group on Aircraft Survivability

5.1.8. JTCG/AS-90-T-003, Fire/Explosion Protection Characterization and Optimization: Phase ii Alternative Dry Bay Fire Suppression Agent Screening Everett W. Heinonen, Ted A. Moore, Jonathan S. Nimitz, Stephanie R. Skaggs, and Harold D. Beeson; New Mexico Engineering Research Institute, The University of New Mexico, Albuquerque, NM. October 1990.

5.1.9. JTCG/AS-91-VR-002, Evaluation of the Linear Fire Extinguisher (LFE) Volume ii, Water-Based Explosion Suppression Agents Ballistic Test Program, John F. Barnes and James R. Duzan, Sept 1991.

5.1.10. Kidde Graviner Report Number 32-009-01, Results of Active Ullage Explosion Suppression Trials, NAWC - China Lake, 1-12 May 1995, A.J. Randle, 25 May, 1995.

5.1.11. Kidde Presentation material, Wichita, KS 16 April 1998.

5.1.12. NAWCWPNS TM 8006, Testing of Active Ullage Suppression Systems with Agents Alternate to Halon 1301, Executive summary (Report not completed), A.B. Bernardo, April 1997. Excerpts.

5.1.13. NIST SP 861: Evaluation of Alternative In-Flight Suppressants for Full-Scale Testing in Aircraft Engine Nacelles and Dry Bays. William L. Grosshandler, Richard G. Gann and William M. Pitts, Editors, April 1994.

5.1.14. NIST SP 890: Fire Suppression System Performance of Alternative Agents in Aircraft Engine and Dry Bay Laboratory Simulations, Volumes 1 and 2, Richard G. Gann, Editor, November 1995.

5.1.15. Pacific Scientific - Electro Kinetics Presentation material, Duarte, CA, 1 May 1998.

5.1.16. Primex Aerospace Presentation materials, Wichita, KS, 16 April 1998.

5.1.17. SD90-007: Response to Request for Information, Lockheed Letter 5261 LMK/129/001 P-7A Ullage Protection system, January, 1990.

5.1.18. SURVIAC-TR-89-021 Gas Explosion Suppression Agent Investigation, Final Report, July 1989, Survivability/Vulnerability Information Analysis Center (SURVIAC) Booz - Allen & Hamilton Inc, 4141 Colonel Glenn Highway, Suite 131, Beavercreek, Ohio 45431

5.1.19. Walter Kidde Aerospace, Proposal Number 7300-700: Ullage Protection System for P-7A Aircraft

5.1.20. Whittaker Safety Systems Presentation materials, Simi Valley, CA, 1 May 1998.

5.1.21. WL-TR-91-3008, Fire/Explosion Protection Characterization and Optimization Phase I - Data Analysis and Documentation Ullage Protection via Various Venting and Inertant Combinations - Final Report, N. Albert Moussa, John J. Murphy, Jr., May 1991.

5.2. Interviews conducted:

5.2.1. The following companies, facilities and individuals (in alphabetical order) were contacted:

5.2.1.1. Kidde Aerospace and Defense: Including Fenwal, Kidde Graviner, Santa Barbara Dual Spectrum, L'Hotellier & Walter Kidde Aerospace:
Tom Hillman, 919-237-7004

5.2.1.2. National Institute of Standards and Technology (NIST):
Dr. Richard G. Gann, 301-975-6866

5.2.1.3. Naval Weapons Center, China Lake, CA:
Hardy Tyson, 760-939-3681

5.2.1.4. Pacific Scientific (Electro Kinetics Division):
Bill Meserve, 626-359-9317
Mike Fone, 805-963-2055

5.2.1.5. Primex (formerly Rocket Research of Olin Chemical Co.):
Paul Wierenga, 425-885-5000

5.2.1.6. Whittaker - Safety Systems Division (formerly Systron Donner):
Frank Bosworth, 805-584-4100

5.2.1.7. Wright-Patterson Air Force Base, Survivability Group:
Jim Tucker, 937-255-6052
Martin Lentz, 937-255-6302

5.2.2. The following companies (in alphabetical order) and individuals prepared and conducted presentations on systems, equipment and/or technologies which range from fully developed to a demonstrated promise for development into a usable product:

5.2.2.1. Kidde Aerospace and Defense, with representation from Fenwal: April 16, 1998 in Wichita, KS; Tom Hillman, John J. O'Neill, and Erdem A. Ural, PhD (Fenwal)

5.2.2.2. Pacific Scientific: May 1, 1998 in Duarte, CA; Mike Fone and Bill Meserve

5.2.2.3. Primex Aerospace: April 16, 1998 in Wichita, KS; Paul Wierenga

5.2.2.4. Whittaker Safety Systems: May 1, 1998 in Simi Valley, CA; Frank Bosworth

6. Background:

6.1. Active Explosion Suppression:

Systems have been developed to suppress explosions occurring in enclosed fuel tank spaces and dry bay spaces. This is achieved by very quickly sensing the actual explosion and then very rapidly discharging a suitable suppression agent (suppressant). These systems have successfully demonstrated their ability to extinguish explosions, to prevent damage due to explosive over-pressure, and to prevent sustained fires in extensively documented military research and testing.

Similar explosion protection systems have been used in various industrial applications, in military aircraft in the fuel tank ullage and dry bay applications, and in commercial aircraft in vent box applications.

Typical systems designed for the most recent use on military aircraft in dry-bay protection systems, consist of optical detector systems, control unit/power supply systems, and suppressor systems.

6.1.1. Detector System:

The detector system provides an output to the control unit/power supply system, identifying that a hydrocarbon fire is present and, by the nature of the detector installation design, where the fire is located. Due to the extremely rapid response time required, optical detection is necessary.

6.1.2. Control Unit / Power Supply System:

The control unit / power supply system receives the electrical output from the detectors, and any other necessary input (such as fuel level information in the case of fuel tank ullage protection case), and commands the discharge of the suppressant system. Current technology allows a wide range of design configurations, from numerous small, simple systems, monitoring neighboring portions of the area to be protected, each capable of discharging suppressant within their specific area of influence, to large integrated systems which monitor the entire area to be protected, adjusting for changes in ullage volume, and capable of controlling the discharge of suppressant throughout the entire area or partial areas.

6.1.3. Suppressor System:

The suppressor system consists of the suppressant (suppression agent), the suppressant storage container, the suppressant release mechanism (solenoid valves, squibs and rupture disks, etc.) and the distribution network (ports or tubing if appropriate). The signal from the control unit / power supply system is used to activate the suppressant release system.

Current technology offers a number of different types of suppressant dispersal systems. Solid propellant gas generators produce inert gaseous exhaust (N_2, CO_2 and H_2O) which can be used directly to purge a volume of combustible vapors or air (principally O_2), or can be used to drive a quantity of suppressant from the associated canister and into the volume being protected, low vapor pressure suppressants (such as Pentane, water or water/AFFF mix) can be thrown from a scored container by the shock action of a small explosive within the canister, or a high vapor pressure or pressurized suppressant (such as Halons or pressurized water, AFFF mix) can be released by the explosive rupture of the pressurized storage container or associated rupture disks. These technologies have been demonstrated in numerous ground tests and shown to have significant merit.

6.2. Why the Military uses this technology:

During the Viet Nam War, a significant percentage of the aircraft losses were directly attributed to the US aircraft being highly vulnerable and minimally survivable when hit by small -to-medium arms fire. As a result of this assessment, the Armed Services formed joint services task groups dedicated to identifying combat aircraft vulnerability and improving their inherent survivability. One such task group is the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) based at Wright-Patterson AFB, Ohio. In roughly the same time frame, the UK began development of fuel tank ullage protection systems.

6.3. Military Service Experience and History with this technology:

In the UK, Graviner, LTD designed and fielded a fuel tank ullage protection system which utilized an Infrared (IR) optical sensor, a controller and a series of canisters filled with liquid Pentane, strategically positioned within the fuel tank. Field experience has been accumulated on the AVRO Vulcan, the Handley Page Victor, the Vicker Valiant and the Hawker Hunter, but the general data available does not provide a complete service history. Some of these aircraft were still in operation in the early 1990’s, and as far as this writer knows, the ullage protection systems also remained operational.

This is the only ‘operational’ fuel tank ullage protection system uncovered in this technology investigation and as such, provides limited confirmation of the technology’s overall success. In practice, the Graviner system has been credited with a number of ‘saves’ (suppression of actual fuel ignition), but has also been credited with a number of ‘false alarms’ (uncommanded discharges).

7. Design Alternatives:

No alternative designs were investigated.

8. Design and Installation Requirements:

This section identifies the considerations that need to be addressed in the design and installation of possible systems developed around the explosion suppression technologies described within this report.

8.1. Optical Detector Systems:

8.1.1. Design:

The number and placement of detectors required to protect a fuel tank ullage space or a dry bay is dependent upon the volume of the tank or space, the area affected, and the internal physical geometry, including physical obstructions such as spars, ribs, bulkheads, baffles, stringers, fluid lines and quantity indication probes, which obstruct the clear visual fields of the detector.

Hydrocarbon fuel fires produce radiant energy in the spectral range of 0.10 to 100 micron wavelengths, with most of the radiant energy emitted in the infrared region between 0.7 and 10 microns and a strong emission band at 4.4 microns due to the carbon dioxide molecule excitation. It should be noted that commonly used aviation fuels, including Avgas, exhibit almost identical spectral characteristics.

Optical detectors are of two general types, thermal and photon.

8.1.1.1. Thermal Detectors:

Thermal detectors produce an electrical output in response to absorbed, radiant energy and the subsequent heating of a sensing element. These detectors have a response time dependent on the amount of energy received per unit time by the sensing element and the temperature change rate per unit of time of the sensing element.

8.1.1.2. Photon Detectors:

Photon detectors produce an electrical output in response to absorbed photons. Appropriate filtering lenses are utilized to ‘focus’ each photoelectric sensor on the desired wavelength and color temperature, thereby tailoring the sensor to respond to a specific input. Since heating of a sensing element is not required, photon detectors have much sorter response times and can detect smaller energy sources reliably over a greater range of distances.

Discriminating detectors have an ability to distinguish between anticipated extraneous light sources such as electrical sparks, welding arcs, lightning, maintenance lighting, sunlight, etc., and the actual ignition event. Current technology sensors may contain multiple photoelectric sensors within a detector, each filtered to a different, specific wavelength and utilization logic. These detectors can greatly reduce or eliminate the potential for false alarms.

8.1.2. Installation:

The current technology in detectors allow a range of installations from completely within the fuel tanks and ullage spaces, to remote mounting outside the fuel tank and ullage space, using optical cables and appropriate penetrations or windows to monitor the volume within.

A significant number of sensors are required due to the sensor’s limited field of view and the internal tank obstructions. In a new aircraft design, such concerns can be optimized to provide the best coverage with the fewest number of sensors.

8.2. Control Unit / Power Supply Systems:

8.2.1. Design:

The number of control / power supply units are dependent on the ‘zone’ definition used in the overall protection scheme being implemented. Each unit is designed to electrically receive signals from a number of sensors and to electrically trigger the appropriate number of suppression systems in response. Additionally, some technologies reviewed can require the input of liquid levels within the tank to minimize the pressure rise effects from the discharge of the suppressors. If the installation of such a system is to be made in an aircraft which has an MMEL item for inoperative fuel quantity indication systems, an independent means of determining the fuel level (or ullage volume) will be necessary.

If a single unit is expected to provide protection for an entire tank or tank system, then all sensors report to the single control / power supply unit (a single ‘zone’ system). Similarly, multiple ‘zones’ might be defined to protect an extended tank system.

Due to the importance of systems such as these, functional status from either power-up BIT checks or continuous BIT checks must be reported to the cockpit, in the preferred format for the particular aircraft type or design.

8.2.2. Installation:

The control / power supply is designed to be installed in a dry environment, and electrically connected to the sensor systems and the suppressor systems. Inputs from the aircraft fuel quantity indicating system or a dedicated liquid level indication system may be required.

8.3. Suppressor Systems:

8.3.1. Design:

The number and placement of suppressors required to protect a fuel tank ullage space or a dry bay is dependent upon the volume of the tank or space, the area affected, and the internal physical geometry, including physical obstructions such as spars, ribs, bulkheads, baffles, stringers, fluid lines and quantity indication probes, which impede the dispersal of the suppressant.

The systems design must provide protection for the worst case situations, i.e., turbulent, hot, high aromatic fuel. The basic requirements to be addressed in the design are:

a) Rapid dispersal time: Dispersal of the suppressant must occur in 10 to 25 msec.

b) Adequate Suppressant Concentration:

c) Ability to discharge the agent without creating unacceptable loads in the mounting and adjacent structure.

d) Ability to adjust the amount of suppressant discharged to account for varying ullage volume.

e) The initiating system and its attendant electrical power source and supply system must not add an explosion hazard to the fuel tank environment.

f) Suitable safeguards and maintenance procedures must be in place to ensure inadvertent suppressant discharge does not occur with personnel in the tanks.

g) Suitable power-up or continuous BIT capability must be provided.

8.3.1.1. Suppressant:

The suppressant used or chosen-

a) Must fully transform at the lowest predicted in-service temperature

b) Must have satisfactory fire suppression characteristics.

c) Must be environmentally acceptable and governmentally approved.

d) Must not present a substance health hazard to maintenance personnel.

e) Must not have any adverse effects on the fuel usability following agent discharge into a tank.

f) Must not have an adverse effect on the tank structure or other tank mounted equipment through corrosion or other deterioration.

8.3.1.2. Suppression System Container:

The container types developed thus far have the following shapes: tubular, cylindrical, hemispherical, and conventional fire bottle design. The means of initiating the agent discharge is electrical operation of solenoid valves, fire extinguishing agent squibs, and other pyrotechnic initiators.

The suppression system used must possess the following qualities:

a) At discharge, the tank over-pressure created must be acceptable.

b) At discharge, the thrust loads imposed on support structure must be acceptable.

c) Must provide long life of the assembly including the contents and the initiating system.

8.3.2. Installation:

A typical system requirement is for sufficient electrical system capacity to provide the combined current draw for simultaneous initiation of multiple suppressors. While this current draw is high, it is of brief duration. If an existing aircraft electrical system were unable to meet this requirement, means are available to provide it.

Special structural provisions may be required to handle the high thrust loads created by the tubular linear fire extinguisher system (LFE®) manufactured by Whittaker. Lesser addition thrust loads may also be exhibited by the Kidde hemispherical suppressors and by the Primex gas generator system. No thrust loads are generated by the Kidde cylindrical suppressor system.

9. Technical Data:

9.1. Kidde Aerospace and Defense

Kidde Aerospace and Defense now includes Fenwal Safety Systems, Kidde Graviner, Santa Barbara Dual Spectrum, L'Hotellier, and Walter Kidde Aerospace.

The research conducted on the original Graviner system dates prior to 1951. In 1954, a British patent was granted to Graviner Manufacturing Ltd. (Now Kidde-Graviner)

Graviner suppression systems utilizing IR optical sensors and pentane suppressant were fitted to the following British military aircraft: AVRO Vulcan, Handley Page Victor, Vickers Valiant, and Hawker Hunter. It is reported that "saves" have occurred with these systems. False initiations also were experienced.

A lot of IR sensor development has occurred since the original systems were installed. The status of present day IR sensor technology as used in Kidde dry bay suppression systems being flown on the F-18, F-22, EH-101, and V-22 aircraft allows for the successful recognition of and response to hydrocarbon fires and the exclusion of response to specific anticipated false light sources. Present sensors weigh 0.25 pounds and utilize 28 VDC power at 5 mA. The response time is 2 to 3 milliseconds and can be made quicker. Sensors would be located outside the tank, with optical viewing ports through the tank walls or flange mounted on the inside tank wall with wires passing directly through the wall. The number of sensors will vary with the size of the tank. The controller / power supply unit would be provided to satisfy the various system requirements when established, including BITE and flight deck annunciation. Sequential firing can be provided should the simultaneous firing current exceed the instantaneous current capacity of the aircraft electrical system.

9.1.1. Kidde Technical Data

9.1.1.1. Weight

The system weights were provided and are shown on Figure 9.1.

If the threat area within a tank can be considered localized, the system can be tailored to the localized area and all impacts would be greatly reduced, accordingly. Such a concept, if feasible, would be highly desirable.

9.1.1.2. Size (cargo/passengers/fuel displaced)

No size estimates were performed.

9.1.1.3. Range Impact

No range impacts were performed.

9.1.2. Certifiability status

While this technology has been used on military aircraft, it has not been used on commercial aircraft in fuel tank ullage explosion suppression. Use on commercial aircraft would require design, structural and electrical load analysis, and testing of effectiveness of a specific system, a reliability analysis, operational impact determination, and approval of a suitable suppressant.

9.1.2.1. Similarity to previous tests or flight experience

The Graviner system has received substantial laboratory testing and has been used on the following British aircraft in fuel tank ullage protection: AVRO Vulcan, Handley Page Victor, Vickers Valiant, and Hawker Hunter. Very similar dry bay protection systems have been used in the following US aircraft: F-18, F-22, EH-101, and V-22.

9.1.2.2. Additional Testing or Analysis

A test program for a proposed commercial aircraft design would need to be accomplished, as discussed in 9.1.2. Later technology sensors would need to be verified to not cause inadvertent initiation. The final design should be tested at various fuel quantities to verify prevention of over-pressure.

9.1.2.3. Other Effects on the Aircraft

No other effects have been identified.

9.1.3. Safety

Ullage explosion protection systems have been installed in British military aircraft used in service. No safety problems are known.

9.1.3.1. Effectiveness in preventing over-pressure hazard (from the explosion)

Substantial testing has proven that an explosion suppression system of this type can prevent structurally damaging over-pressures, even for threats due to high energy ignition sources resulting from tank penetrations by various types of armaments.

9.1.3.2. Evaluation against Historical Commercial Aircraft Over-pressure events

It is believed that explosions resulting from the lower energy ignition sources, which might occur in commercial aircraft, could be successfully suppressed based on the protection which is currently provided against the much higher energy ignition sources caused by armament penetrations of dry bays on F-18, F-22, EH-101, and V-22 aircraft.

9.1.3.3. Negative Impacts

9.1.3.3.1. Increased Landings due to range reduction (due to the added weight)

Increased landings would occur due to fuel volume reduction only if portions of the suppression system are located below the surface of the fuel. It is anticipated that all the sensors and most or all of the currently available hemispherical type suppressors could be located in the ullage, no fuel volume reduction would occur and no increases in landings would be expected.

Aircraft range reduction due to the added weight of a hemispherical type suppressor system has been calculated to be approximately as follows:

Large Transport:	6.38 nautical miles
Medium Transport:	8.19 nautical miles
Small Transport:	11.88 nautical miles
747 Center Wing Tank only:	2.24 nautical miles

Therefore, the effect of range reduction on landings is considered negligible.

9.1.3.3.2. Increased landings due to extra fuel consumed

Increased landings, due to increased fuel consumption caused by added system weight, would occur. The magnitude of the increase could vary, due to the complexity of the system configuration chosen. The maximum suppression system weights are shown in the data table included in 9.1.4, Cost Impact.

The additional block fuel consumed at constant range due to the added weight of a hemispherical type suppressor system has been calculated to be as follows:

Large Transport:	0.080 % increase
Medium Transport:	0.082 % increase
Small Transport:	0.092 % increase
747 Center Wing Tank only:	0.028 % increase

Therefore, the effect of additional fuel consumption on landings is considered negligible.

If the option was chosen, of protecting only the ignition source threat area in only one tank, the negative impact would be greatly reduced due to a minimum system weight. The weight of this option has not been defined.

9.1.3.3.3. Personnel Hazards

Inadvertent system operation has occurred with early type sensors. This is not expected with the later technology sensors presently being used. The observation of proper in-tank maintenance procedures is necessary with any such systems and must include system disarming prior to tank entry for maintenance.

9.1.3.3.4. Aircraft Hazards or Effects

To avoid any hazard related to tank over-pressure associated with the discharge of the system, it is designed to sense fuel level and discharge the amount of suppressant required by the ullage volume present.

To avoid or minimize the addition of wiring within the tank, the design can provide for sensors mounted against the inside surface of outside tank walls with wiring outside the tank. Tank level information can be provided from level sensors mounted inside the tank, with wiring in conduits where sensors are not mounted on tank outside walls.

For any suppressors which can not be mounted on outside tank walls, wiring for suppressor initiation at a momentary 5 amps per suppressor, must be housed in conduits inside the tank.

9.1.3.3.5. Other Equipment Hazards or Effects

Other equipment hazards have not been identified.

An equipment effect worthy of note is the possibility of the fuel quantity system MEL item being deleted in support of the suppressor system. The suppressant system, in most applications, requires some type of fuel quantity or fuel level input. The fuel quantity system, if used for this purpose, might be removed from the MEL, as one option..

9.1.4. Cost Impact

9.1.4.1. Component Costs and Standard Aircraft Matrix Summary

The system cost and weight are shown in Table 9.1.

9.1.4.2. Retrofit

9.1.4.2.1 Design Costs

These costs have not been calculated due to lack of data.

9.1.4.2.2 Installation Costs

The installation labor cost per aircraft is estimated to be as follows if accomplished during scheduled maintenance while fuel tanks are open and are based on a labor rate of $45 / m-hr:

Large Transport:	$16,650
Medium Transport:	$11,925
Small Transport:	$6,840
747 Center Wing Tank only:	$9,540

9.1.4.2.3 Operational Costs

There are no known system operational costs.

9.1.4.2.3.1 Maintenance Costs

9.1.4.2.3.1.1 Scheduled Maintenance Costs

The scheduled maintenance man-hour requirements are estimated to be as follows:

Note: Check interval varies with aircraft type and operation.

Daily / Weekly: None.
C-checks (@ 18 to 24 mo.): 1 m-hr for BITE check.
D-checks (@ 6 to 8 years): 1 m-hr for BITE check.

9.1.4.2.3.1.2 Periodic Parts Replacement Costs

Detonator replacement is estimated to be required at 10 year intervals and would occur at heavy maintenance; however, the material cost is not available.

9.1.4.2.3.1.3 Unscheduled Maintenance Costs

These costs, comprised of costs of delays, cancellations, out-of-service time, and maintenance man-hours and materials, have not been determined due to lack of reliability data.

9.1.4.3. Current Aircraft (Production Incorporation and Continued Production)

9.1.4.3.1 Design Costs

These costs have not been calculated due to lack of data.

9.1.4.3.2 Installation Costs

These costs have not been calculated due to lack of data.

9.1.4.3.3 Operational Costs

There are no known system operational costs.

9.1.4.3.3.1 Maintenance Costs

9.1.4.3.3.1.1 Scheduled Maintenance Costs

The scheduled maintenance man-hour requirements are estimated to be as follows:

Note: Check interval varies with aircraft type and operation.

Daily / Weekly: None.
C-checks (@ 18 to 24 mo.): 1 m-hr for BITE check.
D-checks (@ 6 to 8 years): 1 m-hr for BITE check.

9.1.4.3.3.1.2 Periodic Parts Replacement Costs

Detonator replacement is estimated to be required at 10 year intervals and would occur at heavy maintenance; however, the material cost is not available.

9.1.4.3.3.1.3 Unscheduled Maintenance Costs

These costs, comprised of costs of delays, cancellations, out-of-service time, and maintenance man-hours and materials, have not been determined due to lack of reliability data.

9.1.4.4. New Aircraft

9.1.4.4.1 Design Costs

These costs have not been calculated due to lack of data.

9.1.4.4.2 Installation Costs

These costs have not been calculated due to lack of data.

9.1.4.4.3 Operational Costs

There are no known system operational costs.

9.1.4.4.3.1 Maintenance Costs

9.1.4.4.3.1.1 Scheduled Maintenance Costs

These costs have not been calculated due to lack of data.

9.1.4.4.3.1.2 Periodic Parts Replacement Costs

Detonator replacement is estimated to be required at 10 year intervals and would occur at heavy maintenance; however, the material cost is not available.

9.1.4.4.3.1.3 Unscheduled Maintenance Costs

These costs, comprised of costs of delays, cancellations, out-of-service time, and maintenance man-hours and materials, have not been determined due to lack of reliability data.

Table 9.1. Estimated Explosively Discharged Suppressant Systems Weight and Procurement Costs

Kidde - Explosion Suppression System

Estimates are for Pentane-based Suppressant

	Tank Vol. (US Gal)	Sensors qty/wt (#/lb)	Suppressor qty/wt (#/lb)	Controller weight (lb)	Misc weight (lb)	Total System weight (lb)	Est Costs ($) *
Large Transport							
+ Canister Suppressor	25000	50/20.0	400/280.0	4	20	324	$303,000
Hemi Suppressor		50/20.0	125/312.5	4	62.5	399	$150,500
Medium Transport							
+ Canister Suppressor	10000	35/14.0	250/175.0	4	15	208	$196,500
Hemi Suppressor		35/14.0	85/212.5	4	42.5	273	$106,000
Small Transport							
+ Canister Suppressor	2000	20/8.0	100/70.0	4	10	92	$90,000
Hemi Suppressor		20/8.0	40/100.0	4	20	132	$58,000

747 CWT							
+ Canister Suppressor	17000	40/16.0	378/264.6	4	18	302.6	$278,800
Hemi Suppressor		40/16.0	40/100.0	4	20	140	$76,000

+ Canister is an out-of-production design

* Ball-park costs based on units identified in study and current production costs.
No estimates made for installation on new acft or as a retrofit on existing acft.

9.2. Pacific Scientific / HTL

Pacific Scientific is a major supplier of cargo compartment fire extinguishing systems and components, pneumatic products for missiles, automatic fire suppressions systems for military ground vehicles. The technology applicable to explosion suppression are optical sensors, Halon-discharge bottles, and a near “drop in” Halon replacement agent called Triodide.

9.2.1. Pacific Scientific / HTL Technical Data

The military ground vehicle explosion suppressions systems must suppress a fire/explosion in occupied vehicles such as tanks and armored personnel carriers. The over-pressures, heat, oxygen concentration, hydrocarbon combustion by-products, and the toxicity of the agent must be survivable and meet military specifications. The sensor is a discriminating, three-frequency optical sensor which has good false alarm immunity and will not fire the suppressant for a long list of false light sources. The Halon bottles are solenoid activated, not squib activated. The F-22 dry bay protection system has multiple bottles with sensors on each bottle, and BITE check capability.

Pacific Scientific / HTL does not manufacture and have not tested explosion suppression systems for fuel tanks, only for applications in dry bay and occupied areas. Significant development would be required to adapt their current technologies to fuel tank applications. It is not known how much signal attenuation and signature shift would occur with a fuel film over the sensors and how their discharge bottles would react in a submerged environment. Further development would be required to account for variable ullage and discharge pressure by using microprocessor controls and multiple bottle arrays.

9.2.1.1. Weight

No weight estimates were developed since the applicability of this technology is not known for explosion suppression in fuel tanks. No detailed design was performed and no weight data was submitted

9.2.1.2. Size (cargo/passengers/fuel displaced)

No sizing estimates were developed.

9.2.1.3. Range Impact

No range impact estimates were developed.

9.2.2. Certifiability status

Pacific Scientific explosion suppression systems have not flown on commercial airplane and have not been previously certified. This technology has been qualified in military applications, but not on commercial aircraft. Consequently, an extensive and rigorous analyses and testing programs would be required to prove the effectiveness of the technology and design, the safety of the aircraft, and the system reliability.

9.2.2.1. Similarity to previous tests or flight experience

No previous ground or flight testing have been done for this technology on commercial aircraft.

9.2.2.2. Additional Testing or Analysis

A complete testing program will have to be performed to demonstrate proof of concept and design, before any certification testing can be performed. Prevention of tank over-pressures in a variable ullage volume and the effects of discharging the agent under the fuel would have to be demonstrated.

9.2.2.3. Other Effects on the Aircraft

No other effects on the aircraft have been identified.

9.2.3. Safety

The effectiveness of this technology for explosion suppression in fuel tanks has not been demonstrated or determined. If this could be demonstrated, then the safety of discharging into a variable ullage volume and possible discharges under the fuel would have to be demonstrated. Possible wing over-pressurization could result if the system designed for an empty tank discharges into a full tank. Also, the hydraulic ram effect of discharging the agent under the fuel could cause the tank to rupture.

9.2.3.1. Effectiveness in preventing over-pressure hazard (from the explosion)

The effectiveness of this technology has not been demonstrated in preventing over-pressures in fuel tanks, only in military aircraft dry-bays.

9.2.3.2. Evaluation against Historical Commercial Aircraft Over-pressure events

No evaluation was performed since the capabilities of the technology has not been demonstrated for explosion suppression in fuel tanks.

9.2.3.3. Negative Impacts

9.2.3.3.1. Increased Landings due to range reduction (due to the added weight)

No evaluation was made.

9.2.3.3.2. Increased landings due to extra fuel consumed

No evaluation was made.

9.2.3.3.3. Personnel Hazards

Since the inadvertent firing of the agent when personnel are in the tank is a potential threat, the system would be de-energized before entering the tank.

9.2.3.3.4. Aircraft Hazards or Effects

Possible tank over-pressures could result from the discharge of agent sized for an empty tank when the tank is full. Also the hydraulic ram effect if the agent is discharged under the fuel could rupture the tank. System designs would need to avoid these conditions.

9.2.3.3.5. Other Equipment Hazards or Effects

None has been identified.

9.2.4. Cost Impact

Since the technology has not been demonstrated to protect against explosions in fuel tanks and an system design was not developed, an exhausting cost benefit was not performed. Only the ROM costs below was provided by Pacific Scientific / HTL:

DESCRIPTION	QTY	$ EACH	$ TOTAL
Optical Sensor	8	900.00	7,200.00
Amplifier	1	5,000.00	5,000.00
Extinguisher	8	1,600.00	12,800.00
Control Unit	1	5,000.00	5,000.00
Cable Harness	1 set	15,000.00	15,000.00
Brackets/Misc. fixing devices	1 set	10,000.00	10,000.00
		TOTAL	$45K.

9.2.4.1. Component Costs and Standard Aircraft Matrix Summary

No data available.

9.2.4.2. Retrofit

No data available.

9.2.4.3. Current Aircraft (Production Incorporation and Continued Production)

No data available.

9.2.4.4. New Aircraft

No data available.

9.3. **Primex Aerospace Company** (Including the former Olin Aerospace Company)

9.3.1. Primex Technical Data

Primex produces various fire suppression and explosion protection technologies which are installed on various military aircraft. The technology applicable to explosion protection are chemical gas generator systems, similar to the gas-air-bag technology in automobiles. This generates a large volume of gas in milliseconds from an electrically initiated, exothermic reaction releasing carbon dioxide, nitrogen, water and trace compounds. The gas generation technology has been successfully demonstrated in live fire testing to protect a fuel tank from catastrophic over-pressure for armor piercing incendiary threats (API), but was to slow to protect a fuel tank against a 23mm high energy incendiary (HEI). However, the initiation of the gas generators was triggered by the test apparatus or personnel and was not initiated by a reactive sensing devise which would be required for explosion suppression systems on aircraft. There is sensing technology available which could trigger the gas generation technology fast enough to suppress an explosion, but this has not been demonstrated. Sensor initiated gas generation systems have demonstrated compliance for aircraft dry bay fire/explosion protection on the V-22 and F-18E/F aircraft.

The advantages to gas generation technology are as follows:

a) Quickly disperses non-corrosive inerting agents without pressurized containers

b) Long shelf life (20 years)

c) Low maintenance

d) No freezing point depression issues

e) Canisters are not powered except to trigger

f) Canisters can be installed in tank where required

g) Can be selectively discharged by a remote controller

h) Gas is radially discharged resulting in good suppressant dispersion and creates no reaction loads on the aircraft structure

The disadvantages of gas generation technology are as follows

a) High temperatures of discharge gases

b) Controller must know ullage volume and fuel level (FQIS) to ensure tank is not over-pressurized from variable ullage volumes and to ensure canister is not activated under the fuel level (hydraulic ram effect may rupture tank)

c) Canister wiring must be routed in tank

d) Have not tested volumes larger than 120 cubic feet

e) Single shot canisters

    1) Require tank entry after discharge

    2) Containers are not re-usable

Another configuration that Primex has developed is a hybrid system where a liquid suppressant is discharged by the gas generator. The expanding gases from the gas generator expel a liquid suppression agent. This has been successfully tested in live fire testing but the has not been demonstrated for fuel tank explosions. The advantages are as follows:

a) Long shelf life

b) Low maintenance

c) Usable with any low pressure suppressant

d) No high pressure discharge into ullage

e) Low propellant weigh requirement

f) Ullage volume (FQIS) input to controller desired but not required

g) Canisters are not powered except to trigger

h) Can be BITE checked

i) Controllers can selectively discharge canisters

j) Faster discharge rates than nitrogen charged systems

The disadvantages of the gas generator-hybrid system are:

a) Suitable low pressure suppressant needed

b) Water has been demonstrated effective but has freezing point issues

c) Canister triggering wiring and squibs-initiators must be located in tank

d) Single shot canisters

e) Requires tank entry to replace after discharge

9.3.1.1. Weight

The weight estimates shown in Table 1 are for the total tank volume, mains and CWT. The bizjet tank volume is shown as 2000 gallons, but the standard volume is 1200 gallons. The weights are quite low for all models compared to other methods such as foam and nitrogen inerting. Any airplane structural changes are not shown but would be minor.

9.3.1.2. Size (cargo/passengers/fuel displaced)

The canisters are 1-2" in diameter and up to 1' long and would occupy a minimal tank volume. The controller located outside of the tank would occupy a small volume and would require no modifications to the airplane to install.

9.3.1.3. Range Impact

The only range impact would be carrying the additional weight shown in Table 9.3.

9.3.2. Certifiability status

9.3.2.1. Similarity to previous tests or flight experience

The Fenwal system on the Boeing 707 and 747-100 airplanes had an old technology Halon fire extinguishing system, installed in the surge tanks to prevent ground fires entering the wing. This system was only for fire protection and not intended to be fast enough for explosion suppression. Although this system was qualified and certified, there is little similarity to an explosion suppression system in the tanks, other than the similar technology used. Putting additional wiring and squib initiators in the fuel tanks presents a new set of safety concerns which need to be addressed. A complete new certification program would be required from proof of concept and design, considering failure modes and effects analysis, full scale testing and flight testing would be required for certification.

9.3.2.2. Additional Testing or Analysis

A complete new certification program is required from proof of concept and design, failure modes and effects analysis, full scale testing and flight testing would be required for certification.

9.3.2.3. Other Effects on the Aircraft

The FQIS would need to be functional for the controller to determine ullage volume, this could not be MEL dispatchable as it is today. Accessing the data bus would be required.

An alternative is to provide a dedicated fuel quantity measuring system to provide an input to the suppression system, thereby eliminating the effect on the aircraft FQIS and any MMEL alleviation provided.

9.3.3. Safety

9.3.3.1. Effectiveness in preventing over-pressure hazard (from the explosion)

The gas generator technology has demonstrated effective in suppressing fuel tank explosions for military threats up to API rounds. This is in excess to any threats internal to the tanks. However, the gas generation technology was not tested with a reactive sensor and has not been demonstrated system effectiveness as would be installed on the airplane. There are extremely fast sensors which have demonstrated effectiveness with other explosion suppression technology in fuel tanks. Therefore it is likely that the gas generation technology could be effective in suppressing fuel tank explosions. The gas generation-hybrid technology has shown effective in dry bay applications but not in fuel tank applications.

9.3.3.2. Evaluation against Historical Commercial Aircraft Over-pressure events

This technology was not evaluated against the historical events because the total system (sensors and gas generators) has not demonstrated effectiveness for fuel tank explosion protection.

9.3.3.3. Negative Impacts

9.3.3.3.1. Increased Landings due to range reduction (due to the added weight)

No evaluation was made.

9.3.3.3.2. Increased landings due to extra fuel consumed

No evaluation was made.

9.3.3.3.3. Personnel Hazards

Certainly if the system was activated with personnel in the tanks this could result in serious injury. The system would have to be de-activated prior to any entry into the fuel tank.

9.3.3.3.4. Aircraft Hazards or Effects

Putting pyrotechnic devices (squib or pyrotechnic initiators) into the tank may present a risk to the aircraft. A full safety analysis would be required to determine the resulting level of safety for the system. Presumably the fact that explosion suppressant would be released if the squib was activated would ensure any ensuing explosion would be suppressed.

9.3.3.3.5. Other Equipment Hazards or Effects

None have been identified.

9.3.4. Cost Impact

Only cost of procurement, shown in Table 9.3., have been evaluated. Since the complete system (sensor and gas generators) have not been demonstrated effective in suppressing fuel tank explosion, a complete costs analysis was not performed.

9.3.4.1. Component Costs and Standard Aircraft Matrix Summary

Refer to Table 9.3.

9.3.4.2. Retrofit

No data available.

9.3.4.3. Current Aircraft (Production Incorporation and Continued Production)

No data available.

9.3.4.4. New Aircraft

No data available.

Table 9.3. Estimated Gas Generation and Hybrid Systems Weight and Procurement Costs

Primex - Solid Propellant Gas Generator Systems

Insert Gas produced by solid propellant

	Tank Vol (US Gal)	Sensors qty/wt (#/lb)	Suppressors qty/wt (#/lb)	Controller weight (#)	Misc Weight (lb)	Tot System Wt (lb)	Est. Tot System Cost ($)*
Large Transport							
Active	54,000	30 / 15.0	58 / 290	12.0	40.0	360	$163,500
Hybrid		30 / 15.0	29 / 145	8.0	30.0	200	$141,750
Medium Transport							
Active	24,000	15 / 7.5	26 / 130	8.0	15.0	160	$92,000
Hybrid		15 / 7.5	13 / 65	5.5	10.0	90	$82,250
Business Jet							
Active	2,000	4 / 2.0	4 / 10	3.0	1.0	20	$29,000
Hybrid		4 / 2.0	4 / 10	3.0	1.0	15	$29,000

* Cost estimates based on units identified in study and current production costs.
No estimates made for installation on new aircraft or as a retrofit on existing aircraft.

Based on:
Suppressor unit weight = 5.0 lbs each (1000 gram agent)
Sensor weight = 0.5 lb each
Wiring weight = 0.012 lb/ft
Large Transport = 35 ft per component
Medium Transport = 25 ft per component
Business Jet = 10 ft per component

9.4. Whittaker Safety Systems

Whittaker Safety Systems (previously known as the John E. Lindberg Company and as Systron Donner) is a major supplier of fire, smoke and bleed air leak detection and suppression and detection control systems equipment for military and commercial aviation aircraft.

Whittaker designed the Linear Fire Extinguisher (LFE®) explosion suppression system in response to a military RFP in 1985 for dry-bay protection against API and HEI threat. Original requirements were for aluminum oxide powder as the suppressant, but testing showed this to be a poor requirement and Whittaker Safety Systems moved to develop a Halon system using a similar tubular container design.

9.4.1. Whittaker Technical Data

9.4.1.1. Weight

A comparison of weights, provided by Whittaker, of the Tubular Storage systems to other protection systems (rigid foam, N_2 Inerting, Halon Inerting, Scott Foam, etc.) show the Tubular Storage system to be the lightest system per unit volume protected. Specific weights are dependent on the detailed requirements and the configuration of the installation being evaluated.

9.4.1.2. Size (cargo/passengers/fuel displaced)

Since the concept of the LFE® allows any physical length of tubing to be used, it is not limited in length sizing. However, it is necessary that the container be sized in diameter according to the amount of suppressant needed to protect the volume of the tank being considered; the greater the container diameter, the greater the resulting volume of suppressant to be released.

Due to the pressurized nature of the container, the volume of fuel displaced by the suppressant storage system is minimized.

9.4.1.3. Range Impact

The only range impact would be carrying the additional weight of the system.

9.4.2. Certifiability status

9.4.2.1. Similarity to previous tests or flight experience

Whittaker Explosion Suppression System components were designed into the wing structure and first tested on the Bell V-22 Tiltrotor aircraft. Later, similar Whittaker components were tested on equivalent structures of the F/A-18 Naval fighter. These tests were done in controlled testing environments where flight conditions were simulated, but to this date, no system of this sort has flight experience.

9.4.2.2. Additional Testing or Analysis

Further testing is required to determine the compatibility of the suppressant with the environment and the fuels requiring protecting, especially considering alternative suppressants. Testing must address the concerns associated with potential over-pressures, the effects of discharging the LFE® when completely submerged in fuel and the ability of successfully dispersing the agent into the fueled areas.

Further design and development work is necessary to understand and to minimize the reactive loads that are imposed on the aircraft structure when the LFE® is discharged. The testing to date have not shown these loads to be a structural problem, but the nature of high magnitude, impulse loads require a dedicated look at the effects, or potential effects.

A certification program is required to address the complete installation and operation of the finalized system.

9.4.2.3. Other Effects on the Aircraft

The FQIS would need to be functional for the controller to determine ullage volume, this could not be MEL dispatchable as it is today. Accessing the data buss would be required.

An alternative is to provide a dedicated fuel quantity measuring system to provide an input to the suppression system, thereby eliminating the effect on the aircraft FQIS and any MMEL alleviation provided.

9.4.3. Safety

9.4.3.1. Effectiveness in preventing over-pressure hazard (from the explosion)

As described in 9.4.2.2. above, testing to address the concerns of over-pressures must be conducted.

9.4.3.2. Evaluation against Historical Commercial Aircraft Over-pressure events

No evaluation was made.

9.4.3.3. Negative Impacts

9.4.3.3.1. Increased Landings due to range reduction (due to the added weight)

No evaluation was made.

9.4.3.3.2. Increased landings due to extra fuel consumed

No evaluation was made.

9.4.3.3.3. Personnel Hazards

Activation of this system with maintenance personnel in the tank presents a hazard of serious injury. Positive and appropriate deactivation procedures must be incorporated prior to entry into a tank equipped with this suppression system.

9.4.3.3.4. Aircraft Hazards or Effects

Pyrotechnic devices in aircraft fuel tanks presents a risk to the aircraft. A full safety analysis would be required to evaluate the resulting level of safety of the aircraft. In the case of this suppression system, a discharge of the system would release an explosion / fire suppressant into the fuel tank and reduce any threat due to fire or explosion.

9.4.3.3.5. Other Equipment Hazards or Effects

None have been identified.

9.4.4. Cost Impact

9.4.4.1. Component Costs and Standard Aircraft Matrix Summary

Only ROM cost of procurement, shown in Table 9.4., have been evaluated.

DESCRIPTION	$ EACH
Optical Sensors	$1,500
LFE® Units	$800
Controller	TBD
Brackets	TBD

9.4.4.2. Retrofit

No installation data available.

9.4.4.3. Current Aircraft (Production Incorporation and Continued Production)

No installation data available.

9.4.4.4. New Aircraft

No installation data available.

Table 9.4. Estimated Linear Fire Extinguisher System Component Costs

Whittaker Safety Systems - LFE® Suppressant System

FUEL TANK PROTECTION SYSTEMS

Rough Order of Magnitude
SYSTEM COST MATRIX SUMMARY

AIRCRAFT TYPES (MTOGW - MLW)	PROJECTED NUMBER OF TANKS	FUEL VOLUME (US GAL)	PROJECTED NUMBER OF DETECTORS	DETECTOR COSTS	PROJECTED NUMBER OF EXTINGUISHERS	EXTINGUISHER COSTS	TOTAL COSTS
LARGE (800K - 600K)	5	54,000	10	$15,000	30	$24,000	$39,000
MEDIUM (330K - 270K)	5	24,000	10	$15,000	20	$16,000	$31,000
SMALL (160K - 130K)	3	4,000	6	$9,000	12	$9,600	$18,600
REGIONAL T/FAN (76K-69K)	3	3,200	6	$9,000	6	$4,800	$13,800
REGIONAL T/PROP (40K-38K)	2	1,400	4	$6,000	4	$3,200	$9,200
LARGE BIZJET (35K-30K)	3	2,000	4	$9,000	6	$4,800	$13,800

10. Other Supporting Data

10.1 Standard Aircraft Matrix

Proposed Standards for evaluation airplane types

Units:			
Weight	pounds	Volume	US gallons
Speed	knots	Pressure	psi
Altitude	feet		

Model	Large	Medium	Small	Regional T/fan	Regional T/prop	Bizjet
General						
Fleet size	2,000	1,400	8,600	1,000	2,000	8,600
MTOGW	800,000	330,000	160,000	78,000	40,000	23,000
MLW	600,000	270,000	130,000	69,000	38,000	20,000
Fuel Volume:						
Total	54,000	24,000	5,000	3200	1400	1200
Center	25,000	10,000	3,000	800	0	0
Wing	26,000	12,000	2,000	2400	1400	800
Tail	3,000	2,000	0	0		
Body	(optional)	(optional)	(optional)	0	0	400
Tank Configurations						
% fleet with Center Tanks	89	97				6
% of Center Tanks with Heat Input						0
% fleet with Tail Tanks	36	25				0
% fleet with Body Tanks	2	0				54
Tank Pressure						
Positive	+1.5	+1.5	+1.5	2	2	+1.5
Negative	-0.5	-0.5	-0.5	-1	-1	-0.5
Bleed flow available after ECS Bleed pressure avail after ECS Bleed temperature avail after ECS						
Precooler flow avail after ECS Precooler max outlet temperature at max flow						
Payload (lbs)	100,000	55,000	40,000	35,000	22,000	1,200
passengers	400	250	150	75	50	6
Short mission						
Range (nm)	2,000	1,000	500			1000
Ground Time (hr)	2.00	1.50	1.25			
Block Time (hr)	4.6	2.3	1.6			
# of flights per day (AOG data)	1,103	1,599	14,682			
# of airplanes in AOG data	757	608	3,552			
# of flights per day	2,914	3,682	35,548			
Medium Mission						
Range (nm)	4,000	2,000	1,000	450	250	3000
Ground Time (hr)	2.00	1.50	1.25	0.33	0.33	
Block Time (hr)	8.6	4.6	2.8	1.4	1.1	
# of flights per day (AOG data)	432	399	4,152			
# of flights per day	1,141	919	10,053	10,000	20,000	
Long mission						
Range (nm)	6,000	4,000	2,000			6500
Ground Time (hr)	2.00	1.50	1.25			
Block Time (hr)	12.7	8.9	5.1			
# of flights per day (AOG data)	206	235	1,060			
# of flights per day	544	541	2,566			
Distribution						
% short missions	63	72	74			54
% medium missions	25	18	21	100	100	27
% long missions	12	11	5			19
Operating environment						
Max. Cruise Alt.	43,000	43,000	37,000	35,000	25,000	41,000
Ground temp max	130 Deg F	130 Deg F	130 Deg F	122 Deg F	122 Deg F	122 Deg F
Ground temp min	-65 Deg F	-65 Deg F	-65 Deg F	-40 Deg F	-40 Deg F	-40 Deg F
Distribution of Ground Temp	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F
Distribution of Cruise Temp	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F
Distribution of Flash Point	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F
Vmo	365	360	340	320	250	360
Mmo	0.92	0.85	0.82	.0.80	0.5	0.83
M cruise	0.85	0.80	0.77	0.75	290T/220E	0.8
Climb rate (Max, Sea Level)	5,000	5,000	4,500	3000	2000	
Descent rate (Normal)	2,000	1,500	2,000	2000	2000	
Descent rate (Max)	3,500	4,000	3,000			

Aviation Rulemaking Advisory Committee

Fuel Tank Inerting

Task Group 3

Abstract

This report is the findings of the Inerting Task Group, which was formed as a portion of the Fuel Tank Harmonization Working Group activity established in January 1998. The FAA initiated this activity by the issuance of a Harmonization Terms of Reference entitled “Prevention of Fuel Tank Explosions” on 16 Dec 1997. The Working Group’s stated task was to study means to reduce or eliminate fuel tank flammability and to propose regulatory changes to the FAA Aircraft Rulemaking Advisory Committee.

The Inerting Task Group’s assignment was to provide a feasibility analysis of fuel tank inerting systems. The analysis was to focus on reducing or eliminating exposure to explosive mixtures for transport airplane operations. A cost/benefit analysis for inerting systems was to be included for the fleet of aircraft requiring retrofit, for current production aircraft, and for new type design aircraft.

Summary

The Inerting Task Group studied the technologies offered by the respondents to the FAA's Request for Information. Several technologies for providing inert gas were reviewed including carbon dioxide in gaseous form and as dry ice, nitrogen in gaseous and liquid form, and exhaust gas.

The group analyzed the impacts of carrying an on-board inerting system versus a ground-based system. In addition, the group studied the cost and benefit of inerting the center wing tank only versus inerting all of the aircraft's fuel tanks. Finally, two methods of purging oxygen from the tank were reviewed i.e. "scrubbing" the fuel and "washing" the ullage space above the fuel.

A ground-based system provides the potential for the least costly (non-recurring cost) system on the aircraft. However, it requires a substantial investment in ground equipment to supply inerting gas, plus the recurring costs of the inerting gas and operation of the equipment.

Scrubbing fuel at the airport fuel farm, or on the aircraft during refueling, is the least effective form of tank inerting. The ullage remains flammable during taxi, takeoff, and initial climb until inert gas evolves from the fuel. As fuel is consumed from a fuel tank, ambient air flows in to replace it and raises the oxygen concentration. The tank may only be inerted for the latter portion of climb and the beginning of cruise and is highly dependent of the initial fuel load. Clearly, this method provides little added protection to today's design. In addition, this method would provide no added protection for empty fuel tanks, as was the case for the TWA800 center wing tank.

Ground-based ullage washing is effective when considered in combination with the normal changes to fuel temperature during a flight. On average, the exposure to a flammable, non-inert ullage is approximately 1%.

On-board systems could provide inert gas throughout the flight and offer zero exposure to a flammable, non-inert ullage. There are several existing methods for providing nitrogen on board an aircraft. It can be stored as a gas in bottles or as a liquid in Dewar bottles, such as on the C-5. Either of these would require replenishment at an airport, which adds to the cost of the airport infrastructure.

An alternative to storing gases or liquids, on-board inert gas generating systems (OBIGGS) separate nitrogen from engine bleed air. Such systems exist on military aircraft today, notably the C-17 as well as some fighters and helicopters. All of these systems extract a performance penalty from the aircraft. A new aircraft design offers the best opportunity to minimize these penalties. Current production aircraft and the retrofit fleet may incur redesign and operational penalties that make them uneconomical to fly. Operational compromises will almost certainly be required. Many of today's aircraft do not have enough bleed air available to supply these systems.

Whatever the type of inerting that might be used, there are potential hazards to personnel. Gaseous inerting agents present a suffocation hazard and liquid nitrogen presents the additional hazards of freezing trauma to skin and eyes.

Several other on-board systems were reviewed. Exhaust gas from the jet's engines and auxiliary power unit (APU) was deemed infeasible primarily because the exhaust contains too much oxygen. Carbon dioxide in gaseous and solid (dry ice) form was also deemed infeasible because it's a greenhouse gas that adversely affects the environment. Also, except for nitrogen systems, none of the systems were mature enough to be considered for installation on commercial aircraft. Nitrogen is the best candidate at this time.

The following table provides a summary of the cost and benefit of each system.

Technology	**Effectiveness**	**Cost over 10 Years (US Dollars)**
On-board Liquid Nitrogen for All Tanks	100%	$35.7B
On-board Gaseous Nitrogen for All Tanks	100%	$33.9B
Air Separator Modules for All Tanks	100%	$37.3B
Air Separator Modules for the Center Tank	100%	$32.6B
Ground-based Ullage Washing with natural Fuel Cooling for Center Tank	99%	$4B with gaseous nitrogen $3B with liquid nitrogen

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1. Introduction

Task Group 3, the Fuel Tank Inerting Group, of the Fuel Tank Harmonization Working Group was tasked to assess current and future technologies which could drastically reduce or eliminate flammable mixtures in fuel tanks of Part 25 aircraft. Inerting systems provide an inert gas to displace the oxygen in the fuel and/or ullage resulting in a mixture that cannot sustain combustion.

In early 1997, the FAA issued a Request for Comment asking the industry and the public to propose and evaluate methods to reduce fuel tank flammability. Those respondents who recommended inerting suggested the use of nitrogen, carbon dioxide, or exhaust gases from engines or fuel burners as the inerting agent. Task Group 3 contacted all of these respondents to learn more about their proposals and worked with several of them to determine the viability of their proposals for existing and future aircraft.

Many of the respondents had hardware available or in the prototype stage and so were best able to provide estimated cost, weight, and size of their proposed hardware for our evaluation. Some of the respondents provided their conceptual ideas or patent information. Given more time, the Task Group would have attempted to better define the concepts and make an estimate of the cost, weight, and size of the system for inclusion in the report. While this wasn't possible, due to the short time available for the task, the Task Group felt it important to include the conceptual ideas for future reference. The Task Group also commented on the potential benefits and problems of the proposed technology when fitted to a present day aircraft.

The Task Group also evaluated methods of displacing the oxygen in the fuel and/or ullage with inert gas. We evaluated on-board systems to provide inerting gas on the aircraft at all times during a flight as well as ground-based systems that provide inert gas to the aircraft prior to flight. Fuel "scrubbing" and ullage "washing" were studied for effectiveness and efficient use of the inert gas.

2. References

2.1. Documents

[1] "Test and Evaluation of Halon 1301 and Nitrogen Inerting against 23MM HEI", Charles Anderson, AFFDL-78-66, May 1978

[2] "A Study of the Blast and Combustion Over-Pressure Characteristics of the 23MM High Explosive Incendiary-Tracer (HEI-T)", Charles M. Pedriani and Thomas Hogan, USAAVRADCOM-TR-80-D-33, November 1980

[3] "Inerting Conditions for Aircraft Fuel Tanks", Paul B. Stewart and Ernest S. Starkman, at University of California, WADC Technical Report 55-418, September 1955

2.2. Interviews

Mr. Alankar Gupta, Seattle, WA

Mr. Harley Harmon, Renton, WA

Mr. Elmer Luehring, Cleveland, OH

Mr. Daniel Gonzales Gellert, Sequim, WA

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2.3. Presentations (arranged by company)

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3. Background

3.1. How Inerting Technology Works

Inerting, as applied to aircraft fuel tanks, can be defined as the inclusion of a gas in the ullage prior to ignition of the vapor that will suppress that ignition, independent of the fuel air mixture. The gas used can be one that simply reduces the oxygen available for combustion, such as nitrogen, or one that chemically interferes with the combustion process, such as Halon 1301.

Although the military has investigated and used many types of inerting systems (and gasses) the presently available and viable systems all use nitrogen as the inerting gas. Systems using exhaust gas (B-50), CO2 and dry ice (B-47 and B-36) where used by the military but discontinued because of technical problems. Systems using flame-suppressing agents (Halon 1301) are presently being used on some smaller military aircraft. However, the ban on the production of Halon 1301 and the lack of any replacement agent makes that a nonviable technology for commercial use. Therefore, the only presently viable and acceptable inerting gas is nitrogen.

Nitrogen inerting works by reducing the oxygen concentration in the fuel tank ullage below that necessary to support combustion. Literature indicates that at 9% oxygen or below no reaction will occur in a tank with Jet A fuel regardless of the fuel air mixture or the ignition energy. Some testing has indicated that for most conditions 10-11% oxygen levels provides the same level of protection. Oxygen levels above the no reaction level but below 16% have been shown to provide some protection and reduce the pressure rise in reactions that do occur.

In order to initially inert a fuel tank with nitrogen, the nitrogen must be introduced into the tank in such quantity as to reduce the oxygen level below the desired 9%. In order to maintain an inert tank additional nitrogen must be introduced to counter the oxygen in the air drawn into the tank due to pressure changes and fuel usage. In addition, dissolved oxygen in the fuel released into the ullage as the pressure on the fuel decreases must be diluted with additional nitrogen. In order to minimize the need for additional nitrogen, systems normally include check valves at the fuel tank vents to maintain a slight pressure differential to ambient. This minimizes the introduction of air (21% oxygen) during minor pressure changes. Scrubbing (bubbling nitrogen through the fuel) prior to takeoff can reduce dissolved oxygen in the fuel.

Present inerting systems require the use of additional nitrogen during flight. The nitrogen is either loaded prior to flight and stored in liquid or gaseous form onboard, or generated in-flight by separating the components of air. The liquid nitrogen systems require ground based refilling at all landing locations, and a cryogenic nitrogen storage vessel onboard. Additional valving and plumbing is necessary to make sure only gaseous nitrogen enters the fuel tanks. Onboard inert gas generating systems (OBIGGS) can be of two types, the molecular sieve or the permeable membrane. Both types of systems require compressed air, usually engine bleed air, and produce a mixture of nitrogen enriched air (NEA) that is not pure nitrogen (but is usually less than 5% oxygen).

The molecular sieve utilizes a minimum of two beds of oxygen adsorbing medium, such as zeolite. As air passes through the medium oxygen is adsorbed. Thus, the gas that passes through is nitrogen rich. That gas is collected and passed on as the bed is back flushed, with the enriched oxygen gas exhausted overboard. Two beds are used such that as one is collecting nitrogen enriched gas the other is being cleansed of adsorbed oxygen.

The permeable membrane system is comprised of many very small hollow tubes made of a material that allows all the constituents of air to pass through more easily than nitrogen. Air is supplied to the tubing under pressure. Oxygen from the air permeates the tubing walls and is collected and exhausted overboard. What is left is nitrogen enriched air (NEA) usable for inerting.

3.2. Why Military Uses This Technology

The US military looks at aircraft vulnerability based on the mission for that aircraft. Inerting systems are installed on combat aircraft and aircraft likely to be fired upon during the conduct of its mission. The inerting system is designed to enhance the ability to survive enemy fire into a possibly explosive fuel tank. Although the military owns and operates many commercial type aircraft (including Air Force One, a Boeing 747) none of those aircraft have inerting systems or any other method of explosion protection for the fuel tanks.

Initial inerting systems, such as on the C5, utilized stored liquid nitrogen. These systems are heavy and rely on a large ground support system. As technology has advanced, the OBIGGS systems have become more practical. The system weight and inlet airflow and pressure to volume of nitrogen produced has vastly improved. All of the recently designed and installed nitrogen inerting systems have been of the OBIGGS type.

3.3. Military Service Experience and History with this technology

Very little data is available publicly on the effectiveness or reliability of nitrogen inerting systems presently used on military aircraft. What can be ascertained is that they are very effective in preventing fuel tank vapor ignition and the reliability (maintainability) is a problem. Information presented at the Transport Fuel Flammability Conference, October 7-9, 1997 in Washington DC. showed that the major reliability problems were with the Air Separation Module, ASM Filter and the Compressor. The valves and sensors had a high degree of reliability. Overall system Reliability was said to be <200 hours between failures and <100 hours between maintenance. Information presented on the C-5 indicated a similar reliability (maintainability) problem. The main problem on the C-5 was reported as the storage and refrigeration system for the LN2.

4. Design Alternatives

There are several possible design alternatives for an inerting system. The various options are:

1. a self-contained system on the aircraft;
2. a completely ground-based system (no aircraft-mounted equipment);
3. a hybrid system with the distribution pipes on the aircraft and the inert gas supply on the ground;
4. a hybrid system with the distribution pipes and a small inert gas supply on the aircraft and a ground-based inert gas supply for initially inerting the fuel tanks.

In addition, the system could be used to inert the body tanks only (center wing tanks and fuselage-mounted tanks) or all of the fuel tanks.

Also, there are three methods of inerting the fuel tank:

1. “fuel scrubbing”;
2. “ullage washing”;
3. providing inert gas to the tanks as fuel is depleted or during altitude changes.

There are a variety of gases that will inert fuel tanks and a variety of means to produce those gases. Lastly, there is a system for enriching the ullage above the upper flammability limit, which will be briefly discussed.

4.1. Self-contained (aircraft-based) system

An aircraft-based system has a supply of inerting gas, regulators to supply the gas to the fuel tanks at acceptable pressures, and vent check valves to prevent outside air from diluting the inert gas in the tanks.

The primary advantage to this system is that the fuel tanks will stay inert for most or all of the flight provided the system can maintain the flow demanded by the aircraft operation. The primary disadvantages are additional system weight, cost, loss of range due to the added weight, and loss of revenue because the aircraft can no longer carry as many passengers or as much cargo.

4.2. Ground-based system

This design alternative involves inerting the fuel at the airport’s fuel storage tanks or with a mechanism between the fuel trucks and the aircraft. This design is the best for the aircraft because no equipment is added. However, without a supply of inerting gas, air will eventually enter the aircraft fuel tank and raise the oxygen level so that the fuel tanks will not be inerted at some time during the flight. The safety of this alternative will be discussed in section 8.

4.3. Hybrid systems

Another alternative would be to install an inert gas distribution system in the aircraft fuel tanks and leave the supply of inerting gas on the ground. This reduces the weight impact on the aircraft compared to an aircraft-based system. Again, without a supply of inerting gas on the aircraft air will eventually enter the tank and raise the oxygen level so that the fuel tanks will not be inerted at some time during the flight.

Another alternative is to install the inert gas distribution system and a small inert gas supply on the aircraft while retaining the inert gas supply on the ground. The concept is that the ground-based supply of inert gas would be used to inert the fuel tanks during refueling. During flight the aircraft's inert gas supply would provide inert gas to the fuel tanks as the fuel is depleted and during altitude changes. This system could be sized to keep the fuel tanks inert throughout the flight but it obviously adds more weight to the aircraft than the ground-based system or the hybrid system above.

4.4. Body Tank or All Tanks

The Working Group's preliminary findings showed that the wing tanks were less likely to have a flammable mixture than the body tank. A safety analysis of the historical fuel system events showed that the wing tanks have demonstrated an acceptable level of safety and no further improvement is required. (Reference the report by Task Group 1.) A variation of all of the arrangements in sections 4.1 through 4.3 would distribute inert gas to the body tank only. This would put the inert gas where it is most needed, simplify the system, and minimize the cost and weight impact to the aircraft.

4.5. Fuel Scrubbing

Fuel scrubbing uses inerting gas to dilute the dissolved air in the fuel. This could be accomplished in the aircraft during refueling (Ref. Figure 1), or at the airport storage tanks when the fuel is delivered from the refinery. The scrubbers would be built in to the refueling system of the tank (or put inline between the truck and the aircraft) and mix the inerting gas with the fuel as the tank is filled.

During climb the air in the fuel, which is mostly nitrogen due to the scrubbing, will evolve out of the fuel to the ullage. This inerts the ullage during climb and for the early portion of the cruise flight phase. However, the ullage is not inert during refueling, taxi and takeoff. Refer to Figures 2 and 3.

Scrubbers require a minimum flow in order to work properly. If the flow from the truck or refinery is too slow then the inert gas will not be mixed into the fuel and it will not be inerted. The scrubber also adds some pressure drop to the system so more time would be required to fill the fuel tank(s). The primary disadvantage to fuel scrubbing is that it only works if a tank receives fuel. An empty tank, such as the TWA800 center tank, would not be inerted. Refer to Figure 4.

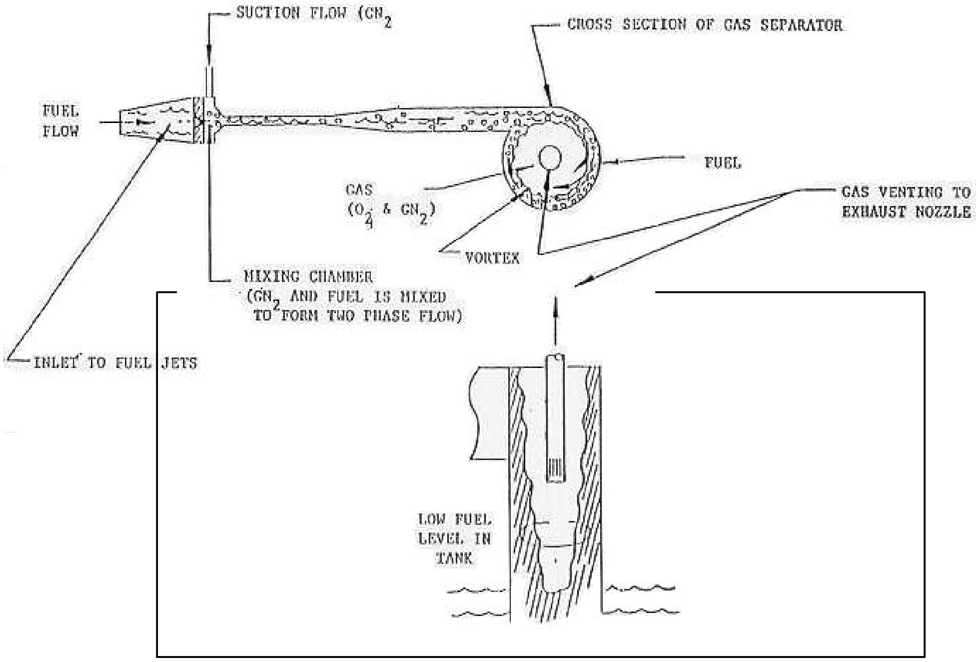
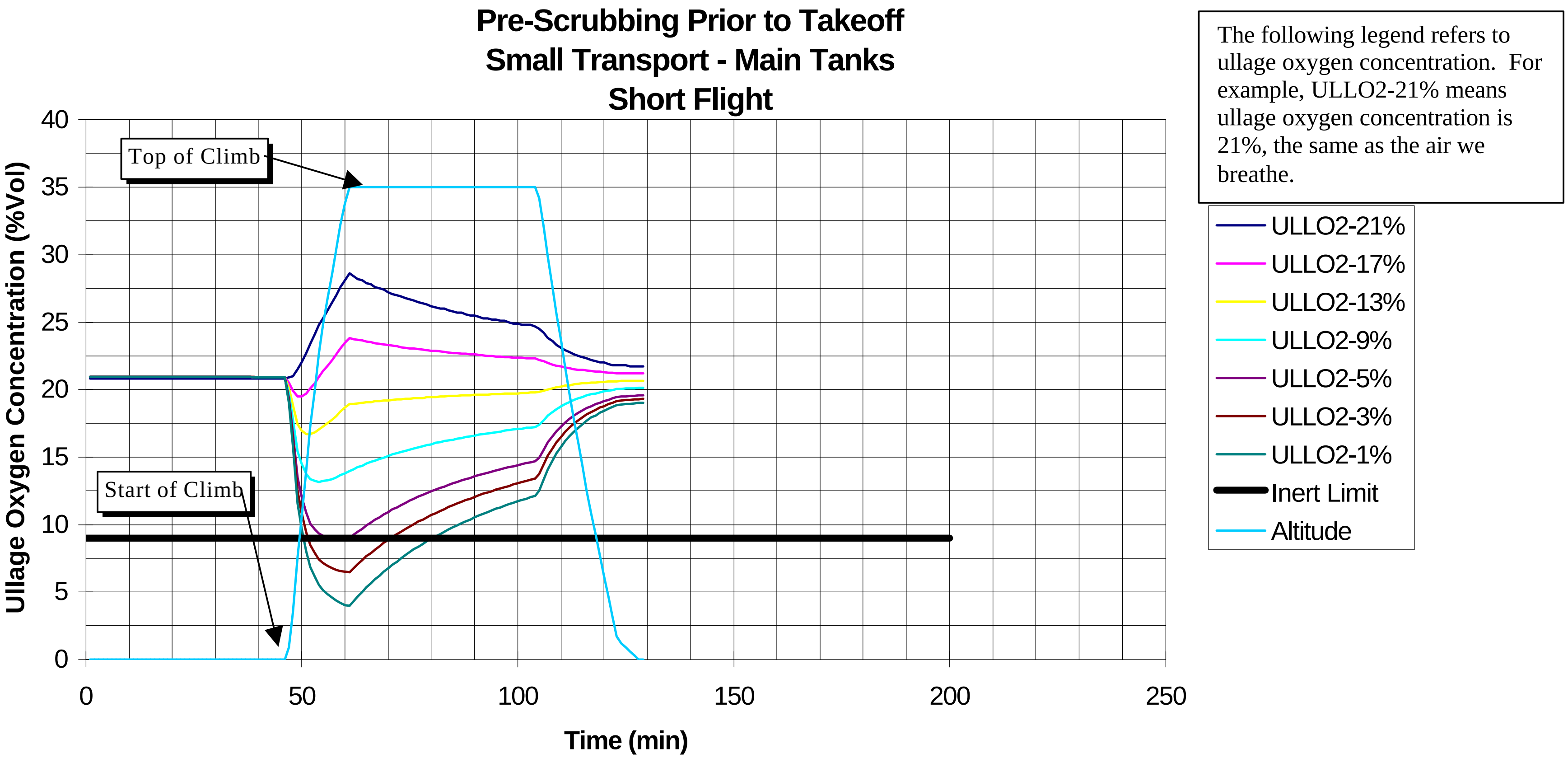


Figure 1
Cross Section of Fuel Scrubbing System
Mounted in a Fuel tank



The following legend refers to ullage oxygen concentration. For example, ULLO2-21% means ullage oxygen concentration is 21%, the same as the air we breathe.

Figure 2 – This figure shows the effect of scrubbing the fuel in the wing (main) tanks during refueling. Note that the ullage oxygen concentration remains at 21% until the start of climb when dissolved nitrogen and oxygen evolve out of the fuel. The oxygen concentration reaches a minimum (or maximum, depending on initial oxygen concentration) at the top of climb just as the aircraft's cruise phase begins. The oxygen concentration then begins to rise (or fall) as the fuel is depleted and ambient air replaces it.

Also, note that if the fuel is not scrubbed during refueling (the ULLO2-17 and -21% line) then the ullage oxygen concentration actually increases during climb as oxygen evolves out of the fuel. Oxygen dissolves and evolves more readily than nitrogen.

The following legend refers to ullage oxygen concentration. For example, ULLO2-21% means ullage oxygen concentration is 21%, the same as the air we breathe.

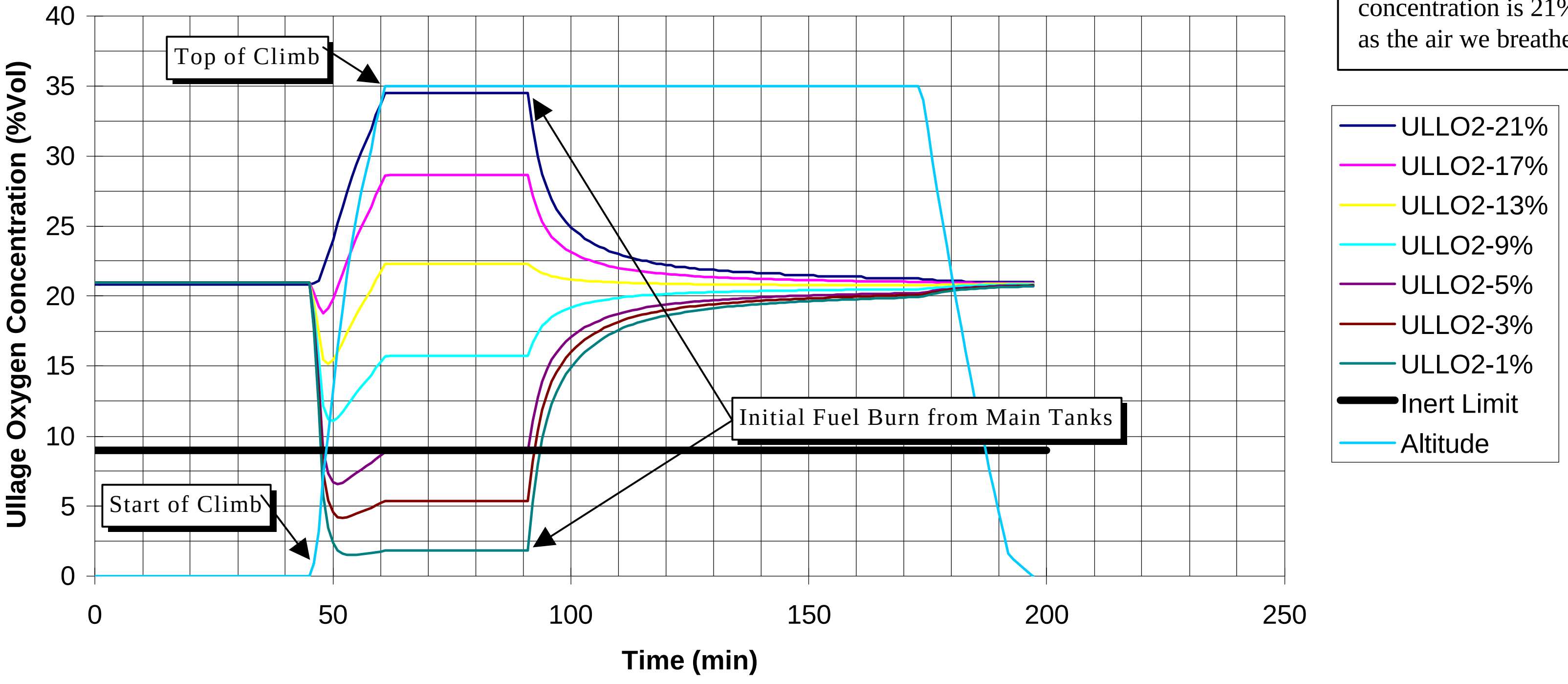
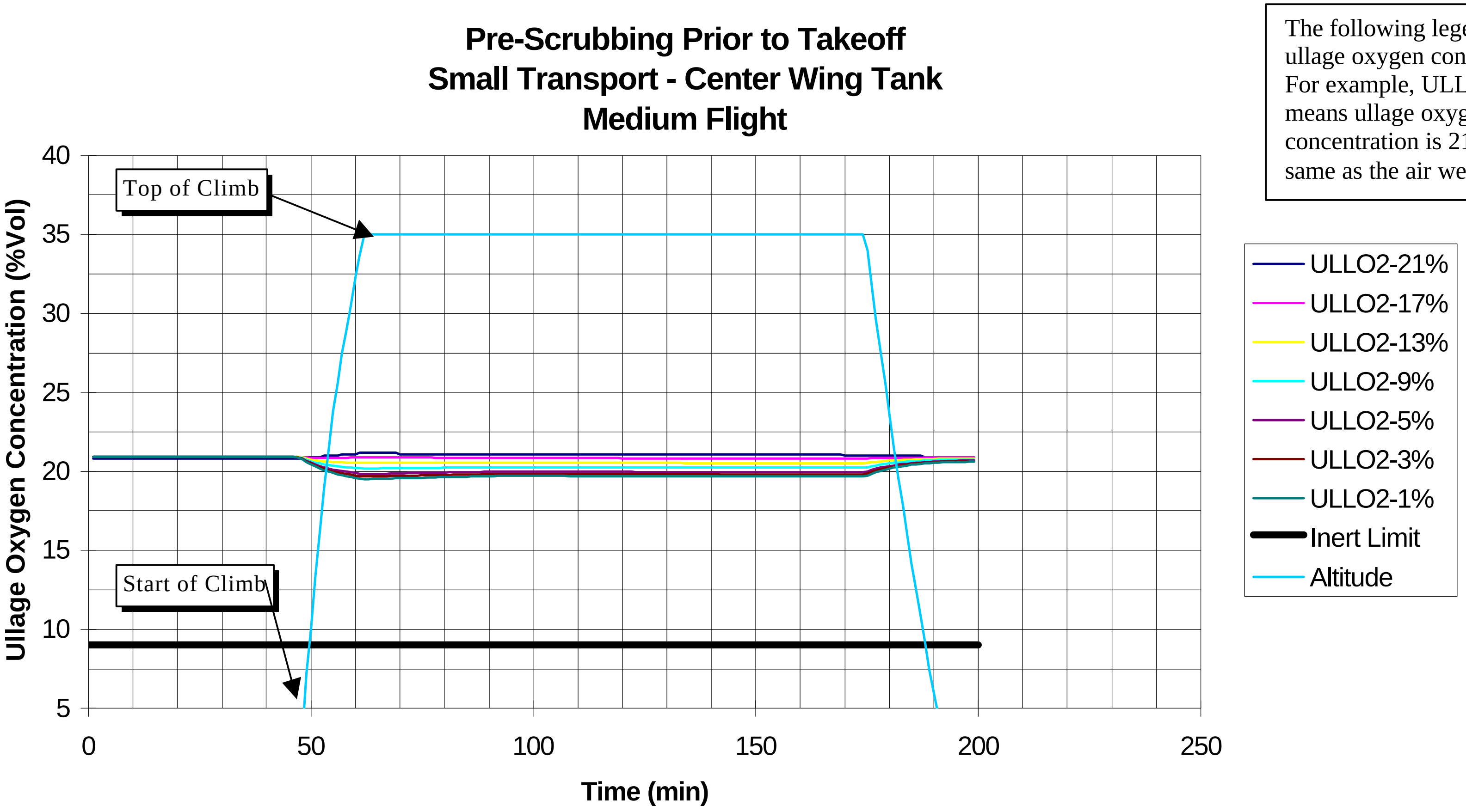


Figure 3 – This figure shows the effect of scrubbing the fuel in the wing (main) tanks during refueling. This differs from the previous figure because it's a medium length flight that requires fuel in the body tank (center wing tank) as well as the wing tanks. The center fuel is depleted before the wing fuel is used so the oxygen concentration remains constant in the wing tanks for a period of time. Note that there is a slight increase of oxygen concentration right after the start of climb due to evolving oxygen.



The following legend refers to ullage oxygen concentration. For example, ULLO2-21% means ullage oxygen concentration is 21%, the same as the air we breathe.

Figure 4 – This figure shows that scrubbing is not very effective for fuel tanks that have a small amount of fuel because there’s only a small amount of nitrogen evolution from the fuel compared to the large air volume in the ullage space.

4.6. Ullage Washing

Ullage washing uses inert gas to dilute the air above the fuel. Refer to Figure 5. To be effective, this can only be accomplished on the aircraft. A truck or cart with inerting gas would be connected to a distribution system in the aircraft to deliver the inerting gas to the fuel tanks. Alternatively, an onboard system could provide the inerting gas to the distribution system.

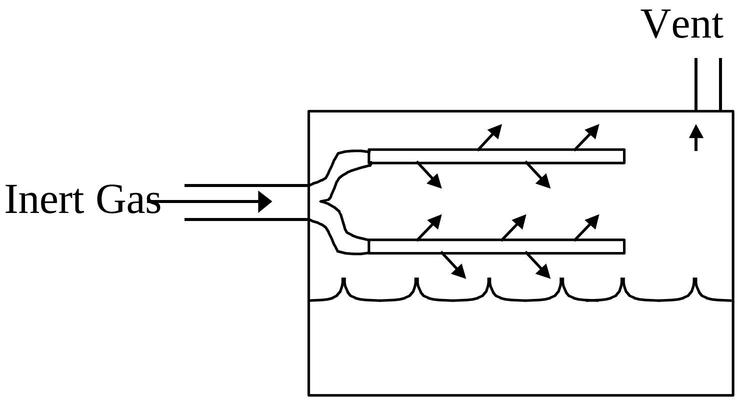


Figure 5 - Cross-Section of Ullage Washing System

The primary disadvantage to ullage washing is that it requires more nitrogen to inert the fuel tank than fuel scrubbing requires. There’s also a potential for fuel tank structural damage if the source of inerting gas isn’t regulated properly. Ullage washing works well in tanks with little fuel but is ineffective in tanks that are full of fuel. This is because the dissolved oxygen in the fuel evolves out during climb and mixes with the inert gas causing the ullage to exceed a 9% oxygen concentration. A large amount of fuel also means more oxygen is introduced into the tank as fuel is depleted and raises the oxygen concentration above the inert level. On the other hand, an empty tank will stay inerted until descent when the pressure change causes ambient air to enter the fuel tank. Ullage washing of a tank with a fuel quantity of 25% or less using NEA that contains 5% oxygen or less will remain inert until descent, provided there is no ventilation of the tank during operation. Figures 6 and 7 show the effectiveness of ullage washing for a nearly full and a partially full tank. Figures 8, 9, and 10 show that the combination of ullage washing and the normal drop in fuel temperature during a flight can help to limit a fuel tank’s exposure to a flammable, non-inert ullage.

A combination of fuel scrubbing and ullage washing avoids the problem of evolving oxygen for nearly full tanks. The ullage oxygen concentration decreased during climb. However, as the fuel is depleted from the tanks the oxygen concentration eventually exceeds 9% because ambient air replaces the depleted fuel.

Ullage washing combined with normal fuel temperature changes did prove effective. A statistical analysis combined fuel temperature and flash point, calculated by Task Group 5, with the ullage oxygen concentration that occurs on typical flights in the body (center wing) tank. This generated a time of exposure to a flammable, non-inert ullage. On average, the aircraft was exposed less than 1% of the time. Figures 8 and 9 show a sample of the fuel temperature, flash point, and ullage oxygen concentration for two of the several thousand flight conditions that were studied. This represents a significant improvement over present aircraft. The cost of this system will be provided in Section 9.

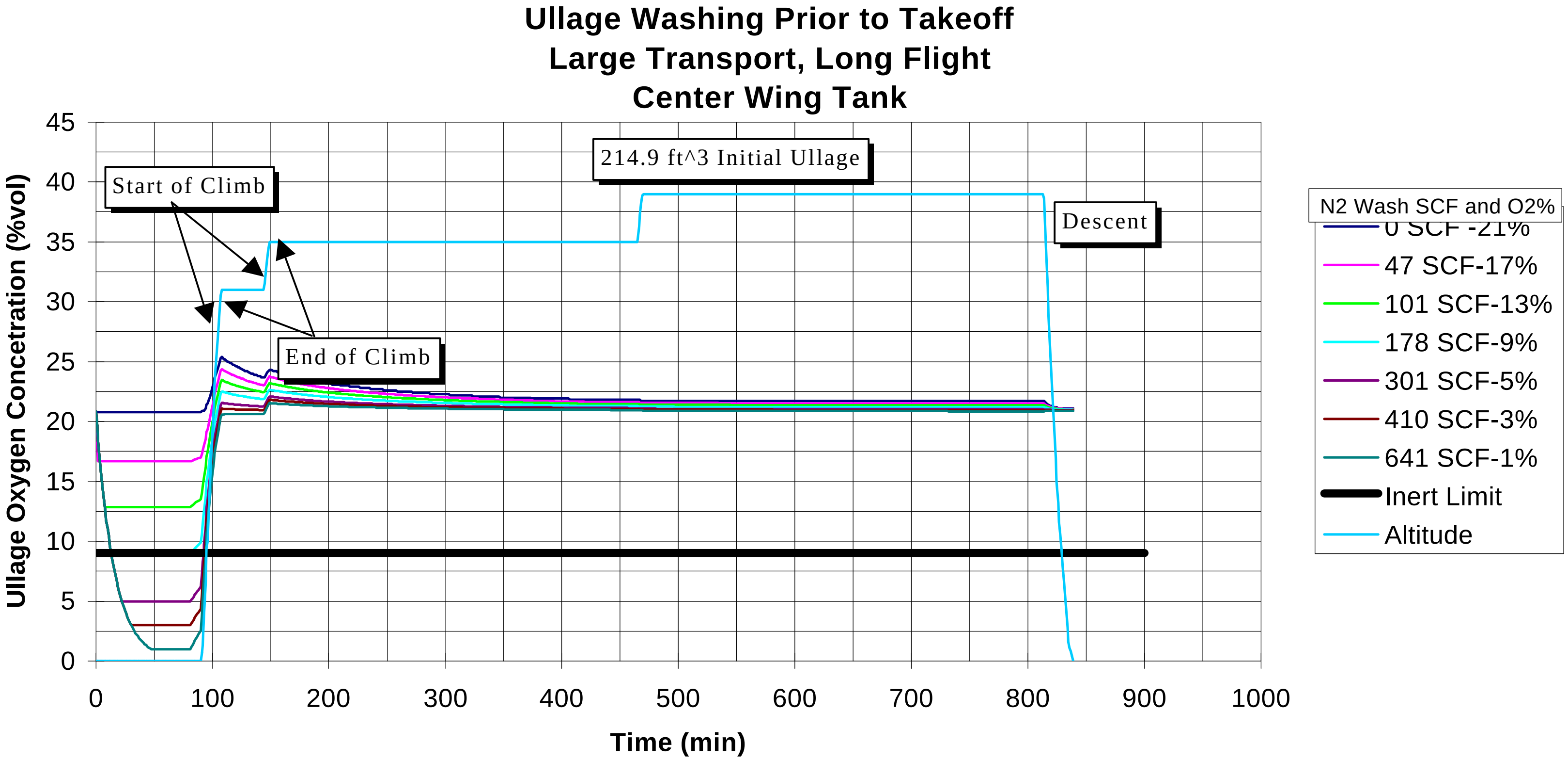


Figure 6 - Ullage washing has little effect on a tank with a large fuel quantity. Because of the large fuel quantity, a great deal of air evolves from the fuel during climb into the relatively small ullage space. The nitrogen in the ullage is diluted by the evolving air and quickly exceeds 9% oxygen.

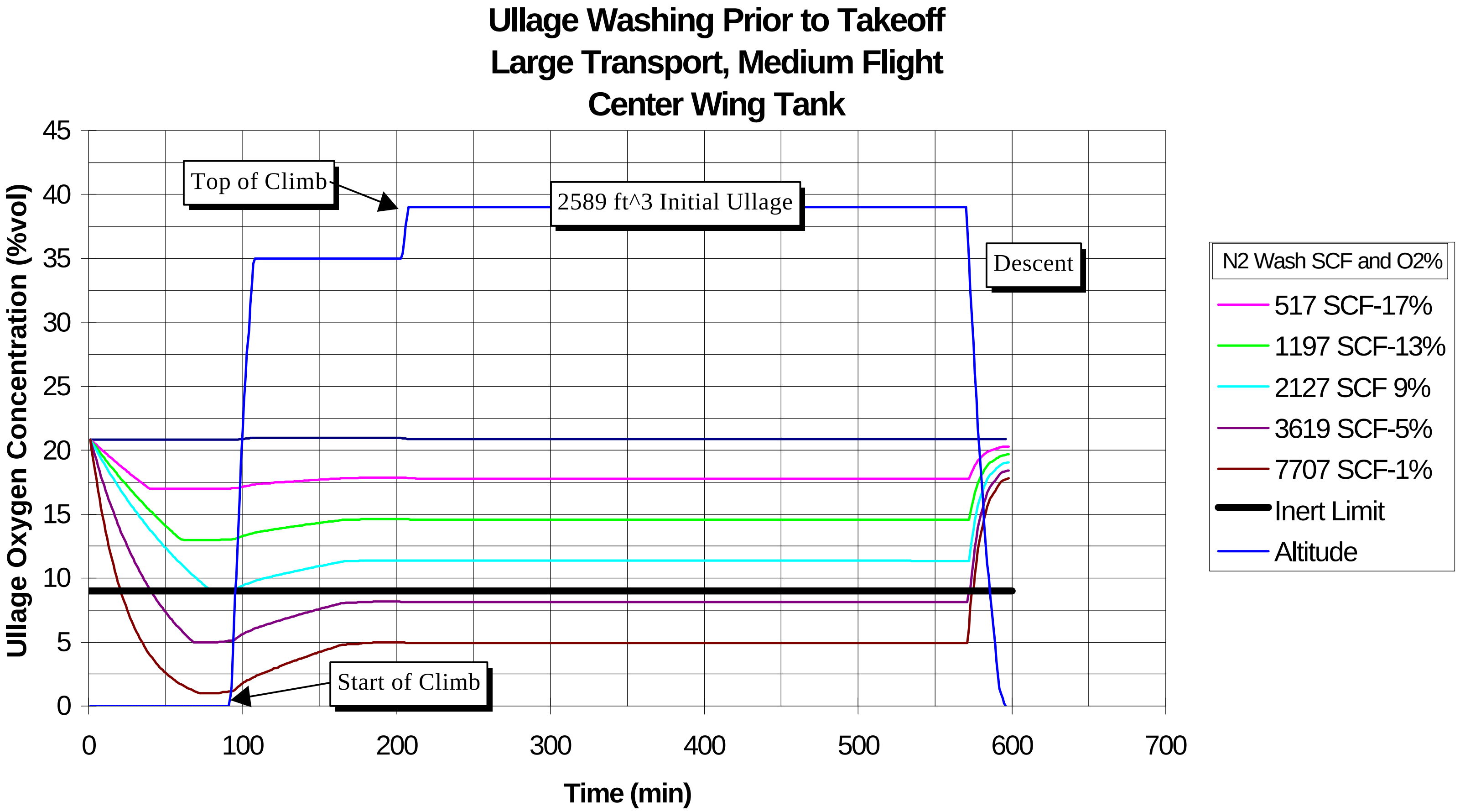
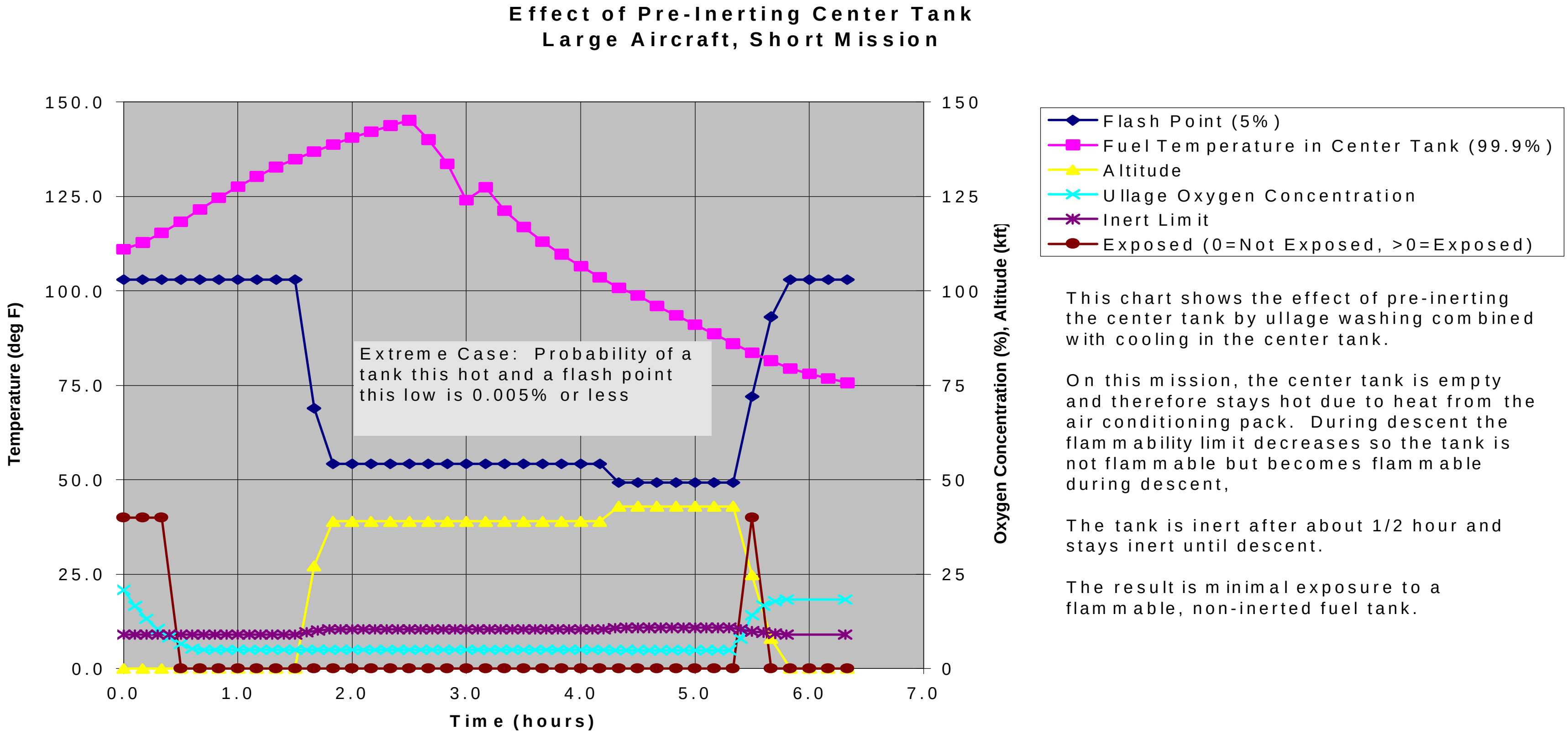


Figure 7 - Ullage washing is quite effective for a tank with little or no fuel (like the TWA800 center tank). The small quantity of fuel does not evolve enough air to dilute the nitrogen in the ullage. As a result, the tank will remain inerted until descent at which time ambient air enters the tank through the vent system.



Extreme Case: Probability of a tank this hot and a flash point this low is 0.005% or less

This chart shows the effect of pre-inerting the center tank by ullage washing combined with cooling in the center tank.

On this mission, the center tank is empty and therefore stays hot due to heat from the air conditioning pack. During descent the flammability limit decreases so the tank is not flammable but becomes flammable during descent,

The tank is inert after about 1/2 hour and stays inert until descent.

The result is minimal exposure to a flammable, non-inerted fuel tank.

Figure 8 Ullage washing on the ground helps to limit exposure to a flammable, non-inert fuel tank. This chart represents an extremely hot day combined with a very low flash point fuel. The likelihood of this combination is less than 0.005%. Also, the body (center) tank is empty for this mission.

The chart shows that the tank is flammable for most of the flight because the fuel tank temperature is higher than the flash point of the fuel. However, the oxygen concentration drops below the inert limit at about ½ hour into the mission and stays there until descent (at about 5.5 hours in the mission). So the tank is only exposed at the beginning of the mission and for about 15 minutes during descent as shown by the brown (exposed) line. Most flights would be exposed for an even lesser amount of time.

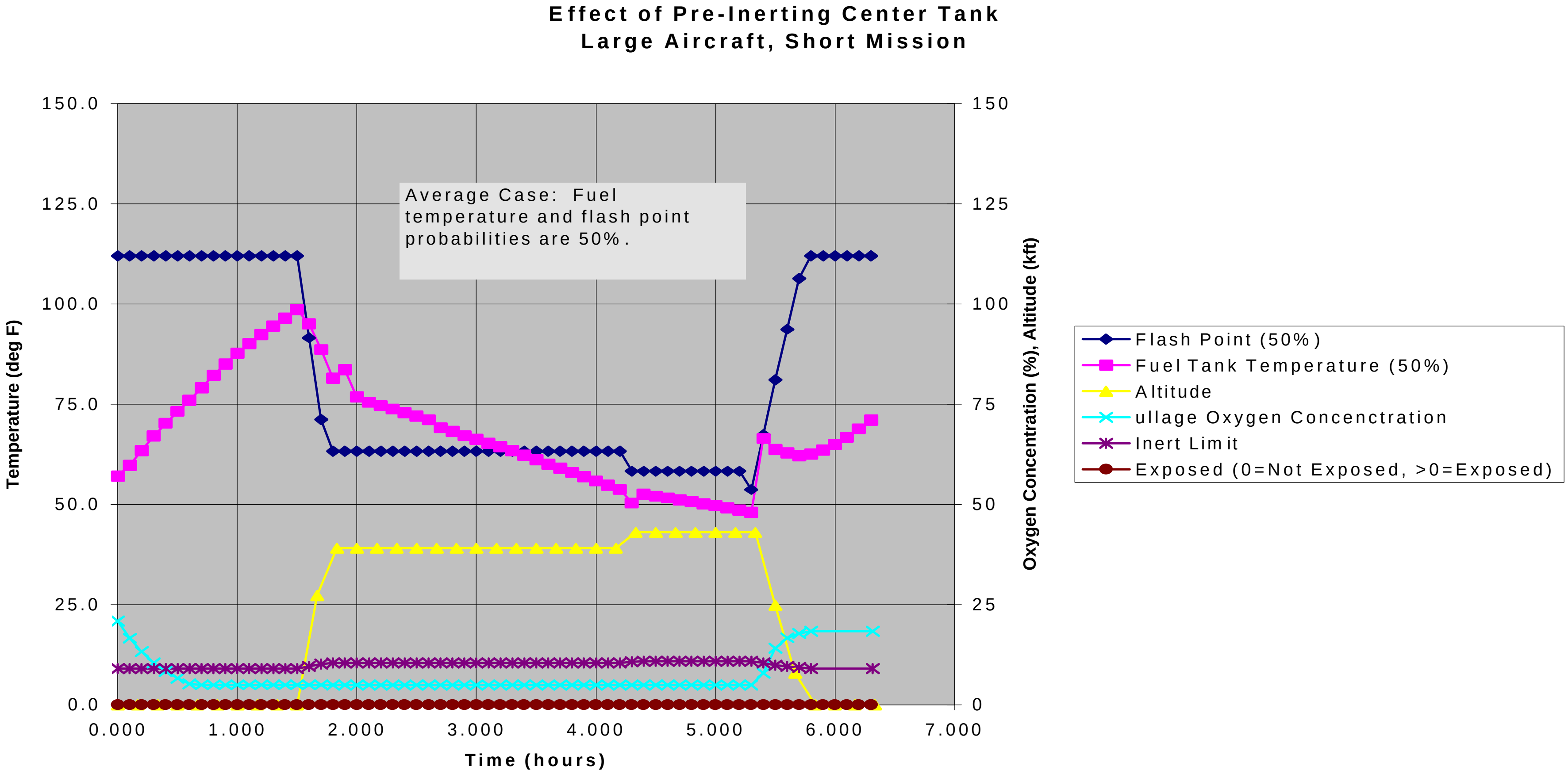


Figure 9 Ullage washing on the ground limits exposure to a flammable, non-inert fuel tank essentially to zero probability. This chart represents an average day combined with an average flash point fuel. The body (center) tank is almost filled for this mission.

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4.7. Inert Gas Supply

Several methods of supplying inerting gas were presented to the task group. Most of the methods used nitrogen, but carbon dioxide and exhaust gas were also presented.

4.7.1. Nitrogen

There are three types of nitrogen supplies: liquid nitrogen in Dewar bottles, gaseous nitrogen in high-pressure storage bottles, and gaseous nitrogen extracted from engine bleed air as mentioned in Section 3.1. Some of this technology exists while some of it is still in development.

Liquid nitrogen and gaseous nitrogen in storage bottles both require servicing at the airport to refill them. The on-board inert gas generating system (OBIGGS) does not require refilling but does require periodic maintenance and filter changes.

The two types of OBIGGS available presently are molecular sieve and permeable membrane. Molecular sieve systems have been in use since 1975 on various military aircraft. Molecular sieves adsorb oxygen from the air and can operate with source air pressures as low as 20 psig and temperatures between –20 ^{o}F and +120 ^{o}F. They are sensitive to liquids however and may need to be replaced if wetted. The adsorbed oxygen must also be flushed from the sieve at regular intervals. In operation, this means that two molecular sieves must be available and a valve cycles the source air between them to maintain a constant flow of inerting gas.

By contrast, permeable membrane systems are completely passive. They rely on the polymer membranes to separate nitrogen from air. These systems have been in commercial use since 1975 but have only recently been applied to aircraft. Permeable membranes work best with source air pressures of 60 psig and temperatures near 140 ^{o}F. A reduction of source air pressure to 30 psig would require approximately 3 times more membrane material to maintain the same output flow. A reduction to 15 psig would require 10 times more material. Thus, the system weight and its impact on the aircraft are sensitive to the source pressure.

Permeable membranes are also sensitive to source air flow. More source air is required to provide better purity (lower oxygen concentration). Three times more source air is required to achieve an oxygen concentration of 3% than for an oxygen concentration of 9%. The impact on aircraft resources can be minimized if a higher oxygen concentration can be permitted. Contaminates that could plug the membrane material would also require more bleed air to get the same effectiveness as an unplugged membrane.

4.7.2. Carbon Dioxide

There are three types of carbon dioxide (CO2) supplies: solid CO2 kept in cold storage (dry ice), gaseous CO2 in high-pressure storage bottles, and products of combustion. The dry ice and gaseous CO2 in bottles require servicing at the airport. Servicing for the combustion system is dependent on whether fuel or carbon is burned. Carbon combustion would require frequent servicing. Fuel combustion would likely require only periodic maintenance for filter changes, etc. These systems are conceptual at this time although dry ice was tried briefly in the 1950s.

It takes less carbon dioxide than nitrogen to inert a fuel tank. However, carbon dioxide dissolves into solution and evolves out of solution more readily than nitrogen. Consequently, fuel boost pump cavitation may occur because of altitude changes, pressure loss in fuel pipes or any other event that causes pressure changes. However, carbon dioxide was not pursued further in this study because it is a greenhouse gas that adversely affects the environment. Its use might be subject to future environmental restrictions or banned completely. Therefore, a more detailed study would be required to determine the feasibility of carbon dioxide as an inerting agent.

Due to the lack of hardware and test data required to complete a cost/benefit/feasibility analysis, this solution was not evaluated for this report.

4.7.3. Exhaust Gas

The use of exhaust gas was suggested as a means to inert the fuel tanks without adding bulky storage systems to the aircraft. The system would be self-contained and would likely only require periodic maintenance for filter changes. This is a concept only. There is presently no technology to evaluate at this time. Therefore, it was not considered further for cost, benefit, or feasibility in this report. However, there are some concerns with the concept.

Jet engines and auxiliary power units (APUs) do not burn fuel at a stoichiometric mixture ratio. They burn the fuel leaner than stoichiometric so that the exhaust gas is higher in oxygen than the typical combustion process. The oxygen level can range from 11% to 15% depending on the power setting for the engine and other factors. These levels are too high to be considered inert.

The exhaust stream of commercial aircraft engines is primarily ambient air due to the high fan-bypass ratio of these engines. This air contains 21% oxygen and is not inert. The lower oxygen concentrations (11-15%) must be drawn from the turbine section directly, or very close behind it, to avoid the fan bypass air. This section of the engine is typically at 1000 ^{o}F or higher and special materials are required to withstand the heat. Any penetration of the turbine case to install a bleed line would weaken the turbine case and increase the chance of engine damage from temperature stresses and vibration. Re-certification would be required to install a bleed line in the turbine case for existing engines and the cost would likely be prohibitive. A failure of the bleed line would create an unacceptable hazard to the aircraft.

Although the autoignition temperature of fuel is 450 ^{o}F, the exhaust gas must be cooled to 160 ^{o}F or less before it can be introduced into the fuel tank to protect components, fuel tank sealants, protective coatings, and fuel bladders. A large precooler would be required to reduce the gas temperature from >1000 °F to < 160 °F. Most transport aircraft have their engines mounted on the wings near the fuel tank so the location of a precooler is limited to the engine or engine pylon. On many aircraft, the addition of a larger, or an additional, precooler is not feasible due to space limitations in the pylon area. Other locations, such as the cargo compartment or the fuselage area could also be difficult due to space limitations and the need to provide outside cooling air to the precooler. This would require a duct and two air scoops on the side of the aircraft that add to the drag.

Another concern is a high concentration of water vapor in jet engine exhaust that would have to be removed before reaching the fuel tank. This is not desirable as water causes tank corrosion, promotes the growth of microbes in the fuel, and possibly would freeze at high altitude and block fuel pump inlets. Aircraft manufacturers design to avoid water in fuel tanks and the airlines perform frequent ground checks to make sure water is removed from the tanks before flight. Anything that adds water would require more systems and/or more frequent checking to avoid these problems.

There is also a fuel burn penalty for using exhaust or turbine gas. Turbine gases contribute to the energy needed to drive the engine fan to produce thrust. Exhaust gases expand and help to produce thrust. If some of the gas is diverted for other purposes then there is less thrust. The throttle setting must be increased to make up for the loss of thrust so more fuel is consumed. The estimated fuel penalty would be 5-10%.

Finally, there are contaminates in the exhaust gas that would have to be filtered prior to being introduced into the fuel tank. This would add to the size, cost, weight and maintenance of this method. There is a concern about the corrosive effects of the oxides of nitrogen and sulfur in the exhaust gases on the fuel system and tank. Filters would have to be maintained and a monitoring program would be required to avoid adverse affects to the fuel tank.

4.7.4. Fuel Enrichment of the Ullage

This concept atomizes fuel in the ullage space of the tank providing an atmosphere that is too rich for combustion. A pump would be energized when a tank sensor determined that the ullage might be combustible. The tank could never be emptied because there wouldn’t be any fuel to atomize into the ullage. The minimum fuel volume within a tank could not drop below 10% of the tank volume. This is a concept only. There is presently no technology to evaluate at this time. Therefore, it was not considered further for cost, benefit, or feasibility in this report. However, there are some concerns with the concept.

The primary concern for this system is that it could increase the severity of a post-crash fire if the tank was damaged. It’s also unclear if the sensor would deteriorate due to aging, how it predicts flammability, and what effect fuel slosh would have on it.

5. Installation Requirements

Ground-based fuel tank inerting consists of fuel scrubbing and ullage washing. Aircraft-based inerting consists of these same methods plus supplying inert gas to the tanks as fuel is depleted and/or during descent.

5.1. Installation of Ground-Based Inert Gas Supply

A ground-based inerting system requires a source of inerting gas at the airport. The most likely sources are liquid nitrogen or gaseous nitrogen produced by an air separation plant similar to, but larger than, the air separation equipment previously discussed. There are several manufacturers of air separation plants that may be willing to install a plant for free because their profit is obtained by selling the nitrogen to the airport's customers (airlines). The gaseous nitrogen could then be delivered to the aircraft by truck or by a pipeline between the plant and the terminal buildings. Another possibility would be portable air separation plants on trucks that could drive up to the aircraft prior to refueling.

Liquid nitrogen would probably have to be trucked into the airport storage area. The liquid nitrogen could then be delivered to aircraft by a separate truck or by a pipeline between the storage facility and the terminal buildings.

Figure 11 shows a typical airport arrangement. The fuel farm is located far from the terminal buildings. In this case, the distance from the fuel farm to the farthest terminal building is approximately 2 miles. The most likely location for a nitrogen storage facility is near the fuel farm. A pipeline from the nitrogen storage facility to the terminal buildings is a major construction project at most airports and will likely disrupt operations if the runways, taxiways or ramps have to be torn up to add the pipeline.

A better solution for the airport would be to scrub the fuel as it is delivered from the refinery. The inerting gas plant could be located nearby to provide nitrogen directly to the scrubbers with less disruption to the airport operations. However, this would still be a major change to the airport's fuel storage facility and could disrupt fuel delivery to the airlines during installation. In addition, fuel scrubbers decrease the flow rate into the fuel tanks, as previously discussed. At a time when refineries can barely keep up with current demand, due to the limitations of delivery pipelines between the refineries and the airports, this could have severe consequences for the airlines.

Another option is to deliver the nitrogen to the terminal with trucks. An additional truck near an aircraft at the terminal increases the risk of accidents with potential damage to the aircraft. If the trucks are carrying liquid nitrogen then there is an additional risk of spilling it on aircraft or people.

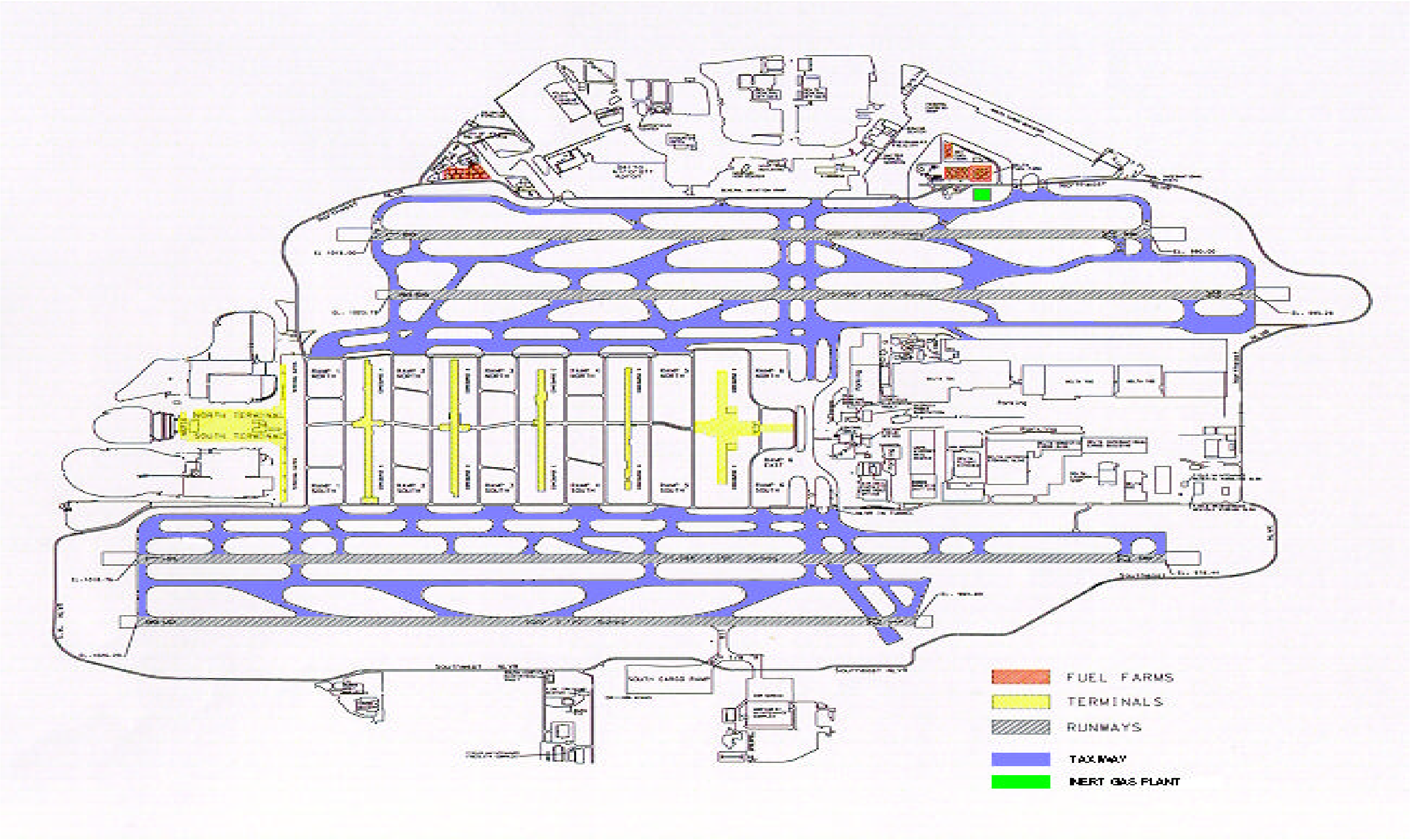

Figure 10 - Typical Airport Layout

The last option considered is to place small nitrogen generation units at each terminal. The effect on airport operations would probably be less than that caused by running a pipeline from a central nitrogen unit. Unit installation could be phased to minimize the impact on terminal gate operations. However, the economies of scale would probably not be realized and the overall cost might be equal to or greater than a central unit.

No attempt was made to estimate the cost impact of adding a nitrogen storage or generating facility to an airport's infrastructure. This would have required reviewing the layout of several hundred airports to determine the most likely location for the facility, the cost of construction in the local area of each airport, local building codes, etc. An attempt was made to estimate the cost of trucks carrying nitrogen from the storage facility to the terminal buildings. A basic assumption was that there would be one nitrogen truck for every fuel truck at the airport.

5.1.1. Ground-based scrubbing

Ground based scrubbing occurs during aircraft refueling or during the filling of the airport's fuel storage tanks. This can be accomplished in one of three ways: scrubbing the fuel as it comes from the refinery into the airport storage tanks or from the airport storage tanks to the airport fuel pit/trucks; scrubbing the fuel during refueling of the aircraft using a ground-based scrubber; and scrubbing the fuel during refueling using an aircraft-based scrubber. The first method, scrubbing the fuel as in enters the airport storage tanks or fuel pit/truck, does not require any aircraft equipment but requires modifications to the airport infrastructure or fuel trucks. The second method also does not require aircraft modification but requires that a device be coupled to the fuel pit/truck and that a source of inerting gas be available. The third method requires that fuel scrubbers be added to the aircraft and a supply of inerting gas be available during refueling.

5.1.2. Ullage Washing

Washing the tank ullage with nitrogen would require aircraft modifications to include a servicing/supply port, check valve, isolation valves and a distribution system. The servicing/supply port provides a means for introducing nitrogen into the aircraft tank(s). The distribution system provides nitrogen to vented tanks or incorporates isolation valves to selected tanks. Vent box mounted check or climb/dive valves prevent ambient air from diluting the nitrogen in the fuel tanks. The check valve prevents fuel from exiting the nitrogen servicing port.

Although the installation of ullage washing components would be similar for all aircraft, distribution systems will vary according to the fuel tank size and location on the aircraft. Distribution systems on aircraft with non-traditional tanks, e.g. tail tanks, would require more elaborate distribution systems. Ullage washing does not require any fuel delivery modifications, but would require minor airframe modifications.

5.2. Installation of Aircraft-Based Fuel Tank Inerting

5.2.1. Overview

Aircraft inerting systems will require extensive aircraft modifications. Aircraft inerting systems require the same equipment as the hybrid system plus a means of inert agent development, inert agent storage, and possibly indication systems and oxygen sensors. With the exception of inert agent generation, all aircraft inerting systems are principally the same. The currently viable technologies are nitrogen storage and air separation. Future possibilities may include exhaust gas and CO2.

5.2.2. Air Separation

Permeable membranes and molecular sieves both require a conditioned air source to develop the nitrogen enriched air. Currently, the only air source available in flight is engine bleed air.

On medium and large aircraft, bleed air could be obtained from either existing pneumatic systems or the ECS systems. Many smaller turboprop aircraft simply do not have sufficient bleed air available to spare; therefore, small transport aircraft would require an additional source separate from the engine to supply bleed air.

Present day aircraft are optimized for certain flight regimes and their systems are highly integrated. Engine bleed air is used by the environmental control system to pressurize the cabin and by the anti-ice system to minimize wing and tail icing. Under some flight conditions, such as takeoff or descent, all of the engine bleed air is used for existing aircraft equipment. There isn't any more available to supply OBIGGS systems. This was found to be the case for four of the six generic airplanes studied. (Data was not available for the other two aircraft types.) The suppliers assumed an ullage washing system and a gas purity of 9% for their calculations but the lack of bleed air prevented the OBIGGS systems from supplying inert air to the fuel tanks throughout the flight profiles.

5.2.3. Exhaust Gas

While the Task Group does not believe that this technology is currently viable, it may be of value to aircraft designers in the future.

The collection of engine exhaust gas would require the installation of a bleed air port within the engine's turbine stage(s). Since nearly all engines use fan air to assist in cooling the engine's turbine, the location of the bleed air port would have to be properly located to avoid the fan air. Tapping into an existing engine turbine stage would require extensive and costly engine re-work and re-certification.

Adding to the complexity of installing an exhaust bleed-air port, engine exhaust systems will require conditioning, filtering, overheat protection and a distributing system. For estimating purposes, existing ECS systems could provide a minimum baseline for determining the size and cooling requirements of an engine exhaust system.

Engine exhaust gas contaminates include high levels of sulfur, nitrogen, oxygen, water, carbon dioxide, hydrocarbons and other engine ingested chemical compounds. These contaminates must be filtered to avoid introducing corrosives into the fuel tanks and the resultant structural integrity inspections that would be required.

5.2.4. Combustion (Carbon Dioxide) Systems

While the Task Group does not believe that this technology is currently viable it may be of value to aircraft designers in the future.

Combustion systems are currently in the concept or prototype stage of development. The following description is based on the information provided to the Task Group by a supplier of a prototype system.

Combustion inerting systems require that a combustion process occur to develop carbon dioxide (CO2) which is used as the inerting agent. To support the combustion process, a combustion chamber is required which operates at extremely high temperatures and appears to be large in size and shape. The hot CO2 would be cooled to the required temperature using air-to-air heat exchangers and a source of cool air. These systems must be treated as a fire hazard, which requires they be located in existing fire zones or that a fire zone be created specially for them. A combustion system could be frugal with aircraft resources requiring little power or bleed air for operation.

5.2.5. Cryogenic Systems

Cryogenic inerting systems require a system reservoir to store liquid agent. Sizing of reservoirs is dependent on aircraft application and is sensitive to changes in external pressures and temperatures.

Due to pressures and temperatures within the vessel, containment vessels tend to be very large and bulky. Although larger aircraft could accommodate these vessels, smaller aircraft might not so easily accommodate them. Also, to accommodate these vessels, aircraft will require extensive airframe structural modifications and/or analysis to insure the airframe’s integrity.

5.3. Installation Requirements for All Inerting Systems

5.3.1. Ground-based Systems

Installation of ground based inerting systems at a minimum will require approximately 51 man-hours over an elapsed time of 70-75 hours. Table 1 summarizes total expected installation effort to inert the center wing tank.

Table 1 – Installation Time for Ground-Based Center Tank Inerting System

	Small Aircraft		Medium Aircraft		Large Aircraft	
BASIC SYSTEM REQUIREMENTS	Hours	Men	Hours	Men	Hours	Men
Drain Tanks	1	2	1.5	2	2	2
Open Tanks	1	2	1	2	1	3
Purge Fuel Tanks	24	1	24	1	24	1
Install Quick Disconnect	4	2	1	2	1	2
Install Check Valve	2	1	1	1	1	1
Install Regulator	2	1	2	1	2	1
Install Indication System	7.5	2	7.5	2	7.5	2
Install Climb/Dive Valve	6	2	6	2	6	2
Test System	2	2	2	2	2	2
Close/Seal tanks	1	2	1	2	1	3
System Leak Check	2	2	2	2	2	2
TOTAL INSTALLATION ELAPSED TIME	50.5		51		51.5	
TOTAL INSTALLATION MANHOURS	71		72		75	

5.3.2. Aircraft-based Systems

All aircraft inerting systems may require an indication system in the cockpit and at the servicing location. Cockpit indication provides for crew monitoring while servicing location indication provides for maintenance monitoring. Indication systems will vary in complexity based on the type of inerting agents used and the arrangement of the fuel tanks to be inerted. Indicating systems would warn crews and/or maintenance personnel of the loss of system operation and any degradation of function. Indicator sizing requirements are comparable on all fleet types but would be more restrictive on smaller transport aircraft due to limited space within cockpits.

Installation of aircraft inerting systems at a minimum will require approximately 60 man-hours over an elapsed time of 150 hours. Smaller aircraft would require smaller distribution systems, but may require additional installation time for components since accessibility and spacing are at a premium. Engine bleed air and/or engine exhaust systems would add 15 man-hours per engine exclusive of any engine re-work, if necessary. Reservoirs and indication systems will add 30 and 15 man-hours respectively. Tables 2, 3 & 4 provide estimates of installation effort.

Table 2 – Installation Time for Aircraft-Based OBIGGS System (All Tanks)

	Small Aircraft		Medium Aircraft		Large Aircraft	
AIR SEPARATION TECHNOLOGY	Hours	Men	Hours	Men	Hours	Men
Basic Effort (Above)	71	-----	72	-----	75	-----
Module Installation	15	2	15	2	15	2
Engine Bleed/Exhaust Collection	7.5	2	7.5	2	3.75	4
Bleed/Exhaust Conditioning and Distribution System	4	2	6	4	12	6
Filtration System	2	2	2	2	2	2
TOTAL ELAPSED TIME	60.5		61		61.5	
TOTAL MAN HOURS	127		144		196	

Table 3 – Installation Time for Aircraft-Based Combustion System

	Small Aircraft		Medium Aircraft		Large Aircraft	
COMBUSTION TECHNOLOGY	Hours	Men	Hours	Men	Hours	Men
Basic Effort (Above)	71	-----	72	-----	75	-----
Combustion Vessel	15	2	15	2	15	2
Distribution System	3	2	5	2	8	2
TOTAL ELAPSED TIME	60.5		61		61.5	
TOTAL MAN HOURS	107		112		121	

Table 4 – Installation Time for Aircraft-Based Cryogenic (Liquid Nitrogen) System

	Small Aircraft		Medium Aircraft		Large Aircraft	
CRYOGENIC TECHNOLOGY	Hours	Men	Hours	Men	Hours	Men
Basic Effort (Above)	71	-----	72	-----	75	-----
Cryogenic Vessel	15	2	15	2	15	2
Distribution System	3	2	5	2	8	2
TOTAL ELAPSED TIME	60.5		61		61.5	
TOTAL MAN HOURS	107		112		121	

6. Technical Data

The following data provides estimates of the impact of the various systems on the generic aircraft that formed the basis of this study. Several suppliers spent long hours analyzing the generic aircraft data and sized their systems accordingly. The suppliers based their estimates on an analysis of the various generic aircraft, specifically their fuel volume, mission length, starting fuel volume, engine bleed performance, climb and descent rates, and the setting of the vent check valves that keep ambient air out of the fuel tanks.

6.1. Weight

The following weights, in Table 5, are a composite of the weights estimated by various suppliers of air separation modules. The suppliers assumed that at least 30 psig to 60 psig of engine bleed air would be available at the necessary flows and that the bleed air would be cooled to an acceptable temperature for the module. Ullage washing was assumed, which requires less purity of the nitrogen and minimizes the bleed air requirement. This system was intended to inert all fuel tanks on the aircraft.

Because of the lack of available bleed air on present day aircraft and the resulting lack of inerting during some phases of the flight profile, OBIGGS systems are not considered a viable option for incorporation into existing aircraft or for retrofit. Therefore, there is no air separator weight estimate for present day aircraft or for those requiring retrofit.

The additional system weight consists of precoolers to cool the engine bleed air for the air separator modules, fans to blow cool air over the precoolers during ground operations, water/dust separators to avoid contaminating the air separation modules, valves to control flow to the tanks and to shut off some of the air separator modules during cruise (when only "make up" gas is required to replace depleted fuel), a distribution system, pressure sensors, pressure regulators, oxygen sensors, and vent check valves.

Table 5
Future Aircraft Air Separator Technology Weight

	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
Module Weight (lbs.)	805	408	158	134	110	173
Additional System Weight (lbs.)	1547	941	558	522	486	581
Total Weight (lbs.)	2352	1349	716	656	596	754

For present day aircraft and those requiring retrofit, a system that does not require bleed air is a better match for the aircraft. However, they carry the penalty of higher weight than the air separation technology. The following estimate, in Table 6, is based on a liquid nitrogen storage system sized to inert all fuel tanks on the aircraft.

The additional system weight consists of a distribution system, fuel scrubbers, pressure sensors, pressure regulators, oxygen sensors, electrical wiring, mounting hardware, finish installation cover panels, and vent check valves. Since this installation had not been previously analyzed, the additional system weight for the air separator technology was semi-arbitrarily divided by two for this estimate. For this estimate, fuel scrubbing and a "make-up" system were assumed since this requires less nitrogen than ullage washing. (A "make-up" system replaces the consumed fuel with inert gas instead of letting ambient air replace the consumed fuel.) This assumption is valid since liquid nitrogen is pure i.e. it contains no oxygen.

Table 6
Present Day Aircraft Liquid Nitrogen Technology Weight

	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
LN2 Weight + Storage Vessel & Controls (lbs.)	1611	765	230	179	128	262
Additional System Weight (lbs.)	774	642	558	551	543	564
Total Weight (lbs.)	2385	1407	788	730	671	826

6.2. Size (cargo/passengers/fuel displaced)

The suppliers of air separation modules have only grossly estimated the approximate size of their module package. The largest would occupy the equivalent of a cube that is 5 feet on each side while the smallest would be approximately 14 inches on each side. Due to the severe time constraint imposed by the FAA for this study, the Task Group has been unable to determine the size of the additional equipment needed to mount the air separator modules and cool the engine bleed air to acceptable levels. It is probable that the package would be double the size of the module package and displace some cargo, as the cargo compartment is the most likely location for mounting this equipment. Therefore, no cost will be associated with this item and the Task Group will assume that it is somewhat compensated by the weight penalty listed in section 6.1 and it's associated costs listed in Section 9.

6.3. Cost

The following module costs, in Table 7, are a composite of the costs estimated by various suppliers of air separation modules. The costs quoted are for a shipset of modules where a shipset has the capability to inert all fuel tanks on the aircraft. Design and installation costs will be discussed in Section 9.

Table 7
Future Aircraft Air Separator Technology Cost

Shipset Cost (US Dollars)	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
Modules	$606,000	$304,000	$113,000	$95,000	$77,000	$125,000

7. FAA Certification Requirements

7.1. Similarity/Previous Test or Flight Experience

There is no previous test or flight experience in commercial aircraft. In addition, it is not yet clear what regulations might be enacted by the FAA for the certification of fuel tank flammability reduction systems. Thus, the certification requirements and costs cannot be estimated at this time.

7.2. Additional Analysis and Testing

Analysis and testing is dependent of the regulation. Since it is not yet clear what requirements might be enacted by the FAA, the Task Group cannot estimate the certification requirements or costs to comply with the new regulation. However, there are existing requirements for the certification of aircraft systems that would be expected to apply to inerting. The costs to comply with the existing requirements are shown as part of the design cost in Section 9.

7.3. Other Effects on Aircraft

All of the systems add substantial weight to the aircraft. Some existing aircraft could be re-certified for the additional weight allowing the airlines to carry the same payload as they currently do. However, there will be some impact on operations resulting from the increased weight. Runway lengths for takeoff and landing will increase slightly. Fuel costs will increase also and these are estimated in Section 9.

All of the proposed systems utilize a vent check valve to keep the inert gas in the tank and to delay the introduction of ambient air. By holding inert gas in the tank during climb and cruise, the vent check valves cause the wing to become slightly pressurized. By keeping ambient air out of the tank during descents, the vent check valves allow the tank to be slightly compressed by outside air. The fuel tank structure may have to be re-certified to show that it still complies with all strength requirements imposed by the FAA due to the change in loads.

Air separation technologies may be viable for some aircraft that can supply the required engine bleed air. This may require re-certification of the engine by the engine manufacturer and re-certification of the aircraft by the aircraft manufacturer to show that the additional bleed air requirement does not adversely impact engine operation and aircraft performance. In addition, it is possible that during certain phases of the flight the loss of an engine and its bleed air may require operational changes. For example, the loss of one engine’s bleed air on a twin may require choosing between pressurizing the cabin or inerting the fuel tanks.

8. Safety

8.1. Effectiveness in Preventing Overpressure Hazard

Military, live-fire testing has demonstrated that nitrogen inerting prevented catastrophic tank over pressures with an ullage oxygen concentration from 12% [1] and 10% [2] at sea level for up to 23mm high energy incendiary (HEI) rounds. The military has adopted 9% oxygen concentration as the inert limit. Laboratory testing showed that inert limits for combustion increased with altitude from less than 10% to over 13% oxygen concentration from sea level to 60 kft [3]. Since the 9% oxygen concentration limit prevents tank over-pressures for energetic ignitions sources up to 23mm HEI rounds, this would also protect against any internal threats from within intact commercial aircraft fuel systems. However, in events where the fuel system has ruptured from other causes allowing air to enter the fuel system or fuel to leak, nitrogen inerting may not prevent fuel fires or explosions inside or outside the fuel system.

8.2. Evaluation against Historical Commercial Aircraft Overpressure Events

The list of commercial aircraft over-pressure events is presented in Table 1. An evaluation of the effectiveness of a full time inerting system is also shown in Table 1, assuming the inerting system was functional and the entire fuel/vent system was inerted at the time of the incident. Inerting may not have prevented catastrophic results in all of the events where the fuel tanks were open or had been open for maintenance or ruptured from other causes. These are the engine separation events (3,4, and 5), the 727 sabotage event (6), and ground maintenance events where the tanks were open or had been opened (13 and 14). The evidence in the727 bomb-sabotage event (6) suggested that the force caused by the bomb blast compromised the structural integrity in this area, causing a fuel tank rupture, fire, and in-flight structural breakup of the right wing. Whether, the initial bomb blast would have caused a hull loss without the subsequent fire is not known. Also, it is not known that if had the fuel tank been inerted if the subsequent fire would have occurred. Therefore, we can only conjecture whether inerting would have prevented a hull loss in this sabotage event.

Inerting could have prevented the catastrophic results in all of the remaining events, the lightning strikes (1 and 2), refueling events (9-12), the TWA and PAL CWT events (7 and 8), and the DC9 ground maintenance event (15).

Table 8
Evaluation of Effectiveness of Inerting For Historic Fuel Tank Explosion Events

		Operational Phase				Ignition Source					
No.	Year – airplane	Inflight	Ground Ops	Ground Maint.	Refueling	Lightning	Overwing Fire - Inflight	Static Discharge	Sabotage	Unknown	Could Inerting[1] have prevented catastrophic outcome?
1	1963 – 707	X				x					Yes
2	1976 – 747	X				x					Yes
3	1965 Eng Sep 707	X					x				No
4	1970 Eng Sep DC8	X					x				No
5	1992 Eng Sep 707	X					x				No
6	1989 - 727 Sabotage	X							x		Unknown
7	1996 - 747 TWA	X								x	Yes
8	1990 – 737-300 PAL		X							x	Yes
9	1970 – 727				x			x			Yes
10	1970 – 727				x			x			Yes
11	1973 – DC8				x					x	Yes
12	1989 – Beech 400				x			x[2]			Yes
13	1967 – 727			x				x			No
14	1974 – DC8			x						x	No
15	1982 – DC9			x						x[3]	Yes

[1] Assuming fuel/vent system was inert at the time of the incident

[2] Static charge generated by non-conductive foam in another tank

[3] Suspect Dry Running Boost Pump

8.3. Negative Impacts

The impacts to the aircraft have been previously covered in Sections 4 and 5.

8.4. Increased Landings due to Range Reduction (due to added system weight)

The Task Group was not able to define all of the cost impacts due to the limited time frame for the report.

8.5. Increased Landings due to Extra Fuel Consumed

The Task Group was not able to define all of the cost impacts due to the limited time frame for the report.

8.6. Personnel Hazards

All inerting systems are designed to minimize the accumulation of oxygen in a confined space. Nearly all inerting systems produce environments hostile to humans. In all cases, a person will lose consciousness if exposed to an inert atmosphere. Death is possible if the person cannot be removed from the inerted fuel tank within a few minutes.

Liquid nitrogen systems require the cryogenic transport and/or storage of nitrogen in liquid form, which boils at -195 °C or -315 °F. Transport, storage and handling of liquid nitrogen requires precautions to prevent severe skin burns upon contact.

Gaseous nitrogen systems lessen the burn risk associated with liquid nitrogen. However, the pressurized containers present a hazard. A broken bottle or distribution line can flood the compartment with nitrogen causing asphyxiation. The high pressure gas escaping the bottle or line could injure someone nearby. And if the storage bottle mounting hardware was loosened, to change the bottle for example, the bottle could move rapidly and injure someone.

Like liquid nitrogen, carbon dioxide generators using dry ice pose the same threat of severe skin burns and asphyxiation.

Combustion systems that produce carbon dioxide and exhaust gas inerting systems operate at high temperatures. There is a potential for severe burns while servicing the equipment.

All types of inerting systems will require almost daily interaction with maintenance and other ground personnel of all cultures and education levels. Inerting system dangers will grow proportionally with the desire to launch an aircraft, and mistakes will be made.

8.7. Aircraft Hazards or Effects

Fuel tank inerting adds additional threats to aircraft from additional system complexity, pressure vessel ruptures and failure modes that may impact other systems.

Inerting systems using heat also pose threats. Burn chambers/engine exhaust systems expose aircraft and occupants to the threat of extreme heat if unconfined. Besides the obvious threat of fire, structural airframe damage is also possible. Airframe structure heated beyond design limitations loses strength, which is not apparent to visual inspections. With temperatures nearing 900°F for chambers and 1000°C for engine exhaust, system failures could easily start a chain reaction resulting in hull loss with little warning.

Aircraft weight and balance must also be considered for all aircraft inerting systems and will vary with aircraft size and system size.

8.8. Other Equipment Hazards or Effects

Equipment required to support inerting systems also pose threats. Ground support equipment will require maintenance and testing to verify proper operation. The same threats that could occur on the aircraft are possible with ground support equipment

Existing airport gate and ramp space is already congested with numerous types of support equipment. Each piece of new equipment introduced in the airport ramp areas increases the likelihood of accidents. Accidents involving cryogenic vessels will dramatically increase the severity of injury to ground personnel and aircraft and/or equipment.

Waste products associated with the combustion type inerting systems require the disposal of burned carbon. Due to the high temperatures, there is a threat to the aircraft, personnel and storage facilities during removal of hot waste product. Exposing the airport ramp environment to the hot waste product could be comparable to an open flame in the area. Generally, open flames are kept at least 50 feet from the aircraft. A combustion system will require careful design to eliminate these hazards.

The production of CO2 is also an environmental concern as a “green-house” gas. The Environmental Protective Agency (EPA) has successfully lobbied for the passage of numerous clean air acts. The EPA’s vigilance in preventing “green-house” gases may prevent or severely restrict the use of this technology.

9. Cost Impact

9.1. Retrofit

9.1.1. Air Separator Technology

The Task Group was not able to define all of the cost impacts due to the limited time frame for the report.

9.1.2. Liquid Nitrogen Technology

The Task Group was not able to define all of the cost impacts due to the limited time frame for the report.

9.1.3. Simple Hybrid System

The Task Group was not able to define all of the cost impacts due to the limited time frame for the report.

9.2. Current Aircraft

9.2.1. Air Separator Technology

Air separator technology requires more bleed air than is available from present day aircraft. Therefore, this technology is not considered viable and no costs are provided for current aircraft. However, the cost of this technology for future aircraft has been estimated in section 9.3.

9.2.2. Liquid Nitrogen Technology – All Tanks

The following liquid nitrogen storage bottle costs were provided by the suppliers. The other costs are scaled from estimates made by Boeing for the OBIGGS system in the industry response (July 1997) to the FAA Request for Comment. This system includes check valves, distribution pipes, pressure regulators, control orifices, pressure sensors, and climb/dive check valves.

The Task Group was not able to define all of the cost impacts due to the limited time frame for the report, so they are left blank. The system was assumed to be installed only on aircraft with heated body tanks and provides inerting for all tanks. The Task Group was not able to determine if the Regional Turbofan and Turboprop had heated body tanks for this analysis. Therefore, the cost estimate for these aircraft is unknown.

Table 9
Present Day Aircraft with Heated Body Tanks, Liquid Nitrogen Technology, Non-recurring Costs

Fleet Cost (US Dollars)	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
LN2 Bottle	$31,306	$16,600	$7,269	$7,111	$5,287	$
Design	$34M	$32.7M	$31.9M	$31.8M	$31.7M	$31.9M
Installation	$3.9B	$3.3B	$18.9B	$2M	$1.5M	$1.2M
Operational						
Maintenance						
Infrastructure						
Range Lost						
Total Cost	$3.94B	$3.36B	$18.9B	Unknown	Unknown	0
# of Aircraft	1280	1092	6192	Unknown	Unknown	0
Cost per Aircraft	$3.0M	$3.1M	$3.1M	Unknown	Unknown	0

There is also a penalty to the aircraft due to the added weight of the system. In most cases, the added weight merely results in extra fuel consumed to travel the same distance. However, if the aircraft is at its maximum weight limit then some passengers cannot be carried in order to put in the extra fuel. This results in an additional penalty for lost revenue and appears in the row labeled “Long Mission” where the aircraft is the most full.

Table 10
Present Day Aircraft with Heated Body Tanks, Liquid Nitrogen Technology, Annual Recurring Costs
Due to Added System Weight

Annual Fleet Cost	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
	$423.6M	$138.0M	$244.3M	Unknown	Unknown	$1.2M

In addition, liquid nitrogen would have to be transported to the aircraft at each refueling. This incurs costs at the airport to maintain a supply of liquid nitrogen, the means to transport it to the aircraft, and the training of personnel to handle it. For this estimate, trucks of liquid nitrogen were assumed as the means of transport for the reasons listed in Section 5.1. The Task Group was not able to define all of the cost impacts due to the limited time frame for the report, so they are left blank.

Table 11
Airport Costs for Liquid Nitrogen Technology

Non-recurring		
Nitrogen Trucks	$3.3M	Assumes 20 per airport
O2 Detectors	$16,500	Assumes 22 per airport
Annual Recurring		
Inerting Truck Fuel	$11,000	Assume 5,000 miles at 10 mpg and $1.10 per gallon
Inerting Truck Maint	???	No data at this time
Inerting Truck Operator Training	???	No data at this time
Inerting Truck Inspection	$10,000	20 trucks at $500 per inspection
O2 Detector Calibration	$2,640	Assumes 22 sensors per airport and recalibration twice per year at mechanic's rate of $60/hour
O2 Detector Training	???	No data at this time

9.2.3. Simple Hybrid System – Body (Center Tank) Only

The following costs are the estimate for a very simple system to inert the body tank only. The assumed system is a hybrid system with a distribution system in the aircraft and the inert gas supply on the ground. The distribution system consists of a quick disconnect port for hookup to the inert gas supply, a regulator to avoid damage to the tank structure, a check valve to keep fuel from flowing out of the tank to the nitrogen supply, distribution pipes in the tank, and 2 vent check valves to hold the inert gas in the tank.

Equipment must be installed on the aircraft and at the airport. The airport equipment consists of trucks carrying nitrogen in liquid or gaseous form and an oxygen detector. Although nitrogen could be provided to each aircraft by underground pipes it's virtually impossible to estimate the cost impact of installing the piping at every airport. However, it is possible to estimate the number of trucks that would be required; this task group has assumed there would be one nitrogen truck for each refueling truck at a typical airport. This follows since the inerting would occur during or immediately after the aircraft was refueled. For a "typical" airport, 20 fuel trucks were assumed which is probably much lower than the actual value. Large airports such as LAX, JFK and ORD would have many more while smaller airports may have fewer.

The oxygen detector is needed to ensure that the fuel tanks' oxygen content is safe. This would be determined by having the inerting truck operator measure the oxygen level coming out of the vent system while adding nitrogen to the tank. The operator would have to be properly trained to use the detector and the detector would require recalibration periodically.

The Task Group was not able to define all of the cost impacts due to the limited time frame for the report, so they are left blank. The system was assumed to be installed only on aircraft with heated body tanks. The Task Group was not able to determine if the Regional Turbofan and Turboprop had heated body tanks for this analysis. Therefore, the cost estimate for these aircraft is unknown. Also, the Task Group was not able to define the system weight due to limited time so the recurring cost estimate accounts only for the nitrogen used for inerting.

Table 12
Production Aircraft with Heated Body Tanks, Hybrid Inerting System, Non-Recurring Cost

Fleet Cost (US Dollars)	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
Design	$2.3M	$2.2M	$4.3M	Unknown	Unknown	$0
Installation	$99.9M	$85.3M	$483.5M	Unknown	Unknown	$0
Operational				Unknown	Unknown	$0
Maintenance				Unknown	Unknown	$0
Infrastructure				Unknown	Unknown	$0
Range Lost				Unknown	Unknown	$0
Total Cost	$102M	$87M	$488M	Unknown	Unknown	$0
# of Aircraft	1280	1092	6192	Unknown	Unknown	0
Cost per Aircraft	$150,000	$144,000	$145,000	Unknown	Unknown	$0

Table 13
Production Aircraft with Heated Body Tanks, Hybrid Inerting System, Annual Recurring Cost
No Weight Penalty Assumed

Fleet Cost (US Dollars)	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
Liquid Nitrogen	$92,067	$49,216	$866,770	Unknown	Unknown	$0
Cost per Aircraft	$71	$45	$140	Unknown	Unknown	$0
OR						
Gaseous Nitrogen	$36.2M	$19.3M	$35.1M	Unknown	Unknown	$0
Cost per Aircraft	$28,266	$17,711	$5,676	Unknown	Unknown	$0

Table 14
Airport Costs for Body Tank Hybrid Inerting System

Non-recurring		
Nitrogen Trucks	$3.3M	Assumes 20 per airport
O2 Detectors	$16,500	Assumes 22 per airport
Annual Recurring		
Inerting Truck Fuel	$11,000	Assume 5,000 miles at 10 mpg and $1.10 per gallon
Inerting Truck Maint	???	No data at this time
Inerting Truck Operator Training	???	No data at this time
Inerting Truck Inspection	$10,000	20 trucks at $500 per inspection
O2 Detector Calibration	$2,640	Assumes 22 sensors per airport and recalibration twice per year at mechanic's rate of $60/hour
O2 Detector Training	???	No data at this time

9.3. New Aircraft

9.3.1. Air Separation Technology – All Tanks

The following module costs are a composite of the costs estimated by various suppliers of air separation modules, assuming that all fuel tanks are inerted. The other costs are scaled from estimates made by Boeing for the industry response (July 1997) to the FAA Request for Comment. This system includes the air separator modules, precoolers, water/dust separator, shutoff valves, flow control valves, check valves, distribution pipes, pressure regulators, control orifices, pressure sensors, and climb/dive check valves.

Table 15
Future Aircraft Air Separator Technology Non-recurring Costs

Fleet Cost (US Dollars)	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
Modules	$606,000	$304,000	$113,000	$95,000	$77,000	$125,000
Design	$34M	$32.7M	$31.9M	$31.8M	$31.7M	$31.9M
Installation	$3.9B	$3.3B	$18.9B	$2M	$1.5M	$1.2M
Operational						
Maintenance						
Infrastructure						
Range Lost						
Total Cost	$3.94B	$3.36B	$18.9B	Unknown	Unknown	0
# of Aircraft	1280	1092	6192	Unknown	Unknown	0
Cost per Aircraft	$8.3M	$4.7M	$3.4M	Unknown	Unknown	0

There is also a penalty to the aircraft due to the added weight of the system. In most cases, the added weight merely results in extra fuel consumed to travel the same distance. However, if the aircraft is at its maximum weight limit then some passengers cannot be carried in order to put in the extra fuel. This results in an additional penalty for lost revenue and appears in the row labeled "Long Mission" where the aircraft is the most full of fuel.

Table 16
Future Aircraft Air Separator Technology Recurring Costs

Annual Fleet Cost	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
	$652.4M	$190.7M	$262.7M	Unknown	Unknown	Unknown

9.3.2. Air Separation Technology – Center Tank Only

The following module costs are a composite of the costs estimated by various suppliers of air separation modules. The other costs are scaled from estimates made by Boeing for the industry response (July 1997) to the FAA Request for Comment. This system includes the air separator modules, precoolers, water/dust separator, shutoff valves, flow control valves, check valves, distribution pipes, pressure regulators, control orifices, pressure sensors, and climb/dive check valves.

Table 17
Future Aircraft Air Separator Technology Non-recurring Costs

Fleet Cost (US Dollars)	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
Modules	$606,000	$304,000	$113,000	$95,000	$77,000	$125,000
Design	$34M	$32.7M	$31.9M	$31.8M	$31.7M	$31.9M
Installation	$3.9B	$3.3B	$18.9B	$2M	$1.5M	$1.2M
Operational						
Maintenance						
Infrastructure						
Range Lost						
Total Cost	$3.94B	$3.36B	$18.9B	Unknown	Unknown	0
# of Aircraft	1280	1092	6192	Unknown	Unknown	0
Cost per Aircraft	$8.3M	$4.7M	$3.4M	Unknown	Unknown	0

There is also a penalty to the aircraft due to the added weight of the system. In most cases, the added weight merely results in extra fuel consumed to travel the same distance. However, if the aircraft is at its maximum weight limit then some passengers cannot be carried in order to put in the extra fuel. This results in an additional penalty for lost revenue and appears in the row labeled “Long Mission” where the aircraft is the most full.

Table 18
Future Aircraft Air Separator Technology Recurring Costs Due to Added System Weight

Annual Fleet Cost	Large Transport	Medium Transport	Small Transport	Regional Turbofan	Regional Turboprop	Business Jet
	$333.6M	$108.7M	$191.7M	Unknown	Unknown	Unknown

10. Conclusions

At this time, nitrogen appears to be the best inerting agent and there are several means of providing it to the aircraft. Ground-based ullage washing in combination with the drop in temperature within the tank reduces exposure to a flammable, non-inerted tank to approximately 1%. This is the most cost effective solution studied, with the cost over a 10-year period estimated at approximately $3-4 billion.

Present day aircraft do not have enough bleed air, in most cases, to supply an OBIGGS type system. However, OBIGGS systems can be designed into future aircraft without adverse effects for the engine.

If a full time inerting system is required for present day aircraft or retrofit aircraft then liquid or gaseous nitrogen storage could be placed aboard the aircraft. These systems tend to be a little heavier than OBIGGS and require additional airport infrastructure to support them. The overall cost for a 10-year period is similar to OBIGGS.

The following table provides a summary of the cost and benefit of each system.

Technology	**Effectiveness**	**Cost over 10 Years (US Dollars)**
On-board Liquid Nitrogen for All Tanks	100%	$35.7B
On-board Gaseous Nitrogen for All Tanks	100%	$33.9B
Air Separator Modules for All Tanks	100%	$37.3B
Air Separator Modules for the Center Tank	100%	$32.6B
Ground-based Ullage Washing with natural Fuel Cooling for Center Tank	99%	$4B with gaseous nitrogen $3B with liquid nitrogen

Aviation Rulemaking
Advisory Committee

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Foam

Task Group 4

Abstract

This report is the findings of the Fuel Tank Foam and Expanded Metal Products Task Group, which was formed as a portion of the Fuel Tank Harmonization Working Group activity established in January 1998. The FAA initiated this activity by the issuance of a Harmonization Terms of Reference entitled "Prevention of Fuel Tank Explosions" on 16 Dec 1997. The Working Group's stated task was to study means to eliminate or reduce fuel tank flammability and to propose regulatory changes to the FAA Aircraft Rulemaking Advisory Committee.

The Fuel Tank Foam and Expanded Metal Products Task Group's assignment was to provide a feasibility analysis of fuel tank foam and expanded metal products installation systems. The analysis was to focus on the use of foam and expanded metal products in prevention of fuel tank explosion for transport airplane operations. A cost/benefit analysis for fuel tank foam installation systems was to be included for the fleet of aircraft requiring retrofit, for current production aircraft, and for new type design aircraft.

The findings for this Task Group indicates that foam or expanded metal products can be used effectively in the prevention of structural failure of fuel tanks as a result of an explosion. However, when installed foam or expanded metal products will reduce aircraft payload and available fuel volume. These reductions are the two most important factors that would result in severe economic impact for airlines

Summary

This report provides information on two types of materials available for installation inside aircraft fuel tanks which will reduce the risks of hull losses of aircraft in case of explosions:

1. Reticulated polyether foam
2. Expanded metal products.

Both have more than one application, and both will require FAA certification. Some will require extensive qualification tests to aircraft standards. When installed inside fuel tank both materials create its own disadvantages such as weight increase, fuel volume loss, increase pack bay temperature causing degradation of aircraft structural integrity, FOD and maintenance difficulties.

The installation of either system has no real effect on normal fuel system operation and the each system is virtually maintenance free. However, the presence of the materials in the fuel tank greatly impacts the removal/replacement of in-tank components. Time to remove, store, and reinstall the materials must be added to the normal time necessary for fuel system components maintenance. This effect on operational aircraft has been accounted for in the cost estimate.

Foam also requires special handling and wrapping if it is to be out of the tank for an appreciable length of time. Further, foam which is no longer usable, is difficult to dispose of without environmental damage.

Costs associated with using one alternative of each product have been estimated for generic center tanks, which have adjacent heat sources. These estimates account for total cost, i.e., designs, installations, and operations. The estimates are based on data collected from vendors, from the United States Department of Defense, from aircraft manufacturers, and from airlines.

These cost estimates, for center wing tank with adjacent heat source, are summarized in the following two tables:

In service aircraft

Aircraft Size	**Foam Nonrecurring**	**Foam Annual**	**Exp Metal Nonrecurring**	**Exp Metal Annual**
Large	**$390,740**	**$1,584,121**	**$848,273**	**$1,329,017**
Medium	**$187,427**	**$653,497**	**$366,057**	**$538,951**
Small	**$64,161**	**$120,448**	**$112,605**	**$88,992**

Production Aircraft

Aircraft Size	**Foam Nonrecurring**	**Foam Annual**	**Exp Metal Nonrecurring**	**Exp Metal Annual**
Large	**$353,884**	**$1,584,121**	**$811,416**	**$1,329,017**
Medium	**$166,334**	**$653,497**	**$344,964**	**$538,951**
Small	**$54,636**	**$120,448**	**$103,081**	**$88,992**

It is estimated that it would cost the industry , in a 10 year period, over 22 billion dollar to use Expanded Metal Products and over 25 billion dollar to use Foam on inservice aircraft.

Acknowledgments

The members of the Airworthiness Rulemaking Advisory Committee, Fuel Tank Harmonization Working Group, Task Group 4 wishes to thank the following people for their cooperation, advice, and information:

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- Pearl Alexander Robins AFB,
- Donald Miller, Warner Robins AFB
- Harry Mattox, Lockheed Martin Support Services Co., Jacksonville, Fl.
- Roger Boone, NAS Jacksonville, and various members of NAS Jacksonville's maintenance squadrons.

The members of Task Group 4 also wish to thank the following vendors for providing data on reticulated foam and expanded metal products:

Foam Products:

Crest Foam
100 Carol Place
Moonachie, NJ 07074

Engineered Fabrics Corporation
669 Goodyear St.
Rockmart, GA 30153

Foamex
1500 East Second Street
Eddystone, PA 19022

Middle Georgia Easter Seal Society, Inc.
Kellam Road, P.O. Box 847
Dublin, GA. 31040

Expanded Metal Products:

AT&E Engineering
425 East Main St. P.O. Box 8
East Moriches, NY 11940

Deto-Stop, Inc.
1665 Townhurst, Suite 100
Houston, TX 77043

Explosafe North America
16 ESNA Park Dr. Suite 101
Markham. Ontario Canada, L3R5X1

Firexx Corporation
Suite 1000, 1611 North Kent St.
Arlington, VA 22209

International Door
8001 Ronda Dr.
Canton, MI 48187

SafetyTech
Suite 300
1749 Golf Road
Mount Prospect, IL 60056

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1. Terms Of Reference, ARAC, FTHWG, January 1998

2. Advisory Group for Aerospace Research & Development, Report No. 771, Fuel Tank Technology

3. MIL-F-87260 (7 February 1992) Foam Material, Explosion Suppression, Inherently Electrically Conductive, For Aircraft Fuel Tank and Dry Bay Areas**.**

4. MIL-B-83054B, 17 May 1978, Baffle and Inerting Material, Aircraft Fuel Tank

5. MIL-B-87162 Baffle Materials, Explosion Suppression, Expanded Aluminum Mesh, for Aircraft Fuel Tank.

6. Society of Automotive Engineers Aerospace Information Report**,** AIR4170, 12 February, 1991, Reticulated Polyurethane Foam Explosion Suppression Material for Fuel Systems and Dry Bays.

7. AFWAL-TL-80-2043 Evaluation of Explosafe Explosion Suppression System for Aircraft Fuel Tank Protection.

Table of Contents

1.0 Background of Explosion Suppressive Materials

The explosion suppressive materials acts as suppressants when installed in fuel tanks because they:

1. Act as heat sinks, thus reducing the temperatures at spark points,

2. Break up compression waves that precede flame fronts in an explosion, and

3. Enrich the mixture of vapors in the ullage of fuel tanks, especially in tanks with JP-4 or similar fuels are used.

In this report the two types of Explosion Suppressive Materials under examined are Foam and Expanded Metal Products.

Both types of materials provide passive systems. No moving parts are required, and no cockpit instrumentation equipment is required. When the systems are properly designed and installed, ullage protection is ensured during all ground and flight conditions.

However, there are disadvantages to utilizing these materials:

- Both reduce gross take off weight and/or range of aircraft due to the system weight increase and reduction in usable fuel quantities.

- Both increase aircraft maintenance down time and labor cost due to the additional time required to drain the tanks, and to remove and replace the products for in tank maintenance.

- Foam when installed inside the center wing tank may act as an insulator, which could hinder the thermal dissipation of heat energy produced by the air-condition packs mounted underneath the tank. This could elevate the air-condition packs bay and degrade the surrounding structure integrity.

- Storage of removed materials will require special facilities.
- Foam does have a limited life (approximately 15 to 20 years). Therefore, disposal of fuel soaked foam will be an environmental issue.

1.1 Foam Products

Military aircraft are highly vulnerable to fires and explosions resulting from combat threats such as gunfire, especially high explosive incendiary (HEI) rounds. During the late 1960s, the United States Air Force began using reticulated polyester polyurethane foam to suppress fires and explosions inside fuel tanks. Figure 1 and Figure 2 are photographs of a typical C-130 tank with foam installed. Since that time, several materials have been tried, the latest being per MIL-F-87260, Reference 4. A typical C-130 requires 1540 pieces of foam. A P-3 requires 1388 pieces. Figure 3 is a photograph of the foam for a P-3 fuel tank.

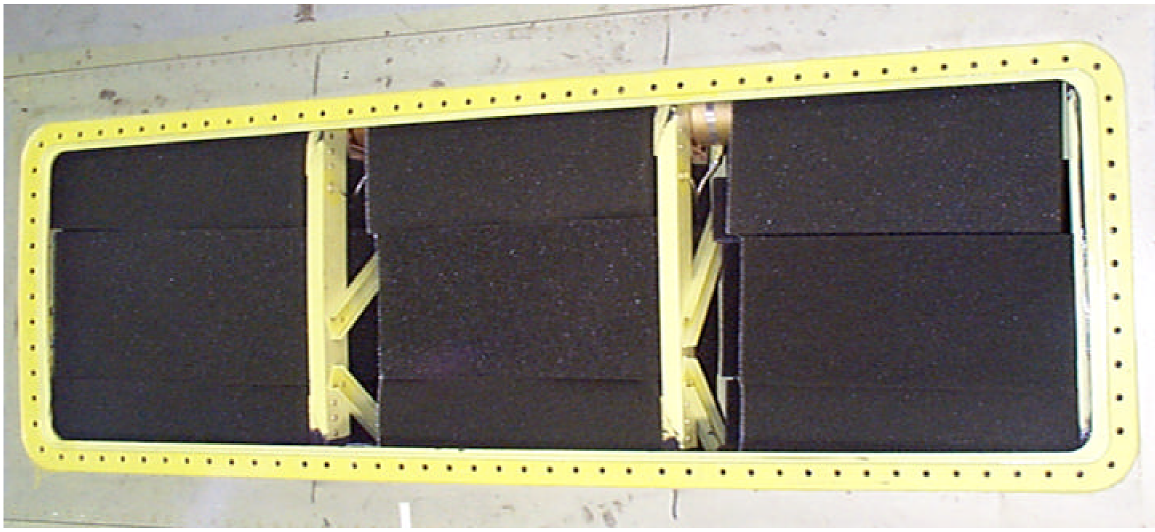

Figure 1 - C-130 Fuel Tank with Foam Installed

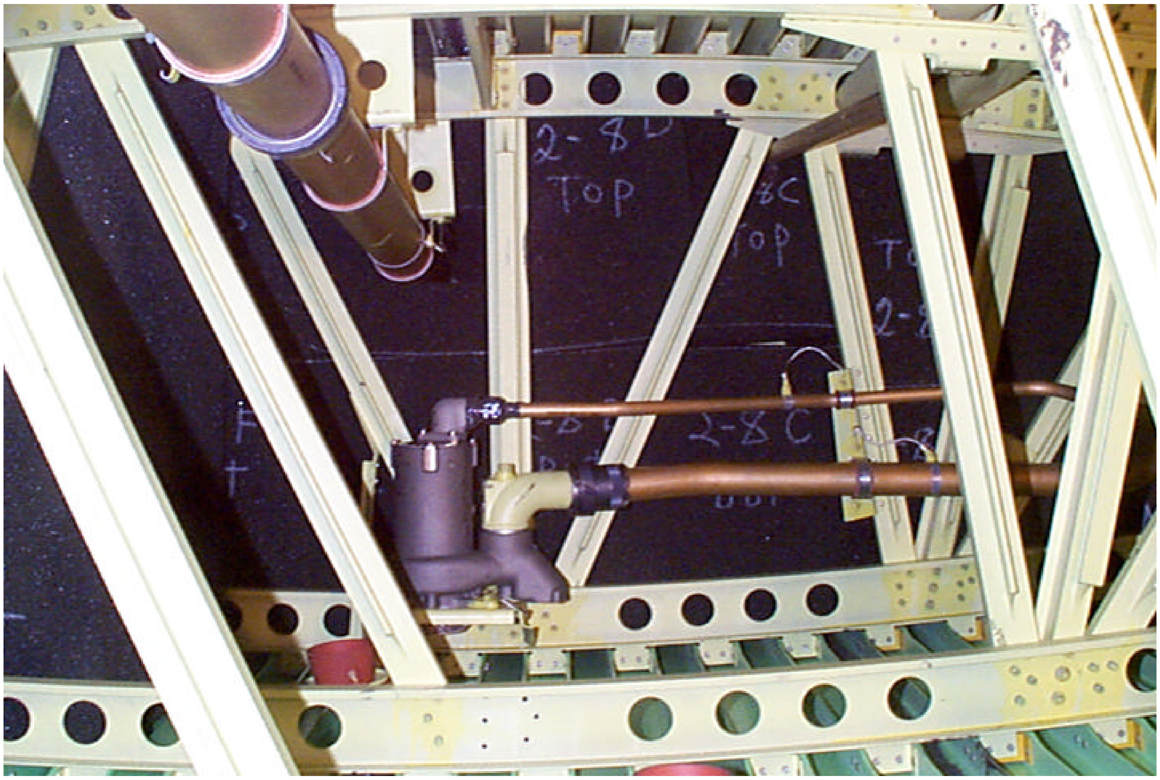

Figure 2 - C-130 Fuel Tank with Foam Installation Ongoing

View Looking Inbd

Soon after the development and incorporation of fuel tank foams, the Air Force discovered that the materials used for the foam were susceptible to hydrolytic degradation. Better materials were developed; producing what is commonly called blue foam.

The blue foam improved hydrolytic stability, but the blue foam had electrical resistance properties much higher than the original foam materials, causing a capacitance effect resulting in static charge potentials greater than 10,000 volts. Soon after incorporation of the blue foam kits, the USAF experienced fuel tank fires in the A-10 and the C-130 aircraft. Thousands of fuel tank fire remnants were discovered in the C-130 fleet, but no loss of an aircraft was ever attributed to fuel tank fires. This static electrical discharge problem led to the development of the conductive foams, which are now being produced and installed in quite a number of USAF and USN aircraft.

Figure 3 - A P-3 Foam Kit Being Prepared for Shipment

1.2 Expanded Metal Products

The expanded metal products have been used in fuel tanks and storage containers, and many tests have been conducted to prove that the products, mostly aluminum alloys, will protect fuel tanks from explosions as a result of internal ignition. However, as of the time this document was written, the United States Department of Defense has not approved any of the expanded metal products for use on any particular aircraft weapon system. MIL-B-87162, Ref. 5, was approved for expanded metal blocks, but the product has been incorporated on a limited basis. Likewise, the FAA has not yet issued a type certificate for any aircraft that uses the expanded metal products for explosion protection. However, this does not mean they are not effective or will never be used. For example, several of the expanded metal products can be purchased in the form of ellipsoidal or cylindrical shaped objects such as those shown in Figure 4. Aircraft fuel tanks will require design changes to incorporate constraining baffles or cages to ensure the particles remain in position, especially in an aircraft without access to the tank interiors from the top of the wings. This and other concerns require more design and development. Figure 5 is a photograph of the expanded aluminum blocks that conform to MIL-B-87162.

1.3 Some Weight Increase and Fuel Volume Loss Comparison

Beside additional maintenance burdens and environment issue the most severe penalties as a result of foam installation, are the fuel volume loss and the weight increase. These two factors directly effect the bottom line of airlines operation. The following tables summarize the weight and fuel volume penalty for the 3 classes of aircraft between the two types of material.

Foam

	Volume Loss (Gallon)	Weight Increase (Lb)
Large	**1250**	**8532**
Medium	**500**	**3413**
Small	**150**	**1024**

Expanded Metal Products

	Volume Loss (Gallon)	Weight Increase (Lb)
Large	**600**	**9362**
Medium	**240**	**3745**
Small	**72**	**1123**

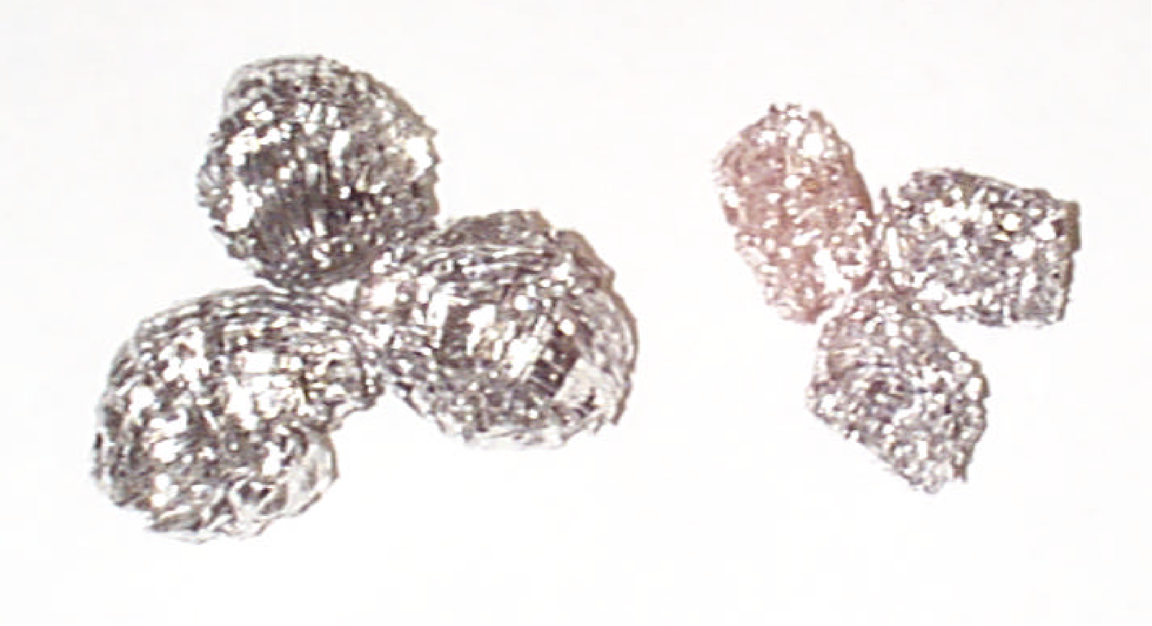

Figure 4 - Ellipsoidal and Cylindrical Shaped Expanded Metal Products

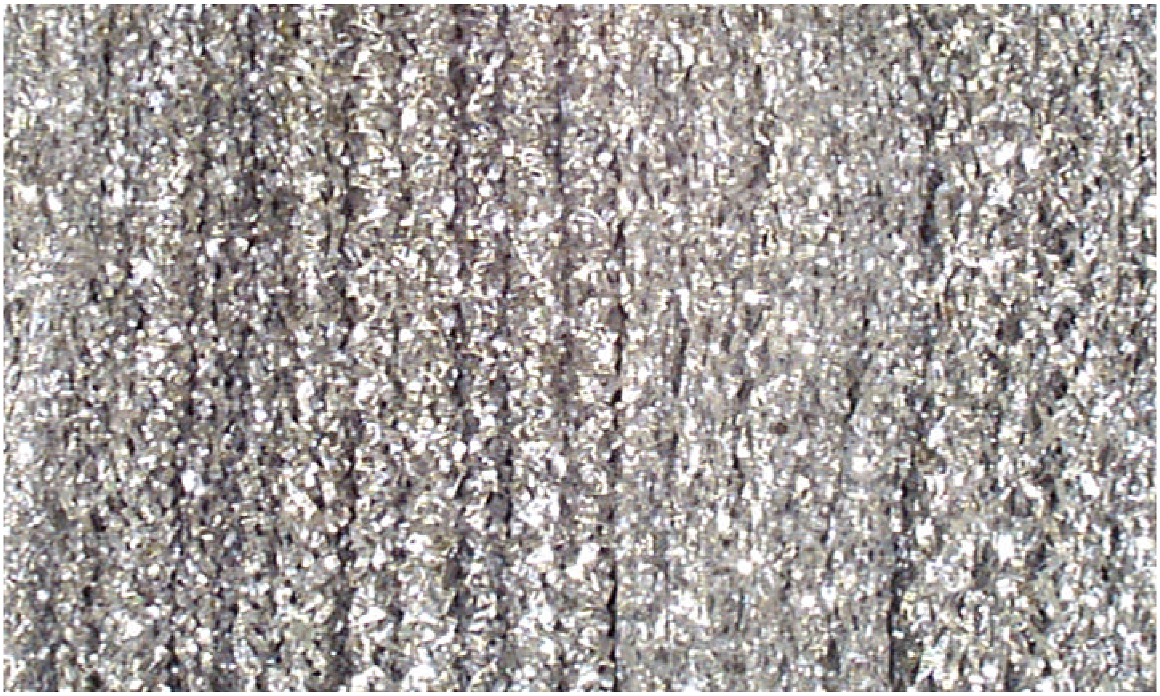

Figure 5 - Expanded Metal Blocks

2.0 Design Alternatives

2.1 Introduction

There are several design alternatives for design and installation of explosion suppression material, both with respect to type of material and installation design. This section will outline the various alternatives, explain the benefits, drawbacks, service experience and anticipated certification requirements of each, and select a baseline alternative based on best proven suitability for transport aircraft. Other alternatives may be suitable for specific applications, as determined by the aircraft manufacturer or modifier and certifying authority; however, additional testing may be required to establish suitability. The alternatives to be considered are:

- Fully packed coarse pore reticulated foam
- Grossly voided fine pore reticulated foam
- Expanded Aluminum Mesh, Block Form
- Expanded Aluminum Mesh, Ellipsoid Form
- Selective Tank Installation
- Selective Installation Around Ignition Sources

Figure 6 presents a graph of explosion overpressure versus void volume for various alternative materials. Table 1 presents a comparison of other properties of various alternative materials, and Table 2 summarizes major advantages and disadvantages of alternative materials and designs. These will be referred to within the sections discussing each alternative.

