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INVESTIGATION AND CHARACTERISTICS OF MAJOR FIRE-RELATED ACCIDENTS IN CIVIL AIR TRANSPORTS OVER THE PAST TEN YEARS

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SUMMARY

This paper will summarize a number of fire-related accidents and incidents that have occurred during the present decade. The selection of accidents/incidents was based on information availability and perceived importance of those chosen. A brief summary of accident data for the past ten years is presented. A methodology is shown for logically calculating the effects of cabin fire safety improvements on survivability utilizing past accidents. Eight accidents and four incidents are discussed and their link to safety improvements is described. The paper concludes with a call for better information from accident investigations.

INTRODUCTION

In 1987, the Federal Aviation Administration (FAA) developed a computer model for calculating the benefits of fire safety improvements. This calculation is based on a detailed analysis of past accidents (1). The model is based on the manipulation of two curves, one being the mobility and the other being the fire hazard.

The mobility rate profile describes the loss in passenger mobility due to physical effects. They could include the number of usable exits, poor visibility due to smoke or inadequate lighting, or blockage of the aisles by passengers or debris.

The thermal hazard profile is based on the buildup of hazard that could cause incapacitation, such as heat, toxic gases, oxygen depletion, and smoke or direct exposure to flames.

It is recognized that the output from the model is based on the subjective input of the operator. The model itself makes no assumptions regarding an accident, it only supplies a logical framework for analyzing the input of the operator. This methodology was employed by the Civil Aviation Authority (CAA) of the United Kingdom (2) for analyzing the safety benefit of smoke hoods.

Table 1 lists the major transport accidents (in-flight and survivable postcrash) having reported fire fatalities during the last ten years (1,2,3).

TABLE 1

Civil Transport Aircraft Accidents (1979-1988) With Fire-Related Deaths or Destruction of the Aircraft by Fire

	Date	Carrier	Place of Accident	Type of Aircraft	Number of Passengers	Number of Fatalities
1	3/13/79	Alia	Doha	B-727	64	44
2	4/26/79	Indian Airlines	Madras	B-737	67	0
3	10/7/79	Swissair	Athens	DC-8	154	14
4	2/27/80	China Airlines	Manila	B-707	135	2
5	8/19/80	Saudia	Riyadh	L-1011	301	301
6	11/4/80	TAAG	Benguela	B-737	134	0
7	11/19/80	Korean	Seoul	B-747	226	15
8	11/21/80	Continental	Yap Island	B-727	73	0
9	2/17/81	Air Cal	Santa Anna	B-737	110	0
10	7/27/81	Aeromexico	Chihuahua	DC-9	66	30
11	3/17/82	Air France	Sanaa	A-300	124	0
12	8/26/82	Southwest	Ishigaki	B-737	138	0
13	9/13/82	Spantax	Malaga	DC-10	393	51
14	3/11/83	Avensa	Barquisimeto	DC-9	50	23
15	6/2/83	Air Canada	Cincinnati	DC-9	46	23
16	6/11/83	United	Chicago	B-727	142	0
17	7/2/83	Altair	Milan	Caravele	89	0
18	12/7/83	Aviaco	Madrid	DC-9	42	42
19	12/7/83	Iberia	Madrid	B-727	93	51
20	12/18/83	Malaysian	Kuala Lumpur	A-300	247	0
21	3/10/84	UTA	Ndjamena	DC-8	23	0
22	3/22/84	Pacific Western	Calgary	B-737	119	0
23	8/30/84	Air Cameroon	Douala	B-737	118	2
24	10/13/84	Cyprus Airways	Zurich	B-707	10	0
25	8/22/85	British Airtours	Manchester	B-737	137	55
26	11/30/85	Mandala	Medan	L-188	45	0
27	11/28/87	South African	Indian Ocean	B-747	161	161
28	8/31/88	Delta	Dallas	B-727	108	14

Table 2 lists the accidents discussed in this paper and the reason for their inclusion.

TABLE 2

Carrier and Type of Aircraft	Reason For Inclusion
Saudia L-1011	Led to cargo rule changes.
Korean Airlines 747	No jet fuel involvement - post crash materials fire.
Spantax DC-10	Evacuation problems and rapid growing materials fire.
Air Canada DC-9	Led to many cabin fire safety rule changes.
Gulf Air 737	Incendiary - What do we protect against?
British Airtours 737	Research into passenger protective breathing devices and cabin water mist systems.
South African Airlines 747	Proposed rule change class "B" cargo compartment ("Combi").
Delta Airlines 727	First commercial aircraft, involved in a survivable accident with postcrash fire, equipped with fire blocked seats.

Table 3 lists the incidents discussed in this paper and the reason for their inclusion.

TABLE 3

Carrier and Type of Aircraft	Reason for Inclusion
UTA 747	Problems of cargo seams, joints, fasteners. Rapid material involvement.
ATA DC-10	Same as above, and solid oxygen system.
Jordanian Air L-1011	Titanium fires.
Monarch Airlines 757	Electrical (arc tracking) problems.

Safety improvements are judged by their expected benefit versus their cost. Since future benefit is most often based on past accident experience, it is very important to have enough information about past accidents as a basis for that judgement. In evaluating a safety improvement, a wide range of accident scenarios must be studied, making sure that improvement in some scenarios is not a detriment in others.

ACCIDENTS

1. Saudia L-1011, August 19, 1980.

In August of 1980, a Saudia L-1011 experienced an in-flight fire. A short time after takeoff from Riyadh, a cargo fire warning light activated in the cockpit. After the crew experienced some problems in determining the proper procedures, the aircraft returned to Riyadh. The voice recorder indicated an uncontrolled fire in the rear of the aircraft prior to touchdown. The aircraft did not stop on the runway, however, it ran the full length and turned onto the taxiway before stopping (figures 1 and 2). The investigation concluded that "the probable cause of the accident was the initiation of fire in the C-3 cargo compartment. The source of the ignition of the fire is undetermined" (4).

