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Study of Aircraft Crashworthiness for Fire Protection

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16. Abstract

This is the final technical report covering the review of accident data, the association between crash characteristics and fire, injuries, the identification of typical postcrash fire scenarios, and fire safety concepts and their cost/benefit parameters.

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PREFACE

This report was prepared by the Douglas Aircraft Company, McDonnell Douglas Corporation, Long Beach, California, under contract NAS2-10583. It is the final technical report covering the review of accidents involving postcrash fire, the association between crash characteristics and fire injuries, the identification of typical postcrash fire scenarios, fire safety concepts and their cost and benefit parameters. This work was conducted between April 15, 1980 and February 28, 1981.

This study is the first of a two-phase study program to formulate a hazard analysis capability by which concepts or systems for improvement of postcrash fire safety may be assessed for integration into a given commercial aircraft system.

The following Douglas personnel were the principal contributors to the study:

A. Cominsky	Principal Investigator
F. Duskin	Interiors Engineering
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M. Platte	Systems Analysis

The project was sponsored by the National Aeronautics and Space Administration (NASA), Ames Research Center. Dr. Demetrius Kourtides was the project engineer for NASA.

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SECTION 1
SUMMARY AND CONCLUSIONS

This is the final report for the Phase I portion of the Postcrash Fire Study. The total data base consists of 80 accidents of predominantly jet aircraft flown by domestic airlines. Of these 80 accidents, only 33 are sufficiently well documented for detailed study leading directly to generalized postcrash fire scenarios. Several approach, landing, and takeoff scenarios are developed herein, but more work in this area is recommended.

The development and study of safety concepts are the main purpose of this program. Of the 20 concepts suggested and listed in this report, three have been developed in sufficient detail so that operating and acquisition costs could be estimated. These safety concepts are:

- C_2 – Improved fire-resistant seat material
- P_2 – Anti-misting kerosene (AMK)
- S_1 – Additional cabin emergency exits

Effectiveness estimates were performed for Concepts C_2 and P_2 and two variations of Concept S1. These estimates are summarized in the latter pages of Section 6.

It is clear that more study is required in the areas of those concepts which thus far have not received the attention they deserve. This would provide increased variety in concept design, cost, and effectiveness, and result in a more thorough concept comparison.

SECTION 2
INTRODUCTION

The United States is a leader in the design and production of large commercial aircraft. The aircraft produced by the aircraft industry have been improved continuously because of the industry's concern for reliability and safety. Government regulatory and research activities share in the interest of improved services and increased safety for the public.

Although the fire-safety record in commercial transport aircraft has been continuously improved, aircraft fires still occur.

Recently improved materials placed in use by the aircraft industry represent a step forward in fire-retardant characteristics. Generalized fire scenarios are needed for analysis and development of fire prevention and control. Reliable risk assessment methods should also be developed and systematically applied.

This program is part of a complete study to formulate a hazard analysis capability by which concepts or systems for the improvement of postcrash fire safety may be assessed for integration into a given aircraft system.

In this initial phase (Phase I), the current crash fire problem was characterized to the extent possible by available data. Concepts for improving crash fire safety were defined, and some were evaluated by reviewing their benefit and cost parameters.

Phase I will form the data base for the subsequent activities of establishing the threat response and defining the merit function.

This report contains the results of the Phase I study of the postcrash fires. This study consisted of three tasks:

Task 1 — Definition of the Crash Fire Problem
Task 2 — Crash Fire Safety Concepts
Task 3 — Concept Characterization

For Task 1, a survey was made of impact-survivable postcrash fire accidents. The data base included foreign and domestic accidents involving airlines and jet aircraft. However, the emphasis was placed on domestic accidents, airlines, and jet aircraft due principally to availability of information. This study covered only transport category aircraft in commercial service designed under FAR Part 25.

The relationships between the accident characteristics and the fire fatalities are shown in a matrix (Appendix C) which tends to reveal the severity of each characteristic. Some typical postcrash fire scenarios have been identified.

The Task 2 study produced 20 safety concepts related to areas of the aircraft as follows:

- Five to the cabin interior
- Four to the fuel system and power plant
- Eleven to the primary structure.

The parameters to be used for concept evaluation were identified as belonging to three basic categories:

1. Cost
2. Effectiveness
3. Societal Concerns.

The Task 3 effort consisted of a characterization study of three concepts:

1. Improved fire-resistant passenger seats
2. Anti-misting kerosene (AMK)
3. Additional cabin emergency exits.

SECTION 3
DEFINITION OF CRASH FIRE PROBLEM

This task consisted of reviewing accounts of aircraft accidents of the past 20 years and forming a data base of fire-related accidents. Aircraft fires can be divided into three categories:

1. Ramp fires
2. Inflight fires
3. Postcrash fires

The postcrash fire, usually resulting from impact-survivable crashes of commercial passenger, cargo, and training flights, is the only fire category considered in this study.

An impact-survivable accident is defined in this study as an accident in which all occupants did not receive fatal injuries as a result of impact forces imposed during the crash sequence. An accident is classified as a fatal accident if one or more occupants received fatal injuries. Substantial damage is damage which adversely affects the structural strength, performance, or flight characteristics of the aircraft and which would normally require replacement or major repair unless the accident results in destruction of the aircraft. Accidents and incidents resulting in nonsurvivable impact and minor or no damage were not considered in the crashworthiness analysis.

