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ECONOMIC ANALYSIS ON THE USE OF GELLED FUELS IN JET TRANSPORT AIRCRAFT

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16. Abstract

A previous study described in FAA Final Report No. DS-70-1 examined the technical aspects of using gelled or emulsified fuel in a DC-8-62 commercial jet transport and identified associated problems. This study examined the economics of jet fleet conversion to the use of 2 percent gelled fuel. Based on the technical findings, a DC-8-62 modification program was outlined, costed, and analyzed. Based on the DC-8-62 analysis, it was estimated that conversion and operation for the ten years 1972-81 of all U.S. air carrier jet passenger airplanes would add about four billion dollars to their operating costs for the decade. This is approximately a 4.5 percent increase to total operating costs.

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INTRODUCTION

Fuels thickened by emulsification or gelation have been proposed as a means of improving crash safety by reducing the hazards of fuel fires. Two studies, under contract from the Federal Aviation Administration, were designed to provide insight into the technical problems and economics that might be associated with the everyday use of such fuels. The first study, Report No. FAA-DS-70-1, "A Study of the Compatibility of a Four Engine Commercial Jet Transport Aircraft Fuel System with Gelled and Emulsified Fuels" (Reference 1) examined the technical implications of adapting a DC-8-62 fuel system to the use of gelled and emulsified turbine fuels. It found that the existing airplane fuel system is not compatible without extensive modifications with the use of thickened fuels; and it identified a number of problem areas associated with the requisite fuel system modifications (Table 1). The study found insufficient evidence at this time to reach a determination of engine system compatibility or of requisite engine system modifications; although the short-time operation of a jet engine on gelled fuel has been demonstrated, there are many potential problem areas that need to be examined before a determination of engine system feasibility can be made. Of the thickened fuels investigated, a proprietary formulation 2-percent-by-weight concentration gel, designated gelled fuel G, appeared to be the most promising for adaptation to an aircraft fuel system.

This second study was a follow-on economic analysis, based on what is known today and using the technical findings of the first study (Reference 1) to develop an initial estimate of the economic costs that would be associated with United States jet fleet conversion to and operation with gelled fuel G. The study made a comparative analysis between the economics of the existing DC-8-62 using present liquid fuel, and those of a hypothetical modification of the same airplane using gelled fuel G.

Building on the findings of the first study, a DC-8-62 modification program was outlined, costed, and analyzed, and the time-phased economic costs associated with its conversion and subsequent operation were ascertained. These per-DC-8-62 economic costs were translated into costs per billion revenue-passenger-nautical-miles, which were then applied to projected United States jet passenger traffic for the 10 years 1972-81, providing an estimate of the overall economic costs to the United States air carrier industry for the decade.

This economic analysis used limited present knowledge to estimate broad general implications. It is recognized that there are many problem areas in regard to thickened fuels themselves, engine systems, and other airplane systems that have not yet been systematically investigated, the knowledge of which might greatly change the estimates. It should accordingly be borne in mind that the findings of this study are hypothetical and preliminary.

TABLE 1. – PROBLEM AREAS

Problems associated with conversion of a DC-8-62 to use of gelled fuel

- Engine system problems that remain to be investigated
- Pumps
- Gaging
- Filters
- Ground servicing equipment
- Ground servicing procedures
- Low fill rates
- Overfill pressures
- Fill valves
- Float switches
- Line pressures
- Gravity fuel transfer
- Jettison flow rates
- Jettison fuel state
- Parts accessibility
- Dried fuel residue
- Unusable fuel
- Expansion space
- Fuel in vent systems
- Fuel management
- Dispatch inoperative (minimum equipment) list
- Reliability
- Systems analysis and testing

Source: Previous study, FAA-DS-70-1 (Reference 1)

PURPOSE AND SCOPE

The purpose of this economic analysis was to make a preliminary comparison of the dollar costs in the next decade of using the 2-percent concentration gelled fuel G in United States air carrier jet aircraft against the use of conventional fuels. The scope included consideration of the modifications necessary to convert a DC-8-62, and their implications to cost, performance, payload, range, maintenance, insurance, and depreciation. Probable airline practice was used as the criterion for setting amortization policy, for postulating a retrofit program and schedule, and for handling the retirement of aircraft from service. Differentiation was made between retrofit and new aircraft models. Supersonic aircraft were not included in this study.

Engine system adaptation was treated only in a very gross way. The gelled fuels have not undergone extensive engine testing and only minor engine runs have been made with gelled fuel G (References 2 and 3). There were insufficient data to identify or evaluate the problems and costs of jet engine adaptation from development through flight test and certification.

A general study intent was to seek, at minimal cost of funds and time, a reasonable first-order estimate of probable economic impact. Neither the state of knowledge in regard to gelled and emulsified fuels themselves, nor of all the complexities involved in adapting operational commercial jets to their use, were sufficient to warrant more than a preliminary economic appraisal at this time.

BASIC APPROACH

The basic approach taken in this economic analysis was to analyze one airplane in some detail, then to project the generalized effects to the full United States air carrier jet fleet for a decade (see Figure 1).

The DC-8-62 airplane was selected for this analysis for several reasons: (1) It was the airplane considered in the previous study (Reference 1), so pertinent technical findings were available and this study would be a consistent follow-on; (2) The DC-8-62, although an advanced version, is reasonably representative of the current generation of commercial jet airplanes, and its differences and similarities in respect to the rest of the current fleet are known; (3) One characteristic, that it has the greatest range of any of the current commercial jet airplanes, makes it a good selection for examination of the economic impact of a substantial range reduction.

From the data developed in the previous study (Reference 1) a preliminary design was evolved to describe the modifications that would be needed to convert a DC-8-62 to the use of gelled fuel G. The modifications represent an initial approach to resolution of the problem areas discussed in the technical study and listed in Table 1. Short of a development program there is no way to be sure that the outlined modifications would prove to be acceptable, or even that acceptable solutions could be found for all the problem areas.

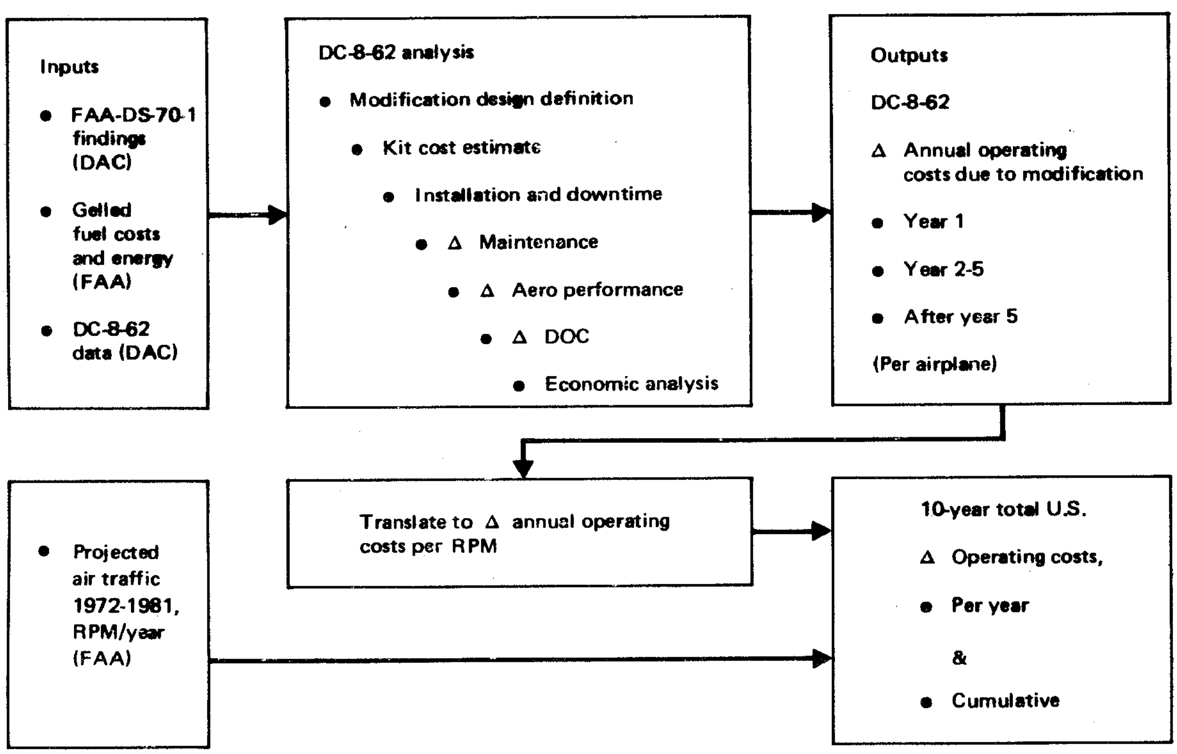

Figure 1. Basic approach.

The preliminary design was carried to sufficient detail only to permit identification and assessment of the major effects that could be expected on airplane weights, cost, performance, and operating economics. A design, development, and aircraft fleet retrofit program was postulated; a budgetary cost estimate was prepared; and with the design and cost data, the aerodynamic performance characteristics and operating economics of the modified airplane were estimated. Comparison with the unmodified airplane indicated the effects of the modification. Each effect caused a change in airplane annual operating costs, which were estimated and evaluated in various ways. The summation of the annual operating cost changes represented the dollar impact of the modification on the operating economics of the airplane for a year. An assumption was made that the airplane would continue to serve essentially the same air traffic demand after modification as before, at the same fares and load factors; hence it would handle the same number of revenue-passenger-miles (RPM) (nautical miles are used in this study unless otherwise indicated) and generate the same revenue. On the whole, this assumption seems valid, since very little if any change in total air traffic demand would be expected to accompany the initial conversion of the entire jet fleet. This assumption made it possible to omit consideration of possible changed revenues, and to focus on changed costs to measure the effects of the conversion program.

The next step was to project the findings on the one airplane for one year to the full United States air carrier jet fleet for a decade. The initial study plan was to continue with a similar but abbreviated analysis of every airplane model in the fleet, basing cost and performance effects on suitable analogy with the DC-8-62 data previously determined. It became apparent, however, that the uncertainties introduced by this method, due to inadequate data and analogy criteria, might be as bad as the uncertainties it resolved. It was decided instead to translate the per-airplane dollar effects into dollar effects per-billion RPM, and then to base the projection on forecasted total RPM carried by the full United States air carrier jet fleet for the decade. To translate the effects from a per-airplane to a generalized per-billion-RPM basis entailed the implicit assumption that the per-RPM economics of operational jets are similar. It also constrained the analysis to passenger operations. Both these conditions were felt to be acceptable in the interest of providing a fairly simple, straightforward and reasonable first-order estimate of overall economic impact.

EFFECT ON A DC-8-62 OF CONVERTING TO GELLED FUEL

Definition of DC-8-62 System Modification

A characteristic of the gelled fuel G is that it is more viscous and flows less freely than liquid fuel. Its thermal energy is the same. The modification task, therefore, was mainly to adapt the airplane and ground support equipment (GSE) systems to the increased viscosity of the gelled fuel G. Present gravity flow and suction systems were found to be ineffective and had to be replaced by positive pressure fuel flow.

This required the addition of parts in locations where easy access was not originally provided; the addition of plumbing in the tanks, some of which penetrates lightening holes; and an increase in the number of operating parts; all of which would tend to increase fuel system complexity and maintenance costs, and degrade system reliability.

The major system changes are listed below and then discussed in the following paragraphs:

- Fill System (Enlarge plumbing)
- Tank Overpressure System (Install)
- Vent System (Little or no change)
- Transfer and Feed Systems (Pump and plumbing additions)
- Electrical System (Increased emergency electric load)
- Engine Systems (Pump and pressure changes)
- Jettison System (Convert to pressure system)
- Quantity Systems (All new)
- Ground Support Equipment (Mix fuel and additive to make gelled fuel; enlarge pumps and plumbing)
- Miscellaneous (Controls, metering and monitoring)

Fill System – The production fuel system can be changed to incorporate a crossfeed manifold which has enlarged line sizes, so that present fueling rates could be maintained with gelled fuel. Without this change, fueling time with gelled fuel would approximately double, which would increase terminal time in many situations and be disruptive to schedules and utilizations. The crossfeed manifold line would be increased from 2 to 2-1/2 inches. Available space does not allow increases in line size in the present routing. Therefore, the crossfeed manifold would be moved inside the tank as shown by the heavy line on

Figure 2. The hydromechanical (pressure operated) fill valves would be replaced by slow-closing electric gate valves because the gelled fuel will not flow through the small sensing passages of the fill valve. The electric valves would be controlled by a sensing from the preselect setting on the fuel quantity system, or by fluid level limit switches placed at the maximum fuel level permitted in the tank.

Tank Overpressure Prevention for Use with Gelled Fuels – A system for prevention of overpressure in the fuel tanks should be installed during modification of the aircraft for use with gelled fuels. Normal shutoff can be accomplished by using a slow-closing electric gate valve which is slaved to a level selection at the fuel quantity gage. The overpressure protection may be provided by a parallel backup circuit for fuel shutoff which uses a flush-mounted pressure sensing device. The device would be located where it would always be in the ullage space during ground refuel. The flush mount is necessary to prevent any accumulation of fuel residuals in flow passages which could change operating characteristics. The overpressure device would be used to operate a backup electric shutoff valve.

Vent System – The vent system could remain essentially as it is. Because of the large allowance necessary for expansion of the fuel volume, the vent inlets may have to be repositioned to preclude fuel flow into the vents during high angles of attack. The aircraft will be nearly level at high altitudes where fuel volume expansion is greatest, especially with high fuel loadings. A bubble travel study would be made to be certain that the vent inlets were properly located.

Transfer System – The fuel tank pumping and transfer concept used on the basic DC-8-62 is not compatible with thickened fuels. A modification would be required to provide positive transfer of fuel from remote areas of the fuel tanks and to the engine.

Intra-Tank Transfer (see Figure 3): Fuel transfer from the remote areas of each tank to a central collection point in each tank would be accomplished by installing 99 small, positive displacement, ac electrically powered pumps. These pumps would be distributed over the electrical power circuits so as to maximize their independence. The pumps in the tip fuel tank should have separate control from those in the alternate fuel tank. Each pump delivers flow to the collection boxes through 1 inch – 035 lines. These pumps are estimated to require a minimum of 0.08 kVA each. No parts are currently existing.

Inter-Tank Transfer and Engine Fuel (see Figure 2): Gelled fuels incur large pressure losses in plumbing systems. Therefore, the current boost pumps would be replaced by larger pumps providing higher pressure for engine feed and inter-tank transfer operations. These boost pumps would be installed as shown in the figure, providing each tank with a redundant transfer system. These pumps would weigh approximately 8 lb each and require approximately 1.75 kVA each.