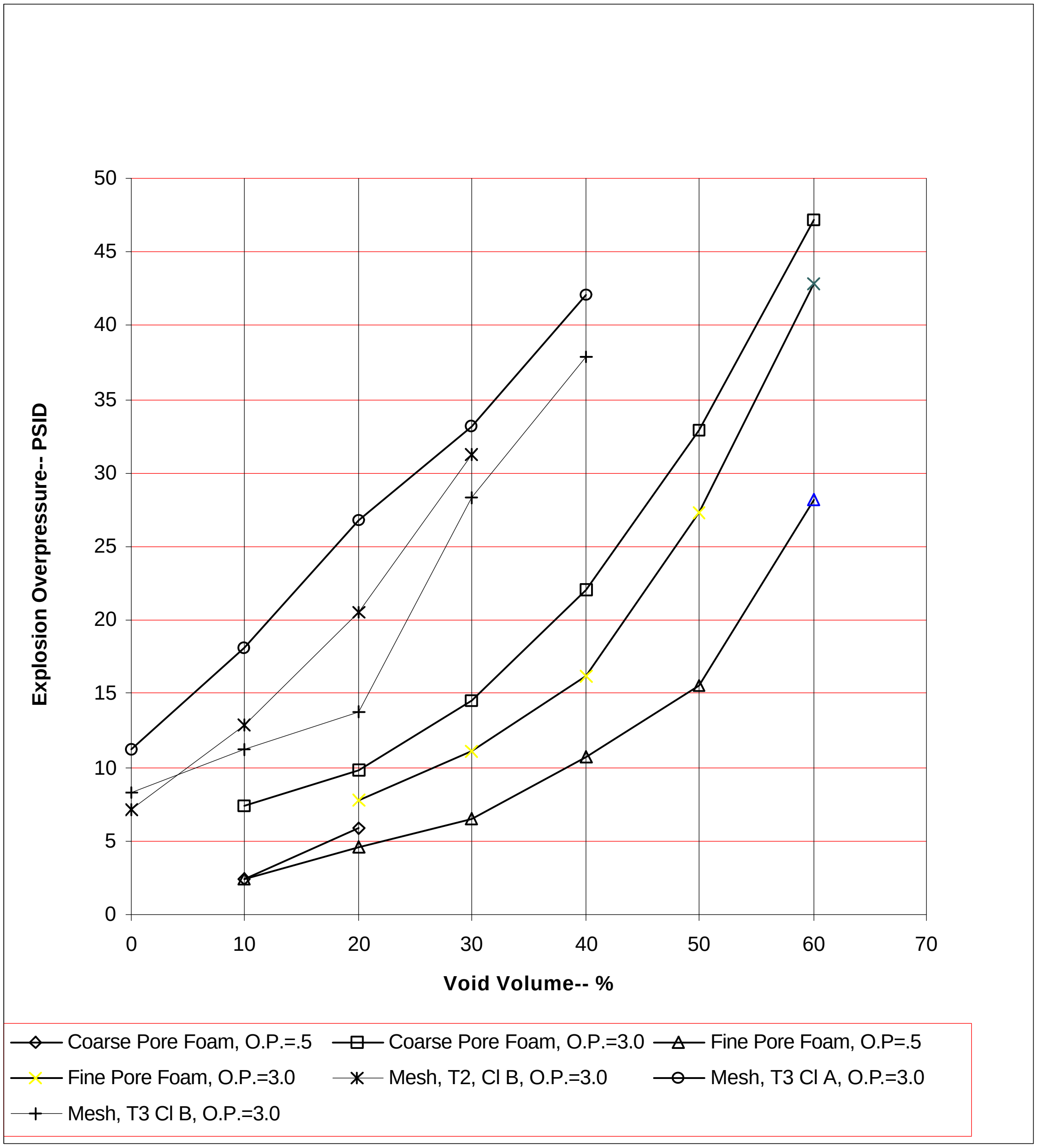

Figure 6

Explosion Overpressure versus Void Volume and Operating Pressure

Comparison Item	Coarse Pore Foam	Fine Pore Foam	Aluminum Mesh, Block Type					Aluminum Mesh, Ellipsoid Type
Specification	MIL-F-87260	MIL-F-87260	MIL-B-87162					None
Normal Installation	Fully Packed	Grossly Voided	Fully Packed					Fully Packed
Class, Grade, Type	Class 1 or 2, Grade IC	Class 1 or 2, Grade IIC	Type I	Type II, Class A	Type II, Class B	Type III, Class A	Type III, Class B	N/A
Material	Polyether	Polyether	3000 Series Aluminum Foil					Aluminum Foil
Max. Density, lb/ft^3	1.50	1.50	1.7	2.0	2.3	2.7	3.2	3.0 (est)
Max. Fuel Displacement-%	2.50	2.50	1.2	1.2	1.4	1.6	1.9	1.0—2.0 (est)
Max. Fuel Retention-%	2.50	5.00	1.0	.8	1.0	.8	.9	1.0 (est)
Conductive	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nominal Pore/Cell Count-No./In.	15	29	3.5	3.1	3.5	3.0	3.4	3.0 (est)
Foil Thickness Mils	N/A	N/A	1.5	2.0	2.0	3.0	3.0	Unknown
Entrained Solid Contamination mg/ ft^3	11.0 Max	11.0 Max	14.0 Max	14.0 Max	14.0 Max	14.0 Max	14.0 Max	Unknown
Estimated Cost, Uninstalled, $/cu. Ft.	12.00-24.00	12.00-24.00	33.00-66.00	33.00-66.00	33.00-66.00	33.00-66.00	33.00-66.00	28.0-75.00

Table 1

Explosion Suppression Material Properties

Note

Variation in uninstalled cost is due to vendor estimate variation and uncertainties as to production quantity and number and configuration of individual blocks.

Type Of Installation	**Advantages**	**Disadvantages**
Coarse Pore Foam, Fully Packed	Well proven including transport type aircraft Low overpressure Complete protection	Weight and fuel volume penalties Contamination potential Deterioration potential Maintenance time penalty
Fine Pore Foam, Grossly Voided	Lower weight and fuel volume penalties Complete protection	Higher overpressure Requirement to prevent propagation between bays Foam retention requirement Contamination potential Deterioration potential Maintenance time penalty
Aluminum Mesh, Block Type, Fully Packed	Lower fuel volume penalty Less deterioration potential Complete protection	Not proven in aircraft applications Higher weight penalty More difficult installation and removal Contamination potential Maintenance time penalty
Aluminum Mesh, Ellipsoid Type, Fully Packed	Lower fuel volume penalty Less deterioration potential Complete protection	Not proven in aircraft applications No aircraft application specification or testing Higher weight penalty More difficult installation and removal Contamination potential Maintenance time penalty
Selective Tank Installation	Lower weight, fuel volume, cost, maintenance time penalties	Same as selected material Requirement to prevent propagation to unprotected tanks.
Selective Installation Around Potential Ignition Sources	Much lower weight, fuel volume, cost, maintenance time penalties	Same as selected material Requirement to prevent propagation to unprotected portions of tanks. Difficult to apply to potential ignition sources in other than discrete locations

TABLE 2

Design Alternatives Comparison

2.2 *Fully Packed Coarse Pore Reticulated Foam*

This alternative consists of installation of reticulated foam with a small amount of voiding so that the foam occupies the majority of the affected tank volume. Current and future design utilizes conductive polyether foam per MIL-F-87260, Class 1, Grade IC or Class 2, Grade IC. These foam grades incorporate improvements to prevent deterioration and electrostatic discharge problems experienced with earlier types of foam, as previously discussed. The difference between Classes is that Class 1 maintains electrical conductivity down to 10° F and Class 2 maintains electrical conductivity down to -20° F. There is currently one qualified manufacturer of the preferred Class 2 foam, however, another manufacturer, qualified for Class 1 foam, is currently undergoing qualification.

The absence of electrical conductivity at these low temperatures is not considered to constitute an ignition source for normally used kerosene type fuels and extensive military experience has shown that ignition of wide cut fuels is not a safety hazard since thousands of ignitions have occurred with no aircraft losses, and no significant aircraft damage except in a few instances of improperly or incompletely installed foam. In many instances, ignition was not detected until the foam was removed and found singed during later maintenance. It may be advisable to prohibit over-wing refueling at low temperatures when using wide cut fuels; however, this situation very rarely occurs and is not considered a significant penalty for transport category aircraft operations.

This alternative has been widely used in all of military transport type aircraft foam installations (C-130 and P-3), many other military aircraft installations, and in certain business jet fuselage tank installations.

The foam is installed in the form of blocks cut into engineering defined shapes. Voids of dimensions recommended in SAE AIR 4170 are located to provide clearance around components such as pumps, valves, fuel quantity probes, flapper valves, plumbing inlets and outlets, etc. Additional voiding up to the limit suitable for the particular application is located in individual blocks and typically consists of 4.0” diameter horizontal holes located so that holes in adjacent blocks do not line up. It is typical for total void volume to not exceed 20%. As can be seen from Figure 6, a 20% void installation with a tank ullage operating pressure of 0.5 psig, which is typical of transport category aircraft, produces a combustion overpressure of 6.0 psig. This is likely to be within the limit pressure capability of most transport aircraft fuel tanks. If necessary, the combustion overpressure could be reduced to 2.5 psig by reducing the void volume to 10%.

Foam blocks are designed to near nominal shape and size, with the specified voids, and become self-supporting by 10-20% swelling when wet with fuel. Retainers or guards are recommended practice only for components with exposed floats, but may also be considered for other components with exposed moving parts, such as flapper valves, and for fuel quantity probes. The number of blocks required is a function of bay size, access opening size, and internal plumbing and structure complexity. A typical practice is to not install foam in sump or pump bay areas where the installation may be difficult and which are always full of fuel down to the fuel level where fuel exhaustion is imminent. Application of this practice to commercial transport aircraft would vary with different fuel system designs. C-130 and P-3 aircraft have tanks, which appear to be of greater complexity than comparable size narrow body airliners. It is beyond the scope of this report to determine design factors for specific aircraft; however, it is estimated that the number of blocks is unlikely to be less than 250 or more than 6,000 over the complete range of transport category aircraft.

Based on the extensive experience and data which show suitability for transport category aircraft, the fully packed reticulated foam system is considered to be the baseline system for purposes of this report, with cost data presented in Section 8.

2.3 Grossly Voided Fine Pore Reticulated Foam

This alternative consists of designs that have a much higher proportion of the fuel tank volume, which is devoid of foam than the baseline fully packed alternative. The intent of this design is to minimize the weight and fuel volume penalties. Current and future design utilizes conductive polyether foam per MIL-F-87260, Class 1 Grade IIC or Class 2, Grade IIC. A typical design would involve tanks divided into bays by spars, bulkheads, and ribs, where the foam is installed at the bay boundaries to prevent explosion propagation from one bay to another. It is necessary to incorporate means to retain the foam in place. Adhesives have been successfully used. Void volumes have been as high as 70%.

Table 1 shows that the density and fuel displacement of fine pore foam is the same as coarse pore foam, while fuel retention is twice as much. It is, therefore, necessary for the void volume to be at least approximately 40% for this alternative to be of benefit. Figure 6 shows a combustion overpressure of 10.7 psig for a void volume of 40% with a tank operating pressure of 0.5 psig. The combustion overpressure rises to 28.2 psig at a 60% void volume where significant benefits are available. The exact amount of overpressure and its extent depends on the expansion characteristics of combustion products and is an application specific function of number of bays, bay size and arrangement, and intercommunication among bays. For this reason, military applications of grossly voided designs have been limited to tanks capable of significant overpressure, such as fighter aircraft wing tanks. The F-15 wing tanks are one example. This design cannot be considered generally suitable for transport category aircraft for this reason, although it may be suitable for some tanks or portions of tanks on some aircraft, if substantiated by tests.

Certification considerations for this alternative are similar to those for fully packed design, discussed in Section 3, with the additional requirements that explosion suppression testing is considered mandatory to determine the amount of overpressure, the ability of the design to prevent propagation between bays, and the ability of the tank structure to withstand the resulting localized overpressure.

A grossly voided reticulated foam design has not been selected as the baseline for transport category aircraft application due to the above considerations, and, therefore, no cost data is presented in Section 8.

2.4 Expanded Aluminum Mesh, Block Form

This alternative consists of a nominally fully packed installation of shaped blocks of expanded aluminum foil mesh. Material is defined by MIL-B-87162, and as shown in Table 1, several different combinations of foil thickness and density are defined. Currently available material has not been qualified to this specification. This generic type of material has been subjected to explosion suppression and material qualification testing, and installation evaluation in several small tanks, as documented in Report AFWAL-TR-80-2043, however there are no known military aircraft applications, including test applications. There may have been a small number of civil and military aircraft applications, either on small experimental aircraft or production aircraft, not in the transport category, approved on an individual aircraft, non-hazard basis.

As shown on Figure 6, overpressure potential is higher than foam under equivalent test conditions. For this reason, explosion suppression testing may be required for at least the first aircraft application.

As shown in Table 1, the aluminum mesh material has a higher weight but lower fuel displacement and retention than foam, with the amount varying depending on the specific type.

Due to the lack of flexibility and compressibility compared to foam, this installation is likely to require a larger number of individual blocks and to be more difficult to handle. Methods to prevent the blocks from shifting and to provide required clearance for components would require development. It is likely that more guards or retainers would be required than for foam.

One item of concern is that effect of long term installation on the integrity of both the mesh material and the protective coatings on the internal tank structure. The mesh material integrity question relates to vibration, sloshing and other mechanical action, since it is less susceptible to material deterioration than foam. MIL-B-87162 addresses this question by requiring slosh tests on both a metal tanks, with the mesh material in contact with representative coating and sealant patches, and on a bladder tank. Report AFWAL-TR-80-2043 addresses these issues in an apparent satisfactory manner except for unresolved questions regarding the tendency of the material to settle and create additional unintended void volume.

Certification for transport category aircraft application would involve considerations similar to those discussed in Section 3 plus expansion to adequately quantify the explosion protection characteristics in relation to the aircraft fuel tank structural capability, and to demonstrate that installation compatibility and continued airworthiness requirements can be satisfied in a consistent manner.

Expanded aluminum mesh in block form in a fully packed installation is considered to be a potentially feasible alternative for transport category aircraft application. Although additional development is required, it is considered sufficiently feasible that cost data is presented in Section 8 for the selective tank installation option (heated center wing tanks) discussed further in Section 2.6.

2.5 Expanded Aluminum Mesh, Ellipsoid Form

This alternative consists of expanded aluminum mesh material similar to that discussed above, except that the material is formed into small ellipsoid or cylindrical shapes, with a maximum dimension of approximately 1-2”. Military aircraft experience is limited to a recent application in an U.S. manufactured helicopter in European service. Little detailed information is available.

Testing has been done to demonstrate explosion suppression capability in applications such as ground vehicle fuel tanks, however the test conditions are not similar enough to provide direct comparison with aircraft application requirements. Weight, fuel displacement, and fuel retention characteristics are estimated to be similar to block form expanded aluminum mesh discussed in Section 2.4.

Installation in tanks with access openings on the top could be done by gravity methods, however, for the more common case of tanks with access openings on the bottom, a method such as blowing in the ellipsoids with forced air would require development. Installation concerns would include requirements for assuring complete filling, especially near the top of the tank, and installation of access covers without escape of the material. Removal of the material for maintenance or inspection would be anticipated to be a problem with either top or bottom openings. Extensive guards to provide component clearance and prevent material entrance into plumbing passages are anticipated to be necessary. Concerns regarding settling of the material are similar to those for block type aluminum mesh material.

Certification for transport category aircraft application would involve considerations similar to those discussed in Section 3 plus expansion to adequately quantify the explosion protection characteristics in relation to the aircraft fuel tank structural capability, and to demonstrate that installation compatibility and continued airworthiness requirements can be satisfied in a consistent manner.

It is unclear whether expanded aluminum mesh in ellipsoid form in a fully packed installation can be considered to be a potentially feasible alternative for transport category aircraft application without further testing and development. It is not selected as the baseline system due to the disadvantages discussed and the lack of aircraft service experience. Cost data is, therefore not presented in Section 8. It is noted, however, that costs would be very similar to the data presented for block type expanded aluminum mesh, subject to satisfactory installation development.

2.6 Selective Tank Explosion Suppression Material Installation

This alternative involves installation of one the alternatives discussed above in only selected tanks instead of all tanks of a particular aircraft model. The considerations, advantages, disadvantages, and certification considerations for the particular type of system would apply in a smaller scale in proportion to the tank volume protected.

One exception that is important for selective tank installation is the possibility of self generated ignition, which could propagate to an unprotected tank. This would apply if the protected tank was interconnected to unprotected tanks in a manner which could propagate an explosion. The most obvious example is tanks interconnected to a common vent surge box, however interconnection through transfer, refuel/defuel, or other systems may require consideration.

The only identified explosion caused by reticulated foam is static electrical charge accumulation and ignition of wide cut fuel at low temperatures where the foam becomes much less conductive. Prohibition of operation with wide cut fuels is considered an acceptable means to address this concern. Another means would be to eliminate any interconnection by which an explosion could propagate. It is uncertain whether other means traditionally used to minimize static charge ignition probability could be substantiated to the necessary high confidence level and extreme improbability of occurrence.

Static electricity charge accumulation is not a consideration with expanded aluminum mesh, however, other ignition modes, such as sparking when the mesh is conducting lightning strike current, would require consideration. This would be a particular concern with composite tanks, which are not widely used in transport category aircraft.

Certification considerations for selective tank explosion suppression material installation in transport category aircraft would involve the considerations applicable to the method chosen, determination of which tanks require explosion suppression, and prevention of explosion propagation to unprotected tanks.

This alternative is considered to be a feasible alternative for transport category aircraft, subject to the considerations discussed, and subject to the requirement to minimize explosion hazards to a required level, as opposed to eliminating them.

2.7 Selective Installation of Foam or Aluminum Foil Around Ignition Sources

This alternative involves installation of explosion suppression material around theoretical potential ignition sources in a manner, which will prevent an ignition at that source from propagating. This involves consideration of the flame arresting characteristics of the material. It should be noted that MIL-F-87260 requires flame arrestor testing of Class IIC fine pore foam at maximum thicknesses of three to five inches, depending on void volume and operating pressure, and that such a requirement is not established for other materials. This is not a critical concern since the flame arresting capability would also be installation dependent and would require testing for any material.

This alternative is most applicable to discrete theoretical potential ignition sources, such as fuel quantity probes, electrical motors and other electrical components within the tanks. Application to more widely spread theoretical potential ignition sources such as wires, potential points of static charge accumulation, or ignition sources external to the tanks, is more difficult, and sources such as these may be more appropriately addressed by other ignition prevention means which are outside the defined scope of this report.

Explosion suppression material installation may take two possible forms, depending on the size and configuration of the fuel systems involved:

The first, which is most applicable to smaller systems or smaller tank bays, would consist of installation in the entire bay where the potential ignition source is located. It would be necessary to assure propagation to adjacent bays is prevented especially where the potential ignition source is located adjacent to a bay boundary with openings.

The second method consists of localized explosion suppression material installation around the ignition source. It would be necessary to suitably retain and restrain the material, and prevent explosion propagation through any joints in the material and at interface boundaries between the material and tank structure or other components.

Means to prevent self induced ignition and explosion propagation in the unprotected portions of the tank, as previously discussed in Section 2.6, are required. Considerations are much the same as discussed in Section 2.6. It is noted that this alternative may have less susceptibility to static charge accumulation in reticulated foam, or lightning strike current in expanded mesh, due to limited amount and specific configuration of the material.

Certification considerations for selective explosion suppression material installation around theoretically potential ignition sources in transport category aircraft would involve the considerations applicable to the material chosen, determination of which ignition sources require explosion suppression, and demonstration of no explosion propagation, either self induced or from the ignition source.

This alternative is considered to be a feasible alternative for transport category aircraft, subject to the considerations discussed, and subject to the requirement to minimize explosion hazards to a required level, as opposed to eliminating them. It is not selected as the baseline alternative, since compliance with the FTHWG Terms of Reference is not entirely clear.

3.0 FAA Certification Requirements

3.1 General

This section discusses FAA certification requirements, which are recommended for the baseline fully packed reticulated foam installation alternative. Other alternatives may include additional certification requirements discussed in Sections 2.2 through 2.7, including demonstration of explosion protection effectiveness, showing absence of self induced ignition hazards, and aircraft

3.2 Similarity and Previous Test or Flight Experience

Explosion suppression testing is not considered to be necessary based on foam qualification testing and extensive military experience. Analysis would determine the void fraction and overpressure from available test data, which would then be compared to allowable tank limit pressure based on existing certification data. Other factors discussed below, such as effects on refueling or fuel flow and pressure delivery, may be acceptable on the basis of similarity for additional models with similar fuel systems and foam installations, after testing on the first model has shown expected minimal effects.

3.3 Additional Analysis and Testing

The following additional analysis and testing is recommended as part of FAA certification:

Flight testing followed by ground inspection is recommended to verify adequacy of the design to properly retain the foam blocks, and to verify adequacy of recommended flushing procedures and contamination inspections.

Usable fuel volume and calibration of fuel quantity indicating systems will be affected by the foam installation and will need to be substantiated during certification. A wet fuel quantity indicating system calibration is acceptable, but not necessarily required, unless otherwise required for the specific type of aircraft and system. Alternative methods would include determination of the reduction in usable fuel either by ground test, or by using the conservative specification or qualification test values, followed by modification of the fuel quantity indication system to incorporate the required scaling factor, and verification of this scaling factor by bench test.

Ground tests for satisfactory refueling, including tank pressure during maximum rate refueling, and for fuel flow and pressure delivery to the engine, and for other operations such as transfer, would be required unless similarity data is available from previous certifications.

Operational documentation requirements for certification include modifications to the Approved Flight Manual, Weight and Balance Manual, Maintenance Manual, Illustrated Parts Manual and other similar documents.

4.0 Safety

4.1 Effectiveness in Preventing Overpressure Hazard

There is extensive military test and operational experience, including thousands of electrostatic self induced ignitions, that indicates that a properly installed fully packed reticulated foam installation is 100% effective in preventing overpressure hazards resulting from any internal or external ignition source. Complete prevention of all hazards when tank structural integrity is breached by mechanism external to the tank cannot be assured due to fire hazards and structural effects of the breach of tank integrity.

4.2 Effects of Range Reduction and Additional Flights

Range would be reduced by up to 5% on flights with full or near full tanks due to the reduced fuel tank capacity. Range would be reduced by the same amount on flights with less than full tanks in cases where weight limitations would not allow sufficient additional fuel to be carried to compensate for foam and retained unusable fuel weight. Range would be reduced by 0-5% on flights where the aircraft is near, but not at the fuel capacity or weight limit. Range reduction due to increased weight on other flights is not a factor, since sufficient additional fuel could be carried to compensate for the increased fuel burn.

If it is assumed that all flights carry no more than the fuel required by the applicable operating regulations, there would be no safety impact due to range reduction. Validation of this assumption is beyond the scope of this report. It is noted, however, that there could be a reduction in the capability to carry more fuel, at the discretion of the operator or flight crew, than the amount required.

It is considered reasonable and conservative to estimate a 1% increase in departures due to the fuel penalty when limited by tank capacity or weight. Applying the 1987 to 1996 overall worldwide hull loss rate of 1.60 per million departures documented in the same industry response, this results in a rate of .016 losses per million departures due to additional departures. It is noted that these statistics involve FAR 121 type operations, however, it is considered reasonable to conclude that they are also representative of operations involving transport category regional airlines and business aircraft.

4.3 Effects of Weight Increase

The weight increase for a flight with full tanks is insignificant due to the foam weight being compensated for by reduced fuel capacity due to displaced fuel. The weight increase for flights with less than full tanks is 5% of the total fuel capacity weight, assuming sufficient fuel is carried for equal range. If the flight is weight limited, there is a potential safety hazard associated with human error resulting in exceeding weight limits. If the flight is not weight limited, the increased weight will still reduce aircraft runway and climb performance and therefore, represents some level of hazard in the event of human error or combination of adverse conditions, such as wind shear, where a small difference in performance could have a decisive impact on the outcome. These effects are not considered quantifiable and would present very low hazards considering normal certification and operational practices. The historical record does not support an assessment of the hazards of such a small performance decrement due to a weight difference equal to 5% of fuel capacity or approximately 1.5-2.5% of maximum takeoff weight.

4.4 Personnel Hazards

The primary personnel hazard associated with a fully packed reticulated foam installation are those associated with maintenance personnel contact with fuel wetted foam and fire protection issues associated with fuel wetted foam during maintenance activities, either during tank entry or when the foam is removed for maintenance. It is noted that fuel wetting of the foam is reduced significantly by extended drainage and tank ventilation time periods prior to tank entry. It is considered that these hazards can be sufficiently mitigated by expansion of existing maintenance precautions associated with these hazards, and that human error or failure to follow procedures is possible but no more hazardous than existing aircraft, especially when considering the potential reduction in fuel tank explosion hazard vulnerability during maintenance. The time and difficulty associated with tank ventilation with foam installed tends to mandate the use of respirators by in-tank maintenance personnel. As discussed in Section 2.2, there is a theoretical personnel hazard associated with over wing refueling using wide-cut fuels at extremely low temperatures, which could be prevented by prohibiting this operation.

5.0 Aircraft Hazards or Effects

5.1 General

This section will address potential theoretical hazards associated with reticulated foam. Some of these are not actual hazards, but the discussion is included due to questions typically raised. These discussions apply to the baseline fully packed reticulated foam installation in all tanks. Other potential hazards associated with other design alternatives are discussed in Section 2, and generally would require resolution during FAA certification.

5.2 Electrostatic Charge Hazards

As discussed in detail in Section 2.2, MIL-B-87162 reticulated foam becomes non-conductive and a potential ignition source for volatile wide cut fuels at extremely low temperatures. Military experience with previous non-conductive foams has included thousands of such incidents with no aircraft losses, and aircraft damage limited to several isolated cases of improper foam installation. This experience, combined with very infrequent use of wide cut fuels, is sufficient to assess that no hazard potential exists for fully packed installations of all tanks. Other design alternatives would require additional hazard assessment as part of certification, as discussed in Section 3.

5.3 Aircondition Pack Bay Temperature and Structure Degradation

All of the foam applications in this report evolve around center wing tanks with adjacent heat source. The heat source in this discussion is the air-condition pack located underneath the center wing.3

In normal operation the center wing structure acts as a heat sink to dissipate the heat rejected by the air-condition pack. This heat transfer causes the fuel inside the fuel tank to heat up and increases the flammability of the fuel vapor. Although foam installed inside the fuel tank would not act as an insulator to prevent external heat transfer, and is not expected to significantly affect natural convection internal heat transfer due to its open cell construction, a significant reduction in heat transfer could cause some adverse effects such as:

- The pack bay temperature will raise and could trip the over heat detection system. This will cause nuisance alerts and or dispatch delays.

- The elevated temperature in some aircraft pack bay could reach over 200° F and this will degrade the strength of the surrounding structure, which is made of mostly Aluminum.

To minimize this potential thermal problem the pack bay temperature must be carefully analyzed, tested with the foam installed. And in some case some source of pack bay ventilation will be required to reduce the pack bay temperature to an acceptable level. The cost estimate in this report does not include pack bay ventilation scheme.

5.4 Fuel Contamination and Foam Deterioration

Research into military and very limited civil, experience with reticulated foam has established three potential mechanisms by which fuel contamination may become a safety issue. These are:

- Fabrication or installation debris resulting from the initial installation or replacement.

- Contamination introduced during in-tank maintenance or foam removal and reinstallation.

- Contamination due to foam deterioration caused by age and environmental exposure.

Military experience has shown no widespread problems with these types of contamination. Several sources indicate an absence of problems since polyether foam was introduced in the mid 1970's, however, there is evidence, not well quantified, of occasional occurrences of foam deterioration and a limited number, on the order of one or two, of incidents of engine flameout attributed to fuel contamination. Favorable experience has included foam installed in aircraft without deterioration since the introduction of second generation polyether foam in the mid 1970's, satisfactory completion of laboratory tests on foam which has been installed for extended periods, and environmental tests required for qualification under extremes of temperature and humidity. It is reported that contamination symptoms involving a small proportion of foam combined with a large proportion of other materials are typically, somewhat incorrectly, attributed to foam. Fuel contamination related to foam could occur in several ways:

- Contamination can be caused by fabrication residue following initial installation or replacement. Procedures to prevent or minimize this include mechanical agitation of the foam blocks after they are cut to remove residue, multiple fuel system flushing operations combined with fuel cleanliness checks, and more frequent fuel filter inspections during the initial operation period following installation. It is noted that there are variations in flushing procedures among different military units and that those units experiencing the most problems were using the least thorough procedures.

- Contamination can be caused by failure to protect the foam from external contamination, either when it is not installed in the aircraft or during in-tank maintenance. It is absolutely essential that the foam be protected from contamination during storage and handling. There is evidence that clothing other than 100% cotton clothing is preferable for in tank maintenance. Cotton clothing rubbing against foam tends to generate contamination from both, but primarily from the clothing. The flushing procedures discussed above are also pertinent. It is typical practice that replacement of more than 25% of the foam in the tank requires flushing.

- Contamination can be caused by foam deterioration. The ultimate life and distribution of useful life of modern polyether foam is not known with certainty. Unfavorable factors include high heat and humidity, including heat associated with any heat exchangers in the fuel tank. Available information indicates that continuous exposure to temperatures up to 150° F and intermittent exposure to temperatures up to 240° F does not cause deterioration. Available information indicates that these temperatures would not be exceeded in center wing tanks with adjacent heat sources. It is noted that information necessary to quantify long term cumulative heat exposure versus deterioration effects is not available. Contamination is typically first detected either by particles in fuel filters or during physical inspection inside the tanks. As previously noted, military experience has not shown significant deterioration problems, and there has not been established a required replacement interval. Limited experience in business jets with foam in fuselage tanks has shown that one model has a required replacement interval of eight years and that a different model from a different manufacturer has no replacement interval and no reported problems. The model with the required replacement interval has shown no overt symptoms of contamination, such as flameouts or particles in drained fuel or fuel filters or filter bypass indications. The interval was established by fleet sampling for items such as foam discoloration and loss of mechanical properties, both of which are normal tendencies of fuel soaked foam, thus raising the possibility the required replacement is unnecessarily conservative. It is pertinent to note that the model involved represents a small fleet (32 aircraft) which may limit the usefulness of this service experience.

Military aircraft experience most relevant to transport category aircraft is the experience with C-130 and P-3 aircraft. Of these aircraft, the amount of experience on the C-130 is far more extensive. AGARD Report No. 771 states that C-130 experience includes 54 production installations from 1968 to 1970, 85 production installations since 1983, and about 500 retrofit installations. Although exact details are not available, it is possible to estimate C-130 fleet experience with foam installed to be on the order of 10^6 to 10^7 flight hours. This experience has included no known accidents, including single or multiple engine shutdowns, caused by foam related contamination. There is one known P-3 single engine shutdown associated with early foam contamination and less rigorous flushing procedures by the unit involved. This experience is sufficient to conclude that foam related engine shutdowns occur at a much lower rate than shutdowns due to other causes, and that foam related contamination is not a common cause event for multiple engine shutdowns when considering the mitigating factors discussed below.

It is concluded that the potential hazards associated with foam related contamination and deterioration can be sufficiently mitigated by careful adherence to cleanliness and flushing procedures, verification of cleanliness and flushing procedure effectiveness during certification, and careful inspection of foam condition at major periodic inspections. As additional civil service history is obtained, it may be possible to justify less extensive procedures. It is possible that it may be advisable, from an economic risk standpoint, to replace the foam in a major portion of a fleet during scheduled major maintenance near the ten year time frame, while a smaller portion would continue operation to demonstrate continued durability.

5.5 Effects on Other Fuel System Components

Military experience has shown only one adverse effect other than the occasional contamination problems discussed above, which mainly affect fuel filters and engine fuel heat exchanges. This effect is erratic fuel quantity indications when improperly installed foam causes the conductive foam to contact fuel capacitance probes. This is mainly a problem with traditional low level alternating current capacitance systems in which the outer probe element forms part of the circuit, and which typically use exposed probe terminals. Some newer systems, which do not have these features, are less likely to be affected. It may be advisable for the design of potentially affected systems to include retainers to insure positive clearance around fuel quantity probes. This would not only mitigate any safety hazards associated with this condition, but it would also eliminate the economic penalty associated with repairing the condition.

5.6 Corrosion, Water Retention, and Biological Contamination

Concerns are sometimes expressed with regard to the corrosion potential associated with foam. These concerns include the foam itself rubbing against the tank structure and protective finish, water retained by the foam, and biological growth in the water retained by the foam. Extensive military and limited civil experience has not shown these to be problems, except for one limited use non-qualified type of foam which was treated for conductivity improvement following manufacture, and which did cause corrosion problems. It is important to note that foam does not hold water or fuel like a sponge, and that there is essentially no known difference in the ability of water in foam to drain compared to water suspended in fuel. It is further noted that the primary means to protect against corrosion does not change with the installation of foam and includes such items as maintaining the integrity of corrosion protective finishes and adherence to good housekeeping procedures. Based on this experience, it is concluded that corrosion potential with foam installed does not exceed that currently experienced and that the installation of foam does not represent an additional safety hazard.

One further issue is whether foam will increase the amount of water condensation in the tanks due to the greater surface area exposed to moist air in the ullage. This phenomenon is most severe when an aircraft cold soaked at altitude descends into warm moist air, which is drawn in to the tank and comes into contact with cold interior surfaces. The presence of foam will not change the amount of moisture subject to condensation or the much larger heat capacity of structure and fuel compared to air in the ullage. It may, however, change the rate of condensation, and, therefore, the amount condensed in the time prior to refueling or natural warming of the structure and fuel. It is readily observable that cold soaked structure not in direct contact with fuel warms to ambient temperature much more rapidly than structure in contact with fuel. This reduces condensation potential and would occur with foam in the ullage space due to the limited thermal capacity and thermal conductivity of foam. A severe, but not extreme, case of air at 100° F and 100% relative humidity contacting tank interior surfaces at 0° F results in condensation of approximately .05 pound of water per pound of dry air if 100% condensation occurs. If the tank is 10% full of fuel, this results in a volumetric water concentration of .055% water in the fuel, compared to the sump capacity of .10% of entire tank volume required by FAR 25.971. This water concentration is higher than the .02% free water specified for fuel icing by FAR 25.951 but would be reduced to within this limit by refueling or removal of the water through sump drains. It is, therefore, concluded that any additional water condensation does not constitute a safety hazard, however, additional research would be required if it were necessary to determine the rate and exact amount of such condensation.

5.7 Other Equipment Hazards or Effects

This type of hazard is related to the fire hazards to ground equipment and facilities associated with handling and storage of fuel wetted foam when it is removed from the aircraft. It has been previously discussed, and is sufficiently mitigated by use of designated storage equipment and facilities and use of standard fire protection procedures.

7.0 Overall Safety Assessments

Based on the historical record, foam was assessed as effective in four operational overpressure events and of unknown effectiveness in four operational overpressure events also involving breach of tank integrity and external fire. Negative effects over this time period would include potential for five additional accidents due to increased flights based on the .016/million departure rate and the 317 million departures for the airline transport fleet. Factors, which could improve the overall foam safety effectiveness, include the possibility that foam would be effective in some or all of the unknown events. Factors which could degrade the overall foam safety effectiveness would include the possibility of events caused by those negative factors previously discussed, which were assessed as very low-non-quantifiable hazards that could be sufficiently mitigated, or the possibility that reduced range would, in fact, have negative safety effect.

The above overall safety assessment applies primarily to airline transport aircraft, of approximately 100 seats or more in size, in primarily Part 121 operations. An overall assessment based on the historical record for regional airline aircraft and business jets would be entirely negative due to the absence of any historical overpressure events. It is acknowledged that these aircraft have had less fleet operating time exposure, by perhaps an order of magnitude. If it were assumed that an overpressure event were to occur in the near future, the overall safety assessment for aircraft losses would be similar to that for airline transport aircraft, although fatalities to the traveling public would be lower for regional aircraft and much lower for business jet aircraft. It is also possible, however, that the absence of overpressure events may be due to other design and operational factors beyond the scope of this report. It is, therefore, not possible to conclude that foam installation would produce positive effects for regional transport and business jet aircraft. It is noted, however, that these aircraft may have reduced susceptibility to any potential hazards associated with reduced range, due to the greater tendency to fly multiple flight legs without refueling, for operational and economic reasons, and the resulting greater fuel reserves on many flight legs.

8.0 Cost Analysis

The two types of material, which evaluated for cost, in this report are: Foam with 100% filled and Expanded Metal Products. Both are installed on aircraft center wing tank with adjacent heat source. Two classes of aircraft are considered in this cost for the 2 types of material. The first one is retrofit cost for aircraft that are in service and the second is for new and or production aircraft.

The cost is broken down into nonrecurring and recurring cost.

Nonrecurring Cost

The nonrecurring cost is made up of:

- Engineering
- Tooling and Planning
- Test and certification
- Operation and Customer Support
- Material (Foam requires replacement each 15 year period)
- Cost of disposal of material
- Infrastructure is the storage facility required to store foam or expanded metal during maintenance.

Recurring Costs

- The recurring cost is made up of:
- Fuel burn cost to carry the added weight

- Additional maintenance cost
- Loss of revenue when aircraft operate at maximum weight limit and or fuel capacity.

The next four tables provide a complete cost structure for the 2 types of material used on the two classes of aircraft

Foam for Inservice Aircraft			
One time cost	Large	Medium	Small
Development	$10,546	$5,536	$3,430
Installation	$345,147	$154,559	$57,234
Infrastructure	$35,047	$27,332	$3,497
Total Per Aircraft	$390,740	$187,427	$64,191
Total Effected Aircraft	$501,710,160	$205,607,419	$394,525,989
Total Industry Cost	**$1,101,843,568**		
Annual Recurring			
Foam Replacement	$23,239	$10,395	$3,843
Additional Fuel Burn	$66,453	$22,216	$7,202
Loss of Revenue	$1,455,773	$596,726	$99,739
Additional Maintenance	$38,656	$24,160	$9,664
Total per Aircraft	$1,584,121	$653,497	$120,448
Total effected Aircraft	$2,034,011,364	$716,886,209	$740,634,752
Total Industry Cost	**$3,491,532,325**		

Foam for Production Aircraft

One time cost	Large	Medium	Small
Development	$8,210	$4,169	$2,536
Installation	$310,627	$134,833	$48,603
Infrastructure	$35,047	$27,332	$3,497
Total Per Aircraft	$353,884	$166,334	$54,636
Annual Recurring			
Foam Replacement	$23,239	$10,395	$3,843
Additional Fuel Burn	$66,453	$22,216	$7,202
Loss of Revenue	$1,455,773	$596,726	$99,739
Additional Maintenance	$38,656	$24,160	$9,664
Total per Aircraft	$1,584,121	$653,497	$120,448

Expanded Metal Products for Inservice Aircraft			
One time cost	Large	Medium	Small
Development	$11,581	$6,186	$3,869
Installation	$801,645	$332,539	$105,239
Infrastructure	$35,047	$27,332	$3,497
Total Per Aircraft	$848,273	$366,057	$112,605
Total Effected Aircraft	$1,089,182,532	$401,564,529	$692,408,145
Total Industry Cost	**$2,183,155,206**		
Annual Recurring			
Additional Fuel Burn	$72,917	$24,377	$7,899
Loss of Revenue	$1,217,444	$490,414	$71,429
Additional Maintenance	$38,656	$24,160	$9,664
Total per Aircraft	$1,329,017	$538,951	$88,992
Total effected Aircraft	$1,706,457,828	$591,229,247	$547,211,808
Total Industry Cost	**$2,844,898,883**		

Expanded Metal Products for Production Aircraft

One time cost	Large	Medium	Small
Development	$9,245	$4,819	$2,975
Installation	$767,124	$312,813	$96,609
Infrastructure	$35,047	$27,332	$3,497
Total Per Aircraft	$811,416	$344,964	$103,081
Annual Recurring			
Additional Fuel Burn	$72,917	$24,377	$7,899
Loss of Revenue	$1,217,444	$490,414	$71,429
Additional Maintenance	$38,656	$24,160	$9,664
Total per Aircraft	$1,329,017	$538,951	$88,992

8.1 Assumptions

- Foam requires replacement every 15 years.
- Cost to destroy foam is the same as cost to destroy jet fuel at 79 cents /lb.
- 2 days for down time is estimated for installation. Cost is estimated as the cost of money for this period.
- 1 day added to production span time for installation of foam on production aircraft - Cost is estimated as the cost of money for this period.
- Development cost per aircraft is the development cost per model multiplied by the number of models, and divided by the number of aircraft with heated center wing tanks.
- Aluminum mesh and foam costs provided by vendors (aluminum mesh costs approximate 3 times more than foam)
- Fuel cost is 62 cents per gallon.
- Annual fuel burn cost is computed using the cost estimator spreadsheet provided by Task Group 8.
- Loss of revenue is computed using the cost estimator spreadsheet provided by Task Group 8.
- Interest rate is 7%
- Loss of revenue is calculated using long mission flights. The assumption is 50% of flights are weight limited and 50% are fuel limited.
- Cost information in this report is only for aircraft with center wing tank with adjacent heat source.
- Storage facility cost is estimated at $150,000, $100,000 and $75,000 for large, medium and small aircraft respectively.
- There are 100, 100 and 150 maintenance bases for large, medium and small aircraft respectively.
- Three storage facilities are required at each base.

END

Aviation Rulemaking
Advisory Committee

Fuel Vapor Reduction

Task Group 5

1. ABSTRACT

The FAA/JAA initiated a Fuel Tank Harmonisation Working Group in January 1998 by the issuance of a Harmonisation Terms of Reference entitled "Prevention of Fuel Tank Explosions" on December the 16th 1997.

The Working Groups stated task was to study means to mitigate or eliminate fuel tank flammability and to propose regulatory changes to the FAA/JAA Aircraft Rulemaking Advisory Committee (ARAC).

The Working Group established eight Task Groups to report on the following:

1. Service History and Safety Assessment
2. Explosion Suppression
3. Fuel Tank Inerting
4. Fuel Tank Foam
5. Evaluation and mitigation of Fuel Tank Exposure to Flammable Fuel Vapours
6. Fuel Properties Aircraft Effects
7. Fuel Properties Infrastructure Effects
8. Evaluation Standards Advisory and Proposed Regulation Action

This document is the report of Task Group Five whose tasks were:

(i) To evaluate the present exposure of aeroplane fuel tanks to flammable fuel vapour.
(ii) To assess means of mitigating the exposure of aeroplane fuel tanks with adjacent heat sources to flammable fuel vapour.
(iii) To evaluate the exposure of aeroplane fuel tanks to flammable fuel vapour by changing the fuel flashpoint modifications proposed by Task Group Five, or other Task Groups.

Task Group Five had six principle members coming from across the aeronautical transport industry.

▪ Propulsion Systems Design Manager	Aerospatiale
▪ Senior Fuel Systems Engineer	Airbus Industrie
▪ Chemical Engineer, Fuel Systems Safety	Boeing
▪ Senior Engineer, Aircraft and Systems Safety	British Airways
▪ Propulsion/Thermodynamics Staff Scientist	Gulfstream
▪ Independent Transportation Safety Consultant	TRC

Numerous personnel within the six principle members own organisations, other Task Groups and members of the aeronautical transport industry worked for and or contributed to this report.

2. SUMMARY

This report attempts to quantify the exposure of fuel tanks to flammable vapour and evaluate methods to mitigate the exposure considering the related impacts: safety, certification, environmental, aeroplane design, operational and cost. Analysis has also been performed to assess the effects of ground inerting and changing the fuel flashpoint specification in mitigating the exposure to flammable vapours (see reports of Task Groups 6/7 and 3 for the impacts of these modifications). This analysis has been completed for generic aeroplanes and therefore does not relate to any specific aeroplane design.

Thermal analysis has shown that all generic fuel tanks have some exposure to flammable fuel vapour.

- Tanks without adjacent heat sources, independent of location, (wing or fuselage), have equivalent exposure of approximately 5%.
- Tanks with adjacent heat sources have exposure of approximately 30%.

Other factors affecting exposure are:

- Ambient temperature (of which control is not possible)
- Fuel loading (which is discussed further, see option 3)
- Altitude (which is not discussed within this report)

Following from the above, thirteen methods of mitigating the effects of heat sources adjacent to fuel tanks have been analysed. Only one eliminates exposure to fuel vapours. This is achieved by disabling the fuel tank and thus has severe operational consequences that can only be evaluated for individual airlines operations, and thus no conclusion is provided within this report.

Five options considered reduce the exposure to flammable fuel vapour, and have been evaluated for the Small, Medium and Large transport Aeroplanes:

1. Insulate the heat source adjacent to fuel tanks
2. Ventilate the space between fuel tanks and adjacent heat sources
3. Redistribute mission fuel into fuel tanks adjacent to heat sources
4. Locate significant heat sources away from fuel tanks.
5. Sweep the ullage of empty fuel tanks

Options 2 and 4 have been shown to reduce the exposure of fuel tanks with adjacent heat sources to a level similar to fuel tanks without adjacent heat sources. (Option 4 is only applicable to new aeroplane designs).

Option 5 requires significant further research before a conclusion on its feasibility can be reached.

Table 2.1 summarises the effects and impact of the five options.

In addition the effects of ground inerting and changing the fuel flashpoint were assessed. Either method could reduce the exposure of fuel tanks with adjacent heat sources to a level similar to fuel tanks without adjacent heat sources.

Table 2.2 summarises the effects on exposure of ground inerting, changing the flash point specification, and some potential combinations of modifications (that could be evaluated in the timeframe available).

Table 2.1 Summary of impacts and applicability of the five methods evaluated

Centre Wing Tanks With Adjacent Heat Sources Exposure to Flammable Vapours **30%**					
Fuel Tanks Without Adjacent Heat Sources Exposure to Flammable Vapours **5 %**					
OPTION **IMPACT**	1. Insulate Heat Sources	2. Ventilate (Directed)	3. Redistribute Fuel	4. Locate Heat Sources	5. Sweep Ullage
Estimated Exposure to Flammable Vapours after Modification	**20%**	**5%**	**20%**	**5%**	Not quantified
New safety Concerns	*minor*	*None*	**Medium**	*none*	**Medium**
Certification Impact	*minor*	*Minor*	*Minor*	*none*	**MAJOR**
Environmental Impact	*none*	*None*	*None*	*none*	**YES**
Aeroplane Impact	*minor*	**Medium**	*Minor*	**MAJOR**	**Medium**
Operational Impact	*minor*	*Minor*	**MAJOR**	*minor*	**MAJOR**
One Time Small	160	500	4	160	2,000
Fleet Costs Medium	50	60	2	50	650
($\$$ x 10^6) Large	100	300	3	100	1,200
Annual Fleet Small	10	170	7	?	370
Costs Medium	2	20	3	?	80
($\$$ x 10^6) Large	2	70	14	?	180
10 Year Fleet Costs ($\$$ x 10^6)	**450**	**3,500**	**250**	**?**	**10,000**
Applicability	MOST	MOST	MOST	**NEW DESIGNS**	MOST

Table 2.2 Summary of the effects of changing the fuel flashpoint, ground inerting and combinations of different modifications.

Modification	**Wing Tanks Without heat sources**	**Centre Tanks without heat sources**	**Centre Tanks with heat sources**
Current Aeroplanes	*5%*	*5%*	*30%*
120°F Flashpoint Fuel	**< 1%**	**< 1%**	**10 to 20%**
130°F Flashpoint Fuel	**< 1%**	**< 1%**	**5 to 10%**
140°F Flashpoint Fuel	**< 1%**	**< 1%**	**1 to 5%**
150°F Flashpoint Fuel	**< 1%**	**< 1%**	**1%**
Ground Based Inerting of Fuel Tanks	*Not applicable*	**< 1%**	**1%**

Combinations of Modifications			
Direct Ventilate and 120°F	*Not applicable*	*Not applicable*	**< 1%**
Insulate and 120°F	*Not applicable*	*Not applicable*	**5%**
Insulate and 130°F	*Not applicable*	*Not applicable*	**1%**

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4. INTRODUCTION

4.1. Objective

The objective of this report is to quantify the exposure of fuel tanks to flammable vapour and to discuss different methods by which that exposure can be minimised including the related; safety, certification, environmental, aeroplane, operational and cost impacts.

4.2. Scope

The methods of reducing the exposure considered are:

- (a) Minimise Effects of Onboard Heat Sources
- (b) Cooling
- (c) Pressurisation
- (d) Eliminating the Ullage
- (e) Sweeping Ullage

This report does not concern itself with:

- (i) The safety, certification, environmental, aeroplane, operational and cost impacts of the reduction of oxygen concentration, e.g. nitrogen inerting, (see Task Group 3 report).
- (ii) The safety, certification, environmental, aeroplane, operational and cost impacts of the change to the specification of flash point for JET A/A1, (see Task Group 6 report).
- (iii) Ignition sources (see the terms of reference for this ARAC FTHWG).

4.3. Assumptions, Definitions and Limitations

For the purposes of this report in order to quantify the exposure of fuel tanks to flammable vapour the following assumptions and limitations have been made:

(a) The lower flammability limit in terms of fuel vapour concentration in air is defined as 0.6% by volume or 0.35% by mass (reference "Handbook of Properties of Common Petroleum Fuels").

(b) The lower flammability limit in terms of temperature, (as defined by the fuel flash point as defined in the specification of JET A/A1 fuel, (reference ASTM D56)), is used as the basis for quantifying the flammability of fuel vapour and hence the flammability of fuel tanks.

(c) The fuel flash point, (as defined above), is assumed to decrease linearly at the rate of 1°F for every 800ft increase in altitude, (1°C for every 439m increase in altitude), (reference "Handbook of Aviation Fuel Properties", published by the Co-ordinating Research Council Inc.).

* *(The definition and assumption stated above, (a), (b) and (c) cover static conditions).*

(d) Investigations into dynamic flammability of fuel have been performed with no consistent or conclusive definition at the date of writing this report. Therefore dynamic conditions have not been used to quantify the exposure of fuel tanks to flammable fuel vapour.

(e) Probability profiles of ambient static air temperatures, based on historical measurements, have been used, (reference Task Group 8).

(f) The ground refuel temperature is assumed to be the same as the ambient air temperature.

(g) The distribution of JET A/A1 flash points has been compiled from petroleum industry data, (reference Task Group 6/7).

(h) The world fleet of aeroplanes has been divided into size categories, (reference Task Group 8).

(i) For each of these generic aeroplane categories, fuel tank volumes, fuel usage and flight profiles have been defined for the thermal model analysis.

5. EVALUATION OF EXPOSURE TO FLAMMABLE VAPOURS

5.1 Thermal Modelling

To quantify the current fleet exposure of fuel tanks to flammable vapour a process was developed to quantify the amount of time that the fuel temperature is above the flash point of the fuel on a fleet wide basis.

To predict fuel temperatures, the worldwide fleet of transport aeroplanes was divided into six generic size categories of aeroplanes (from Task Group 8). A representative aeroplane from each of the six categories was then chosen for development of a specific thermal model. The choice aeroplane to model was dependent upon three factors:

1. Availability of an existing thermal model, (preference given to those validated by flight test).
2. Number of aeroplanes that model represents in that size category.
3. Involvement in past events, (from Task Group 1).

For the Large and Small aeroplane, both the main wing tanks and the centre wing tank were modelled. For the Medium aeroplane a model was developed for the centre wing tank and results from an inactive model were available for the main wing tanks. A second Small aeroplane was also modelled, which had a centre wing tank without adjacent heat sources. A matrix of the aeroplane sizes and fuel tank configurations modelled is shown Table 5.1.

Table 5.1 Aeroplane sizes and fuel tank configurations modelled

Large	Main Wing Tank	Centre Wing Tank (with adjacent heat source)	*(no thermal model results available)*
Medium	Main Wing Tank (inactive model)	Centre Wing Tank (with adjacent heat source)	*(no thermal model results available)*
Small	Main Wing Tank	Centre Wing Tank (with adjacent heat source)	Centre Wing Tank (without adjacent heat source)
Regional Turbofan	Main Wing Tank	*(no thermal model results available)*	Centre Wing Tank (without adjacent heat source)
Regional Turboprop	*(no thermal model results available)*		
Business Jet	Main Wing Tank	(not applicable)	

5.1 Thermal Modelling (cont.)

The thermal models were developed independently by six different aeroplane manufacturers using seven different thermal codes, and therefore represent a wide range of complexity, from simple differential equation solutions to one-dimensional heat transfer balances, to complex finite element fluid/thermal codes. Because of this wide diversity, the assumptions made in each model were not always the same, but are documented in the descriptions of each thermal model in the Appendix in section 15.1, (with the exception of the Medium aeroplane main wing tank).

In order to produce consistent results, the inputs to and results from each model were processed through Task Group 5 and Task Group 8.

Each model was run through three generic flight profiles representing short, medium and long missions for that size aeroplane. Each flight profile included altitude, Mach number, fuel remaining in each tank and body angle as a function of time. Each model was then run for seven cases, for each mission length, representing a wide range of ambient temperature conditions. The seven ambient temperature profiles ranged from cold (1% cumulative probability) to extremely hot (99.9% cumulative probability). Each model therefore ran a total of 21 cases for each aeroplane/tank configuration and the results, (predicted fuel temperature profiles versus time), were then formatted in a consistent manor.

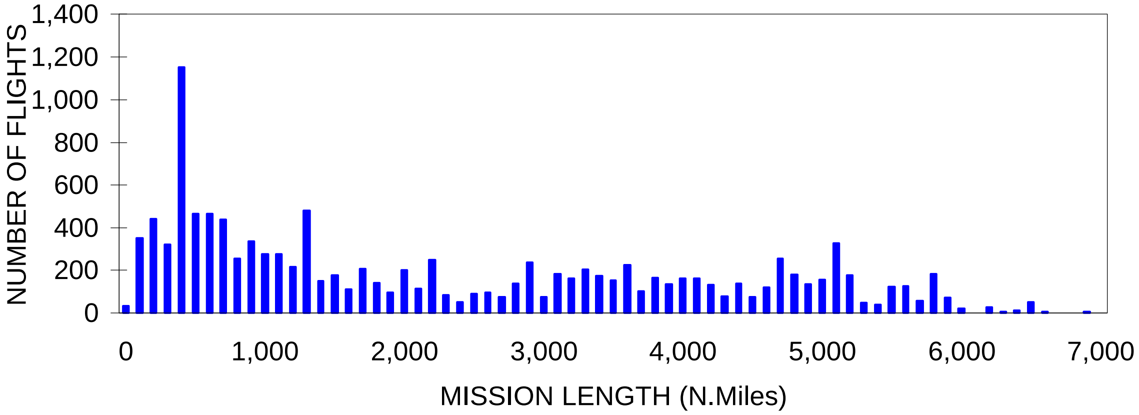
(For the Medium aeroplane main wing tank the model was no longer active and so the 21 cases above could not be run. The data available covered four representative missions with two fuel temperatures and two ambient air temperatures. This data was used to do a simple comparison to verify that the main wing tanks of the Medium aeroplane have a similar exposure to the Large and Small aeroplanes. The exposure analysis, described below was not applied to this model).

5.2 Exposure Analysis

To quantify the current fleet exposure of the fuel tanks to flammable vapour, a process was developed to quantify the amount of time that the fuel temperature is above the flash point of the fuel on a fleet wide basis.
A statistical process was developed using three key variables; mission length, fuel temperature, and flash point, all of which have a defined distribution.

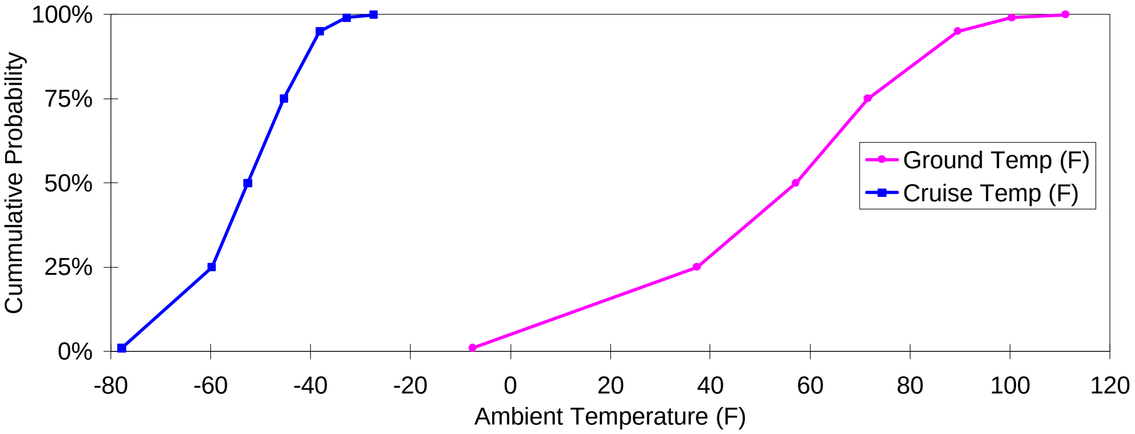
Mission length - Task Group 8 used current fleet statistics to predict the percentage of flights for the three mission lengths, for each size aeroplane. For example; the large aeroplane fleet is estimated to have 63% short missions, 25% medium missions, and 12% long missions, (see Chart 5.2.1).

Chart 5.2.1 Distribution of Mission Lengths (Large Aeroplane)



Fuel temperature - The air ambient temperature profiles used as thermal model inputs were derived from ground and in-flight atmospheric data, based on the probability of a flight encountering that ambient condition, (see Chart 5.2.2).

Chart 5.2.2 Fleetwide Distribution of Ambient Ground and Cruise Temperatures



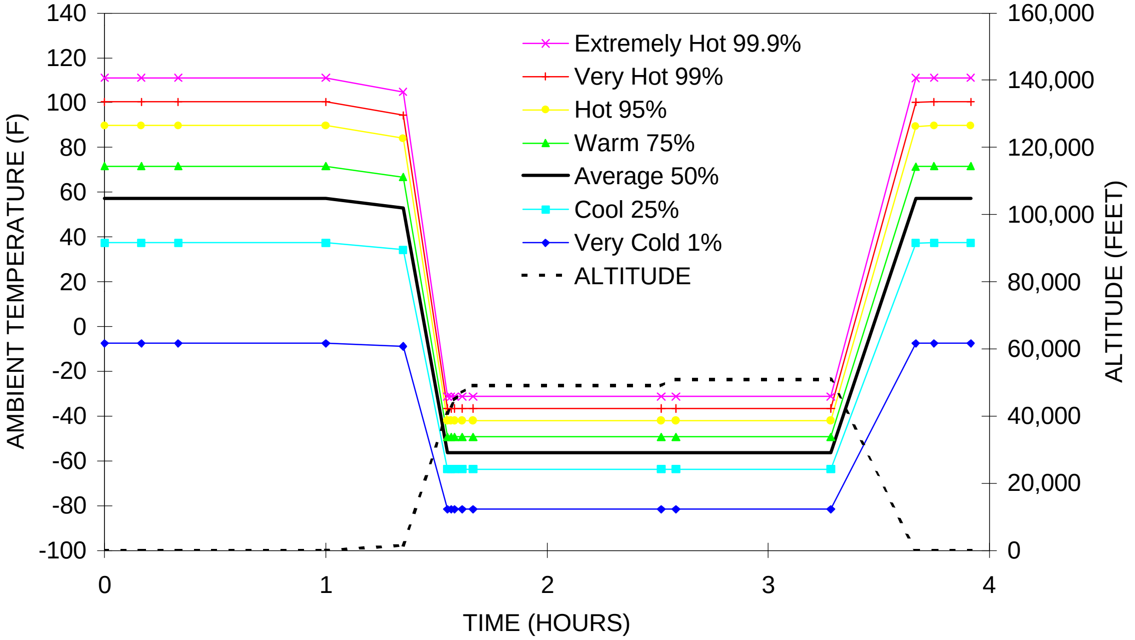
It can be seen that the distribution of ground temperatures is broader than the distribution of cruise temperatures. Seven points on the distributions, (as shown), were chosen to represent a wide range of conditions. Profiles were developed for these conditions. (See Table 5.2.3 below).

Table 5.2.3 Distribution of Ground and Cruise Ambient Temperatures

Condition of Day	Cumulative Probability	Ground Temp Sea Level	Cruise Temp 35,000 feet
Very Cold	1%	-8°F	-78°F
Cold	25%	37°F	-60°F
Average	50%	57°F	-53°F
Warm	75%	72°F	-45°F
Hot	95%	90°F	-38°F
Very Hot	99%	100°F	-33°F
Extremely Hot	99.9%	111°F	-27°F

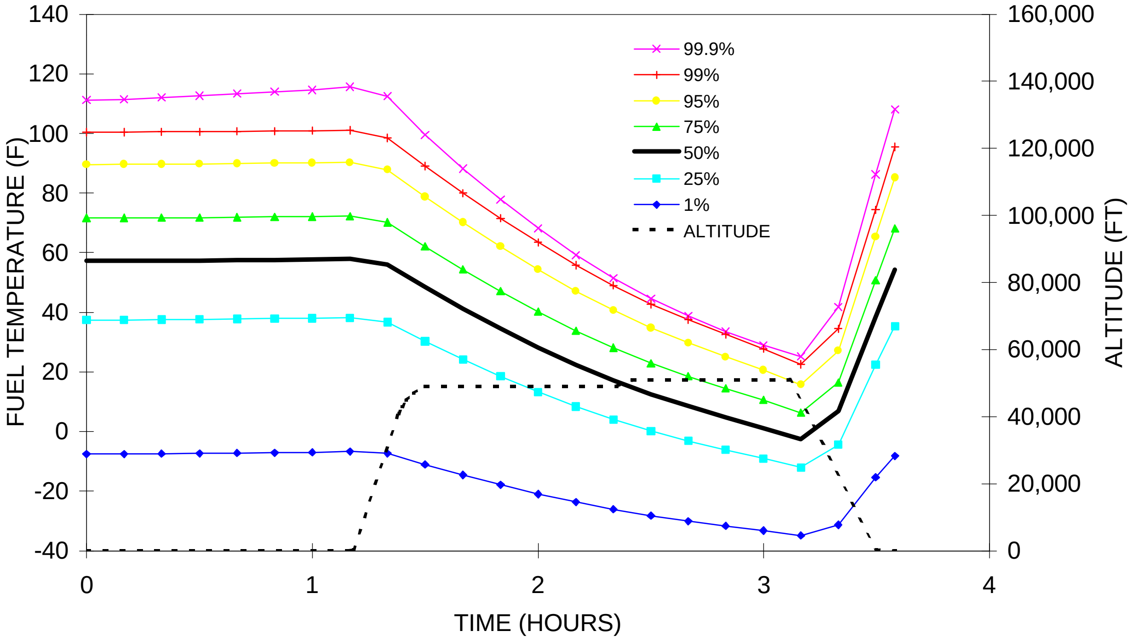
For each aeroplane mission, the seven ambient temperature profiles versus time were developed. For example; the Business Jet – Short Mission ambient temperature profiles are shown below in chart 5.2.4.

Chart 5.2.4 Business Jet – Short Mission. Range of Ambient Temperatures



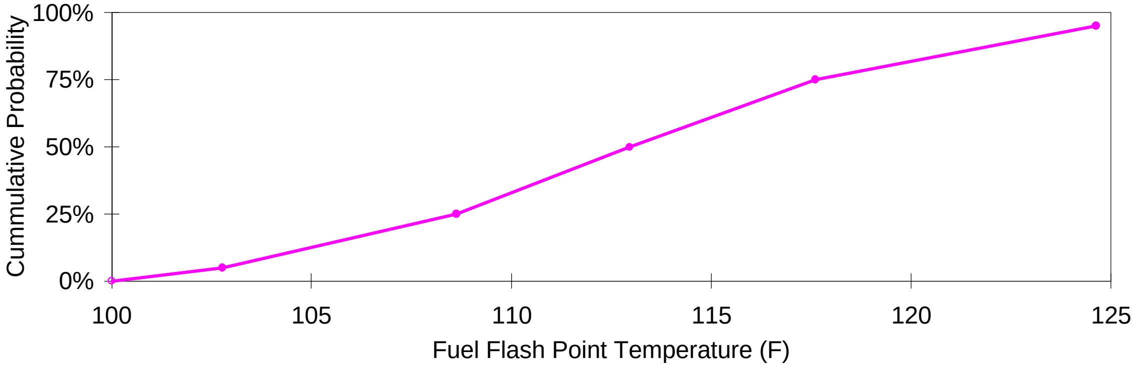
Using these ambient temperature profiles as the input to the thermal model, the output from the thermal model will also be a range of fuel temperatures. The results will be seven profiles with the same probabilities as the ambient temperature profiles. For example; the fuel temperature profiles predicted from the Business Jet – Short Mission thermal model are shown in Chart 5.2.5.

Chart 5.2.5 Business Jet – Short Mission. Predicted Fuel Temperatures for a Range of Ambient Temperatures



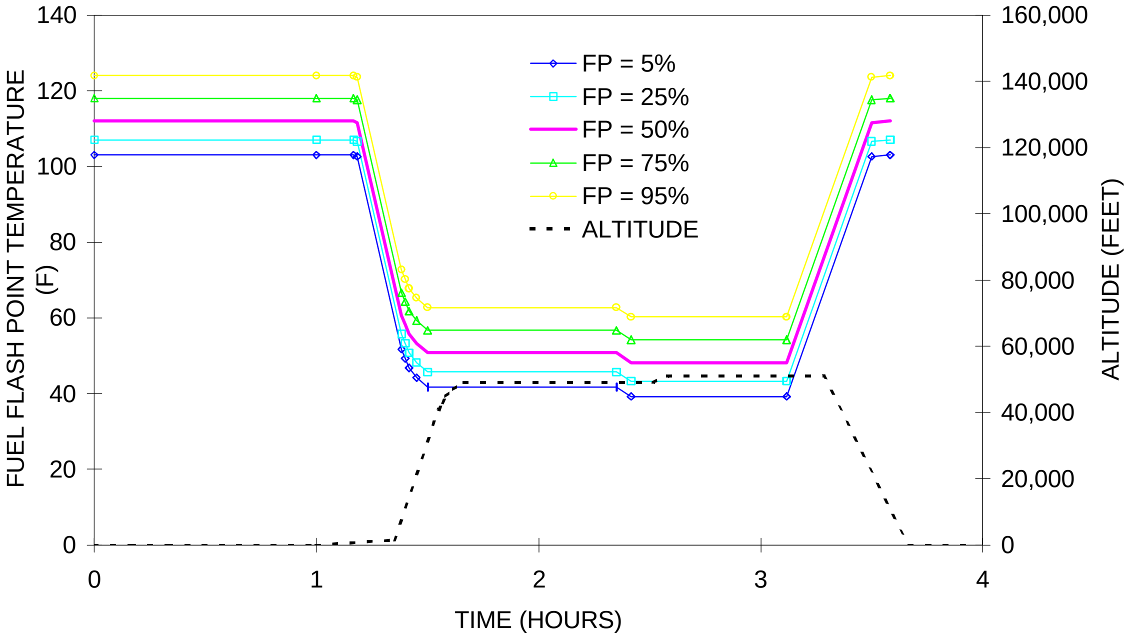
Flash point - To define the flash point of the fuel, the initial assumption was to use the specification limit of 100°F. However, as the objective was to define the exposure of the current fleet of aeroplanes as they actually operate, it was decided to increase the accuracy of the analysis by using the flash point of the fuel that is loaded onto the aeroplane. Task Group 6 provided data on the current distribution of flash points delivered worldwide and assigned probabilities of a specific mission being fuelled with a fuel at a specific flash point. See Chart 5.2.6 below.

Chart 5.2.6 Fleetwide Distribution of Fuel Flashpoint



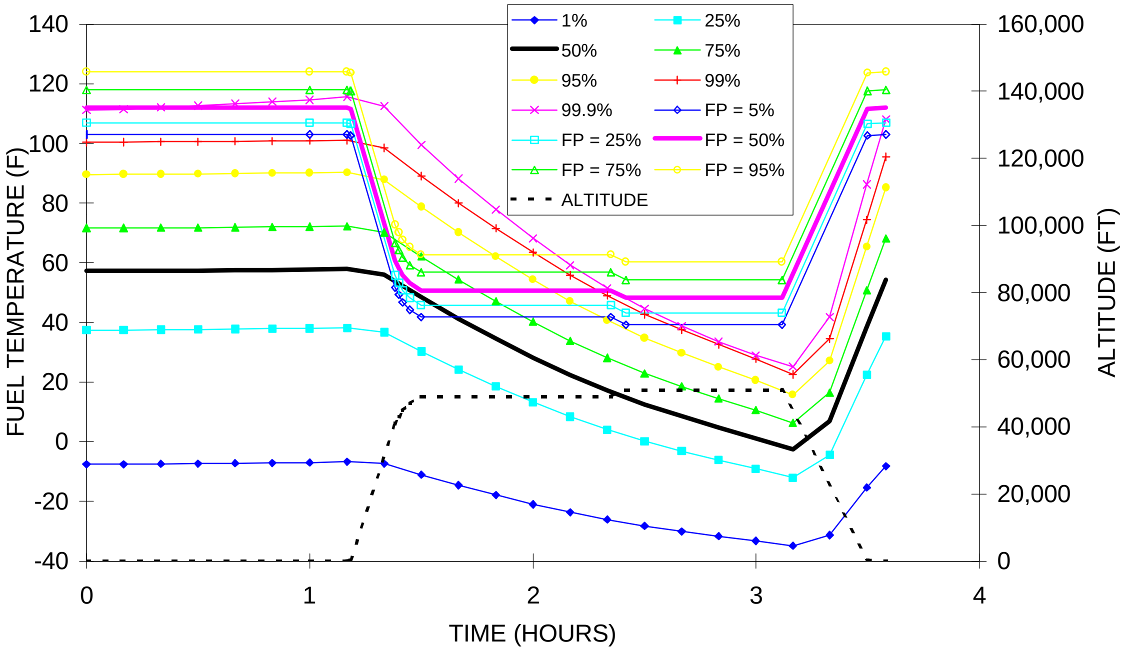
Task Group 5 then used this data to derive the flashpoint versus time profiles that correspond to each fuel temperature profile, for each mission profile of each aeroplane tank configuration. For example; the Business Jet – Short Mission flashpoint profiles are shown in Chart 5.2.7.

Chart 5.2.7 Business Jet – Short Mission. Range of Fuel Flashpoints



The next step was to over lay the fuel temperature profiles with the corresponding flashpoint profiles for each mission profile and for each aeroplane tank configuration. For example; the Business Jet – Short Mission profiles are shown in Chart 5.2.8.

Chart 5.2.8 Business Jet – Short Mission. Predicted Fuel Temperatures for a Range of Ambient Temperatures and Flashpoints.

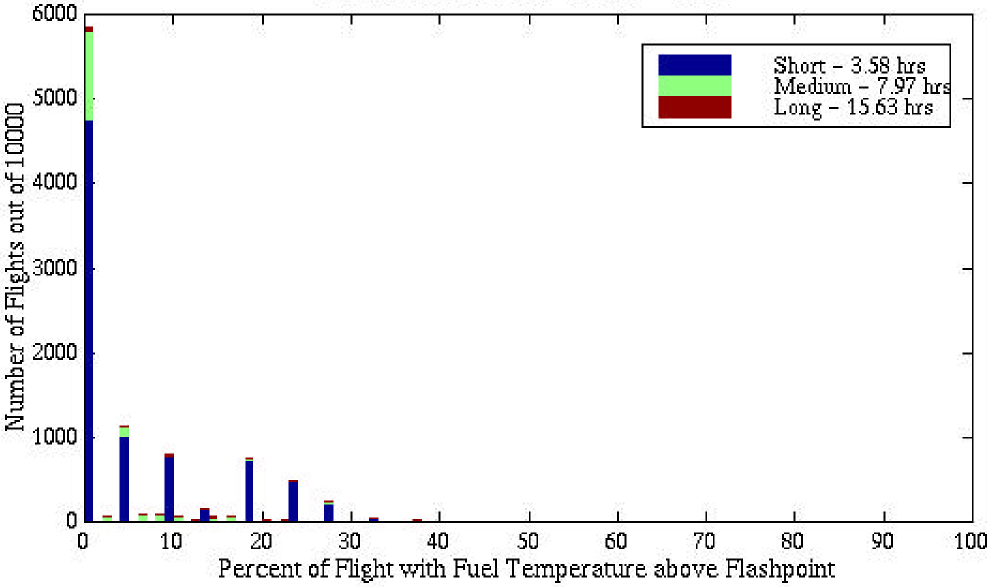


The time of exposure can be visualised by looking at the part of the mission where the band of fuel temperature lines (filled in symbols) are above the band on flash point line (open symbols). Another way to visualise the time of exposure is to focus only on the overlap of the two solid lines representing the average fuel temperature and the average flash point.

To quantify the fleet exposure, a statistical analysis approach was applied to a statistically significant number (10,000) of randomly selected flights. The flights were then selected to be representative of the fleet using the defined distributions of the three variables. For example, flight one may be a short mission on a cold day with an average flash point fuel, and flight two may be a long mission on an average day with a low flash point fuel, and on and on until 10,000 flights have been defined in this manner. For every one of the 10,000 flights, the time that the fuel temperature was above the flash points was calculated.

These statistical analysis results are best displayed in the form of a histogram showing the number of flights at each percentage of flight time. For example; a histogram the Business Jet which accounts for all three mission lengths is shown in Chart 5.2.9.

Chart 5.2.9 Histogram of 10,000 Business Jet Flights
(Average exposure 5.6%)



Averaging the results for all 10,000 flights provides an average percentage of the flight time that any particular flight could be expected to be exposed to a fuel temperature above the fuel flash point. These fleet average exposure results are given for each aeroplane size/tank configuration in table 5.2.10.

Table 5.2.10 Exposure Analysis Results For Centre and Wing Tanks

Wing Tanks				**CentreTanks**				
WITHOUT adjacent heat sources				WITHOUT adjacent heat sources		WITH adjacent heat sources		WITH adjacent heat sources and directed ventilation
large	small	regional turbofan	bizjet	small	regional turbofan	large	small	medium
5%				5%		**30%**		5%

(Due to differences between the various thermal models and thus differences in the possible errors in calculation the analysis results have been rounded to within 5%).

Once the current fleet exposures to fuel tanks with flammable vapours are calculated, the same method of thermal analysis is used to systematically study methods to reduce the exposure in fuel tanks.

6. METHODS CONSIDERED

6.1. Reducing the Evolution of Fuel Vapours

Fuel flammability is dependent upon fuel vapour-air ratios which are a function of temperature and pressure. Therefore by controlling either of these two parameters the flammability of fuel tanks can be manipulated. The methods considered in this section are therefore separated between controlling temperature, (6.1.1. and 6.1.2.), and controlling pressure, (6.1.3.), (the control of temperature is sub-divided into minimising the effects of heat sources, (6.1.1.), and active cooling, (6.1.2.).

6.1.1. Controlling Temperature

These methods have only been considered for Large, Medium and Small jet transport aeroplanes as these are the only aeroplanes identified by Task Group One as having centre wing tanks with adjacent heat sources.

6.1.1.1. Insulate Fuel Tanks from Adjacent Heat Sources

For fuel tanks located in aeroplane wings, apart from solar radiation, they are not materially affected by heat sources therefore the insulation of these tanks is not considered appropriate. However for centre wing tanks with adjacent heat sources, insulation is considered.

Thermal analysis shows that the benefits that could be achieved on the ground by thermal insulation of the bottom surface of centre wing tanks, (reducing the heating effects from air-conditioning packs, e.t.c.), would be offset by the lower cooling rate experienced in flight, (prolonging the exposure during flight).

Due to;

a) the questionable benefits such a modification would provide
b) a comparison to other options discussed in this report

this option is not considered further within this report.

6.1.1.2. Insulate Heat Sources Adjacent to Fuel Tanks

Insulation of heat sources adjacent to centre wing tanks would reduce the heating of the contained fuel on the ground without being detrimental to the cooling of that fuel in flight. The potential modifications could be relatively simple to design and retrofit onto many, (but not all), existing aeroplanes, however the affect on the operation of the systems insulated requires specific evaluation. Thermal analysis predicts this modification will reduce the exposure of the Large generic centre wing tank from 27% to 19%.

The benefits of this method of reducing the heating effects on the centre wing tank are considered further by means of thermal analysis within section 8 of this report.

6.1.1.3. Ventilate Heat Sources Adjacent to Fuel Tanks

Ventilation of heat sources with ambient air in flight will reduce the heating of the fuel tank. Thermal modelling and flight testing on a large aeroplane has shown that this method provides only minimal reductions in fuel temperature. Thermal analysis predicts this modification will reduce the exposure of the Large generic centre wing tank from 27% to 22%.

The analysis suggests that for a ventilation system to be effective, it must operate on the ground with a cooler source of air and must be directed effectively between the heat source and the fuel tank. (See section 6.1.1.4.).

Due to;

a) the results of thermal analysis

b) a comparison to 6.1.1.4. discussed in this report

this option is not considered further within this report.

6.1.1.4. Ventilate the Space Between Fuel Tanks and Adjacent Heat Sources

Directed forced ventilation in the space between heat sources and fuel tanks is implemented on some aircraft today to limit the temperature of the aircraft structure. The cooling effect is equally effective on the ground and flight. The systems presently used are simple in principle, but implementation on existing aeroplanes, which do not have such a system, would require significant modifications.

Thermal analysis predicts the exposure of the Medium generic centre wing tank with this modification will be 4%.

The benefits of this system in reducing the heating effects of the centre wing tank are considered further by means of thermal analysis within section 9 of this report.

6.1.1.5. Redistribute Mission Fuel into Fuel Tanks Adjacent to Heat Sources

Increasing the quantity of fuel uplifted into the centre wing tank has been shown, by thermal analysis, to slow the effective rate of temperature increase of the contained fuel on the ground. This approach could involve significant changes to the operation of the aeroplane and require re-examination of the aeroplane strength criteria, which affects the effective life of an aeroplane.

The benefits of this method in reducing the heating effects in the centre wing tank are considered further by means of thermal analysis within section 10 of this report.

6.1.1.6. Locate Significant Heat Sources Away From Fuel Tanks

On most, (but not all), aeroplanes the main heat sources are the environmental control system packs and the associated pneumatic ducts, normally situated beneath the centre wing tank. The packs can not be removed from the aeroplane, as they are essential for flight, to provide pressurised air for heating/cooling and pressurisation of the cabin/fuselage/equipment.

For those aeroplanes with environmental control system packs and the associated pneumatic ducts situated beneath the centre wing tank their relocation is impractical. This is due to the utilisation and optimisation of all available space on an aeroplane. The relocation of such large components would disrupt many other aeroplane components and systems.

Thermal analysis predicts the exposure of a Small generic centre wing tank without adjacent heat sources to be 1%.

For existing aeroplanes this option is not considered further within this report, due to;

(a) the fact that aeroplane design is optimised leaving no practicable location to reposition the equipment
(b) that if the necessary space was available the estimated significant costs of redesign, certification and retrofit are prohibitive.
(c) a comparison to other options discussed in this report

New aeroplane designs could locate the environmental control system packs away from the fuel tanks. However this would have a very significant effect becoming a principle driver in the overall configuration and design of the aeroplane, (due to the significant mass and volume environmental control systems occupy.

The benefits of this approach are considered further by means of thermal analysis within section 11 of this report.

6.1.2. Active Cooling

6.1.2.1. Cool the Fuel During Refuelling

Loading cooled fuel is already proposed for very small business aeroplanes. This is done not as a method of reducing fuel tank flammability, but as a means of increasing range by enabling the uplift of additional fuel mass. The exposure of empty fuel tanks is not significantly affected.

If such a measure was required for all commercial flights, (as a means of reducing the exposure of fuel tanks to flammable vapours), it would necessitate a massive capital investment at all the world's airports, to purchase and install cooling equipment. The cooling equipment would need to cool the fuel very fast to prevent impacting on the aeroplane dispatch time, and thus would be physically large. For airports having fuel hydrant systems then the cooling equipment could be stored underground. However for airports using fuelling trucks then the cooling equipment would need to be towed on a trailer which would increase further the congestion around the aeroplane.

Additionally cooling would increase the operational costs associated with uplifting fuel:

- It requires approximately 45kJ to cool 1kg of JETA from 40°C to 20°C, (104°F to 68°F).
- A medium size aircraft flying a medium length mission requires 25,000kg of fuel and therefore an energy requirement of 1,125,000kJ.

Present certification regulations require that each fuel tank must have an expansion space not less than 2% of the tank capacity. The loading of fuel cooler than the ambient air temperature would result in either;

(i) A restriction on the maximum fuel volume that could be uplifted.
(ii) A time limitation between refuelling and take-off which if exceeded due to airport constraints, would require defuelling of the aeroplane.

These are due to the fact that the fuel will heat up inside the fuel tank and thus expand with the potential of a fuel spillage onto the ground, which would represent a very real fire hazard.

Due to;

(a) This option would not be effective for empty fuel tanks.
(b) The significant capital investment which would be required at all airports.
(c) The estimation that a significant increase in operational costs related to cooling would be incurred with (present technology).
(d) The significant limitations that this option could impose on aeroplane operation.
(e) A comparison to other options discussed in this report.

this option is not considered further within this report.

6.1.2.2. Cool the Fuel in the Fuel Tanks

The cooling of fuel tanks, together with the contained fuel, would require a very significant cooling capability, which is currently not available from any existing aeroplane system. Further the ability to use ground equipment to cool the tank would require the introduction of a new dedicated aeroplane subsystem and a massive investment in ground equipment. This, in turn, would lead to further ramp congestion and be detrimental to the environment. It would also introduce, under failure conditions, the possibility of fuel being dumped overboard due to expansion.

Due to;

(a) the impracticalities of providing the necessary energy to cool the fuel
(b) the estimation that a significant increase in operational costs related to cooling would be incurred
(c) a comparison to other options discussed in this report

this option is not considered further within this report.

6.1.2.3. Cool the Heat Sources Adjacent to Fuel Tanks

The main heat sources on most aeroplanes are the environmental control system packs and the associated pneumatic ducts situated beneath the centre wing tank. Under high ambient temperatures, when the necessity to cool these sources would be greatest, the packs would be working hardest and running hottest. Thus maximum heat rejection from the packs/ducts would coincide with the requirement for maximum cooling of the heat sources.

Due to;

(a) the impracticalities of providing the necessary energy to cool
(b) a comparison to other options discussed in this report

this option is not considered further within this report.

6.1.3. Controlling Pressure

6.1.3.1. Pressurise the Fuel Tanks

The aim of this measure is to increase the flammability lean limit temperature by increasing the pressure, with respect to the ambient pressure, within fuel tanks.

Examples of the possible increase in the flammability lean limit temperature that could be obtained if a fuel tank is pressurised to 200 mb above the ambient pressure are approximately; 5°C (from 37°C to 42°C) at 6,000ft; 12°C (from 10°C

To pressurise fuel tanks to 200mb would require;

a) a pressurisation system.
b) an over-pressurisation protection system.
c) structural reinforcement.

The majority of present aeroplanes have structural limitations restricting the pressurisation of fuel tanks to approximately +/- 35 mb. (Aeroplanes with pressurised fuel tanks do exist today but this is mainly small business jets and the pressurisation constituted part of the initial design).

Due to;

(a) requirements for large structural reinforcements
(b) new hazards such a system would introduce
(c) a comparison to other options discussed in this report

this option is not considered further within this report.

6.2. Eliminating the Ullage

The elimination of the ullage removes the flammable fuel vapour air mixture and thus significantly reduces the potential of ignition within a fuel tank.

6.2.1. Actively Minimise the Ullage space

The aim of this measure is to minimise the ullage so that there is virtually no space for fuel vapours. This principle is used in some ground storage tanks.

The two principle means considered are:

(i) To cover the fuel surface with a sheet of impermeable material.
(ii) To fill the ullage space with an inflatable bag.

The main problem with both approaches is that, (unlike ground storage tanks), there is considerable structure within aeroplane fuel tanks. This structure causes the fuel surface to change shape as fuel is used. These changes in shape are such that it is not practicable to use a semi-rigid sheet or inflatable bag due to the snagging of structure. The use of a large number of low density impermeable “balls” would overcome the problems of snagging. However this solution would have problems of ensuring the tank vent system does not become blocked and that the “balls” do not become heaped in one corner. The heaping of balls in one corner would allow fuel vapour to fill the ullage space. (The above issues would be compounded further on aeroplanes where fuel transfers between tanks occur).

(Some military aeroplanes use collapsible fuel tanks. These eliminate the ullage by collapsing as fuel is used. Installing such devices into commercial transport aeroplanes is not practicable for similar reasons as filing the ullage space with inflatable bags).

This option is considered impractical and is not considered further within this report.

6.2.2. Remove Residual Fuel from Unused Fuel Tanks

The aim of this measure is that by removing all residual fuel you eliminate fuel vapours.

Aeroplane maintenance manuals specify that several days are required to clean and vent fuel tanks to eliminate fuel vapours. It is therefore considered impracticable to perform this task on aeroplane operations where tanks are nominally empty only intermittently.

However, for a limited number of aeroplane operations where fuel tanks are never (or extremely infrequently) used conversion from a fuel tank to a dry bay may be possible. Though preventing fuel vapours from other tanks being drawn into the “tank” during descent is a significant issue that would need to be solved. The actual conversion would require measures that, not only prevent the “tank” from being fuelled, but also prevent fuel leaks and/or provide means of detection of fuel leakage into the “tank”. Maintenance procedures would also have to be put in place to prevent any seal within the “tank” drying out. This is to prevent heavy maintenance action if the tank was to be reactivated.

For most aeroplane operations the only tank which is frequently left empty is the centre wing tank.

This measure is only practicable for fuel tanks that are intermittently if ever used. To analyse the economic impact of such a modification it would be necessary for each individual airline to analyse it’s operations.

6.3. Sweeping the Ullage

Sweeping the ullage is a method of purging the fuel vapours from the ullage space in a fuel tank with ambient air. The aim of this process is to reduce the concentration of fuel vapours to below the lower flammability limit.

6.3.1. Sweeping the Ullage of Empty Fuel Tanks

Laboratory testing of this concept has shown significant fuel evaporation. Therefore, the evaluation of this method has specifically considered only empty tanks (defined as containing only unusable fuel).

The source of air would be different for ground and flight and would depend on the specific aeroplane design. The source of air on the ground could either be a fan (on the aeroplane or on ground equipment), or the source could be pressurised air bottles. The source of air in flight could be a ram air inlet, or modifications to the vent system. To be effective, the air would have to be correctly distributed within the bays of the tank to prevent direct through flow which could leave flammable ullage. The swept air, containing fuel vapour, could exit the tank via the existing vent system.

To minimise the exposure, both a ground and flight system would be required.
Fuel that is lost through evaporation, could be condensed out in a heat exchanger and drained into a main wing tank minimising the environmental impact and waste of fuel. Testing has been conducted on a laboratory scale to evaluate this concept. Details of the testing are described in the appendix section 15.3.

The benefits of this approach have been the subject of specific testing and are considered further within section 12 of this report.

7. METHODS SELECTED FOR FURTHER EVALUATION

7.1. Insulate Heat Sources Adjacent to Fuel Tanks

The evaluation of this method has specifically considered the installation of insulation blankets around environmental control system pneumatic ducts under centre wing tanks. This evaluation was performed for the large generic aeroplane only. The results are therefore not directly applicable to any specific design.

7.2. Ventilate the Space Between Fuel Tanks and Adjacent Heat Sources

The evaluation of this method has specifically considered forced ventilation directed into the area between the environmental control system packs and the lower surface of the centre wing tanks on the ground and in flight. This evaluation was performed for the medium generic aeroplane only. The results are therefore not directly applicable to any specific design.

7.3. Redistribute Mission Fuel into Fuel Tanks Adjacent to Heat Sources

The evaluation of this method has specifically considered a change to the fuelling procedures to re-distribute a portion of mission fuel from the main wing tanks to the centre wing tank. The fuel in the centre wing tank would then be used during the initial stages of flight as part of the mission fuel. This evaluation was performed for the large generic aeroplane only. The results are therefore not directly applicable to any specific design and the potential impact on the fatigue life of the aeroplane has not been included in the assessment.

7.4. Locate Significant Heat Sources Away From Fuel Tanks

This method is only applicable for new designs of aeroplanes.

7.5. Sweeping the Ullage of Empty Fuel Tanks

The evaluation of this method has specifically considered an aeroplane system using a fan to supply air on the ground and a ram air inlet in flight.

8. INSULATE HEAT SOURCES ADJACENT TO FUEL TANKS

8.1. Safety Impact

8.1.1. Effectiveness in minimising the hazard

This method is effective in reducing the exposure of centre wing tanks to flammable vapour by limiting the heating effects of environmental control system packs, but does not eliminate the exposure. This conclusion is supported by thermal analysis of the large and small generic aeroplanes with environmental control system packs beneath the centre wing tank and insulation blankets on the pneumatic ducts in the air-conditioning pack bay. Analysis for these generic aeroplanes predicts the fleet average exposures to be reduced from **27% to 19%** for the large aeroplane.

8.1.2. Negative impacts

Specific studies of the affect on insulated equipment would need to be performed for each aeroplane model. This is necessary to ensure that there are no detrimental effects on the related system. To date there have been no negative impacts on safety identified.

8.2. Certification Impact

This method would have minimal certification impact using already approved insulation materials, but may require additional certification for new optimised insulation materials.

8.2. Environmental Impact

No additional environmental impact identified.

8.4. Aeroplane Impact

- Increased weight.
- Some aeroplanes may require system modifications to compensate for adverse effects.
- A new dedicated leak detection system may be required due to reduced accessibility.
- Insulation may not be possible in some confined spaces.

8.5. Operational Impact

- Increased maintenance of the environmental control system or other effected systems.
- Insulation could result in a reduction in the reliability of some environmental control system components due to increased running temperatures.

8.6. Cost Impact

The following estimated costs are for modifying existing aeroplane designs:

Reason for costs	Estimated cost	Conversion to $	Cost $
Evaluation and Design	750 man hrs	1 man hour = $85	$63,750
Flight Tests Required to Verify System effects	10 flight test hrs	1 flight test hour = $100,000	$1,000,000
Development Costs per Aeroplane Design			**$1,063,750**
Hardware, (insulation material and fixings)	$4,000	$1 = $1	$4,000
Installation Time	8 man hrs	1 man hour = $60	$480
Installation Costs per Production Aeroplane			**$4,480**
Hardware, (insulation material and fixings)	$4,000	$1 = $1	$4,000
Installation Time	80 man hrs	1 man hour = $60	$4,800
Lost Revenue due to down time	2 days	1 day = $6,700 S 1 day = $15,350 M 1 day = $26,800 L	$13,400 $30,700 $53,600
Retrofit Costs per In-Service Aeroplane		Small Medium Large	**$22,200** **$39,500** **$62,400**
Additional Weight of Hardware	30lbs	1lb = $9,35 S 1lb = $14,10 M 1lb = $9, 55 L	$281 $423 $287
Additional Maintenance	20 man hrs	1man hour = $60	$1,200
Additional Aeroplane Operational Costs per Aeroplane per year		Small Medium Large	**$1,481** **$1,623** **$1,487**

Total Fleet Costs to Insulate Heat Sources Adjacent to Fuel Tanks

	Small	Medium	Large
N° aeroplanes affected	*6203*	*1091*	*1350*
N° models affected	*17*	*9*	*12*
New production per year	*200*	*50*	*100*
Design (1 off)	$18,083,750	$9,573,750	$12,765,000
Retrofit costs (1 off)	$137,706,600	$43,094,500	$84,240,000
Total one time costs	**$155,790,350**	**$52,668,250**	**$97,005,000**
Production (per year)	$896,000	$224,000	$448,000
Operation (per year)	$9,186,643	$1,770,693	$2,007,450
Total annual costs	**$10,082,643**	**$1,994,693**	**$2,455,450**

9. VENTILATE THE SPACE BETWEEN FUEL TANKS AND ADJACENT HEAT SOURCES

9.1. Safety Impact

9.1.1. Effectiveness of minimising the hazard

This method is effective in minimising the exposure of centre wing tanks to flammable vapour by limiting the heating effects of environmental control system packs, but does not eliminate the exposure. This conclusion is supported by thermal analysis of the medium generic aeroplane with centre wing tank with environmental control system packs beneath the centre wing tank, with forced ventilation directed to the area between the environmental control system packs and the lower surface of the with centre wing tank. Analysis for these generic aeroplanes predicts the fleet average exposures to be **4**% for the medium aeroplane.

9.1.2. Negative impacts

There have been no negative impacts on safety identified.

9.2. Certification Impact

There is flight experience with this type of system on current aeroplanes. Specific aeroplane designs would have to be certified with some minimal ground and flight-testing.

9.3. Environmental Impact

No additional environmental impact identified.

9.4. Aeroplane Impact

- Increased weight
- Performance drag penalty
- Effective ventilation may not be possible in some confined spaces

9.5. Operational Impact

- Increased maintenance of new system

9.6. Cost Impact

The following costs have been estimated for present aeroplane designs:

Reason for costs	Estimated cost	Conversion to $	Cost $
Evaluation and Design	10,000 man hrs	1 man hour = $80	$800,000
Flight Tests Required to Verify System effects	20 flight test hrs	1 flight test hour = $100,000	$2,000,000
Development Costs per Aeroplane Design			**$2,800,000**
Hardware, (equipment ducts and fixings)	$20,000	$1 = $1	$20,000
Installation Time	20 man hrs	1 man hour = $60	$1,200
Installation Costs per Production Aeroplane			**$21,200**
Hardware, (insulation material and fixings)	$20,000	$1 = $1	$20,000
Installation Time	300 man hrs	1 man hour = $60	$18,000
Lost Revenue due to down time	7 days	1 day = $6,700 S 1 day = $15,350 M 1 day = $26,800 L	$46,900 $107,450 $187,600
Training of Personnel	3 man hrs	1 man hour = $60	$180
Retrofit Costs per In-Service Aeroplane		Small Medium Large	**$85,080** **$145,630** **$225,780**
Operational Delays	8 hrs	I hour = $2,875	$23,000
Additional Weight of Hardware	50lbs	1lb = $9,35 S 1lb = $14,10 M 1lb = $9, 55 L	$468 $705 $478
Additional Maintenance	40 man hrs	1 man hour = $60	$240
Lost Revenue due to down time	1 day	1 day = $6,700 S 1 day = $15,350 M 1 day = $26,800 L	$6,700 $15,350 $26,800
Additional Aeroplane Operational Costs per Aeroplane per year		Small Medium Large	**$30,408** **$39,295** **$50,518**

9.6. Cost Impact (cont.)

Total fleet costs to ventilate the space between fuel tanks and adjacent heat sources			
	Small	Medium	Large
N° aeroplanes affected	*5448*	*445*	*1350*
N° models affected	*14*	*4*	*12*
New production per year	*200*	*50*	*100*
Design (1 off)	$39,200,000	$11,200,000	$33,600,000
Retrofit costs (1 off)	$463,515,840	$43,094,500	$84,240,000
Total one time costs	**$502,715,840**	**$64,805,350**	**$304,803,000**
Production (per year)	$4,240,000	$1,060,000	$2,120,000
Operation (per year)	$165,662,784	$17,486,275	$68,199,300
Total annual costs	**$169,902,784**	**$18,546,275**	**$70,319,300**

10. REDISTRIBUTE MISSION FUEL INTO FUEL TANKS ADJACENT TO HEAT SOURCES

10.1. Safety Impact

10.1.1. Effectiveness in minimising the hazard

This method is effective in reducing the exposure of centre wing tanks to flammable vapour by limiting the heating effects of environmental control system packs, but does not eliminate the exposure. This conclusion is supported by thermal analysis of the large generic aeroplane with centre wing tanks with environmental control system packs beneath the centre wing tank. With a portion of mission the fuel initially loaded into the centre wing tank (10-15% full), analysis for this generic aeroplane predicts the fleet average exposure to be reduced from **27% to 20%** for the large aeroplane.

10.1.2. Negative impacts

The possibility of fuel system mismanagement could have a negative impact on safety. There would also be increased crew workload, which for short missions would occur during already heavy workload periods.

10.2. Certification Impact

There would be some structural analysis required to assess the impact on structural fatigue and system analysis/flight testing to verify the behaviour of the aeroplane.

10.3. Environmental Impact

No additional environmental impact identified.

10.4. Aeroplane Impact

- Structural impacts would need to be analysed for each aeroplane model to verify the impact on the fatigue life of the wing structure
- New procedures would need to be written and approved
- Changes to system warnings and alarms may be required
- Re-programming of fuelling systems may be required

10.5. Operational Impact

- Ground crews and flight crews would have to be retrained on the new procedures for all operations worldwide.
- Dependant on the optimised fuel mass to be loaded into the centre wing tank and the resultant structural impact analysis, some operations may be cargo and/or fuel load restricted. The costs associated with this payload penalty have been estimated assuming (a) an optimum fuel load would be approx. 7% of a full tank and (b) approximately 90% flights are normally operated without fuel in the centre tank of which 10% would be payload limited.

10.6. Cost Impact

The following costs have been estimated for applying this procedural modification to existing aeroplane designs:

Reason for costs	Estimated cost	Conversion to $	Cost $
Evaluation and Design of Installation	750 man hrs	1 man hour = $80	$60,000
Flight Tests Required to Verify System effects	2 flight test hrs	1 flight test hour = $100,000	$200,000
Development Costs per Aeroplane Design			**$260,000**
Training of Personnel	5 man hrs	1 man hour = $60	$300
Lost Revenue due to Payload Penalty	S 1,500 lbs M 4,500 lbs L 12,000 lbs	1lb = $9,35 S 1lb = $14,10 M 1lb = $9, 55 L	$14,025 $63,450 $114,600
Additional Aeroplane Operational Costs per Aeroplane per year		Small Medium Large	**$14,325** **$63,750** **$114,900**

Total fleet costs to redistribute mission fuel into fuel tanks adjacent to heat sources

	Small	Medium	Large
N° aeroplanes affected	*5,448*	*445*	*1350*
N° flights affected	*9.5%*	*9.0%*	*8.8%*
N° models affected	*17*	*6*	*12*
New production per year	*200*	*50*	*100*
Design (1 off)	$4,420,000	$1,560,000	$3,120,000
Total one time costs	**$4,420,000**	**$1,560,000**	**$3,120,000**
Operation (per year)	$ 7,414,047	$2,553,188	$13,650,120
Total annual costs	**$ 7,414,047**	**$2,553,188**	**$13,650,120**

11. LOCATE SIGNIFICANT HEAT SOURCES AWAY FROM FUEL TANKS

11.1. Safety Impact

11.1.1. Effectiveness in minimising the hazard

This method is effective in minimising the exposure of centre wing tanks to flammable vapour by removing the heating effects of environmental control system packs, but does not eliminate the exposure. This conclusion is supported by thermal analysis of a small aeroplane without environmental control system packs beneath the centre wing tank. The fleet average exposure for this generic aeroplane is estimated to be **1%.**

11.1.2. Negative impacts

There have been no negative safety impacts identified.

11.2. Certification Impact

No additional certification work required for new aeroplane designs.

11.3. Environmental Impact

No additional environmental impact identified.

11.4. Aeroplane Impact

Space is a precious commodity on all aircraft. The use of any space is optimised particularly on the issues of system weight and complexity.

Recent aeroplane designs have been affected by the size of jet engines, the effect of which has lead to designs with wing mounted engines. On such aeroplanes it has been shown that the optimised location for environmental control system packs is beneath the centre wing tank. Relocation of the environmental control system packs would be a significant driver for the total aeroplane configuration as well as increasing the weight and complexity of the systems. Quantifying the impact of this method would only be possible for specific new designs.

11.5. Operational Impact

The operation of the aircraft could be impacted by the location of the ground service ports, (dependent on the specific designs).

11.6. Cost Impact

The following costs have been estimated for applying this requirement to New aeroplane designs:

Reason for costs	Estimated cost	Conversion to $	Cost $
Reconfiguration of Aeroplane	50,000 man hrs	1 man hour = $80	$4,000,000
Flight Tests Required to Verify System effects	100 flight test hrs	1 flight test hour = $100,000	$10,000,000
Development Costs per Aeroplane Design			**$14,000,000**

Hardware, (additional material and fixings)	$ **?**	$1 = $2,875	$?
Installation Costs per Production Aeroplane			**$?**

Additional Weight of Hardware	**?** lbs	1lb = $9,35 S 1lb = $14,10 M 1lb = $9, 55 L	$? $? $?
Additional Aeroplane Operational Costs per Aeroplane per year		Small Medium Large	**$?** **$?** **$?**

Total fleet costs to locate significant heat sources away from fuel tanks			
	Small	Medium	Large
N° models affected	*2*	*1*	*1*
New production per year	*50*	*50*	*50*
Design (1 off)	$28,000,000	$14,000,000	$14,000,000
Total one time costs	**$155,790,350**	**$52,668,250**	**$97,005,000**
Production (per year)	$?	$?	$?
Operation (per year)	$?	$?	$?
Total annual costs	**$?**	**$?**	**$?**

12. SWEEP THE ULLAGE OF EMPTY FUEL TANKS

12.1. Safety Impact

12.1.1. Effectiveness of minimising the hazard
Quantifying the reduction in exposure that could be achieved in an actual aeroplane environment will require further testing and analyses.

12.1.2. Negative impacts
By introducing a new system into the fuel system, there are increased risks of failure conditions. One such risk is over-pressurisation of the fuel tanks if fuelling and sweeping occur at the same time. A second risk is the loss of mission fuel if sweeping occurs in a non-empty tank, due to evaporation.

12.2. Certification Impact

This method would require further laboratory, and aeroplane testing, (both ground and flight), and would require complete system certification. Proving the tank to be in a non-flammable condition requires vapour sampling instrumentation, for which speciality equipment is available for laboratory use, but no such equipment is available for aeroplane installations.

12.3. Environmental Impact

Sweeping the ullage would increase fuel vapour emissions out of the fuel tank. A system could be designed to collect the fuel vapour, but would add system complexity.

12.4. Aeroplane Impact

- There would be additional weight of an air distribution system in the fuel tank.
- There may also be additional weight if a fuel vapour collection system is required.
- The addition of a new sweeping system would require additional fire protection systems.

12.5. Operational Impact

- A source of air would be required, both on the ground and in flight. A ground system could increase ground time and involve ground crew training. A flight system would incur a drag penalty to the aircraft performance.

12.6. Cost Impact

The following costs have been estimated for applying this modification to existing aeroplane designs:

Reason for costs	Estimated cost	Conversion to $	Cost $
Evaluation and Design	20,000 man hrs	1 man hour = $80	$1,600,000
Flight Tests Required to Verify System effect	100 flight test hrs	1 flight test hour = $100,000	$10,000,000
Development Costs per Aeroplane Design			**$11,600,000**
Hardware, (equipment, pipe-work and fixings)	$60,000	$1 = $1	$60,000
Installation Time	50 man hrs	1man hour = $60	$3,000
Installation Costs per Production Aeroplane			**$63,000**
Hardware, (equipment, pipe-work and fixings)	$60,000	$1 = $1	$60,000
Installation Time	1,000 man hrs	1 man hour = $60	$60,000
Lost Revenue due to down time	25 days	1 day = $6,700 S 1 day = $15,350 M 1 day = $26,800 L	$167,500 $383,750 $670,000
One Time Training of Personnel	3 man hrs	1 man hour = $60	$180
Retrofit Costs per In-Service Aeroplane		Small Medium Large	**$287,680** **$503,930** **$790,180**
Operational Delays	16 hrs	I hour = $2,875	$46,000
Additional Weight of Hardware	70lbs	1lb = $9.35 S 1lb = $14.10 M 1lb = $9.55 L	$655 $987 $669
Additional Maintenance	60 man hrs	1 man hour = $60	$3,600
Lost Revenue due to down time	1 day	1 day = $6,700 S 1 day = $15,350 M 1 day = $26,800 L	$6,700 $15,350 $26,800
Additional Aeroplane Operational Costs per Aeroplane per year		Small Medium Large	**$56,955** **$65,937** **$77,069**

12.6. Cost Impact (cont.)

Total fleet costs to sweep the ullage of empty fuel tanks			
	Small	Medium	Large
N° aeroplanes affected	*6203*	*1091*	*1350*
N° models affected	*17*	*9*	*12*
New production per year	*200*	*50*	*100*
Design (1 off)	$197,200,000	$104,400,000	$139,200,000
Retrofit costs (1 off)	$1,784,479,040	$549,787,630	$1,066,743,000
Total one time costs	**$1,981,679,040**	**$654,187,630**	**$1,205,943,000**
Production (per year)	$12,600,000	$3,150,000	$6,300,000
Operation (per year)	$353,291,865	$71,937,267	$175,980,417
Total annual costs	**$365,891,865**	**$75,087,267**	**$182,280,417**

13. CONCLUSIONS

Thermal analysis has shown that all generic fuel tank designs have some exposure to flammable fuel vapour.

- Tanks without adjacent heat sources, independent of their location in the aeroplane, (wing or fuselage), have equivalent exposure of approximately 5%.
- Tanks that have adjacent heat sources have exposure of approximately 30%.

Thirteen options have been considered. Only one eliminates exposure to fuel vapours. This is achieved by disabling the fuel tank and thus has severe operational consequences that can only be evaluated for individual airlines operations, and thus no conclusion is provided within this report.

Five of the methods considered reduce the exposure to flammable fuel vapour, and have been evaluated for the Small, Medium and Large transport Aeroplanes:

1. Insulate the heat source adjacent to fuel tanks
2. Ventilate the space between fuel tanks and adjacent heat sources
3. Redistribute mission fuel into fuel tanks adjacent to heat sources
4. Locate significant heat sources away from fuel tanks.
5. Sweep the ullage of empty fuel tanks

Options 2 and 4 have been shown to reduce the exposure of fuel tanks with adjacent heat sources to a level similar to fuel tanks without adjacent heat sources. (Option 4 is only applicable to new aeroplane designs).

Option 5 requires significant further research before a conclusion on its feasibility can be reached. (Table 13.1 summarises the effects and impact of the five options).

In addition the effects of ground inerting and changing the fuel flashpoint specification have been assessed. Either of these methods could reduce the exposure of fuel tanks with adjacent heat sources to a level similar to fuel tanks without adjacent heat sources. (Table 13.2 summarises the effects on exposure of ground inerting, changing the flashpoint, and some potential combinations of modifications (that could be evaluated in the timeframe available).

Table 13.1 Summary of impacts and applicability of the five methods evaluated

Centre Wing Tanks With Adjacent Heat Sources Exposure to Flammable Vapours **30%**					
Fuel Tanks Without Adjacent Heat Sources Exposure to Flammable Vapours **5 %**					
OPTION **IMPACT**	1. Insulate	2. Ventilate	3. Redistribute	4. Locate	5. Sweep
Estimated Exposure to Flammable Vapours after Modification	**20%**	**5%**	**20%**	**5%**	Not quantified
New safety Concerns	*minor*	*none*	**Medium**	*none*	**Medium**
Certification Impact	*minor*	*minor*	*minor*	*none*	**MAJOR**
Environmental Impact	*none*	*none*	*none*	*none*	**YES**
Aeroplane Impact	*minor*	**Medium**	*minor*	**MAJOR**	**Medium**
Operational Impact	*minor*	*minor*	**MAJOR**	*minor*	**MAJOR**
One Time Fleet Costs ($ x 10^{6}) Small	160	500	4	160	2,000
Medium	50	60	2	50	650
Large	100	300	3	100	1,200
Annual Fleet Costs ($ x 10^{6}) Small	10	170	7	?	370
Medium	2	20	3	?	80
Large	2	70	14	?	180
Applicability	MOST	MOST	MOST	**NEW DESIGNS**	MOST

Table 13.2 Summary of the effects of changing the fuel flashpoint, ground inerting and combinations of different modifications.

Modification	**Wing Tanks Without heat sources**	**Centre Tanks without heat sources**	**Centre Tanks with heat sources**
Current Aeroplanes	***5%***	***5%***	*30%*
120°F Flashpoint Fuel	**< 1%**	**< 1%**	**10 to 20%**
130°F Flashpoint Fuel	**< 1%**	**< 1%**	**5 to 10%**
140°F Flashpoint Fuel	**< 1%**	**< 1%**	**1 to 5%**
150°F Flashpoint Fuel	**< 1%**	**< 1%**	**1%**
Ground Based Inerting of Fuel Tanks	*Not applicable*	**< 1%**	**1%**

Combinations of Modifications			
Ventilate and 120°F	*Not applicable*	*Not applicable*	**< 1%**
Insulate and 120°F	*Not applicable*	*Not applicable*	**5%**
Insulate and 130°F	*Not applicable*	*Not applicable*	**1%**

14. REFERENCES

Boeing Document, D6-52754, “Handbook of Properties of Common Petroleum Fuels,” John E. Schmidt, Dec. 1984, Boeing Commercial Airplane Group, Seattle, WA.

Handbook of Aviation Fuel Properties
(Co-ordinating Research Council, Inc)

15. APPENDIX

15.1 Thermal Model Descriptions

15.1.1 Centre Wing Tank (Large Aeroplane)

A thermal model was developed and correlated for a large aeroplane centre fuel tank. It predicts liquid & ullage temperatures on the ground and during flight for various ambient and operational conditions. Operational conditions include tank fuel volumes, aeroplane pitch, environmental control system pack component temperatures, and mission length. The model also assesses the effect of aeroplane structural and operational changes on fuel and ullage temperature profiles for a range of ambient temperature profiles. The model can handle the following changes:

1. Environmental control system pack surfaces with and without insulation.
2. Environmental control system pack ventilation
3. Varying fuel volumes in tanks
4. Varying aeroplane attitude

The model evaluates the effect of the following operational and design modifications on centre wing tank, fuel and ullage temperatures for 3 mission lengths and 7 ambient air temperature profiles:

1. Existing aeroplane configuration
2. Ventilating the environmental control system pack bay with ambient air
3. Insulating the environmental control system pack bay ducts.

The model is transient and includes the following elements and influences:

1. centre wing tank
2. inboard wing tanks
3. wing structure
4. body structure
5. air conditioning (a/c) packs
6. heat transfer to and from ambient

<u>Analytical Tools</u>

Computer modelling was performed using the SINDA85 / FLUINT thermal/fluid analysis program. This program is an industry standard finite difference code, designed to handle lumped parameter thermal/fluid systems that include radiation, convection, and conduction heat transfer and single, or two-phase, fluid flow.

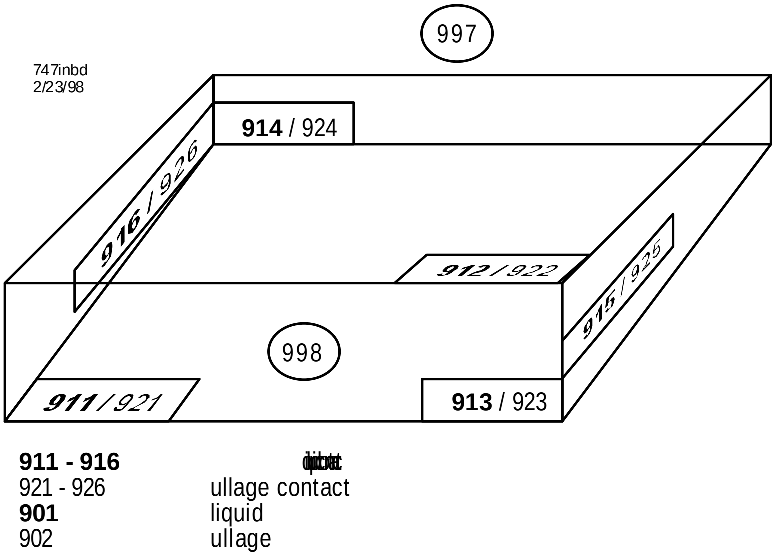
The overall model was created using three sub-models for fluid flow and one sub-model for thermal transfer. The fluid sub-models analyse air movement between the inboard wing tank and ambient, centre wing tanks and ambient, and between the pack bay and ambient through drainage holes in the environmental control system pack bay fairing.

The thermal sub-model analyses the conduction and radiation heat transfer within and between the centre wing tank, environmental control system packs and bay, and the inboard wing tanks. This high level of detail is driven by the need to identify the relative influence of a large number of variables on tank fuel temperatures.

Inboard Wing Tank

The inboard wing tank was included in the thermal/fluid model in order to provide a centre tank side boundary temperature. It consists of a six-sided box, as shown in figure 15.1.1.1, below. In order to capture temperature differences between surfaces in contact with the ullage and liquid each tank surface has two nodes corresponding to the surface areas in contact with ullage and liquid.

Figure 15.1.1.1



Depending on the volume of fuel in the tank and the aeroplane pitch and roll, each side of the box may be in contact with liquid or vapour, or both liquid and vapour. For example, on the ground before takeoff the lower and inboard surfaces are typically completely covered with liquid while the remaining surfaces are in contact with both liquid and ullage. During flight as fuel is withdrawn from the tank the program automatically changes the fuel and tank node thermal capacitance and conductor values to account for the new wetted contact areas. If a surface becomes completely dry during a mission then the corresponding liquid node is mathematically isolated from the model.

Tank internal heat transfer includes free convection between the tank surfaces and the liquid and ullage, and between the liquid surface and ullage and radiation from the liquid to the upper wing surface not in contact with the liquid. A discussion of the heat transfer calculation occurs later in this write up. Internal radiation is only analysed between the liquid surface and the upper tank (wing) surface.

Tank external heat transfer includes forced convection to a total air temperature node, radiation to sky and/or ground temperature nodes and a solar load on the upper wing surface.

The ullage is modelled in the fluid sub-model as a single air node connected to ambient, which allows airflow into and out of the tank through the tank vent system as the aeroplane altitude changes. The liquid is modelled in the thermal sub-model as a single thermal node.

Center Wing Tank

The centre tank model consists of a thermal sub-model, and ullage and environmental control system pack air fluid sub-models.

The centre wing tank thermal sub-model includes the tank bottom & top, spanwise beams, front & rear spars, environmental control system pack components and, environmental control system pack bay fairing. Nodal density is greatest on the tank bottom surfaces, with 140 nodes, since these surfaces have the greatest effect on fuel temperatures, and temperature gradients are large due to uneven heating from the environmental control system packs located directly below. The node density on the remaining surfaces is less in order to minimise model run times. Nodal maps for the thermal sub-models are provided in figures 15.1.1.2 through 15.1.1.4.

The tank ullage fluid sub-model simulates ullage movement between the tank compartments and through the tank venting ducts to ambient. The environmental control system pack bay fluid sub-model models pack leakage into the environmental control system pack bay, airflow between the environmental control system pack bay and the adjacent dry bay, and ambient air leakage into and out of the pack bay through drainage holes in the pack bay fairing.

The tank bottom was divided into the 7 by 20 node grid. Unlike the inboard wing tank model the centre tank model assumes each node is in contact with either the liquid or ullage. FORTRAN control logic ensures that radiation and free convection occurs from either the liquid or tank surface for each tank bottom surface node depending on the fuel location through out the mission.

The frequency of nodes along the axis of the aeroplane is greater in order to capture the effect of fuel movement within the tank caused by changes in aeroplane pitch. Because the slope of the tank bottom is so gradual small variations in aeroplane pitch can have a large effect on the location of the fuel within the tank and more important, the total contact area between the fuel and tank bottom. As the contact area increases total heat transfer to the fuel increases since the convective heat transfer from the fuel to the tank bottom is larger than the convective heat transfer and radiation from the fuel surface to the tank ullage and inner surfaces.

The location of the fuel within the tank and the amount of fuel remaining in the tank also have a large effect on the fuel temperature. This is due to variations in heat transfer between the environmental control system pack surfaces and the tank bottom surface. To capture the effect of fuel location on fuel temperature, the fuel location and total fuel to tank bottom surface contact area is input in the model array data block. The wetted surface area between the centre wing tank fuel and tank bottom, tank side and spanwise beams which also varies with aeroplane pitch and the amount of fuel remaining in the tank is calculated on an Excel spreadsheet and imported in data arrays.

CWT Thermal Nodal Maps

Figure 15.1.1.2 Centre Wing Tank Bottom Surface Nodes

forward spar

111	112	113	114	115	116	117
121	122	123	124	125	126	127
131	132	133	134	135	136	137
141	142	143	144	145	146	147
211	212	213	214	215	216	217
221	222	223	224	225	226	227
231	232	233	234	235	236	237
241	242	243	244	245	246	247
311	312	313	314	315	316	317
321	322	323	324	325	326	327
331	332	333	334	335	336	337
341	342	343	344	345	346	347
411	412	413	414	415	416	417
421	422	423	424	425	426	427
431	432	433	434	435	436	437
441	442	443	444	445	446	447
511	512	513	514	515	516	517
521	522	523	524	525	526	527
531	532	533	534	535	536	537
541	542	543	544	545	546	547

rear spar

Figure 15.1.1.3 Centre Wing Tank Vapour and Vertical Surface Nodes

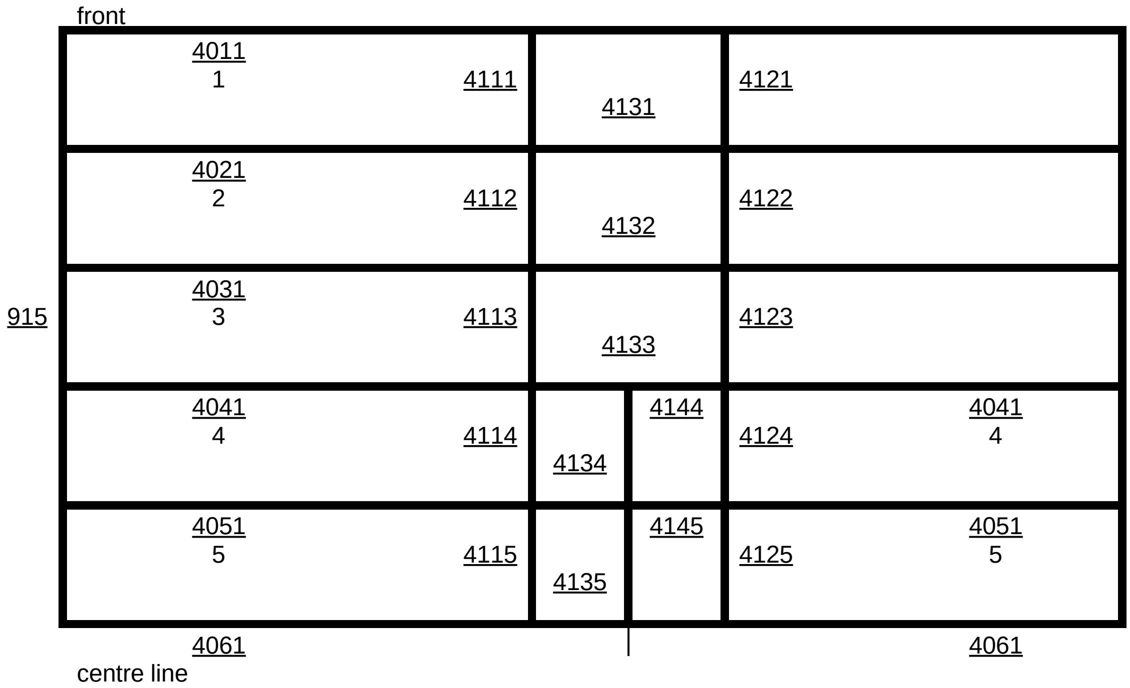


Figure 15.1.1.4 Fairing Interior and Exterior Nodes

forward spar

2811 3811	2812 3812	2813 3813	2814 3814	2815 3815	2816 3816	2817 3817
2111 3111	2112 3112	2113 3113	2114 3114	2115 3115	2116 3116	2117 3117
2211 3211	2212 3212	2213 3213	2214 3214	2215 3215	2216 3216	2217 3217
2311 3311	2312 3312	2313	2314 3314	2315 3315	2316 3316	2317 3317
2411 3411	2412 3412	2413 3413	2414 3414	2415 3415	2416 3416	2417 3417
2511 3511	2512 3512	2513 3513	2514 3514	2515 3515	2516 3516	2517 3517
2611 3611	2612 3612	2613 3613	2614 3614	2615 3615	2616 3616	2617 3617
2711 3711	2712	2713	2714	2715	2716	2717 3717

rear spar

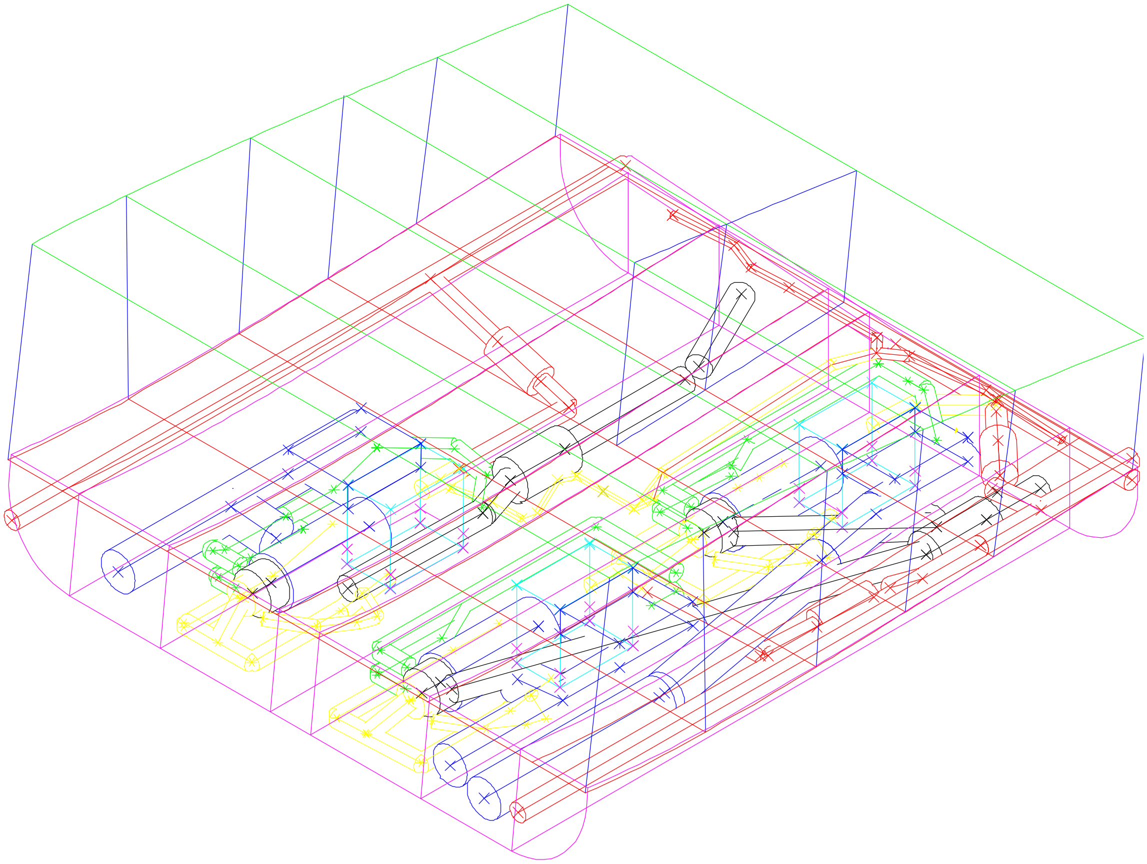
Radiation Models

The environmental control system pack bay and centre wing tank internal thermal sub-models include about 900 and 2600 radiation conductors respectively, (see figure 15.1.1.5). Radiation conductors inside the environmental control system pack bay and centre wing tank internal tank were created using Radsim, a Boeing proprietary radiation simulation program.

The environmental control system pack, bleed air, APU and supply air duct are broken up into 32 surfaces which radiate to the centre wing tank bottom and pack bay fairing interior surfaces. Each surface is assigned a unique boundary temperature, which varies during and between missions due to changes in ambient temperature and predicted pack performance. Environmental control system pack surface boundary temperatures are based on test data and predictions from a pack computer model.

Insulated ducts are modelled with an additional insulation outer surface arithmetic node connected to the duct boundary node through a conduction heat transfer path.

Figure 15.1.1.5 Environmental Control System Pack Bay Radiation Model



Convective Heat Transfer

Convection heat transfer from the exterior surfaces outside the inboard wing tank and pack bay fairing is modelled using a standard forced convection heat transfer correlation for flow over a flat plate. The program models convection heat transfer from the aeroplane exterior surfaces to a boundary ambient total air temperature node. The total air temperature assumes a 100% temperature recovery factor. For the ground conditions a 3 mile per hour wind speed is used in calculating the heat transfer coefficient.

Natural convection heat transfer coefficients are calculated for all model surfaces not in contact with the aeroplane exterior, which includes tank inner surfaces and a/c pack components. For natural convection, the heat transfer correlations are a function of temperature difference between the fluid and surface, surface orientation, fluid properties and (for horizontal surfaces) whether the surface is warmer then adjacent fluid. The program chooses the appropriate correlation, based on the above mentioned information and continuously updates all natural convection heat transfer coefficients.

Fuel Properties

The program was designed to model various fuels, (JET A, Aviation Gas, JP-4, JP-5), by setting the fuel type flag. Jet A was used for this study.

15.1.2 Main Wing Tank (Small and Large Aeroplane)

The wing tank thermal model simulates heat transfer between a fuel system and its surroundings during an aeroplane flight. This model was designed to predict in-flight fuel temperatures for (main) integral wing tanks of commercial aeroplanes using quasi-steady state equations of heat transfer.

A fuel system consists of fuel tanks, plumbing lines and components such as pumps, valves, pressure switches and the like for fuel management. There may be several fuel tanks with a provision of fuel transfer between tanks.

The time dependent heat transfer process is influenced by factors including the environment and the aeroplane flight profile. The initial fuel tank quantity also changes depending on the engine feed rate and fuel transfers from other tanks.

The principal mechanisms of heat transfer considered in this model are:

- Convective heat transfer from the aerodynamic boundary layer outside the tank to/from the tank surface
- Conductive heat transfer through the tank wall
- Convective heat transfer from the wetted tank inside wall to/from bulk fuel
- Radiative heat transfer from the fuel surface to the dry areas of tank inside wall
- Conductive heat transfer through the dry area of tank wall
- Radiative heat loss/gain from the tank outside surfaces to sky or ground
- Solar radiation to the tank surfaces

Assumption

The thermodynamic properties do not change rapidly so that the heat transfer process can be considered quasi-steady state.

Method of Solution

The generalised mass and energy conservation equations are developed for a tank. These are applied for a small time increment Δt. At each time step, recovery temperature for the aerodynamic boundary layer and Reynolds number at the tank leading edge (for determining the aerodynamic heat transfer coefficient) are calculated based on the flight profile. Similarly, tank wetted and dry areas based on fuel quantity remaining are determined. The equations are solved numerically to obtain the bulk fuel temperature at the end of the time interval for all the tanks. The process is repeated to cover the entire flight profile.

Inputs

Inputs required include:

- Fuel System Details - Number of tanks, fuel volume versus tank wetted area for each tank, tank material properties

- Atmospheric Data - Altitude versus pressure, air temperature, sky and ground temperatures
- Flight Profile - Aeroplane speed and altitude as a function of time
- Fuel Management Data - Engine feed rate and tank-to-tank fuel transfer schedules
- Internal Heat Sources - Heat inputs as a function of time
- Initial Conditions - Fuel quantity and temperature in each tank, specific gravity

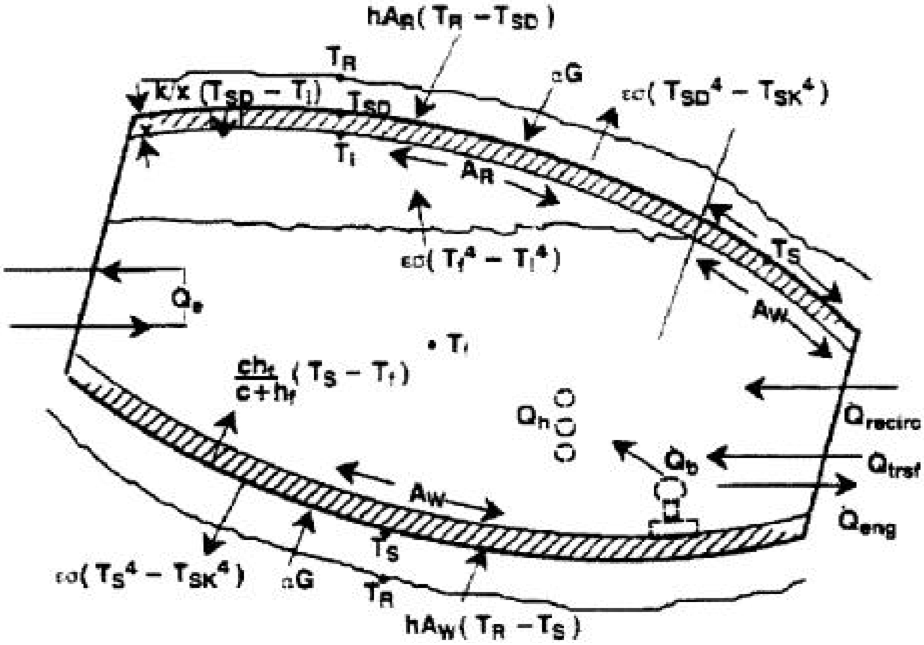
Output

The main output of the computer program is a history of fuel quantity and temperature in each tank of the fuel system.

The model described above has evolved over many years. It is highly versatile in dealing with fuel systems with a large number of tanks and complex fuel management schemes. It can also predict fuel temperature variation while the aeroplane is on the ground. The only major is its inability to provide any information on fuel temperature stratification within tanks. It is well known that such stratification, principally in the vertical plane, does occur. Fuel is mixed in flight, but not nearly enough to maintain thermal continuity. However, the model has not been designed to address this behaviour mainly to avoid complexity and to keep run times short.

Schematic

The following sketch shows various modes of heat transfer.



In addition to the heat transfer mechanisms listed above, there also is a provision for heat sources internal to the tank.

15.1.3 Centre Wing Tank (Small Aeroplane)

Model Assumptions

The wing tank thermal model described in Section 15.1.2 was used as the basis for the development of a thermal model for centre wing tanks. The centre wing tank thermal model is simplified from the main tank model by the following assumptions:

- Aerodynamic heating or cooling of the tank surfaces is not applicable.
- The tank is a basic cube, six flat surfaces without internal structure (bays).

Both models utilise the following assumptions:

- Steady state equations apply over a short time interval (0.5 minutes).
- Constant heat transfer coefficients and emissivities.
- The surface temperatures of the tank walls are uniform (uniform boundary conditions).
- Calculated fuel temperature is uniform throughout the fuel layer.
- Calculated ullage temperature is uniform throughout the ullage space.
- Ambient temperature and pressure gradients with altitude are standard atmosphere.

Boundary Conditions

For the tank wall surface temperatures, the model assumes a constant 70°F for the top wall (floor of the passenger cabin) and front wall (cargo bay). Over the flight profile, the sidewalls track the main tank fuel temperature (input from the wing tank thermal model), and the rear wall (wheel well) tracks total air temperature. The bottom wall surface temperature is calculated in the model as the boundary between the environmental control system bay and fuel tank. The bottom surface of the environmental control system bay tracks total air temperature.

Initial Conditions

For the initial conditions, the model assumes that the initial fuel, ullage, and environmental control system bay air temperatures equal the initial ambient temperature.

Model Inputs

The inputs to the program by the user are:

- Dimensions and volumes of the centre wing tank and environmental control system bay for the specific model aeroplane
- Flight profile - Altitude vs. time, including Mach No., vs. time (used to calculate total air temperature)
- environmental control system pack surface temperature vs. time
- Fuel temperature of main wing tanks vs. time

- Fuel load vs. time, including the area of the bottom surface wetted by the fuel (for small quantities only)
- Initial ambient temperature on the ground (default of 60°F)
- Initial fuel temperature (default is equal to initial ambient temperature)
- The type of fuel in the tank (specifically the flash point)
- Addition of a layer of insulation, with specified thermal conductivity and thickness, onto the bottom of the tank to study the thermal effects.

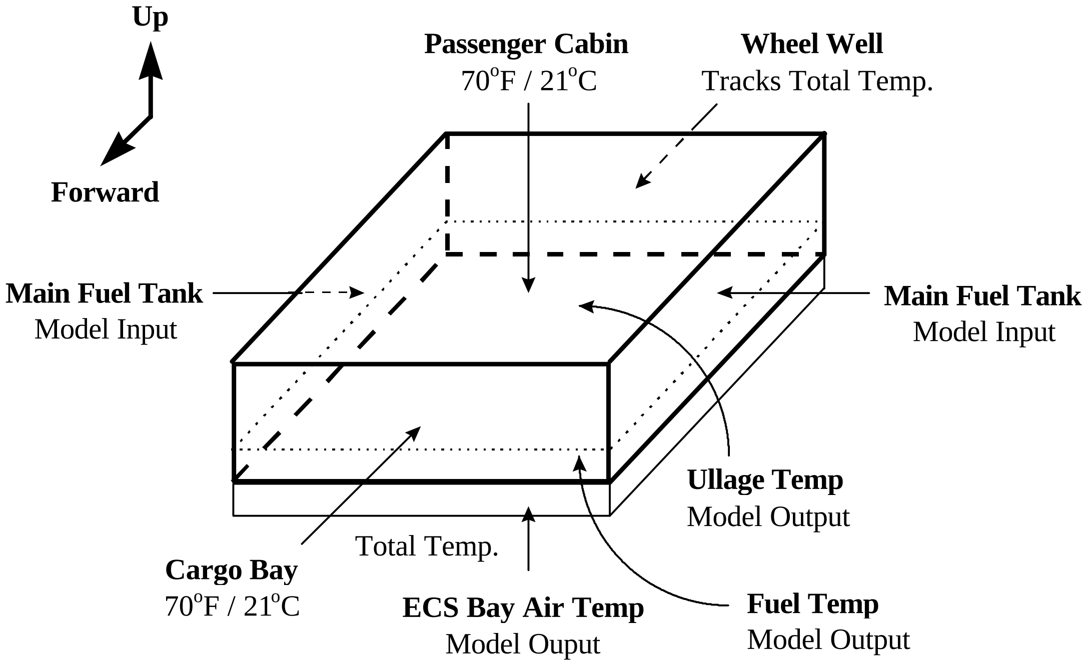
Model Output

The output of the thermal model is the predicted fuel, ullage, and environmental control system bay air temperatures over time.

Model Validation

The model has been validated with average fuel, ullage, and environmental control system bay air temperatures measured in ground and flight tests on a large aeroplane. The model does not always track the data exactly, but always predicts the trends accurately. Therefore, this simple model used in this study provides adequately accurate results to compare the effect of several options.

Center Wing Tank Thermal Model



15.1.4 Main Wing Tank (Medium Aeroplane)

A fuel wing tank model was created within British Aerospace to study the evolution of fuel temperatures during flight for both subsonic and supersonic flight. This model is presently inactive but results for a medium aeroplane both inner and outer tanks are shown in 15.2.4.

Though the model has not been used to calculate a total fleet wide exposure figure it has been used to estimate that Medium aeroplanes do not have an exposure to flammable fuel vapours significantly different to Small are Large aeroplanes.

The model calculated skin and the bulk mean fuel temperature by solving the steady state heat transfer equations for consecutive short time intervals. The results were validated against flight test and found to be within +/- 2°C.

The model considers three variables; flight profile, ground fuel temperature and ambient air temperature. The results shown in 15.2.4 use; four different flight profiles, two ground fuel temperatures and two ambient air temperatures. By use of data shown in 15.2.4 figure 7 it is possible to correct the data for other ambient air temperatures.

15.1.5 Centre Wing Tank (Medium Aeroplane)

A thermal model has been developed for a centre wing tank of generic medium size aeroplane, with directed ventilation of the space beneath the tank and a vapour seal. The model determines the temperature of fuel and ullage within the centre wing tank and the air in the compartments adjacent to the centre wing tank.

The model uses basic thermodynamic principles, in particular heat transfer by;

- convection
- conduction
- radiation

The relevant aeroplane compartments considered are;

- the environmental control system pack bay beneath the centre wing tank
- the vapour seal directly beneath the centre wing tank
- the fuel volume within the centre wing tank
- the ullage within the centre wing tank

and are shown in figure 15.1.5.1.

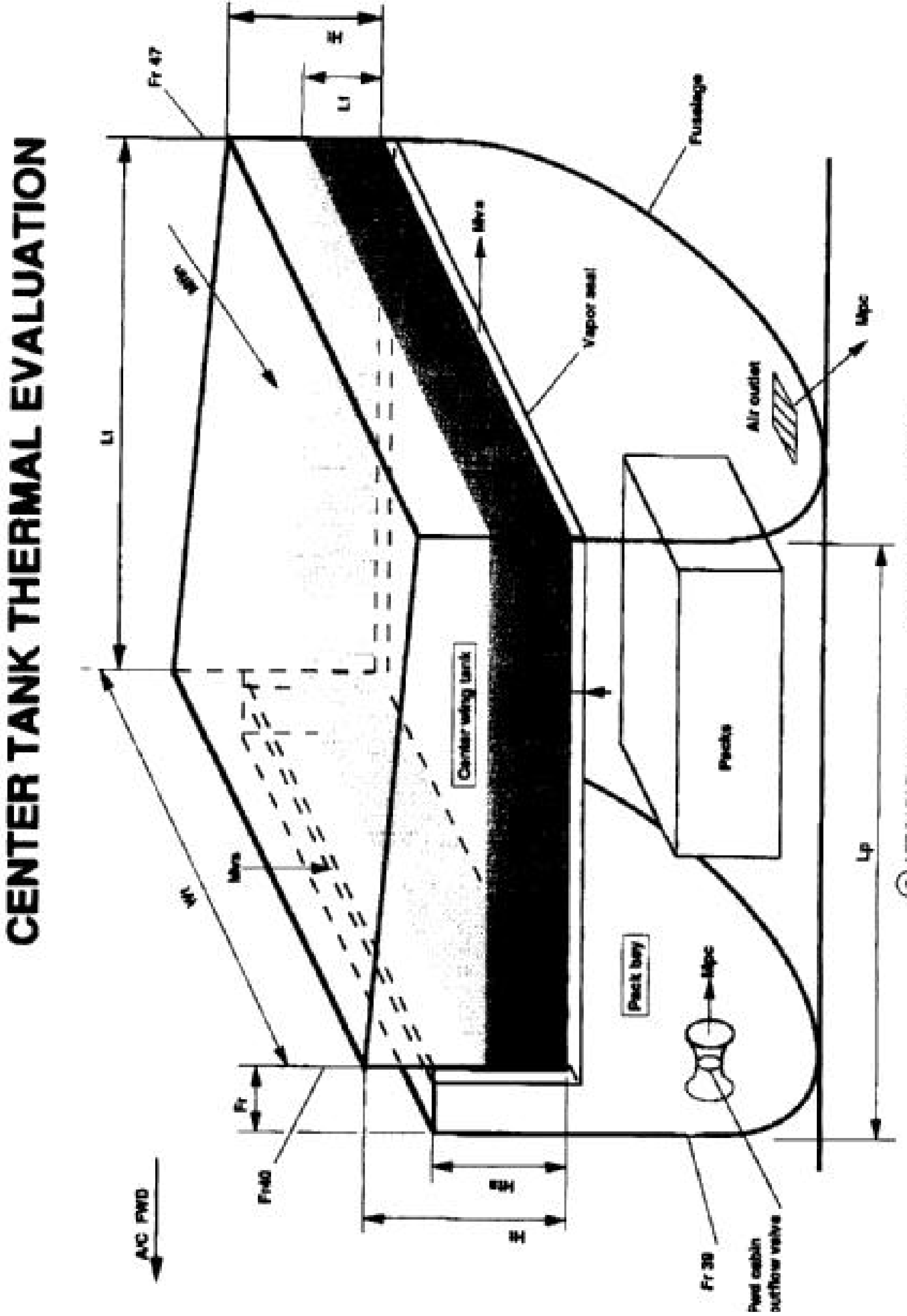
For each compartment a differential thermal balance equation has been established considering a global heat transfer of the fluid, (air, fuel and ullage), within the compartment, with the relevant surfaces in contact with the fluid.

Four thermal differential equations have been used to determine the required temperature variations during aircraft operations. These equations are resolved by use of a MATLAB software programme.

The programme takes into account the fuel consumption and hence the variation in fuel mass and level, within the centre tank during flight. Flight test data has been used to provide the temperatures of the fuel masses in the left and right wings.

The various convection coefficients of air and ullage have been corrected for changes in aeroplane altitude.

Figure 15.1.5.1 Aeroplane Compartments Considered



15.1.6 Main Wing Tank (Business Jet and Regional Turbofan)

A Thermal/Fluid fuel tank model was created to evaluate the effects of a Heated Fuel Return System (HFRS) in a bizjet wing fuel tank, (the same model was adapted to asses a generic regional turbofan). It was developed using a transient Thermal analysis program. This technique utilises the finite difference method and applies a forward time stepping approach to solve a matrix of non-linear simultaneous equations. The model is made up of a number of lumped parameters (nodes) that represent selected masses associated with the physical problem.

The program is capable of addressing conduction, convection and radiation heat transfer as well as heat sources and sinks. Subroutines are provided internally that enable the user to code detailed physical logic into the analytical model. Because of the fluid nature of the HFRS, major innovations were made in the Thermal technique in order to model in detail, the predicted fuel flows/levels throughout the tank. This has the effect of modifying both the fuel node masses and dimensions with time.

The Thermal network also utilises this embedded Fluid nodal model to account for the heat flux resulting from the liquid mass transfer. Each Thermal fuel node has an associated Fluid conductor. The model is made up of:

- 57 iterated nodes (to be solved for),
- 24 zero capacitance nodes (air nodes, to limit calculation time),
- 245 boundary nodes (used for boundary conditions, input ports or fluid links),
- 376 thermal and fluid conduction links,
- one internal heat source
- Eight external solar inputs.

The model is divided into an external reheated fuel segment and eight internal regions representing partitioned wing bays #0 through #6 and the inboard located hopper. The internal segments are connected in a series loop via fluid conductors with an internal parallel link existing between the hopper and bay #0 to account for its continuous fuel overflow.

Each bay is divided into upper and lower aluminium skins, an internal air node above the fuel and five fuel nodes. The skins are connected to the ambient turbulent recovery temperature by a turbulent forced convection coupling. The fuel nodes are connected internally by conduction and convection couplings and an additional flow couplings to allow heat to flow, (due to the fuel flow mass transfer), to connect them.

As fuel is depleted, the nodes reduce in size (height/mass) from the uppermost one, and collapse onto each other and eventually down to the lower skin. The bays are connected to each other only by flow couplings (i.e., no conduction through the ribs which is insignificant). The model utilises fuel loading/burn data in tabular form to define the amount of fuel present in any bay at any instant.

The internal convective fluid heat transfer coefficients were modified based on data obtained from two flight tests (they essentially represent the mixing caused by vibration). The first case had the HFRS off and the second had the HFRS turned on. The modified coefficients enabled the model to accurately predict the recorded data with the system both operating and not operating. The model was then applied to the second flight test with the HFRS "turned" off in the model. There was a significant difference in the results, indicating that the system was working as designed and that the model was capable of handling a broad spectrum of cases.

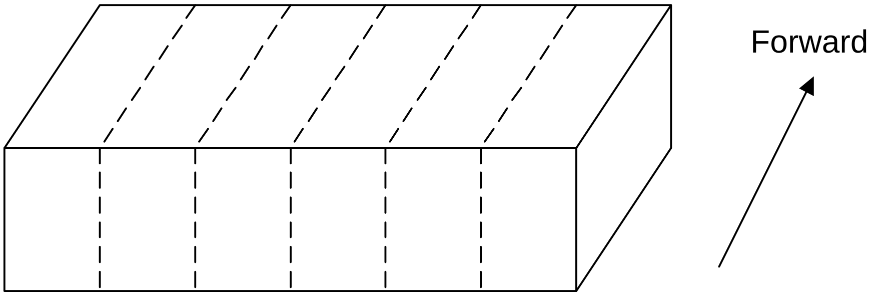
Based on these empirical/analytical results, additional test instrumentation was added to the non-heated wing (LH) and an extended flight was conducted. The results of this test were analysed using the model without further modification and the results were in good agreement with the data for both wings. As a result, it has been demonstrated that the Thermal model satisfactorily predicts the bizjet fuel temperatures and temperature stratification throughout the entire wing tank.

The model described above was used to predict the Thermal response of the fuel in the bizjet wing tank for three mission profiles and seven different temperature atmospheres. The reported results are for the innermost wing tank section (bay#1) which by virtue of containing the most fuel, cools down the slowest and results in the most severe exposure condition.

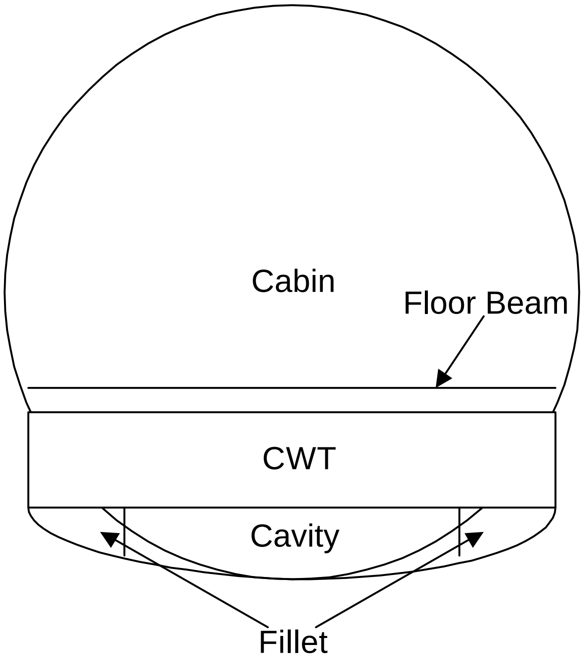
15.1.7 Centre Wing Tank
(Small Aeroplane without Adjacent Heat Source)

Centre Wing Tank

The centre wing tank is simulated as a basic cube with 6 fuel cells.



The following figure shows the relative position of the centre wing tank.



Analysis Tools

The System Improved Numerical Differencing Analyser (SINDA/G) thermal modelling system was used to model the centre wing tank. SINDA/G is a software system for solving lumped parameter representations of physical problems governed by diffusion-type equations. It is a general thermal analyser accepting conductor-capacitor (G-C) network representations of thermal systems.

A transient model was built to calculate the fuel temperature history inside the centre wing tank with various flight profiles. Microsoft Excel spreadsheet is used to calculate the adiabatic wall temperature vs. time.

Model Assumptions

- The surface temperatures of the tank walls are uniform.
- Radiation heat transfer is not considered.
- No heat transferred from fuel to the ullage or from ullage to fuel.
- Calculated fuel temperature and ullage temperature are uniform throughout the centre wing tank.
- Adiabatic wall temperature is used to simulate the air in the wheel well compartment and in the fillet.
- Top of the centre wing tank was exposed to the warm air between the floor beam and the centre wing tank, the heat transfer coefficient from the air to the top of the centre wing tank wall is constant.
- Both the left and right side of the centre wing tank walls were exposed to the fuel in the main fuel tank. Natural convection is assumed for the heat transfer from these walls to the fuel in the main tank.
- The Centre Auxiliary Compartment is forward of the centre wing tank, the heat transfer coefficient from the air in Centre Auxiliary Compartment to the centre wing tank wall is constant.
- The wheel well compartment is located aft of the centre wing tank, the fillets are connected to the wheel well compartment. The heat transfer coefficient is varied with time in flight depending on Mach number.
- Underneath the centre wing tank is the cavity. The air temperature in the cavity is assumed to be the adiabatic wall temperature and the heat transfer from the cavity to the bottom of the centre wing tank is assumed to natural convection.
- Ambient temperature and pressure gradients with altitude are standard atmosphere.

Boundary Conditions

For the air temperature between the floor beam and the top of the centre wing tank wall is 75° Fahrenheit. The air temperature in the Centre Auxiliary Compartment (forward of the centre wing tank) is also 75°F. Over the flight profile, the side walls tract the main tank fuel temperature (average temperature of the fuel in the centre wing tank and the main tank in the previous time step). The air temperature in the wheel well and the tunnels is equal to the adiabatic wall temperature. The air temperature under the centre wing tank wall is equal to the air temperature in the wheel well compartment.

Initial Conditions

The model assumes that the initial fuel, ullage temperatures are equal to the ambient temperature. Packs are operating on the ground before the flight. The air temperature in Centre Auxiliary Compartment and between the floor beam and the centre wing tank top wall is 75°F.

Model Inputs

- Dimensions and volumes of the centre wing tank.
- Flight profile - Fuel quantity in centre wing tank vs. time, adiabatic wall temperature vs. time, heat transfer coefficient vs. time.
- Initial ambient temperature on the ground.
- Initial fuel temperature.
- Centre Auxiliary Compartment air temperature and air temperature under the floor beam.

Model Output

The outputs of the model are the predicted fuel temperature and tank wall temperature vs. time.

15.1.8 Centre Wing Tank (Regional Turbofan)

The mission profiles considered were short and long mission lengths of 400 and 800 nautical miles. These were chosen as the proportion of flights with mission lengths between 0- 650 N.M is estimated to be 85% (short mission), and mission lengths between 650-1000 N.M at 15% (long mission).

Flight profiles were based on the delta ISA condition in flight as specified by Task Group 8 for the altitude range 20,000ft and above. For the altitude range below 20,000ft an incremental approximation was made starting at the specified ground delta ISA condition and finishing at specified delta ISA condition at 20,000ft.

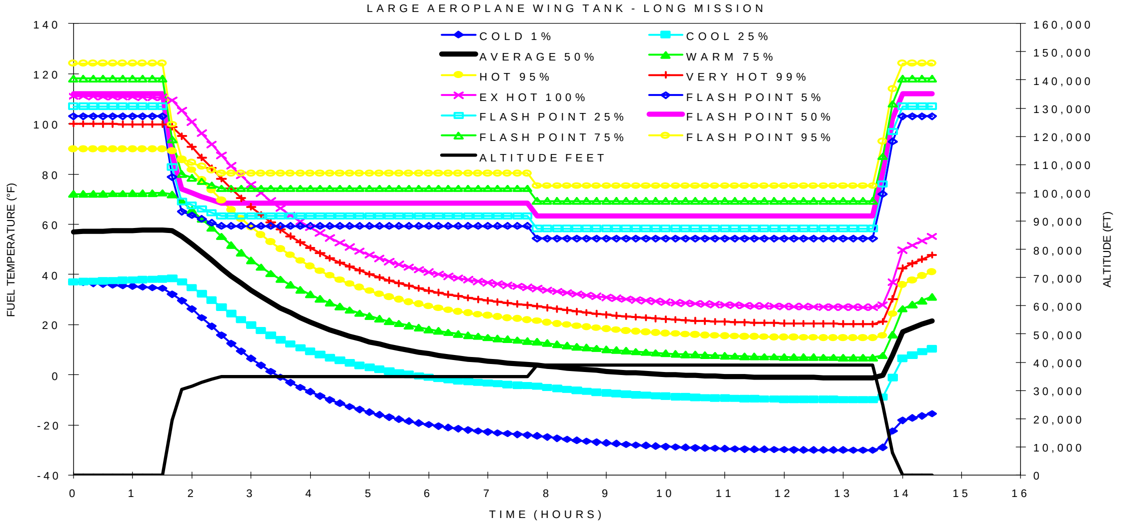
The rate of climb is based on actual engine performance for these temperatures. Ground time is 15 minutes before takeoff and 15 minutes after landing.

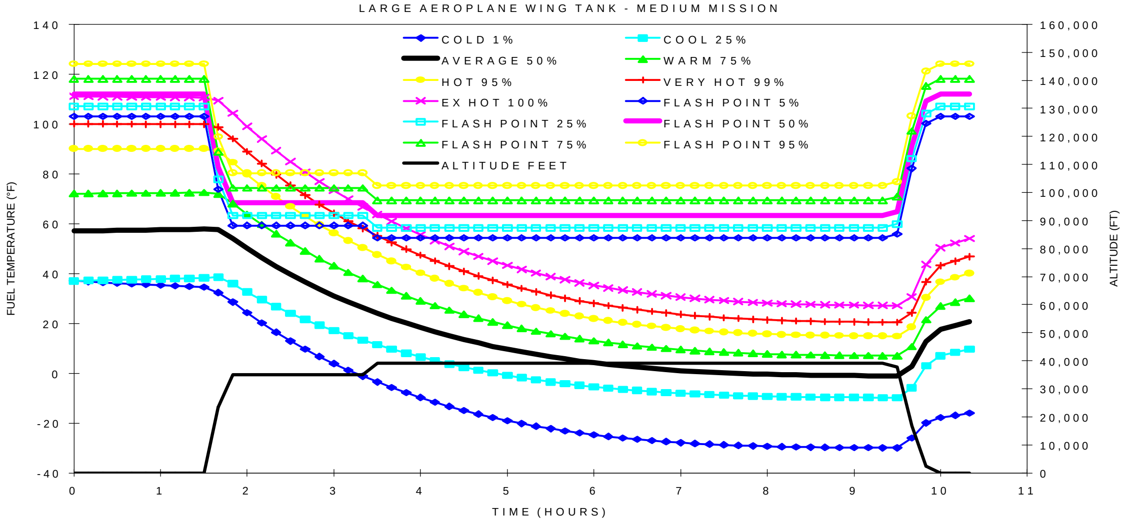
Fuel load in the centre wing tank is assumed for both mission lengths. This is very conservative and only representative for fuel tankering, i.e. flying several hops without refuelling. Normally the centre wing tank is not filled for mission lengths below 950 N.M but it may be assumed that 5% of all missions are with fuel in the centre wing tank to account for tankering. To indicate the effect of an empty centre wing tank the flight profiles are also given for 400 and 800 nautical miles for the "extremely hot" condition. For lower ambient temperature conditions the exposure % is close to zero hence not of interest in this regard.

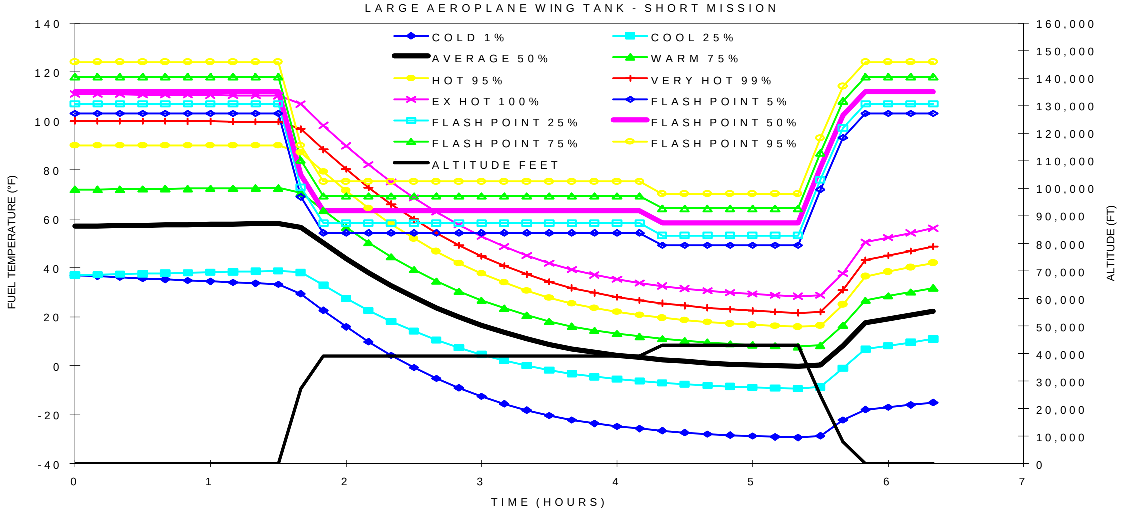
The fuel temperature always equals the ambient temperature at the start of flight. The thermal model does not account for the radiation effects because of the low temperature of air and equipment surrounding the centre wing tank. In the future, the model may need some refinement to correctly address time constants of tank structure etc.