The data base given in Appendix A primarily involved Boeing, Convair, Douglas, and Lockheed aircraft models B747, B737, B727, B707, C880, C990, DC-10, DC-9, DC-8 and L-1011. The data base reviewed was as large as practical since scenarios have maximum utility if they represent accidents having a high probability of causing a significant portion of the annual lives lost from fire.

Sufficient crash and fire data required for developing fire scenarios were discovered for only 33 of the 80 accidents of the data base (Ref. Tables A-1, A-2, and A-3). These 33 accidents are listed in Table 1.

ACCIDENT DATA BASE

Altogether, 80 substantial damage accidents are included in this survey. This total consists of 46 accidents experienced by U.S. operators on or near U.S. airports; 10 accidents by U.S. operators at airports outside the U.S.; 3 accidents by foreign operators at U.S. airports; and 21 accidents by foreign operators outside the U.S.

TABLE 1
SCENARIO CANDIDATE ACCIDENTS

FLIGHT MODE		
APPROACH	LANDING	TAKEOFF
1-1	2-1	3-1
1-2	2-17	3-3
1-6	2-18	3-7
1-15	2-19	3-8
1-16	2-21	3-9
1-18	2-24	3-12
1-21	2-25	3-14
1-22	2-26	3-17
1-23		3-18
1-24		3-19
1-25		3-21
		3-23
		3-27
		3-28

The accidents of this data base are presented in three groups where each group pertains to the flight mode preceding the crash. These groups are:

1. Approach
2. Landing
3. Takeoff

Approach accidents occur while the aircraft is descending on approach before reaching the airport. This flight mode is generally characterized by flight along or near the glide slope with approach speed, power, flaps, and gross weight with landing gear down. Impact can be with trees, level or sloping ground, ditch, embankment, dike, water, vehicles, buildings or light support structures. These accidents are numbered 1-1 to 1-27 in Table A-1 of Appendix A.

Landing accidents occur when the aircraft touches down on or near the runway, and overruns or veers off the runway after touchdown. This flight mode is characterized by flared-out flight with landing speed, power, flaps, and gross weight with landing gear down. These accidents are numbered 2-1 to 2-27 in Table A-2 of Appendix A.

Takeoff accidents occur while the aircraft is moving on the runway for takeoff or after liftoff prior to retracting the landing gear and flaps. A tire or engine failure usually occurs. The wheel or engine braking action is thus reduced and asymmetrical, and the aircraft overruns the airport runway. These accidents are numbered 3-1 to 3-25 in Table A-3 of Appendix A.

Some taxiing and parking accidents produce aircraft damage. However, resulting injuries and fire damage are insubstantial. These accident types will not be studied.

Some totals and subtotals of all the injuries for the 80 accidents of Appendix A which form the data base for this study are presented in Table 2. Here are found totals per accident group (approach, landing, and takeoff) as well as totals for airplane size groups (small, medium, and large).

Aircraft Grouped by Size:

Small – B737, CV-580, CV-640, DC-9, FH-227, and L-382
Medium – B707, B727, B720, CL-44, CV-880, CV-990, DC-8, L-188
Large – B747, DC-10, L-1011.

A comparison among these size and flight mode groups is given on the basis of:

1. Injuries per accident
2. Percentage of total injuries.

Some conclusions that can be drawn from the values of Table 2 are:

1. Approach accidents resulted in the largest number of fatalities (1041) or 46 percent of all fatalities, whereas takeoff accidents produced the largest number of fire fatalities (505).

2. Approach accidents produced the largest number of fatalities (39) per accident, whereas takeoff accidents produced most fire fatalities (20) per accident.

3. The statistical prominence of fire deaths among takeoff accidents is due entirely to the Tenerife double accident, which claimed a total of 390 fire deaths.

4. Medium-sized aircraft have produced the greatest number of fire fatalities for approach and landing accidents (19 and 14 respectively). Large-sized aircraft have produced the greatest numbers of fire fatalities during takeoff (78) due again to the Tenerife accident.

FIRE DYNAMICS DATA BASE

The accident data base given in Appendix A has been reviewed to extract a list of fire accidents which have substantial fire, injuries, and fire damage. Detailed descriptions of these accidents have also been studied. With a serious accident, these characteristics are generally present.

There are 33 accidents with descriptions adequate to become candidates for scenario development, listed in Table 1. The principal source of these data was the NTSB blue books.

TABLE 2
INJURY SURVEY: POSTCRASH FIRE – SURVIVABLE ACCIDENTS

ACCIDENT GROUP	NUMBER OF ACCIDENTS	NUMBER OF PASSENGERS AND CREW					AVG INJURIES PER ACCIDENT			PERCENTAGE OF TOTAL			
		TOTAL	N/M*	SERIOUS	FATAL		SERIOUS	FATAL		SERIOUS	FATAL		
					TOTAL	FIRE		TOTAL	FIRE		TOTAL	FIRE	
1. APPROACH	27	1810	388	293	1041	450	11	39	17	37	46	34	
2. LANDING	28	2067	1454	192	421	357	7	15	13	24	19	27	
3. TAKEOFF	25	3120	1999	307	813	505	12	33	20	39	36	39	
TOTAL	80	6997	3841	792	2275	1312	10	28	16				
SMALL													
1. APPROACH	10	489	40	50	392	147	5	39	15	37	84	80	B 737 CV-580 CV-640 DC-9 FH-227 L-382
2. LANDING	4	203	124	22	62	24	6	16	6	16	13	13	
3. TAKEOFF	3	372	295	63	13	12	21	4	4	47	3	7	
TOTAL	17	1069	459	135	467	183	8	27	11				
MEDIUM													
1. APPROACH	15	978	248	179	550	289	12	37	19	35	51	40	B 707 B 727 B 720 CL-44 CV-880 CV-990 DC-8 L-188
2. LANDING	24	1859	1330	170	359	333	7	15	14	34	33	46	
3. TAKEOFF	17	1608	1286	157	165	103	9	10	6	31	15	14	
TOTAL	56	4445	2864	506	1074	725	9	19	13				
LARGE													
1. APPROACH	2	343	180	64	99	14	32	50	7	42	13	3	B 747 DC-10 L-1011
2. LANDING	0	0	0	0	0	0	0	0	0	0	0	0	
3. TAKEOFF	5	1140	418	87	635	392	17	127	78	58	87	97	
TOTAL	7	1483	598	151	734	406	22	105	58				