Electrical Requirements – Positive engine feed would be required at all times and fuel would have to be transferred to the main feed pumps in the main tanks at all times. Therefore, the emergency electrical load will include all the pumps in the main tanks and possibly all the pumps in the alternate tank. This would be in addition to the current continuous emergency electrical load attributable to fuel system operation (nearly zero

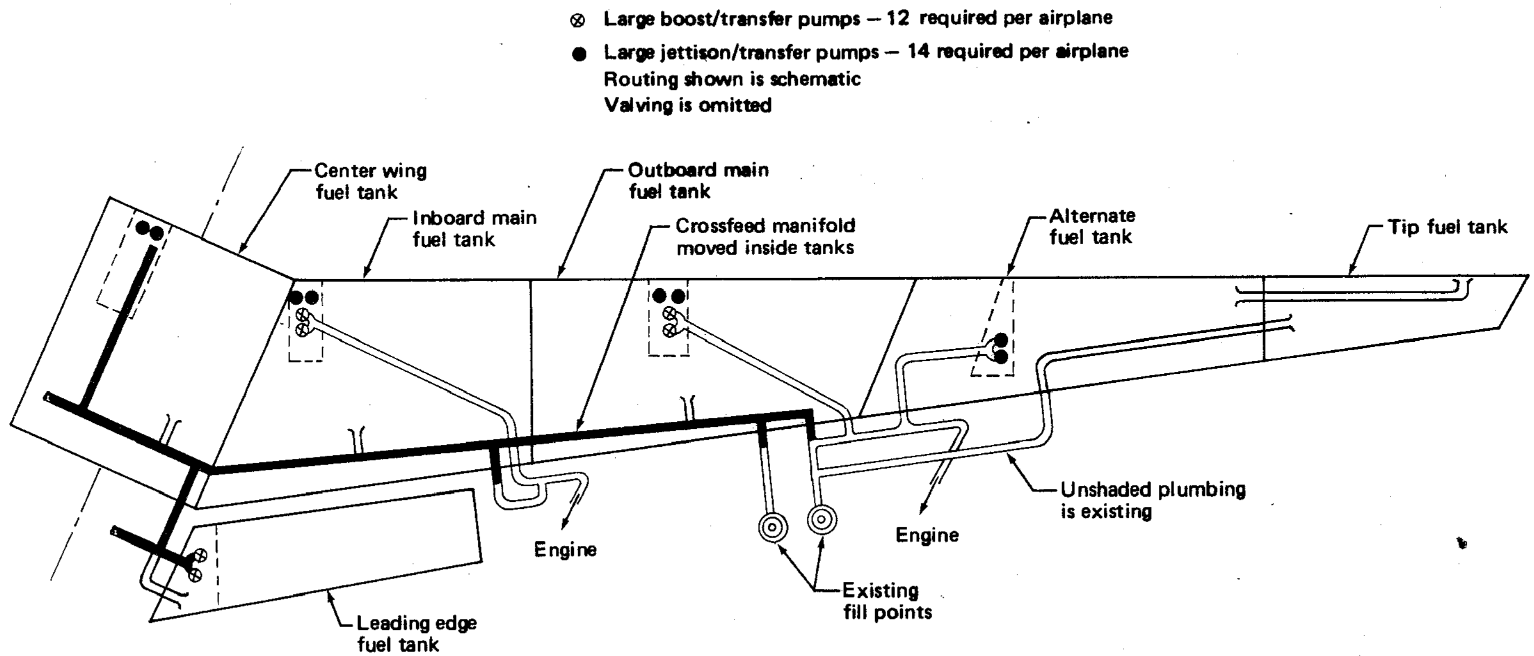

Figure 2. Fill system crossfeed manifold, DC-8-62 modification for gelled fuels.

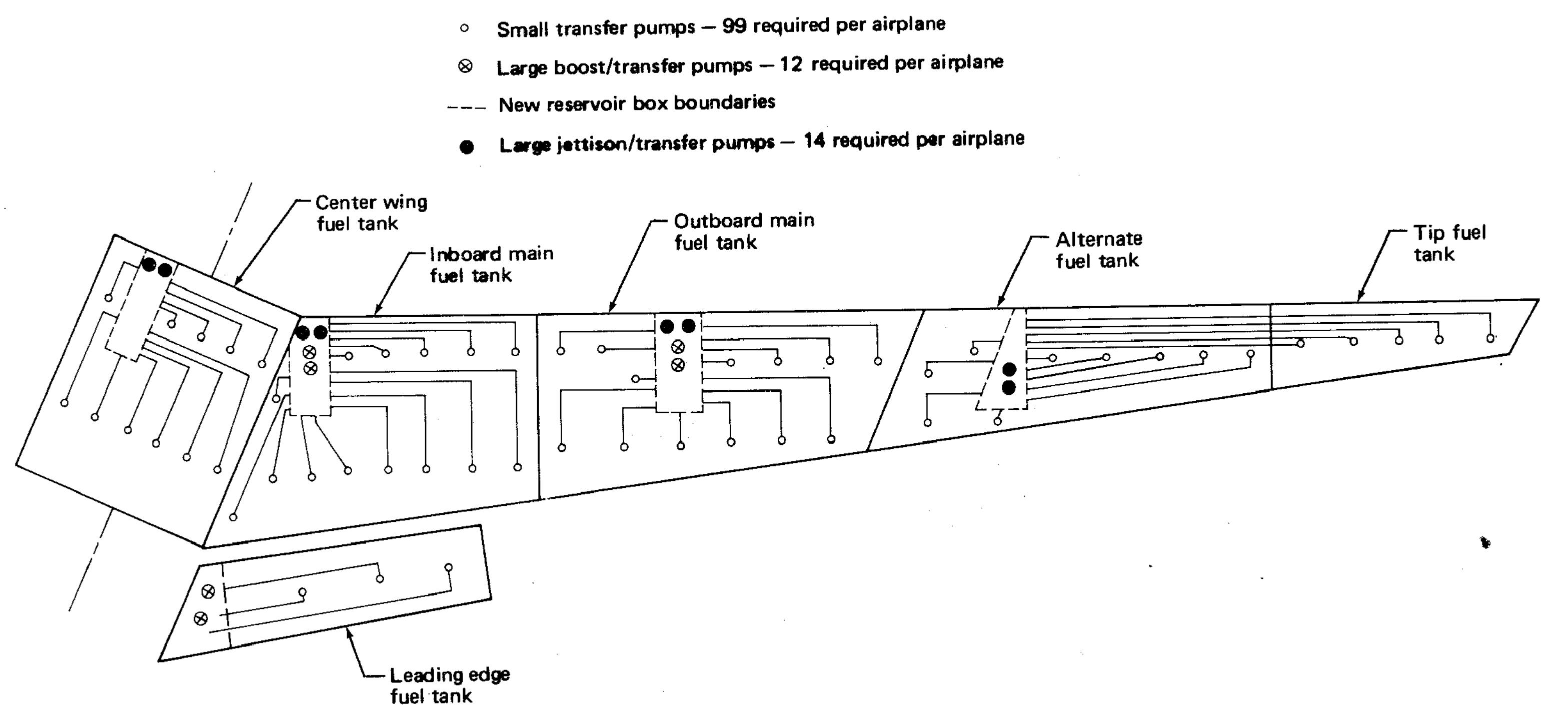

Figure 3. Intra tank fuel transfer system, DC-8-62 modification for gelled fuels.

because of suction feed capability). The DC-8-62 electrical load analysis indicates that one-generator-out dispatch capability could probably not be retained because of the increased jettison power requirement.

Engine Systems – Several changes may have to be made to the engine fuel system to utilize the gelled fuels. Engine oil cooling may have to be provided by an air/oil cooler as on the DC-8-61. Flow metering would have to be developed. Pump pressure capability may have to be increased at low flows and low rotational speeds. Fuel filtering and fuel heating could probably be accomplished in the engine system in a manner similar to the DC-9/JT8D installation.

Jettison System – The existing gravity jettison system is not compatible with the gelled fuel G. Change 17 to the FAR (Reference 4) may make the retention of a jettison capability unnecessary; however, for this study it was desired to maintain an equivalent jettison capability to keep the modified airplane as comparable as possible to the unmodified airplane. To dump gelled fuel G at the present jettison rate (1 percent of maximum gross weight per minute, or approximately 3500 pounds-per-minute) would require conversion from a gravity to a pressure system. The existing jettison plumbing and dump chutes would be retained, and 14 jettison pumps would be installed as shown in Figures 2 and 3. In the outboard alternate tanks and the center wing tank these pumps will also serve as transfer pumps. Each jettison pump will weigh approximately 11 pounds and require approximately 4.7 kVA. Check valves with each pump weigh 1/2 pound each.

Fuel Availability – Modifications were assumed to the fuel system which would permit unusable fuel levels of approximately 4 percent of the total tank volume. Expansion space requirements are expected to be approximately 10 percent of total tank volume. This is made up of the 2-percent normal thermal expansion required plus an 8-percent allowance for fuel swelling in climb to altitude. Therefore, the usable fuel quantity on the aircraft is approximately 86 percent of tank volume or 21,408.8 gallons and corresponds to 143,446 pounds of kerosene at 6.7 lb/gal. This value of fuel availability was used when determining changes to the payload-range curve and in considerations of staging routes currently flown nonstop with liquid fuel loadings above 143,446 pounds.

Quantity Gaging Systems – A new gaging system would have to be developed and retrofitted. This may take the form of a capacitance system with larger diameter probes, or perhaps a nucleonic system. The capacitance system would be the most straightforward and probably would require lower development costs as a modification to an existing certified system. The capacitance system has been estimated to involve a weight increase of approximately 80 pounds. It was taken as the model for this economic analysis.

Ground Support Equipment – Ground facilities for the mixing of fuels before delivery to the aircraft would be required. These facilities may be placed on the real estate currently occupied by settling tanks in the tank farm. Mixing of fuel and additive at the tank farm and mixing farther downstream, as part of the fueling process, are alternatives to be considered. Fueling trucks and hydrant systems would have to be modified to handle the gelled fuel. The exact modifications would be dependent on what the fuel could stand after it was optimized for aircraft use. In general, all new pumps and control systems would probably be required.

Weight Change Summary – Major items affecting weight change have been identified and are shown in Table 2. The net effect would be to increase airplane empty weight 1,490 pounds.

TABLE 2. – EMPTY WEIGHT CHANGE SUMMARY

	Wt. out (pounds)	Wt. in (pounds)	Δ Wt. (pounds)
• Revise transfer, boost and jettison pumps	757	2082	+1325
• Revise piping for ground fill	14	20	+6
• Fuel gaging	47	130	+83
• Heat exchanger	105	131	+26
• Revise engine fuel pumps	40	65	+25
• Other	0	25	+25
Total	963	2453	+1490

DC-8-62 Retrofit Program Schedule

In view of the rather extensive redesign, component development and qualification, flight test, and certification requirements, it was estimated that an intensive program for the DC-8-62 would require approximately 18 months from its start to completed certification of the modified airplane (see Figure 4). The first 9 months would be required for configuration design and component development and qualification, even assuming considerable overlap or concurrency. A 6-month flight test program would be required, involving approximately 200 flight hours and 150,000 manhours, culminating in certification of the modified airplane. Fabrication and installation of the first production test set would have to be accomplished between these operations, making a tight 18-month program with little room for slippage.

The 2-year installation period that follows certification corresponds with the total jet fleet modification schedule that was assumed in the final section of this study. For the particular fleet of DC-8-62 airplanes to be modified this is probably more time than would be required.

It should be noted that this schedule is based on the assumption that the DC-8-62 program would be the first or "pilot" program of a total jet fleet conversion program. Many of the design criteria and components developed for the DC-8-62 would undoubtedly have application to the other airplane models in the total United States jet fleet. In fact, the DC-8-63 has the same fuel system and, therefore, could use the same modification package.

The DC-8-61 and earlier DC-8 models have a slightly different fuel system that would require slightly different modification design, but that still would benefit considerably from commonalities with the DC-8-62/63 development. To test this assumption a "coattail" development for the DC-8-61 also was examined, and indicated considerable benefits. For instance, presupposing completion of the DC-8-62/63 development, the DC-8-61 flight test program would then require only 2 months, involving 65 flight hours and 50,000 manhours; and except for the test phase the two developments could run almost concurrently.

Since this sort of "family" relationship between models is fairly typical of the current United States air carrier jet airplanes, it was given due consideration in the program, kit, and installation cost estimates discussed in the following sections.

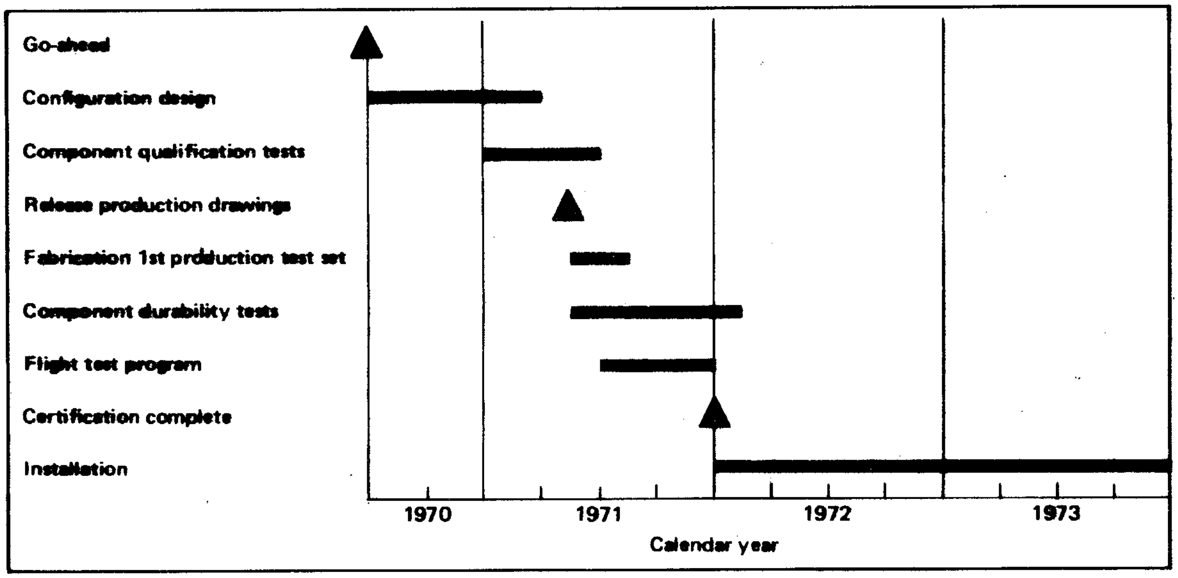

Figure 4. Retrofit program schedule

Retrofit Program Cost Estimate, DC-8-62

The budgetary cost of a program to retrofit the applicable fleet of DC-8 airplanes was estimated in the same way that a competitive cost quotation would be prepared. The modification design was defined to a level of detail sufficient to enable an incremental cost analysis by major tasks and components. A retrofit program plan was defined around an integrated schedule which encompassed the nonrecurring elements of engineering development and initial production tooling, plus the recurring elements of manufacturing and retrofit installation.

The modification design and program schedule were discussed in the preceding section. Based on the design definition and schedule, the nonrecurring cost elements of engineering development and initial production tooling were estimated as follows. Each affected engineering group prepared estimates of the manhours, materials, and special facilities needed to perform its part of the tasks. These estimates were aggregated and increased by the appropriate overhead and support burden factors. A test program to encompass ground and flight tests through certification was similarly outlined and broken down by cost elements. Other major identifiable costs such as laboratory support, computing machine time, and initial production tooling were likewise estimated and included. Current labor and material rates were applied to these estimates to arrive at the total program development cost estimate.