15.2 Thermal Model Predicted Bulk Fuel Temperatures Results Charts

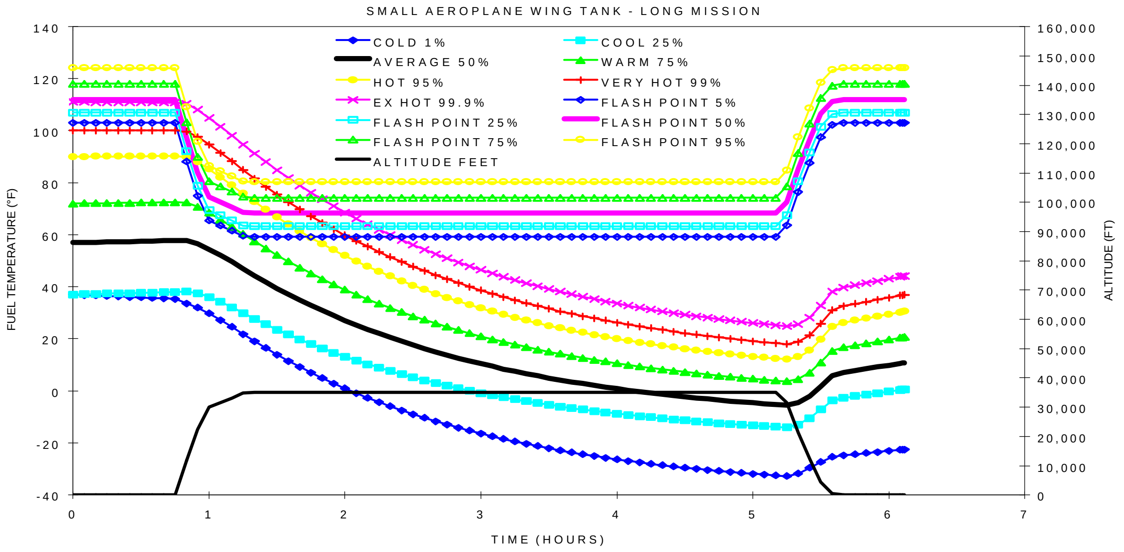
15.2.1 Large Aeroplane Wing Tank

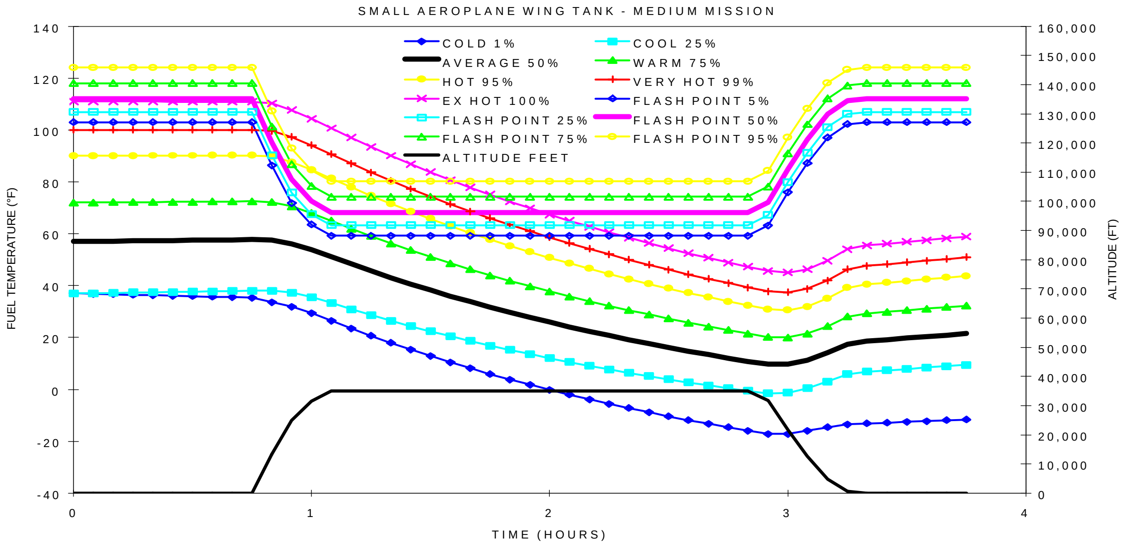


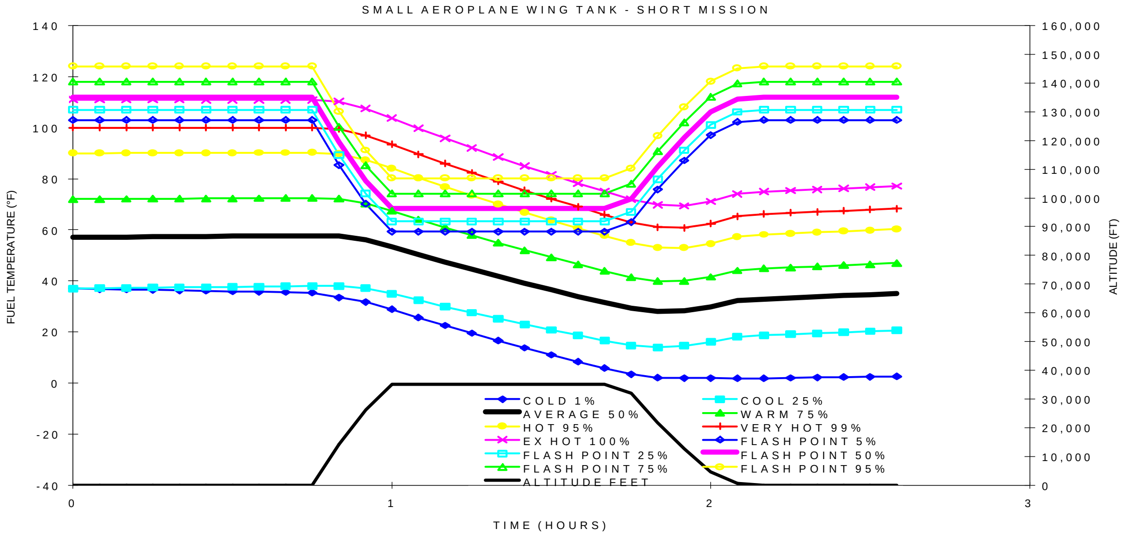




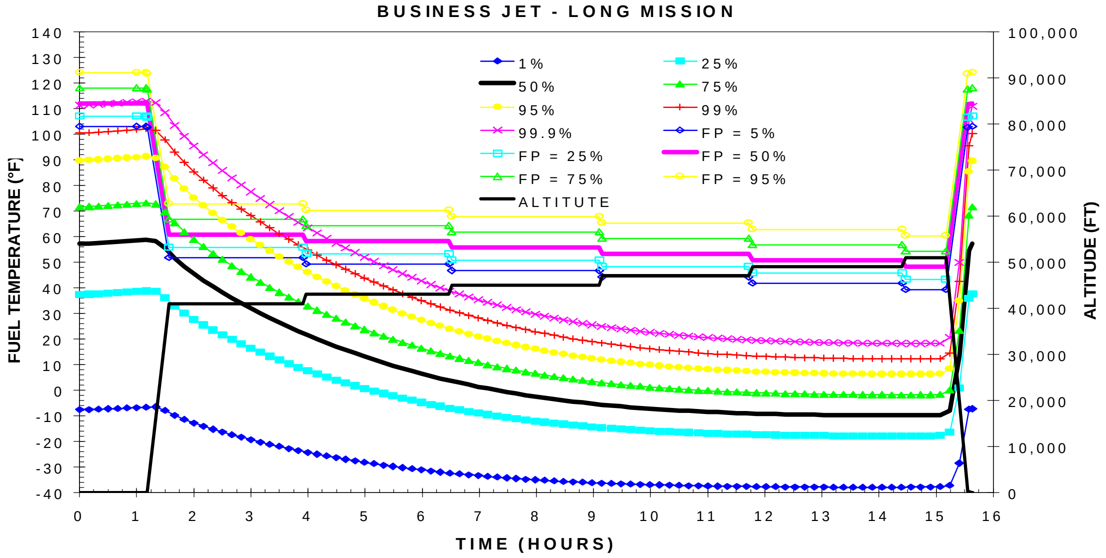
15.2.2 Small Aeroplane Wing Tank

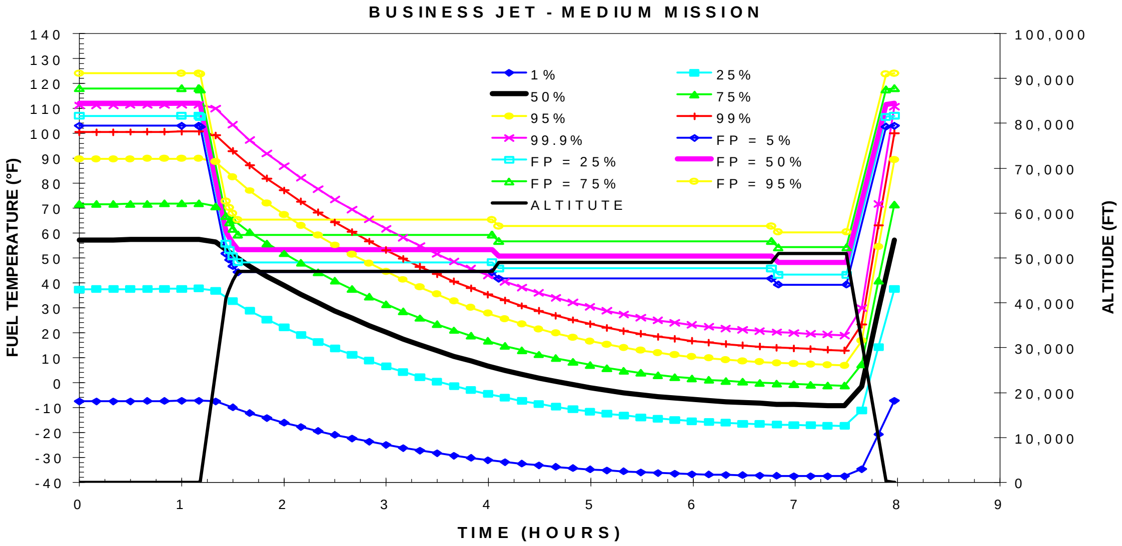


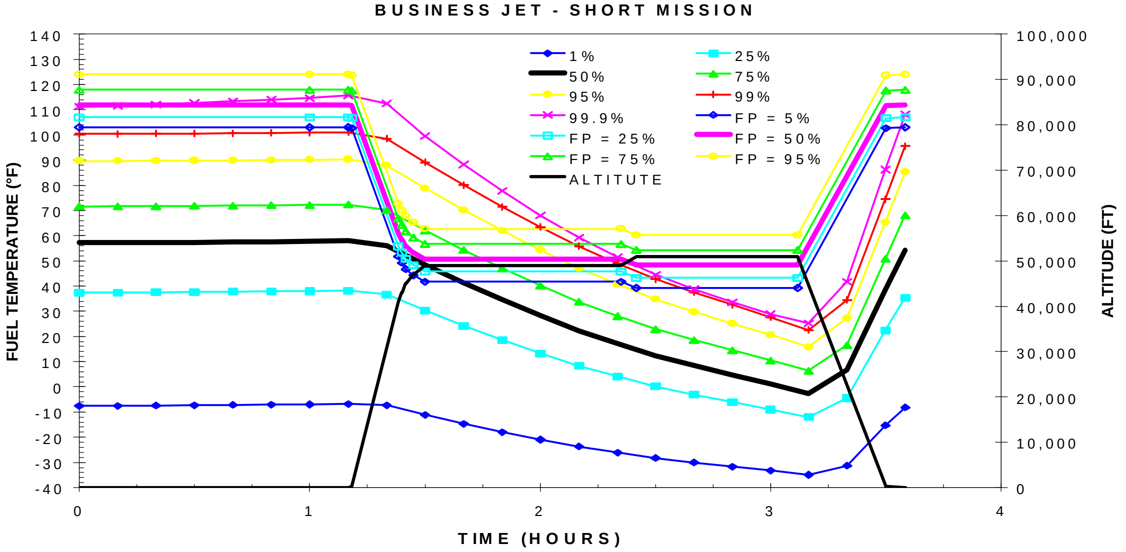




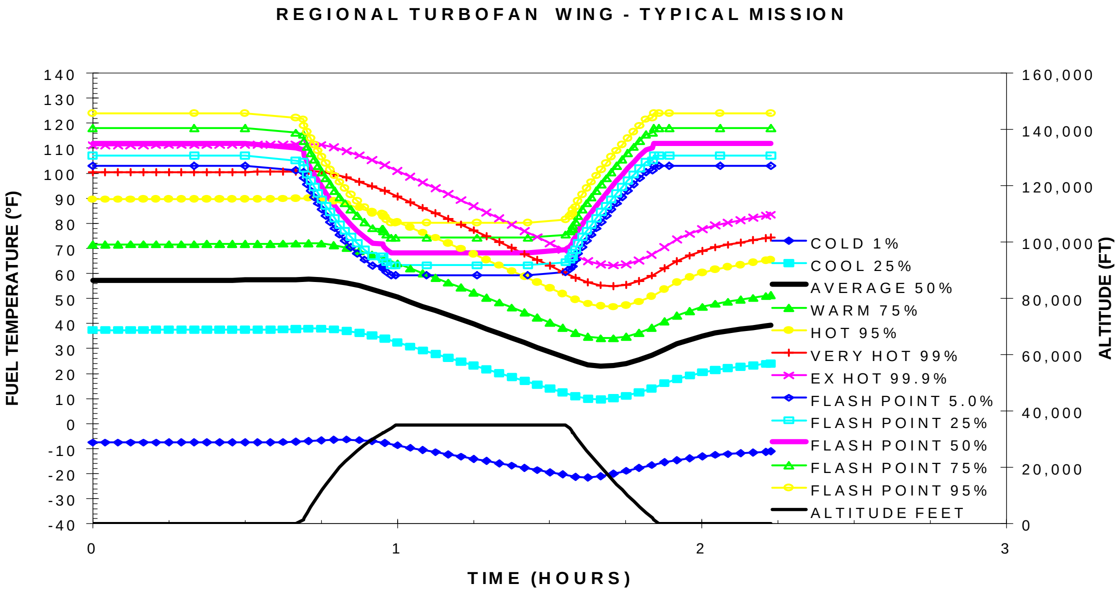
15.2.3 Business Jet Wing Tank





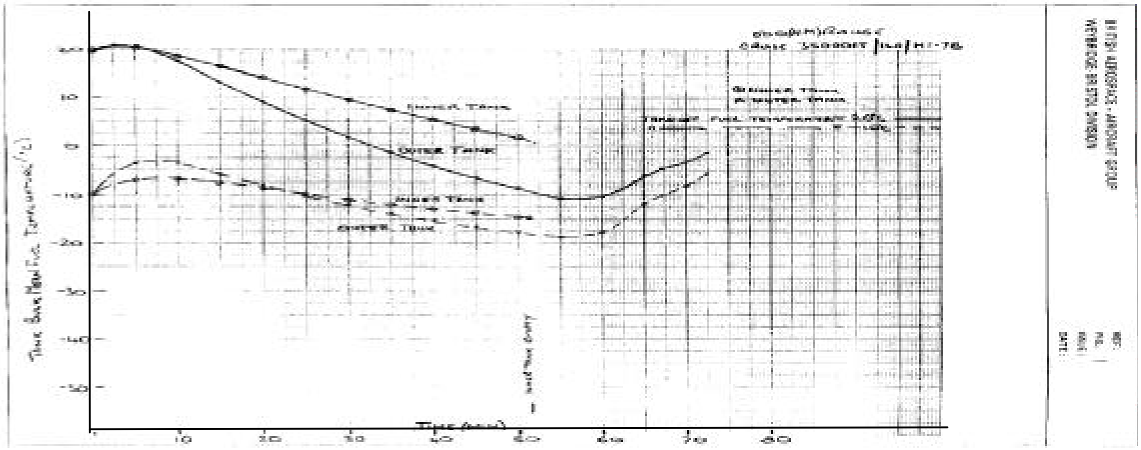


15.2.4 Regional Turbofan Wing Tank

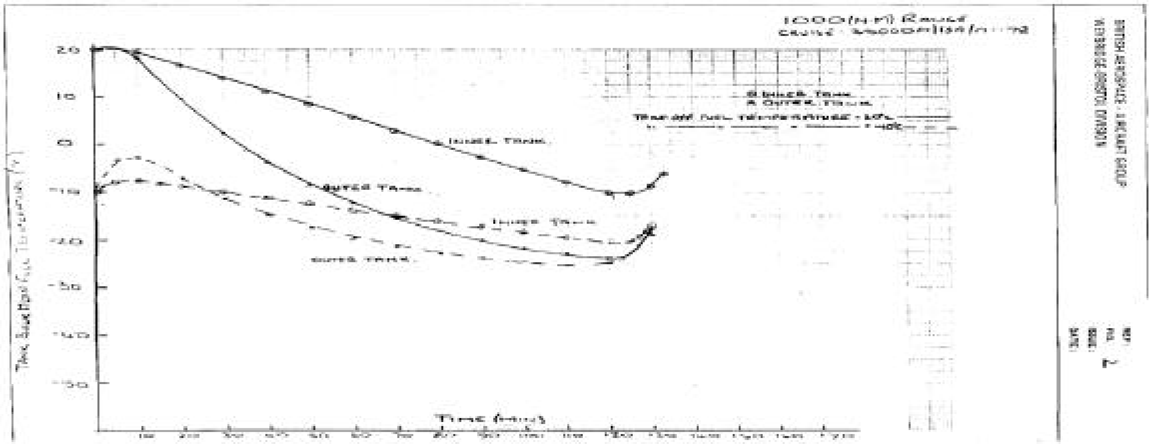


15.2.5 Medium Aeroplane Wing Tank

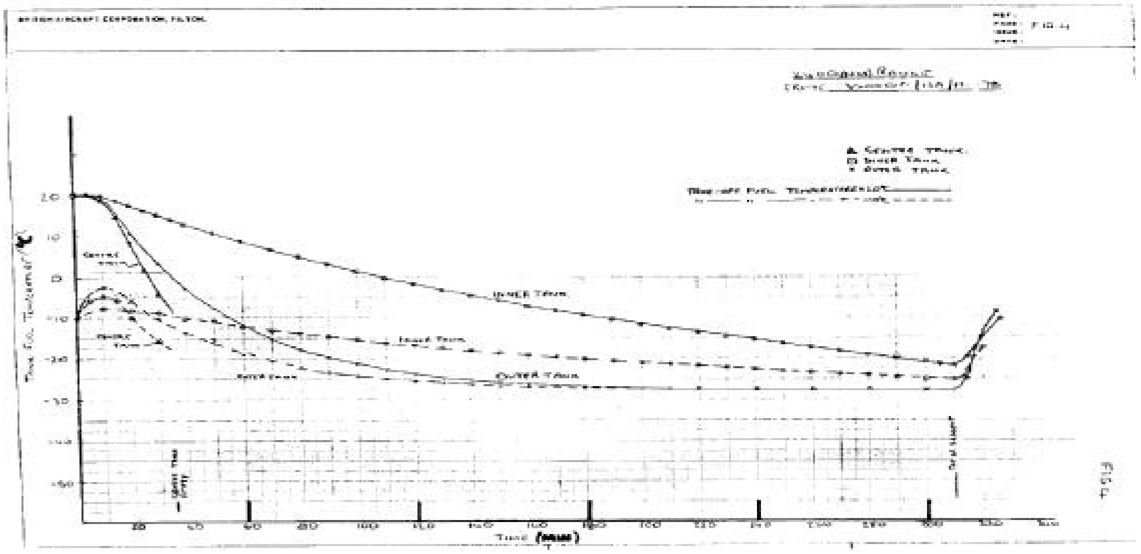
(short mission 500 nm)



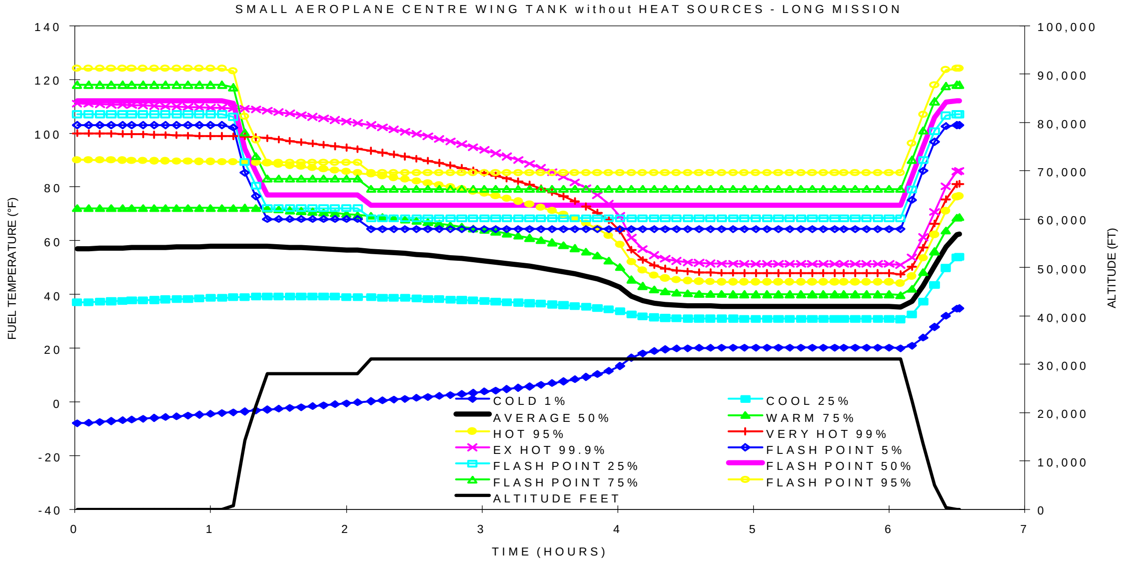
(medium mission 1,000 nm)

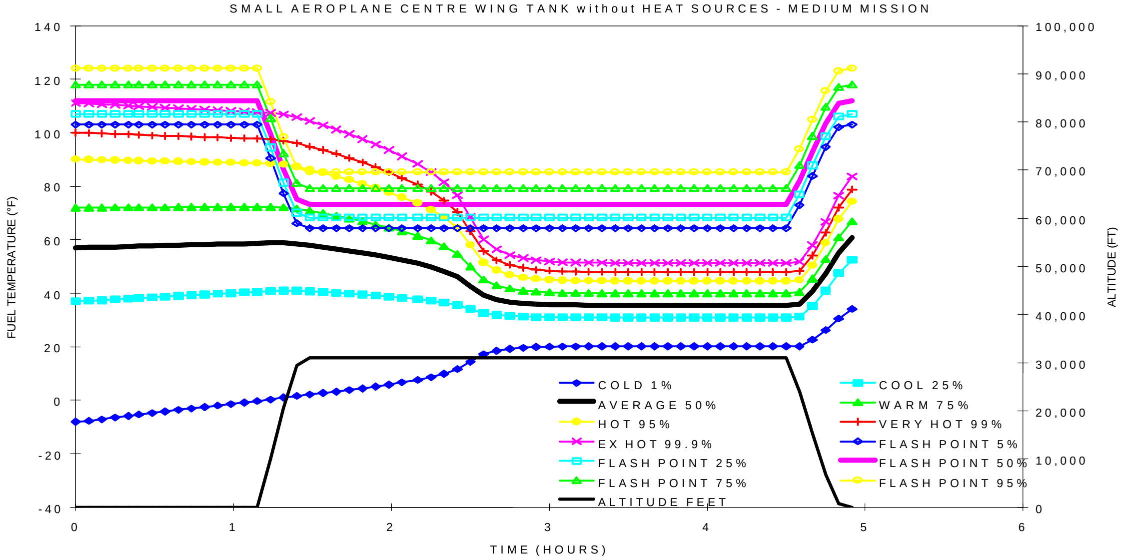


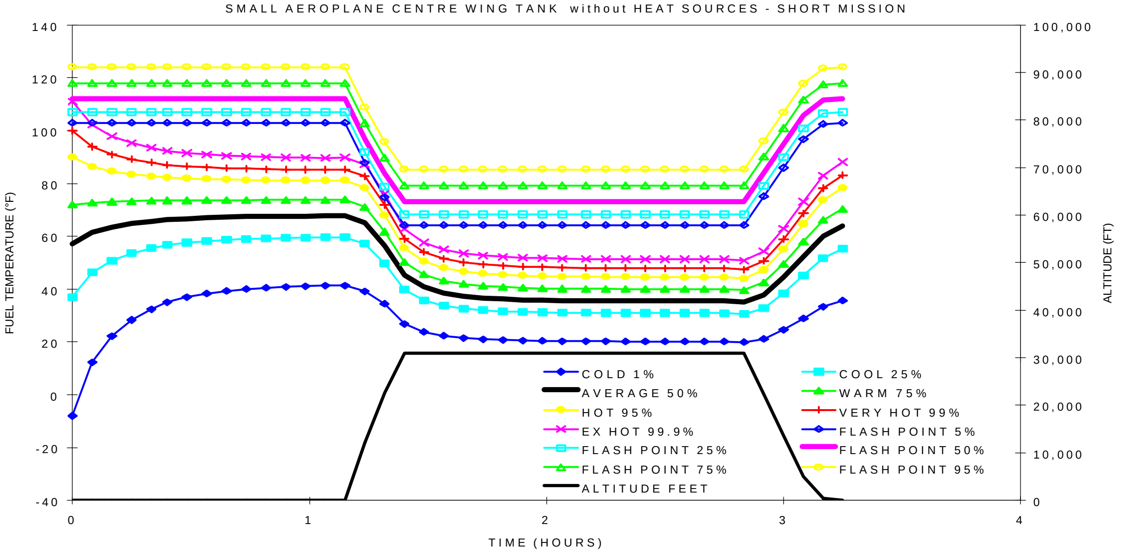
(long mission 2,400 nm)



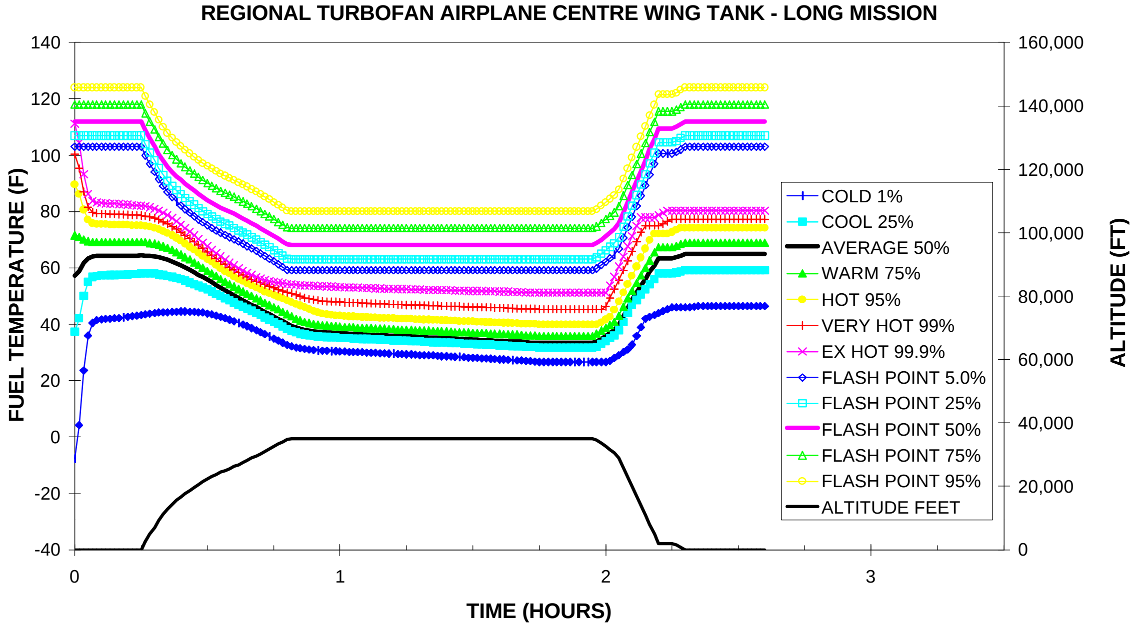
15.2.6 Small Aeroplane Centre Wing Tank (without heat source)

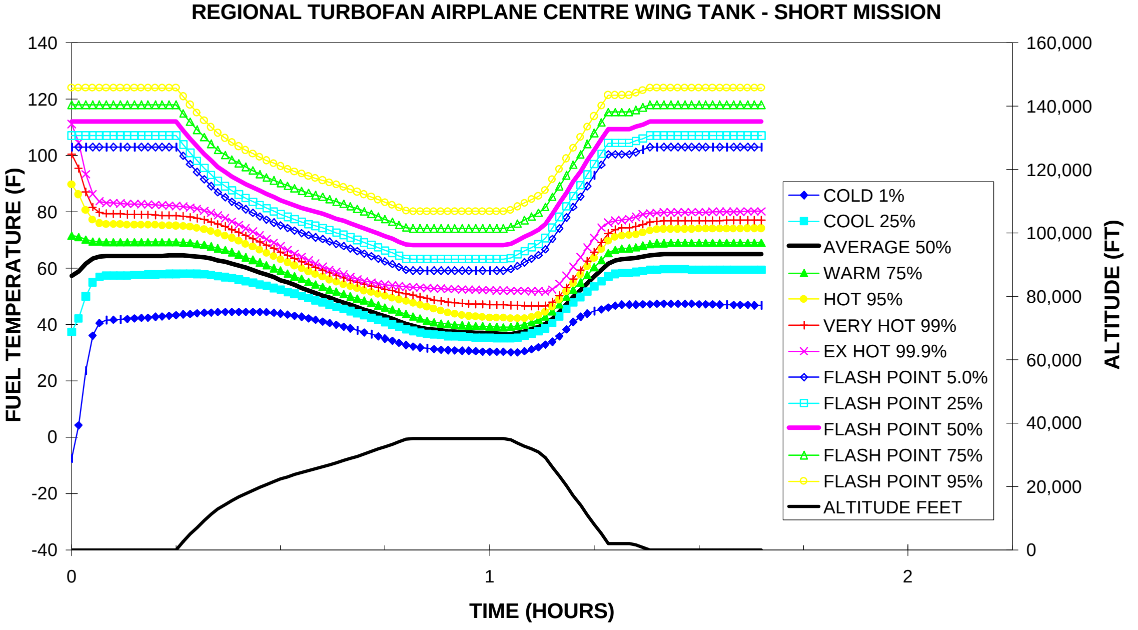






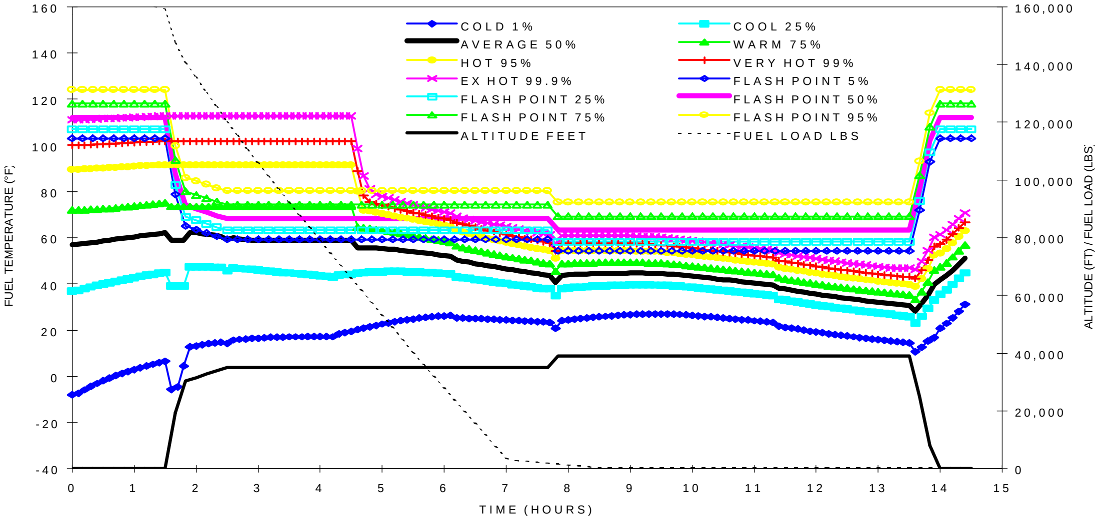
15.2.7 Regional Turbofan Centre Wing Tank (without heat source)



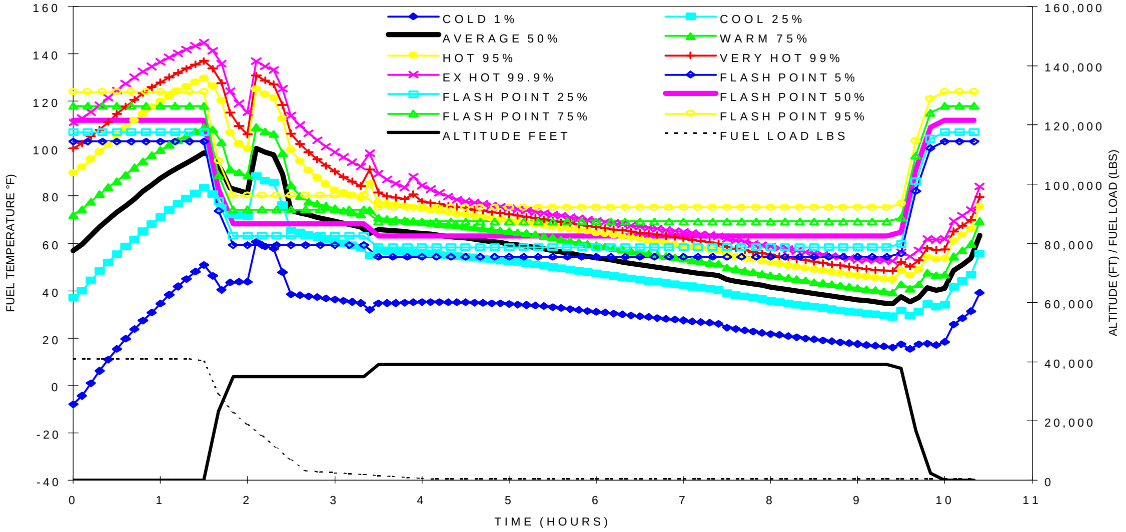


15.2.8 Large Aeroplane Centre Wing Tank (with heat source)

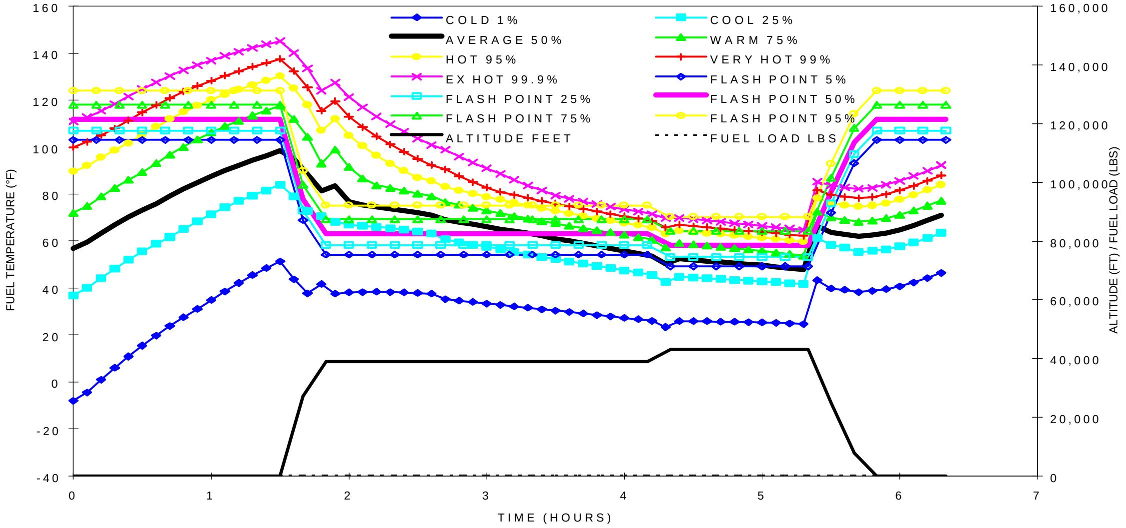
LARGE AEROPLANE CENTRE WING TANK - LONG MISSION



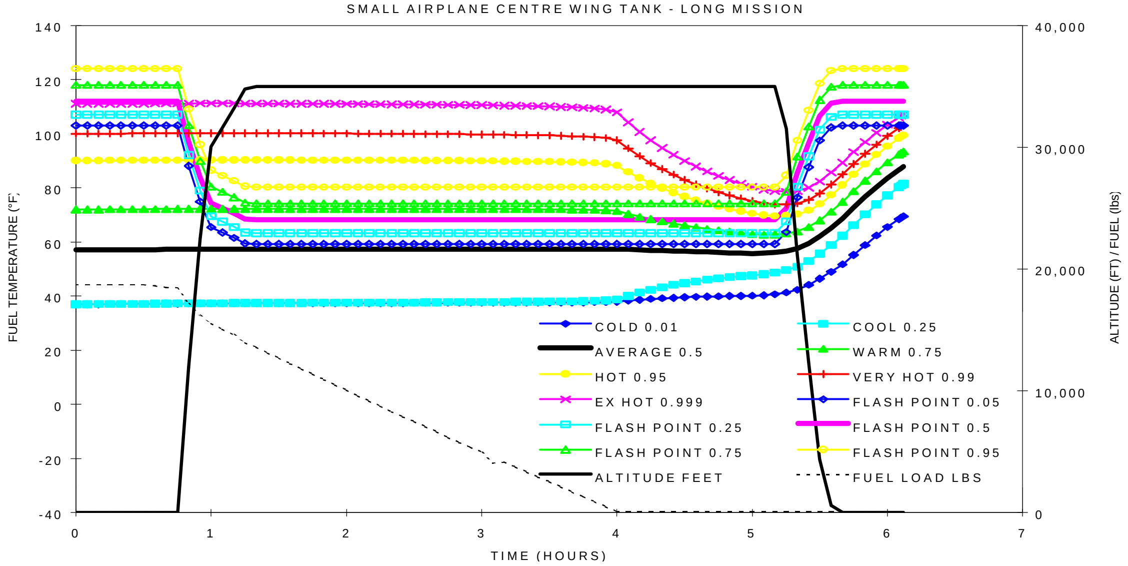
LARGE AEROPLANE CENTRE WING TANK - MEDIUM MISSION

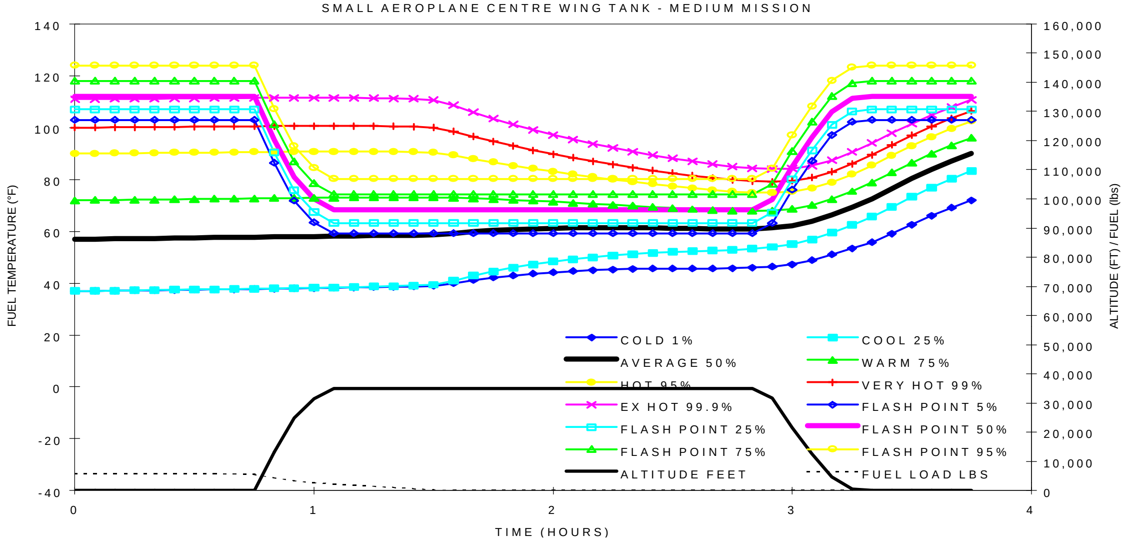


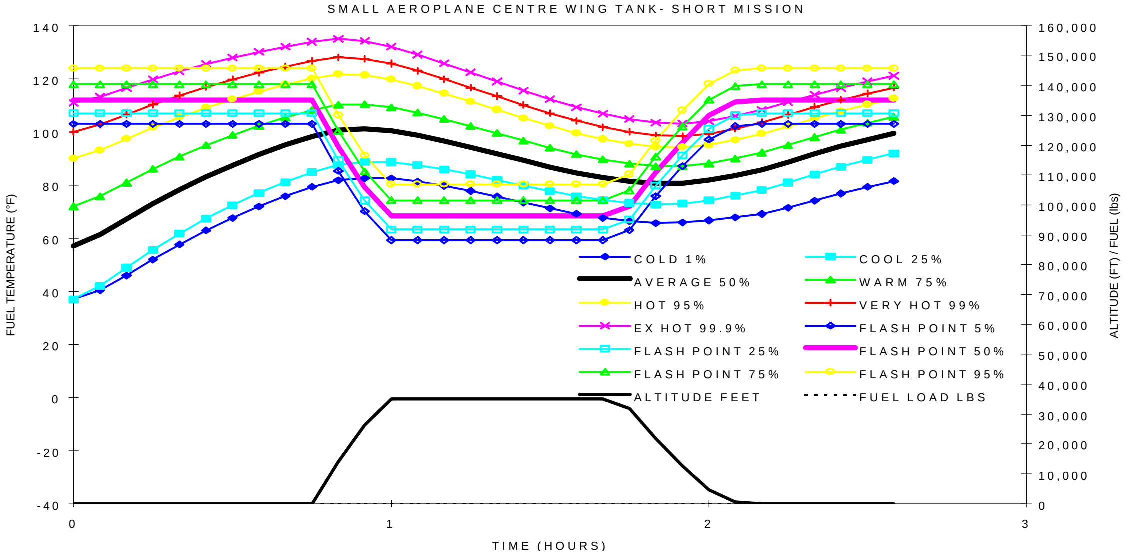
LARGE AEROPLANE CENTRE WING TANK - SHORT MISSION



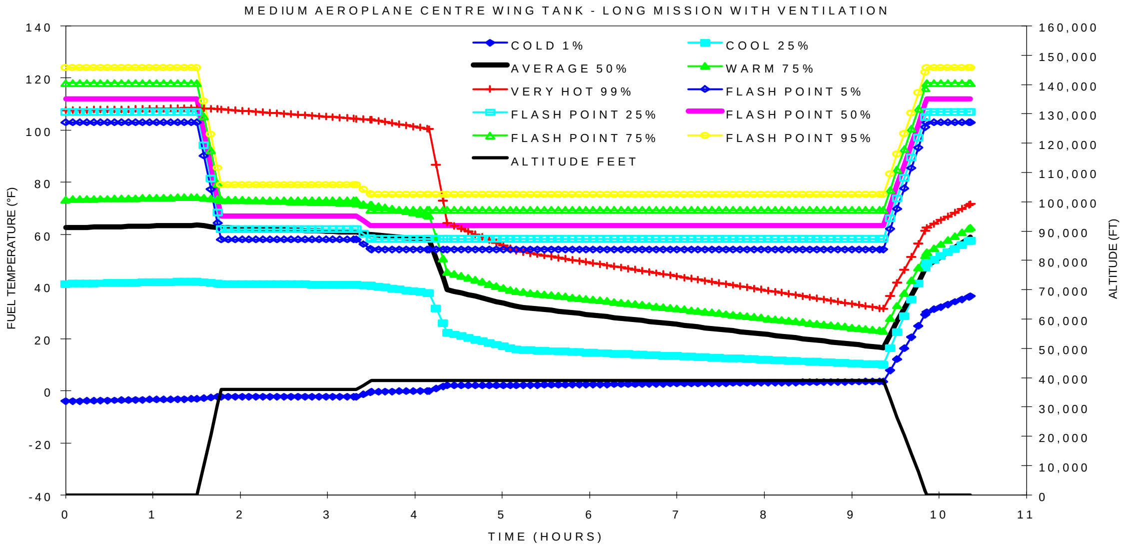
15.2.9 Small Aeroplane Centre Wing Tank (with heat source)

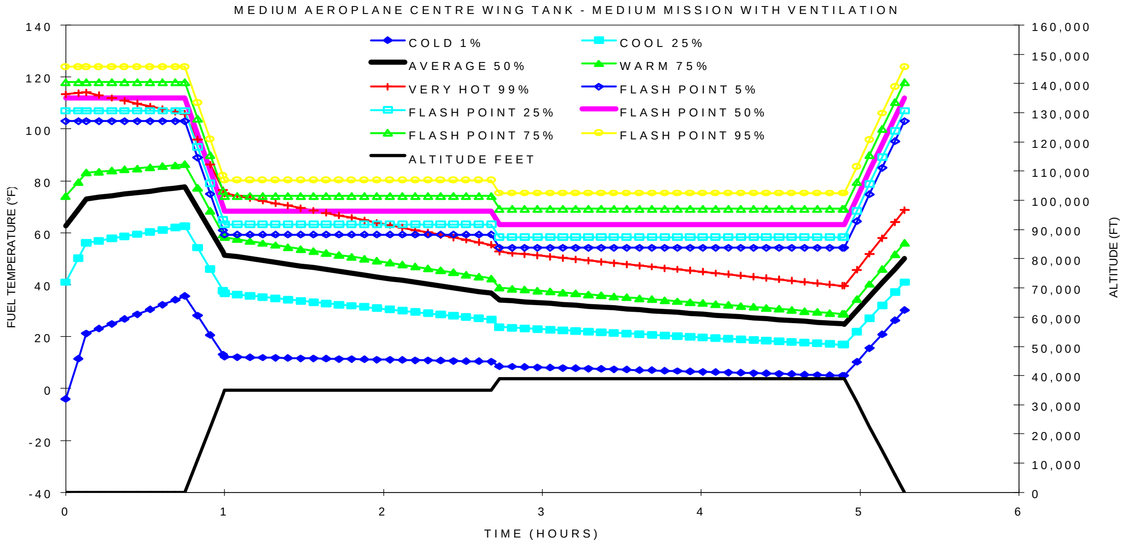


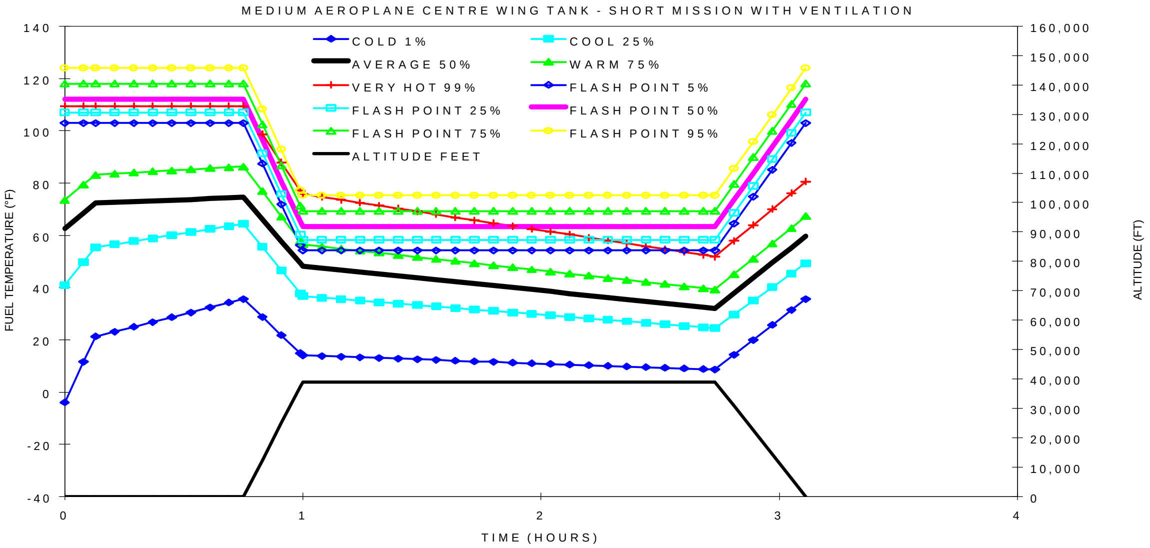




15.2.10 Medium Aeroplane Centre Wing Tank (with heat source)


MEDIUM AEROPLANE CENTRE WING TANK - LONG MISSION WITH VENTILATION

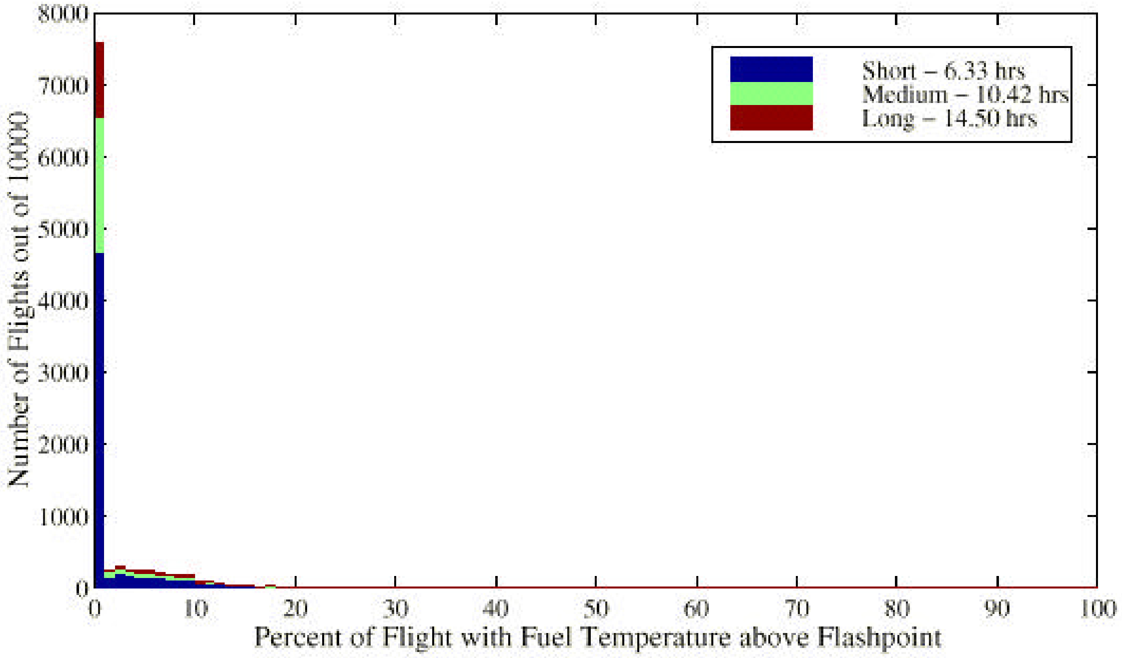

MEDIUM AEROPLANE CENTRE WING TANK - MEDIUM MISSION WITH VENTILATION


MEDIUM AEROPLANE CENTRE WING TANK - SHORT MISSION WITH VENTILATION

15.3 Exposure Analysis Results Charts

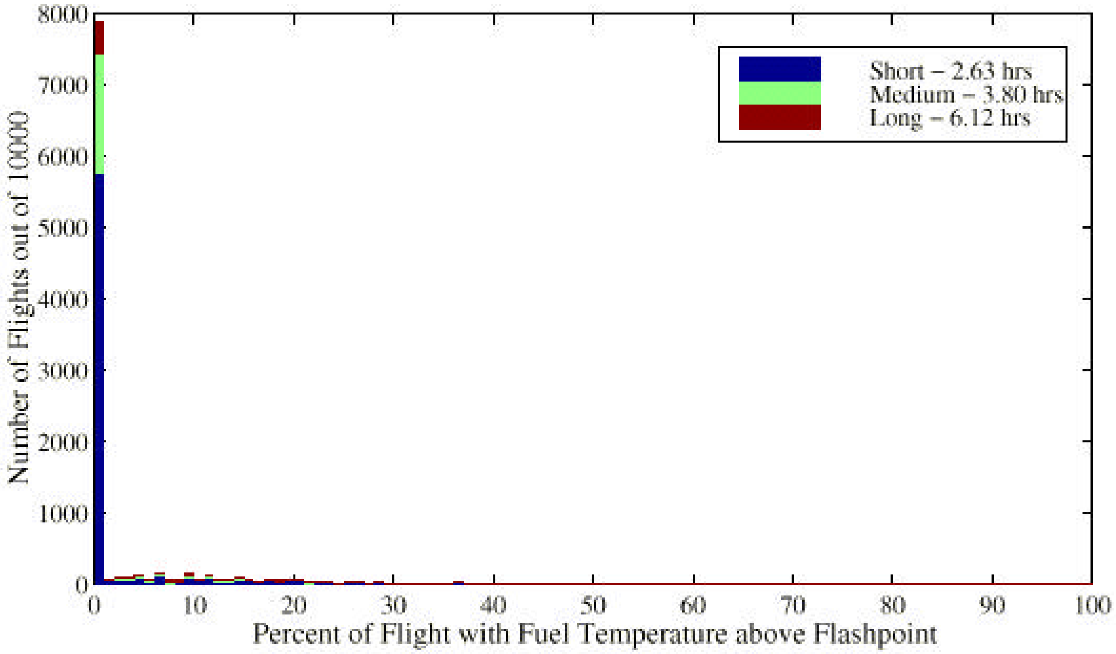
15.3.1 Large Aeroplane Wing Tank

average 1.6%



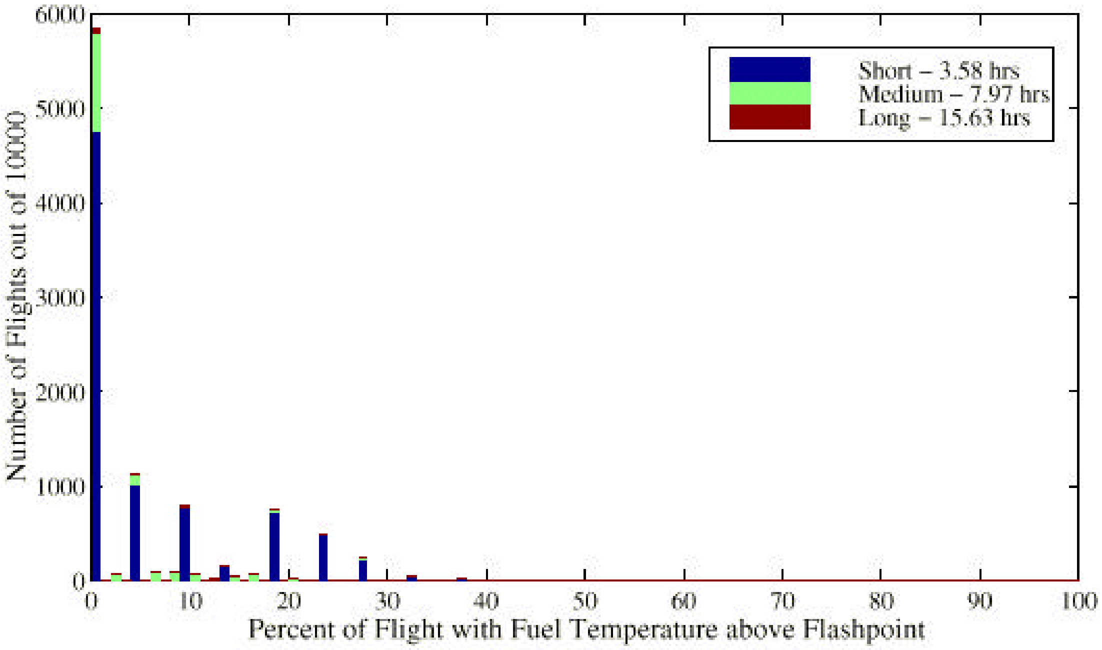
15.3.2 Small Aeroplane Wing Tank

average 3.0%



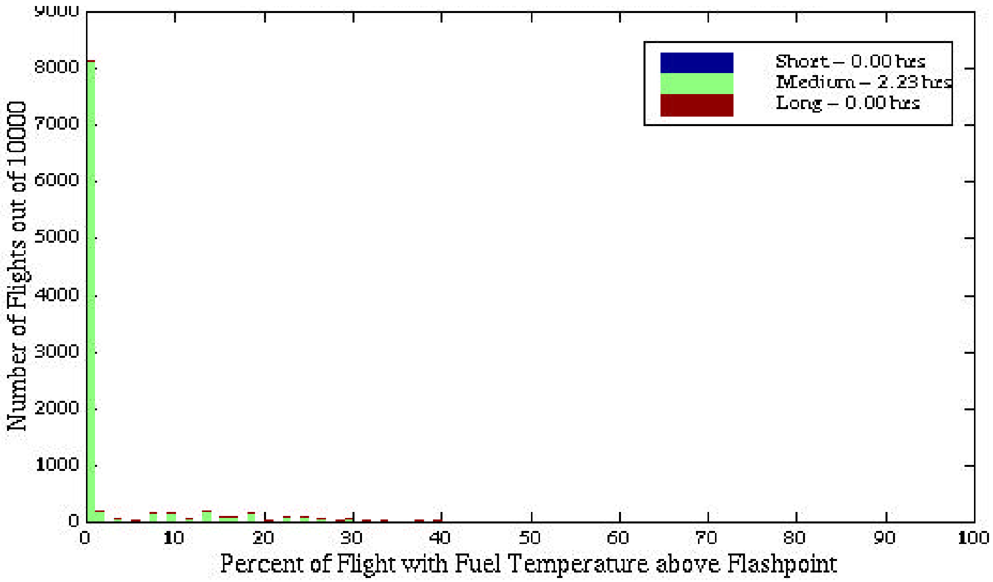
15.3.3 Business Jet Wing Tank

average 5.6%



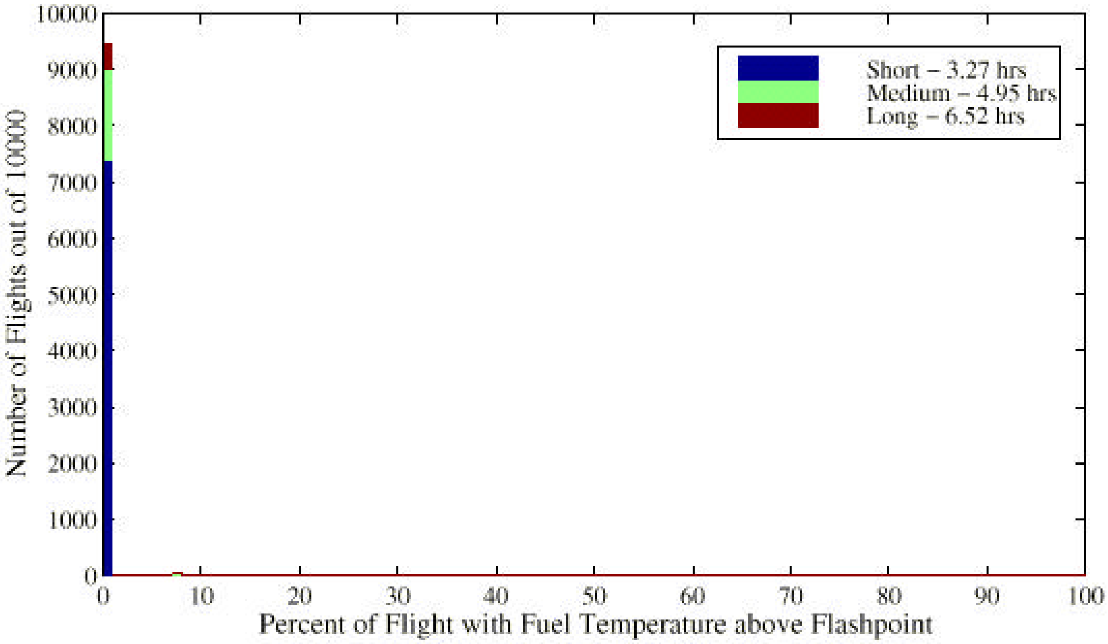
15.3.4 Regional Turbofan Wing Tank

average < 0.1%



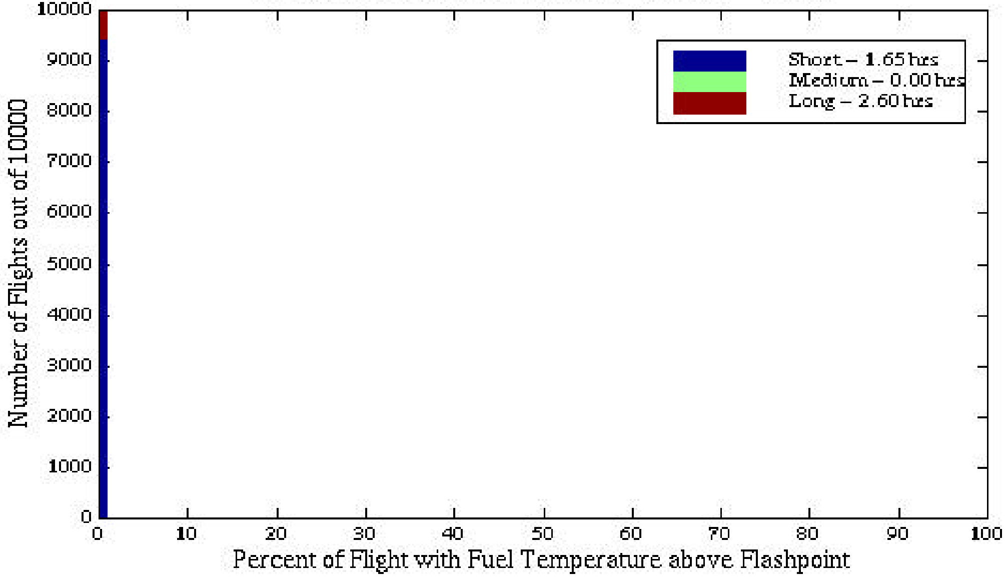
15.3.5 Small Aeroplane Centre Wing Tank (without heat source)

average 0.9%

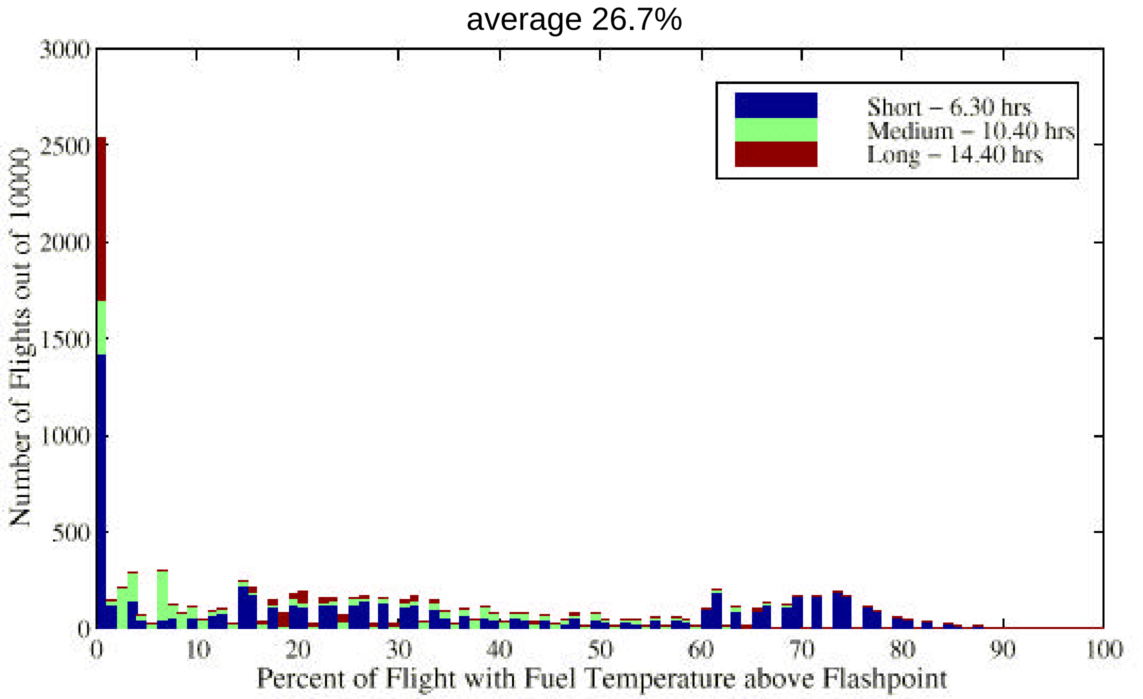


15.3.6 Regional Turbofan Centre Wing Tank (without heat source)

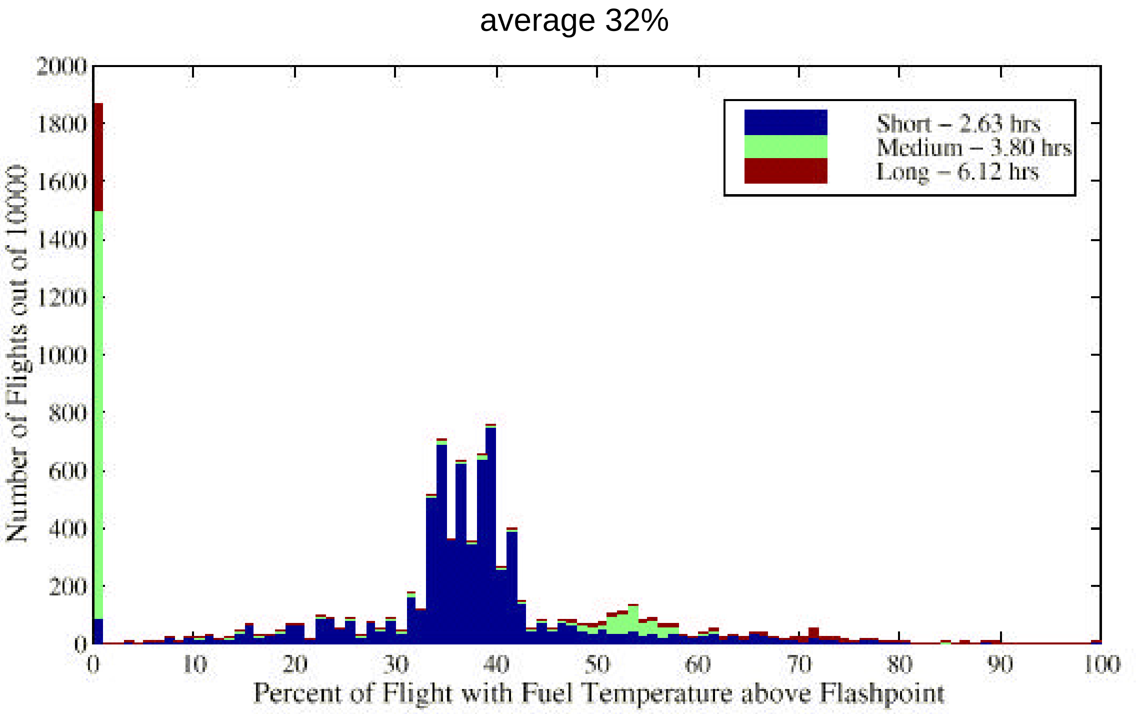
average 3.0%



15.3.7 Large Aeroplane Centre Wing Tank (with heat source)

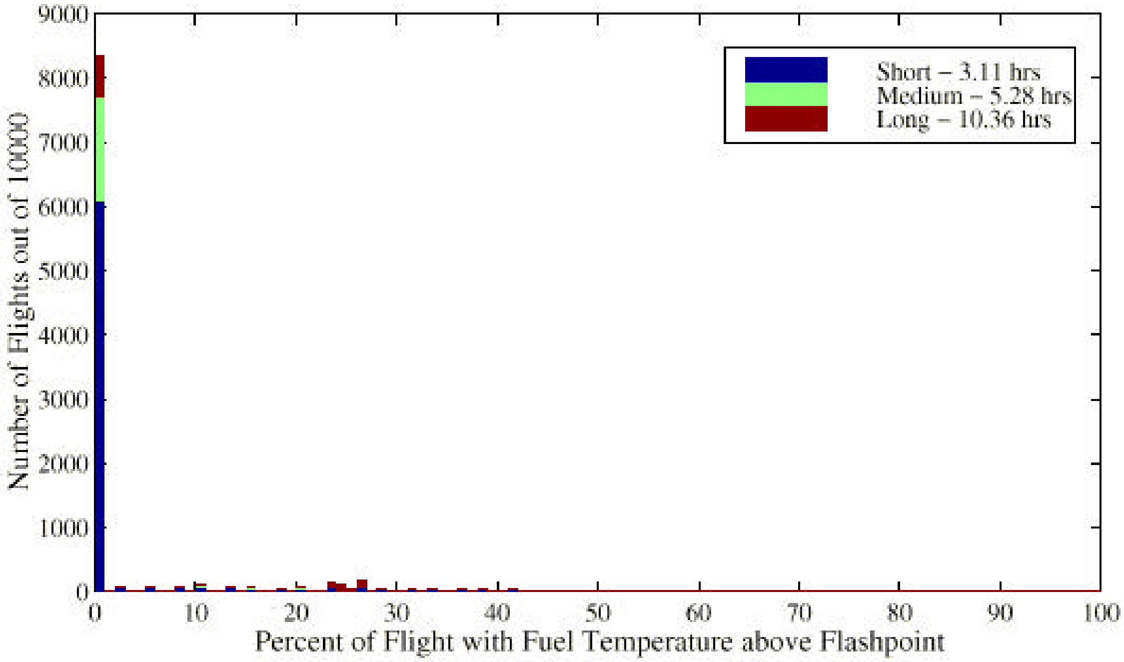

average 26.7%

15.3.8 Small Aeroplane Centre Wing Tank (with heat source)


average 32%

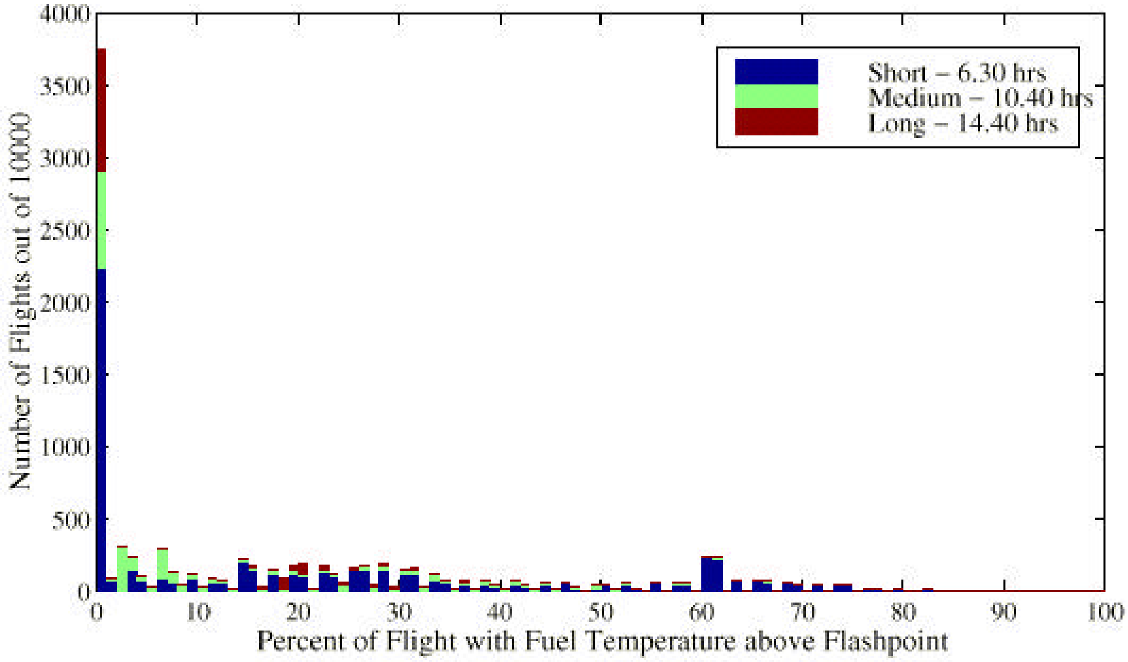
15.3.9 Medium Aeroplane Centre Wing Tank (with heat source and directed forced ventilation)

average 3.9%



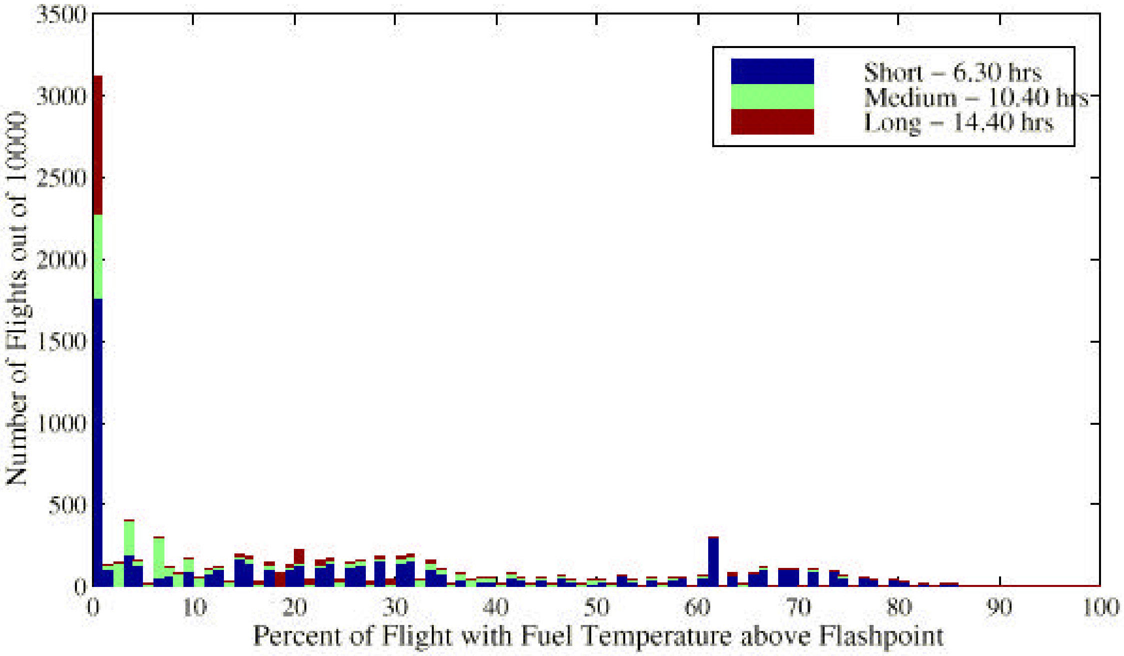
15.3.10 Large Aeroplane Centre Wing Tank With Insulation (of heat sources)

average 18.9%



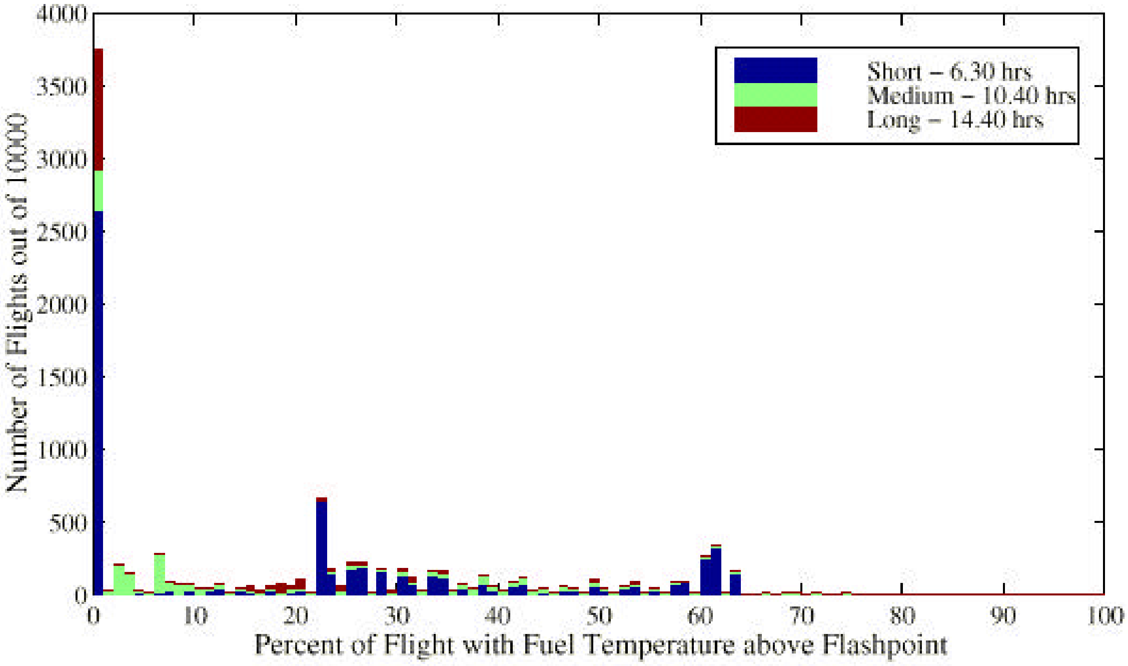
15.3.11 Large Aeroplane Centre Wing Tank With Ventilation (of heat source)

average 22%



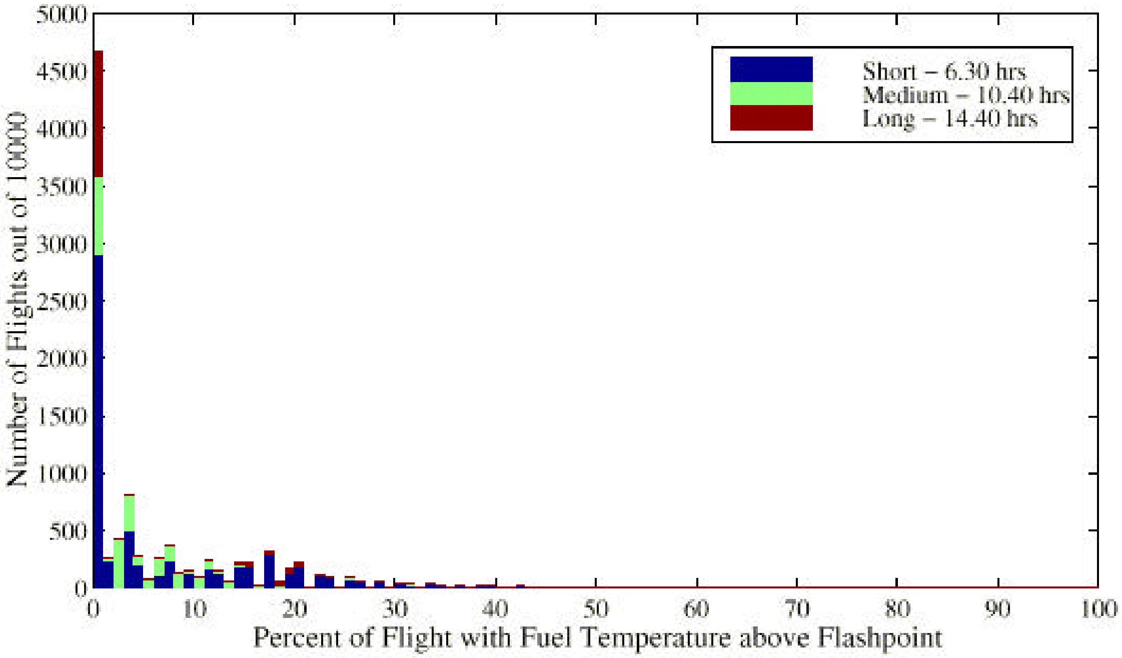
15.3.12 Large Aeroplane Centre Wing Tank With Redistributed Fuel

average 20.3%



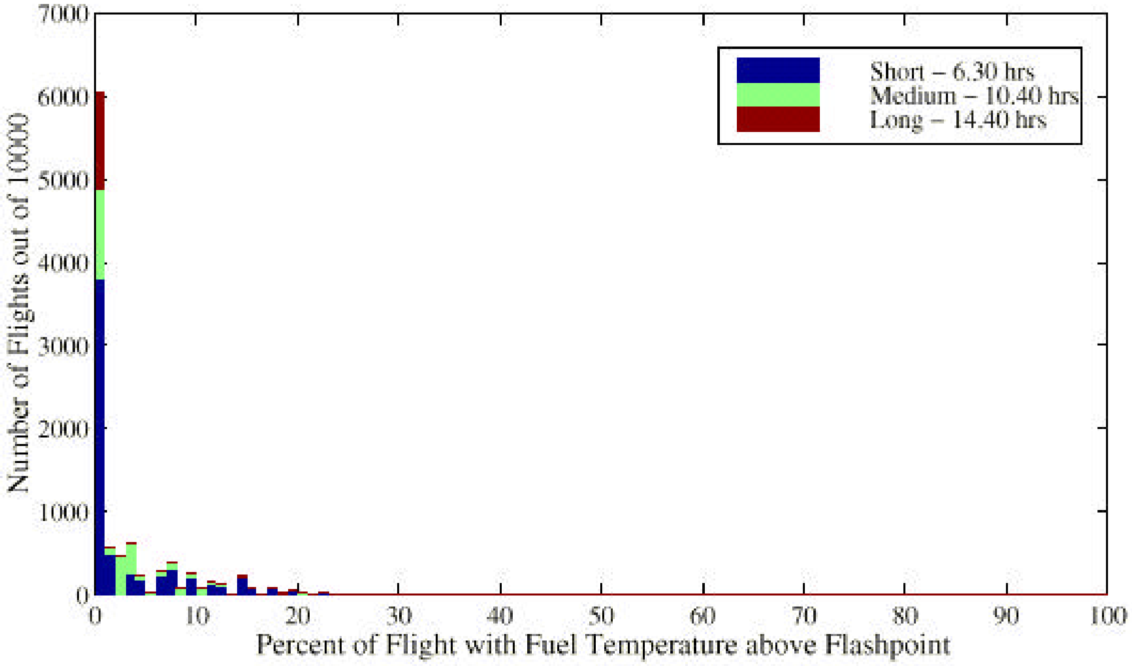
15.3.13 Large Aeroplane Centre Wing Tank With 120°F Flashpoint

average 6.5%



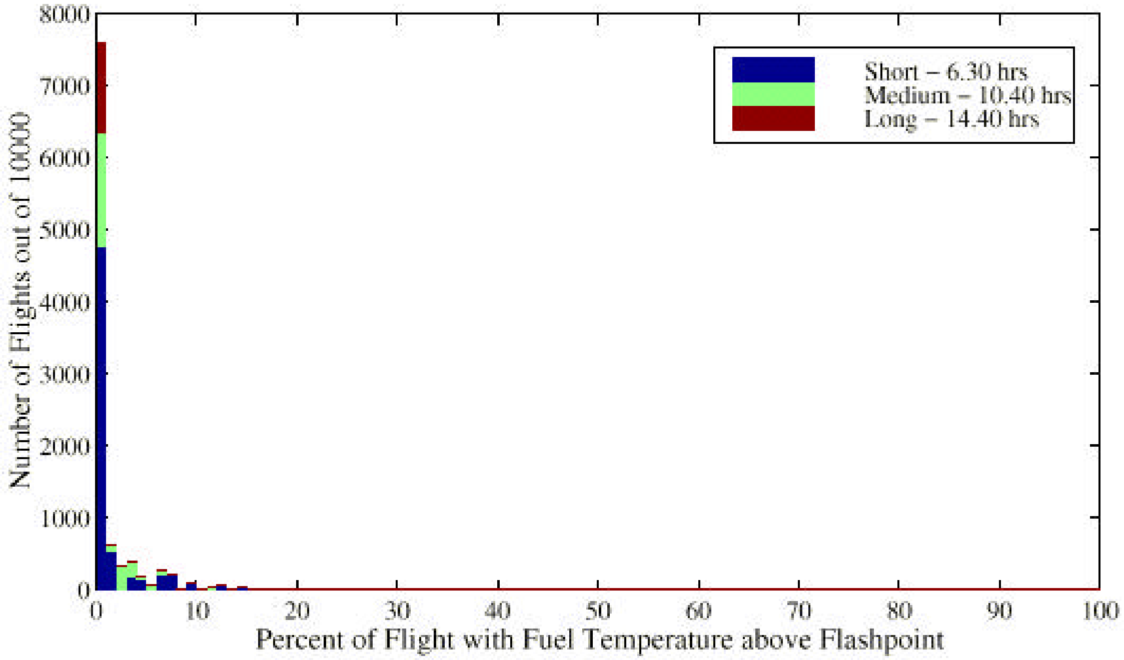
15.3.14 Large Aeroplane Centre Wing Tank With 130°F Flashpoint

average 3%



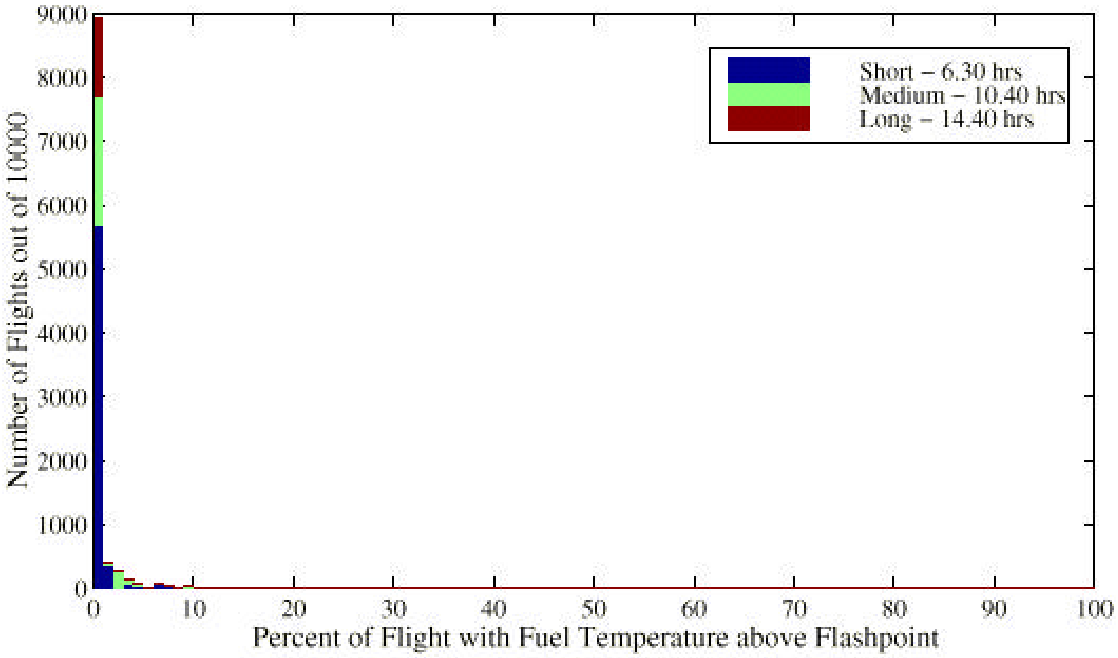
15.3.15 Large Aeroplane Centre Wing Tank With 140°F Flashpoint

average 1.2%



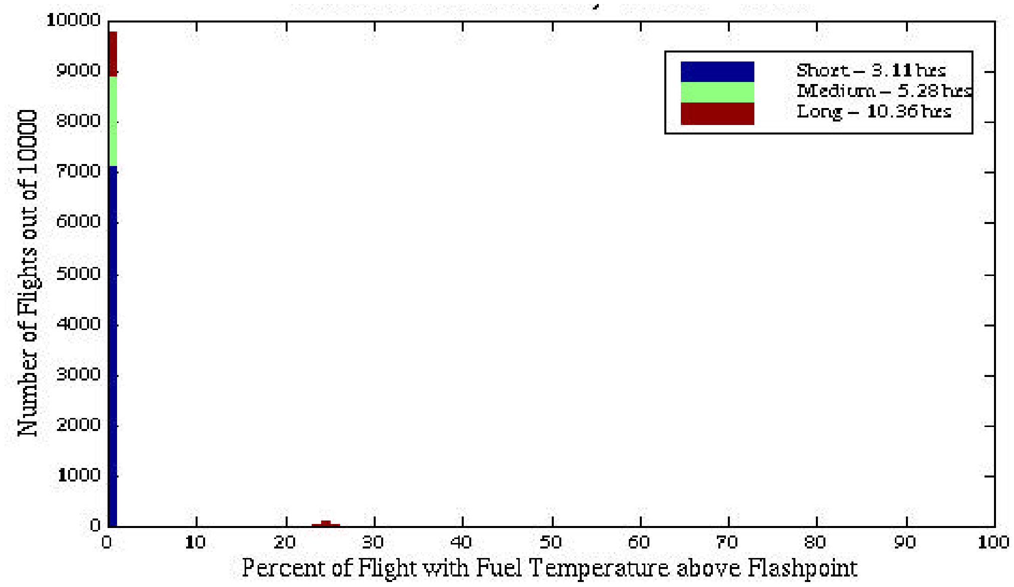
15.3.16 Large Aeroplane Centre Wing Tank With 150°F Flashpoint

average 0.4%



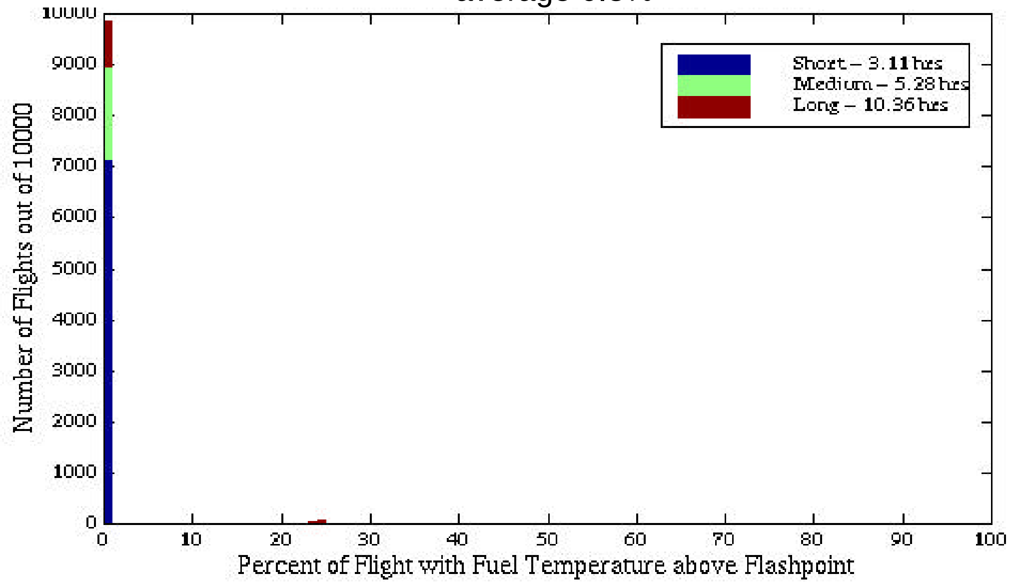
15.3.17 Medium Aeroplane Centre Wing Tank With 120°F Flashpoint

average 0.5%

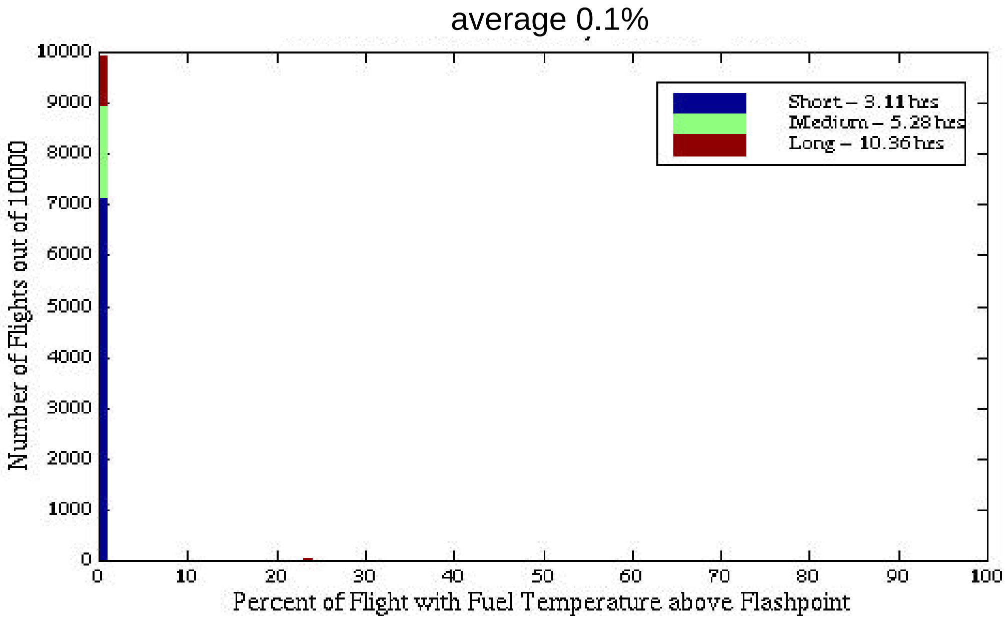


15.3.18 Medium Aeroplane Centre Wing Tank With 130°F Flashpoint

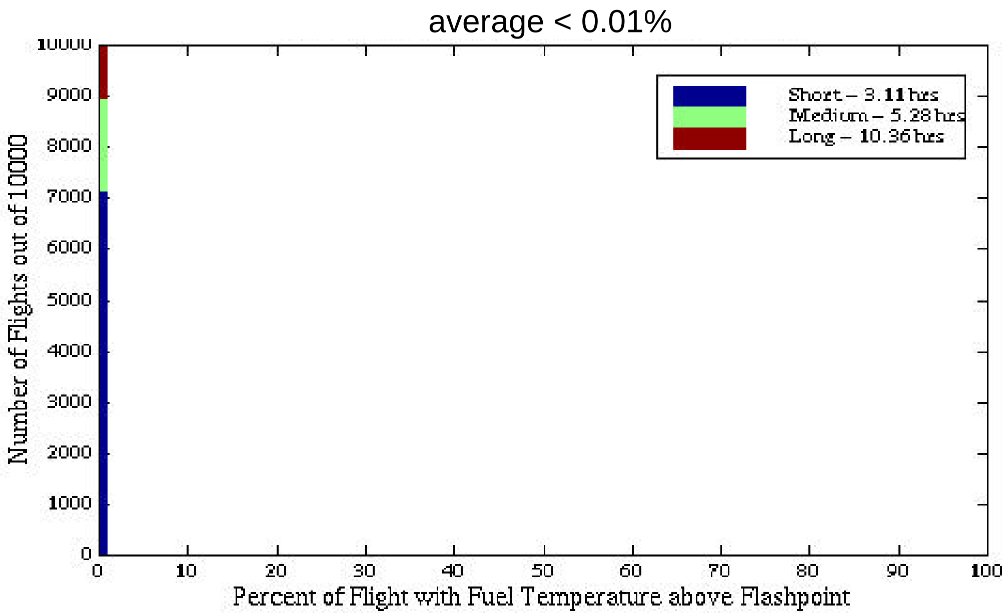
average 0.3%



15.3.19 Medium Aeroplane Centre Wing Tank With 140°F Flashpoint

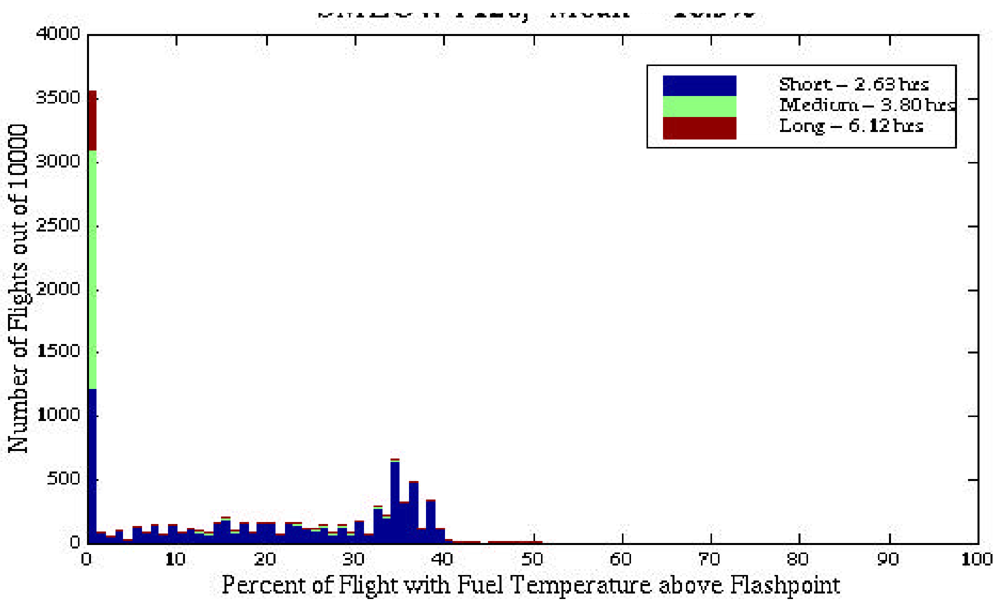


15.3.20 Medium Aeroplane Centre Wing Tank With 150°F Flashpoint



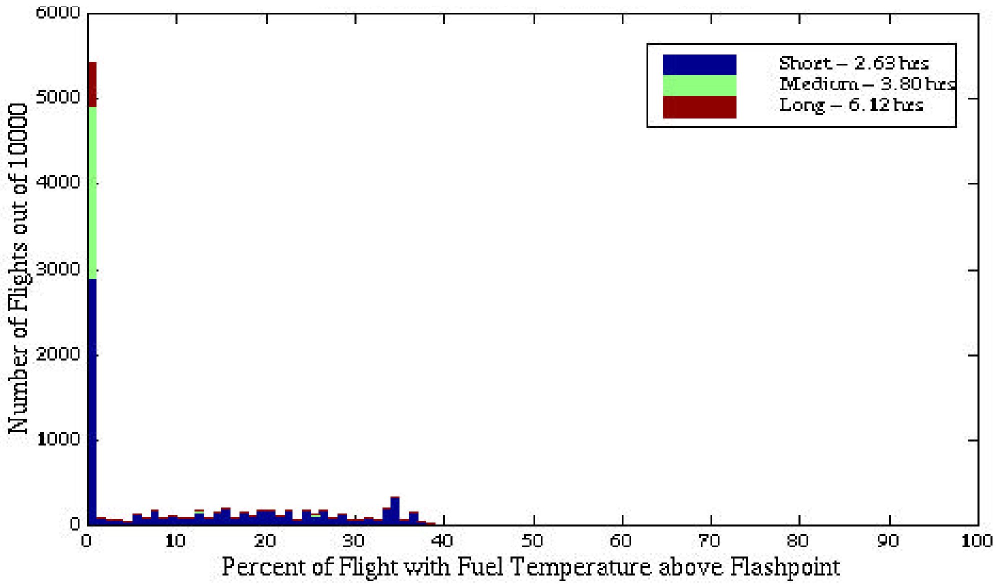
15.3.21 Small Aeroplane Centre Wing Tank With 120°F Flashpoint

average 16.5%



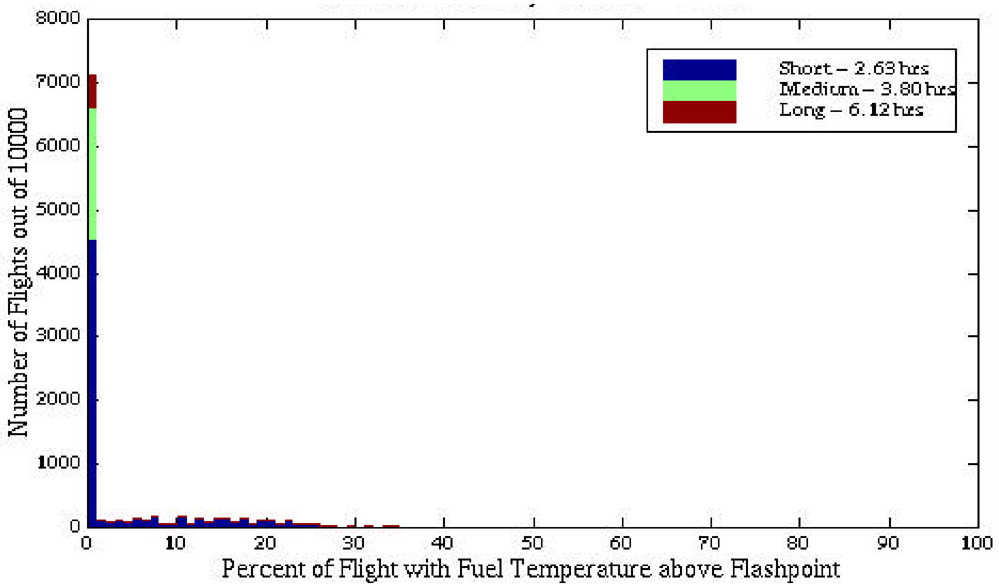
Flashpoint

average 9.5%



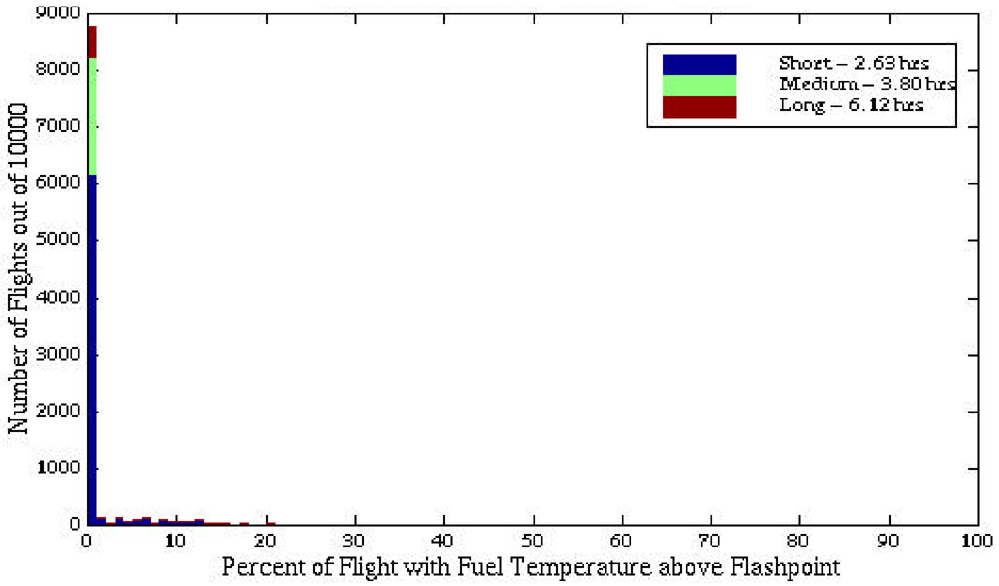
15.3.23 Small Aeroplane Centre Wing Tank With 140°F Flashpoint

average 4.0%



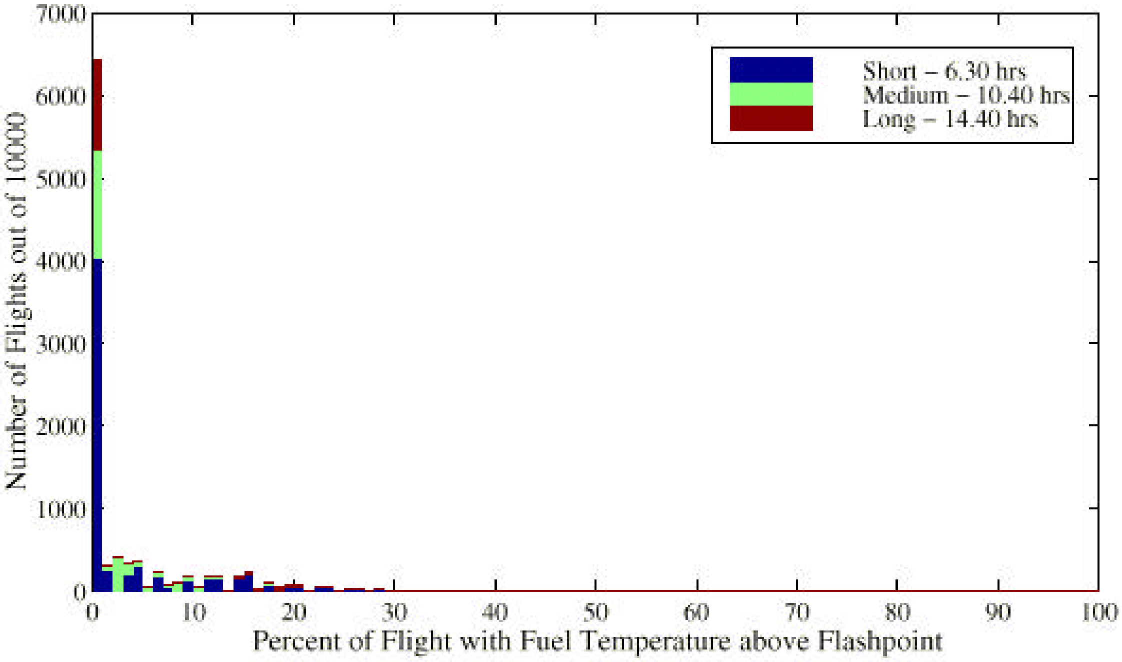
Flashpoint

average 1.1%



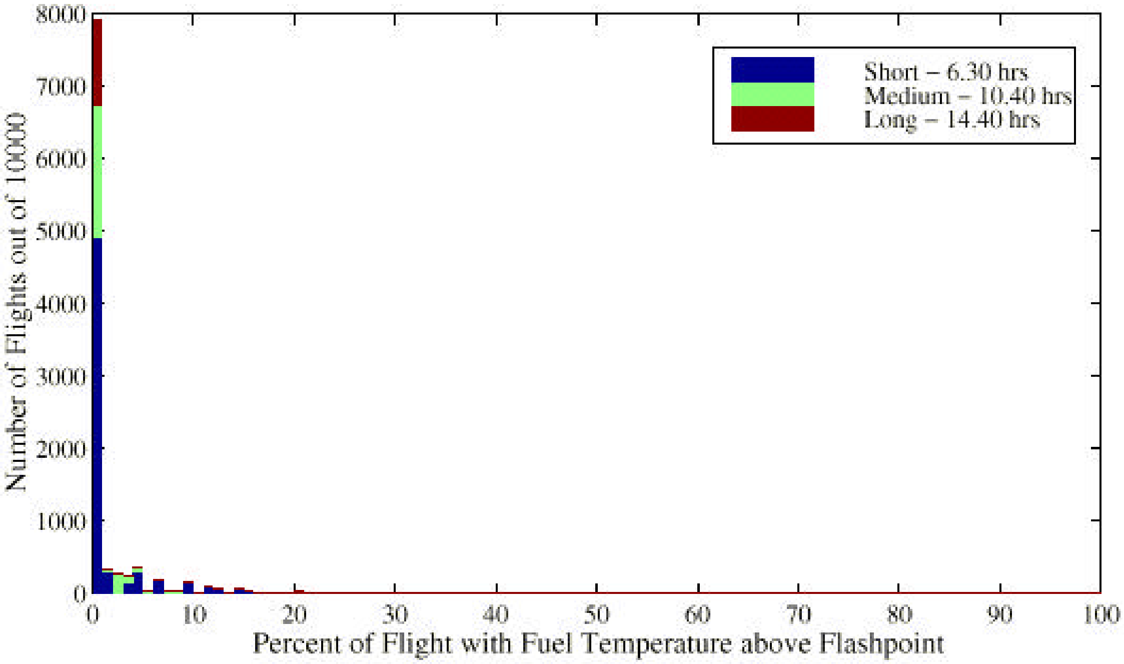
15.3.25 Large Aeroplane Centre Wing Tank COMBINATION of Insulate Heat Sources AND 120°F Flashpoint

average 3.5%



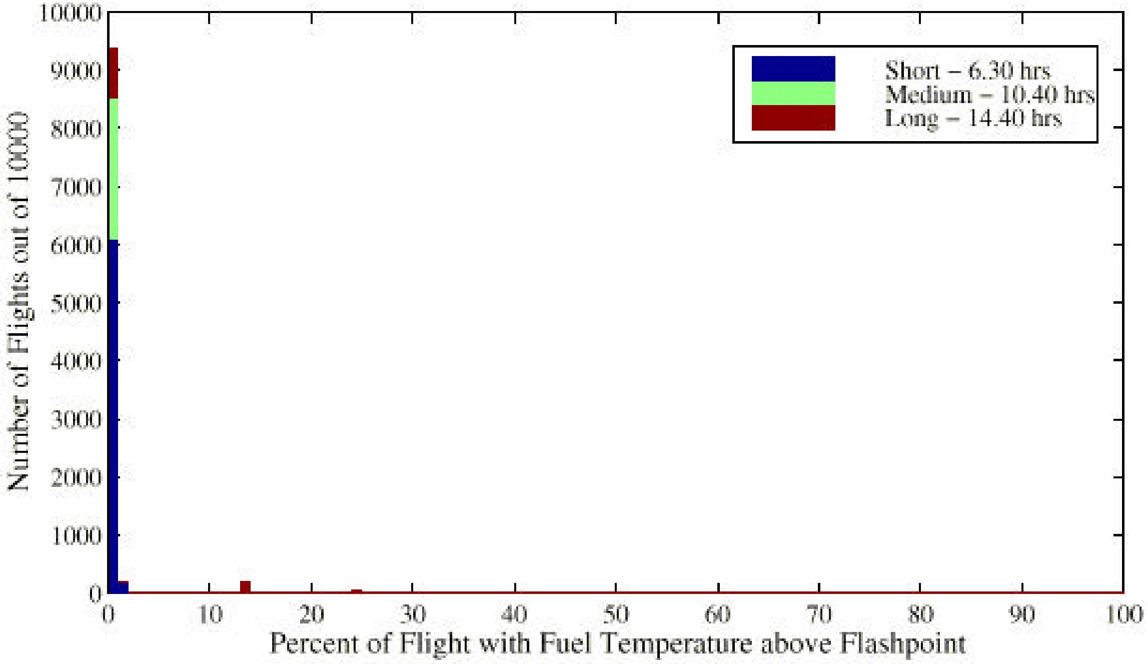
15.3.26 Large Aeroplane Centre Wing Tank COMBINATION of Insulate Heat Sources AND 130°F Flashpoint

average 1.3%



15.3.27 Large Aeroplane Centre Wing Tank With Ground Inerting

average 0.8%



15.4 Exposure Analysis Process

A Monte Carlo analysis was run to determine the percent of fuel tank temperature above flashpoint. The randomised variables were; flight length, ground temperature and flashpoint. The fuel tank temperature was input to the Monte Carlo analysis. Models of different aeroplane fuel tanks were developed and run for specified ground temperatures.

Input Data

There were four data inputs into the Monte Carlo analysis:

a) Aeroplane type; this is needed to determine the set of flight lengths to use. Task Group 8 provided this data.

b) Fuel tank temperature; this file determines which data file to load. This is independent of the aeroplane type as there are various models for the same aeroplane type such as; wing tank, centre wing tank with heating and centre wing tank without heating. This data was generated from various sources.

c) Flashpoint; this is needed to determine the range of flashpoints used. The basic flashpoint range was received from Task Group 6. The other ranges used were generated within Task Group 5 and have less spread. The basic flashpoint data was used for most analyses.

d) The final input is the seed for the random number generator. The same seed was used for basic analyses of different models. Several seeds were used to determine the variance of the random numbers generated.

Load Aeroplane Data

With the fuel tank temperature file defined, loading the data is a matter of using the correct format and assigning the data to the correct variables.

Random Numbers Generation

The analysis was started assuming 10,000 runs were required, with 3 randomised variables, this became 30,000 random numbers. A uniform random number generator that gave numbers between 0 and 1 generated the numbers.

The first 10,000 numbers were assigned to the ground temperature probability. As the distribution for these did not have data below 1% or above 99.9%, any numbers outside of this range were assigned to these values. The values were left as probability since the temperature files data were listed as probability.

The second 10,000 numbers were assigned to the flashpoint probability. Using the appropriate flashpoint distribution and the random numbers, flashpoints were generated for the 10,000 runs.

The last set of 10,000 was assigned to mission length. Using the appropriate mission length distribution and the random numbers, mission lengths were determined (short, medium or long).

Percentage Calculation

For each of the 10,000 runs, the ground temperature for each run is used to interpolate the fuel temperature profile from the appropriate fuel temperature data for each run's flight length. Using the altitude data for each run's flight length and the run's flashpoint, the flashpoint for each segment of the flight is calculated.

With the fuel temperature and flashpoint profiles created, the flight segments where the fuel temperature is above the flashpoint are determined. The time spent in each segment is summed and divided by the total length of the flight. This gives the percent of each particular flight where the average fuel temperature is above the flashpoint. The percentages are then averaged, for the 10,000 runs, to produce the average percentage of time that the average fuel temperature is above the flashpoint.

Process Flow Charts

Chart 15.4.1 Monte Carlo Analysis of Fuel Tank Temperature

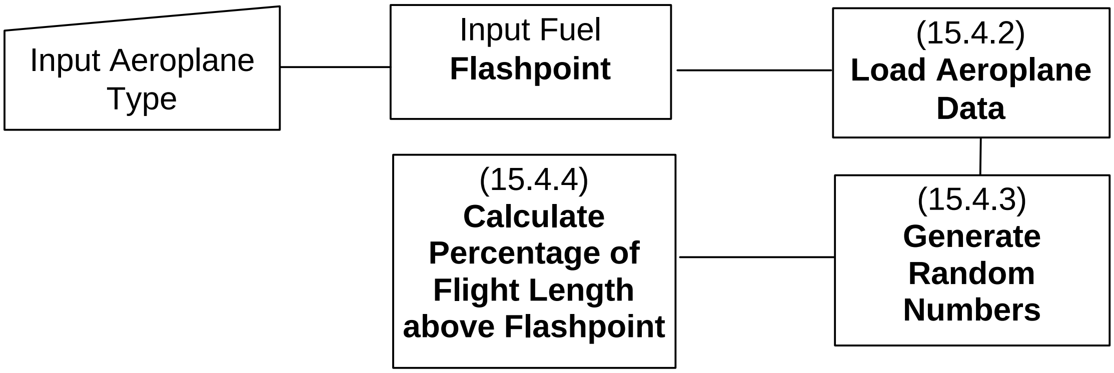


Chart 15.4.2 Load Aeroplane Data

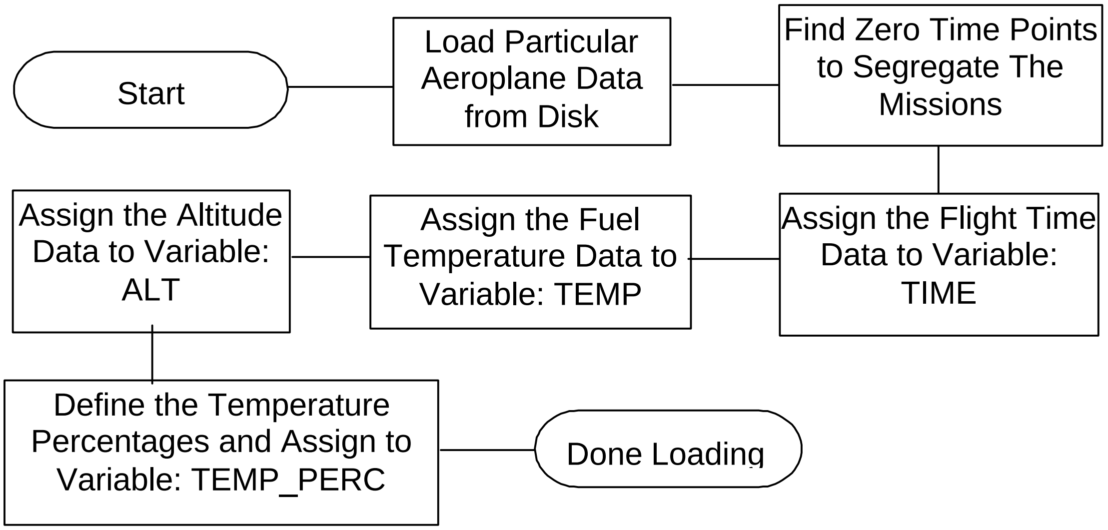


Chart 15.4.3 Generate Random Numbers

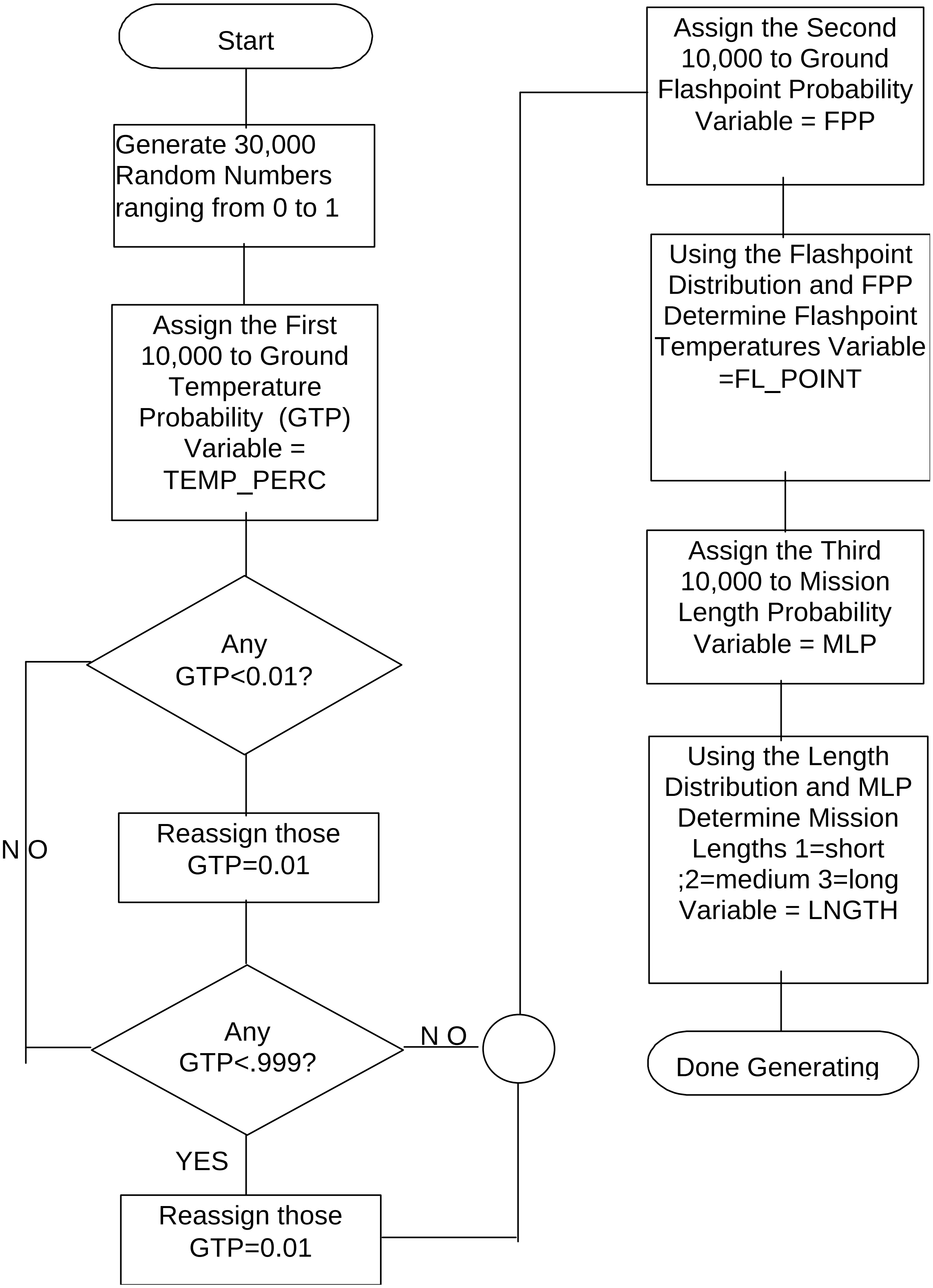
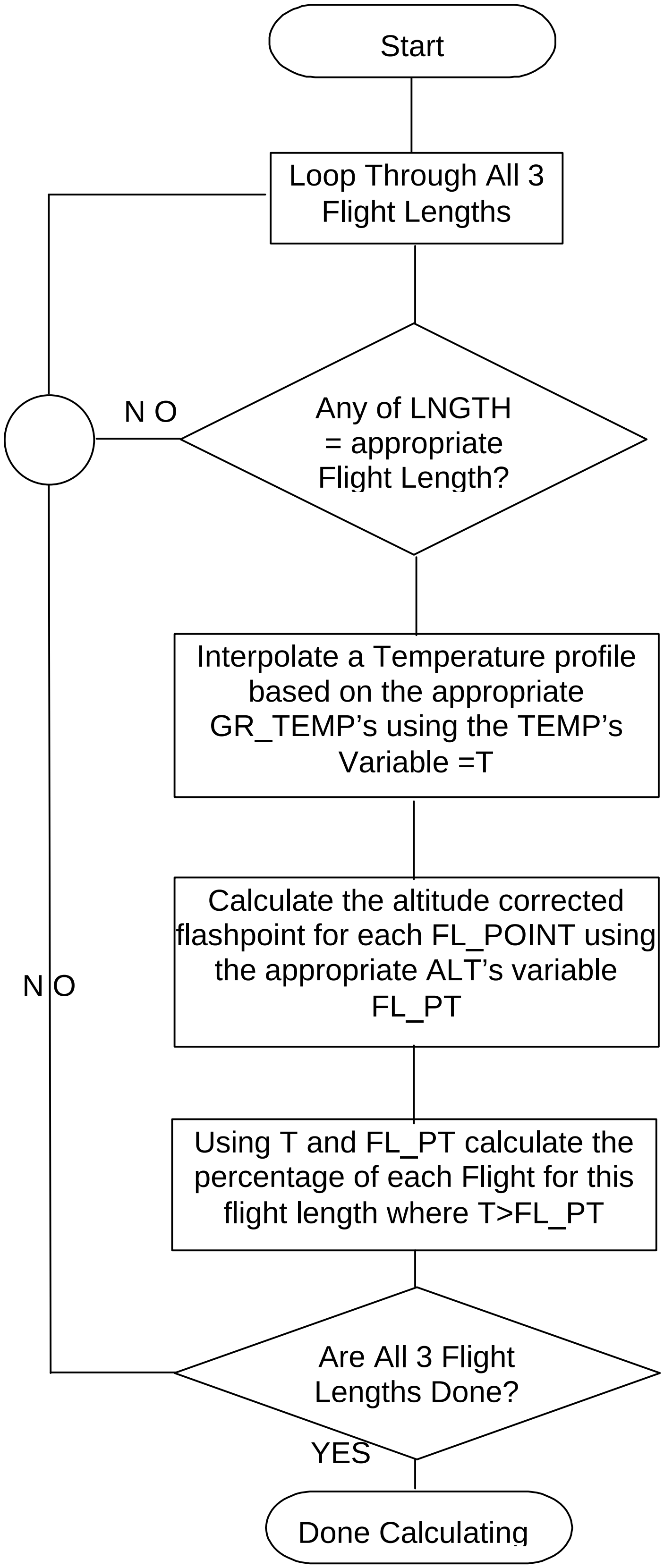


Chart 15.4.4 Calculate Percentage of Flight Length Above Flashpoint



15.5 ULLAGE SWEEPING TESTING

Preliminary laboratory scale tests were conducted to study the concept of ullage sweeping. The test set up was a 55-gallon (US) drum loaded with 1 gallon (US) of fuel. See Figure 15.5.1. The test tank was heated for four hours to a fuel temperature of 120°F which was 14°F above the flashpoint of the fuel. The fuel vapour concentration was measured at two locations within the test tank and several times during the test. The concentration meter gave results in terms of %LFL which is the fuel vapour concentration as a fraction of the lower flammability limit of 0.6% by volume. For example, 100%LFL on the meter equals 0.6% by volume, and so 50%LFL equals 0.3% by volume. Results of the heating test are shown in figure 15.5.2.

After the tank had been heated for four hours, the ullage was swept with ambient air for 1½ hours. The flow rate of the air was 25 standard cubic feet per hour, (SCFH), which simulates 1 test tank volume change in 20 minutes. The fuel vapour concentration was reduced to 80%LFL in the first 30 minutes and to 60%LFL after 1½ hours. Test results are shown in Figure 15.5.3. During this test approximately 3% of the fuel mass was evaporated and lost through the vent.

The fuel vapour concentration was measured with a custom built, 10 channel combustible gas monitoring system from Mine Safety Appliance Corp. The gas samples are measured with a low temperature catalytic bead sensor utilising Ultima combustible gas transmitters. The unit measures percent lower flammability limit by sampling the fuel vapour at rates of one litre per minute. The unit was acquired from Autoline Controls of Redmond, Washington, USA.

Figure 15.5.1 Fuel Tank Ullage Sweeping / Vapour Condensing Test Set-up

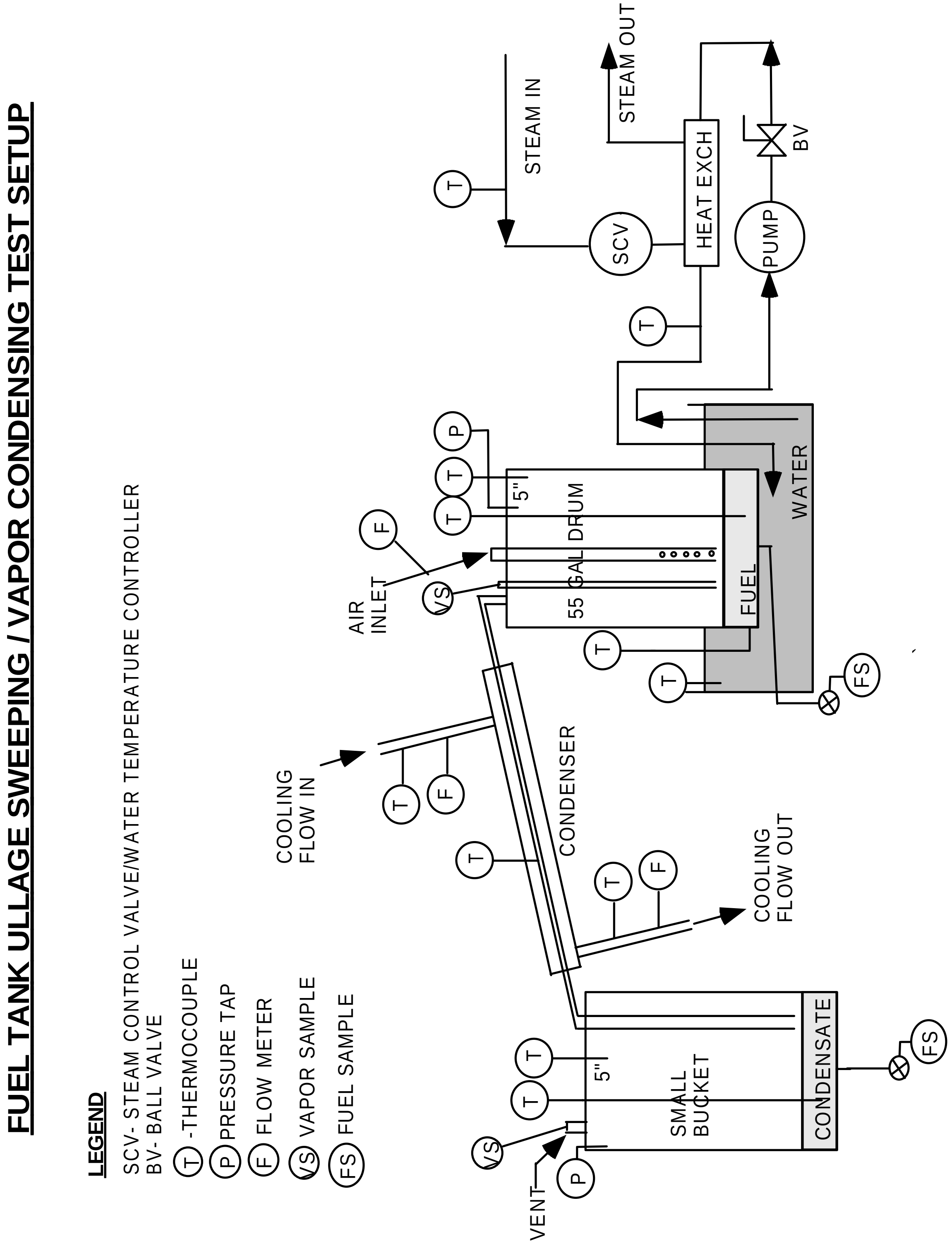


Figure 15.5.2 Flammability of a Nearly Empty Fuel Tank

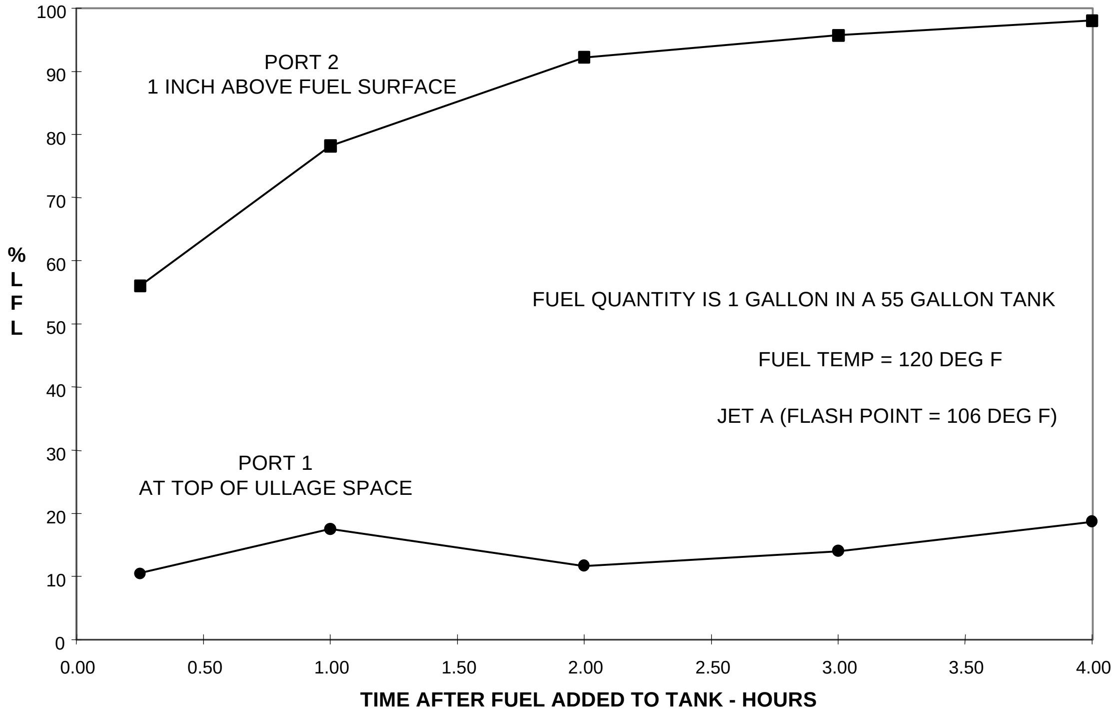
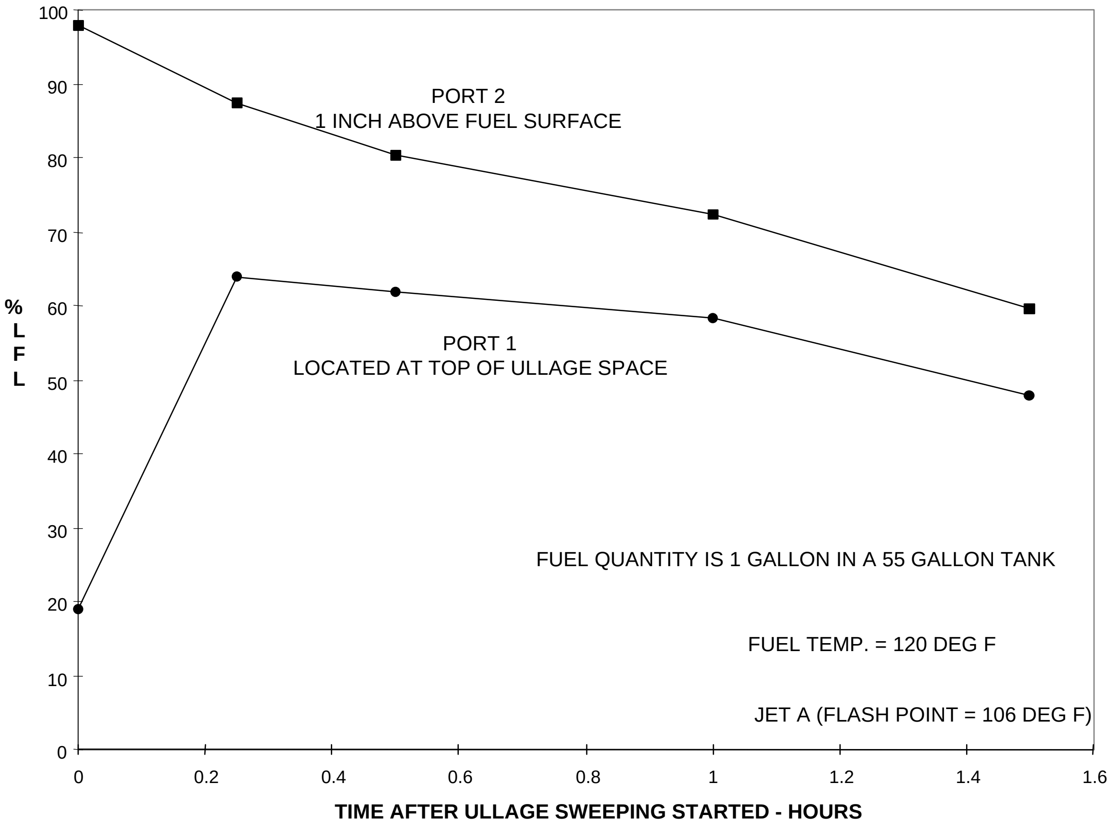


Figure 15.5.3 Effect of Ullage Sweeping by Ambient Airflow of 25 SCFH



Aviation Rulemaking
Advisory Committee

Fuel Properties - Effect on Aircraft and Infrastructure

Task Group 6/7

FINAL REPORT—Revised 7/15/98a
Task Group 6/7 on Fuel Properties
Report to the Fuel Tank Harmonization Working Group of the FAA Aviation Rulemaking Advisory Committee

1.0 ABSTRACT

The Fuels Properties Task Group was charged with assessing the feasibility of using jet fuel with a higher flash point in the civil transport airplane fleet than required by current Jet A/Jet A-1 Specification, as a means of reducing the exposure of the fleet to flammable/explosive tank vapors. This report describes the efforts performed by Task Group 6/7 for the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group.

Raising the minimum flash point of jet fuel will result in a combination of changes to other fuel properties, such as viscosity. The magnitude of change is dependent on the severity of flash point increase. The engine and APU manufacturers have no experience base for such modified fuels, and are concerned about the risk of adverse impact on altitude relight and low temperature operations (especially Extended Twin Operations, ETOPS). Mitigating actions, including hardware modifications, fuel specification revisions, use of additives and revised operational limits, have also been reviewed. Dependent on magnitude of change, laboratory, rig and/or full-scale engine testing on reference fuels may be required to quantify the impacts.

Raising the minimum flash point could also significantly raise the manufacturing cost and decrease the availability of the modified jet fuel. The predicted impact on jet fuel price could be significant. Again, the higher the flash point, the more severe the affect.
The fuel impacts are most severe outside of the U.S. because of the differences in overseas refinery configurations and product demand. Some countries indicated that changes in flash point are not viable options to which they would subscribe (Canada, United Kingdom, New Zealand, Australia, Japan, Russia and the Commonwealth of Independent States).

2.0 SUMMARY

The Fuels Properties Task Group (Task Group 6/7) was formed by the FAA-ARAC Fuel Tank Harmonization Working Group to assess the impacts of raising the minimum flash point, and possibly lowering the freeze point, of commercial Jet-A/A-1 aviation fuel. Task Group 6/7 was comprised of representatives from the engine powerplant and auxiliary power unit (APU) manufacturers, petroleum industry, airframe manufacturers, air carriers, and the Department of Defense. The impacts on Engines, APU's, hardware manufacturers, jet fuel availability and cost are based on evidence and information drawn from surveys conducted of refiners in the U.S. (by API/NPRA), Europe (by Europia), and Japan (by PAJ), as well as responses from other international refiners.

The findings of the Task Group are summarized below:

2.1 Impact on Engine Integrity, Operation and Maintenance

The predicted fuel changes identified will result in a combination of fuel properties that can fall outside the current experience base. The magnitude of property change and potential introduction of new molecules increases with increasing flash point. Evaluation of such changes identifies the following key issues:

- Increases in low temperature viscosity and decreases in volatility are fuel property changes that may adversely impact operation /safety including failure of engine/APU cold starts and high altitude relight (including cold soak relight).

- Reduced fuel pump life due to increased wear rate when operating on lower lubricity fuels which may result in component failure.

- The following increased maintenance cost effects were identified but not quantified:

    ⇒ Increased maintenance of combustion and turbine components due to poorer combustion quality.
    ⇒ Fuel system and injector nozzle cleaning at more frequent intervals due to fuel lacquering and coking.
    ⇒ Reduced fuel pump life due to increased wear rate.

- Depending on the magnitude of the flash point increase**,** laboratory rig or full engine testing on representative high flash point reference fuels may be required to fully evaluate/quantify these effects.

- Emissions testing to verify EPA / ICAO regulatory requirements becomes increasingly probable with magnitude of flash point change.

- Mitigating actions were examined. They may include: hardware modifications, fuel specification revisions, and revised aircraft operational limits. The use of new additives will require extensive evaluation and approval programs.

- Any change to the minimum flash point will also necessitate the installation of heated auxiliary power units at an estimated cost of $1 million per APU model.

- The magnitude of the flash point change will dictate the actions required and cost incurred to continue to meet civil airworthiness requirements.

2.2 Impact on Jet Fuel Properties

- An increase in the jet fuel flash point specification will result in shifts of fuel properties. At some increase in the flash point specification, a high flash Jet-A becomes a new fuel, never before produced or used, with properties unlike any other fuel. For example, the viscosity is expected to be significantly higher than JP-5.

- The uncertainty concerning jet fuel properties resulting from a large flash point specification increase is a significant concern. The engine manufacturers have no experience base for such modified fuels.

- As the minimum flash point is increased, the average flash point of the jet fuel pool is predicted to be 12-15°F (6-8°C) above the flash point specification in the U.S. due to pipeline specifications and test method precision

- The shifts in jet fuel properties are expected to occur by three mechanisms:

    1. By changes in the distillation cut points of conventional refining.
    2. By creating incentives for jet fuel to be produced by modified processing schemes.
    3. By causing localities relying on unique refinery configurations or crude sources to experience “magnified” shifts in jet fuel properties.

2.2.1 Changes in Distillation Cut Points of Conventional Refining

- The impact of mechanism 1 was quantified by the Jet Fuel Properties Survey. The results found potentially important adverse impacts on:

    ⇒ 10% Boiling Point
    ⇒ Viscosity
    ⇒ Aromatics Content
    ⇒ Smoke Point
    ⇒ Density
    ⇒ Jet Fuel Availability

        – Jet fuel distillation yield is reduced by more than 1% per °F flash point increase.
        – Many of the crude oils examined cannot produce Jet A-1 with a very high flash point.

  - Extrapolations in the growth of jet fuel consumption indicate pressure already exists on jet fuel availability and properties. The yield loss associated with an increased flash point specification exacerbates this situation.

2.2.2 Creating Incentives to Produce Jet Fuel by Modified Processing

- The yield loss associated with an increased flash point specification can create incentives for jet fuel to be produced by modified processing schemes. The impact could not be quantified on the short time scale of this study but the use of unconventional refinery processing is a significant concern:

  ⇒ Larger flash point changes result in greater incentives for the use of modified processing schemes.

  ⇒ One example of an unconventional processing scheme results in the increased use of hydrotreated cracked stocks in jet fuel. This could push certain properties towards the specification limits resulting in adverse impacts on:

    - Aromatics Content
    - Smoke Point
    - Thermal Stability

  ⇒ The production of jet fuel by a different mix of conventional processing schemes should not impact fuel properties as much as the use of unconventional processing. However, the increased use of severe hydrotreating (a conventional process) is expected to negatively impact fuel lubricity**.**

2.2.3 Magnified Shifts in Localities with Unique Refinery Configurations or Crude Sources

- Localities relying on unique refinery configurations or crude sources may experience “magnified” shifts in jet fuel properties. Although this could not be quantified in the short time frame of this report, the following examples illustrate this concern:

  ⇒ Areas using predominately naphthenic crude oils (such as those found in California) might experience viscosity shifts much larger than average resulting in a significant number of batches being produced close to the specification limit.

- The increased use of severe hydroprocessing, to restore fuel availability, may cause some localities to receive mostly low lubricity fuel.

- Some fuel properties may be addressed by the use of additives.

2.3 Impact on Jet Fuel Availability and Manufacturing Cost

- The higher the flash point the more severe the impact.

- Higher flash points could result in significant shortfalls of jet fuel availability and could require at least five years for industry to endeavor to meet jet fuel demand.

- In the U.S., average refinery shortfalls of about 5% at 120 degrees and about 20% at 150 degrees could occur (weighted average, assuming 1 - 2 years lead time

- Outside the United States, requirements for higher flash point jet fuels could result in production shortfalls of 12% at 120 degrees and up to 49% at 150 degrees (weighted average, assuming 1 - 2 year lead time).

- The API survey results address jet fuel demand at 1998 levels. The survey does not address long-term changes in jet fuel demand, which is projected to grow by 6 - 15% more than other refined products by 2010. Environmentally driven reformulation of other fuels, (e.g., toward “light” diesel) will further increase demand for the jet fuel portion of the barrel. These pressures are likely to amplify the difficulties predicted for the 1998 level.

- Requirements for higher flash point jet fuels could result in United States refinery production cost increases of 1.5-2.2 cents per gallon at 120 degrees and 6-7.5 cents per gallon at 150 degrees (assuming 7% ROI). Based on current U.S. jet demand, this translates into annual costs of $350-520 million at 120 degrees and $1.4-1.7 billion at 150 degrees.

- Outside the United States, requirements for higher flash point jet fuel will result in refinery production cost increases of 3-15 cents per gallon at 120 degrees and more that 20 cents per gallon at 150 degrees. Based on current jet demand, this translates into annual costs of $320-900 million for the 120 to 150 range of flash points (assuming 15% ROI).

- The potential for increased production cost and decreased capacity could dramatically impact the market price of jet fuel. Price elasticity models have been used to calculate the increases in price that could occur for various combinations of capacity reductions and price elasticities. Based on a price elasticity of 0.2, the annual cost is $4 to $13 billion. No substitutions for jet fuel were assumed to be available.

2.3.1 Impact Outside the United States

- The difference between U. S. and non-U.S. availability and cost result from:

    - ⇒ The lower yields associated with the manufacture of lower freezing point Jet A-1, which is the predominant jet fuel outside the U.S.
    - ⇒ Markedly different regional petroleum product demand and refinery structure.

- Based on the surveys, more refiners worldwide than in the U.S. reported that it is not feasible to produce higher flash point jet fuels in the current refinery installations.

- The Task Group attempted to determine the potential for localized supply and demand imbalances due to increased flash point requirements. Results of informal surveys showed that individual refineries vary greatly in their flexibility to provide the same fuel volume at various flash points, but it was not generally possible to pinpoint specific airport supply imbalances in the U.S. Australia, New Zealand, and Japan were identified as subject to potential shortages of Jet A-1 fuel if flash point requirements are increased.

2.4 Other Issues

- As the minimum flash point increase, more refiners are likely to have difficulty producing gasoline and diesel that complies with current state and federal environmental regulations.

- Engine emissions may need to be remeasured for reporting purposes, and some number of engine models may been to be recertified.

- Commercial airlines will continue to uplift low flash fuels particularly in Russia and the Commonwealth of Independent States (C.I.S.) and Wide-Cut fuels in Northern Canada. In today's global market, there is no practical way to avoid mixing fuels from different parts of the world.

- Cold climate operation could become an issue at higher minimum flash points. Increasing the flash point would reduce the more volatile, low-boiling components of the fuel, which in turn leads to an increase in viscosity and exacerbates an already tenuous cold starting situation and APU in-flight starting problems.

- Russian aircraft and engines have not been designed to operate on high flash fuel. Impacts on their operability and airworthiness have not been determined.

The aviation fuel community has a high confidence level with currently produced fuel because of a long experience base. Task Group 6/7 cannot readily measure the existing margin to alter the fuel for all aircraft engine types. Effects from changes at a single source are difficult to determine because they are usually lost in the pool fuel volume, so that continuous operation at the extremes of the property limits is infrequent. Conversely, changes to the jet fuel pool as a whole, must of necessity, be viewed with concern. The concern for a change in minimum flash point to 110-120ºF is significant; for a change to 140ºF it is many times higher because refiners can be expected to change production methods and reduce specification margins on a broad scale. Possible mitigating actions to offset adverse effects on engine and APU operation might include hardware modifications, adjustments and re-calibrations. Other revisions of fuel specification requirements may be necessary in addition to the flash point increase the impact of such additional changes on availability has not been evaluated.

3.0 TABLE OF CONTENTS

4.0 INTRODUCTION

The purpose of this report is to evaluate the availability, cost, and risk associated with changing to a high flash point jet fuel for commercial aviation.

In November 1997, the FAA requested that the American Petroleum Institute (API) examine the ramifications (production, cost, schedule) of the United States commercial aviation industry utilizing a Jet A/A-1 type of fuel with a minimum flash point of 140°F(60°C) to 150°F(66°C) in place of the current Jet A/A-1 fuel. The FAA also requested that the API participate in a dialogue with FAA and industry technical specialists regarding this proposal. In a subsequent letter from the FAA dated February 26, 1998 to API, the petroleum industry was asked by the FAA-ARAC Fuel Tank Harmonization Working Group to develop and compile data on the availability of a Jet A type fuel (both domestic and international) with a higher flash and a possible lower freezing point. The FAA requested the assessment of possible impact on production volumes; short- and long-term cost increments and capital investments to make up any loss in production. For this assessment, flash points of 120°F(49°C) to 150°F(66°C) in ten degree increments were identified, as well as freezing points of -40°F(-40°C) and -53°F(-47°C).

The API, in conjunction with the National Petrochemical & Refiners Association (NPRA) conducted a survey of individual refineries to assess the availability and cost of producing high flash point fuel for commercial aviation in the U. S., Europe, and other parts of the world. This report presents the combined results of the API/NPRA survey (Appendix 1), European (EUROPIA) survey (Appendix 2), and the PAJ (Petroleum Association of Japan) survey (Appendix 3) and correspondence with some refineries in other parts of the world.

The aviation industry representatives assigned to Task Group 6/7 include jet fuel suppliers who are represented by the API, airlines, engine, auxiliary power unit (APU), and airframe manufacturers as well as government representatives, including the FAA. This Task Group has investigated the complex issues associated with raising the flash point and lowering the freezing point of commercial aviation jet fuel. The impacts on aircraft engines, APUs, aircraft systems, fuel transportation, fuel availability, and fuel cost as well as the possible implications on the production of other petroleum products have been studied. In addition, the Task Group has considered flight safety, certification issues, emissions, military experience, and the impact on fuel price.

5.0 REFERENCES

References are included in the individual sections.

6.0 BACKGROUND

6.1 The Development of Specifications

Just as military jet operation preceded commercial flights by more than 10 years, military fuel and commercial specifications showed the same time lag. The earliest U. S. Air Force specifications for grades JP-1 and JP-2 never achieved wide usage. Published in 1947, grade JP-3 maximized availability by a blend of kerosene and gasoline with the vapor pressure of aviation gasoline. After this wide-cut fuel caused high boiling losses in high altitude operations, subsequent changes were directed toward tightening quality, particularly volatility. First the wide-cut JP-4 reduced vapor pressure drastically in 1951; then the kerosene-type JP-8 removed lighter components altogether in 1979. By closely modeling JP-8 after the commercial Jet A-1 grade the Air Force hoped to maximize its availability. These volatility decreases were possible in part because of a continuing decrease in DOD fuel consumption, but JP-8 caused numerous performance problems, particularly with older equipment. In 1952 the U.S. Navy developed JP-5, a low volatility fuel, to protect aircraft carrier tankage. Because of the restrictive combination of high flash point and low freezing point and because its use has been primarily restricted to carrier operations, this fuel has always had limited use and availability.

ASTM specifications have included both kerosene and wide-cut grades since 1959, but the wide-cut grade, Jet B, has seen no use in the U. S. and only limited use outside the U.S.. Instead the Jet A grade has represented the best compromise between the properties of commercial kerosene and the requirements of aircraft operation within the U.S.. For international operations the Jet A-1 grade followed the British lead with a lower freezing point. Over the years the compromise between availability and performance has held up well except for two specification areas where shortages forced relaxations. Due to supply dislocations which required blending with less desirable crudes in 1973 an increase in aromatic content and a decrease in smoke point was permitted, provided the deviations were reported to the operators. At the same time the freezing point of Jet A-1 was raised from -50 to -47°C, a relaxation which was carried over into other specifications. Today the reporting requirements have been dropped and the decreases in combustion requirements have been made permanent in recognition of satisfactory aircraft performance. The changes were made only after reviews of equipment performance to assure the absence of unexpected secondary effects.

Selected requirements of U. S. military and commercial specifications are summarized in Table 1, attached. Only those properties thought to be influenced by an increase in flash point or freezing point have been included. For a later comparison Table 1 also contains the same requirements of the Russian specification, TS-1.

Overall, the current jet fuel specifications are experience based and tend to reflect solutions to past problems. Specifications, therefore, cannot be expected to anticipate new problems that might occur with fuels meeting current specifications. An example is the current focus on fuel lubricity difficulties that seem to have increased as refinery processing has been changing. Because this property has not caused difficulties in past commercial operations it is not currently limited. However, as this problem has become more prominent, efforts are underway to modify specifications to control this property. In the case of fuels produced from novel sources or new processes it is necessary to review the performance of such products before deciding on the applicability of existing specifications.

Specification→	ASTM D1655	Joint Check List	MIL-T-5624	MIL-T-5624	GOST 10227
Grade →	Jet A/A-1	Jet A-1	JP-5	JP-4	TS-1
Property ↓					
Aromatics, vol. % Max.	25	22 [a]	25.0	25.0	22
Sulfur, mass % Max.	0.3	0.30	0.40	0.40	0.25
Distillation, °C (°F)					
IBP		Report	Report	Report	150 Max.
10% rec. Max.	205 (400)	205 (400)	206 (403)	Report	
20% rec.		Report	Report	100 max.	
50% rec.	Report	Report	Report	125 max.	195 Max.
90% rec.	Report	Report	Report	Report	230 Max.
98% rec.					250 Max.
Final BP Max.	300 (575)	300 (575)	300 (575)	270	
Flash point, °C (°F) Min.	38* (100)	40* (104)	60** (140)		28 (82)
RVP, kPa (psi)				14 - 21 (2.0-3.0)	
Density, kg/m^3	775 – 840	775 – 840	788 - 845		775 Min.
Freezing point, °C (°F) Max.	-40 [b] (-40)	-47 (-53)	-46 (-51)	-58 (-72)	-50 (-58)
Viscosity @-20°C, cs Max.	8	8.0	8.5		8 @ -40
Specific energy, MJ/kg Min.	42.8	42.8	42.6	42.8	42.9
Smoke point, mm or Min.	25	25	19	20.0	25
Smoke point , mm + Min.	18	19			
Naphthalenes, vol. % Max.	3.0	3.0			
JFTOT @ 260°C	[c]				
Tube rating Max.	< 3	< 3	< 3	< 3	18 mg/100 mL Max.[d]
Pressure drop, mm Hg Max.	25	25	25	25	
Additives					
Anti-icing, vol. %	Agreement	Agreement	0.15 – 0.20	0.10 – 0.15	Agreement
Antioxidant	Permitted	Agreement[e]	Agreement[e]	Agreement[e]	Agreement
Corrosion inhibitor/	Agreement	Agreement	Required	Required	
Lubricity agent					Agreement
Metal deactivator	Permitted	Permitted	Permitted	Permitted	
Conductivity improver	Permitted	Required	Not permitted	Required	Agreement
Conductivity, pS/m	50 – 450 [f]	50 - 450		150 – 600	50 – 600[f]

Section 6-1, Table 1--Critical Fuel Properties in Specifications

[a] or 25% max + report % hydrogen
[b] Jet A-1 freezing point is -47°C (-53°F) maximum.
[c] ASTM D1655 permits retesting at 245°C.
[d] Different test method. Correlation with D 3241 (JFTOT) being established.
[e] Required if hydrotreated
[f] If conductivity improver is used
* Flash point by D 56 (Tag)
** Flash point by D 93 (PM)

6.2 The Manufacture of Jet Fuel

Generally in the US, the system to produce and consume petroleum products is well balanced. This actually is an operational constraint because there is relatively little storage capacity for refined products built into the distribution system. The U.S. refinery system is optimized to produce a large amount of motor gasoline and smaller amounts of "No. 2 fuels" (diesel fuel/heating oil) and "No. 1 fuels" (jet fuel, No. 1 diesel fuel and No. 1 fuel oil).

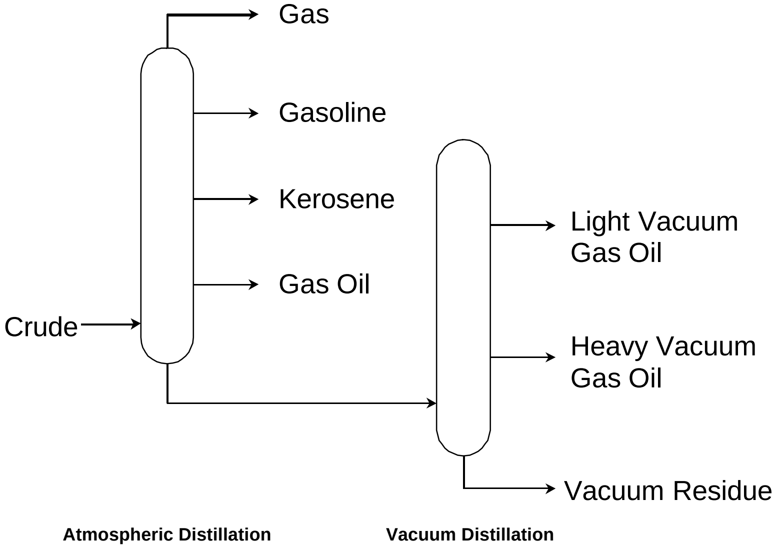
The production of petroleum products is a complex process. Some of the complexity of the system is retained in this overview, despite the temptation to simplify, because the impact of jet fuel specification changes can only be appreciated with some knowledge of the complexity of the production system.

6.2.1 Conventional Processes

6.2.1.1 The Crude Unit

Petroleum products originate from crude oil. There is no such thing as a "typical" crude oil. All crude oils are unique mixes of many different chemical compounds. An important variable of crude oils is the yield of light products (gasoline, No. 1 fuels, and No. 2 fuels) that they can produce when distilled. The demand for a crude oil generally correlates with the yield of light products that can be produced from it. Crude oil is processed into petroleum products at refineries. Refineries vary greatly in complexity. The simplest refinery consists of only an atmospheric crude distillation unit. Most refineries, however, also have a vacuum distillation unit in which case the units, together, are known as the crude unit (Section 6.2, Figure 1.)

Section 6.2 Figure 1. Schematic Diagram of a Crude Unit.



The crude unit separates crude oil into various fractions (or streams) by distillation. The typical streams produced from a crude unit are:

Stream	Typical Boiling Range °F	°C	Finished Products or Disposition
Gas	<100	<38	Liquefied Petroleum Gas
Gasoline	100 – 400	38 – 205	Gasoline/Naphtha
Kerosene	300 – 500	150 – 260	Jet Fuel, No. 1 Diesel, No. 1 Fuel Oil
Gas Oil	400 – 650	205 – 345	Diesel Fuel, No. 2 Fuel Oil, Heating Oil, Cracker Feed
Vacuum Gas Oil	600 – 1000	315 – 540	Lube, Cracker Feed
Residue	>1000	>540	Asphalt, Coker Feed

According to the API/NPRA Aviation Fuel Properties Survey (Appendix 1), 78% of the capacity to make jet fuel in the U.S. is production from crude units.

In operating a crude unit there are basically only three parameters that can be adjusted to influence the yield of jet fuel:

1. The selection of crude oil(s) processed.
2. The front end cut point (lower end of boiling range) of the jet fuel stream (to trade off with naphtha yield).
3. The back end cut point (upper end of boiling range) of the jet fuel stream (to trade off with diesel fuel yield).

Jet fuel is generally the most highly specified fuel (ASTM D1655 in the U.S) that a refiner makes. The flash point specification limits the amount of naphtha that can be incorporated into jet fuel. The aromatics, smoke point, naphthalenes, freeze point, and viscosity specifications often constrain the back end cut point of jet fuel.

The challenge facing the operator of a simple refinery in reacting to flash point specification changes is illustrated by considering jet fuel yield changes from a common crude oil. With this light crude about half the jet fuel yield is lost at 140°F (60°C) flash point versus the current specification. The following table was prepared assuming perfect distillation, and a release limit 8°F (4.4°C) above the specification minimum. It shows that the light crude yield loss would be:

Flash Point Specification, °F (°C)	**100 (38)**	**120 (49)**	**140 (60)**
Initial Boiling Point, °F (°C)	260 (127)	302 (150)	353 (178)
End Point, °F (°C)	555 (291)	538 (281)	501 (261)
Yield Loss, %	0	19	48
Freeze Point, °F (°C)	-40 (-40)	-40 (-40)	-40 (-40)
Flash Point, °F(°C)	108 (42)	128 (53)	148 (64)

Note that for crudes, such as this, where jet fuel yield is constrained by freeze point, jet fuel yield is lost both at the front end (increased initial boiling point to meet flash point) and the back end (reduced end point). To understand this, it is necessary to appreciate that jet fuel distilled from crude oil usually contains a small but significant amount of higher boiling straight-chain paraffin molecules. When the fuel is cooled to low temperatures, these paraffin molecules can associate to form wax crystals. To avoid the possibility of fuel flow problems, a freeze point specification is included in ASTM D1655 to ensure that wax crystals do not form at fuel temperatures normally encountered during aviation operations. The lower boiling portions of jet fuel are effective solvents for dissolving wax crystals. As the initial boiling point of a jet fuel is increased (to reduce flash point), solvency for wax crystals is lost. This requires that the end point of the fuel be reduced to remove the straight-chain paraffin molecules that can form wax so that the fuel can meet the freeze point specification.

In reality, crude units do not provide perfect distillation. Capital for upgrading the refineries is required to improve stripping to sharpen the cut point between the naphtha and jet fuel streams.

6.2.1.2 Jet Fuel Hydrotreating/Hydrodesulfurization

Most refineries have one or more units to “finish” jet fuel. Kerosene from the crude unit may, depending upon crude sources, contain too much sulfur and/or mercaptan sulfur (R-SH) to meet specifications. A common unit that removes both forms of sulfur from jet fuel is the catalytic hydrotreater. In this unit, jet fuel is treated with hydrogen at moderately high pressure (200-800 psi) and temperature (500-700°F, 260-370°C) in the presence of a metal catalyst to reduce sulfur and remove it from the fuel.

6.2.1.3 Merox Process

An alternative process often used for finishing jet fuel that has acceptable sulfur content but high mercaptan sulfur is the Merox process. The Merox process converts mercaptans to disulfides by the following oxidation reaction:

$$2\ RSH + \tfrac{1}{2}\ O_2 \rightarrow RSSR + H_2O$$

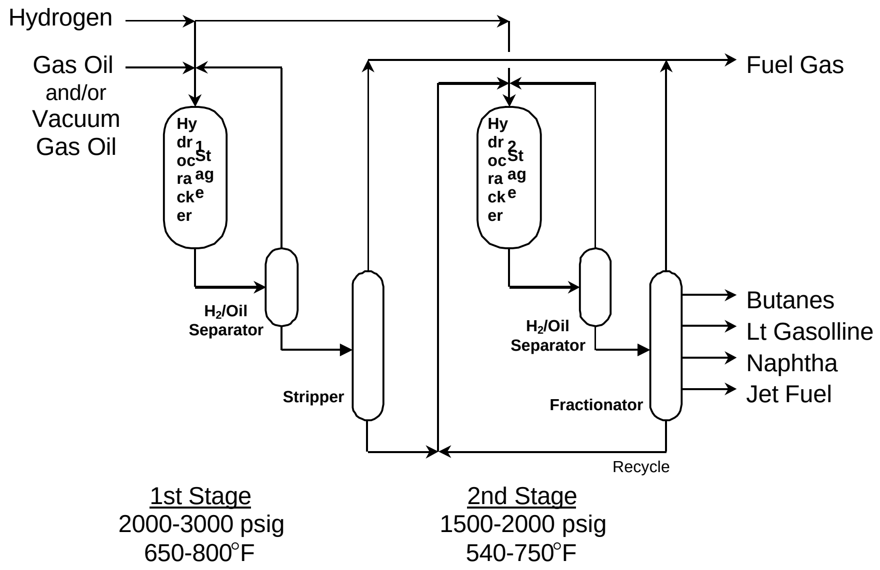
6.2.1.4 High Pressure Hydrotreating/Hydrocracking

According to the API/NPRA Aviation Fuel Properties Survey (Appendix 1), 22% of the capacity to make jet fuel in the U.S. is found in hydrocracking units. Hydrocracker units (Section 6.2, Figure 2) are used in complex refineries to convert low-value petroleum fractions into valuable light components by breaking large, high boiling molecules, into smaller molecules. The large molecules are cracked by the action of a catalyst at very high temperature (600-800°F, 315-425°C) in the presence of very high pressure (up to 3000 psi) hydrogen. The operating conditions are such that hydrogen adds to unsaturated (cracked) molecules to prevent the formation of coke that would deactivate the catalyst. Hydrocrackers produce good quality jet fuel in terms of aromatics content, smoke point, and oxidative thermal stability.

Hydrocrackers units are expensive to install and operate because they use hydrogen gas at very high pressure and temperature. The expense arises both from the unit construction/installation (driven by the cost of the large, high-pressure vessel and the hydrogen compressors) and operation (cost of hydrogen and energy to compress it). Because of their high cost, many U.S. refineries and a large proportion of the refineries outside of the U.S. do not have hydrocracking units.

Hydrocracking is not a means to tailor molecules to any required form: increased jet fuel flash point specifications are expected to reduce jet fuel yields from existing hydrocrackers by the same mechanisms as crude unit yield losses described above. Note that this is seen in the API survey where refineries both with and without hydrocrackers predict similar jet fuel yield losses. Hydrocracker operators have some (limited) ability to tune the mix of products produced by the unit. Typical parameters are hydrocracking severity (function of temperature and hydrogen pressure) and recycle (proportion of product streams fed back into the hydrocracker). For example, some hydrocracker units are operated to recycle diesel fuel to extinction so that gasoline and jet fuel yields are enhanced and diesel fuel production is eliminated. A disadvantage of increased severity and recycle-to-extinction is that both strategies tend to increase the yield of gaseous products that have relatively little value versus light products.

Section 6.2 Figure 2. Schematic Diagram of a Two-Stage Hydrocracker



6.2.1.5 Catalytic Cracking/Thermal Cracking

Catalytic and thermal cracking units are often found in complex refineries. There are many variations in the way that these processes are implemented in various refineries including:

- FCC (Fluidized Catalytic Cracker)
- Delayed Coker
- Visbreaker

These units use high temperature, with catalyst in the case of FCC, to crack large molecules to light products. The units do not use high hydrogen pressure so cracked products are relatively high in unsaturated compounds.

This provides high octane quality in the gasoline produced but most of the product produced in the boiling range compatible with No. 1 and No. 2 fuels is used for diesel fuel or is used as feed to hydrocracker units. In principle thermally or catalytically cracked streams boiling in the No. 1 fuel range could be hydrotreated to stabilize them and then blended into jet fuel. This is not usually done for several reasons. Some of the streams (FCC distillates, for example) contain so much aromatics that only a very small amount can be blended into jet fuel before exceeding D1655 aromatics and/or smoke point specifications. The streams from these processes are more difficult to hydrotreat and cause operational problems in the jet fuel hydrotreater operation. Further, if hydrotreating is not done properly, the fuel can have poor stability performance despite meeting specifications. With sufficient incentive, refiners having these streams might use them to increase jet fuel yield. Note that if this type of blending were done, many more batches of jet fuel pushing the aromatics and/or smoke point specifications would be produced than currently occur.

6.2.2 Refinery Configuration Issues

Existing refineries have specific processing units that may constrain their upgrade path. For example, if a refinery has an FCC unit to upgrade gas oil and/or vacuum gas oil, the refinery is unlikely to add a new hydrocracker unit and mothball the FCC unit.

6.2.3 Advanced Processes for Jet Fuel Production

6.2.3.1 Aromatics Saturation of Cracked or Aromatic Streams

With sufficient incentive, a refiner might choose to install a new high-pressure hydrogenation unit to saturate the aromatics and olefins in thermally or catalytically cracked streams boiling in the No. 1 fuel range. This would tend to increase the content of naphthenes in jet fuel. Increased naphthenes in jet fuel are not expected to cause problems but equipment/engine builders need to confirm this before widespread implementation. The aromatic saturation process can also be employed to increase jet fuel yields from aromatic crude oils.

