# "Emerging Technology – Improvements in Aircraft Passenger Safety"

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## ABSTRACT

The purpose of this paper is to discuss some of the research and development activities being conducted in the Boeing Commercial Airplane Group (BCAG) that are related to safety improvements in the passenger cabin of commercial jet aircraft.

## INTRODUCTION

Who would have guessed that when the Icarus Aviation Company fabricated the artificial wings used by its founder in his ill-fated attempt to escape imprisonment, this event would give birth to the idea of aviation safety. When viewed in modern terms of aircraft safety regulations, Icarus and aviation's first manned flight has long term ramifications. First, he attempted to fly without a pilots license or any simulator training. The aircraft had not been certified as experimental nor had rudimentary structural or wind tunnel tests been done to verify its strength and stability. Icarus failed to carry a parachute for this experimental flight, and carried no life raft or personal flotation device, nor was the aircraft equipped with an emergency transponder, cockpit voice recorder, flight data recorder or any navigational aids. He also failed to file a proper flight plan or notify the the Greek authorities of his historical flight.

On his first and only flight he pushed his feathered craft to the limits of its performance envelope, and exceeded the thermal capabilities of the waxen adhesives when he experienced a close encounter with the sun. As a result of the structural failure, ill conceived plans and no preflight preparation, Icarus crashed into the sea and drowned.

Unlike Icarus Aviation, Boeing Commercial Airplane Group has, for many years, maintained a staff of experts to assure that the aircraft we build and deliver to our customers are the safest in the world. There are two principal groups that influence and lead our efforts to improve commercial aircraft passenger cabin safety: the Cabin Smoke/Fire Committee and the Aircraft Safety Committee. Both committees are concerned with ongoing safety improvements in our commercial airplane family. The Cabin Smoke/Fire Committee operates under the direction of a Payload Systems Chief Engineer who reports to the Director of Payloads Systems.

The Aircraft Safety Committee is under the direction of the Chief Engineer responsible for Airworthiness, Reliability, Maintainability, and Safety (ARMS). This organization is concerned with all aspects of aircraft safety, including the passenger cabin. There are other committees that are concerned with flight deck and aircraft flight safety, but their activity is not a subject of this paper.

It is the safety development activities of Payload Systems–Advanced Programs, in support of the Cabin Smoke/Fire Committee that is the focus of this paper.

The Cabin Smoke/Fire Committee is composed of expert members from the multi-discipline organizations found in BCAG, such as Payloads, Electrical/Mechanical Systems, Product Safety, Structures, Airworthiness, Flight Controls, Crew Operations, Materials Technology and others. The group meets on a monthly basis and reviews: regulatory issues such as changes in seat rules, exit door type and spacing, handicapped evacuation; new developments in products and materials such as cargo compartment liners, smoke/fire detectors, cabin furnishings (carpets, seat covers, cushions, sidewall and ceiling panels); and accident/incident reports to help identify improvements and initiate corrective actions to prevent further occurrence.

## INTERIOR FURNISHINGS/MATERIALS TECHNOLOGY

Payload Systems and Boeing Materials Technology (BMT) in conjunction with guidance and direction from the Cabin Smoke/Fire Committee, have been extensively involved with implementing the requirements of Federal Airworthiness Regulation (FAR) Amendments 25-61 and Part 121-89 that specify the 65/65/200 heat release rules for cabin furnishingss and materials. These rules established the maximum amount of heat and smoke that an interior furnishing material can release when measured in calibrated test chambers designed and developed by Ohio State University (OSU), Figure 1. This requirement has led to considerable R&D activity to develop both materials and processes that will pass the OSU test procedures, is producible and, in addition, will satisfy the decorative requirements of a diverse customer base.

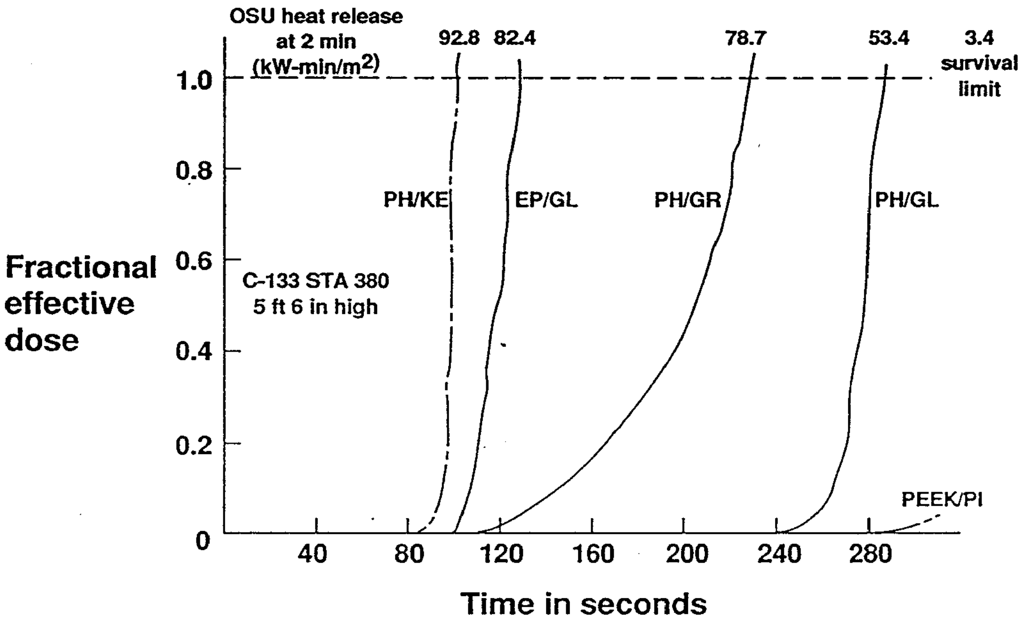
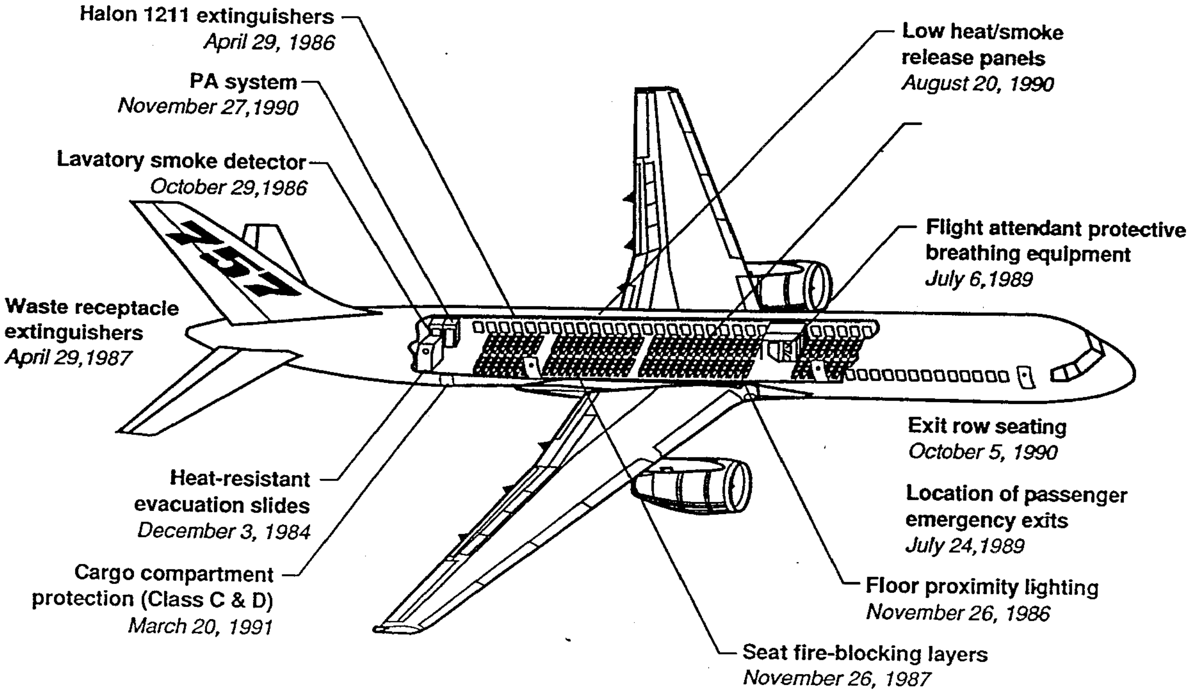


*Figure 1. Interior Panel Full-Scale Test Results.*

FAR 25-59 required the addition of fire blocking to seat cushions to inhibit the flammability of the urethane foam in the event of a fire. Implementation of these rules has been at great expense to the aircraft industry, the materials and furnishings industry, and operators, but have resulted in considerable improvement in cabin safety by requiring protective coverings over 600,000 aircraft passenger seats. Performance of fire blocking materials has been verified by actual full scale fire tests that have been extensively documented and published by the FAA Technical Center in Atlantic City, New Jersey.

Previous regulatory and development activities have led to improved smoke and fire detection systems for the cargo compartments as well as the installation of halon suppression systems for Class C compartments and burn through resistant liners for both Class C and D cargo compartments. Figure 2 illustrates the type and dates of various regulatory cabin safety features that have been implemented during the past 7 years.