Manufacturing cost estimates were similarly constructed from manhours and materials requirements, based on experience with similar production operations on the DC-8 production lines. Major cost elements considered included production planning, tooling, manufacturing facilities, overhead, and support burden increments.

To determine per-airplane costs it was necessary to estimate the number of airplanes to which this design/development would be applicable. As of November 1969 there were 303 DC-8 airplanes on hand or firm order for delivery prior to 1971 in the United States air carriers fleet (Table 3). Additional orders and the exercising of options would increase this total, while retirement and attrition would reduce it. Furthermore, the airline operators might choose to retire some of their older aircraft rather than incur the expenses of retrofitting them. No DC-8 airplanes have been retired yet. Airline plans on the subject vary widely, but are believed to be essentially flexible at present. A planning number was selected of approximately 270 DC-8 airplanes to be retrofit in 1972-73. Adding a 10-percent factor for spares meant the production of about 300 aircraft retrofit kits, and this is the quantity that was used in this study. In view of the many uncertainties involved, this quantity must be considered more an assumption than an estimate.

Kit Cost – From the foregoing considerations, estimates of total retrofit kit cost were constructed for various numbers of kits up to 300, as illustrated in Figure 5. A composite development program for the two distinct (but similar) DC-8 fuel systems, taking advantage of all commonalities and carrying both through flight test and certification, was estimated to total approximately 19 million dollars. This amount was allocated to kit cost by spreading it evenly over the number of kits to be produced. The remainder of the per-kit cost shown in the figure represents the estimated recurring cost of manufacturing, which also decreases with quantity due to increased efficiency (the experience factor) and economies of scale. At the assumed production quantity of 300 retrofit kits (for approximately 270 airplanes plus spares), the cost-per-kit used in this study was $311,000.

It may be noted that at the greater quantities, as the cost curve tends to flatten out, the change in unit cost becomes relatively small with variations in quantity. As previously noted, some imprecision in the assumed quantity would, therefore, introduce only a relatively small imprecision in the estimated unit cost.

TABLE 3. – TURBINE-POWERED AIRCRAFT ON ORDER BY UNITED STATES AIR CARRIERS

Aircraft type		Aircraft fleet 6/30/69	Additional aircraft on order for delivery					
			1969	1970	1971	1972	1973 or later	Total
Total aircraft		2,386	137	146	69	89	207	648
Jet		1,969	128	140	69	89	105	531
2-engine:	BAC-111	60	–	–	–	–	–	–
	Boeing 737	123	24	6	–	–	–	30
	Douglas DC-9	311	13	15	–	–	–	28
	Hansa 320	1	–	–	–	–	–	–
	Sud Caravelle	20	–	–	–	–	–	–
3-engine:	Boeing 727	589	52	27	–	–	–	79
	McDonnell-Douglas DC-10	–	–	–	17	35	32	84
	Lockheed L-1011	–	–	–	8	45	73	126
4-engine:	Boeing 707	425	6	–	–	–	–	6
	Boeing 720	134	–	–	–	–	–	–
	Boeing 747	–	–	81	44	9	–	134
	Convair 880/990	47	–	–	–	–	–	–
	Douglas DC-8	259	33	11	–	–	–	44
Turboprop		402	9	6	–	–	–	15
1-engine:	Turbo Porter	7	–	–	–	–	–	–
2-engine:	F-27/FH-227	100	–	–	–	–	–	–
	Convair 580/600	142	–	–	–	–	–	–
	DeHav. Twin Otter	7	4	–	–	–	–	4
	Grumman G-21T	1	–	–	–	–	–	–
	Grumman Gulfstream	1	–	–	–	–	–	–
	Nihon YS-11	10	5	6	–	–	–	11
	Nord 262	9	–	–	–	–	–	–
	Short Skyvan	2	–	–	–	–	–	–
4-engine:	AW-650 Argosy	8	–	–	–	–	–	–
	Canadair CL-44	10	–	–	–	–	–	–
	Lockheed Electra	82	–	–	–	–	–	–
	Lockheed Hercules	19	–	–	–	–	–	–
	Vickers Viscount	4	–	–	–	–	–	–
Helicopters		15	–	–	–	–	–	–
1-engine:	Bell JetRanger	3	–	–	–	–	–	–
2-engine:	Boeing Vertol 107	4	–	–	–	–	–	–
	Sikorsky S-61	8	–	–	–	–	–	–
Supersonic Transports		–	–	–	–	–	102	102
Concorde		–	–	–	–	–	38	38
U.S. – SST		–	–	–	–	–	64	64

Note. – Included here are all turbine-powered aircraft on order by United States certified route, supplemental, intrastate and commercial air carriers to the extent reported by the aircraft manufacturers and air carriers through November 1969. Aircraft on option are excluded. Aircraft leased or to be delivered under a lease agreement are included. Supersonic transport figures relate only to reserved delivery positions.

Source: Aviation Forecasts, FAA (Reference 5)

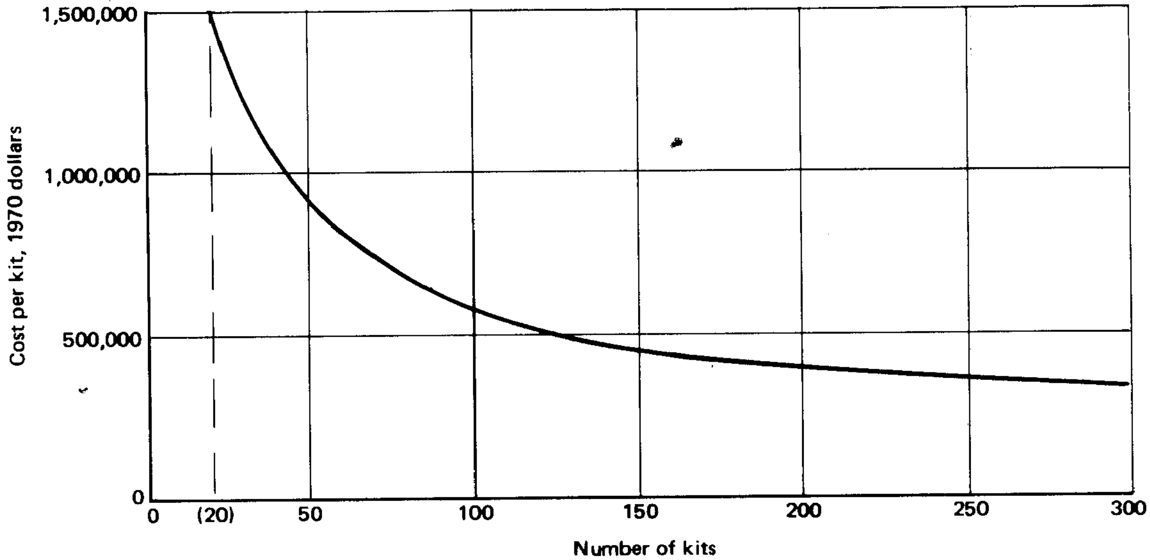

Figure 5. Cost-per-kit variation with quantity.

Cost of Initial Spares – It was assumed that along with each retrofit kit, the airline operators would also procure and stock spares. The initial spares requirement was assumed to be 10 percent. This is the level of airframe spares which the Air Transport Association (ATA) recommends be used in comparing the direct operating costs of similar airplanes (Reference 6). Therefore, in this study the cost of initial spares was treated as a 10-percent addition to retrofit kit cost, or $31,000 per airplane at the assumed number of airplanes to be retrofitted.

Installation and Downtime Costs – Because of the nature of the retrofit modification, it was apparent that installation would be a significant cost element in itself, and that the necessary airplane downtime to accomplish the installation would also be significant. A task analysis was prepared to examine and accumulate, by tasks, the man-hours and airplane-hours required. The assumptions and conclusions of the task analysis are summarized in Table 4. An itemization by task is shown in Table 5. This task analysis represents average labor and elapsed time requirements for the DC-8 fleet; therefore, it is a flat amount that does not decrease with quantity. This is a reasonable reflection of how such a program would be priced, since it would be unacceptable to penalize early installations with higher prices.

Applying current rates, the installation task as defined was estimated to total approximately $120,000 per airplane. For another recent R&D program, a test DC-8 was leased for approximately $5,000 per day. Applying this rate, the 10-days downtime represents an additional cost (more precisely a loss-of-revenue) of approximately $50,000 per airplane.

To keep this study uncluttered, all the cost elements were estimated in terms of current 1970 prices. These values were used throughout the study, with no adjustment for inflationary or deflationary trends.

To recapitulate, for the assumed number of airplanes the initial costs of DC-8 fleet retrofit were estimated as follows:

Retrofit Kit	$311,000 per airplane
10% Initial Spares	31,000 per airplane
Installation	120,000 per airplane
Airplane Downtime	50,000 per airplane

Maintenance Cost Changes – The present maintenance material and labor cost for the DC-8 fuel system is $1.26 per flight-hour. The following distribution of this cost between major fuel system components was assumed:

20 percent for pumps

70 percent for quantity system

10 percent for other components.

TABLE 4. – RETROFIT INSTALLATION AND DOWNTIME SUMMARY DC-8-62 AND 61*

Assumptions:	32	Men-per-shift
	3	8-hour shifts-per-day
	7	Days-a-week operation
	40%	Contingency or performance factor, due to inefficient use of manpower to minimize airplane downtime.
Manhours:	22	Enumerated tasks
	5516	Total effective manhours
	2206	40% factor (contingency or performance)
	7722	Total actual manhours
Airplane downtime:	10	Days

*Negligible differences between DC-8 models

TABLE 5. – RETROFIT INSTALLATION TASK ESTIMATE, DC-8 62

	Task	No. of men	Elapsed hours	Manhours
1.	Ramp in, inventory, defuel and position aircraft.	6	8	48
2.	Remove tank access doors, interior panels as required for electrical access. Purge tanks.	20*	12	40
3.	Remove existing pumps, fuel lines, reservoir boxes, valves.	20	8	160
4.	Install new reservoir boxes (9).	16	20	320
5.	Install new boost/transfer jettison pump mounting provisions (26).	18	10	180
6.	Install new small transfer pump mounting provisions (99).	32	30	960
7.	Install intertank and front spar bulkhead fittings and new large crossfeed line. Install supports at ribs.	24	20	480
8.	Install fuel lines from small transfer pumps (99) to reservoir boxes.	28	6	168
9.	Install support brackets and clamps for fuel lines from small transfer pumps (99) to reservoir boxes.	28	20	560
10.	Install aft spar bulkhead fittings for electrical power to small transfer pumps.	8	10	80
11.	Install electrical conduit in tanks to conduct power to small transfer pumps.	16	20	320
12.	Install fuel and electrical fittings from pressurized fuselage to wing.	4	6	24
13.	Install electrical wiring to switches, warning lights and circuit breakers in electrical power center and instrument panels (from pumps in tanks).	16	72	1152
14.	Install boost/transfer and jettison pumps (26).	8	2	16
15.	Install small transfer pumps (99).	16	4	64
16.	Check electrical operation of pumps and warning system.	4	8	32
17.	Check electrical operation of control, fill and shut-off valves.	8	4	32
18.	Clean and seal tanks where required.	8	8	64
19.	Cure period for sealant. Reinstall interior panels.	8*	8	48
20.	Install tank access doors.	20	8	160
21.	Fuel.	8	4	32
22.	Preflight.	8	72	576
			Total	5516
			Contingency or performance	2206
			Adjusted total	7722

Elapsed time – 10 days (based on 3 8-hour shifts, 32 men per shift, 7 days a week. (Many tasks concurrent.)

*Peak man-loading (not maintained through elapsed time).

Pumps: The present DC-8 fuel system has 12 pumps, so the present maintenance cost per flight-hour per pump would be $0.0208. Due to the increased difficulty of access to the 99 new small pumps, and the problems of defueling gelled fuel to get at many of them, a complexity factor of 5 was assumed. This would result in a new maintenance cost per flight-hour per pump of $0.10, a total of $10.28 for the 99 new small transfer pumps. Due to the increased size and output pressure of the 26 new boost/transfer and jettison pumps, a complexity factor of 2 was assumed, making the new maintenance cost per flight-hour per boost pump $0.04, or a total of $1.00 for the 26 larger boost/transfer and jettison pumps.

Fuel Quantity System: The present DC-8 fuel system has 56 probes whose total maintenance cost per flight-hour is $0.88. It was assumed that the new larger probe system would require twice as much for maintenance, or $1.76 per flight-hour.

Other Components: Other components of the present DC-8 fuel system cost $0.12 per flight-hour for maintenance. Due to the considerably increased complexity of the added pipes and connections, a factor of 10 was assumed for maintenance of the new system, raising the maintenance cost for other components to $1.20 per flight-hour.

These data are summarized in Table 6. The total maintenance cost for the new fuel system would be $14.24 per flight-hour, an increase of $12.98 per flight-hour, or more than 10 times the present fuel system maintenance cost.

Fuel Cost Changes – The gelling of jet fuel was assumed not to change the usable energy of the fuel, but it was estimated to add 2-1/2 cents per gallon to the base cost of Jet A-1 jet fuel, approximately a 25-percent increase. The elements of this fuel cost change, discussed in the following paragraphs, may be summarized as follows:

Element	Change ($/Gallon)
Usable energy of fuel	No change
Jet fuel additive	+ 0.022 (mid-range)
Mixing of additive and fuel	+ 0.002
GSE changes to handle and deliver gelled fuel	+ 0.001
Total	+ 0.025

Usable Energy: Table 7, furnished by the FAA, indicated that the heat of combustion of Jet A-1 jet fuel was not perceptibly affected by addition of the jet fuel additive. For this study it was therefore assumed that the usable energy of gelled fuel G would be the same as that of liquid jet fuel.

TABLE 6. – MAINTENANCE INCREMENT

Present DC-8 Fuel Sys maint costs $/flt hr	Main components requiring maint	% distrib of maint costs	Old sys $/flt hr	Old sys no./units	Old sys $/unit/ flt hr	Assumed complexity factor for new	New component $/unit/ flt hr	New sys no./units	New sys maint cost $/flt hr	
$1.26	Pumps	20	~.26	12	.0208	5	.10	99	10.28	Transfer pumps
						2	.04	26	1.00	Boost/transfer and jettison pumps
	Qty Sys	70	~.88			2			1.76	Fuel quantity system
	Other	10	~.12			10			1.20	Other
Total	(Present)		$1.26				(New)		14.24	
							(Present)		1.26	
							Increment		12.98/Flight hour	

Notes: (1) Fuel system maintenance and increments same for all DC-8's.
(2) Cyclic effect considered in estimating complexity factors.