6.2.3.2 Jet Fuel Synthesis by Fischer-Tropsch Chemistry

Kerosene from Fischer-Tropsch synthesis will be used to enhance jet fuel production in South Africa. Fischer-Tropsch chemistry produces pure paraffins (after hydrotreating to remove oxygenates) from synthesis gas (made from natural gas or coal). This kerosene is so low in aromatics that specifications require that it be blended with conventionally produced streams to avoid problems with seal shrinkage. Furthermore, specification changes have been proposed to define a lubricity and minimum aromatics requirement. Blending also helps to improve the poor lubricity performance of this kerosene. The production of blending streams for jet fuel by Fischer-Tropsch synthesis contributes little to jet fuel production on a world-wide basis because Fischer-Tropsch processing is generally more expensive than conventional processing.

6.2.4 Experimental Processes for Jet Fuel Production

The following processes have not been used commercially for jet fuel production and are not expected to contribute to jet fuel production in the near term. They are included here for the sake of completeness.

6.2.4.1 Catalytic Dewaxing

Catalytic dewaxing is not used commercially for jet fuel production. Catalytic dewaxing was developed and commercially implemented to improve the low temperature performance of diesel fuel. It could be adapted and installed in refineries to increase jet fuel yield. The use of this processing would permit many crudes to be distilled to higher end points resulting in raw kerosene streams failing jet fuel freeze point specifications.

Catalytic dewaxing could then be applied to the kerosenes to bring the freeze point of the finished fuel into compliance with the specification.

Catalytic dewaxing works by selectively removing the straight-chain paraffin molecules that form wax. Catalytic dewaxing probably will not provide a significant increase in jet fuel yield from crude oils where yield is constrained by smoke point instead of freeze point.

6.2.4.2 Jet Fuel Synthesis by Alkylation

Alkylation is not used commercially to produce jet fuel. Alkylation units are used by refiners to make high octane, non-aromatic gasoline and aviation gasoline from *I*-butane and olefins (butenes, or mixtures of butenes with propylene or amylenes) via acid catalysis. Refiners use the process because it converts gaseous by-products to valuable gasoline. In principle, it is possible to employ alkylation to produce jet fuel-range molecules. This type of processing might play a role in jet fuel production if incentives become large enough, but significant process development and refinery capital investment would be required before commercialization. An even greater amount of work should be done to ensure that the resulting jet fuel is suitable for aviation operations. In particular, any impact of impurities arising from the acid catalyst would need to be known and judged acceptable by equipment/engine manufacturers.

6.3 Transportation from Refinery Gate to Airport

Jet fuel leaving the shipping tank in a refinery is generally destined for a terminal which is a distribution center for more local deliveries. The fuel can travel by water, pipeline, rail or road, but almost always in large volumes. In the U. S. most jet fuel goes to terminals by large common carrier pipelines which are both multi-product and fungible in nature. These lines carry all distillate products, from gasoline to diesel fuel and heating oil and each product grade contains products from numerous shippers, all meeting the same specification (“fungible product”). Product grades follow each other with no physical separation and individual product quality is maintained by using very large tenders and minimizing inter-product mixing by turbulent flow in the pipeline. In addition, pipelines often add a shipping margin on critical properties. Additives in all products are carefully controlled to avoid cross-contamination. Mixed product or interface is minimized by cutting the higher quality product into the lower quality wherever possible. Because jet fuel is in contact with gasoline and/or diesel fuel, care must be taken to prevent jet fuel flash point decreases through gasoline mixing and thermal stability and freezing points deterioration by diesel or heating oil addition. An additional U. S. problem is the presence of dyed high sulfur diesel and heating oil which cannot be allowed to mix with jet fuel.

In much of the rest of the world jet fuel is most likely to be delivered by pipelines or ocean tankers. These ships may carry jet fuel in dedicated compartments or may depend on cleaning and careful product sequence to operate as multi-product vessels. Because batches are smaller, supplier identity is usually maintained. While commercial U. S. jet fuel moves by rail cars only in Alaska, such transport is common elsewhere. Road transport to terminals is used only where distances are short. Product is usually unfiltered until it reaches the terminal.

During terminal to airport transport most jet fuel is moved by single product means. Some pipelines are fungible and carry only jet fuel. Road transports are segregated by supplier and tend to be restricted to jet fuel. Wherever possible, barges carry only jet fuel because of cleaning difficulties. In this portion of the system much of the equipment is internally coated to minimize contamination. Product is always filtered when leaving the terminal.

On airports the fuel may travel from storage to the aircraft by special trucks equipped with their own pumps (“fuelers”) or it may move underground to loading gates through pressurized piping (“hydrant system”). The fuel is always filtered into and out of storage and again into aircraft. Water and solid contaminants are constantly removed to furnish clean and dry product to the aircraft. Product at airports is normally commingled among suppliers, but some airports may have single suppliers, thereby amplifying the effects of any property changes.

A major difference between the U. S and the rest of the world is the fuel custody on the airport. In the U. S., custody is transferred at the airport boundary and the fuel on the airport belongs to the airline. Generally, outside the U. S. the fuel supplier maintains ownership and handles fuel up to the aircraft skin. Because the responsibility for quality control is with the owner, U. S. airport quality controls rests with the airlines, while elsewhere the fuel suppliers are responsible.

6.4 Aircraft Fuel System Design

The major components of a typical commercial air transport fuel system are (1) vented tanks using primarily the wing box, (2) an engine fuel feed and transfer system, and (3) a fuel quantity measurement and indication system. Fuel tanks are usually located within the wing box of the airplane. A minimum of one tank is required for each engine. For example, on a twin engine aircraft, there is at least one tank located in each wing of the aircraft. If the aircraft size and range require additional fuel capacity, then the center wing box is designed to hold fuel. On a four engine aircraft there are two main tanks in each wing with additional capacity provided by the center tank. For long-range aircraft, fuel can be stored in reserve tanks also located in the wings, in the horizontal stabilizer, and occasionally in body tanks. All tanks (except body tanks) are integral with aircraft structure and are sealed on the inside to eliminate leaks.

The tanks are vented to the atmosphere such that there is at least one open vent port for each tank under all conditions. The vent system maintains inside tank pressure at near ambient pressure by allowing airflow into and out of the tanks during refueling, fuel use, and during climb and descent. The vent system is designed not to exceed the pressure limits for tanks.

Tanks are designed to minimize trapped fuel and a sump (drain) is provided in each tank to collect water and particles of debris. Most large aircraft have continuously operating water scavenging (removal) system or the sumps are manually drained regularly. An independent fuel feed system is required for each engine with a capability to cross-feed to the other engine(s) when necessary. A typical engine fuel feed system consists of electrically driven boost pumps in the tanks, fuel lines, valves and fittings. In addition, the engine has the capability to draw fuel from the tank if for some reason the boost pumps become inoperative. An independent fuel feed system is also provided for the auxiliary power unit (APU). The system is designed for rapid pressure fueling and for defueling. Some aircraft are designed to jettison fuel overboard if it becomes necessary to land before enough fuel is used to reduce aircraft weight in order to satisfy landing requirements.

The system design philosophy, along with experience gained in fleet operation, has evolved into current design standards. Each aircraft is certified to fly on specified fuel types. These generic fuel types include the kerosene fuels — Jet A/A-1, JP-8, JP-5, & TS-1, and wide-cut fuels — JP-4 & Jet B. However, some of the newer airplane models are not certified to use any wide-cut fuel. Flight tests are conducted under extreme operating conditions to ensure that the fuel system as designed will provide the specified fuel to the engine without interruption.

6.5 Current Jet Fuel Demand

Jet fuels delivered to the airlines conform to the property requirements identified in one or more of the many different jet fuel specifications used throughout the world. The majority of these fuels can be grouped into three main types of kerosene fuels. They are Jet A, Jet A-1, and TS-1. There is a very small amount of wide-cut fuel (JP-4 and Jet B) used by commercial airlines in Northern Canada and at some remote locations worldwide that also serve as military airfields.

About 38% of the jet fuel is up-lifted in the United States. (See Table 1) U. S. consumption together with Western Europe accounts for 57% of the world jet fuel demand. It is estimated that a change in jet fuel flash point, which may be implemented in the U.S. and Europe, would prompt similar changes in other jet fuel specifications effectively covering over 70% of the delivered jet fuel. Today, only about 7% of all jet fuel manufactured for the worldwide fleet has a flash point less than 100°F(38°C). These data[1] are estimates only, since details are not available on consumption of jet fuel by type.

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[1] Section 6.5 Ref. 1. Derived from the International Energy Annual, DOE/EIA-0219(96), February 1998.

	Jet A	Jet A-1	TS-1
U. S.	1,514		
Other North America	65	66	
Central & South America		146	
Western Europe		771	
Africa		125	
Middle East		154	
Former Soviet Union			267
Eastern Europe		25	
China		86	20
Other Far East		753	
Total	1,579	2,126	287

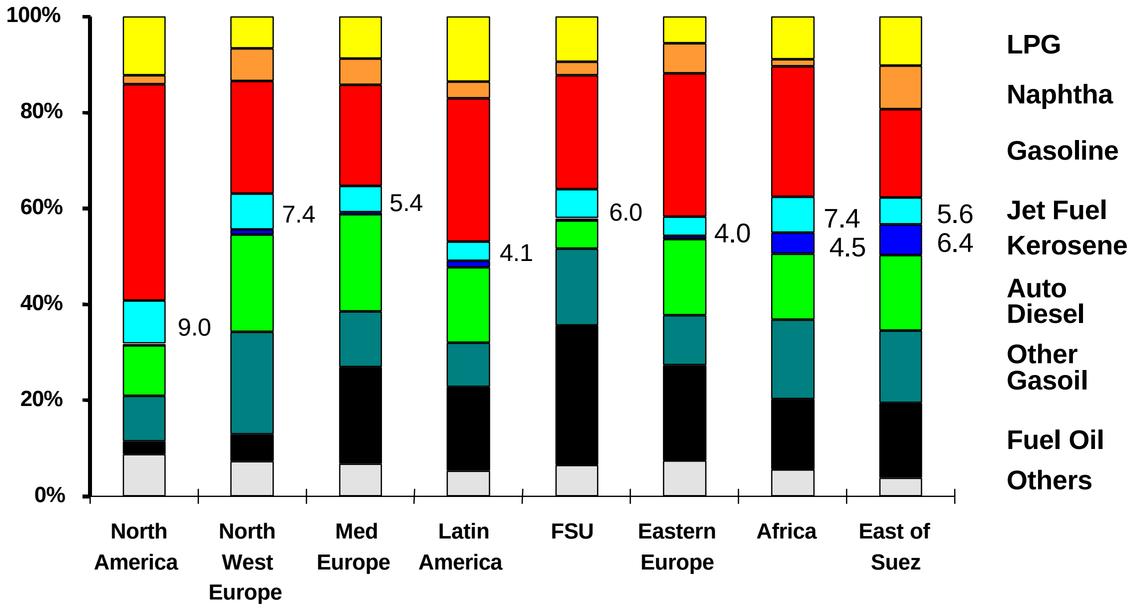
Section 6.5, Table 1—Approximate Consumption of Jet Fuel in 1995 (thousands of barrels per day; barrel = 42 U.S. gallons)

6.6 Demand for Other Distillates

Oil refineries produce a wide spectrum of products from crude oil, ranging from Liquefied Petroleum Gas (LPG) to Bitumen. The demand for each of these products varies from region to region depending on local circumstances. For example, in some regions fuel oil is used for power generation and kerosene is a domestic cooking fuel, in others power generation and domestic cooking are both fueled by natural gas.

One of the most striking differences is gasoline/gas oil balance between North America and Europe, illustrated in Figure 1. North America is primarily a gasoline economy and refineries are configured to maximize gasoline production. Diesel/gas oil demand and production is relatively low. In Europe, the demand for gasoline and gas oil is much more balanced. This European balance is typical of most regions of the world. In this context, North America has the unusual demand pattern.

One of the consequences of this difference is that, in Europe and the rest of the world, there is real competition between jet fuel and gas oil/diesel for the distillate fraction of the barrel in addition to the more constrained freeze point of Jet A-1.



Section 6.6, Figure 1--Variation in the Demand for Products Across Different Regions of the World

This dramatic difference in cut of the barrel demands between North America and Europe is one of the main reasons for the different impacts on jet fuel availability predicted for changes in flash point.

It should also be noted that forthcoming legislative changes for diesel fuel in Europe are likely to raise the competition for kerosene molecules as diesel fuels are required by legislation to decrease and more kerosene will be required to meet the diesel fuel demand.

6.7 Military Experiences

During the most recent fiscal year (FY 1997, ending 30 September 1997), the Defense Energy Support Center (DESC, formerly the Defense Fuel Supply Center, or DFSC) purchased worldwide, on behalf of the U.S. government (mostly the military), 82.8 million barrels (MMB) of jet fuels, or about 227 thousand barrels per day (MBD). These purchase volumes are on the same order of magnitude as the largest airlines. Of these volumes, about 216MBD (95.5 percent) were purchased “in bulk” – mostly large pipeline, tanker, or barge lots lifted directly from a refinery or large terminal. Worldwide “intoplane” volumes, those delivered directly by vendors to the wings of aircraft being refueled at commercial airports, totaled about 10MBD. While military fuel use has declined markedly with the current defense downsizing (down 42.1 percent since FY 1988), it is expected to be level near current levels for the next several years.

U.S. military jet fuels are almost entirely kerosene-based fuels. Of the FY 1997 volumes, only 2.8MBD, or 1.2 percent of the total, was wide cut JP-4 fuel (similar to commercial Jet B fuel). Bulk JP-8 accounted for 165MBD (72.6 percent) of total volumes. JP-8 is very similar to the commercial Jet A-1 fuel, which is the predominant kerojet fuel outside of North America. It is used by land-based U.S. military aircraft – Air Force and Army aircraft, plus some Navy and Marine Corps aircraft that do not routinely visit aircraft carriers during their missions. Intoplane volumes (4.5 percent of the total) are almost entirely Jet A-1 or Jet A, the commercial fuel most commonly sold in the United States. The remaining 49.1MBD (21.7 percent) of U.S. military jet fuel volumes are bulk JP-5, a high flash point kerojet fuel for the Navy and Marine Corps

Of U.S. military bulk fuel volumes, 72.3 percent are purchased in the United States. Given that the military jet fuels do not meet U.S. domestic commercial specifications, they cannot be handled fungibly with commercial product. Thus, they must often be custom manufactured, and segregated from commercial fuels – whether at the refinery or throughout the downstream distribution system. Overseas, the situation is less complicated, because JP-8 is essentially Jet A-1 plus an additive package (which can often be injected downstream of the refinery). Some U.S. domestic refiners who are U.S. military suppliers are understood to make their commercial fuel to the more restrictive military specifications in order to rationalize their on-site operations. Despite the specification differences, The DESC has been able to procure JP-8 in the United States at prices which are approximately equal to domestic Jet A prices. The more restrictive JP-5 specification results in fewer suppliers and prices that run some 1 to 3 cents per gallon above commercial jet fuel on the U.S. Gulf Coast. It should be noted that JP-5 is a very low volume specialty project that accounts for about 3 percent of U.S. jet fuel production.

Throughout most of the post-World War Two period, most land-based U.S. turbine powered military aircraft have used the wide cut JP-4 fuel, which was developed in 1951. The U.S. Air Force developed the JP-8 specification in 1972 in response to their combat experience in Vietnam. The new fuel specification promised better survivability in combat and greater safety in operations and handling. Land-based U.S. military aircraft have been interoperable among JP-4, JP-5, and JP-8 since 1976.

The worldwide conversion of land-based U.S. military aircraft took place in several phases from 1979 through 1995. The impending conversion of domestic military requirements was announced in November 1991, and carried out in a regional phase-in from October 1993 through October 1995. Because the domestic conversion involved some 200 MBD of JP-4 requirements (about 15 percent of U.S. jet fuel consumption at the time), the military anticipated problems with product availability, and cost increases of some 5 to 10 cents per gallon over JP-4.

The U.S. domestic conversion was completed successfully in 1995, with actual product costs only 2 to 3 cents above JP-4 prices. The successful conversion was due to several factors: 1) projected JP-8 requirements declined due to force downsizing, 2) a U.S. recession reduced overall U.S. jet fuel consumption, 3) aircraft operating efficiency continued to improve, and 4) the U.S. refining industry had leadtime of 2 to 4 years to prepare for the change.

The Air Force experienced some operational impacts as a result of conversion from JP-4 to JP-8. The two most significant issues were (1) efficient operation of older aircraft/engines, and (2) seal/sealant material leaks. As a result of the changes in viscosity and volatility between JP-4 and JP-8 the Air Force did experience some operational difficulties with specific older model aircraft and engines. This was particularly true in cold weather locations. Some aircraft and engines experienced cold weather start difficulties and lost some altitude relight capability. Most of these issues were addressed by changes to fuel scheduling systems, fuel controls, nozzles and burners. The small volumes of JP-4 that continue to be procured are in response to these lingering, minor issues.

The Air Force also experienced a widespread problem with seals and sealant materials that were related to differences in aromatic content between JP-4 and JP-8. This was predominately resolved by changing “O” rings. Although it did require maintenance action to change the seals this was a one-time issue and not a major impediment to the conversion. In addition to these issues related to the JP-4/JP-8 conversion, DESC and the services have experienced quality problems with kerosene-based jet fuels, which are related to changes in refinery processes and feedstocks. In general, these issues have been resolved on an individual basis.

7.0 DESIGN ALTERNATIVES

Task Group 6/7 examined the impact of a range of minimum flash points as design alternatives.

Other design alternatives would be the consideration of other technologies, or flash point changes in combination with other technologies. It is beyond the scope the Task Group 6/7 to make such comparisons.

8.0 INSTALLATION/RETROFIT REQUIREMENTS

8.1 Fuel Phase-in Requirements

Major fuel specification changes (such as flash point) require large lead times for refineries to implement the necessary investments if they should decide to do so and continue to produce the fuel and greater lead time for refiners to make potential investments to produce the fuel. Typically, refineries need four to five years to complete major capital projects, which includes design and planning, obtaining the necessary permits, construction, and start up. For example, Federal reformulated gasoline was implemented in 1995 (five years after the Clean Air Act mandating RFG was passed). In addition, a transition period of three months should be considered to allow the new fuels to replace the current fuels in the supply and distribution system.

8.2 Retrofit Requirements

If the fuel flash point is increased over current levels, addition of a fuel heater at the aircraft Auxiliary Power Unit (APU) inlet would be required to maintain the fuel temperature above that corresponding to a maximum viscosity of 12 centistoke, to ensure reliable starting for all ambient conditions. Section 8.2.3.1 provides a detailed explanation of the effects of a fuel flash point increase on APU cold and altitude starting. The cost impact of an APU fuel heater is provided in Section 12.6.2.

Approximately 24 months would be required for development and qualification of a direct current (DC) powered APU fuel heater with BITE (Built In Test Equipment) prior to delivery to the aircraft manufacturer. An additional 12 to 24 months would be required to incorporate the fuel heater in the field. There would be an increase of approximately 4 lb. in APU weight. The fuel heater could be run off the APU battery in-flight, using the existing battery charger powered by the main engine generators.

Additional time and effort would be required to complete any aircraft modifications or flight-testing required. Aircraft changes that may be required include wiring from the APU to the electronic control unit (usually located in a different compartment), modifications to the flight deck display, modifications to the APU battery or charger, modifications to the main engine generators, modifications to aircraft operational procedures, and any airplane manual revisions.

Additional development time, additional weight, and additional aircraft modifications would be required if an AC powered fuel heater were employed.

9.0 TECHNICAL DATA

9.1 Flash Point

9.1.1 Tank Ullage Flammability

Jet fuel has one basic purpose, to burn and release large quantities of heat. Ideally this process would occur only in the engine's combustion system, but jet fuel characteristics can also create a combustible mixture in tankage vapor space or ullage under certain conditions. Three ingredients are needed to cause a fire: fuel vapors, air (oxygen) in proper proportion and an ignition source. It therefore makes sense to first discuss fuel evaporation and then its impact on flammability.

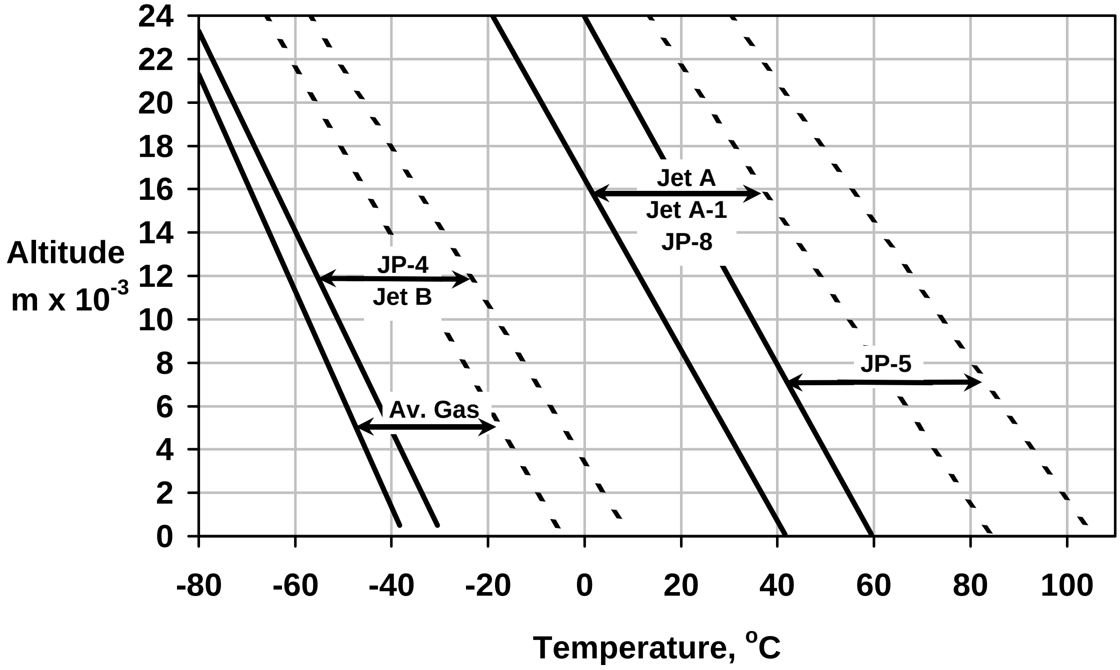
The rate of evaporation and the concentration of evaporated fuel in ullage depend on fuel vapor pressure, fuel temperature and air pressure and temperature. Of these parameters fuel vapor pressure is the most difficult to precisely establish because jet fuel is a complex mixture of hydrocarbons whose vapor pressure is the sum of the partial pressures of all the constituents. Evaporation alters the composition of the fuel and the vapor pressure decreases with the quantity of fuel evaporated. A relatively simple test to measure the vapor pressure of gasoline exists as ASTM D 323, but it only approximates the true vapor pressure of fuel. Vapor pressure measurements of kerosene by this method are further unreliable because they are very near the lower detectable limit of the method. Very specialized equipment is required to measure true jet fuel vapor pressure.

Fuel volatility or its tendency to evaporate, is therefore controlled by other, more empirical means. In the refinery distillate products are separated by boiling range, which is measured by a simple distillation. In this method (ASTM Test Method D 86) product is boiled off, condensed and recovered, while vapor temperature is monitored. The resultant temperature vs. per cent recovered serves as a general characterization, but the test method does not account for up to 1.5% of the most volatile products which are not condensed. However, these constituents determine vapor flammability, so they are characterized by determining the temperature at which the vapor first becomes flammable. This temperature is called the flash point. Details and limitations of flash point methods are discussed in the remainder of this section.

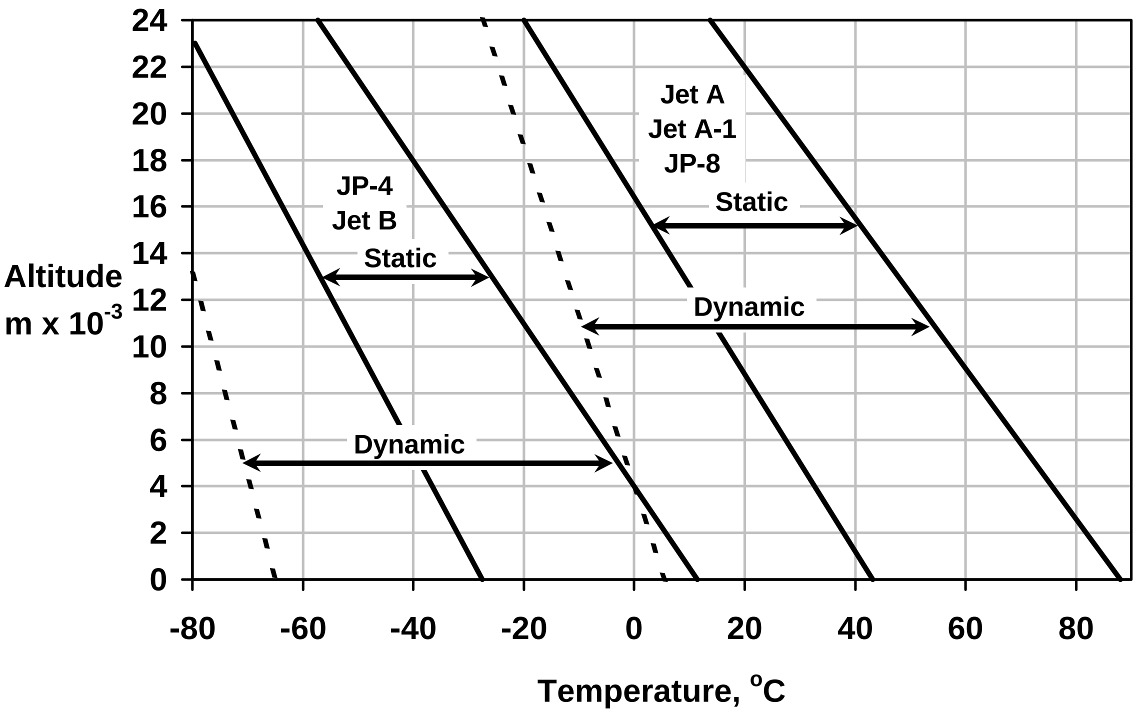
Relating jet fuel characteristics to ullage flammability is complex. Aside from the imprecise characterization of volatility, ullage vapor concentrations do not reach equilibrium when fuel is withdrawn from tanks vented to atmosphere. Air flows out of the tanks as air pressure decreases during climb, and dissolved gases can evolve from the fuel. Possible tank agitation resulting in sloshing or misting adds to the complexity. In the simplest test case, a tank is partially filled with fuel and the fuel is allowed to evaporate as temperature is increased in steps at constant pressure. In letting all conditions come to equilibrium at each temperature, a temperature is reached when enough fuel is evaporated to first form a flammable mixture. This temperature is called the lower flammability limit (LFL) or lean limit. As the system temperature is increased, the vapor space remains flammable until so much fuel is evaporated that there is insufficient oxygen to permit combustion. This temperature is the upper flammable limit (UFL) or rich limit. Conducting these experiments at reduced air pressures – increasing altitudes – results in curves such as are contained in Figure 1(1). Because of decreasing air density less fuel vapor is needed at altitude to maintain a constant fuel/air ratio and a lower system temperature will maintain the LFL.

Figure 1 also illustrates the difference between different fuel grades. Adding factors such as outgassing shifts the limits as does misting or sloshing. The large effect on flammability limits resulting from extreme sloshing is illustrated in Figure 2. Unfortunately this effect depends entirely upon the conditions under which the tests were conducted and will differ greatly in real life situations. In tankage the vapor concentration will be highest just above the liquid level and lowest at the top surface. At very low fuel levels the non-homogeneity of fuel vapors becomes even greater because of uneven fuel warming and the cooling effects of vertical tank members. As a result, the relationships between existing fuel tests and tank flammability are not precise and not directly related on a one-to-one basis. Therefore, flammability conditions can be difficult to predict. In fact, the Executive Summary of the recently published FAA Final Report *A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks* (DOT/FAA/AR-98/26) states the following:

> "In addition to finding a need for more data on the flammability of Jet A fuel, the task group found present methods for predicting in-flight fuel temperatures to be inadequate. The development of reliable heat transfer models and the ability to calculate the flammability of the ullage space in an aircraft fuel tank under different environmental and operational conditions are in the early stages. Therefore the ability to reliably evaluate different strategies to reduce the flammability of jet fuel in the center wing tank of a B747 has not been proven."



Section 9.1.1, Figure 1--Fuels Flammability Limits vs. Altitude



Section 9.1.1, Figure 2--Effect of Tank Dynamics on the Relative Flammability Limits of Jet Fuels

9.1.2 Flash Point Methods and Significance

Liquid fuels all exhibit an equilibrium vapor pressure that is dependent on the temperature of the fuel. As the temperature of the fuel is raised, the fuel vapor in equilibrium with the liquid fuel reaches a sufficient concentration to ignite when mixed with air and exposed to a strong ignition source such as a flame. The temperature of the fuel at this point is known as the *lower flash point temperature*. If the temperature of the fuel is increased, the equilibrium vapor pressure increases to a point where the air-vapor mixture contains so much vapor that it is above the upper flammable limit for the fuel. The temperature at which combustion will not occur is known as the *upper flash point temperature.* For kerosene-based jet fuels such as Jet A and Jet A1, the relevant temperature is the *lower flash point temperature* and is commonly referred to as the *flash point.* This convention is used in this report.

In actual practice, the flash point is measured in several standardized pieces of apparatus. The most reproducible are “closed” cup methods. In these methods a sample is placed in a closed sample container and stirred. The temperature is increased at a prescribed rate. Periodically, the vapor is exposed to a flame and observation of whether combustion occurs is made. The lowest temperature at which the vapor ignites with a distinct flash is taken as the *flash point*. This observed measurement is then corrected for pressure by the equation:

Flash Point (^{o}F) = Observed Flash Point (^{o}F) +0.06 [760-Ambient Pressure (mm Hg)]

While the methods all measure the Flash point, the actual value measured and the test reproducibility can differ. There are four closed cup methods that are used commonly in aviation fuel specifications. These are shown in Section 9.1.1, Table 2. ”Repeatability” is the maximum expected difference in two test results by the same operator and instrument; “Reproducibility” is the maximum expected difference in two test results by different operators in different laboratories. At the current flash point specification the reproducibility and repeatability are given in Section 9.1.1, Table 2. Section 9.1.1, Table 3 gives the flash point as measured by each apparatus for n-decane and n-undecane. As seen from this table, slightly different results are obtained with each method. In this study, flash point results are measured or adjusted to be the same as measured by ASTM D56. In specifications, ASTM D 1655, the commercial specification, uses D56 as the referee method, MIL-T-5624N and MIL-T-83133D, the United States Military Specifications use D 93 as the referee method, and DEFStan 91-91, the British specification uses IP 170 as the referee method. Care needs to be taken when reporting data to understand which method was used.

Method	**Title**	**Repeatability for 100^{o}F &140^{o}F Fl.Pt.**	**Reproducibility 100^{o}F &140^{o}F Fl.Pt.**
ASTM D 56	Standard Test Method for Flash Point by Tag Closed Tester	2.0^{o}F/2.0^{o}F	8^{o}F/8^{o}F
ASTM D 93	Standard Test Method for Flash Point by Pensky-Martens Closed Cup Tester	2.4^{o}F/3.8^{o}F	5.1^{o}F/8^{o}F
ASTM D 3828	Standard Test Methods for Flash Point by Small Scale Closed Tester	0.9^{o}F/0.9^{o}F	3.7^{o}F/3.7^{o}F
ISO 170	Petroleum Products – Determination of Flash Point – Abel Closed Cup Method	1.8^{o}F	2.7^{o}F

Section 9.1.2, Table 1–Closed Cup Flash Point Temperatures

Method	**Flash Point ^{o}C**	
	n-Decane	**n-undecane**
D56	50.9	67.1
D93	52.8	68.9
D 3828	49.8	65.9
IP 170	48.9[a]	65.1[a]

[a] *Result inferred from DefStan 91-91 Specification Limits; Calibration procedure not listed in standard*

<u>Section 9.1.2, Table 2–Flash Point Differences in Test Methods</u>

The flash point results can vary substantially from the actual lower flammability limit. While a definite difference has not been defined, ignition as much at 8-10°F below the actual flash point have been observed. Actual ignition of fuel vapors can be affected by factors such as:

- Direction of flame propagation – vertical upward flame requires less hydrocarbon to ignite than downward propagation induced in these methods.

- Non-equilibrium effects -- vapor concentration may not be uniform throughout a container, and time is needed for liquid to evaporate or for vapor condensation as conditions change.

- The ullage to liquid volume ratio -- the amount of hydrocarbon vapor differs and hence composition of the vapors can be different- this effect is particularly significant for fuels such as kerosene, which are mixtures of hydrocarbons with different volatility, not pure compounds.

- Liquid mass transfer --can determine the rate of vaporization and other diffusional effects which can have an effect on the flash

- Mixing in ullage space -- can determine when ignition can occur.

Thus, while the flash point adjusted for actual conditions can be used as a surrogate for the temperature at the lower flammability temperature, it should be understood that actual ignition can occur several degrees above or below this value.

While slightly different results can be obtained from the several test methods which are commonly used, these differences are small compared to the range of flash points found for kerosene as sold in the marketplace. Practices established for use and application must generally be based on an expectation that kerosene has the minimum allowed flash point; survey data shows that is improbable. It might be advisable to harmonize on a single method for use in all specifications, and consideration of that is underway and will likely occur if flash point requirements for jet fuel are changed to a higher minimum value.

9.1.3 Flash Point Distributions

Flash point distributions are subject to some variation depending on the source and timing. In this study we attempt to find a sufficiently large database which would be meaningful, and test it where possible against other data or databases. However, because of the nature of the data, the results are presented as numerical averages -- they have not been weighted on a volume basis or other possible schemes. In fact, there can be significant debate as to which average is best for this study. The numerical data presented in this study should be sufficient to provide necessary data for further analysis.

9.1.3.1 United States Data

One of the largest readily available databases on flash points at United States Airports is provided by measurements by the U.S. military at commercial airports. This database[2] provides measurements of flash point at all contract commercial airports. These samples were taken from a period of August 1994 to September 1996.

A summary of the data is shown in Section 9.1.3, Figure 1.

Section 9.1.3, Figure 1--Flash Point Distribution in U.S.

Based on these data and other survey, results indicate that the average flash point in the United States would be between 124^{o}F and 127^{o}F with a standard deviation of 10 to 12 ^{o}F.

9.1.3.2 United Kingdom Defense Research Agency Flash Point Data[3]

The Defense Research Agency publishes survey data annually. One thousand four hundred forty four (1444) samples were analyzed for flash point. A summary of the 1997 data is shown in Section 9.1.3, Figure 2. The mean flash point was 111.6^{o}F with a standard deviation of 4.5^{o}F, when the flash point is adjusted to be equivalent to ASTM D56.

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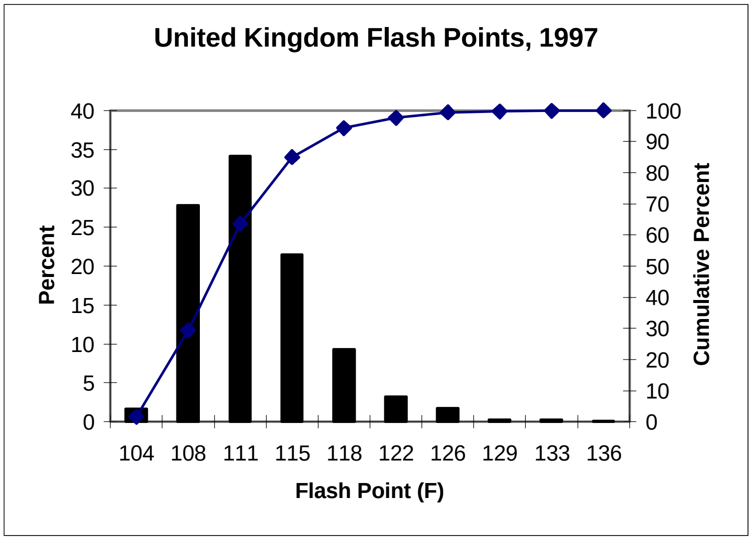
[2] **Into Plane Contract Testing** Air Force Directorate of Aerospace Fuels, Technical Division (SFT) Kelly Air Force Base, Texas (January 15, 1997)

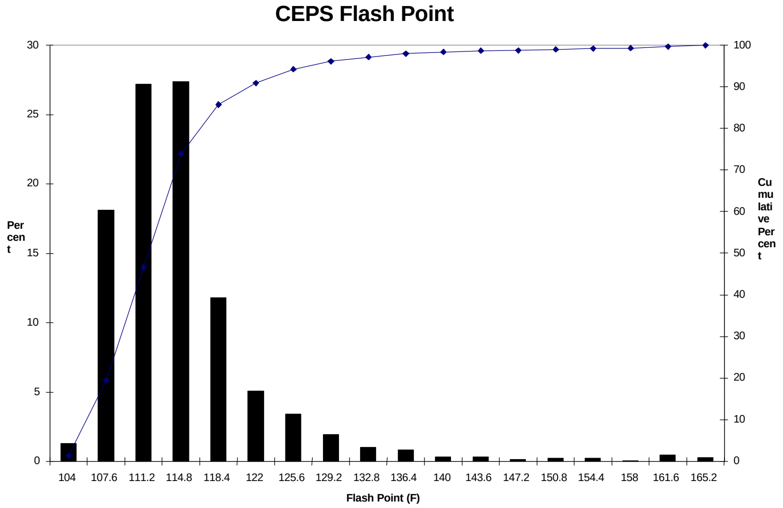
[3] ***The Quality of Aviation Fuel Available in the United Kingdom Annual Survey, 1997*** Defence Research Agency, Land Systems, Fuels & Lubricants Centre (1997 - to be published)



Section 9.1.3, Figure 2--Flash Point Data for Fuels Available in United Kingdom

9.1.3.3 European Flash Point Distributions

The Central Europe Pipeline System[4] publishes survey data annually. The data is compiled from 15 different sources located in the Netherlands, Belgium, France, and Germany. One thousand five hundred twenty three (1523) samples were analyzed for flash point. A summary of the 1996 data is shown in Section 9.1.3, Figure 3. Assuming a normal distribution, the mean flash point was 114.8^{o}F with a standard deviation of 8.0^{o}F, when the flash point is adjusted to be equivalent to ASTM D56.



Section 9.1.3, Figure 3–Flash Point Distribution in Europe

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[4] Central Europe Pipeline System *Characteristics of Aviation Fuel within the CEPS 1996*

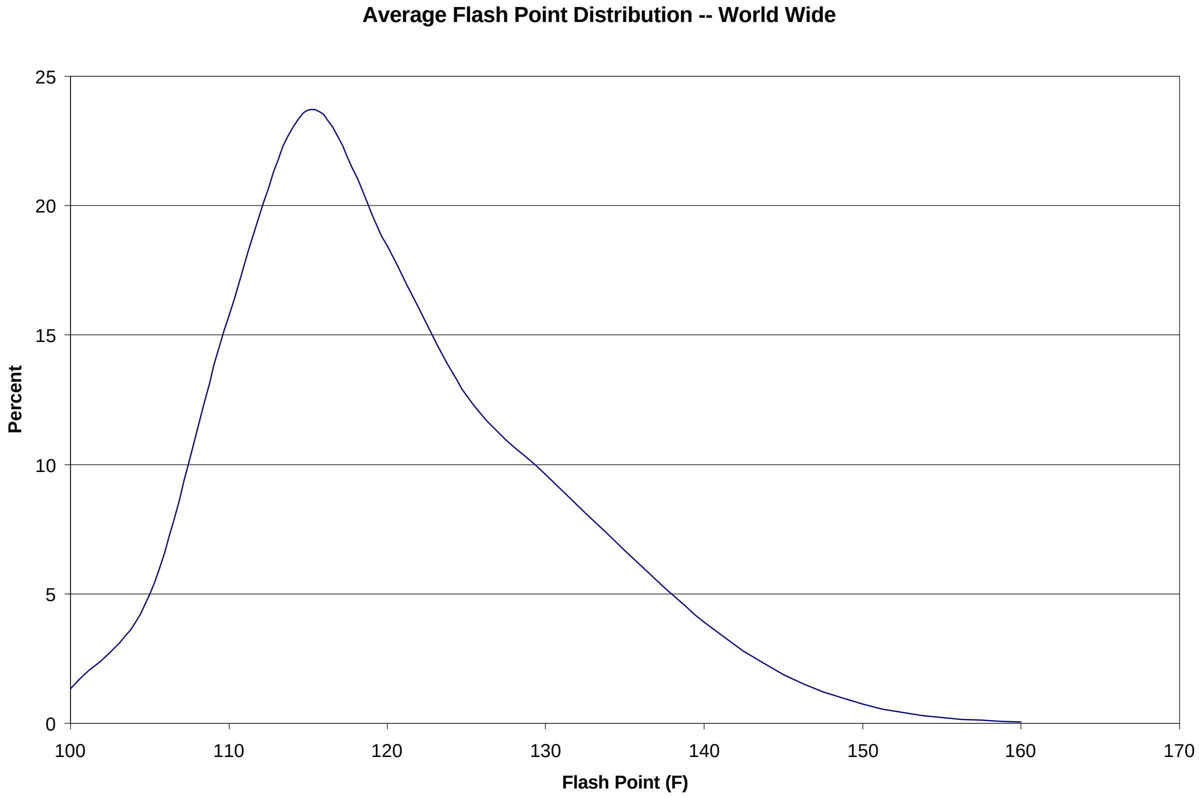
9.1.3.4 Average Flash Point Distribution Curve Worldwide

To simulate an average flash point distribution worldwide, the flash point distributions from the United States, United Kingdom, and CEPS (Europe) were weighted in the following way:

- The United States flash point distribution was weighted by the percent of jet fuel consumed in the United States and 1/3rd the jet fuel consumption in Central and South America. Weighting Factor = 45%

- The United Kingdom flash point distribution was weighted by the percent consumed in the United Kingdom, the Middle East, Africa, and the Far East and 1/3rd the jet fuel consumed in Central and South America. Weighting factor = 34%

- The CEPS flash point distribution was weighted by the percent consumed in the Western Europe and 1/3rd the jet fuel consumed in Central and South America. Weighting factor = 21%



Section 9.1.3, Figure 4–Flash Point Distribution –Worldwide Average

Lack of data precluded assignment of weights to production in Mexico, Canada, China, and C.I.S. Thus the flash point distributions are for Jet A and Jet A-1 only. Other fuels are not included in this averaging, but the average of 13 samples taken in Russia and the C.I.S is 95.7 °F (35.4 °C). Based on this calculation, the distribution of worldwide flash points is given in Section 9.1.3, Figure 4. The actual values are in Section 9.1.3, Table 1.

Flash Point F	Cumulative Percent
100	1.3
105	6.3
110	22.1
115	45.7
120	64.2
125	76.9
130	86.5
135	93.1
140	97.1
145	99.0
150	99.7
155	99.9
160	100.0

Section 9.1.3, Table 1--Flash Point Distribution – Worldwide Average

A summary of the flash points given in Section 9.1.3, Table 2.

PADD	Mean Flash Point (°F)	Std. Deviation (°F)	# of Samples
U.S.	124.1	10.5	1497
PADD 1	127.5	10.0	446
PADD 2	126.0	9.1	405
PADD 3	120.0	11.4	357
PADD 4	123.3	10.4	109
PADD 5 ex California	119.2	8.6	91
California	121.1	8.1	86
United Kingdom	111.6	4.5	1444
Central Europe Pipeline System	114.8	8.0	1523

Section 9.1.3, Table 2--Statistical Summary of Flash Point Data

9.1.4 Flash Point Margins

In the United States, the average value of flash point is approximately 19-27°F above the specification limit. This is not entirely product give-away, i.e., higher flash resulting from inefficient and/or most economical operating point for a refinery. Increasing the flash point specification will not permit producers operating above the new specification to maintain status quo. The producer will have to increase his production limit commensurably. Section 9.1.4, Figure 1 shows a schematic of the factors involved in producing on-spec fuel at the airport. The components going into the flash point produced are as follows:

Pipeline Specification --	8^{o}F
Test Tolerance --	4.9^{o}F
Process Control --	$3\text{-}8^{o}$F
Product Give-away --	??

As a check on this model, the United Kingdom data (Section 9.1.3, Figure 2) can be examined. Here, the producers are trying to maximize middle distillate. It is highly likely that they are attempting to optimize Jet A-1 operations. Since they do not have to meet pipeline specifications, the flash point produced at the refinery should be $7\text{-}13^{o}$F over the specification value. The observed average is 11.6^{o}F -- within the estimate proposed.

Assuming product give-away is eliminated, one can make an estimate of the variance for delivery of fuel through a pipeline. The variance is the sum of the individual variances, i.e.,

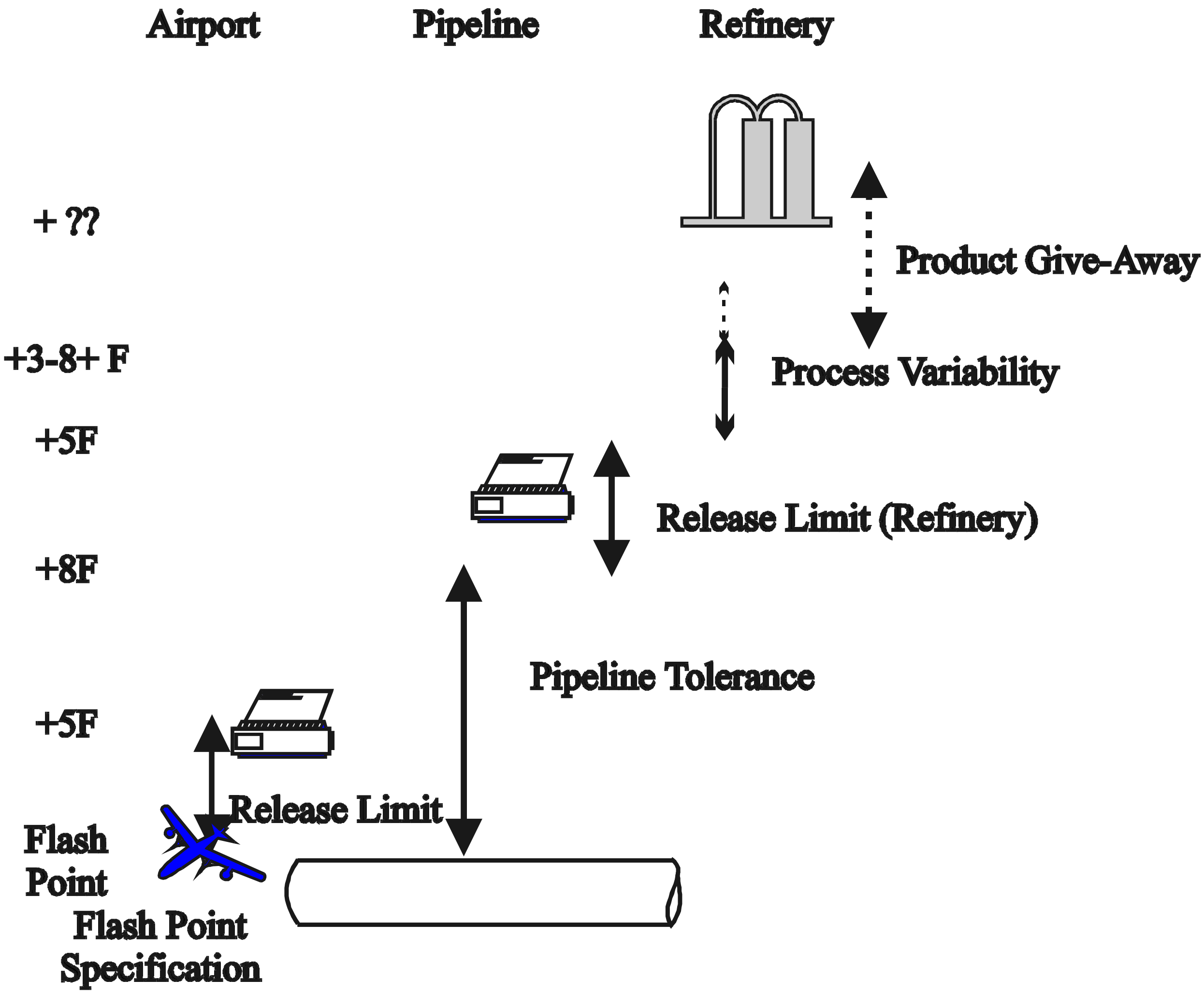
$$s^{2} = \sum s_{i}^{2}$$

If one assume 95% confidence in test tolerance at airport and into pipeline as well as a 2 degree process control limit at 95% confidence limits, the standard deviation could be as low as 4.3^{o}F. If the pipeline maintains its requirement of specification plus test reproducibility into pipeline the standard deviation can be as high as 5.8^{o}F. This assumes no product give-away.

As the flash point specification is raised, the flash point will also rise commensurately (approximately12 - 15^{o}*F) at the refinery to assure on-spec product is delivered to the airport in the United States.* Where pipelines are not involved, i.e., where there is a single transfer, the flash point on average can be as low as 8^{o}F higher than the specification. The standard deviation could be as little as 3.13^{o}F for this case. This will result in an additional cost to most, if not all refiners, to achieve any increase in specification.

For the purpose of this study, $\sigma = 5.8^{o}$F for fuel consumed in the United States and 3.13^{o}F for fuel consumed in the rest of the world. Future changes such as the NATO pipeline becoming a multi-product pipeline typical of the pipelines in the United States would change the standard deviation to be more like the United States.

A final option could be to carry out multiple flash point tests at each transfer. For example if four flash point tests were done at transfer, the reproducibility would be 4^{o}F rather than 8^{o}F for a single measurement. This would reduce the standard deviation to 3.1^{o}F for the United States and 2.7^{o}F for the rest of the world. This case is also presented in Section 9.1.5.



Section 9.1.4, Figure 1--Achieving Flash Point Specification Versus Flash Point at Refinery

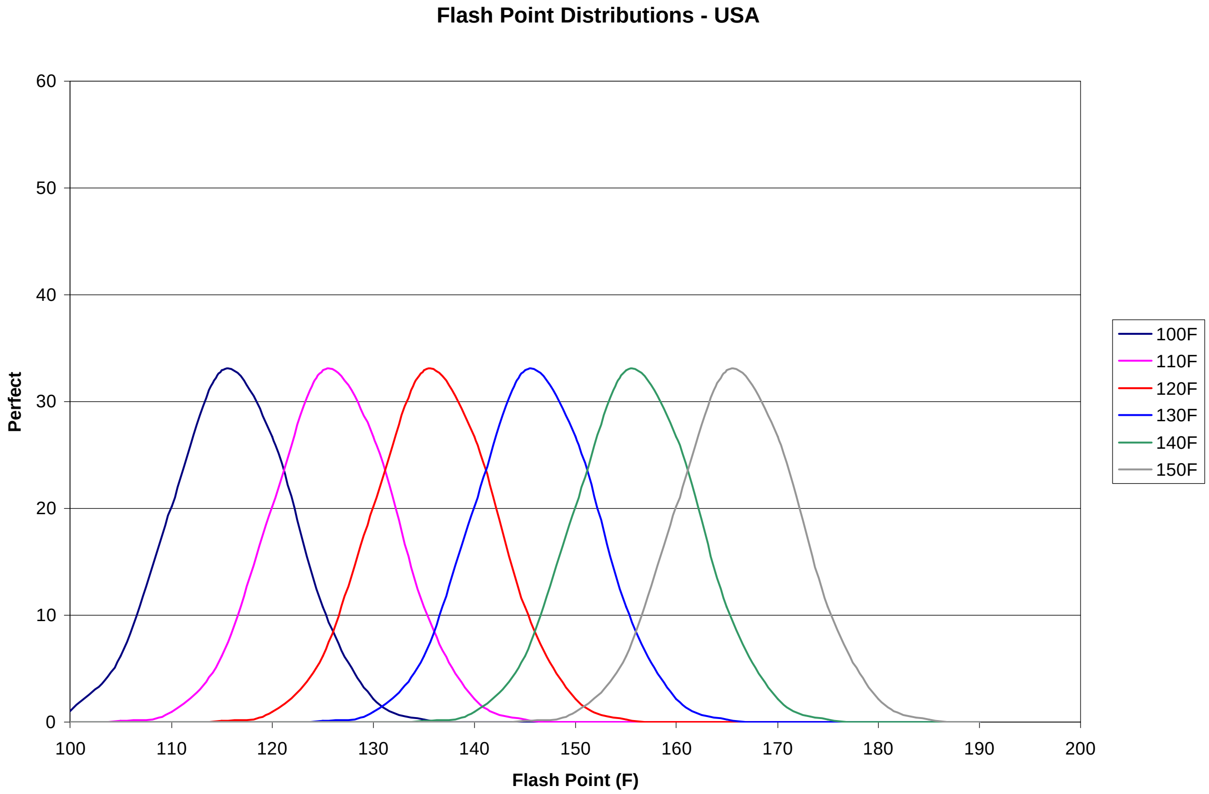
9.1.5 Flash Point Predictions

For the future, it is assumed that the manufacturer will not give product quality away. While this assumption is inevitably true for high flash, e.g., flash points greater than 130-140^{o}F, the amount of give-away for lower level of flash point is debatable. It is assumed that for the United States the standard deviation of the product will be 5.8^{o}F and that 99% of the product will be meet specification. The United Kingdom and European will have a standard deviation of 3.13^{o}F.

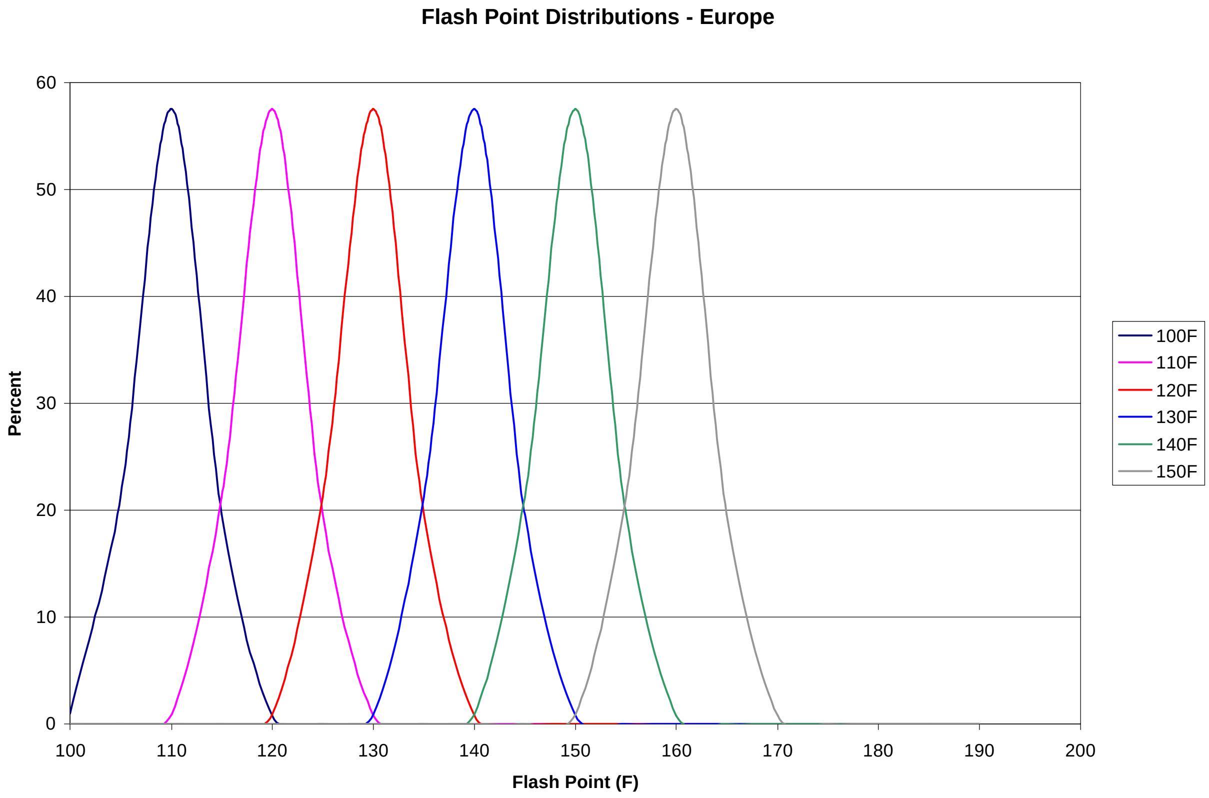
An average worldwide distribution was obtained by adding 45% of the United States flash point distribution to 55% of the European flash point distribution.

The results of these calculations are shown in Section 9.1.5, Figures 2 to Section 9.1.5, Figure 4. For the United States the flash point is 13.5^{o}F higher than the specification, the European is 7.4^{o}F higher than the specification.

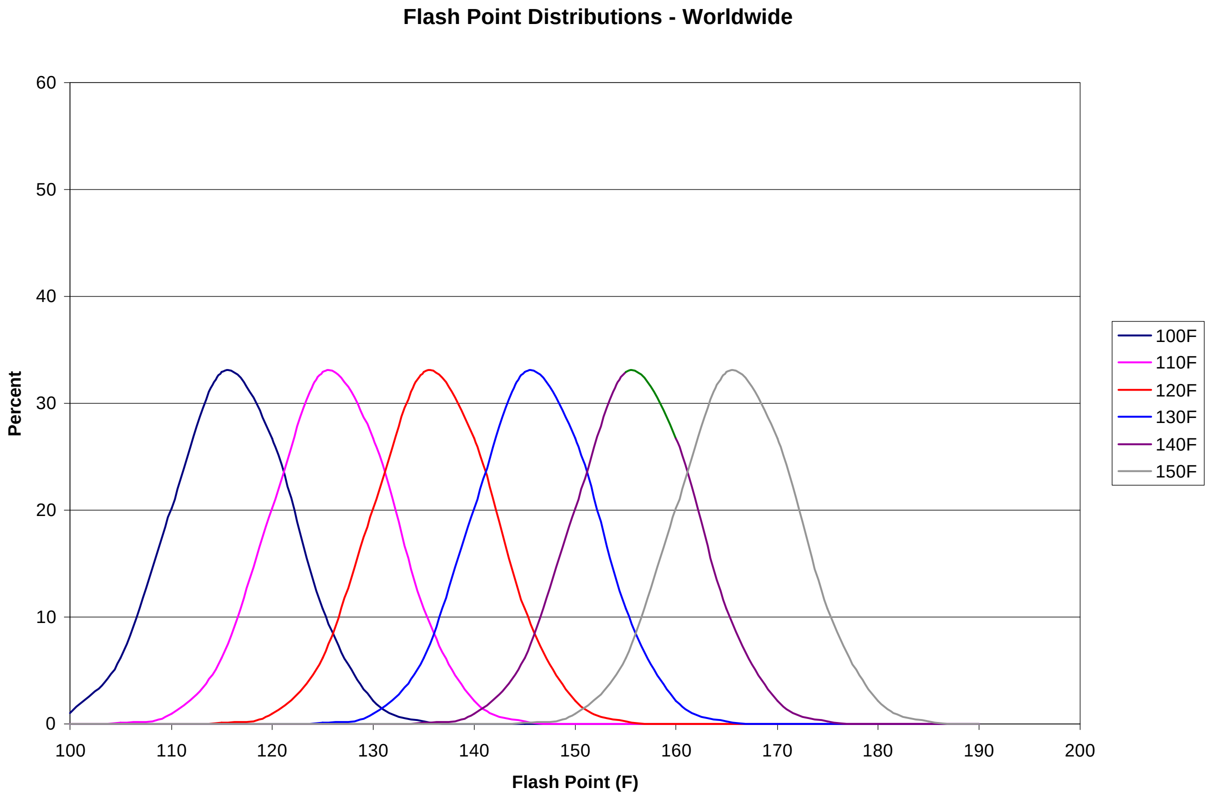
If four flash point measurements were taken at each transfer, the mean temperature for the United States would be about 7.4°F above the specification and worldwide would be about 6.4°F.



Section 9.1.5, Figure 2–Predicted Flash Point Distribution in United States with No-Give-Away



Section 9.1.5, Figure 3–Predicted Flash Point Distribution in Europe with No-Give-Away



Section 9.1.5, Figure 4–Average Worldwide Predicted Flash Point Distribution with No-Give-Away

9.1 Fuel Property Effects

9.2.1 Fuel Property Effect Predictions

9.2.1.1 Introduction

An increase in the jet fuel flash point specification can be expected to affect the properties of jet fuel in three ways:

1. By causing refiners to modify jet fuel distillation properties in conventional refinery processes to meet the new specification.

2. By increasing the probability that refiners will extend yield by modifying jet fuel processing schemes. Both the greater use of conventional processing such as severe hydrocracking and the implementation of unconventional refinery processing may occur

3. By causing significant property shifts in the jet fuel made by conventional refinery processing in some areas that rely on unique refinery configurations or atypical crude oils.

It is important to note that a higher flash point Jet A is a new jet fuel specification. Experience gained with JP-5 [140°F (60°C) flash point, -51°F (-46°C) freeze point] is not relevant because:

- JP-5 is a niche product made by few refiners (who presumably are well situated to produce it). A fuel made in commercial quantities, where maximizing yield is an issue, will have different properties.

- The higher freeze point [-40°F, (-40°C)] of a high flash point Jet A results in significantly changed properties, such as higher viscosity, versus JP-5.

9.2.1.2 The Impact of Modified Distillation Properties: Jet Fuel Properties Survey

Task Group 6/7 reviewed the literature and developed a number of cases to predict the fuel properties that would result from changes in the distillation profile if the flash point specification were raised from 100°F (38°C) to a higher limit. A survey was conducted where selected properties were calculated (by participants' proprietary analysis/predictive systems) for a number of crudes as function of flash point and freeze point. The feedback from the various participants was collected and regressed to calculate average values. The crude oils included in this analysis are shown in Section 9.2.1, Table 1.

1. Nigerian Light	6. Arab Light (Saudi Arabia)	11. Brent North Sea
2. Arabian Light	7. Maya (Mexico)	12. Sumatran Light Waxy
3. North Sea	8. Cano Limon (Colombia)	13. Arab Light
4. Alaska North Slope	9. Alaska North Slope	14. Mexico Maya Heavy
5. Maya	10. California LA Basin	15. Venezuela Merey Export Blend

Section 9.2.1, Table 1--Crude Oils Included in the Jet Fuel Property Survey

The crude oils were chosen to represent a broad range of those currently refined. No effort was made to balance the selection of crudes to match the "average" slate commercially refined to produce jet fuel. Thus, the current jet fuel pool average for any given property is expected to be offset from the average from this study. The changes in jet fuel properties found in this study are expected to be substantially more predictive than average values. The changes in distillation properties are shown in Section 9.2.1, Table 2. The non-distillation property changes are presented in Section 9.2.1, Table 3.

Flash Point °F (°C)	Freeze Point °F (°C)	Change in Flash Point °F (°C)	Change in Initial Boiling Point °F (°C)	Change in 10% Boiling Point °F (°C)	Change in 50% Boiling Point °F (°C)	Change in 90% Boiling Point °F (°C)	Change in Final Boiling Point °F (°C)
120 (49)	-40 (-40)	20 (11)	38 (21)	24 (13)	12 (7)	-3 (-2)	-14 (-8)
140 (60)	-40 (-40)	40 (22)	76 (42)	49 (27)	24 (13)	-7 (-4)	-28 (-16)
150 (66)	-40 (-40)	50 (28)	94 (52)	60 (33)	30 (17)	-9 (-5)	-35 (-19)
100 (38)	-53 (-47)	0 (0)	8 (4)	0 (0)	-15 (-8)	-31 (-17)	-36 (-20)
120 (49)	-53 (-47)	20 (11)	65 (36)	24 (13)	-3 (-2)	-35 (-19)	-51 (-28)
140 (60)	-53 (-47)	40 (22)	123 (68)	49 (27)	9 (5)	-38 (-21)	-67 (-37)
150 (66)	-53 (-47)	50 (28)	152 (84)	60 (33)	15 (8)	-40 (-22)	-15 (-8)

Section 9.2.1, Table 2--The Change in Distillation Properties versus Base from the Jet Fuel Properties Survey

Flash Point °F (°C)	Freeze Point °F (°C)	Change in Freeze Point °F (°C)	Change in Viscosity at –4°F (-20°C) (centistoke)	Change in Smoke Point (mm)	Change in Density (kg/m^3)	Change in Aromatics Contents (%)	Change in Heat of Combustion (mJ/kg)
120 (49)	-40 (-40)	0 (0)	0.6	-1.4	8	0.4	0.0
140 (60)	-40 (-40)	0 (0)	1.2	-2.8	17	0.7	-0.1
150 (66)	-40 (-40)	0 (0)	1.5	-3.4	21	0.9	-0.1
100 (38)	-53 (-47)	-13 (-7)	-1.1	0.7	-7	0.0	0.1
120 (49)	-53 (-47)	-13 (-7)	-0.5	-0.6	2	0.4	0.0
140 (60)	-53 (-47)	-13 (-7)	0.1	-2.0	10	0.8	-0.1
150 (66)	-53 (-47)	-13 (-7)	0.4	-2.7	14	1.0	-0.1

Section 9.2.1, Table 3--The Change in Average Non-Distillation Properties versus base from the Jet Fuel Properties Survey

Participants provided property predictions and yields at specification flash points of 100°F (38°C), 120 °F (49°C), 140 °F (60°C), 150°F(66°C) and freeze points of -40°F(-40°C) and -53°F (-47°C). The averages of the results are shown in Section 9.2.1, Table 4 and Section 9.2.1, Table 5. Note that the properties are a function of the distillation cut, crude type and other factors which causes significant scatter in the data.

Flash Point °F (°C)	Freeze Point °F (°C)	Yield Loss (%)	Initial Boiling Point °F (°C)	10% Boiling Point °F (°C)	50% Boiling Point °F (°C)	90% Boiling Point °F (°C)	Final Boiling Point °F (°C)
100 (38)	-40 (-40)	0	279 (137)	344 (173)	402 (206)	481 (249)	555 (291)
120 (49)	-40 (-40)	25	317 (158)	368 (187)	414 (212)	478 (248)	541 (283)
140 (60)	-40 (-40)	50	355 (179)	393 (201)	426 (219)	474 (246)	527 (275)
150 (66)	-40 (-40)	62	373 (189)	404 (207)	432 (222)	472 (244)	520 (271)
100 (38)	-47 (-53)	28	287 (142)	344 (173)	387 (197)	450 (232)	519 (271)
120 (49)	-47 (-53)	53	344 (173)	368 (187)	399 (204)	446 (230)	504 (262)
140 (60)	-47 (-53)	78	370 (188)	393 (201)	411 (211)	443 (228)	488 (253)
150 (66)	-47 (-53)	90	391 (199)	404 (207)	417 (214)	441 (227)	540 (282)

Section 9.2.1, Table 4--Average Yields and Distillation Properties from the Jet Fuel Properties Survey

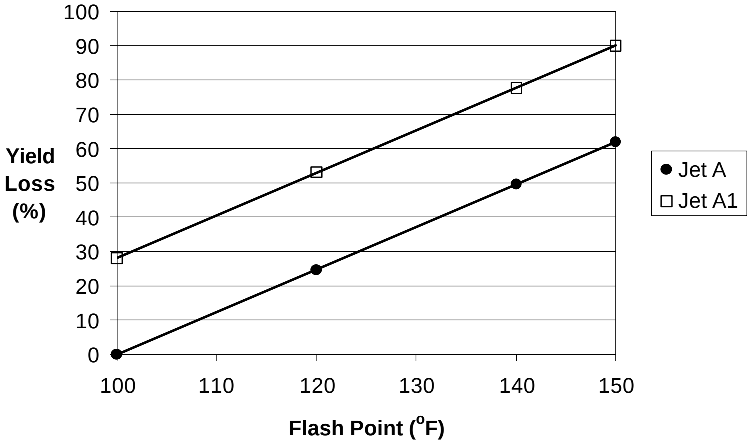
Flash Point °F (°C)	Freeze Point °F (°C)	Viscosity at –4°F (-20°C) (centistoke)	Smoke Point (mm)	Density (kg/m^3)	Aromatics Content (%)	Heat of Combustion (mJ/kg)
100 (38)	-40 (-40)	5.7	22.0	815	18.0	43.1
120 (49)	-40 (-40)	6.3	20.6	823	18.4	43.1
140 (60)	-40 (-40)	6.9	19.2	832	18.7	43.0
150 (66)	-40 (-40)	7.2	18.6	836	18.9	43.0
100 (38)	-53 (-47)	4.6	22.7	808	18.0	43.2
120 (49)	-53 (-47)	5.2	21.4	817	18.4	43.1
140 (60)	-53 (-47)	5.8	20.0	825	18.8	43.0
150 (66)	-53 (-47)	6.1	19.3	829	19.0	43.0

Section 9.2.1, Table 5--Average Non-Distillation Properties from the Jet Fuel Properties Survey

The loss in yield from any increase in the flash point specification is significant (>1% yield per °F flash point) as shown in Section 9.2.1, Figure 1. The "yield loss" in Section 9.2.1, Table 4 and Section 9.2.1, Figure 1 is calculated versus the Jet A base case [100°F (38°C) flash point, -40°F (-40°C) freeze point]. It represents the production lost when distillation cut points are changed to keep the fuel within specification limits. At the higher flash points and lower freeze point, many crude oils would produce no jet fuel at all. [This leads to the apparent anomaly in Section 9.2.1, Table 4 where the final boiling point for the 150°F (66°C) flash point Jet A-1 of 540°F (282°C) seems higher than expected from the other final boiling points. This is caused by most of the crude oils dropping out leaving only those with intrinsically good freeze point performance remaining to average properties.]

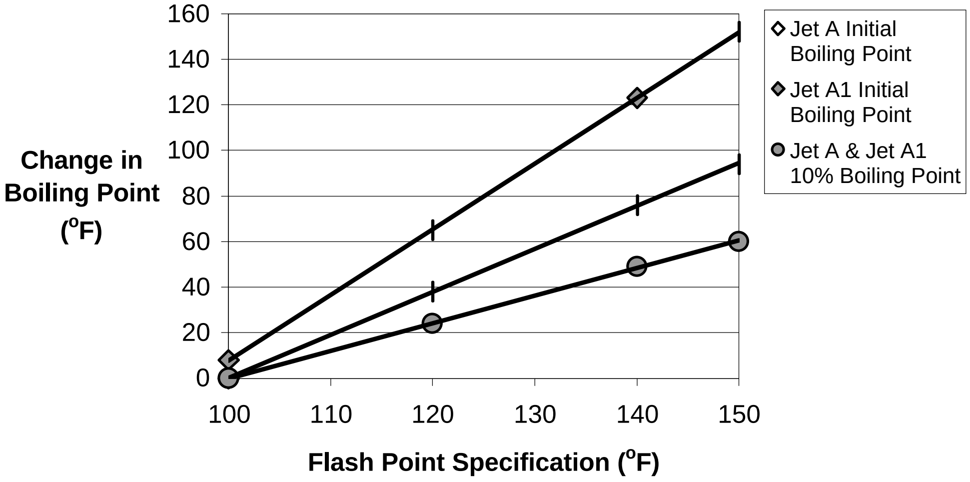
Note that the higher growth rate of jet fuel production and use versus other fuels, described in Section 12.2.4, is expected to apply pressure to future jet fuel availability.

The loss in jet fuel yield associated with an increased flash point specification should exacerbate this situation.



Section 9.2.1, Figure 1--The Loss in Jet Fuel Yield (from the Distillation of Crude Oil) as a Function of the Flash Point Specification

The 10% boiling points (temperature at which 10% of the material has distilled) and initial boiling points vary linearly with the flash point specification temperature as shown in Section 9.2.1, Figure 2.



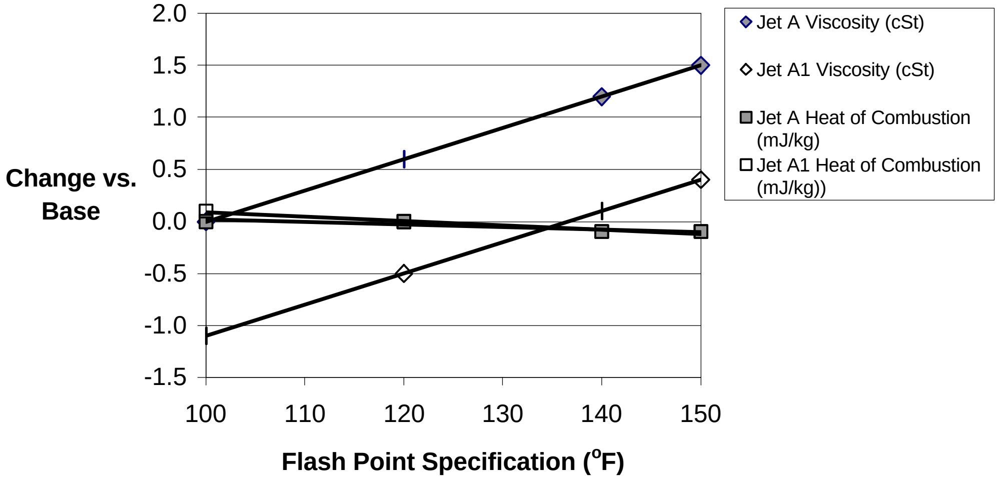
Section 9.2.1, Figure 2--The Linear Relationship between the Front End Distillation Parameters and the Flash Point Specification Temperature Found in the Jet Fuel Properties Survey

These distillation results (Section 9.2.1, Table 2) provide insight concerning why jet fuel properties change when the flash point is raised. Material is excluded from the "front end" (more volatile end) of jet fuel to meet the flash point specification resulting in increased initial boiling and 10% boiling points. The front end of jet fuel helps to dissolve straight chain paraffin molecules that can crystallize at low temperatures to form wax. The loss of the front end material requires the back end to be reduced (resulting in lower 90% and final boiling points) to remove large straight-chain paraffin molecules to maintain freeze point performance.

The difference in Jet A [-40°F (-40°C) freeze point] and Jet A-1 [-53°F (-47°C) freeze point] is mostly the reduced back end fraction in Jet A-1 (lower 90% and final boiling points). This acts to reject more of the large straight-chain paraffin molecules that can form wax.

The jet fuel property most impacted by a change in flash point specification appears to be viscosity. Viscosity increases are linear with flash point (Section 9.2.1, Figure 3). The results demonstrate the role that the back end material plays in jet fuel viscosity: the viscosities for Jet A-1 fuels [–53°F (-47°C) freeze point] were significantly lower than those for Jet A were [–40°F (–40°C) freeze point].

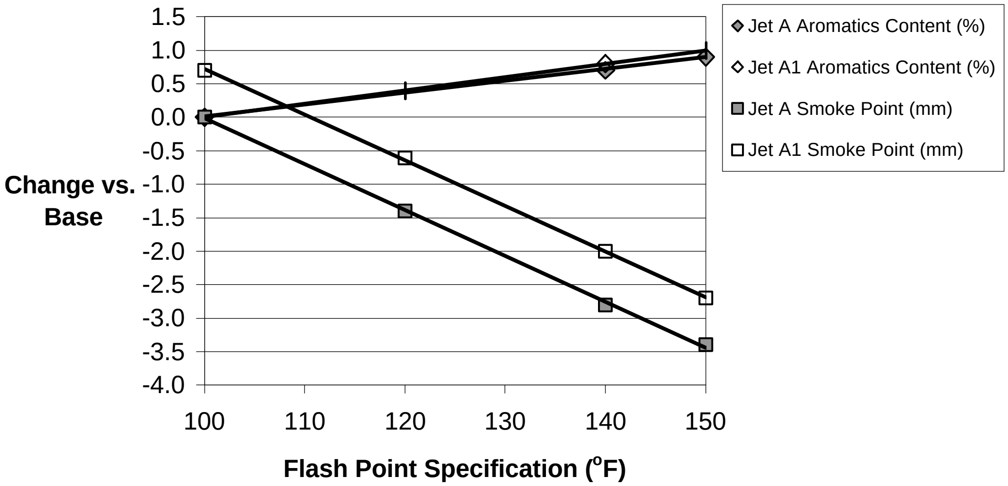
The results indicate that a flash point specification of 120°F (49°C) could result in an increase to 5.77 centistoke for the jet fuel pool viscosity at -4°F (-20°C). This is based on an estimate of 5.17 centistoke for the current jet fuel pool viscosity at -4°F (-20°C).



Section 9.2.1, Figure 3--The Changes in Jet Fuel Viscosity [at -4°F (-20°C)] and Heat of Combustion versus Flash Point found in the Jet Fuel Properties Survey

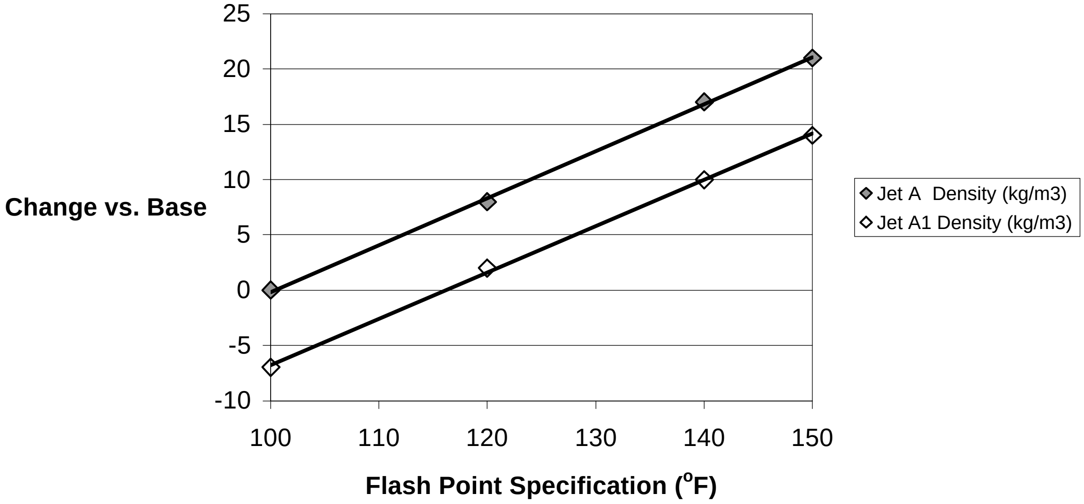
The combustion properties (aromatics content and smoke point) showed degradation in high flash point fuels (Section 9.2.1, Figure 4). The results were linear with smaller flash point changes showing smaller property changes.

These results indicate that a flash point specification of 120°F (49°C) could result in an increase of the average jet fuel aromatics content to 19.0% and a reduction in the average smoke point to 20.3mm. This is based on current jet fuel pool estimates of 18.6% for aromatics content and 21.7mm for smoke point.



Section 9.2.1, Figure 4--The Changes in Jet Fuel Aromatics Content and Smoke Point versus Flash Point Specification found in the Jet Fuel Properties Survey

The density shows a small, linear increase as the flash point specification increases (Section 9.2.1, Figure 5). Based on an estimate**Error! Bookmark not defined.** of the current jet fuel pool density of 814 kg/m^3, a flash point specification of 120°F (49°C) would increase the average jet fuel density to about 822 kg/m^3.



Section 9.2.1, Figure 5--The Changes in Jet Fuel Density versus Flash Point Specification found in the Jet Fuel Properties Survey.

The heat of combustion was slightly negatively impacted by increased fuel flash point specifications (Section 9.2.1 Figure 3).

On average, jet fuel sulfur content was essentially unaffected by the changes in distillation.

9.2.1.3 The Impact of Modified Jet Fuel Refining

An increased flash point specification could cause more jet fuel to be produced to the smoke point, aromatics content, or JFTOT specification limits but the magnitude of this change cannot be estimated with current knowledge. The scenario is that an increased flash point specification could cause reduced jet fuel availability. Reduced availability could invite refiners to maximize jet fuel yield by blending refinery streams, not normally used for jet fuel, as jet fuel. For example, kerosenes from catalytic crackers and coker units have high aromatics contents, low smoke points, and poor thermal oxidative stabilities. If hydrotreated to improve stability, these can be blended as jet fuel but generally are not because the increased yields are small compared to the effort required to maintain compliance with the limiting smoke point, aromatics, and JFTOT specifications. A shortage of jet fuel could result in incentives for using these streams in jet fuel with the result that the jet fuel pool would shift towards the specification limits with regard to these properties.

Another possibility that cannot be quantified on the short time scale of this study is that an increased flash point specification is likely to cause more jet fuel to be produced by severe hydroprocessing. In general, severe hydroprocessing improves jet fuel thermal stability. However the pressure to maximize productivity may lead to increased catalyst run life with resultant degradation in thermal stability in localized situations. Another issue with severe hydroprocessing is that the produced jet fuel can have poor lubricity properties. Lubricity is usually restored by blending with good lubricity fuel or corrosion inhibitor/lubricity additives.

9.2.1.4 Local Impacts

The average overall shifts in jet fuel properties resulting from an increased flash point specification, described above, may be magnified in some locations. A specific example is that the increased flash point specification may cause a high proportion of jet fuel in some local areas to be produced to the viscosity limit. The issue, here, is that some naphthenic crude oils produce jet fuels that have low freezing points and relatively high viscosities. If the initial boiling points of these jet fuels are raised to increase flash points, the viscosities will increase because the light material is removed but not much of the heaviest material. (Little change is needed in the distillation final boiling points to meet the freeze point specification.) Depending upon the extent of a flash point specification change, refineries processing primarily these naphthenic crude oils (for example some California refineries) may find the viscosity specification to be yield constraining. The result is that some jet fuel batches may have viscosities at -4°F (-20°C) very close to 8 centistoke instead of the 5.2-6.7 centistoke range predicted from the results shown above.

Another example of a possible local impact results if the increased use of severe hydroprocessing to produce jet fuel leads to a locality having predominately low lubricity jet fuel.

9.2.1.5 The Impact of Uncertainty in Fuel Properties

The uncertainty concerning the performance-related properties of a high flash point jet fuel should be viewed as a risk.[5] The impacts cannot be quantified at this time, but greater flash point specification changes increase the significance of the concerns raised above.[6] This uncertainty brings the risk that properties may shift sufficiently to impact equipment operation.

9.2.2 Fuel Property Effects on Airframes

9.2.2.1 Material Compatibility

Aircraft materials are evaluated for compatibility with jet fuels. Metals, coatings, seals and sealants are tested with a representative fuel and with a fuel that contains 30% toluene and 0.4% sulfur. Any high flash point fuel would not exceed the extremes in properties already checked since the fuel must meet the 25% aromatics and 0.3% sulfur limits in the fuel specification. No material compatibility problems in the airframe are anticipated from using high flash point fuels.

9.2.2.2 Heat Content and Density

The heat content and density of jet fuel are controlled by the fuel specification. Any higher flash point fuel would meet the current fuel specification requirements. However, on the average, a 140^{o}F(60^{o}C) flash point fuel will have a higher fuel density per gallon but a lower energy per unit weight when compared to delivered Jet A/A-1. There could be a slight benefit for those aircraft that are limited by fuel tank volume and a slight penalty for those aircraft that are limited by gross weight at takeoff. The anticipated aircraft performance change for burning a high flash point fuel (HHF) is shown in Table 1. The performance change is based on a Jet fuel with a density of 6.7 pounds per gallon and a lower heating value of 18,580 Btu per pound as compared with a high flash jet fuel with a density of 6.8 pounds per gallon and a lower heating value of 18,525 Btu per pound.

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[5] For more discussion see Section 11.4.

[6] Sections 9.2.1.3 and 9.2.1.4.

	Δ Design Range (nmi) Constant TOGW, Payload	Δ Range at Fuel Volume Limit (nmi) Constant Payload, Fuel Volume	Δ Payload (lbs) Constant TOGW, Range	Δ Block Fuel (%) Constant Payload, Range
Airplane	HFF - Jet A	HFF - Jet A	HFF - Jet A	$\frac{\text{HFF - Jet A}}{\text{Jet A}}$
737-300	-6	40	-52	0.3%
737-700	-7	60	-48	0.3%
747-400	15*	85	-753	0.4%
757-200	-9	50	-114	0.3%
767-300	60**	60	-347	0.4%
777-200	-23	100	-539	0.4%

* Fuel volume limited with Jet A
** Fuel volume limited with both Jet A and High Flash Fuel (HFF)
TOGW - Takeoff gross weight

Section 9.2.2.2, Table 1--Delta Change in Airplane Performance with High Flash Point Fuel.

The changes identified in Table 1 would result if the flash point was increased by 20^{o}F(11^{o}C). [See section on fuel property effects predictions for property changes versus flash point increase.] For the U. S., 120^{o}F(49^{o}C) minimum flash point fuel will not differ significantly in heat content and density from the currently delivered Jet A fuel and no impact to range or payload is expected.

9.2.2.3 Freezing Point

The requirement for freezing point of jet fuel is independent of flash point. The requirement is to deliver to the engine fuel with a temperature 5.4^{o}F(3^{o}C) above its freezing point. For Jet A, the pilot must initiate action to keep the fuel from getting any colder if the fuel temperature reaches -35^{o}F(-37^{o}C). A high flash point fuel is not expected to behave differently from other kerosene fuels. Currently the freezing point of delivered Jet A in the U. S. averages well above the specification minimum of -40^{o}F (-40^{o}C). Although airlines do not take advantage of the better than specification minimum fuel, aircraft have operated with additional margin as a result of the product quality give away.

The freezing point of Jet A is becoming an issue for the new routes opening up over the Northern latitudes. The fuel temperature in wing tanks can get as low as -44^{o}C(-47^{o}F) during long range flights on polar and Siberian routes in the winter. A Jet A type of fuel may not be satisfactory for commercial aviation operations on these routes in the winter. Some aircraft dispatched from the U. S. may require a lower freezing point fuel. The need for a low freezing point fuel is currently being assessed by the airlines. Implementing a high flash point fuel is likely to end the freezing point quality give away currently being provided to the airlines and end all efforts to identify the actual fuel freezing point at the time of refueling.

9.2.2.4 Viscosity

Viscosity at low temperatures is an engine and APU concern and not an issue in the airframe fuel system (see Section 9.2.3).

9.2.3 Fuel Property Effects on Engines and Auxiliary Power Units

9.2.3.1 General

This section describes how the predicted changes in fuel properties, as flash point requirement is increased, could affect gas turbine engine operability and performance. This information is presented as a consensus view based analysis of fuel property information provided by API in its survey and model reported in 9.2.1 and inputs from engine and APU manufacturers within Task Groups 6 and 7. The engine manufacturers considered a wide range of engine types, thrust ratings and aircraft applications (turboprop, turbojet and turbofan designs have been included in the deliberations).

Engine and APU aerothermal and fuel delivery system performance, integrity and durability are affected in many complex ways by the properties of fuel being used. Section 9.2.3, Table 1 which is included as Appendix 4, summarizes the potential impact changes in fuel properties can have on engine and APU operation. The proposed increase in flash point would, if achieved without change to other fuel properties, have minor effects on engine/APU operability but would not improve the overall safety of these units. However, the API model calculations clearly indicate that in order to achieve production that meets the current demand for jet fuel there would be a significant shift in several important fuel properties. It is therefore important to consider the impact of all these property changes when assessing the overall risks and benefit of increasing fuel flash point.

Since most civil engines and APUs are approved to run on both JetA/A-1 and military high flash point JP-5 it would appear that if the proposed fuel fell within these bounds there would be no problems or risks associated with its use. This is, however, a gross over-simplification.

As the flash point requirement rises, predicted fuel properties and combinations thereof increasingly depart from current experience of either Jet A/A-1 or JP-5 both in-service or used in validation testing. Further, API input clearly indicates the use of alternative raw materials and processes to recover yields to current levels may result in hitherto unknown changes in fuel properties by, for instance, the introduction of new molecule types/species.

The following paragraphs highlight the most important implications of operating on the fuel types predicted by the API model calculations described in Section 9.2.1.2. The predicted effects on engine and APU operation are our best judgment at this time given there is no operating experience for a civil flash point modified fuel and only very limited documented experience of extended civil operation with military JP-5 fuels. It is also important to note that the model only provides predicted mean values; no population data is available to indicate value distribution around the mean or variations between geographic locations. The full range of possible scenarios cannot therefore be addressed.

Testing to evaluate the effects and provide quantitative data would be required to assess the impact on the engine/APU in many instances. Such testing would have to be carried out on referee fuels manufactured specifically to represent examples of the fuels likely to be encountered in service. The type of testing which may be required is described under the fuel property headings below and may include laboratory, rig or full engine testing. (In service monitoring may also be required to determine long term effects). An internationally coordinated and funded program would be an appropriate way forward.

9.2.3.2 Flash Point and Distillation

Progressive increases in flash point and the associated change in distillation will by definition reduce fuel volatility. This makes combustion initiation more difficult under adverse conditions such as altitude relighting and cold starting. The potential impact becomes increasingly severe as the flash point increases. Task Group 6/7 is concerned that high flash point fuels could adversely impact both ignition performance and/or engine start times at the extremes of the relight envelope and on the ground during cold temperature starting.

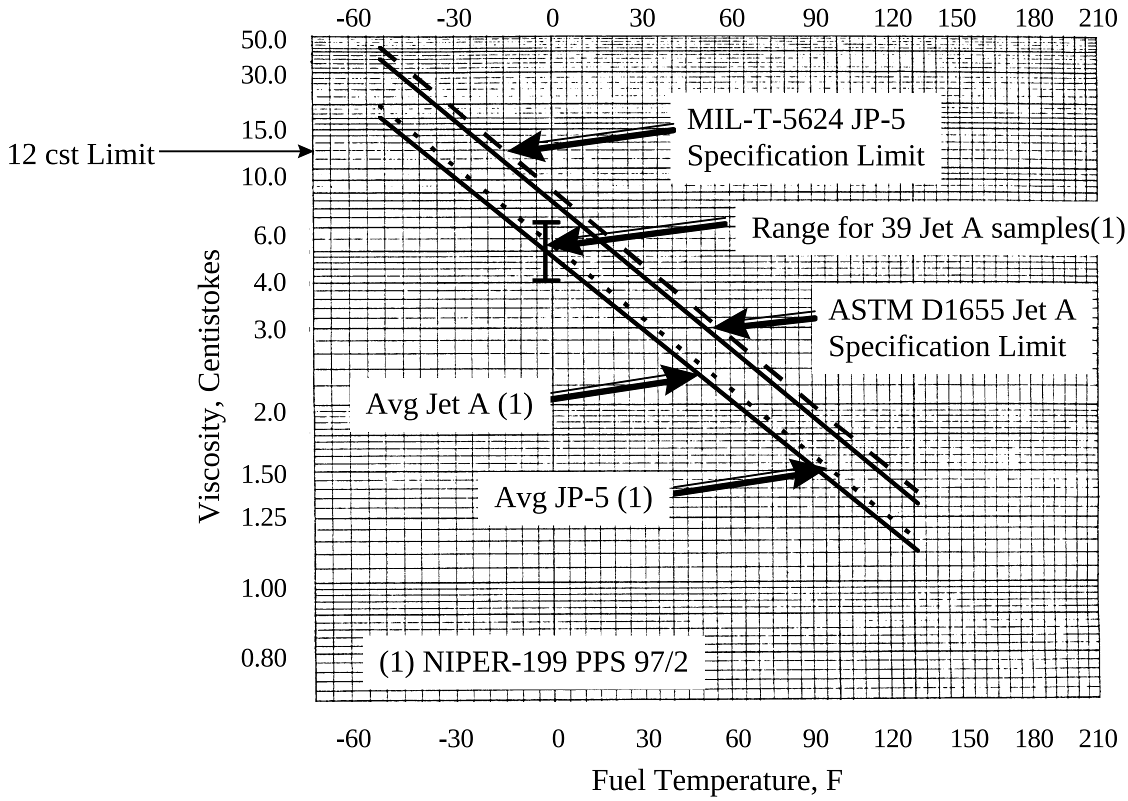
The requirement to fully evaluate the actual impact on ignition and relight performance would be a serious consideration for the higher reference flash point fuels.

Mitigating actions include re-scheduling of fuel control systems, or revision of the engine relight envelopes.

9.2.3.3 Viscosity

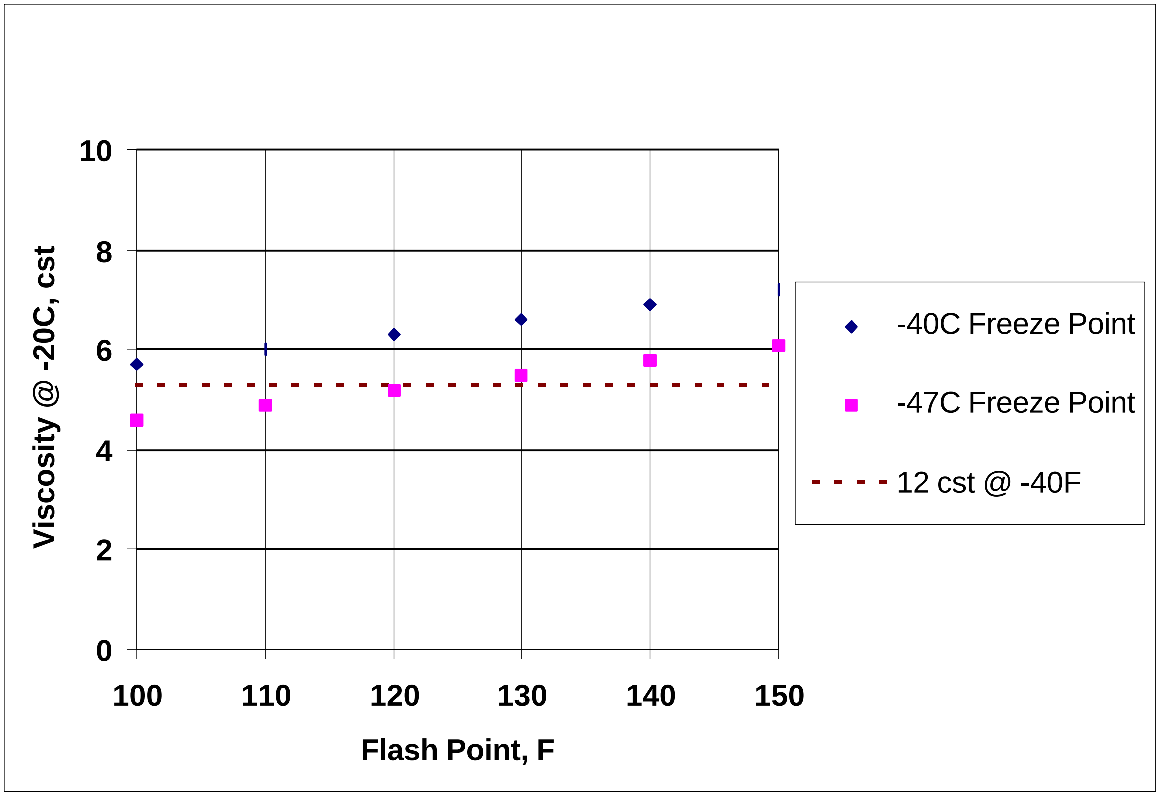
Main engines and APUs are designed to start and operate using a variety of kerosene and wide-cut fuels, up to a maximum fuel viscosity of 12 centistokes (cSt). At extreme cold start conditions the viscosity becomes the prime limiting factor. With the current pool of jet fuels, engine cold starting has not presented a significant problem in the continental United States (U.S.) or Europe. However, engine cold starting is an operational concern in extreme cold conditions (see Section 11.2).

Section 9.2.3.3, Figure 1 shows fuel viscosity as a function of temperature for Jet A and JP-5 fuels. As shown, the current ASTM D1655 specification maximum Jet A fuel (8 cSt max. at –20°C) can reach the 12 cSt viscosity limit at approximately –20°F, However, the viscosity range for current jet fuels is well away from the specification limit. For reference, the U.S. mean jet fuel viscosity is approximately 5 cSt at –20°C (Section 9.2.3.3, Reference 1) and the United Kingdom (UK) mean viscosity is approximately 3.8 cSt at –20°C (Section 9.2.3.3, Reference 2). Note that Europe and the UK use Jet A-1 fuel, which has a lower freeze point than Jet A fuel (usually accompanied by lower fuel viscosity).



Section 9.2.3.3, Figure 1--Fuel Viscosity as a Function of Temperature

The API survey has indicated that an increase in the commercial jet fuel flash point would result in an increase in fuel viscosity. A high flash point fuel will therefore reach the 12 cSt maximum viscosity limit at a higher temperature than current commercial jet fuels. Section 9.2.3.3, Figure 2 shows the API predicted fuel viscosity at –20°C as a function of the fuel flash point. As seen in Figure 2, any increase in flash point will increase the average viscosity above current levels for Jet A (-40°C freeze point) fuel, and for any increase above approximately 130°F for Jet A-1 (-47°C freeze point) fuels.



Section 9.2.3.3, Figure 2--Predicted Fuel Viscosity as a Function of Fuel Flash Point

As the fuel viscosity exceeds the 12 cSt point, there will be an increasingly deleterious effect on fuel atomization. The combination of increased viscosity and reduced fuel volatility with the high flash point fuels could result in slow and difficult engine starting, or a no-start. An increase in engine ground start problems in cold weather would be a major operability concern. Engines that currently have a reduced operating envelope (higher minimum operating temperatures) when using high flash point JP-5 fuel, may need to also restrict cold weather operation with a commercial high flash point fuel.

An additional concern would be APU starting during or after a long flight, or after extensive time on the ground in extreme cold conditions. APU ground start problems could result in an increase in flight delays while backup ground start carts are brought up. Cancellations of some flights (ETOPS) may occur if there is significant risk of the APU failing to start after long flights. See Section 9.2.3.10 for additional information on the effect of fuel property changes on APU operation and mitigating actions.

The risk of engine and APU cold starting problems could be mitigated by revising the viscosity limit to a maximum of 12 cSt at -40°C. Based on a viscosity correlation provided by the petroleum industry, a fuel viscosity of 5.3 cSt at -20°C corresponds to a viscosity of 12 cSt at -40°C (-40°F). Further study on reference fuels would be required to finalize this value.

Comparison of the U.S. data (Jet A -freeze point -40°C) and European data (Jet A-1 -freeze point -47°C) also shows that to some extent the higher viscosity levels are avoided when a -47°C freeze point is specified. The downside of changing U.S. production to -47°C would introduce further yield limitations over and above the levels already predicted by the API/EUROPIA survey (see Section 12.2, Appendix 14.1 and 14.2).

Increased viscosity would also slightly reduce the heat transfer efficiency of fuel/oil heat exchangers, and cause increased oil temperatures. Fuel injector cooling by the fuel will also be reduced slightly by the same effect. These effects need to be modeled or tested using the target properties of the proposed high flash point fuels to determine the ultimate impact (if any) on component or system operation and durability.

9.2.3.4 Aromatics and Smoke Point

The relatively small increase in aromatics levels from 18.0 (for 100°F flash) to 19.0% (for 150°F flash) are not of concern per se. The decrease in smoke point which is closely related to aromatic content and type does however change significantly, falling from 22-23 mm for 100°F flash point fuel to 19 mm for 150°F flash (current minimum is 18 mm). Based on established relationships between aromatics level and smoke point, this data implies that either the aromatic types would be changing with potentially increased multi-ring species, or, there is inaccuracy in the smoke point prediction. Assuming the model is correct the changes have two potential impacts:

1. Aromatics content and type influence swell of certain elastomer types. Significant change from current swell levels could cause seal problems leading to potential additional corrective maintenance actions.

2. Lower smoke point fuels have lower combustion quality. Such fuels increase the potential for smoke and flame radiation reducing overall hot-end durability. The magnitude of these effects and impact on operating costs are likely to be engine type specific.

Laboratory testing on reference fuels to evaluate elastomer compatibility and impact on emissions and hot-end durability may be appropriate when the revised specification is finalized. Increasing the minimum smoke point specification requirement is an option that should be given serious consideration to offset combustion-related problems.

Given the predicted downward shift in combustion properties the current requirements for certification emissions testing reference (see Section 9.2.5.1) may need to be redefined for future engine certifications.

9.2.3.5 Total Sulfur Content

The API model did not predict any impact on the sulfur level of the final product. Any increase in sulfur level from the initial distillation would be offset by the use of hydroprocessing. No significant effect of fuel sulfur content on engine operation is expected.

9.2.3.6 Thermal Stability

No quantitative data is available on the impact of the proposed changes in flash point on thermal stability. The API survey identifies that there will be an increasing incentive to use less desirable streams and processes to offset the reduction in yield. This has the potential to reduce both storage and thermal stability of the fuel pool. Conversely, there are indications that increased use of hydrogen-based processing will be used, which could improve thermal stability.

A significant reduction in the stability of the fuel pool would increase deposition and consequent fouling of fuel control units and injectors, increasing operating costs due to the increased maintenance. The magnitude of this effect cannot be estimated with the current data, which is only qualitative. Laboratory and rig scale testing would provide a quantitative prediction on the long-term impact of using these fuels.

At this stage removal of the two tier thermal stability limit present in the ASTM D1655 specification and introduce a single requirement of 260°C, or higher, could mitigate thermal stability related problems.

9.2.3.7 Freeze Point (Cold Flow Properties)

Freeze point (the point at which wax-like crystal disappears when warming the fuel) is one of the primary yield limiting parameters. To maximize jet fuel yield, high flash point fuels may be much nearer to the freeze point than at present (less margin). Also, the increased use of hydrocracked product will lead to a much sharper transition between liquid and almost solid phases. Pour points of the fuel (the temperature at which the fuel will not flow) are likely to be much closer to the freeze point and potentially there will be changes in crystal size distribution compared to existing fuels.

Engine fuel systems are designed on the assumption that fuel is free from wax and water crystals at the entry to the low pressure (LP) fuel filter, so filter element blockage will not occur under normal circumstances. Most engines use a fuel/oil heat exchanger to heat the fuel prior to entering the LP filter, which will prevent filter blockage during operation (not during cold starting on the ground however). For engines without an upstream fuel heater or a filter bypass, LP filter blockage is considered a hazard to engine safety. However, low pressure filter blockage by wax crystals would normally only cause bypass flow warnings and require subsequent maintenance action.

Given the potential changes in cold flow properties of the high flash point fuels, evaluation is required to ensure heat input to fuel is sufficient to ensure that very cold fuel will un-freeze prior to the low-pressure fuel filter.

9.2.3.8 Lubricity (Lubricating Quality)

Pressure on the producers to maintain yield will almost inevitably result in increase the use of hydrocrackers, hydroprocessors and the possible blending of synthesized product. These types of processes reduce fuel lubricity significantly. Low lubricity fuels can cause increased wear rates in pump and control system components. This is primarily a component life limiting issue and hence operating cost would increase if lubricity reduced significantly. However, recent isolated incidents have demonstrated that with a continuous diet of poor lubricity fuel sudden component failure can occur.

Lubricity is not currently a specification test requirement. Inclusion of a lubricity requirement in the specification would significantly reduce the risks described. However, further debate is required to define the limit to be imposed and how it would be applied. An alternative option is to increase the use of lubricity improving additives. If it became necessary to use these additives on a regular basis this would incur cost and logistics penalties.

9.2.3.9 Heat of Combustion and Density

Predicted changes in both heat of combustion and density are not expected to adversely impact engine performance. Lower heat of combustion will increase fuel consumption (on a weight basis). A significant shift in the population of density or heat of combustion or the established relationship between these two parameters may necessitate re-calibration of fuel control units and flowmeters. Note that flowmeters may also be sensitive to viscosity changes.

9.2.3.10 APU Operational Impact

The Auxiliary Power Unit (APU) is a small gas turbine engine used on all major transport aircraft and on most regional and executive aircraft. The APU is typically used as a power source for the aircraft air-conditioning units and electrical systems during ground taxi and gate operations, and as a power source for main engine starting during rollback from the gate. The APU is only used in-flight as an alternate electrical source in the event of a failure of a main engine generator.

Under normal conditions the APU is considered non-essential equipment. Non-essential equipment may be non-operational without jeopardizing safe operation of the aircraft either on the ground or in-flight. There are certain conditions however, when the APU is considered essential equipment on the aircraft minimum equipment list. Essential equipment is necessary for maintaining safe operation of the aircraft either on the ground or in-flight. For example, the APU may be considered essential equipment for ETOPS (Extended Twin Operations) flights, where a twin-engine aircraft is more than a specified flight time away from an airport (such as on most overseas flights). To obtain and maintain an ETOPS rating, an APU must demonstrate reliable altitude and cold starting capability, usually up to the maximum aircraft cruise altitude (some ETOPS APUs must be operating prior to entering the ETOPS flight leg). This is significantly different than main engine relight requirements, which are typically only up to 20 to 25 thousand feet altitude.

Since the APU compartment is usually not heated, the APU and the fuel are cold soaked at the prevailing total air temperature conditions in-flight. Some regional and executive aircraft do not have an APU inlet door, resulting in increased airflow through the engine during flight with a corresponding decrease in time to stabilize at the cold soak temperature. Even with a closed APU inlet door, the APU and fuel are usually stabilized at the cold soak conditions after three to four hours in-flight. Typical APU cold soak temperatures for a long range flight would be in the -20°F to -40°F range, but they can be significantly lower for extreme cold or arctic conditions. The combination of the high altitude and extreme cold soak requirements make APU starting a major design consideration. APU usage varies considerably depending on the operator, the aircraft type, and any local airport restrictions, but the APU is frequently started after landing and prior to arriving at the gate.

APUs are designed to start and operate using a variety of kerosene and wide-cut fuels, up to a maximum fuel viscosity of 12 centistoke. The refinery survey has indicated that an increase in the flash point of commercial jet fuel would result in an increase in fuel viscosity. The combination of reduced fuel volatility and increased viscosity with the high flash point fuels could result in slow and difficult APU starting, or a no-start. Of particular concern would be APU starting during or after a long flight, or after extensive time on the ground in extreme cold conditions. APU ground start problems could result in an increase in flight delays while backup ground start carts are brought up, or cancellations of some flights (ETOPS).

If the fuel flash point is increased over current levels, addition of a fuel heater at the APU inlet may be required to maintain the fuel temperature above that corresponding to a maximum viscosity of 12 centistoke, to ensure reliable starting for all ambient conditions. Detailed measurement of fuel temperatures at the APU fuel control inlet for various aircraft would be required to fully evaluate the impact of a fuel flash point change on APU starting. The fuel heater could be run off the APU battery in-flight, using the existing battery charger powered by the main engine generators. The fuel heater could only be used on the ground when the electric power was provided by the gate in order to prevent the APU battery from being discharged too low for subsequent starts. Retrofit requirements for an APU fuel heater are provided in Section 8.2, with cost information provided in Section 12.6.2.

9.2.4 Ground Infrastructure & Fungibility

Raising the minimum flash point of jet fuel would not impose significant constraints on the U.S. fungible pipeline system. However, this is based on the assumption that this constitutes a change in the current fuel specification as opposed to adding an additional grade of jet fuel. (See Section 6.3 for additional information on pipeline transportation).

There are significant differences in the operation of multiproduct pipelines between Europe and the U.S. Traditionally, Europe has adopted a process of recertification after any movement of jet fuel where contamination with the products can occur. In this process, contamination sensitive properties such as distillation, flash point, freeze point, existent gum are measured after the operation and results compared with the original values. If any of the values have changed by more than permitted amounts (based on reproducibility of the test method), contamination is suspected and an investigation is conducted.

In the corresponding U.S. process, the fuel is simply tested against the specification. Provided that the values still meet the specification, all is well. Traditionally, pipeline companies set specifications for entry into their systems which exceed the product specification by a considerable margin to give them a buffer to absorb the effect of cross grade contamination.

Entry specifications for flash point in the U.S. are significantly higher than the flash point minimum, probably reflecting the potential for contamination with gasoline. In Europe, jet fuel is usually buffered between gas oil or diesel tenders (no likelihood of a flash point decrease even if contamination occurs). In the U.S., the lower demand for gas oil/diesel increases the likelihood that jet fuel will be buffered by gasoline tenders thereby increasing the risk of flash point reduction from interface mingling. The net effect of this is that jet fuel is normally produced much closer to the minimum flash point specification than in North America.

9.2.5 Environmental Effects

9.2.5.1 Aircraft Emissions

Since the 1980's, gas turbine engine emissions have been regulated by the U.S. Environmental Protection Agency (EPA) as defined by 40CFR Part 87, Control of Air Pollution from Aircraft and Aircraft Engines; Emission Standards and Test Procedures. Within this regulation visible emissions (smoke) are regulated on all turbo-prop engines with a shaft horsepower of 1000 kW (1340 HP) or greater, and all gas turbine engines, Class T3, T8, and TF, of a rated output of 26.7 kN (6000 # Fn) thrust or greater. The invisible emissions (unburned hydrocarbons, carbon monoxide and oxides of nitrogen) are regulated for all gas turbine engines, Class T3, T8, and TF, of a rated output of 26.7 kN (6000 # Fn) thrust or greater. The current regulatory levels are:

Unburned Hydrocarbons - 19.6 grams/ kilonewton
Carbon Monoxide - 118.0 grams/kilonewton
Oxides of Nitrogen - (40 + 2 (Rated Pressure Ratio))g/kN
Smoke For T3, T8 & TF Class - 83.6 (Rated Output, kN)^ -0.274 SN

The engine manufacturer's approach to meeting emission regulations has been by careful design of both the fuel injectors, and the combustors into which these fuel injectors fit. Because of this, most modern gas turbine engines have emissions levels which are well below the regulatory values noted above, and the slight influence of fuel properties has not been considered that important. It is considered unlikely that the changes in fuel's properties will drive any engine over the regulatory limits. If some particular engine model is required to recertify, there will be some cost to the manufacturer, in as much as three engine tests are required plus the cost of the report.

If and when a higher flash point commercial fuel is selected, the engine manufacturers will have to emissions test their engines to determine how emissions levels have changed. This is necessary because stationary facilities, such as airports, are required to do an emissions inventory (including aircraft emissions) and report the results of these surveys to the EPA. Any increase in emissions must be reported.

Based on the fuel properties extrapolations done by API, and for a significant (+40 degrees F) increase in fuel flash point, increases in fuel viscosity, density and surface tension will generally result in slightly larger fuel droplets from the fuel injectors at the engine idle operating condition. This in turn reduces the initial vaporizing rate of the fuel, which can result in local fuel rich pockets in the combustor primary burning zone. These rich pockets, when burned, produce fractionally higher levels of unburned hydrocarbons and carbon monoxide. Further, if the increase in fuel flash point does result in higher aromatics for the pool of fuels available, then it is possible that smoke emissions will increase slightly for some engine models. But for many engine models this increase will be so small as to lie within the ability to measure smoke level.

Relative to fuel properties, there is insufficient information to analytically quantify how emissions would change. Studies of fuels effects done by the Air Force in the late 1970's and early 1980's, were done on combustor and fuel nozzle designs that have been superseded by the technology used in today's engines. The only way to determine the fuel property change effects on engine emissions would be to test today's engines.

In summary, it is felt that increasing fuel flash point could cause some, very minor, increases in gas turbine emissions levels, depending on how large a flash point change is selected. Up to about a 15 degree increase in flash point it is unlikely that the change in important fuel properties would be sufficient to cause measurable change. As the selected value of flash point increases away from the current fuels, it becomes more likely that engine manufacturers will have to run emissions tests on their engines to (1) quantify the increases in emissions levels for airport operator's reports to the EPA and (2) assure that engine models did not exceed EPA regulatory values for those engines which might now be marginal in a particular contaminant.

9.2.5.2 Jet Fuel Manufacturing Emissions

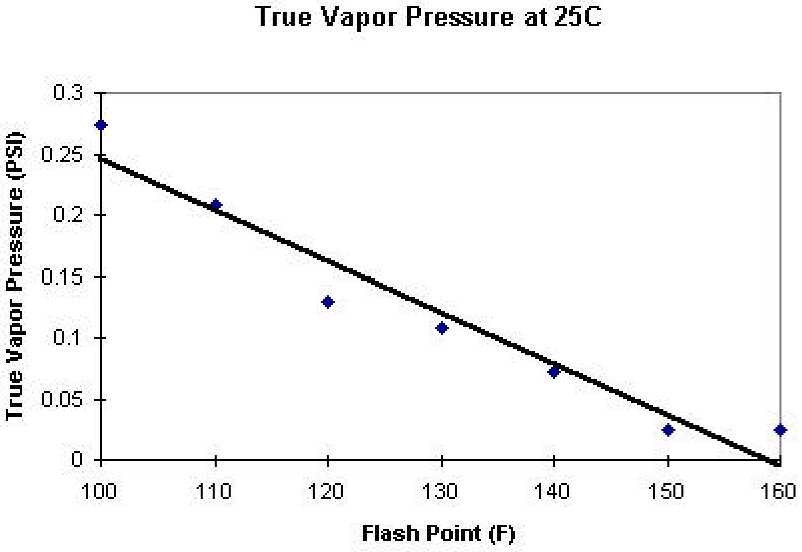
CONCAWE, the European oil industry organization for environmental, health, and safety, examined the effects of changing the jet fuel flash-point specification in the range of 100°F to 140°F. The study involved an assessment of the effects on distillation yields and an assessment of an EU refining simulation evaluating the overall impact and remedial actions to restore the specified future demand quantity.

CONCAWE determined that restoring the jet demand would involve substantial European investments in hydrocracking of approximately 25 million tons per year (Mtpa) additional capacity with associated investments in hydrogen generation facilities. The additional energy use in hydrocracking as well as the extra hydrogen consumption leads to an increase in CO2 emissions estimated at 7-8 Mtpa.

The Task Group recommends that a linear interpolation of this data be used, which leads to an estimated increase in CO2 emissions of 1.75-2 Mtpa per 10°F increase in jet flash-point for the EU-15 countries. The increase in CO2 due to a 10°F increase in jet fuel flash point would add about 1% to the total CO2 emissions from EU-15 refineries. However, as a result of the Kyoto conference, there is a worldwide pressure to reduce overall CO2 emissions.

9.2.5.3 Evaporative Emissions

Evaporation of fuel from tanks at airports, terminals, and refinery storage tanks depends on the vapor pressure of fuel at ambient temperatures. Because jet fuel is a mixture, the amount of fuel that can evaporate varies as a function of ullage to fuel volume, the amount of weathering of the fuel, and other factors. One way to obtain an estimate of the amount of evaporative emissions that can occur is to examine changes in the true vapor pressure with flash point. The true vapor pressure is the pressure exerted by vapors of a fuel in equilibrium at a specific temperature when the ullage to liquid volume ratio tends to zero. Using the data of Section 9.2.1 and ASTM D2889, the true vapor pressure at 25^{o}C as a function of flash point for jet fuel with a freezing point of -40^{o}C can be determined as shown in Section 9.2.5.3, Figure 1. Fuel with a freezing point of -47^{o}C should have comparable values.



Section 9.2.5.3, Figure 1--True Vapor Pressure of High Flash Jet A Fuel

Evaporative emissions should be reduced with increasing flash point as the ratio of the true vapor pressure. Section 9.2.5.3, Table 1 shows the approximate reduction in evaporative emissions anticipated.

Flash Point (^{o}F)	**% Reduction in Evaporative Emissions**
100	0
110	24
120	53
130	60
140	73
150	91

Section 9.2.5.3, Table 1--Reduction in Evaporative Emissions with Increasing Flash Point

Since its initial boiling point and T10 distillation point largely drive a fuel's vapor pressure, raising the minimum flash point will lower the vapor pressure of jet fuel, further diminishing its already low evaporative emissions.

9.2.6 Additives in High Flash Jet Fuels

Additives are used in jet fuel to affect its properties. In general, additives are effective when used to control minor constituents in the fuel, or when they are used to affect some property, which is sensitive to minor constituents. Additive concentrations, with one exception, are in the parts-per-million range. Bulk properties are not normally affected. Hence, it is not anticipated that an additive could be found which could affect flash point, freezing point, distillation, or other compositional properties.

A variety of optional and mandatory additives are used in jet fuels. The probable changes in performance, and any increased need for these additives are discussed in the following paragraphs.

9.2.6.1 Antioxidants

These additives are used to prevent the formation of peroxides during storage of fuels that have been hydrogen-treated. Use of 17-24 parts per million (ppm) is mandatory in hydrogen –treated fuels outside the U.S. and in U.S. Military jet fuels. Use is optional in jet fuels meeting ASTM D 1655. The performance of these additives is unlikely to show any dependence on the flash point of the fuel; they have been used effectively in JP-5 high flash fuel for many years.

While the need for antioxidants is not affected by flash point, a somewhat larger fraction of jet fuel outside the U.S. might require them if hydrocracking or other hydrogen-treating processes are used to maximize the availability of jet fuels.

9.2.6.2 Metal Deactivator Additive

Metal deactivator additive (MDA) is used in jet fuel to counter-act the tendency for dissolved trace metals to reduce stability of jet fuel during storage and during high temperature exposure in the turbine engine. A small proportion of jet fuel is treated with MDA, mainly when minute traces of copper could be dissolved in fuel during refining or during transportation. Use of 2 – 5.7 ppm of this additive is optional. No change in performance or the frequency of use for this additive is expected based on flash point considerations.

9.2.6.3 Static Dissipator Additive

Static dissipator additive (SDA) use is optional in U.S. civil jet fuels meeting ASTM D 1655, but is mandatory in some military jet fuel requirements and in most other civil jet fuel specifications. This additive increases the fuel conductivity and hence aids in dissipating electrostatic charge that has been generated by the fuel passing through filters used during fuel transportation and at airports. Minimizing the static charge is necessary to prevent the possibility of a spark that could ignite fuel vapors or mists. Increasing the flash point may not change the need for this additive, especially if lower flash point jet fuels (TS-1 and Jet B) may still be present in aircraft tanks.

An increase in the minimum flash point of jet fuel would require an increased concentration (normally 0.5 to 1.5 ppm) of SDA to give the necessary conductivity increase, but will not otherwise affect performance. Studies (see 9.2.1) show that jet fuels with higher flash point will have a higher average viscosity, and the performance of SDA will be slightly reduced since response is, in part, determined by this property.

9.2.6.4 Corrosion Inhibitor/Lubricity Additives

These additives are required at concentrations of 9-15 ppm in military jet fuels to improve the lubricity of jet fuel in engine parts such as pumps and engine controls, and can be used in civil jet fuels with the permission of the purchaser. Currently, a very small portion of civil jet fuel contains lubricity improver additive. Lubricity of hydrogen treated fuels is variable and may be poor; lubricity of non-hydrogen treated jet fuel is normally adequate. A steady diet of poor lubricity fuel can cause component failure in flight. It is known that only a few percent of fuel with good lubricity needs to be commingled to give satisfactory performance. Military aircraft operating from fixed bases may not benefit from commingling and wear problems have been eliminated by use of lubricity additives.

Except in very rare circumstances, civil aircraft receive an adequately varied fuel diet to ensure good performance, and these rare circumstances are being managed satisfactorily. However, the current equilibrium might be disturbed by significant changes in fuel production methods and distribution, and the potential for serious lubricity problems in a rapidly changing situation should not be taken lightly. Lubricity properties are a current concern in jet fuel specification activities.

Corrosion inhibitor/lubricity additives may be added at any point during distribution. Currently, broad use of this additive in civil fuels is inhibited by specification requirements, which usually require acceptance by purchasers. These additives have a negative effect on the performance of filter coalescers used to remove particulates and water from jet fuels. Improved coalescers being developed for military use have increased resistance to these and other additives, and might reduce the risks of using lubricity improvers. At this time, however, broad use of lubricity improver is strongly inhibited by water separation concerns.

9.2.6.5 Fuel System Icing Inhibitor (Anti-icing Additive)

This additive, diethyleneglycol monomethyl ether (DiEGME) is used in high concentrations (0.10 to 0.15 volume percent) relative to other additives. It dissolves in water, which may precipitate from the fuel and prevents freezing in cold climates or at high altitude. Large commercial aircraft with filter heaters do not require this additive, but many small aircraft need it. Because this additive has been used successfully in JP-5 for many years, there is no reason to expect any change in efficacy, or to expect any change in the need for its use.

9.2.6.6 Miscellaneous Additives

- Biocides are used intermittently in some aircraft to inhibit microbiological growth. There will be no change in the need for or the performance of these additives.

- Tracer A is a new additive being developed for intermittent use to detect leaks in airport fuel hydrant systems. There will be no change in the need for or performance of this additive.

- JP-8+100 Stabilizer is a new additive being developed for use in military aircraft, to improve the thermal stability of jet fuel. While not yet approved for use in civil fuels, this additive is likely to be used in the future. There is no likely change in performance of this additive based on flash point alone, but these additives have performed differently in different fuels. If unusual components are more commonly used to meet flash point and availability, the need for the additive could increase or new formulations may have to be developed. Improved filter coalescers, under development for military use of this additive, would probably be required. Use concentrations are 100 ppm or higher.

9.2.6.7 Research Opportunities for Additives

Freezing point is a property that is a strong function of the types of molecules present in the fuel. It is highly unlikely that wax solubility could be affected by an additive. However, pour point depressants could affect flow properties at low temperature. These work by altering the size of the wax crystals formed. While this has worked well in diesel fuels, there are occasionally times when agglomeration of the wax occurs, causing operational problems. This would not be tolerated in aircraft. However, if the jet fuel specifications were changed to a minimum pour point instead of freezing point, and better additives were developed, increases in productivity would occur. It is unlikely that this research effort and related no-harm testing could be completed in less than five years.

10.0 AIRWORTHINESS REQUIREMENTS

Based on the API model predictions, a higher flash point fuel is likely to depart from the current engine and API test and service experience in terms described previously. The magnitude of changes is increasingly severe as flash point increases.

Possible mitigating actions to off-set adverse impacts on engine and APU operation (where available) were discussed in Section 9.2.3. These include:

- Hardware modifications, adjustments and re-calibrations
- Revisions to the fuel specification requirements in additions to the increase in flash point
- Revised aircraft operational limits

The influence on airworthiness may be initially modest with respect to main powerplant considerations for minor increases in flash point, to requiring significant corrective actions for the highest flash point fuels. Moreover, there is the potential for the APU to be significantly affected by relatively small increases in the flash point.

Dependent on the magnitude of changes in fuel properties, specification limits, and hardware changes, further actions may be required by the engine, APU, hardware (e.g., fuel system unit and component) manufacturers and airworthiness agencies to ensure that civil airworthiness requirements continue to be met.

11.0 SAFETY

11.1 Operation on Low/High Flash Fuels

Commercial airlines make frequent flights to other parts of the World and it is unknown if some parts of the World will, or will be able to change to a high flash point fuel. Therefore aircraft will continue to uplift low flash fuels particularly in Russia and the Commonwealth of Independent States (C.I.S.). Defueling and the transfer of fuel between tanks is not practical for commercial operations. In today's global market, there is no practical way to avoid mixing fuels from different parts of the world.

European airlines with a high number of flights to Russia and the C.I.S will have the greatest exposure, uplifting approximately 35% of the fuel required in these States.

Aircraft manufacturers will also need to continue to certify aircraft for safe use of these fuels particularly when sold to an operator in these regions.

11.2 Operation in Cold Climates

11.2.1 Canada

From the Canadian point of view, an increase in flash point of kerosene-type aviation fuels would be a move in the wrong direction. Increasing the flash point would reduce the more volatile, low-boiling components of the fuel, which in turn leads to an increase in viscosity and exacerbates an already tenuous cold starting situation. Cold starting problems and "hung starts" are currently not uncommon during cold weather operations at major Canadian airports such as Winnipeg and Edmonton, even though these airports operate on Jet A-1 fuel. In the far north, commercial operations are mostly on Jet B / JP-4 although some Jet A-1 is in use.

Additionally, the Air Element of the Canadian Forces, despite a total conversion to kerosene-type fuels by all its allies, continues to use wide-cut JP-4 as its standard fuel for all land-based operations in order to insure starts under all conditions at any time of the year. A one-year trial of JP-8 at a Canadian Forces base located near Vancouver proved unsuccessful due to starting problems, particularly with rotary aircraft. The base reverted back to JP-4 following the trial period.

In the Canadian view raising the flash point of kerosene fuels will, in all likelihood, create more problems than it will solve and is not viewed as an improvement to flight safety.

11.2.2 Scandinavia and the Baltic States

Scandinavian and Baltic States operators are similarly concerned with the proposal to raise the flash point of the fuel and the resulting effect on the fuel viscosity and subsequent cold starting problems which would severely disrupt their operation in winter months.

11.2.3 Russia and the C.I.S.

Russia and the C.I.S use a kerosene fuel whose properties are controlled by the Russian specification GOST 10227 Grade RT and TS-1. The distillation range, viscosity and freeze point limits of Russian fuels is designed to allow operation, cold starting and engine re-light at very cold temperatures experienced in Siberia. These fuels are more volatile than Jet A/A-1 with a minimum flash point of 28°C (82.4°F).

The Chinese also specify two grades of fuel, RP1/2 with similar characteristics and flash points to the Russian fuels but state that they now only deliver Jet Fuel No.3 (RP3) to specification GB 6537-94 at all major International airports which meets International Specifications including ASTM D1655 for Jet A-1.

11.3 Russian and C.I.S. Aircraft Operation on High Flash Fuel.

Russian aircraft and engines have not been designed to operate on high flash fuel. Impacts on their operability and airworthiness have not been determined.
In the past they have experienced problems operating on Jet A from the U.S. and Merox treated fuels resulting in lacquering of engine components.

11.4 Changing the Experience Database

The aviation fuel community is by nature very conservative. It has a high confidence level with currently produced fuel because of a long experience base. Collectively, we cannot readily measure the existing margin to alter the nature of the fuel for all aircraft engine types. Effects from changes at a single source are difficult to determine because they are usually lost in the pool fuel volume, so that continuous operation at the extremes of the property limits is infrequent. Conversely, changes to the jet fuel pool as a whole must of necessity be viewed with concern. The concern level for a change in minimum flash point to 110-120ºF is significant. The concern level for a change to 140ºF is many times higher because refiners can be expected to change production methods and reduce specification margins on a broad scale.

Possible mitigating actions to off-set adverse effects on engine and APU operation might include hardware modifications, adjustments and re-calibrations. There is a potential that increased viscosity may require measures to moderate low temperature extremes in the APU environment, or a change in the viscosity requirement. Other revisions of fuel specification requirements might be necessary in addition to the increase in flash point, and aircraft operational limits might require consideration. The current effort has not included evaluation of impact on availability from other possible specification changes.

Conceptually, an increase in only the flash point should not markedly affect the properties or suitability of jet fuel for its intended purpose. Some high volatility components would be eliminated to increase flash point, and some low volatility components would be eliminated to assure jet fuel still meets freezing point requirements. Thus it would appear that all of the fuel would remain within the criteria bounded by the previous requirements. This view, however, is an over-simplification. API review (see

Section 9.2.1.1) of likely changes indicates the propensity to produce fuel with properties and molecular composition outside current experience increases significantly with increasing flash point requirements. This raises concerns about departure from current engine and APU test and service experience for key specification limits and actual property values in the population. This is true for individual key properties and combinations thereof.

The vast majority of the world's airline fleet operates on a varied diet of jet fuels as they refuel at each destination. Major destinations in turn receive their fuel from more than one refinery. Because most planes are exposed to an "average" diet of fuels, they experience an averaged exposure to fuel property extremes. Changes to flash point are likely to cause drift for several fuel properties, especially viscosity at low temperature, aromatics content, thermal stability, and smoke point.

Jet fuel properties are largely determined by four variables: the initial and final boiling points (together these define the boiling range), processing, and the type of crude oil feedstock. Currently, nearly all jet fuel is either a boiling range fraction from the crude oil distillation column (with further mild processing to improve properties without significantly changing the hydrocarbons present) or a mixture of this fraction with hydrocarbons of a similar boiling range obtained from a hydrocracking unit. Use of hydrocracker component is more recent, and was introduced slowly; a few jet fuels now contain only this component but most of the time it is blended with the kerosene boiling range product from crude distillation.

A complex issue for further consideration, however, is that changes to increase the minimum flash point may cause abrupt shifts in refinery process components which are used to make up jet fuel, to maintain the current product volume. The motivation for such shifts is proportional to the increase in minimum flash point. At 110-120F, motivation would be light to moderate for Jet A production in the U.S., and moderate for Jet A-1 elsewhere. At 140ºF flash point pressure to include non-conventional streams would be strong in the U.S., and can only be described as extreme elsewhere. Stated differently, at a 140ºF flash point a large enough proportion of jet fuel refiners could be expected to include presently atypical components that the pool composition of fuel could be changed outside of the current experience base.

For example, a component with a similar boiling range to kerosene can be obtained from a fluid catalytic cracking unit, present on most refineries. This material is not normally used in jet fuel because it has poor thermal stability, very high aromatics content and very low smoke point. It can be expected that many refiners will need to produce at the extremities of the specification by including such marginal streams, to meet fuel demand. This will result in a reduction of the margin for these properties in the overall jet pool, proportional to the increase in flash point.

Overall, at the extremes of contemplated flash point increases, such changes have a characteristic unparalleled in aviation fuel history. Up until now, changes in fuel composition and properties could be described as carefully measured and controlled, slowly evolving over time. Changes brought about by a significant change in minimum flash point, it is feared, are likely to be rapid and uncontrolled, driven by urgent needs to make up shortfalls in product volume, especially at refineries maximizing jet fuel production. In the past, small adjustments have been agreed to after lengthy debate and after gathering data on the suitability of the revised fuel specifications. For example, the maximum freezing point of Jet A-1 was changed from –50° to –47°C after several years of in-flight measurements and development of detailed climatic data. Maximum aromatics content of fuel has slowly increased from a maximum of 20% to 22% to 25% over a period of years, during which time refiners were required to report to customers when fuels had aromatics content higher than 20% (later 22%). Inclusion of small volumes of Fischer-Tropsch liquids sparked healthy debate and investigations over a period of two years that have not yet been concluded.

Most of the jet fuel was totally unaffected by these changes, but by expanding the envelope of allowed properties slightly, adequate fuel supplies were assured in select areas. The average effect on jet pool quality was minor, and difficult to measure. Because the increase in flash point will, for the first time, significantly **restrict** availability, nearly all refiners, rather than a few, will be changing their production methods and thus the properties of the most of the jet fuel pool could be modified. Again, the magnitude of these changes is proportional to the change in minimum flash point.

12.0 COST AND AVAILABILITY IMPACT OF HIGH FLASH JET FUEL

The API/NPRA survey results are included as Appendix 1. Seventy-eight refiners completed the survey, which represented nearly 87% of the refining crude capacity and practically 100% of jet fuel production, based on Department of Energy (DOE) weekly production figures.

The survey was designed to assess the industry's ability to manufacture jet fuel with a higher flash point and estimate the impact on manufacturing costs associated with a range of property changes. Respondents were asked to complete a questionnaire for each refinery in which they currently produce commercial aviation Jet A fuel. The first question requested general information regarding the capacities of each refinery. The second set of questions (2a through 2g) assumed a series of revised minimum flash points and asked the respondents to determine:

a. Changes in jet fuel production volume
b. Total short term cost resulting from potential specification changes
c. Other product volume reductions or increases
d. Amount of reduction from (a) that could be made up in the short term
e. Total cost in (d) resulting from potential specification changes
f. Capital investments to make up as much of the lost production as feasible
g. Total cost of long term changes in (f) to recover this jet fuel production

The third set of questions (3a through 3g) assumed a series of revised minimum flash points and a reduction of the freeze point minimum specification as a basis for determining the same information (a through g) as above. The fourth question asked whether any of the changes to the flash point specification would create difficulties in complying with gasoline parameters.

The API/NPRA Survey was also distributed internationally. Survey responses from 33 European refineries were submitted by EUROPIA, the European Petroleum Industry Association (Appendix 2) representing more than two thirds of the jet fuel production and 50% of the crude distillation capacity in Europe. The Petroleum Association of Japan also submitted data from 24 refineries representing 85% of the jet fuel production and 72% of the crude distillation capacity in Japan (Appendix 3).

All survey results address jet fuel demand at 1998 levels. The survey does not address long-term changes in jet fuel demand or changes that could result from environmental regulations on other fuels. However, increases in demand or environmentally driven fuel changes are likely to amplify the difficulties predicted for the 1998 level (see Section 12.2.4).

Further, anticipated growth in jet fuel demand will put pressure on jet fuel availability even without a flash point change. Any increase in flash point will further complicated this situation.

12.1 Fuel Cost Estimates

All cost estimates reported are the estimated manufacturing costs to produce the new fuels. *The actual price for these fuels will be set by the marketplace.* In addition, refiners reported that these costs do not provide for 100% replacement of jet fuel production lost as a result of the higher minimum flash points (see Section 12.2).

12.1.1 United States

The API/NPRA survey results indicated that requirements for higher flash point jet fuels could result in United States refinery short-term (up to 24 months) production cost increases of 2-3 cents per gallon at 120 degrees F up to 5-7 cents per gallon at 150 degrees F. These short term costs do not include capital investments, but include incremental operating costs and economic losses through downgrades or changed product slates.

Long-term (up to five year) cost estimates, which include potential capital investments, ranged from 1.5-2.2 cents per gallon at 120 degrees F to 6-7.5 cents per gallon at 150 degrees F. Long term costs assumed 1998 dollars, 7% ROI for capital investment decisions and 10% return on capital. Based on current U.S. jet fuel demand, this translates into annual costs of $350-520 million at 120 degrees F to $1.4-1.7 billion at 150 degrees F.

U.S. refiners estimate their required capital investment to produce 120 degree F jet fuel at about $3 billion up to about $9 billion for 150 degree F fuel.

12.1.2 Europe

The EUROPIA survey results indicated that the requirements for higher flash point jet fuel could result in European refinery short-term (up to 24 months) production cost increases of 9 cents per gallon at 120 degrees F to more than 15 cents per gallon at 150 degrees F. Long term cost increases were 8 cents per gallon at 120 degrees F to more than 20 cents per gallon at 150 degrees F. European refiners estimate their capital investment to produce 120 degree F jet fuel at about $5 billion for 120 degree F fuel up to over $17 billion for 150 degree F fuel.

EUROPIA indicated that the impact in Europe is greater than the U.S. due to:

- The manufacture of the lower freeze point Jet A-1 grade in Europe which additionally reduces the potential jet fuel yield on crude;

- The demand barrel shape in Europe differs with less motor gasoline and more middle distillates required from a barrel of crude oil. This tends to produce higher front end cut points and flash points for U.S. jet fuel;

- Europe has a stronger demand for diesel fuel for which kerosene is also required. Environmental pressures in Europe are likely to require a lighter diesel fuel containing more kerosene in the near future.

12.1.3 Rest of the World

Survey results submitted by the Petroleum Association of Japan were consistent with data submitted by EUROPIA for the three reasons given in 12.1.2. Further, the Japanese reported that in order to manufacture a new specification of jet fuel, most of their refiners would have to give up their current refinery slate and install new facilities to produce jet fuel possibly including hydrocracking units. However, installing new units, or facilities in Japan is difficult due to space limitations and environmental/safety regulations so their report concluded that it would be economically infeasible to attempt to recover the lost volume.

12.2 Availability of Fuel

It was generally agreed that worldwide, higher flash points would result in less availability of jet fuel, and would require longer lead times for industry to meet demand. It is impossible to speculate on the future business plans of refiners regarding their decision to ensure that there would be an adequate supply of jet fuel.

12.2.1 United States

The API/NPRA survey results indicate that requirements for higher flash point jet fuel will result in U.S. refinery shortfalls of up to five percent at 120 degrees F and up to approximately 20 percent at 150 degrees F (assuming 1 to 2 years lead time and the required short term investments are made.). Actual shortfalls will vary considerably by refinery, season and area of the country.

12.2.2 Europe

EUROPIA reported European refinery shortfalls of 12% at 120 degrees F up to 49% at 150 degrees F (assuming 1 to 2 years lead time).

12.2.3 Rest of the World

Similar to EUROPIA, the Petroleum Industry of Japan reported significant short term production losses of 26% at 120 degrees F and 67% production loss at 150 degrees F. They concluded that for reasons discussed in Section 12.1.3, proposed specification changes would create serious availability effect in Japan, not only on jet fuel, but also only on household heating kerosene.

12.2.4 Future Projection of Jet Fuel Demand

The projected demand for jet fuel needs to be viewed in context with that for other refined petroleum products, including gasoline, diesel fuel, and fuel oil distillates. If growth in jet fuel demand is matched by increased demand for other products, there will be no dislocation requiring increased conversion of the crude barrel to jet fuel, and the increased demand can be readily absorbed by overall increases in refining capacity.

In the United States, jet fuel demand has grown at a rate of about 1.8 % per year over the past six years, and was in balance with similar growth in demand for gasoline, diesel fuel, and fuel oil.[1] However, jet fuel demand has been projected to increase 1.7% in 1998, compared to about 1% higher demand for motor gasoline, and 1.2% increased demand for other distillate fuels.[2]

World-wide demand for jet fuel is likely to grow at a rate of about 2.6-4.1% per year.[3] The Pacific Rim, Europe, and many other areas outside the United States will show higher demand growth rates. In the meantime, world-wide refined petroleum product demand is expected to increase at a rate of just under 2.5% per year.[4] On a world-wide basis, demand growth for jet fuel will likely exceed production of other refined transportation fuels by about 0.5 to1% each year. Thus by 2010, world-wide demand for jet fuel is projected to grow 6 to 15% more than other refined petroleum products.

While this appears to be a modest dislocation, other forces are expected to magnify its importance. The composition of gasoline and diesel fuels is increasingly being reformulated to reduce environmental impact. These required changes to other fuels will impact the supply and properties of jet fuel and some of these fuels may in fact compete directly for the same portion of the barrel. For example, the rate of growth of diesel fuel is high in Europe, and regulations may require greater use of “light” diesel fuels, which compete for the jet fuel portion of the barrel.[5]

References

[1] Oil and Gas Journal, week of December 29, 1997.

[2] Oil and Gas Journal, week of January 26, 1998.

[3] ICAO Journal, March 1996, p 9.

[4] SN Crewson, “Oil Markets – Industry Supply and Demand Dynamics”, presented at the IATA Fuel Trade Meeting, Prague, May 7/8, 1997.

[5] EUROPIA report to the ARAC Task Group 6/7, Atlanta, April 15/16, 1998.

12.2.5 Local Situations

From the beginning, members of Task Group 6/7 expressed concerns about the possible reduction of jet fuel supply at some airports if flash point was raised significantly, possibly resulting in localized shortages. Unfortunately the formal surveys by EUROPIA and API, to avoid anti-competitive practices, provided only broad area pictures of how fuel availability would be effected by changes in the minimum flash point requirements.

A few non-petroleum company members of Task Group 6/7 carried out a confidential, informal survey in cooperation with a few U.S. and international airlines, to better define localized supply and demand imbalances, which might result from minimum flash point changes. This effort was not highly successful, mainly because it was not possible to fully develop an overall view of alternate supply feasibility for various airports.

In this survey, airlines asked their suppliers to advise the immediate impact of a change in flash point, and did not request information on recovery of lost capacity (if any).
While it was generally not possible to define effects on specific airports, a review of the responses by individual suppliers revealed tremendous variation in the impact on supply. Availability from a few refiners was unaffected by minimum flash point requirements of 120 or 130ºF. Others were significantly affected at these levels. Thus flexibility of refiners to adapt varied markedly. In addition, those refiners known to be currently maximizing the yield of jet fuel universally suffered significant production losses. Results of the survey also indicated that refiners generally assumed that the current freezing point requirements for their area would remain in place.

An informal Australian/New Zealand survey encompassed all nine refiners in that region. The data again showed significant variation from refinery to refinery. Currently, supply availability and demand are in balance. However, demand for jet fuel has been growing in this area at a rate of 4-5% for the past ten years, while demand for gasoline has been growing at a rate of 1-2%. Refiners were predicting difficulties in meeting jet fuel demand during the next several years, even prior to the high flash jet fuel initiative. Data are shown below in Section 12.2, Table 1 below. These data show immediate impact without investment or other changes to improve jet fuel production, and in general assume the fuel supplied would be Jet A-1 fuel with a maximum freezing point of –47ºC (-53ºF).

Flash Point	**49C**	**54C**	**60C**	**65C**
Region I	10-30%	45-50%	>50%	>50%
Region II	5-10%	10-40%	20-50%	20-100%
Region III	5-50%	5-50%	20-100%	20-100%
Region IV	5-50%	>50%	>50%	>50%
Region V	20-30%	>50%	>50%	100%

Section 12.2.5, Table 1. Percent Reduction in Australian/New Zealand Jet Fuel Availability at Higher Flash Points

12.3 Impact of Availability on Price

Note: The American Petroleum Institute, EUROPIA and member companies did not participate in the analysis in Section 12.3 and do not endorse any conclusions, stated or inferred regarding such impacts.

The proposed flash point changes for jet fuel will increase the cost of production and shrink the available capacity to produce the fuel. Just like any commodity these events will both impact the market price for jet fuel. The extra production costs will raise the market price to the extent the market follows perfectly competitive marginal cost pricing behavior. Given the industry survey results, the cost increase may have some upward price repercussions. The reduction in capacity will create a temporary shortage of jet fuel that will be relieved only when the capacity has been added by the industry. Increasing the capacity will take approximately two years. The capacity shortage has the potential for substantial price increases until the capacity constraint is lifted.

Price elasticity models are used to predict the impact of a decrease in quantity, to the price of a commodity, relative to the demand. For this analysis, we did not assign a specific price elasticity to jet fuel, but we can assume that it is likely very inelastic. Inelastic demand means that the quantity demanded will decrease by less than one percent given a one percent increase in price. A price elasticity of .5 means that a one-percent increase in price will lead to a .5% reduction in quantity.

To demonstrate what possible outcomes would be given a range of possible price elasticities, we calculated the increases in price that could occur for various combinations of capacity reductions and price elasticities. Also for this analysis we assume no substitutions exist for jet fuel. In other words, we have assumed that the consumers would not be able to switch to another petroleum product such as diesel as the jet fuel price increased.

As Table 1 demonstrates, the possible potential impact on price from capacity constraints is dramatic. The price increases will be more substantial the greater the capacity reduction as a result of higher flash points, or the more inelastic the demand for jet fuel.

Cost impact of higher jet fuel flash points

Higher prices due to lowered capacity

Percentage price increase due to capacity reduction

	Capacity	Price elasticity for jet fuel market				
Flash	Reduction	1.0	0.8	0.6	0.4	0.2
120	8.11%	8.11%	10.14%	13.52%	20.28%	40.55%
130	16.74%	16.74%	20.93%	27.90%	41.85%	83.70%
140	24.72%	24.72%	30.90%	41.20%	61.80%	123.60%
150	32.13%	32.13%	40.16%	53.55%	80.33%	160.65%

*note: % change in price = % change in quantity / price elasticity**

Base price per gallon: $0.50

Price increase due to capacity reduction

	Capacity	Price elasticity for jet fuel market				
Flash	Reduction	1.0	0.8	0.6	0.4	0.2
120	8.11%	$0.04	$0.05	$0.07	$0.10	$0.20
130	16.74%	$0.08	$0.10	$0.14	$0.21	$0.42
140	24.72%	$0.12	$0.15	$0.21	$0.31	$0.62
150	32.13%	$0.16	$0.20	$0.27	$0.40	$0.80

Base quantity consumed: 23 (Billion gallons)

Years until capacity added: 2

Cost of flash point increase until capacity added

	Capacity	Price elasticity for jet fuel market				
Flash	Reduction	1.0	0.8	0.6	0.4	0.2
120	8.11%	$1,714,024,170	$2,142,530,213	$2,856,706,950	$4,285,060,425	$8,570,120,850
130	16.74%	$3,205,676,520	$4,007,095,650	$5,342,794,200	$8,014,191,300	$16,028,382,600
140	24.72%	$4,280,119,680	$5,350,149,600	$7,133,532,800	$10,700,299,200	$21,400,598,400
150	32.13%	$5,015,525,130	$6,269,406,413	$8,359,208,550	$12,538,812,825	$25,077,625,650

Section 12.3, Table 1—Impact of Availability on Price

Notes:

1. *Costs are not adjusted for inflation*
2. *Costs are calculated using only the gallons still purchased. This analysis does not include any indirect costs of using alternates to jet fuel and air travel.*
3. *These costs also do not include the additional costs of the fuel once the capacity has been added to relieve the capacity constraint.*
4. *This analysis ignores growth in demand for jet fuel that would occur over the time period observed.*

* *Carlton, Dennis W., and Perloff, Jeffrey M., Modern Industrial Organization, 2nd Edition, Harper Collins College Publishers, 1994.*

12.4 Effects on Crude Oil Selection

An increased jet fuel flash point specification may impact the market for crude oils. The mechanism of impact is complex and effects cannot be predicted at this time.

The issue is that crude oils differ with respect to the amount of jet fuel that they produce at higher flash points. To illustrate this, the coded individual crude oil results from the Jet Fuel Properties Survey (Section 9.2.1, Table 1) were used to make Section 12.4 ,Table 1 for Jet A [-40°F (-40°C) freeze point] and Section 12.4, Table 2 [-53°F (-47°C) freeze point]. The Tables show the percentage of the base case [100°F (38°C) flash point specification and -40°F (-40°F) freeze point] that the crude oil could produce at higher flash point specification values. The Tables indicate only "Avail" (jet fuel produced) and "Not Avail" (no jet fuel produced) for the three crude oils (B, N and D) where only qualitative data were supplied.

Coded Crude	100°F	110°F	120°F	130°F	140°F	150°F
L	100	96	92	87	83	79
J	100	94	89	83	78	72
E	100	94	89	83	78	72
G	100	90	79	69	59	48
I	100	87	74	61	49	36
O	100	89	76	63	49	36
A	100	87	74	60	47	34
H	100	84	67	51	35	18
K	100	86	73	59	45	31
F	100	81	62	43	24	5
C	100	77	54	31	8	0
M	100	72	43	15	0	0
B	Avail	Avail	Avail	Avail	Avail	Avail
N	Avail	Avail	Avail	Avail	Avail	Avail
D	Avail	Avail	Avail	Avail	Not Avail	Not Avail

Section 12.4, Table 1-- Relative Jet A yields (%) at selected flash point specification values from the Jet Fuel Properties Survey.

Coded Crude	100°F	110°F	120°F	130°F	140°F	150°F
L	81	76	70	65	60	54
J	74	69	63	57	52	46
E	69	64	58	52	47	41
G	85	73	62	50	38	27
I	85	69	52	35	18	1
O	77	60	44	28	11	0
A	79	60	40	21	1	0
H	67	47	27	7	0	0
K	65	44	24	4	0	0
F	60	41	22	4	0	0
C	60	41	22	4	0	0
M	43	6	0	0	0	0
B	Avail	Avail	Avail	Not Avail	Not Avail	Not Avail
N	Avail	Avail	Avail	Avail	Not Avail	Not Avail
D	Avail	Avail	Avail	Avail	Not Avail	Not Avail

Section 12.4, Table 2-- Relative Jet A-1 yields (%) at selected flash point specification values from the Jet Fuel Properties Survey

The results show that, for the representative crude oils evaluated here, jet fuel production by distillation is greatly reduced at the higher flash point specification values for a number of crude oils.

The impact of this is that if the flash point specification is increased enough to affect availability that:

- The demand may increase for crude oils having higher jet fuel yield coupled with reduced demand for other crude oils.
- Refineries and localities having little flexibility concerning crude oil source may be impacted significantly better or worse than average.

12.5 Effect on Refining

The impact on the manufacturing cost of other fuels (gasoline and diesel) of a higher minimum flash point was not assessed.

The API/NPRA survey results indicate that, as the minimum flash point increases, more refiners could have difficulty producing gasoline and diesel that complies with current state and federal environmental regulations. This impact would be particularly severe in California and the East Coast (PADD 1), where the refiners surveyed reported that even raising the jet fuel flash point to 120°F could severely affect their ability to comply with the aromatics and distillation requirements for gasoline.

12.6 Effect on APU Cost

If the fuel flash point is increased over current levels, addition of a fuel heater at the APU inlet may be required to ensure reliable APU starting for all ambient conditions.

The rough order of magnitude (ROM) cost to develop and certify a direct current (DC) powered APU fuel heater with BITE (Built in Test Equipment) was estimated to be up to $1M per APU model. Approximately 24 months would be required for development and qualification prior to delivery to the aircraft manufacturer. The reoccurring cost was estimated to be approximately $10,000 per engine, with an increase of approximately 4 lb. in APU weight. An additional 12 to 24 months would be required to incorporate the fuel heater in the field. The operator maintenance time to add the fuel heater and implement other necessary changes is estimated to be approximately 8 hours.

Additional time and cost would be required to complete any aircraft modifications or flight-testing required. Aircraft changes that may be required include wiring from the APU to the electronic control unit (usually located in a different compartment), modifications to the flight deck display, modifications to the APU battery or charger, modifications to the main engine generators, modifications to aircraft operational procedures, and any airplane manual revisions.

Additional recurring and non-recurring costs would be involved if an alternating current (AC) powered fuel heater were employed.

13.0 BIBLIOGRAPHY

This Section was not used.

14.0 APPENDIXES

14.1 Final Report API/NPRA Aviation Fuel Properties Survey

14.2 EUROPIA Effect of Jet A-1 Flash Point on Product Availability and Properties

14.3 PAJ Impacts of Jet A-1 Flash Point Changes

14.4 Fuel Property Effects on Engines (Section 9.3.2, Table 1)

14.5 Estimate of Ten-Year Cost of Fuel Change

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Final Report
American Petroleum Institute/ National Petrochemical & Refiners Association Aviation Fuel Properties Survey

APRIL 1998

National Petrochemical &
Refiners Association

American
Petroleum
Institute

Brief Review of the Aviation Fuel Survey

As a result of the TWA Flight 800 accident, the FAA is investigating methods to reduce the likelihood of airplane fuel tank ignition. The National Safety Board has made a number of safety related recommendations to the FAA, focusing not only on the elimination of ignition sources within tanks, but also on tank cooling, inerting systems, and raising the flash point of Jet -A aviation fuel.

The American Petroleum Institute (API) was asked to respond to one of these initiatives that may result in the modification of aviation fuel properties. Specifically, the FAA asked the API to assess the ramifications of producing a jet fuel with a higher flash point than the currently used Jet-A and, possibly, a modified freeze point consistent with Jet A-1. In order to provide an accurate assessment of the industry's capability to cope with fuel property changes, API, in conjunction with the National Petrochemical & Refiners Association (NPRA), formerly the National Petroleum Refiners Association, developed an industry-wide survey.

The survey was designed to assess the industry's ability to manufacture jet fuel with a higher flash point and estimate the impact on manufacturing costs associated with a range of property changes. Respondents were asked to complete a questionnaire for each refinery in which they currently produce commercial aviation Jet-A fuel. The first question requested general information regarding the capacities of each refinery. The second set of questions (2a through 2g) assumed a series of revised minimum flash points and asked the respondents to determine:

a. Changes in jet fuel production volume
b. Total short term cost resulting from potential specification changes
c. Other product volume reductions or increases
d. Amount of reduction from (a) that could be made up in the short term
e. Total cost in (d) resulting from potential specification changes
f. Capital investments to make up the lost production
g. Total cost of long term changes in (f) to recover jet fuel production

The third set of questions (3a through 3g) assumed a series of revised minimum flash points and a reduction of the freeze point minimum specification as a basis for determining the same information (a through g) as above. The fourth question asked whether any of the changes to the flash point specification would create difficulties in complying with gasoline parameters.

Committee representatives from both the NPRA and the API distributed the survey to virtually all US refiners. Harold S Haller & Company of Cleveland, Ohio was employed to administer the survey. All responses were sent directly to Haller & Company offices. Only Haller & Company employees viewed the completed survey forms, which will be destroyed after the survey has been completed upon receipt of written authorization from officials at API and NPRA. An Excel™ spreadsheet database was created to store, retrieve, and analyze the survey data.

The surveys were distributed during the week of March 16th . Responders were asked to have the survey completed and mailed or faxed to the Haller offices by no later than Friday, March 27th . Response to the survey was very good. Seventy-eight refiners completed the survey which represented nearly 87 % of refining crude capacity and practically 100% of jet fuel production based on Department of Energy (DOE) weekly production figures.

Review of Jet Fuel Manufacturing in a Typical Refinery

The industry standard for commercial jet fuel is ASTM D1655. This standard specifies values for 16 properties including gravity, freeze, flash, distillation, aromatics content, sulfur and thermal stability (see Appendix, page 50). Because of these stringent specifications, jet fuel production is only possible from a limited number of sources. The most common source occurs naturally in crude oil. It is removed as kerosene in the middle distillate area of the atmospheric crude fractionation column. In order to reduce sulfur to meet Jet-A specifications, kerosene must generally be hydrogen treated in a processing unit called a Hydrotreater. After the Hydrotreater, the product must pass extensive testing before it is sold as Jet -A product. The other source of jet fuel production is hydrocracking. This process converts heavy oil from the bottom of the atmospheric crude column or the middle and top of the vacuum column to lighter products. Hydrogen reduction of heavy oils to lighter oils is accomplished by reacting the heavy oil with hydrogen at high temperatures and very high pressures under the influence of a hydrocracking catalyst. The product slate from a hydrocracker can be adjusted by varying the hydrocracking conditions such as temperature and pressure. Hydrocracking products are equivalent, or in some cases superior, to hydrotreated products and must also pass a rigid testing regimen before being shipped as jet fuel.

While a hydrocracker can produce large quantities of jet fuel, new units generally have very high capital and operating cost. Production from naturally occurring crude oil sources is much more economical but limited by the quantity of jet fuel in crude oil. The refiner has a number of alternative market choices for the jet fuel product fraction. These markets include K1 kerosene, specialty diesel fuel and aliphatic solvents. Most alternative markets do not have the stringent specifications associated with jet fuel.

Survey Comparisons by PADD

Survey analyses were performed in aggregate and by region represented by Petroleum Administration for Defense Districts, PADD. A U.S. map showing the five PADDs is included as Figure 1 on page 17 in the Appendix. PADD 3 is the largest processing PADD. These six southern, Gulf Coast states process nearly 7 million barrels of crude oil per day and produce about 615 thousand barrels per day of jet fuel. The second largest region by processing is the Midwest region, PADD 2. These 15 states process about 3 million barrels per day of crude oil and produce 250 thousands barrels of jet fuel. The West Coast PADD 5 is the third largest processing area. This region processes over 2.5 million barrels per day of crude oil and produces 350 thousand barrels of jet fuel per day. PADD 1 which includes the East Coast states is the fourth largest and processes about 1.5 million barrels per day of crude oil and produces over 100 thousand barrels per day of jet fuel. The Rocky Mountain area, PADD 4, is the smallest. This region processes about 450 thousand barrels of crude oil and produces 25 thousand barrels per day of jet fuel. A complete list of states by PADD is included in the Appendix, page 18. All PADD processing data was taken from the weekly Department of Energy (DOE) petroleum numbers that are posted on the Internet.

To provide data that would assist in the analysis of the impact of possible changes in jet fuel specifications, the data on California refineries were entered separately from the rest of PADD 5 because of California's unique gasoline and diesel requirements.

Survey Procedures

Each survey mailed or faxed to Haller & Company offices in Cleveland, Ohio was reviewed for validity and then either entered into an Excel™ spreadsheet database, or in case of problems, an inquiry was made to the API staff. A few surveys were received during the week ending March 27th. Most were received early in the week ending April 3rd . Calculations and analyses were done during the week ending April 3rd and a draft report was submitted on Friday, April 3rd .

Survey Data

Seventy-eight responses were received and used. This represented 12 million barrels of crude processing and 1.5 million barrels of jet fuel production. This response represented 87% of US crude oil processing and practically all of jet fuel production. Most surveys were well marked and completed in total. Some had inconsistencies and were not fully completed. In some cases the responder was called to resolve questions. In a few cases zero was used for a response that was marked by a comment when it was obvious that zero was intended. Also, questions that were not answered were not included in the survey.

Data Summaries and Survey Analyses

Data Entry

Most of the response categories in the survey that were available for selection by the respondents were given as ranges. In these cases, the midpoint for each category was entered into the Excel ™ database as the response to the question. In this way the estimates for range response categories were unbiased. If the response category indicated "greater than" or "less than" a specific value, this specific value was entered into the Excel™ spread sheet in order to avoid skewing the data without any basis for doing so. Specific values like "zero change" or "zero incremental cost" were recorded as such in the database. Responses to questions on incremental capital expenditures were occasionally "not feasible.". These responses had to be treated in two different ways. If volume changes reported due to specification changes were from zero to five percent, "not feasible" was entered as a zero incremental capital value. If volume changes due to specification changes were greater than five percent, the maximum incremental capital value was entered into the database to reflect the large economic impact to the refinery.

Data Summaries

The survey responses, once quantified for each question as described above, were summarized or aggregated by computing the volume weighted average for each question. For questions related to jet fuel such as percent losses, incremental costs in the short term and overall, and incremental capital required to recover jet volume losses, the weighing factors were the thousands of barrels of jet produced per calendar day (mb/cd) per refiner divided by the total barrels for the group expressed in thousands of barrels per calendar day (mb/cd). The general formula for this was:

Weighted Average Response =

$$\sum \left(\text{jet produced by refinery}\right)\left(\text{refinery response}\right) \div \left(\text{total jet produced in group}\right)$$

where the summation (Σ) is over all refineries in the group. Here the group could be a PADD or all refineries in the United States.

For questions related to a refinery's overall product slate, the weighing factors were based on the crude processed per refinery expressed in thousands of barrels per calendar day (mb/cd) divided by the overall crude processed in the refinery grouping expressed in thousands of barrels per calendar day (mb/cd). The formula in these cases is as follows:

Weighted Average Response =

$$\sum \left(\text{crude processed by refinery}\right)\left(\text{refinery response}\right) \div \left(\text{total crude processed in group}\right)$$

where the summation (Σ) is over all refineries in the group. Here the group could be a PADD or all refineries in the United States.

There is one main reason why volume weighted averages were chosen as the optimum statistic for summarizing the responses relative to the survey questions. With the data aggregated using weighted averages as described above, the total change in a PADD or the overall refining industry caused by a proposed specification change simply can be calculated by multiplying the weighted average response for a refining group by the total product produced or crude processed by the refining group, i.e. PADD or overall US industry. In this way the total impact of proposed specification changes to, for example, the volume loss or incremental capital requirements can be estimated by refining segment. For each question, bar charts were drawn for the weighted averages by PADD and for the overall US refining industry at each flash point.

Survey Analyses

Because the completed survey responses from each PADD that were received by Haller & Company represented a sample from each region, how representative are the weighted averages described above? This question can be answered based on the Analysis of Means. Using

1.) the variation in the responses to each question from each group (PADD or all US refineries),

2.) the fraction of crude processed by each refinery participating in the survey,

3.) the percentage of total crude reported to the DOE from those groups participating in the survey,

maximum and minimum estimates of the weighted averages were calculated for each question. These maximum and minimum estimates provide 95% confidence limits for the weighted averages shown in the charts based on the three uncertainties listed above. Table 1 in the Appendix on pages 46–49 summarizes the maximum, average, and minimum weighted estimates for Questions 2 and 3 (a), (d), and (f) for each flash point, and for each PADD as well as for all US refineries. Only maximum and minimum were summarized for Questions 2 and 3 (b), (e), and (g) for each flash point, and for each PADD as well as for all US refineries.

Survey Detailed Analysis by Question

Question 1

Please indicate the following information regarding your refinery

Crude thruput, mb/cd

Hydrocracking capacity, for jet fuel, mb/cd

RFG & CARB production as a % of total gasoline

Current Jet A/A1 Production, mb/cd

Current JP-5 Production, mb/cd

Current JP-8 Production, mb/cd

	Number of Responses	Crude Runs	Hydro-cracking	RFG & CARB %	Current Jet A/A	Current JP-5	Current JP-8	Total Jet
PADD 1	5	1,100.0	0.0	55.0	87.0	0.0	8.0	95.0
PADD 2	17	2,494.5	29.0	9.8	183.0	0.0	10.9	193.8
PADD 3	34	6,183.1	89.2	13.5	757.1	27.5	41.0	825.6
PADD 4	4	267.1	4.2	8.3	19.6	0.0	0.8	20.4
PADD 5	8	645.4	18.0	13.0	102.6	0.0	2.1	104.7
CALIF	10	1,570.9	207.3	85.0	294.9	15.7	25.7	336.3
TOTAL	78	12,260.9	347.7	24.2	1,444.2	43.2	88.4	1,575.7

Question 2a
If the flash point specification minimum was raised, with no other specification changes, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

Listed below is a summary of the responses from Question 2a. All responses are in weighted averages and represent the mid-point of the percentage ranges given in the survey question. As expected, the percent jet fuel losses increase with increasing flash. PADD 5 has the highest averages of the group and PADD 2 has the lowest. All numbers are in percent and represent product loss.

		% Product Loss		
Flash	**120**	**130**	**140**	**150**
PADD 1	6.50	18.11	21.32	27.84
PADD 2	1.70	10.55	17.42	22.66
PADD 3	8.17	16.26	24.02	31.38
PADD 4	3.75	16.37	24.17	39.22
PADD 5	16.85	33.58	45.09	47.20
CALIF	9.65	15.88	25.30	35.50
TOTAL	8.11	16.74	24.72	32.13

Refer to the bar chart on page 19.

Question 2b
What would be the total cost in the short term of these changes in jet fuel production resulting from flash point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below is a summary of the analyses of the responses for Question 2b. The entries in the table are the upper (max) and lower (min) 95% confidence limits for the averages of the incremental costs in cents per gallon for added expenses from the changes described in Question 2a. As in Question 2a, the responses that were analyzed were midpoints of the question ranges. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

Question 2b

Flash		**120**	**130**	**140**	**150**
PADD 1	Max	2.46	11.42	11.32	12.16
	Min	0.29	0.00	0.00	0.00
PADD 2	Max	0.43	2.46	5.81	8.71
	Min	0.15	0.71	1.51	2.87
PADD 3	Max	1.00	2.33	4.42	6.68
	Min	0.82	1.94	3.81	5.93
PADD 4	Max	5.72	16.62	16.31	18.32
	Min	0.00	0.00	0.00	1.33
PADD 5	Max	4.38	8.40	10.39	15.29
	Min	2.22	5.33	5.86	10.08
CALIF	Max	1.67	5.14	8.58	10.54
	Min	1.13	3.82	6.20	7.88
TOTAL	Max	1.30	3.46	5.62	7.96
	Min	0.94	2.63	4.48	6.61

Question 2c
What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Gasoline
Kerosene
On-road diesel
Off-road diesel
Heating oil
Exports (naphtha or gasoline)
Other

This question asked for changes in other refinery products as a consequence of the jet fuel specification changes. Charts of the averages are included in the Appendix on pages 21 to 27.

Question 2d
If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

The table below is a summary of the responses to Question 2d. They are expressed as mid-point averages. PADD 2 has responded that they could recover the most fuel of the group, and PADD 5 indicated that they could recover the least.