• Modifiy from Aviation Safety Journal, Summer 1991

*Figure 2. Advances in Cabin Safety.*

## PASSENGER CABIN IMPROVEMENTS

During the period from January 1974 through September 1989, Boeing safety data records indicate there were 892 persistent (5 minutes or more) smoke/fire events recorded for all models of commercial jet aircraft for both ground and inflight conditions, twenty of which progressed to the level of accident. Further analysis of the data for the 892 events indicate that 558 occurred inflight. These data are approximate totals, however the location and distribution of these events is considered to be representative of all smoke/fire events.

Of the twenty accidents, nine occurred in flight with six of these resulting in fatalities. The most severe of these was the Saudi Arabian L-1011 (August 19, 1980) followed by the Pakistan Air International 707 (November 26, 1979), the Air Canada DC-9 (June 2, 1983) and the Gulf Air 737 (September 23, 1983), all of which resulted in the loss of life. In general, the types of fires with the greatest loss of life are those originating in an inaccessible areas of the aircraft, hence the continued interest in early detection of these types of fires.

Figure 3 indicates the location and frequency of the 558 events and fatalities. Analysis of grim statistics is often necessary in order to provide some of the insight necessary to determine how to best design more capable and reliable systems. However, put into proper perspective, during this same period of time, the airlines of the free world recorded over 60-million departures, a truly remarkable safety record.

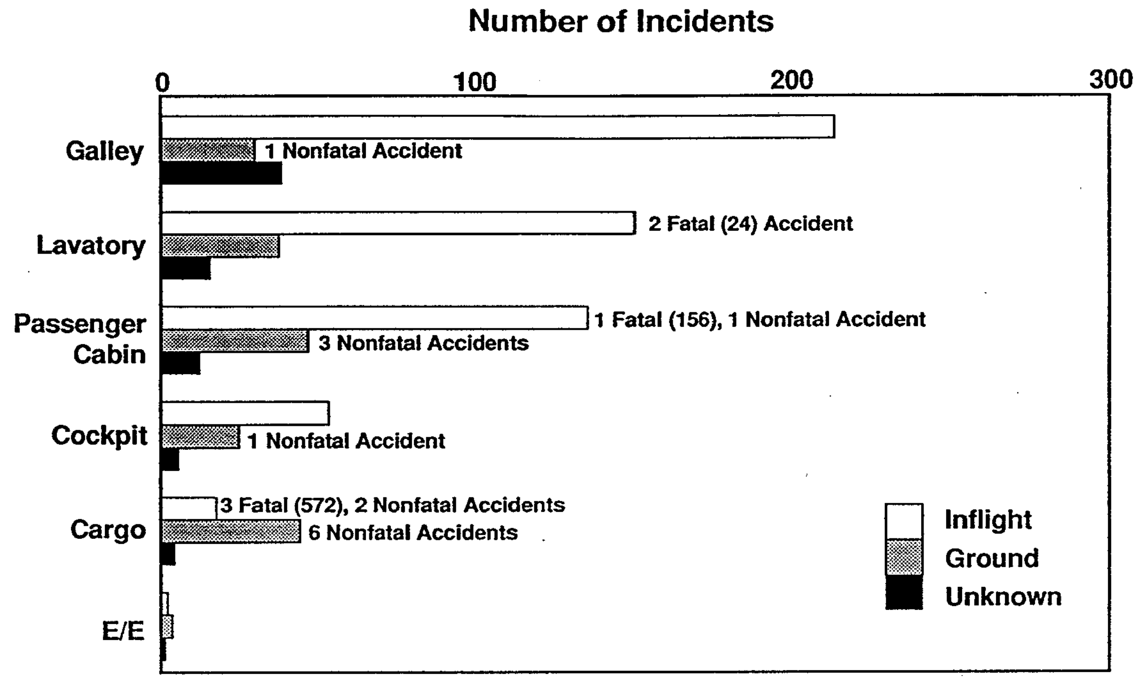


*Figure 3. Total Smoke/Fire Incidents.*

Table 1 reflects the trend in airline safety over the previous decade. In only two of the last ten years have there been less than 611 fatalities, with 451 in 1984 and 607 in 1986. In 1990 28 of the 35 accidents recorded were Third World and USSR airlines. During these same ten years, however, annual world departures increases by 30% and passengers by 50%. The largest single factor identified in all accidents is aircrew error, accounting for 34% of the total accidents in 1990, down from 60% in 1989, but was still the most common single cause resulting in more than half of the fatalities.

*Table 1. Fatalities and Accidents in Last Ten Years.*

| Year | Fatalities | Accidents |
|---|---|---|
| 1990 | 611 | 35 |
| 1989 | 1,450 | 51 |
| 1988 | 1,007 | 54 |
| 1987 | 994 | 29 |
| 1986 | 607 | 31 |
| 1985 | 1,800 | 39 |
| 1984 | 451 | 29 |
| 1983 | 1,202 | 34 |
| 1982 | 1,012 | 33 |
| 1981 | 710 | 29 |
| Total | 9,844 | 364 |
| Decade annual average | 984 | 36 |

- Source: Flight International, January 1991

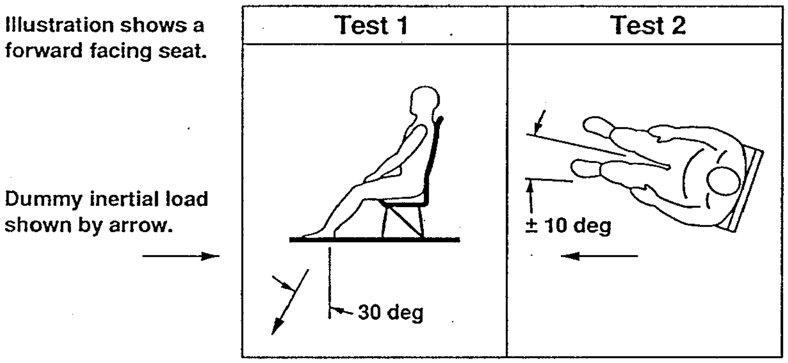
Additional improvements in passenger cabin safety were achieved with the implementation of smoke detectors in the lavatories and further enhanced with the ban on smoking on U.S. domestic flights. Lavatory smoke detectors were mandated for passenger aircraft to provide for earlier detection following the tragic inflight fire aboard an Air Canada flight in 1985.

Floor proximity lighting that allows passengers to identify cabin aisles and exits that would aid the evacuation of an aircraft in darkness during an emergency, were implemented under the requirements of FAR Amendments 25-58 and 121-183, 310.

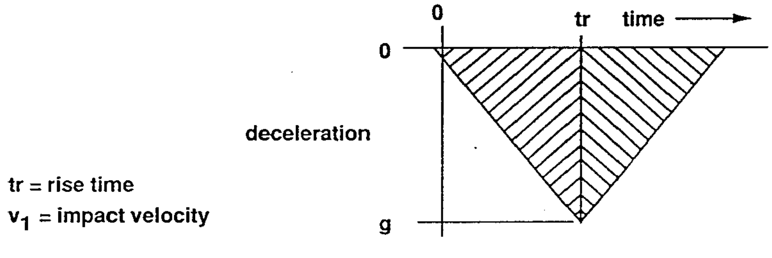
More recently, BCAG has been involved with conducting investigative research and development projects in support of pending changes to the FARs.

Following the tragic loss of the South African 747 combi aircraft in November, 1987, FAR 25.857 was written for implementation of the requirement for 60-second smoke/fire detection in combi type aircraft equipped with a Class B main deck cargo compartment. Multi function detectors and new types of sensors have been evaluated for combi aircraft to provide surveillance of the unoccupied Class B compartment. On some aircraft, fire blankets (smother covers) are being evaluated for additional protection and containment. Extensive testing of this type cover is being conducted by the FAA Technical Center.

An analysis of the data collected during the investigation of the British Midlands 737 short field crash at Kegworth prompted the airworthiness authorities to further review the pending changes in seat regulations in work at that time. The authorities increased the requirements to further strengthen and improve the passenger seats and seat belts. FAR 25.562 now requires that passenger seats, crew seats and restraints be dynamically tested to 16g deceleration under the conditions illustrated in Figure 4. The rule further defines criteria for passengers seated behind structures such as galleys, lavatories or cabin dividers, and applies to newly design aircraft certifications only, such as the Boeing 777.



| | Test 1 | Test 2 |
|---|---|---|
| Min $V^1$, ft/sec | 35 | 44 |
| Max tr, sec | 0.08 | 0.09 |
| Min g | 14 | 16 |
| Deform floor | | |
| degrees roll | 0 | 10 |
| degrees pitch | 0 | 10 |



tr = rise time

$v_1$ = impact velocity

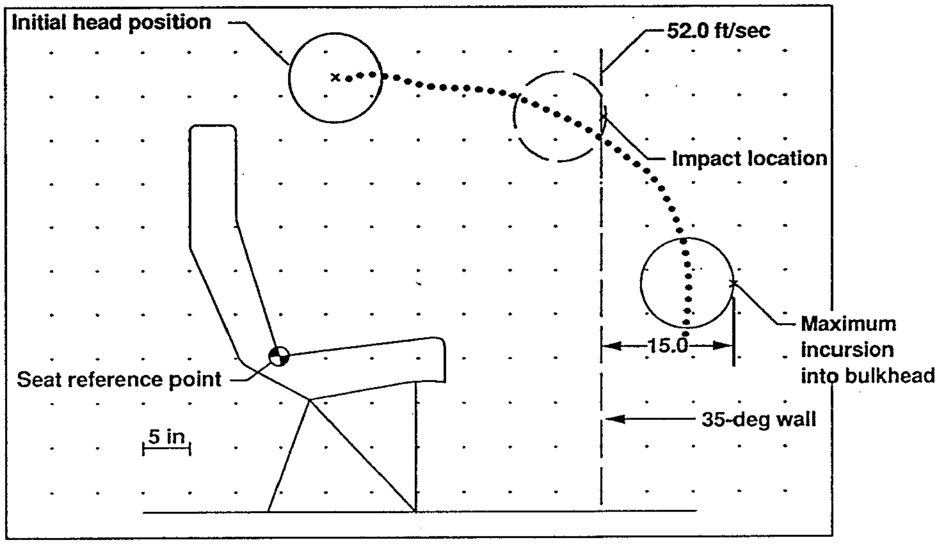
- FAR 25.562
  - Emergency landing dynamic conditions
  - Seat and restraints must be dynamically tested