TABLE 7. – EXHIBIT "A"

Federal Aviation Administration
National Aviation Facilities Experimental Center

Contract No.: FA68NF-273

Title: Heat of Combustion Data for Gelled Fuel G

Date: 3 September 1969

Furnished are the following heat of combustion values for Jet A-1 jet fuel thickened with jet fuel additive, designated gelled fuel G. The data were obtained by a Thermal Laboratory using ASTM Specification 2382-65. ASTM 2382-65 is the same procedure as ASTM D-240 except that the allowable experimental error is 20 BTU'S/lb for ASTM 2382-65 and 55 BTU's/lb for ASTM D-240. The exact data obtained are as follows:

Fuel	Gross heat of combustion	Net heat of combustion
Jet A-1	19,840 BTU's/lb	18,570 BTU's/lb
2 percent additive in Jet A-1	19,830 BTU's/lb	18,565 BTU's/lb
1.6 percent additive in Jet A-1	19,820 BTU's/lb	18,550 BTU's/lb

The jet fuel specifications call for only the net heat of combustion and lists a minimum of 18,400 BTU's/lb for Jet A-1. As you will note all of the values are well within the experimental error tolerance of the specification and thus show no difference in the heat of combustion value with the addition of the jet fuel additive, i.e., for gelled fuel G.

Jet Fuel Additive: Figure 6, also furnished by the FAA, gives the estimated cost in volume production of the jet fuel additive needed to convert liquid fuel to gelled fuel G. These cost data are in the form of a nomogram which provides the high and low estimates for the costs to be added to the price of a gallon of jet fuel as functions of the additive concentration in the fuel and the fiscal year under consideration. The nomogram is to be used by extending a horizontal line from the fiscal year ordinate to the desired additive concentration, a vertical line from the intersection to the high and low boundary lines for the corresponding additive concentration, and horizontal lines from these intersections to the additional cost/gallon ordinate.

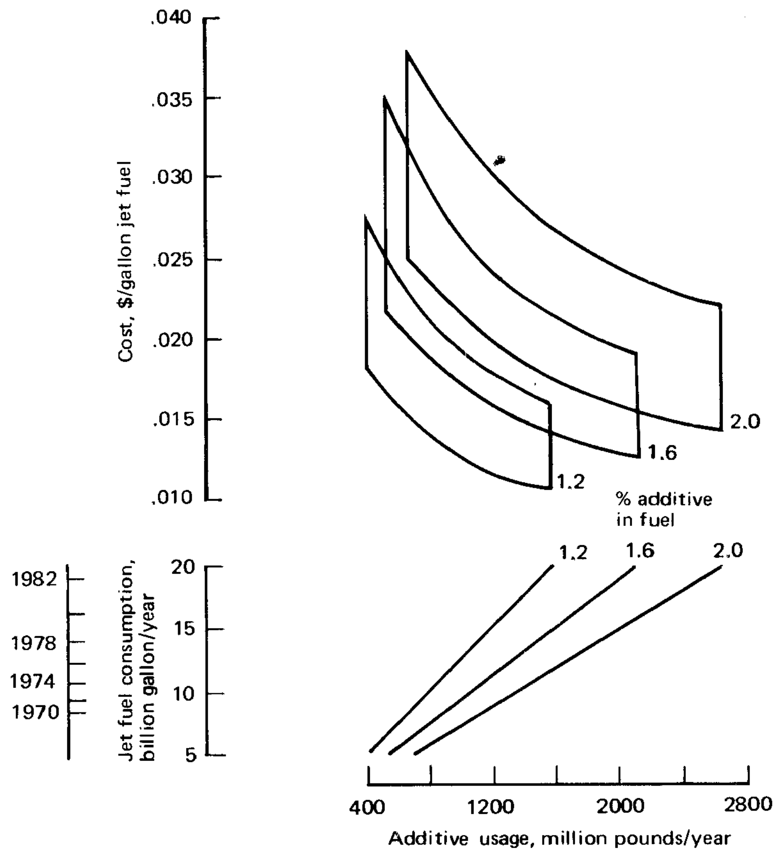

Figure 6. Cost vs volume projection – jet fuel additive for gelled fuel G.

As an example, a mid-range 2-percent additive concentration in 1976 would add an additive cost of 2.2 cents per gallon of jet fuel. This is the nominal additive cost used in this study, although iterations also were performed at the high and low 2-percent extremes and at the 1.2-percent mid-range value.

For this study, the price per gallon of gelled fuel delivered into the airplane tanks was increased (over price of liquid jet fuel) by the following four increments ($/gal.):

	Very Low	Low	(Nominal Case) Mid	High
Additive	0.012	0.017	0.022	0.027
Mixing	←	←	0.002	→
Delivery	←	←	0.001	→
Total	0.015	0.020	0.025	0.030

Mixing of additive and fuel: The cost of mixing the additive with jet fuel to produce gelled fuel G, including adequate provision for quality control of the process before pumping the gelled fuel into airplane tanks, was estimated at 0.2 cents per gallon. Several inputs were considered in arriving at this estimate, which are summarized in Table 8.

Ground Support Equipment (GSE) changes to handle and deliver gelled fuel G: It was evident that the GSE which handles and delivers fuel from the tank farm to the airplane would require modifications somewhat analogous to the airplane modifications studied, to similarly adapt it to the gelled fuel. This would also add an increment to the cost of the fuel delivered into the airplane tanks.

Two ground handling systems for servicing gelled fuel were examined. It became readily apparent that, due to the numerous problems associated with the handling of gelled fuels, the further downstream that additive could be mixed with fuel, the less equipment would be affected. Greater flexibility, especially during a possibly extended change-over period, would be a major consideration. Plan 1 considered mixing the fuel at a remote site, probably the existing bulk storage area. Plan 2 considered mixing the fuel at the fuel pit or in close proximity to the aircraft. In each plan, the costs were calculated for servicing a single satellite of five loading gates such as exists at many large airports today. The model gelation plant (see Table 8) had approximately the correct capacity to service this size unit.

Both plans assumed that Jet A jet fuel would be the base fuel used for gelation; that bonded fuel requirements would not be a determinant; that both systems would be protected as required against extreme temperatures; and that gelled fuel G could be pumped adequately through 12-inch or larger pipes at high rates, and through 2-1/2-inch lines at adequate rates.

TABLE 8. – MIXING COST ESTIMATES FOR GELLED FUEL

1.	Cost of a JP-4 gelation plant* (9,000 gph)	$64,000
	• Amortized over 10 years (continuous operation, 10 percent downtime)	.009 ¢/gal
	• Total operating cost (less cost of additive) @ .02 ¢/lb of fuel*	.134 ¢/gal
	• Total cost of mixing: (SRI estimate)*	.143 ¢/gal
2.	Cost of mixing gel in production quantities (additive manufacturer's estimate)	0.0 to .500 ¢/gal
3.	Recommended study cost	.2 ¢/gal

*Based on SRI 4822, APL TDR 64-99, Vol. 1, pp. 56, 58

With either approach it was found that the cost of GSE changes would add less than 0.1 cent per gallon to the cost of fuel. The remote handling (Plan 1) was slightly the more expensive of the two plans examined. For this study a rounded value of 0.1 cent per gallon was used to represent the cost of GSE changes.

The findings of the two ground handling plans are outlined in the following paragraphs.

(1) Plan 1. Perform Mixing and Storage at Remote Site: Under this plan the gelation plant would be located either at the existing bulk storage area or at a site convenient to existing on-airport pipe lines. New requirements would include a change from centrifugal to constant displacement pumps, which have higher power requirements for similar capacities and more refined control accessories, which increase the cost considerably. Present filters would have to be enlarged or cascaded. Downstream pipes would have to be enlarged or their numbers increased to handle peak capacity flow rates. As the distance between the gelation plant and the ramp fuel pits increased, additional line boosters would be required. Fuel pit hardware, meters, and filters would have to be changed to be compatible with gelled fuel, and new hydrant carts would be needed. The estimated costs of Plan 1 would be as follows:

• Cost of Gelation Plant	$ 64,000.00
• Cost of Constant Displacement Pumps (2)	16,000.00
• Cost of Underground Pipe Replacement (1,000 feet of 12 inch pipe)	50,000.00
• Cost of Fuel Pit Retrofit @ $9,000.00 per Pit (5 Pits)	45,000.00
• Cost of 4 New Hydrant Carts @ $28,000	112,000.00
	$287,000.00
• Miscellaneous Contingencies @ 10%	28,000.00
	$315,000.00

Service life of the equipment listed is at least 10 years, during which time it would have theoretically handled 775 million gallons of fuel. Thus the cost increment per gallon would be:

10 Year Amortization = $315,000 ÷ 775,000,000 = $0.0004/Gal.

5 Year Amortization = $315,000 ÷ 387,500,000 = $0. 0008/Gal.

Advantages of Plan 1:

- Centralized mixing control.
- Larger mixing plant possible.
- Less fire hazard at gate positions.
- Simple location for gelled fuel storage and handling.
- Quality control at one area.

Disadvantages of Plan 1:

- Requires the most new equipment and resizing of pipelines.
- Would require a separate parallel system modification for bonded fuel.
- Costs are harder to estimate accurately due to airport conditions (fuel lines presently buried under concrete ramps, etc.).
- Gelled fuel storage may be problem, because resin concentration would increase with fuel evaporation.
- Least flexible during changeover period.
- Some servicing pits are 1 to 3 miles from tank farm. There may be unanticipated problems involved in pumping gelled fuel long distances.

(2) Plan 2. Perform Mixing and Immediate Service at Fuel Pit: In Plan 2, a new piece of equipment would be developed, which would in effect be a self-powered portable gelation plant with two gelled fuel containers of optimum size (approximately 10,000 gallons), an additive container sufficient for several refueling operations (could be a separate bulk loading truck), and metering, pumping, and quality control equipment necessary to carry out the gelling operation at the fuel pit. With this plan, one mobile tank at a time would be filled with jet fuel and additive to make gelled fuel, with the mixing performed while the mobile tank was being filled. Quality control of the batch of gelled fuel would be assured in the mobile tank before it was pumped into the airplane. While one mobile tank was pumping gelled fuel into the airplane, the other would be filling, mixing, and undergoing quality control. This mobile gelation process would be intervened between the existing refueling equipment and the airplane, replacing the hydrant carts and requiring no modifications to the existing equipment.

A 10,000-gallon self-propelled tank with pumping and metering equipment would cost approximately $55,000, and a 10,000-gallon trailer about $20,000. Additional gelation-related equipment is estimated at $9,000 per unit. The estimated costs of Plan 2 would be as follows:

• 4 Tank/Trailer Units @ $84,000	$336,000
• Less 4 Hydrant Carts @ $28,000	112,000
	$224,000
• Miscellaneous Contingencies @ 10%	22,000
	$246,000

Using the same gallonage figure as Plan 1, the costs would be as follows:

10 Year Amortization = $246,000 ÷ 775,000,000 = $0.00032/Gal.

5 Year Amortization = $246,000 ÷ 387,500,000 = $0.00064/Gal.

Advantages of Plan 2:

- No immediate changes to existing equipment.
- Bonded fuel handling not affected.
- Fuel mixed as needed, no storage problem.
- Both modified and unmodified aircraft could be fueled at same pit.
- Phase-in of gelation equipment could be time-phased over a longer period.
- Total fixed cost lower.
- Better fuel filtering at pit area.
- Fresh gelled fuel mixture at servicing point.

Disadvantages of Plan 2:

- Quality control more difficult.
- Gelation plant, as a portable unit, may introduce unanticipated problems.
- Fire hazards increased at pit area, because of increased processing and equipment.

Insurance Cost Changes – It was assumed that a reduction in insurance costs would accompany the conversion of jet airplanes to the use of gelled fuel. Insurance costs may be expected to vary directly with the risks that are insured; therefore, a reduction in risk should bring a corresponding reduction in insurance cost. It was assumed that conversion to gelled fuel would bring a reduction in risk, since that would be a reason for initiating such a program.

Present knowledge, however, was insufficient to reasonably estimate how much of a reduction in insurance costs might be expected. There are trade-offs to be resolved between the benefits of using gelled fuel and the degradations due to the attendant increased system complexity and other problem areas introduced by the airplane modifications. The optimal gel concentration is still to be determined, as are the characteristics and effects of other than the 2-percent gel concentration examined in this study; and there are preliminary indications that a lower-concentration gel might be desirable. These determinations and trade-offs are interrelated, and need to be more fully investigated and better understood before the overall effect on system risks and insurance costs can be ascertained with acceptable confidence.

For this study an arbitrary 20-percent reduction in total insurance costs was assumed. The effect of the assumed reduction on the annual operating costs of a DC-8-62 in average service was calculated as shown on the worksheet, Table 9. The same 20-percent reduction was applied to both hull and liability insurance costs, which again was entirely arbitrary. The total effect, as shown, was a saving of $48,000 per year.

Hull insurance was assumed to cost (per year) 2 percent of the initial cost of the airplane. This is the rate which the 1967 ATA method of calculating airplane direct operating cost (DOC) recommended as representative of industry-average experience (Reference 6). The insured value of the airplane hull was increased by the capitalized cost of the modification, $462,000, or about 5 percent for the DC-8-62; the new reduced rate was then applied to this increased value to determine the new hull insurance cost.

Liability insurance was assumed to cost 3 percent of indirect operating cost (IOC), again representative of average United States experience. IOC was taken to be 42 percent of gross annual revenue. A representative gross annual revenue for a DC-8-62 in average service was calculated to be $7,511,000. The new reduced liability insurance cost is a proportional reduction of the base (unmodified) liability insurance cost.

To simplify reassessment of the insurance cost effect when there are better data available than the arbitrary 20 percent used herein, a normalized Change in Insurance Cost chart has been prepared (Figure 7). The chart gives variation in annual insurance costs as the insurance rate is changed. It is not necessary to have the same rate change in hull and liability insurance, since the resulting cost variations may be separately read and then summed. The chart is based on the rates and relationships used in the worksheet, Table 9, and is normalized for a hypothetical airplane that serves 100 million revenue-passenger-nautical-miles per year, making it applicable to direct traffic projections or to other comparable aircraft.