In the years since the accident there has been much second guessing as to the probable cause. Some people believe that it could have been a hydraulic or electrical fire next to or behind the C-3 compartment. However, test work sighted in the accident report (4) and the results of tests in references 5 and 6 are consistent with a cargo fire origin.

Based on factual information and test data, a likely fire scenario is as follows: Shortly after takeoff a fire developed in cargo in the C-3 compartment. The fire could have been started by a cigarette left on a bag, matches igniting in a bag or other small ignition sources. A smoke detector in the compartment activated, sending a warning to the cockpit. Smoke began drifting into the aft cabin through the floor grills. Detectors in the compartment became oversaturate with smoke, causing the alarm in the cockpit to go out. The flight engineer inspected the cabin and returned, stating there was smoke in the aft. By then the pilot had turned the aircraft and was returning to Riyadh.

The fire in the cargo compartment had burned through the cargo liner and impinged on the cabin floor, fanning out between the cargo compartment ceiling and the cabin floor. The heat melted the pulleys for the number two throttle cable. Oxygen was consumed in the cargo compartment and the fire subsided in the compartment. As the pulleys cooled, the plastic hardened and the number two engine throttle stuck. Air was then drawn into the compartment through the hole as it cooled, until the flames began again. This time the fire entered the cabin through the floor. Passengers in the aft section were moved forward in the cabin. Flight attendants fought the fire with handheld extinguishers. The fire cycled from flaming to smoldering a number of times.

As the plane began its final approach, the airflow to the cabin was turned off and the outflow valves were closed. At that time, little or no smoke was observed in the forward cabin or on the flight deck. The flight crew were convincing themselves that there was no big problem. Upon landing, the crew took the aircraft to the end of the runway and onto the taxiway before stopping. The flight crew did not use smoke masks in the cockpit. The flight crew reported to the tower that they were beginning an evacuation. However, back in the cabin, as the plane touched down, the flames had impinged on the seats above the C-3 cargo compartment and began to spread. Because the airflow was shut off and the fuselage was closed up, the combustible gases collected at and above the ceiling. Before the evacuation could begin, a flash fire occurred. Flames shot forward at and above the ceiling, producing large amounts of gases and consuming most of the oxygen. All of the 301 passengers and crew were quickly incapacitated and were soon dead.

This accident led to rule changes in the area of cargo compartment fire protection (7). Tests showed that had the seats been fire blocked, they could have stopped the spread of fire from the cargo area to the cabin and prevented the flash fire.

2. <u>Korean Airlines, November 19, 1980</u>.

A Korean Airlines 747 landed short of the runway at Seoul, Korea, causing the main landing gear to collapse into the cargo compartment aft of the gear. The aircraft slid approximately 7,000 feet down the runway before stopping. A fire began in the ruptured cargo compartment from sparks igniting the strut fluid and cargo in the compartment. As the aircraft came to a stop, the fire spread up into the cabin through the air grills and through ruptured cargo liners and the cabin floor. Of the 208 passengers and 18 crew members, 15 (9 passengers and 6 crew members) did not survive (figure 3).

The important fact concerning this accident was that there was no jet fuel involvement in the fire (the tanks remained intact). The major contribution to survivability was from the burning of the interior materials. This accident changed the minds of many people who believed that the fuel fire dominated the fire hazards in all aircraft accidents and that material improvements would not substantially improve aircraft safety.

3. <u>Spantax, September 13, 1982</u>.

A Spantax DC-10 aborted a takeoff and overran the runway in Malaga, Spain, stopping in a field just off the airport. The right wing was torn off the aircraft and a large fuel fire encompassed the aft end of the fuselage (aft of the wings). The fire entered the cabin in the aft areas through tears in the fuselage and burnthrough of the skin. There were 51 fatalities out of the 393 occupants.

This accident pointed out the problems of evacuation. Evacuation was slowed by debris in the aisles and some passengers failed to begin evacuation because of emotional trauma. The fire burned into the cabin in a very rapid manner. This accident also pointed out the problem that the crash fire rescue crews have in extinguishing a cabin fire. Photographs (figure 4) show that the fuselage was almost fully intact when the first trucks arrived and extinguished the external fire; however, the fire in the cabin almost totally consumed the fuselage before it was extinguished.

4. <u>Air Canada, June 2, 1983</u>.

An Air Canada DC-9 experienced an in-flight fire in the area of the left aft lavatory. The fire produced heavy smoke in-flight and progressed very rapidly after the aircraft landed. Twenty-three of the forty-six occupants were able to egress before a flash fire occurred (figure 5).

Investigation into this accident indicated that a fire started in the hidden area of the aft lavatory (figure 6). The actual ignition source or fuel was not determined. It could have been electrical in nature or it could have been caused by a cigarette and trash behind the vanity area. The fire spread rapidly to the aft seats after the aircraft landed (figure 7). Many of the passengers attempted to use some form of protection against the smoke (wet towels, clothing, etc); however, there seems to be no correlation between attempts at smoke protection and survivability.

The Air Canada accident led to a number of regulatory changes in the United States. Requirements for smoke detectors in lavatories, fixed fire extinguishers in trash containers, and at least two Halon fire extinguishers onboard transport aircraft (8) were incorporated. Also, floor proximity lighting (9) and seat fire blocking rules (10) were hastened in their adoption because of this accident.