Question 2d

Flash	**120**	**130**	**140**	**150**
PADD 1	31.45	27.96	33.87	33.87
PADD 2	63.20	54.74	48.48	51.52
PADD 3	43.51	42.55	32.67	30.92
PADD 4	46.48	36.15	31.99	29.90
PADD 5	28.30	40.96	39.94	41.26
CALIF	41.54	51.30	50.30	48.53
TOTAL	42.03	44.19	38.98	38.23

Refer to the bar chart on page 28.

Question 2e
What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from flash point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 2e. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

	Flash	**120**	**130**	**140**	**150**
PADD 1	Max	15.63	15.75	15.59	15.59
	Min	2.54	3.26	3.46	3.46
PADD 2	Max	0.28	3.46	5.48	7.52
	Min	0.03	0.55	1.51	3.04
PADD 3	Max	2.64	3.32	4.40	5.72
	Min	2.04	2.73	3.73	5.01
PADD 4	Max	12.84	12.85	13.38	13.74
	Min	0.00	0.00	0.00	0.00
PADD 5	Max	6.88	7.80	9.02	11.73
	Min	2.42	3.39	4.78	7.34
CALIF	Max	3.81	5.58	6.27	7.21
	Min	1.41	2.76	3.47	4.34
TOTAL	Max	3.18	4.23	5.26	6.57
	Min	2.19	3.19	4.15	5.40

Question 2f
If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

The capital cost in Question 2f are expressed as mid-point averages in millions of dollars for recovery of lost jet fuel. PADD 5 is by far the highest cost and PADD 1 is the lowest.

Flash	**120**	**130**	**140**	**150**
PADD 1	1.63	10.95	10.95	18.53
PADD 2	15.19	49.43	51.96	67.25
PADD 3	35.57	74.72	107.28	124.47
PADD 4	0.74	25.00	20.59	20.59
PADD 5	125.76	136.17	185.26	185.45
CALIF	61.66	81.96	74.09	132.10
TOTAL	42.12	72.75	91.64	115.38

Refer to the bar chart on page 30.

Question 2g
What would be the estimated total cost of these long term changes to recover jet fuel production resulting from flash point changes, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 2g. All numbers are expressed as incremental total costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

Question 2g

	Flash	120	130	140	150
PADD 1	Max	16.15	17.20	17.74	17.74
	Min	1.80	3.66	4.46	4.46
PADD 2	Max	0.95	3.42	7.20	8.82
	Min	0.29	0.75	1.65	2.78
PADD 3	Max	1.80	3.50	6.23	8.91
	Min	1.44	2.96	5.52	8.03
PADD 4	Max	17.01	17.26	20.42	19.84
	Min	0.00	0.00	0.00	0.00
PADD 5	Max	11.02	13.79	15.71	15.68
	Min	5.75	7.73	9.47	9.57
CALIF	Max	2.66	6.14	11.01	12.46
	Min	1.87	3.15	6.88	8.34
TOTAL	Max	3.00	4.94	7.86	9.77
	Min	2.07	3.75	6.38	8.23

Question 3a
If the freeze point specification minimum was reduced to –53 deg F, in addition to the flash point changes projected above, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

The summary below shows the averages of the volume losses expressed as percent. PADD 3 indicates the overall highest losses and PADD 1 indicates the lowest losses.

		% Product Loss		
Flash	**120**	**130**	**140**	**150**
PADD 1	5.13	13.58	18.84	22.42
PADD 2	11.10	16.36	20.71	22.72
PADD 3	20.87	30.13	35.59	39.25
PADD 4	13.43	22.50	32.01	46.57
PADD 5	17.02	27.44	36.12	36.51
CALIF	8.85	15.93	33.89	39.02
TOTAL	15.80	24.13	32.37	36.07

Refer to the bar chart on page 32.

Question 3b
What would be the total cost in the short term of these changes in jet fuel production resulting from flash point and freeze point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 3b. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

	Flash	**120**	**130**	**140**	**150**
PADD 1	Max	9.75	11.17	12.37	13.72
	Min	0.00	0.00	0.20	2.21
PADD 2	Max	1.77	4.72	7.00	8.64
	Min	0.41	1.04	1.87	2.68
PADD 3	Max	3.89	5.53	6.40	8.49
	Min	3.27	4.82	5.39	7.36
PADD 4	Max	7.80	17.44	18.32	21.72
	Min	0.00	0.00	1.33	5.78
PADD 5	Max	5.91	8.85	9.71	13.17
	Min	1.65	3.75	4.48	7.15
CALIF	Max	5.31	7.06	10.19	11.52
	Min	3.58	5.04	7.52	8.93
TOTAL	Max	3.93	5.71	7.24	9.18
	Min	3.01	4.55	5.77	7.55

Question 3c
What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Like Question 2c, this question called for estimates of changes to the other refinery products as a consequence of the jet fuel changes. Refer to bar charts of the averages in the Appendix on pages 34 to 40.

Question 3d
If you indicated a reduction in jet fuel production in question 3a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

The recovery table below is a summary of the volume recoveries expressed as a percent with lowered freeze points. PADD 2 indicated the best recovery and PADD 1 indicated the worst.

Flash	**120**	**130**	**140**	**150**
PADD 1	27.11	27.89	33.68	33.68
PADD 2	68.31	58.94	53.38	54.98
PADD 3	41.55	33.06	28.55	28.43
PADD 4	57.48	33.70	30.76	21.32
PADD 5	31.20	41.47	40.15	39.49
CALIF	36.81	44.89	47.46	42.58
TOTAL	40.36	38.64	36.93	35.94

Refer to the bar chart on page 41.

Question 3e
What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from flash and freeze point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 3e. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

Question 3e

	Flash	120	130	140	150
PADD 1	Max	20.90	20.90	21.26	22.08
	Min	3.90	3.90	4.89	5.75
PADD 2	Max	4.25	6.72	8.48	9.98
	Min	0.00	1.01	2.08	3.65
PADD 3	Max	4.68	5.10	6.79	7.58
	Min	3.83	4.25	5.85	6.60
PADD 4	Max	17.46	16.74	18.28	20.09
	Min	0.00	0.00	0.00	0.00
PADD 5	Max	8.41	8.41	9.57	11.01
	Min	2.14	2.14	3.58	5.13
CALIF	Max	6.36	6.74	7.88	9.49
	Min	2.76	3.30	4.56	6.21
TOTAL	Max	5.31	5.89	7.38	8.51
	Min	3.85	4.41	5.82	6.90

Question 3f
If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production? Check one box for each flash point.

PADD 5 and California would require the highest recovery capital dollars and PADD 1 the lowest under the proposed specification. All entries in the table are mid-point averages and are expressed in millions of dollars.

Flash	120	130	140	150
PADD 1	7.00	10.95	10.95	18.53
PADD 2	22.38	55.51	67.02	70.50
PADD 3	93.82	73.64	99.41	95.61
PADD 4	7.84	3.43	20.59	20.59
PADD 5	119.68	119.68	119.33	119.33
CALIF	142.90	71.75	81.90	131.75
TOTAL	90.88	69.38	86.66	96.19

Refer to the chart on page 43.

Question 3g
What would be the estimated total cost of these long term changes to recover jet fuel production resulting from flash and freeze point changes, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 10% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 3g. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

	Flash	**120**	**130**	**140**	**150**
PADD 1	Max	14.55	15.42	15.23	15.82
	Min	4.20	5.46	6.81	7.91
PADD 2	Max	3.33	4.42	6.45	7.30
	Min	0.46	1.09	1.88	2.77
PADD 3	Max	5.63	6.34	8.21	8.81
	Min	4.99	5.68	7.47	8.06
PADD 4	Max	12.89	15.13	15.19	14.61
	Min	0.00	0.00	0.00	2.15
PADD 5	Max	9.69	9.69	9.73	9.73
	Min	5.01	5.01	5.33	5.33
CALIF	Max	6.34	7.64	9.42	11.22
	Min	3.69	5.20	6.63	8.15
TOTAL	Max	5.73	6.58	8.17	9.03
	Min	4.62	5.46	6.97	7.82

Question 4
Would any of the changes to flash point specifications create difficulty with gasoline compliance parameters?

Included in the appendix on page 45 is a table summarizing the responses to Question 4. No conclusions were drawn from the responses, except that a surprising number of refineries did believe that jet fuel changes would impact RFG and CARB production.

Survey Conclusions

The survey has been a very successful attempt to measure the impact of significant jet fuel specification changes on the US refining industry. Given the short time that the refineries had to respond to this request for data, the response rate was excellent. Over 87% of crude processing refineries responded which included virtually all of Jet-A production. In PADD 4 where there was some scatter in confidence levels, volume response was good although the number of responses was somewhat lower. But overall, the results established clear trends about what refiners believe about the impact of the proposed specification changes. The level of response to the survey also showed a great deal of interest and concern for the subject matter.

Appendix

to

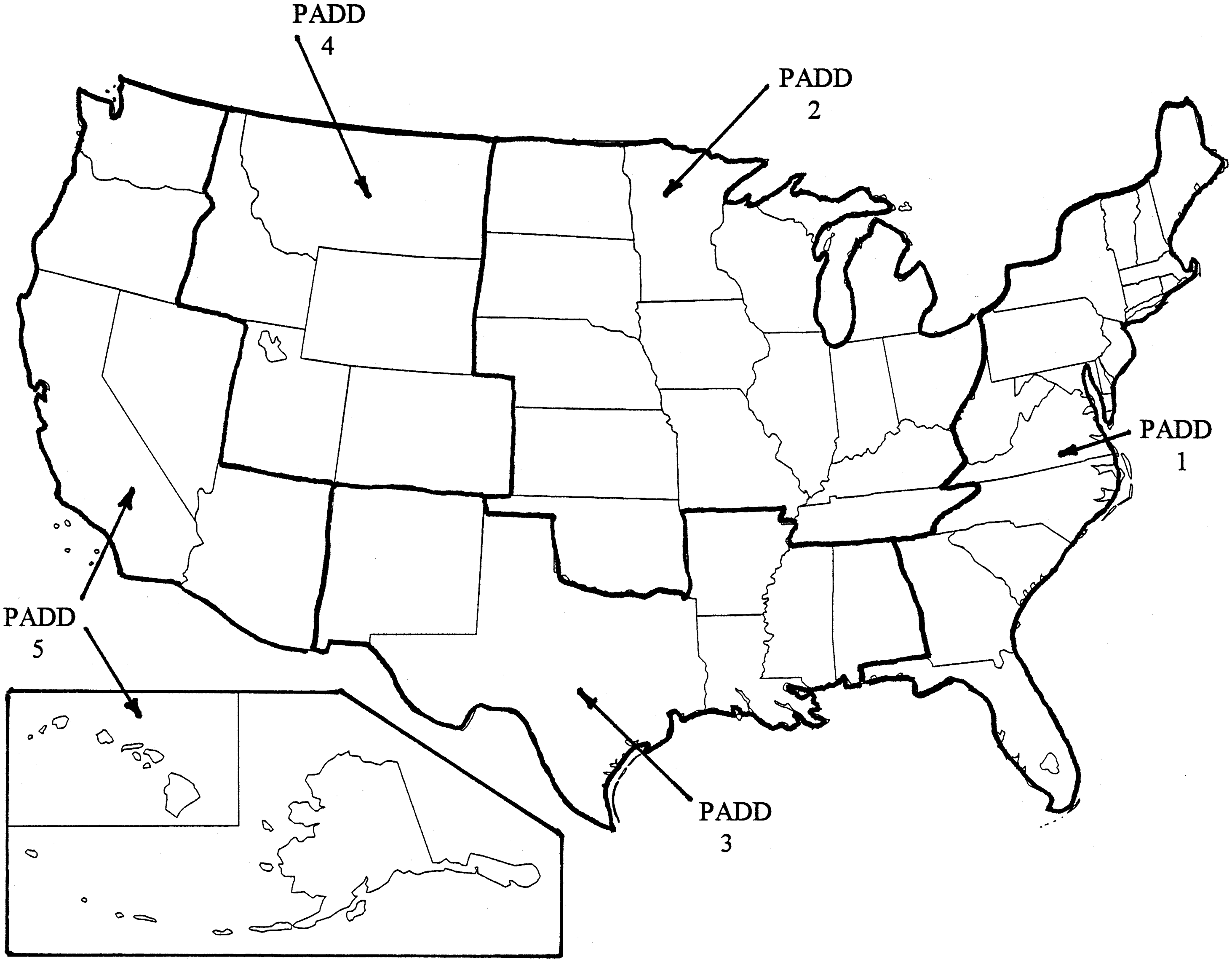
Final Report

on

API/NPRA AVIATION FUEL PROPERTIES SURVEY

Figure 1

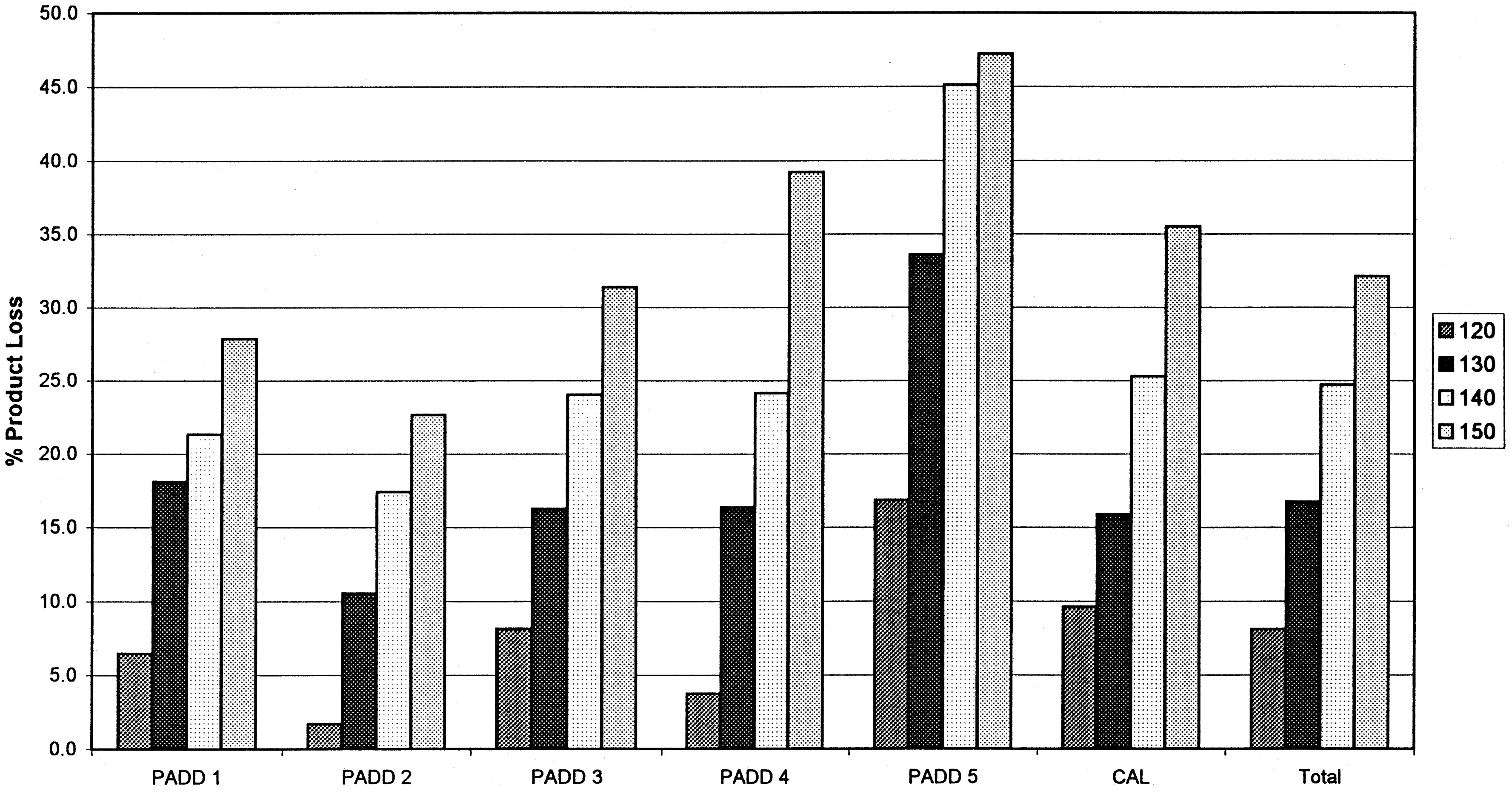
PADD MAP



PADD BY LOCATION

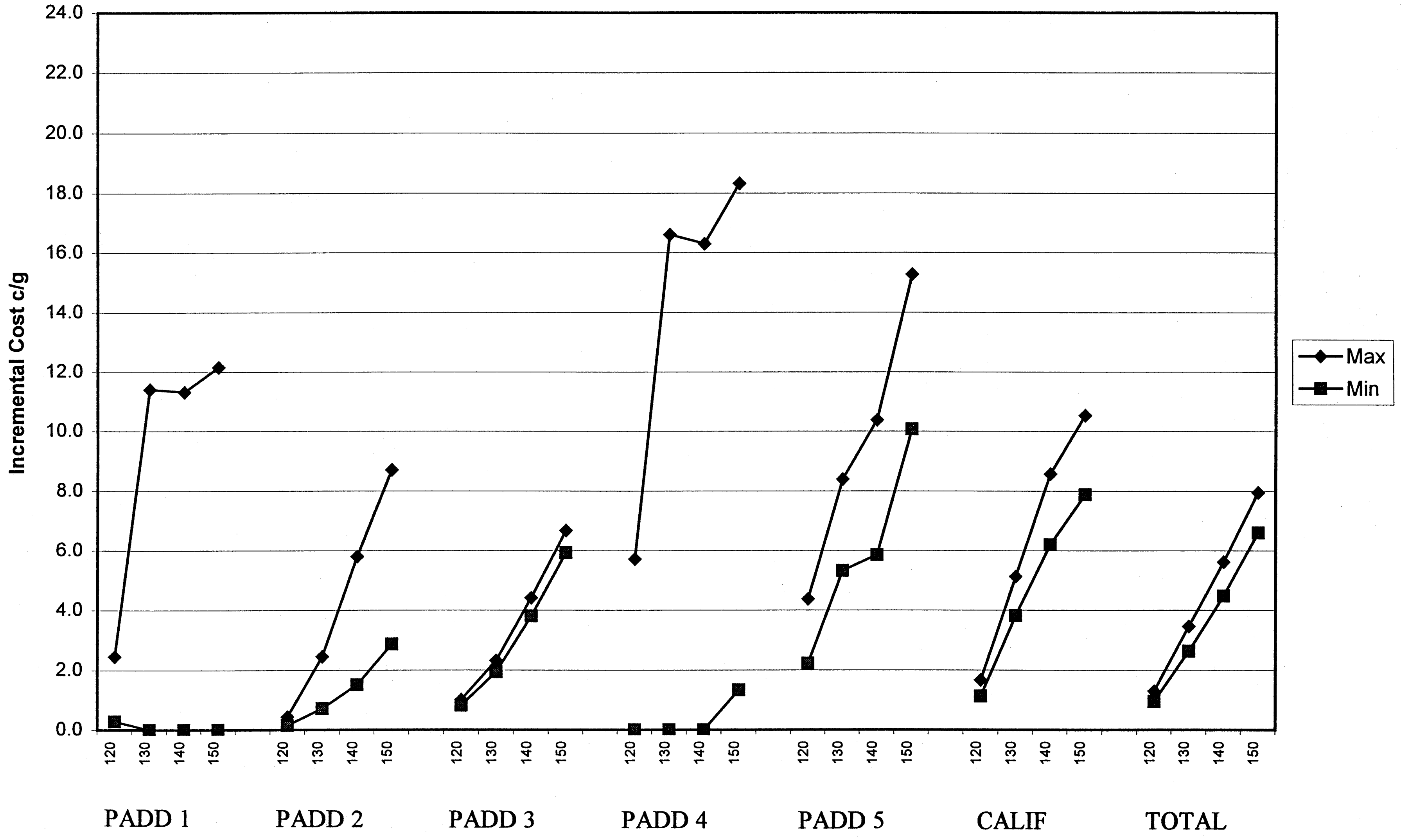
Alphabetical Sort				*PADD Sort*	
States	**PADD**			**States**	**PADD**
Alabama	3			Connecticut	1
Alaska	5			Delaware	1
Arizona	5			District of Columbia	1
Arkansas	3			Florida	1
California	5			Georgia	1
Colorado	4			Maine	1
Connecticut	1			Maryland	1
Delaware	1			Massachusetts	1
District of Columbia	1			New Hampshire	1
Florida	1			New Jersey	1
Georgia	1			New York	1
Hawaii	5			North Carolina	1
Idaho	4			Pennsylvania	1
Illinois	2			Rhode Island	1
Indiana	2			South Carolina	1
Iowa	2			Vermont	1
Kansas	2			Virginia	1
Kentucky	2			West Virginia	1
Louisiana	3			Illinois	2
Maine	1			Indiana	2
Maryland	1			Iowa	2
Massachusetts	1			Kansas	2
Michigan	2			Kentucky	2
Minnesota	2			Michigan	2
Mississippi	3			Minnesota	2
Missouri	2			Missouri	2
Montana	4			Nebraska	2
Nebraska	2			North Dakota	2
Nevada	5			Ohio	2
New Hampshire	1			Oklahoma	2
New Jersey	1			South Dakota	2
New Mexico	3			Tennessee	2
New York	1			Wisconsin	2
North Carolina	1			Alabama	3
North Dakota	2			Arkansas	3
Ohio	2			Louisiana	3
Oklahoma	2			Mississippi	3
Oregon	5			New Mexico	3
Pennsylvania	1			Texas	3
Rhode Island	1			Colorado	4
South Carolina	1			Idaho	4
South Dakota	2			Montana	4
Tennessee	2			Utah	4
Texas	3			Wyoming	4
Utah	4			Alaska	5
Vermont	1			Arizona	5
Virginia	1			California	5
Washington	5			Hawaii	5
West Virginia	1			Nevada	5
Wisconsin	2			Oregon	5
Wyoming	4			Washington	5

Question 2a Comparisons by PADD



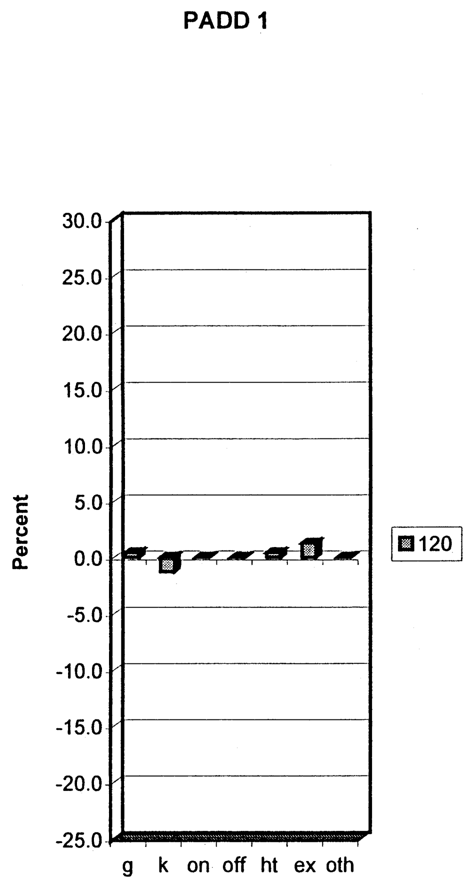
2a. **If the flash point specification minimum was raised, with no other specification changes,** what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

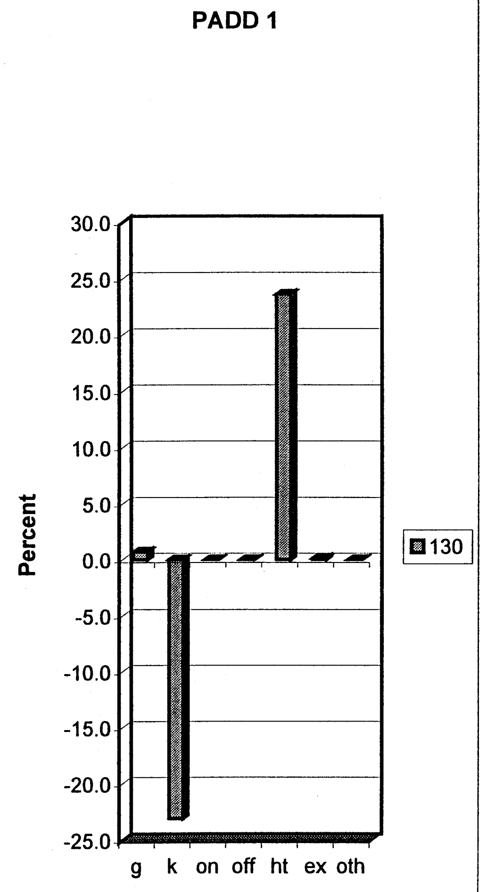
Question 2b Comparison by PADD

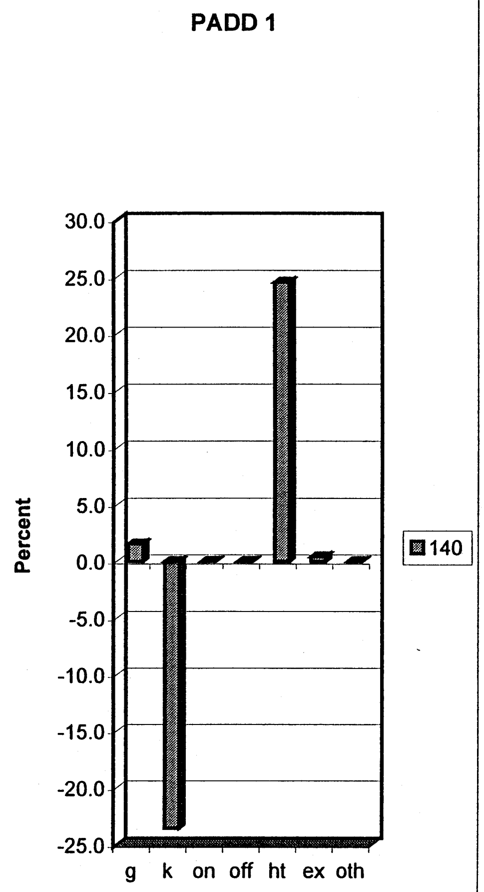


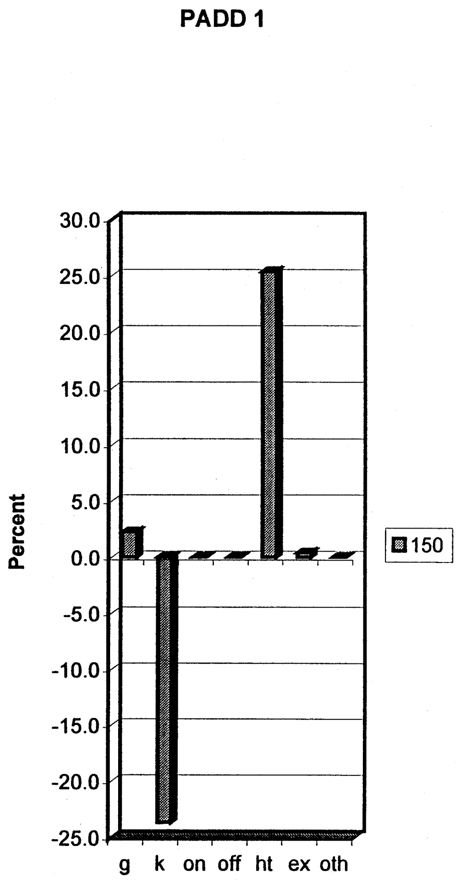
2b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 2C Comparisons for PADD 1





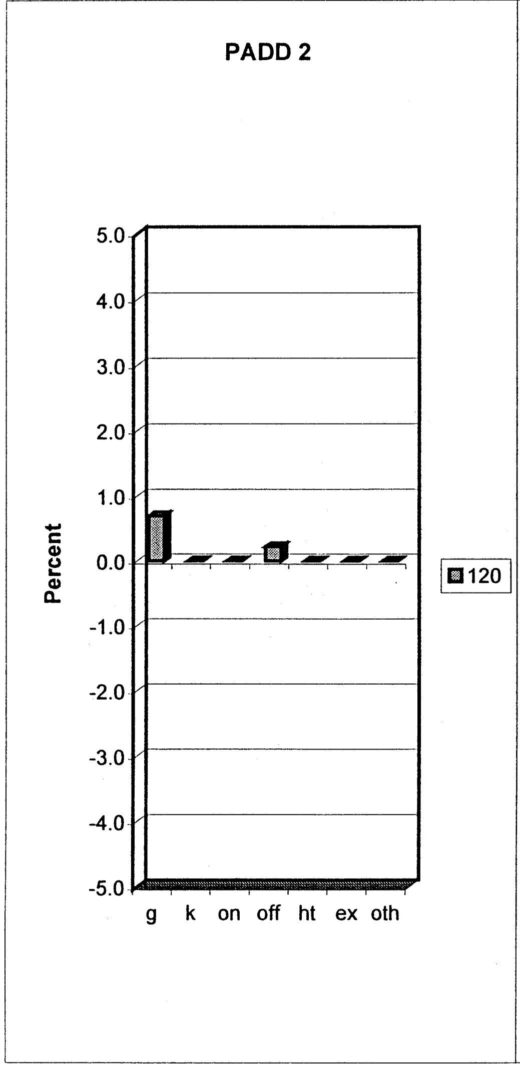


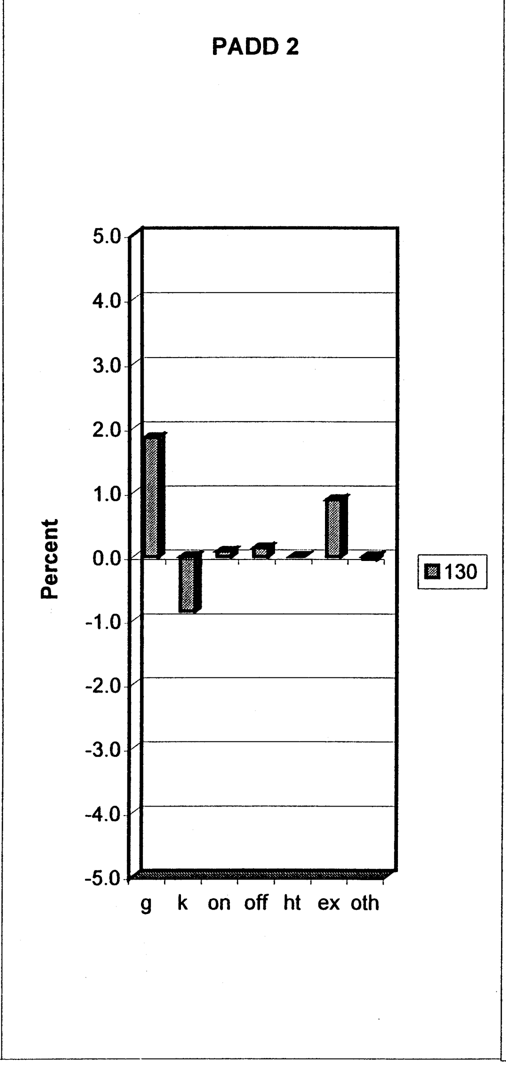


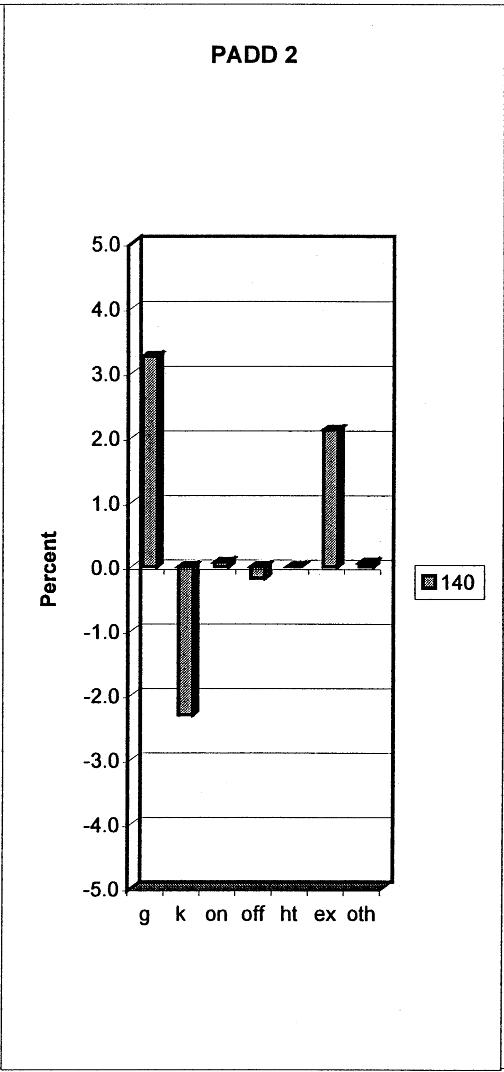
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

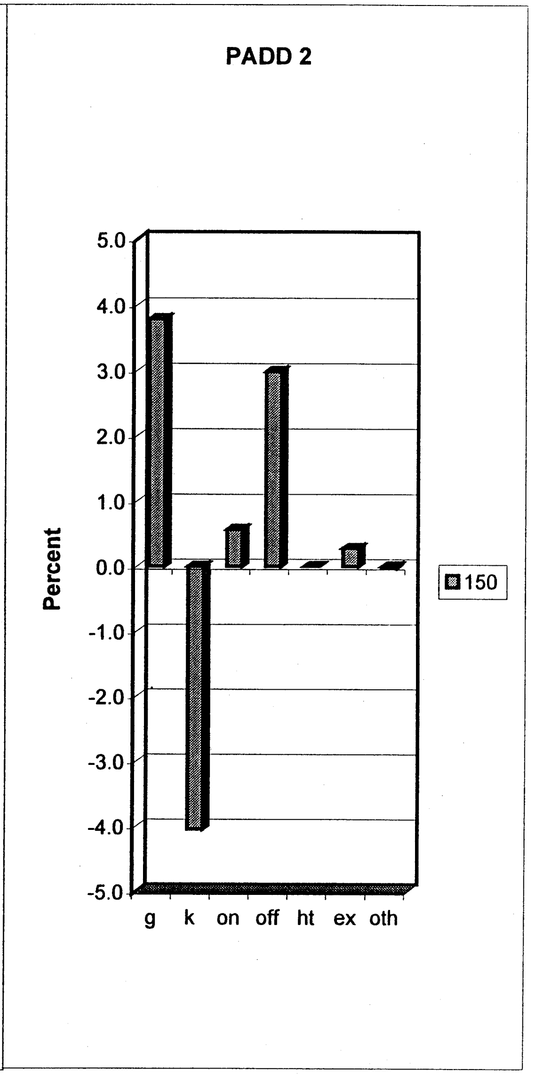
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for PADD 2





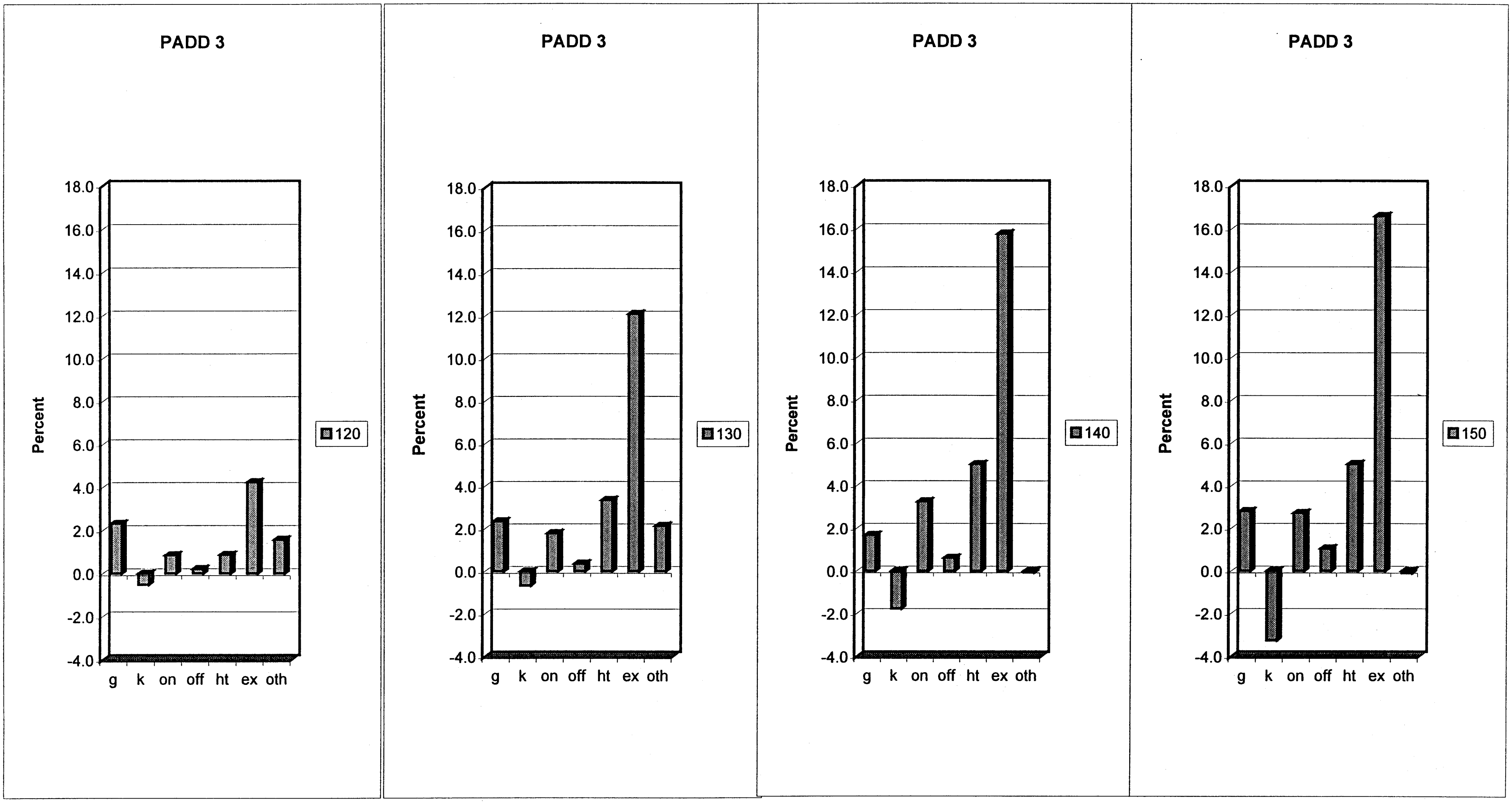




Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

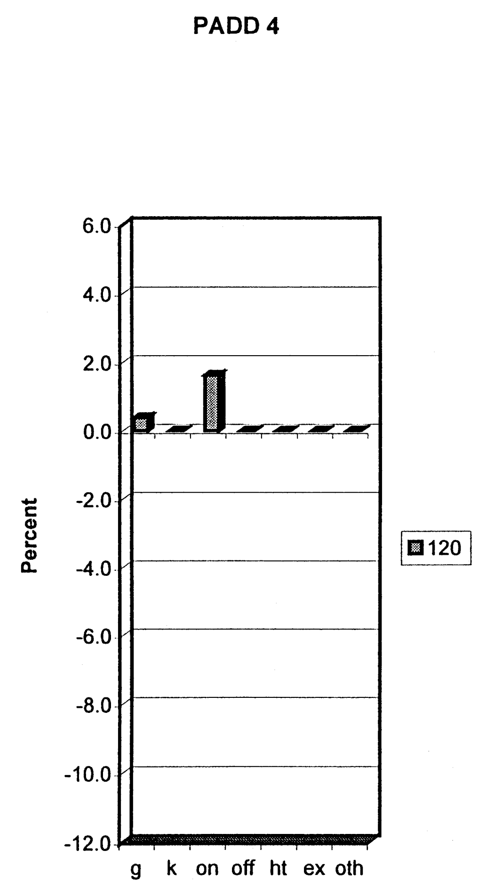
Question 2C Comparisons for PADD 3

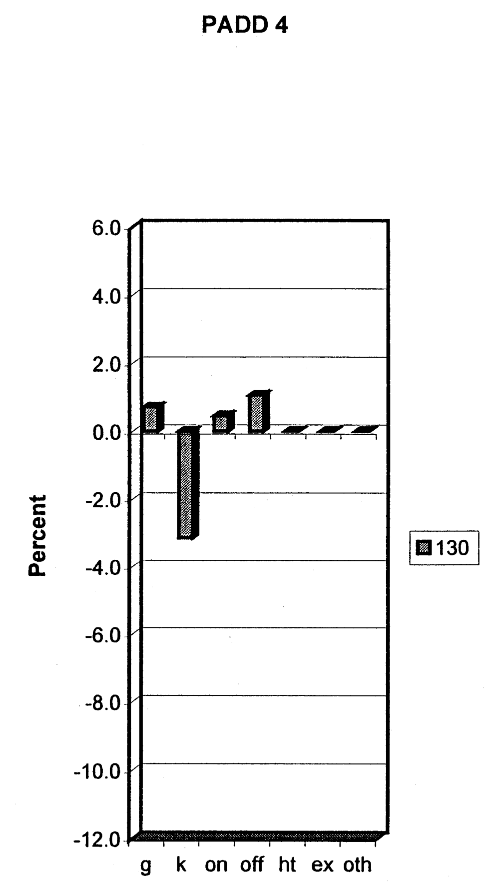


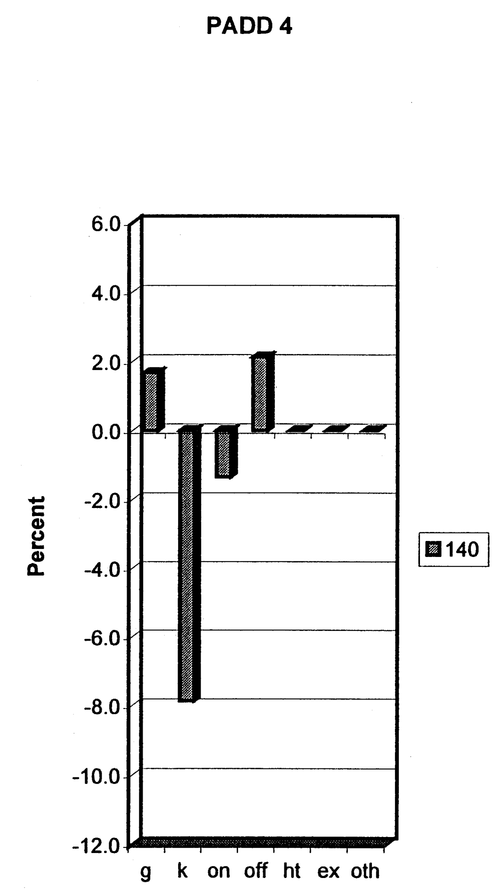
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

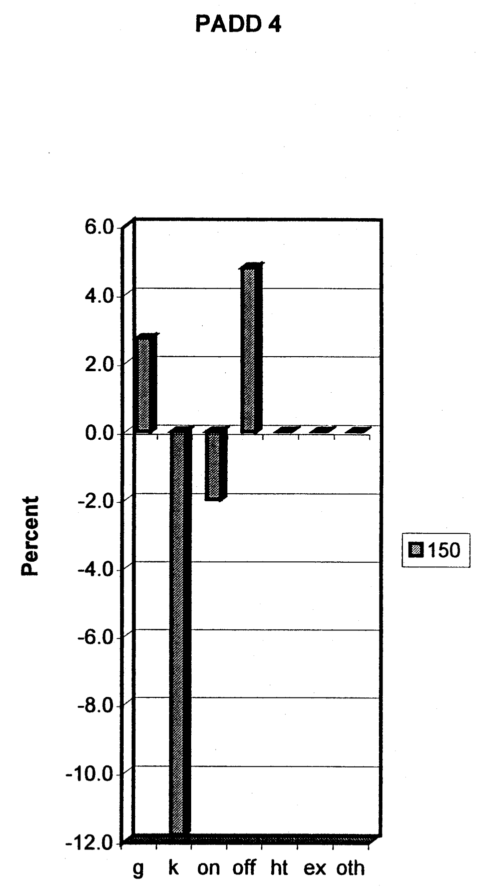
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for PADD 4





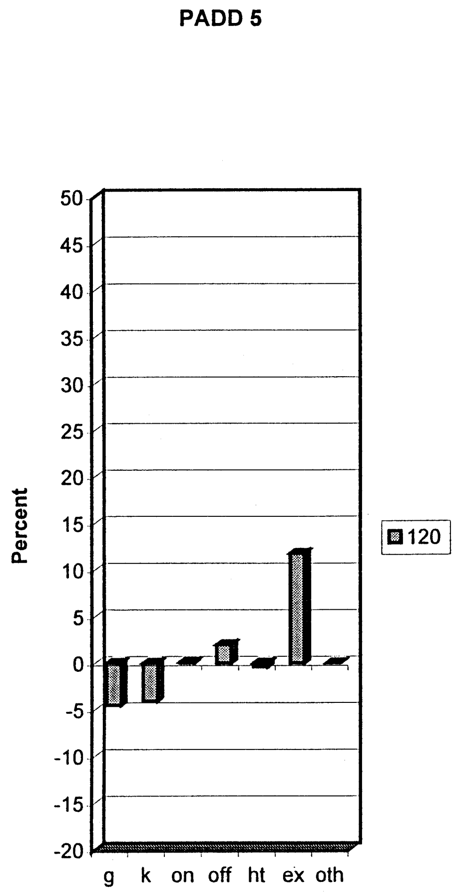


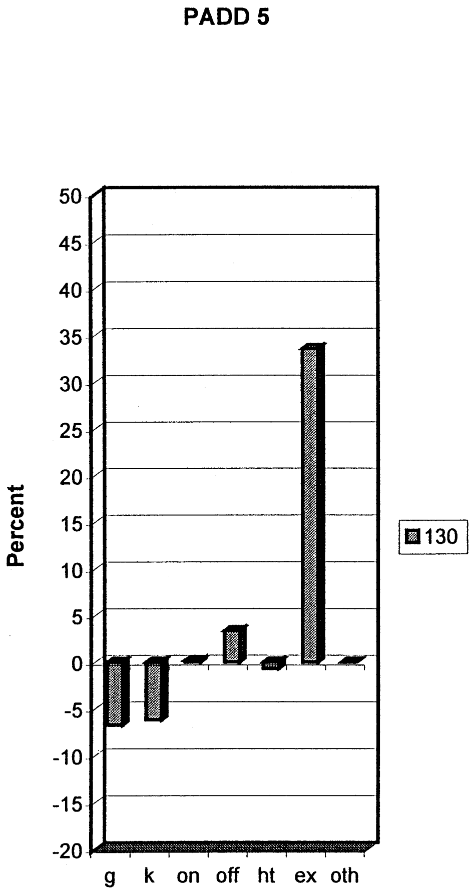


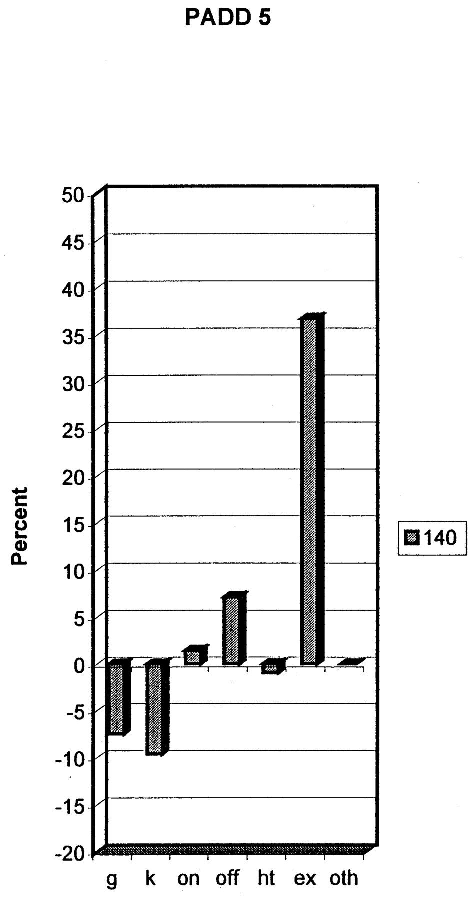
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

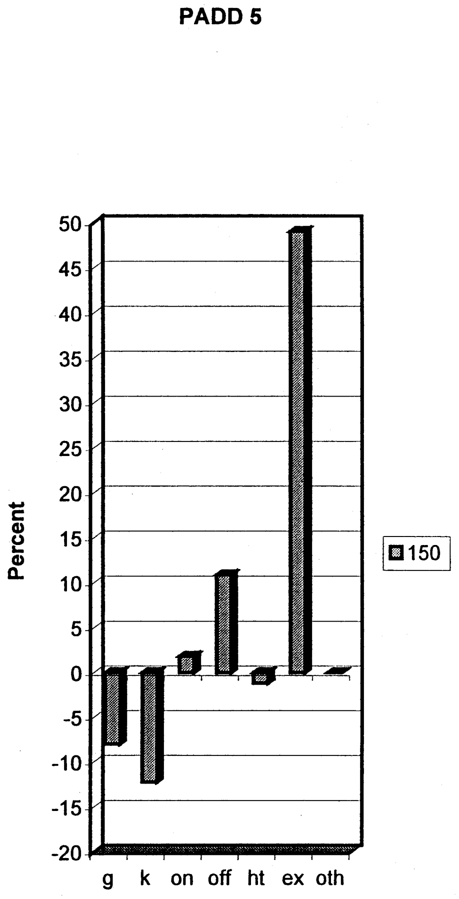
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for PADD 5





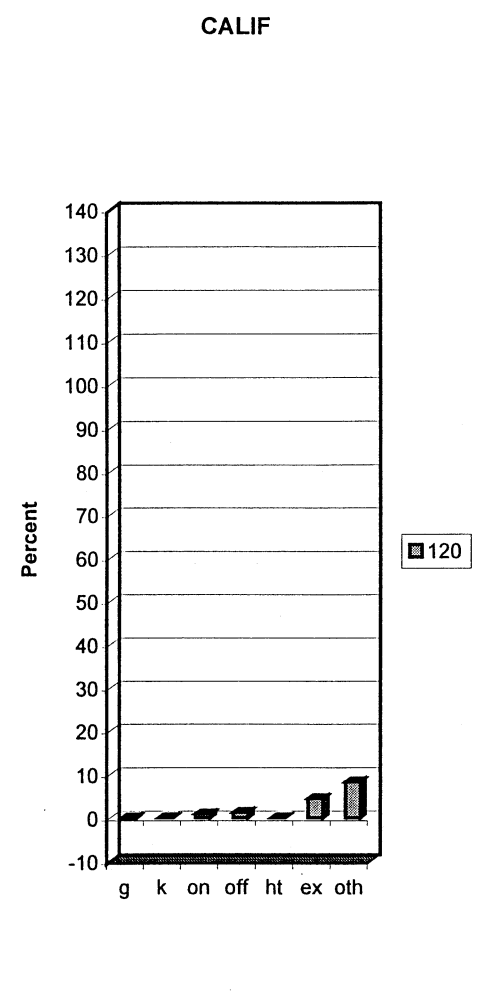


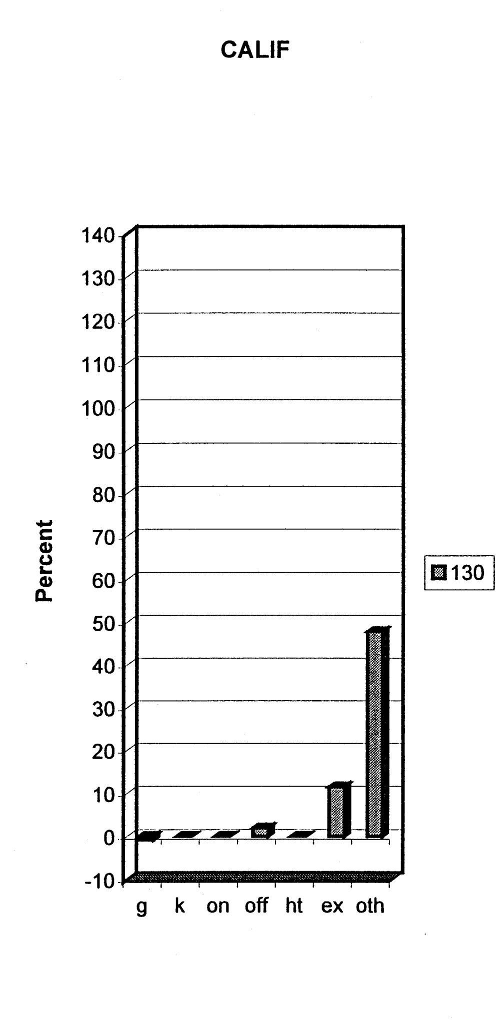


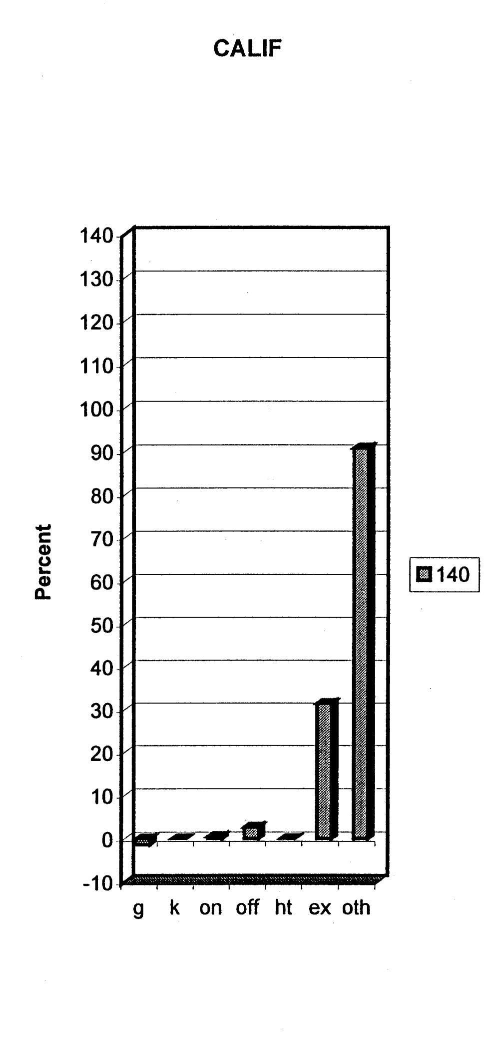
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

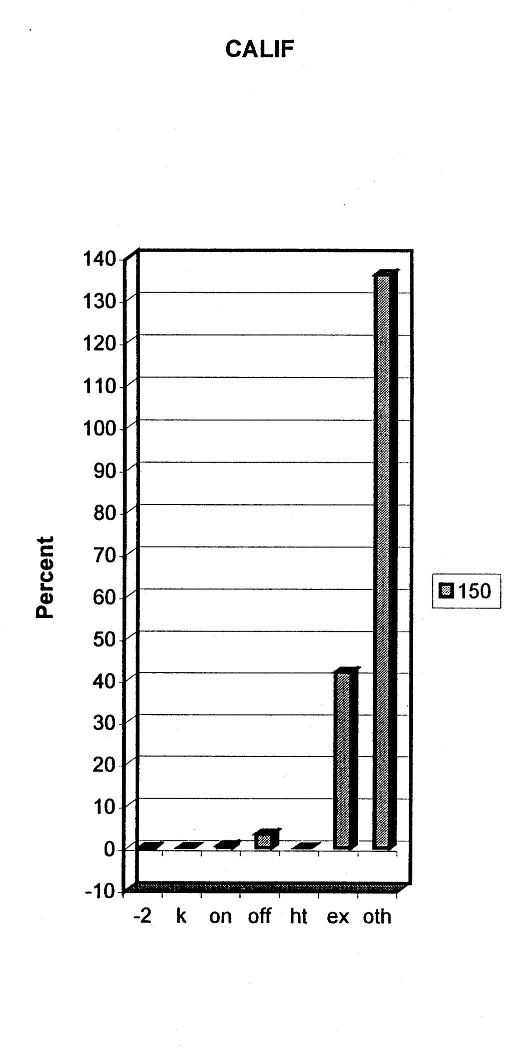
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for CALIF





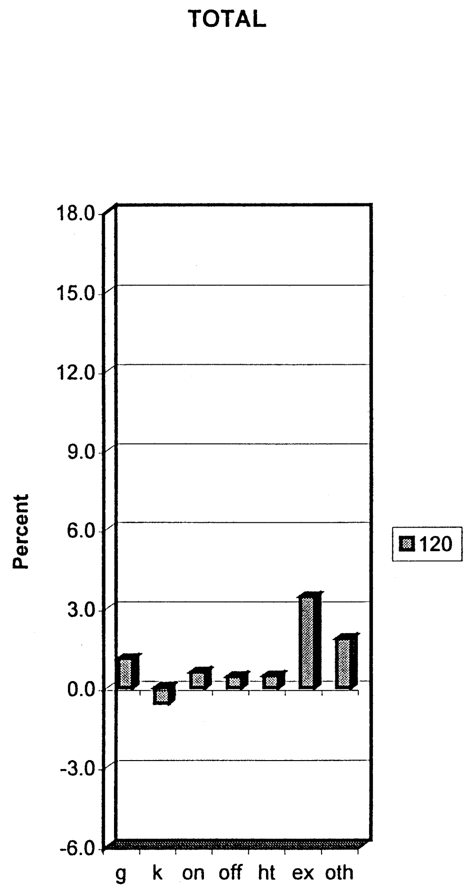


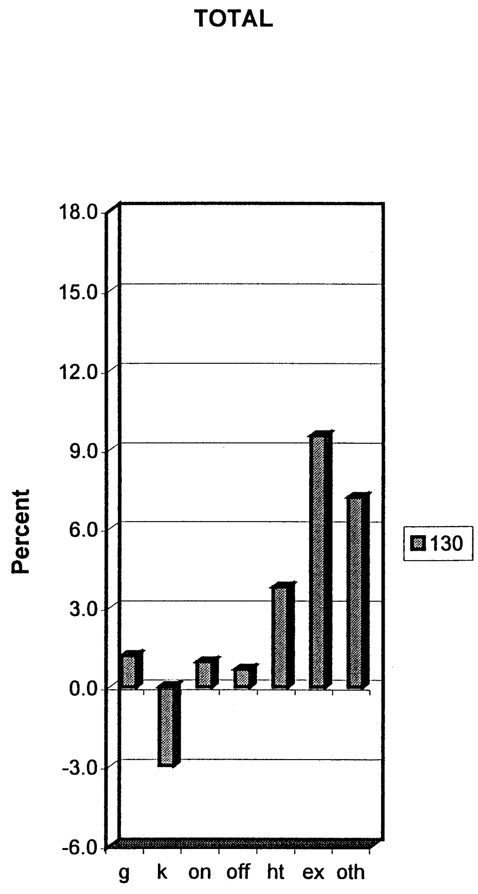


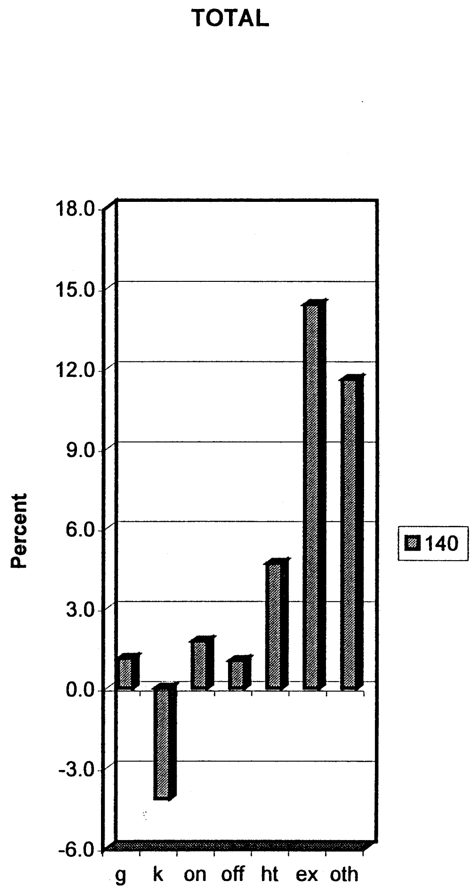
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

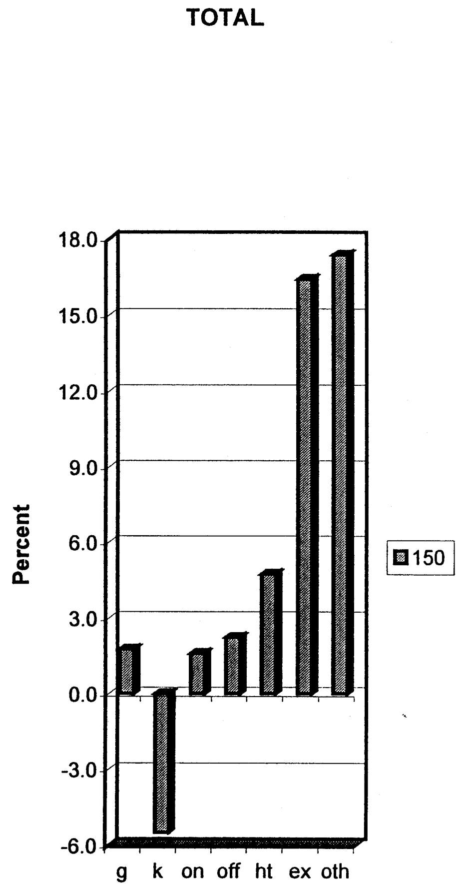
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for TOTAL



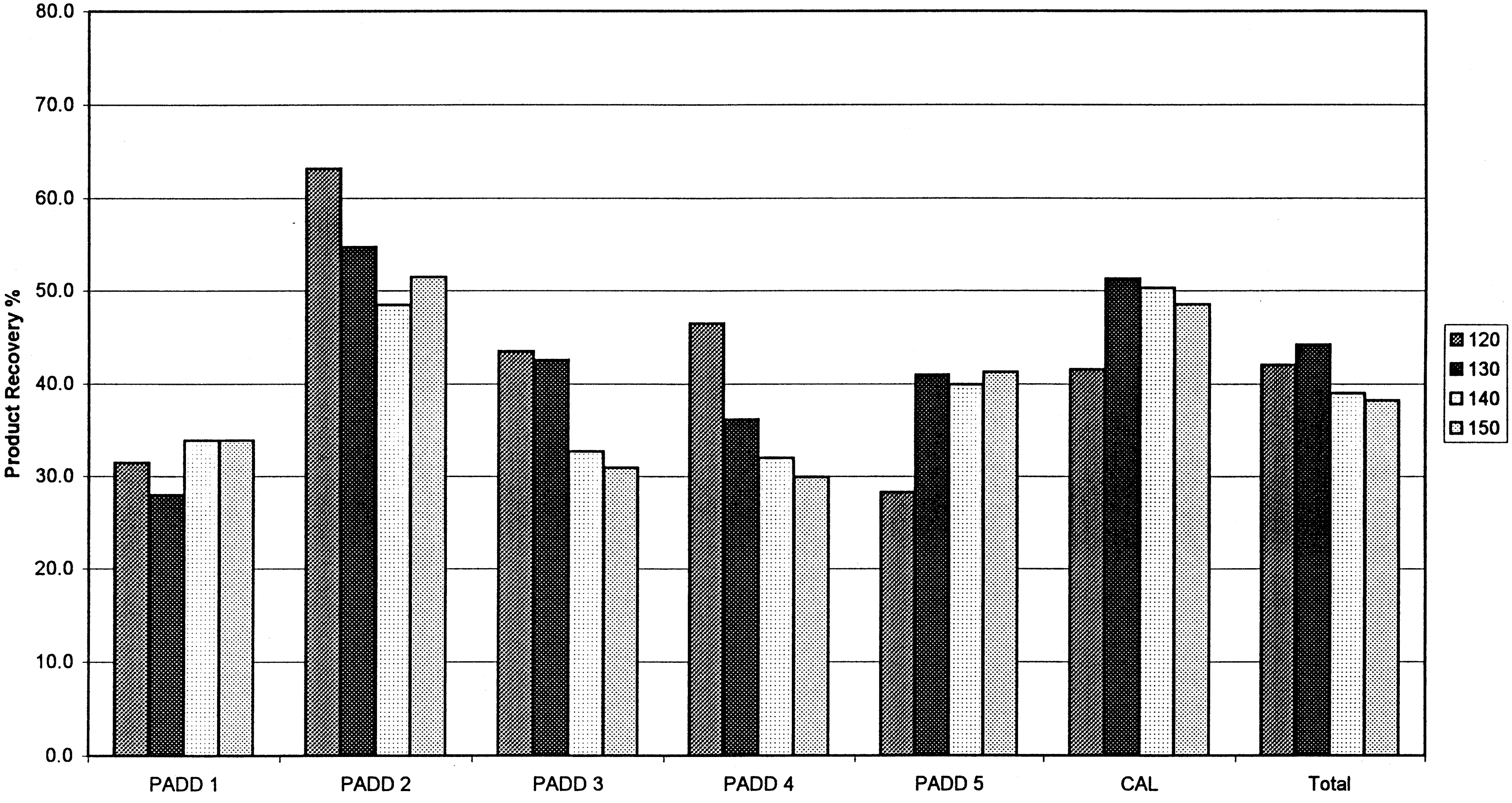






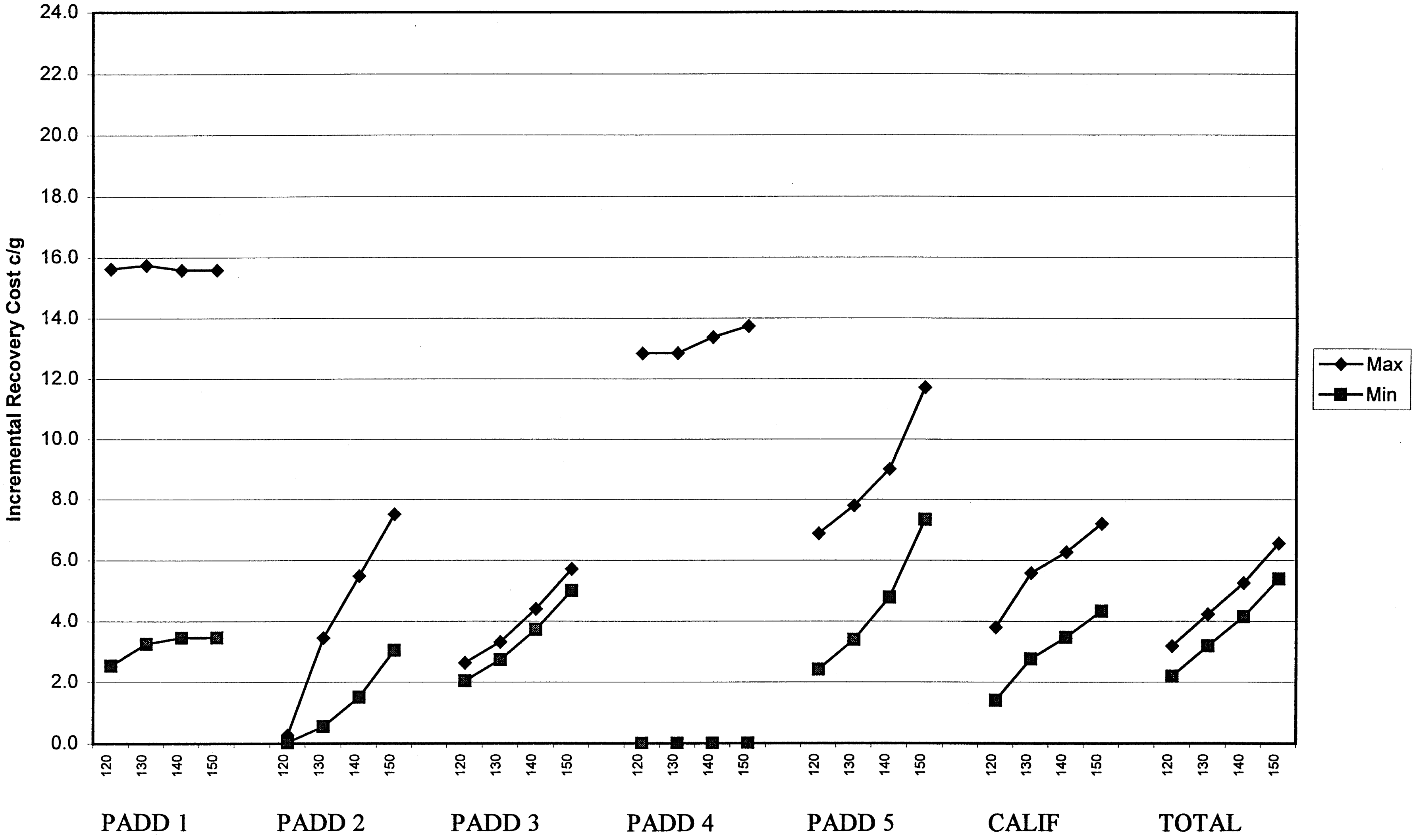
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect?
Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2d Comparison by PADD



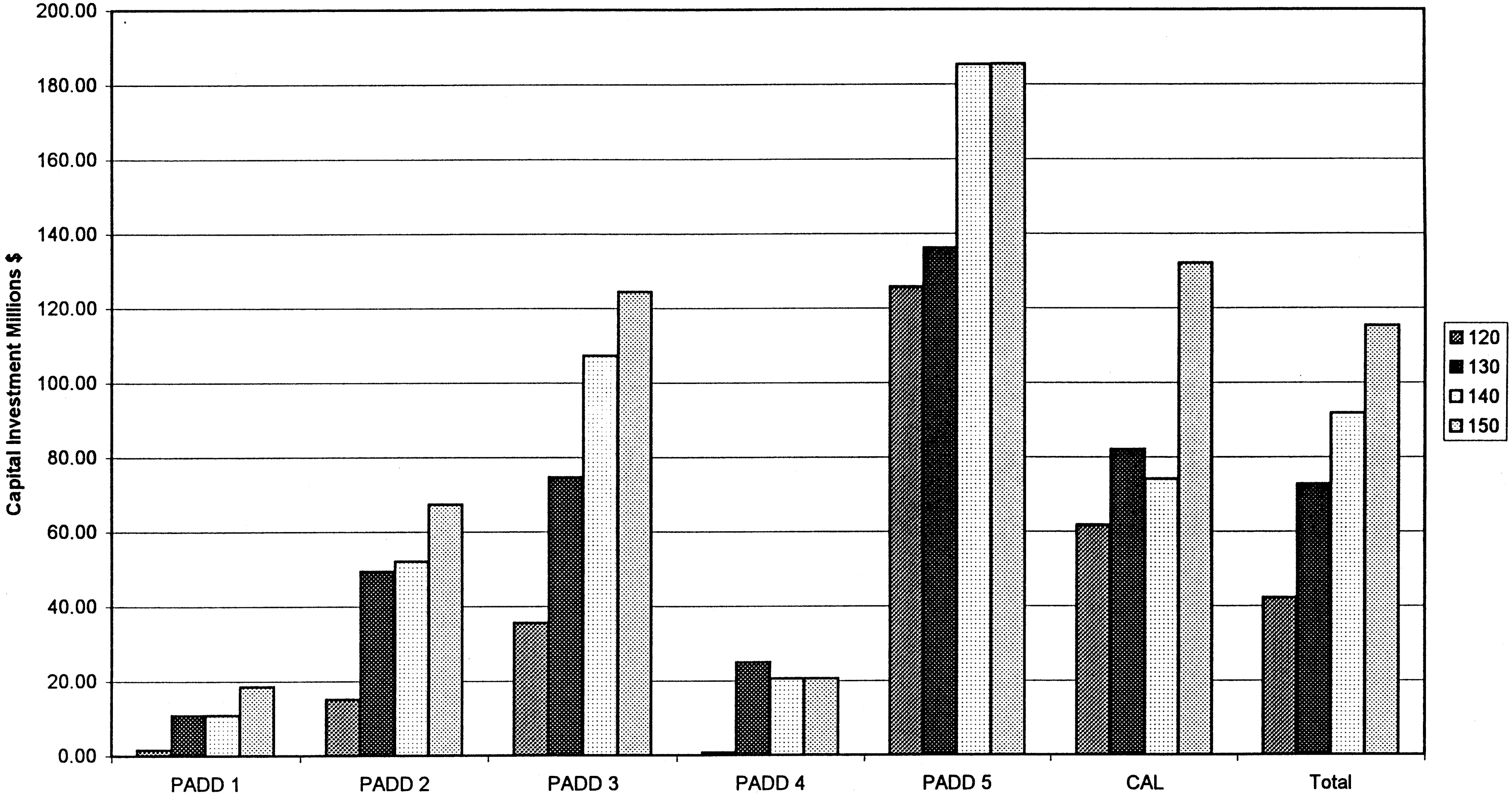
2d. If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Question 2e Comparison by PADD



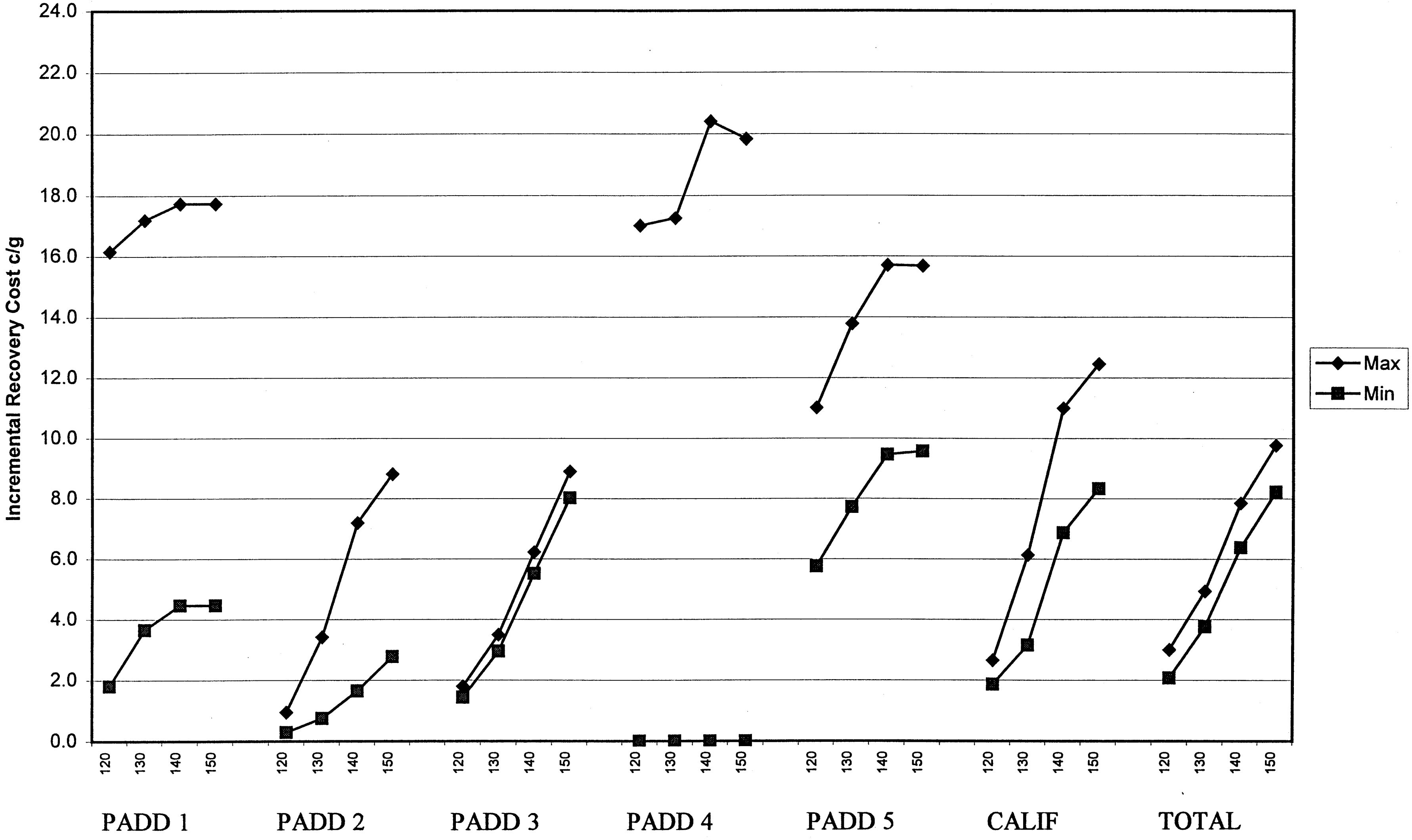
2e. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 2f Comparison by PADD



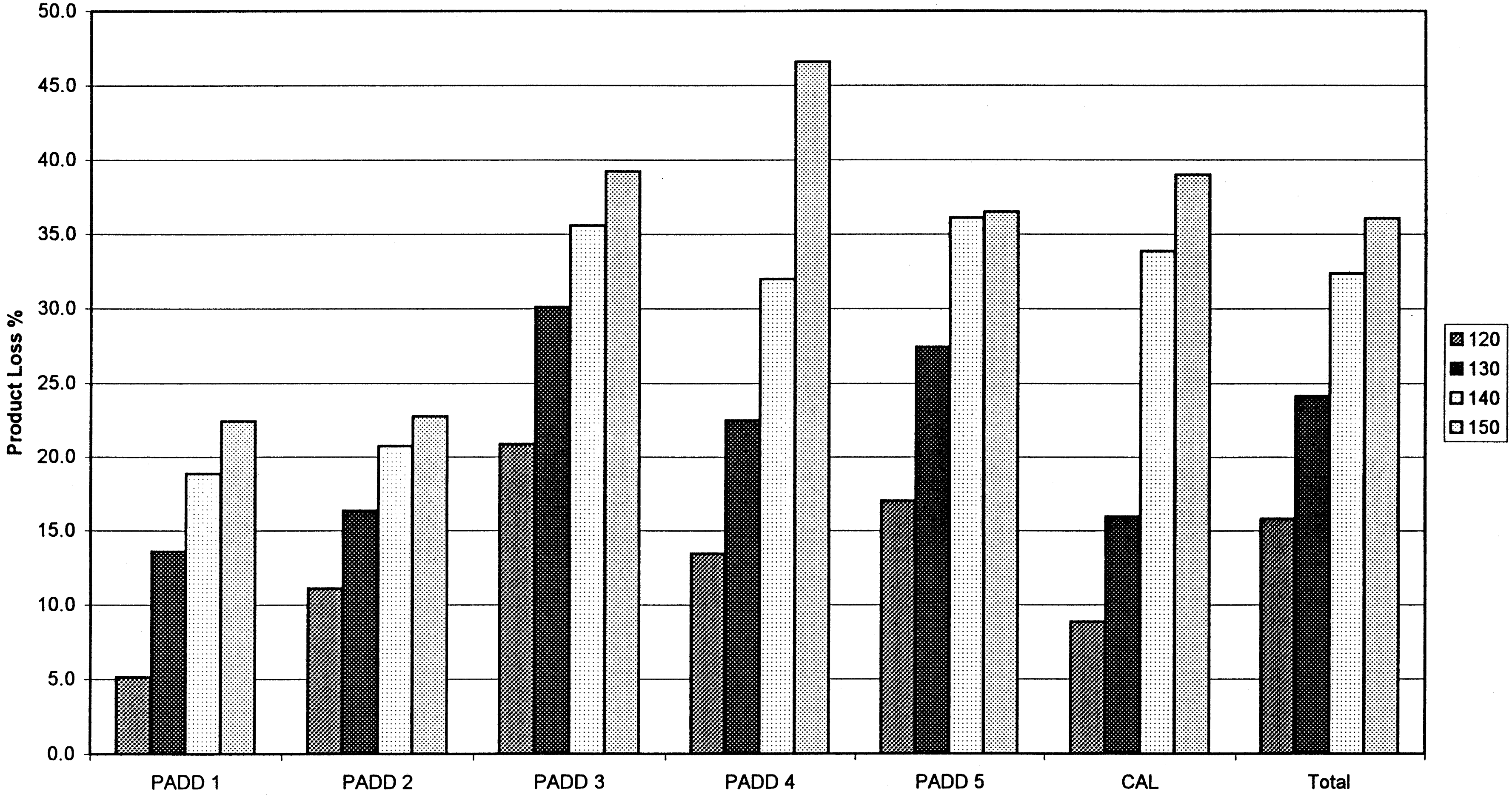
2f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

Question 2g Comparison by PADD



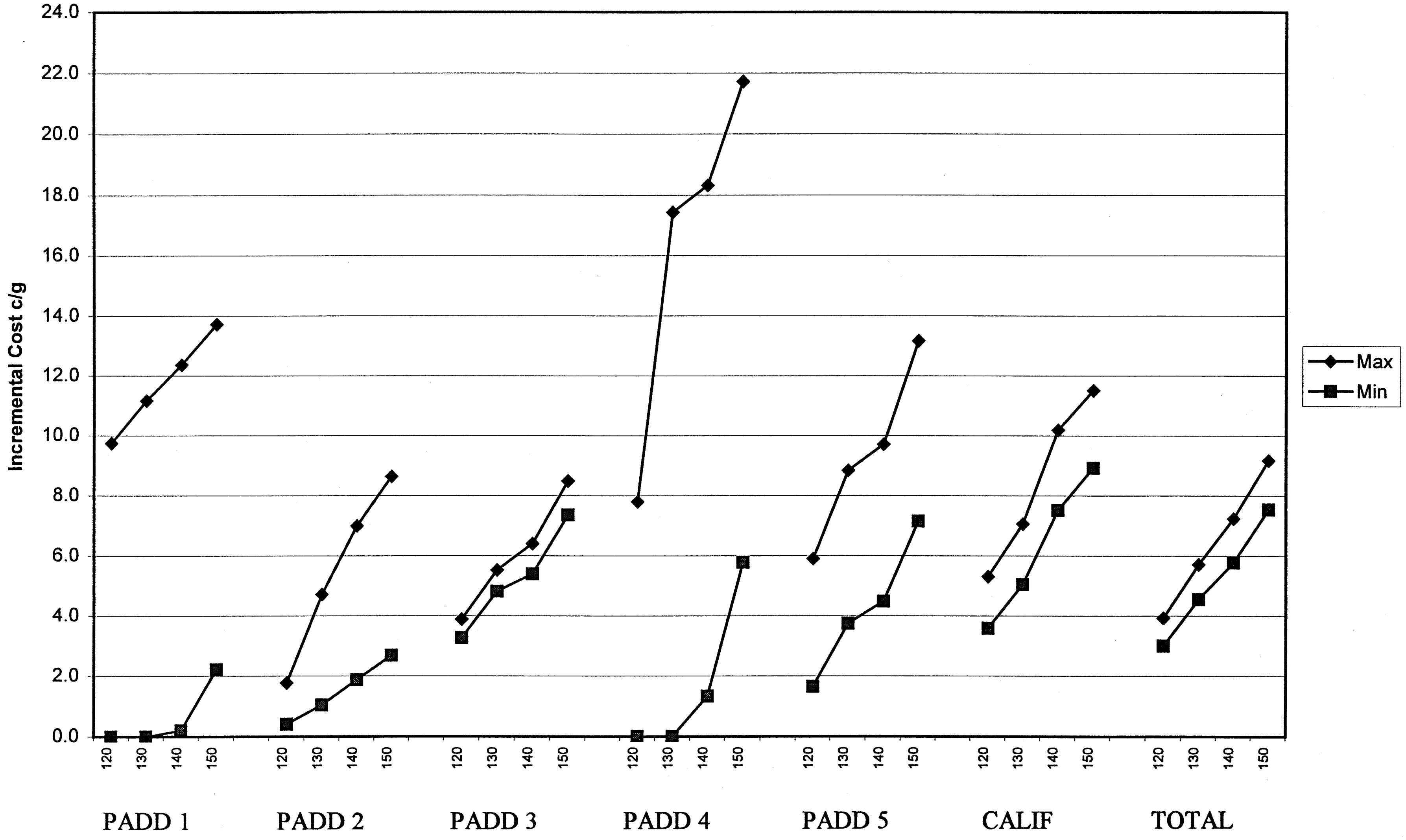
2g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash point changes,** including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for deetermining per gal capital charges. Check one box for each flash point

Question 3a Comparison by PADD



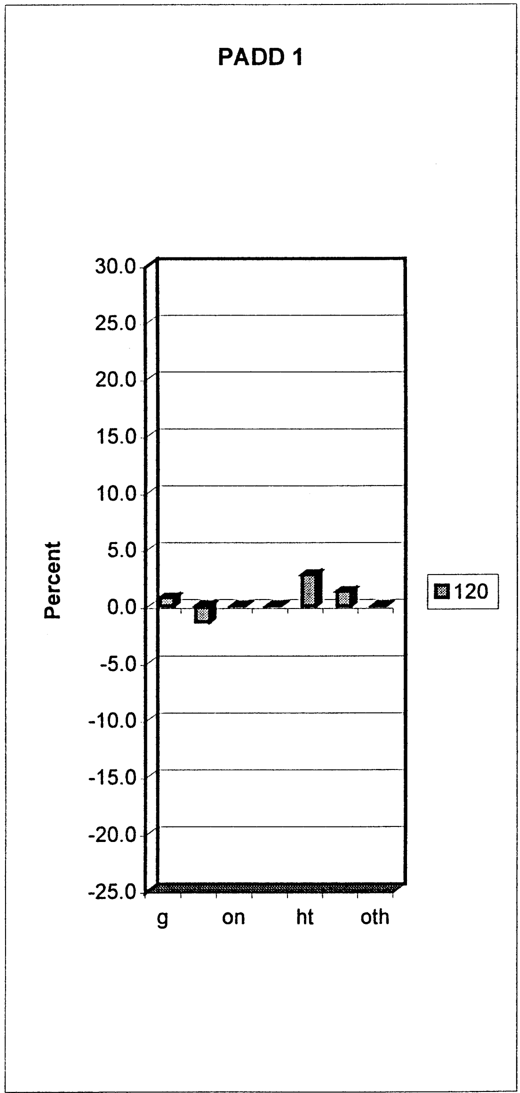
3a. If the **freeze point specification minimum was reduced to –53 deg F, in addition to the flash point changes projected above,** what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

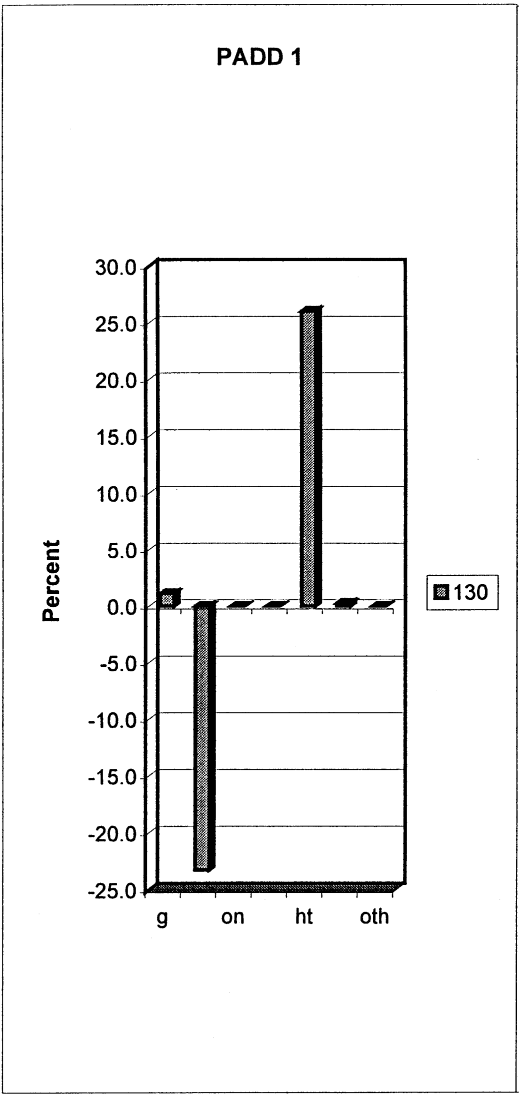
Question 3b Comparison by PADD

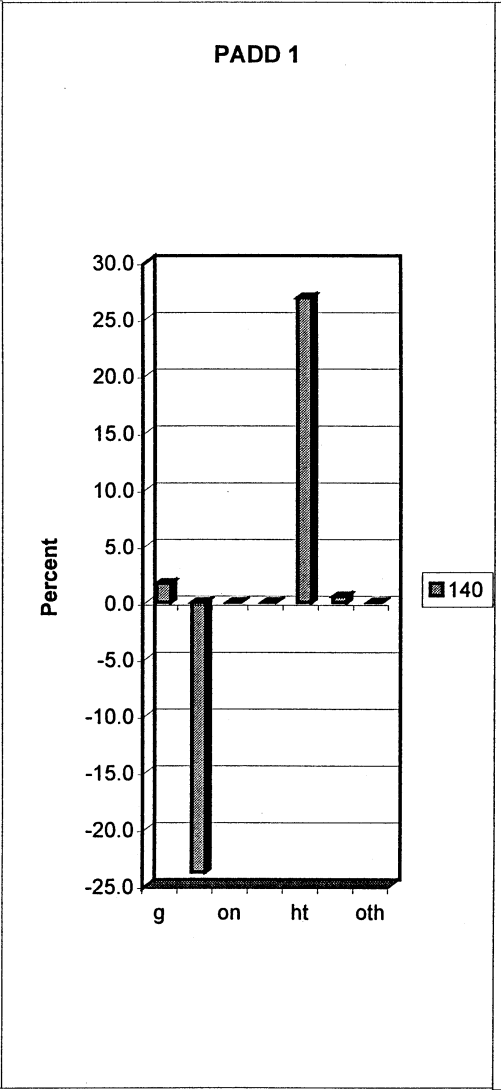


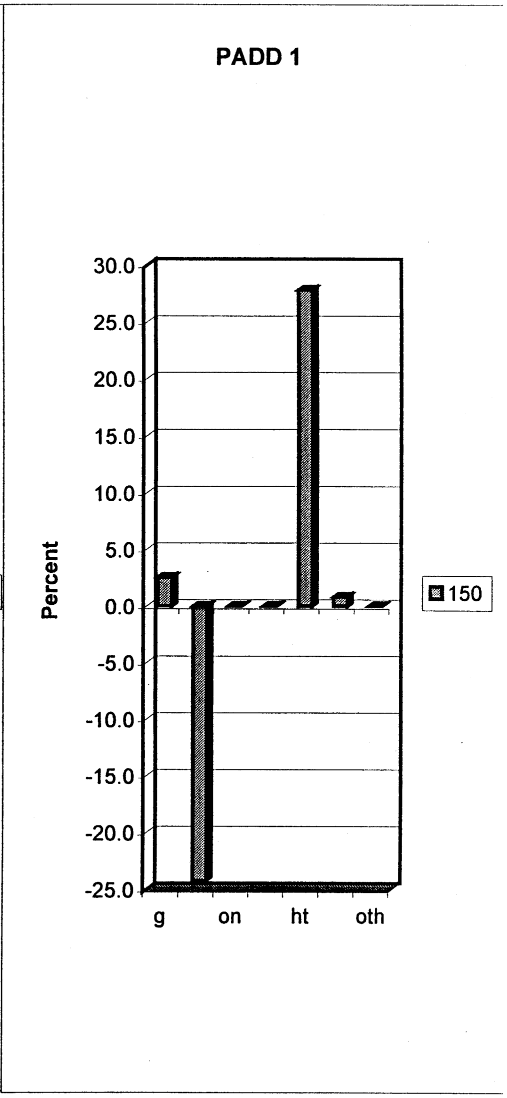
3b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point and freeze specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 3C Comparisons for PADD 1





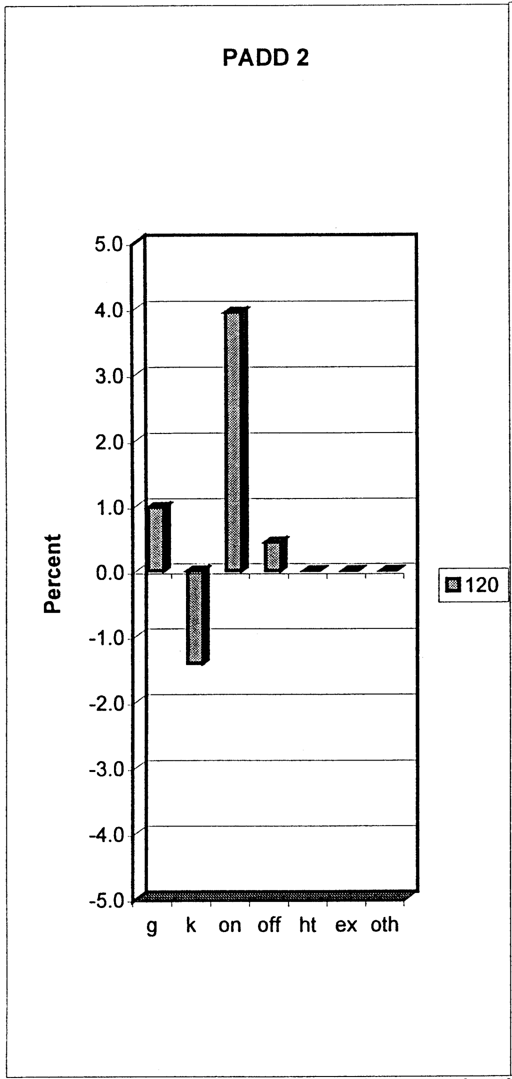


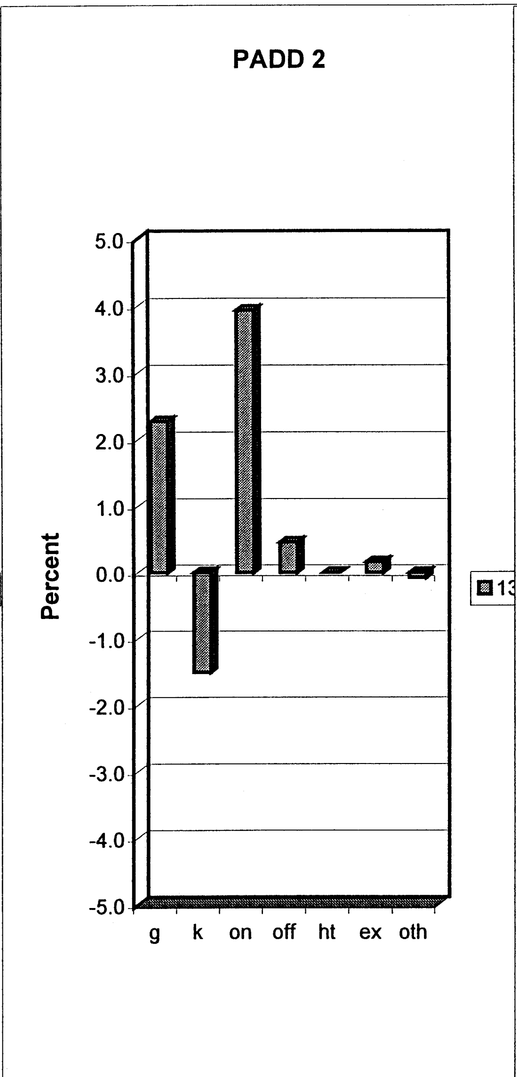


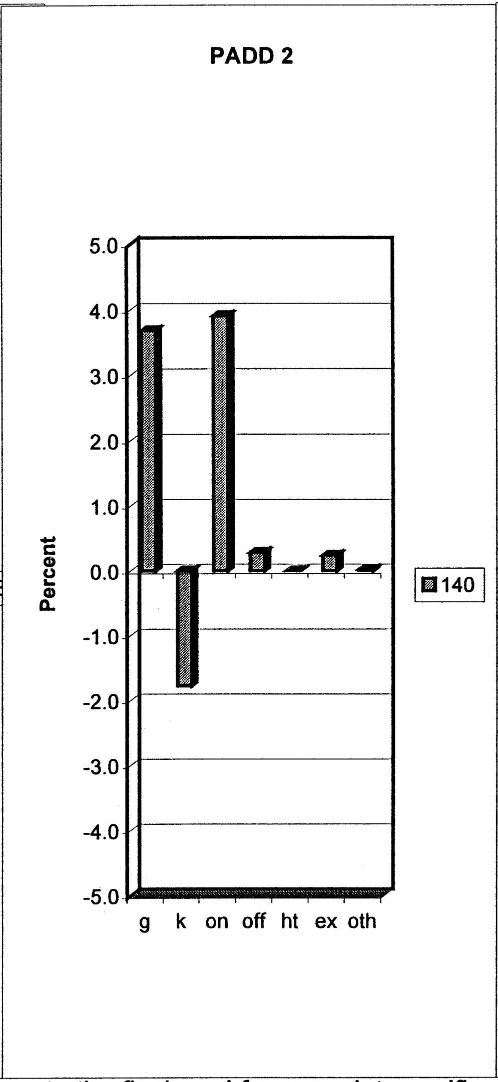
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

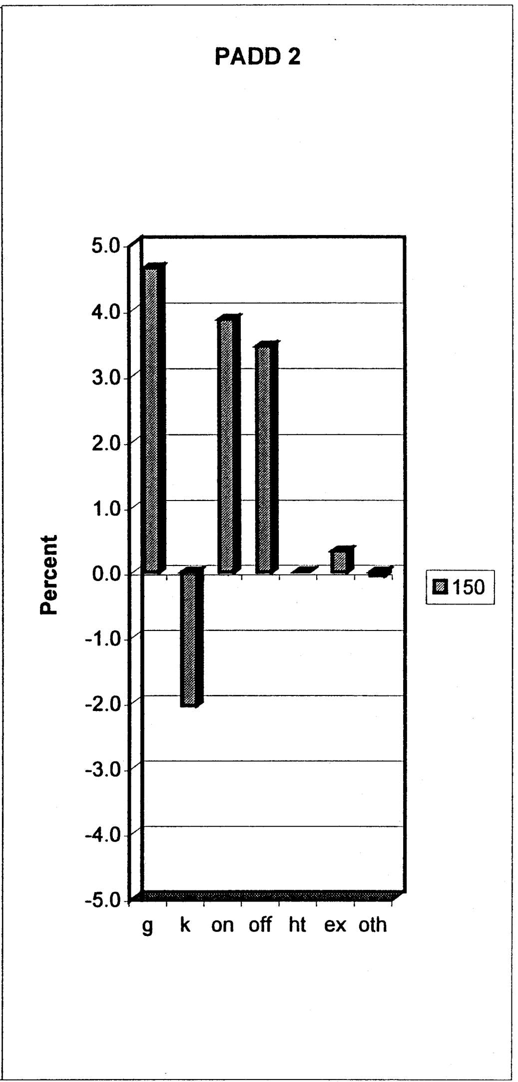
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 2





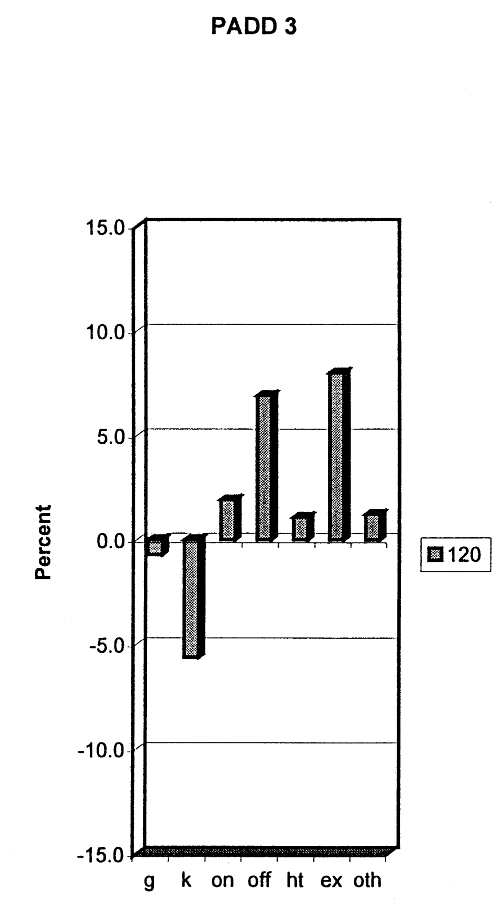


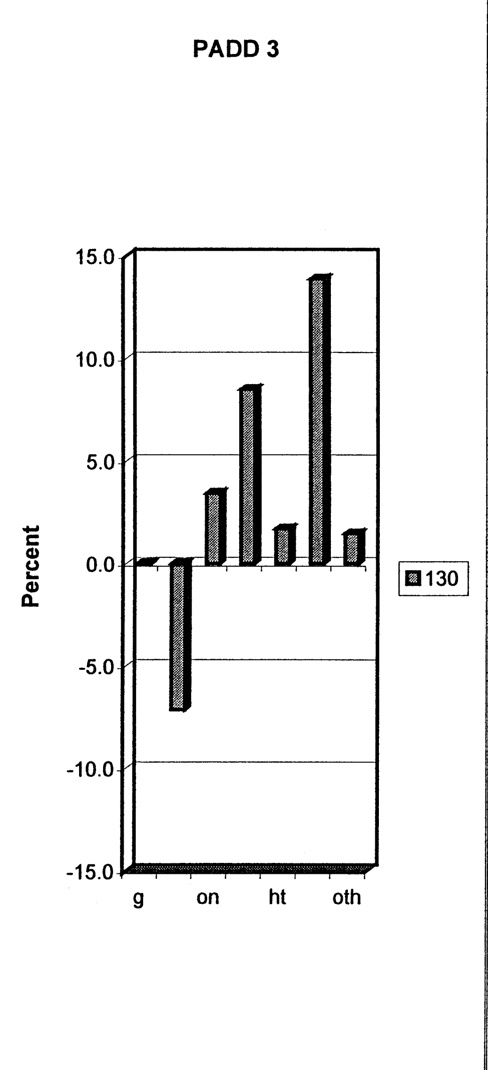


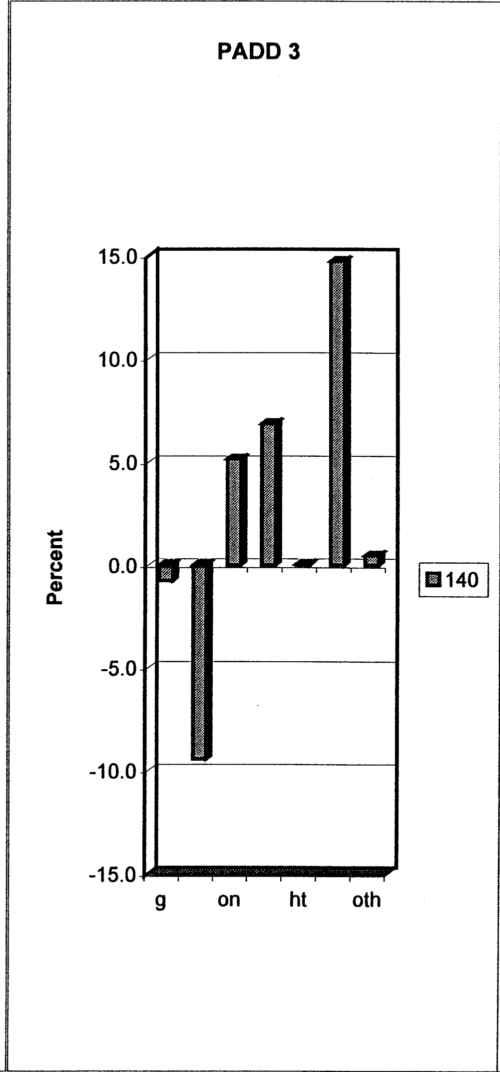
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

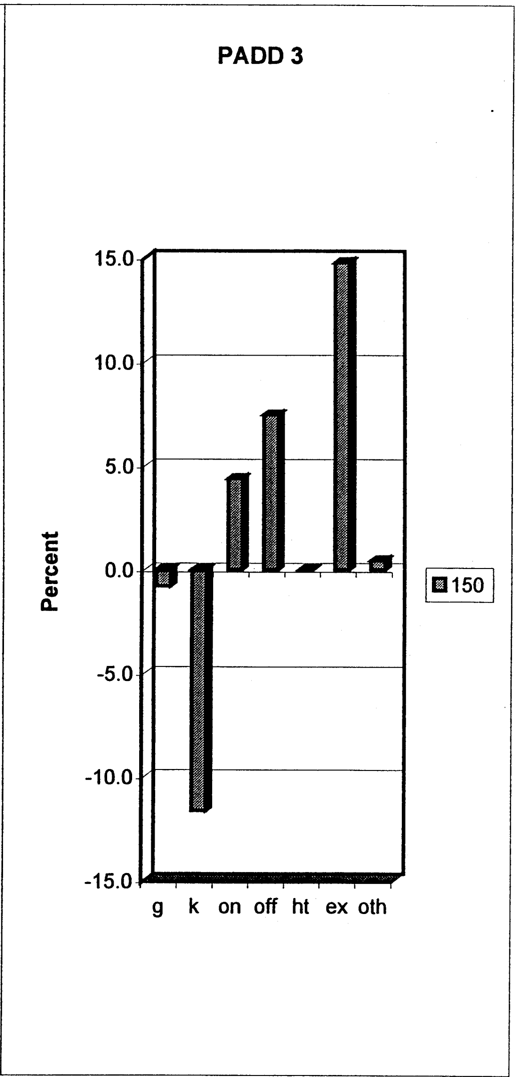
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 3



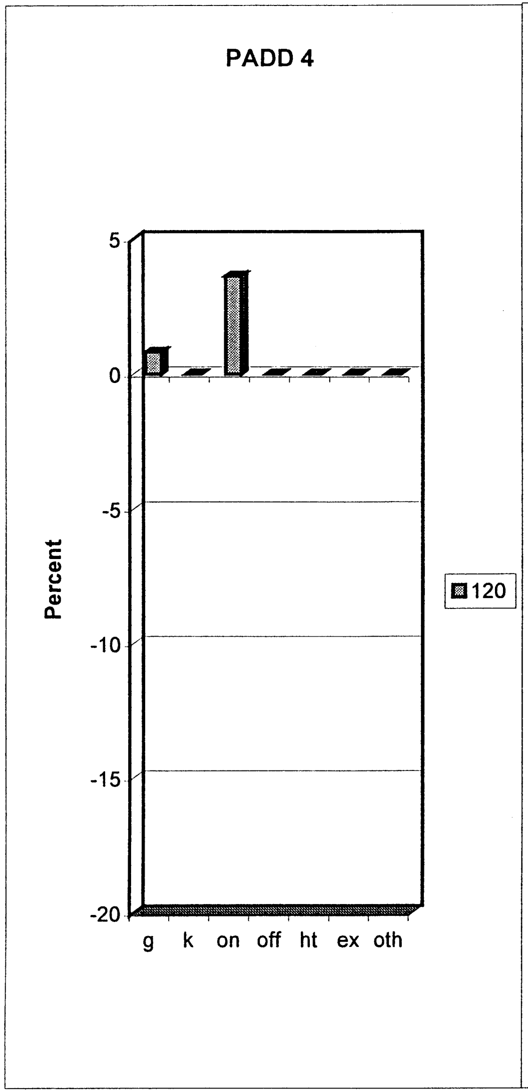


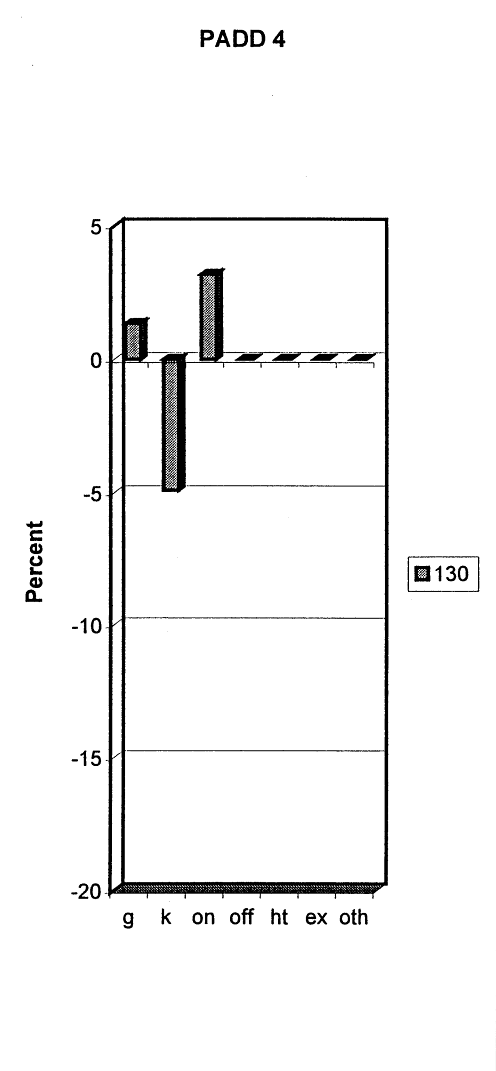


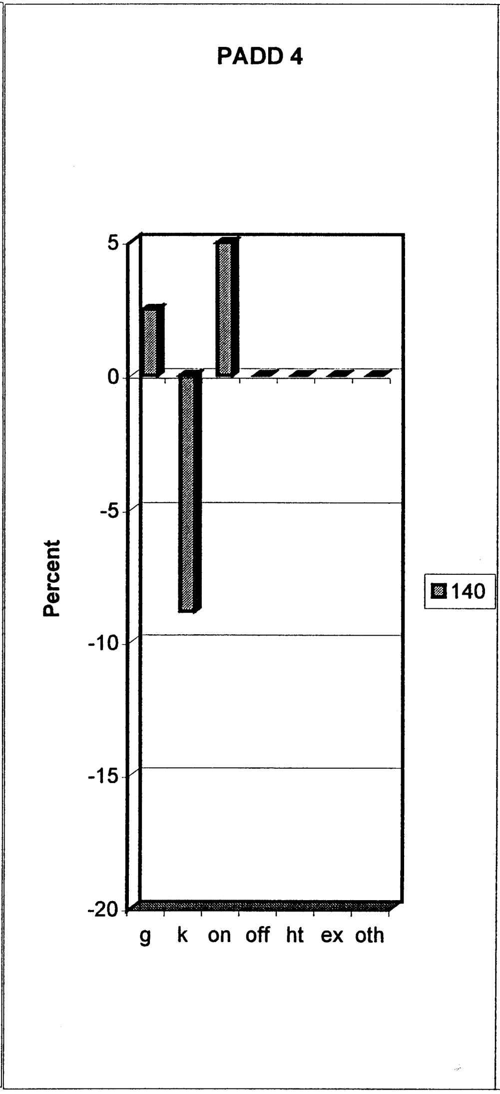


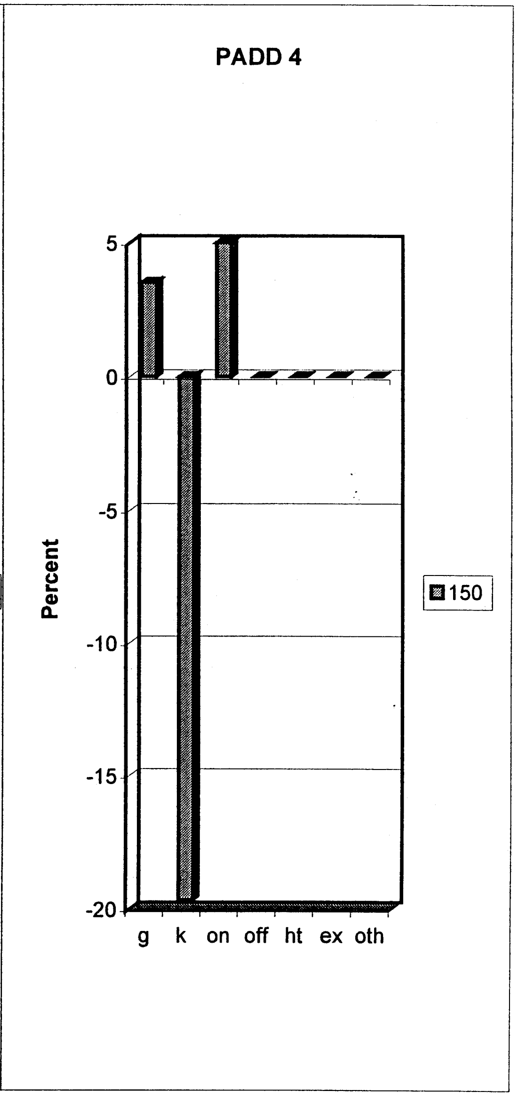
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 4





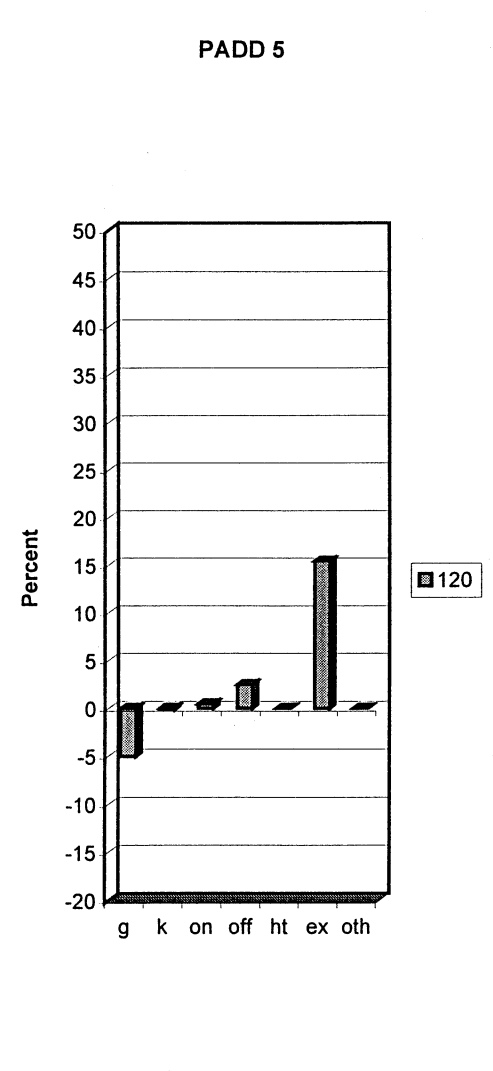


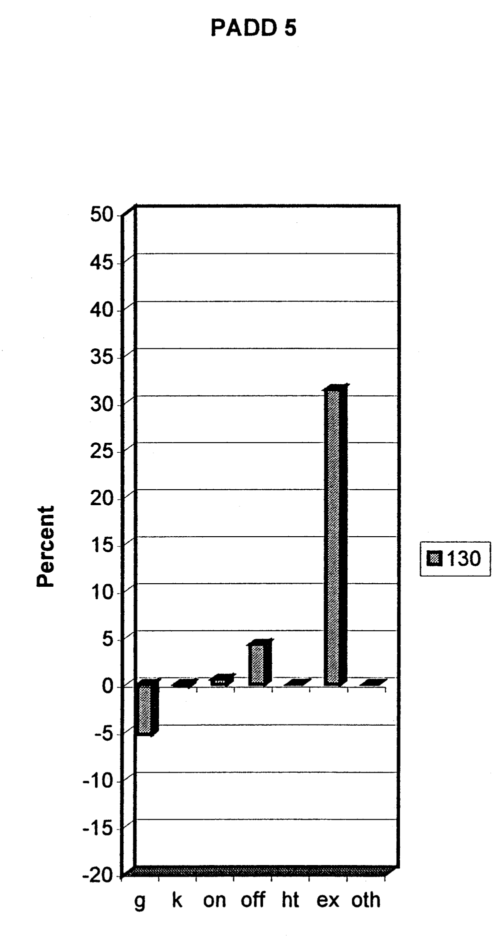


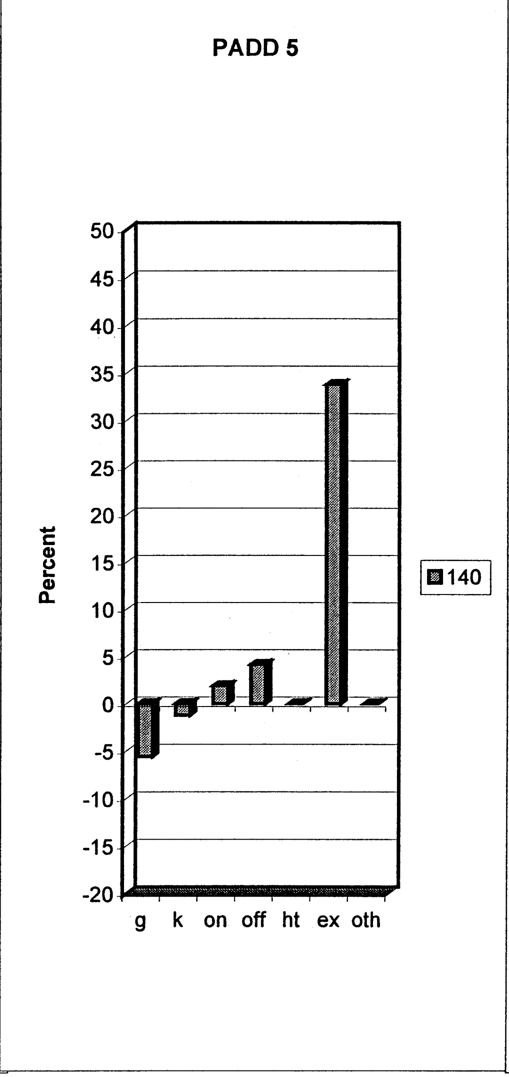
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

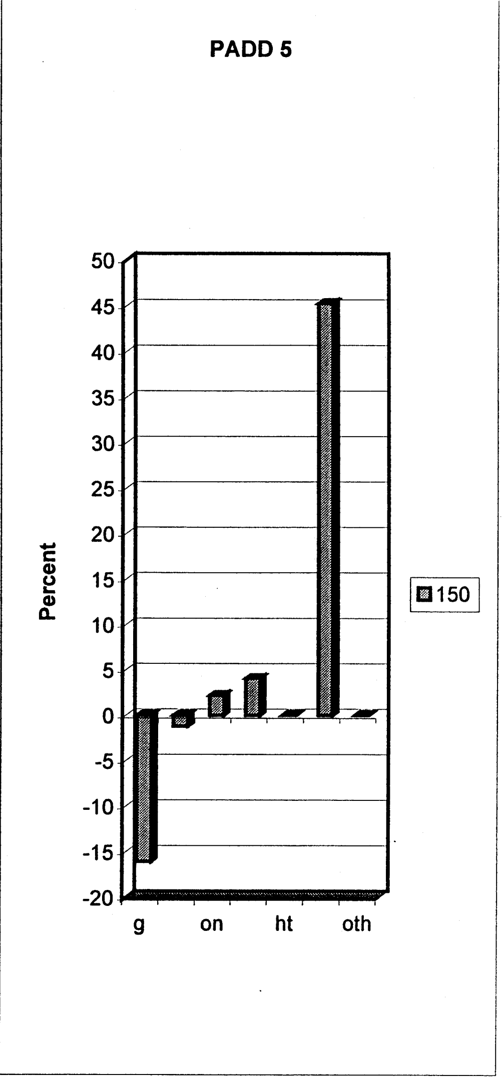
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 5





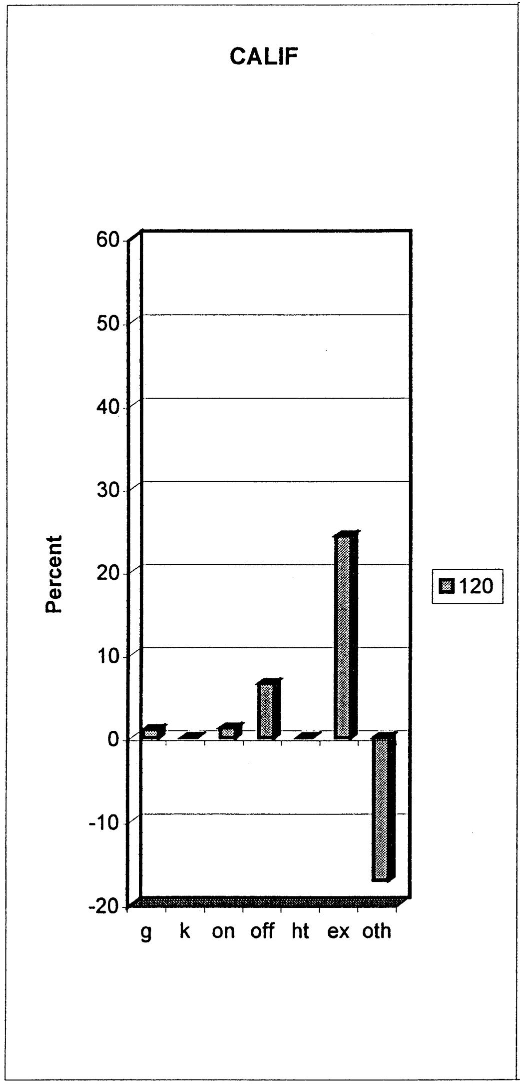


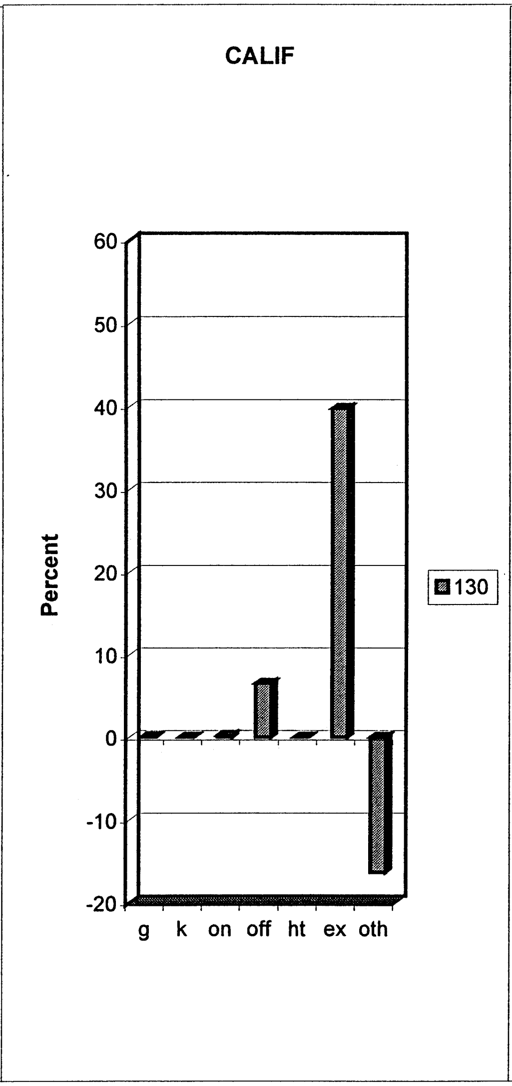


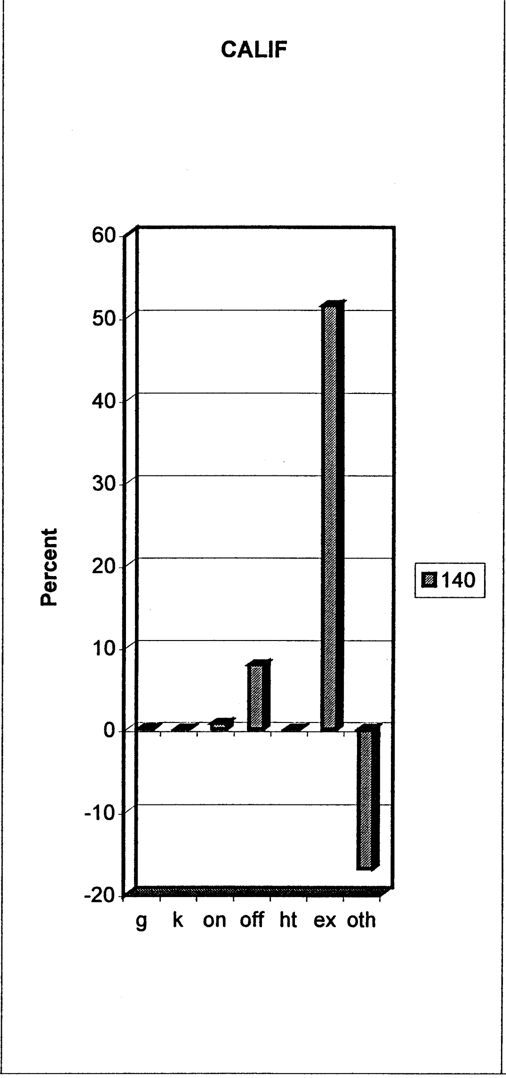
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

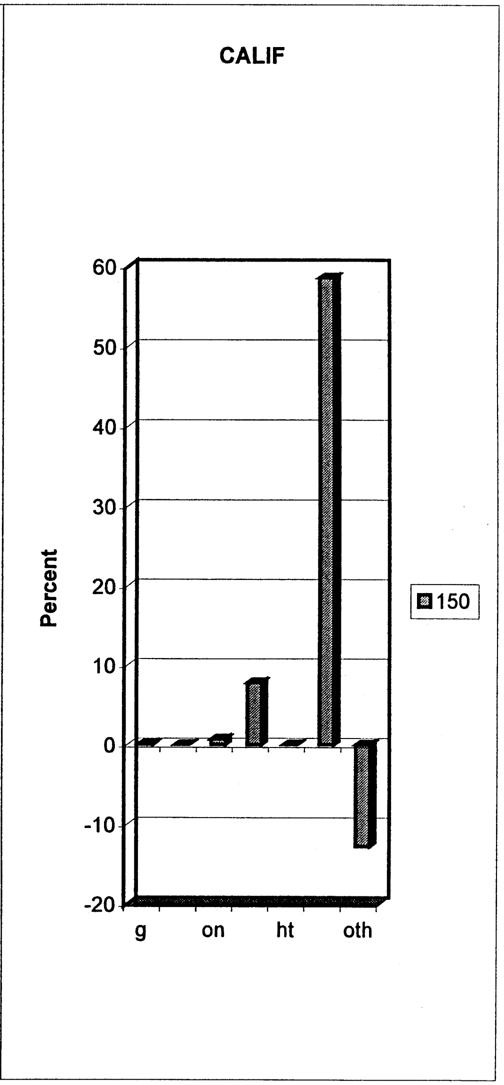
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for CALIF





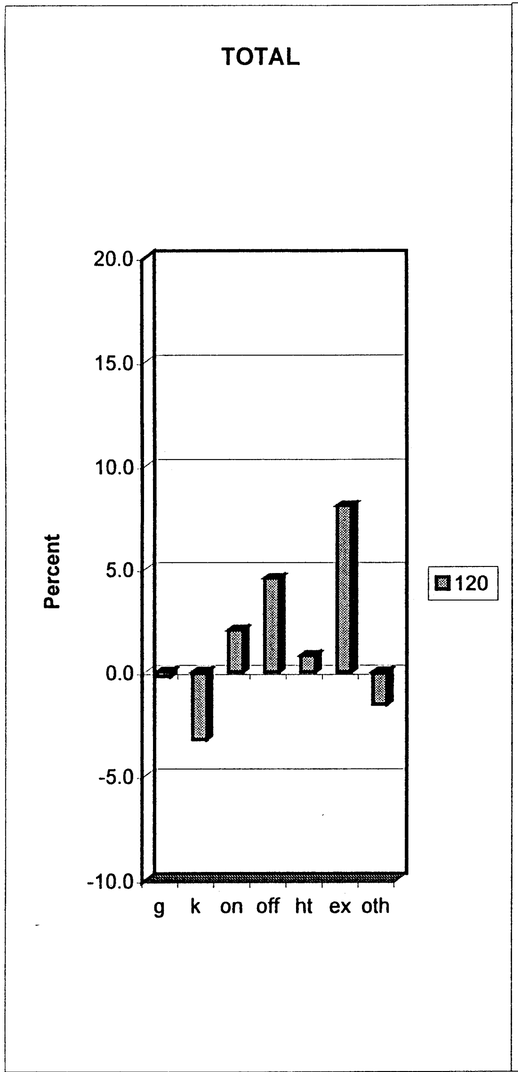


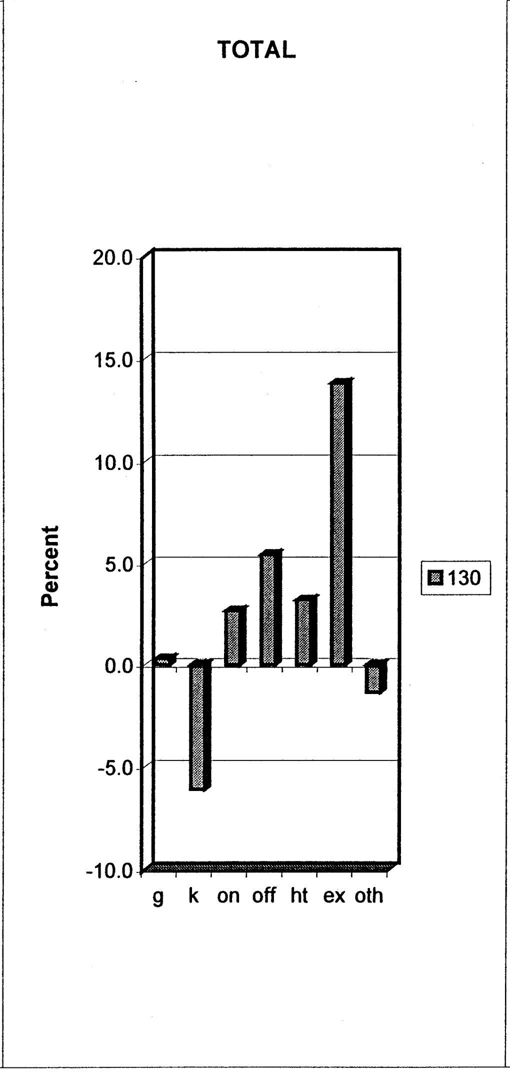


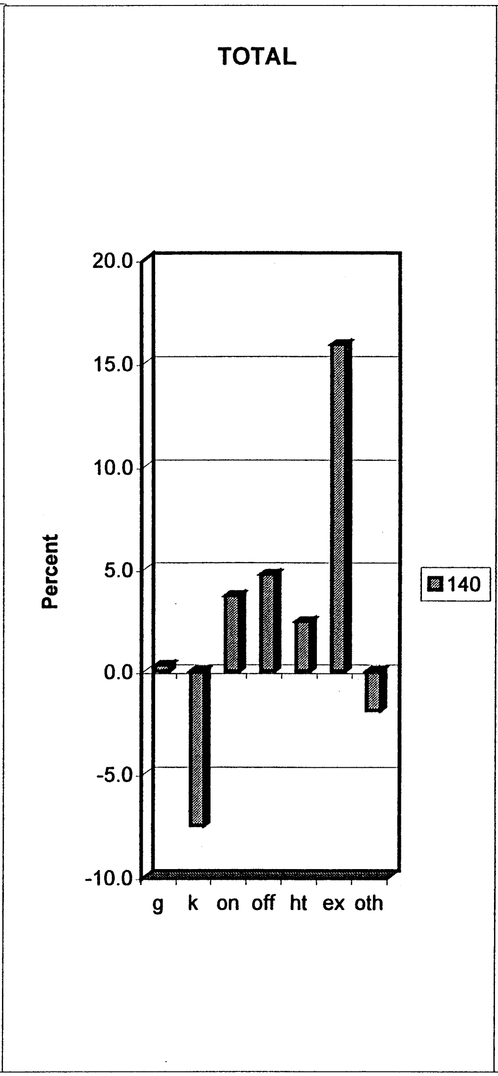
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

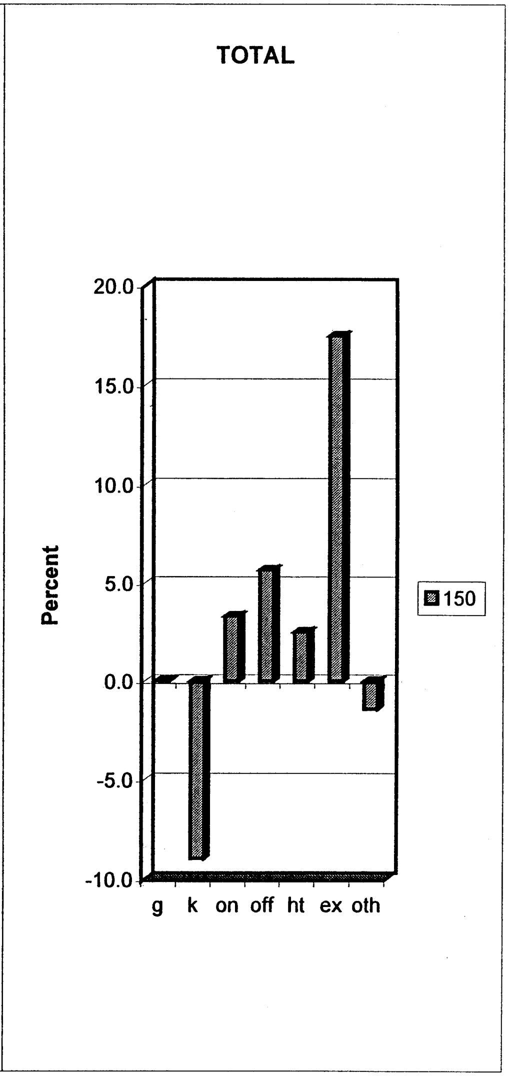
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for TOTAL





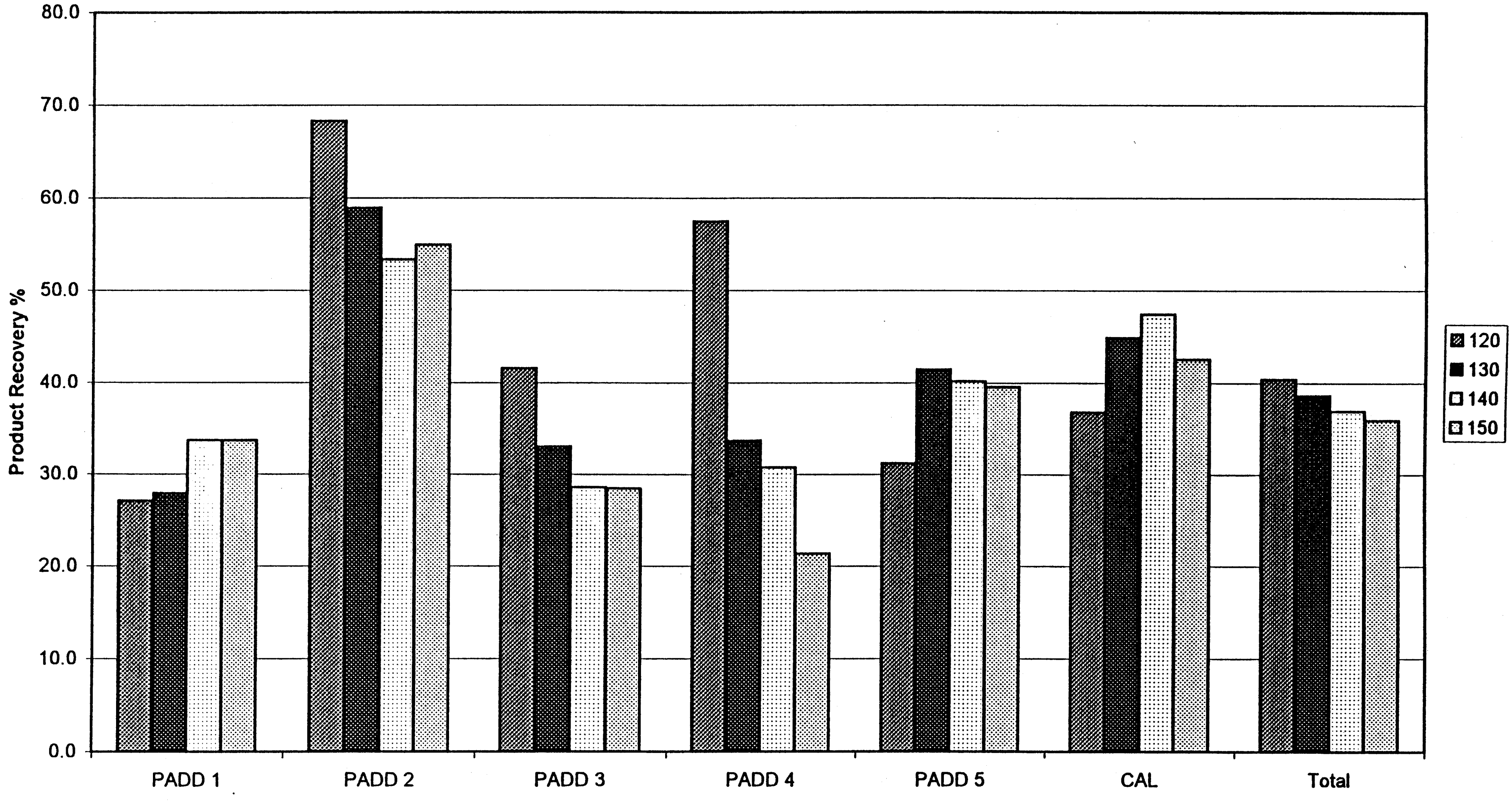




Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

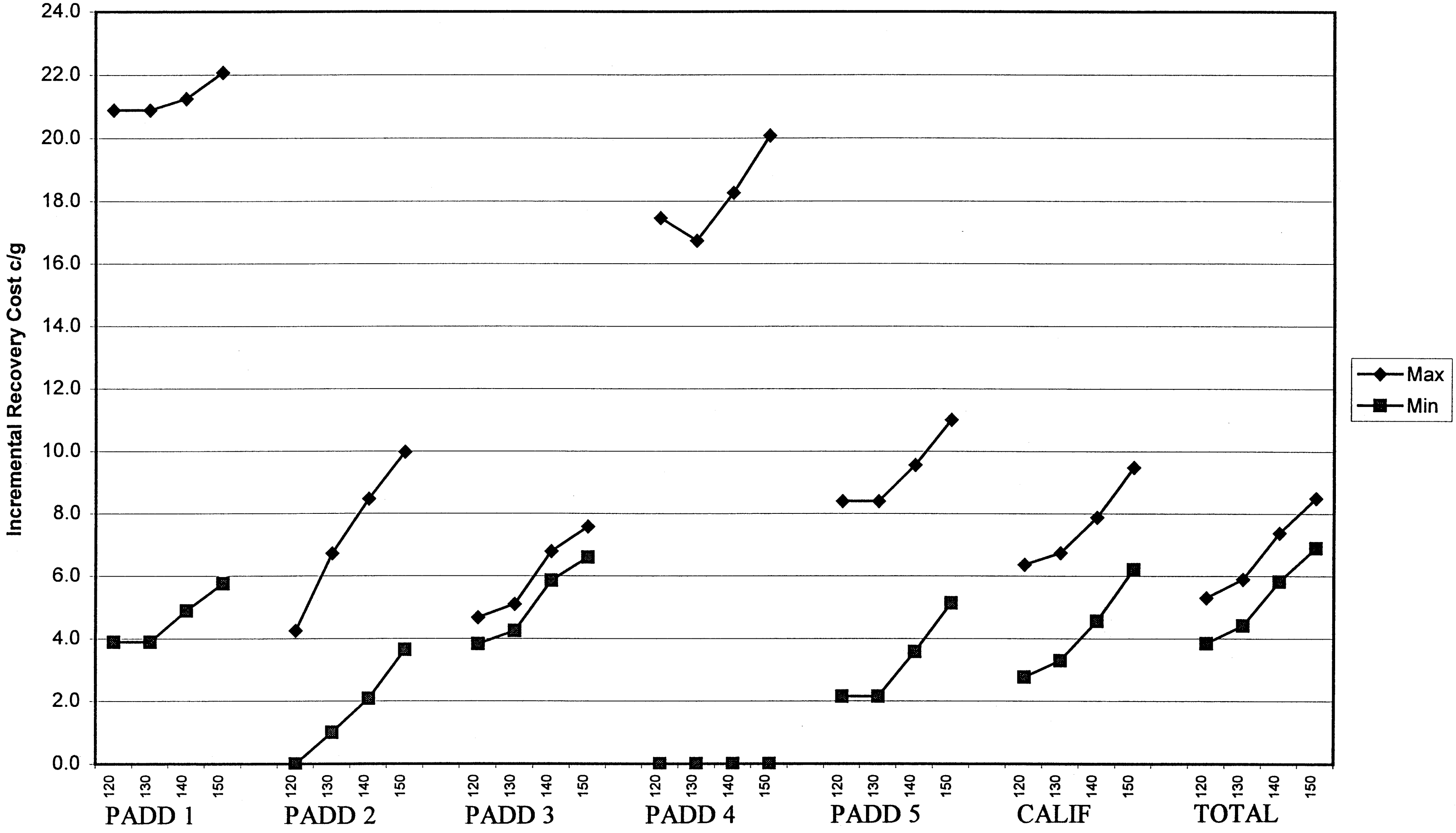
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3d Comparison by PADD



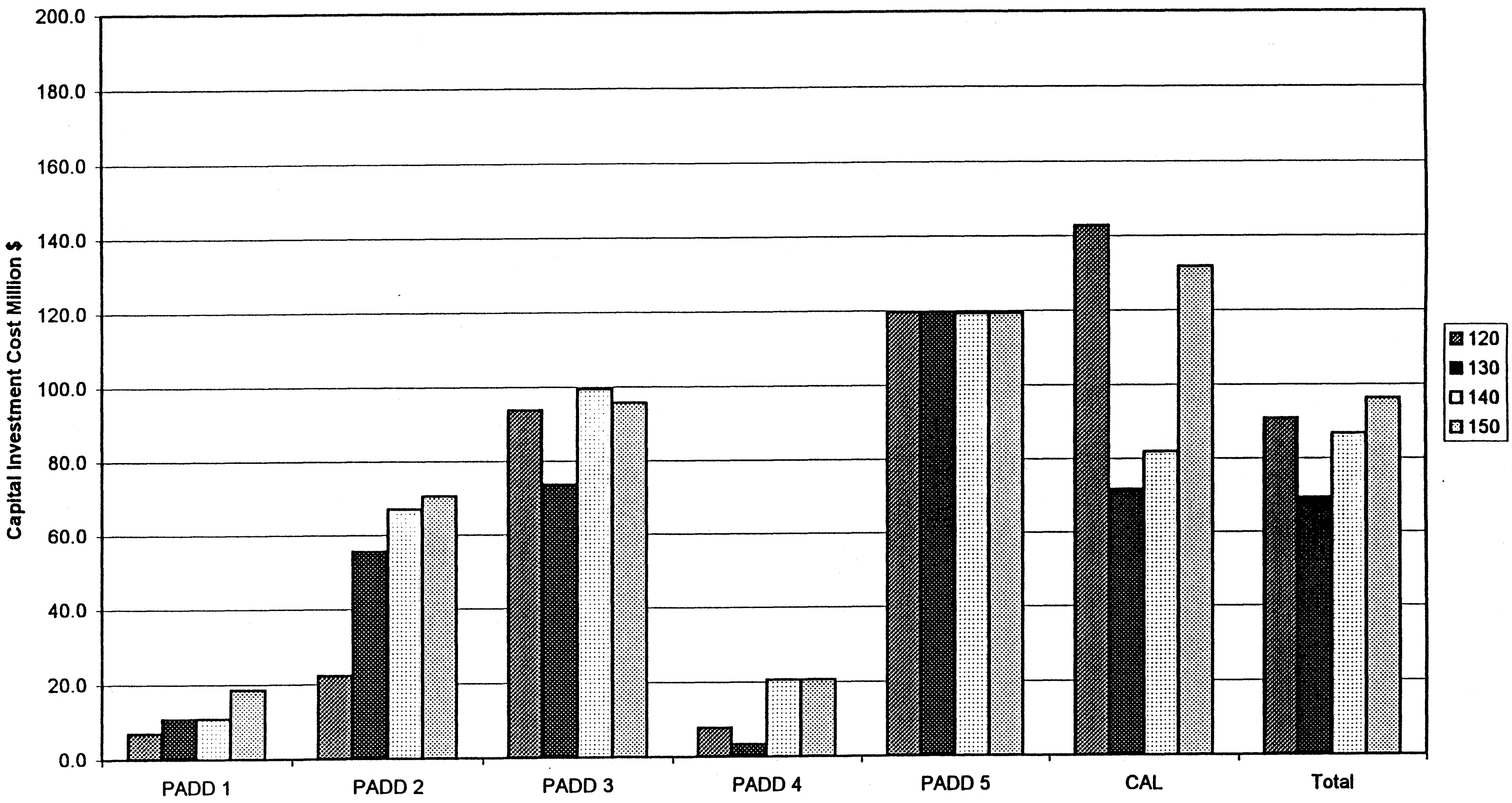
3d. If you indicated a reduction in jet fuel production in question 3a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Question 3e Comparison by PADD



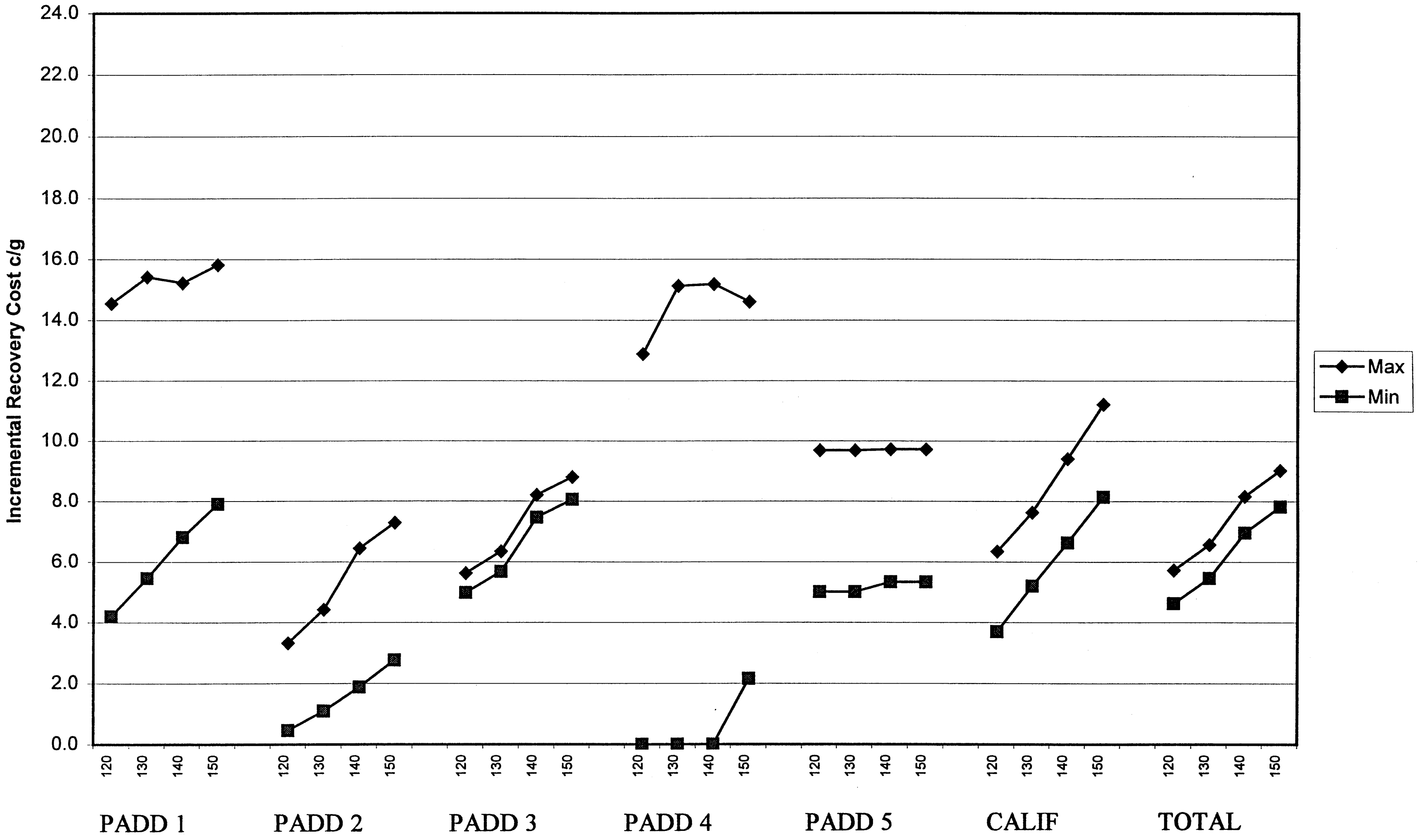
3e. What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from **flash and freeze point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 3f Comparison by PADD



3f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in milllions of dollars to make up 100% of the lost production? Check one box for each flash point.

Question 3g Comparison by PADD



3g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash and freeze point changes,** including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 10% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point

Summary of Question 4

PADD 1	FLASH 120	FLASH 120		FLASH 130	FLASH 130		FLASH 140	FLASH 140		FLASH 150	FLASH 150
	YES	NO		YES	NO		YES	NO		YES	NO
4 Benzene	0%	100%		20%	80%		20%	80%		20%	80%
4 Aromatics	40%	60%		60%	40%		60%	40%		60%	40%
4 Distillates E300/T90	40%	60%		40%	60%		40%	60%		40%	60%
4 Distillates E200/T50	0%	100%		20%	80%		0%	100%		20%	80%
Sulfur	0%	100%		0%	100%		0%	100%		0%	100%
Other	0%	100%		0%	100%		0%	100%		0%	100%
PADD 2	FLASH 120	FLASH 120		FLASH 130	FLASH 130		FLASH 140	FLASH 140		FLASH 150	FLASH 150
	YES	NO		YES	NO		YES	NO		YES	NO
4 Benzene	0%	100%		6%	94%		6%	94%		6%	94%
4 Aromatics	0%	100%		12.5%	87.5%		12.5%	87.5%		12.5%	87.5%
4 Distillates E300/T90	6%	94%		31%	69%		38%	63%		44%	56%
4 Distillates E200/T50	6%	94%		12.5%	87.5%		19%	81%		25%	75%
Sulfur	6%	94%		12.5%	87.5%		12.5%	87.5%		12.5%	87.5%
Other	0%	100%		0%	100%		6%	94%		6%	94%
PADD 3	FLASH 120	FLASH 120		FLASH 130	FLASH 130		FLASH 140	FLASH 140		FLASH 150	FLASH 150
	YES	NO		YES	NO		YES	NO		YES	NO
4 Benzene	3%	97%		6%	94%		9%	91%		12%	88%
4 Aromatics	6%	94%		12%	88%		26%	74%		32%	68%
4 Distillates E300/T90	6%	94%		18%	82%		32%	68%		41%	59%
4 Distillates E200/T50	0%	100%		9%	91%		15%	85%		18%	82%
Sulfur	6%	94%		12%	88%		12%	88%		15%	85%
Other	0%	100%		9%	91%		9%	91%		9%	91%
PADD 4	FLASH 120	FLASH 120		FLASH 130	FLASH 130		FLASH 140	FLASH 140		FLASH 150	FLASH 150
	YES	NO		YES	NO		YES	NO		YES	NO
4 Benzene	0%	100%		0%	100%		0%	100%		0%	100%
4 Aromatics	25%	75%		25%	75%		25%	75%		25%	75%
4 Distillates E300/T90	25%	75%		25%	75%		0%	100%		25%	75%
4 Distillates E200/T50	25%	75%		25%	75%		25%	75%		50%	50%
Sulfur	0%	100%		0%	100%		0%	100%		0%	100%
Other	0%	100%		0%	100%		0%	100%		0%	100%
PADD 5	FLASH 120	FLASH 120		FLASH 130	FLASH 130		FLASH 140	FLASH 140		FLASH 150	FLASH 150
	YES	NO		YES	NO		YES	NO		YES	NO
4 Benzene	12.5%	87.5%		12.5%	87.5%		12.5%	87.5%		12.5%	87.5%
4 Aromatics	25.0%	75.0%		37.5%	62.5%		50%	50%		50%	50%
4 Distillates E300/T90	12.5%	87.5%		25.0%	75.0%		37.5%	62.5%		37.5%	62.5%
4 Distillates E200/T50	12.5%	87.5%		25%	75%		25%	75%		25%	75%
Sulfur	25%	75%		25%	75%		25%	75%		25%	75%
Other	0%	100%		0%	100%		0%	100%		0%	100%
CALIF	FLASH 120	FLASH 120		FLASH 130	FLASH 130		FLASH 140	FLASH 140		FLASH 150	FLASH 150
	YES	NO		YES	NO		YES	NO		YES	NO
4 Benzene	0%	100%		0%	100%		0%	100%		0%	100%
4 Aromatics	30%	70%		30%	70%		50%	50%		50%	50%
4 Distillates E300/T90	40%	60%		50%	50%		70%	30%		70%	30%
4 Distillates E200/T50	40%	60%		50%	50%		60%	40%		60%	40%
Sulfur	20%	80%		20%	80%		20%	80%		20%	80%
Other	10%	90%		0%	100%		10%	90%		10%	90%
TOTAL	FLASH 120	FLASH 120		FLASH 130	FLASH 130		FLASH 140	FLASH 140		FLASH 150	FLASH 150
	YES	NO		YES	NO		YES	NO		YES	NO
4 Benzene	3%	97%		6%	94%		8%	92%		9%	91%
4 Aromatics	13%	87%		21%	79%		31%	69%		34%	66%
4 Distillates E300/T90	14%	86%		27%	73%		38%	62%		44%	56%
4 Distillates E200/T50	9%	91%		18%	82%		22%	78%		27%	73%
Sulfur	9%	91%		13%	87%		13%	87%		14%	86%
Other	1%	99%		4%	96%		6%	94%		6%	94%

Appendix Table 1

Questions	Units			120	130	140	150
2A	% Loss	PADD 1	Avg	6.50	18.11	21.32	27.84
			Max	9.44	34.73	36.96	44.13
			Min	3.56	1.49	5.68	11.55
		PADD 2	Avg	1.70	10.55	17.42	22.66
			Max	2.62	14.56	24.25	30.01
			Min	0.79	6.53	10.59	15.32
		PADD 3	Avg	8.17	16.26	24.02	31.38
			Max	8.76	17.31	25.45	32.82
			Min	7.57	15.21	22.59	29.94
		PADD 4	Avg	3.75	16.37	24.17	39.22
			Max	26.96	44.13	46.43	49.39
			Min	0.00	0.00	1.91	29.05
		PADD 5	Avg	16.85	33.58	45.09	47.20
			Max	20.78	40.49	51.88	53.42
			Min	12.93	26.66	38.31	40.99
		CALIF	Avg	9.65	15.88	25.30	35.50
			Max	11.21	18.94	29.15	39.06
			Min	8.08	12.82	21.45	31.95
		TOTAL	Avg	8.11	16.74	24.72	32.13
			Max	9.00	18.37	26.81	34.23
			Min	7.21	15.11	22.63	30.02
2B	Cents/gal	PADD 1	Max	2.46	11.42	11.32	12.16
			Min	0.29	0.00	0.00	0.00
		PADD 2	Max	0.43	2.46	5.81	8.71
			Min	0.15	0.71	1.51	2.87
		PADD 3	Max	1.00	2.33	4.42	6.68
			Min	0.82	1.94	3.81	5.93
		PADD 4	Max	5.72	16.62	16.31	18.32
			Min	0.00	0.00	0.00	1.33
		PADD 5	Max	4.38	8.40	10.39	15.29
			Min	2.22	5.33	5.86	10.08
		CALIF	Max	1.67	5.14	8.58	10.54
			Min	1.13	3.82	6.20	7.88
		TOTAL	Max	1.30	3.46	5.62	7.96
			Min	0.94	2.63	4.48	6.61
2D	%	PADD 1	Avg	31.45	27.96	33.87	33.87
			Max	47.06	33.16	49.48	49.48
			Min	15.85	22.76	18.27	18.27
		PADD 2	Avg	63.20	54.74	48.48	51.52
			Max	77.76	66.12	61.66	65.71
			Min	48.64	43.35	35.31	37.32
		PADD 3	Avg	43.51	42.55	32.67	30.92
			Max	45.46	44.49	34.34	32.47
			Min	41.55	40.61	31.00	29.36
		PADD 4	Avg	46.48	36.15	31.99	29.90
			Max	119.14	78.63	58.95	52.52
			Min	0.00	0.00	5.02	7.28
		PADD 5	Avg	28.30	40.96	39.94	41.26
			Max	38.98	52.73	50.23	53.13
			Min	17.62	29.19	29.65	29.39
		CALIF	Avg	41.54	51.30	50.30	48.53
			Max	50.26	60.83	58.92	56.58
			Min	32.82	41.77	41.68	40.48
		TOTAL	Avg	42.03	44.19	38.98	38.23
			Max	45.25	47.27	41.91	41.26
			Min	38.81	41.10	36.05	35.19

Appendix Table 1

Questions	Units			120	130	140	150
2E	Cents/gal	PADD 1	Max	15.63	15.75	15.59	15.59
			Min	2.54	3.26	3.46	3.46
		PADD 2	Max	0.28	3.46	5.48	7.52
			Min	0.03	0.55	1.51	3.04
		PADD 3	Max	2.64	3.32	4.40	5.72
			Min	2.04	2.73	3.73	5.01
		PADD 4	Max	12.84	12.85	13.38	13.74
			Min	0.00	0.00	0.00	0.00
		PADD 5	Max	6.88	7.80	9.02	11.73
			Min	2.42	3.39	4.78	7.34
		CALIF	Max	3.81	5.58	6.27	7.21
			Min	1.41	2.76	3.47	4.34
		TOTAL	Max	3.18	4.23	5.26	6.57
			Min	2.19	3.19	4.15	5.40
2F	Millions of Dollars	PADD 1	Avg	1.63	10.95	10.95	18.53
			Max	4.03	24.27	24.27	47.06
			Min	0.00	0.00	0.00	0.00
		PADD 2	Avg	15.19	49.43	51.96	67.25
			Max	22.13	76.09	78.59	116.90
			Min	8.25	22.77	25.33	17.60
		PADD 3	Avg	35.57	74.72	107.28	124.47
			Max	38.80	80.01	115.45	133.46
			Min	32.34	69.43	99.12	115.47
		PADD 4	Avg	0.74	25.00	20.59	20.59
			Max	5.82	25.00	51.10	51.10
			Min	0.00	25.00	0.00	0.00
		PADD 5	Avg	125.76	136.17	185.26	185.45
			Max	172.35	181.67	238.25	238.17
			Min	79.16	90.67	132.28	132.73
		CALIF	Avg	61.66	81.96	74.09	132.10
			Max	84.87	111.79	104.26	168.96
			Min	38.46	52.14	43.92	95.25
		TOTAL	Avg	42.12	72.75	91.64	115.38
			Max	48.87	81.86	103.36	129.24
			Min	35.38	63.63	79.93	101.51
2G	Cents/gal	PADD 1	Max	16.15	17.20	17.74	17.74
			Min	1.80	3.66	4.46	4.46
		PADD 2	Max	0.95	3.42	7.20	8.82
			Min	0.29	0.75	1.65	2.78
		PADD 3	Max	1.80	3.50	6.23	8.91
			Min	1.44	2.96	5.52	8.03
		PADD 4	Max	17.01	17.26	20.42	19.84
			Min	0.00	0.00	0.00	0.00
		PADD 5	Max	11.02	13.79	15.71	15.68
			Min	5.75	7.73	9.47	9.57
		CALIF	Max	2.66	6.14	11.01	12.46
			Min	1.87	3.15	6.88	8.34
		TOTAL	Max	3.00	4.94	7.86	9.77
			Min	2.07	3.75	6.38	8.23

Appendix Table 1

Questions	**Units**			**120**	**130**	**140**	**150**
3A	% Loss	PADD 1	Avg	5.13	13.58	18.84	22.42
			Max	16.49	31.03	34.06	36.66
			Min	0.00	0.00	3.62	8.19
		PADD 2	Avg	11.10	16.36	20.71	22.72
			Max	16.47	22.40	28.09	30.10
			Min	5.73	10.33	13.33	15.34
		PADD 3	Avg	20.87	30.13	35.59	39.25
			Max	21.90	31.34	37.02	40.62
			Min	19.83	28.93	34.15	37.88
		PADD 4	Avg	13.43	22.50	32.01	46.57
			Max	36.27	43.97	47.95	50.16
			Min	0.00	1.03	16.06	42.97
		PADD 5	Avg	17.02	27.44	36.12	36.51
			Max	23.45	34.10	42.98	43.07
			Min	10.60	20.79	29.26	29.95
		CALIF	Avg	8.85	15.93	33.89	39.02
			Max	10.95	19.77	38.02	42.68
			Min	6.75	12.08	29.76	35.36
		TOTAL	Avg	15.80	24.13	32.37	36.07
			Max	17.36	25.98	34.50	38.14
			Min	14.24	22.28	30.25	34.00
3B	Cents/gal	PADD 1	Max	9.75	11.17	12.37	13.72
			Min	0.00	0.00	0.20	2.21
		PADD 2	Max	1.77	4.72	7.00	8.64
			Min	0.41	1.04	1.87	2.68
		PADD 3	Max	3.89	5.53	6.40	8.49
			Min	3.27	4.82	5.39	7.36
		PADD 4	Max	7.80	17.44	18.32	21.72
			Min	0.00	0.00	1.33	5.78
		PADD 5	Max	5.91	8.85	9.71	13.17
			Min	1.65	3.75	4.48	7.15
		CALIF	Max	5.31	7.06	10.19	11.52
			Min	3.58	5.04	7.52	8.93
		TOTAL	Max	3.93	5.71	7.24	9.18
			Min	3.01	4.55	5.77	7.55
3D	%	PADD 1	Avg	27.11	27.89	33.68	33.68
			Max	31.76	32.55	47.64	47.64
			Min	22.45	23.24	19.73	19.73
		PADD 2	Avg	68.31	58.94	53.38	54.98
			Max	81.24	71.34	67.12	68.93
			Min	55.39	46.54	39.64	41.03
		PADD 3	Avg	41.55	33.06	28.55	28.43
			Max	43.20	34.70	29.97	29.85
			Min	39.90	31.43	27.13	27.00
		PADD 4	Avg	57.48	33.70	30.76	21.32
			Max	116.87	70.76	56.18	39.30
			Min	0.00	0.00	5.34	3.35
		PADD 5	Avg	31.20	41.47	40.15	39.49
			Max	39.92	50.89	48.87	48.39
			Min	22.48	32.05	31.43	30.59
		CALIF	Avg	36.81	44.89	47.46	42.58
			Max	43.50	53.85	55.87	50.21
			Min	30.12	35.93	39.06	34.95
		TOTAL	Avg	40.36	38.64	36.93	35.94
			Max	43.38	41.52	39.84	38.83
			Min	37.34	35.76	34.01	33.06

Appendix Table 1

Questions	**Units**			**120**	**130**	**140**	**150**
3E	Cents/gal	PADD 1	Max	20.90	20.90	21.26	22.08
			Min	3.90	3.90	4.89	5.75
		PADD 2	Max	4.25	6.72	8.48	9.98
			Min	0.00	1.01	2.08	3.65
		PADD 3	Max	4.68	5.10	6.79	7.58
			Min	3.83	4.25	5.85	6.60
		PADD 4	Max	17.46	16.74	18.28	20.09
			Min	0.00	0.00	0.00	0.00
		PADD 5	Max	8.41	8.41	9.57	11.01
			Min	2.14	2.14	3.58	5.13
		CALIF	Max	6.36	6.74	7.88	9.49
			Min	2.76	3.30	4.56	6.21
		TOTAL	Max	5.31	5.89	7.38	8.51
			Min	3.85	4.41	5.82	6.90
3F	Millions of Dollars	PADD 1	Avg	7.00	10.95	10.95	18.53
			Max	18.27	24.27	24.27	47.06
			Min	0.00	0.00	0.00	0.00
		PADD 2	Avg	22.38	55.51	67.02	70.50
			Max	29.66	82.55	117.13	120.53
			Min	15.11	28.47	16.91	20.47
		PADD 3	Avg	93.82	73.64	99.41	95.61
			Max	100.57	80.49	108.47	104.68
			Min	87.07	66.79	90.35	86.55
		PADD 4	Avg	7.84	3.43	20.59	20.59
			Max	33.27	8.52	51.10	51.10
			Min	0.00	0.00	0.00	0.00
		PADD 5	Avg	119.68	119.68	119.33	119.33
			Max	168.73	168.73	170.73	170.73
			Min	70.64	70.64	67.92	67.92
		CALIF	Avg	142.90	71.75	81.90	131.75
			Max	188.03	104.09	112.38	168.60
			Min	97.76	39.41	51.42	94.90
		TOTAL	Avg	90.88	69.38	86.66	96.19
			Max	101.78	79.79	100.05	110.05
			Min	79.97	58.97	73.26	82.33
3G	Cents/gal	PADD 1	Max	14.55	15.42	15.23	15.82
			Min	4.20	5.46	6.81	7.91
		PADD 2	Max	3.33	4.42	6.45	7.30
			Min	0.46	1.09	1.88	2.77
		PADD 3	Max	5.63	6.34	8.21	8.81
			Min	4.99	5.68	7.47	8.06
		PADD 4	Max	12.89	15.13	15.19	14.61
			Min	0.00	0.00	0.00	2.15
		PADD 5	Max	9.69	9.69	9.73	9.73
			Min	5.01	5.01	5.33	5.33
		CALIF	Max	6.34	7.64	9.42	11.22
			Min	3.69	5.20	6.63	8.15
		TOTAL	Max	5.73	6.58	8.17	9.03
			Min	4.62	5.46	6.97	7.82

Product: Jet "A" Turbine Fuel

Spec Sheet:

SPECIFICATION POINTS	ASTM METHOD	SPECIFICATION LIMIT
Gravity, API	D1298/D4052	37-51
Total Acidity, mgKOH/gr, Max	D3242	0.1
Freezing Point, F(C), Max	D2386	-40 (-40)
Existent Gum, mg/100 ml, Max	D381	7.0
Sulfur, Total Wt%, Max	D1226/D1552/ D2622/D4294	0.3
Mercaptan Sulfur, Wt% (1), Max	D3227	0.003
Corrosion, Copper Strip, 2 Hrs. @ 212F(100C), Max	D130	1
Water Separation Rating, Min	D3948	85
Water Tolerance, M1, Vol Interface Rating, Max	D1094	1b
Aromatics, Vol%, Max (3)	D1319	22
Net Heat of Combustion BTU/Pound, Min	D3338/D4529/D4809	18,400
Flash, TCC F(C), Min (2)	D56	100
Viscosity, CST @ -4F(-20C), Max	D445	8
Thermal Stability: Filter Pressure Drop, (4) mm. Hg, Max	D3241	25
Tube Deposit		Less Than Code 3
Distillation, F(C)	D86	
10% Recovered, Max		401 (205)
50% Recovered		Report
90% Recovered		Report
End Point, Max		572 (300)
Residue, Vol%, Max		1.5
Loss, Vol%, Max		1.5

EUROPIA Input to Discussions of ARAC FTHWG
Task Group No 6/7: »Fuel Properties«

Effect of Jet A-1 Flash Point on Product Availability and Properties

Introduction

Following the investigations into the cause of the TWA Flight 800 accident in 1996, the US Federal Aviation Administration (FAA) has set up a working group to reduce the likelihood of aeroplane fuel tank ignition. API is participating in the ARAC FTHWG task groups (Aviation Rulemaking Advisory Committee's Fuel Tank Harmonisation Working Groups) together with representatives of the US government, airlines and aircraft builders. API have invited EUROPIA as well as other oil industry groups around the world to contribute to the discussions. One options under consideration is raising the flash point of Jet A from min. 100°F / 38°C to the limit presently applied for JP-5 military jet fuel (min. 140°F / 60°C). This change would have a serious impact on manufacturing yields of jet fuel.