*Figure 4. 16g Dyanmic Seat Testing.*

The Head Impact Criteria (HIC) equation, Figure 5, adapted from the automotive industry, is based on extensive testing conducted by the Department of Transportation, industry and university research. This rule, when applied to automobiles, specifies that the HIC equation should not produce a value in excess of 1,000, a value established to be the maximum allowable limit for a passenger without serious injury. There are technical opinions that question the direct transfer of this equation to aircraft without further testing and analysis.

$$\mathrm{HIC} = (t_2 - t_1)\left[(1/(t_2 - t_1)) \int_{t_1}^{t_2} a(t)\,dt\right]^{2.5}_{\mathrm{MAX}}$$

**Where: $t_1$ and $t_2$ are any two points in time during head impact, and a(t) is the resultant head acceleration (expressed in gs) during head impact).**



- Maximum injury criteria given, including Head Impact Criteria (HIC)

*Figure 5. Head Impact Criteria (HIC).*

As an example of the implications of the rule, consider the example of a 50 percentile male seated in a front row seat (behind a bulkhead), set back 35-inches, an industry standard, from a wall-type structure, the deceleration produced by a 16g load would cause the passenger head to impact the structure with an velocity in excess of 50 feet/second. When the elasticity of the seat belts and human body are considered in the absence of a rigid structure, then the passenger's upper body could theoretically experience an incursion into a bulkhead of approximately 15-inches. Obviously, one way to inhibit this from happening is to move the seats back 15-inches, but this has a "ripple" effect causing the loss of revenue seats at the back of the aircraft. If an aircraft seat is worth $1 million per seat over the life of the aircraft, seat setback represents a significant loss of revenue to the operator and provides marginal safety for passengers outside the 50 percentile range, such as professional athletes.

BCAG is investigating alternate approaches to seat setback to avoid loss of revenue seats, yet provide enhanced safety for front row seated passengers. Working in conjunction with industry organizations such as the Air Transportation Association (ATA), Airline Industry Association (AIA) and the FAAs Civil Aeromedical Institute (CAMI), BCAG has begun development projects that will evaluate and establish the value of technologies such as airbags, frangible or collapsible structures, energy absorbing padding, and a new seat design concepts that absorb and redirect the applied loads.

## AIRBAG TECHNOLOGY

Developed primarily for the automotive industry, airbag technology has become of significant interest to BCAG due to its potential to afford protection to front row seated passengers and preserve revenue seats, Figure 6. A work statement has been submitted to selected suppliers that describes our requirements for a development program that will lead to dynamic testing and an evaluation of a prototype airbag system for commercial aircraft applications. Initial proof of concept demonstrations are scheduled for December 1991.

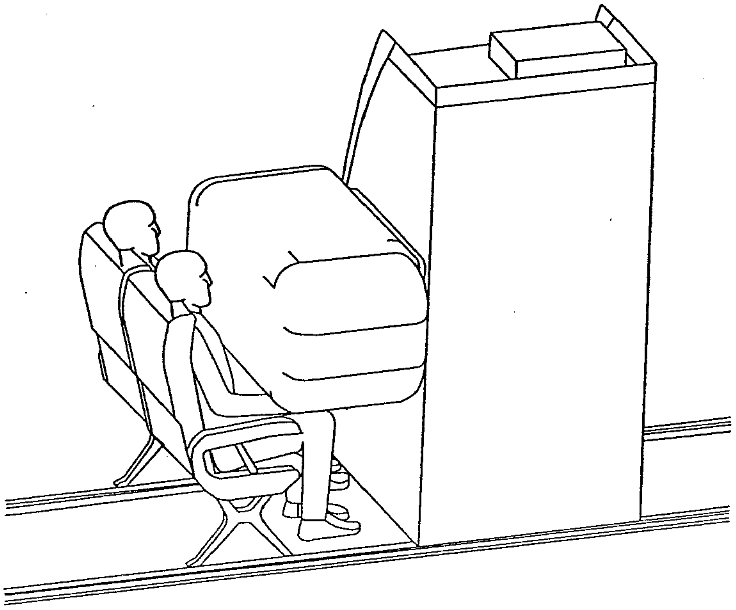


***Figure 6. Airbag Restraint System (Bulkhead Mounted).***

Two additional aircraft issues are being evaluated concurrent with airbag evaluation: determine the crash dynamics that will be involved in activating the airbag system and how to assure protection for all aspects of passenger seating accommodations. Since no two crashes are alike, the sensing system must be designed such that all variations such as nose or tail strike or odd angle crashes can be sensed in time to provide adequate passenger protection. In addition, the length of time a crash pulse is applied has a significant bearing on the design of the sensors, the control system, the inflator, and bag itself. Just as important as having the bag inflate at the proper moment is the necessity of having it deflate after the cessation of deceleration so as not inhibit subsequent evacuation. The system must provide adequate protection for the variety of sizes of people comprising the flying public.

## ENERGY ABSORBING STRUCTURES

Another approach under investigation is the evaluation of the effectiveness of various types of energy absorbing structures and materials to absorb head impact energy. Panels made from different types of honeycomb core are being evaluated in a dynamic environment. Nomex and aluminum honeycombs, rigid foams, crushable ceramics and air damped padding are a few to mention. Anthropomorphic dummies are being utilized as "volunteers" in actual sled tests being conducted at CAMI, Figure 7.

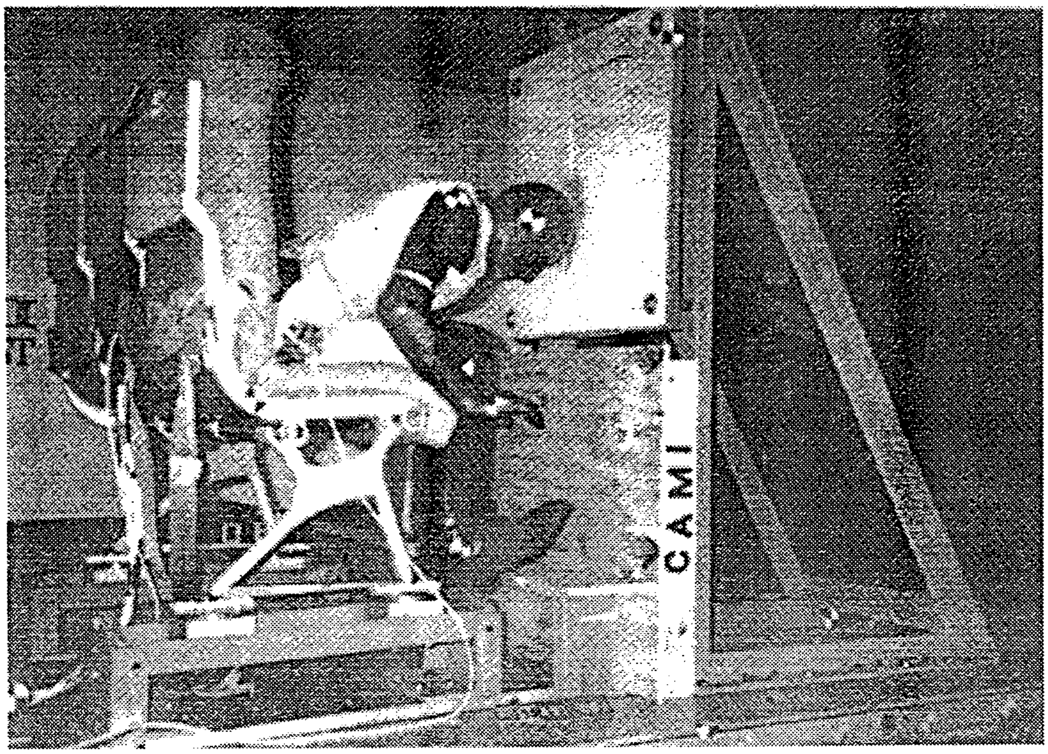


*Figure 7. Energy Absorbing Structures Test (CAMI).*

## MOVEABLE SEAT PAN

A movable seat pan restraint concept, developed for the automotive industry to inhibit "submarining," has been proposed by two competitive companies for prototype development, Figure 8. In the event of a crash, the bottom of the seat will articulate downward at the back and upward at the front forcing the occupants lower torso and thighs into the seat pan in a line more perpendicular to the direction of the applied load. While interesting in concept, the moveable seat pan has only been demonstrated by computer simulation and remains to be verified by hardware testing.