5. Gulf Air, September 1983.

A Gulf Air 737 experienced an in-flight fire probably caused by an incendiary device exploding in the forward cargo compartment. The pressure from the explosion, although not rupturing the pressure vessel, did dislodge cargo lines, thus destroying the integrity of the class "D" compartment. The fire spread to the cabin and caused the aircraft to crash into the desert killing all on board (figures 8 and 9).

Testing indicated that a detection and suppression system, that is, as required in a class "C" cargo compartment design, could possibly contain (extinguish) some types of incendiary devices. This testwork raises the question of to what level of fire threat an aircraft should be designed.

6. British Airtours, August 22, 1985.

A British Air Tours 737 experienced an engine fire during the takeoff roll at Manchester, United Kingdom, causing an aborted takeoff and a large fuel fire from a ruptured fuel tank. As the aircraft came to a stop, the fire quickly spread into the cabin. Of the total of 137 occupants, 55 succumbed to the fire.

As a result of this accident, two major test programs were initiated. The first addressed passenger protective breathing equipment (1,2). Although regulatory requirements do not seem imminent for smoke hoods, specifications have been developed by the CAA. The second is an active program in water mist for interior cabin fire protection. A multi-national test program to determine the possible benefits and disbenefits of an on board, cabin water mist system during various scenarios is now underway.

7. South African Airlines, November 1987.

A South African Airlines 747 "Combi" (passengers and cargo on the main deck) experienced an in-flight fire while flying over the Indian Ocean. The plane crashed into the Indian Ocean and all on board were killed. Although the investigation is still ongoing, initial reports indicate a fire occurred in the class "B" main deck cargo compartment, grew out of control, and caused the destruction of the aircraft.

As a result of this accident, the FAA has issued a Notice of Proposed Rulemaking (NPRM) that would require fire safety improvements in class "B" compartments (11).

8. Delta Airlines, August 31, 1988.

A Delta Airlines 727 crashed on takeoff from the Dallas/Fort Worth Airport. The aircraft suffered severe structural damage as it slid to a stop approximately 3,000 feet from the end of the runway. The right wing was ripped from the fuselage, causing a large fuel spill; and the aft two cargo doors opened and a large section of the fuselage above and forward of the main aft cargo door was torn away. A large circumferential break also occurred just aft of the cockpit. A large fuel fire separated the aft section from the rest of the fuselage at the aft break. All but two of the fatalities were trapped in the aft section. The doors in that area could not be opened from inside because of the angle at which that portion of the fuselage was resting (figures 10 and 11). The evacuation in the forward portion of the cabin was through breaks in the fuselage and the two left over-wing exits. It was estimated that evacuation time from aircraft stop, until the last passenger was out, was 4 minutes and 20 seconds. This was based on recorded crash/fire crews response time, and that the last survivors exited the aircraft as the first truck began fire-fighting. There were two passengers in the forward cabin that succumbed to the effects of the fire.

This accident is of extreme interest since it was the first survivable accident involving fire since the implementation of the floor proximity and fire blocking rules. Initial indications from passenger interviews were that no one utilized the floor lighting in the egress of the aircraft. That could be expected since the accident occurred during daylight and large breaks in the fuselage provided visible means out of the aircraft. From visible remains of the cabin materials and passenger accounts of the evacuation, it could be concluded that fire blocking on the seats did extend the survival time in the forward portion of the cabin. Although an exact additional escape time or added number of survivors that could be attributed to fire blocking cannot be determined, an estimate utilizing past test data was made. The estimate of additional time is based on figure 12, taken from reference 5, which shows curves of survival time versus fire threat for blocked and unblocked seats. If we find the point on the blocked curve equating to 4 minutes 20 seconds, and then find the survival time on the unblocked curve for the same fire threat, the time equals 2 minutes and 50 seconds. Therefore, using this method, an estimate of 1 minute and 30 seconds of added survival time was provided in this accident due to the incorporation of fire blocking.

To estimate the number of added survivors we can utilize the model from reference 1. Knowing that the last person exited at about 4 minutes 20 seconds, and because of the breakage in the fuselage and trauma caused by impact, it was estimated that the full evacuation began 30 seconds after stopping, with a few passengers near breaks evacuating in the 15 to 30 second range. Figure 13 shows the curves developed for this accident. The same figure also shows the curves developed under the assumption of no fire blocking (using an evacuation time of 2 minutes 50 seconds). In that case, the total survivors would have been 57. Therefore, the calculated number of lives saved due to fire blocking was 37.

INCIDENTS

In many cases, the difference between an accident and an incident is pure luck. The probability of the next aircraft accident having similarities to a given past incident are the same as the probability of similarities to a given past accident. It is therefore extremely important that all incidents, considered aircraft or life-threatening, be investigated, analyzed, and understood. It should be noted that because of the limited damage in some incidents, much more information concerning the start and spread of a fire can be learned than in an accident. The following are examples of incidents that have led to research and/or safety improvements in aircraft:

1. UTA - Paris, France.

A fire ignited in the lower area of the forward cargo compartment of a UTA 747 as maintenance personnel were cleaning rollers and track in that compartment. The cleaners had some rags and cleaning solvent in the compartment at the time. The maintenance personnel tried to fight the fire and notified CFR. The fire spread rapidly around the cargo liners and up into the cabin. The oxygen system was breached causing a localized, high intensity fire. By the time the fire was extinguished by the CFR, both the main deck and upper deck cabins had been gutted by fire (figures 14, 15, and 16).

Investigators found that the fire in the cargo compartment destroyed many seams, joints, and fastening systems allowing liners to fall and provide paths of fire egress from the compartment (figure 17). The fire also spread up around the bottom cargo liner seal on the thermal insulations' outer covering. Flames entered into the cabin through the floor grills in the passenger cabin.

This incident was a major force in including seams, joints, and fasteners in the new testing requirements for class "C" and "D" compartments. The requirement for cargo lining material on the lower sidewall of the cargo compartment was also an outgrowth of this incident.