TABLE 9. – CHANGE IN INSURANCE COST/YEAR AT 20% REDUCTION DC-8-62

1. Assume gelled fuel reduces the insured risks, resulting in a 20 percent reduction of insurance costs.

2. Hull insurance:

   Assume: Initial cost (C_t) of DC-8-62 = \$9,100,000

   Initial hull insurance rate (IR) = 2%

   Modification increases C_t by $\frac{462,000}{9,100,000}$, or ~5%

   Modification reduces IR by 20%

   Hull insurance $_{base}$ = IR x C_t

   = .02 x \$9,100,000/yr

   = \$182,000/yr

   Hull insurance $_{modification}$ = 1.05 x .80 x (hull insurance $_{base}$)

   = \$153,000/yr

   Δ Hull insurance = –\$29,000/yr

3. Liability insurance:

   Assume: Liability insurance = 3% of IOC

   IOC = 42% of gross revenue (GR)

   GR = \$7,511,000/yr

   Modification reduces liability insurance by 20 percent

   Liability insurance $_{base}$ = .03 x .42 x \$7,511,000/yr

   = \$94,000/yr

   Liability insurance $_{modification}$ = .80 x liability insurance $_{base}$

   = \$75,000/yr

   Δ Liability insurance = –\$19,000/yr

4. Total Δ insurance: = Δ Hull insurance + Δ liability insurance

   = –\$48,000/yr

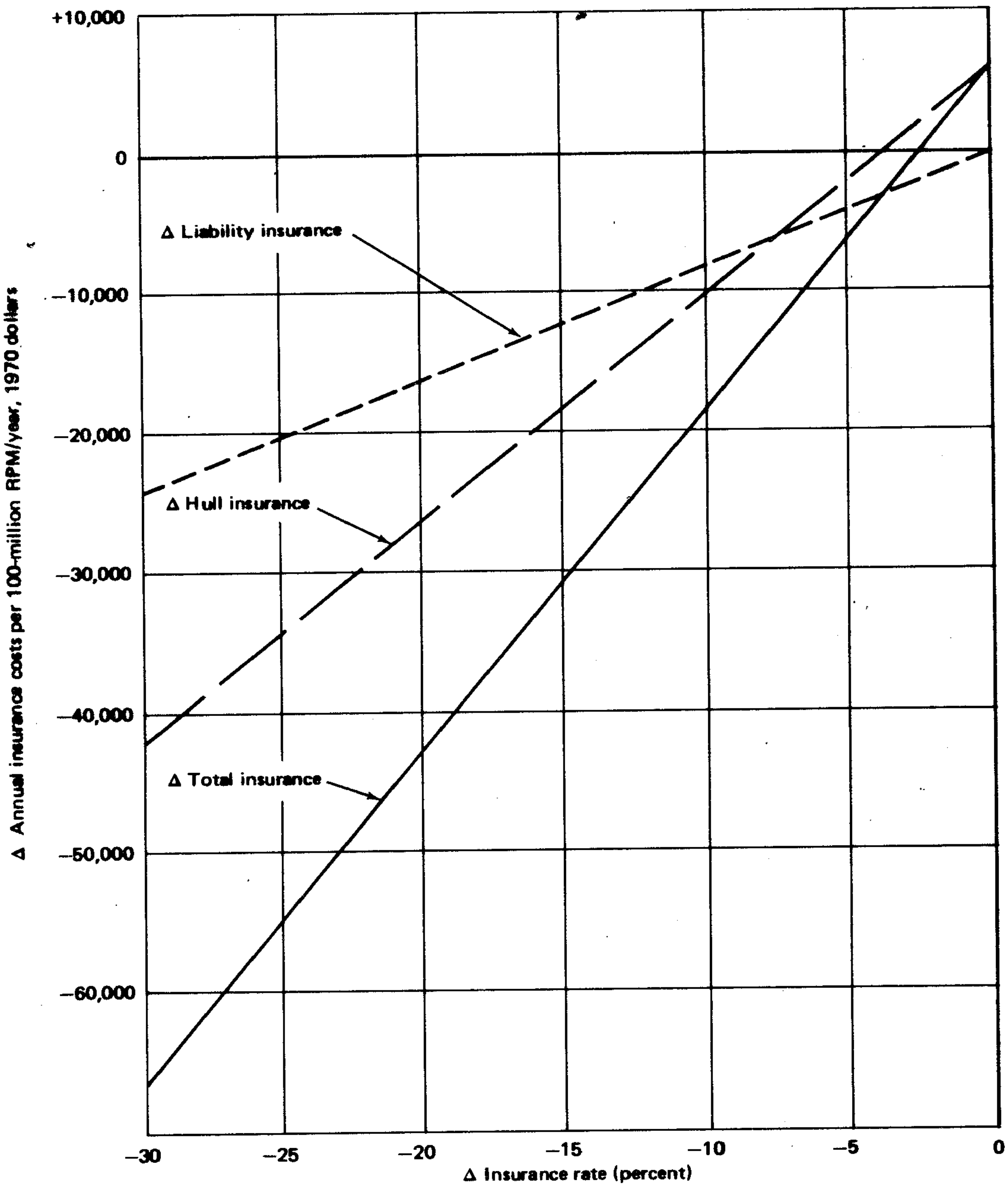

Figure 7. Change in insurance cost per 100-million RPM/year. (RPM – revenue-passenger-nautical miles) (Basis – DC-8-62 data normalized to RPM/year).

Changes in Aerodynamic Performance and Operating Cost, DC-8-62

The aerodynamic evaluation began with a restatement of the changes that have been discussed in the previous sections. These were mainly in terms of weight, fuel, and cost changes (see Table 10). A supporting worksheet, Table 11, itemizes the changes and effects involving fuel capacities. Based upon the modification design definition and the foregoing changes, aerodynamic performance and operating cost effects are discussed in the following paragraphs.

Drag – The change in airplane drag due to revised oil cooler air flow was so small as to be negligible. For all practical purposes, therefore, both thrust and drag characteristics were effectively unchanged.

M.W.E. – Manufacturer's Weight Empty increased 1,490 pounds, from 134,554 pounds to 136,044 pounds, due to increased empty airplane structural weight resulting from the modifications.

O.W.E. – Operating Weight Empty increased 7,680 pounds, from 142,606 pounds to 150,286 pounds. This was due to the 1,490 pounds increased M.W.E., plus 6,190 pounds increased unusable fuel.

TABLE 10. – CHANGES DUE TO MODIFICATION, DC-8-62

Δ Weight, airplane structure		+1490 lb
Δ Weight, unusable fuel (have to carry but can't use – 923.7 gal. @ 6.7 lb/gal.)		+6190 lb
Δ Maximum usable fuel (due to increased expansion space – 2867.1 gal. @ 6.7 lb/gal.)		–19,203 lb
Δ Airplane costs:	Retrofit kit	+$311,000
	Installation	+$120,000
	Spares	+$31,000
	Downtime expense	+$50,000
Δ Maintenance cost		+$12.73/flight hour
Δ Insurance cost (reduced)		–20%
Δ Cost of fuel		+2.5¢/gallon
Δ Thrust (no change)		0

Fuel Cost – Fuel Cost increased 2.5 cents per United States gallon, from 10 cents/gal. to 12.5 cents/gal. (This is the mid-range fuel price.)

Block Time – Due to the extra weight, time-to-climb was slightly increased, resulting in a slightly increased block time. This is a very small increase, on the order of 0.007 hour for an average 2-hour flight, which has negligible schedule and operational significance except that it adds an increment to trip cost.

Initial Cruise Altitude – The increased weight also resulted in a 500-foot degradation in maximum initial cruise altitude capability. For flight safety, only specified cruise altitudes are allowed and these are separated by 4,000-foot increments. The 500-foot loss in initial cruise altitude capability might require the acceptance of a cruise altitude which is 4,000 feet lower than would be possible without the gelled fuel system. Due to the limitations imposed by Air Traffic Control, it may not be possible to "step-climb" to a more optimum altitude even after burning enough fuel to obtain the required performance capability. The resulting increase in fuel for the mission would impose an increased economic penalty on the gelled fuel system. However, such problems would probably affect only a small percentage of the missions, making the overall economic penalty small.

TABLE 11. – COMPARISON OF DC-8-62 FUEL CAPACITIES (LIQUID VS 2 PERCENT GEL)

			U.S. gallons
1.	Total fuel volume (including crossfeed manifold)		24,915.6
2.	Liquid fuel		
	Maximum usable liquid		24,275.9
	Expansion space (2 percent of total volume)		566.8
	Tank-trapped liquid	25.5	
	Inflight unusable liquid	47.4	
	Total unusable liquid		72.9
3.	2-percent gelled fuel		
	Maximum usable gel		21,408.8
	Expansion space (10 percent of total volume)		2,491.6
	Trapped gel (4 percent of total volume)		996.6
	Total unusable gel		996.6
4.	Comparisons		
	Δ Maximum usable fuel		–2,867.1
	Δ Unusable fuel		+923.7

Payload-Range – The effect on payload-range is shown in Figure 8. At a constant (reference) payload, maximum range would be reduced approximately 13 percent. This is due to the decrease in usable fuel capacity of 19,203 pounds, plus the penalty of 7,680 pounds increased unusable fuel and structural weight.

Direct Operating Cost – Assuming a 5-year depreciation of the retrofit cost, the direct operating cost (DOC) increased approximately 9 percent (see Figures 9 and 10). Approximately 2/3 of this increase was due to the 2.5 cents/gal. increase in the cost of fuel, and 1/3 of the increase was due to amortizing the cost of retrofit kit, installation and spares ($462,000) over a 5-year period. The other changes in operating costs approximately balanced each other out. The dominant effect of the increased fuel cost is further demonstrated by the way the percentage increase in DOC rises from approximately 8.5 percent at 1000 nmi to approximately 9.5 percent at maximum range (with reference payload), since the proportion of fuel cost to total DOC rises similarly with increased range.

Field Length Requirements – Figure 11 shows takeoff and landing field length requirements and how they were changed by the retrofit. Takeoff field length was increased approximately 550 feet for a given range, due to the increased weight previously noted. A 6500-foot runway could still accommodate all takeoff requirements for flights up to 3000 nmi. At extreme ranges the unmodified airplane loaded for maximum range would still require up to 650 feet more runway than the modified airplane at its (13-percent reduced) extreme range.

Effect on DOC of Staging Flights

To serve the traffic demand at ranges that are greater than the modified airplane can achieve on a nonstop basis, it was assumed that the flight would be made in two legs with an intermediate fuel stop. This section develops an estimate of the increase in annual operating cost that would be caused by such staging.

The maximum range loss is 13 percent, 700-800 nautical miles [from Range Effect (Δ range) Worksheet, Table 12]. This range loss accounts for 1 to 2 percent of revenue-passenger-nautical-miles (RPM) (from Figures 12 and 13, Distribution of RPM with Range). To account for the trend toward longer trips in the 70's, the higher value, 2 percent, was used in this study.

An assumption of 55 minutes for staging one fuel stop cycle (typical of international stop – see Figure 14, Fueling Time vs Total Terminal Time) and $6.00 per minute for cost of ground delay (FAA & Airline Data, projected into the 70's, see Reference 7) can be used to compute the cost for a fuel stop for staging as follows:

Cost of Ground Delay:	55 x $6.00 =	$330
Cost of Landing and Takeoff Cycle:	=	220 (cyclical maintenance cost)
Total Δ DOC for the trip	=	+$550
Δ Time for the trip	+	55 minutes (0.917 hours)

Model DC-8-62
JT3D-7 engines
standard day

	OWE	Additional unused fuel
———— Standard aircraft	142,606	0
— — — Gelled fuel	143,196	6190

Note:

1. Domestic reserves with 200 nmi to alternate
2. Payload = 162 passengers at 205 lb plus 2500 lb cargo
3. Step altitude cruise at .82 Mach No. for ranges shorter than indicated by ⊙
4. Step altitude cruise at 99% maximum nmi/lb for ranges longer than indicated by ⊡

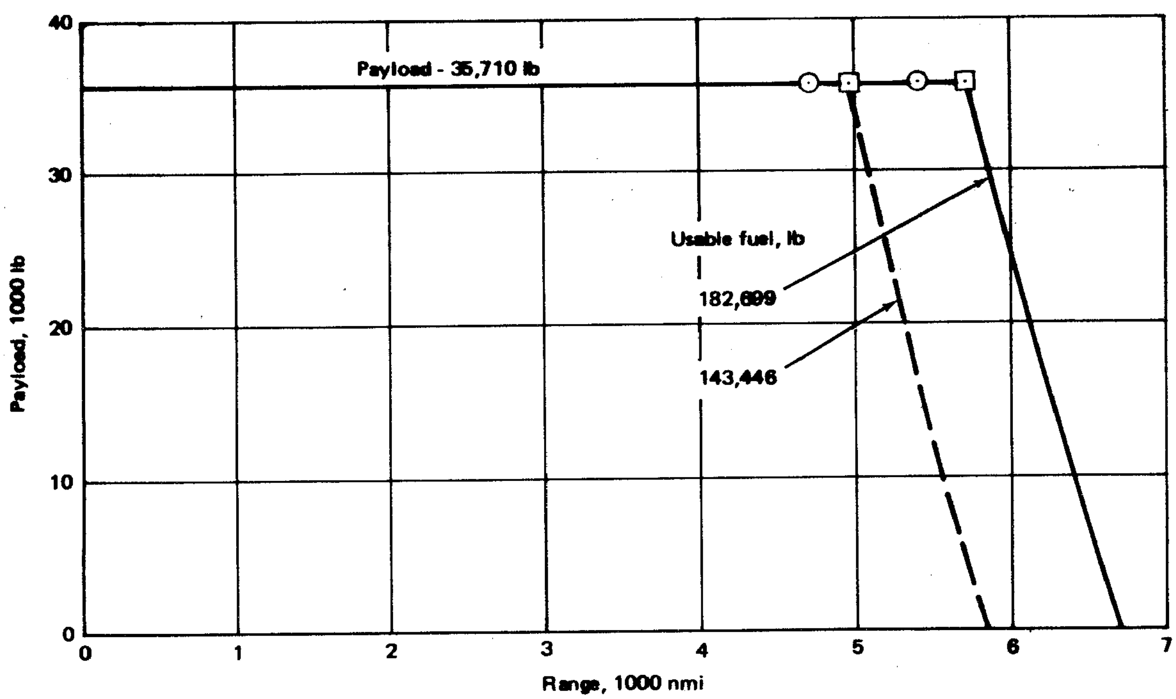

Figure 8. Payload-range comparisons.