*N/M = NONE OR MINOR INJURY

(REF TABLES A-1, A-2 A-3)

The descriptions of the candidate accidents are given in Appendix B. The descriptions of each of the 11 approach and 8 landing accidents are in the form of fire scenarios. These are a set of chronologically arranged events starting from the flight mode just prior to the accident and ending when the fire is extinguished.

Descriptions of the candidate takeoff accidents are presented in six paragraphs of Appendix B, each of which contains information according to headings given on the first page of the Appendix.

CRASH CHARACTERISTICS AND ASSOCIATED INJURIES

The accident scenarios and fire dynamics descriptions assembled in Appendix B were used to determine a relationship between crash characteristics and associated injuries. For this purpose, a matrix was prepared for each of the three accident categories: approach, landing, and takeoff. Each row of the matrix represents an accident with about 35 crash characteristics entered in the matrix columns.

An estimate of the numbers of fire fatalities attributed to the significant crash characteristics is presented in the bottom four rows of each matrix. These rows provide some indication of the seriousness of each characteristic.

The accident characteristics are placed in columns in the matrices located in Appendix C. These columns are assembled into seven groups which are discussed and listed in the preamble to Appendix C.

The matrix of approach accidents, with 11 events recorded, is presented in Table C-1. The most serious structural failure appears to be the "ruptured wing tank" with a rating of 40 fire fatalities per accident. The most common structural failure is shown in the "landing gear separated" column where 9 occurrences are recorded, resulting in a rating of 28.4 fire fatalities per accident.

The most dangerous terrain consists of trees and dikes or walls. This kind of terrain is rated at 47 fire fatalities per accident. Most if not all of these impacts occurred in off-runway landings. This matrix method of rating crash characteristics helps to provide an indication of which crash characteristics belong in the generalized crash scenarios.

The matrix of landing accidents, with eight events recorded, is presented in Table C-2. The most serious structural failure is the "wing separated" with a rating of 32.5 fire fatalities per accident. The "engine separated" damage is more common but not as lethal per accident. "Explosion" appears to have the highest fire fatality rating (55.5 fire fatalities per accident). The "bounced back into air" characteristic was a substantial factor in the high number of fatalities for accident No. 2-17.

The matrix of takeoff accidents, with 16 events entered, is presented in Table C-3. The structural failure with the highest rating of fire fatalities per accident is the "wing separated" failure. However, the most common failure is the "ruptured wing tank" (12 accidents) followed closely by the "separated landing gear".

"Fuselage breaks" become prominent in the category of takeoff accidents, with 60.5 fire fatalities per accident rating, in spite of the fact that this accident characteristic permits occupants access to safety. Other factors that deserve serious consideration in this accident category are:

1. "Vehicles" in the path of motion (63 fire fatalities per accident)
2. "Cabin debris" which interferes with egress (79.7 fire fatalities per accident rating)
3. "Fuel spill" with a rating of 62.4 fire fatalities per accident.

GENERALIZED POSTCRASH FIRE SCENARIOS

Three groups of Generalized Postcrash Fire Scenarios (GPFS) were developed. These break down into:

1. Approach flight mode
2. Landing flight mode
3. Aborted takeoff.

These scenarios were constructed from data derived from actual accidents, with emphasis on the more serious mishaps. This is a preliminary effort to define typical GPFSs that are vital for judging the availability of adequate passenger egress capability in existing and future aircraft. The GPFSs given in this report were based on data from past accidents and may be satisfactory for existing aircraft. Adjustments to these GPFSs may be required for aircraft designed in the future.

The events of the GPFS grouped in the approach flight mode and in the landing flight mode are arranged in chronological order. The aborted takeoff GPFSs are presented in the form of failures of high probability that result in serious consequences. These aborted takeoff GPFSs are divided into three basic types:

1A — Aircraft does not become airborne
1B — Aircraft becomes airborne but returns to land before retracting landing gear or flaps
2 — Collision with aircraft or other object during the takeoff roll.

The approach flight mode GPFS contains six variations.

The landing flight mode GPFS contains two variations.

The aborted takeoff GPFS has three variations.

1. **Approach Flight Mode**

The approach flight mode GPFS consists of 13 chronologically arranged events that describe the principal scenario elements which influence the survivability of the aircraft occupants.

The 13 scenario elements are not taken from one accident but some elements represent average values for a group of accidents while other scenario elements represent critical minimum or maximum values from the same group of accidents (Reference Appendices B and C).

The numbers of aircraft occupants for this scenario are average values taken from Table C-1.

Average total = 1043/11 = 95

Average number of serious injuries = 169/11 = 15

Average number of fatalities

Impact trauma = 263/11 = 24

Fire = 310/11 = 28

1. Performance at impact

This scenario is considered to occur at less than full flaps (approximately 25 degrees). Thus the aircraft speed should be taken to be about 15 percent above V_{STALL} and should account for adverse ground winds of about 7.5 knots. The rate of descent is derived from the average of the data of Table C-1.