2. ATA - Chicago, Illinois.

A fire ignited in the forward cargo compartment of a DC-10 as cleaners were servicing the cabin area. The fire was started in a container by an activated solid oxygen generator (the generator had accidentally been activated by a mechanic who a few minutes prior to the fire had entered the compartment and container in search of a replacement seat back) in contact with some bubble plastic wrap. The fire spread quickly, with seams, joints, and fastening systems failing, causing cargo liners to fall and the fire to gain access to the cabin area through the floor. By the time the CFR personnel extinguished the fire it had destroyed the aircraft, burning through the fuselage along the top (figures 18, 19, and 20).

Besides reemphasizing the same problems as seen in the UTA incident, concern was focused on solid oxygen generators and their safety.

3. Jordanian Airlines - Singapore.

A Jordanian Airline L-1011 experienced an in-flight fire while at 24,000 feet approaching Singapore Airport. The flight crew experienced electrical faults and an overheat warning in the cheek-area adjacent to the C-3 cargo compartment. Shortly thereafter, a fire warning occurred for the number two engine. Smoke began pouring into the aft cabin, and flames were seen entering the cabin through a floor grill in the aft left side. A flight attendant reported firing a Halon extinguisher at the flames and they disappeared. At about 14,000 feet, the aircraft experienced a sudden depressurization. The smoke subsided in the cabin, and the aircraft landed with no further problems.

Investigation revealed that a fire began with an arc from a power feeder cable to a titanium bleed air duct. The titanium, ignited and fed by the 400 °F bleed air which exited the ruptured duct, continued to burn. A 3-foot length of duct was consumed in the incident. The hot air and molten titanium (3200 °F) then ignited some epoxy/fiberglass ductwork in the area, and the gases produced by the overheated resins caused the fire to spread around the aft pressure bulkhead and into the overhead. Fire impingement on the aft pressure bulkhead melted and shorted wiring, causing the number two engine fire warning, and then causing a rupture of the bulkhead and depressurization of the cabin (figures 21 and 22). Since most of the burning was on the surfaces of materials and gases produced, the sudden rush of air due to the hole in the bulkhead blew the fire out. Luck was with this flight for, as shown in figure 23, the main fuel line running just under the cabin floor, was almost penetrated by fire just forward of the aft pressure bulkhead. What if the fire had started at a higher altitude, further from an airport, or the pressure bulkhead had not burned through?

4. Monarch Airlines, United Kingdom.

A Monarch Airlines 757 experienced an electrical failure in flight causing the loss of almost all electrical power. An investigation revealed that in stamping wire numbers on some Kapton™ cabling, the insulation had been cracked. Moisture had caused a carbon buildup and a phenomenon known as wet arc tracking had occurred. This incident focused attention on Kapton wire. A program studying wet and dry arc tracking (12), as well as smoke and flammability of electrical wiring, is now being conducted by the Federal Aviation Administration.

FINAL COMMENTS

It should be noted that although past accidents have been used to determine possible benefits from safety improvements, past individual accidents cannot be used to predict the future. Benefits were derived by trying to determine what would have happened in a past accident had various improvements been installed. In order to roughly approximate future accidents, it is necessary to generalize past accidents and look at trends. In doing so, there are two classes of fire accidents: in-flight and postcrash.

In-flight Fires

The major in-flight fires are hidden fires. The major emphasis must be improved materials in hidden areas (behind sidewalls, above ceilings, and in lavatories) and better fire protection systems in cargo compartments and other hidden areas. Another area of concern should be the protection of passengers and crew from smoke and gases generated by an in-flight fire. That protection could be in the form of better smoke venting; protective breathing devices; or less flammable and less smokey materials.

Postcrash Fires

Analysis of past accidents shows that passengers must be given more protection from the spread of the external fuel fire into and through the cabin. This may be done by minimizing the external fuel fire (less flammable fuel, better CFR, etc.), by reducing burning in the cabin (improved materials, fire suppression systems, or fuselage burnthrough protection), and by improving passenger evacuation.

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(10) Flammability Requirements for Aircraft Seat Cushions; Final Rule, DOT/FAA, Federal Register, Vol. 49, No. 209, p. 43, 188, October 26, 1984.

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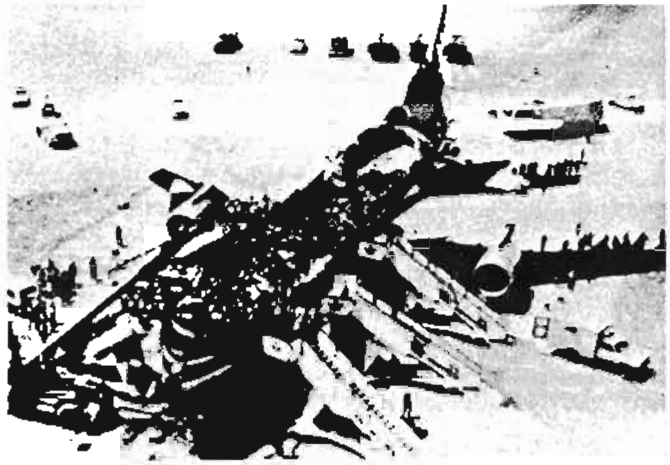

Figure 1. Saudi L-1011 parked on taxiway.