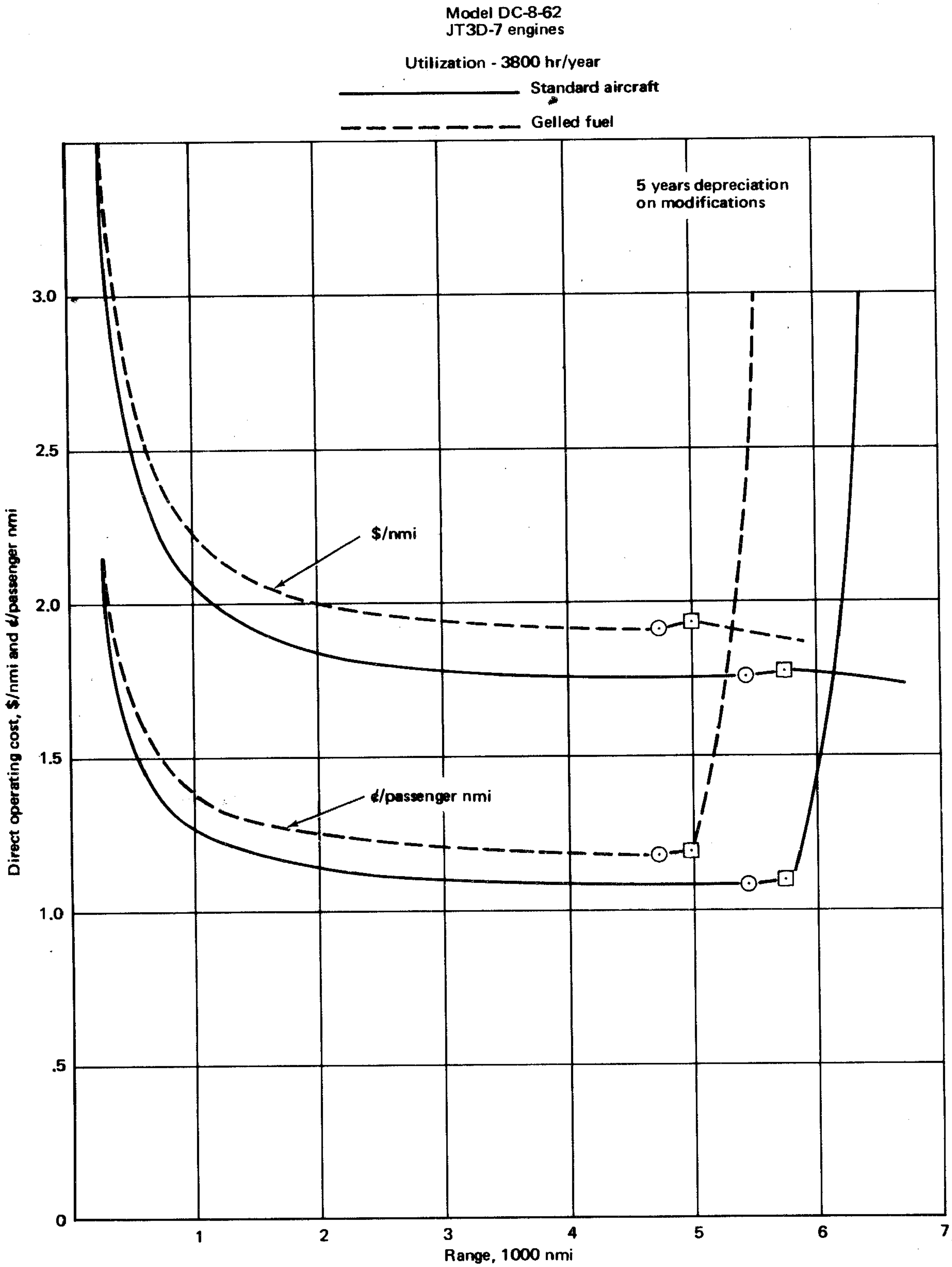

Figure 9. Direct operating cost comparisons.

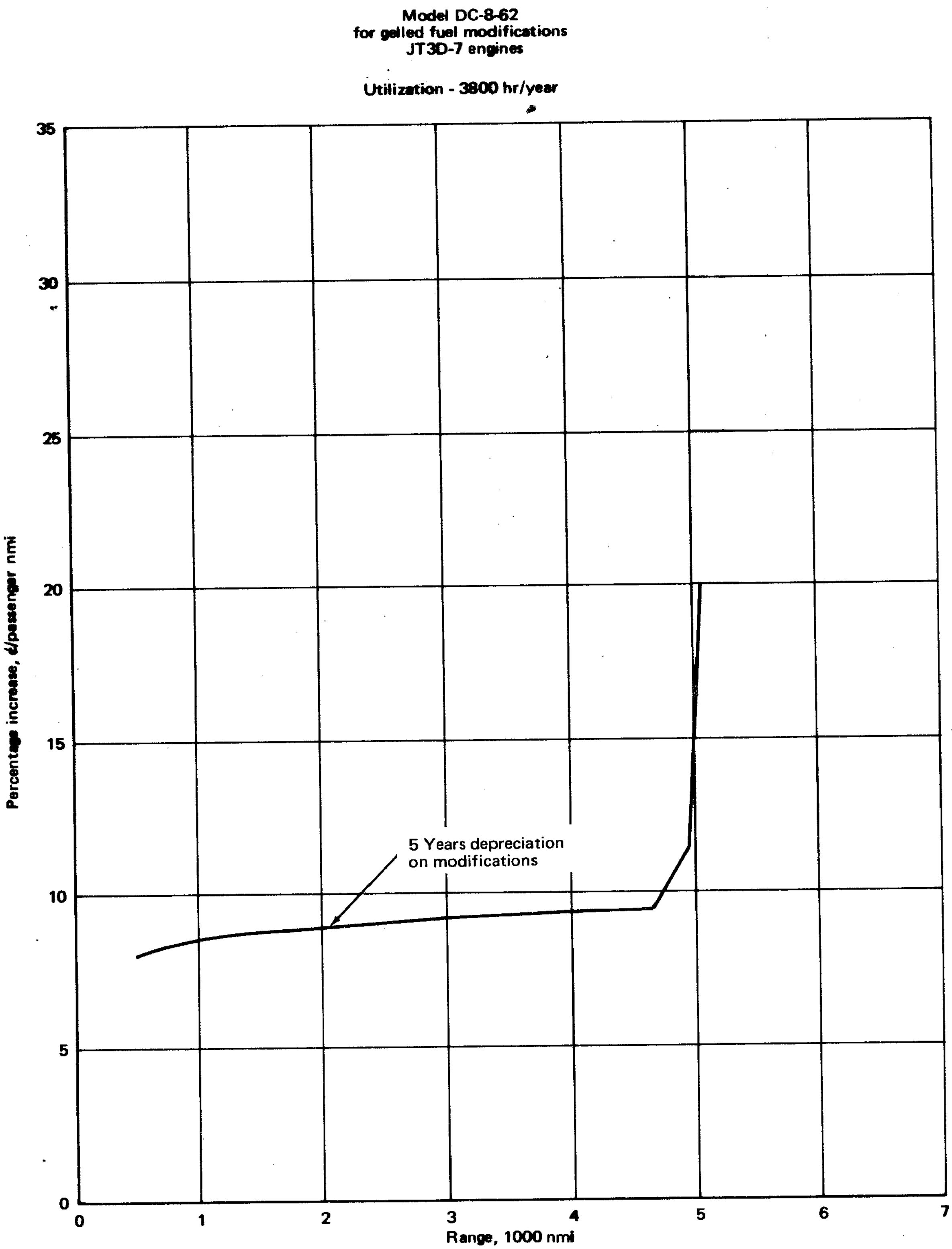

Figure 10. Increase in direct operating cost for gelled fuel modifications.

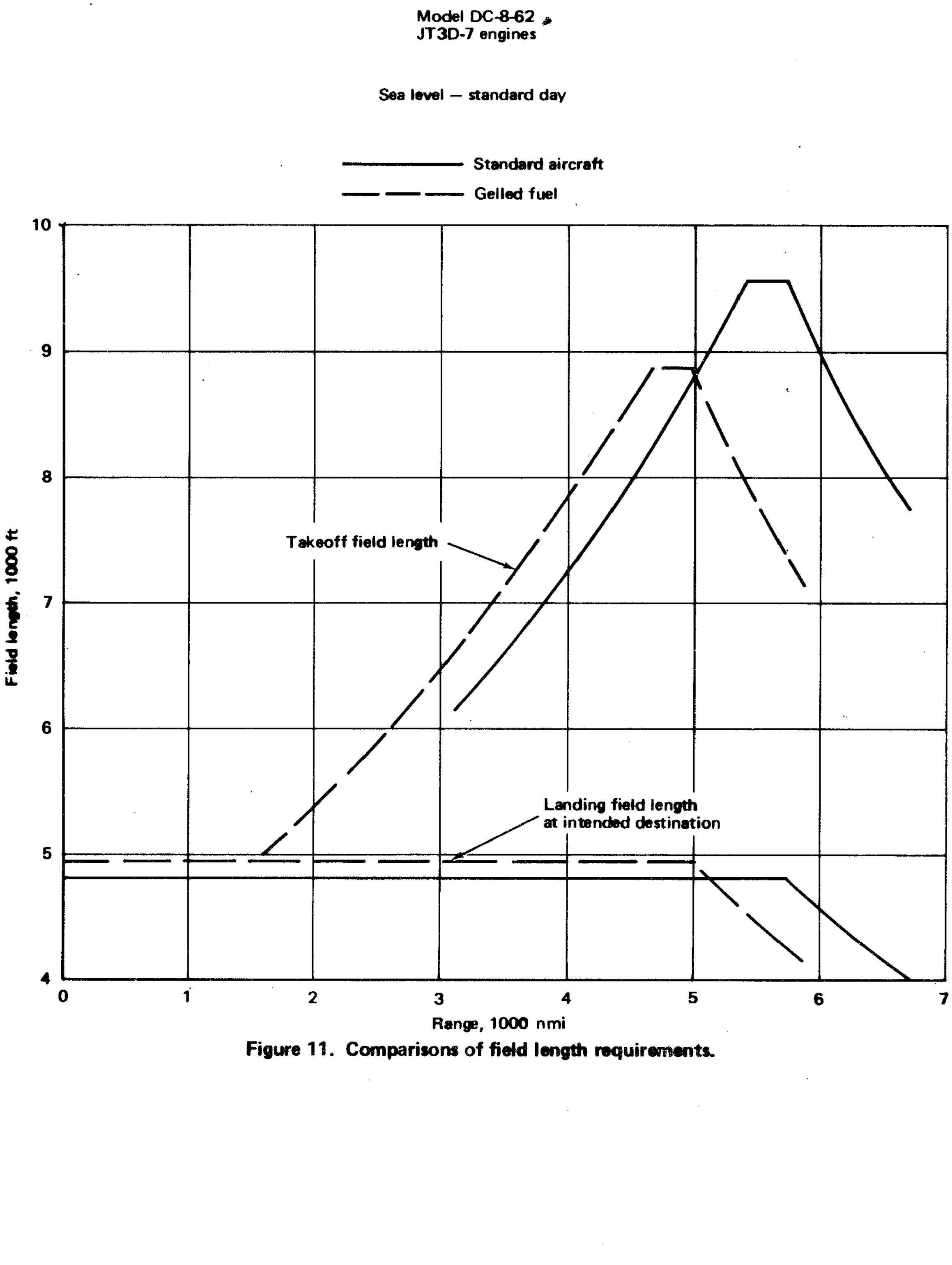

Figure 11. Comparisons of field length requirements.

TABLE 12. – RANGE EFFECT (Δ RANGE) OF GELLED FUEL MODIFICATION, DC-8-62

	HSC R_{max} full payload	LRC R_{max} full payload	LRC R_{max} half payload
Payload (lb)	35,710	35,710	18,000
R_{base} (nmi)	5,418	5,730	6,206
R_{mod} (nmi)	4,709	4,966	5,386
ΔR (nmi)	–709	–764	–820
	(13.1%)	(13.3%)	(13.2%)

Conclusions: DC-8-62 loses 700-800 nautical miles of maximum range capability due to gelled fuel modification.

Suppose the staging used two High-Speed Cruise (HSC) legs to make the same total range. Actually the intermediate airport would probably be to one side or the other rather than directly on the Long-Range Cruise (LRC) route; therefore, the sum of the two HSC legs would probably be a few miles greater than the direct LRC course. The comparison that follows in Table 13 was made with the base unmodified airplane making the trip in the two ways, so as to provide a measure of the difference in trip cost between a nonstop LRC flight and two staged HSC legs. The staged HSC flight cost $325 to $702 more (for 32 and 188 extra miles, respectively), and added 55 minutes (0.917 hour) ground time but very little extra operating time. In fact, if a refueling point requiring no extra mileage could be found, the staged HSC flights would require 0.042 hour less operating time than the nonstop LRC flight.

Based on both the foregoing approaches, the value of +$500 was selected as being reasonably representative of the additional trip cost for staging two HSC legs instead of flying one nonstop LRC leg. This allows for the time, fuel, and associated cost penalties of the extra landing and takeoff cycle, ground fueling time, faster cruise, and some extra mileage (~110 n mi) to reach the refueling point.

DOC for the maximum full-payload range of 5730 nautical miles, at LRC, is $9,511. The trip cost penalty of staging, $500, is approximately a 5-percent increment. This 5-percent increment on 2 percent of RPM may be equivalenced by adding 0.1 percent to total DOC for serving 100 percent of RPM; i.e., the effect on total DOC of the necessary staging to continue to handle the same traffic as before the modification is +1/10 of 1 percent. For the unmodified DC-8-62 in average service, annual DOC is approximately $3,100,000. The staging effect, at 1/10 of 1 percent of this, is approximately $3,100/yr.

Distribution of RPM with range
total free world, scheduled passenger traffic
detail of ranges, maximum scheduled down to 3500 nmi

(Basis: 1966 data, projected to 1971)

(RPM — Revenue-passenger-nautical-miles)

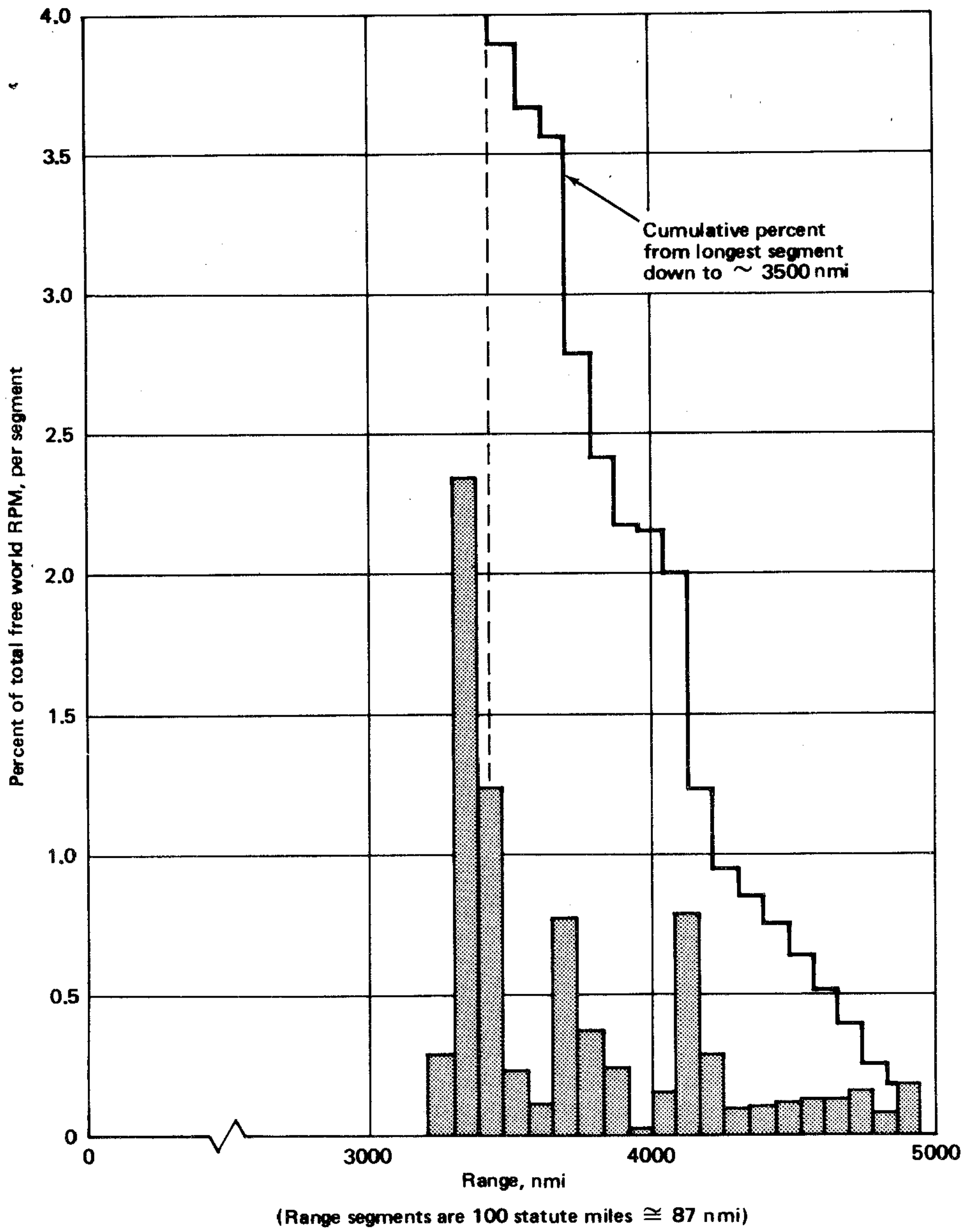

Figure 12. Distribution of RPM with range (detail).