Terms of reference for the committees have been issued in January 1998 and a report is due in six months time with a deadline of July 23. The ARAC-FTHWG recommendations for rule-making advice to FAA will impact not only domestic US but also world-wide regulations.

Other means to be investigated to further reduce the risk of aeroplane tank explosions are auditing and improving, if necessary, the hardware installation, enhancing maintenance practices of fuel systems, exploring better ways to rule-out ignition sources in aeroplane tanks, and reducing flammability of jet fuel by reliable, safe means. This includes technologies like fuel-tank cooling, inerting the atmosphere in the fuel tank, using articulated foam in the fuel tanks, ullage sweeping or active explosion suppression. For all these options the feasibility and cost/benefits will be investigated.

Current Flash Point Levels for Jet A-1 in Europe

Current flash points of Jet A-1 production in Europe are close to the specification of min. 100°F (min. 38°C). The MOD survey for the U.K. reports an average of 108°F (42°C), and individual refineries report averages of 103°F (39.5°C) to 113°F (45°C). Based on these data and an additional evaluation carried out by P. Brook (DERA, Pyestock) the following distributions for Jet A-1 flash points were estimated at levels from the 5%tile up to the 95%tile (Table 1). As requested by ARAC FTHWG TG 5 and 8 also estimates were made for flash point specifications of 120°F, 130°F, 140°F and 150°F in addition to the current specification of 100°F. All these distributions are skewed with most data points close to the specification limit. For the higher flash point specification cases it was assumed that the distribution would become more narrow as refineries are getting more limited to produce aviation kerosene.

Table 1
Flash Point Distributions for Jet A-1 Production in the U.K. at Present Specification of 100°F and Estimates for Higher Specification Limits

	Flash Points [°F] for Different Percentiles of the Distribution				
	5%	**25%**	**50%**	**75%**	**95%**
Current Distribution for Flash Point Specification of min. 100°F:					
Summer	101.1	104.2	106.5	109.7	116.5
Winter	100.6	102.4	104.6	106.9	112.3
Whole Year	100.8	103.5	106.2	109.4	114.6
Estimated Distribution for Flash Point Specification Limits of:					
120°F	121.0	124.0	126.0	129.5	134.0
130°F	131.0	133.5	135.0	137.5	141.0
140°F	141.0	143.0	144.0	146.0	148.5
150°F	151.0	152.5	153.5	154.5	156.0

API/NPRA Aviation Fuels Survey

Regarding the refinery impacts of raising flash point of Jet A / A-1 above the current specification of 100°F (38°C) API/NPRA (American Petroleum Institute / National Petrochemical & Refiners Association) have prepared a questionnaire which has been sent to US refining companies. It investigates the effects of raising flash point to specifications of 120°F (49°C), 130°F (54°C), 140°F (60°C) and 150°F (66°C) on

- Jet A / A-1 yield,
- incremental production costs,
- potential for short term recovery of lost yield,
- short and long term operating costs and capital requirements to recover the lost yield,
- impact on yields and properties of other products

at two freeze point levels, viz. -40°C (-40°F, Jet A) and -47°C (-53°F, Jet A-1). EUROPIA member companies have also used this questionnaire but only covered the -47°C freeze point case as this is the current specification outside the US. A copy of the questionnaire is given in Appendix 1.

All information obtained in Europe from individual refining companies is based on the assumption that present specification for other fuels products remain unchanged, and, therefore, represent a short-term view. However, ongoing discussions within the 15 countries of the European Union (EU) will impact severely on specifications of unleaded gasolines and automotive diesel fuel with subsequent effects on product availability and processing requirements.

In addition to obtaining information form individual refinery companies, the effects were also investigated by using the CONCAWE refinery LP model which simulates the effects for the overall European refinery industry. With this model also the implications of future automotive fuels specifications have been investigated.

Responses from Individual European Refinery Companies

Responses representing 33 refineries in Europe were obtained at EUROPIA and were included in the analysis. These are representing more than two thirds of the present jet fuel production in Europe but less than 50% of the crude distillation capacity. Some of the refineries presently not producing jet fuel use all their kerosene stocks to manufacture a special diesel fuel (City Diesel).

For an easy interpretation of the results it is important to show not only the distribution of the responses but also the weighted averages of the effect of increasing jet fuel flash point on product yields and manufacturing costs. However, the questionnaire yielded ranges rather than exact numbers. For the purpose of estimating weighted averages, it is assumed that for each response the mean of the range allowed as response would represent the exact value. In cases where responses were given as "greater than" the exact value was assumed to be the limiting value plus the last defined step change. Weighted averaged were always based on total Jet A-1 production and not on total crude processing capacity.

Due to the time constraints in a number of cases individual refineries responded only to part of the questions. Where not all refineries responded to a question, we have worked with the data from those that did respond. This assumes that a similar distribution of responses would apply. Also in some cases the reply "not feasible" was obtained, and this was added to the list of possible answers.

Detailed Survey Analysis by Question

The first question was related to general information on the refinery processing capacity related to jet fuel. The consolidated response is given in Table 2 below.

Question 1:
Please indicate the following information regarding your refinery
Crude thruput, b/cd
Hydrocracking capacity, for jet fuel b/cd
RFG and CARB production as a % of total gasoline
Current Jet A/A1 Production, b/cd
Current JP-5 Production, b/cd
Current JP-8 Production, b/cd

Table 2
General Information on European Refineries Responding to API/NPRA Survey

Number of Refineries Covered	36
Crude thruput, b/cd	5,372,500
Hydrocracking capacity, for jet fuel b/cd	160,700
RFG and CARB production as a % of total gasoline	0
Current Jet A/A1 Production, b/cd	472,450
Current JP-5 Production, b/cd	1,500
Current JP-8 Production, b/cd	414

This represents a crude throughput capacity of 5,372,500 b/cd (Total EU crude distillation capacity 12,300,000 b/cd). Hydrocracking capacity for jet fuel production is 160,700 b/cd. Current Jet A-1 production of these 36 refineries is 472,450 b/cd (total EU production 640,000 b/cd in 1995) ranging from 2% to 22% of the refinery crude throughput. Production of reformulated gasoline as well as JP-5 and JP-8 production are not important in Europe: none of the refineries surveyed produced reformulated or CARB gasolines; only one refinery reported JP-5 production (1,500 b/cd), and two refineries manufactured JP-8 at a total of 414 b/cd. In Europe, military jet fuel grade JP-8 and the civil aviation Jet A-1 differ only in the military requiring extra additives.

> *Question 2.a:*
> *If the flash point specification minimum was raised,* ***with no other specification changes****, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.*

Listed below in Table 3 is a summary of the production volumes affected.

Table 3
Jet Fuel Production Affected by Raising the Flash Point Specification from min. 100°F to Levels Between 120 and 150°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. increase of greater than 5%	0	0	0	0
b. increase of 0-5%	0	0	0	0
c. no change	42,300	15,800	15,800	15,800
d. reduction of 0 - 4.9%	2,000	0	0	0
e. reduction of 5 - 9.9%	146,000	2,000	0	0
f. reduction of 10 - 19.9%	40,400	11,000	2,000	0
g. reduction of 20 - 29.9%	111,300	168,400	0	0
h. reduction of 30 - 39.9%	97,550	95,600	24,400	0
i. reduction of 40 - 49.9%	0	24,950	207,600	24,400
j. reduction of greater than 50%	30,900	132,600	162,950	363,150
k. not feasible	0	13,300	39,900	49,300
Total Production Covered:	**470,450**	**463,650**	**452,650**	**452,650**
% Production Loss	**21%**	**39%**	**53%**	**61%**

The data clearly indicates that with increasing flash point specification an increasing portion of today's jet fuel production volume can no longer be produced as production losses are 30% and higher.

This information also allows to estimate the weighted average production loss, and the complementing remaining production when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 3, last line, and Figure 1). When increasing the flash point specification to 120°F 21% are lost, and this effect increase to a loss of 61% at a flash point specification of 150°F.

> *Question 2.b:*
> *What would be the total cost in the short term of these changes in jet fuel production resulting from* ***flash point specification changes****, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.*

Listed in Table 3 below are the jet fuel production volumes affected. Except for a few refineries production cost increases are in the moderate to high range for the higher flash points discussed.

The data also allow to estimate the weighted average cost increases when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 3, last line, and Figure 2). When increasing the flash point specification to 120°F the average cost increase is estimated at 11.2 cpg, and it is greater than 20 cpg at a flash point specification of 150°F.

Table 4
Short Term Jet Fuel Production Costs Resulting from Raising the Flash Point Specification from min. 100°F to Levels Between 120 and 150°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. zero	33,600	0	0	0
b. 0.1 - 1.9 cpg	4,000	33,600	15,800	15,800
c. 2 - 4.9 cpg	150,30	48,000	2,000	0
d. 5 - 9.9 cpg	29,400	85,900	83,300	48,000
e. 10 - 14.9 cpg	8,900	7,400	24,000	59,300
f. 15 - 19.9 cpg	166,00	0	0	0
g. greater than 20 cpg	47,550	213,550	220,950	213,550
h. not feasible	0	51,300	77,900	87,300
Total Capacity Covered:	**441,750**	**441,750**	**423,950**	**423,950**
Weighted Average cpg	**11.2**	**17.1**	**19.9**	**> 20**

Question 2.c:
What other product volume reduction/increase (-/+)would result by the changes to the ***flash point specification*** *and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.*

Gasoline
Kerosene
On-road diesel
Off-road diesel
Heating oil
Exports (naphtha or gasoline)
Other

Short terms production cost changes are mainly arising from the requirement use a narrower kerosene cut to blend Jet A-1 at increased flash point levels while keeping freeze point at the -47°C/-53°F level. These fractions have to be down-graded as gasoline or diesel or — in more cases — exported as naphtha. Although most refineries responding to the questionnaire gave a qualitative indication little information exists on the quantitative effects.

The next question (2.d.) asked how much of the "lost" jet fuel production could be made up in the short term:

> *Question 2.d:*
> *If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.*

Listed in Table 5 below are the jet fuel production volumes affected. Except for a few refineries only a small fraction of the lost volumes can be recovered in the short term when raising flash point specification above the present limit of 100°F.

Table 5
Short Term Jet Fuel Production Recovery

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. 100% of the reduction	68,700	22,400	17,800	15,800
b. 75 - 99%	24,000	35,300	0	0
c. 50 - 74%	30,000	24,000	59,300	35,300
d. 25 - 49%	144,00	30,000	30,000	24,000
e. less than 25%	151,80	268,850	235,850	265,850
f. not feasible	7,400	45,400	45,400	45,400
Total:	**425,950**	**425,950**	**388,350**	**386,350**
Weighted Average Recoverable on Short Term Basis, %	**42%**	**26%**	**24%**	**20%**
Percent Production Compared to 100°F Flash Point Spec.	**88%**	**71%**	**60%**	**51%**

This information also allows to estimate the weighted average production recovery, and how this would affect the remaining jet fuel production when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 4, last two lines and Figure 3). When adjusting refinery processing in the short term to make up for the production losses from increasing the flash point specification to 120°F some of the 20% "loss" are recovered leading to a 88% production compared to the present specification of 100°F. At a flash point specification of 150°F the production capacity recovers from the 37% obtained under question 2.a. to a 51% production compared to the present situation at a flash point specification of 100°F.

> *Question 2.e.*
> *What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from* ***flash point specification changes,*** *including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.*

Listed in Table 6 below are the jet fuel production volumes affected. Expect for a few refineries production costs to recover the losses in jet fuel production are in the moderate to high range for the higher flash points discussed.

Table 6
Costs for Short Term Recovery of Lost Jet Fuel Production Resulting from Raising the Flash Point Specification from min. 100°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. zero	15,800	15,800	15,800	15,800
b. 0.1 - 1.9 cpg	2,000	0	0	0
c. 2 - 4.9 cpg	194,600	32,000	30,000	0
d. 5 - 9.9 cpg	22,000	148,600	2,000	30,000
e. 10 - 14.9 cpg	59,300	0	144,000	0
f. greater than 15 cpg	85,550	182,850	182,850	326,850
Total	**379,250**	**379,250**	**374,650**	**372,650**
Weighted Average, cpg	**8.7**	**12.9**	**14.9**	**> 15**

This information also allows to estimate the weighted average cost for recovering the lost production volumes when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 6, last line, and Figure 4). When increasing the flash point specification to 120°F the average cost for the recovery of the lost volume is estimated at 8.7 cpg, and greater than 15 cpg at a flash point specification of 150°F.

Question 2.f:
If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

Listed in Table 7 below are the jet fuel production volumes affected and the cost ranges involved. Heavy investment will be required to make up the lost production. For a flash point specification of 140°F and above this will be for most existing refineries in the range of 100 to 500 MM$ indicating installation of hydrocracking units. The weighted average investment required to make up 100% of the lost jet fuel production is also shown in Figure 5.

Table 7
Capital Investment Required to Make up 100% of Lost Jet Fuel Production Resulting from Raising the Flash Point Specification from min. 100°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. 0 - 9.9 $million	85,900	35,600	17,800	17,800
b. 10 - 49.9 $million	202,600	4,600	0	0
c. 50 - 99.9 $million	22,000	270,300	30,000	0
d. 100 - 499.9 $million	9,400	9,400	249,700	202,300
e. not feasible	48,450	48,450	48,450	125,850
Total Production Covered:	**368,350**	**368,350**	**345,950**	**345,950**
Weighted Average Investment, $million	**148**	**182**	**349**	**> 500**

Question 2.g.
*What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash point changes**, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.*

Listed in Table 8 below are the jet fuel production capacities affected. They indicate that heavy investment will be required to make up the lost production. For a flash point specification of 140°F and above the costs will be for most existing refineries in Europe higher than 20 cpg. The effect of increased flash point on additional costs is also shown in Figure 6.

Table 8
Costs for Long Term Recovery of Lost Jet Fuel Production Resulting from Raising the Flash Point Specification from min. 100°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. zero	0	0	0	0
b. 0.1 - 1.9 cpg	57,000	11,000	0	0
c. 2 - 4.9 cpg	144,000	46,000	0	0
d. 5 - 9.9 cpg	22,000	0	46,000	0
e. 10 - 14.9 cpg	0	166,000	0	0
f. 15 - 19.9 cpg	0	0	0	0
g. greater than 20 cpg	54,950	54,950	220,950	259,550
h. not feasible	0	0	0	7,400
Total Production Covered:	**277,950**	**277,950**	**266,950**	**266,950**
Weighted Average Costs, cpg	**7.6**	**13.0**	**22.0**	**> 20**

LP Modelling for the European Refinery Industry
In addition to the responses from individual refineries the CONCAWE LP model has been used to estimate the expected effects on available volumes of jet fuel in relation to increasing the flash point specification.

The range of flash points from the current level of 100°F (38°C) to a potential of 140°F (60°C) has been investigated in order to assess

- jet fuel availability,
- effects on products other than jet fuel.

Distillation
In order to meet an increased flash point of 140°F (60°C), it is expected that the effective cut point between naphtha and kerosene needs to be raised to 170 to 180°C depending on crude and distillation column performance; an increase of the IBP of the jet fuel also requires a reduction of FBP to around 250°C to meet the freeze point specification of -47°C. Based on available crude yield data this may entail a loss of potential kerosene fraction (mainly used for jet fuel and automotive diesel blending) of some 30 to 40% compared to the current maximum yield on crude.

A further complication would be a potential gap developing between naphtha feed to the reformer (when end point is limited due to gasoline specifications) and such a high flash point kerosene fraction when used in jet fuel. The current hardware does not allow for producing this 'gap'-product, and new distillation hardware would be required. In addition, there will be a serious loss of flexibility for optimisation of summer/winter demand slates.

Overall EU Supply

Jet fuel volume is expected to grow substantially to a level of around 50 MTPA (1,000,000 b/cd) by the year 2010. Using the CONCAWE model for the EU-15, we have investigated the potential effects of an increase in jet fuel flash point up to 140°F (60°C). As a basis we have used the year 2000 qualities of other transportation fuels as defined in the EU Council Common Position of October 1997.

In order to maintain the future production volume of 50 MTPA, substantial investments would be required in creating new molecules suitable for aviation kerosene blending. The model predicts a requirement for some 25 MTPA additional hydrocracking capacity.

The EU-wide optimal LP based solution for transport fuel reformulation (2000 specifications) for a high flash point jet fuel is very different from that for the current flash point jet fuel. This reflects the higher availability of naphtha (due to the increase in average cutpoint) and the need for more hydrocracking capacity at the expense of FCC processing.

Conclusions from LP Modelling

- An increase in kerosene flash point leads to a substantially reduced flexibility in product slate adjustments (selection of naphtha/kerosene cutpoint).
- The restrictions in cutpoint flexibility may lead to additional separation requirements (separation sharpness and/or production of 'gap' product (heavy naphtha 150 - 180°C fraction).
- Substantial investments in additional hydrocracking to replace the losses in kerosene yield from crude distillation.
- The selection of a high flash point Jet-A1 specification impacts severely on the preferred solution for changes in specifications for ground transportation fuels (gasoline and automotive diesel fuel).

Summary

The data from the survey of European refineries and the CONCAWE LP modelling demonstrate the following impact of increasing jet fuel flash point:

- **Even at a 120°F flash point specification, Jet A-1 availability will be severely limited. Due to the cut point changes required Jet A-1 availability will be reduced by 21%, and the effect increases to 61% at 150°F flash point. Clearly, this indicates the effects a short term rule on aviation fuel flash point would impose on civil aviation.**

- **The API/NPRA survey does not take into account the future growth expected for jet fuel demand.**

- **The impact in Europe in greater than in the US. This is due to:**
  - **a) the manufacture of the lower freeze point Jet A-1 grade in Europe which additionally reduces the potential jet fuel yield on crude;**
  - **b) the demand barrel shape in Europe differs with less motor gasoline and more middle distillates required from a barrel of crude oil. This tends to produce higher front end cut points and flash points for US jet fuel;**
  - **c) Europe has a stronger demand for diesel fuel for which kerosene is also required. Environmental pressures in Europe are likely to require a lighter diesel fuel containing more kerosene in the near future.**

- **Short term cost increases are estimated at 11.2 cpg for 120°F flash point and more than 20 cpg for 150°F.**

- **In order to make up for the lost volumes in Europe heavy investment would be required including additional hydrocracking capacity.**

Figure 1

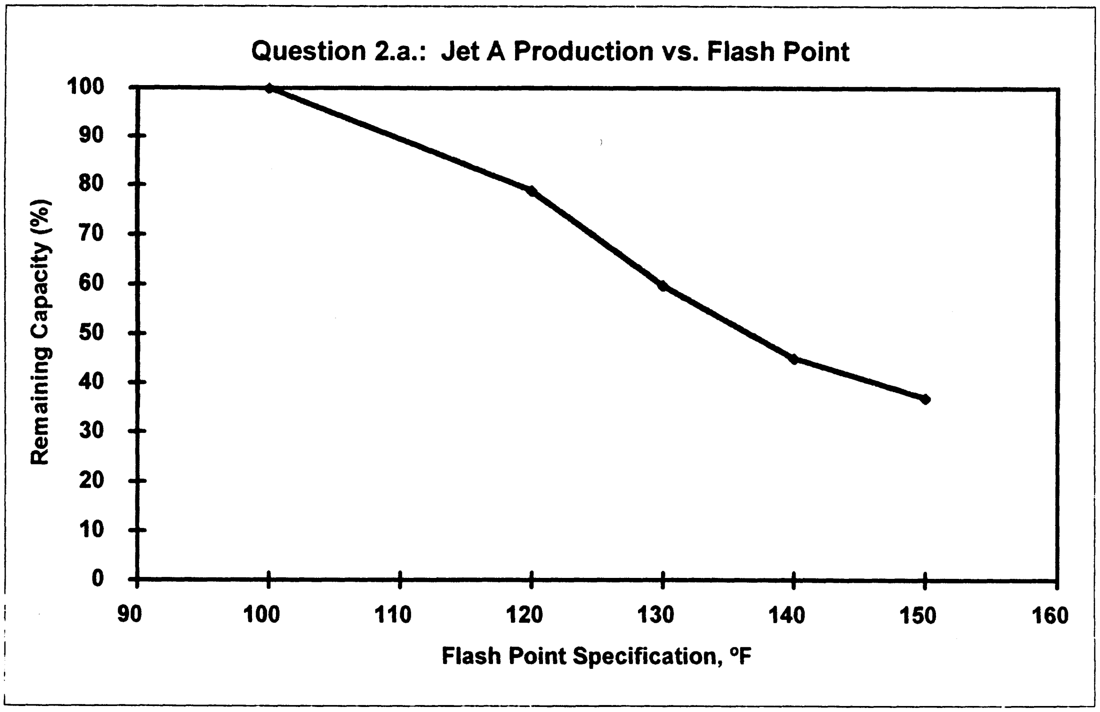


Figure 2

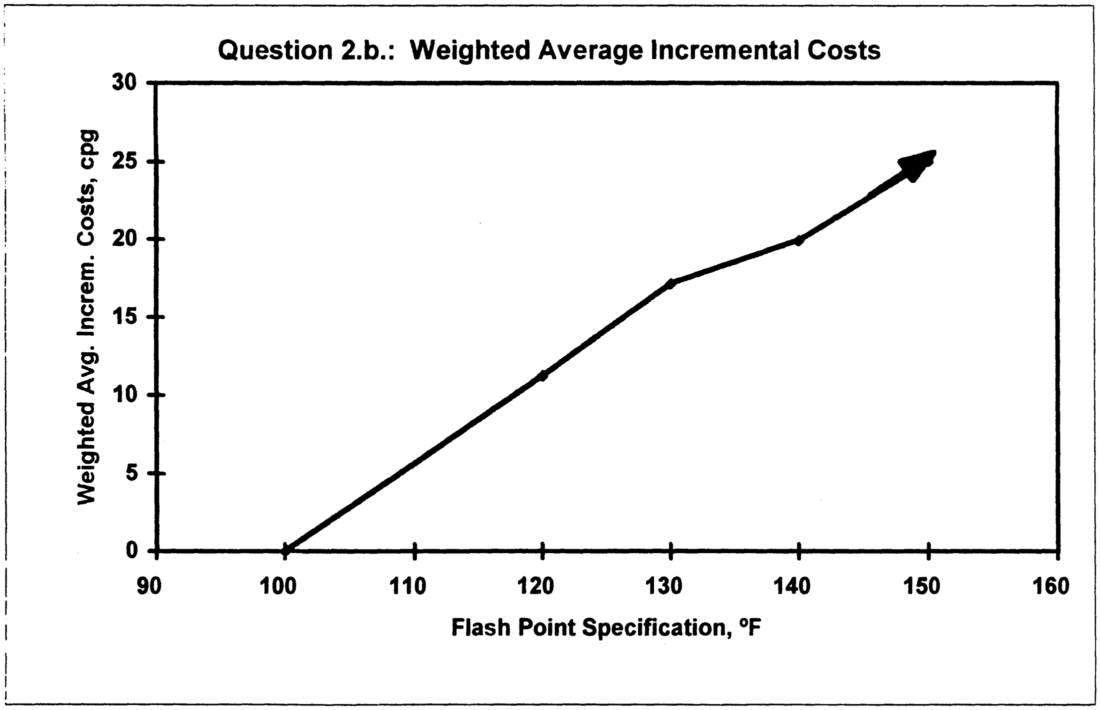


Figure 3

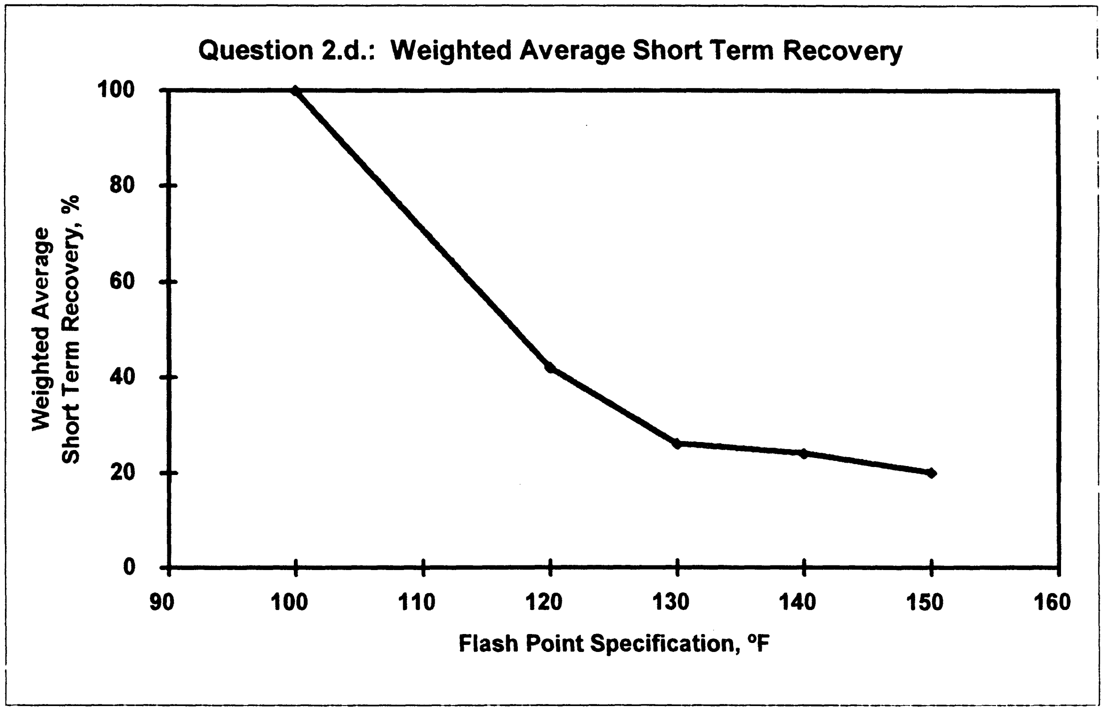


Figure 4

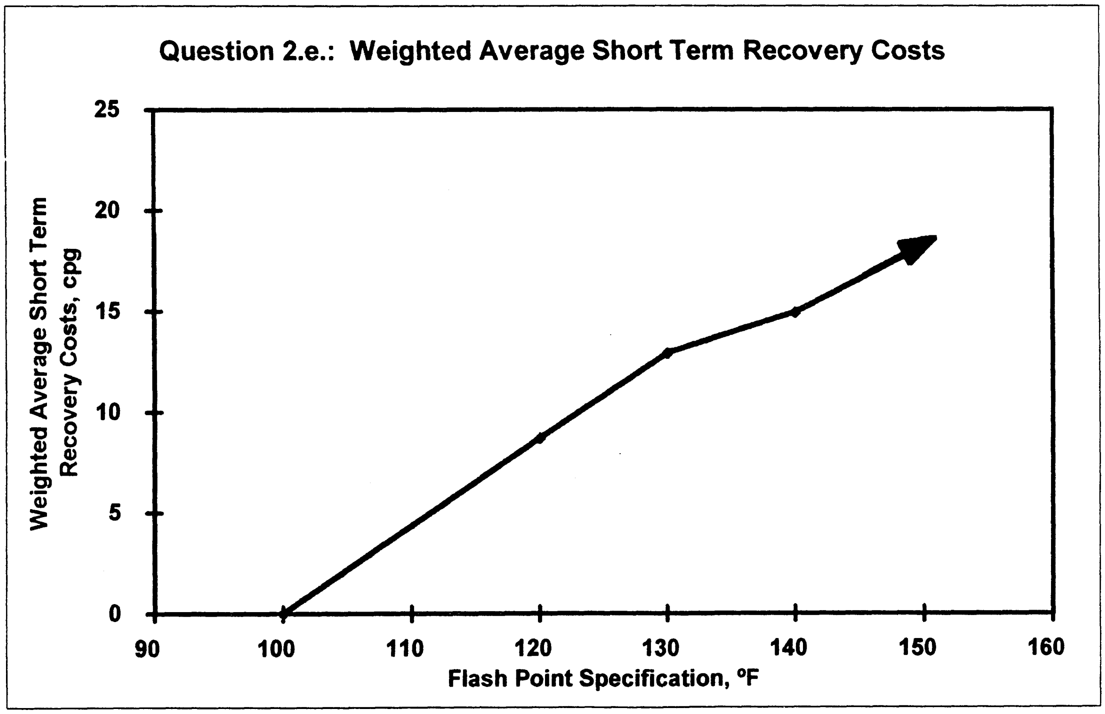


Figure 5

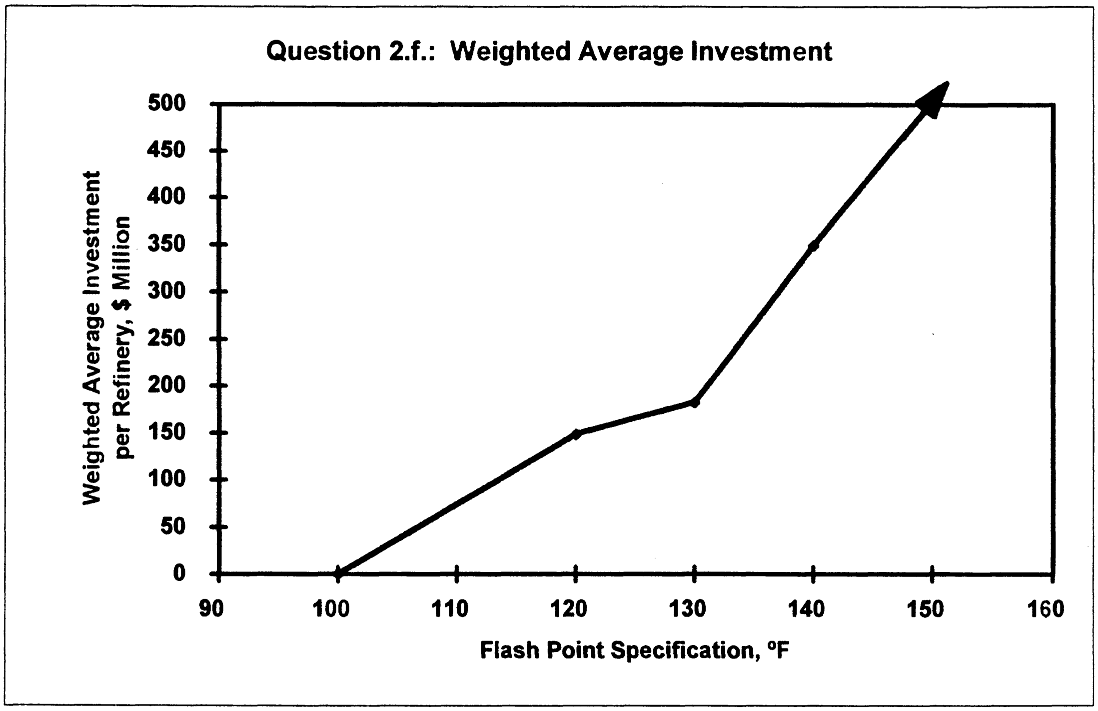
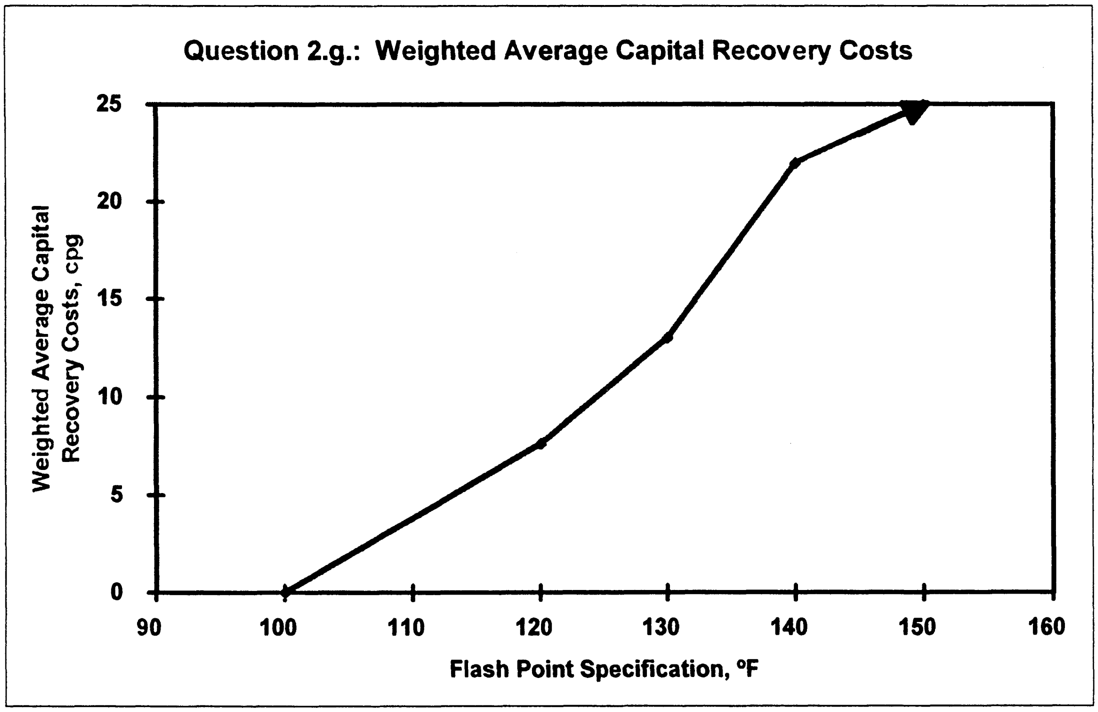


Figure 6



API/NPRA Aviation Fuel Properties Survey

Please fill out this Questionnaire for each refinery in which you produce Commercial Aviation Jet A. Use 1997 calendar year data. If seasonality is a significant factor in your refineries, fill out a copy of your questionnaire for each season.

If applicable, indicate:
Months in winter season________ Months in summer season ________

PADD_________________

1. Please indicate the following information regarding your refinery

Crude thruput, b/cd	____________
Hydrocracking capacity, for jet fuel b/cd	____________
RFG and CARB production as a % of total gasoline	____________
Current JetA/A1 Production, b/cd	____________
Current JP-5 Production, b/cd	____________
Current JP-8 Production, b/cd	____________

THE FOLLOWING SERIES OF QUESTIONS REFER ONLY TO RAISING THE FLASH POINT MINIMUM SPECIFICATION FROM 100 DEGREES F.

2a. **If the flash point specification minimum was raised, with no other specification changes**, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. increase of greater than 5%	☐	☐	☐	☐
b. increase of 0-5%	☐	☐	☐	☐
c. no change	☐	☐	☐	☐
d. reduction of 0-4.9%	☐	☐	☐	☐
e. reduction of 5-9.9%	☐	☐	☐	☐
f. reduction of 10-19.9%	☐	☐	☐	☐
g. reduction of 20-29.9%	☐	☐	☐	☐
h. reduction of 30-39.9%	☐	☐	☐	☐
i. reduction of 40-49.9%	☐	☐	☐	☐
j. reduction of greater than 50%	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

2b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point specification changes**, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

	Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a.	zero	☐	☐	☐	☐
b.	.1-1.9 cpg	☐	☐	☐	☐
c.	2-4.9 cpg	☐	☐	☐	☐
d.	5-9.9 cpg	☐	☐	☐	☐
e.	10-14.9 cpg	☐	☐	☐	☐
f.	15-19.9 cpg	☐	☐	☐	☐
g.	greater than 20 cpg	☐	☐	☐	☐

2c. What other product volume reduction/increase (-/+)would result by the changes to the **flash point specification** and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
gasoline	____	____	____	____
kerosene	____	____	____	____
on-road diesel	____	____	____	____
off-road diesel	____	____	____	____
heating oil	____	____	____	____
exports (naptha or gasoline)	____	____	____	____
other________________________	____	____	____	____

API/NPRA Aviation Fuel Properties Survey

2d. If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 100% of the reduction	☐	☐	☐	☐
b. 75-99%	☐	☐	☐	☐
c. 50-74%	☐	☐	☐	☐
d. 25-49%	☐	☐	☐	☐
e. less than 25%	☐	☐	☐	☐

2e. What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from **flash point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero	☐	☐	☐	☐
b. .1-1.9 cpg	☐	☐	☐	☐
c. 2-4.9 cpg	☐	☐	☐	☐
d. 5-9.9 cpg	☐	☐	☐	☐
e. 10-14.9 cpg	☐	☐	☐	☐
f. greater than 15 cpg	☐	☐	☐	☐

2f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 0-9.9 $million	☐	☐	☐	☐
b. 10-49.9 $million	☐	☐	☐	☐
c. 50-99.9 $million	☐	☐	☐	☐
d. 100-499.9 $million	☐	☐	☐	☐
e. not feasible	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

2g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash point changes**, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero	☐	☐	☐	☐
b. .1-1.9 cpg	☐	☐	☐	☐
c. 2-4.9 cpg	☐	☐	☐	☐
d. 5-9.9 cpg	☐	☐	☐	☐
e. 10-14.9 cpg	☐	☐	☐	☐
f. 15-19.9 cpg	☐	☐	☐	☐
g. greater than 20 cpg	☐	☐	☐	☐

THE FOLLOWING SERIES OF QUESTION REFER TO RAISING THE FLASH POINT MINIMUM SPECIFICATION FROM 100 DEGREES F AND REDUCING THE FREEZE POINT MINIMUM SPECIFICATION TO -53 DEGREES F.

3a. If the **freeze point specification minimum was reduced to -53 deg F, in addition to the flash point changes projected above**, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. increase of greater than 5%	☐	☐	☐	☐
b. increase of 0-5%	☐	☐	☐	☐
c. no change	☐	☐	☐	☐
d. reduction of 0-4.9%	☐	☐	☐	☐
e. reduction of 5-9.9%	☐	☐	☐	☐
f. reduction of 10-19.9%	☐	☐	☐	☐
g. reduction of 20-29.9%	☐	☐	☐	☐
h. reduction of 30-39.9%	☐	☐	☐	☐
i. reduction of 40-49.9%	☐	☐	☐	☐
j. reduction of greater than 50%	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

3b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point and freeze point specification changes**, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

	Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a.	zero	☐	☐	☐	☐
b.	.1-1.9 cpg	☐	☐	☐	☐
c.	2-4.9 cpg	☐	☐	☐	☐
d.	5-9.9 cpg	☐	☐	☐	☐
e.	10-14.9 cpg	☐	☐	☐	☐
f.	15-19.9 cpg	☐	☐	☐	☐
g.	greater than 20 cpg	☐	☐	☐	☐

3c. What other product volume reduction/increase (-/+)would result by the changes to the **flash and freeze point specifications** and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
gasoline	____	____	____	____
kerosene	____	____	____	____
on-road diesel	____	____	____	____
off-road diesel	____	____	____	____
heating oil	____	____	____	____
exports (naptha or gasoline)	____	____	____	____
other________________________	____	____	____	____

API/NPRA Aviation Fuel Properties Survey

3d. If you indicated a reduction in jet fuel production in question 3a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 100% of the reduction	☐	☐	☐	☐
b. 75-99%	☐	☐	☐	☐
c. 50-74%	☐	☐	☐	☐
d. 25-49%	☐	☐	☐	☐
e. less than 25%	☐	☐	☐	☐

3e. What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from **flash and freeze point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero	☐	☐	☐	☐
b. .1-1.9 cpg	☐	☐	☐	☐
c. 2-4.9 cpg	☐	☐	☐	☐
d. 5-9.9 cpg	☐	☐	☐	☐
e. 10-14.9 cpg	☐	☐	☐	☐
f. 15-19.9 cpg	☐	☐	☐	☐
g. greater than 20 cpg	☐	☐	☐	☐

3f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 0-9.9 $million	☐	☐	☐	☐
b. 10-49.9 $million	☐	☐	☐	☐
c. 50-99.9 $million	☐	☐	☐	☐
d. 100-499.9 $million	☐	☐	☐	☐
e. not feasible	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

3g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash and freeze point changes**, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero	☐	☐	☐	☐
b. .1-1.9 cpg	☐	☐	☐	☐
c. 2-4.9 cpg	☐	☐	☐	☐
d. 5-9.9 cpg	☐	☐	☐	☐
e. 10-14.9 cpg	☐	☐	☐	☐
f. greater than 15 cpg	☐	☐	☐	☐

---

4. Would any of the changes to flash point specifications create difficulty with gasoline compliance parameters

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
yes	☐	☐	☐	☐
no	☐	☐	☐	☐
If yes, which ones, in particular				
benzene	☐	☐	☐	☐
aromatics	☐	☐	☐	☐
distillates E300/T90	☐	☐	☐	☐
distillates E200/T50	☐	☐	☐	☐
sulfur	☐	☐	☐	☐
other_____________	☐	☐	☐	☐

Please return completed survey to:

Harold S. Haller & Company
24803 Detroit Road
Cleveland, Ohio 44145
Phone: 440.871.6597
Fax: 440.871.1182

[Report on API/NPRA Jet Fuel Survey]

May 1998

IMPACTS OF JET A-1 FLASH POINT CHANGES

Petroleum Association of Japan

Introduction

This is the report of Petroleum Association of Japan(PAJ) on member refiners' state of manufacturing jet fuel and simulation of suggested Jet A-1 specification changes which was requested by American Petroleum Institute(API) requiring on the letter of March 13, 1998.

As a commercial aviation fuel, in Japan, there is not Jet A but Jet A-1, which is produced in accordance with "PAJ Joint Fueling System Checklist Issue12", referred to "Aviation Fuel Quality Requirements for Jointly Operated Systems Joint Fueling System Checklist Issue 16 for Jet A-1".

Supply and Demand

Balance of supply and demand of Jet fuel including bond stock during FY1997 (from April 1997 to March 1998) in Japan are showed in Table 1.

Table 1 : Supply and Demand of Jet Fuel in Japan (FY 1997)

-Supply		
Production	9,557,000kl	(165,000bcd)
Import	3,162,000kl	(54,000bcd)
-Demand		
Domestic Sales	4,779,000kl	(82,000bcd)
Export	8,190,000kl	(135,000bcd)

Ref.:Production of Household Heating Kerosene 28,230,000kl(486,000bcd)

(Source: Ministry of International Trade and Industry)

Coverage of the Survey

PAJ asked for refining companies of "Refining Technology Working Group" member to respond to the questionnaires formatted by API, and obtained responses from 24 refineries (12 companies), out of 26 refineries manufacturing Jet fuel. Then those responded data were compiled by the working group.

These are representing 85% of jet fuel production and 72% of the crude distillation capacity in Japan.

-Coverage rate of jet fuel production:

140,000bcd / 165,000bcd = 85%

-Coverage rate of crude distillation capacity:

3,809,000BPSD / 5,323,000BPSD = 72%

Detailed Survey Analysis by Questions

1. General information on the refineries responded

Table 2: General Information on the Refineries Responded.

Crude thruput (FY1997)	3,078,040bcd
Hydrocracking capacity for jet fuel (Mar.'98)	21,000bcd
RFG and CARB production	0%
Current Jet A-1 production (FY1997)	138,084bcd
Current JP-5 production (FY1997)	2,002bcd
Current JP-8 production (FY1997)	0bcd

-Yield of Jet A-1:

138,000bcd / 3,078,000bcd = 4.5%

-Hydrocracking rate

(assumption of Jet fuel yield : 30%, 21,000bcd × 0.3 = 6,300bcd)

vs. crude thruput: 6,300bcd / 3,078,000bcd = 0.2%

vs. Jet A-1 production: 6,300bcd / 138,000bcd = 4.6%

Manufacturing Jet A-1 in Japan almost depends on straight run kerosene, so the rate of hydrocracking kerosene is low.

2. Production Affected by Specification Changes

Since the yield of household heating kerosene is extremely high in Japan(11%) compared to other OECD countries, raising the minimum flash point of Jet A-1, which shared the same yield with household heating kerosene, may affect serious impacts for jet fuel supply including aspects of manufacturing, storage, transportation and so on.

Table 3: Production Yield of Heating Kerosene (1996)

Japan	10.8 %
United State	0.38%
United Kingdom	3.63%
France	0.11%
Germany	0.03%
Holland	0.26%

(Source: OECD)

Table 4 : Production Affected by Raising Minimum Flash Point

	Jet Fuel Affected, bcd			
Revised min. flash point spec.°F	120	130	140	150
℃	49	54	60	66
a. increase of greater than 5%	0	0	0	0
b. increase of 0-5%	0	0	0	0
c. no change	6,882	0	0	0
d. reduction of 0-4.9%	12,220	4,120	4,120	0
e. reduction of 5-9.9%	3,800	0	0	4,120
f. reduction of 10-19.9%	42,782	8,100	0	0
g. reduction of 20-29.9%	34,560	16,830	11,500	0
h. reduction of 30-39.9%	37,900	41,862	9,630	3,400
i. reduction of 40-49.9%	0	67,172	28,162	8,100
j. reduction of greater than 50%	0	0	84,672	122,464
% Production Loss	26%	37%	51%	67%

When raising Jet A-1 minimum flash point, production volume shall lose with regardless of the level. Volume of its loss becomes bigger, according to the flash point level from 120°F(49℃) to 150°F(66℃).
The survey shows 10-30% production may loses when flash point change from current 100℉(38℃) to 120℉(49℃), 20-40% loss at 130℉(54℃), and majority of refiners loses greater than 60% of production at 150℉(66℃).
For reference, quantitative analysis estimated on this result indicates 26% production loss in the minimum case of 120 ℉(49℃) and 67% in the maximum case of 150 ℉(66℃). Those figures are very similar to EUROPIA's result (Table 4).

As to the reduction of freezing point, we have no serious impact, because we produce kerosene with less than 53℉(-47℃). Accordingly PAJ omits the survey of third set of questions (3a though 3g).

In order to manufacture new specification of jet fuel, most of Japanese refiners have to give up the current pattern of refining, which is same range cut of both household heating kerosene and Jet A-1 in crude distillation units, and to build new segregated lines and tanks for new jet fuel. Also we could consider to build new hydrocracking units.
However it is very difficult to install new units or facilities with reasons of limitation of refinery space and environmental/safety regulations at this moment in Japan. So that we conclude incremental costs are infeasible in case of requiring capital investment, for this time. (Question 2b., 2e.,2f. and 2g.)

3. Technical Feasibility to Recover Volume

Both household heating kerosene and Jet A-1 have been drawn in same cut range, and Jet A-1 has been adjusted specification just before loading in Japan.
If lifting the minimum flash point, almost Japanese refiners must change the current refining pattern to new one, drawing the yield of jet fuel including kerosene from narrow cut (short cut) and, then, producing household heating kerosene blended light kerosene and heavy kerosene which are cut separately.
In above case, refineries shall be required an option from following countermeasures technically;

a. To process in topper increased number of trays. (Figure 1)

b. To cut the same yield of current kerosene and jet fuel in topper, next, to fractionate in new re-run units, and then to process hydro-de-sulferization (HDS) units. (Figure 2)

c. To cut the same yield of current kerosene and jet fuel in topper, next, to process HDS units, and then to fractionate in re-run units.(Figure 3)

Further, refineries need to build new segregated off-site facilities(e.g. storage tanks, pipe laying) for Jet A-1 from current dual purpose facilities. As well as, responding this specification changes, we have to face additional problems of increasing energy utilization to increasing CO2 emission, or utilization of surplus heavy naphtha.
It is also infeasible to build new hydrocracking units as mentioned above.

Conclusion

Proposed specification changes of commercial aviation fuel flash point may introduce serious affection toward not only jet fuel supply but also household heating kerosene in Japan, and shall be too difficult to respond actually. PAJ will stand a pessimistic position at this moment.
Though we considered to respond with import jet fuel from Asian market, this changes might have world-wide impact. Accordingly it is necessary to judge based on comprehensive assessments of its impacts not only in Western market but also in Asian market.

Figure 1 : To process in crude distillate unit (topper) increasing of number of traies .

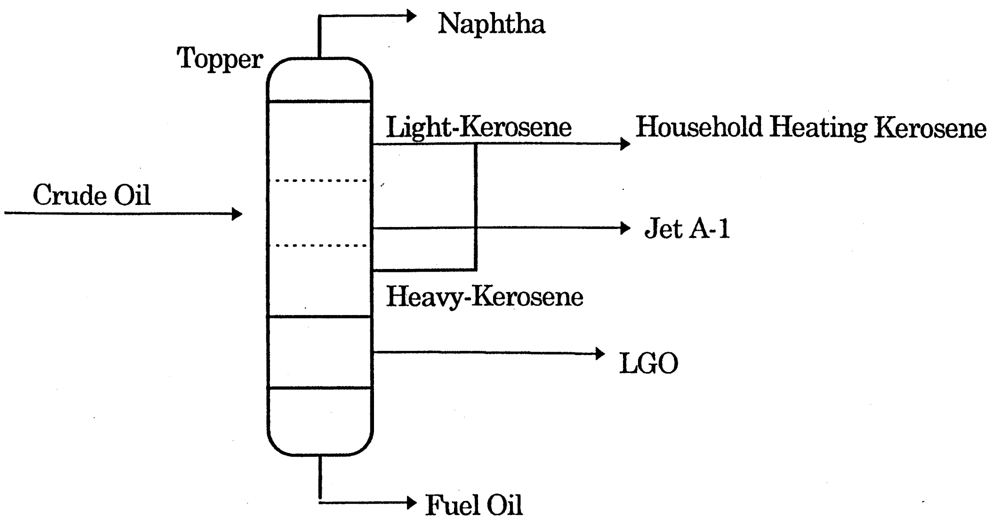


Figure 2 : To cut the same yield of current kerosene and jet fuel in topper, next, to fractionate in new re-run units, and then to process hydro-de-sulferization (HDS) units.

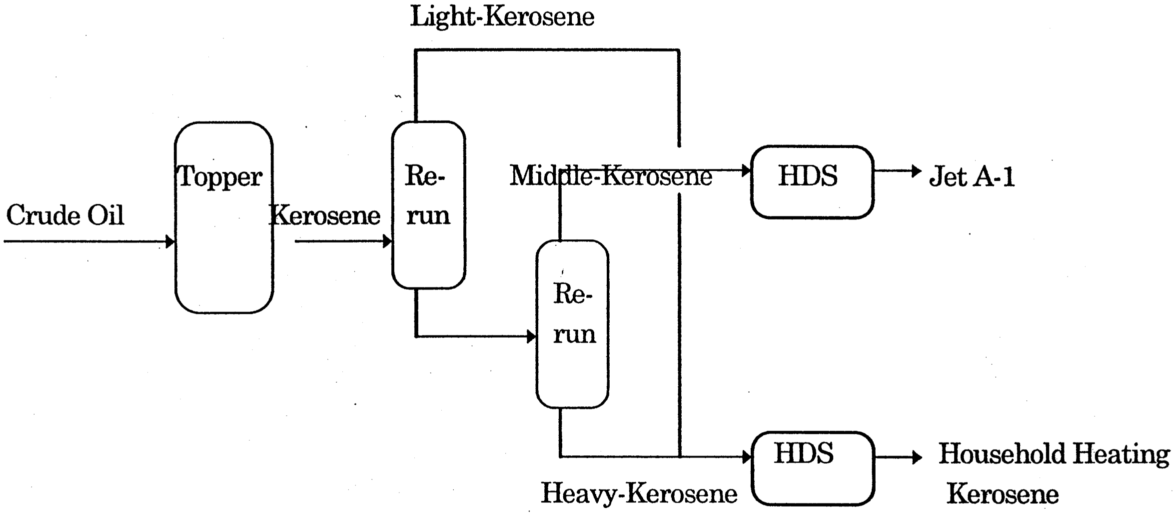
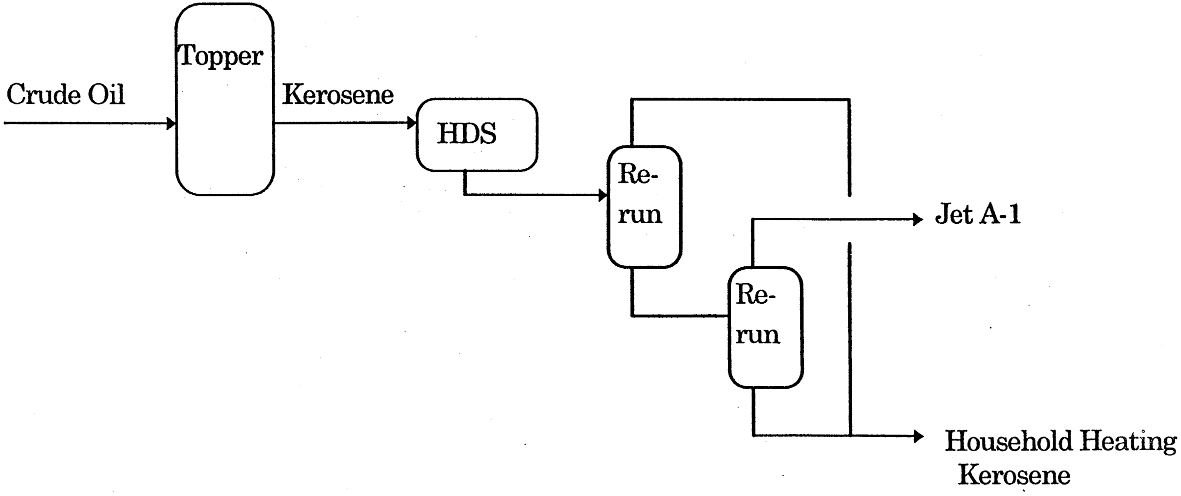


Figure 3 :To cut the same yield of current kerosene and jet fuel in topper, next, to process HDS units, and then to fractionate in re-run units.



OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

See notes below						
			FUEL DELIVERY SYSTEM			
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**
9.2.3.2	Inc. Flash Point	Yes			Suction lift performance improved	Reduced risk of vapor locking and lower TVP
9.2.3.2	Inc. IBP				Suction lift performance improved	Reduced risk of vapor locking and lower TVP
9.2.3.2	Inc. 10% Distilled				Suction lift performance improved	Reduced risk of vapor locking and lower TVP
9.2.3.2	Inc. 90% Distilled					
9.2.3.2	Inc. FBP					
9.2.3.3	Inc. Viscosity @ -20°	Poss.	Decreased	Loss of cold day operations	Red. cold start performance Dec. filter life Red. Heat exchange efficiency	Red. Control/pump perf. (dec. pumpability) + red. heat transfer effy
9.2.3.3	Change Visc. vs. T		Decreased	Loss of cold day operations	Cold start performance	Failure to control/pump fuel (dec. pumpability)
9.2.3.4	Inc. Aromatics		Inc. seal failures	Increase		Aromatics causing excessive swell
9.2.3.4	Change Arom. Types					
9.2.3.4	Dec. smoke point	Poss.				
9.2.3.5	Inc. total sulphur					
9.2.3.5	Dec. total sulphur					
9.2.3.6	Dec. thermal stab		Decreased	Increased maintenance	Inc. cleaning frequency	Fuel coking on critical parts
9.2.3.6	Inc. Thermal stab		Increased	Reduced maintenance	Dec. cleaning frequency	Improved due to reduced coking
9.2.3.7	Change Fz Pt. Characteristics**		Dec. reliability	Cold fuel operational limits***	Interruption of fuel supply	Blockage of pumps, filters and orifices etc.

*Denotes high proportion of population likely to be

**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

			FUEL DELIVERY SYSTEM			
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**
9.2.3.8	Improve lubricity		Increased	Reduced maintenance	Inc. fuel pump performance and life	Reduced pump wear
9.2.3.8	Reduce lubricity		Decreased	Increased maintenance	Dec. fuel pump performance and life	Inc. pump wear and failure rates
9.2.3.9	Inc. Density				Flow meter and control calibration & less accuarate fuel sched.	Change in density
9.2.3.9	Dec. Net. Ht. Comb.		Modified fuel control increased	Inadequate high power fuel supply	Insufficient heat at max. flow	

*Denotes high proportion of population likely to be
**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

			COMBUSTION SYSTEM				HOT-END				EMMISIONS
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	
9.2.3.2	Inc. Flash Point	Yes	Decreased	Hard starting	More difficult ignition	Dec. atomization and evaporation efficiency					
9.2.3.2	Inc. IBP		?	?	Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.2	Inc. 10% Distilled				Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.2	Inc. 90% Distilled				Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.2	Inc. FBP		Inc. carbon deposition & red . liner life	Increased	Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.3	Inc. Viscosity @ - 20°	Poss.				Red. heat transfer effy.					Higher smoke
9.2.3.3	Change Visc. vs. T										Secondary effects due to inefficiency in combustor

*Denotes high proportion of population likely to be
**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

COMBUSTION SYSTEM							HOT-END				EMISSIONS
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	
9.2.3.4	Inc. Aromatics			Increased maintenance liner and injector life	Increased wall temps/carbon depostion + low power emissions	Inc. flame radiation and carbon production		increase	Blade and guide vane life	Carbon	Increased smoke/UHC/CO
9.2.3.4	Change Arom. Types			??	??	??					??
9.2.3.4	Dec. smoke point	Poss.		Increased maintenance	Excessive wall temps/carbon deposition	Inc. flame radiation and carbon production		Increase	Blade and guide vane life	Carbon	Higher smoke
9.2.3.5	Inc. total sulphur			Increased maintenance	Nozzle flow and spray pattern	Fuel nozzle coking	decrease	Increased maintenance	Hot and component	Increased	Increased SOx
9.2.3.5	Dec. total sulphur						Increased	Decreased maintenance	Hot and component	Decreased	Reduced Sox
9.2.3.6	Dec. thermal stab			Increased maintenance		Inc. fuel nozzle coking					
9.2.3.6	Inc. Thermal stab			Reduced maintenance		Dec. fuel nozzle coking					
9.2.3.7	Change Fz Pt. Characteristics**										
9.2.3.8	Improve lubricity			Less maintenance	Dec. sticking of fuel nozzle divider valves	Lubrication of moving parts					

*Denotes high proportion of population likely to be

**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

			COMBUSTION SYSTEM				HOT-END				EMISSIONS
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	
9.2.3.8	Reduce lubricity			More maintenance	Inc. sticking of fuel nozzle divider valves	Lubrication of moving parts					
9.2.3.9	Inc. Density			Increased range (same HV assumed)		Higher energy density fuel					Increased due to lower comb
9.2.3.9	Dec. Net. Ht. Comb.			May require component changes	Fuel nozzle max. flow – new nozzles	Insufficient heat at max. flow					Poss. Increase in all emissions

*Denotes high proportion of population likely to be
**Denotes sharper transition to solid and larger xtals/filter blocking

APPENDIX --- Section 14.5 --- Estimate of Ten-Year Cost of Flash Point Change for Jet Fuel

In drafting the Executive Summary of the FTHWG Report (see request at end of this note), the "Ten-Year" Cost of the various Technology Options was estimated. For Flash Point Changes, the attached spreadsheet was constructed to estimate the cost of a Flash Point Change.

The estimate is straightforward based on the annual-cost information in the API/NPRA and EUROPIA Surveys (Sections 14.1 and 14.2). These annual-cost information (basically the Answers to Survey Question 2g) include "incremental operating costs, capital charges and any economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced." Therefore the spreadsheet displays the "Ten-Year" Cost for different "annual-cost" cpg numbers. Per the attached request, the "Ten-Year" Cost can be for Jet Fuel Volume with / without a growth rate (ex. is 3.5%).

If, in response to a Flash Point Change from 100F->120F, the Annual-Cost (for 7% ROI) was 2 cpg for U.S. Jet Fuel (with 1.6 Million Barrels/Day) and 8 cpg for Rest-of-World Jet Fuel (with 2.1 Million Barrels/Day) ::

…the no-growth "Ten-Year" Costs are $ 4.9 Billion + $25.8 Billion ➔ $30.7 Billion
(with 3.5% growth ➔ $38.0 Billion)

Different Volumes and cpg numbers can be estimated by simple interpolation/extrapolation of the values in the tables …or … by simple calculation using the selected cpg number and volume for gallons/ ten-years.

==
==== Question from Ivor Thomas for "FTHWG Overview Report / Summary" ====
==

From: Thomas, Ivor[SMTP:Ivor.Thomas@PSS.Boeing.com]
Sent: Thursday, July 02, 1998 10:21 AM
To: Lieder CA (Chuck) at MSXWHWTC
Subject: Question about "Deltas / Increases" in Cost of Jet Fuel

Chuck, thanks for the input. On another subject: In order to do a cost benefit analysis we are trying to estimate the US and World fleet cost to implement the various solutions over a ten year duration. This would include cost of design and installation and running costs for ten years. We haven't got enough to time worry implementation schedules. If I look at the 120 Flash Fuel, can you project out a ten year cost to the airlines. Oren did a quick look which assumed a straight $.02/gal (US) and $.08/gal (Rest of the World) and a 3.5% pa growth rate. This comes to $4.6B for US and $12.4B for Rest of the World. Is there any logic to assume the $.02/gal would come down over time as the refineries use the added capability to make more profit on other components and as the cost gets lost in the overall price Competition.

...from Ivor Thomas
==

Some Cost Estimation of Jet Fuel SCENARIOs

....Assumptions....	MB/D	Gallons/D	Gallons/Yr
U.S. Jet Fuel Use	1.60E+06	6.72E+07	2.45E+10
Rest-of-World Use	2.10E+06	8.82E+07	3.22E+10

Quickie Results....	**DELTA CO$T "Summary"**	**...with Vol Increase**	**...No Vol Increase**
	if US => 2 cpg ; WorldWide => 8 cpg	**$35,968,451,430**	**$30,660,000,000**
	if US => 2 cpg ; WorldWide => 5 cpg	**$24,638,389,230**	**$21,002,100,000**
	if US => 3 cpg ; WorldWide => 8 cpg	**$38,845,927,545**	**$33,112,800,000**

U.S. Jet Fuel Use	Delta CO$T =	1 cpg	**2 cpg**	3 cpg	4 cpg	6 cpg
	Volume Increase from ZERO Year					
Year ZERO	0	$245,280,000	$490,560,000	$735,840,000	$981,120,000	$1,471,680,000
ONE	3.5	$253,864,800	$507,729,600	$761,594,400	$1,015,459,200	$1,523,188,800
TWO	7.1	$262,750,068	$525,500,136	$788,250,204	$1,051,000,272	$1,576,500,408
THREE	10.9	$271,946,320	$543,892,641	$815,838,961	$1,087,785,282	$1,631,677,922
FOUR	14.8	$281,464,442	$562,928,883	$844,393,325	$1,125,857,766	$1,688,786,650
FIVE	18.8	$291,315,697	$582,631,394	$873,947,091	$1,165,262,788	$1,747,894,182
SIX	22.9	$301,511,746	$603,023,493	$904,535,239	$1,206,046,986	$1,809,070,479
SEVEN	27.2	$312,064,658	$624,129,315	$936,193,973	$1,248,258,630	$1,872,387,945
EIGHT	31.7	$322,986,921	$645,973,841	$968,960,762	$1,291,947,682	$1,937,921,524
NINE	36.3	$334,291,463	$668,582,926	$1,002,874,388	$1,337,165,851	$2,005,748,777
=TOTAL=	**=TOTAL=**	$2,877,476,114	**$5,754,952,229**	$8,632,428,343	$11,509,904,458	$17,264,856,687
	TOTAL...if no Growth --->	$2,452,800,000	$4,905,600,000	$7,358,400,000	$9,811,200,000	$14,716,800,000

Rest-of-World Use	Delta CO$T =	3cpg	5 cpg	**8 cpg**	10 cpg	15 cpg
	Volume Increase from ZERO Year					
Year ZERO	0	$965,790,000	$1,609,650,000	$2,575,440,000	$3,219,300,000	$4,828,950,000
ONE	3.5	$999,592,650	$1,665,987,750	$2,665,580,400	$3,331,975,500	$4,997,963,250
TWO	7.1	$1,034,578,393	$1,724,297,321	$2,758,875,714	$3,448,594,643	$5,172,891,964
THREE	10.9	$1,070,788,636	$1,784,647,727	$2,855,436,364	$3,569,295,455	$5,353,943,182
FOUR	14.8	$1,108,266,239	$1,847,110,398	$2,955,376,637	$3,694,220,796	$5,541,331,194
FIVE	18.8	$1,147,055,557	$1,911,759,262	$3,058,814,819	$3,823,518,524	$5,735,277,786
SIX	22.9	$1,187,202,502	$1,978,670,836	$3,165,873,338	$3,957,341,672	$5,936,012,508
SEVEN	27.2	$1,228,754,589	$2,047,924,315	$3,276,678,904	$4,095,848,631	$6,143,772,946
EIGHT	31.7	$1,271,761,000	$2,119,601,666	$3,391,362,666	$4,239,203,333	$6,358,804,999
NINE	36.3	$1,316,272,635	$2,193,787,725	$3,510,060,359	$4,387,575,449	$6,581,363,174
=TOTAL=	**=TOTAL=**	$11,330,062,201	$18,883,437,001	**$30,213,499,202**	$37,766,874,002	$56,650,311,003
	TOTAL...if no Growth --->	$9,657,900,000	$16,096,500,000	$25,754,400,000	$32,193,000,000	$48,289,500,000

	Scenarios for Estimates =>	**U.S. +1 / W +3cpg**	**U.S. +2 / W +5cpg**	**U.S. +3 / W +8cpg**	**U.S. +4 / W +10cpg**	**U.S. +6 / W +15cpg**
= WorldWide TOTAL =	**= WorldWide TOTAL =**	**$14,207,538,315**	**$24,638,389,230**	**$38,845,927,545**	**$49,276,778,460**	**$73,915,167,689**
	TOTAL...if no Growth --->	**$12,110,700,000**	**$21,002,100,000**	**$33,112,800,000**	**$42,004,200,000**	**$63,006,300,000**

Aviation Rulemaking
Advisory Committee

Evaluation Standards and Proposed Regulatory Action Advisory Group

Task Group 8

14th July, 1998

1. Background

Task Group # 8 had two objectives;

1, Provide a common set of definitions to the other Task Groups so there was consistency in the data used by all groups, and

2, Define Proposed regulatory Action

2. Summary

2.1 Objective 1,

Technical support was provided to all TG's in the form of generic airplane definitions and missions for use in assessing potential safety enhancements. A spreadsheet was developed to provide a common source of data to be used by the task groups in order to ensure that the potential methods were evaluated using consistent data and assumptions. Data were included in the spreadsheet for six generic airplane types: small, medium and large transports, regional turbofans, regional turboprops and business jets. The data included summaries for each airplane type, such as fleet size, weights, fuel volumes and flight distributions. Mission profile data such as weight, altitude, Mach number, fuel remaining in each tank and body angle as a function of time was included for each generic airplane type. Temperature profiles ranging from cold to extremely hot were also included in the mission profiles. Performance trades and cost trades were also included to allow the consistent calculation of performance and cost impacts.

2.2 Objective 2,

A proposed change to FAR 25 has been drafted together with the body of a supporting Advisory Circular. The intent of the proposed regulatory action is to create a revised FAR 25.981 which will have two sections, the first addressing ignition source prevention in fuel systems, and the second part addressing controlling the flammability exposure within fuel tanks. The first part of the proposed FAR 25.981 will be addressed by the FAA directly and is outside the TOR for the FTHWG. The intent of the second part of the proposed FAR is to require that either the exposure of any tank to flammable fuel air mixtures be no greater than 7 % of fleet operational time, or that protective systems be provided for tanks that can not meet the flammability requirement. The requirement for flammability control is based on the fleet history as provided by TG1 coupled with the flammability exposure for the current fleet being provided by TG5. The other task groups have defined methods to satisfy the requirements of the proposed regulation and provided costs of implementation. Task Group 8 developed the proposed regulatory action and supporting AC/ACJ to allow the other groups to develop and cost different means to satisfy the proposed regulation. The cost benefits of each proposed means must be examined by the FTHWG to determine if a suitable means to satisfy the regulation exists and should such a regulation be proposed.

The supporting AC material is drafted to provide the methodology for assessing any given tank against the proposed rule, and will incorporate information on what alternatives are available to the applicant to satisfy the requirement. This section includes information on Foam, Inerting, Higher Flash Point Fuel etc.

3.1 Objective 1, Generic Standards

Technical support was provided to all TG's in the form of generic airplane definitions and

A spreadsheet was developed

to provide a common source of data to be used by the task groups in order to ensure that

included in the spreadsheet for six generic airplane types: small, medium and large transports, regional turbofans, regional turboprops and business jets. The data included

volumes and flight

in each tank and body angle as a function of time was included for each generic airplane type. Temperature profiles ranging from cold to extremely hot were also included in the

consistent calculation of performance and cost impacts.

3.2 Objective 2, Proposed Regulatory Action

In order to enhance fuel system safety, the task group 8 recommended to the FTHWG that the following regulation be proposed to the FAA/JAA provided that the cost benefit studies show a net gain to the aviation system:

Create a revised paragraph FAR 25.981 to address fuel tank protection from airplane created threats that could prevent continued safe flight and landing. The proposed revision is as follows:

> **Section 25.981 Fuel Tank Ignition Prevention**
>
> **The fuel system must be designed and arranged to prevent the ignition of fuel vapor within the tanks, or mitigate the effects of such an ignition by addressing:**
>
> **(a) Ignition Sources**
>
> ***(a)1.*** *Place the current 25.981 requirement here*
> ***(a)2.*** *Additional requirements in ignition source mitigation as defined by the FAA would be in section (a)2, (a)3, etc. as defined by the SFAR effort underway*
>
> **(b) Flammable Vapors**
> **Limit the development of flammable conditions in the fuel tanks, based on the intended fuel types, to less than 7% of the expected fleet operational time, or**
> **Provide means to mitigate the effects of an ignition of fuel vapors within the fuel tanks such that any damage caused by an ignition will not prevent continued safe flight and landing.**

3.2.1 Discussion on the intent of the proposed requirement

The proposed regulatory action provides a single regulation to address ignition prevention, thereby avoiding having several paragraphs which must be linked and interpreted in conjunction with each other. It provides the industry with a requirement that addresses all aspects of fuel tank ignition prevention/mitigation, which can be treated as a comprehensive requirement and addressed as one issue. The existing requirements set forth in sections 25.901, 25.954 and 25.981 are intended to preclude ignition sources from being present in airplane fuel tanks. As proposed, Paragraph (a) maintains these requirements, which have been, are, and shall continue to be, the essential primary elements in fuel tank safety. Paragraph (b) provides a requirement to address flammability mitigation as a new layer of protection to the fuel system. The intent of the combined regulation is to prevent an applicant relying solely on ignition prevention or on flammability reduction as the means to protect the fuel system from ignition events.

It is considered that there should be some ability on the part of the applicant to trade improvement in ignition prevention for relief in flammability reduction, but only in specific cases, for example, where the applicant had taken steps to significantly reduce potential ignition sources such as designing a tank with no pumps or a non electric gauging system.

The Concept of flammability exposure as a “Percentage of Expected Fleet Operational Time” is a measure of how much time will a given tank, in a fleet of a specific airplane type, be operating within the flammable range, as determined by the fuel properties and fuel temperature in that tank. This measure determines the likelihood of an ignition occurring in a tank that contains a flammable mixture. This is based on the hypothesis that ignition events occur very infrequently and randomly in any tank of a given airplane type and thus ignition is dependent on the flammability probability. The “less than 7% of the expected fleet operational time”, used in Section (b) is derived from examination of the current fleet exposure, as reported by Task Group 1, which indicates that wing tanks are statistically less likely to be involved in events than center wing tanks. Task Group 5, corroborated the fleet history by providing analysis to show there is a significant difference in fleet average exposure to flammable conditions between wing tanks (2% to 6%) and center wing tanks with nearby heat sources (approximately 30%). Using this data it was concluded that a 7% fleet average exposure would provide a significant improvement in safety without unduly penalizing current tanks without heat sources in, or nearby the tank. The combination of ignition source control, which is currently being upgraded through the SFAR activity, and flammability control will provide fuel systems whose exposure to a catastrophic event is much improved over today’s high standards.

Section (b) implicitly includes the option of using inerting of some form, or higher flash point fuel, to satisfy the 7% criterion, and for the use of foam, or explosion protection means, to satisfy the intent of mitigating the effects of an ignition in a tank where a designer chooses to use that option.

3.3 Supporting AC/ACJ Material

The wording below represents the proposed body of an AC/ACJ to support the proposed new FAR 25.981(b). The AC/ACJ in support of the proposed FAR 25.981(a) is a separate AC/ACJ and must be developed by the FAA/JAA either in house, or through a new Harmonization Working Group.
It should be noted that the AC/ACJ material includes two methods of assessing fuel tank flammability. The second method was developed late in the task group's efforts and has not been as thoroughly developed as the first method. Additional testing of the method is required to validate it prior to adoption within the AC/ACJ.

AC/ACJ 25.981(b)

1 - Purpose

This ACJ sets forth an acceptable method of compliance with the requirements of FAR/JAR 25.981(b). The guidance provided within this AC is harmonized with the US Federal Aviation Administration (FAA) and Joint Aviation Authority (JAA) and is intended to provide a method of compliance that has been found acceptable. As with all ACJ material, it is not mandatory and does not constitute a regulation.

2 - Applicability

This ACJ applies to part 25 airplanes for which a new, amended, or supplemental type certificate is requested.

3 - Related Documents

FAR/JAR 25.901
FAR/JAR 25.954
FTHWG Report
TBD by FAA

4 - Background

The regulation is intended to provide requirements to reduce the probability of a fuel tank explosion to an extremely improbable level. The regulation is divided into two parts,

Part (a) dealing with ignition prevention and
Part (b) dealing with fuel flammability limitation and explosion related damage prevention.

Part (a) is the subject of a separate AC/ACJ.
Part (b) is addressed herein.

25.981(b) requires that either;

the probability of having a flammable fuel vapor/air mixture in a fuel tank is reduced to an acceptable level,
or
means are used to prevent airplane damage if an explosion is initiated in a tank that has a higher than acceptable fleet average flammability exposure.

This AC/ACJ provides an acceptable process for determining the fleet average flammability exposure of a design, and discusses options that may be used to achieve the required level, and discusses explosion suppression means that may be used in lieu of reducing fleet average flammability exposure.

5 - Definitions

- ***Flammability;*** The ability for an fuel vapor/air mixture to be ignited when exposed to a sufficiently energetic source of energy (electrical, such as a spark; thermal, such as a hot surface; and mechanical, such as two metal parts rubbing together at high speed to produce sparks).
- ***Flammability range;*** The pressure (i.e. altitude) / temperature domain where the fuel vapor/ air mixture is flammable. The lower flammability limit (lfl), also known as the lower explosive limit (lel), defines the temperature/ altitude below which the fuel vapor/air mixture is too lean to burn. The upper flammability limit (ufl) defines the upper part of the domain, above which the fuel vapor/air mixture is too rich to burn. This domain is dependent of the type of fuel used.

Lower Flammability Limit; For the purpose of this AC, the lower flammability limit should be taken to be equal to the fuel flash point (FP) as determined by ASTM D-56 and corrected for altitude by -1°F per 800ft altitude increase from sea level.

Upper Flammability Limit; For the purpose of this AC, the upper flammability limit should be taken to be equal to the fuel flash point +70°F, and corrected for altitude by -1°F per 600 ft altitude increase from sea level.

> Note; This simple approach to define lfl and ufl has been taken in lieu of any conclusive data on flammability versus ignition energy versus altitude, and the lack of any data on the probability of an ignition source of a given energy level being present in a fuel tank if an ignition source were to be present. (The FAA Document DOT/FAA/AR-98/26 provides further information on this subject.)

Fuel types; Different fuels are approved for use in turbine powered aircraft. The most widely used fuel types are JET-A/JET-A1, JET-B (JP-4). For an aircraft, the approved fuel types are listed in the Airplane Flight Manual (AFM). Each fuel type has its own properties, those directly related to flammability are flash point and distillation characteristics. Property differences can occur in a given fuel type as a results of variations in the source crude oil properties and the refining process used to produce the fuel.

Fuel tank; An aircraft volume containing fuel. Tanks contains both liquid fuel and, in the ullage space, a fuel vapor/air mixture, with some water vapor depending on the relative humidity in the tank.

Ullage, or Ullage Space; The volume within the tank not occupied by liquid fuel.

Operational time; The time from the start of preparing the aircraft for flight, (turning on the APU/Ground Power, Starting Environmental Control Systems etc.,), through the actual flight and landing and the time to disembark any payload/passengers and crew.

6 - Design considerations to limit the probability of flammable conditions

Generally, the drivers in limiting the probability of a flammable mixture in the tank are the fuel type, fuel temperature and any design feature that increases the potential for fuel mists to be created. Current design practices which reduce the potential for fuel agitation should be continued. This prevents the flammability range from widening at the lean end because of the presence of fuel mist, which may be flammable at temperatures well below the flash point.

Design practices that reduce the overall risk are described within this paragraph of this ACJ. Airplane designs submitted for evaluation by the regulatory authorities will be evaluated against these practices.

The intent of the regulation is to limit the exposure to flammable fuel vapor/air mixtures to a small amount of the operational time for that aircraft type. Analysis has shown that this exposure needs to be less than 7% of operational time to provide an acceptably low risk of a fuel tank explosion. Practical design precautions should be used achieve this criterion. On any one aircraft type, the most effective methods may vary between different tanks, according to their exposure to the risk. For instance, tanks located in the wings with little or no heat input from aircraft systems have been analyzed and shown to meet the regulation, whereas tanks located within the fuselage contours will require more design attention. Such tanks may have less ability to reject heat to ambient air, both on the ground and in flight, and might be subject to heat sources from equipment located nearby in the fuselage such as the air conditioning packs that supply cool air to the cabin. For tanks that, because of installation location and/or other factors, do not readily meet the 7% flammability exposure criterion of 25.981(b), additional design considerations should be considered. The following are provide as examples, but are not the only design solutions that may be proposed;

a- Limiting heat transfer to the tank

The transfer of significant heat quantities into fuel tanks under normal operation conditions should be prevented to satisfy the requirement. Locating heat producing systems away from the tanks should be considered. If this is not a practical solution, controlling heat transfer to the fuel tank should be addressed. Possible technical solutions are the use of thermal blankets and/or providing ventilation to remove excess heat from the area near the tank.

b- **Fuel tank ullage sweeping**

A positive ventilation system may be used to “sweep” the ullage of flammable fuel vapor/air mixtures at a rate that keeps the ullage lean in spite of a higher than desirable fuel temperature. This ventilation system may be used as needed to satisfy the requirement of the regulation, but should address any negative effects such as sweeping unburned hydrocarbons into the atmosphere. Evidence that the ullage sweeping system does not leave pockets of flammable fuel vapor-air mixtures within the tank should be provided.

c- **Fuel tank inerting**

Fuel tank inerting is another way of reducing the flammability exposure within a given tank. The accepted level for tank inerting is to reduce the oxygen content of the tank ullage to less than 9%. The applicant may show that inerting is only needed for certain missions or parts of a mission to bring the tank fuel vapor/air mixture average exposure down to an acceptable level. Inerting may be achieved be supplying inert gas from on-board storage bottles, holding either gas or liquid inertant, on board inert gas generation systems (OBIGGS) or from a ground storage system if the tank is inerted only on the ground. Evidence that the inerting system does not leave pockets of high oxygen concentration within the tank should be provided. The effect of oxygen evolving from the fuel during pressure reduction conditions, such as during climb, should be addressed. The applicant should demonstrate that the added system does not decrease the overall safety of the aircraft.

d- Higher Flash Point Fuels

The applicant may consider using only high flash point fuels to reduce the flammability exposure to an acceptable level.

7 Acceptable means to mitigate of the effects of an explosion

An alternative means of satisfying 25.981(b) is to provide a means to protect a tank from structural and systems damage that could prevent continued safe flight and landing. This alternative recognizes that an applicant may choose to accept a high flammability exposure in a given tank and to provide additional protection to extinguish or suppress an explosion in a tank if an ignition occurs. The following are provide as examples, but are not the only design solutions that may be proposed;

a- Foam

The use of appropriate foams to fill the fuel tank and thereby control the pressure rise following an ignition of the fuel vapor/air mixture has been demonstrated by the USAF and other military forces to be effective, and is in use on several airplane types. The applicant may use such a foam installation to satisfy the requirement of 25.981(b). The foam type should be demonstrated to be effective in suppressing explosions to a level where structural and system damage is prevented.

The applicant should;

Provide data on the foam, including material, pore size, and intended method for installing the foam in the tank.

Address the potential for, and the effects of, degradation of the foam, from any environmental effects and long term aging, on both the airplane and engine fuel systems

Address the effect of the foam installation on the airplane fuel system, as well as the APU and engine fuel systems, and

Develop maintenance procedures to ensure the foam is correctly installed both initially and when reinstalled, if removed for access to the tank.
Address the effects of the foam installation on fuel system performance , including engine feed, venting, fueling and defueling including the effect of the foam on electrostatic build up in the tank.

b- **Explosion suppression**

The use of a simple flame propagation suppression system has been approved by the FAA for use in fuel system surge tanks on some commercial transport aircraft. This technology has not been proven for use inside fuel tanks but may be pursued by an applicant. An explosion suppression system typically consists of one or more optical sensors which are capable of rapidly detecting a flame within their field of view, and then the system commands the release of extinguishing agent from one or more containers sufficiently quickly to extinguish the fire before a damaging over-pressure can develop. These systems may be considered for use in fuel tanks to satisfy 25.981(b).
The applicant should consider the following:
1, Do the sensors' field of view cover enough of the tank volume to effectively recognize a explosion developing anywhere in the tank?
2, Is the sensor field of view and sensitive affected by the presence of fuel in the field of view?,
3, Will the release of extinguishing agent in the tank cause an over pressure, particularly if the agent is released below the fuel surface?.
4 Will failures of the systems cause over-pressure of the tank?

8- Acceptable Means of Determining the Flammability Exposure of a Given Tank.

In service experience indicates that a satisfactory level of safety can be achieved if the presence of flammable vapors is less than approximately 7% of operational time as determined by either of the methods set forth below.

Method I

The presence of flammable vapors should be determined independently for each tank. Within each tank, separate volumes where barriers or walls prevent mixing of the fuel /air mixtures, should be treated independently to determine the worst case exposure for that tank.
The analysis should take into account all fuel types for which certification is sought and listed in the AFM, and the expected usage of each fuel type.

To ensure that a consistent method and assumptions are used in this process, specific ground rules have been developed and must be followed by the applicant.
The amount of ground operation time to be included in determining Airplane Operational Time as defined in this ACJ, should use the following:
Pre-flight Time;
Small airplanes (maximum TOGW equivalent to a 130 passenger airplane or smaller,) = 45 min,
Medium airplanes (maximum TOGW equivalent to a 130 to 300 passenger airplane) = 1 hr,
Large (maximum TOGW equivalent to more than a 300 passenger airplane) = 1.5 hr, and
Post Flight time;
30 minutes after completion of the landing roll landing for all airplanes.

For each tank in the airplane under consideration, the applicant should determine the exposure to flammable mixtures in the tank as a percentage of operational time for the expected fleet as follows;

The applicant should develop a computer model of the thermal environment of the tank so as to calculate the temperature of the fuel in the tank as a function of operational time as defined above, including normal airplane system usage, and the effects of any heating or cooling systems operating in or nearby the tank.
This model may be a detailed thermodynamic of all the heat flows into and out of the tank in question, or may be a simple model based on sufficient flight tests to allow accurate corrections for outside conditions and internal heat flow changes with flight conditions.

The applicant should define the flammability regions of the certified or proposed fuel types as a function of altitude and determine the statistical variation of the flammability range based on known or expected characteristics of the fuel as delivered to the airplane or airport. The attached figure is to be used for jet A type fuels, and similar data should be used in considering the use of higher flash point fuels

The thermal model should be used to calculate the total time the fuel in the tank is in the flammable region as a percentage of the total operational time of each flight, for a sufficient number of flights over various range flights, in various ambient temperatures and with a variety of fuel properties within the specifications of the expected fuel types, to assess the average fleet exposure to being in the flammability region.
The following factors are to be used in determining fleet exposure.

1, The fleet of airplanes is in use on a world wide basis, i.e. the effect of initial deliveries to a small number of users in a given part of the world should not be considered in this analysis but rather assume that the mature fleet will be used throughout the world.

2, The operational environment is world wide when considering both airport ambient and flight temperatures, as defined on the first figure below

> 3 The properties of certified fuels (as defined in the AFM) should be based on the distributions defined on second figure below,

In order to simplify the process, the airplane flight times may be reduced to three types, a short flight and medium flight and a long flight.
A random selection process is used to define a set of “flights” from which the fleet average exposure is determined.
The technique is described as follows:
Sets of values are created for each variable that define a given flight, such as fuel flash point, ground ambient temperature, cruise ambient temperature, range, fuel load and usage, etc. Each set will contain a large number of values (typically several thousands) such that the data in each set matches the distribution of the values expected in service. Each data set is then “shuffled” to generate a random order. By selecting the nth value of variables from each set a “random” flight is created. This is then used to compute the fuel temperature and time of flammability for a single flight. This process is repeated several thousand times and the individual flight flammability exposures are summed to develop a fleet average flammability exposure. Computing time can be reduced considerably by calculating a matrix of flight cases for a range of ambient and flight conditions and interpolating for each random flight case being considered.
An example of the process is attached as appendix 1.

To satisfy the requirement of the FAR/JAR, the fleet average exposure for each tank should be less than 7% of total operational time. If the 7% level cannot be achieved, the applicant should consider alternative means to reduce flammability, or to mitigate the effect of an ignition in the tank. These are discussed in Section 6 above.

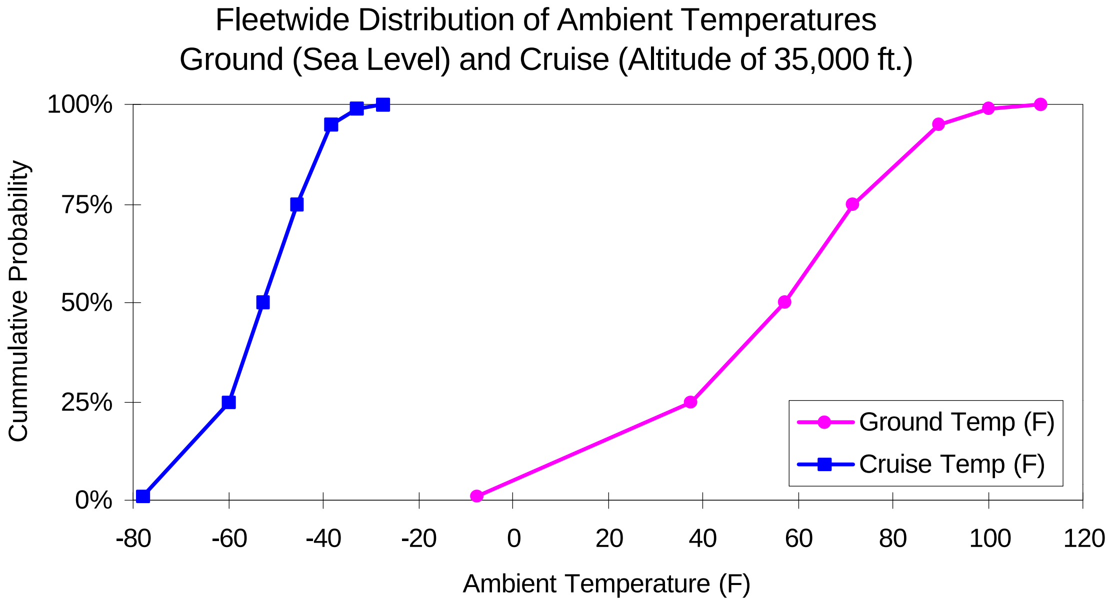
Method II
This process may only be used on airplanes which have approved fuels with a flash point of 100°F or above.
In flight, the fuel temperature in a typical wing fuel tank responds to a step change in TAT (total air temperature) with an exponential decay response to eventually reach the new TAT, assuming the flight continues for a long enough time. (The most common analogy to this process is the decay of capacitor voltage during discharge across a fixed resistance). Analysis of such tanks on a variety of certified airplanes, using Jet A type fuels, has shown that tanks with a rapid enough response to changes in total air temperature will result in a satisfactory flammability exposure as required by 25.981(b), provided there is no large heat input on the ground to increase fuel temperatures in the tank prior to flight or significant heat input from airplane systems in flight.
This method of demonstrating an acceptable flammability exposure is therefore to show by analysis or test the thermal response of each tank on the ground and in flight. The response of the fuel temperature to a change in TAT may be expressed as an exponential response as follows:

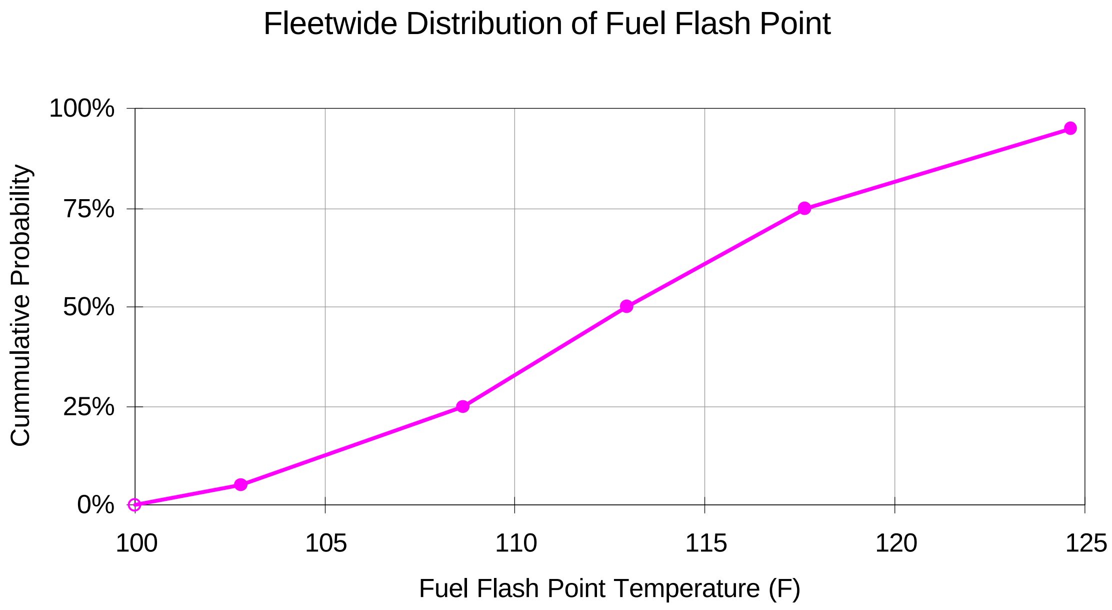
$$\text{Delta FT}_t = \text{Delta TAT x } (1\text{-}e^{-t/T})$$

Where Delta FT_t is the change in fuel temperature at time t, and Delta TAT is a step change in TAT, and T is the time constant for the fuel temperature in the subject tank.

A tank will meet the intent of the flammability exposure requirement of 25.981(b) if the tank satisfies the following;

1, The response of the fuel temperature is such that the time constant T is less than 120 minutes with a full tank,
(Note: at the time of submittal of this report the value of the time constant had not been finalized and needs to be verified)
2, The time constant, T, decreases as fuel is used and is not subject to additional heat load at lower fuel quantities,
3, The fuel temperature does not increase on the ground from heat input from other airplane systems during normal operation, by more that 5°F per hour with any amount of fuel in the tank from unusable to full.



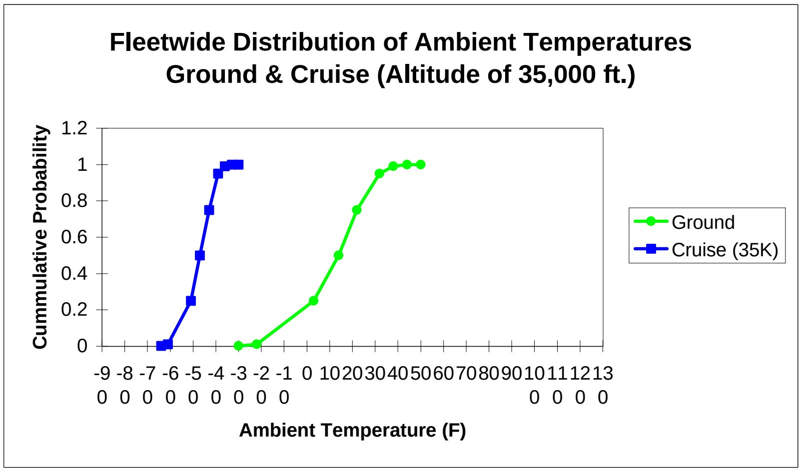


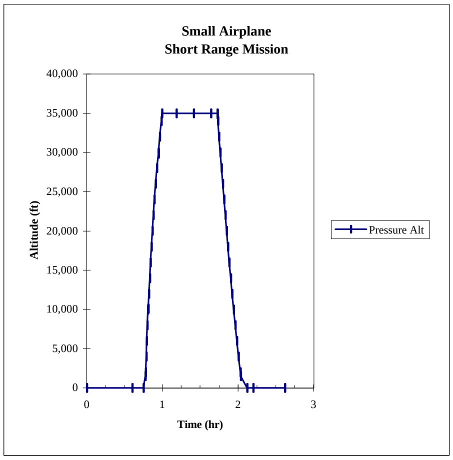
Jet A Fuel, Worldwide Distribution

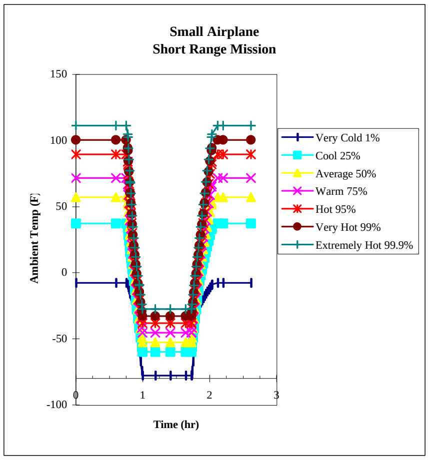
14th July, 1998

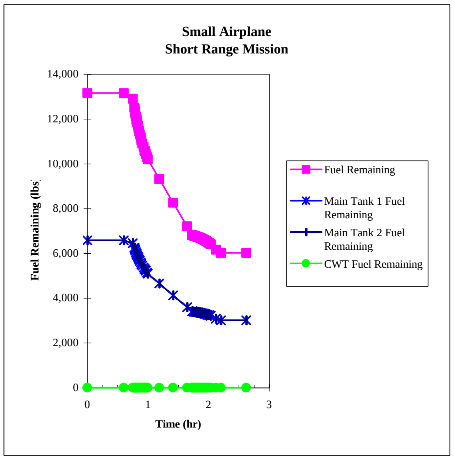
Attachment to Task Group 8 Report

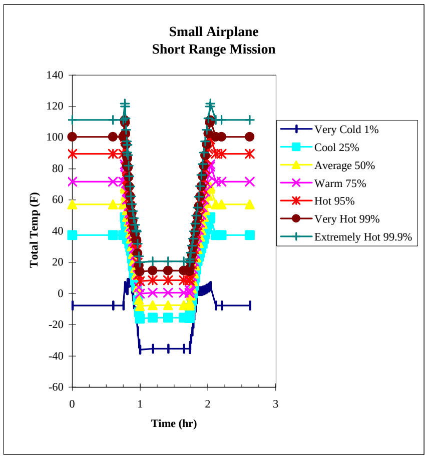
Common Airplane and Mission Data
and
Performance Trades and Cost Trades

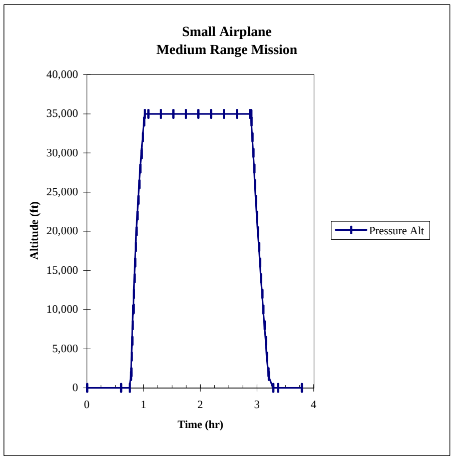

Fleetwide Distribution of Ambient Temperatures
Ground & Cruise (Altitude of 35,000 ft.)
Cummulative Probability
1.2
1
0.8
0.6
0.4
0.2
0
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Ambient Temperature (F)
Ground
Cruise (35K)

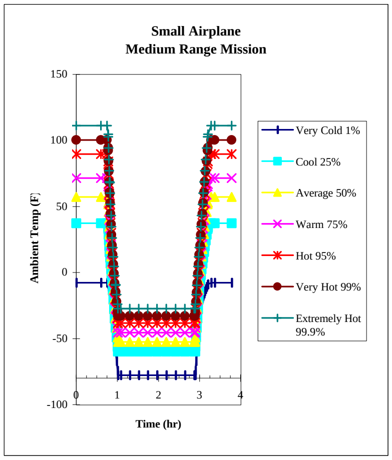

Small Airplane
Short Range Mission
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Altitude (ft)
0
1
2
3
Time (hr)
Pressure Alt

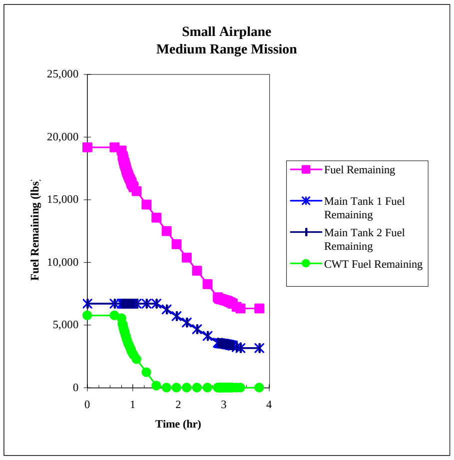

Small Airplane
Short Range Mission
150
100
50
0
-50
-100
Ambient Temp (F)
0
1
2
3
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

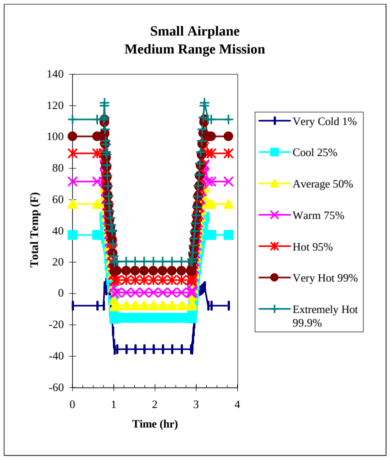

Small Airplane
Short Range Mission
Fuel Remaining (lbs)
Time (hr)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
1
2
3
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

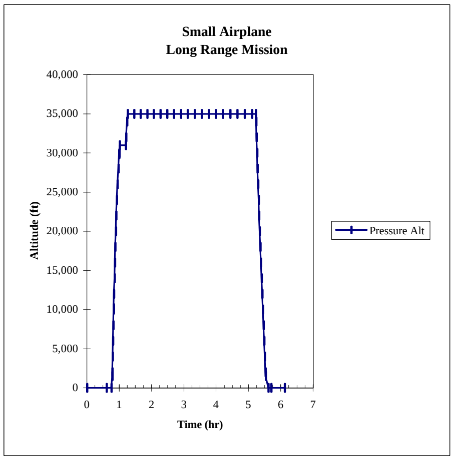

Small Airplane
Short Range Mission
Total Temp (F)
Time (hr)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

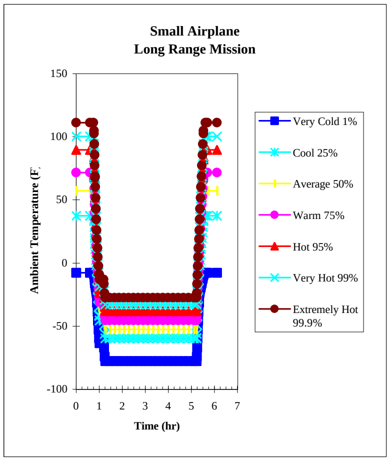

Small Airplane
Medium Range Mission
Altitude (ft)
Time (hr)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
Pressure Alt

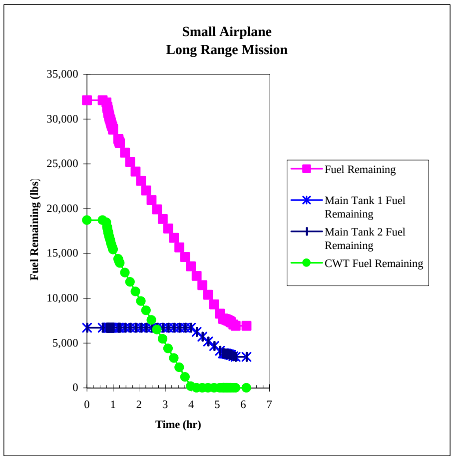

Small Airplane
Medium Range Mission
Ambient Temp (F)
Time (hr)
150
100
50
0
-50
-100
0
1
2
3
4
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

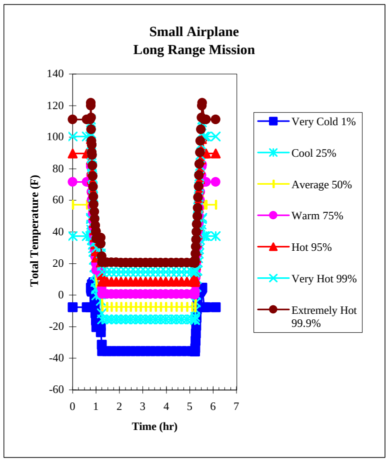

Small Airplane
Medium Range Mission
Fuel Remaining (lbs)
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

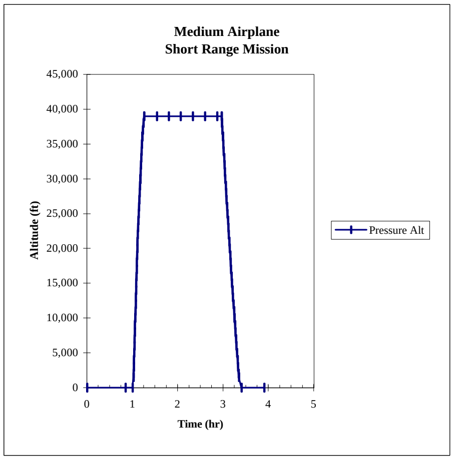

Small Airplane
Medium Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

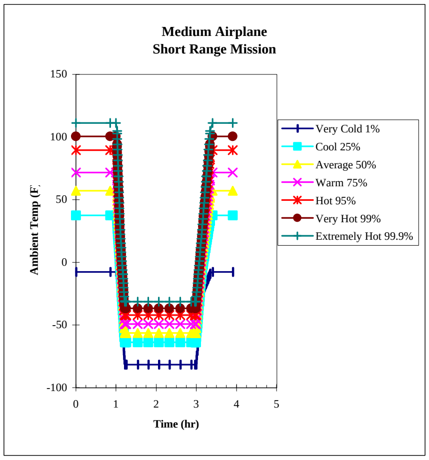

Small Airplane
Long Range Mission
Altitude (ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
Time (hr)
Pressure Alt

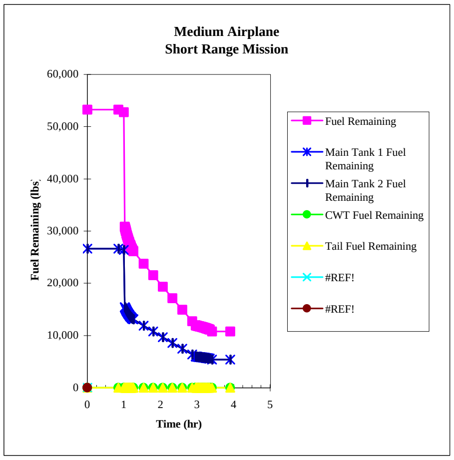

Small Airplane
Long Range Mission
Ambient Temperature (F)
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

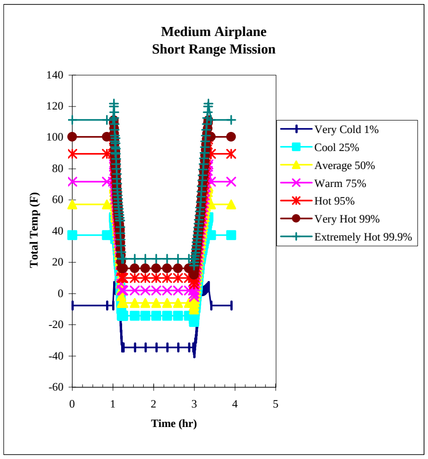

Small Airplane
Long Range Mission
Fuel Remaining (lbs)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

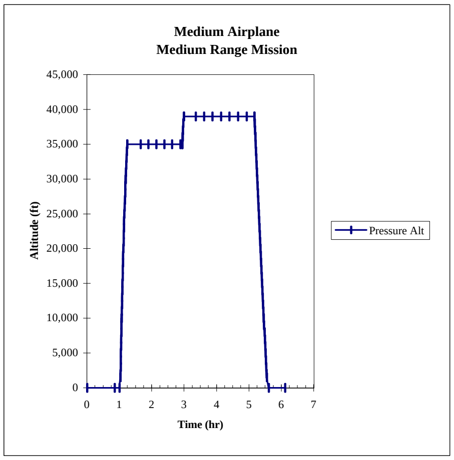

Small Airplane
Long Range Mission
Total Temperature (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

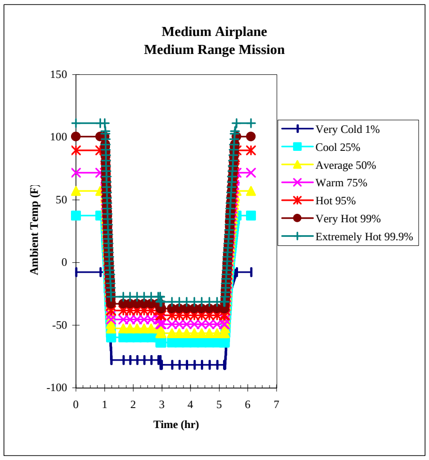

Medium Airplane
Short Range Mission
Altitude (ft)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
Time (hr)
Pressure Alt

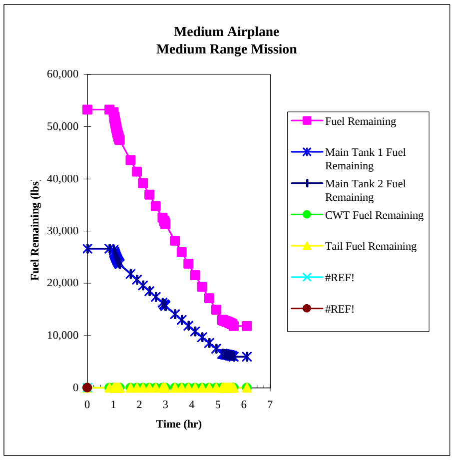

Medium Airplane
Short Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
5
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

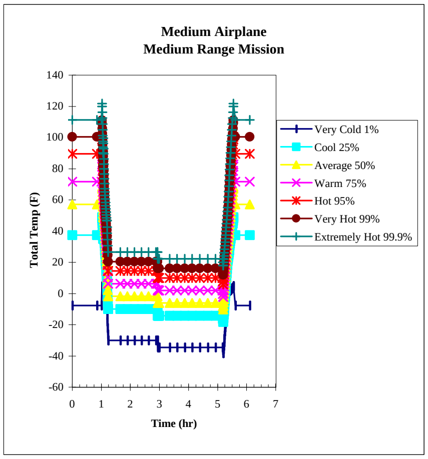

Medium Airplane
Short Range Mission
Fuel Remaining (lbs)
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining
#REF!
#REF!

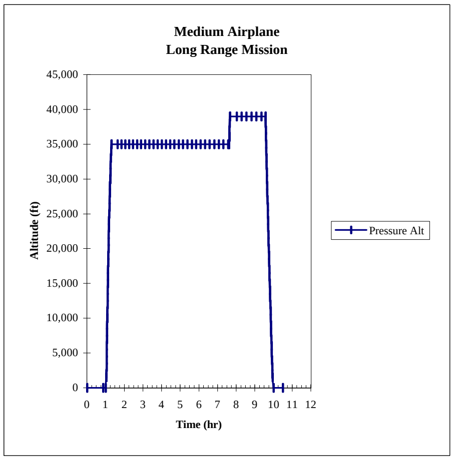

Medium Airplane
Short Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

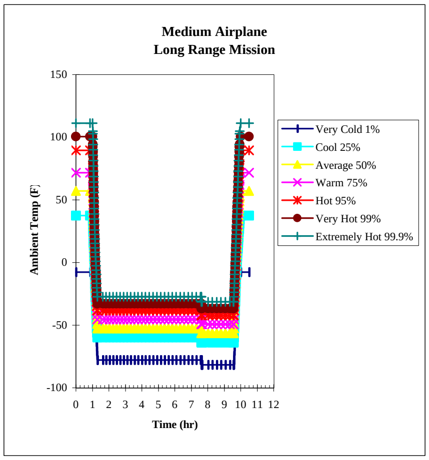

Medium Airplane
Medium Range Mission
Altitude (ft)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
Time (hr)
Pressure Alt

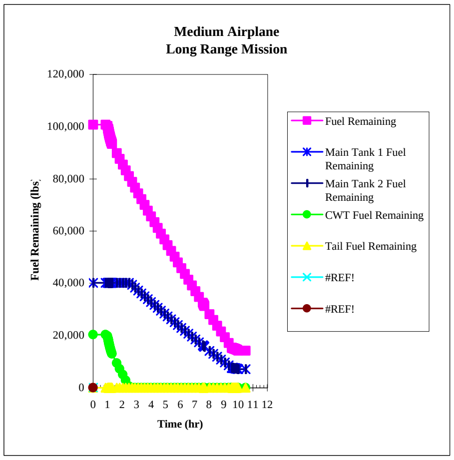

Medium Airplane
Medium Range Mission
Ambient Temp (F)
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Medium Airplane
Medium Range Mission
Fuel Remaining (lbs)
Time (hr)
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
6
7
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining
#REF!
#REF!

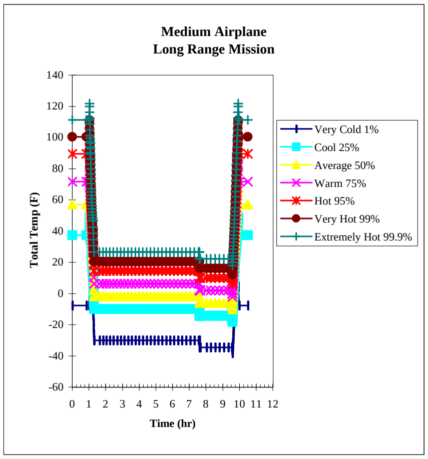

Medium Airplane
Medium Range Mission
Total Temp (F)
Time (hr)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Medium Airplane
Long Range Mission
Altitude (ft)
Time (hr)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8
9
10
11
12
Pressure Alt

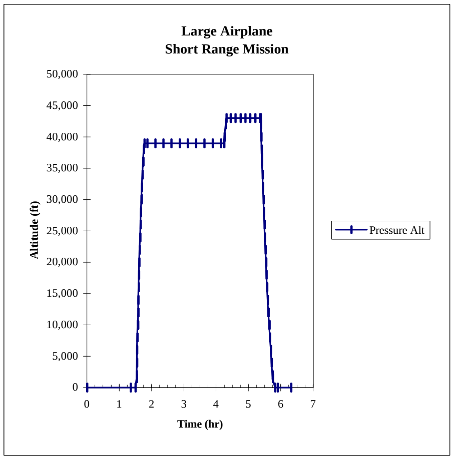

Medium Airplane
Long Range Mission
Ambient Temp (F)
Time (hr)
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
8
9
10
11
12
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%



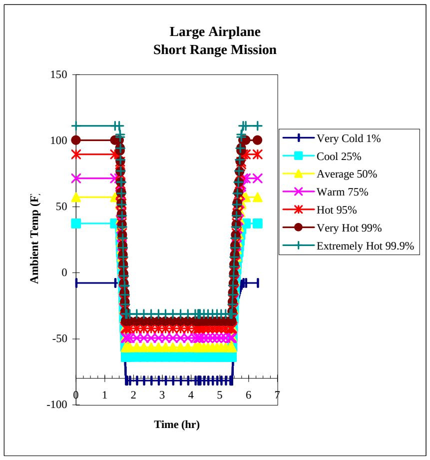
**Medium Airplane
Long Range Mission**



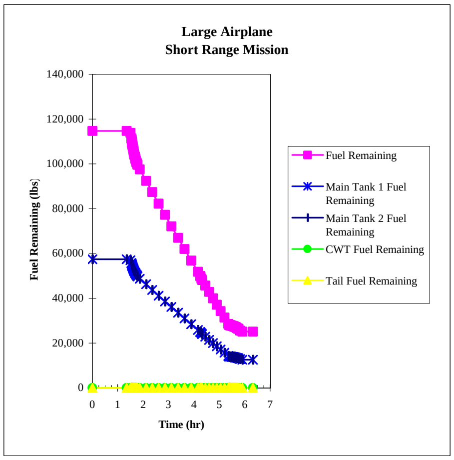
**Medium Airplane
Long Range Mission**

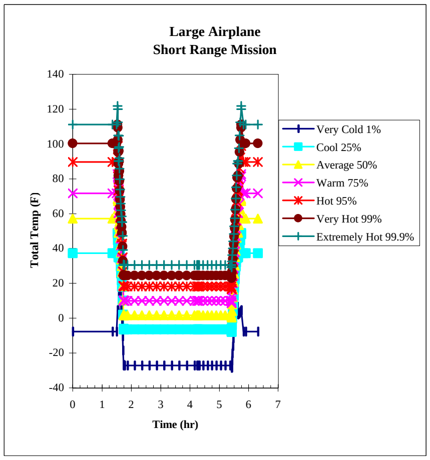


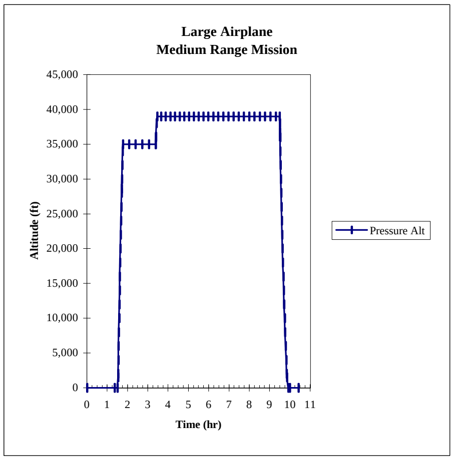
**Large Airplane
Short Range Mission**

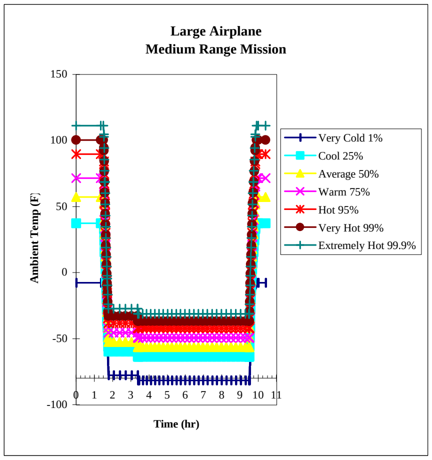


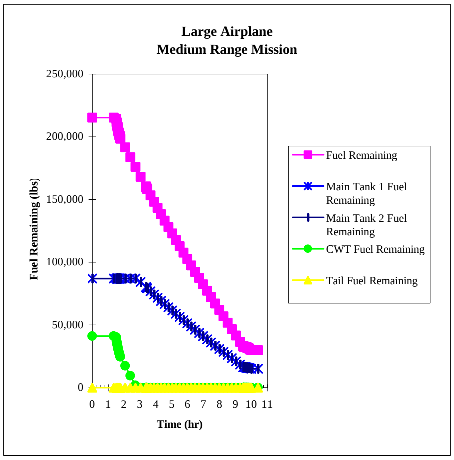
**Large Airplane
Short Range Mission**

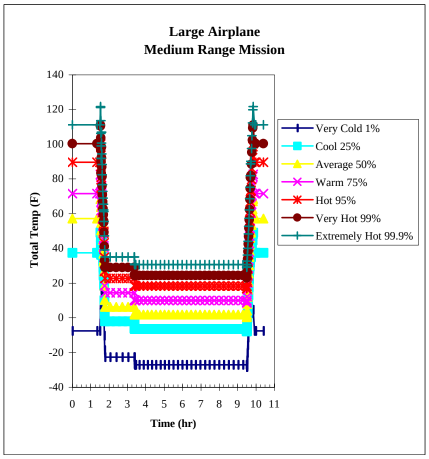

Large Airplane
Short Range Mission
Fuel Remaining (lbs)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
1
2
3
4
5
6
7
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining

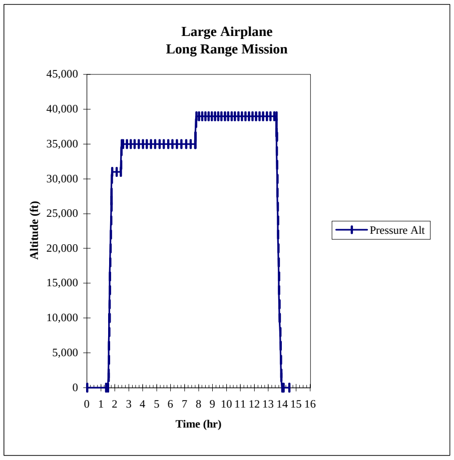

Large Airplane
Short Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

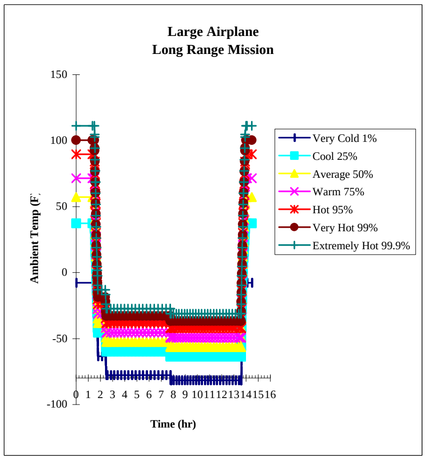

Large Airplane
Medium Range Mission
Altitude (ft)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8
9
10
11
Time (hr)
Pressure Alt

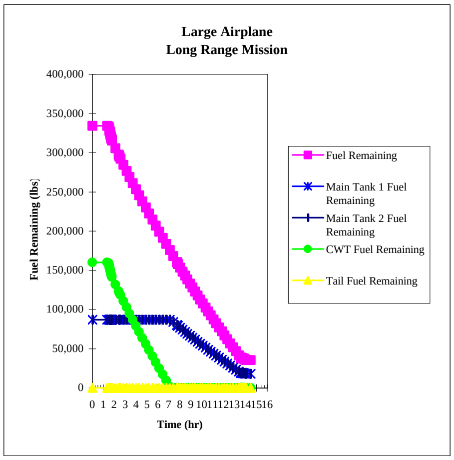

Large Airplane
Medium Range Mission
Ambient Temp (F)
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
8
9
10
11
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

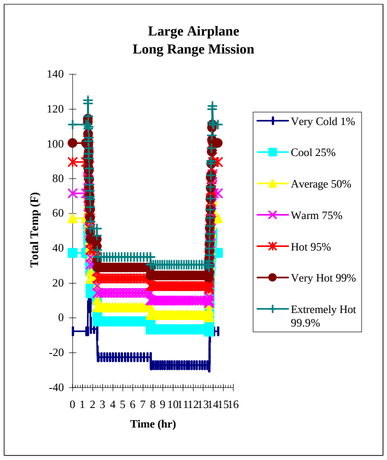

Large Airplane
Medium Range Mission
Fuel Remaining (lbs)
250,000
200,000
150,000
100,000
50,000
0
0 1 2 3 4 5 6 7 8 9 10 11
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining

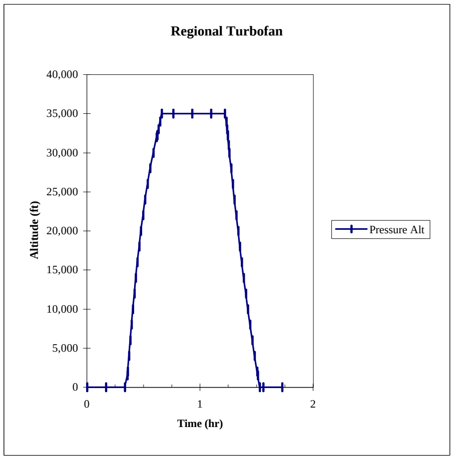

Large Airplane
Medium Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
0 1 2 3 4 5 6 7 8 9 10 11
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

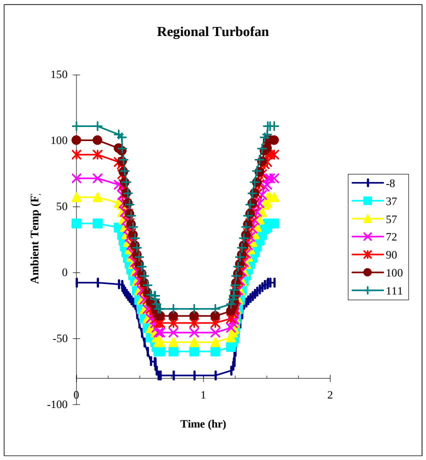

Large Airplane
Long Range Mission
Altitude (ft)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Pressure Alt

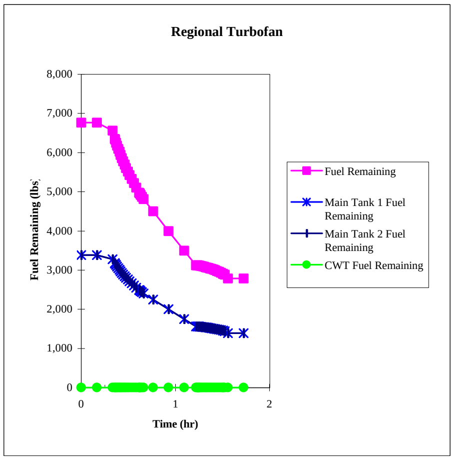

Large Airplane
Long Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

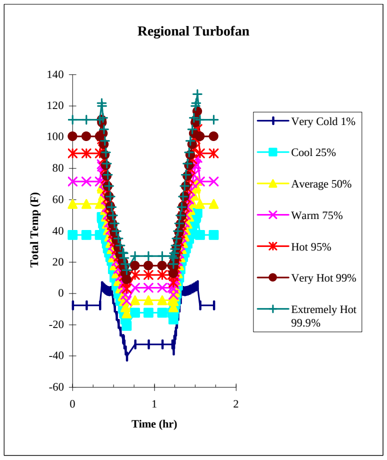

Large Airplane
Long Range Mission
Fuel Remaining (lbs)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining

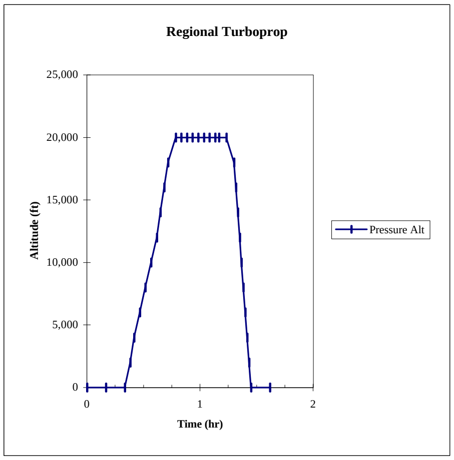

Large Airplane
Long Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

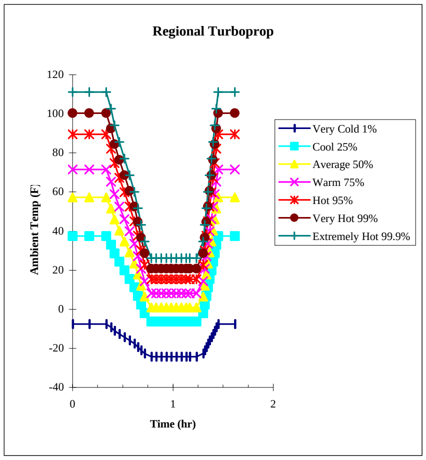

Regional Turbofan
Altitude (ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
Time (hr)
Pressure Alt

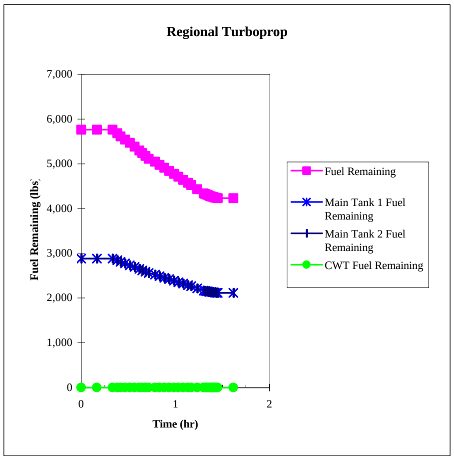

Regional Turbofan
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
Time (hr)
-8
37
57
72
90
100
111

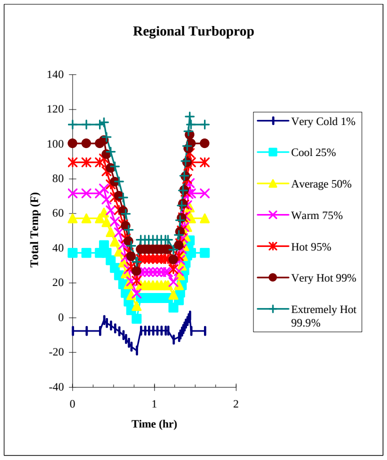

Regional Turbofan
Fuel Remaining (lbs)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
1
2
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

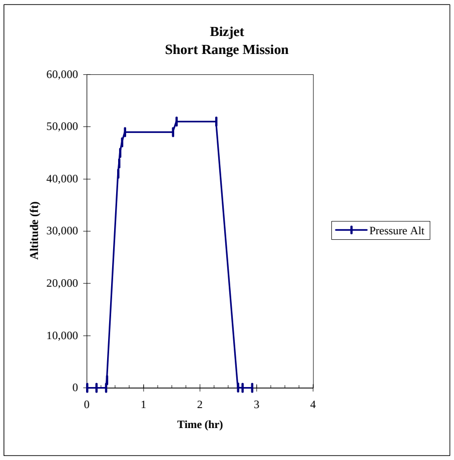

Regional Turbofan
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

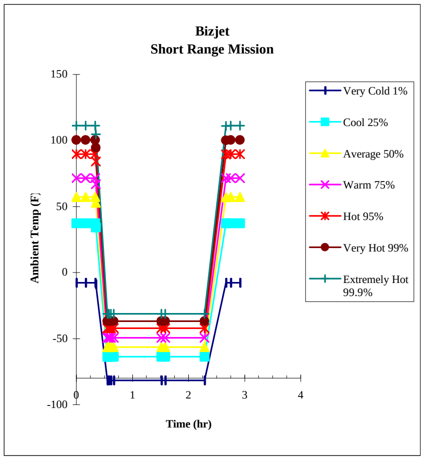

Regional Turboprop
Altitude (ft)
25,000
20,000
15,000
10,000
5,000
0
0
1
2
Time (hr)
Pressure Alt

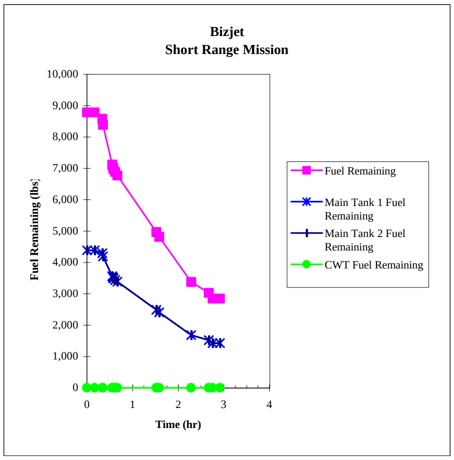

Regional Turboprop
Ambient Temp (F)
120
100
80
60
40
20
0
-20
-40
0
1
2
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

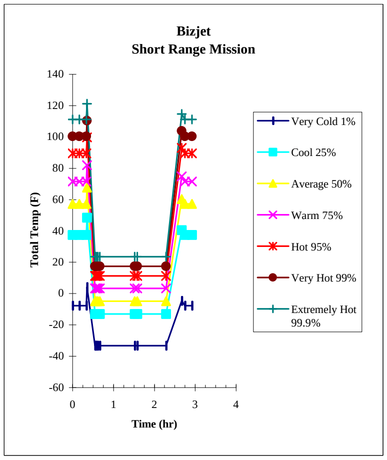

Regional Turboprop
Fuel Remaining (lbs)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
1
2
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

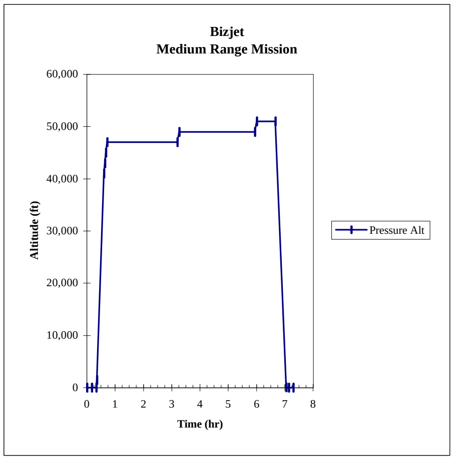

Regional Turboprop
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
0
1
2
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

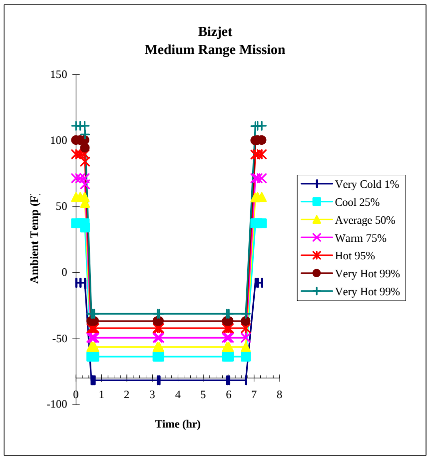

Bizjet
Short Range Mission
Altitude (ft)
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
Time (hr)
Pressure Alt

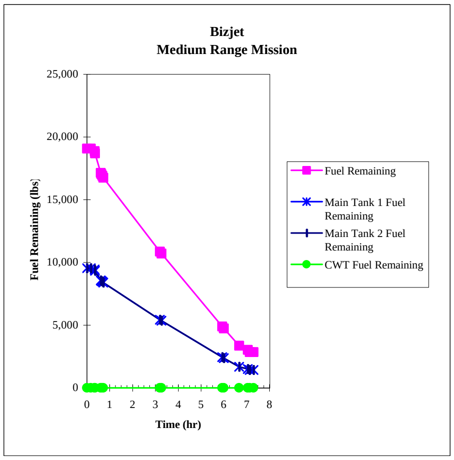

Bizjet
Short Range Mission
Ambient Temp (F)
150
100
50
0
-50
-100
0
1
2
3
4
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

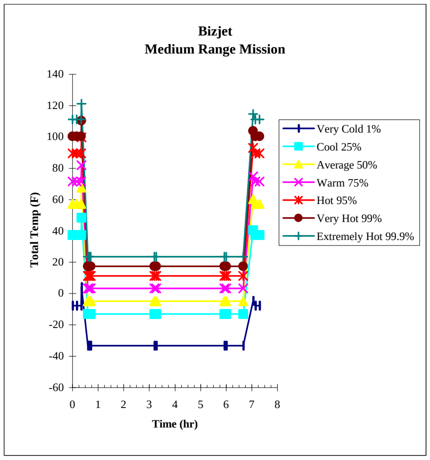

Bizjet
Short Range Mission
Fuel Remaining (lbs)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
1
2
3
4
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining


Bizjet
Short Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Bizjet
Medium Range Mission
Altitude (ft)
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
6
7
8
Time (hr)
Pressure Alt


Bizjet
Medium Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
8
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Very Hot 99%


Bizjet
Medium Range Mission
Fuel Remaining (lbs)
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining


Bizjet
Medium Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
8
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

Standards-generic

Model	Large	Medium	Small	Regional T/fan	Regional T/prop	Bizjet
General						
Fleet size	2,000	1,400	8,600	1,000	2,000	8,600
MTOGW	800,000	330,000	160,000	78,000	40,000	23,000
MLW	600,000	270,000	130,000	69,000	38,000	20,000
Fuel Volume:						
Total	54,000	24,000	5,000	3200	1400	1200
Center	25,000	10,000	3,000	800	0	0
Wing	26,000	12,000	2,000	2400	1400	800
Tail	3,000	2,000	0	0		
Body	(optional)	(optional)	(optional)	0	0	400
Tank Configurations						
% fleet with Center Tanks	92	97	97			6
% of Center Tanks with Heat Input	64	78	72			0
% fleet with Tail Tanks	36	25	0			0
% fleet with Body Tanks	2	0	8			54
Tank Pressure						
Positive	+1.5	+1.5	+1.5	2	2	+1.5
Negative	-0.5	-0.5	-0.5	-1	-1	-0.5
Bleed flow available after ECS						
Bleed pressure avail after ECS						
Bleed temperature avail after ECS						
Precooler flow avail after ECS						
Precooler max outlet temperature at max flow						
Payload (lbs)	100,000	55,000	40,000	35,000	22,000	1,200
passengers	400	250	150	75	50	6
Short mission						
Range (nm)	2,000	1,000	500			1000
Ground Time (hr)	2.00	1.50	1.25			
Block Time (hr)	4.6	2.3	1.6			
# of flights per day	2,914	3,682	35,548			
Medium Mission						
Range (nm)	4,000	2,000	1,000	450	250	3000
Ground Time (hr)	2.00	1.50	1.25	0.33	0.33	
Block Time (hr)	8.6	4.6	2.8	1.4	1.1	
# of flights per day	1,141	919	10,053	10,000	20,000	
Long mission						
Range (nm)	6,000	4,000	2,000			6500
Ground Time (hr)	2.00	1.50	1.25			
Block Time (hr)	12.7	8.9	5.1			
# of flights per day	544	541	2,566			
Distribution						
% short missions	63%	72%	74%			54%
%medium missions	25%	18%	21%	100%	100%	27%
%long missions	12%	11%	5%			19%
Operating environment						
Max. Cruise Alt.	43,000	43,000	37,000	35,000	25,000	41,000
Ground temp max	130 Deg F	130 Deg F	130 Deg F	122 Deg F	122 Deg F	122 Deg F
Ground temp min	-65 Deg F	-65 Deg F	-65 Deg F	-40 Deg F	-40 Deg F	-40 Deg F
Distribution of Ground Temp	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F
Distribution of Cruise Temp	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F
Distribtuion of Flash Point	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F
Vmo	365	360	340	320	250	360
Mmo	0.92	0.85	0.82	.0.80	0.5	0.83
M cruise	0.85	0.80	0.77	0.75	290T/220E	0.8
Climb rate (Max, Sea Level)	5,000	5,000	4,500	3000	2000	
Descent rate (Normal)	2,000	1,500	2,000	2000	2000	
Descent rate (Max)	3,500	4,000	3,000			

Standards-modeled

Model	Large	Medium	Small	Regional T/fan	Regional T/prop	Bizjet
General						
Fleet size	2,000	1,400	8,600	1,000	2,000	787
MTOGW	800,000	330,000	160,000	78,000	40,000	90,500
MLW	600,000	270,000	130,000	69,000	38,000	75,300
Fuel Volume:	0	0	0	0	0	
Total	54,000	24,000	5,000	3,200	1,400	6,150
Center	25,000	10,000	3,000	800	0	0
Wing	26,000	12,000	2,000	2,400	1,400	6,150
Tail	3,000	2,000	0	0	0	0
Body	(optional)	(optional)	(optional)	0	0	0
Tank Configurations						
% fleet with Center Tanks	92	97	97			0
% of Center Tanks with Heat Input	64	78	72			0
% fleet with Tail Tanks	36	25	0			0
% fleet with Body Tanks	2	0	8			0
Tank Pressure						
Positive	+1.5	+1.5	+1.5	2	2	2
Negative	-0.5	-0.5	-0.5	-1	-1	-0.5
Bleed flow available after ECS						-
Bleed pressure avail after ECS						-
Bleed temperature avail after ECS						-
Precooler flow avail after ECS						-
Precooler max outlet temperature at max flow						-
Payload (lbs)	100,000	55,000	40,000	35,000	22,000	6,500
passengers	400	250	150	75	50	6 to19
Short mission						
Range (nm)	2,000	1,000	500			1,000
Ground Time (hr)	2.0	1.5	1.3			1
Block Time (hr)	4.6	2.3	1.6			3
# of flights per day	2,914	3,682	35,548			1
Medium Mission						
Range (nm)	4,000	2,000	1,000	400	250	3,000
Ground Time (hr)	2.0	1.5	1.3	0.5	0.3	1
Block Time (hr)	8.6	4.6	2.8	1.0	1.1	7
# of flights per day	1,141	919	10,053		20,000	1
Long mission						
Range (nm)	6,000	4,000	2,000	800		6,000
Ground Time (hr)	2.0	1.5	1.3	0.5		1
Block Time (hr)	12.7	8.9	5.1	2.0		15
# of flights per day	544	541	2,566			1
Distribution						Now/2002
% short missions	63.4%	71.6%	73.8%	0.0%	0.0%	82.9/74.4
%medium missions	24.8%	17.9%	20.9%	100.0%	100.0%	16.5/20.2
%long missions	11.8%	10.5%	5.3%	0.0%	0.0%	0.6/5.4
Operating environment						
Max. Cruise Alt.	43,000	43,000	37,000	35,000	25,000	51,000
Ground temp max	130 Deg F	130 Deg F	130 Deg F	122 Deg F	122 Deg F	133°F
Ground temp min	-65 Deg F	-65 Deg F	-65 Deg F	-40 Deg F	-40 Deg F	-65°F
Distribution of Ground Temp	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F	-40 to 122 F
Distribution of Cruise Temp	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F	-87 to -22 F
Distribtuion of Flash Point	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F	100 to 150 F
Vmo	365	360	340	320	250	340kTAS
Mmo	1	1	1	.0.80	1	1
M cruise	1	1	1	1	290T/220E	1
Climb rate (Max, Sea Level)	5,000	5,000	4,500	3,000	2,000	6700/3600 @ 51,000# / 90,500
Descent rate (Normal)	2,000	1,500	2,000	2,000	2,000	2,000
Descent rate (Max)	3,500	4,000	3,000	0	0	20,000

Cost Estimator

NOTES:

This page attempts to estimate the performance related costs to the airlines of increased airplane weight and / or reduced fuel volume. These costs include increased fuel burn and payload reduction. They do not include airline maintenance costs, manufacturers cost or airplane price changes.

The assumptions used in this cost estimate are shown on the top of the Peformance & Cost Trades worksheet

Data is not ready for the Regional Turboprop.

Input airplane weight increase and / or fuel volume decrease. The airline cost will update automatically.

Model	Large	Medium	Small	Regional T/fan	Regional T/prop	Bizjet
Input :						
Airplane weight increase (lb)	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Fuel volume decrease (gal)	**100**	**100**	**100**	**100**	**100**	**100**
Airline cost increase (total fleet per year)						
short mission	$16,050,712	$8,691,207	$63,252,006	$0	$0	$2,041,454
medium mission	$8,212,986	$2,932,221	$21,346,537	$19,765,404	$0	$1,895,636
long mission (takeoff weight limited)	$153,400,000	$86,450,000	$224,318,714	$0	$0	$592,000,794
long mission (fuel volume limited)	$306,800,000	$181,545,000	$717,819,886	$0	$0	$1,340,923,194
Output:						
Total Airline Cost Increase (entire fleet per year)	$484,463,698	$279,618,429	$1,026,737,144	$19,765,404	$0	$1,936,861,077
Total Airline Cost Increase (per airplane per year)	$242,232	$199,727	$119,388	$19,765	$0	$225,216

Performance & Cost Trades

Assumptions:

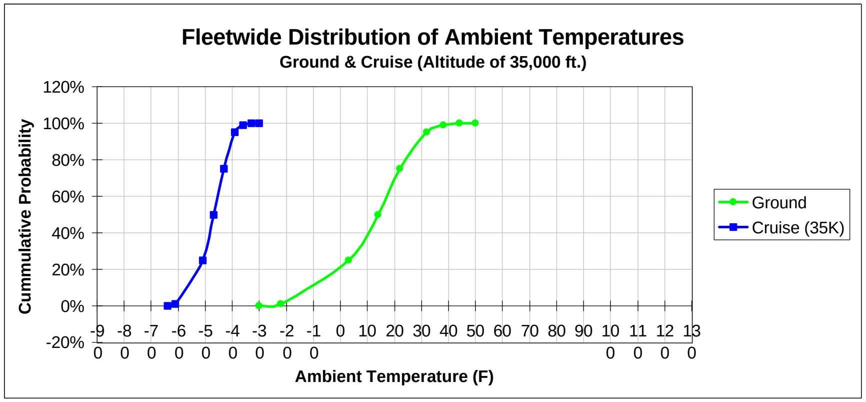
Fuel Density = 6.70 Lbs/Gal

Model	Large	Medium	Small	Regional T/fan	Regional T/prop	Bizjet
Assumed Fuel Price ($ / gallon)	**$0.70**	**$0.70**	**$0.70**	**$0.70**	**$0.70**	**$1.50**
Trades when not limited by takeoff weight or fuel volume (short / medium missions)						
(i.e. add extra fuel to carry extra aircraft weight over a fixed range with a fixed payload)						Bizjet data based on generic bizjet, not the modelled bizjet
Airline Cost per Airplane						
Short mission						
Range (nm)	2,000	1,000	500			400
# of flights per year per airplane	795	1,300	2,120			149
% Block fuel / 1000 lbs OEW	0.17%	0.30%	0.63%			0.34%
Block Fuel (lb)	89,647	21,279	7,142			2100
Lbs block fuel / 1000 lbs OEW / Flight	152	64	45			7
Lbs block fuel / 1000 lbs OEW / Year	121,158	82,988	95,389			1,060
$ / 1000 lbs OEW / Year	12,658	8,670	9,966			237
Medium mission						
Range (nm)	4,000	2,000	1,000	450	250	1000
# of flights per year per airplane	475	795	1,300	3650	3650	74
% Block fuel / 1000 lbs OEW	0.18%	0.34%	0.68%	1.30%	0%	0.34%
Block Fuel (lb)	185,366	41,433	12,859	3987	1534	3900
Lbs block fuel / 1000 lbs OEW / Flight	334	141	87	52	0	13
Lbs block fuel / 1000 lbs OEW / Year	158,488	111,993	113,674	189,183	0	985
$ / 1000 lbs OEW / Year	16,558	11,701	11,876	19,765	0	220
Long mission						
Range (nm)	6,000	4,000	2,000			2000
# of flights per year per airplane	350	475	795			52
% Block fuel / 1000 lbs OEW	0.19%	0.35%	0.81%			0.34%
Block Fuel (lb)	298,697	86,603	25,174			6400
Lbs block fuel / 1000 lbs OEW / Flight	568	303	204			22
Lbs block fuel / 1000 lbs OEW / Year	198,634	143,977	162,108			1,137
$ / 1000 lbs OEW / Year	20,753	15,042	16,937			255
Trades when limited by takeoff weight (50% of long missions)						
(i.e. reduce payload by amount of increased aircraft weight to maintain fixed range)						
Range Trade (N. Mi. / 1000 lbs OEW)	-25	-45	-90	-160		-300
Payload Trade (Reduced payload / 1000 lbs OEW)	1,000	1,000	1,000	1000	1000	1000
Airline Cost						
Reduced Payload (lb)	1,000	1,000	1,000	1000	1000	1000
Passengers left behind (210 lbs/pass)	4.8	4.8	4.8	4.8	4.8	4.8
Range (nm)	6,000	4,000	2,000			2000
$ per Revenue Seat Mile	$0.130	$0.130	$0.130	$0.135	$0.135	$0.138
# of flights per year per airplane	350	475	795			52
$ / 1000 lbs OEW / airplane / year	1,300,000	1,176,190	984,286	0	0	68,837
Cost assumes the airplane is takeoff weight limited on every flight.						
Trades when limited by fuel volume (50% of long missions)						
(i.e. reduce payload by amount of increased aircraft weight and OEW/gallon trade)						
Range Trade (N. Mi. / 1000 lbs OEW)	-12	-20	-25			
Airline Cost						
Increased OEW effect (per 1000 lbs)						
$ / 1000 lbs OEW / airplane / year	1,300,000	1,176,190	984,286	0	0	68,837
(Same as takeoff weight limited case)						
Decreased fuel volume effect (per 100 gal)						
Payload reduction per gal of fuel	10	11	22	0	0	43
Reduced Payload (lb)	1,000	1,100	2,200	0	0	
Passengers left behind (210 lbs/pass)	4.8	5.2	10.5	0.0	0.0	
Range (nm)	6,000	4,000	2,000			
$ per Revenue Seat Mile	$0.130	$0.130	$0.130	$0.135	$0.135	
# of flights per year per airplane	350	475	795			
$ / 100 gal / airplane / year	1,300,000	1,293,810	2,165,429	0	0	87,084
Cost assumes the flight is fuel volume limited on every flight.						