Relative ground airspeed, $V_{RGA} = 1.15\ V_S + 7.5$

Vertical rate of descent = 2 x airline recommendations

$\approx$ 7.62 m/s (1500 fpm)

2. Preimpact Preparation

This type of accident generally occurs with the crew not fully aware of the true altitude of the aircraft. Thus it will be assumed that:

A. The crew has not issued last minute instructions to the passengers but the safety belts are fastened.

B. The airport fire department has not been alerted to the imminent aircraft ground impact.

3. Location of ground impact

The approach type of accident generally impacts the ground short of the runway anywhere from a few meters to several kilometers. Thus there will be two possible locations.

A. Short of the runway

B. On the runway

4. Structural damage

The following structural systems are prominently involved in approach scenario accidents.

Separated main gear
Separated wing
Ruptured wing tank or fuel line
Separated engine
Fuselage breaks

5. Ground Slide

The ground slide will be short if the aircraft impacts an obstacle but will be long if no sizable obstacle is encountered two lengths of aircraft slide is recommended.

A. 183 m (600 feet) off runway – stopped abruptly at a tree or wall. This is an average for Approach Accidents 1-1, 1-6, 1-23, and 1-25.

B. 792 m (2600 feet) on runway – uniform deceleration. This is an average for Approach Accidents 1-2, 1-15, 1-21, and 1-22.

6. Fire start

A fire can start almost at the time of impact. The source of fuel is a ruptured tank or fuel line. The ignition sources are hot temperature engine parts, electric wiring and/or friction sparks.

A. Five seconds after impact
Source – separated main gear
Fuel – ruptured wing tank
Ignition – electric wiring or friction sparks

B. Six seconds after impact
Source – separated engine
Fuel – ruptured wing tank
Ignition – hot engine parts

C. Six seconds after impact
Source – ruptured fuel line
Fuel – fuel line
Ignition – electric wiring

7. Ground slide time
This is the time from ground impact to when the aircraft comes to a stop. The slide time is a function of impact airspeed and the length of the slide (Ref. Items 1 and 5).

A. Aircraft stops in $\frac{183}{V_{RGA}/1.944}$ seconds (approx.)

B. Aircraft stops in $\frac{792}{V_{RGA}/3.888}$ seconds (approx.)

8. Cabin environment
Substantial cabin debris, many seat failures
Emergency cabin lights fail

9. Fire Department is alerted by control tower.

10. Passengers start to move toward exits when the aircraft becomes stationary.

11. Time available for egress
Time of useful function from impact = 90 seconds (Reference Accident 1-2)

12. Exits used for egress *
Total number of aircraft exits = X
Average total number of aircraft exits = 7.2 (Table C-1)
Average number of exits used when the fuselage breaks = 1 (Table C-1)
Average number of exits used when the fuselage does not break =
1/5 (6 + 2 + 1 + 5 + 4) = 3.6 (Table C-1)

13. Rate of egress
The rates of egress for various types of exits were derived from the data of Approach Accident 1-2. This is one of the very few accidents from which data of this type is available.

Escape time after aircraft came to a halt = 63 seconds

*The numbers of exits used for egress by cabin occupants in these accidents does not reflect the total number of exits usable in all cases.

Exit	Total Number of Survivors	Egress Time Per Survivor
Overwing		
2 Left	17	63 x 2/17 = 7.4 sec
Left Aft	13	63/13 = 4.8 sec
2 Right	5	
Fwd Main Door	11	63/11 = 5.7 sec
Galley Door	9	63/9 = 7.0 sec

2. Landing Flight Mode

As was done for the approach scenarios, landing mode GPFS consist of 13 chronological accident scenario elements which affect passenger and crew survivability. These elements were derived from the landing category accident data described in Appendices B and C.

Passenger egress rates and time of useful function (TUF) were taken from Accident 2-1 whereas some average type values were derived from Table C-2.

The numbers of aircraft occupants for this scenario are average values taken from Table C-2.

Average total = 702/8 = 88

Average number of scenario injuries = 106/8 = 13

Average number of fatalities

Impact trauma = 57/8 = 7

Fire = 171/8 = 21

1. Performance at impact

   This scenario is considered to occur at full flaps (approximately 45 degrees). The airspeed at the point of impact will be taken as V_{STALL} with an increase of ten percent for the possibility of encountering wind shear situation. The V_{WIND} is assumed to be zero. The rate of descent is derived from the average of the data of Table C-2.

   Relative ground airspeed, $V_{RGA} = 1.10\ V_S$

   Vertical rate of descent = 1.4 x airline recommendation

   $\approx$ 5.33 m/s (1050 fpm)

2. Preimpact preparation

   The crew is aware that a landing is imminent. Thus it will be assumed that

   A. The crew has issued last minute instructions to the passengers. The safety belts are fastened.

B. The airport fire department has been alerted if there is a probability of trouble.

3. Location of ground impact
   The aircraft impacts the airport runway
4. Structural damage
   These structural systems are involved in many serious landing scenario accidents
   - Separated engine or wing
   - Wing tank rupture
   - Main and/or nose gear separation
   - Fuselage breaks

5. Ground slide
   The use of wheel braking, reduced reverse engine thrust and approximately V_{STALL} with full flaps helps produce a moderate airport slide average of 320m (1050 feet) in spite of a wet runway. Reference Table C-2.