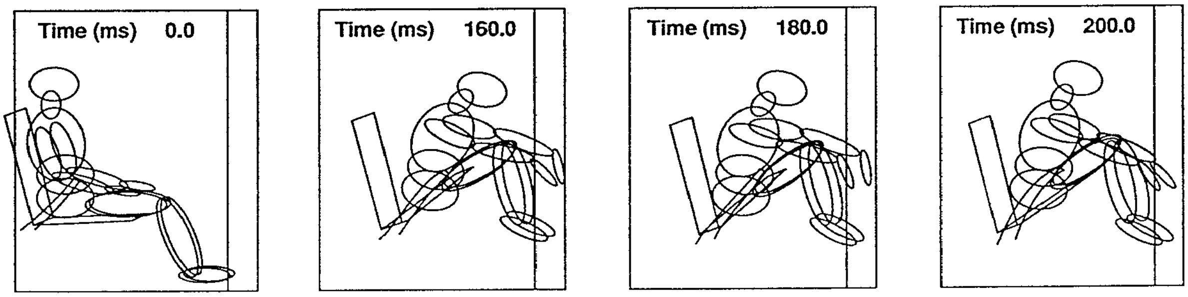


*Figure 8. Movable Seat-Pan Restraint System.*

## AIRCRAFT COMMAND IN EMERGENCY SITUATIONS (ACES)

Boeing, under contract with the FAA Technical Center since late 1989, is conducting a multi-phased product development study that addresses the FAAs concerns with the early detection and control of inflight smoke/ fire incidents aboard commercial jet aircraft. The study was motivated by recent developments such as the computerization of the modern flight deck, the move toward the two-person flight crew and the documented times taken to locate and correctly implement the appropriate emergency procedures during past smoke/fire incidents.

The purpose of the Phase 1 study was to identify two systems and their associated hardware that would provide for faster and more reliable detection of an inflight smoke/fire event, resulting in a timely and correct response. The primary objective of an ACES system is to provide the capability to decrease the time required to make a decision to land the aircraft at the nearest suitable airport.

During Phase 1, two Concepts (A and B) were developed using the Boeing 757-200 as the baseline aircraft, Figure 9. Concept A identified new types of ionization and photoelectric smoke detectors and additional areas for coverage in the fuselage. Some of the new types of detectors have analog and multiple pulse outputs that significantly reduce the potential for false alarm over the older binary detection systems.

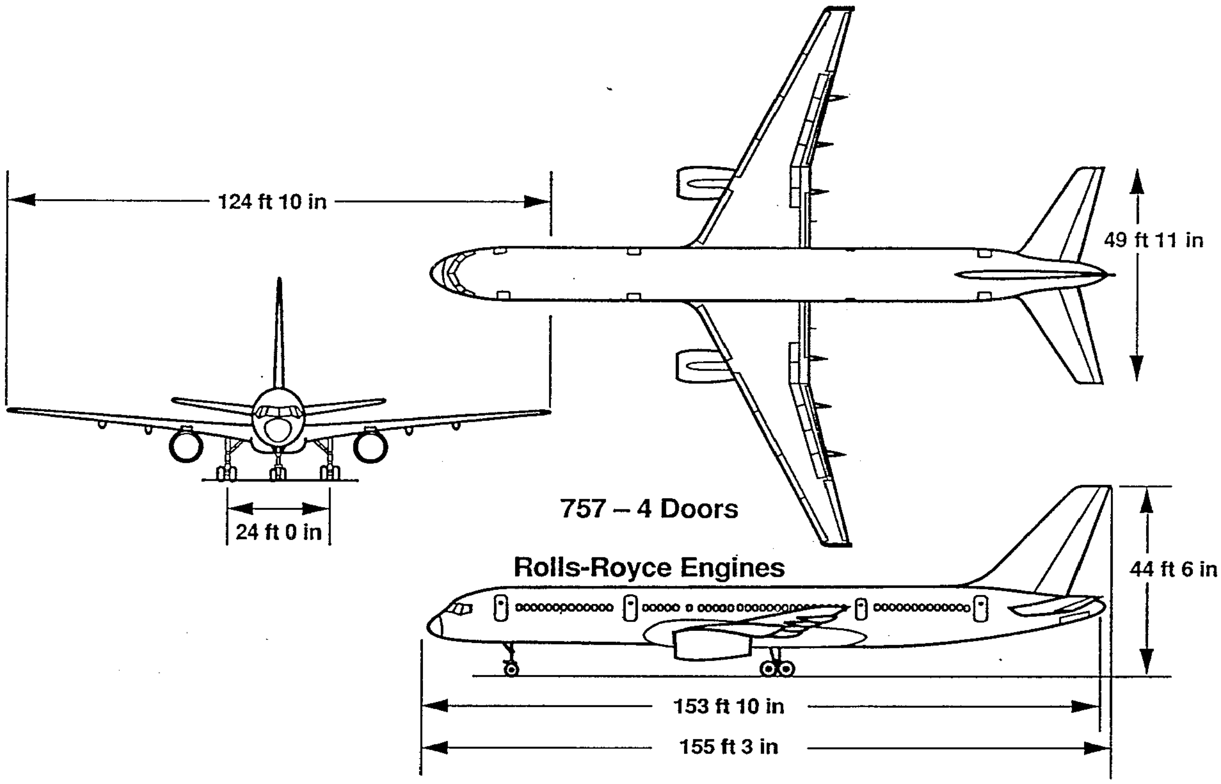
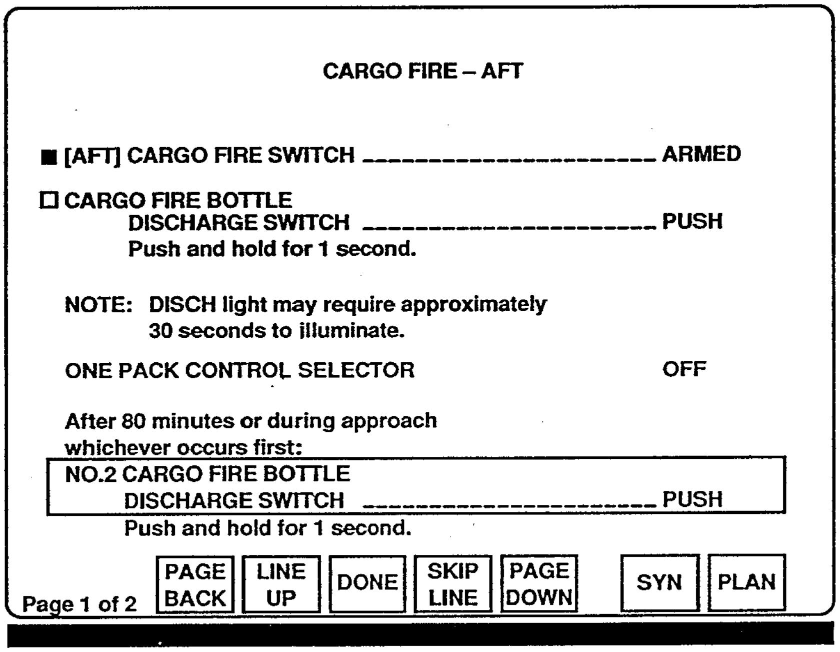


*Figure 9. 757-200 General Arrangement*

An electronic check list that would replace the flight crew's Quick Reference Handbook (QRH) was also proposed, Figure 10. This feature will provide a ready reference tailored to the type of alert signaled to the flight deck. The automated check list will keep the pilots in the command loop, requiring them to initiate each step of the emergency procedure and provide feedback to the crew when checklist events are completed or remain to completed.



CARGO FIRE – AFT

■ [AFT] CARGO FIRE SWITCH ______________________ ARMED

☐ CARGO FIRE BOTTLE
DISCHARGE SWITCH ______________________ PUSH
Push and hold for 1 second.

NOTE: DISCH light may require approximately
30 seconds to illuminate.

ONE PACK CONTROL SELECTOR OFF

After 80 minutes or during approach
whichever occurs first:

NO.2 CARGO FIRE BOTTLE
DISCHARGE SWITCH ______________________ PUSH
Push and hold for 1 second.

Page 1 of 2

*Figure 10. Format for the Electronic Checklist – (Aft Cargo Fire).*

Concept B further expanded on the detection capabilities of Concept A: monitoring more areas of the fuselage, making greater use of analog and digital sensors, and adding thermal detection and monitoring capability (acoustic wire and fiber optic). An inflight diversion planner was added to assist the crew, if diversion to an alternative airport is necessary, Figure 11. The diversion planner would have the capability to be updated at the start of each flight as part of the preflight activity or in the future be updated in flight through ground and satellite data links.