Temperatures

Condition of Day	Cummulative Probability	Ground (Deg C)	Cruise (35K) (Deg C)	Ground (Deg F)	Cruise (35K) (Deg F)
Min	0.01%	-40	-66	-40	-87
Extremely Cold	0.1%	-30	-64	-22	-83
Very Cold	**1%**	**-22**	**-61**	**-8**	**-78**
Cold	**25%**	**3**	**-51**	**37**	**-60**
Average	**50%**	**14**	**-47**	**57**	**-53**
Warm	**75%**	**22**	**-43**	**72**	**-45**
Hot	**95%**	**32**	**-39**	**90**	**-38**
Very Hot	**99%**	**38**	**-36**	**100**	**-33**
Extremely Hot	**99.9%**	**44**	**-33**	**111**	**-27**
Max	99.99%	50	-30	122	-22

BOLD Indicates cases to run in thermal model



NOTE: This temperature data is built into the profiles

	Very Cold 1%	Cool 25%	Average 50%	Warm 75%	Hot 95%	Very Hot 99%	Extremely Hot 99.9%
Ground Ambient (F)	**-8**	**37**	**57**	**72**	**90**	**100**	**111**
Enroute Ambient (35k, Deg F)	**-78**	**-60**	**-53**	**-45**	**-38**	**-33**	**-27**
Enroute Isa +(F)	-12	6	13	20	28	33	38

Altitude	**Ambient Temperature - Degrees F**						
0	-8	37	57	72	90	100	111
1000	-8	35	54	68	86	96	107
2000	-9	33	52	65	82	92	103
3000	-10	31	49	62	78	88	98
4000	-11	29	46	59	75	84	94
5000	-12	26	43	56	71	80	90
6000	-13	24	40	53	67	76	86
7000	-13	22	37	49	64	73	81
8000	-14	20	35	46	60	69	77
9000	-15	18	32	43	56	65	73
10000	-16	16	29	40	52	61	69
11000	-17	13	26	37	49	57	64
12000	-18	11	23	33	45	53	60
13000	-18	9	21	30	41	49	56
14000	-19	7	18	27	38	45	52
15000	-20	5	15	24	34	41	47
16000	-21	2	12	21	30	37	43
17000	-22	0	9	18	26	33	39
18000	-23	-2	7	14	23	29	35
19000	-23	-4	4	11	19	25	30
20000	-24	-6	1	8	15	21	26
21000	-28	-10	-3	5	12	17	23
22000	-31	-13	-6	1	8	14	19
23000	-35	-17	-10	-3	5	10	15
24000	-39	-21	-13	-6	1	6	12
25000	-42	-24	-17	-10	-3	3	8
26000	-46	-28	-21	-13	-6	-1	5
27000	-49	-31	-24	-17	-10	-4	1
28000	-53	-35	-28	-20	-13	-8	-2
29000	-56	-38	-31	-24	-17	-11	-6
30000	-60	-42	-35	-28	-20	-15	-10
31000	-64	-46	-38	-31	-24	-19	-13
32000	-67	-49	-42	-35	-27	-22	-17
33000	-71	-53	-45	-38	-31	-26	-20
34000	-74	-56	-49	-42	-35	-29	-24
35000	-78	-60	-53	-45	-38	-33	-27
36000	-81	-63	-56	-49	-42	-36	-31
36089	-82	-64	-56	-49	-42	-37	-31
37000	-82	-64	-56	-49	-42	-37	-31
38000	-82	-64	-56	-49	-42	-37	-31
39000	-82	-64	-56	-49	-42	-37	-31
40000	-82	-64	-56	-49	-42	-37	-31
41000	-82	-64	-56	-49	-42	-37	-31
42000	-82	-64	-56	-49	-42	-37	-31
43000	-82	-64	-56	-49	-42	-37	-31
44000	-82	-64	-56	-49	-42	-37	-31
45000	-82	-64	-56	-49	-42	-37	-31
46000	-82	-64	-56	-49	-42	-37	-31
47000	-82	-64	-56	-49	-42	-37	-31
48000	-82	-64	-56	-49	-42	-37	-31
49000	-82	-64	-56	-49	-42	-37	-31
50000	-82	-64	-56	-49	-42	-37	-31
51000	-82	-64	-56	-49	-42	-37	-31
52000	-82	-64	-56	-49	-42	-37	-31
53000	-82	-64	-56	-49	-42	-37	-31
54000	-82	-64	-56	-49	-42	-37	-31
55000	-82	-64	-56	-49	-42	-37	-31
56000	-82	-64	-56	-49	-42	-37	-31
57000	-82	-64	-56	-49	-42	-37	-31
58000	-82	-64	-56	-49	-42	-37	-31
59000	-82	-64	-56	-49	-42	-37	-31
60000	-82	-64	-56	-49	-42	-37	-31

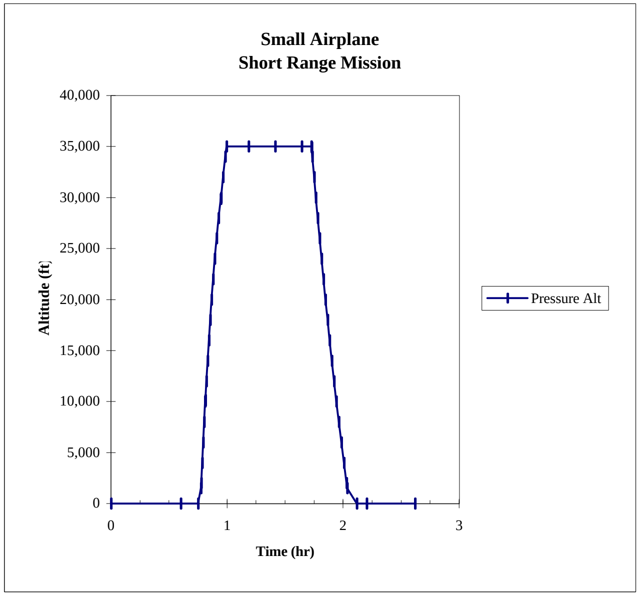
Small Commercial Transport
Short Range Mission

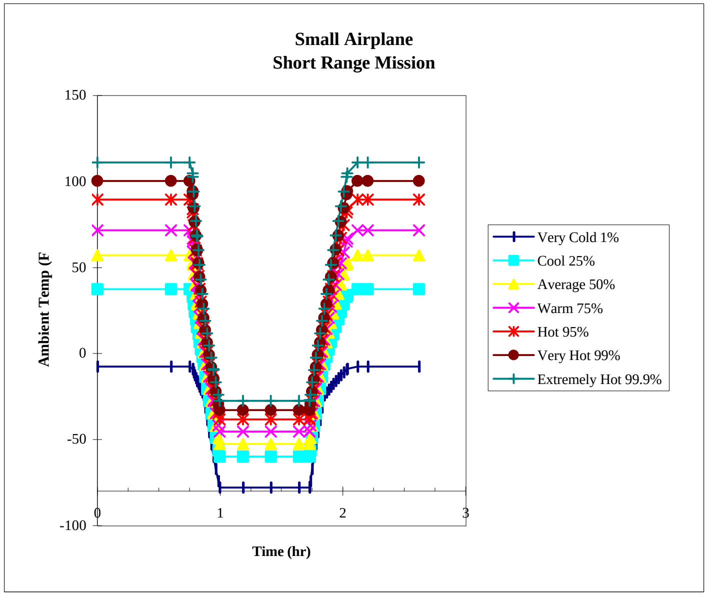
Ground Time (takeoff) = 45.000 minutes
Ground Time (landing) = 30.000 minutes

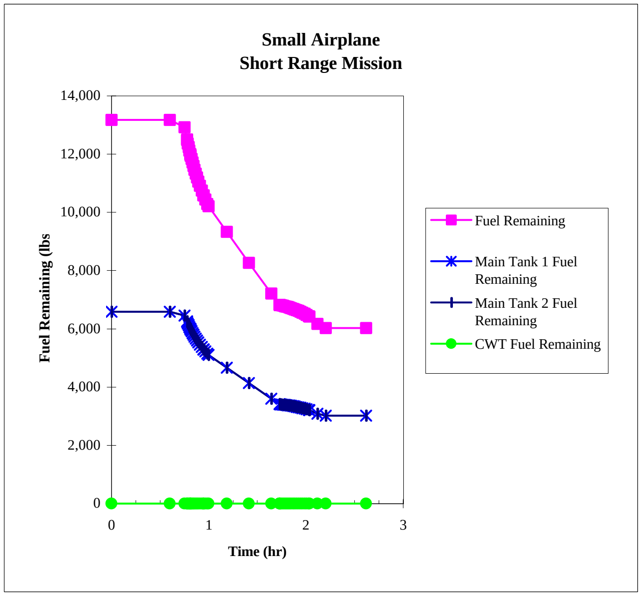
Main 1 Fuel Volume = 1000 gal
Main 2 Fuel Volume = 1000 gal
CWT Fuel Volume = 3,000 gal

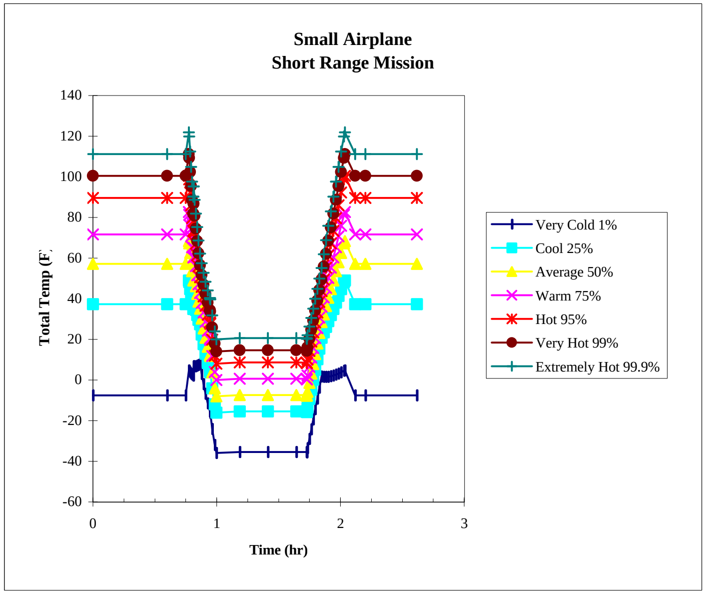
Tank Volume 1020
Tank Volume 1020
Tank Volume 3060

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent	Body Pitch Attitude
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min	degrees
0.0	0.0	0	0.0	0.000	110874	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	13173	6587	6587	0	0	
36.0	0.6	0	0.0	0.000	110874	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	1680	28	13173	6587	6587	0	0	
45.0	0.8	0	0.0	0.000	110622	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	16119	269	12921	6461	6461	0	0	
46.6	0.8	1500	3.5	0.388	110211	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	16119	269	12510	6255	6255	0	4525	14.3
46.7	0.8	2000	4.0	0.391	110181	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	15950	266	12480	6240	6240	0	4482	14.1
47.1	0.8	4000	5.9	0.406	110063	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	15290	255	12362	6181	6181	0	4309	13.4
47.6	0.8	6000	8.0	0.420	109945	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	14649	244	12244	6122	6122	0	4135	12.8
48.1	0.8	8000	10.3	0.436	109826	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	14004	233	12125	6063	6063	0	3950	12.2
48.6	0.8	10000	12.7	0.452	109708	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	13350	223	12007	6004	6004	0	3753	11.6
48.6	0.8	10000	12.7	0.452	109708	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	13350	223	12007	6004	6004	0	500	5.2
48.9	0.8	10126	14.0	0.507	109651	-16	15	29	39	52	60	68	7	40	54	65	78	87	95	13555	226	11950	5975	5975	0	500	4.0
48.9	0.8	10126	14.0	0.507	109651	-16	15	29	39	52	60	68	7	40	54	65	78	87	95	13553	226	11950	5975	5975	0	3783	9.8
49.4	0.8	12000	16.8	0.525	109539	-18	11	23	33	45	53	60	7	37	50	61	73	81	89	12980	216	11838	5919	5919	0	3577	9.2
50.0	0.8	14000	20.0	0.544	109417	-19	7	18	27	38	45	52	7	34	46	56	67	74	82	12377	206	11716	5858	5858	0	3355	8.7
50.6	0.8	16000	23.6	0.565	109293	-21	2	12	21	30	37	43	7	32	42	51	61	68	75	11750	196	11592	5796	5796	0	3125	8.1
51.2	0.9	18000	27.5	0.587	109166	-23	-2	7	14	23	29	35	7	30	39	47	56	62	69	11125	185	11465	5733	5733	0	2889	7.6
52.0	0.9	20000	32.0	0.610	109036	-24	-6	1	8	15	21	26	8	27	35	43	51	56	62	10562	176	11335	5668	5668	0	2658	7.1
52.7	0.9	22000	36.9	0.634	108900	-31	-13	-6	1	8	14	19	3	22	30	38	46	52	57	10082	168	11199	5600	5600	0	2438	6.6
53.6	0.9	24000	42.6	0.659	108759	-39	-21	-13	-6	1	6	12	-2	18	25	33	41	47	53	9600	160	11058	5529	5529	0	2217	6.2
54.6	0.9	26000	49.0	0.685	108611	-46	-28	-21	-13	-6	-1	5	-7	13	21	29	37	42	48	9125	152	10910	5455	5455	0	1986	5.7
55.6	0.9	28000	56.5	0.713	108451	-53	-35	-28	-20	-13	-8	-2	-11	8	16	24	32	38	44	8679	145	10750	5375	5375	0	1752	5.2
56.8	0.9	29855	64.6	0.740	108291	-59	-41	-34	-27	-20	-14	-9	-16	4	12	20	28	34	40	8289	138	10590	5295	5295	0	1531	4.8
56.8	0.9	29855	64.6	0.740	108291	-59	-41	-34	-27	-20	-14	-9	-16	4	12	20	28	34	40	8289	138	10590	5295	5295	0	2091	5.5
56.8	0.9	30000	65.1	0.740	108282	-60	-42	-35	-28	-20	-15	-10	-16	4	12	20	28	34	40	8248	137	10581	5291	5291	0	2072	5.5
57.9	1.0	32000	72.6	0.740	108144	-67	-49	-42	-35	-27	-22	-17	-24	-4	4	12	20	26	32	7682	128	10443	5222	5222	0	1806	5.5
59.1	1.0	34000	81.3	0.740	107995	-74	-56	-49	-42	-35	-29	-24	-32	-12	-4	4	12	18	24	7134	119	10294	5147	5147	0	1521	5.5
59.8	1.0	35000	86.2	0.740	107914	-78	-60	-53	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	6868	114	10213	5107	5107	0	1373	5.5
71.1	1.2	35000	167.5	0.745	107029	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4665	78	9328	4664	4664	0	0	3.5
84.8	1.4	35000	265.2	0.745	105970	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4633	77	8269	4135	4135	0	0	3.5
98.6	1.6	35000	363.7	0.745	104912	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4602	77	7211	3606	3606	0	0	3.5
103.6	1.7	35000	400.1	0.745	104523	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4590	77	6822	3411	3411	0	0	3.5
103.7	1.7	34923	400.3	0.740	104522	-78	-60	-52	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	760	13	6821	3411	3411	0	3101	-0.6
103.7	1.7	34923	400.3	0.740	104522	-78	-60	-52	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	760	13	6821	3411	3411	0	2274	0.5
104.1	1.7	34000	403.1	0.726	104517	-74	-56	-49	-42	-35	-29	-24	-34	-14	-6	2	10	16	22	760	13	6816	3408	3408	0	2239	0.5
105.0	1.7	32000	409.4	0.696	104506	-67	-49	-42	-35	-27	-22	-17	-29	-9	-1	6	14	20	26	775	13	6805	3403	3403	0	2195	0.6
105.9	1.8	30000	415.5	0.668	104493	-60	-42	-35	-28	-20	-15	-10	-24	-5	3	11	19	25	31	820	14	6792	3396	3396	0	2143	0.7
106.8	1.8	28000	421.6	0.641	104480	-53	-35	-28	-20	-13	-8	-2	-19	0	8	16	23	29	35	877	15	6779	3390	3390	0	2091	0.7
107.8	1.8	26000	427.6	0.616	104465	-46	-28	-21	-13	-6	-1	5	-14	5	13	21	28	34	40	933	16	6764	3382	3382	0	2039	0.7
108.8	1.8	24000	433.6	0.592	104449	-39	-21	-13	-6	1	6	12	-9	10	18	26	33	39	45	996	17	6748	3374	3374	0	1989	0.8
109.8	1.8	22000	439.6	0.569	104432	-31	-13	-6	1	8	14	19	-4	15	23	31	38	44	50	1062	18	6731	3366	3366	0	1941	0.8
110.9	1.8	20000	445.5	0.547	104413	-24	-6	1	8	15	21	26	2	21	28	36	44	49	55	1132	19	6712	3356	3356	0	1894	0.7
111.9	1.9	18000	451.4	0.526	104392	-23	-2	7	14	23	29	35	2	23	32	41	49	56	62	1206	20	6691	3346	3346	0	1843	0.8
113.0	1.9	16000	457.3	0.506	104369	-21	2	12	21	30	37	43	2	26	36	45	55	62	69	1283	21	6668	3334	3334	0	1792	0.8
114.2	1.9	14000	463.2	0.487	104344	-19	7	18	27	38	45	52	2	29	40	50	61	69	76	1365	23	6643	3322	3322	0	1741	0.8
115.3	1.9	12000	469.0	0.469	104317	-18	11	23	33	45	53	60	2	32	45	55	67	75	83	1450	24	6616	3308	3308	0	1691	0.7
116.5	1.9	10000	474.9	0.452	104287	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	1540	26	6586	3293	3293	0	1640	0.7
117.8	2.0	8000	480.7	0.436	104254	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	1633	27	6553	3277	3277	0	1591	0.7
119.1	2.0	6000	486.6	0.420	104218	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	1732	29	6517	3259	3259	0	1541	0.8
120.4	2.0	4000	492.5	0.406	104179	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	1853	31	6478	3239	3239	0	1483	0.8
121.8	2.0	2000	498.5	0.391	104134	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	2004	33	6433	3217	3217	0	1421	0.8
122.1	2.0	1500	500.0	0.388	104122	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	2045	34	6421	3211	3211	0	1405	0.8
127.1	2.1	0	500.0	0.000	103872	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	1680	28	6171	3086	3086	0	0	
132.1	2.2	0	500.0	0.000	103732	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	6031	3016	3016	0	0	
157.1	2.6	0	500.0	0.000	103732	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	6031	3016	3016	0	0	


Small Airplane
Short Range Mission
Altitude (ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
Time (hr)
Pressure Alt


Small Airplane
Short Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Small Airplane
Short Range Mission
Fuel Remaining (lbs
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
1
2
3
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining


Small Airplane
Short Range Mission
Total Temp (F
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

Small Commercial Transport
Medium Range Mission

Ground Time (takeoff) = 45.000 minutes
Ground Time (landing) = 30.000 minutes

Main 1 Fuel Volume = 1000 gal   Tank Volume 1020
Main 2 Fuel Volume = 1000 gal   Tank Volume 1020
CWT Fuel Volume = 3,000 gal   Tank Volume 3060

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remainin	Main Tank 2 Fuel Remainin	CWT Fuel Remaining	Rate of Climb / Descent	Body Pitch Attitude
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min	degrees
0.0	0.0	0	0.0	0.000	116876	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	19176	6700	6700	5776	0	
36.0	0.6	0	0.0	0.000	116876	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	1680	28	19176	6700	6700	5776	0	
45.0	0.8	0	0.0	0.000	116624	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	16119	269	18924	6700	6700	5524	0	
46.6	0.8	1500	3.6	0.388	116192	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	16119	269	18492	6700	6700	5092	4236	13.9
46.7	0.8	2000	4.1	0.391	116160	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	15950	266	18460	6700	6700	5060	4195	13.8
47.2	0.8	4000	6.2	0.406	116033	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	15290	255	18333	6700	6700	4933	4029	13.1
47.7	0.8	6000	8.4	0.420	115907	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	14649	244	18207	6700	6700	4807	3863	12.5
48.2	0.8	8000	10.9	0.436	115780	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	14004	233	18080	6700	6700	4680	3686	11.9
48.8	0.8	10000	13.5	0.452	115653	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	13350	223	17953	6700	6700	4553	3498	11.3
48.8	0.8	10000	13.5	0.452	115653	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	13350	223	17953	6700	6700	4553	500	5.5
49.0	0.8	10137	14.9	0.507	115592	-16	15	29	39	52	60	68	7	40	54	65	78	87	95	13551	226	17892	6700	6700	4492	500	4.2
49.0	0.8	10137	14.9	0.507	115592	-16	15	29	39	52	60	68	7	40	54	65	78	87	95	13550	226	17892	6700	6700	4492	3536	9.5
49.6	0.8	12000	17.8	0.525	115472	-18	11	23	33	45	53	60	7	37	50	61	73	81	89	12980	216	17772	6700	6700	4372	3341	9.0
50.2	0.8	14000	21.3	0.544	115342	-19	7	18	27	38	45	52	7	34	46	56	67	74	82	12377	206	17642	6700	6700	4242	3129	8.5
50.9	0.8	16000	25.1	0.565	115208	-21	2	12	21	30	37	43	7	32	42	51	61	68	75	11750	196	17508	6700	6700	4108	2910	8.0
51.6	0.9	18000	29.4	0.587	115072	-23	-2	7	14	23	29	35	7	30	39	47	56	62	69	11125	185	17372	6700	6700	3972	2685	7.5
52.4	0.9	20000	34.2	0.610	114932	-24	-6	1	8	15	21	26	8	27	35	43	51	56	62	10562	176	17232	6700	6700	3832	2463	7.0
53.2	0.9	22000	39.5	0.634	114786	-31	-13	-6	1	8	14	19	3	22	30	38	46	52	57	10082	168	17086	6700	6700	3686	2253	6.5
54.1	0.9	24000	45.6	0.659	114633	-39	-21	-13	-6	1	6	12	-2	18	25	33	41	47	53	9600	160	16933	6700	6700	3533	2042	6.1
55.2	0.9	26000	52.6	0.685	114471	-46	-28	-21	-13	-6	-1	5	-7	13	21	29	37	42	48	9125	152	16771	6700	6700	3371	1822	5.7
56.3	0.9	28000	60.8	0.713	114297	-53	-35	-28	-20	-13	-8	-2	-11	8	16	24	32	38	44	8679	145	16597	6700	6700	3197	1598	5.2
57.6	1.0	29855	69.8	0.740	114120	-59	-41	-34	-27	-20	-14	-9	-16	4	12	20	28	34	40	8289	138	16420	6700	6700	3020	1383	4.8
57.6	1.0	29855	69.8	0.740	114120	-59	-41	-34	-27	-20	-14	-9	-16	4	12	20	28	34	40	8289	138	16420	6700	6700	3020	1889	5.4
57.7	1.0	30000	70.3	0.740	114110	-60	-42	-35	-28	-20	-15	-10	-16	4	12	20	28	34	40	8248	137	16410	6700	6700	3010	1871	5.4
58.8	1.0	32000	78.7	0.740	113956	-67	-49	-42	-35	-27	-22	-17	-24	-4	4	12	20	26	32	7682	128	16256	6700	6700	2856	1605	5.4
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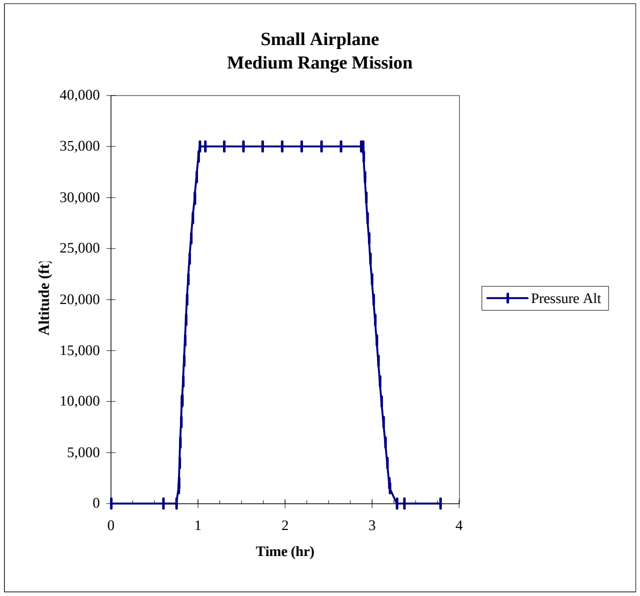
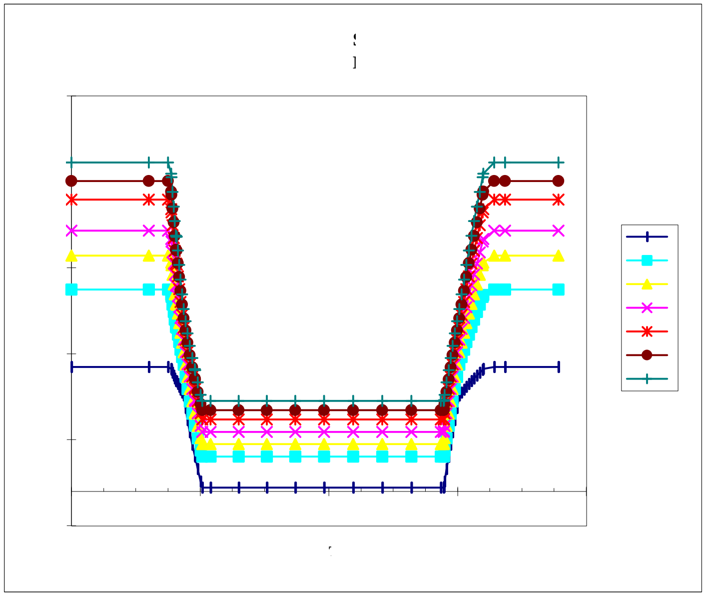
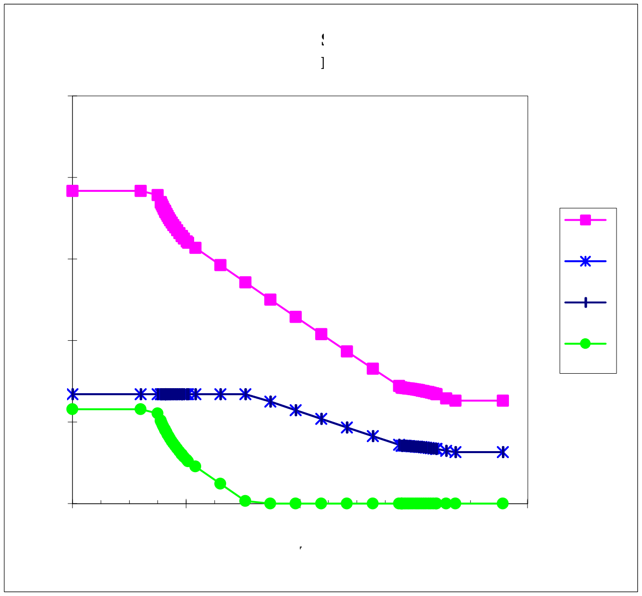
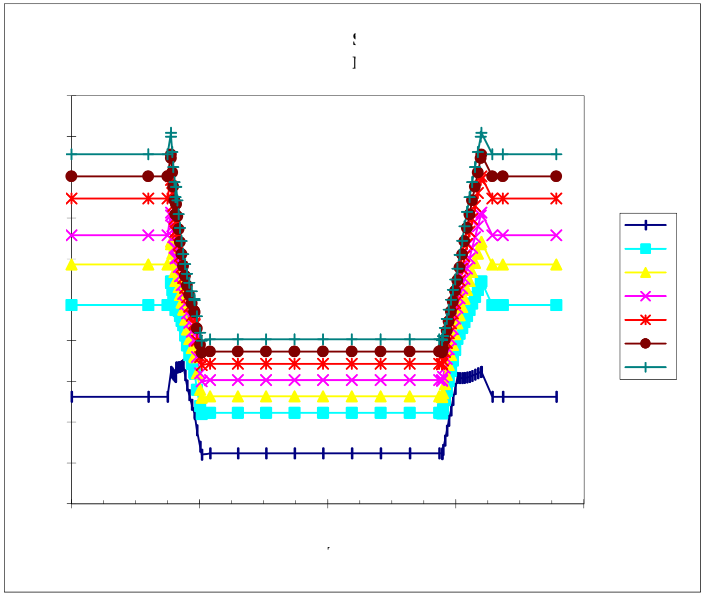
61.0	1.0	35000	94.3	0.740	113693	-78	-60	-53	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	6868	114	15993	6700	6700	2593	1173	5.4
64.9	1.1	35000	121.9	0.745	113379	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4873	81	15679	6700	6700	2279	0	3.8
78.0	1.3	35000	215.5	0.745	112321	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4837	81	14621	6700	6700	1221	0	3.8
91.1	1.5	35000	309.8	0.745	111263	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4801	80	13563	6700	6700	163	0	3.7
104.4	1.7	35000	404.9	0.745	110204	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4766	79	12504	6252	6252	0	0	3.7
117.8	2.0	35000	500.6	0.745	109146	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4732	79	11446	5723	5723	0	0	3.6
131.3	2.2	35000	597.0	0.745	108087	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4698	78	10387	5194	5194	0	0	3.6
144.8	2.4	35000	694.1	0.745	107029	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4665	78	9329	4665	4665	0	0	3.5
158.5	2.6	35000	791.8	0.745	105970	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4633	77	8270	4135	4135	0	0	3.5
172.2	2.9	35000	890.3	0.745	104912	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4602	77	7212	3606	3606	0	0	3.5
173.6	2.9	35000	900.0	0.745	104808	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4599	77	7108	3554	3554	0	0	3.5
173.6	2.9	34923	900.2	0.740	104808	-78	-60	-52	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	760	13	7108	3554	3554	0	3099	-0.6
173.6	2.9	34923	900.2	0.740	104808	-78	-60	-52	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	760	13	7108	3554	3554	0	2272	0.5
174.0	2.9	34000	903.1	0.726	104802	-74	-56	-49	-42	-35	-29	-24	-34	-14	-6	2	10	16	22	760	13	7102	3551	3551	0	2237	0.6
174.9	2.9	32000	909.3	0.696	104791	-67	-49	-42	-35	-27	-22	-17	-29	-9	-1	6	14	20	26	775	13	7091	3546	3546	0	2193	0.6
175.8	2.9	30000	915.4	0.668	104779	-60	-42	-35	-28	-20	-15	-10	-24	-5	3	11	19	25	31	820	14	7079	3540	3540	0	2142	0.7
176.8	2.9	28000	921.5	0.641	104765	-53	-35	-28	-20	-13	-8	-2	-19	0	8	16	23	29	35	877	15	7065	3533	3533	0	2089	0.7
177.8	3.0	26000	927.6	0.616	104751	-46	-28	-21	-13	-6	-1	5	-14	5	13	21	28	34	40	933	16	7051	3526	3526	0	2037	0.8
178.8	3.0	24000	933.6	0.592	104735	-39	-21	-13	-6	1	6	12	-9	10	18	26	33	39	45	996	17	7035	3518	3518	0	1987	0.8
179.8	3.0	22000	939.6	0.569	104717	-31	-13	-6	1	8	14	19	-4	15	23	31	38	44	50	1062	18	7017	3509	3509	0	1940	0.8
180.8	3.0	20000	945.5	0.547	104698	-24	-6	1	8	15	21	26	2	21	28	36	44	49	55	1132	19	6998	3499	3499	0	1892	0.8
181.9	3.0	18000	951.4	0.526	104677	-23	-2	7	14	23	29	35	2	23	32	41	49	56	62	1206	20	6977	3489	3489	0	1841	0.8
183.0	3.0	16000	957.3	0.506	104654	-21	2	12	21	30	37	43	2	26	36	45	55	62	69	1283	21	6954	3477	3477	0	1790	0.8
184.1	3.1	14000	963.1	0.487	104629	-19	7	18	27	38	45	52	2	29	40	50	61	69	76	1365	23	6929	3465	3465	0	1740	0.8
185.3	3.1	12000	969.0	0.469	104602	-18	11	23	33	45	53	60	2	32	45	55	67	75	83	1450	24	6902	3451	3451	0	1690	0.8
186.5	3.1	10000	974.8	0.452	104572	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	1540	26	6872	3436	3436	0	1639	0.8
187.7	3.1	8000	980.7	0.436	104539	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	1633	27	6839	3420	3420	0	1590	0.8
189.0	3.2	6000	986.6	0.420	104503	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	1732	29	6803	3402	3402	0	1539	0.8
190.3	3.2	4000	992.5	0.406	104464	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	1853	31	6764	3382	3382	0	1482	0.8
191.7	3.2	2000	998.5	0.391	104419	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	2004	33	6719	3360	3360	0	1420	0.8
192.1	3.2	1500	1000.0	0.388	104407	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	2045	34	6707	3354	3354	0	1404	0.9
197.1	3.3	0	1000.0	0.000	104157	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	1680	28	6457	3229	3229	0	0	
202.1	3.4	0	1000.0	0.000	104017	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	6317	3159	3159	0	0	
227.1	3.8	0	1000.0	0.000	104017	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	6317	3159	3159	0	0	


Small Airplane
Medium Range Mission
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Altitude (ft)
0
1
2
3
4
Time (hr)
Pressure Alt







Small Commercial Transport
Long Range Mission

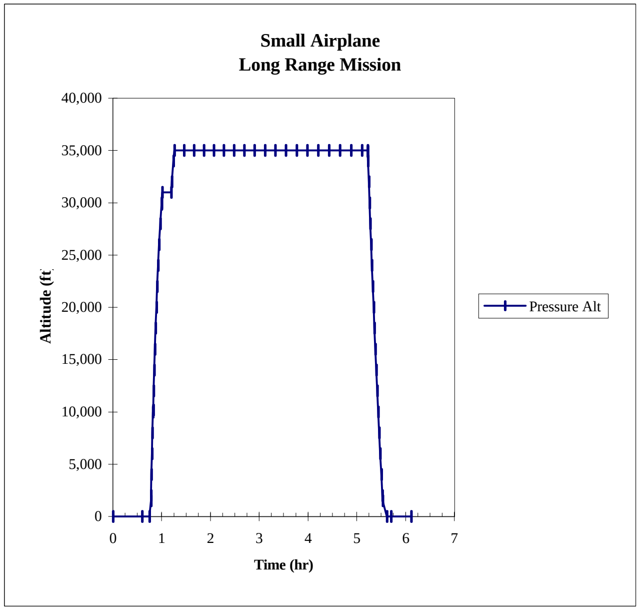
Ground Time (takeoff) = 45.000 minutes
Ground Time (landing) = 30.000 minutes

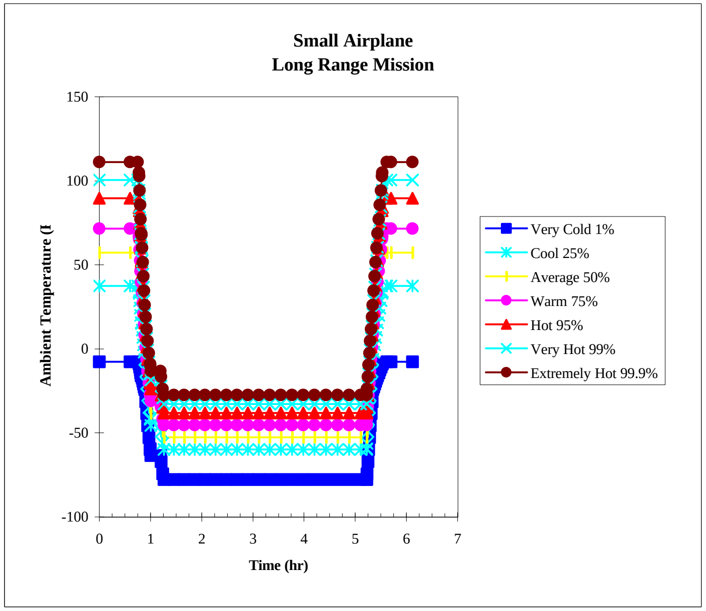
Main 1 Fuel Volume = 1000 gal Tank Volume 1020
Main 2 Fuel Volume = 1000 gal Tank Volume 1020
CWT Fuel Volume = 3,000 gal Tank Volume 3060

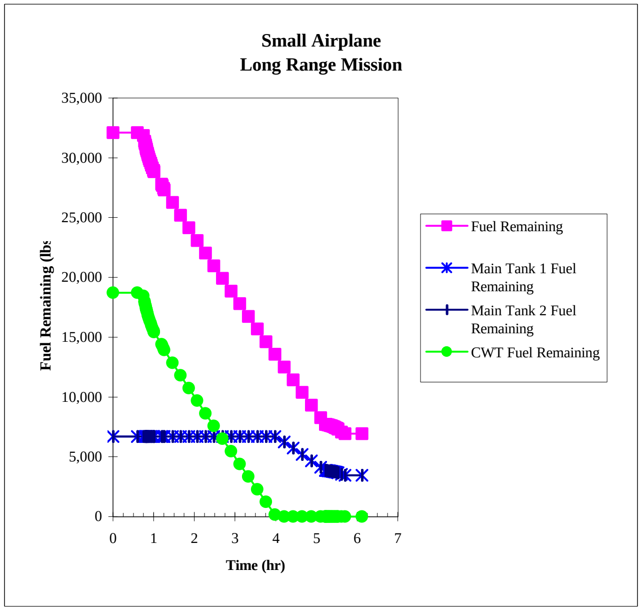
Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent	Body Pitch Attitude
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min	degrees
0.0	0.0	0	0.0	0.000	129807	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	32108	6700	6700	18708	0	
36.0	0.6	0	0.0	0.000	129807	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	1680	28	32108	6700	6700	18708	0	
45.0	0.8	0	0.0	0.000	129555	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	16119	269	31856	6700	6700	18456	0	
46.7	0.8	1500	3.8	0.388	129082	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	16119	269	31383	6700	6700	17983	3694	13.3
46.8	0.8	2000	4.4	0.391	129045	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	15950	266	31346	6700	6700	17946	3657	13.2
47.4	0.8	4000	6.8	0.406	128900	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	15290	255	31201	6700	6700	17801	3505	12.6
48.0	0.8	6000	9.4	0.420	128754	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	14649	244	31055	6700	6700	17655	3353	12.1
48.6	0.8	8000	12.2	0.436	128608	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	14004	233	30909	6700	6700	17509	3190	11.5
49.2	0.8	10000	15.2	0.452	128461	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	13350	223	30762	6700	6700	17362	3016	11.0
49.2	0.8	10000	15.2	0.452	128461	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	13350	223	30762	6700	6700	17362	500	6.1
49.6	0.8	10162	16.9	0.507	128389	-16	15	29	39	52	60	68	7	40	54	65	78	87	95	13544	226	30690	6700	6700	17290	500	4.7
49.6	0.8	10162	16.9	0.507	128389	-16	15	29	39	52	60	68	7	40	54	65	78	87	95	13542	226	30690	6700	6700	17290	3070	9.2
50.2	0.8	12000	20.2	0.525	128253	-18	11	23	33	45	53	60	7	37	50	61	73	81	89	12980	216	30554	6700	6700	17154	2895	8.7
50.9	0.8	14000	24.2	0.544	128101	-19	7	18	27	38	45	52	7	34	46	56	67	74	82	12377	206	30402	6700	6700	17002	2701	8.3
51.7	0.9	16000	28.7	0.565	127947	-21	2	12	21	30	37	43	7	32	42	51	61	68	75	11750	196	30248	6700	6700	16848	2502	7.8
52.5	0.9	18000	33.7	0.587	127788	-23	-2	7	14	23	29	35	7	30	39	47	56	62	69	11125	185	30089	6700	6700	16689	2296	7.3
53.4	0.9	20000	39.3	0.610	127623	-24	-6	1	8	15	21	26	8	27	35	43	51	56	62	10562	176	29924	6700	6700	16524	2093	6.9
54.4	0.9	22000	45.6	0.634	127450	-31	-13	-6	1	8	14	19	3	22	30	38	46	52	57	10082	168	29751	6700	6700	16351	1901	6.5
55.5	0.9	24000	52.9	0.659	127268	-39	-21	-13	-6	1	6	12	-2	18	25	33	41	47	53	9600	160	29569	6700	6700	16169	1708	6.0
56.8	0.9	26000	61.3	0.685	127074	-46	-28	-21	-13	-6	-1	5	-7	13	21	29	37	42	48	9125	152	29375	6700	6700	15975	1507	5.6
58.2	1.0	28000	71.3	0.713	126862	-53	-35	-28	-20	-13	-8	-2	-11	8	16	24	32	38	44	8679	145	29163	6700	6700	15763	1301	5.2
59.8	1.0	29855	82.5	0.740	126641	-59	-41	-34	-27	-20	-14	-9	-16	4	12	20	28	34	40	8289	138	28942	6700	6700	15542	1094	4.8
59.8	1.0	29855	82.5	0.740	126641	-59	-41	-34	-27	-20	-14	-9	-16	4	12	20	28	34	40	8289	138	28942	6700	6700	15542	1495	5.3
59.9	1.0	30000	83.2	0.740	126628	-60	-42	-35	-28	-20	-15	-10	-16	4	12	20	28	34	40	8248	137	28929	6700	6700	15529	1476	5.3
60.6	1.0	31000	88.3	0.740	126532	-64	-46	-38	-31	-24	-19	-13	-20	0	8	16	24	30	36	7965	133	28833	6700	6700	15433	1349	5.3
71.8	1.2	31000	170.0	0.745	125495	-64	-46	-38	-31	-24	-19	-13	-20	0	8	16	24	30	36	5531	92	27796	6700	6700	14396	0	3.4
72.6	1.2	32000	175.7	0.745	125394	-67	-49	-42	-35	-27	-22	-17	-24	-4	4	12	20	26	32	7705	128	27695	6700	6700	14295	1220	5.2
74.5	1.2	34000	189.4	0.745	125159	-74	-56	-49	-42	-35	-29	-24	-31	-11	-3	5	13	19	25	7156	119	27460	6700	6700	14060	924	5.2
75.7	1.3	35000	198.0	0.745	125019	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	6891	115	27320	6700	6700	13920	761	5.2
87.6	1.5	35000	283.1	0.745	123964	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	5300	88	26265	6700	6700	12865	0	4.2
99.6	1.7	35000	369.3	0.745	122905	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	5253	88	25206	6700	6700	11806	0	4.1
111.7	1.9	35000	456.3	0.745	121847	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	5206	87	24148	6700	6700	10748	0	4.1
124.0	2.1	35000	544.0	0.745	120789	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	5161	86	23090	6700	6700	9690	0	4.1
136.4	2.3	35000	632.5	0.745	119730	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	5116	85	22031	6700	6700	8631	0	4.0
148.8	2.5	35000	721.8	0.745	118672	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	5072	85	20973	6700	6700	7573	0	4.0
161.4	2.7	35000	811.8	0.745	117613	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	5030	84	19914	6700	6700	6514	0	4.0
174.1	2.9	35000	902.5	0.745	116555	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4989	83	18856	6700	6700	5456	0	3.9
186.9	3.1	35000	994.0	0.745	115496	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4950	82	17797	6700	6700	4397	0	3.9
199.7	3.3	35000	1086.2	0.745	114438	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4911	82	16739	6700	6700	3339	0	3.8
212.7	3.5	35000	1179.1	0.745	113379	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4873	81	15680	6700	6700	2280	0	3.8
225.8	3.8	35000	1272.7	0.745	112321	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4837	81	14622	6700	6700	1222	0	3.8
239.0	4.0	35000	1367.0	0.745	111263	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4801	80	13564	6700	6700	164	0	3.7
252.3	4.2	35000	1462.0	0.745	110204	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4766	79	12505	6253	6253	0	0	3.7
265.6	4.4	35000	1557.8	0.745	109146	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4732	79	11447	5724	5724	0	0	3.6
279.1	4.7	35000	1654.2	0.745	108087	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4698	78	10388	5194	5194	0	0	3.6
292.7	4.9	35000	1751.3	0.745	107029	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4665	78	9330	4665	4665	0	0	3.5
306.3	5.1	35000	1849.0	0.745	105970	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4633	77	8271	4136	4136	0	0	3.5
313.4	5.2	35000	1899.7	0.745	105424	-78	-60	-53	-45	-38	-33	-27	-35	-15	-7	1	9	15	21	4617	77	7725	3863	3863	0	0	3.5
313.4	5.2	34923	1899.9	0.740	105424	-78	-60	-52	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	760	13	7725	3863	3863	0	3094	-0.6
313.4	5.2	34923	1899.9	0.740	105424	-78	-60	-52	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	760	13	7725	3863	3863	0	2269	0.5
313.8	5.2	34000	1902.8	0.726	105419	-74	-56	-49	-42	-35	-29	-24	-34	-14	-6	2	10	16	22	760	13	7720	3860	3860	0	2233	0.6
314.7	5.2	32000	1909.0	0.696	105407	-67	-49	-42	-35	-27	-22	-17	-29	-9	-1	6	14	20	26	775	13	7708	3854	3854	0	2189	0.7
315.7	5.3	30000	1915.2	0.668	105395	-60	-42	-35	-28	-20	-15	-10	-24	-5	3	11	19	25	31	820	14	7696	3848	3848	0	2138	0.7
316.6	5.3	28000	1921.3	0.641	105381	-53	-35	-28	-20	-13	-8	-2	-19	0	8	16	23	29	35	877	15	7682	3841	3841	0	2085	0.8
317.6	5.3	26000	1927.3	0.616	105367	-46	-28	-21	-13	-6	-1	5	-14	5	13	21	28	34	40	933	16	7668	3834	3834	0	2034	0.8
318.6	5.3	24000	1933.4	0.592	105351	-39	-21	-13	-6	1	6	12	-9	10	18	26	33	39	45	996	17	7652	3826	3826	0	1983	0.8
319.6	5.3	22000	1939.3	0.569	105333	-31	-13	-6	1	8	14	19	-4	15	23	31	38	44	50	1062	18	7634	3817	3817	0	1936	0.8
320.6	5.3	20000	1945.3	0.547	105314	-24	-6	1	8	15	21	26	2	21	28	36	44	49	55	1132	19	7615	3808	3808	0	1888	0.8
321.7	5.4	18000	1951.2	0.526	105293	-23	-2	7	14	23	29	35	2	23	32	41	49	56	62	1206	20	7594	3797	3797	0	1838	0.8
322.8	5.4	16000	1957.1	0.506	105270	-21	2	12	21	30	37	43	2	26	36	45	55	62	69	1283	21	7571	3786	3786	0	1787	0.8
324.0	5.4	14000	1963.0	0.487	105245	-19	7	18	27	38	45	52	2	29	40	50	61	69	76	1365	23	7546	3773	3773	0	1737	0.8
325.1	5.4	12000	1968.8	0.469	105218	-18	11	23	33	45	53	60	2	32	45	55	67	75	83	1450	24	7519	3760	3760	0	1686	0.8
326.3	5.4	10000	1974.7	0.452	105188	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	1540	26	7489	3745	3745	0	1636	0.8
327.6	5.5	8000	1980.6	0.436	105155	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	1633	27	7456	3728	3728	0	1587	0.8
328.9	5.5	6000	1986.5	0.420	105119	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	1732	29	7420	3710	3710	0	1537	0.8
330.2	5.5	4000	1992.4	0.406	105079	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	1853	31	7380	3690	3690	0	1480	0.8
331.6	5.5	2000	1998.4	0.391	105035	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	2004	33	7336	3668	3668	0	1417	0.9
331.9	5.5	1500	1999.9	0.388	105023	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	2045	34	7324	3662	3662	0	1402	0.9
336.9	5.6	0	1999.9	0.000	104773	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	1680	28	7074	3537	3537	0	0	
341.9	5.7	0	1999.9	0.000	104633	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	6934	3467	3467	0	0	

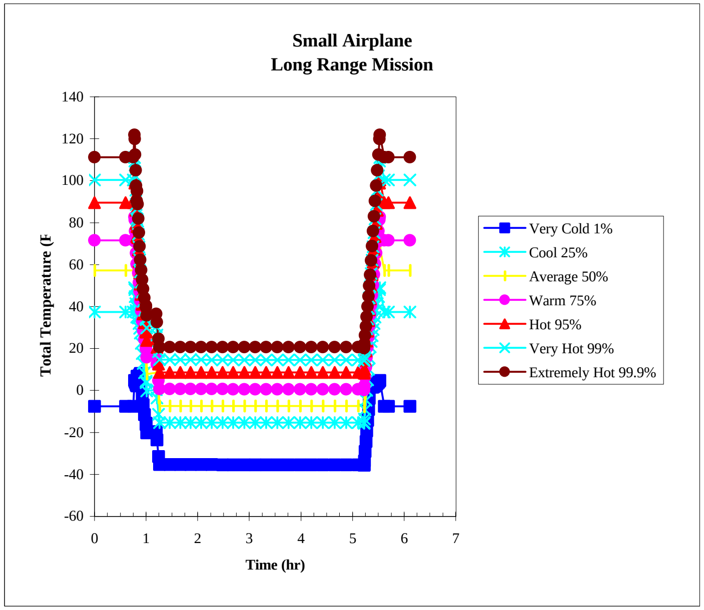
Small Commercial Transport
Long Range Mission

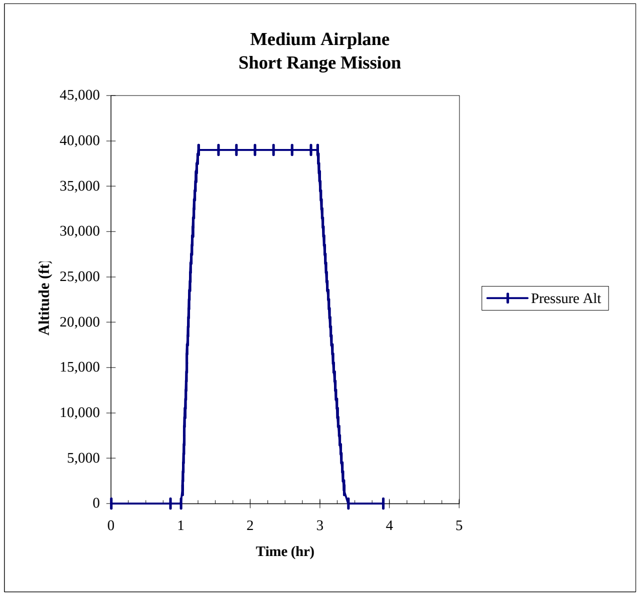
366.9	6.1	0	1999.9	0.000	104633	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	6934	3467	3467	0	0

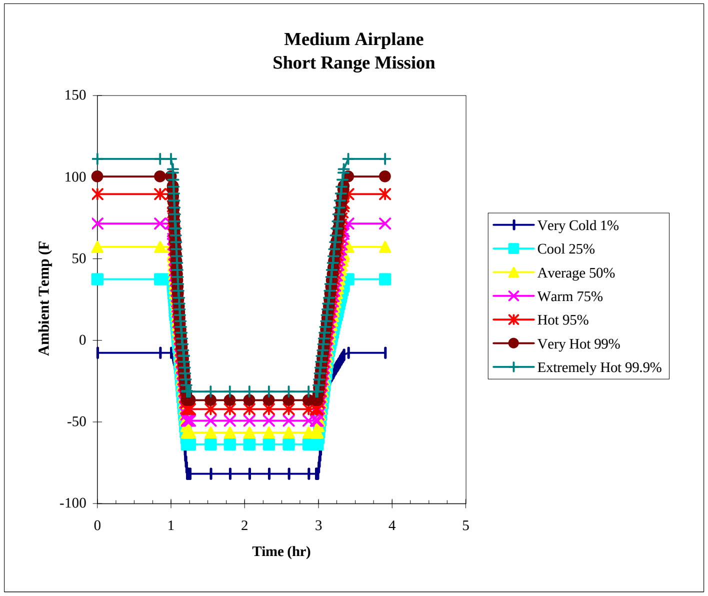

Small Airplane
Long Range Mission
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Altitude (ft
0
1
2
3
4
5
6
7
Time (hr)
Pressure Alt

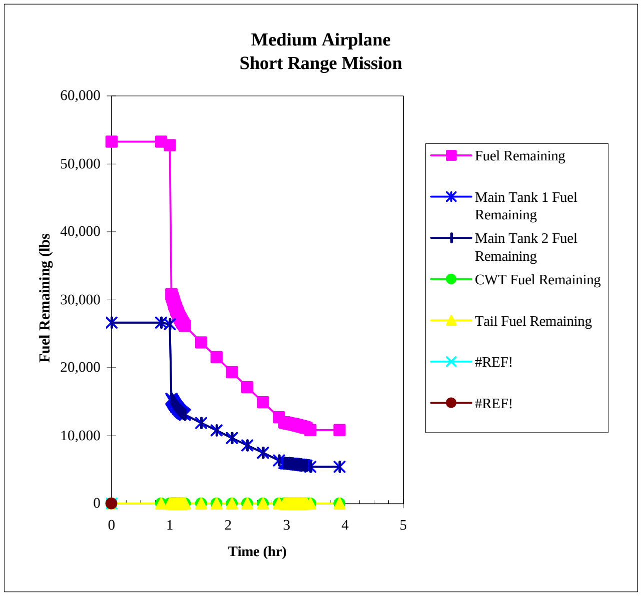

Small Airplane
Long Range Mission
150
100
50
0
-50
-100
Ambient Temperature (F
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

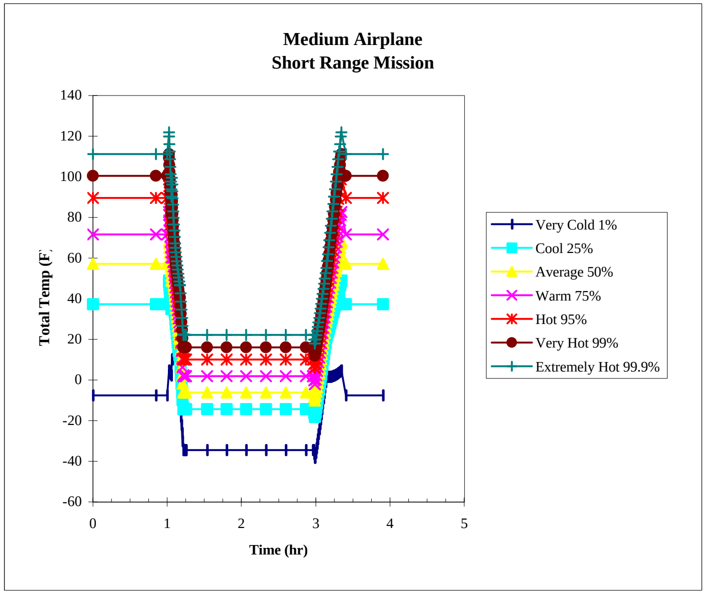

Small Airplane
Long Range Mission
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Fuel Remaining (lbs
0
1
2
3
4
5
6
7
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

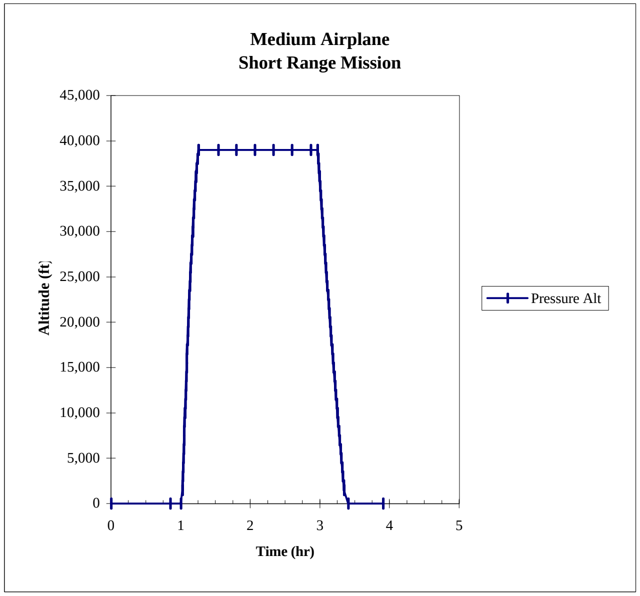

Small Airplane
Long Range Mission
140
120
100
80
60
40
20
0
-20
-40
-60
Total Temperature (F
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

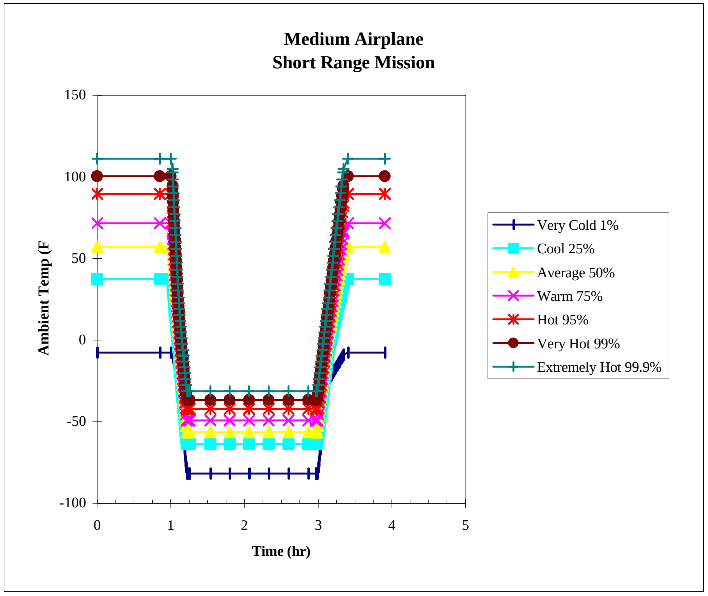

Medium Airplane
Short Range Mission
Altitude (ft
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
Time (hr)
Pressure Alt

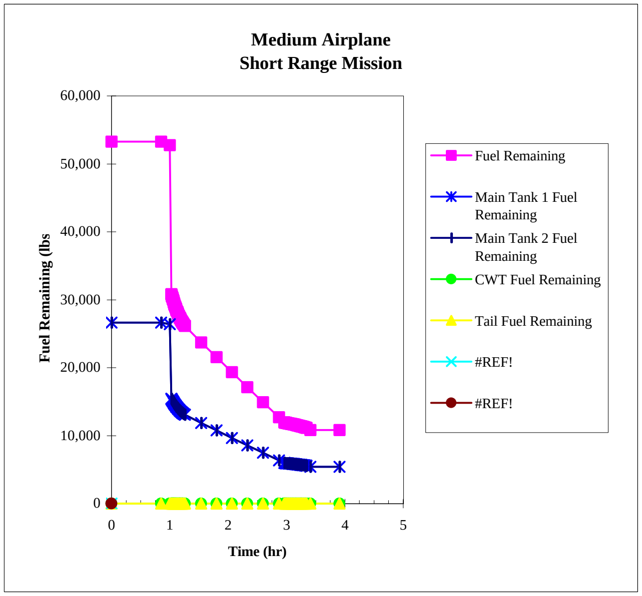

Medium Airplane
Short Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
5
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

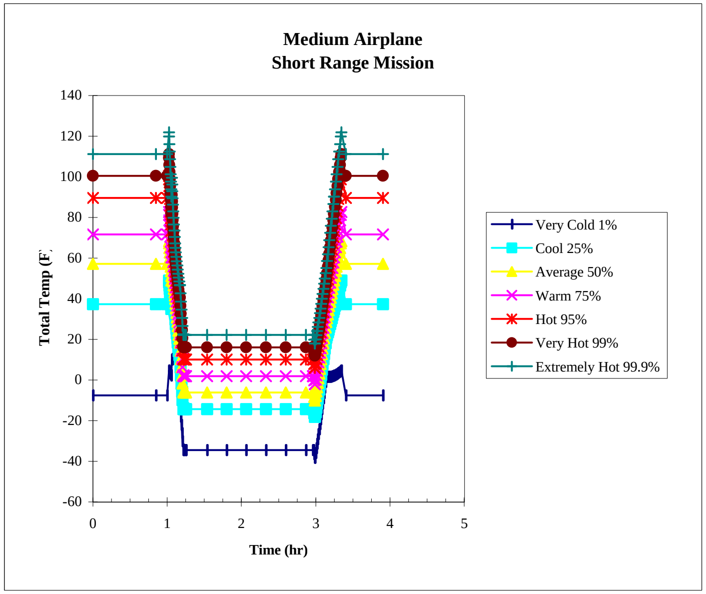

Medium Airplane
Short Range Mission
Fuel Remaining (lbs
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining
#REF!
#REF!


Medium Airplane
Short Range Mission
Total Temp (F,
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Medium Airplane
Short Range Mission
Altitude (ft
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
Time (hr)
Pressure Alt


Medium Airplane
Short Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
5
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Medium Airplane
Short Range Mission
Fuel Remaining (lbs
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining
#REF!
#REF!


Medium Airplane
Short Range Mission
Total Temp (F
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

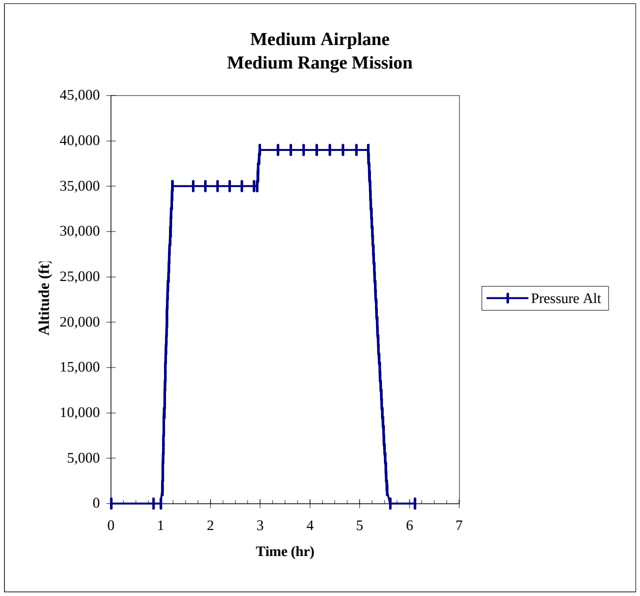
Medium Commercial Transport
Medium Range Mission

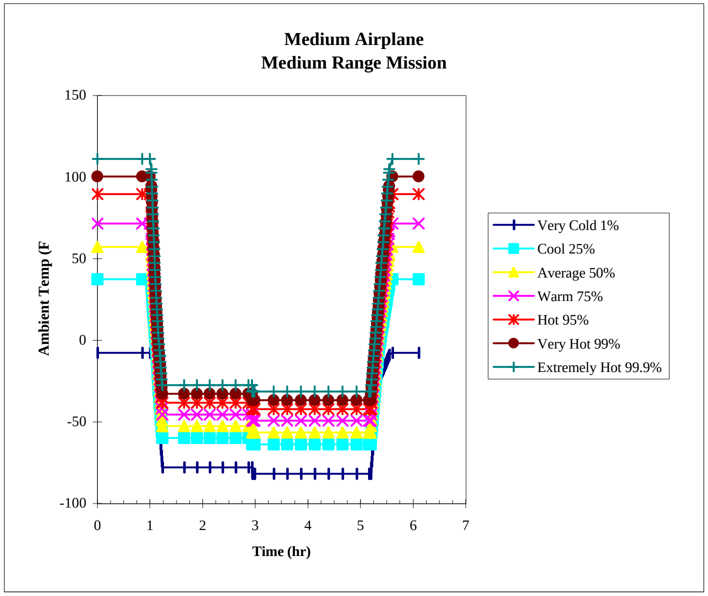
Ground Time (takeoff) = 60.000 minutes
Ground Time (landing) = 30.000 minutes

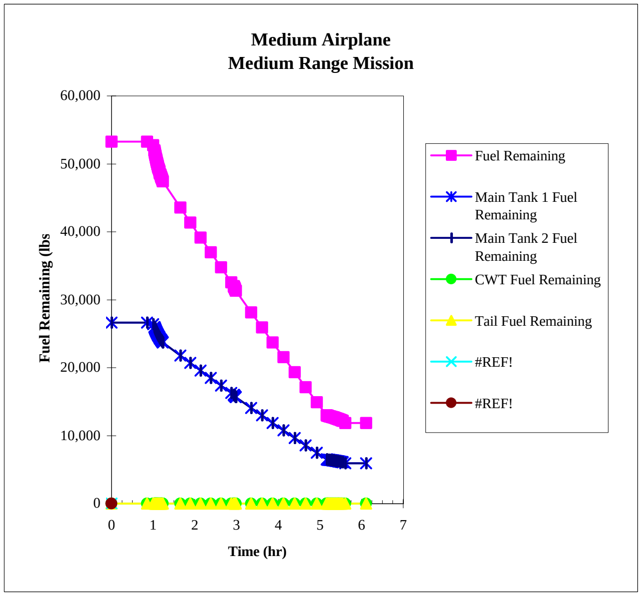
Main 1 Fuel Volume = 6,000 gal Tank Volume 6,120
Main 2 Fuel Volume = 6,000 gal Tank Volume 6,120
CWT Fuel Volume = 10,000 gal Tank Volume 10,200
Tail Tank Fuel Volume = 2,000 gal Tank Volume 2,040

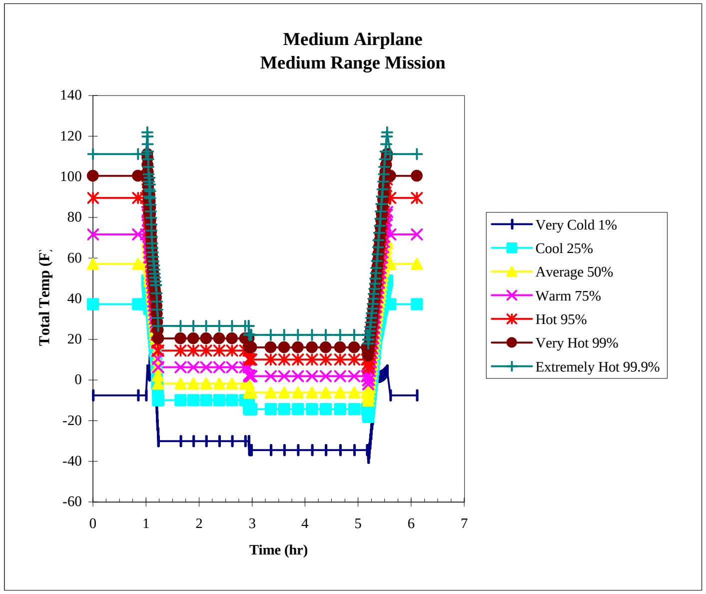
Threshold fuel in CWT to trigger
tail fuel transfer = 4,000 gal

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Fuel Distribution (Generic Tanks)				Rate of Climb / Descent	Body Pitch Attitude
																							Main Tank 1 Fuel Remainin	Main Tank 2 Fuel Remainin	CWT Fuel Remaining	Tail Fuel Remaining		
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	lbs	ft/min	degrees
0.0	0.0	0	0.0	0.000	278650	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	53272	26636	26636	0	0	0	0.0
51.0	0.9	0	0.0	0.000	278650	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	3307	55	53272	26636	26636	0	0	0	0.0
60.0	1.0	0	0.0	0.000	278154	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	29301	488	52776	26388	26388	0	0	0	0.0
61.6	1.0	1500	3.3	0.388	277359	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	29301	488	51980	25990	25990	0	0	3946	12.0
61.8	1.0	2000	3.8	0.391	277297	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	29290	488	51918	25959	25959	0	0	3960	12.0
62.0	1.0	3000	4.9	0.398	277173	-10	31	49	62	78	88	98	4	46	65	79	96	106	116	29323	489	51795	25897	25897	0	0	3995	11.9
62.3	1.0	4000	6.0	0.406	277052	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	29259	488	51674	25837	25837	0	0	4018	11.8
62.5	1.0	5000	7.1	0.413	276931	-12	26	43	56	71	80	90	4	43	60	73	89	99	109	29458	491	51552	25776	25776	0	0	4092	11.9
62.8	1.0	6000	8.2	0.420	276812	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	29385	490	51433	25717	25717	0	0	4117	11.8
63.0	1.1	7000	9.3	0.428	276693	-13	22	37	49	64	73	81	3	40	56	68	83	92	101	28997	483	51314	25657	25657	0	0	4071	11.6
63.3	1.1	8000	10.4	0.436	276576	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	28587	476	51197	25599	25599	0	0	4012	11.3
63.5	1.1	9000	11.6	0.444	276457	-15	18	32	43	56	65	73	2	37	51	63	77	85	94	28307	472	51078	25539	25539	0	0	3975	11.1
63.8	1.1	10000	12.8	0.452	276338	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	27987	466	50959	25480	25480	0	0	3931	10.9
64.1	1.1	10000	14.6	0.541	276172	-16	16	29	40	52	61	69	10	43	58	69	82	91	100	28455	474	50794	25397	25397	0	0	4035	8.2
64.4	1.1	11000	16.1	0.551	276053	-17	13	26	37	49	57	64	10	42	56	67	80	88	96	27875	465	50675	25337	25337	0	0	3934	7.9
64.6	1.1	12000	17.6	0.561	275937	-18	11	23	33	45	53	60	10	41	54	65	77	85	93	27278	455	50558	25279	25279	0	0	3825	7.6
64.9	1.1	13000	19.2	0.571	275815	-18	9	21	30	41	49	56	10	40	52	62	74	82	90	26662	444	50437	25218	25218	0	0	3711	7.4
65.2	1.1	14000	20.8	0.582	275696	-19	7	18	27	38	45	52	11	38	50	60	71	79	86	26056	434	50318	25159	25159	0	0	3592	7.1
65.4	1.1	15000	22.5	0.593	275575	-20	5	15	24	34	41	47	11	37	48	58	69	76	83	25468	424	50197	25098	25098	0	0	3472	6.8
65.7	1.1	16000	24.4	0.604	275452	-21	2	12	21	30	37	43	11	36	47	56	66	73	80	24983	416	50073	25037	25037	0	0	3368	6.6
66.0	1.1	17000	26.3	0.615	275328	-22	0	9	18	26	33	39	11	35	45	54	63	70	77	24464	408	49950	24975	24975	0	0	3259	6.3
66.3	1.1	18000	28.3	0.627	275200	-23	-2	7	14	23	29	35	12	34	43	52	61	67	73	23902	398	49822	24911	24911	0	0	3140	6.1
66.7	1.1	19000	30.4	0.639	275072	-23	-4	4	11	19	25	30	12	33	42	50	58	64	70	23303	388	49694	24847	24847	0	0	3012	5.8
67.0	1.1	20000	32.6	0.651	274942	-24	-6	1	8	15	21	26	13	32	40	48	56	61	67	22672	378	49564	24782	24782	0	0	2876	5.5
67.4	1.1	21000	35.0	0.664	274810	-28	-10	-3	5	12	17	23	10	30	38	45	53	59	65	22300	372	49432	24716	24716	0	0	2783	5.3
67.7	1.1	22000	37.5	0.677	274676	-31	-13	-6	1	8	14	19	8	27	35	43	51	57	63	21854	364	49297	24649	24649	0	0	2677	5.1
68.1	1.1	23000	40.1	0.690	274539	-35	-17	-10	-3	5	10	15	5	25	33	41	49	55	61	21343	356	49160	24580	24580	0	0	2560	4.9
68.5	1.1	24000	42.9	0.703	274398	-39	-21	-13	-6	1	6	12	3	23	31	39	47	53	58	20772	346	49019	24510	24510	0	0	2433	4.7
68.9	1.1	25000	45.9	0.717	274254	-42	-24	-17	-10	-3	3	8	1	21	29	37	44	50	56	20152	336	48876	24438	24438	0	0	2300	4.4
69.4	1.2	26000	49.2	0.731	274107	-46	-28	-21	-13	-6	-1	5	-1	18	26	34	42	48	54	19700	328	48728	24364	24364	0	0	2190	4.2
69.8	1.2	27000	52.6	0.745	273955	-49	-31	-24	-17	-10	-4	1	-4	16	24	32	40	46	52	19220	320	48576	24288	24288	0	0	2073	4.0
70.3	1.2	28000	56.3	0.760	273796	-53	-35	-28	-20	-13	-8	-2	-6	14	22	30	38	44	50	18715	312	48417	24209	24209	0	0	1952	3.7
70.9	1.2	29000	60.3	0.775	273635	-56	-38	-31	-24	-17	-11	-6	-8	12	20	28	36	42	48	18184	303	48256	24128	24128	0	0	1835	3.5
71.4	1.2	29959	64.5	0.790	273472	-60	-42	-35	-27	-20	-15	-9	-10	10	18	27	35	41	47	17657	294	48093	24047	24047	0	0	1709	3.2
71.4	1.2	29959	64.5	0.790	273472	-60	-42	-35	-27	-20	-15	-9	-10	10	18	27	35	41	47	17657	294	48093	24047	24047	0	0	2417	4.1
71.4	1.2	30000	64.6	0.790	273467	-60	-42	-35	-28	-20	-15	-10	-10	10	18	26	34	41	47	17635	294	48089	24044	24044	0	0	2413	4.1
71.9	1.2	31000	67.9	0.790	273344	-64	-46	-38	-31	-24	-19	-13	-14	6	14	22	30	37	43	16953	283	47965	23983	23983	0	0	2266	4.1
72.3	1.2	32000	71.5	0.790	273218	-67	-49	-42	-35	-27	-22	-17	-18	2	10	18	26	33	39	16285	271	47840	23920	23920	0	0	2115	4.1
72.8	1.2	33000	75.2	0.790	273086	-71	-53	-45	-38	-31	-26	-20	-22	-2	6	14	22	29	35	15684	261	47708	23854	23854	0	0	1960	4.0
73.3	1.2	34000	79.3	0.790	272949	-74	-56	-49	-42	-35	-29	-24	-26	-6	2	10	18	24	31	15084	251	47571	23785	23785	0	0	1796	4.0
73.9	1.2	35000	83.7	0.790	272806	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	14493	242	47428	23714	23714	0	0	1628	4.0
73.9	1.2	35000	83.7	0.790	272808	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9259	154	47428	23714	23714	0	0	0	2.0
99.0	1.6	35000	273.9	0.790	268961	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9156	153	43581	21790	21790	0	0	0	1.9
113.5	1.9	35000	383.9	0.790	266757	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9098	152	41376	20688	20688	0	0	0	1.9
128.1	2.1	35000	494.6	0.790	264552	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9041	151	39171	19586	19586	0	0	0	1.9
142.7	2.4	35000	606.0	0.790	262347	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8986	150	36967	18483	18483	0	0	0	1.8
157.5	2.6	35000	718.0	0.790	260143	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8931	149	34762	17381	17381	0	0	0	1.8
172.4	2.9	35000	830.8	0.790	257938	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8876	148	32558	16279	16279	0	0	0	1.8
176.1	2.9	35000	859.3	0.790	257383	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8862	148	32002	16001	16001	0	0	0	1.8
176.1	2.9	35000	859.3	0.790	257383	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	14493	242	32002	16001	16001	0	0	1867	4.1
176.7	2.9	36000	863.6	0.790	257250	-81	-63	-56	-49	-42	-36	-31	-34	-14	-6	2	10	16	23	13823	230	31870	15935	15935	0	0	1675	4.0
176.7	2.9	36089	864.0	0.790	257237	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	13766	229	31856	15928	15928	0	0	1519	3.9
176.7	2.9	36089	864.0	0.790	257237	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	13766	229	31856	15928	15928	0	0	1519	3.9
177.4	3.0	37000	868.8	0.790	257094	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	13243	221	31713	15857	15857	0	0	1358	3.8
178.2	3.0	38000	874.7	0.790	256924	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	12690	211	31543	15772	15772	0	0	1173	3.8
179.1	3.0	39000	881.9	0.790	256728	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	12039	201	31347	15674	15674	0	0	945	3.7
179.1	3.0	39000	881.9	0.790	256730	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8788	146	31347	15674	15674	0	0	0	2.5
201.1	3.4	39000	1048.2	0.790	253529	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8653	144	28146	14073	14073	0	0	0	2.5
216.5	3.6	39000	1164.3	0.790	251324	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8565	143	25942	12971	12971	0	0	0	2.5
232.0	3.9	39000	1281.5	0.790	249120	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8477	141	23737	11868	11868	0	0	0	2.4
247.7	4.1	39000	1399.9	0.790	246915	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8391	140	21532	10766	10766	0	0	0	2.4
263.5	4.4	39000	1519.5	0.790	244711	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8316	139	19328	9664	9664	0	0	0	2.3
279.5	4.7	39000	1640.2	0.790	242506	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8243	137	17123	8562	8562	0	0	0	2.3
295.6	4.9	39000	1761.9	0.790	240301	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8170	136	14919	7459	7459	0	0	0	2.3
310.0	5.2	39000	1870.0	0.790	238359	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8106	135	12976	6488	6488	0	0	0	2.2
310.0	5.2	39000	1870.0	0.790	238359	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	2088	35	12976	6488	6488	0	0	-2340	-0.7
310.4	5.2	38036	1873.1	0.790	238344	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	2103	35	12961	6480	6480	0	0	-2355	-0.9
310.4	5.2	38035	1873.1	0.790	238344	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	2103	35	12961	6480	6480	0	0	-1708	-0.1
311.0	5.2	37000	1877.6	0.773	238324	-82	-64	-56	-49	-42	-37	-31	-37	-16	-8	0	8	14	20	2061	34	12941	6471	6471	0	0	-1689	-0.1
311.5	5.2	36089	1881.6	0.758	238304	-82	-64	-56	-49	-42	-37	-31	-38	-18	-10	-2	6	12	18	1993	33	12921	6461	6461	0	0	-1687	0.0
311.5	5.2	36089	1881.6	0.758	238304	-82	-64	-56	-49	-42	-37	-31	-38	-18	-10	-2	6	12	18	1993	33	12921	6461	6461	0	0	-1788	-0.1


Medium Airplane
Medium Range Mission
Altitude (ft)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
Time (hr)
Pressure Alt

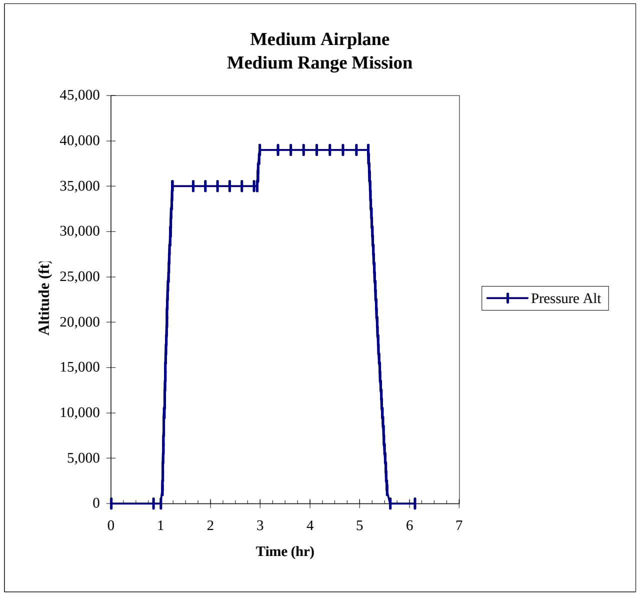

Medium Airplane
Medium Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

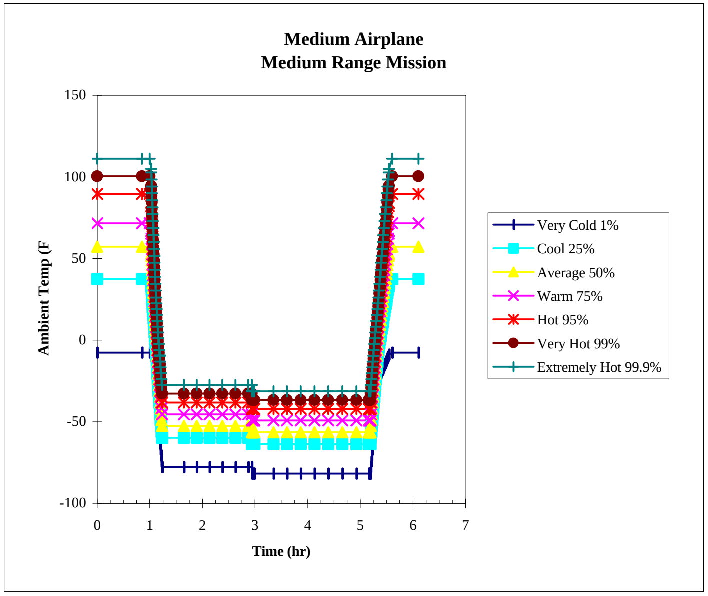

Medium Airplane
Medium Range Mission
Fuel Remaining (lbs
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
6
7
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining
#REF!
#REF!

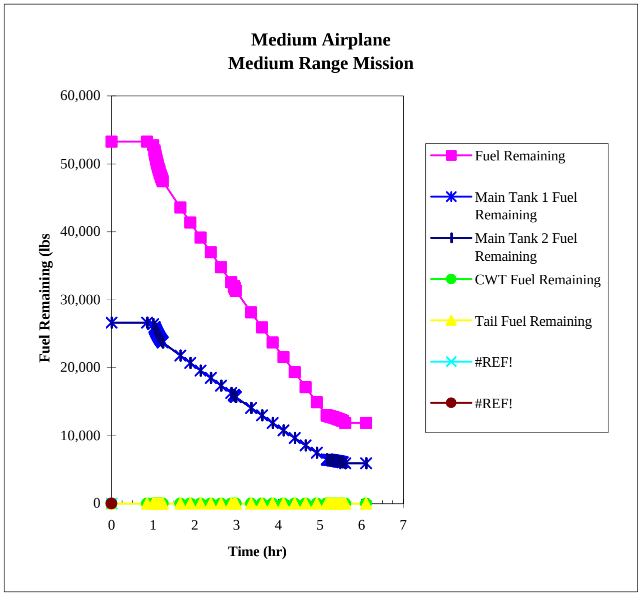

Medium Airplane
Medium Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

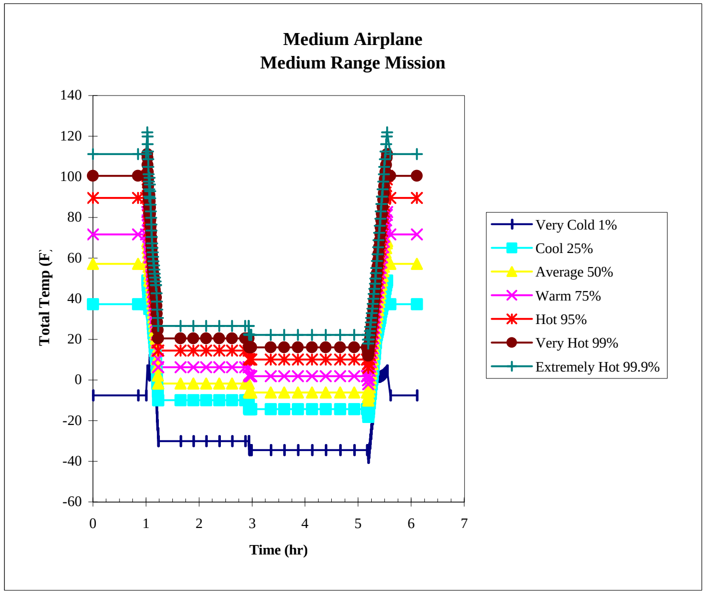
Medium Commercial Transport
Medium Range Mission

312.1	5.2	35000	1886.0	0.741	238284	-78	-60	-53	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	1916	32	12901	6451	6451	0	0	-1786	-0.1
312.7	5.2	34000	1889.9	0.726	238267	-74	-56	-49	-42	-35	-29	-24	-34	-14	-6	2	10	16	22	1836	31	12884	6442	6442	0	0	-1793	-0.1
313.2	5.2	33000	1893.8	0.711	238249	-71	-53	-45	-38	-31	-26	-20	-31	-12	-4	4	12	18	24	1750	29	12866	6433	6433	0	0	-1807	-0.2
313.8	5.2	32000	1897.5	0.696	238233	-67	-49	-42	-35	-27	-22	-17	-29	-9	-1	6	14	20	26	1656	28	12851	6425	6425	0	0	-1828	-0.1
314.3	5.2	31000	1901.2	0.682	238218	-64	-46	-38	-31	-24	-19	-13	-27	-7	1	9	17	23	28	1675	28	12835	6418	6418	0	0	-1814	-0.2
314.9	5.2	30000	1904.9	0.668	238203	-60	-42	-35	-28	-20	-15	-10	-24	-5	3	11	19	25	31	1698	28	12820	6410	6410	0	0	-1800	-0.2
315.4	5.3	29000	1908.5	0.655	238187	-56	-38	-31	-24	-17	-11	-6	-22	-2	6	13	21	27	33	1709	28	12804	6402	6402	0	0	-1789	-0.2
316.0	5.3	28000	1912.1	0.641	238172	-53	-35	-28	-20	-13	-8	-2	-19	0	8	16	23	29	35	1709	28	12789	6394	6394	0	0	-1781	-0.1
316.6	5.3	27000	1915.6	0.628	238156	-49	-31	-24	-17	-10	-4	1	-17	3	10	18	26	32	37	1746	29	12773	6387	6387	0	0	-1762	-0.2
317.1	5.3	26000	1919.2	0.616	238139	-46	-28	-21	-13	-6	-1	5	-14	5	13	21	28	34	40	1786	30	12756	6378	6378	0	0	-1743	-0.2
317.7	5.3	25000	1922.7	0.604	238121	-42	-24	-17	-10	-3	3	8	-12	8	15	23	31	37	42	1823	30	12738	6369	6369	0	0	-1725	-0.2
318.3	5.3	24000	1926.2	0.592	238103	-39	-21	-13	-6	1	6	12	-9	10	18	26	33	39	45	1861	31	12721	6360	6360	0	0	-1707	-0.2
318.9	5.3	23000	1929.7	0.580	238086	-35	-17	-10	-3	5	10	15	-6	13	20	28	36	42	47	1896	32	12703	6351	6351	0	0	-1690	-0.2
319.5	5.3	22000	1933.1	0.569	238068	-31	-13	-6	1	8	14	19	-4	15	23	31	38	44	50	1922	32	12685	6343	6343	0	0	-1677	-0.2
320.1	5.3	21000	1936.6	0.558	238048	-28	-10	-3	5	12	17	23	-1	18	26	33	41	47	53	1940	32	12665	6333	6333	0	0	-1666	-0.2
320.7	5.3	20000	1939.9	0.547	238028	-24	-6	1	8	15	21	26	2	21	28	36	44	49	55	1951	33	12646	6323	6323	0	0	-1658	-0.2
321.3	5.4	19000	1943.3	0.536	238009	-23	-4	4	11	19	25	30	2	22	30	38	47	53	59	2006	33	12626	6313	6313	0	0	-1638	-0.2
321.9	5.4	18000	1946.7	0.526	237989	-23	-2	7	14	23	29	35	2	23	32	41	49	56	62	2059	34	12606	6303	6303	0	0	-1619	-0.2
322.5	5.4	17000	1950.0	0.516	237967	-22	0	9	18	26	33	39	2	25	34	43	52	59	65	2110	35	12584	6292	6292	0	0	-1602	-0.2
323.2	5.4	16000	1953.3	0.506	237947	-21	2	12	21	30	37	43	2	26	36	45	55	62	69	2154	36	12564	6282	6282	0	0	-1588	-0.2
323.8	5.4	15000	1956.6	0.497	237923	-20	5	15	24	34	41	47	2	28	38	48	58	65	72	2202	37	12540	6270	6270	0	0	-1572	-0.3
324.4	5.4	14000	1959.9	0.487	237901	-19	7	18	27	38	45	52	2	29	40	50	61	69	76	2251	38	12518	6259	6259	0	0	-1556	-0.3
325.1	5.4	13000	1963.2	0.478	237876	-18	9	21	30	41	49	56	2	30	43	53	64	72	79	2295	38	12493	6247	6247	0	0	-1541	-0.3
325.7	5.4	12000	1966.4	0.469	237850	-18	11	23	33	45	53	60	2	32	45	55	67	75	83	2337	39	12467	6234	6234	0	0	-1528	-0.3
326.4	5.4	11000	1969.7	0.461	237826	-17	13	26	37	49	57	64	2	33	47	58	70	79	87	2372	40	12443	6221	6221	0	0	-1517	-0.3
327.0	5.5	10000	1972.9	0.452	237799	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	2394	40	12416	6208	6208	0	0	-1511	-0.4
327.0	5.5	10000	1972.9	0.452	237799	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	2394	40	12416	6208	6208	0	0	-1511	-0.4
327.7	5.5	9000	1976.0	0.444	237773	-15	18	32	43	56	65	73	2	37	51	63	77	85	94	2394	40	12390	6195	6195	0	0	-1511	-0.4
328.4	5.5	8000	1979.1	0.436	237746	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	2392	40	12363	6182	6182	0	0	-1513	-0.5
329.0	5.5	7000	1982.2	0.428	237720	-13	22	37	49	64	73	81	3	40	56	68	83	92	101	2429	40	12337	6168	6168	0	0	-1501	-0.5
329.7	5.5	6000	1985.3	0.420	237693	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	2478	41	12310	6155	6155	0	0	-1487	-0.5
330.4	5.5	5000	1988.3	0.413	237665	-12	26	43	56	71	80	90	4	43	60	73	89	99	109	2524	42	12282	6141	6141	0	0	-1473	-0.5
331.1	5.5	4000	1991.3	0.406	237636	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	2568	43	12253	6127	6127	0	0	-1461	-0.5
331.7	5.5	3000	1994.3	0.398	237607	-10	31	49	62	78	88	98	4	46	65	79	96	106	116	2621	44	12225	6112	6112	0	0	-1447	-0.5
332.4	5.5	2000	1997.3	0.391	237577	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	2670	44	12194	6097	6097	0	0	-1433	-0.6
332.8	5.5	1500	1998.8	0.388	237561	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	2692	45	12178	6089	6089	0	0	-1427	-0.6
336.5	5.6	0	1998.8	0.000	237222	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	11839	5919	5919	0	0	0	0.0
366.5	6.1	0	1998.8	0.000	237222	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	11839	5919	5919	0	0	0	0.0


Medium Airplane
Medium Range Mission
Altitude (ft)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
Time (hr)
Pressure Alt


Medium Airplane
Medium Range Mission
Ambient Temp (F)
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Medium Airplane
Medium Range Mission
Fuel Remaining (lbs)
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
6
7
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining
#REF!
#REF!


Medium Airplane
Medium Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

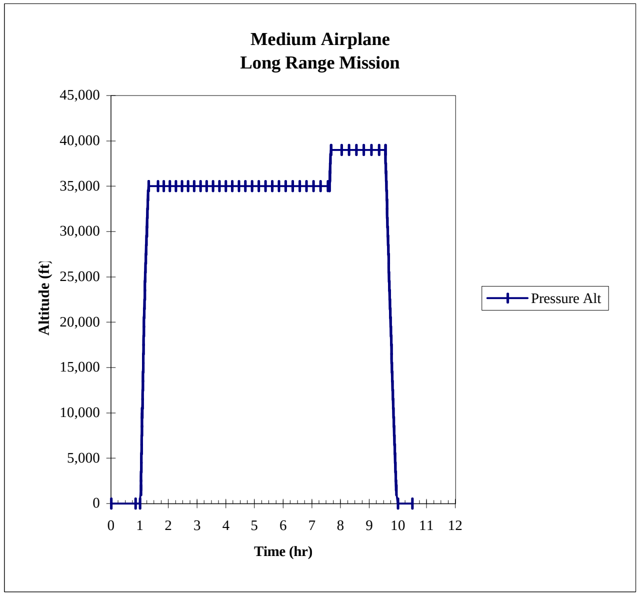
Medium Commercial Transport
Long Range Mission

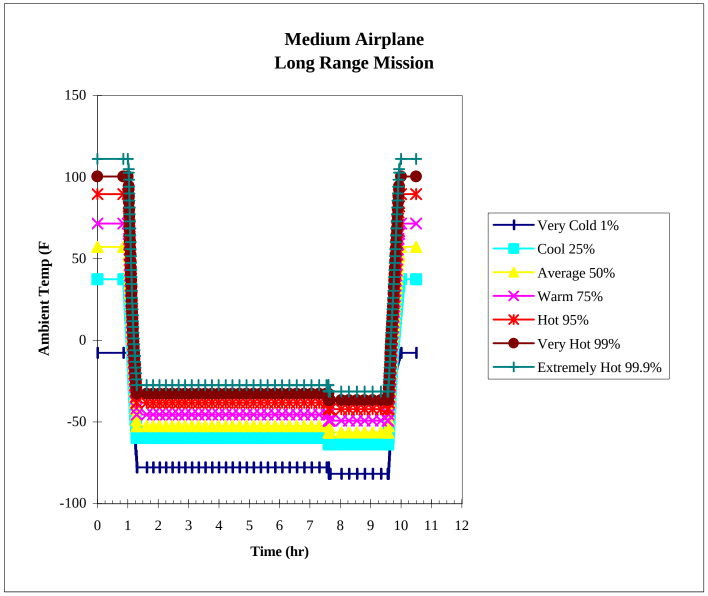
Ground Time (takeoff) = 60.000 minutes
Ground Time (landing) = 30.000 minutes

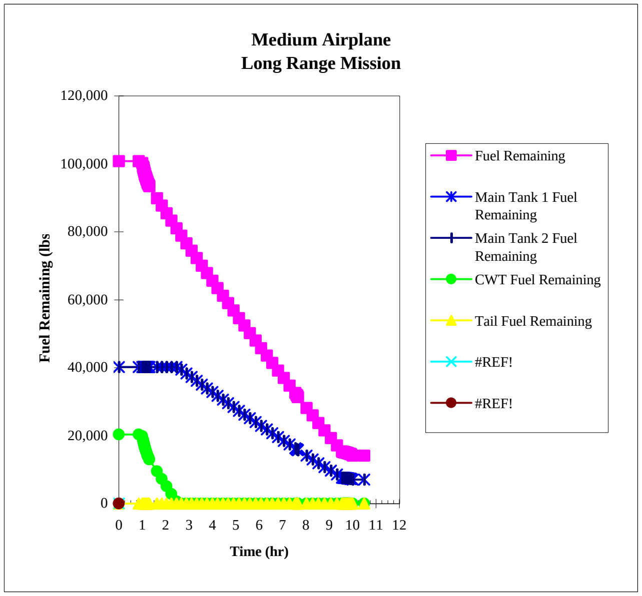
Main 1 Fuel Volume = 6,000 gal Tank Volume 6,120
Main 2 Fuel Volume = 6,000 gal Tank Volume 6,120
CWT Fuel Volume = 10,000 gal Tank Volume 10,200
Tail Tank Fuel Volume = 2,000 gal Tank Volume 2,040

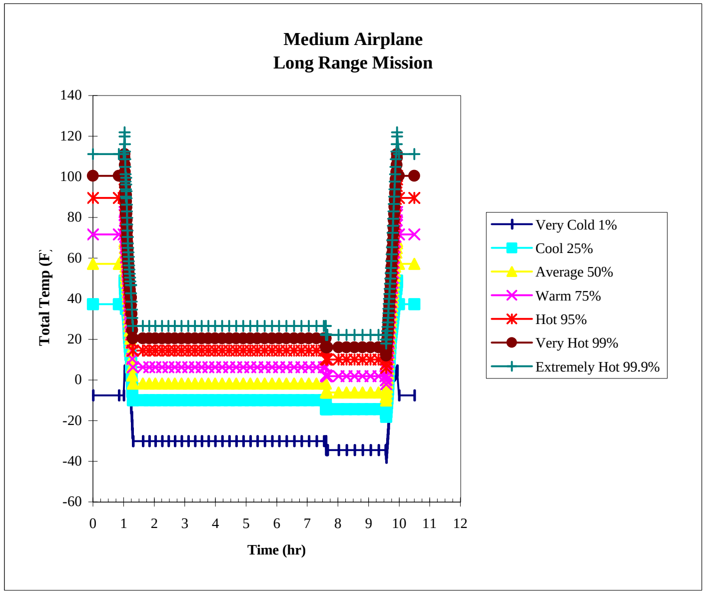
Threshold fuel in CWT to trigger
tail fuel transfer = 4,000 gal

						Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)										Fuel Distribution (Generic Tanks)					
Time	Time	Pressure Alt	Dist	Mach Number	Weight															Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remainin	Main Tank 2 Fuel Remainin	CWT Fuel Remaining	Tail Fuel Remaining	Rate of Climb / Descent	Body Pitch Attitude
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	lbs	ft/min	degrees
0.0	0.0	0	0.0	0.000	326138	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	100763	40200	40200	20363	0	0	0.0
51.0	0.9	0	0.0	0.000	326138	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	3307	55	100763	40200	40200	20363	0	0	0.0
60.0	1.0	0	0.0	0.000	325641	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	29301	488	100267	40200	40200	19867	0	0	0.0
61.9	1.0	1500	3.9	0.388	324678	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	29301	488	99304	40200	40200	18904	0	3198	11.3
62.1	1.0	2000	4.6	0.391	324601	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	29290	488	99227	40200	40200	18827	0	3209	11.2
62.4	1.0	3000	5.9	0.398	324449	-10	31	49	62	78	88	98	4	46	65	79	96	106	116	29323	489	99075	40200	40200	18675	0	3237	11.2
62.7	1.0	4000	7.3	0.406	324299	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	29259	488	98925	40200	40200	18525	0	3254	11.1
63.0	1.1	5000	8.6	0.413	324151	-12	26	43	56	71	80	90	4	43	60	73	89	99	109	29458	491	98777	40200	40200	18377	0	3316	11.1
63.3	1.1	6000	9.9	0.420	324003	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	29385	490	98629	40200	40200	18229	0	3334	11.1
63.6	1.1	7000	11.3	0.428	323856	-13	22	37	49	64	73	81	3	40	56	68	83	92	101	28997	483	98482	40200	40200	18082	0	3293	10.9
63.9	1.1	8000	12.7	0.436	323708	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	28587	476	98334	40200	40200	17934	0	3240	10.7
64.2	1.1	9000	14.2	0.444	323563	-15	18	32	43	56	65	73	2	37	51	63	77	85	94	28307	472	98188	40200	40200	17788	0	3206	10.5
64.6	1.1	10000	15.7	0.452	323415	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	27987	466	98041	40200	40200	17641	0	3166	10.4
65.0	1.1	10000	18.0	0.541	323210	-16	16	29	40	52	61	69	10	43	58	69	82	91	100	28455	474	97836	40200	40200	17436	0	3299	7.6
65.3	1.1	11000	19.7	0.551	323066	-17	13	26	37	49	57	64	10	42	56	67	80	88	96	27875	465	97692	40200	40200	17292	0	3211	7.4
65.6	1.1	12000	21.6	0.561	322921	-18	11	23	33	45	53	60	10	41	54	65	77	85	93	27278	455	97547	40200	40200	17147	0	3116	7.1
65.9	1.1	13000	23.5	0.571	322775	-18	9	21	30	41	49	56	10	40	52	62	74	82	90	26662	444	97401	40200	40200	17001	0	3016	6.9
66.3	1.1	14000	25.6	0.582	322626	-19	7	18	27	38	45	52	11	38	50	60	71	79	86	26056	434	97252	40200	40200	16852	0	2912	6.7
66.6	1.1	15000	27.7	0.593	322476	-20	5	15	24	34	41	47	11	37	48	58	69	76	83	25468	424	97102	40200	40200	16702	0	2807	6.4
67.0	1.1	16000	30.0	0.604	322324	-21	2	12	21	30	37	43	11	36	47	56	66	73	80	24983	416	96949	40200	40200	16549	0	2716	6.2
67.4	1.1	17000	32.3	0.615	322169	-22	0	9	18	26	33	39	11	35	45	54	63	70	77	24464	408	96795	40200	40200	16395	0	2621	6.0
67.7	1.1	18000	34.8	0.627	322013	-23	-2	7	14	23	29	35	12	34	43	52	61	67	73	23902	398	96639	40200	40200	16239	0	2517	5.8
68.2	1.1	19000	37.5	0.639	321854	-23	-4	4	11	19	25	30	12	33	42	50	58	64	70	23303	388	96480	40200	40200	16080	0	2406	5.5
68.6	1.1	20000	40.3	0.651	321689	-24	-6	1	8	15	21	26	13	32	40	48	56	61	67	22672	378	96315	40200	40200	15915	0	2287	5.3
69.0	1.2	21000	43.3	0.664	321523	-28	-10	-3	5	12	17	23	10	30	38	45	53	59	65	22300	372	96149	40200	40200	15749	0	2205	5.1
69.5	1.2	22000	46.4	0.677	321351	-31	-13	-6	1	8	14	19	8	27	35	43	51	57	63	21854	364	95977	40200	40200	15577	0	2112	4.9
70.0	1.2	23000	49.8	0.690	321177	-35	-17	-10	-3	5	10	15	5	25	33	41	49	55	61	21343	356	95803	40200	40200	15403	0	2010	4.7
70.5	1.2	24000	53.4	0.703	320999	-39	-21	-13	-6	1	6	12	3	23	31	39	47	53	58	20772	346	95625	40200	40200	15225	0	1900	4.5
71.0	1.2	25000	57.2	0.717	320813	-42	-24	-17	-10	-3	3	8	1	21	29	37	44	50	56	20152	336	95439	40200	40200	15039	0	1785	4.3
71.6	1.2	26000	61.4	0.731	320622	-46	-28	-21	-13	-6	-1	5	-1	18	26	34	42	48	54	19700	328	95248	40200	40200	14848	0	1691	4.1
72.2	1.2	27000	65.9	0.745	320425	-49	-31	-24	-17	-10	-4	1	-4	16	24	32	40	46	52	19220	320	95051	40200	40200	14651	0	1591	3.9
72.9	1.2	28000	70.7	0.760	320218	-53	-35	-28	-20	-13	-8	-2	-6	14	22	30	38	44	50	18715	312	94844	40200	40200	14444	0	1491	3.7
73.6	1.2	29000	76.0	0.775	320004	-56	-38	-31	-24	-17	-11	-6	-8	12	20	28	36	42	48	18184	303	94630	40200	40200	14230	0	1384	3.5
74.3	1.2	29959	81.6	0.790	319788	-60	-42	-35	-27	-20	-15	-9	-10	10	18	27	35	41	47	17657	294	94414	40200	40200	14014	0	1269	3.2
74.3	1.2	29959	81.6	0.790	319788	-60	-42	-35	-27	-20	-15	-9	-10	10	18	27	35	41	47	17657	294	94414	40200	40200	14014	0	1795	3.9
74.3	1.2	30000	81.7	0.790	319782	-60	-42	-35	-28	-20	-15	-10	-10	10	18	26	34	41	47	17635	294	94408	40200	40200	14008	0	1790	3.9
74.9	1.2	31000	86.3	0.790	319614	-64	-46	-38	-31	-24	-19	-13	-14	6	14	22	30	37	43	16953	283	94240	40200	40200	13840	0	1638	3.9
75.5	1.3	32000	91.2	0.790	319438	-67	-49	-42	-35	-27	-22	-17	-18	2	10	18	26	33	39	16285	271	94064	40200	40200	13664	0	1480	3.9
76.2	1.3	33000	96.7	0.790	319246	-71	-53	-45	-38	-31	-26	-20	-22	-2	6	14	22	29	35	15684	261	93872	40200	40200	13472	0	1313	3.9
77.1	1.3	34000	103.0	0.790	319036	-74	-56	-49	-42	-35	-29	-24	-26	-6	2	10	18	24	31	15084	251	93662	40200	40200	13262	0	1128	3.8
78.0	1.3	35000	110.4	0.790	318794	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	14493	242	93420	40200	40200	13020	0	914	3.8
78.0	1.3	35000	110.4	0.790	318798	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10924	182	93420	40200	40200	13020	0	0	2.7
97.6	1.6	35000	259.1	0.790	315258	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10758	179	89879	40200	40200	9479	0	0	2.6
110.0	1.8	35000	352.9	0.790	313053	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10655	178	87675	40200	40200	7275	0	0	2.6
122.5	2.0	35000	447.5	0.790	310849	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10556	176	85470	40200	40200	5070	0	0	2.5
135.1	2.3	35000	543.1	0.790	308644	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10461	174	83266	40200	40200	2866	0	0	2.5
147.8	2.5	35000	639.5	0.790	306439	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10373	173	81061	40200	40200	661	0	0	2.5
160.6	2.7	35000	736.7	0.790	304235	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10284	171	78856	39428	39428	0	0	0	2.4
173.5	2.9	35000	834.7	0.790	302030	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10196	170	76652	38326	38326	0	0	0	2.4
186.5	3.1	35000	933.6	0.790	299826	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10108	168	74447	37224	37224	0	0	0	2.4
199.6	3.3	35000	1033.3	0.790	297621	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	10031	167	72243	36121	36121	0	0	0	2.4
212.9	3.5	35000	1133.7	0.790	295416	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9956	166	70038	35019	35019	0	0	0	2.3
226.2	3.8	35000	1234.9	0.790	293212	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9883	165	67833	33917	33917	0	0	0	2.3
239.6	4.0	35000	1336.9	0.790	291007	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9810	164	65629	32814	32814	0	0	0	2.3
253.2	4.2	35000	1439.6	0.790	288803	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9738	162	63424	31712	31712	0	0	0	2.2
266.8	4.4	35000	1543.1	0.790	286598	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9667	161	61220	30610	30610	0	0	0	2.2
280.5	4.7	35000	1647.3	0.790	284393	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9599	160	59015	29507	29507	0	0	0	2.2
294.4	4.9	35000	1752.2	0.790	282189	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9530	159	56810	28405	28405	0	0	0	2.1
308.3	5.1	35000	1857.9	0.790	279984	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9464	158	54606	27303	27303	0	0	0	2.1
322.3	5.4	35000	1964.4	0.790	277780	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9396	157	52401	26201	26201	0	0	0	2.1
336.5	5.6	35000	2071.6	0.790	275575	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9336	156	50197	25098	25098	0	0	0	2.0
350.7	5.8	35000	2179.5	0.790	273370	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9275	155	47992	23996	23996	0	0	0	2.0
365.0	6.1	35000	2288.0	0.790	271166	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9215	154	45787	22894	22894	0	0	0	2.0
379.4	6.3	35000	2397.3	0.790	268961	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9156	153	43583	21791	21791	0	0	0	1.9
393.9	6.6	35000	2507.3	0.790	266757	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9098	152	41378	20689	20689	0	0	0	1.9
408.4	6.8	35000	2618.0	0.790	264552	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	9041	151	39174	19587	19587	0	0	0	1.9
423.1	7.1	35000	2729.4	0.790	262347	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8986	150	36969	18484	18484	0	0	0	1.8
437.9	7.3	35000	2841.4	0.790	260143	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8931	149	34764	17382	17382	0	0	0	1.8
452.7	7.5	35000	2954.2	0.790	257938	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8876	148	32560	16280	16280	0	0	0	1.8
456.4	7.6	35000	2981.8	0.790	257400	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	8862	148	32022	16011	16011	0	0	0	1.8
456.4	7.6	35000	2981.8	0.790	257400	-78	-60	-53	-45	-38	-33	-27	-30	-10	-2	6	14	20	27	14493	242	32022	16011	16011	0	0	1867	4.1


Medium Airplane
Long Range Mission
Altitude (ft
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12
Time (hr)
Pressure Alt


Medium Airplane
Long Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0 1 2 3 4 5 6 7 8 9 10 11 12
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Medium Airplane
Long Range Mission
Fuel Remaining (lbs
120,000
100,000
80,000
60,000
40,000
20,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining
#REF!
#REF!


Medium Airplane
Long Range Mission
Total Temp (F
140
120
100
80
60
40
20
0
-20
-40
-60
0 1 2 3 4 5 6 7 8 9 10 11 12
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

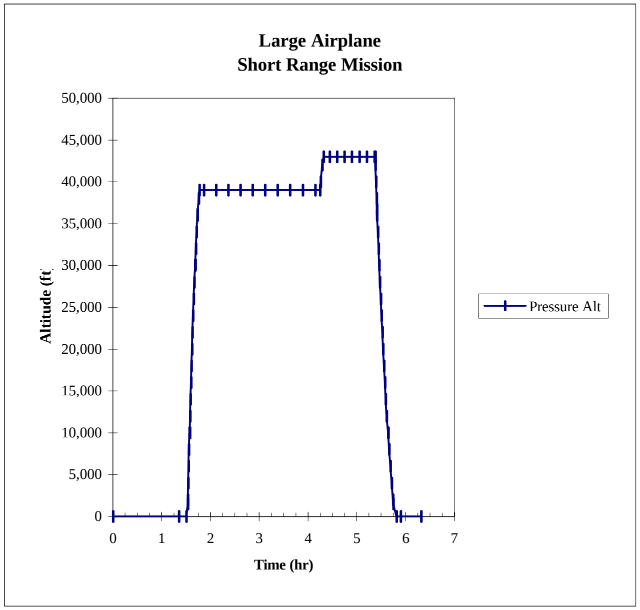
Large Commercial Transport
Short Range Mission

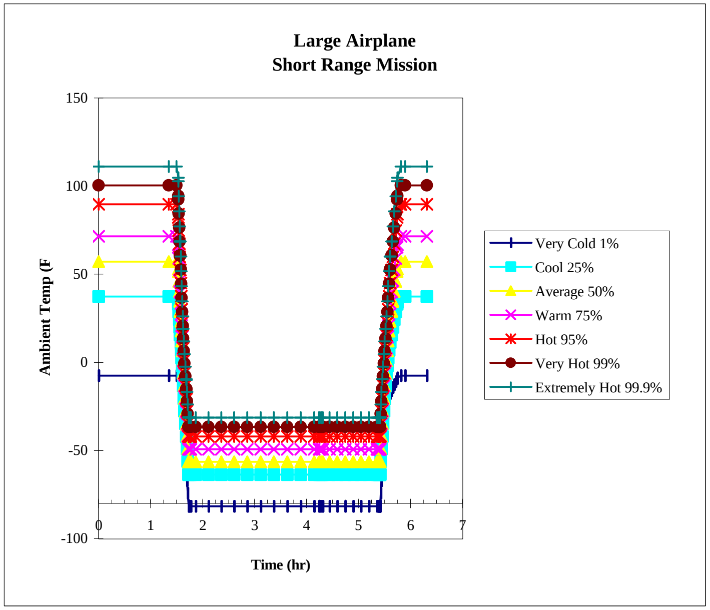
Ground Time (takeoff) = 90.000 minutes
Ground Time (landing) = 30.000 minutes

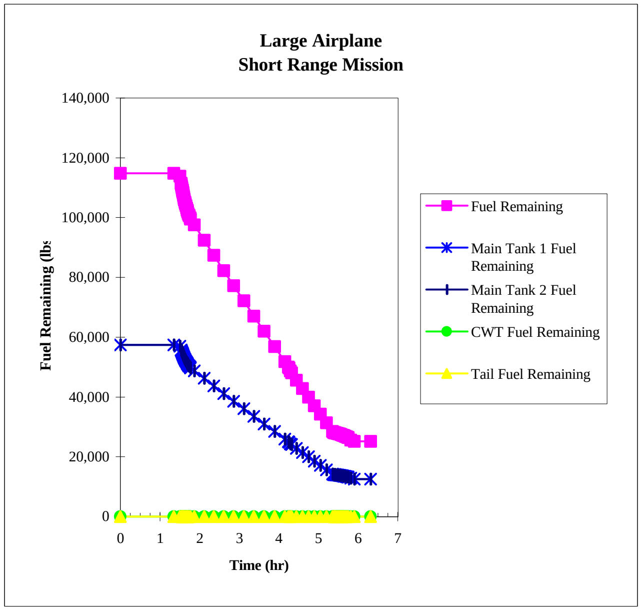
Main 1 Fuel Volume = 13,000 gal — Tank Volume 13,260
Main 2 Fuel Volume = 13,000 gal — Tank Volume 13,260
CWT Fuel Volume = 25,000 gal — Tank Volume 25,500
Tail Tank Fuel Volume = 3,000 gal — Tank Volume 3,060

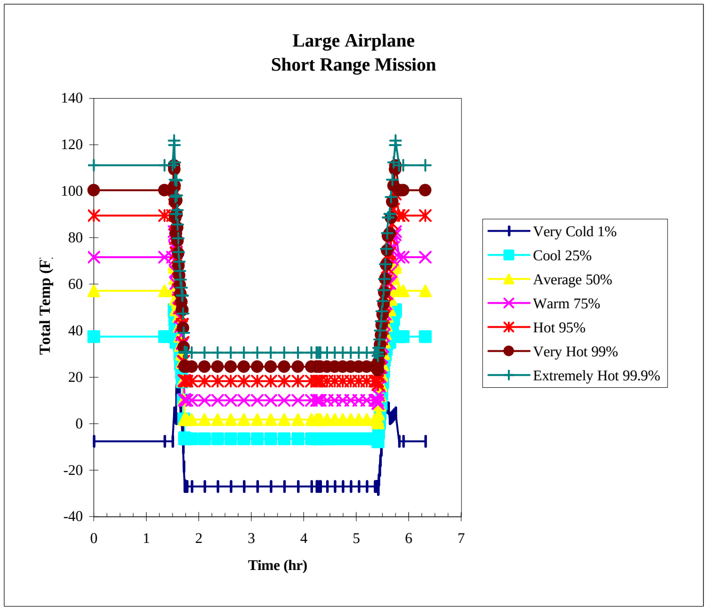
Threshold fuel in CWT to trigger tail fuel transfer = 10,000 gal

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Tail Fuel Remaining	Rate of Climb / Descent	Body Pitch Attitude
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	lbs	ft/min	degrees
0.0	0.0	0	0.0	0.000	574995	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	114775	57388	57388	0	0	0	
81.0	1.4	0	0.0	0.000	574995	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	6000	100	114775	57388	57388	0	0	0	
90.0	1.5	0	0.0	0.000	574095	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	75955	1266	113875	56938	56938	0	0	0	
92.0	1.5	1500	4.9	0.388	571691	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	75955	1266	111471	55736	55736	0	0	4629	12.6
92.1	1.5	2000	5.4	0.391	571554	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	75487	1258	111334	55667	55667	0	0	4613	12.5
92.5	1.5	4000	7.2	0.406	571011	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	73623	1227	110791	55396	55396	0	0	4537	12.2
93.0	1.5	6000	9.2	0.420	570471	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	71491	1192	110251	55126	55126	0	0	4425	11.8
93.5	1.6	8000	11.3	0.436	569933	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	69018	1150	109713	54857	54857	0	0	4274	11.3
93.9	1.6	10000	13.5	0.452	569394	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	66503	1108	109174	54587	54587	0	0	4114	10.8
93.9	1.6	10000	13.5	0.452	569394	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	66503	1108	109174	54587	54587	0	0	0	2.8
94.4	1.6	10000	16.3	0.584	568823	-16	16	29	40	52	61	69	14	48	62	74	87	96	105	69827	1164	108603	54302	54302	0	0	0	1.5
94.4	1.6	10000	16.3	0.584	568823	-16	16	29	40	52	61	69	14	48	62	74	87	96	105	69827	1164	108603	54302	54302	0	0	4429	8.2
94.9	1.6	12000	19.2	0.605	568293	-18	11	23	33	45	53	60	15	46	59	70	82	90	98	66844	1114	108073	54037	54037	0	0	4170	7.7
95.4	1.6	14000	22.4	0.628	567752	-19	7	18	27	38	45	52	15	44	55	65	77	84	92	63860	1064	107532	53766	53766	0	0	3896	7.1
95.9	1.6	16000	26.0	0.651	567199	-21	2	12	21	30	37	43	16	42	52	62	72	79	86	61097	1018	106979	53490	53490	0	0	3640	6.6
96.5	1.6	18000	29.9	0.676	566633	-23	-2	7	14	23	29	35	17	40	49	58	67	73	80	58500	975	106413	53207	53207	0	0	3403	6.1
97.1	1.6	20000	34.2	0.701	566050	-24	-6	1	8	15	21	26	18	38	46	54	62	68	74	55160	919	105830	52915	52915	0	0	3098	5.5
97.8	1.6	22000	39.0	0.728	565449	-31	-13	-6	1	8	14	19	14	34	42	50	58	64	70	53553	893	105229	52615	52615	0	0	2932	5.1
98.5	1.6	24000	44.4	0.756	564828	-39	-21	-13	-6	1	6	12	10	30	38	46	54	60	66	51555	859	104608	52304	52304	0	0	2716	4.7
99.3	1.7	26000	50.3	0.785	564179	-46	-28	-21	-13	-6	-1	5	5	26	34	42	50	56	62	49211	820	103959	51980	51980	0	0	2466	4.2
100.1	1.7	28000	57.2	0.816	563491	-53	-35	-28	-20	-13	-8	-2	1	22	30	38	46	52	58	46567	776	103271	51636	51636	0	0	2183	3.7
101.1	1.7	30000	65.4	0.848	562740	-60	-42	-35	-28	-20	-15	-10	-2	18	26	35	43	49	55	43799	730	102520	51260	51260	0	0	1847	3.1
101.2	1.7	30097	65.9	0.850	562701	-60	-42	-35	-28	-21	-15	-10	-3	18	26	34	43	49	55	43653	728	102481	51241	51241	0	0	1828	3.1
101.2	1.7	30097	65.9	0.850	562701	-60	-42	-35	-28	-21	-15	-10	-3	18	26	34	43	49	55	43653	728	102481	51241	51241	0	0	2700	4.1
101.9	1.7	32000	72.1	0.850	562178	-67	-49	-42	-35	-27	-22	-17	-10	10	18	27	35	41	47	40354	673	101958	50979	50979	0	0	2397	4.0
102.8	1.7	34000	79.5	0.850	561600	-74	-56	-49	-42	-35	-29	-24	-19	2	10	19	27	33	39	36957	616	101380	50690	50690	0	0	2069	4.0
103.9	1.7	36000	88.2	0.850	560973	-81	-63	-56	-49	-42	-36	-31	-27	-6	2	10	19	25	31	33491	558	100753	50377	50377	0	0	1699	3.9
103.9	1.7	36089	88.7	0.850	560944	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	33334	556	100724	50362	50362	0	0	1681	3.9
103.9	1.7	36089	88.7	0.850	560944	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	33334	556	100724	50362	50362	0	0	1519	3.7
105.4	1.8	38000	100.4	0.850	560182	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	30422	507	99962	49981	49981	0	0	1175	3.6
106.3	1.8	39000	107.9	0.850	559723	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	29009	483	99503	49752	49752	0	0	994	3.6
112.0	1.9	39000	153.9	0.850	557761	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20758	346	97541	48771	48771	0	0	0	2.4
126.7	2.1	39000	273.7	0.850	552682	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20584	343	92462	46231	46231	0	0	0	2.4
141.6	2.4	39000	394.5	0.850	547603	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20416	340	87383	43692	43692	0	0	0	2.4
156.6	2.6	39000	516.3	0.850	542525	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20253	338	82305	41153	41153	0	0	0	2.3
171.7	2.9	39000	639.0	0.850	537446	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20096	335	77226	38613	38613	0	0	0	2.3
186.9	3.1	39000	762.7	0.850	532367	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19940	332	72147	36074	36074	0	0	0	2.2
202.2	3.4	39000	887.3	0.850	527288	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19789	330	67068	33534	33534	0	0	0	2.2
217.7	3.6	39000	1012.9	0.850	522209	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19641	327	61989	30995	30995	0	0	0	2.2
233.3	3.9	39000	1139.5	0.850	517130	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19494	325	56910	28455	28455	0	0	0	2.1
249.0	4.1	39000	1267.0	0.850	512051	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19351	323	51831	25916	25916	0	0	0	2.1
254.5	4.2	39000	1311.8	0.850	510274	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19302	322	50054	25027	25027	0	0	0	2.1
255.3	4.3	40000	1318.4	0.850	509892	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	27464	458	49672	24836	24836	0	0	1144	3.6
257.5	4.3	42000	1336.1	0.850	508954	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	24874	415	48734	24367	24367	0	0	770	3.5
259.0	4.3	43000	1348.3	0.850	508348	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	23669	394	48128	24064	24064	0	0	585	3.5
266.6	4.4	43000	1410.5	0.850	505898	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19150	319	45678	22839	22839	0	0	0	2.8
275.6	4.6	43000	1483.6	0.850	503037	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19036	317	42817	21409	21409	0	0	0	2.8
284.7	4.7	43000	1557.1	0.850	500175	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	18922	315	39955	19978	19978	0	0	0	2.8
293.8	4.9	43000	1631.0	0.850	497314	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	18811	314	37094	18547	18547	0	0	0	2.7
302.9	5.0	43000	1705.4	0.850	494453	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	18698	312	34233	17117	17117	0	0	0	2.7
312.1	5.2	43000	1780.2	0.850	491591	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	18584	310	31371	15686	15686	0	0	0	2.7
321.4	5.4	43000	1855.5	0.850	488730	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	18472	308	28510	14255	14255	0	0	0	2.7
322.6	5.4	43000	1865.2	0.850	488363	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	18457	308	28143	14072	14072	0	0	0	2.7
322.9	5.4	42000	1867.9	0.850	488349	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	2622	44	28129	14065	14065	0	0	3028	-1.0
323.6	5.4	40000	1873.2	0.850	488319	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	2817	47	28099	14050	14050	0	0	3068	-1.5
324.2	5.4	38000	1878.4	0.850	488288	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	2980	50	28068	14034	14034	0	0	3178	-1.9
324.6	5.4	36672	1881.8	0.850	488267	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	3087	51	28047	14024	14024	0	0	3277	-2.3
324.6	5.4	36672	1881.8	0.850	488267	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	3087	51	28047	14024	14024	0	0	2292	-1.1
324.9	5.4	36089	1883.8	0.840	488254	-82	-64	-56	-49	-42	-37	-31	-28	-8	0	9	17	23	29	3120	52	28034	14017	14017	0	0	2257	-1.1
324.9	5.4	36089	1883.8	0.840	488254	-82	-64	-56	-49	-42	-37	-31	-28	-8	0	9	17	23	29	3120	52	28034	14017	14017	0	0	2417	-1.3
324.9	5.4	36000	1884.1	0.838	488252	-81	-63	-56	-49	-42	-36	-31	-28	-8	1	9	17	23	29	3124	52	28032	14016	14016	0	0	2412	-1.2
325.8	5.4	34000	1890.8	0.805	488208	-74	-56	-49	-42	-35	-29	-24	-24	-4	4	12	20	27	33	3213	54	27988	13994	13994	0	0	2336	-1.1
326.6	5.4	32000	1897.4	0.773	488161	-67	-49	-42	-35	-27	-22	-17	-20	0	8	16	24	30	36	3304	55	27941	13971	13971	0	0	2286	-1.0
327.5	5.5	30000	1903.9	0.742	488111	-60	-42	-35	-28	-20	-15	-10	-16	4	12	20	28	34	40	3407	57	27891	13946	13946	0	0	2239	-1.0
328.4	5.5	28000	1910.4	0.713	488058	-53	-35	-28	-20	-13	-8	-2	-11	8	16	24	32	38	44	3571	60	27838	13919	13919	0	0	2180	-0.9
329.3	5.5	26000	1916.9	0.685	488002	-46	-28	-21	-13	-6	-1	5	-7	13	21	29	37	42	48	3738	62	27782	13891	13891	0	0	2124	-0.9
330.3	5.5	24000	1923.3	0.659	487941	-39	-21	-13	-6	1	6	12	-2	18	25	33	41	47	53	3926	65	27721	13861	13861	0	0	2066	-0.9
331.3	5.5	22000	1929.7	0.634	487875	-31	-13	-6	1	8	14	19	3	22	30	38	46	52	57	4135	69	27655	13828	13828	0	0	2008	-0.9
332.3	5.5	20000	1936.1	0.610	487803	-24	-6	1	8	15	21	26	8	27	35	43	51	56	62	4346	72	27583	13792	13792	0	0	1954	-0.9
333.3	5.6	18000	1942.4	0.587	487727	-23	-2	7	14	23	29	35	7	30	39	47	56	62	69	4542	76	27507	13754	13754	0	0	1914	-1.0
334.4	5.6	16000	1948.7	0.565	487645	-21	2	12	21	30	37	43	7	32	42	51	61	68	75	4749	79	27425	13713	13713	0	0	1881	-1.1
335.5	5.6	14000	1954.9	0.544	487558	-19	7	18	27	38	45	52	7	34	46	56	67	74	82	5023	84	27338	13669	13669	0	0	1841	-1.1
336.6	5.6	12000	1961.1	0.525	487462	-18	11	23	33	45	53	60	7	37	50	61	73	81	89	5359	89	27242	13621	13621	0	0	1793	-1.2
336.6	5.6	12000	1961.1	0.525	487462	-18	11	23	33	45	53	60	7	37	50	61	73	81	89	5359	89	27242	13621	13621	0	0	1250	-0.3
338.4	5.6	10000	1970.5	0.452	487293	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	5704	95	27073	13537	13537	0	0	976	0.4
338.4	5.6	10000	1970.5	0.452	487293	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	5704	95	27073	13537	13537	0	0	1370	-0.4


Large Airplane
Short Range Mission
Altitude (ft
Time (hr)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
Pressure Alt


Large Airplane
Short Range Mission
Ambient Temp (F
Time (hr)
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

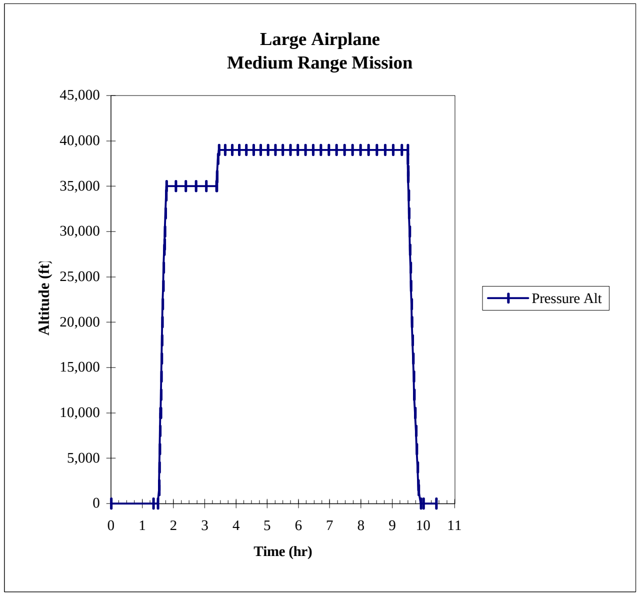

Large Airplane
Short Range Mission
Fuel Remaining (lbs
Time (hr)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
1
2
3
4
5
6
7
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining

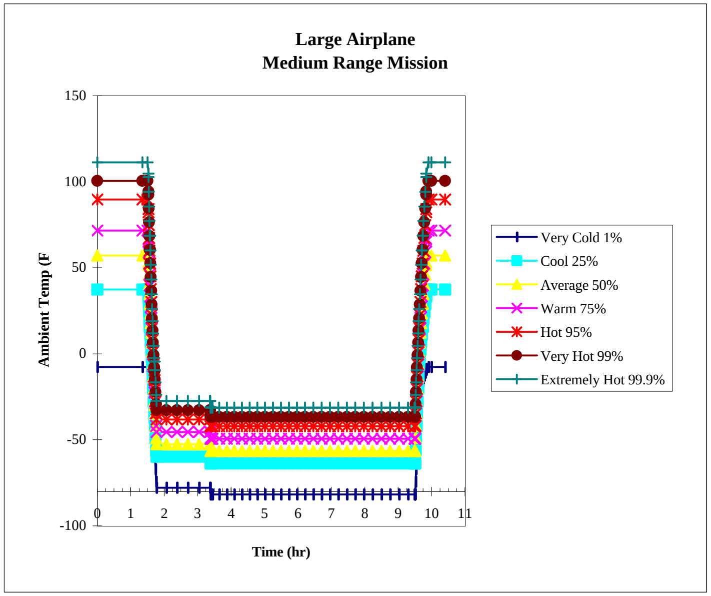

Large Airplane
Short Range Mission
Total Temp (F
Time (hr)
140
120
100
80
60
40
20
0
-20
-40
0
1
2
3
4
5
6
7
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

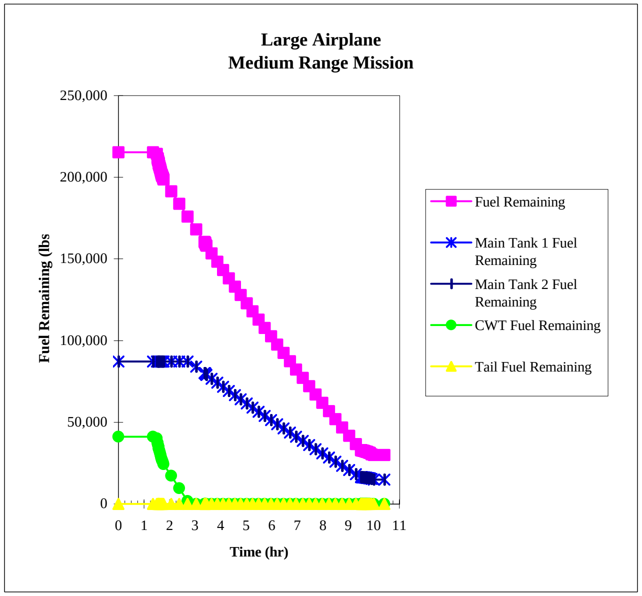
Large Commercial Transport
Medium Range Mission

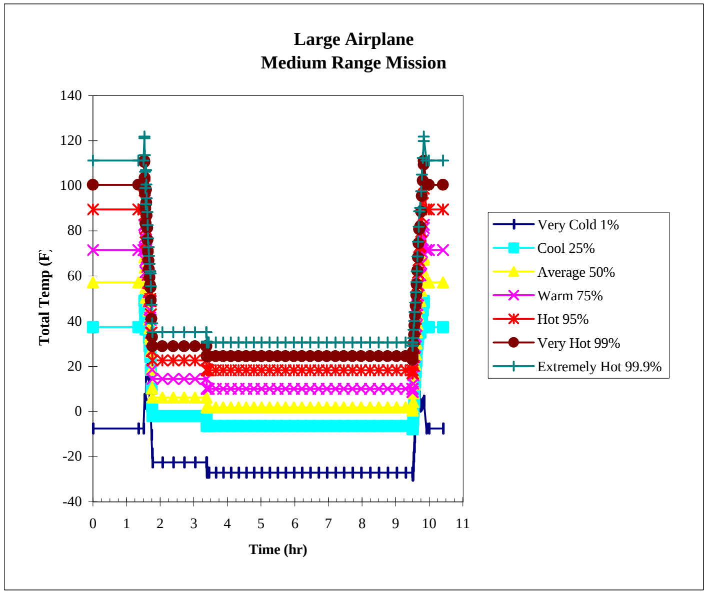
Ground Time (takeoff) =	90.000	minutes	Main 1 Fuel Volume =	13,000	gal	Tank Volume	13,260	Threshold fuel in CWT to trigger		
Ground Time (landing) =	30.000	minutes	Main 2 Fuel Volume =	13,000	gal	Tank Volume	13,260	tail fuel transfer =	10,000	gal
			CWT Fuel Volume =	25,000	gal	Tank Volume	25,500			
			Tail Tank Fuel Volume =	3,000	gal	Tank Volume	3,060			

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)				
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**
0.0	0.0	0	0.0	0.000	675500	-8	37	57	72	90	100	111	-8	37	57	72	90
81.0	1.4	0	0.0	0.000	675500	-8	37	57	72	90	100	111	-8	37	57	72	90
90.0	1.5	0	0.0	0.000	674600	-8	37	57	72	90	100	111	-8	37	57	72	90
92.0	1.5	1500	5.4	0.388	671951	-9	34	53	67	84	94	105	5	49	68	83	100
92.1	1.5	2000	6.0	0.405	671785	-9	33	52	65	82	92	103	6	49	68	82	100
92.7	1.5	4000	8.3	0.420	671124	-11	29	46	59	75	84	94	5	46	64	77	94
93.2	1.6	6000	10.8	0.435	670466	-13	24	40	53	67	76	86	4	43	59	72	87
93.8	1.6	8000	13.5	0.451	669807	-14	20	35	46	60	69	77	4	39	55	67	81
94.3	1.6	10000	16.3	0.468	669146	-16	16	29	40	52	61	69	3	36	50	62	75
94.3	1.6	10000	16.3	0.468	669146	-16	16	29	40	52	61	69	3	36	50	62	75
95.0	1.6	10000	20.0	0.602	668409	-16	16	29	40	52	61	69	16	50	65	76	90
95.0	1.6	10000	20.0	0.602	668409	-16	16	29	40	52	61	69	16	50	65	76	90
95.6	1.6	12000	23.7	0.624	667754	-18	11	23	33	45	53	60	17	48	61	72	84
96.2	1.6	14000	27.8	0.647	667082	-19	7	18	27	38	45	52	18	46	58	68	79
96.8	1.6	16000	32.3	0.671	666390	-21	2	12	21	30	37	43	19	44	55	64	74
97.6	1.6	18000	37.4	0.696	665677	-23	-2	7	14	23	29	35	20	42	52	60	70
98.3	1.6	20000	43.0	0.723	664936	-24	-6	1	8	15	21	26	21	41	49	57	65
99.2	1.7	22000	49.3	0.750	664165	-31	-13	-6	1	8	14	19	17	37	45	53	61
100.1	1.7	24000	56.3	0.779	663360	-39	-21	-13	-6	1	6	12	13	33	41	49	57
101.1	1.7	26000	64.3	0.809	662507	-46	-28	-21	-13	-6	-1	5	8	29	37	45	53
102.2	1.7	28000	73.8	0.840	661583	-53	-35	-28	-20	-13	-8	-2	5	25	33	42	50
102.6	1.7	28599	76.9	0.850	661286	-55	-37	-30	-23	-15	-10	-5	4	24	32	41	49
102.6	1.7	28599	76.9	0.850	661286	-55	-37	-30	-23	-15	-10	-5	4	24	32	41	49
103.3	1.7	30000	82.4	0.850	660799	-60	-42	-35	-28	-20	-15	-10	-2	18	27	35	43
104.3	1.7	32000	91.1	0.850	660063	-67	-49	-42	-35	-27	-22	-17	-10	10	18	27	35
105.6	1.8	34000	101.6	0.850	659250	-74	-56	-49	-42	-35	-29	-24	-19	2	10	19	27
106.3	1.8	35000	107.7	0.850	658800	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23
123.8	2.1	35000	250.8	0.850	651689	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23
143.2	2.4	35000	408.5	0.850	643927	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23
162.7	2.7	35000	567.9	0.850	636164	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23
182.4	3.0	35000	728.9	0.850	628401	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23
202.3	3.4	35000	891.4	0.850	620639	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23
202.7	3.4	35000	894.8	0.850	620477	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23
203.4	3.4	36000	900.6	0.850	620069	-81	-63	-56	-49	-42	-36	-31	-27	-6	2	10	19
203.5	3.4	36089	901.2	0.850	620031	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
203.5	3.4	36089	901.2	0.850	620031	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
205.5	3.4	38000	917.5	0.850	618978	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
206.9	3.4	39000	929.1	0.850	618279	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
219.1	3.7	39000	1027.7	0.850	613629	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
232.4	3.9	39000	1136.3	0.850	608550	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
245.9	4.1	39000	1245.9	0.850	603471	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
259.5	4.3	39000	1356.5	0.850	598392	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
273.3	4.6	39000	1468.1	0.850	593313	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
287.1	4.8	39000	1580.8	0.850	588234	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
301.1	5.0	39000	1694.4	0.850	583155	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
315.2	5.3	39000	1809.2	0.850	578077	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
329.5	5.5	39000	1924.9	0.850	572998	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
343.9	5.7	39000	2041.7	0.850	567919	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
358.4	6.0	39000	2159.4	0.850	562840	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
373.0	6.2	39000	2278.2	0.850	557761	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
387.7	6.5	39000	2398.0	0.850	552682	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
402.6	6.7	39000	2518.8	0.850	547603	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
417.6	7.0	39000	2640.6	0.850	542525	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
432.7	7.2	39000	2763.3	0.850	537446	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
447.9	7.5	39000	2887.0	0.850	532367	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
463.2	7.7	39000	3011.7	0.850	527288	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
478.7	8.0	39000	3137.2	0.850	522209	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
494.3	8.2	39000	3263.8	0.850	517130	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
510.0	8.5	39000	3391.3	0.850	512051	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
525.8	8.8	39000	3519.7	0.850	506972	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
541.7	9.0	39000	3649.0	0.850	501893	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
557.7	9.3	39000	3779.3	0.850	496815	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
569.5	9.5	39000	3875.2	0.850	493096	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
569.8	9.5	38000	3877.8	0.850	493080	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
570.3	9.5	36672	3881.2	0.850	493059	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
570.3	9.5	36672	3881.2	0.850	493059	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18
570.5	9.5	36089	3883.3	0.840	493046	-82	-64	-56	-49	-42	-37	-31	-28	-8	0	9	17
570.5	9.5	36089	3883.3	0.840	493046	-82	-64	-56	-49	-42	-37	-31	-28	-8	0	9	17
570.6	9.5	36000	3883.6	0.838	493044	-81	-63	-56	-49	-42	-36	-31	-28	-8	1	9	17
571.4	9.5	34000	3890.2	0.805	492999	-74	-56	-49	-42	-35	-29	-24	-24	-4	4	12	20
572.3	9.5	32000	3896.9	0.773	492952	-67	-49	-42	-35	-27	-22	-17	-20	0	8	16	24
573.2	9.6	30000	3903.4	0.742	492902	-60	-42	-35	-28	-20	-15	-10	-16	4	12	20	28
574.1	9.6	28000	3910.0	0.713	492850	-53	-35	-28	-20	-13	-8	-2	-11	8	16	24	32
575.0	9.6	26000	3916.4	0.685	492793	-46	-28	-21	-13	-6	-1	5	-7	13	21	29	37
576.0	9.6	24000	3922.9	0.659	492731	-39	-21	-13	-6	1	6	12	-2	18	25	33	41
576.9	9.6	22000	3929.3	0.634	492665	-31	-13	-6	1	8	14	19	3	22	30	38	46
578.0	9.6	20000	3935.8	0.610	492593	-24	-6	1	8	15	21	26	8	27	35	43	51
579.0	9.6	18000	3942.1	0.587	492516	-23	-2	7	14	23	29	35	7	30	39	47	56
580.1	9.7	16000	3948.4	0.565	492434	-21	2	12	21	30	37	43	7	32	42	51	61
581.1	9.7	14000	3954.7	0.544	492346	-19	7	18	27	38	45	52	7	34	46	56	67
582.2	9.7	12000	3960.9	0.525	492251	-18	11	23	33	45	53	60	7	37	50	61	73
582.2	9.7	12000	3960.9	0.525	492251	-18	11	23	33	45	53	60	7	37	50	61	73
584.1	9.7	10000	3970.3	0.452	492081	-16	16	29	40	52	61	69	2	35	49	60	73
584.1	9.7	10000	3970.3	0.452	492081	-16	16	29	40	52	61	69	2	35	49	60	73
585.6	9.8	8000	3977.3	0.436	491939	-14	20	35	46	60	69	77	3	38	53	65	80
587.1	9.8	6000	3984.3	0.420	491790	-13	24	40	53	67	76	86	3	41	58	71	86
588.6	9.8	4000	3991.3	0.406	491635	-11	29	46	59	75	84	94	4	45	63	76	92
590.2	9.8	2000	3998.2	0.391	491475	-9	33	52	65	82	92	103	5	48	67	81	99
590.6	9.8	1500	3999.9	0.388	491434	-9	34	53	67	84	94	105	5	49	68	83	100
594.6	9.9	0	3999.9	0.000	490634	-8	37	57	72	90	100	111	-8	37	57	72	90
599.6	10.0	0	3999.9	0.000	490134	-8	37	57	72	90	100	111	-8	37	57	72	90
624.6	10.4	0	3999.9	0.000	490134	-8	37	57	72	90	100	111	-8	37	57	72	90


Large Airplane
Medium Range Mission
Altitude (ft
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0 1 2 3 4 5 6 7 8 9 10 11
Time (hr)
Pressure Alt


Large Airplane
Medium Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0 1 2 3 4 5 6 7 8 9 10 11
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Large Airplane
Medium Range Mission
Fuel Remaining (lbs
250,000
200,000
150,000
100,000
50,000
0
0 1 2 3 4 5 6 7 8 9 10 11
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining


Large Airplane
Medium Range Mission
Total Temp (F)
140
120
100
80
60
40
20
0
-20
-40
0 1 2 3 4 5 6 7 8 9 10 11
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

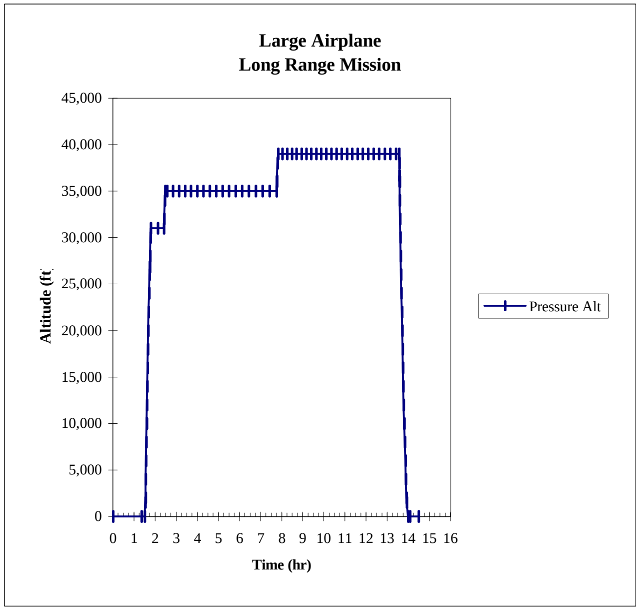
Large Commercial Transport
Long Range Mission

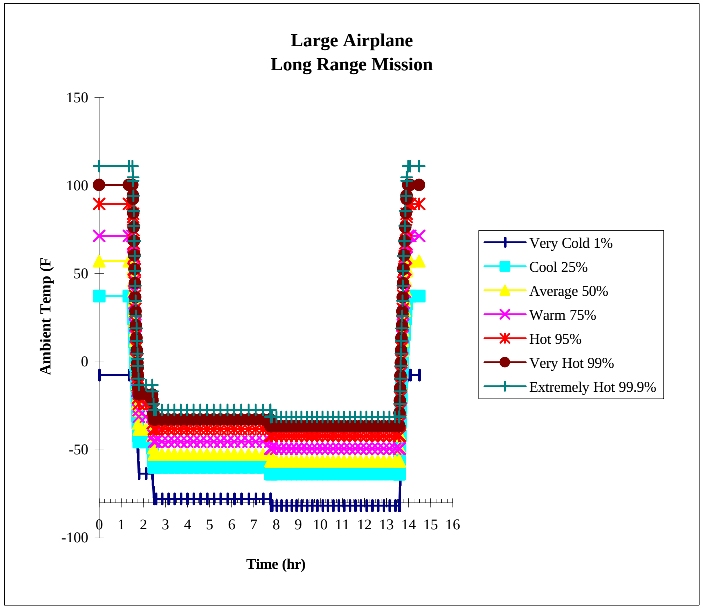
Ground Time (takeoff) = 90.000 minutes
Ground Time (landing) = 30.000 minutes

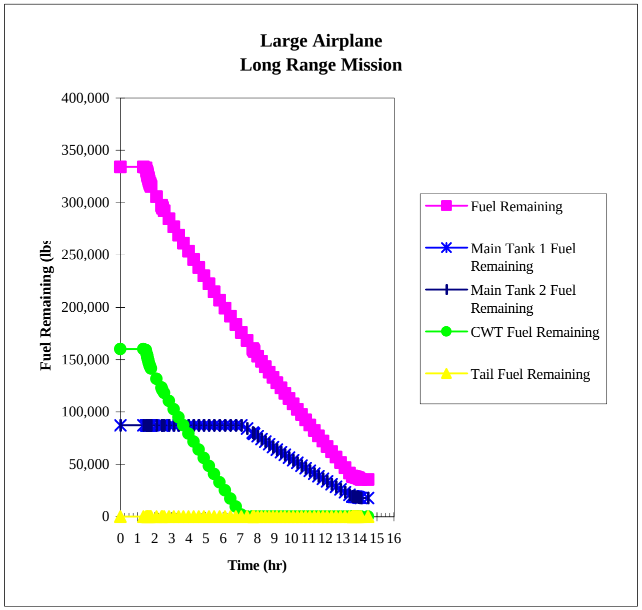
Main 1 Fuel Volume = 13,000 gal   Tank Volume 13,260
Main 2 Fuel Volume = 13,000 gal   Tank Volume 13,260
CWT Fuel Volume = 25,000 gal   Tank Volume 25,500
Tail Tank Fuel Volume = 3,000 gal   Tank Volume 3,060

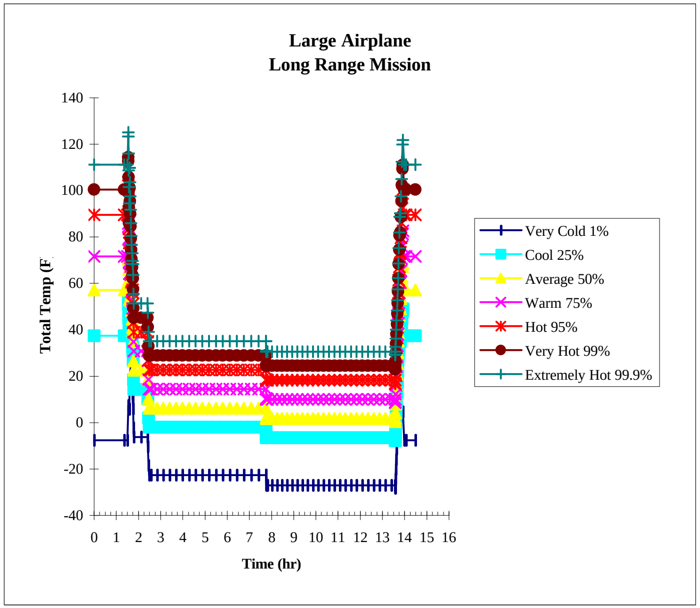
Threshold fuel in CWT to trigger tail fuel transfer = 10,000 gal

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Tail Fuel Remaining	Rate of Climb / Descent	Body Pitch Attitude
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	lbs	ft/min	degrees
0.0	0.0	0	0.0	0.000	794498	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	334278	87100	87100	160078	0	0	
81.0	1.4	0	0.0	0.000	794498	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	6000	100	334278	87100	87100	160078	0	0	
90.0	1.5	0	0.0	0.000	793598	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	76691	1278	333378	87100	87100	159178	0	0	
92.3	1.5	1500	6.4	0.425	790626	-9	34	53	67	84	94	105	7	52	71	86	104	114	125	76691	1278	330406	87100	87100	156206	0	3130	9.4
92.5	1.5	2000	7.1	0.428	790422	-9	33	52	65	82	92	103	7	51	70	85	102	113	123	76259	1271	330202	87100	87100	156002	0	3117	9.4
93.1	1.6	4000	10.2	0.444	789608	-11	29	46	59	75	84	94	7	48	66	79	96	106	116	74464	1241	329388	87100	87100	155188	0	3054	9.2
93.8	1.6	6000	13.5	0.460	788793	-13	24	40	53	67	76	86	6	45	61	74	90	99	109	72317	1205	328573	87100	87100	154373	0	2956	8.9
94.5	1.6	8000	16.9	0.477	787974	-14	20	35	46	60	69	77	6	42	57	69	83	93	102	69890	1165	327754	87100	87100	153554	0	2829	8.7
95.2	1.6	10000	20.7	0.494	787146	-16	16	29	40	52	61	69	6	39	53	64	77	86	94	67394	1123	326926	87100	87100	152726	0	2695	8.4
95.2	1.6	10000	20.7	0.494	787146	-16	16	29	40	52	61	69	6	39	53	64	77	86	94	67394	1123	326926	87100	87100	152726	0	0	3.6
96.0	1.6	10000	25.5	0.624	786215	-16	16	29	40	52	61	69	19	53	67	79	92	101	110	70690	1178	325995	87100	87100	151795	0	0	2.1
96.0	1.6	10000	25.5	0.624	786215	-16	16	29	40	52	61	69	19	53	67	79	92	101	110	70690	1178	325995	87100	87100	151795	0	2869	6.2
96.7	1.6	12000	30.4	0.647	785380	-18	11	23	33	45	53	60	19	51	64	75	87	95	104	67607	1127	325160	87100	87100	150960	0	2656	5.8
97.5	1.6	14000	35.8	0.670	784515	-19	7	18	27	38	45	52	20	49	61	71	82	90	98	64672	1078	324295	87100	87100	150095	0	2445	5.4
98.4	1.6	16000	41.9	0.695	783615	-21	2	12	21	30	37	43	21	47	58	67	77	85	92	61943	1032	323395	87100	87100	149195	0	2249	5.0
99.3	1.7	18000	48.7	0.721	782679	-23	-2	7	14	23	29	35	23	46	55	64	73	79	86	59848	997	322459	87100	87100	148259	0	2092	4.7
100.3	1.7	20000	56.3	0.748	781695	-24	-6	1	8	15	21	26	24	44	52	60	68	74	80	56856	948	321475	87100	87100	147275	0	1869	4.3
101.4	1.7	22000	65.0	0.776	780656	-31	-13	-6	1	8	14	19	20	40	48	56	65	71	77	55074	918	320436	87100	87100	146236	0	1725	3.9
102.6	1.7	24000	74.8	0.806	779554	-39	-21	-13	-6	1	6	12	16	36	45	53	61	67	73	52962	883	319334	87100	87100	145134	0	1551	3.6
104.0	1.7	26000	86.2	0.836	778359	-46	-28	-21	-13	-6	-1	5	12	33	41	49	57	64	70	50660	844	318139	87100	87100	143939	0	1348	3.2
104.7	1.7	26854	91.7	0.850	777807	-49	-31	-24	-16	-9	-4	2	11	31	39	48	56	62	68	49459	824	317587	87100	87100	143387	0	1237	3.0
104.7	1.7	26854	91.7	0.850	777807	-49	-31	-24	-16	-9	-4	2	11	31	39	48	56	62	68	49459	824	317587	87100	87100	143387	0	1828	3.6
105.3	1.8	28000	97.3	0.850	777280	-53	-35	-28	-20	-13	-8	-2	6	27	35	43	51	57	64	47350	789	317060	87100	87100	142860	0	1682	3.6
106.6	1.8	30000	108.2	0.850	776291	-60	-42	-35	-28	-20	-15	-10	-2	18	27	35	43	49	55	43826	730	316071	87100	87100	141871	0	1405	3.7
107.4	1.8	31000	114.5	0.850	775750	-64	-46	-38	-31	-24	-19	-13	-6	14	23	31	39	45	51	42064	701	315530	87100	87100	141330	0	1248	3.7
127.1	2.1	31000	278.3	0.850	766100	-64	-46	-38	-31	-24	-19	-13	-6	14	23	31	39	45	51	29215	487	305880	87100	87100	131680	0	0	2.2
144.6	2.4	31000	423.6	0.850	757630	-64	-46	-38	-31	-24	-19	-13	-6	14	23	31	39	45	51	28922	482	297410	87100	87100	123210	0	0	2.1
145.4	2.4	32000	430.1	0.850	757092	-67	-49	-42	-35	-27	-22	-17	-10	10	18	27	35	41	47	40074	668	296872	87100	87100	122672	0	1191	3.7
147.4	2.5	34000	446.8	0.850	755805	-74	-56	-49	-42	-35	-29	-24	-19	2	10	19	27	33	39	36700	612	295585	87100	87100	121385	0	843	3.7
148.8	2.5	35000	457.9	0.850	754999	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	35058	584	294779	87100	87100	120579	0	660	3.7
153.8	2.6	35000	499.4	0.850	752602	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	28210	470	292382	87100	87100	118182	0	0	2.9
170.5	2.8	35000	635.1	0.850	744840	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	27855	464	284620	87100	87100	110420	0	0	2.8
187.3	3.1	35000	772.5	0.850	737077	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	27517	459	276857	87100	87100	102657	0	0	2.8
204.3	3.4	35000	911.6	0.850	729315	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	27187	453	269095	87100	87100	94895	0	0	2.7
221.6	3.7	35000	1052.3	0.850	721552	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	26854	448	261332	87100	87100	87132	0	0	2.7
239.0	4.0	35000	1194.8	0.850	713790	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	26527	442	253570	87100	87100	79370	0	0	2.6
256.7	4.3	35000	1339.1	0.850	706027	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	26211	437	245807	87100	87100	71607	0	0	2.6
274.5	4.6	35000	1485.0	0.850	698264	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	25904	432	238044	87100	87100	63844	0	0	2.6
292.6	4.9	35000	1632.7	0.850	690502	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	25609	427	230282	87100	87100	56082	0	0	2.5
310.9	5.2	35000	1782.1	0.850	682739	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	25322	422	222519	87100	87100	48319	0	0	2.5
329.4	5.5	35000	1933.1	0.850	674977	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	25038	417	214757	87100	87100	40557	0	0	2.4
348.1	5.8	35000	2085.8	0.850	667214	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	24762	413	206994	87100	87100	32794	0	0	2.4
367.0	6.1	35000	2240.3	0.850	659452	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	24493	408	199232	87100	87100	25032	0	0	2.3
386.2	6.4	35000	2396.4	0.850	651689	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	24233	404	191469	87100	87100	17269	0	0	2.3
405.5	6.8	35000	2554.2	0.850	643927	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	23985	400	183707	87100	87100	9507	0	0	2.2
425.0	7.1	35000	2713.5	0.850	636164	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	23745	396	175944	87100	87100	1744	0	0	2.2
444.7	7.4	35000	2874.5	0.850	628401	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	23510	392	168181	84091	84091	0	0	0	2.1
464.6	7.7	35000	3037.1	0.850	620639	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	23281	388	160419	80210	80210	0	0	0	2.1
465.0	7.8	35000	3040.5	0.850	620477	-78	-60	-53	-45	-38	-33	-27	-23	-2	6	14	23	29	35	23277	388	160257	80129	80129	0	0	0	2.1
465.7	7.8	36000	3046.3	0.850	620069	-81	-63	-56	-49	-42	-36	-31	-27	-6	2	10	19	25	31	33259	554	159849	79925	79925	0	0	1301	3.8
465.8	7.8	36089	3046.9	0.850	620031	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	33102	552	159811	79906	79906	0	0	1283	3.8
465.8	7.8	36089	3046.9	0.850	620031	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	33102	552	159811	79906	79906	0	0	1159	3.6
467.8	7.8	38000	3063.2	0.850	618978	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	30211	504	158758	79379	79379	0	0	805	3.6
469.2	7.8	39000	3074.8	0.850	618279	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	28807	480	158059	79030	79030	0	0	621	3.6
481.4	8.0	39000	3173.4	0.850	613629	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	22903	382	153409	76705	76705	0	0	0	2.8
494.7	8.2	39000	3282.0	0.850	608550	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	22696	378	148330	74165	74165	0	0	0	2.8
508.2	8.5	39000	3391.6	0.850	603471	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	22491	375	143251	71626	71626	0	0	0	2.8
521.8	8.7	39000	3502.2	0.850	598392	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	22285	371	138172	69086	69086	0	0	0	2.7
535.6	8.9	39000	3613.8	0.850	593313	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	22081	368	133093	66547	66547	0	0	0	2.7
549.4	9.2	39000	3726.5	0.850	588234	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	21879	365	128014	64007	64007	0	0	0	2.6
563.4	9.4	39000	3840.1	0.850	583155	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	21681	361	122935	61468	61468	0	0	0	2.6
577.6	9.6	39000	3954.9	0.850	578077	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	21488	358	117857	58929	58929	0	0	0	2.6
591.8	9.9	39000	4070.6	0.850	572998	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	21299	355	112778	56389	56389	0	0	0	2.5
606.2	10.1	39000	4187.4	0.850	567919	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	21116	352	107699	53850	53850	0	0	0	2.5
620.7	10.3	39000	4305.1	0.850	562840	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20936	349	102620	51310	51310	0	0	0	2.5
635.3	10.6	39000	4423.9	0.850	557761	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20758	346	97541	48771	48771	0	0	0	2.4
650.0	10.8	39000	4543.7	0.850	552682	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20584	343	92462	46231	46231	0	0	0	2.4
664.9	11.1	39000	4664.5	0.850	547603	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20416	340	87383	43692	43692	0	0	0	2.4
679.9	11.3	39000	4786.3	0.850	542525	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20253	338	82305	41153	41153	0	0	0	2.3
695.0	11.6	39000	4909.0	0.850	537446	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	20096	335	77226	38613	38613	0	0	0	2.3
710.2	11.8	39000	5032.7	0.850	532367	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19940	332	72147	36074	36074	0	0	0	2.2
725.5	12.1	39000	5157.4	0.850	527288	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19789	330	67068	33534	33534	0	0	0	2.2
741.0	12.3	39000	5282.9	0.850	522209	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19641	327	61989	30995	30995	0	0	0	2.2
756.6	12.6	39000	5409.5	0.850	517130	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19494	325	56910	28455	28455	0	0	0	2.1
772.3	12.9	39000	5537.0	0.850	512051	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19351	323	51831	25916	25916	0	0	0	2.1
788.1	13.1	39000	5665.4	0.850	506972	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19212	320	46752	23376	23376	0	0	0	2.1


Large Airplane
Long Range Mission
Altitude (ft
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Pressure Alt


Large Airplane
Long Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Large Airplane
Long Range Mission
Fuel Remaining (lbs
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining
Tail Fuel Remaining


Large Airplane
Long Range Mission
Total Temp (F
140
120
100
80
60
40
20
0
-20
-40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

Regional Turbofan Mission

Ground Time (takeoff) =	20	minutes	Main 1 Fuel Volume =	1,200	gal	Tank Volume	1,224
Ground Time (landing) =	10	minutes	Main 2 Fuel Volume =	1,200	gal	Tank Volume	1,224
	^		CWT Fuel Volume =	800	gal	Tank Volume	816
	JRS Guess						

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min
0.0	0.0	0	0.0	0.000	64270	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	6770	3385	3385	0	0
10.0	0.2	0	0.0	0.000	64270	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	1260	21	6770	3385	3385	0	0
20.0	0.3	0	0.0	0.000	64060	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	9000	150	6560	3280	3280	0	0
21.5	0.4	1500	1.9	0.388	63851	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	7471	125	6351	3176	3176	0	3194
21.6	0.4	2000	2.6	0.391	63832	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	7405	123	6332	3166	3166	0	3166
22.3	0.4	4000	5.4	0.406	63754	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	7143	119	6254	3127	3127	0	3053
22.9	0.4	6000	8.4	0.420	63676	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	6887	115	6176	3088	3088	0	2937
23.6	0.4	8000	11.5	0.436	63598	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	6637	111	6098	3049	3049	0	2817
24.4	0.4	10000	15.0	0.452	63519	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	6386	106	6019	3010	3010	0	2693
25.1	0.4	12000	18.7	0.469	63439	-18	11	23	33	45	53	60	2	32	45	55	67	75	83	6148	102	5939	2970	2970	0	2559
25.9	0.4	14000	22.7	0.487	63359	-19	7	18	27	38	45	52	2	29	40	50	61	69	76	5910	99	5859	2930	2930	0	2422
26.8	0.4	16000	27.1	0.506	63276	-21	2	12	21	30	37	43	2	26	36	45	55	62	69	5678	95	5776	2888	2888	0	2280
27.7	0.5	18000	31.9	0.526	63192	-23	-2	7	14	23	29	35	2	23	32	41	49	56	62	5454	91	5692	2846	2846	0	2137
28.6	0.5	20000	37.3	0.547	63106	-24	-6	1	8	15	21	26	2	21	28	36	44	49	55	5231	87	5606	2803	2803	0	1994
29.7	0.5	22000	43.2	0.569	63017	-31	-13	-6	1	8	14	19	-4	15	23	31	38	44	50	5012	84	5517	2759	2759	0	1832
30.8	0.5	24000	49.9	0.592	62924	-39	-21	-13	-6	1	6	12	-9	10	18	26	33	39	45	4795	80	5424	2712	2712	0	1670
32.1	0.5	26000	57.5	0.616	62825	-46	-28	-21	-13	-6	-1	5	-14	5	13	21	28	34	40	4582	76	5325	2663	2663	0	1503
33.5	0.6	28000	66.4	0.641	62720	-53	-35	-28	-20	-13	-8	-2	-19	0	8	16	23	29	35	4375	73	5220	2610	2610	0	1331
35.1	0.6	30000	76.8	0.668	62605	-60	-42	-35	-28	-20	-15	-10	-24	-5	3	11	19	25	31	4171	70	5105	2553	2553	0	1157
37.0	0.6	32000	89.3	0.696	62478	-67	-49	-42	-35	-27	-22	-17	-29	-9	-1	6	14	20	26	3972	66	4978	2489	2489	0	978
37.2	0.6	32200	90.7	0.699	62464	-68	-50	-43	-35	-28	-23	-17	-30	-10	-2	6	14	20	26	3952	66	4964	2482	2482	0	960
37.3	0.6	32250	91.0	0.700	62461	-68	-50	-43	-36	-28	-23	-18	-30	-10	-2	6	14	20	26	3947	66	4961	2481	2481	0	955
37.9	0.6	33000	95.2	0.700	62421	-71	-53	-45	-38	-31	-26	-20	-33	-13	-5	3	11	17	23	3852	64	4921	2461	2461	0	1205
38.8	0.6	34000	101.0	0.700	62367	-74	-56	-49	-42	-35	-29	-24	-36	-17	-9	-1	7	13	19	3728	62	4867	2434	2434	0	1117
39.7	0.7	35000	107.3	0.700	62309	-78	-60	-53	-45	-38	-33	-27	-40	-21	-13	-5	3	9	15	3604	60	4809	2405	2405	0	1019
45.8	0.8	35000	152.5	0.770	62000	-78	-60	-53	-45	-38	-33	-27	-33	-12	-4	4	12	18	24	3039	51	4500	2250	2250	0	0
55.7	0.9	35000	225.6	0.770	61500	-78	-60	-53	-45	-38	-33	-27	-33	-12	-4	4	12	18	24	3029	50	4000	2000	2000	0	0
65.7	1.1	35000	299.1	0.770	61000	-78	-60	-53	-45	-38	-33	-27	-33	-12	-4	4	12	18	24	3018	50	3500	1750	1750	0	0
73.1	1.2	35000	355.0	0.770	60620	-78	-60	-53	-45	-38	-33	-27	-33	-12	-4	4	12	18	24	3009	50	3120	1560	1560	0	0
74.0	1.2	34000	360.7	0.700	60622	-74	-56	-49	-42	-35	-29	-24	-36	-17	-9	-1	7	13	19	2992	50	3122	1561	1561	0	434
74.3	1.2	33000	362.9	0.700	60620	-71	-53	-45	-38	-31	-26	-20	-33	-13	-5	3	11	17	23	3054	51	3120	1560	1560	0	445
74.6	1.2	32250	364.6	0.700	60618	-68	-50	-43	-36	-28	-23	-18	-30	-10	-2	6	14	20	26	2342	39	3118	1559	1559	0	457
74.6	1.2	32200	364.7	0.699	60618	-68	-50	-43	-35	-28	-23	-17	-30	-10	-2	6	14	20	26	2341	39	3118	1559	1559	0	458
75.1	1.3	31000	368.2	0.682	60614	-64	-46	-38	-31	-24	-19	-13	-27	-7	1	9	17	23	28	2312	39	3114	1557	1557	0	476
75.5	1.3	30000	371.0	0.668	60610	-60	-42	-35	-28	-20	-15	-10	-24	-5	3	11	19	25	31	2289	38	3110	1555	1555	0	491
76.4	1.3	28000	376.7	0.641	60603	-53	-35	-28	-20	-13	-8	-2	-19	0	8	16	23	29	35	2242	37	3103	1552	1552	0	524
77.3	1.3	26000	382.4	0.616	60595	-46	-28	-21	-13	-6	-1	5	-14	5	13	21	28	34	40	2193	37	3095	1548	1548	0	558
78.2	1.3	24000	387.9	0.592	60586	-39	-21	-13	-6	1	6	12	-9	10	18	26	33	39	45	2144	36	3086	1543	1543	0	596
79.2	1.3	22000	393.5	0.569	60576	-31	-13	-6	1	8	14	19	-4	15	23	31	38	44	50	2095	35	3076	1538	1538	0	636
80.1	1.3	20000	398.9	0.547	60566	-24	-6	1	8	15	21	26	2	21	28	36	44	49	55	2044	34	3066	1533	1533	0	675
81.1	1.4	18000	404.4	0.526	60554	-23	-2	7	14	23	29	35	2	23	32	41	49	56	62	1991	33	3054	1527	1527	0	723
82.2	1.4	16000	409.8	0.506	60541	-21	2	12	21	30	37	43	2	26	36	45	55	62	69	1938	32	3041	1521	1521	0	770
83.2	1.4	14000	415.3	0.487	60528	-19	7	18	27	38	45	52	2	29	40	50	61	69	76	1884	31	3028	1514	1514	0	821
84.3	1.4	12000	420.7	0.469	60512	-18	11	23	33	45	53	60	2	32	45	55	67	75	83	1829	30	3012	1506	1506	0	875
85.4	1.4	10000	426.1	0.452	60496	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	1773	30	2996	1498	1498	0	929
86.5	1.4	8000	431.5	0.436	60477	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	1717	29	2977	1489	1489	0	990
87.7	1.5	6000	436.9	0.420	60457	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	1661	28	2957	1479	1479	0	1054
88.9	1.5	4000	442.4	0.406	60435	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	1604	27	2935	1468	1468	0	1124
90.2	1.5	2000	447.9	0.391	60410	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	1544	26	2910	1455	1455	0	1201
90.5	1.5	1500	449.3	0.388	60404	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	1529	25	2904	1452	1452	0	1222
91.5	1.5	0	453.5	0.378	60383	-8	37	57	72	90	100	111	5	52	72	87	105	116	128	1484	25	2883	1442	1442	0	1284
93.5	1.6	0	453.5	0.000	60283	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	3000	50	2783	1392	1392	0	0
103.5	1.7	0	453.5	0.000	60283	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	2783	1392	1392	0	0

Large Commercial Transport
Long Range Mission

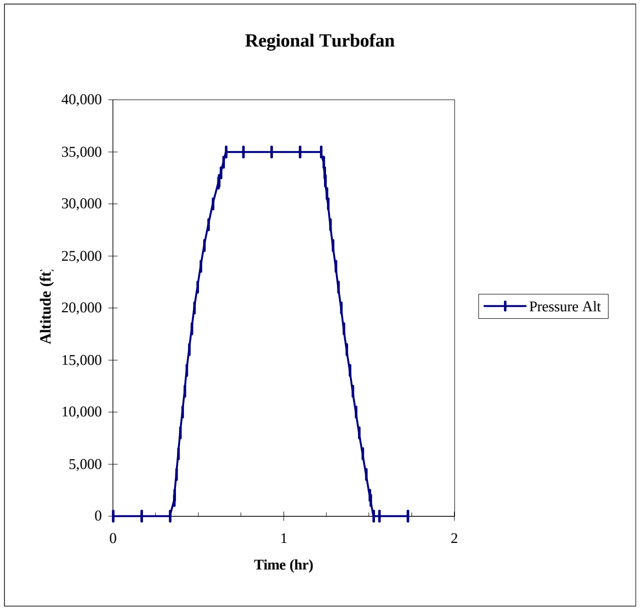
804.0	13.4	39000	5794.7	0.850	501893	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	19076	318	41673	20837	20837	0	0	0	2.0
813.8	13.6	39000	5874.8	0.850	498769	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	18994	317	38549	19275	19275	0	0	0	2.0
814.2	13.6	38000	5877.4	0.850	498754	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	2980	50	38534	19267	19267	0	0	3149	-1.8
814.6	13.6	36672	5880.7	0.850	498733	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	3087	51	38513	19257	19257	0	0	3242	-2.2
814.6	13.6	36672	5880.7	0.850	498733	-82	-64	-56	-49	-42	-37	-31	-27	-6	2	10	18	24	31	3087	51	38513	19257	19257	0	0	2267	-1.0
814.8	13.6	36089	5882.8	0.840	498719	-82	-64	-56	-49	-42	-37	-31	-28	-8	0	9	17	23	29	3120	52	38499	19250	19250	0	0	2233	-1.0
814.8	13.6	36089	5882.8	0.840	498719	-82	-64	-56	-49	-42	-37	-31	-28	-8	0	9	17	23	29	3120	52	38499	19250	19250	0	0	2391	-1.2
814.9	13.6	36000	5883.1	0.838	498717	-81	-63	-56	-49	-42	-36	-31	-28	-8	1	9	17	23	29	3124	52	38497	19249	19249	0	0	2386	-1.1
815.7	13.6	34000	5889.8	0.805	498672	-74	-56	-49	-42	-35	-29	-24	-24	-4	4	12	20	27	33	3213	54	38452	19226	19226	0	0	2311	-1.0
816.6	13.6	32000	5896.5	0.773	498625	-67	-49	-42	-35	-27	-22	-17	-20	0	8	16	24	30	36	3304	55	38405	19203	19203	0	0	2262	-0.9
817.5	13.6	30000	5903.1	0.742	498575	-60	-42	-35	-28	-20	-15	-10	-16	4	12	20	28	34	40	3407	57	38355	19178	19178	0	0	2217	-0.9
818.4	13.6	28000	5909.7	0.713	498522	-53	-35	-28	-20	-13	-8	-2	-11	8	16	24	32	38	44	3571	60	38302	19151	19151	0	0	2159	-0.8
819.3	13.7	26000	5916.2	0.685	498465	-46	-28	-21	-13	-6	-1	5	-7	13	21	29	37	42	48	3738	62	38245	19123	19123	0	0	2104	-0.8
820.3	13.7	24000	5922.7	0.659	498403	-39	-21	-13	-6	1	6	12	-2	18	25	33	41	47	53	3926	65	38183	19092	19092	0	0	2046	-0.8
821.3	13.7	22000	5929.1	0.634	498336	-31	-13	-6	1	8	14	19	3	22	30	38	46	52	57	4135	69	38116	19058	19058	0	0	1989	-0.8
822.3	13.7	20000	5935.6	0.610	498264	-24	-6	1	8	15	21	26	8	27	35	43	51	56	62	4346	72	38044	19022	19022	0	0	1935	-0.9
823.4	13.7	18000	5942.0	0.587	498187	-23	-2	7	14	23	29	35	7	30	39	47	56	62	69	4542	76	37967	18984	18984	0	0	1896	-0.9
824.4	13.7	16000	5948.4	0.565	498105	-21	2	12	21	30	37	43	7	32	42	51	61	68	75	4749	79	37885	18943	18943	0	0	1862	-1.0
825.5	13.8	14000	5954.6	0.544	498016	-19	7	18	27	38	45	52	7	34	46	56	67	74	82	5023	84	37796	18898	18898	0	0	1823	-1.0
826.6	13.8	12000	5960.9	0.525	497920	-18	11	23	33	45	53	60	7	37	50	61	73	81	89	5359	89	37700	18850	18850	0	0	1776	-1.1
826.6	13.8	12000	5960.9	0.525	497920	-18	11	23	33	45	53	60	7	37	50	61	73	81	89	5359	89	37700	18850	18850	0	0	1237	-0.2
828.5	13.8	10000	5970.3	0.452	497750	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	5704	95	37530	18765	18765	0	0	970	0.4
828.5	13.8	10000	5970.3	0.452	497750	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	5704	95	37530	18765	18765	0	0	1362	-0.3
829.9	13.8	8000	5977.3	0.436	497607	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	5810	97	37387	18694	18694	0	0	1328	-0.4
831.5	13.9	6000	5984.4	0.420	497458	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	5924	99	37238	18619	18619	0	0	1295	-0.5
833.0	13.9	4000	5991.3	0.406	497302	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	6008	100	37082	18541	18541	0	0	1262	-0.6
834.6	13.9	2000	5998.3	0.391	497142	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	6061	101	36922	18461	18461	0	0	1243	-0.7
835.0	13.9	1500	6000.0	0.388	497101	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	6074	101	36881	18441	18441	0	0	1241	-0.7
839.0	14.0	0	6000.0	0.000	496301	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	12000	200	36081	18041	18041	0	0	0	
844.0	14.1	0	6000.0	0.000	495801	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	6000	100	35581	17791	17791	0	0	0	
869.0	14.5	0	6000.0	0.000	495801	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	35581	17791	17791	0	0	0	

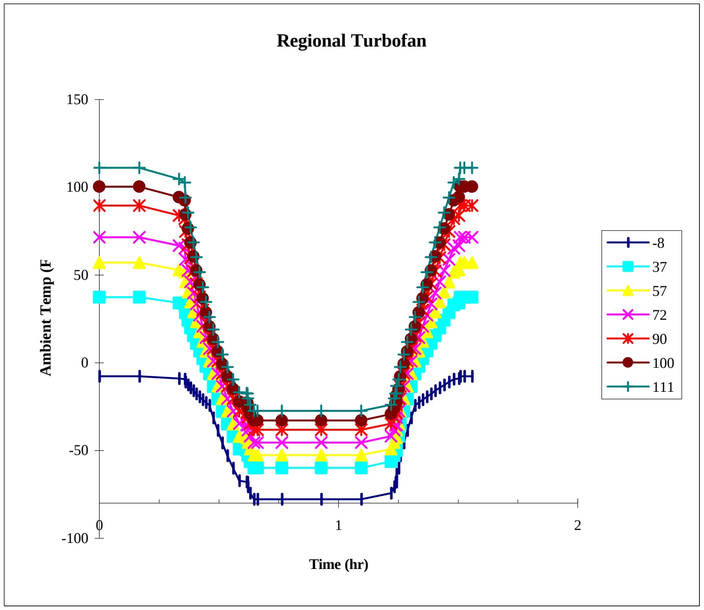
Large Commercial Transport
Short Range Mission

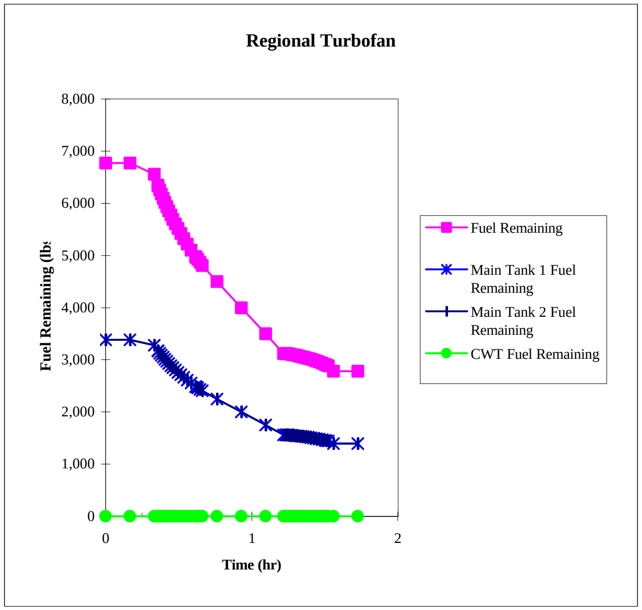
339.9	5.7	8000	1977.5	0.436	487152	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	5810	97	26932	13466	13466	0	0	1336	-0.5
341.4	5.7	6000	1984.4	0.420	487003	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	5924	99	26783	13392	13392	0	0	1303	-0.6
342.9	5.7	4000	1991.4	0.406	486849	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	6008	100	26629	13315	13315	0	0	1269	-0.7
344.5	5.7	2000	1998.3	0.391	486689	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	6061	101	26469	13235	13235	0	0	1250	-0.8
344.9	5.7	1500	2000.0	0.388	486648	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	6074	101	26428	13214	13214	0	0	1249	-0.8
348.9	5.8	0	2000.0	0.000	485848	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	12000	200	25628	12814	12814	0	0	0	
353.9	5.9	0	2000.0	0.000	485348	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	6000	100	25128	12564	12564	0	0	0	
378.9	6.3	0	2000.0	0.000	485348	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	25128	12564	12564	0	0	0	