6. Fire start
   A fire can start almost at the time of impact. The source of fuel is a ruptured tank or fuel line. The ignition sources are hot temperature engine parts, electric wiring and/or friction sparks.

   Average value for ground wind = 9 knots. This type of accident is very frequently accompanied by fog or rain.

   A. Five seconds after impact
      Source – separated main gear
      Fuel – ruptured wing tank
      Ignition – electric wiring or friction sparks

   B. Six seconds after impact
      Source – separated engine
      Fuel – ruptured wing tank
      Ignition – hot engine parts

7. Ground slide time
   This is the time from ground impact to when the aircraft comes to a stop

   The aircraft stops in $\dfrac{320}{V_{RGA}/3.888}$ seconds (approx)

8. Many seat failures
   Emergency cabin lights failed.

9. Fire Department
   The first fire truck arrives at the wreckage at about 1-1/2 minutes (average) after the aircraft has stopped when impact occurred on the runway of a domestic airport.

10. Passenger start to move toward the exits when the aircraft movement is halted.

11. Time of useful function
    Time available for egress is three minutes after the aircraft came to a halt. (Reference Accident 2-1)

12. Exits used for egress
    Total number of aircraft exits = X
    Average total number of aircraft exits = 8.4 (Table C-2)
    Average number of exits used when the fuselage does or does not have breaks = 4.6 (Table C-1).

13. Rate of egress
    The rates of egress for various types of exits were derived from the data of Landing Accident 2-1 described in Reference 2. Witnesses estimated that the evacuation was completed within three-to-five minutes after the aircraft came to a halt. An average of four minutes will be used for actual egress rate estimates.

Exit	Total Number of Survivors	Estimated Minimal Evacuation Time (Sec)	Estimated Actual Evacuation Time (Sec)	Estimated Actual Egress Time Per Survivor (Sec)
Left Fwd Main Door	32	90	180	180/32 = 5.6
Right Fwd Window	1	20	40	
Right Aft Window	25	65	130	130/25 = 5.2
Right Rear Galley Door	40	120	240	240/40 = 6.0

Minimal time estimates derived from evacuation demonstrations showed that evacuation was completed within two minutes (Figure 13, Reference 2).

3. Aborted Takeoff Scenario

Type IA – Aborted Takeoff (Airplane does not get airborne)

This event is an aborted takeoff where the airplane did not get airborne prior to the attempt to stop the airplane. There are a variety of reasons for aborting takeoff, typically tire failures, engine failures, other types of hardware failures, or false signals to the cockpit. The characteristic results are that the airplane leaves the runway or taxiway, resulting in failure of the main gear (8 out of 10). Failure of the main gear causes a rupture of the fuel tank either from the impact forces on the wings (5 out of 8) or from direct damage (3 out of 8) from the failed landing gear. This results in a fuel spill (8 out of 8) and usually a fire (6 out of 8). In two of the eight cases studied, where fuel was spilled and no fire occurred, one aborted takeoff occurred with approximately 6 inches of snow on the ground while the other took place in a ground fog. Once the airplane stops moving, the fuel puddles and fire tends to surround the fuselage within a relatively short time.

Accidents studied in forming the above scenario are listed in Table 3.

TABLE 3
ABORTED TAKEOFF SCENARIO (TYPE 1A) CANDIDATES

ACCIDENT NO.	LOCATION	DATE	MODEL	FATALITIES TOTAL	FATALITIES (%)	FIRE FATILITIES TOTAL	FIRE FATILITIES (%)
3-1	ROME	11-23-64	B707	48/73	(66)	48/73	(66)
3-3	KENTUCKY	11-06-67	B707	1/36	(2.7)	1/36	(2.7)
3-9	STOCKTON	10-16-69	DC-8	0/5	(0)	0/5	(0)
3-14	ANCHORAGE	11-27-70	DC-8	47/229	(21)	47/229	(21)
3-19	BANGOR	6-20-73	DC-8	0/261	(0)	0/261	(0)
3-20	GREENSBORO	12-17-73	DC-9	0/90	(0)	0/90	(0)
3-21	JFK	11-12-75	DC-10	0/139	(0)	0/139	(0)
3-23	DENVER	11-16-76	DC-9	0/86	(0)	0/86	(0)
3-27	LOS ANGELES	3-1-78	DC-10	2/200	(1)	2/200	(0)
3-28	TORONTO	6-6-78	DC-9	2/107	(1.9)	0/107	(0)

TYPE 1B – Aborted Takeoff (Airplane gets airborne, then tries to land on remaining runway)

During the course of a normal takeoff, an initial event occurs during or after rotation which causes an attempt to abort the takeoff and land on the remaining runway. The airplane then contacts the runway again and overruns or slides off the side of the runway, resulting in landing gear failure (if extended) and breakup of the airplane. There is fuel spilled as the airplane breaks up. In the cases that were examined where fire occurred following the fuel spill, the fatalities were 60 to 80 percent of the total number of passengers onboard. Where no fire occurred, even though fuel was spilled, there were no fatalities. (See Table 4.)

TABLE 4
ABORTED TAKEOFF SCENARIO (TYPE IB) CANDIDATES

ACCIDENT NO.	LOCATION	DATE	MODEL	PERCENT OF TOTAL ABOARD	
				IMPACT AND FIRE FATALITIES	FIRE FATALITIES
3-7	SIOUX CITY, IOWA	12/27/78	DC-9-15	0	0
3-8	MOSES LAKE, WASHINGTON	6/24/69	CV880	60	60
3-12	PHILADELPHIA, PA	7/19/70	737-222	0	0
3-17	MOSCOW, USSR	11/28/72	DC-8-62	80	UNKNOWN

TYPE 2 – Aborted Takeoff (Ground collision with other vehicle)

During the takeoff roll, there is a collision that renders the airplane incapable of sustained flight and causes both structural damage and fuel leakage. When the airplane comes to rest, fire consumes most of its structure where there has been damage to the fuel tanks. (See Table 5.)