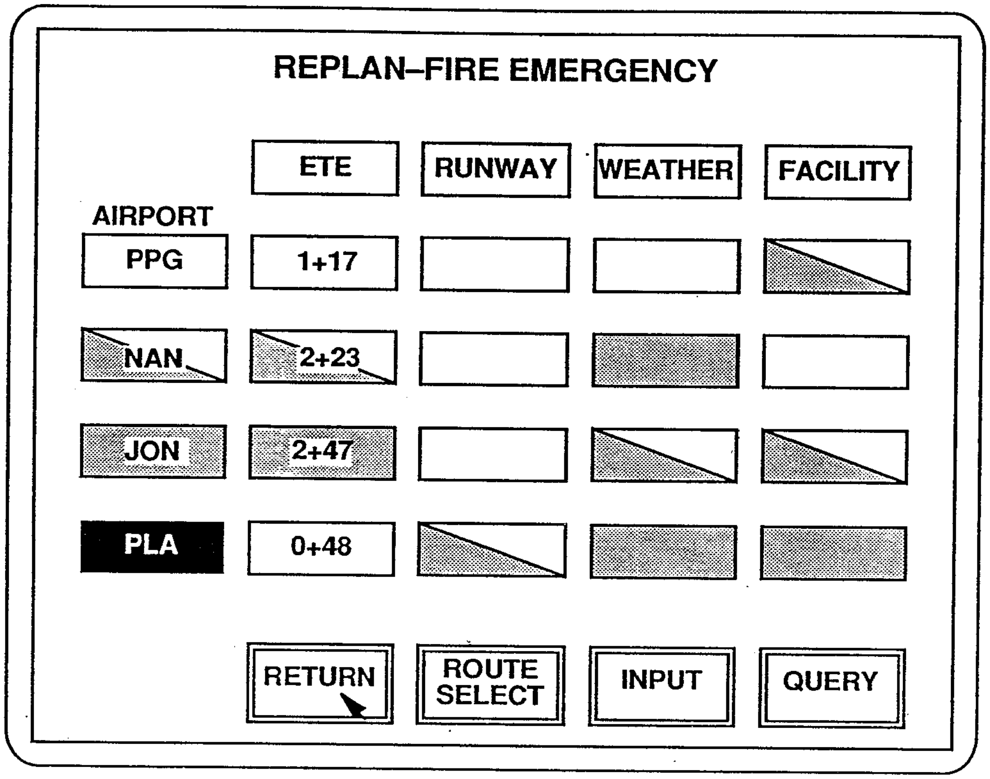


*Figure 11. Inflight Diversion Planner Display Format.*

New technology sensors include improvements in both photoelectric and ionization smoke/particle detectors and thermal sensing systems capable of monitoring and establishing a thermal profile of the areas where they are installed. All detectors were interfaced with the aircraft data bus and flight management computer system, providing alarm indications directly to the flight deck. The generation of a smoke/fire signal causes the automated emergency checklist to be activated and displayed to the flight crew through the normal crew alerting system.

A final report titled: Aircraft Command in Emergency Situations (ACES), Phase 1: Concept Development, No. DOT/FAA/CT-90/21 was published by the FAA Technical Center in April 1991. This report describes in detail the development and function of each of the two concepts identified in Phase 1.

ACES–Phase 2, began in October 1990, and is the prototype hardware development and functional test of the two concept systems defined in Phase 1. In this phase the two ACES concepts will be functional demonstrated in a laboratory environment using a plywood mockup as a test chamber. Sensors and detectors will be installed in the mockup chamber, Figures 12 and 13. A Dolce 486 computer will be used to simulate the 757 aircraft flight deck displays on video monitors that present the emergency checklist, the diversion planner and synoptic parameters. The Dolce will be interfaced to the sensor systems through a Keithley 576-2 Data Acquisition and Control System using GPIB Interface (View DAC 2.0) software.

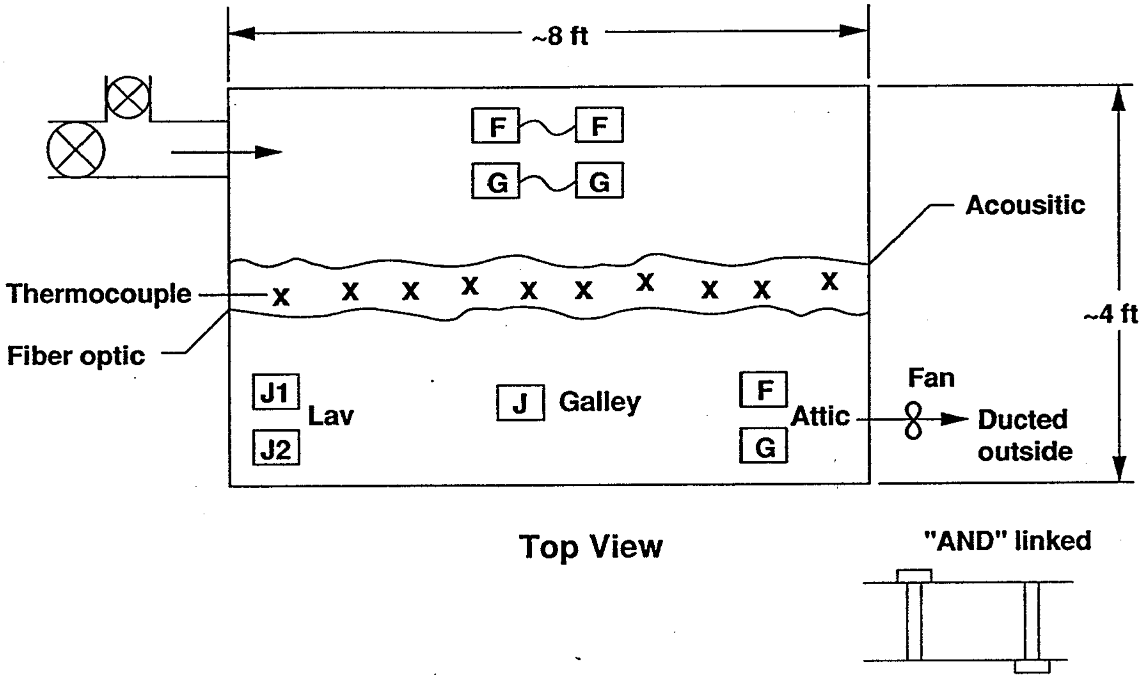
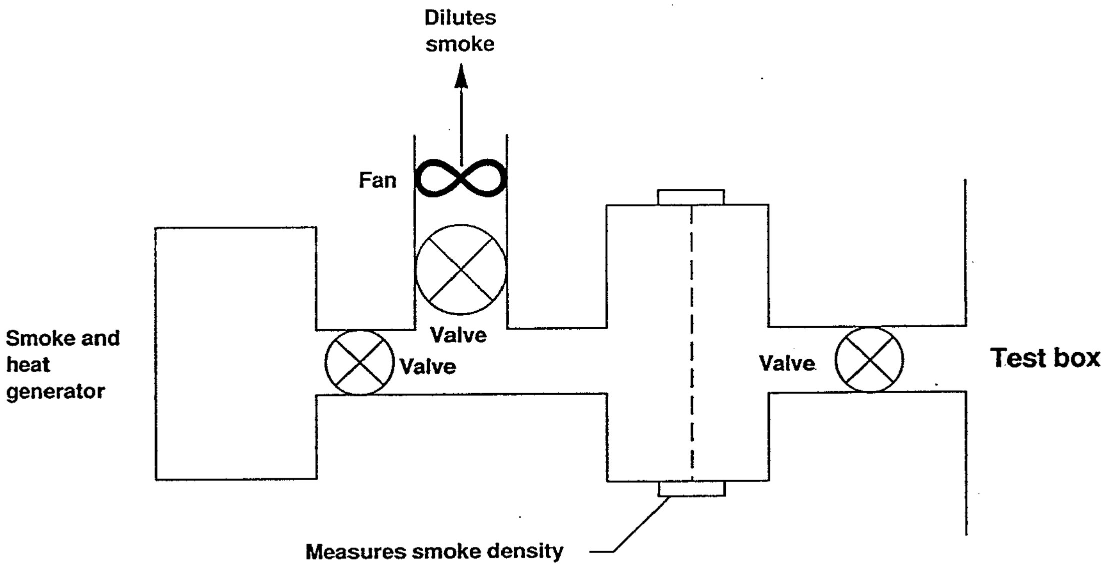


*Figure 12. ACES Smoke Test Chamber.*



- Smoke sources
  - Tobacco
  - Mineral oil
  - Aerosols
- Heat sources
  - Hot plate
  - Heat gun
  - Candle

*Figure 13. ACES Smoke Generator.*

The demonstration system software consists of a graphic interface and an imbedded expert system, NEXTPERT OBJECT. The interface is a Microsoft Windows application written in "C". The expert system consists of a rule base containing Pilot/engineer knowledge and supporting object architecture with an inference engine to reason about the current situation. "WinMain" is the driver for the ACES system. It is a Microsoft Windows program and therefore performs routine Windows housekeeping tasks. All global variables are defined in this program. These include variables to define which sensors have been selected by the user, messages to be sent to NEXTPERT OBJECT and variables associated with the objects in the graphic interface.

Current test plans call for injecting smoke and heat into the chamber to simulate various types of aircraft emergency events such as cabin, lavatory and cargo compartment smoke/fire incidents; hidden fires, and engine bleed duct failures. Multiple pulse and analog detectors will be demonstrated along with two types of thermal detection systems (York's fiber optic and Schlumberger's acoustic wire thermal detection systems, Figures 14 and 15 respectively).