Distribution of RPM with range
Total free world scheduled passenger traffic.

(Basis — 1966 data, projected to 1971)

(RPM — Revenue-passenger-nautical-miles)

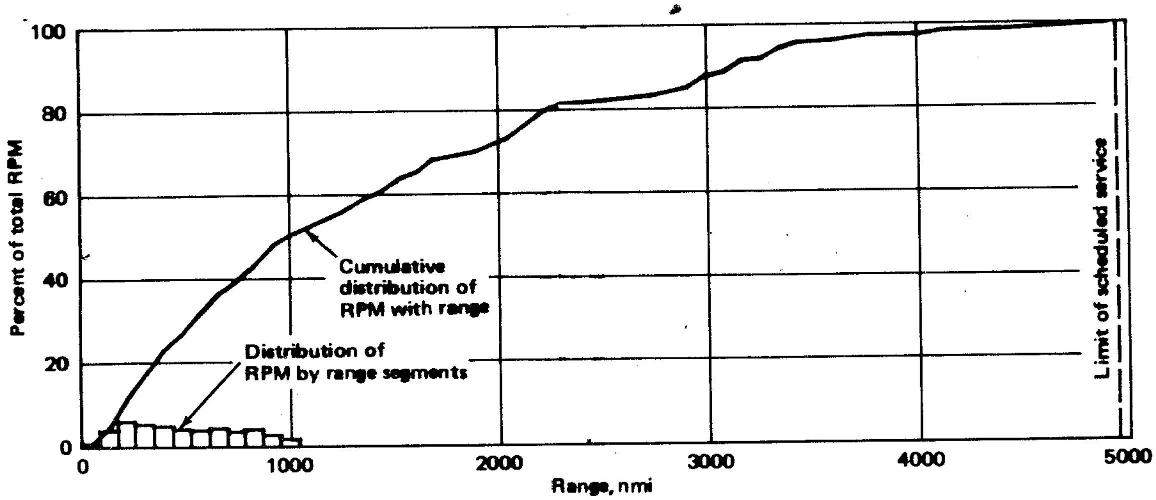

Figure 13. Distribution of RPM with range, full.

At the ranges in question, trip times for the unmodified DC-8-62 vary from close to 12 hours (maximum HSC range at reference payload) to 15 hours (maximum LRC range with zero payload). The added time for staging would not affect a one-way-trip-per-day schedule, and the trip time already is too great to accommodate a regular round-trip-per-day schedule. For the DC-8-62, such staging should, therefore, not present serious schedule or utilization problems. It should be borne in mind, however, that such schedule problems might be troublesome with other airplanes.

There may be practical reservations about the foregoing methodology. It assumes that for the trips in question it will be practical to get some extra time per trip (which may be on the order of an extra 0.28 hour per day) of operating utilization from the airplane, on a continuing regular basis. It also assumes that the staging (and approximately 1 hour extra trip time) will have no adverse effect on traffic demand. From the experience of several high-intensity users it would appear that the slightly increased utilization should be no problem. On the other hand, it is possible that the degraded service would hurt traffic demand. The net effect, therefore, might differ from this assessment.

It is recognized that the preponderance of airplane accidents are associated with landings and takeoffs, as pointed out in the Aerospace Industries Association of America report "Prevention of Crash Fires in Transport Airplanes" (Reference 8). The reduced reliability and the increased number of takeoffs and landings due to staging formerly nonstop flights could have an adverse effect on safety, which should be weighed against any safety advantages which may accrue from using gelled fuels.

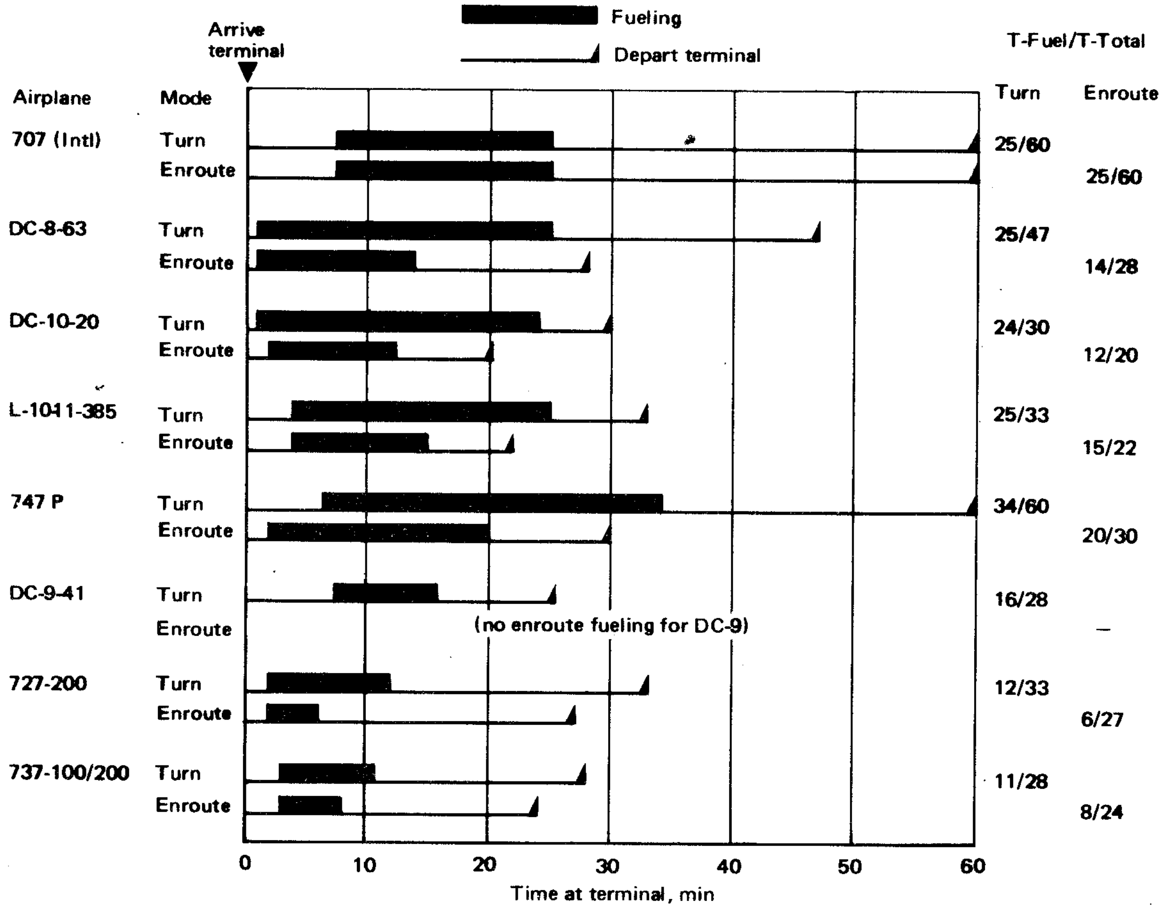

Figure 14. Fueling time vs total terminal time.

Economic Analysis, DC-8-62

The foregoing sections have laid a basis for consideration of the changes in the time-phased economic performance of the DC-8-62 that would be expected from the modification program that has been described.

Each change that was expected or that has been identified in the preceding sections was defined and analyzed to the point that it could be expressed in terms of its dollar effect on 1 year's operating costs. In respect to time, these dollar effects may now be restated as discussed below and as summarized in Table 14:

(1) Airplane downtime is treated as a one-time cost that is not capitalized but that may be allowed as a tax-deductible expense in the year the airplane is retrofit.

(2) The retrofit kit, installed, plus initial spares, is treated as an increase to the airplane capital investment. Thus, it may be capitalized and amortized over a period of time, just as the initial airplane investment is usually treated. Various airline operations undoubtedly will handle this in various ways: It might be

TABLE 13. – MODE COMPARISONS
COST AND TIME DIFFERENCES BETWEEN
STAGING A TRIP IN TWO SHORTER LEGS WITH AN
INTERMEDIATE FUEL STOP
VS
ONE LONGER DIRECT NONSTOP TRIP

Example	Range	Trip Cost	Time
Example 1			
Short leg 1	4262 HSC	$ 7,034	9.408 hr
Short leg 2	1500 HSC	2,802	3.575 hr
Sum 1 + 2	5762 HSC	$ 9,836	12.983 hr
Equivalent long leg	5730 LRC	9,511	12.959 hr
	Δ +32	Δ +$ 325	Δ + .024 + .917 = +.941
Example 2			
Short leg 1	5418 HSC	$ 8,896	11.823
Short leg 2	500 HSC	1,317	1.414
Sum 1 and 2	5918 HSC	$10,213	13.237
Equivalent long leg	5730 LRC	9,511	12.959
	Δ +188	Δ +$ 702	Δ + .278 + .917 = +1.195
By straight-line extrapolation, the zero Δ-range point is:			
	Δ ±0	+$ 275	Δ –.042 + .917 = +.875

TABLE 14. – CHANGES IN OPERATING COSTS DUE TO MODIFICATION – DC-8-62

			Dollars per year
1.	For airplane downtime to install the modification (10 days @ $5,000 per day). (A one-time tax-deductible cost in the first year only.)		50,000
2.	For increased depreciation to amortize cost of the retrofit kit, installed, plus initial spares, over 5 years (per-year for 5 years).		92,000
3.	For other operating cost elements (per year for the remaining life of the airplane):		
	Maintenance	+43,900	
	Fuel	+173,000	
	Insurance	–48,000	
	Staging	+3,100	
	Total		172,000

treated in effect as another one-time cost, paid and treated as a tax-deductible expense in the year the airplane is retrofit; it might be amortized over the remaining years of the initial airplane investment; or it might be treated in other ways. For this study a middle course was assumed: That the retrofit kit, installed, plus initial spares, would be capitalized and then depreciated over a 5-year period of time. Treated thus, this cost element would apply to the first 5 years after retrofit, but not thereafter.

(3) The third category is the cost changes that will remain with the airplane the rest of its operating life. These include the estimated annual cost effects of staging, and the changes in annual costs of insurance, maintenance, and fuel. The 20-percent reduction in insurance that was assumed approximately balances out the increases for staging and maintenance. The increased annual fuel cost is by far the largest of these cost effects, and is approximately the same as the total annual cost increment due to all four of these together.

Table 15 sums the foregoing annual operating cost effects for the three pertinent time periods, Year 1, Years 2-5, and After Year 5.

TABLE 15. – SUMMARY EFFECT BY TIME PERIODS OF CHANGES IN DC-8-62 ANNUAL OPERATING COSTS DUE TO RETROFIT MODIFICATION

(Per airplane, 2-percent gelled fuel G, at mid-range additive cost)

Annual operating cost category	Year 1		Years 2-5		After year 5	
	Dollars	Distrib.	Dollars	Distrib.	Dollars	Distrib.
Downtime	50,000	16%	–	–	–	–
Depreciation	92,000	29%	92,000	35%	–	–
Other	172,000	55%	172,000	65%	172,000	100%
Total	314,000	100%	264,000	100%	172,000	100%

Because of the dominant effect of the change in fuel cost, and the difficulty at this point in time of reliably predicting the ultimate additive cost level when in full volume production and use, the analysis was iterated at four levels of additive cost. The results, again spread by pertinent time periods, are summarized on the worksheet, Table 16. These represent the Low, Mid, and High additive costs read off the Additive Cost Nomograph, Figure 6, adjusted for mixing and GSE cost increments; plus the inclusion of a Very Low level such as might be expected if a lower 1.2-percent gel concentration were to prove feasible. As previously noted, this Very Low level is entirely speculative at present and is included only as an indication of its possible effect on costs.

Summary – In summary, the time-phased economic impact of the gelled fuel modification on one DC-8-62 (within the constraints and with the assumptions noted) may be expressed as a set of three increments in operating cost (example is at "Mid" level of additive cost):

Year	Increase in Operating Cost
1	\$314,000 first year
2-5	\$264,000 per year
After Yr 5	\$172,000 per year

TABLE 16. – WORKSHEET, CHANGES IN DC-8-62 ANNUAL OPERATING COSTS DUE TO RETROFIT MODIFICATION AT FOUR LEVELS OF ADDITIVE COST (PER AIRPLANE) (SPREAD BY YEARS)

Additive cost level	Very low	Low	Mid (Nominal case)	High
Cost of additive, ¢/gal. fuel	.015	.020	.025	.030
Δ Fuel cost, $thousands/year	111	142	173	204
Δ "Other" costs, $thousands/year:				
Maintenance	←	←	43.9	→
Fuel	111	142	173.0	204
Insurance	←	←	–48.0	→
Staging	←	←	3.1	→
Total	110	141	172	203
Year 1, $thousands/year:				
Downtime	←	←	50	→
Depreciation	←	←	92	→
Other	110	141	172	203
Total	252	283	314	345
Years 2-5, $thousands/year:				
Depreciation	←	←	92	→
Other	110	141	172	203
Total	202	233	264	295
After year 5, $thousands/year:				
Other only	110	141	172	203

Over a 10-year period the cumulative increase in operating cost of a DC-8-62 would total approximately $2,230,000. Gross revenue would be unchanged – a basic study assumption was that the airplane would serve the same traffic demand and thus generate the same gross revenue with the modification as it would have without the modification. This assumption may, of course, not be entirely valid; but it was desirable to compare both versions of the airplane against the same traffic demand task to get a clear-cut measure of the dollar effect of the modification. To complete the 10-year cash flow analysis, the $2,230,000 operating cost increase, with unchanged revenue, would mean a $2,230,000 decrease in profit-before-taxes. At the current 48-percent federal income tax rate on corporate profits, this would mean a $1,070,000 decrease in federal income taxes paid; and the balance, $1,160,000, would be a decrease in profit-after-federal-income-taxes. Total cash flow would increase by the $462,000 of increased depreciation, and decrease by the $1,160,000 of decreased profit-after-taxes, a net reduction of $698,000.

Table 17 is a cash flow analysis of 5 years of operation of a DC-8-62, in typical (or average) service, after being retrofit for gelled fuel use. The assumptions are listed at the top of the printout, then the annual cash flows are summarized below. This example represents Year 1 and Years 2-5 after modification. Comparison of this analysis with a similar 5-year analysis of the base (unmodified) DC-8-62 indicated the differences in annual cash flows due to the modification.