TABLE 5
ABORTED TAKEOFF SCENARIO (TYPE 2) CANDIDATES

ACCIDENT NO.	LOCATION	DATE	MODEL	PERCENT OF TOTAL ABOARD	
				IMPACT AND FIRE FATALITIES	FIRE FATALITIES
3-18	CHICAGO, Ill.	12/20/72	DC-9-31 AND CV880	22	22
3-25	TENERIFE, CANARY ISLANDS	3/27/77	B747 P.A. AND B747 KLM	89	61

SECTION 4
CRASH FIRE SAFETY CONCEPTS

A review of the crash characteristics and associated injuries shown in Tables C-1, C-2 and C-3 revealed subsystems which deserved to be investigated. These subsystems belonged within the responsibilities of one of the three following engineering groups:

1. Cabin Interiors — cabin subsystems
2. Power Plant — engines and fuel systems
3. Structural Mechanics — primary and secondary structures.

The call for safety concepts brought the following response. These concept descriptions are brief. The concepts that were chosen as candidates for concept characterization in Section 6 have received further definition there.

CABIN INTERIORS — SAFETY CONCEPTS

C1 — Evaluate the effect of reducing the amount of combustible materials in the cabin.

C2 — Appraise the use of more fire-resistant seat materials, such as providing a fire barrier material for the polyurethane seat foams.

C3 — Form an assessment of improving the burnthrough time of various fuselage and cabin sidewall configurations.

C4 — Judge the effect on the use of evacuation slides which have a protective aluminized coating.

C5 — Appraise the use of fire-resistant curtains to divide the aircraft cabin into compartments so as to limit the spread of smoke and flames.

POWER PLANT — SAFETY CONCEPTS

P1 — Appraise the installation of an extinguishing foam application system into the airplane to control internal or external fires.

P2 — Evaluate the use of fuels with anti-misting properties.

P3 — Evaluate methods to alter the flow from open fuel lines.

P4 – Examine concepts of controlling fuel leakage from ruptures at highly stressed attach points (during accidents) by installing localized flexible tank walls.

STRUCTURES – SAFETY CONCEPTS

S1 – Assess the effect of providing additional cabin emergency exit.

S2 – Evaluate the effect on the crashworthiness of aircraft cabins if selected crash scenarios were used as aircraft design conditions.

S3 – Assess the use of more severe criteria for the attachment and structural design of galleys, ceiling panels, lavatories, and other cabin equipment.

S4 – Establish the effect on the crashworthiness of an aircraft of attaching the main landing gear to the fuselage.

S5 – Determine the effect of placing the wing attach fittings for the main landing gear some distance away from the wing tank areas.

S6 – Evaluate the use of intercostals and seals to keep the fuel away from engine, landing gear, and control surface fittings that are attached to the wing tank structure.

S7 – Assess the value of moving the forward edge of the wing tank aft and/or installing fuel bags along the forward edge of the wing fuel tank, to minimize the effect of aircraft accidents involving impact with trees or utility poles.

S8 – Rate the effect of placing wing-mounted engines on top of the wing between the front and rear spars.

S9 – Study the crashworthiness of a high wing design.

S10 – Evaluate the effect of moving the boundary of the wing inboard fuel tank a prescribed distance outboard of the side of the fuselage.

S11 – Assess the influence on impact energy levels of reductions in approach, landing, and takeoff speeds.

SECTION 5
PARAMETERS USED IN CONCEPT EVALUATION

Appropriate parameters were used to evaluate the degree of merit of various concepts for improving aircraft crashworthiness. The parameters fell into three categories: cost, effectiveness, and societal concern.

The merit of a concept is a function of parameters that are intimate with the design objective of the concept. For each design or conceptual alternative, these parameters take on a specific set of magnitudes. These parameters will be combined into a single number which expresses the merit of the design. The best design among competing alternatives produces the largest merit value.

The cost element can be represented in one of two ways: acquisition cost, or direct operating cost. From the viewpoint of airline management, direct operating cost is the most desirable measure, since it includes the acquisition cost of each incremental change to the airplane. From the manufacturer's point of view he must know, with some precision, the magnitude of costs involved with proposed modifications. In any event, a baseline must be identified and its cost established so as to derive the effect of incremental changes.

Direct operating costs are derived by use of the Douglas Advanced Engineering Method, which represents a continuum of updating of the 1967 ATA Method. The major modifications made for updating include 1980 price levels, current operating practices, profiles and performance, and system attributes. The basic constituents of the direct operating cost (DOC) of aircraft are flight crew, cabin crew, airframe depreciation, engine depreciation, insurance, landing fees, airframe maintenance, engine maintenance, and fuel costs. A typical DOC schedule represents a single airplane with a representative type of operation.