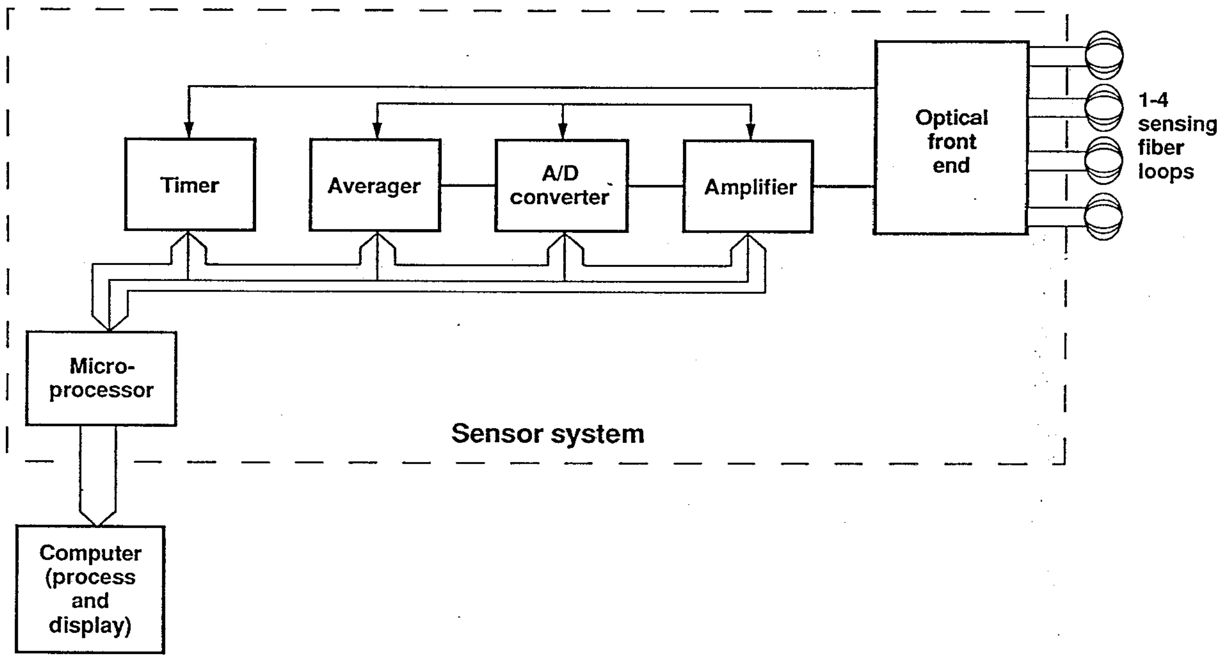


*Figure 14. Schematic Layout of the York Fiber-Optic DTS System.*

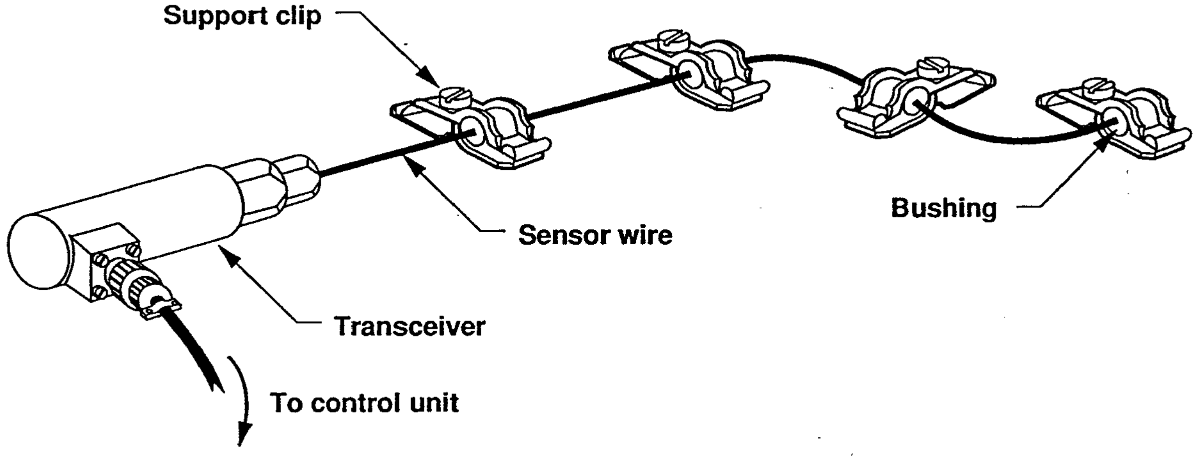


*Figure 15. Schlumberger Acoustic Thermal Monitoring System.*

Functional demonstrations of the Phase 2 prototype system will began in October, 1991. The final report for Phase 2 is scheduled to be published in early 1992.

Future development phases are under discussion that would provide for the installation and ground testing of the ACES Phase 2 systems on a Convair 880 at the FAA Technical Center during 1992.

## CABIN WATER SPRAY (CWS)

A "proof-of-concept" on-board water spray system has been developed in the United Kingdom (UK) that demonstrates the ability to suppress aircraft interior cabin fires. This system has been demonstrated on a fully furnished aircraft and the results published in CAA Paper 88014 "Aircraft Cabin Fire Suppression by Means of an Interior Water Spray System." More recently, the FAA Technical Center has published a number of articles and reports on their program at the full scale fire test facility in Atlantic City, New Jersey.

Tests have shown potential in improving passenger safety, resulting in the Airworthiness Authorities in both North America and Europe to initiate joint research programs. The programs seek to establish the effectiveness of a cabin water spray system as well as identify associated service considerations. The information gained in these various research programs will enable a net benefit analysis to be carried out. The results of the overall benefits analysis will establish, in part, the basis for action in the future.

In order to obtain a balanced opinion on the benefits of water spray systems, the National Aeronautics and Space Administration and the Federal Aviation Administration have requested BCAG to investigate the potential disadvantages or "disbenefits" of such a system on North American built aircraft.

In August, 1990 BCAG responded to a request for a proposal from the NASA and FAA Technical Center for a "Study of the Disbenefits Created by the Installation of Water Spray Systems for the Protection of Aircraft Cabins." This study was to address the potential "disbenefits" of both commanded and uncommanded operation of a "SAVE" Ltd. cabin water spray system when installed in a commercial jet passenger aircraft and is part of a collaborative study efforts being formulated and initiated by the Airworthiness Authorities in both Europe and North America, Figure 16.

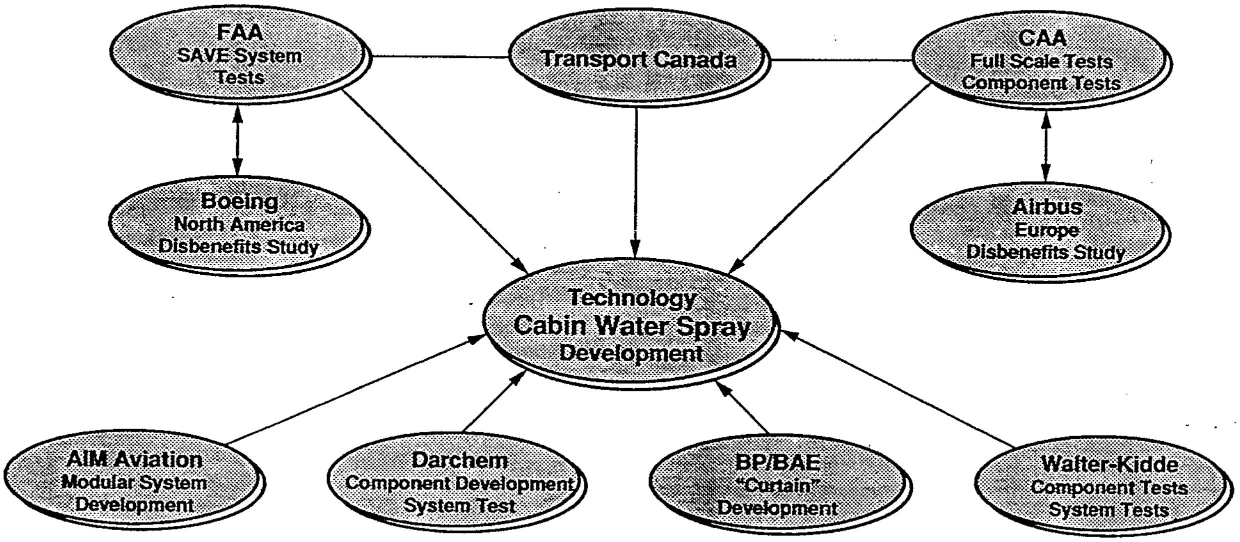


*Figure 16. Cabin Water Spray – A Collaborative Development.*

The 10-month study, funded jointly by Boeing and the FAA in January 1991, is designed to be a broad wide-ranging investigation of water spray systems and their effect on the aircraft systems and emergency evacuation of the aircraft, in both commanded and uncommanded operation of this system.

Specific areas of interest include:

- Activation of the system in the presence of a severe fire external to the aircraft,
- Inadvertent or uncommanded operation of the system when the aircraft is on the ground but in a takeoff roll,
- Inadvertent activation of the system while the aircraft is in level flight and in a landing approach.
- The costs of returning the aircraft to service following the precautionary use or uncommanded activation of the cabin water spray system in the circumstance where the aircraft has not been damaged by fire

The Boeing study will investigate the implications of the activation of the SAVE LTD., cabin water spray system (CWSS) on various models of its commercial jet aircraft, with the 757-200 serving as the baseline/ focus airplane. Other aircraft, from the 1960s vintage 727 to todays modern jetliners, will be studied to account for configurations and system differences across the Boeing product line. Representative versions of each model will be utilized in the investigation and include: the 727-200, 737-200, 737-300, 747-200, 747-400, 757-200 (4-Door), and 767-200.

The system concept as configured for the 757-200 and shown in Figure 17 will have uniform spray distribution pattern over the main passenger cabin floor area. The precipitation rate will be 0.8 mm (0.03 inches) per minute for a maximum of three minutes. A CWSS will be configured for the baseline aircraft for use as a study model.