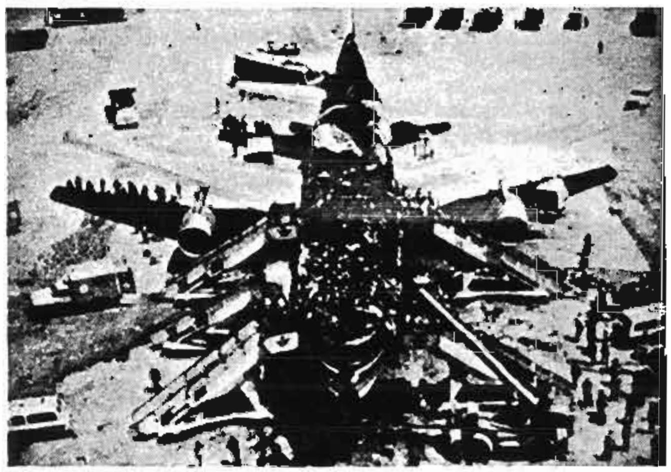

Figure 2. Saudi L-1011 as seen from overhead.

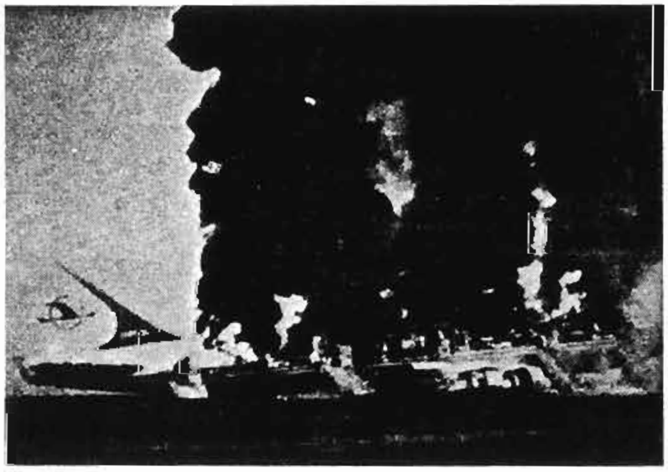

Figure 3. Korean Airlines 747 approximately 5 minutes after coming to rest.

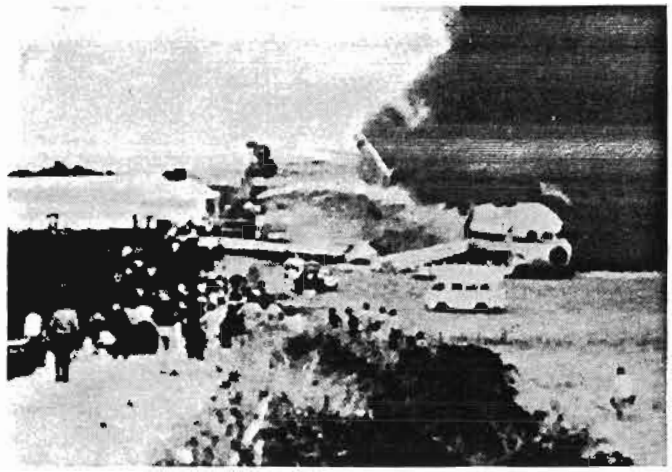

Figure 4. Spantax DC-10 on fire (photo by passanger).

Figure 5. Right side view of Air Canada DC-9 after in-flight fire.

Figure 6. Left, aft lavatory (area of fire origin), Air Canada DC-9.

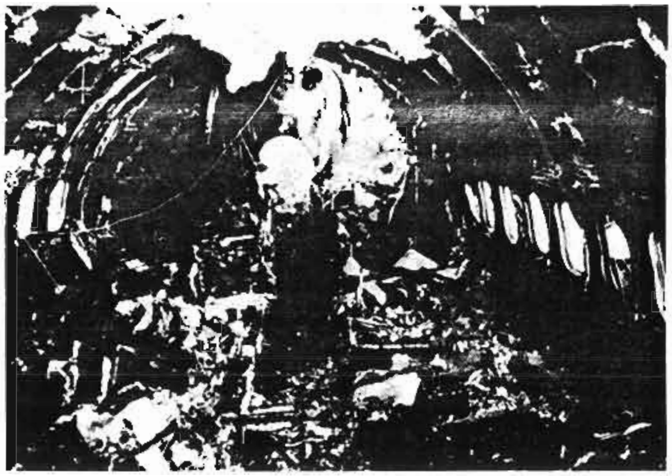

Figure 7. Cabin area looking aft, Air Canada DC-9.

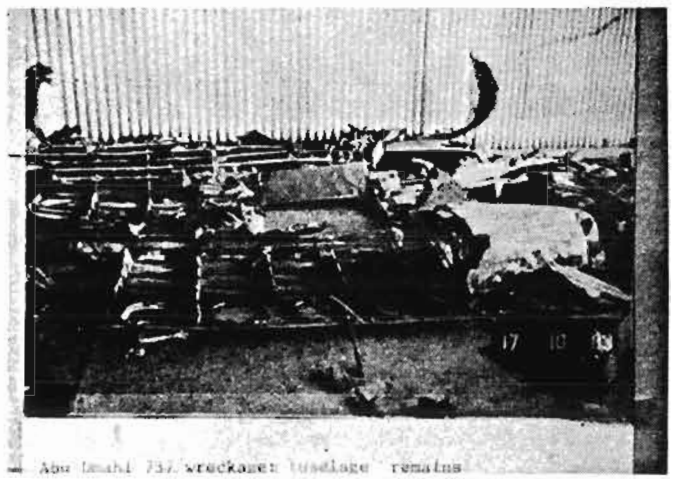

Figure 8. Remains of Gulf Air 737.