Acquisition costs include the price of the aircraft, with estimates of proposed candidates for changes derived on a discrete basis. This means that proposed modifications to the baseline, such as changes in structures configurations, have been reviewed as separate issues for each configuration. The development program, which includes also the type certification, has been summarized over a given quantity designated as a breakeven point. Cost elements used to derive a price are shown below:

- Design Engineering
- Fabrication
- Assembly
- Inspection
- Tooling

- Raw Materials and Purchased Parts
- Instruments and Special Equipment
- Product Support
- Sustaining Engineering
- Sustaining Tooling
- Manufacturing Development
- Planning
- Flight Test
- Laboratories
- Propulsion
- Miscellaneous

The nature of the study dictates very clearly that case examples have to be structured hypothetically, since quantities of airplanes must be assumed for amortization purposes and break-even determinations. Other factors include use of new or existing aircraft, class of airplane, etc.

The parameters for concept evaluation belong to the three categories previously mentioned: cost, effectiveness, and societal concerns. A list of parameters follows:

1.	Cost	—	Direct Operation Cost
			Acquisition Cost
			Weight
2.	Effectiveness	—	Change in the Number of Fatalities
			Change in the Number of Injuries
			Change in the Severity of Injuries
			Change in Time of Useful Function (TUF)
			Change in Litigation Fees and Settlements
3.	Societal Concerns	—	Environmental Pollution
			Energy Conservation

For purposes of cost and effectiveness estimating, acceptable concepts will be considered either of the type which could be retrofited on existing aircraft or of the type which could only be factory installed. However, the effectiveness of the concept applies only to the few aircraft involved in accidents resulting in fire fatalities and injuries. Furthermore, some concepts may benefit more passengers than other concepts. On this account, the costs, effectiveness, and societal concerns applied to aircraft changes are analyzed on the basis of the total number of transport aircraft to be manufactured during the period from 1985 to 2005. This analysis permits making an equitable comparison of different concepts. It seems fitting to estimate the costs, effectiveness, and societal concerns from 1985 to 2005 as this is approximately the period that would benefit from any useful concepts resulting from this study. A 20-year period is considered appropriate for a new generation of aircraft. It will be necessary to project existing data into the future to obtain numbers of accidents, fatalities, injuries, aircraft in service, airline flights, and passengers for the 20-year period to be used.

It is possible that some concepts may do better in combinations than other concepts. However, our evaluation has been performed for the selected concepts on the basis that each concept to be analyzed is the only concept added to an otherwise conventional aircraft of current vintage.

SECTION 6
CONCEPT CHARACTERIZATION

The exercise of concept characterization lays the foundation for the concept evaluation task of Phase II of the Postcrash Fire Study. Methods and examples of costing various concepts are given as well as a method of judging concept effectiveness.

There are two types of safety concepts:

1. One type requires a change to the basic structure that can only be incorporated during the construction of the aircraft. These changes will be introduced gradually into the world fleet. Structures concept S1, which calls for additional emergency exits in the cabin, and S8, which calls for engines mounted on top of the wing, are examples of this type of structural modification (see Section 4).

2. This type of concept can be implemented in an aircraft after the aircraft has been completed. The world fleet could be modified to conform with this concept in a finite length of time. Most of the interiors and power plant concepts involve changes of this type.

To make a fair cost comparison between the Type 1 and Type 2 safety concepts, a realistic cost evaluation will be needed. Thus, the Type 1 costs have been computed in a manner compatible with the gradual introduction of such safety concepts into the world fleet. By contrast, Type 2 costs have been assumed to occur soon and to permit world fleet conversion over a period of a few years. Type 2 costs might include labor needed to remove obsolete equipment from the aircraft already in service. Additional costs for Type 2 concepts should also include modified, new aircraft brought into airline service as replacements over a period of years.

Concept effectiveness has been determined by examining each appropriate aircraft accident to judge how a concept could influence the Crashworthiness Index as discussed under Concept Effectiveness later in this section. An example of this technique is an analysis accomplished for two variations of the structural safety concept S1.

Concept costs need to be based on the future size of the world fleet, and concept effectiveness needs to be based on future numbers of aircraft flights and future numbers of airline passengers and crews. To produce these goals, statistical predictions have been made of future world airline usage. These predictions are presented in Appendix D.

Analyses of societal concerns for the concepts of this study are beyond the scope of this investigation.

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RULES FOR CONCEPT EVALUATION

Methods for estimating costs and effectiveness may vary from concept to concept. Thus, certain rules are needed to permit concept estimates to be comparable. The following estimating rules are recommended for utilization in the Cost/Benefit Assessment Task of the Phase II effort.

1. The concept will be considered for only one of three classes of aircraft (i.e. small, intermediate, and jumbo).

2. The design, test, and certification work will be accomplished during the period from 1981 to 1985.

3. The new aircraft will be fabricated during the 1985-2005 period at a rate of 100 per year. This rule is established so as to implement safety concepts which are so radical that they must be designed into the original aircraft.

4. For safety concepts which can be so implemented as to be installed retroactively, it will be assumed that the world fleet is converted during the years 1981-1985.

5. The airline service evaluation of the direct operating cost and effectiveness of a concept will be for the period 1985-2005.

6. The number and types of accidents for a particular class of aircraft without the safety concept will be projected to the future from accident data for the 1960-1979 period.

7. The distribution of yearly departure totals will be as follows:

Small aircraft	2X departures
Intermediate aircraft	2X departures
Jumbo aircraft	X departures

8. Departures of aircraft equipped with the proposed safety concept will be assumed to contain 100-percent load factor.

9. The numbers and types of injuries for accidents of the 1985-2005 period for particular classes of aircraft without the safety concept will be projected directly from accident data for 1960-1979. This projection will serve as the base data for judging the effectiveness of a safety concept.