TABLE 17. – CASH FLOW ANALYSIS, DC-8-62

FOR PROPOSED 62-MOD PURCHASE BY FA68NF-273 GEL FUEL MOD YEARS 1-5 (DFP=05)

ASSUMPTIONS
****

BLOCK DISTANCE	850.	DAILY UTILIZATION	10.4
BLOCK VELOCITY	394.	OPERATING FACTOR	365.
NUMBER OF AIRCRAFT	1.	LOAD FACTOR	0.50
SEATS	162.	TONS	0.
DEPRECIATION PERIOD	5	DEPRECIATION RESIDUAL	0.0
TOTAL COST	4248000.	CAPITALIZATION RATE	0.10
DIRECT OPERATING COST/MILE	1.670	INDIRECT OPERATING COSTS/MILE	2.110
YIELD/MILE	0.062	TAX RATE	0.48
ORDER DATE	0	DELIVERY DATE	1972

FINANCIAL ASSUMPTIONS
****

AMOUNT FINANCED		0.0
PERIOD OF LOAN		12.00
RATE OF INTEREST		0.060
PAYMENT SCHEDULE-		
PAYMENT 1	0.0	
PAYMENT 2	0.0	
PAYMENT 3	0.0	
PAYMENT 4	0.0	

CASH FLOW SUMMARY
MILLIONS OF DOLLARS

	1972 ***	1973 ****	1974 ****	1975 ****	1976 ****	0 ****	0 ****	0 ****	0 ****	0 ****	0 ****	0 ****
REVENUE	7.511	7.511	7.511	7.511	7.511	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CASH COSTS	5.653	5.653	5.653	5.653	5.653	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEPRECIATION	0.850	0.850	0.850	0.850	0.850	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INTEREST CHARGES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
START-UP COSTS	0.050	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRE-TAX PROFIT	0.958	1.008	1.008	1.008	1.008	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME TAXES	0.460	0.484	0.484	0.484	0.484	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX CREDITS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POST TAX PROFIT	0.498	0.524	0.524	0.524	0.524	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL CASH FLOW	1.348	1.374	1.374	1.374	1.374	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CUMULATIVE CASH FLOW	1.348	2.721	4.095	5.469	6.843	0.0	0.0	0.0	0.0	0.0	0.0	0.0

COST EFFECTS OF CONVERTING UNITED STATES AIR CARRIER JET PASSENGER OPERATIONS TO THE USE OF GELLED FUEL

To project the DC-8-62 analysis to the total United States air carrier jet fleet, the DC-8-62 findings (Table 15) first were normalized in terms of revenue-passenger-nautical-miles (RPM), then applied to forecasted RPM for the decade.

While this is far from being a rigorous methodology, it has the advantage of being relatively quick and clear-cut, and its results should be as good as warranted by the accuracy of some of the basic input data. The basic cost increment, for instance, of gelled fuel over liquid, nominally 2.5 cents per gallon, is accurate only within a spread of ±0.5 cent per gallon, or ±20 percent. Until this fairly wide dispersion in present basic knowledge is considerably improved, it might be misleading to project the data in a way that indicated any greater precision in the overall analysis.

Because of the spread in the fuel cost increment, this industry analysis was iterated at four levels, similarly to the DC-8-62 analysis just described, and the results are presented as a range around the nominal mid-range case.

The credibility of the results of this analysis depends on the credibility of the DC-8-62 analysis which has been discussed in considerable detail, and the validity of two conditions that are implied by the projection methodology:

- That the per-RPM economics of competitive operational jets are similar.
- That the analysis be confined to passenger operations.

By per-RPM economics is meant the fundamental cash flow elements compared on a per-revenue-passenger-nautical-mile basis. These include airplane cost and depreciation, revenue earned, operating costs, pre-tax profits, taxes, and after-tax profits. While it is hard for a manufacturer of commercial jet airplanes to acknowledge that competitive products may in any way match his, it is evident from the facts of airline operations that present jets are very similar in respect to many of the criteria listed. They operate under essentially the same fare structure, which varies with range and class of service, but seldom if at all with the make and model of jet airplane. There must be mixed opinions, indicative of similarity (or confusion) on costs, operating costs, and profitabilities, since one finds almost all makes and models operating competitively on the same or very similar routes, in some cases even by the same operator.

Even if there were highly significant per-revenue-passenger-mile differences in these economic criteria between types of jets, the DC-8-62 is reasonably representative (in these respects) of present-generation four-engine jets which include all DC-8, 707, and 720 airplanes. These account for such a preponderance of present traffic that their economic performance sets the norm through shear weight of numbers if nothing else.

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The new generation wide airbus-type jet airplanes are expected to be more efficient, or more productive, on a per-revenue-passenger-mile basis. Their operating cost differentials due to using gelled fuel, however, should be proportionally similar to present-generation jets, but without the costs of retrofitting and of downtime. This assumes that an airplane designed and built for gelled fuel would not cost significantly more than one built for liquid fuel, particularly if the gelled fuel technology had already been developed at the expense of a present-generation retrofit program. Their operating cost differentials due to staging, maintenance, insurance, and fuel should be similar to present-generation jets, softened a little by their improved productivity. Any discrepancy in the analysis for this reason would increase toward the end of the forecast decade with the expected increase in traffic served by the new-generation airbus-type jet airplanes.

As long as it is understood that this analysis is constrained to passenger operations, this condition should cause no difficulty. Passenger operations are the predominant part of air carrier operations, accounting for the largest part of total airline revenue. Since passenger safety is the motivating force behind these studies, it is not unreasonable to speculate that promulgating regulations might apply only to passenger operations, and that because of the substantial cost differential, nonpassenger operations might convert to the use of gelled fuel more slowly or not at all. It was quickly apparent that both types of fuel should be available for a change-over period of several years, and that these double requirements might extend indefinitely if nonpassenger, foreign, and possibly general aviation operations did not convert.

To normalize the DC-8-62 findings in terms of revenue-passenger-nautical-miles (RPM), the three DC-8-62 increases in annual operating costs (for Year 1, Years 2-5, and After Year 5) were factored up by the number of DC-8-62 airplanes in average service that would be required to serve one billion RPM per year. In average service a DC-8-62 would handle approximately 121 million RPM per year; therefore, the factor became 1000/121, or 8.26. This was iterated at the four levels of additive cost, as shown in Table 18.

Table 19 (furnished by FAA) includes a forecast for the decade 1972 through 1981 of total scheduled annual RPM that are expected to be carried by United States certificated route air carriers. Table 20 (furnished by FAA) gives the estimated airplane-miles flown in the same period by the jet and non-jet airplane types in the fleet. Converted to proportions, this indicates that in 1972 all but 6.5 percent of the airplane-miles would be jet service, and the proportion increases to all but 2.1 percent in 1981. Because of the considerably larger capacities of the jets, a factor of 1:3 was used to convert these airplane-mile proportions to RPM proportions, resulting as follows:

TABLE 18. – ANNUAL OPERATING COST PENALTIES PER BILLION RPM (NORMALIZED FROM DC-8-62 DATA, TABLE 14, BY USE OF THE FACTOR 8.26*) (IN $ MILLION PER BILLION RPM)

Additive cost level	Very low	Low	Mid (Nominal case)	High
Year 1	2.08	2.34	2.59	2.85
Years 2 – 5	1.67	1.92	2.18	2.44
After year 5	.91	1.16	1.42	1.68

*Factor = 1,000,000,000/(DC-8-62 annual RPM)
= 1,000,000,000/121,000,000
= 8.26 (see text preceding page)

	Airplane-Miles Flown (Percent)	X	Factor =	RPM Carried (Percent)
1972				
Jets	93.5			97.8
Non-Jets	6.5		1:3	2.2
1981				
Jets	97.9			99.3
Non-Jets	2.1		1:3	0.7

This indicates that of the forecast RPM all but 2.2 percent will be jet traffic in 1972, decreasing to less than 1 percent non-jet in 1981. In the interest of simplicity, it was decided to acknowledge this small difference but not to adjust the revenue-passenger-miles (RPM) forecast (Table 19) for it.

The RPM forecast was completed by interpolating values for 1977-78-79, and converted to nautical RPM (see Worksheet, Table 21, lines 2 and 3).

TABLE 19. – UNITED STATES CERTIFICATED ROUTE AIR CARRIER SCHEDULED PASSENGER TRAFFIC

Fiscal year	Revenue passenger enplanements (millions)			Revenue passenger-miles (billions)		
	Total	Domestic	International	Total	Domestic	International
1965	94.5	84.5	10.0	62.6	47.3	15.3
1966	113.9	102.2	11.7	76.4	57.9	18.5
1967	126.4	113.5	12.9	86.3	65.7	20.6
1968	152.6	137.5	15.1	106.6	81.6	24.9
1969	168.0	150.8	17.2	119.8	91.9	27.9
1970*	176.4	157.1	19.3	130.2	98.8	31.4
1971*	187.2	165.7	21.5	141.3	105.9	35.4
1972*	203.9	180.3	23.6	156.3	116.9	39.4
1973*	226.0	199.5	26.5	176.5	131.5	45.0
1974*	252.0	222.0	30.0	200.0	148.5	51.5
1975*	280.0	245.5	34.5	227.0	167.5	59.5
1976*	309.0	271.0	38.0	254.5	188.0	66.5
1980*	471.5	415.0	56.5	402.5	295.0	107.5
1981*	522.0	460.0	62.0	450.0	329.0	121.0

*Forecast.

Note. – Detail may not add to total due to independent rounding.

Source: Aviation Forecasts, FAA (Reference 5)

TABLE 20. – TOTAL REVENUE STATUTE MILES, UNITED STATES AIR CARRIERS

(Fiscal years – in millions)

Aircraft type	Reported 1969	Forecast 1970	1971	1972	1973	1974	1975	1976	1980	1981
Total aircraft	2,526	2,909	2,977	3,097	3,264	3,353	3,517	3,629	4,526	4,840
Fixed-wing aircraft	2,524	2,906	2,974	3,094	3,261	3,349	3,513	3,625	4,521	4,834
Jet	2,260	2,688	2,774	2,893	3,068	3,169	3,334	3,448	4,409	4,731
2- and 3-engine	940	1,202	1,242	1,294	1,484	1,649	1,828	1,969	2,736	2,954
4-engine	1,320	1,486	1,532	1,599	1,584	1,514	1,440	1,375	1,385	1,410
SST	–	–	–	–	–	6	66	104	288	367
Turboprop	191	174	167	174	169	158	158	157	106	98
1- and 2-engine	125	127	127	135	136	129	130	130	103	96
4-engine	66	47	40	39	33	29	28	27	3	2
Piston	73	44	33	27	24	22	21	20	6	5
1- and 2-engine	45	26	17	14	13	12	11	11	3	4
4-engine	28	18	16	13	11	10	10	9	3	1
Helicopter	2	3	3	3	3	4	4	4	5	6
Piston engine	(Less than .5.)		–	–	–	–	–	–	–	–
Turbine engine	2	3	3	3	3	4	4	4	5	6

Note. – Included here are revenue miles flown by all passenger and cargo aircraft owned or leased by and in the domestic or international service of the United States certificated route, supplemental, intrastate and contract air carriers. Miles for fiscal year 1969 are partially estimated.

Source: Aviation Forecasts, FAA (Reference 5)

TABLE 21. – WORKSHEET, OPERATING COST PENALTIES AT MID LEVEL (Δ FUEL COST = .025 ¢/GAL)

(1) Year (FY)	72	73	74	75	76	77	78	79	80	81	Total
(2) RPM/yr (statute) (bil)	156.3	176.5	200.0	227.0	254.5	–	–	–	402.5	450.0	
(3) RPM/yr (nautical) (bil)	136	153	174	197	221	250	281	314	350	391	2468
Annual fleet mix:											
(5) RPM/yr carried by pre-gel acft	136	136	136	136	136	125	114	102	91	80	1192
(6) RPM/yr carrier by acft built for gel	0	17	38	61	85	125	167	212	259	311	1275
Annual mix by cost phases:											
(8) RPM equivalent, unmodified (5)	68	0									
(9) RPM equivalent, retrofit, in Yr 1	68	68	0								
(10) RPM equivalent, retrofit, in Yrs 2-5	0	68	136	136	68	0					
(11) RPM equivalent, retrofit, After Yr 5					0	57	114	102	91	80	
(12) RPM equivalent, of acft built for gel (6)	0	17	38	61	85	125	167	212	259	311	
Annual cost penalties by cost phases, mid level ($mil/yr)											
(14) Retrofit, in yr 1((9) x $2.59)	176	176	0								352
(15) Retrofit, in yrs 2-5 ((10) x $2.18)	0	148	296	296	296	148	0				1184
(16) Retrofit, after yr 5 ((11) x $1.42)					0	81	162	145	129	114	631
(17) Built for gel ((12) x $1.42)	0	24	54	87	121	177	237	301	368	442	1811
Total and cumulative ($mil/yr)											
(19) Total annual Δ op cost due to gel	176	348	350	383	417	406	399	446	497	556	3978
(20) Cumulative Δ op cost due to gel	176	524	874	1257	1674	2080	2479	2975	3422	3978	

It was assumed that the existing jet fleet would be converted to gelled fuel during the 2 years 1972-73, and that new airplanes delivered after 1972 would be built for gelled fuel. This is consistent with the initial study assumption of a program go-ahead in mid-1970 with retrofit starting in early 1972. With this much advance notice, it is reasonable to assume that new airplane production would also be changed over during 1972, since buyers would be reluctant to buy an airplane that immediately had to be retrofit. The growth in RPM capacity after 1972 accordingly was allocated to airplanes built for gelled fuel (Worksheet, Table 21, lines 5 and 6).

Assuming a uniform rate of retrofit, lines 8 through 11 indicate the RPM equivalence of airplanes, each year, in each of the three cost phases (Year 1, Years 2-5, and After Year 5). Line 12 shows the RPM equivalence of new airplanes built for gelled fuel (which would not be burdened with retrofit and downtime costs, but would be burdened similarly to the After Year 5 category).

Lines 14 through 17 apply the appropriate cost burdens, as noted, to the RPM equivalences of lines 9 through 12, expressing the annual cost penalty by phases. These are totalled for each year in line 19, and cumulated in line 20. This procedure was iterated for each of the other levels of gelled fuel additive cost.

Figure 15 shows the total annual operating cost penalty to United States air carrier scheduled passenger operations for the decade 1972-81 at each of the four additive cost levels. The fluctuations of the first 7 years are due to retrofit and downtime, amortization, and payoff. After 1978 the industry is back to steady-state, with economic penalties at the "After Year 5 level," and the steady upward trend in operating cost penalty is a direct reflection of the projected growth in revenue-passenger-miles. Figure 16 is the same data cumulated. The cumulative cost penalty for the decade would be approximately 4 billion dollars, plus or minus approximately half-a-billion dollars for the high or low additive cost values. As with the DC-8-62 (see Figure 10) this would represent approximately a 9-percent increase to DOC, or approximately a 4-1/2-percent increase in total operating costs.

While only tentative, the lowest (dotted) curve on Figure 16 tends to encourage investigation of lower concentration gels. It indicates that an equivalent 1.2-percent gel program should cost approximately one-third less, on the order of 2.7 billion dollars for the decade.