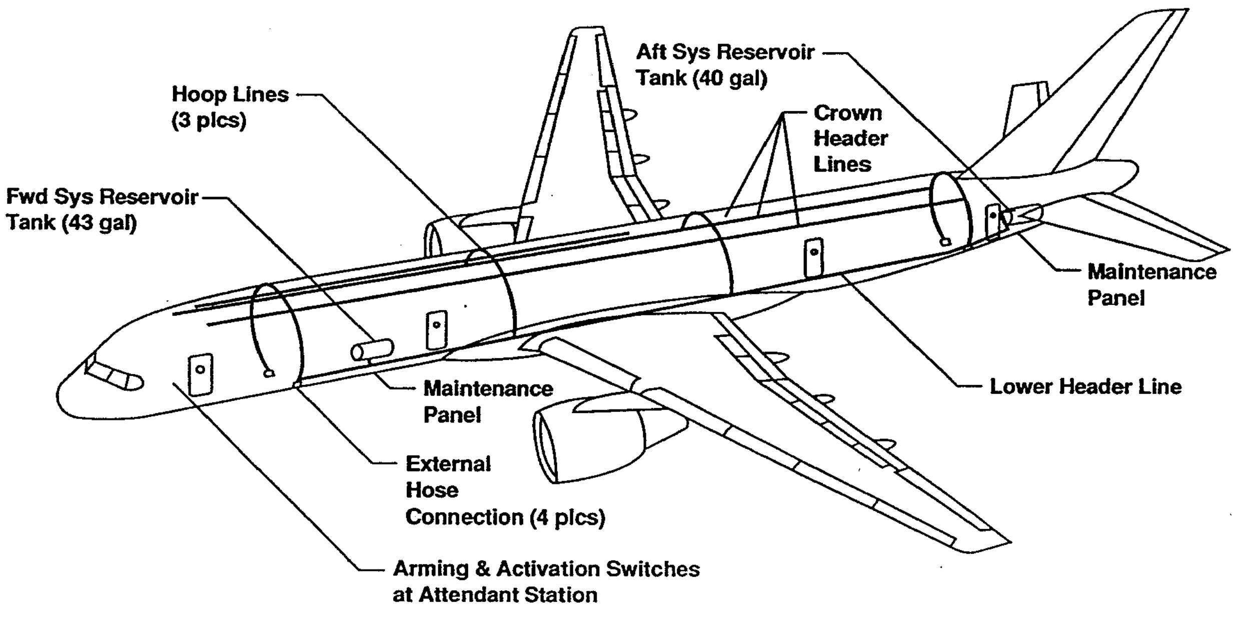


***Figure 17. Cabin Water Spray System Isometric***

Aircraft conditions and system that will be evaluated includes but will not be limited to:

- Effect on primary control systems (e.g.: fly-by-wire, icing of control runs, etc.).
- Effect on essential flight information systems (e.g.: cockpit displays (conventional and "glass"), spurious warnings, inaccurate cockpit information).
- Effect on controllability of aircraft through loss of services (e.g.: brake activation, steering, engine shut-down).
- Effect on operation of emergency evacuation systems (e.g.: door opening, slide deployment, emergency lighting including floor proximity escape path markings, crew communications both between crew and between crew and passengers).
- Effect on evacuation (e.g.: crew instructions, visibility, slippery floor/slides).
- Effect on other significant systems/components (e.g.: pressurization, air-conditioning/ventilation, freezing of passenger doors, communications, etc.).
- Potential of short circuiting of electrical equipment to initiate interior fires (e.g.: galleys, electrical busses, floor proximity lighting).
- Human factors (e.g.: flight/crew workload, operation and use of evacuation systems while wet, effect on passengers during evacuation, including medical consequences-such as electrical shock and occupant survival in low outside air temperature conditions).

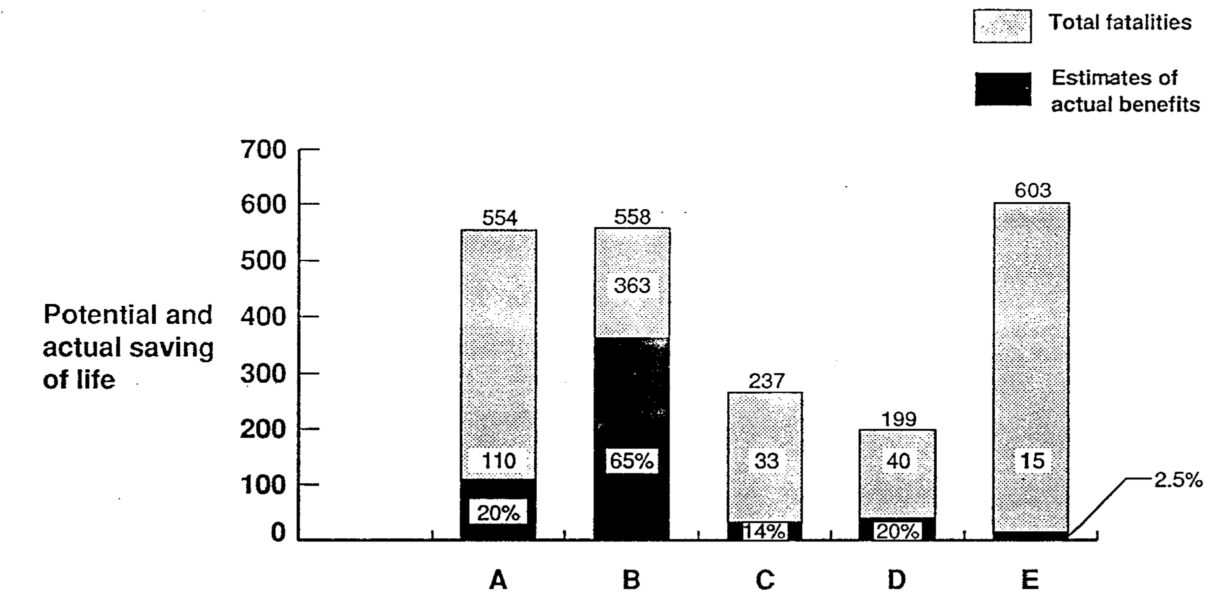
The study will address the cost of returning the aircraft to service following the precautionary use or uncommanded activation of the CWSS in the circumstance where the aircraft has not been damage by fire. Delta Airlines has been brought into the study team as a subcontractor to develop the primary data for this part of the study. Boeing personnel will assist the subcontractor in developing baseline data and provide consultation during the course of this study.

Principal areas of concern that will be investigated include:

- Time and cost of returning aircraft to service (e.g.: drying, system checks/overhaul, structural checks, furnishings checks/replacement, replacement of equipment carried in the cabin, first aid kits, etc.). List of items to be repaired/replaced.
- Additional checks following return to service, modification of the maintenance cycle (e.g.: corrosion, entrapped moisture, freeze damage, electrical/electronic systems checkout).

The 757-200 systems will be analyzed for disbenefits in each of the scenarios specified in the contract. Each of the other Boeing jetliner aircraft will be analyzed and compared to the "baseline". Unique differences will be expanded upon and clarified during the course of the study. The study has been planned as a 10-month effort, concluding in late November of 1991. A final report, detailing our investigation will be published by the FAA in early 1992. Our study results and those of other participating agencies and companies will be part of the data used to establish a net safety and cost benefit analysis prior to any regulatory activity regarding CWS systems in commercial aircraft.

The Civil Aviation Authority (CAA) recently studied 23 world wide accidents to turbine-engined aircraft that occurred during the ten year period from 1980 through 1989. By their estimates, of 1197 fatalities lost in these accidents, 649 lives were judged to attributable to fire. Based on research results and subjective judgements, the CAA then estimated the number of lives that might have been saved if the safety features shown in Figure 18 were uniquely applied for these same accidents. Cabin water spray would have saved 363 additional lives compared of other safety measures such a smoke hoods (110), improved overwing exit access (33), improved materials (40), and minimum seat pitch (15).

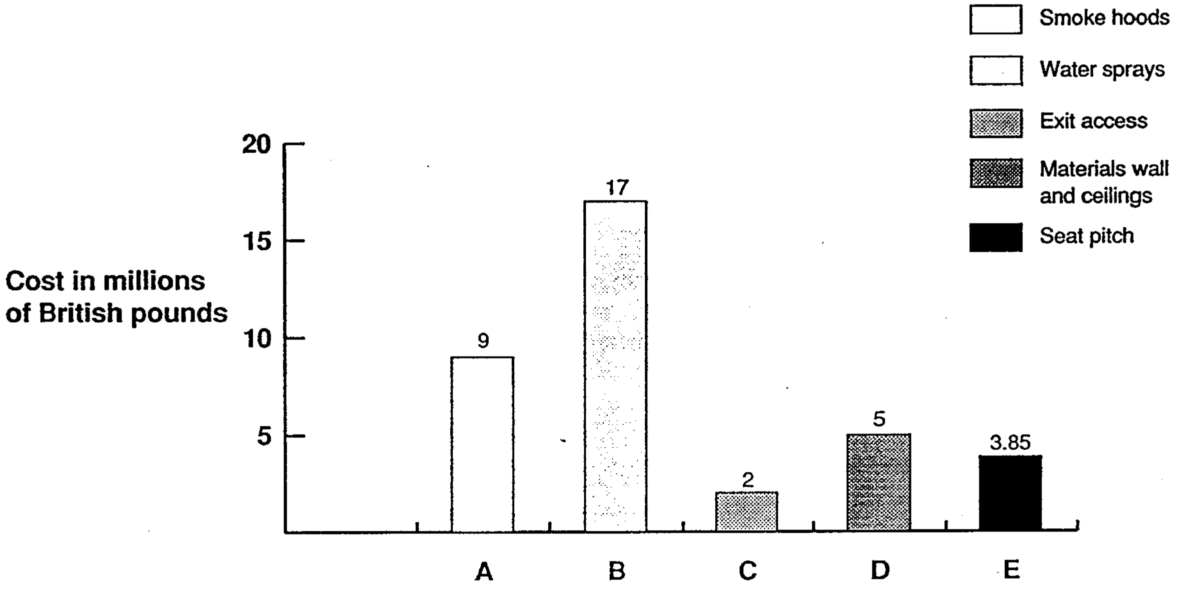


A = Passenger smoke hoods (PPBE)
B = Cabin water sprays
C = Improved overwing exit access
D = Improved wall and ceiling materials
E = Minimum seat space envelope and pitch

• Source: *Aeronautical Journal*, March 1991

*Figure 18. 1980 to 1989 Accidents Involving Fire Deaths.*

The CAA study further extrapolated this data to include only UK lives that could have been saved, which, based on statistical data, would represent approximately 5% of the world total. The cost of the various safety features shown in Figure 19 were then estimated and applied to the number of estimated lives that could be saved. The cost of each life saved for each type of improvement was then calculated and is shown in Table 2. The CAA estimates that the cost for each UK life saved with the implementation of cabin water spray is £9.4 million (U. S. $18 million).