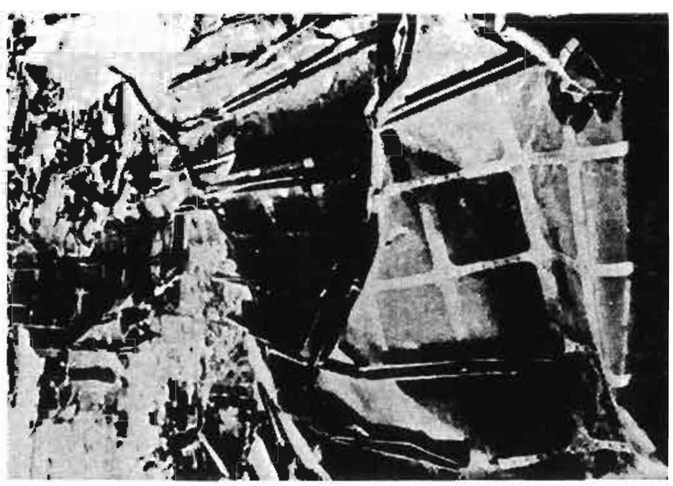

Figure 9. Remains of Gulf Air 737.

Figure 10. Aft right side of Delta 727.

Figure 11. Aft left side of Delta 727.

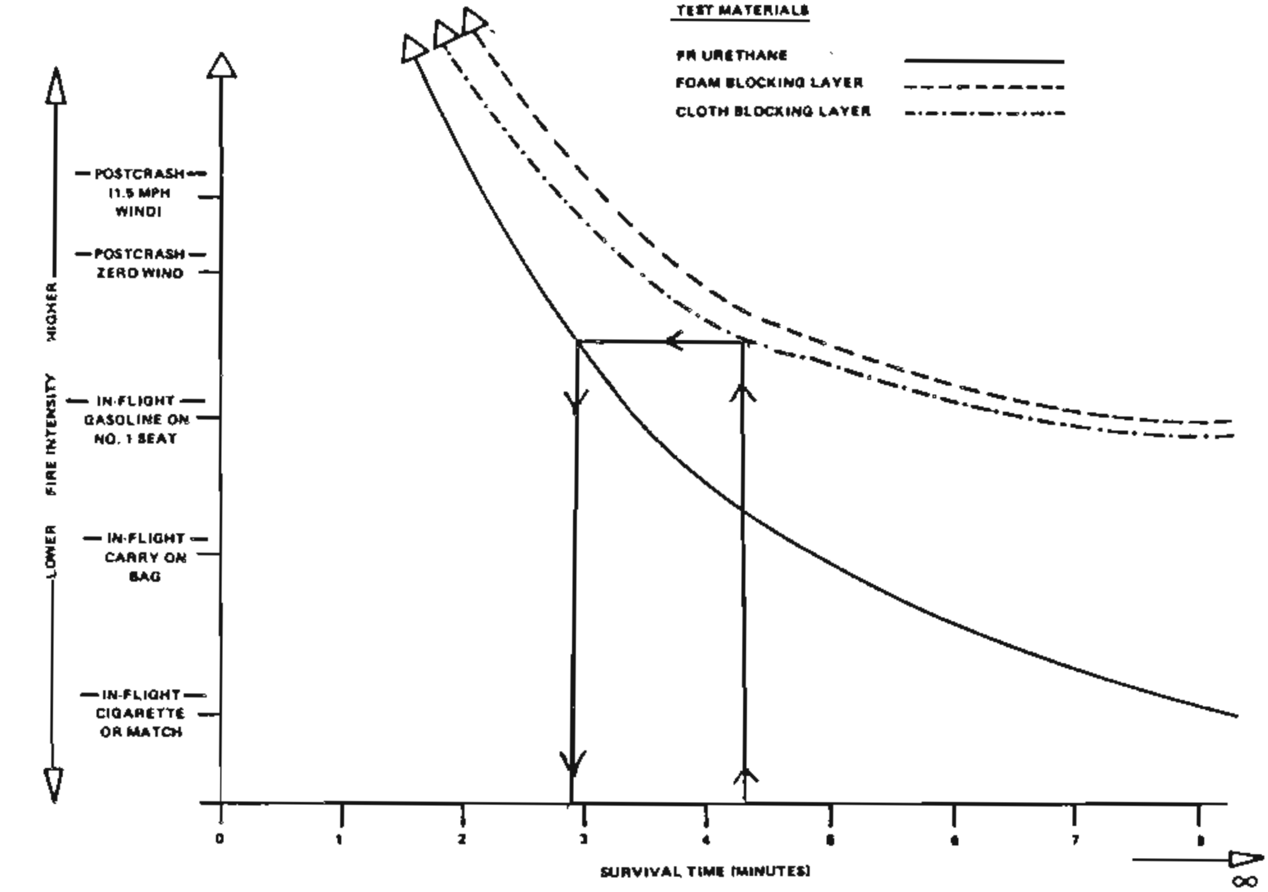

Figure 12. Calculation of added evacuation time due to the use of fire blocked seats.