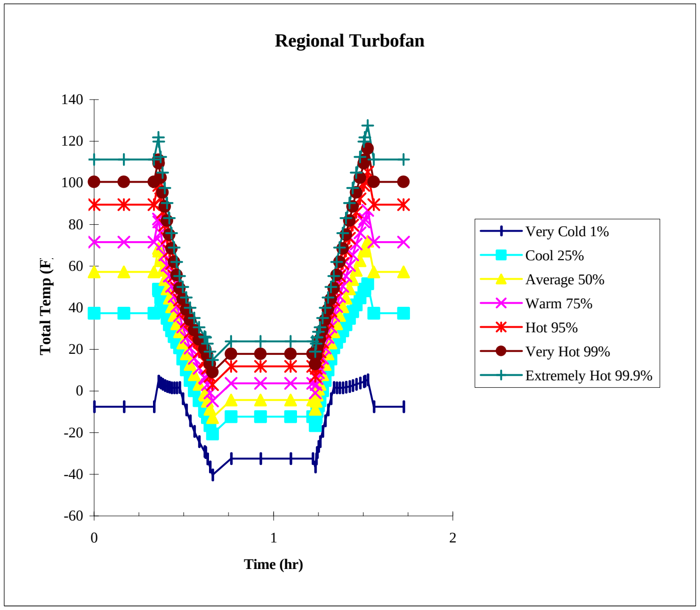
Medium Commercial Transport
Long Range Mission

456.9	7.6	36000	2986.1	0.790	257268	-81	-63	-56	-49	-42	-36	-31	-34	-14	-6	2	10	16	23	13823	230	31890	15945	15945	0	0	1674	4.0
457.0	7.6	36089	2986.5	0.790	257255	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	13766	229	31876	15938	15938	0	0	1519	3.9
457.0	7.6	36089	2986.5	0.790	257255	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	13766	229	31876	15938	15938	0	0	1519	3.9
457.6	7.6	37000	2991.3	0.790	257111	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	13243	221	31733	15867	15867	0	0	1357	3.8
458.4	7.6	38000	2997.2	0.790	256942	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	12690	211	31563	15782	15782	0	0	1173	3.8
459.4	7.7	39000	3004.4	0.790	256746	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	12039	201	31367	15684	15684	0	0	945	3.7
459.4	7.7	39000	3004.4	0.790	256748	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8790	146	31367	15684	15684	0	0	0	2.5
481.5	8.0	39000	3171.6	0.790	253529	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8653	144	28148	14074	14074	0	0	0	2.5
496.9	8.3	39000	3287.7	0.790	251324	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8565	143	25944	12972	12972	0	0	0	2.5
512.4	8.5	39000	3404.9	0.790	249120	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8477	141	23739	11870	11870	0	0	0	2.4
528.1	8.8	39000	3523.3	0.790	246915	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8391	140	21535	10767	10767	0	0	0	2.4
543.9	9.1	39000	3642.9	0.790	244711	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8316	139	19330	9665	9665	0	0	0	2.3
559.9	9.3	39000	3763.6	0.790	242506	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8243	137	17125	8563	8563	0	0	0	2.3
573.3	9.6	39000	3864.4	0.790	240678	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	8181	136	15298	7649	7649	0	0	0	2.3
573.3	9.6	39000	3864.4	0.790	240678	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	2088	35	15298	7649	7649	0	0	-2344	-0.6
573.7	9.6	38035	3867.5	0.790	240665	-82	-64	-56	-49	-42	-37	-31	-34	-14	-6	2	10	16	22	2103	35	15284	7642	7642	0	0	-1709	0.0
574.3	9.6	37000	3872.0	0.773	240643	-82	-64	-56	-49	-42	-37	-31	-37	-16	-8	0	8	14	20	2061	34	15262	7631	7631	0	0	-1689	0.0
574.8	9.6	36089	3876.0	0.758	240623	-82	-64	-56	-49	-42	-37	-31	-38	-18	-10	-2	6	12	18	1993	33	15243	7621	7621	0	0	-1786	-0.1
575.4	9.6	35000	3880.4	0.741	240603	-78	-60	-53	-45	-38	-33	-27	-36	-16	-8	0	8	14	20	1916	32	15223	7611	7611	0	0	-1785	-0.1
576.0	9.6	34000	3884.3	0.726	240586	-74	-56	-49	-42	-35	-29	-24	-34	-14	-6	2	10	16	22	1836	31	15205	7603	7603	0	0	-1791	-0.1
576.5	9.6	33000	3888.2	0.711	240568	-71	-53	-45	-38	-31	-26	-20	-31	-12	-4	4	12	18	24	1750	29	15187	7594	7594	0	0	-1805	-0.1
577.1	9.6	32000	3891.9	0.696	240553	-67	-49	-42	-35	-27	-22	-17	-29	-9	-1	6	14	20	26	1656	28	15172	7586	7586	0	0	-1825	-0.1
577.6	9.6	31000	3895.6	0.682	240537	-64	-46	-38	-31	-24	-19	-13	-27	-7	1	9	17	23	28	1675	28	15157	7578	7578	0	0	-1810	-0.2
578.2	9.6	30000	3899.3	0.668	240522	-60	-42	-35	-28	-20	-15	-10	-24	-5	3	11	19	25	31	1698	28	15141	7571	7571	0	0	-1795	-0.1
578.8	9.6	29000	3902.9	0.655	240506	-56	-38	-31	-24	-17	-11	-6	-22	-2	6	13	21	27	33	1709	28	15126	7563	7563	0	0	-1785	-0.1
579.3	9.7	28000	3906.5	0.641	240491	-53	-35	-28	-20	-13	-8	-2	-19	0	8	16	23	29	35	1709	28	15110	7555	7555	0	0	-1777	-0.1
579.9	9.7	27000	3910.1	0.628	240476	-49	-31	-24	-17	-10	-4	1	-17	3	10	18	26	32	37	1746	29	15095	7547	7547	0	0	-1757	-0.2
580.5	9.7	26000	3913.6	0.616	240458	-46	-28	-21	-13	-6	-1	5	-14	5	13	21	28	34	40	1786	30	15077	7539	7539	0	0	-1738	-0.2
581.0	9.7	25000	3917.2	0.604	240440	-42	-24	-17	-10	-3	3	8	-12	8	15	23	31	37	42	1823	30	15060	7530	7530	0	0	-1720	-0.1
581.6	9.7	24000	3920.7	0.592	240423	-39	-21	-13	-6	1	6	12	-9	10	18	26	33	39	45	1861	31	15042	7521	7521	0	0	-1702	-0.1
582.2	9.7	23000	3924.2	0.580	240405	-35	-17	-10	-3	5	10	15	-6	13	20	28	36	42	47	1896	32	15024	7512	7512	0	0	-1685	-0.1
582.8	9.7	22000	3927.6	0.569	240385	-31	-13	-6	1	8	14	19	-4	15	23	31	38	44	50	1922	32	15005	7502	7502	0	0	-1672	-0.1
583.4	9.7	21000	3931.1	0.558	240368	-28	-10	-3	5	12	17	23	-1	18	26	33	41	47	53	1940	32	14987	7493	7493	0	0	-1661	-0.2
584.0	9.7	20000	3934.5	0.547	240348	-24	-6	1	8	15	21	26	2	21	28	36	44	49	55	1951	33	14967	7484	7484	0	0	-1653	-0.2
584.6	9.7	19000	3937.8	0.536	240328	-23	-4	4	11	19	25	30	2	22	30	38	47	53	59	2006	33	14947	7474	7474	0	0	-1633	-0.2
585.2	9.8	18000	3941.2	0.526	240308	-23	-2	7	14	23	29	35	2	23	32	41	49	56	62	2059	34	14927	7464	7464	0	0	-1615	-0.2
585.9	9.8	17000	3944.6	0.516	240286	-22	0	9	18	26	33	39	2	25	34	43	52	59	65	2110	35	14905	7453	7453	0	0	-1598	-0.2
586.5	9.8	16000	3947.9	0.506	240264	-21	2	12	21	30	37	43	2	26	36	45	55	62	69	2154	36	14883	7442	7442	0	0	-1584	-0.2
587.1	9.8	15000	3951.2	0.497	240242	-20	5	15	24	34	41	47	2	28	38	48	58	65	72	2202	37	14861	7431	7431	0	0	-1568	-0.3
587.8	9.8	14000	3954.5	0.487	240218	-19	7	18	27	38	45	52	2	29	40	50	61	69	76	2251	38	14837	7418	7418	0	0	-1552	-0.3
588.4	9.8	13000	3957.8	0.478	240193	-18	9	21	30	41	49	56	2	30	43	53	64	72	79	2295	38	14813	7406	7406	0	0	-1537	-0.3
589.1	9.8	12000	3961.0	0.469	240169	-18	11	23	33	45	53	60	2	32	45	55	67	75	83	2337	39	14788	7394	7394	0	0	-1524	-0.3
589.7	9.8	11000	3964.3	0.461	240143	-17	13	26	37	49	57	64	2	33	47	58	70	79	87	2372	40	14762	7381	7381	0	0	-1513	-0.3
590.4	9.8	10000	3967.5	0.452	240118	-16	16	29	40	52	61	69	2	35	49	60	73	82	90	2394	40	14738	7369	7369	0	0	-1506	-0.4
591.0	9.9	9000	3970.6	0.444	240092	-15	18	32	43	56	65	73	2	37	51	63	77	85	94	2394	40	14711	7356	7356	0	0	-1507	-0.4
591.7	9.9	8000	3973.8	0.436	240063	-14	20	35	46	60	69	77	3	38	53	65	80	89	98	2392	40	14685	7342	7342	0	0	-1508	-0.4
592.4	9.9	7000	3976.9	0.428	240039	-13	22	37	49	64	73	81	3	40	56	68	83	92	101	2429	40	14658	7329	7329	0	0	-1497	-0.5
593.0	9.9	6000	3979.9	0.420	240010	-13	24	40	53	67	76	86	3	41	58	71	86	95	105	2478	41	14630	7315	7315	0	0	-1482	-0.5
593.7	9.9	5000	3983.0	0.413	239984	-12	26	43	56	71	80	90	4	43	60	73	89	99	109	2524	42	14603	7302	7302	0	0	-1469	-0.5
594.4	9.9	4000	3986.0	0.406	239955	-11	29	46	59	75	84	94	4	45	63	76	92	102	112	2568	43	14575	7287	7287	0	0	-1456	-0.5
595.1	9.9	3000	3989.0	0.398	239924	-10	31	49	62	78	88	98	4	46	65	79	96	106	116	2621	44	14544	7272	7272	0	0	-1443	-0.5
595.8	9.9	2000	3992.0	0.391	239896	-9	33	52	65	82	92	103	5	48	67	81	99	109	120	2670	44	14515	7258	7258	0	0	-1429	-0.5
596.1	9.9	1500	3993.5	0.388	239878	-9	34	53	67	84	94	105	5	49	68	83	100	111	122	2692	45	14497	7249	7249	0	0	-1422	-0.6
599.8	10.0	0	3993.5	0.000	239541	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	14160	7080	7080	0	0	0	0.0
629.8	10.5	0	3993.5	0.000	239541	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	14160	7080	7080	0	0	0	0.0


Regional Turbofan
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Altitude (ft
0
1
2
Time (hr)
Pressure Alt


Regional Turbofan
150
100
50
0
-50
-100
Ambient Temp (F
0
1
2
Time (hr)
-8
37
57
72
90
100
111


Regional Turbofan
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Fuel Remaining (lbs
0
1
2
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining


Regional Turbofan
140
120
100
80
60
40
20
0
-20
-40
-60
Total Temp (F
0
1
2
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

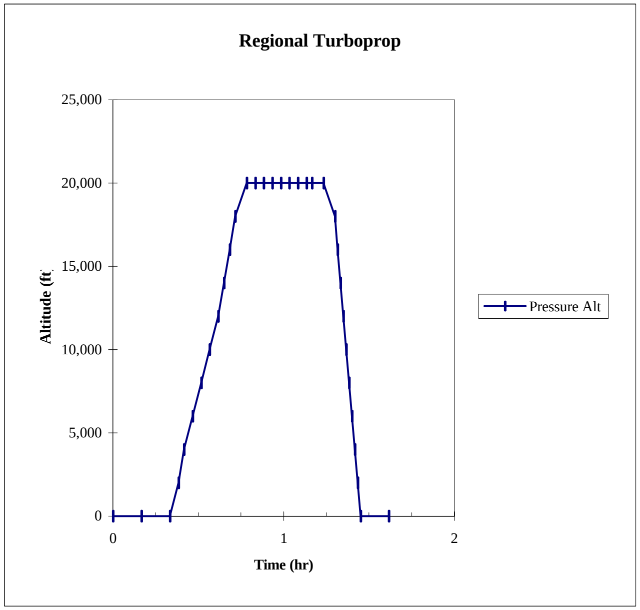
Regional Turboprop Mission

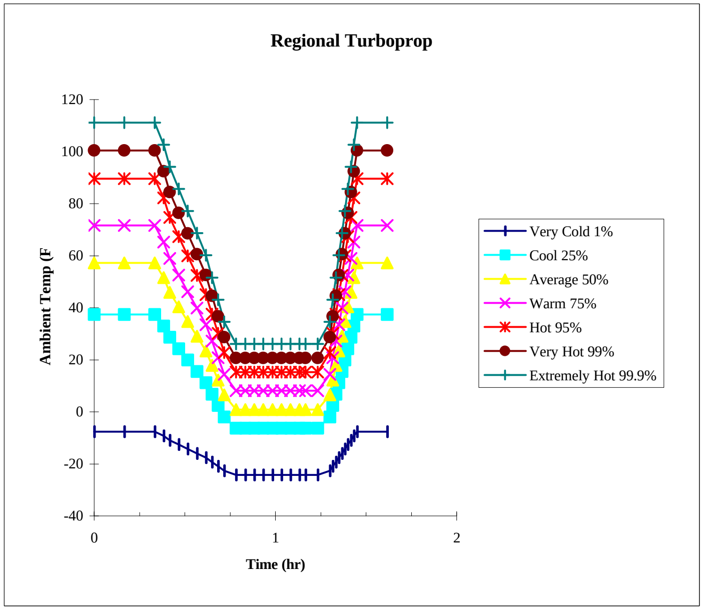
Ground Time (takeoff) = 20 minutes
Ground Time (landing) = 10 minutes
^
JRS Guess

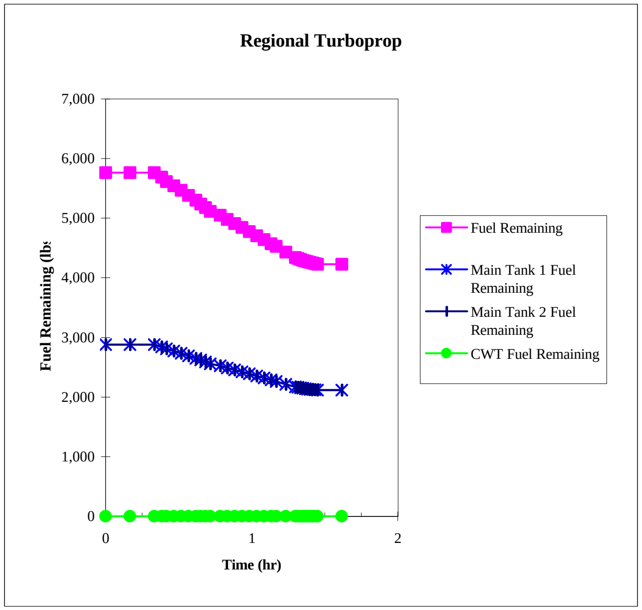
Main 1 Fuel Volume = 700 gal
Main 2 Fuel Volume = 700 gal
CWT Fuel Volume = 0 gal

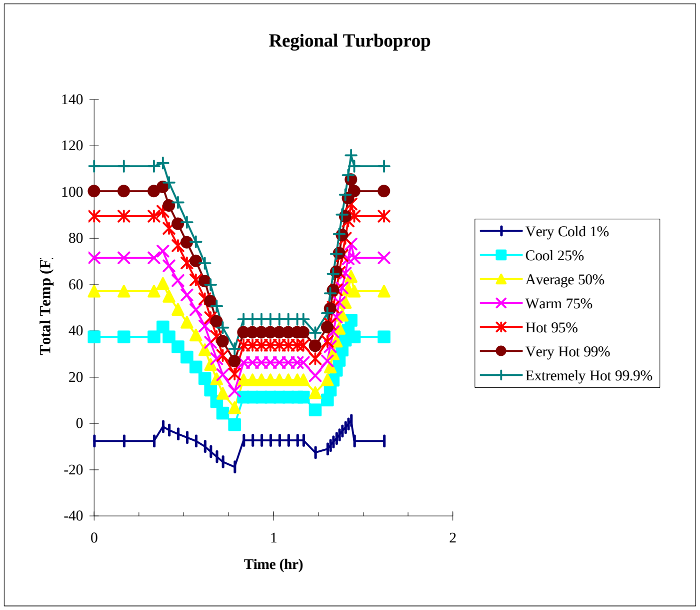
Tank Volume = 714
Tank Volume = 714
Tank Volume = 0

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min
0.0	0.0	0	0.0	0.000	41100	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	5764	2882	2882	0	0
10.0	0.2	0	0.0	0.000	41100	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	5764	2882	2882	0	0
20.0	0.3	0	0.0	0.000	41100	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	5764	2882	2882	0	0
23.0	0.4	2000	8.0	0.297	41023	-9	33	52	65	82	92	103	-1	42	61	75	92	102	113	1784	30	5687	2843	2843	0	667
25.0	0.4	4000	16.0	0.299	40952	-11	29	46	59	75	84	94	-3	37	55	68	84	94	104	1744	29	5616	2808	2808	0	800
28.0	0.5	6000	25.0	0.301	40880	-13	24	40	53	67	76	86	-5	33	49	62	77	86	96	1712	29	5544	2772	2772	0	750
31.0	0.5	8000	36.0	0.303	40802	-14	20	35	46	60	69	77	-6	29	44	56	69	78	87	1682	28	5466	2733	2733	0	727
34.0	0.6	10000	47.0	0.306	40721	-16	16	29	40	52	61	69	-8	24	38	49	62	70	79	1658	28	5385	2692	2692	0	714
37.0	0.6	12000	58.0	0.295	40637	-18	11	23	33	45	53	60	-10	19	32	42	54	62	69	1640	27	5301	2651	2651	0	706
39.0	0.7	14000	65.0	0.285	40575	-19	7	18	27	38	45	52	-12	14	26	35	46	53	60	1636	27	5239	2620	2620	0	737
41.0	0.7	16000	75.0	0.274	40516	-21	2	12	21	30	37	43	-14	9	19	28	38	44	51	1540	26	5180	2590	2590	0	762
43.0	0.7	18000	85.0	0.263	40450	-23	-2	7	14	23	29	35	-17	4	13	21	29	35	41	1446	24	5114	2557	2557	0	783
47.0	0.8	20000	95.0	0.252	40383	-24	-6	1	8	15	21	26	-19	-1	7	14	21	27	32	1356	23	5047	2524	2524	0	741
50.0	0.8	20000	108.6	0.441	40316	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4980	2490	2490	0	0
53.0	0.9	20000	122.1	0.441	40248	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4912	2456	2456	0	0
56.0	0.9	20000	135.7	0.441	40180	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4844	2422	2422	0	0
59.0	1.0	20000	149.2	0.441	40112	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4776	2388	2388	0	0
62.0	1.0	20000	162.8	0.441	40045	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4709	2354	2354	0	0
65.0	1.1	20000	176.3	0.441	39977	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4641	2320	2320	0	0
68.0	1.1	20000	189.9	0.441	39909	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4573	2287	2287	0	0
70.0	1.2	20000	198.9	0.441	39864	-24	-6	1	8	15	21	26	-7	11	19	26	34	39	45	1356	23	4528	2264	2264	0	0
74.0	1.2	20000	215.9	0.366	39766	-24	-6	1	8	15	21	26	-13	6	13	21	28	34	39	1356	23	4430	2215	2215	0	1250
78.0	1.3	18000	235.9	0.363	39676	-23	-2	7	14	23	29	35	-11	10	19	27	35	42	48	1350	23	4340	2170	2170	0	1500
79.0	1.3	16000	241.9	0.361	39661	-21	2	12	21	30	37	43	-10	14	24	33	43	50	56	900	15	4325	2163	2163	0	2000
80.0	1.3	14000	246.9	0.358	39646	-19	7	18	27	38	45	52	-8	19	30	40	50	58	65	900	15	4310	2155	2155	0	2000
81.0	1.4	12000	251.9	0.355	39631	-18	11	23	33	45	53	60	-6	23	36	46	58	66	73	900	15	4295	2148	2148	0	2000
82.0	1.4	10000	255.9	0.353	39616	-16	16	29	40	52	61	69	-5	27	41	52	65	73	82	900	15	4280	2140	2140	0	2000
83.0	1.4	8000	260.9	0.350	39606	-14	20	35	46	60	69	77	-3	32	47	59	73	81	90	600	10	4270	2135	2135	0	2000
84.0	1.4	6000	264.9	0.347	39596	-13	24	40	53	67	76	86	-2	36	52	65	80	89	99	600	10	4260	2130	2130	0	2000
85.0	1.4	4000	268.9	0.345	39586	-11	29	46	59	75	84	94	0	40	58	71	87	97	107	600	10	4250	2125	2125	0	2000
86.0	1.4	2000	273.9	0.343	39576	-9	33	52	65	82	92	103	1	45	64	78	95	105	116	600	10	4240	2120	2120	0	2000
87.0	1.5	0	278.9	0.000	39566	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	4230	2115	2115	0	0
97.0	1.6	0	278.9	0.000	39566	-8	37	57	72	90	100	111	-8	37	57	72	90	100	111	0	0	4230	2115	2115	0	0


Regional Turboprop
25,000
20,000
15,000
10,000
5,000
0
Altitude (ft
0
1
2
Time (hr)
Pressure Alt


Regional Turboprop
120
100
80
60
40
20
0
-20
-40
Ambient Temp (F
0
1
2
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

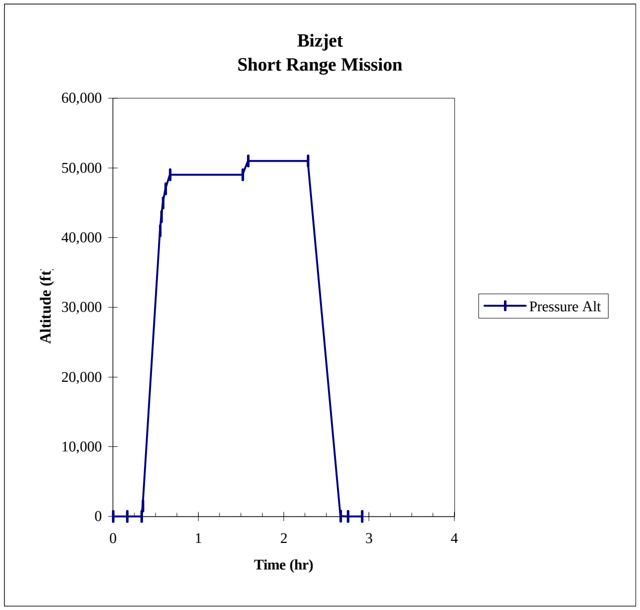

Regional Turboprop
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Fuel Remaining (lbs
0
1
2
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

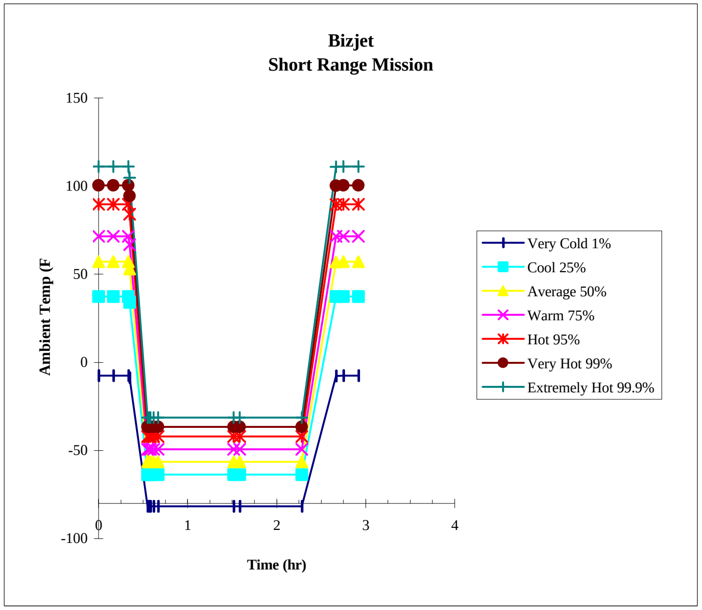

Regional Turboprop
140
120
100
80
60
40
20
0
-20
-40
Total Temp (F
0
1
2
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

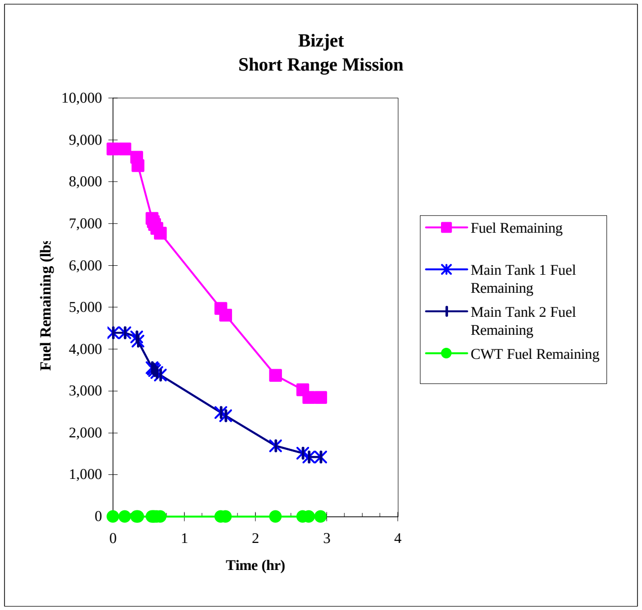
Bizjet
Short Range Mission

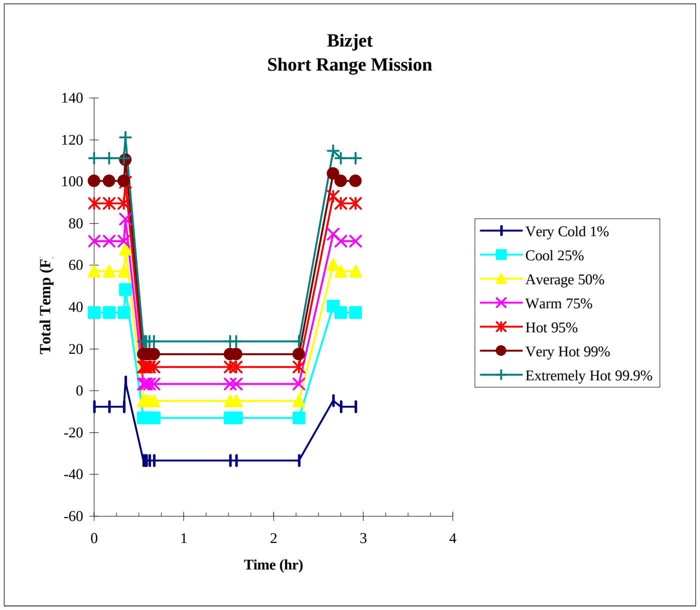
Ground Time (takeoff) = 20 minutes Main 1 Fuel Volume = 3075 gal `ank Volume = 3136.5
Ground Time (landing) = 10 minutes Main 2 Fuel Volume = 3075 gal `ank Volume = 3136.5
^ CWT Fuel Volume = 0 gal `ank Volume = 0
JRS Guess

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min
0.0	0.0	0	0.0	0.000	58385	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	8785	4393	4393	0	0
10.0	0.2	0	0.0	0.000	58385	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	1200	20	8785	4393	4393	0	0
20.0	0.3	0	0.0	0.000	58185	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	12000	200	8585	4293	4293	0	0
21.0	0.4	1500	0.0	0.380	57985	-9	34	53	67	84	94	105	4.17	48.38	67.78	82.04	99.73	110.42	121.12	12000	200	8385	4193	4193	0	3000
33.0	0.6	41000	72.0	0.800	56720	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	6325	105	7120	3560	3560	0	3000
34.0	0.6	43000	80.0	0.800	56650	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	4200	70	7050	3525	3525	0	2000
35.0	0.6	45000	90.0	0.800	56574	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	4560	76	6974	3487	3487	0	1300
37.0	0.6	47000	103.0	0.800	56486	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2640	44	6886	3443	3443	0	800
40.0	0.7	49000	122.0	0.800	56371	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2300	38	6771	3386	3386	0	700
91.0	1.5	49000	513.0	0.800	54571	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2118	35	4971	2486	2486	0	0
95.0	1.6	51000	542.0	0.800	54413	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2370	40	4813	2407	2407	0	500
137.0	2.3	51000	864.0	0.800	52976	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2053	34	3376	1688	1688	0	0
160.0	2.7	50	1002.0	0.180	52633	-8	37	57	71	89	100	111	-4.71	40.51	60.41	74.88	92.97	103.83	114.69	895	15	3033	1517	1517	0	-2000
165.0	2.8	0	1002.0	0.000	52449	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	2208	37	2849	1425	1425	0	0
175.0	2.9	0	1002.0	0.000	52449	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	2849	1425	1425	0	0


Bizjet
Short Range Mission
Altitude (ft
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
Time (hr)
Pressure Alt


Bizjet
Short Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%


Bizjet
Short Range Mission
Fuel Remaining (lbs
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
1
2
3
4
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining


Bizjet
Short Range Mission
Total Temp (F
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

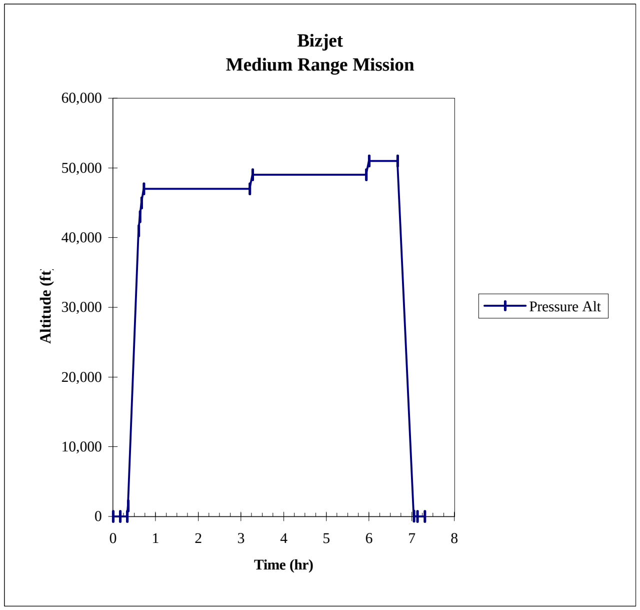
Bizjet
Medium Range Mission

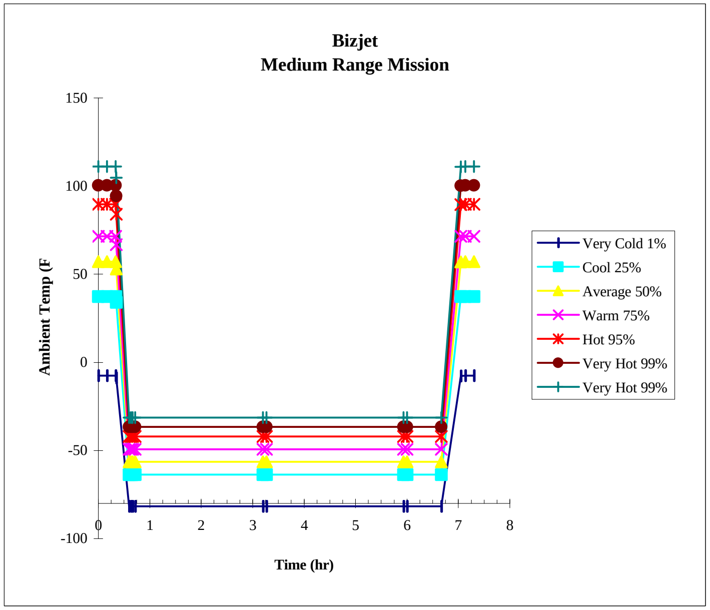
Ground Time (takeoff) = 20 minutes
Ground Time (landing) = 10 minutes
^
JRS Guess

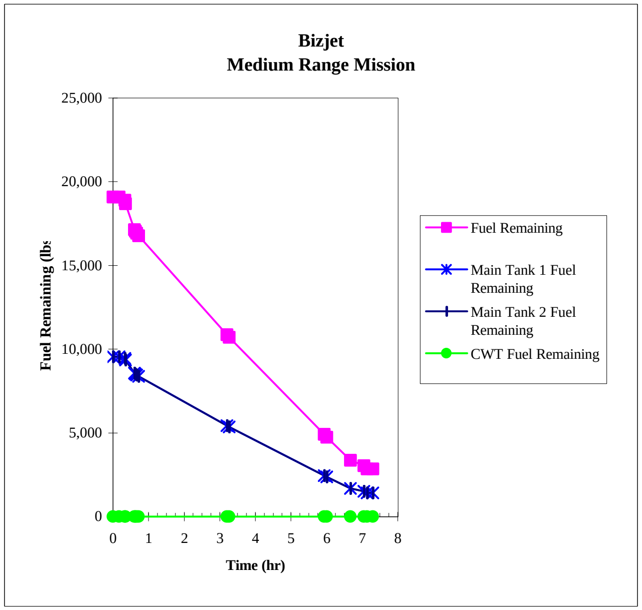
Main 1 Fuel Volume = 3075 gal
Main 2 Fuel Volume = 3075 gal
CWT Fuel Volume = N/A gal

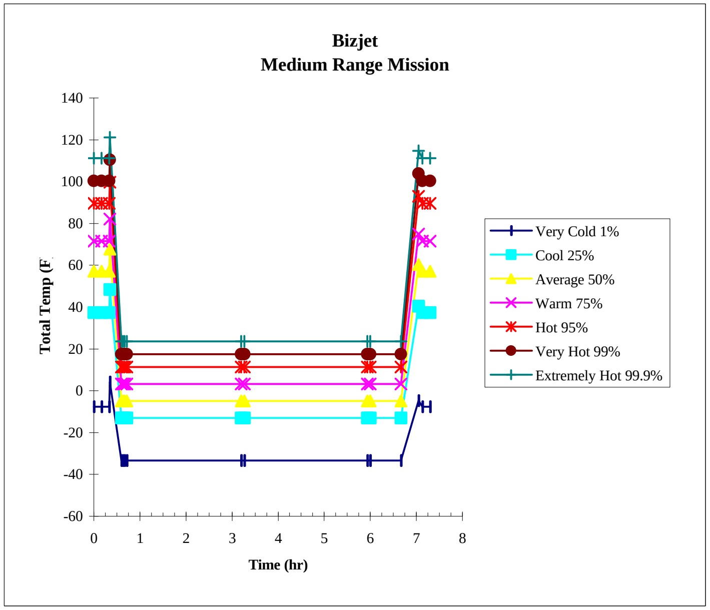
ank Volume = 3136.5
ank Volume = 3136.5
ank Volume = #VALUE!

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Very Hot 99%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min
0.0	0.0	0	0.0	0.000	68689	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	19089	9545	9545	0	
10.0	0.2	0	0.0	0.000	68689	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	1200	20	19089	9545	9545	0	
20.0	0.3	0	0.0	0.000	68489	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	12000	200	18889	9445	9445	0	
21.0	0.4	1500	0.0	0.380	68289	-9	34	53	67	84	94	105	4.17	48.38	67.78	82.04	99.73	110.42	121.12	6224	104	18689	9345	9345	0	2600
36.0	0.6	41000	90.0	0.800	66733	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2910	49	17133	8567	8567	0	2600
38.0	0.6	43000	101.0	0.800	66636	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	3390	57	17036	8518	8518	0	1000
40.0	0.7	45000	115.0	0.800	66523	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	3120	52	16923	8462	8462	0	800
43.0	0.7	47000	137.0	0.800	66367	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2376	40	16767	8384	8384	0	700
192.0	3.2	47000	1276.0	0.800	60467	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2385	40	10867	5434	5434	0	0
196.0	3.3	49000	1302.0	0.800	60308	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2175	36	10708	5354	5354	0	500
356.0	5.9	49000	2527.0	0.800	54508	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2355	39	4908	2454	2454	0	0
360.0	6.0	51000	2556.0	0.800	54351	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2063	34	4751	2376	2376	0	500
400.0	6.7	51000	2864.0	0.800	52976	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	895	15	3376	1688	1688	0	0
423.0	7.1	50	3002.0	0.180	52633	-8	37	57	71	89	100	111	-4.71	40.51	60.41	74.88	92.97	103.83	114.69	2208	37	3033	1517	1517	0	-2000
428.0	7.1	0	3002.0	0.000	52449	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	2849	1425	1425	0	0
438.0	7.3	0	3002.0	0.000	52449	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	2849	1425	1425	0	0


Bizjet
Medium Range Mission
Altitude (ft
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
6
7
8
Time (hr)
Pressure Alt


Bizjet
Medium Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
8
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Very Hot 99%

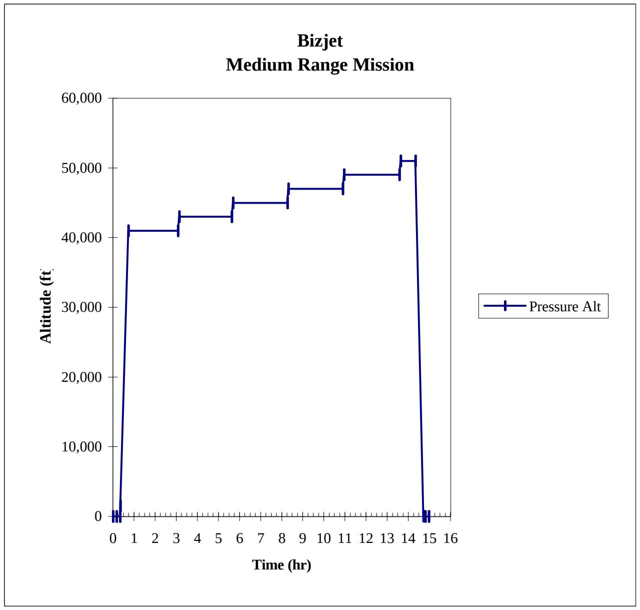

Bizjet
Medium Range Mission
Fuel Remaining (lbs
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining

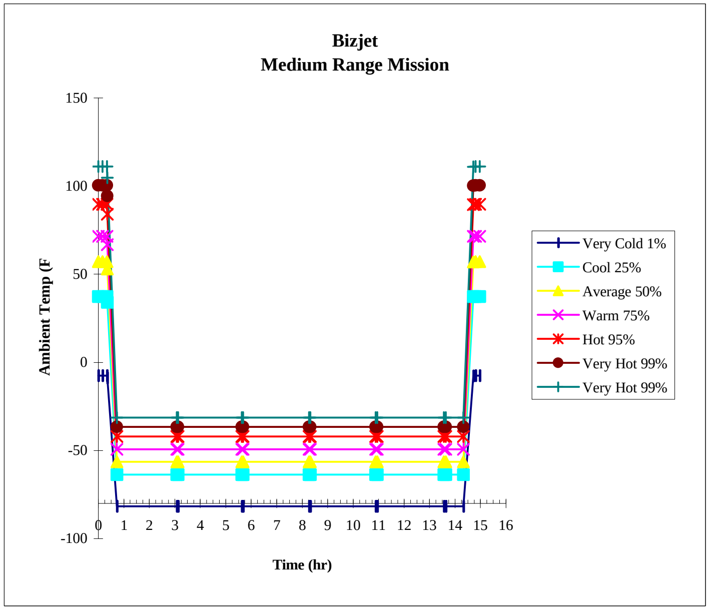

Bizjet
Medium Range Mission
Total Temp (F
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
8
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

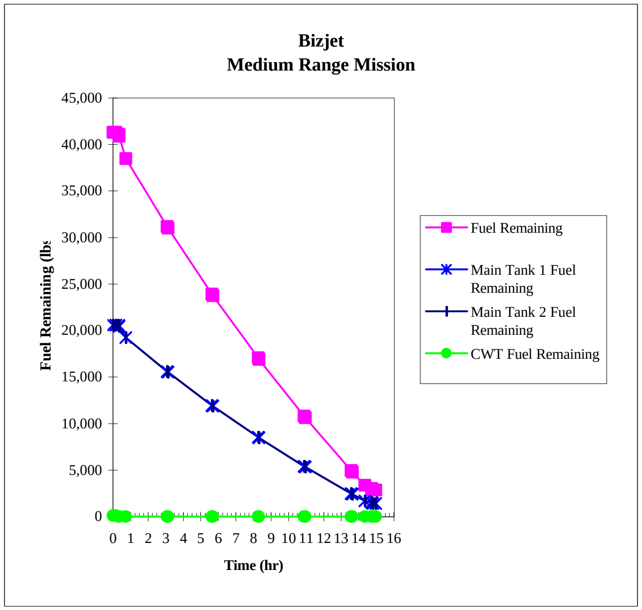
Bizjet
Long Range Mission

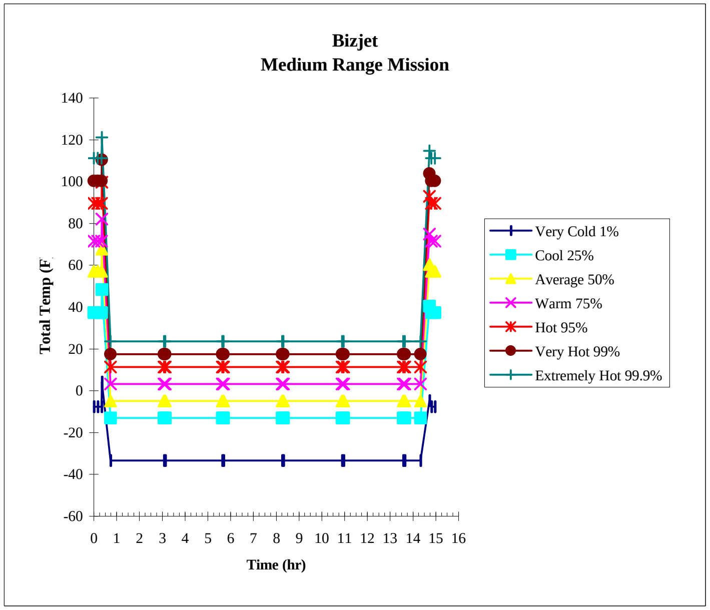
Ground Time (takeoff) =	20	minutes	Main 1 Fuel Volume =	3075	gal	ank Volume =	3136.5
Ground Time (landing) =	10	minutes	Main 2 Fuel Volume =	3075	gal	ank Volume =	3136.5
	^		CWT Fuel Volume =	N/A	gal	ank Volume =	#VALUE!
	JRS Guess						

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temperatures (Degrees F)							Total Temperatures (Degrees F)							Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent
minutes	hours	feet	N. Mi.		lbs	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Very Hot 99%**	**Very Cold 1%**	**Cool 25%**	**Average 50%**	**Warm 75%**	**Hot 95%**	**Very Hot 99%**	**Extremely Hot 99.9%**	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min
0.0	0.0	0	0	0.000	90900	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	41300	20603	20603	95	0
10.0	0.2	0	0	0.000	90900	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	1200	20	41300	20603	20603	95	0
20.0	0.3	0	0	0.000	90700	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	12000	200	41100	20550	20550	0	0
21.0	0.4	1500	0	0.380	90500	-9	34	53	67	84	94	105	4.17	48.38	67.78	82.04	99.73	110.42	121.12	6237	104	40900	20450	20450	0	1550
44.0	0.7	41000	145	0.800	88109	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	3106	52	38509	19255	19255	0	1550
185.0	3.1	41000	1226	0.800	80809	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	3620	60	31209	15605	15605	0	0
188.0	3.1	43000	1247	0.800	80628	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2840	47	31028	15514	15514	0	1500
338.0	5.6	43000	2392	0.800	73528	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	3280	55	23928	11964	11964	0	0
341.0	5.7	45000	2413	0.800	73364	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2594	43	23764	11882	11882	0	1500
496.0	8.3	45000	3595	0.800	66664	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	3160	53	17064	8532	8532	0	0
499.0	8.3	47000	3618	0.800	66506	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2377	40	16906	8453	8453	0	1500
653.0	10.9	47000	4795	0.800	60406	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2370	40	10806	5403	5403	0	0
657.0	11.0	49000	4820	0.800	60248	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2178	36	10648	5324	5324	0	1000
814.0	13.6	49000	6024	0.800	54548	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2370	40	4948	2474	2474	0	0
818.0	13.6	51000	6053	0.800	54390	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	2020	34	4790	2395	2395	0	1000
860.0	14.3	51000	6370	0.800	52976	-82	-64	-56	-49	-42	-37	-31	-33.30	-12.99	-4.87	3.25	11.37	17.46	23.55	895	15	3376	1688	1688	0	0
883.0	14.7	50	6508	0.180	52633	-8	37	57	71	89	100	111	-4.71	40.51	60.41	74.88	92.97	103.83	114.69	2208	37	3033	1517	1517	0	-2000
888.0	14.8	0	6508	0.000	52449	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	2849	1425	1425	0	0
898.0	15.0	0	6508	0.000	52449	-8	37	57	72	90	100	111	-7.60	37.40	57.20	71.60	89.60	100.40	111.20	0	0	2849	1425	1425	0	0


Bizjet
Medium Range Mission
60,000
50,000
40,000
30,000
20,000
10,000
0
Altitude (ft
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Pressure Alt


Bizjet
Medium Range Mission
150
100
50
0
-50
-100
Ambient Temp (F
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Very Hot 99%


Bizjet
Medium Range Mission
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Fuel Remaining (lbs
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining


Bizjet
Medium Range Mission
140
120
100
80
60
40
20
0
-20
-40
-60
Total Temp (F
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%

SMALL AIRPLANE

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
1500	1500	0	0	110211	4525	0.388	16119
2000	2000	0.0019	0.5	110181	4482	0.3914	15950
4000	4000	0.0094	2.4	110063	4309	0.4056	15290
6000	6000	0.0173	4.5	109945	4135	0.4204	14649
8000	8000	0.0256	6.8	109826	3950	0.436	14004
10000	10000	0.0342	9.2	109708	3753	0.4523	13350
10000	10000	0.0342	9.2	109708	500	0.4523	13350
10126	10126	0.0384	10.5	109651	500	0.5068	13555
10126	10126	0.0384	10.5	109651	3783	0.5068	13553
12000	12000	0.0469	13.3	109539	3577	0.5245	12980
14000	14000	0.0566	16.5	109417	3355	0.5443	12377
16000	16000	0.0669	20.1	109293	3125	0.5651	11750
18000	18000	0.078	24	109166	2889	0.5869	11125
20000	20000	0.09	28.5	109036	2658	0.6098	10562
22000	22000	0.1031	33.4	108900	2438	0.6338	10082
24000	24000	0.1175	39.1	108759	2217	0.6589	9600
26000	26000	0.1334	45.5	108611	1986	0.6853	9125
28000	28000	0.1513	53	108451	1752	0.7131	8679
29855	29855	0.1702	61.1	108291	1531	0.74	8289
29855	29855	0.1702	61.1	108291	2091	0.74	8289
30000	30000	0.1714	61.6	108282	2072	0.74	8248
32000	32000	0.1886	69.1	108144	1806	0.74	7682
34000	34000	0.2088	77.8	107995	1521	0.74	7134
35000	35000	0.2204	82.7	107914	1373	0.74	6868

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
1500	1500	0	0	116192	4236	0.388	16119
2000	2000	0.002	0.5	116160	4195	0.3914	15950
4000	4000	0.0101	2.6	116033	4029	0.4056	15290
6000	6000	0.0185	4.8	115907	3863	0.4204	14649
8000	8000	0.0274	7.3	115780	3686	0.436	14004
10000	10000	0.0367	9.9	115653	3498	0.4523	13350
10000	10000	0.0367	9.9	115653	500	0.4523	13350
10137	10137	0.0412	11.3	115592	500	0.5069	13551
10137	10137	0.0412	11.3	115592	3536	0.5069	13550
12000	12000	0.0503	14.2	115472	3341	0.5245	12980
14000	14000	0.0606	17.7	115342	3129	0.5443	12377
16000	16000	0.0716	21.5	115208	2910	0.5651	11750
18000	18000	0.0836	25.8	115072	2685	0.5869	11125
20000	20000	0.0965	30.6	114932	2463	0.6098	10562
22000	22000	0.1107	35.9	114786	2253	0.6338	10082

SMALL AIRPLANE

ENROUT CRUISE ANALYSIS 35000 0 (FEET)
WIND (K NOTS) = 0 DTEMP (EG C.) = 0

WEIGHT LB	DISTAN NMI	TIME HR	FUEL LB	NMI/LB	VELOCI KTS	FUEL FL LB/HR	MACH
107914	0	0	0	0.09151	429.432	4692.7	0.745
107029	81.3	0.1893	886	0.09205	429.432	4665.4	0.745
105970	179	0.4169	1944	0.09268	429.432	4633.4	0.745
104912	277.5	0.6462	3003	0.09332	429.406	4601.6	0.74496
104523	313.9	0.7309	3392	0.09355	429.395	4590.1	0.74494

ENROUT CRUISE ANALYSIS 35000 0 (FEET)
WIND (K NOTS) = 0 DTEMP (EG C.) = 0

WEIGHT LB	DISTAN NMI	TIME HR	FUEL LB	NMI/LB	VELOCI KTS	FUEL FL LB/HR	MACH
113693	0	0	0	0.08792	429.432	4884.4	0.745
113379	27.6	0.0642	313	0.08812	429.432	4873.3	0.745
112321	121.2	0.2822	1372	0.08879	429.432	4836.6	0.745
111263	215.5	0.5019	2430	0.08945	429.432	4800.7	0.745
110204	310.6	0.7232	3489	0.09011	429.432	4765.7	0.745
109146	406.3	0.9461	4547	0.09076	429.432	4731.5	0.745
108087	502.7	1.1706	5606	0.09141	429.432	4698.1	0.745
107029	599.8	1.3967	6664	0.09205	429.432	4665.4	0.745
105970	697.5	1.6243	7722	0.09268	429.432	4633.4	0.745
104912	796	1.8535	8781	0.09332	429.406	4601.6	0.74496
104808	805.7	1.8761	8885	0.09338	429.403	4598.5	0.74495

ENROUT CRUISE ANALYSIS 31000 0 (FEET)
WIND (K NOTS) = 0 DTEMP (EG C.) = 0

WEIGHT LB	DISTAN NMI	TIME HR	FUEL LB	NMI/LB	VELOCI KTS	FUEL FL LB/HR	MACH
126532	0	0	0	0.07859	437.114	5562.2	0.74496
125495	81.7	0.187	1037	0.07903	437.088	5530.8	0.74491

SMALL AIRPLANE

ENROU E DESCENT ANALYSIS
WIND (KNOTS) = 0 DTEMP (DEG

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGH LB	FUEL LB	ROD FPM	MACH	T FF LB/HR
35000	35000	0.3078	99.9	104523	400	3096	0.74	760
34923	34923	0.3074	99.7	104522	400	3101	0.74	760
34923	34923	0.3074	99.7	104522	400	2274	0.74	760
34000	34000	0.3005	96.9	104517	395	2239	0.7258	760
32000	32000	0.2855	90.6	104506	383	2195	0.6962	775
30000	30000	0.2701	84.5	104493	371	2143	0.6681	820
28000	28000	0.2544	78.4	104480	358	2091	0.6414	877
26000	26000	0.2382	72.4	104465	343	2039	0.6159	933
24000	24000	0.2217	66.4	104449	327	1989	0.5917	996
22000	22000	0.2047	60.4	104432	309	1941	0.5687	1062
20000	20000	0.1873	54.5	104413	290	1894	0.5469	1132
18000	18000	0.1695	48.6	104392	270	1843	0.526	1206
16000	16000	0.1512	42.7	104369	247	1792	0.5062	1283
14000	14000	0.1323	36.8	104344	222	1741	0.4874	1365
12000	12000	0.1129	31	104317	194	1691	0.4694	1450
10000	10000	0.0928	25.1	104287	164	1640	0.4523	1540
8000	8000	0.0722	19.3	104254	132	1591	0.436	1633
6000	6000	0.0509	13.4	104218	96	1541	0.4204	1732
4000	4000	0.0289	7.5	104179	56	1483	0.4056	1853
2000	2000	0.0059	1.5	104134	12	1421	0.3914	2004
1500	1500	0	0	104122	0	1405	0.388	2045

ENROU E DESCENT ANALYSIS
WIND (KNOTS) = 0 DTEMP (DEG

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGH LB	FUEL LB	ROD FPM	MACH	T FF LB/HR
35000	35000	0.3081	100	104808	401	3094	0.74	760
34923	34923	0.3076	99.8	104808	400	3099	0.74	760
34923	34923	0.3076	99.8	104808	400	2272	0.74	760
34000	34000	0.3008	96.9	104802	395	2237	0.7258	760
32000	32000	0.2858	90.7	104791	383	2193	0.6962	775
30000	30000	0.2704	84.6	104779	371	2142	0.6681	820
28000	28000	0.2546	78.5	104765	358	2089	0.6414	877
26000	26000	0.2385	72.4	104751	343	2037	0.6159	933
24000	24000	0.2219	66.4	104735	327	1987	0.5917	996

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		A310-308 1000NM ISA conditions															
2													Fuel Distribution				
3	ALT.	A/C WT	MACH	TIME	FUEL	DIST	RATE	GRDT	ALPH	WFE	Loutr	Linr	Ctr	Trim	Rinr	Routr	FOB
4	(FT)	(KG)	( )	(MN)	(KG)	(NM)	(FTMN)	(DEG.)	(DEG.)	(KG/H)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
5	0	117684	0	0	0	0	0		0	0	3000	4726	0	0	4726	3000	15452
6		116559	0	45	1125	0	0	0	0	1500	3000	4163.5	0	0	4163.5	3000	14327
7	1500	116223	0.388	46.51	1462	3	4356.8	9.7	2.78	13291	3000	3995	0	0	3995	3000	13990
8	2000	116198	0.391	46.62	1487	3.5	4371.6	9.66	2.78	13286	3000	3982.5	0	0	3982.5	3000	13965
9	3000	116147	0.398	46.85	1538	4.5	4410.8	9.61	2.79	13301	3000	3957	0	0	3957	3000	13914
10	4000	116097	0.406	47.07	1588	5.4	4436.9	9.53	2.79	13272	3000	3932	0	0	3932	3000	13864
11	5000	116048	0.413	47.3	1637	6.4	4518.5	9.57	2.79	13362	3000	3907.5	0	0	3907.5	3000	13815
12	6000	115999	0.42	47.52	1686	7.4	4545.6	9.49	2.78	13329	3000	3883	0	0	3883	3000	13766
13	7000	115950	0.428	47.74	1735	8.4	4496.8	9.25	2.79	13153	3000	3858.5	0	0	3858.5	3000	13717
14	8000	115901	0.436	47.96	1784	9.4	4434.7	8.99	2.79	12967	3000	3834	0	0	3834	3000	13668
15	9000	115852	0.444	48.19	1833	10.5	4395.6	8.78	2.79	12840	3000	3809.5	0	0	3809.5	3000	13619
16	10000	115804	0.452	48.42	1881	11.6	4348.8	8.55	2.79	12695	3000	3785.5	0	0	3785.5	3000	13571
17	10000	115736	0.541	48.74	1949	13.2	4436.7	7.29	1.27	12907	3000	3751.5	0	0	3751.5	3000	13503
18	11000	115687	0.551	48.96	1998	14.6	4328.1	7.01	1.26	12644	3000	3727	0	0	3727	3000	13454
19	12000	115638	0.561	49.2	2047	15.9	4211	6.72	1.26	12373	3000	3702.5	0	0	3702.5	3000	13405
20	13000	115589	0.571	49.44	2096	17.4	4088.5	6.43	1.26	12094	3000	3678	0	0	3678	3000	13356
21	14000	115540	0.582	49.69	2145	18.8	3961.9	6.14	1.26	11819	3000	3653.5	0	0	3653.5	3000	13307
22	15000	115490	0.593	49.95	2195	20.4	3832.4	5.85	1.26	11552	3000	3628.5	0	0	3628.5	3000	13257
23	16000	115439	0.604	50.21	2246	22.1	3721.6	5.59	1.25	11332	3000	3603	0	0	3603	3000	13206
24	17000	115388	0.615	50.48	2297	23.8	3603.9	5.34	1.24	11097	3000	3577.5	0	0	3577.5	3000	13155
25	18000	115337	0.627	50.77	2348	25.6	3475.7	5.07	1.23	10842	3000	3552	0	0	3552	3000	13104
26	19000	115284	0.639	51.06	2401	27.5	3338.2	4.8	1.21	10570	3000	3525.5	0	0	3525.5	3000	13051
27	20000	115231	0.651	51.37	2454	29.5	3191.6	4.52	1.2	10284	3000	3499	0	0	3499	3000	12998
28	21000	115177	0.664	51.68	2508	31.6	3092.6	4.31	1.19	10115	3000	3472	0	0	3472	3000	12944
29	22000	115122	0.677	52.01	2563	33.9	2980	4.09	1.17	9913	3000	944.5	0	5000	944.5	3000	12889
30	23000	115066	0.69	52.36	2619	36.3	2855.3	3.86	1.16	9681	3000	916.5	0	5000	916.5	3000	12833
31	24000	115009	0.703	52.71	2676	38.8	2719.4	3.62	1.15	9422	3000	888	0	5000	888	3000	12776
32	25000	114950	0.717	53.09	2735	41.5	2575	3.38	1.12	9141	3000	858.5	0	5000	858.5	3000	12717
33	26000	114890	0.731	53.49	2795	44.3	2457.2	3.17	1.09	8936	3000	828.5	0	5000	828.5	3000	12657
34	27000	114829	0.745	53.91	2856	47.4	2331.4	2.97	1.06	8718	3000	798	0	5000	798	3000	12596
35	28000	114766	0.76	54.35	2919	50.7	2201.6	2.76	1.02	8489	3000	766.5	0	5000	766.5	3000	12533
36	29000	114700	0.775	54.82	2985	54.3	2070.5	2.55	0.97	8248	3000	733.5	0	5000	733.5	3000	12467
37	29959	114635	0.79	55.3	3050	57.9	1928.8	2.34	0.92	8009	3000	701	0	5000	701	3000	12402
38	29959	114635	0.79	55.3	3050	57.9	2728.3	3.32	0.92	8009	3000	701	0	5000	701	3000	12402
39	30000	114633	0.79	55.31	3052	58.1	2724.2	3.31	0.93	7999	3000	700	0	5000	700	3000	12400
40	31000	114584	0.79	55.69	3101	61	2579.3	3.15	1.06	7690	3000	675.5	0	5000	675.5	3000	12351
41	32000	114534	0.79	56.09	3151	64	2429.2	2.98	1.2	7387	3000	650.5	0	5000	650.5	3000	12301
42	33000	114483	0.79	56.51	3202	67.3	2279.3	2.81	1.35	7114	3000	625	0	5000	625	3000	12250
43	34000	114430	0.79	56.97	3255	70.8	2118.6	2.62	1.51	6842	3000	598.5	0	5000	598.5	3000	12197
44	35000	114375	0.79	57.46	3310	74.5	1951.1	2.42	1.68	6574	3000	571	0	5000	571	3000	12142
45	36000	114317	0.79	58	3368	78.6	1758.6	2.2	1.86	6270	3000	542	0	5000	542	3000	12084
46	36089	114312	0.79	58.05	3373	79	1596.4	1.99	1.87	6244	3000	539.5	0	5000	539.5	3000	12079
47	36089	114312	0.79	58.05	3373	79	1596.4	1.99	1.87	6244	3000	539.5	0	5000	539.5	3000	12079
48	37000	114250	0.79	58.65	3435	83.5	1437.9	1.8	2.04	6007	3000	508.5	0	5000	508.5	3000	12017
49	38000	114177	0.79	59.39	3508	89.1	1255.4	1.57	2.24	5756	3000	472	0	5000	472	3000	11944
50	39000	114096	0.79	60.27	3589	95.7	1035.6	1.29	2.44	5461	3000	431.5	0	5000	431.5	3000	11863
51	39000	114095	0.79	60.27	3589	95.7	0	0	2.45	3889	3000	431.5	0	5000	431.5	3000	11863
52	39000	113000	0.79	77.26	4684	224	0	0	2.41	3845	3000	431.5	3905	0	431.5	3000	10768
53	39000	112000	0.79	92.94	5684	342.4	0	0	2.37	3806	3000	431.5	2905	0	431.5	3000	9768
54	39000	111000	0.79	108.78	6684	462	0	0	2.33	3772	3000	431.5	1905	0	431.5	3000	8768
55	39000	110000	0.79	124.75	7684	582.7	0	0	2.29	3739	3000	431.5	905	0	431.5	3000	7768
56	39000	109000	0.79	140.87	8684	704.4	0	0	2.25	3706	3000	384	0	0	384	3000	6768
57	39000	108000	0.79	157.13	9684	827.2	0	0	2.22	3673	2884	0	0	0	0	2884	5768
58	39000	107648	0.79	162.89	10036	870.7	0	0	2.2	3662	2708	0	0	0	0	2708	5416
59	39000	107648	0.79	162.89	10036	870.7	-2337.8	-2.9	2.21	947	2708	0	0	0	0	2708	5416
60	38036	107641	0.79	163.3	10043	873.8	-2355.1	-2.9	2.02	954	2704.5	0	0	0	0	2704.5	5409
61	38035	107641	0.79	163.3	10043	873.8	-1708.2	-2.1	2.03	954	2704.5	0	0	0	0	2704.5	5409
62	37000	107632	0.773	163.91	10052	878.4	-1689.8	-2.2	2.11	935	2700	0	0	0	0	2700	5400
63	36089	107623	0.758	164.45	10061	882.3	-1687	-2.2	2.18	904	2695.5	0	0	0	0	2695.5	5391
64	36089	107623	0.758	164.45	10061	882.3	-1788	-2.3	2.18	904	2695.5	0	0	0	0	2695.5	5391
65	35000	107614	0.741	165.06	10070	886.7	-1787	-2.4	2.24	869	2691	0	0	0	0	2691	5382
66	34000	107606	0.726	165.62	10078	890.6	-1793.8	-2.4	2.28	833	2687	0	0	0	0	2687	5374
67	33000	107598	0.711	166.17	10086	894.5	-1808.7	-2.5	2.32	794	2683	0	0	0	0	2683	5366
68	32000	107591	0.696	166.72	10093	898.2	-1829.8	-2.5	2.36	751	2679.5	0	0	0	0	2679.5	5359
69	31000	107584	0.682	167.27	10100	901.9	-1815.7	-2.6	2.38	760	2676	0	0	0	0	2676	5352
70	30000	107577	0.668	167.82	10107	905.6	-1801.4	-2.6	2.4	770	2672.5	0	0	0	0	2672.5	5345
71	29000	107570	0.655	168.38	10114	909.2	-1791	-2.6	2.42	775	2669	0	0	0	0	2669	5338
72	28000	107563	0.641	168.94	10121	912.8	-1783.3	-2.6	2.44	775	2665.5	0	0	0	0	2665.5	5331
73	27000	107556	0.628	169.5	10128	916.3	-1763.9	-2.7	2.47	792	2662	0	0	0	0	2662	5324
74	26000	107548	0.616	170.07	10136	919.8	-1744.8	-2.7	2.49	810	2658	0	0	0	0	2658	5316
75	25000	107540	0.604	170.65	10144	923.4	-1727.1	-2.7	2.51	827	2654	0	0	0	0	2654	5308
76	24000	107533	0.592	171.23	10151	926.8	-1708.8	-2.7	2.52	844	2650.5	0	0	0	0	2650.5	5301
77	23000	107524	0.58	171.82	10160	930.3	-1692.3	-2.7	2.53	860	2646	0	0	0	0	2646	5292
78	22000	107516	0.569	172.41	10168	933.8	-1678.5	-2.7	2.53	872	2642	0	0	0	0	2642	5284
79	21000	107507	0.558	173.01	10177	937.2	-1667.7	-2.8	2.54	880	2637.5	0	0	0	0	2637.5	5275
80	20000	107498	0.547	173.61	10186	940.6	-1659.6	-2.8	2.55	885	2633	0	0	0	0	2633	5266
81	19000	107489	0.536	174.22	10195	943.9	-1639.8	-2.8	2.55	910	2628.5	0	0	0	0	2628.5	5257
82	18000	107480	0.526	174.83	10204	947.3	-1621.3	-2.8	2.56	934	2624	0	0	0	0	2624	5248
83	17000	107471	0.516	175.45	10213	950.6	-1604.1	-2.8	2.57	957	2619.5	0	0	0	0	2619.5	5239
84	16000	107461	0.506	176.08	10223	954	-1589.7	-2.8	2.57	977	2614.5	0	0	0	0	2614.5	5229
85	15000	107450	0.497	176.71	10234	957.3	-1573.9	-2.9	2.58	999	2609	0	0	0	0	2609	5218
86	14000	107440	0.487	177.35	10244	960.5	-1557.7	-2.9	2.58	1021	2604	0	0	0	0	2604	5208
87	13000	107429	0.478	177.99	10255	963.8	-1542.9	-2.9	2.58	1041	2598.5	0	0	0	0	2598.5	5197
88	12000	107418	0.469	178.65	10266	967	-1530	-2.9	2.57	1060	2593	0	0	0	0	2593	5186
89	11000	107406	0.461	179.3	10278	970.3	-1519.3	-2.9	2.57	1076	2587	0	0	0	0	2587	5174
90	10000	107394	0.452	179.96	10290	973.5	-1512.7	-3	2.57	1086	2581	0	0	0	0	2581	5162
91	10000	107394	0.452	179.96	10290	973.5	-1512.7	-3	2.57	1086	2581	0	0	0	0	2581	5162
92	9000	107382	0.444	180.62	10302	976.6	-1513	-3	2.57	1086	2575	0	0	0	0	2575	5150
93	8000	107370	0.436	181.28	10314	979.7	-1515	-3.1	2.57	1085	2569	0	0	0	0	2569	5138
94	7000	107358	0.428	181.94	10326	982.8	-1503.6	-3.1	2.57	1102	2563	0	0	0	0	2563	5126
95	6000	107346	0.42	182.61	10338	985.8	-1488.8	-3.1	2.57	1124	2557	0	0	0	0	2557	5114
96	5000	107334	0.413	183.29	10350	988.9	-1475.3	-3.1	2.57	1145	2551	0	0	0	0	2551	5102
97	4000	107321	0.406	183.97	10363	991.9	-1463.2	-3.1	2.57	1165	2544.5	0	0	0	0	2544.5	5089
98	3000	107307	0.398	184.66	10377	994.9	-1449.4	-3.1	2.57	1189	2537.5	0	0	0	0	2537.5	5075
99	2000	107294	0.391	185.35	10390	997.9	-1435.5	-3.2	2.56	1211	2531	0	0	0	0	2531	5062
100	1500	107287	0.388	185.7	10397	999.4	-1429	-3.2	2.56	1221	2527.5	0	0	0	0	2527.5	5055
101	0	107132	0	189.38	10552	999.4	0	0	0	0	2450	0	0	0	0	2450	4900

	A310-308 4000NM, ISA conditions																					
ALT.	A/C WT	MACH	TIME	FUEL	DIST	RATE	GRDT	ALPH	WFE	Loutr	Linr	Ctr	Trim	Rinr	Routr	FOB			For Calculation use only!			
(FT)	(KG)	( )	(MN)	(KG)	(NM)	(FTMN)	(DEG.)	(DEG.)	(KG/H)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)			delta tim	delta fue	delta dist	
0	127295	0	0	0	0	0	0	0	0	3000	9532	0	0	9532	3000	25064						
0	126170		45	1125	0	0	0	0	1500	3000	8969.5	0	0	8970	3000	23939						
1500	125809	0.388	46.64	1486	3.3	3946.3	8.78	3.2	13291	3000	8789	0	0	8789	3000	23578			1.64	361	3.3	
2000	125781	0.391	46.76	1514	3.8	3959.5	8.75	3.2	13286	3000	8775	0	0	8775	3000	23550			1.76	389	3.8	
3000	125725	0.398	47.02	1570	4.9	3994.8	8.7	3.21	13301	3000	8747	0	0	8747	3000	23494			2.02	445	4.9	
4000	125670	0.406	47.27	1625	6	4018	8.62	3.21	13272	3000	8719.5	0	0	8720	3000	23439			2.27	500	6	
5000	125615	0.413	47.51	1680	7.1	4092.4	8.66	3.2	13362	3000	8692	0	0	8692	3000	23384			2.51	555	7.1	
6000	125561	0.42	47.76	1734	8.2	4116.5	8.59	3.2	13329	3000	8665	0	0	8665	3000	23330			2.76	609	8.2	
7000	125507	0.428	48	1788	9.3	4070.5	8.37	3.2	13153	3000	8638	0	0	8638	3000	23276			3	663	9.3	
8000	125454	0.436	48.25	1841	10.4	4012.1	8.12	3.2	12967	3000	8611.5	0	0	8612	3000	23223			3.25	716	10.4	
9000	125400	0.444	48.5	1895	11.6	3975.1	7.93	3.21	12840	3000	8584.5	0	0	8585	3000	23169			3.5	770	11.6	
10000	125346	0.452	48.75	1949	12.8	3930.8	7.73	3.21	12695	3000	8557.5	0	0	8558	3000	23115			3.75	824	12.8	
10000	125271	0.541	49.1	2024	14.6	4035.2	6.63	1.55	12907	3000	8520	0	0	8520	3000	23040			4.1	899	14.6	
11000	125217	0.551	49.35	2078	16.1	3934	6.37	1.54	12644	3000	8493	0	0	8493	3000	22986			4.35	953	16.1	
12000	125164	0.561	49.61	2131	17.6	3824.9	6.1	1.54	12373	3000	8466.5	0	0	8467	3000	22933			4.61	1006	17.6	
13000	125109	0.571	49.88	2186	19.2	3710.5	5.83	1.54	12094	3000	8439	0	0	8439	3000	22878			4.88	1061	19.2	
14000	125055	0.582	50.15	2240	20.8	3592.4	5.56	1.54	11819	3000	8412	0	0	8412	3000	22824			5.15	1115	20.8	
15000	125000	0.593	50.43	2295	22.5	3471.5	5.3	1.53	11552	3000	8384.5	0	0	8385	3000	22769			5.43	1170	22.5	
16000	124944	0.604	50.73	2351	24.4	3368.1	5.06	1.53	11332	3000	8356.5	0	0	8357	3000	22713			5.73	1226	24.4	
17000	124888	0.615	51.03	2407	26.3	3258.9	4.82	1.51	11097	3000	8328.5	0	0	8329	3000	22657			6.03	1282	26.3	
18000	124830	0.627	51.34	2465	28.3	3139.8	4.58	1.5	10842	3000	8299.5	0	0	8300	3000	22599			6.34	1340	28.3	
19000	124772	0.639	51.67	2523	30.4	3012.1	4.33	1.48	10570	3000	8270.5	0	0	8271	3000	22541			6.67	1398	30.4	
20000	124713	0.651	52	2582	32.6	2875.9	4.07	1.47	10284	3000	8241	0	0	8241	3000	22482			7	1457	32.6	
21000	124653	0.664	52.36	2642	35	2782.7	3.88	1.45	10115	3000	8211	0	0	8211	3000	22422			7.36	1517	35	
22000	124592	0.677	52.72	2703	37.5	2677	3.68	1.44	9913	3000	8135.5	0	90	8136	3000	22361			7.72	1578	37.5	
23000	124530	0.69	53.11	2765	40.1	2559.8	3.46	1.42	9681	3000	8055.8	0	187.5	8056	3000	22299			8.11	1640	40.1	
24000	124466	0.703	53.51	2829	42.9	2432.9	3.24	1.41	9422	3000	7973.8	0	287.5	7974	3000	22235			8.51	1704	42.9	
25000	124401	0.717	53.93	2894	45.9	2299.7	3.02	1.38	9141	3000	7888.8	0	392.5	7889	3000	22170			8.93	1769	45.9	
26000	124334	0.731	54.38	2961	49.2	2189.8	2.83	1.35	8936	3000	7799	0	505	7799	3000	22103			9.38	1836	49.2	
27000	124265	0.745	54.84	3030	52.6	2072.6	2.64	1.31	8718	3000	7707	0	620	7707	3000	22034			9.84	1905	52.6	
28000	124193	0.76	55.34	3102	56.3	1951.5	2.44	1.27	8489	3000	7608.5	0	745	7609	3000	21962			10.34	1977	56.3	
29000	124120	0.775	55.87	3175	60.3	1835	2.26	1.22	8248	3000	7505.8	0	877.5	7506	3000	21889			10.87	2050	60.3	
29959	124046	0.79	56.41	3249	64.5	1708.7	2.08	1.16	8009	3000	7401.3	0	1012.5	7401	3000	21815			11.41	2124	64.5	
29959	124046	0.79	56.41	3249	64.5	2417.1	2.94	1.16	8009	3000	7401.3	0	1012.5	7401	3000	21815			11.41	2124	64.5	
30000	124044	0.79	56.43	3251	64.6	2412.8	2.93	1.16	7999	3000	7397.8	0	1017.5	7398	3000	21813			11.43	2126	64.6	
31000	123988	0.79	56.86	3307	67.9	2266.2	2.77	1.31	7690	3000	7316	0	1125	7316	3000	21757			11.86	2182	67.9	
32000	123931	0.79	57.31	3364	71.5	2114.9	2.59	1.46	7387	3000	7231.3	0	1237.5	7231	3000	21700			12.31	2239	71.5	
33000	123871	0.79	57.8	3424	75.2	1959.5	2.41	1.63	7114	3000	7140	0	1360	7140	3000	21640			12.8	2299	75.2	
34000	123809	0.79	58.34	3486	79.3	1796	2.22	1.8	6842	3000	7041.5	0	1495	7042	3000	21578			13.34	2361	79.3	
35000	123744	0.79	58.92	3551	83.7	1627.7	2.02	1.98	6574	3000	6936.5	0	1640	6937	3000	21513			13.92	2426	83.7	
35000	123745	0.79	58.92	3551	83.7	0	0	1.99	4200	3000	6936.5	0	1640	6937	3000	21513			0	0	0	
35000	122000	0.79	83.99	5296	273.9	0	0	1.93	4153	3000	4384	0	5000	4384	3000	19768			25.07	1745	190.2	
35000	121000	0.79	98.48	6296	383.9	0	0	1.9	4127	3000	3884	0	5000	3884	3000	18768			39.56	2745	300.2	
35000	120000	0.79	113.06	7296	494.6	0	0	1.87	4101	3000	3384	0	5000	3384	3000	17768			54.14	3745	410.9	
35000	119000	0.79	127.74	8296	606	0	0	1.84	4076	3000	2884	0	5000	2884	3000	16768			68.82	4745	522.3	
35000	118000	0.79	142.5	9296	718	0	0	1.81	4051	3000	2384	0	5000	2384	3000	15768			83.58	5745	634.3	

	A310-308 4000NM, ISA conditions																				
												Fuel Distribution									
ALT.	A/C WT	MACH	TIME	FUEL	DIST	RATE	GRDT	ALPH	WFE	Loutr	Linr	Ctr	Trim	Rinr	Routr	FOB			For Calculation use only!		
(FT)	(KG)	( )	(MN)	(KG)	(NM)	(FTMN)	(DEG.)	(DEG.)	(KG/H)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)					
0	148835	0	0	0	0	0	0	0	0	3000	11160	15712	2574	11160	3000	46606			delta tim	delta fue	delta dist
0	147710	0	45	1125	0	0	0	0	1500	3000	11160	14587	2574	11160	3000	45481					
1500	147273	0.388	46.94	1562	3.9	3198.4	7.11	4.14	13291	3000	10942	14587	2574	10942	3000	45044			1.94	437	3.9
2000	147238	0.391	47.09	1597	4.6	3208.7	7.08	4.14	13286	3000	10942	14552	2574	10942	3000	45009			2.09	472	4.6
3000	147169	0.398	47.4	1666	5.9	3236.7	7.04	4.14	13301	3000	10942	14483	2574	10942	3000	44940			2.4	541	5.9
4000	147101	0.406	47.71	1734	7.3	3254.3	6.98	4.14	13272	3000	10942	14415	2574	10942	3000	44872			2.71	609	7.3
5000	147034	0.413	48.01	1801	8.6	3315.8	7.01	4.13	13362	3000	10942	14348	2574	10942	3000	44805			3.01	676	8.6
6000	146967	0.42	48.31	1868	9.9	3334.1	6.94	4.13	13329	3000	10942	14281	2574	10942	3000	44738			3.31	743	9.9
7000	146900	0.428	48.62	1935	11.3	3292.5	6.76	4.13	13153	3000	10942	14214	2574	10942	3000	44671			3.62	810	11.3
8000	146833	0.436	48.92	2002	12.7	3240.2	6.55	4.13	12967	3000	10942	14147	2574	10942	3000	44604			3.92	877	12.7
9000	146767	0.444	49.23	2068	14.2	3206.1	6.39	4.13	12840	3000	10942	14081	2574	10942	3000	44538			4.23	943	14.2
10000	146700	0.452	49.55	2135	15.7	3165.8	6.22	4.13	12695	3000	10942	14014	2574	10942	3000	44471			4.55	1010	15.7
10000	146607	0.541	49.98	2228	18	3299	5.41	2.17	12907	3000	10942	13921	2574	10942	3000	44378			4.98	1103	18
11000	146542	0.551	50.29	2293	19.7	3210.9	5.19	2.17	12644	3000	10942	13856	2574	10942	3000	44313			5.29	1168	19.7
12000	146476	0.561	50.6	2359	21.6	3115.5	4.96	2.16	12373	3000	10942	13790	2574	10942	3000	44247			5.6	1234	21.6
13000	146410	0.571	50.93	2425	23.5	3015.6	4.74	2.16	12094	3000	10942	13724	2574	10942	3000	44181			5.93	1300	23.5
14000	146342	0.582	51.27	2493	25.6	2912.3	4.51	2.15	11819	3000	10942	13656	2574	10942	3000	44113			6.27	1368	25.6
15000	146274	0.593	51.62	2561	27.7	2806.6	4.28	2.15	11552	3000	10942	13588	2574	10942	3000	44045			6.62	1436	27.7
16000	146205	0.604	51.98	2630	30	2716.1	4.08	2.14	11332	3000	10942	13519	2574	10942	3000	43976			6.98	1505	30
17000	146135	0.615	52.35	2700	32.3	2620.9	3.88	2.12	11097	3000	10942	13449	2574	10942	3000	43906			7.35	1575	32.3
18000	146064	0.627	52.74	2771	34.8	2517.1	3.67	2.1	10842	3000	10942	13378	2574	10942	3000	43835			7.74	1646	34.8
19000	145992	0.639	53.15	2843	37.5	2405.6	3.46	2.08	10570	3000	10942	13306	2574	10942	3000	43763			8.15	1718	37.5
20000	145917	0.651	53.57	2918	40.3	2286.8	3.24	2.06	10284	3000	10942	13231	2574	10942	3000	43688			8.57	1793	40.3
21000	145842	0.664	54.02	2993	43.3	2205	3.07	2.05	10115	3000	10942	10730	5000	10942	3000	43613			9.02	1868	43.3
22000	145764	0.677	54.48	3071	46.4	2112.4	2.9	2.03	9913	3000	10942	10652	5000	10942	3000	43535			9.48	1946	46.4
23000	145685	0.69	54.97	3150	49.8	2010.2	2.72	2.01	9681	3000	10942	10573	5000	10942	3000	43456			9.97	2025	49.8
24000	145604	0.703	55.48	3231	53.4	1899.8	2.53	1.99	9422	3000	10942	10492	5000	10942	3000	43375			10.48	2106	53.4
25000	145520	0.717	56.02	3315	57.2	1785.1	2.34	1.95	9141	3000	10942	10408	5000	10942	3000	43291			11.02	2190	57.2
26000	145433	0.731	56.6	3402	61.4	1690.6	2.18	1.92	8936	3000	10942	10321	5000	10942	3000	43204			11.6	2277	61.4
27000	145344	0.745	57.21	3491	65.9	1591.2	2.02	1.87	8718	3000	10942	10232	5000	10942	3000	43115			12.21	2366	65.9
28000	145250	0.76	57.86	3585	70.7	1490.7	1.87	1.82	8489	3000	10942	10138	5000	10942	3000	43021			12.86	2460	70.7
29000	145153	0.775	58.55	3682	76	1384.3	1.71	1.76	8248	3000	10942	10041	5000	10942	3000	42924			13.55	2557	76
29959	145055	0.79	59.27	3780	81.6	1268.9	1.54	1.69	8009	3000	10942	9943	5000	10942	3000	42826			14.27	2655	81.6
29959	145055	0.79	59.27	3780	81.6	1795	2.18	1.69	8009	3000	10942	9943	5000	10942	3000	42826			14.27	2655	81.6
30000	145052	0.79	59.3	3783	81.7	1790.4	2.18	1.7	7999	3000	10942	9940	5000	10942	3000	42823			14.3	2658	81.7
31000	144976	0.79	59.88	3859	86.3	1638	2	1.87	7690	3000	10942	9864	5000	10942	3000	42747			14.88	2734	86.3
32000	144896	0.79	60.52	3939	91.2	1480	1.81	2.05	7387	3000	10942	9784	5000	10942	3000	42667			15.52	2814	91.2
33000	144809	0.79	61.24	4026	96.7	1313	1.62	2.24	7114	3000	10942	9697	5000	10942	3000	42580			16.24	2901	96.7
34000	144714	0.79	62.06	4121	103	1127.5	1.39	2.44	6842	3000	10942	9602	5000	10942	3000	42485			17.06	2996	103
35000	144604	0.79	63.04	4231	110.4	913.9	1.14	2.65	6574	3000	10942	9492	5000	10942	3000	42375			18.04	3106	110.4
35000	144606	0.79	63.04	4231	110.4	0	0	2.65	4955	3000	10942	9492	5000	10942	3000	42375			0	0	0
35000	143000	0.79	82.64	5837	259.1	0	0	2.6	4880	3000	10942	7886	5000	10942	3000	40769			19.6	1606	148.7
35000	142000	0.79	94.99	6837	352.9	0	0	2.57	4833	3000	10942	6886	5000	10942	3000	39769			31.95	2606	242.5
35000	141000	0.79	107.46	7837	447.5	0	0	2.54	4788	3000	10942	5886	5000	10942	3000	38769			44.42	3606	337.1
35000	140000	0.79	120.05	8837	543.1	0	0	2.51	4745	3000	10942	4886	5000	10942	3000	37769			57.01	4606	432.7
35000	139000	0.79	132.75	9837	639.5	0	0	2.48	4705	3000	10942	3886	5000	10942	3000	36769			69.71	5606	529.1

Small Commercial Transport
Short Range Mission

Enroute Temp = STD +	0.000	Degrees C	Main 1 Volume =	505.3	gal
Enroute Temp = STD +	0.000	Degrees C	Main 2 Volume =	505.3	gal
Ground Time (takeoff) =	1.000	minutes	CWT Volume =	0	gal
Ground Time (landing) =	2.000	minutes			

Time	Time	Pressure Alt	Dist	Mach Number	Weight	Ambient Temp	Ambient Temp	Total Temp	Fuel Flow	Fuel Flow	Fuel Remaining	Main Tank 1 Fuel Remaining	Main Tank 2 Fuel Remaining	CWT Fuel Remaining	Rate of Climb / Descent
minutes	hours	feet	N. Mi.		lbs	Degrees C	Degrees F	Degrees F	lb/hr	lb/min	lbs	lbs	lbs	lbs	ft/min
0.0	0.0	0	0.0	0.000	64270	15.0	59.0	59.00	1260	21	6770	3385	3385	0	0
10.0	0.2	0	0.0	0.000	64060	15.0	59.0	59.00	9000	150	6560	3280	3280	0	0
11.5	0.2	1500	1.9	0.388	63851	12.0	53.7	69.11	7471	125	6351	3176	3176	0	3193.7
11.6	0.2	2000	2.6	0.391	63832	11.0	51.9	67.51	7405	123	6332	3166	3166	0	3166.2
12.3	0.2	4000	5.4	0.406	63754	7.1	44.7	61.36	7143	119	6254	3127	3127	0	3053.2
12.9	0.2	6000	8.4	0.420	63676	3.1	37.6	55.15	6887	115	6176	3088	3088	0	2937.1
13.6	0.2	8000	11.5	0.436	63598	-0.8	30.5	49.11	6637	111	6098	3049	3049	0	2816.9
14.4	0.2	10000	15.0	0.452	63519	-4.8	23.3	43.07	6386	106	6019	3010	3010	0	2692.5
15.1	0.3	12000	18.7	0.469	63439	-8.8	16.2	37.14	6148	102	5939	2970	2970	0	2559.1
15.9	0.3	14000	22.7	0.487	63359	-12.7	9.1	31.31	5910	99	5859	2930	2930	0	2421.6
16.8	0.3	16000	27.1	0.506	63276	-16.7	1.9	25.58	5678	95	5776	2888	2888	0	2280.1
17.7	0.3	18000	31.9	0.526	63192	-20.7	-5.2	19.96	5454	91	5692	2846	2846	0	2137.1
18.6	0.3	20000	37.3	0.547	63106	-24.6	-12.3	14.45	5231	87	5606	2803	2803	0	1993.6
19.7	0.3	22000	43.2	0.569	63017	-28.6	-19.5	9.05	5012	84	5517	2759	2759	0	1831.5
20.8	0.3	24000	49.9	0.592	62924	-32.5	-26.6	3.77	4795	80	5424	2712	2712	0	1670.2
22.1	0.4	26000	57.5	0.616	62825	-36.5	-33.7	-1.39	4582	76	5325	2663	2663	0	1502.7
23.5	0.4	28000	66.4	0.641	62720	-40.5	-40.9	-6.44	4375	73	5220	2610	2610	0	1331.1
25.1	0.4	30000	76.8	0.668	62605	-44.4	-48.0	-11.24	4171	70	5105	2553	2553	0	1156.7
27.0	0.4	32000	89.3	0.696	62478	-48.4	-55.1	-15.92	3972	66	4978	2489	2489	0	978
27.2	0.5	32200	90.7	0.699	62464	-48.8	-55.8	-16.37	3952	66	4964	2482	2482	0	959.8
27.3	0.5	32250	91.0	0.700	62461	-48.9	-56.0	-16.45	3947	66	4961	2481	2481	0	955.3
27.9	0.5	33000	95.2	0.700	62421	-50.4	-58.7	-19.39	3852	64	4921	2461	2461	0	1205.1
28.8	0.5	34000	101.0	0.700	62367	-52.4	-62.2	-23.30	3728	62	4867	2434	2434	0	1116.5
29.7	0.5	35000	107.3	0.700	62309	-54.3	-65.8	-27.22	3604	60	4809	2405	2405	0	1019.2
35.8	0.6	35000	152.5	0.770	62000	-54.3	-65.8	-19.11	3039	51	4500	2250	2250	0	0
45.7	0.8	35000	225.6	0.770	61500	-54.3	-65.8	-19.11	3029	50	4000	2000	2000	0	0
55.7	0.9	35000	299.1	0.770	61000	-54.3	-65.8	-19.11	3018	50	3500	1750	1750	0	0
63.1	1.1	35000	355.0	0.770	60620	-54.3	-65.8	-19.11	3009	50	3120	1560	1560	0	0
64.0	1.1	34000	360.7	0.700	60622	-52.4	-62.2	-23.30	2991.6	50	3122	1561	1561	0	433.6
64.3	1.1	33000	362.9	0.700	60620	-50.4	-58.7	-19.39	3054	51	3120	1560	1560	0	445
64.6	1.1	32250	364.6	0.700	60618	-48.9	-56.0	-16.45	2342.2	39	3118	1559	1559	0	457.3
64.6	1.1	32200	364.7	0.699	60618	-48.8	-55.8	-16.37	2340.9	39	3118	1559	1559	0	458
65.1	1.1	31000	368.2	0.682	60614	-46.4	-51.6	-13.59	2312.4	39	3114	1557	1557	0	475.6
65.5	1.1	30000	371.0	0.668	60610	-44.4	-48.0	-11.24	2289	38	3110	1555	1555	0	490.8
66.4	1.1	28000	376.7	0.641	60603	-40.5	-40.9	-6.44	2241.7	37	3103	1552	1552	0	523.5
67.3	1.1	26000	382.4	0.616	60595	-36.5	-33.7	-1.39	2192.5	37	3095	1548	1548	0	558
68.2	1.1	24000	387.9	0.592	60586	-32.5	-26.6	3.77	2143.8	36	3086	1543	1543	0	595.7
69.2	1.2	22000	393.5	0.569	60576	-28.6	-19.5	9.05	2094.6	35	3076	1538	1538	0	635.6
70.1	1.2	20000	398.9	0.547	60566	-24.6	-12.3	14.45	2044.1	34	3066	1533	1533	0	675.2
71.1	1.2	18000	404.4	0.526	60554	-20.7	-5.2	19.96	1991.2	33	3054	1527	1527	0	722.7
72.2	1.2	16000	409.8	0.506	60541	-16.7	1.9	25.58	1938.3	32	3041	1521	1521	0	770.4
73.2	1.2	14000	415.3	0.487	60528	-12.7	9.1	31.31	1883.9	31	3028	1514	1514	0	821.2
74.3	1.2	12000	420.7	0.469	60512	-8.8	16.2	37.14	1828.5	30	3012	1506	1506	0	875.1
75.4	1.3	10000	426.1	0.452	60496	-4.8	23.3	43.07	1773.4	30	2996	1498	1498	0	929.1
76.5	1.3	8000	431.5	0.436	60477	-0.8	30.5	49.11	1717	29	2977	1489	1489	0	989.8
77.7	1.3	6000	436.9	0.420	60457	3.1	37.6	55.15	1661.3	28	2957	1479	1479	0	1053.6
78.9	1.3	4000	442.4	0.406	60435	7.1	44.7	61.36	1604	27	2935	1468	1468	0	1123.9
80.2	1.3	2000	447.9	0.391	60410	11.0	51.9	67.51	1544	26	2910	1455	1455	0	1201.1
80.5	1.3	1500	449.3	0.388	60404	12.0	53.7	69.11	1529.1	25	2904	1452	1452	0	1221.8
81.5	1.4	0	453.5	0.378	60383	15.0	59.0	73.82	1484	25	2883	1442	1442	0	1283.9
83.5	1.4	0	453.5	0.000	60283	15.0	59.0	59.00	3000	50	2783	1392	1392	0	0

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	de	Havilland	Dash 8	Series 301																
2																				
3	Total	Weight	18640 kg /	41000 lbs																
4	Fuel	Full Tank	5764 lbs																	
5																				
6																				
7			Time	Time	Pressure	Distance	Climb /	Rate of	Sonic	Mach	Fuel	Fuel Flow	Fuel Flow	Fuel	Tank 1	Tank 2	Weight	Ambient	Ambient	Total
8					Altitude		Descent	Climb /	Velocity	Number	Consume			Remaining	Fuel Rem.	Fuel Rem.		Temp	Temp	Temp
9							Speed	Descent			Total									
10																				
11			minutes	hours	feet	n. miles	kts	ft/min	ft/s		lbs	lbs/hr	lbs/min	lbs	lbs	lbs	lbs	Celcius	Farenheit	Farenheit
12																				
13	CLIMB		0.00	0.00	0.00	0.00	0.00	0.00	1116.40	0.000	0.00	0.00	0.00	5764.00	2882.00	2882.00	41100.00	15.00	59.00	59.00
14	Type I	High Spee	3.00	0.05	2000.00	8.00	195.00	666.67	1108.70	0.297	77.16	1784.00	29.73	5686.84	2843.42	2843.42	41022.84	11.04	51.87	60.89
15	Propeller	RPM 900	5.00	0.08	4000.00	16.00	195.00	800.00	1101.00	0.299	147.71	1744.00	29.07	5616.29	2808.14	2808.14	40952.29	7.08	44.74	53.75
16	ISA		8.00	0.13	6000.00	25.00	195.00	750.00	1093.20	0.301	220.46	1712.00	28.53	5543.54	2771.77	2771.77	40879.54	3.11	37.60	46.62
17			11.00	0.18	8000.00	36.00	195.00	727.27	1085.30	0.303	297.63	1682.00	28.03	5466.37	2733.19	2733.19	40802.37	-0.85	30.47	39.49
18			14.00	0.23	10000.00	47.00	195.00	714.29	1077.40	0.306	379.20	1658.00	27.63	5384.80	2692.40	2692.40	40720.80	-4.81	23.34	32.36
19			17.00	0.28	12000.00	58.00	187.00	705.88	1069.40	0.295	462.97	1640.00	27.33	5301.03	2650.51	2650.51	40637.03	-8.77	16.21	24.50
20			19.00	0.32	14000.00	65.00	179.00	736.84	1061.30	0.285	524.70	1636.00	27.27	5239.30	2619.65	2619.65	40575.30	-12.74	9.07	16.67
21			21.00	0.35	16000.00	75.00	171.00	761.90	1053.20	0.274	584.23	1540.00	25.67	5179.77	2589.89	2589.89	40515.77	-16.70	1.94	8.88
22			23.00	0.38	18000.00	85.00	163.00	782.61	1045.10	0.263	650.37	1446.00	24.10	5113.63	2556.82	2556.82	40449.63	-20.66	-5.19	1.11
23			27.00	0.45	20000.00	95.00	155.00	740.74	1036.80	0.252	716.51	1356.00	22.60	5047.49	2523.75	2523.75	40383.49	-24.62	-12.32	-6.63
24	CRUISE	Max Cruise	30.00	0.50	20000.00	108.55	271.00	0.00	1036.80	0.441	784.26	1356.00	22.60	4979.74	2489.87	2489.87	40315.74	-24.62	-12.32	5.09
25	Type I	Rating	33.00	0.55	20000.00	122.10	271.00	0.00	1036.80	0.441	852.02	1356.00	22.60	4911.98	2455.99	2455.99	40247.98	-24.62	-12.32	5.09
26		RPM 900	36.00	0.60	20000.00	135.65	271.00	0.00	1036.80	0.441	919.78	1356.00	22.60	4844.22	2422.11	2422.11	40180.22	-24.62	-12.32	5.09
27	Propeller		39.00	0.65	20000.00	149.21	271.00	0.00	1036.80	0.441	987.54	1356.00	22.60	4776.46	2388.23	2388.23	40112.46	-24.62	-12.32	5.09
28	ISA		42.00	0.70	20000.00	162.76	271.00	0.00	1036.80	0.441	1055.29	1356.00	22.60	4708.71	2354.35	2354.35	40044.71	-24.62	-12.32	5.09
29			45.00	0.75	20000.00	176.31	271.00	0.00	1036.80	0.441	1123.05	1356.00	22.60	4640.95	2320.47	2320.47	39976.95	-24.62	-12.32	5.09
30			48.00	0.80	20000.00	189.86	271.00	0.00	1036.80	0.441	1190.81	1356.00	22.60	4573.19	2286.60	2286.60	39909.19	-24.62	-12.32	5.09
31			50.00	0.83	20000.00	198.90	271.00	0.00	1036.80	0.441	1235.98	1356.00	22.60	4528.02	2264.01	2264.01	39864.02	-24.62	-12.32	5.09
32	DESCENT		54.00	0.90	20000.00	215.90	225.00	1250.00	1036.80	0.366	1333.98	1356.00	22.60	4430.02	2215.01	2215.01	39766.02	-24.62	-12.32	-0.32
33	Type I	High Spee	58.00	0.97	18000.00	235.90	225.00	1500.00	1045.10	0.363	1423.98	1350.00	22.50	4340.02	2170.01	2170.01	39676.02	-20.66	-5.19	6.81
34	Propeller	RPM 900	59.00	0.98	16000.00	241.90	225.00	2000.00	1053.20	0.361	1438.98	900.00	15.00	4325.02	2162.51	2162.51	39661.02	-16.70	1.94	13.95
35	ISA		60.00	1.00	14000.00	246.90	225.00	2000.00	1061.30	0.358	1453.98	900.00	15.00	4310.02	2155.01	2155.01	39646.02	-12.74	9.07	21.08
36			61.00	1.02	12000.00	251.90	225.00	2000.00	1069.40	0.355	1468.98	900.00	15.00	4295.02	2147.51	2147.51	39631.02	-8.77	16.21	28.21
37			62.00	1.03	10000.00	255.90	225.00	2000.00	1077.40	0.353	1483.98	900.00	15.00	4280.02	2140.01	2140.01	39616.02	-4.81	23.34	35.34
38			63.00	1.05	8000.00	260.90	225.00	2000.00	1085.30	0.350	1493.98	600.00	10.00	4270.02	2135.01	2135.01	39606.02	-0.85	30.47	42.48
39			64.00	1.07	6000.00	264.90	225.00	2000.00	1093.20	0.347	1503.98	600.00	10.00	4260.02	2130.01	2130.01	39596.02	3.11	37.60	49.61
40			65.00	1.08	4000.00	268.90	225.00	2000.00	1101.00	0.345	1513.98	600.00	10.00	4250.02	2125.01	2125.01	39586.02	7.08	44.74	56.74
41			66.00	1.10	2000.00	273.90	225.00	2000.00	1108.70	0.343	1523.98	600.00	10.00	4240.02	2120.01	2120.01	39576.02	11.04	51.87	63.87
42			67.00	1.12	0.00	278.90	0.00	0.00	1116.40	0.000	1533.98	0.00	0.00	4230.02	2115.01	2115.01	39566.02	15.00	59.00	59.00

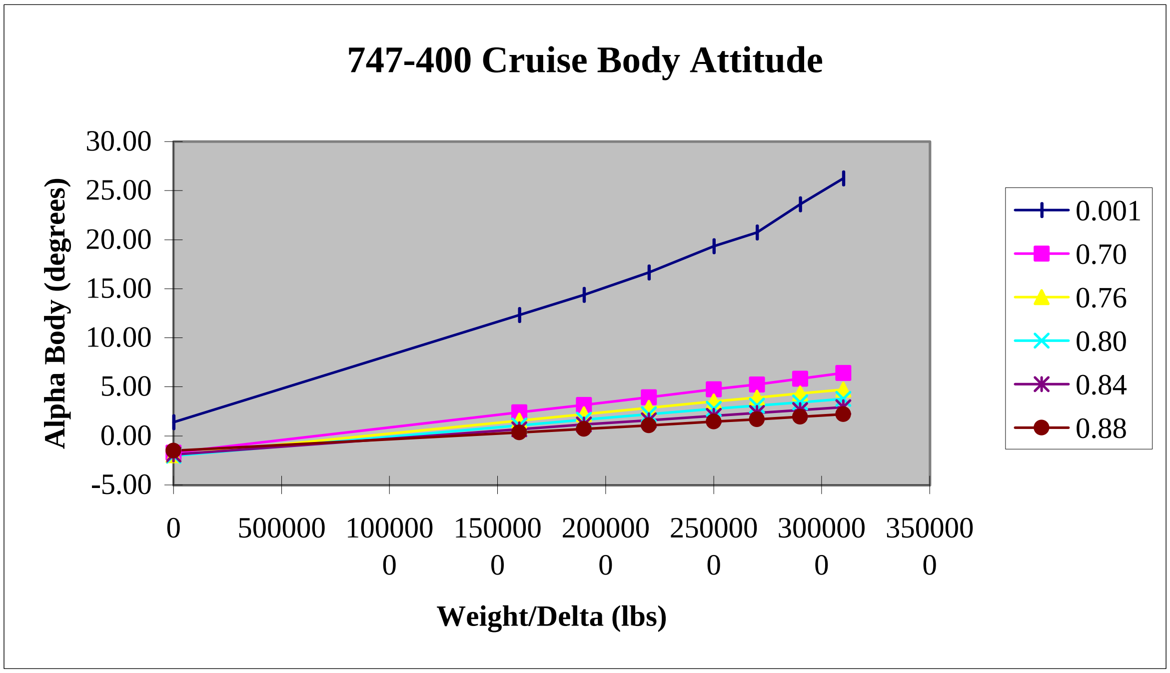
	R	S	T	U	V	W	X	Y	Z
1	GV - Max Range Mission (6506 NM)								
2		ZFW	Ramp Wt	Total Fuel	Reserve Fuel	Landing Wt			
3		49600	90900	41300	2849	52449			
4									
5	Condition	ime - Minute	uel Burn - lb	Distance - NM	irplane Wt - lb	el Remaining -	ach Numb	Fuel Flow	ate of Climb/Desce
6								lbs/hr	ft/min
7	Ground idle	10	200	0	90700	41100	0.00		-
8	Takeoff	1	200	0	90500	40900	0.38	12000	-
9	Climb to 41kft	23	2391	145	88109	38509	0.80	6237	1550
10	Cruise at 41kft	141	7300	1081	80809	31209	0.80	3106	-
11	Climb to 43kft	3	181	21	80628	31028	0.80	3620	1500
12	Cruise at 43kft	150	7100	1145	73528	23928	0.80	2840	-
13	Climb to 45kft	3	164	21	73364	23764	0.80	3280	1500
14	Cruise at 45kft	155	6700	1182	66664	17064	0.80	2594	-
15	Climb to 47kft	3	158	23	66506	16906	0.80	3160	1500
16	Cruise at 47kft	154	6100	1177	60406	10806	0.80	2377	-
17	Climb to 49kft	4	158	25	60248	10648	0.80	2370	1000
18	Cruise at 49kft	157	5700	1204	54548	4948	0.80	2178	-
19	Climb to 51kft	4	158	29	54390	4790	0.80	2370	1000
20	Cruise at 51kft	42	1414	317	52976	3376	0.80	2020	-
21	Descent to 0 ft	23	343	138	52633	3033	0.18	895	2000
22	Approach-Lan	5	184	0	52449	2849	0.00	2208	-

737

						MACH				
		0	0.45	0.50	0.55	0.60	0.65	0.70	0.72	0.74
Cl	0.3	2.13	1.95	1.93	1.91	1.89	1.87	1.83	1.72	1.66
	0.7	6.49	5.77	5.69	5.53	5.35	5.09	4.79	4.65	4.55

747-400

				MACH			
		0.001	0.70	0.76	0.80	0.84	0.88
Wt/Delta	0	1.39	-1.71	-1.97	-2.02	-1.89	-1.52
	1600000	12.32	2.40	1.55	1.07	0.67	0.35
	1900000	14.37	3.17	2.21	1.65	1.15	0.70
	2200000	16.67	3.95	2.86	2.21	1.60	1.06
	2500000	19.33	4.75	3.50	2.75	2.05	1.45
	2700000	20.72	5.24	3.91	3.10	2.35	1.70
	2900000	23.61	5.84	4.32	3.43	2.64	1.95
	3100000	26.25	6.43	4.73	3.76	2.92	2.20



35000	138000	0.79	145.56	10837	736.7	0	0	2.44	4665	3000	10942	2886	5000	10942	3000	35769			82.52	6606	626.3	
35000	137000	0.79	158.47	11837	834.7	0	0	2.41	4625	3000	10942	1886	5000	10942	3000	34769			95.43	7606	724.3	
35000	136000	0.79	171.5	12837	933.6	0	0	2.38	4585	3000	10885	1000	5000	10885	3000	33769			108.46	8606	823.2	
35000	135000	0.79	184.64	13837	1033.3	0	0	2.35	4550	3000	10385	1000	5000	10385	3000	32769			121.6	9606	922.9	
35000	134000	0.79	197.87	14837	1133.7	0	0	2.32	4516	3000	9885	1000	5000	9885	3000	31769			134.83	10606	1023.3	
35000	133000	0.79	211.21	15837	1234.9	0	0	2.28	4483	3000	9385	1000	5000	9385	3000	30769			148.17	11606	1124.5	
35000	132000	0.79	224.64	16837	1336.9	0	0	2.25	4450	3000	8885	1000	5000	8885	3000	29769			161.6	12606	1226.5	
35000	131000	0.79	238.18	17837	1439.6	0	0	2.22	4417	3000	8385	1000	5000	8385	3000	28769			175.14	13606	1329.2	
35000	130000	0.79	251.81	18837	1543.1	0	0	2.19	4385	3000	7885	1000	5000	7885	3000	27769			188.77	14606	1432.7	
35000	129000	0.79	265.54	19837	1647.3	0	0	2.16	4354	3000	7385	1000	5000	7385	3000	26769			202.5	15606	1536.9	
35000	128000	0.79	279.37	20837	1752.2	0	0	2.13	4323	3000	6885	1000	5000	6885	3000	25769			216.33	16606	1641.8	
35000	127000	0.79	293.3	21837	1857.9	0	0	2.09	4293	3000	6385	1000	5000	6385	3000	24769			230.26	17606	1747.5	
35000	126000	0.79	307.32	22837	1964.4	0	0	2.06	4262	3000	5885	1000	5000	5885	3000	23769			244.28	18606	1854	
35000	125000	0.79	321.45	23837	2071.6	0	0	2.03	4235	3000	5385	1000	5000	5385	3000	22769			258.41	19606	1961.2	
35000	124000	0.79	335.66	24837	2179.5	0	0	2	4207	3000	4885	1000	5000	4885	3000	21769			272.62	20606	2069.1	
35000	123000	0.79	349.97	25837	2288	0	0	1.97	4180	3000	4385	1000	5000	4385	3000	20769			286.93	21606	2177.6	
35000	122000	0.79	364.37	26837	2397.3	0	0	1.93	4153	3000	3885	1000	5000	3885	3000	19769			301.33	22606	2286.9	
35000	121000	0.79	378.86	27837	2507.3	0	0	1.9	4127	3000	3385	1000	5000	3385	3000	18769			315.82	23606	2396.9	
35000	120000	0.79	393.44	28837	2618	0	0	1.87	4101	3000	2885	1000	5000	2885	3000	17769			330.4	24606	2507.6	
35000	119000	0.79	408.12	29837	2729.4	0	0	1.84	4076	3000	2385	1000	5000	2385	3000	16769			345.08	25606	2619	
35000	118000	0.79	422.88	30837	2841.4	0	0	1.81	4051	3000	1885	1000	5000	1885	3000	15769			359.84	26606	2731	
35000	117000	0.79	437.74	31837	2954.2	0	0	1.77	4026	3000	1385	1000	5000	1385	3000	14769			374.7	27606	2843.8	
35000	116756	0.79	441.38	32081	2981.8	0	0	1.77	4020	3000	1263	1000	5000	1263	3000	14525			378.34	27850	2871.4	
35000	116756	0.79	441.38	32081	2981.8	1866.9	2.32	1.75	6574	3000	1263	1000	5000	1263	3000	14525			0	0	0	
36000	116696	0.79	441.94	32141	2986.1	1674.2	2.09	1.94	6270	3000	1233	1000	5000	1233	3000	14465			0.56	60	4.3	
36089	116690	0.79	442	32147	2986.5	1518.9	1.9	1.95	6244	3000	1230	1000	5000	1230	3000	14459			0.62	66	4.7	
36089	116690	0.79	442	32147	2986.5	1518.9	1.9	1.95	6244	3000	1230	1000	5000	1230	3000	14459			0.62	66	4.7	
37000	116625	0.79	442.63	32212	2991.3	1357.4	1.7	2.13	6007	3000	1197	1000	5000	1197	3000	14394			1.25	131	9.5	
38000	116548	0.79	443.42	32289	2997.2	1172.6	1.46	2.33	5756	3000	1159	1000	5000	1159	3000	14317			2.04	208	15.4	
39000	116459	0.79	444.37	32378	3004.4	944.6	1.18	2.53	5461	3000	1114	1000	5000	1114	3000	14228			2.99	297	22.6	
39000	116460	0.79	444.37	32378	3004.4	0	0	2.54	3987	3000	1114	1000	5000	1114	3000	14228			0	0	0	
39000	115000	0.79	466.51	33838	3171.6	0	0	2.49	3925	3000	384	1000	5000	384	3000	12768			22.14	1460	167.2	
39000	114000	0.79	481.88	34838	3287.7	0	0	2.45	3885	3000	384	1000	4000	384	3000	11768			37.51	2460	283.3	
39000	113000	0.79	497.4	35838	3404.9	0	0	2.41	3845	3000	384	1000	3000	384	3000	10768			53.03	3460	400.5	
39000	112000	0.79	513.08	36838	3523.3	0	0	2.37	3806	3000	384	1000	2000	384	3000	9768			68.71	4460	518.9	
39000	111000	0.79	528.92	37838	3642.9	0	0	2.33	3772	3000	384	1000	1000	384	3000	8768			84.55	5460	638.5	
39000	110000	0.79	544.89	38838	3763.6	0	0	2.29	3739	3000	384	1000	0	384	3000	7768			100.52	6460	759.2	
39000	109171	0.79	558.25	39667	3864.4	0	0	2.26	3711	3000	384	171	0	384	3000	6939			113.88	7289	860	
39000	109171	0.79	558.25	39667	3864.4	-2344	-2.9	2.27	947	3000	384	171	0	384	3000	6939			0	0	0	
38035	109165	0.79	558.66	39673	3867.5	-1708.7	-2.1	2.08	954	3000	384	165	0	384	3000	6933			0.41	6	3.1	
37000	109155	0.773	559.27	39683	3872	-1688.7	-2.2	2.17	935	3000	384	155	0	384	3000	6923			1.02	16	7.6	
36089	109146	0.758	559.81	39692	3876	-1786.4	-2.3	2.23	904	3000	384	146	0	384	3000	6914			1.56	25	11.6	
35000	109137	0.741	560.42	39701	3880.4	-1784.7	-2.4	2.3	869	3000	384	137	0	384	3000	6905			2.17	34	16	
34000	109129	0.726	560.98	39709	3884.3	-1790.6	-2.4	2.34	833	3000	384	129	0	384	3000	6897			2.73	42	19.9	
33000	109121	0.711	561.54	39717	3888.2	-1804.6	-2.5	2.38	794	3000	384	121	0	384	3000	6889			3.29	50	23.8	
32000	109114	0.696	562.09	39724	3891.9	-1824.7	-2.5	2.42	751	3000	384	114	0	384	3000	6882			3.84	57	27.5	
31000	109107	0.682	562.64	39731	3895.6	-1810	-2.6	2.44	760	3000	384	107	0	384	3000	6875			4.39	64	31.2	
30000	109100	0.668	563.19	39738	3899.3	-1795.3	-2.6	2.46	770	3000	384	100	0	384	3000	6868			4.94	71	34.9	
29000	109093	0.655	563.75	39745	3902.9	-1784.6	-2.6	2.49	775	3000	384	93	0	384	3000	6861			5.5	78	38.5	
28000	109086	0.641	564.31	39752	3906.5	-1776.6	-2.6	2.51	775	3000	384	86	0	384	3000	6854			6.06	85	42.1	

27000	109079	0.628	564.88	39759	3910.1	-1757.1	-2.7	2.53	792	3000	384	79	0	384	3000	6847			6.63	92	45.7	
26000	109071	0.616	565.45	39767	3913.6	-1737.9	-2.7	2.55	810	3000	384	71	0	384	3000	6839			7.2	100	49.2	
25000	109063	0.604	566.03	39775	3917.2	-1720.1	-2.7	2.58	827	3000	384	63	0	384	3000	6831			7.78	108	52.8	
24000	109055	0.592	566.61	39783	3920.7	-1701.8	-2.7	2.59	844	3000	384	55	0	384	3000	6823			8.36	116	56.3	
23000	109047	0.58	567.2	39791	3924.2	-1685.3	-2.7	2.59	860	3000	384	47	0	384	3000	6815			8.95	124	59.8	
22000	109038	0.569	567.8	39800	3927.6	-1671.7	-2.7	2.6	872	3000	384	38	0	384	3000	6806			9.55	133	63.2	
21000	109030	0.558	568.4	39808	3931.1	-1660.9	-2.8	2.61	880	3000	384	30	0	384	3000	6798			10.15	141	66.7	
20000	109021	0.547	569	39817	3934.5	-1652.9	-2.8	2.61	885	3000	384	21	0	384	3000	6789			10.75	150	70.1	
19000	109012	0.536	569.61	39826	3937.8	-1633.4	-2.8	2.62	910	3000	384	12	0	384	3000	6780			11.36	159	73.4	
18000	109003	0.526	570.23	39835	3941.2	-1615	-2.8	2.63	934	3000	384	3	0	384	3000	6771			11.98	168	76.8	
17000	108993	0.516	570.85	39845	3944.6	-1597.9	-2.8	2.63	957	3000	381	0	0	381	3000	6761			12.6	178	80.2	
16000	108983	0.506	571.48	39855	3947.9	-1583.5	-2.8	2.64	977	3000	376	0	0	376	3000	6751			13.23	188	83.5	
15000	108973	0.497	572.11	39865	3951.2	-1567.7	-2.9	2.64	999	3000	371	0	0	371	3000	6741			13.86	198	86.8	
14000	108962	0.487	572.75	39876	3954.5	-1551.5	-2.9	2.64	1021	3000	365	0	0	365	3000	6730			14.5	209	90.1	
13000	108951	0.478	573.4	39887	3957.8	-1536.7	-2.9	2.64	1041	3000	360	0	0	360	3000	6719			15.15	220	93.4	
12000	108940	0.469	574.06	39898	3961	-1523.8	-2.9	2.64	1060	3000	354	0	0	354	3000	6708			15.81	231	96.6	
11000	108928	0.461	574.71	39910	3964.3	-1513	-2.9	2.64	1076	3000	348	0	0	348	3000	6696			16.46	243	99.9	
10000	108917	0.452	575.38	39921	3967.5	-1506.3	-3	2.64	1086	3000	343	0	0	343	3000	6685			17.13	254	103.1	
9000	108905	0.444	576.04	39933	3970.6	-1506.5	-3	2.64	1086	3000	337	0	0	337	3000	6673			17.79	266	106.2	
8000	108892	0.436	576.7	39945	3973.8	-1508.2	-3	2.64	1085	3000	331	0	0	331	3000	6661			18.45	278	109.4	
7000	108881	0.428	577.37	39957	3976.9	-1496.7	-3.1	2.64	1102	3000	325	0	0	325	3000	6649			19.12	290	112.5	
6000	108868	0.42	578.04	39970	3979.9	-1482	-3.1	2.64	1124	3000	318	0	0	318	3000	6636			19.79	303	115.5	
5000	108856	0.413	578.72	39982	3983	-1468.5	-3.1	2.64	1145	3000	312	0	0	312	3000	6624			20.47	315	118.6	
4000	108843	0.406	579.4	39995	3986	-1456.4	-3.1	2.64	1165	3000	306	0	0	306	3000	6611			21.15	328	121.6	
3000	108829	0.398	580.09	40009	3989	-1442.7	-3.1	2.64	1189	3000	299	0	0	299	3000	6597			21.84	342	124.6	
2000	108816	0.391	580.79	40022	3992	-1428.8	-3.1	2.63	1211	3000	292	0	0	292	3000	6584			22.54	355	127.6	
1500	108808	0.388	581.14	40030	3993.5	-1422.3	-3.2	2.63	1221	3000	288	0	0	288	3000	6576			22.89	363	129.1	
0	108655	0	584.79	40183	3993.5	0	0	0	0	3000	212	0	0	212	3000	6423			26.54	516	129.1	

35000	117000	0.79	157.36	10296	830.8	0	0	1.77	4026	3000	1884	0	5000	1884	3000	14768			98.44	6745	747.1	
35000	116748	0.79	161.12	10548	859.3	0	0	1.77	4020	3000	1758	0	5000	1758	3000	14516			102.2	6997	775.6	
35000	116748	0.79	161.12	10548	859.3	1867.1	2.32	1.75	6574	3000	1758	0	5000	1758	3000	14516			0	0	0	
36000	116688	0.79	161.68	10608	863.6	1674.5	2.09	1.94	6270	3000	1728	0	5000	1728	3000	14456			0.56	60	4.3	
36089	116682	0.79	161.74	10614	864	1519.2	1.9	1.95	6244	3000	1725	0	5000	1725	3000	14450			0.62	66	4.7	
36089	116682	0.79	161.74	10614	864	1519.2	1.9	1.95	6244	3000	1725	0	5000	1725	3000	14450			0.62	66	4.7	
37000	116617	0.79	162.37	10679	868.8	1357.7	1.7	2.13	6007	3000	1692.5	0	5000	1693	3000	14385			1.25	131	9.5	
38000	116540	0.79	163.16	10756	874.7	1172.9	1.46	2.33	5756	3000	1654	0	5000	1654	3000	14308			2.04	208	15.4	
39000	116451	0.79	164.11	10845	881.9	944.9	1.18	2.53	5461	3000	1609.5	0	5000	1610	3000	14219			2.99	297	22.6	
39000	116452	0.79	164.11	10845	881.9	0	0	2.54	3986	3000	1609.5	0	5000	1610	3000	14219			0	0	0	
39000	115000	0.79	186.13	12297	1048.2	0	0	2.49	3925	3000	883.5	0	5000	883.5	3000	12767			22.02	1452	166.3	
39000	114000	0.79	201.5	13297	1164.3	0	0	2.45	3885	3000	383.5	1000	4000	383.5	3000	11767			37.39	2452	282.4	
39000	113000	0.79	217.02	14297	1281.5	0	0	2.41	3845	3000	0	1000	3767	0	3000	10767			52.91	3452	399.6	
39000	112000	0.79	232.7	15297	1399.9	0	0	2.37	3806	3000	0	1000	2767	0	3000	9767			68.59	4452	518	
39000	111000	0.79	248.54	16297	1519.5	0	0	2.33	3772	3000	0	1000	1767	0	3000	8767			84.43	5452	637.6	
39000	110000	0.79	264.51	17297	1640.2	0	0	2.29	3739	3000	0	1000	767	0	3000	7767			100.4	6452	758.3	
39000	109000	0.79	280.63	18297	1761.9	0	0	2.25	3706	3000	0	767	0	0	3000	6767			116.52	7452	880	
39000	108119	0.79	294.95	19178	1870	0	0	2.22	3677	2943	0	0	0	0	2943	5886			130.84	8333	988.1	
39000	108119	0.79	294.95	19178	1870	-2339.7	-2.9	2.23	947	2943	0	0	0	0	2943	5886			0	0	0	
38036	108112	0.79	295.36	19185	1873.1	-2354.9	-2.9	2.04	954	2939.5	0	0	0	0	2939.5	5879			0.41	7	3.1	
38035	108112	0.79	295.36	19185	1873.1	-1708	-2.1	2.04	954	2939.5	0	0	0	0	2939.5	5879			0.41	7	3.1	
37000	108103	0.773	295.97	19194	1877.6	-1689.4	-2.2	2.13	935	2935	0	0	0	0	2935	5870			1.02	16	7.6	
36089	108094	0.758	296.51	19203	1881.6	-1686.5	-2.2	2.19	904	2930.5	0	0	0	0	2930.5	5861			1.56	25	11.6	
36089	108094	0.758	296.51	19203	1881.6	-1787.5	-2.3	2.19	904	2930.5	0	0	0	0	2930.5	5861			1.56	25	11.6	
35000	108085	0.741	297.12	19212	1886	-1786.2	-2.4	2.26	869	2926	0	0	0	0	2926	5852			2.17	34	16	
34000	108077	0.726	297.68	19220	1889.9	-1792.7	-2.4	2.3	833	2922	0	0	0	0	2922	5844			2.73	42	19.9	
33000	108069	0.711	298.23	19228	1893.8	-1807.4	-2.5	2.34	794	2918	0	0	0	0	2918	5836			3.28	50	23.8	
32000	108062	0.696	298.78	19235	1897.5	-1828.1	-2.5	2.38	751	2914.5	0	0	0	0	2914.5	5829			3.83	57	27.5	
31000	108055	0.682	299.33	19242	1901.2	-1813.9	-2.6	2.4	760	2911	0	0	0	0	2911	5822			4.38	64	31.2	
30000	108048	0.668	299.89	19249	1904.9	-1799.5	-2.6	2.42	770	2907.5	0	0	0	0	2907.5	5815			4.94	71	34.9	
29000	108041	0.655	300.44	19256	1908.5	-1789	-2.6	2.44	775	2904	0	0	0	0	2904	5808			5.49	78	38.5	
28000	108034	0.641	301	19263	1912.1	-1781.2	-2.6	2.46	775	2900.5	0	0	0	0	2900.5	5801			6.05	85	42.1	
27000	108027	0.628	301.57	19270	1915.6	-1761.8	-2.7	2.49	792	2897	0	0	0	0	2897	5794			6.62	92	45.6	
26000	108019	0.616	302.14	19278	1919.2	-1742.6	-2.7	2.51	810	2893	0	0	0	0	2893	5786			7.19	100	49.2	
25000	108011	0.604	302.72	19286	1922.7	-1724.9	-2.7	2.53	827	2889	0	0	0	0	2889	5778			7.77	108	52.7	
24000	108003	0.592	303.3	19294	1926.2	-1706.6	-2.7	2.54	844	2885	0	0	0	0	2885	5770			8.35	116	56.2	
23000	107995	0.58	303.89	19302	1929.7	-1690.1	-2.7	2.55	860	2881	0	0	0	0	2881	5762			8.94	124	59.7	
22000	107987	0.569	304.48	19310	1933.1	-1676.5	-2.7	2.55	872	2877	0	0	0	0	2877	5754			9.53	132	63.1	
21000	107978	0.558	305.08	19319	1936.6	-1665.7	-2.8	2.56	880	2872.5	0	0	0	0	2872.5	5745			10.13	141	66.6	
20000	107969	0.547	305.68	19328	1939.9	-1657.6	-2.8	2.57	885	2868	0	0	0	0	2868	5736			10.73	150	69.9	
19000	107960	0.536	306.29	19337	1943.3	-1637.8	-2.8	2.57	910	2863.5	0	0	0	0	2863.5	5727			11.34	159	73.3	
18000	107951	0.526	306.9	19346	1946.7	-1619.3	-2.8	2.58	934	2859	0	0	0	0	2859	5718			11.95	168	76.7	
17000	107941	0.516	307.52	19356	1950	-1602.1	-2.8	2.59	957	2854	0	0	0	0	2854	5708			12.57	178	80	
16000	107932	0.506	308.15	19365	1953.3	-1587.7	-2.8	2.59	977	2849.5	0	0	0	0	2849.5	5699			13.2	187	83.3	
15000	107921	0.497	308.78	19376	1956.6	-1572	-2.9	2.6	999	2844	0	0	0	0	2844	5688			13.83	198	86.6	
14000	107911	0.487	309.42	19386	1959.9	-1555.7	-2.9	2.6	1021	2839	0	0	0	0	2839	5678			14.47	208	89.9	
13000	107900	0.478	310.07	19397	1963.2	-1540.9	-2.9	2.6	1041	2833.5	0	0	0	0	2833.5	5667			15.12	219	93.2	
12000	107888	0.469	310.72	19409	1966.4	-1528.1	-2.9	2.59	1060	2827.5	0	0	0	0	2827.5	5655			15.77	231	96.4	
11000	107877	0.461	311.38	19420	1969.7	-1517.3	-2.9	2.59	1076	2822	0	0	0	0	2822	5644			16.43	242	99.7	
10000	107865	0.452	312.04	19432	1972.9	-1510.7	-3	2.59	1086	2816	0	0	0	0	2816	5632			17.09	254	102.9	

10000	107865	0.452	312.04	19432	1972.9	-1510.7	-3	2.59	1086	2816	0	0	0	0	2816	5632			17.09	254	102.9	
9000	107853	0.444	312.7	19444	1976	-1511	-3	2.59	1086	2810	0	0	0	0	2810	5620			17.75	266	106	
8000	107841	0.436	313.36	19456	1979.1	-1512.9	-3.1	2.59	1085	2804	0	0	0	0	2804	5608			18.41	278	109.1	
7000	107829	0.428	314.02	19468	1982.2	-1501.4	-3.1	2.59	1102	2798	0	0	0	0	2798	5596			19.07	290	112.2	
6000	107817	0.42	314.69	19480	1985.3	-1486.6	-3.1	2.59	1124	2792	0	0	0	0	2792	5584			19.74	302	115.3	
5000	107804	0.413	315.37	19493	1988.3	-1473.2	-3.1	2.59	1145	2785.5	0	0	0	0	2785.5	5571			20.42	315	118.3	
4000	107791	0.406	316.05	19506	1991.3	-1461.1	-3.1	2.59	1165	2779	0	0	0	0	2779	5558			21.1	328	121.3	
3000	107778	0.398	316.74	19519	1994.3	-1447.3	-3.1	2.59	1189	2772.5	0	0	0	0	2772.5	5545			21.79	341	124.3	
2000	107764	0.391	317.43	19533	1997.3	-1433.4	-3.2	2.58	1211	2765.5	0	0	0	0	2765.5	5531			22.48	355	127.3	
1500	107757	0.388	317.78	19540	1998.8	-1426.9	-3.2	2.58	1221	2762	0	0	0	0	2762	5524			22.83	362	128.8	
0	107603	0	321.46	19694	1998.8	0	0	0	0	2685	0	0	0	0	2685	5370			26.51	516	128.8	

22000	22000	0.2049	60.4	104717	310	1940	0.5687	1062
20000	20000	0.1875	54.5	104698	291	1892	0.5469	1132
18000	18000	0.1696	48.6	104677	270	1841	0.526	1206
16000	16000	0.1513	42.7	104654	247	1790	0.5062	1283
14000	14000	0.1324	36.9	104629	222	1740	0.4874	1365
12000	12000	0.113	31	104602	195	1690	0.4694	1450
10000	10000	0.0929	25.2	104572	165	1639	0.4523	1540
8000	8000	0.0723	19.3	104539	132	1590	0.436	1633
6000	6000	0.051	13.4	104503	96	1539	0.4204	1732
4000	4000	0.0289	7.5	104464	56	1482	0.4056	1853
2000	2000	0.0059	1.5	104419	12	1420	0.3914	2004
1500	1500	0	0	104407	0	1404	0.388	2045

ENROUTE DESCENT ANALYSIS
WIND (KNOTS) = 0 DTEMP (DEG

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	FUEL LB	ROD FPM	MACH	T FF LB/HR
35000	35000	0.3086	100.2	105424	401	3090	0.74	760
34923	34923	0.3082	100	105424	401	3094	0.74	760
34923	34923	0.3082	100	105424	401	2269	0.74	760
34000	34000	0.3014	97.1	105419	396	2233	0.7258	760
32000	32000	0.2863	90.9	105407	384	2189	0.6962	775
30000	30000	0.2709	84.7	105395	372	2138	0.6681	820
28000	28000	0.2551	78.6	105381	359	2085	0.6414	877
26000	26000	0.2389	72.6	105367	344	2034	0.6159	933
24000	24000	0.2223	66.5	105351	328	1983	0.5917	996
22000	22000	0.2053	60.6	105333	310	1936	0.5687	1062
20000	20000	0.1879	54.6	105314	291	1888	0.5469	1132
18000	18000	0.17	48.7	105293	270	1838	0.526	1206
16000	16000	0.1516	42.8	105270	247	1787	0.5062	1283
14000	14000	0.1326	36.9	105245	222	1737	0.4874	1365
12000	12000	0.1132	31.1	105218	195	1686	0.4694	1450
10000	10000	0.0931	25.2	105188	165	1636	0.4523	1540
8000	8000	0.0724	19.3	105155	132	1587	0.436	1633
6000	6000	0.051	13.4	105119	96	1537	0.4204	1732
4000	4000	0.0289	7.5	105079	56	1480	0.4056	1853
2000	2000	0.0059	1.5	105035	12	1417	0.3914	2004
1500	1500	0	0	105023	0	1402	0.388	2045

LARGE AIRPLANE

ENROUTE DESCENT ANALYSIS

WIN D (KNO TS) = 0 DTEMP (DEG

HPR	HGEO	TIME	DIST	WEIGH	FUEL	ROD	MACH	T FF
FT	FT	HR	NM	LB	LB	FPM		LB/HR
43000	43000	0.3722	134.8	488363	1714	3026	0.85	2524
42000	42000	0.3667	132.1	488349	1700	3028	0.85	2622
40000	40000	0.3558	126.8	488319	1671	3068	0.85	2817
38000	38000	0.3451	121.6	488288	1640	3178	0.85	2980
36672	36672	0.3382	118.2	488267	1619	3277	0.85	3087
36672	36672	0.3382	118.2	488267	1619	2292	0.85	3087
36089	36089	0.334	116.2	488254	1606	2257	0.8399	3120
36089	36089	0.334	116.2	488254	1606	2417	0.8399	3120
36000	36000	0.3333	115.9	488252	1604	2412	0.8384	3124
34000	34000	0.3193	109.2	488208	1559	2336	0.8047	3213
32000	32000	0.3049	102.6	488161	1512	2286	0.7727	3304
30000	30000	0.2901	96.1	488111	1463	2239	0.7422	3407
28000	28000	0.2751	89.6	488058	1410	2180	0.7131	3571
26000	26000	0.2596	83.1	488002	1353	2124	0.6853	3738
24000	24000	0.2436	76.7	487941	1292	2066	0.6589	3926
22000	22000	0.2273	70.3	487875	1226	2008	0.6338	4135
20000	20000	0.2104	63.9	487803	1155	1954	0.6098	4346
18000	18000	0.1932	57.6	487727	1078	1914	0.5869	4542
16000	16000	0.1756	51.3	487645	997	1881	0.5651	4749
14000	14000	0.1577	45.1	487558	909	1841	0.5443	5023
12000	12000	0.1394	38.9	487462	814	1793	0.5245	5359
12000	12000	0.1394	38.9	487462	814	1250	0.5245	5359
10000	10000	0.109	29.5	487293	645	976	0.4523	5704
10000	10000	0.109	29.5	487293	645	1370	0.4523	5704
8000	8000	0.0843	22.5	487152	503	1336	0.436	5810
6000	6000	0.0591	15.6	487003	355	1303	0.4204	5924
4000	4000	0.0331	8.6	486849	200	1269	0.4056	6008
2000	2000	0.0067	1.7	486689	40	1250	0.3914	6061
1500	1500	0	0	486648	0	1249	0.388	6074

ENROU E DESC ENT AN ALYSIS

WIN D (KNO TS) = 0 DTEMP (DEG

HPR	HGEO	TIME	DIST	WEIGH	FUEL	ROD	MACH	T FF
FT	FT	HR	NM	LB	LB	FPM		LB/HR
39000	39000	0.3518	124.7	493096	1661	3105	0.85	2899
38000	38000	0.3464	122.1	493080	1646	3164	0.85	2980
36672	36672	0.3396	118.7	493059	1625	3261	0.85	3087
36672	36672	0.3396	118.7	493059	1625	2280	0.85	3087
36089	36089	0.3353	116.6	493046	1612	2246	0.8399	3120

36089	36089	0.3353	116.6	493046	1612	2404	0.8399	3120
36000	36000	0.3346	116.3	493044	1610	2400	0.8384	3124
34000	34000	0.3205	109.7	492999	1565	2325	0.8047	3213
32000	32000	0.306	103	492952	1518	2275	0.7727	3304
30000	30000	0.2912	96.5	492902	1468	2229	0.7422	3407
28000	28000	0.2761	89.9	492850	1415	2170	0.7131	3571
26000	26000	0.2605	83.5	492793	1358	2115	0.6853	3738
24000	24000	0.2445	77	492731	1297	2057	0.6589	3926
22000	22000	0.2281	70.6	492665	1231	1999	0.6338	4135
20000	20000	0.2112	64.1	492593	1159	1945	0.6098	4346
18000	18000	0.1939	57.8	492516	1082	1906	0.5869	4542
16000	16000	0.1762	51.5	492434	1000	1872	0.5651	4749
14000	14000	0.1582	45.2	492346	912	1833	0.5443	5023
12000	12000	0.1398	39	492251	816	1785	0.5245	5359
12000	12000	0.1398	39	492251	816	1244	0.5245	5359
10000	10000	0.1093	29.6	492081	647	973	0.4523	5704
10000	10000	0.1093	29.6	492081	647	1366	0.4523	5704
8000	8000	0.0846	22.6	491939	504	1332	0.436	5810
6000	6000	0.0592	15.6	491790	356	1300	0.4204	5924
4000	4000	0.0332	8.6	491635	201	1266	0.4056	6008
2000	2000	0.0067	1.7	491475	41	1247	0.3914	6061
1500	1500	0	0	491434	0	1245	0.388	6074

ENROU E DESCENT ANALYSIS

WIND (KNOTS) = 0 DTEMP (DEG

HPR	HGEO	TIME	DIST	WEIGH	FUEL	ROD	MACH	T FF
FT	FT	HR	NM	LB	LB	FPM		LB/HR
39000	39000	0.3534	125.2	498769	1669	3093	0.85	2899
38000	38000	0.348	122.6	498754	1653	3149	0.85	2980
36672	36672	0.3411	119.3	498733	1632	3242	0.85	3087
36672	36672	0.3411	119.3	498733	1632	2267	0.85	3087
36089	36089	0.3368	117.2	498719	1618	2233	0.8399	3120
36089	36089	0.3368	117.2	498719	1618	2391	0.8399	3120
36000	36000	0.3361	116.9	498717	1617	2386	0.8384	3124
34000	34000	0.3219	110.2	498672	1572	2311	0.8047	3213
32000	32000	0.3074	103.5	498625	1524	2262	0.7727	3304
30000	30000	0.2925	96.9	498575	1474	2217	0.7422	3407
28000	28000	0.2772	90.3	498522	1421	2159	0.7131	3571
26000	26000	0.2616	83.8	498465	1364	2104	0.6853	3738
24000	24000	0.2455	77.3	498403	1302	2046	0.6589	3926
22000	22000	0.229	70.9	498336	1235	1989	0.6338	4135
20000	20000	0.212	64.4	498264	1163	1935	0.6098	4346
18000	18000	0.1946	58	498187	1086	1896	0.5869	4542
16000	16000	0.1769	51.6	498105	1004	1862	0.5651	4749

14000	14000	0.1588	45.4	498016	915	1823	0.5443	5023
12000	12000	0.1403	39.1	497920	819	1776	0.5245	5359
12000	12000	0.1403	39.1	497920	819	1237	0.5245	5359
10000	10000	0.1096	29.7	497750	649	970	0.4523	5704
10000	10000	0.1096	29.7	497750	649	1362	0.4523	5704
8000	8000	0.0848	22.7	497607	506	1328	0.436	5810
6000	6000	0.0594	15.6	497458	357	1295	0.4204	5924
4000	4000	0.0333	8.7	497302	201	1262	0.4056	6008
2000	2000	0.0067	1.7	497142	41	1243	0.3914	6061
1500	1500	0	0	497101	0	1241	0.388	6074

ENROUT CRUISE ANALYSIS 35000 0 (FEET)
WIND (K NOTS) = 0 DTEMP (EG C.) = 0

WEIGHT LB	DISTAN NMI	TIME HR	FUEL LB	NMI/LB	VELOCI KTS	FUEL FL LB/HR	MACH
125019	0	0	0	0.08033	429.634	5348.6	0.74535
123964	85.1	0.1982	1055	0.08106	429.647	5300.1	0.74537
122905	171.3	0.3988	2114	0.0818	429.646	5252.6	0.74537
121847	258.3	0.6012	3172	0.08252	429.63	5206.3	0.74534
120789	346	0.8054	4231	0.08324	429.601	5160.9	0.74529
119730	434.5	1.0114	5289	0.08396	429.558	5116	0.74522
118672	523.8	1.2192	6347	0.08468	429.5	5072.3	0.74512
117613	613.8	1.4287	7406	0.08538	429.432	5029.8	0.745
116555	704.5	1.64	8464	0.08607	429.432	4989.1	0.745
115496	796	1.853	9523	0.08676	429.432	4949.5	0.745
114438	888.2	2.0677	10581	0.08744	429.432	4911	0.745
113379	981.1	2.2841	11640	0.08812	429.432	4873.3	0.745
112321	1074.7	2.5021	12698	0.08879	429.432	4836.6	0.745
111263	1169	2.7217	13757	0.08945	429.432	4800.7	0.745
110204	1264	2.943	14815	0.09011	429.432	4765.7	0.745
109146	1359.8	3.1659	15873	0.09076	429.432	4731.5	0.745
108087	1456.2	3.3904	16932	0.09141	429.432	4698.1	0.745
107029	1553.3	3.6165	17990	0.09205	429.432	4665.4	0.745
105970	1651	3.8441	19049	0.09268	429.432	4633.4	0.745
105424	1701.7	3.9622	19595	0.09301	429.42	4616.9	0.74498

LARGE AIRPLANE

ENROUT E CRUIS ANALYSIS 39000 0 (FEET)
WIND (KNOTS) 0 DTEMP (EG C.) = 0

WEIGHT LB	DISTAN NMI	E TIME HR	FUEL LB	NMI/LB	VELOCI KTS	FUEL FL LB/HR	MACH
559723	0	0	0	0.02341	487.534	20826.3	0.85
557761	46	0.0944	1962	0.02349	487.534	20758	0.85
552682	165.8	0.3401	7041	0.02368	487.534	20584.2	0.85
547603	286.6	0.5878	12120	0.02388	487.534	20415.9	0.85
542525	408.4	0.8376	17199	0.02407	487.534	20253.4	0.85
537446	531.1	1.0894	22278	0.02426	487.534	20095.5	0.85

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   532367     654.8    1.3431     27357  0.02445  487.534  19940.3        0.85
   527288     779.4    1.5987     32436  0.02464  487.534  19789.3        0.85
   522209       905    1.8564     37514  0.02482  487.534  19640.5        0.85
   517130    1031.6    2.1159     42593  0.02501  487.534  19494.4        0.85
   512051    1159.1    2.3774     47672  0.02519  487.534  19351.4        0.85
   510274    1203.9    2.4694     49450  0.02526  487.534  19302.1        0.85

ENROUT E CRUIS ANALYSIS               43000 0 (FEET)
WIND (   KNOTS)           0 DTEMP ( EG C.) =        0


WEIGHT DISTANC E   TIME FUEL      NMI/LB   VELOCI FUEL FL MACH
LB     NMI       HR       LB                 KTS      LB/HR

   508348         0         0         0  0.02533  487.534  19249.2        0.85
   505898      62.2    0.1276      2450  0.02546  487.534  19149.8        0.85
   503037     135.3    0.2775      5311  0.02561  487.534  19035.5        0.85
   500175     208.8    0.4282      8172  0.02577  487.534  18922.2        0.85
   497314     282.7    0.5799     11034  0.02592  487.534  18810.8        0.85
   494453     357.1    0.7325     13895  0.02607  487.534  18698.1        0.85
   491591     431.9     0.886     16756  0.02623  487.534  18584.4        0.85
   488730     507.2    1.0404     19618  0.02639  487.534  18471.7        0.85
   488363     516.9    1.0603     19985  0.02641  487.534  18457.3        0.85


ENROUT E CRUIS ANALYSIS               35000 0 (FEET)
WIND (   KNOTS)           0 DTEMP ( EG C.) =        0


WEIGHT DISTANC E   TIME FUEL      NMI/LB   VELOCI FUEL FL MACH
LB     NMI       HR       LB                 KTS      LB/HR

   658800         0         0         0  0.02002  489.956  24470.7        0.85
   651689     143.1     0.292      7111  0.02022  489.956  24233.4        0.85
   643927     300.8     0.614     14873  0.02043  489.956  23984.9        0.85
   636164     460.2    0.9393     22636  0.02063  489.956  23745.3        0.85
   628401     621.2    1.2678     30398  0.02084  489.956  23509.9        0.85
   620639     783.7    1.5996     38161  0.02105  489.956  23281.2        0.85
   620477     787.1    1.6066     38323  0.02105  489.956  23276.5        0.85


ENROUT E CRUIS ANALYSIS               39000 0 (FEET)
WIND (   KNOTS)           0 DTEMP ( EG C.) =        0


WEIGHT DISTANC E   TIME FUEL      NMI/LB   VELOCI FUEL FL MACH
LB     NMI       HR       LB                 KTS      LB/HR
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   618279         0         0         0  0.02111   487.534   23098.3        0.85
   613629      98.6    0.2022      4650  0.02129   487.534   22903.3        0.85
   608550     207.2    0.4249      9729  0.02148   487.534   22695.8        0.85
   603471     316.8    0.6497     14808  0.02168   487.534     22491        0.85
   598392     427.4    0.8766     19887  0.02188   487.534   22285.1        0.85
   593313       539    1.1056     24966  0.02208   487.534   22080.5        0.85
   588234     651.7    1.3366     30044  0.02228   487.534   21878.8        0.85
   583155     765.3    1.5698     35123  0.02249   487.534   21681.1        0.85
   578077     880.1    1.8051     40202  0.02269   487.534   21487.7        0.85
   572998     995.8    2.0426     45281  0.02289   487.534   21299.2        0.85
   567919    1112.6     2.282     50360  0.02309   487.534   21115.6        0.85
   562840    1230.3    2.5236     55439  0.02329   487.534   20936.2        0.85
   557761    1349.1    2.7672     60518  0.02349   487.534     20758        0.85
   552682    1468.9    3.0129     65597  0.02368   487.534   20584.2        0.85
   547603    1589.7    3.2607     70675  0.02388   487.534   20415.9        0.85
   542525    1711.5    3.5105     75754  0.02407   487.534   20253.4        0.85
   537446    1834.2    3.7622     80833  0.02426   487.534   20095.5        0.85
   532367    1957.9    4.0159     85912  0.02445   487.534   19940.3        0.85
   527288    2082.6    4.2716     90991  0.02464   487.534   19789.3        0.85
   522209    2208.1    4.5292     96070  0.02482   487.534   19640.5        0.85
   517130    2334.7    4.7888    101149  0.02501   487.534   19494.4        0.85
   512051    2462.2    5.0503    106228  0.02519   487.534   19351.4        0.85
   506972    2590.6    5.3137    111306  0.02538   487.534   19211.7        0.85
   501893    2719.9     5.579    116385  0.02556   487.534   19075.5        0.85
   496815    2850.2    5.8462    121464  0.02573   487.534   18944.4        0.85
   493096    2946.1     6.043    125183  0.02586   487.534   18851.6        0.85



ENROUTI E CRUISI ANALYSIS          31000 0 (FEET)
WIND (  KNOTS)           0 DTEMP ( EG C.) =      0


WEIGHT DISTAN( E   TIME FUEL      NMI/LB  VELOCI' FUEL FL MACH
LB       NMI       HR       LB                KTS       LB/HR

   775750         0         0         0  0.01688    498.75   29554.4        0.85
   766100     163.8    0.3284      9650  0.01707    498.75   29214.6        0.85
   757630     309.1    0.6198     18120  0.01724    498.75   28922.1        0.85


ENROUTI E CRUISI ANALYSIS          35000 0 (FEET)
WIND (  KNOTS)           0 DTEMP ( EG C.) =      0


WEIGHT DISTAN( E   TIME FUEL      NMI/LB  VELOCI' FUEL FL MACH
LB       NMI       HR       LB                KTS       LB/HR
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754999	0	0	0	0.0173	489.956	28324.6	0.85
752602	41.5	0.0848	2397	0.01737	489.956	28209.8	0.85
744840	177.2	0.3617	10159	0.01759	489.956	27855.1	0.85
737077	314.6	0.6421	17922	0.01781	489.956	27517.1	0.85
729315	453.7	0.9259	25685	0.01802	489.956	27186.6	0.85
721552	594.4	1.2132	33447	0.01825	489.956	26853.6	0.85
713790	736.9	1.5041	41210	0.01847	489.956	26527.2	0.85
706027	881.2	1.7984	48972	0.01869	489.956	26210.8	0.85
698264	1027.1	2.0964	56735	0.01891	489.956	25903.8	0.85
690502	1174.8	2.3978	64497	0.01913	489.956	25608.8	0.85
682739	1324.2	2.7026	72260	0.01935	489.956	25322.2	0.85
674977	1475.2	3.0109	80023	0.01957	489.956	25038.3	0.85
667214	1627.9	3.3226	87785	0.01979	489.956	24761.8	0.85
659452	1782.4	3.6378	95548	0.02	489.956	24493	0.85
651689	1938.5	3.9565	103310	0.02022	489.956	24233.4	0.85
643927	2096.3	4.2785	111073	0.02043	489.956	23984.9	0.85
636164	2255.6	4.6037	118835	0.02063	489.956	23745.3	0.85
628401	2416.6	4.9323	126598	0.02084	489.956	23509.9	0.85
620639	2579.2	5.2641	134360	0.02105	489.956	23281.2	0.85
620477	2582.6	5.271	134523	0.02105	489.956	23276.5	0.85

ENROUTI E CRUISI ANALYSIS 39000 0 (FEET)
WIND (KNOTS) 0 DTEMP (EG C.) = 0

WEIGHT	DISTAN(	E TIME	FUEL	NMI/LB	VELOCI	FUEL FL	MACH
LB	NMI	HR	LB		KTS	LB/HR	
618279	0	0	0	0.02111	487.534	23098.3	0.85
613629	98.6	0.2022	4650	0.02129	487.534	22903.3	0.85
608550	207.2	0.4249	9729	0.02148	487.534	22695.8	0.85
603471	316.8	0.6497	14808	0.02168	487.534	22491	0.85
598392	427.4	0.8766	19887	0.02188	487.534	22285.1	0.85
593313	539	1.1056	24966	0.02208	487.534	22080.5	0.85
588234	651.7	1.3366	30044	0.02228	487.534	21878.8	0.85
583155	765.3	1.5698	35123	0.02249	487.534	21681.1	0.85
578077	880.1	1.8051	40202	0.02269	487.534	21487.7	0.85
572998	995.8	2.0426	45281	0.02289	487.534	21299.2	0.85
567919	1112.6	2.282	50360	0.02309	487.534	21115.6	0.85
562840	1230.3	2.5236	55439	0.02329	487.534	20936.2	0.85
557761	1349.1	2.7672	60518	0.02349	487.534	20758	0.85
552682	1468.9	3.0129	65597	0.02368	487.534	20584.2	0.85
547603	1589.7	3.2607	70675	0.02388	487.534	20415.9	0.85
542525	1711.5	3.5105	75754	0.02407	487.534	20253.4	0.85
537446	1834.2	3.7622	80833	0.02426	487.534	20095.5	0.85
532367	1957.9	4.0159	85912	0.02445	487.534	19940.3	0.85

527288	2082.6	4.2716	90991	0.02464	487.534	19789.3	0.85
522209	2208.1	4.5292	96070	0.02482	487.534	19640.5	0.85
517130	2334.7	4.7888	101149	0.02501	487.534	19494.4	0.85
512051	2462.2	5.0503	106228	0.02519	487.534	19351.4	0.85
506972	2590.6	5.3137	111306	0.02538	487.534	19211.7	0.85
501893	2719.9	5.579	116385	0.02556	487.534	19075.5	0.85
498769	2800	5.7431	119509	0.02567	487.534	18994.4	0.85

24000	24000	0.1263	42	114633	2042	0.6589	9600
26000	26000	0.1436	49	114471	1822	0.6853	9125
28000	28000	0.1631	57.2	114297	1598	0.7131	8679
29855	29855	0.184	66.2	114120	1383	0.74	8289
29855	29855	0.184	66.2	114120	1889	0.74	8289
30000	30000	0.1853	66.7	114110	1871	0.74	8248
32000	32000	0.2046	75.1	113956	1605	0.74	7682
34000	34000	0.2276	85	113787	1322	0.74	7134
35000	35000	0.241	90.7	113693	1173	0.74	6868

HPR	HGEO	TIME	DIST	WEIGHT	ROC	MACH	T FF
FT	FT	HR	NM	LB	FPM		LB/HR
1500	1500	0	0	129082	3694	0.388	16119
2000	2000	0.0023	0.6	129045	3657	0.3914	15950
4000	4000	0.0116	3	128900	3505	0.4056	15290
6000	6000	0.0213	5.6	128754	3353	0.4204	14649
8000	8000	0.0315	8.4	128608	3190	0.436	14004
10000	10000	0.0423	11.4	128461	3016	0.4523	13350
10000	10000	0.0423	11.4	128461	500	0.4523	13350
10162	10162	0.0477	13.1	128389	500	0.5071	13544
10162	10162	0.0477	13.1	128389	3070	0.5071	13542
12000	12000	0.0579	16.4	128253	2895	0.5245	12980
14000	14000	0.0699	20.4	128101	2701	0.5443	12377
16000	16000	0.0827	24.9	127947	2502	0.5651	11750
18000	18000	0.0966	29.9	127788	2296	0.5869	11125
20000	20000	0.1118	35.5	127623	2093	0.6098	10562
22000	22000	0.1286	41.8	127450	1901	0.6338	10082
24000	24000	0.1471	49.1	127268	1708	0.6589	9600
26000	26000	0.1679	57.5	127074	1507	0.6853	9125
28000	28000	0.1918	67.5	126862	1301	0.7131	8679
29855	29855	0.2178	78.7	126641	1094	0.74	8289
29855	29855	0.2178	78.7	126641	1495	0.74	8289
30000	30000	0.2194	79.4	126628	1476	0.74	8248
31000	31000	0.2312	84.5	126532	1349	0.74	7965

HPR	HGEO	TIME	DIST	WEIGHT	ROC	MACH	T FF
FT	FT	HR	NM	LB	FPM		LB/HR
31000	31000	0	0	125495	1357	0.7449	7990
32000	32000	0.013	5.7	125394	1220	0.745	7705
34000	34000	0.0447	19.4	125159	924	0.7452	7156
35000	35000	0.0647	28	125019	761	0.7454	6891

LARGE AIRPLANE

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
1500	1500	0	0	571691	4629	0.388	75955
2000	2000	0.0018	0.5	571554	4613	0.3914	75487
4000	4000	0.0091	2.3	571011	4537	0.4056	73623
6000	6000	0.0165	4.3	570471	4425	0.4204	71491
8000	8000	0.0242	6.4	569933	4274	0.436	69018
10000	10000	0.0321	8.6	569394	4114	0.4523	66503
10000	10000	0.0321	8.6	569394	0	0.4523	66503
10000	10000	0.0405	11.4	568823	0	0.5838	69827
10000	10000	0.0405	11.4	568823	4429	0.5838	69827
12000	12000	0.0483	14.3	568293	4170	0.6052	66844
14000	14000	0.0566	17.5	567752	3896	0.6275	63860
16000	16000	0.0654	21.1	567199	3640	0.651	61097
18000	18000	0.0749	25	566633	3403	0.6755	58500
20000	20000	0.0852	29.3	566050	3098	0.7011	55160
22000	22000	0.0962	34.1	565449	2932	0.728	53553
24000	24000	0.1081	39.5	564828	2716	0.756	51555
26000	26000	0.1209	45.4	564179	2466	0.7854	49211
28000	28000	0.1353	52.3	563491	2183	0.8162	46567
30000	30000	0.152	60.5	562740	1847	0.8484	43799
30097	30097	0.1529	61	562701	1828	0.85	43653
30097	30097	0.1529	61	562701	2700	0.85	43653
32000	32000	0.1654	67.2	562178	2397	0.85	40354
34000	34000	0.1804	74.6	561600	2069	0.85	36957
36000	36000	0.1982	83.3	560973	1699	0.85	33491
36089	36089	0.1991	83.8	560944	1681	0.85	33334
36089	36089	0.1991	83.8	560944	1519	0.85	33334
38000	38000	0.2232	95.5	560182	1175	0.85	30422
39000	39000	0.2386	103	559723	994	0.85	29009

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
39000	39000	0	0	510274	1323	0.85	28807
40000	40000	0.0136	6.6	509892	1144	0.85	27464
42000	42000	0.0498	24.3	508954	770	0.85	24874
43000	43000	0.0749	36.5	508348	585	0.85	23669

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
1500	1500	0	0	671951	3821	0.4017	76160
2000	2000	0.0022	0.6	671785	3808	0.4052	75734
4000	4000	0.011	2.9	671124	3744	0.4198	73957
6000	6000	0.02	5.4	670466	3640	0.4351	71817

8000	8000	0.0294	8.1	669807	3504	0.4512	69356
10000	10000	0.0391	10.9	669146	3359	0.468	66841
10000	10000	0.0391	10.9	669146	0	0.468	66841
10000	10000	0.0498	14.6	668409	0	0.6023	70338
10000	10000	0.0498	14.6	668409	3625	0.6023	70338
12000	12000	0.0594	18.3	667754	3381	0.6242	67182
14000	14000	0.0696	22.4	667082	3141	0.6472	64224
16000	16000	0.0806	26.9	666390	2918	0.6712	61482
18000	18000	0.0925	32	665677	2709	0.6963	58925
20000	20000	0.1054	37.6	664936	2465	0.7226	55941
22000	22000	0.1194	43.9	664165	2304	0.7501	54250
24000	24000	0.1345	50.9	663360	2107	0.7788	52183
26000	26000	0.1513	58.9	662507	1887	0.8089	49818
28000	28000	0.1704	68.4	661583	1621	0.8403	47128
28599	28599	0.1767	71.5	661286	1527	0.85	46266
28599	28599	0.1767	71.5	661286	2255	0.85	46266
30000	30000	0.1876	77	660799	2064	0.85	43826
32000	32000	0.2051	85.7	660063	1759	0.85	40354
34000	34000	0.2262	96.2	659250	1430	0.85	36957
35000	35000	0.2387	102.3	658800	1255	0.85	35304

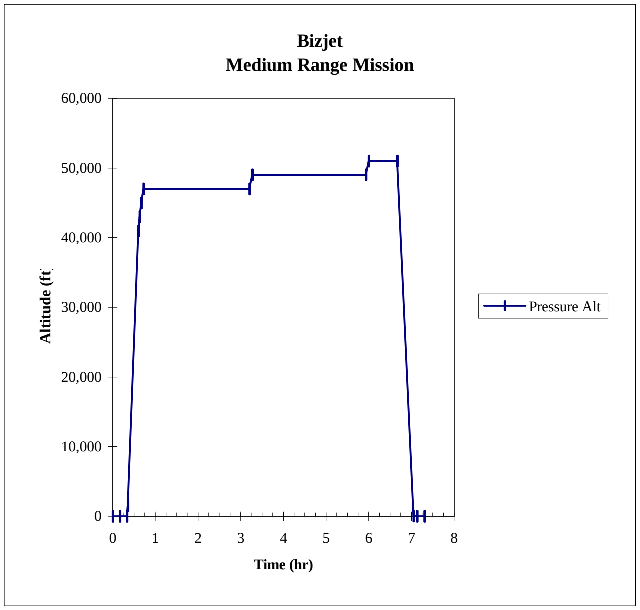
HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
35000	35000	0	0	620477	1500	0.85	35058
36000	36000	0.012	5.8	620069	1301	0.85	33259
36089	36089	0.0131	6.4	620031	1283	0.85	33102
36089	36089	0.0131	6.4	620031	1159	0.85	33102
38000	38000	0.0466	22.7	618978	805	0.85	30211
39000	39000	0.0704	34.3	618279	621	0.85	28807

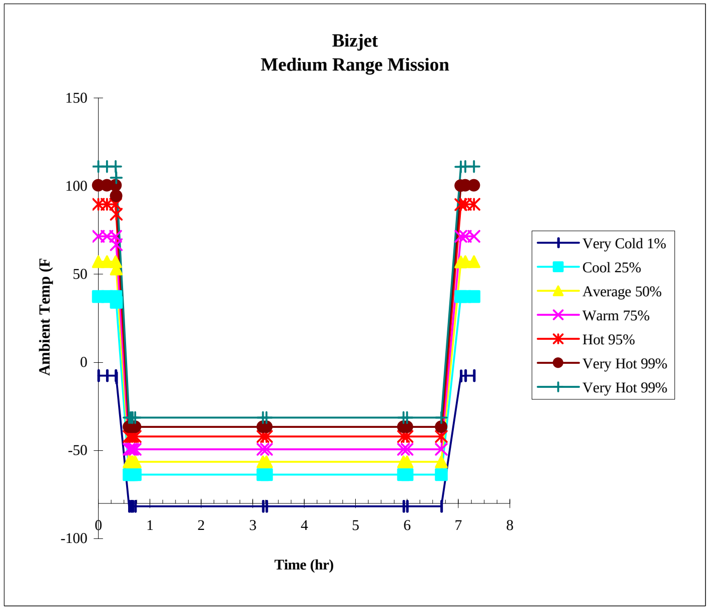
HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
1500	1500	0	0	790626	3130	0.4246	76691
2000	2000	0.0027	0.7	790422	3117	0.4283	76259
4000	4000	0.0135	3.8	789608	3054	0.4437	74464
6000	6000	0.0246	7.1	788793	2956	0.4597	72317
8000	8000	0.0361	10.5	787974	2829	0.4766	69890
10000	10000	0.0482	14.3	787146	2695	0.4943	67394
10000	10000	0.0482	14.3	787146	0	0.4943	67394
10000	10000	0.0616	19.1	786215	0	0.6242	70690
10000	10000	0.0616	19.1	786215	2869	0.6242	70690
12000	12000	0.0737	24	785380	2656	0.6468	67607
14000	14000	0.0868	29.4	784515	2445	0.6704	64672
16000	16000	0.101	35.5	783615	2249	0.6951	61943

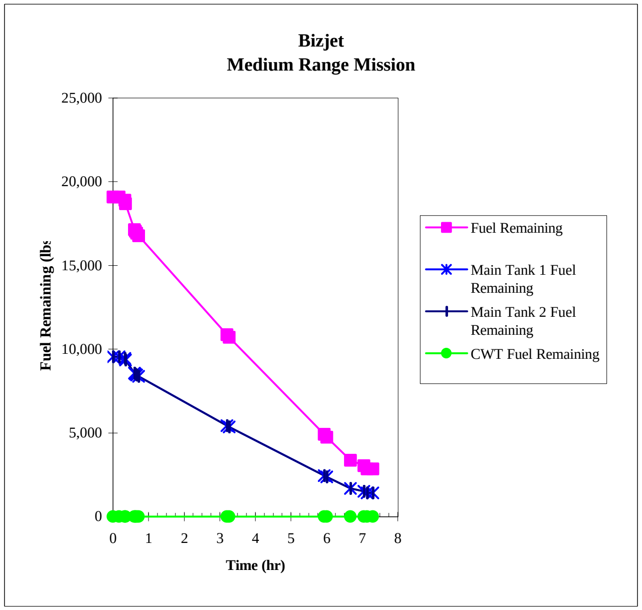
18000	18000	0.1164	42.3	782679	2092	0.7209	59848
20000	20000	0.1333	49.9	781695	1869	0.7479	56856
22000	22000	0.1519	58.6	780656	1725	0.7761	55074
24000	24000	0.1723	68.4	779554	1551	0.8056	52962
26000	26000	0.1954	79.8	778359	1348	0.8364	50660
26854	26854	0.2064	85.3	777807	1237	0.85	49459
26854	26854	0.2064	85.3	777807	1828	0.85	49459
28000	28000	0.2173	90.9	777280	1682	0.85	47350
30000	30000	0.2391	101.8	776291	1405	0.85	43826
31000	31000	0.2517	108.1	775750	1248	0.85	42064

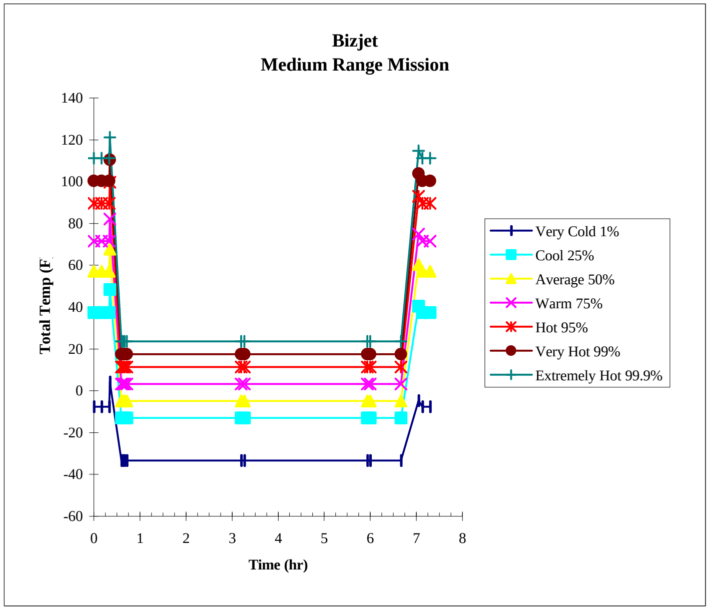
HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
31000	31000	0	0	757630	1352	0.85	41772
32000	32000	0.0132	6.5	757092	1191	0.85	40074
34000	34000	0.0469	23.2	755805	843	0.85	36700
35000	35000	0.0695	34.3	754999	660	0.85	35058

HPR FT	HGEO FT	TIME HR	DIST NM	WEIGHT LB	ROC FPM	MACH	T FF LB/HR
35000	35000	0	0	620477	1500	0.85	35058
36000	36000	0.012	5.8	620069	1301	0.85	33259
36089	36089	0.0131	6.4	620031	1283	0.85	33102
36089	36089	0.0131	6.4	620031	1159	0.85	33102
38000	38000	0.0466	22.7	618978	805	0.85	30211
39000	39000	0.0704	34.3	618279	621	0.85	28807


Bizjet
Medium Range Mission
Altitude (ft
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
6
7
8
Time (hr)
Pressure Alt


Bizjet
Medium Range Mission
Ambient Temp (F
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
8
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Very Hot 99%


Bizjet
Medium Range Mission
Fuel Remaining (lbs
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8
Time (hr)
Fuel Remaining
Main Tank 1 Fuel Remaining
Main Tank 2 Fuel Remaining
CWT Fuel Remaining


Bizjet
Medium Range Mission
Total Temp (F
140
120
100
80
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
8
Time (hr)
Very Cold 1%
Cool 25%
Average 50%
Warm 75%
Hot 95%
Very Hot 99%
Extremely Hot 99.9%