A = Passenger smoke hoods (PPBE)
B = Cabin water sprays
C = Improved overwing exit access
D = Improved wall and ceiling materials
E = Minimum seat space envelope and pitch

• Source: *Aeronautical Journal*, March 1991

*Figure 19. Annual Cost to U.K. Aviation Industry.*

*Table 2. UK Cost/Life Saved for Various Safety Improvements.*

| Safety improvement | Cost per life saved | |
|---|---|---|
| PPBE (smoke hoods) | £16 400 000 | $32 000 000 |
| Water sprays | £9 400 000 | $18 000 000 |
| Improved access to overwing exits AN79 | £12 000 000 | $23 000 000 |
| Improved sidewall and ceiling panels AN61 | £25 000 000 | $49 000 000 |
| Redefined minimum seat pitch AN64 | £51 000 000 | $99 000 000 |

• Source: Ron Ashford, CAA "Air Safety Regulation and its Commercial Impact", Aeronautical Journal, March 1991

## ON BOARD OXYGEN GENERATION SYSTEM (OBOGS)

All commercial passenger aircraft are required to carry oxygen systems for passenger use in the event of sudden loss of pressure within the passenger cabin. Oxygen systems can be of two types: a gaseous system comprised of high pressure oxygen bottles and regulators or a passive pyrotechnic chemical canister that produces oxygen as a result of a chemical reaction. There are advantages and disadvantages to both types of systems. Operational considerations are the primary driver for the selection of one system or the other. Whether an aircraft has one or the other systems, all have a gaseous oxygen system for flight deck crew use. Regulatory Authorities mandates the use of oxygen by the crew on specified flight conditions.

Boeing has recently initiated a development program to explore new technology gaseous oxygen systems, that when installed aboard commercial aircraft provide safety improvements and the potential for cost benefits to the operator. This new technology, developed originally for military aircraft, is called an On Board Oxygen Generation System or OBOGS, Figure 20.

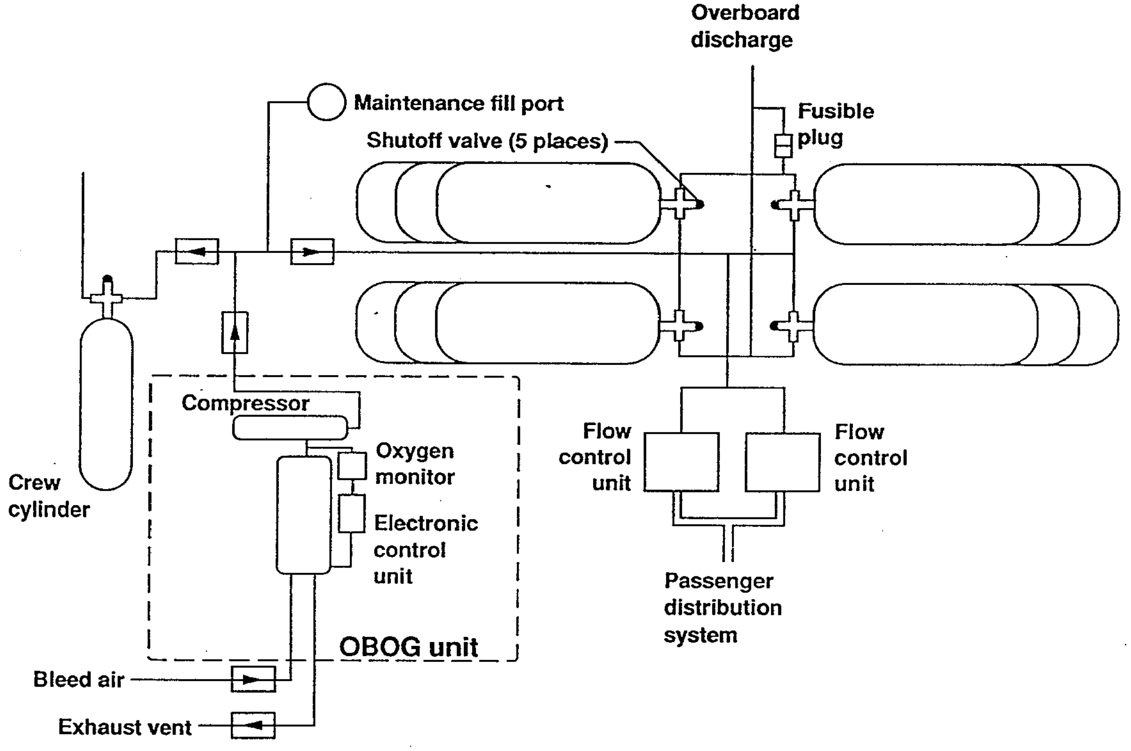


***Figure 20. On Board Oxygen Generator System (OBOGS) Schematic.***

One of the advantages of OBOGS technology is that it virtually eliminates the need of ground servicing of oxygen systems after the initial installation and charging of the storage cylinders. Since the handling of oxygen systems requires special training for ground personnel, special equipment, special procedures, and is easily subject to contamination; the potential for leaks, fire or explosion are always present. Oxygen, when combined with most all materials, including metals will produce extremely hot or explosive fires.

Other factors such as meeting FAA minimum dispatch pressures in the aircraft oxygen system will cancel a flight or keep an aircraft grounded until service can be obtained. As mentioned, servicing can be dangerous for both ground personnel and the aircraft. Typical servicing requires replacement of the 3HT type high pressure cylinders or in some cases servicing the system on the aircraft with a special ground cart.

Our initial efforts are to develop an oxygen replenishment system based on molecular sieve technology that separates oxygen from air under pressure using a nitrogen adsorption process. The OBOG unit will be developed in conjunction with an outside company with an in-service evaluation (ISE) to establish performance and reliability of the OBOG system. The development program is a multi-phased effort that has identified the need for development of a high pressure oxygen compressor and large capacity composite storage vessels. These developments will allow significant weight savings in oxygen systems requiring large storage capacities.

A major European airline has expressed a willingness to participate as the ISE airline. The current development schedule has the ISE occurring between July 1993 through December 1994 including the ISE test of composite high pressure oxygen vessels.

Two new solid electrolytic technologies, ceramic and polymer, that will separate oxygen from air have been demonstrated in laboratory research outside of Boeing. The development of these technologies is being reviewed and studied even though there is no near term commercial aircraft applications.

## SUMMARY

This paper has been prepared to present highlights of some of the cabin safety programs and projects that are currently in development in the Payload Systems Organization in support of Advanced Programs in the Commercial Airplane Group. Unlike the Icarus Aircraft company, our direction to improve safety is clear, our efforts focused, and supported by The Boeing Company at its highest level.

Considerable improvements in passenger safety have been realized over the past decade. The number of accidents that occur have been dramatically reduced to the point that air travel is the safest mode of transportation in the Western world. These improvements in passenger safety and reduction in hull loss have not been without cost. But we are converging on an asymptomatic curve whereby each incremental improvement in passenger cabin safety becomes increasingly costly to achieve.

The implementation of the 16g seat rule under FAR 25.562 will require the retrofit of 0.5 million seat bottoms in the existing U.S. commercial transport fleet. At an estimated cost of $1,000 for each seat bottom, the retrofit costs will be in excess of $0.5 billion. The ATA has estimated (1989) that the total industry cost impact for passenger seat replacement, rebuild, extra fuel required and forgone value to be $1,026 million, making this rule the most costly safety proposal ever, equal to all the TCAS and windshear program costs. There are no estimates for the potential life savings that could be realized with the implementation of this ruling.

Recent Boeing analysis of civil transport accidents for the past decade indicates that 72.5% of the accidents were attributable to pilot error. These errors were grouped into three primary categories: approach and landing, rejected take-off, and controlled flight into terrain (CFIT). Since the Ground Proximity Warning System (GPWS) was introduced in 1975, two thirds (2/3) of the CFIT accidents have involved aircraft that were not equipped with GPWS. The increase in lives saved and the reduction in aircraft losses with the addition of GPWS has been significant.

What accident data is indicating, is that more payoff (lives and aircraft saved) can be realized through investments in the prevention of accidents rather than investments in crashworthiness.

Your interest in aircraft passenger cabin safety and accident prevention is appreciated and your comments are welcomed.

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