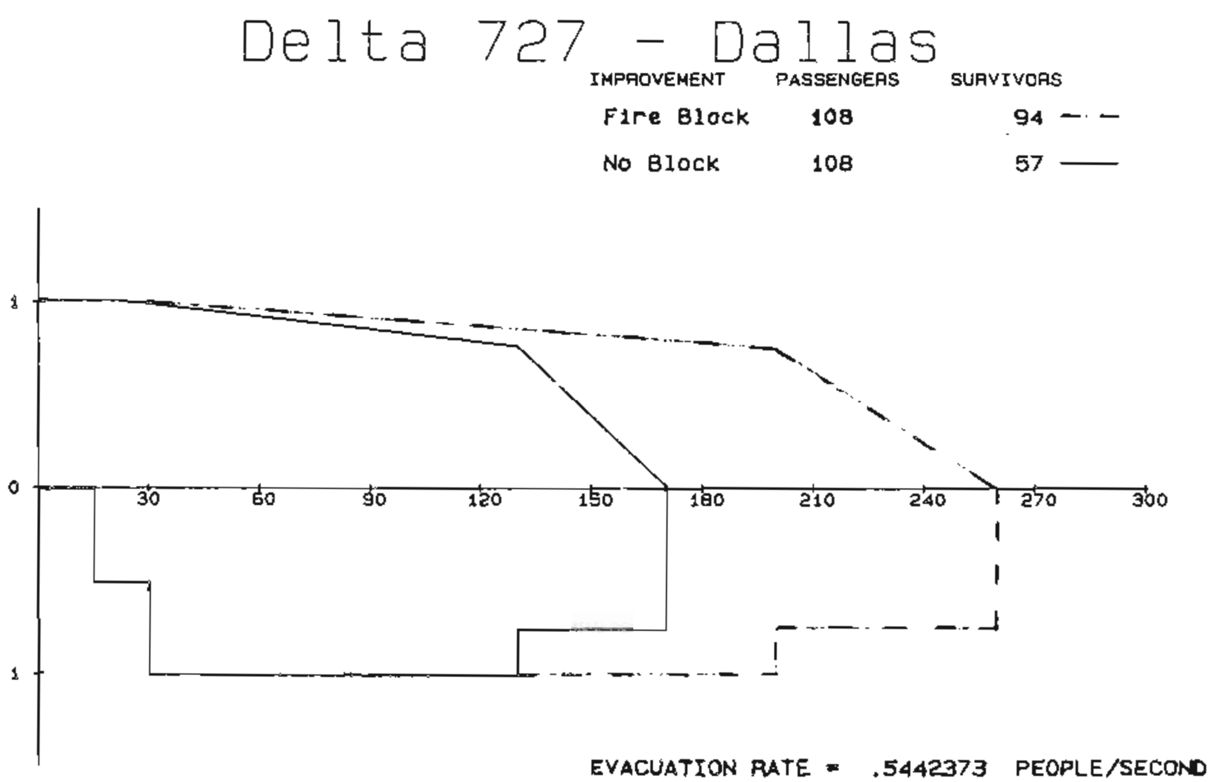

Figure 13. Calculation of added survivors due to the use of fire blocked seats.

Figure 14. Outside view of UTA 747 after ramp fire.

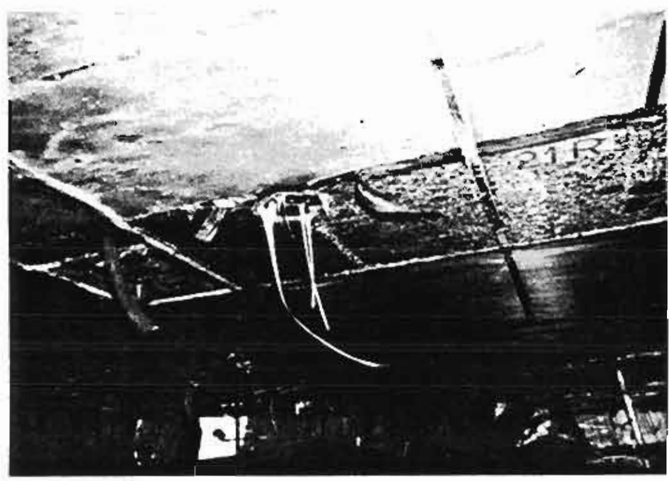

Figure 15. Cargo ceiling with fixtures, UTA 747.

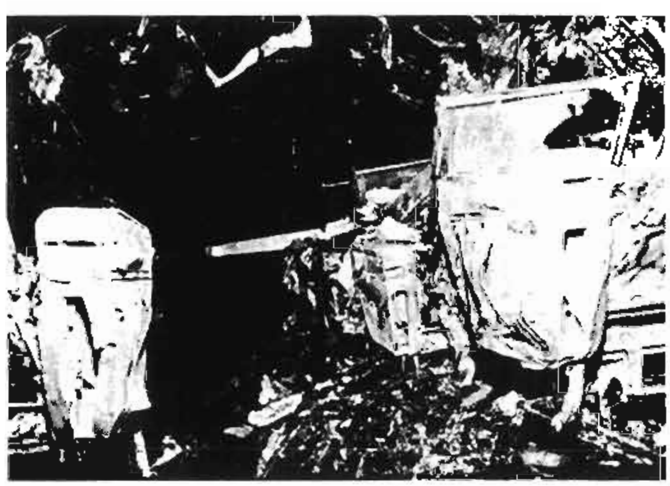

Figure 16. Upper deck view of UTA 747.

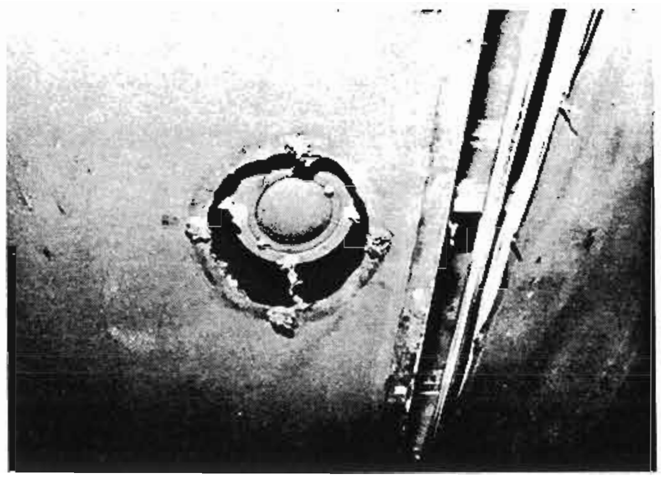

Figure 17. UTA 747 cargo light fixture failure.

Figure 18. Outside view of ATA DC-10 after ramp fire.

Figure 19. View of main cabin, ATA DC-10.

Figure 20. Cargo and cargo liner damage, ATA DC-10.

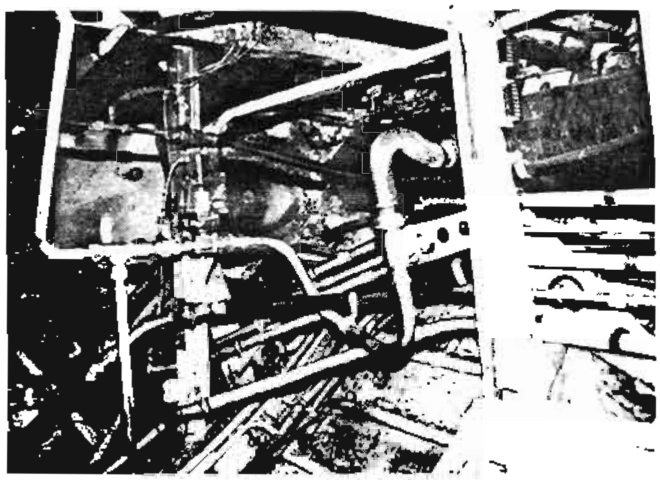

Figure 21. View of the check area adjacent to C-3 cargo campartment, Jordanian Air L-1011.

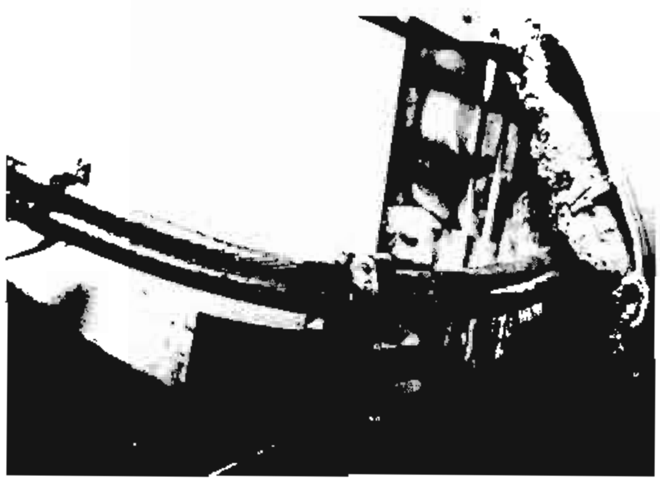

Figure 22. Arced power cable, Jordanian Air L-1011.

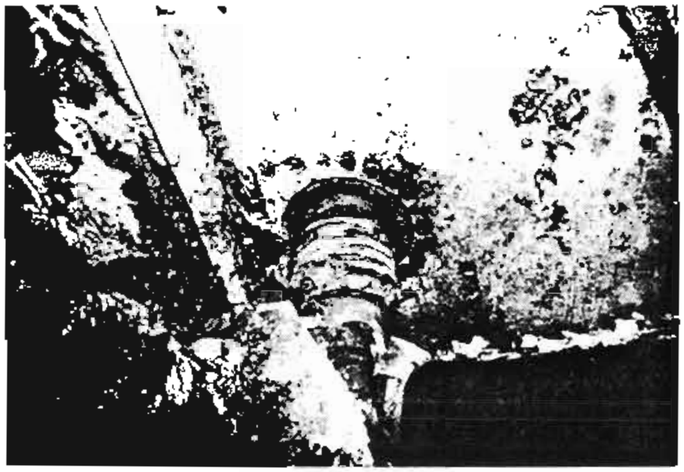

Figure 23. Fire damaged fuel line, Jordanian Air L-1011.

DISCUSSION

I.H. SARAVANAMUTTOO (comment)

I am speaking as a passenger, and my remark is aimed at the airline operator and not the manufacturers. You pointed out the problem with carry-on baggage in the Spantax accident. It is extremely important that operations staff are ruthless in enforcing rules regarding carry and baggage, and this does not require any technical development. In a similar vein, a 747 may carry upwards of 100 gallons duty free (and inflammable) liquor, presenting both a fire hazard and a problem of dangerous missiles being thrown about. All this requires is that all duty free liquor be purchased at the destination rather than the origin. It is well known that many airports make large profits from duty free sales, but it makes no difference whether they sell to outgoing or incoming passengers.

R. RACKE

1.1 What was the cargo lining material used in the Sandia L-1011 accident, august 1980.

1.2 How long did it take for the fire brigade to reach the aircraft after the fire was reported in the ATA accident.

AUTHOR'S REPLY:

1.1 Nomex

1.2 5 minutes

E. PETINGA

As far as the passengers cabin is concerned, what is being done in order to reduce lining materials from poisoning the air with toxic gases and fumes and melting on the occupants.

AUTHOR'S REPLY:

The regulations governing those materials were recently change. More fire resistent materials are now required, and those requirements become even more stringent in 1990.

M. FAVAND

The different pictures showed that there are no enveloppes of blankets left (blankets of thermal and acoustical isolation) even if there are still seats, windowframers, etc.
Do you agree that there is a problem of fire resistance of the enveloppes of blankets.

AUTHOR'S REPLY:

The thermal acoustical isolation is not designed to withstand a fire. However there may be a problem with some covering materials for the isolation in spreading smaller in flight fires.

F. TAYLOR (comment)

About the number of doors, my studies show that loadfactor

(40% or 100%) seems to have no effect on the proportion of people who die. So maybe we do have enough doors or maybe we need to know more of the psychology of evacuation.
Not mentioned so far, but a finding in the AAIB report on the Manchester accident, is that very slight winds can have a dramatic effect on the fire. Amongst their recommendations is one to fit external video cameras to give the crew a view of the aircraft fire and smoke on a cockpit monitor.