DESCRIPTION OF SELECTED SAFETY CONCEPTS

There are a total of twenty safety concepts described in Section 4. By engineering group they are:

Five for cabin interior

Four for power plant

Eleven for structures

Three of these concepts (one from each engineering group) were selected for design definition and cost and effectiveness analysis. This effort is described below and the selected concepts are:

C2: Improved fire-resistant seat materials

P2: Anti-misting kerosene (AMK)

S1: Additional cabin emergency exits

Safety Concept C2: Improved fire-resistant seat materials

Organic materials used to construct passenger seats account for approximately 10 percent of the entire organic weight of aircraft cabins. Seat cushions are largely comprised of fire-retardant polyurethane foam, but there are seat materials being developed which may improve the fire resistance of passenger seats.

A NASA-funded program to evaluate passenger seat materials has provided the following conclusions:

1. Because it is highly fire-resistant at moderate heat flux values and lighter than polyurethane foam, polyimide foam may replace polyurethane in the near future.

2. A polyurethane cushion incorporating a protective fire barrier is a feasible approach.

The cost and weight impacts of improved fire-resistant seat cushions are illustrated by Figures 1 and 2, respectively. Eight configurations are listed, each representing a complete cushion assembly, i.e. upholstery, liner, fire blocking, if applicable, and the cushion itself. The costs include materials and labor. Configuration No. 1 is a baseline, representative of a contemporary in-service cushion assembly. Configurations No. 2, 3, 4, and 5 are polyurethane cushions, each employing a different fire-blocking material. In configurations No. 4 and 5, the wool upholstery is replaced with a Kermel/wool blend. The Airex foam included in configurations No. 4 and 8

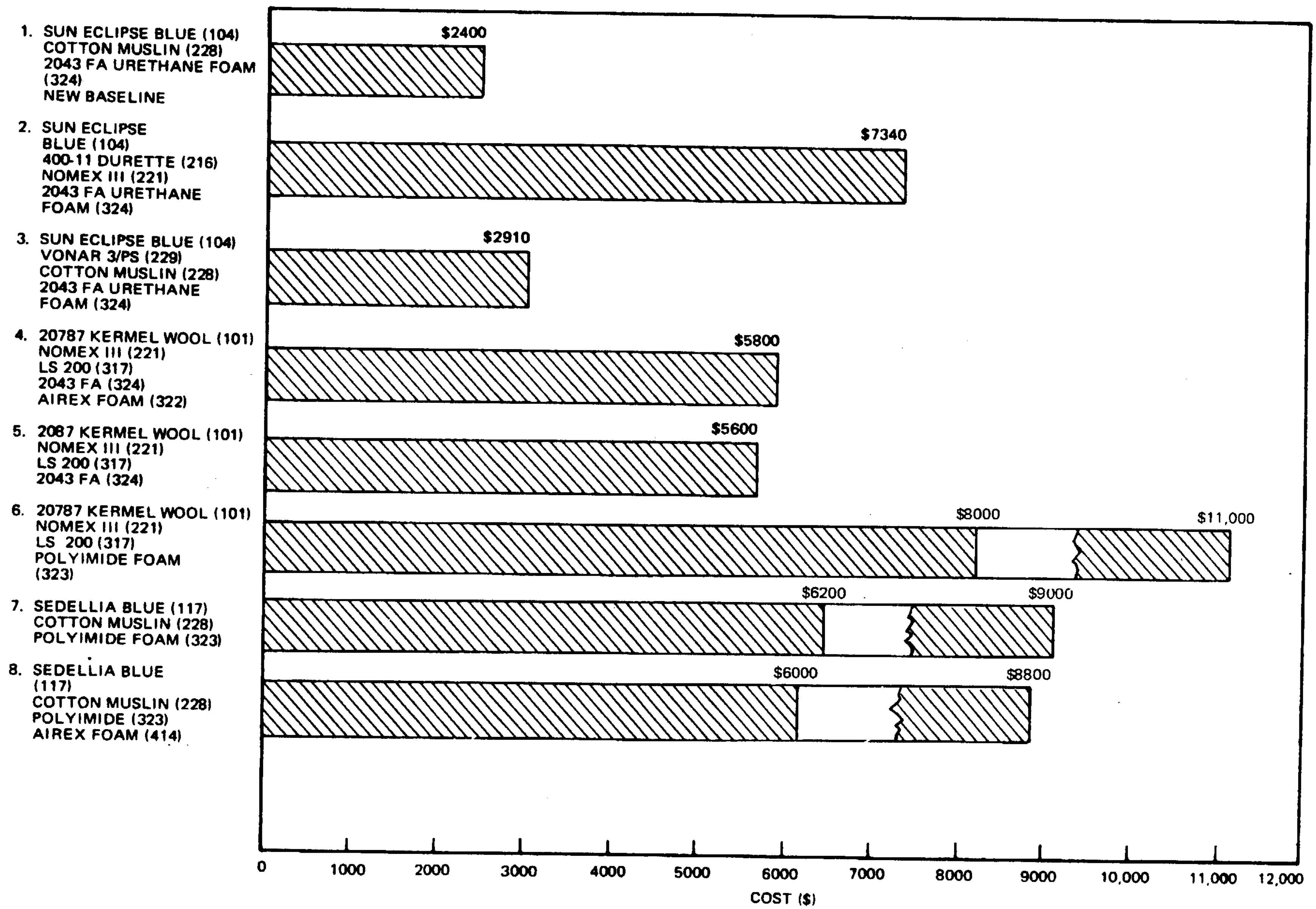

FIGURE 1. COST PER 100 CUSHION SETS (BOTTOM AND BACK)

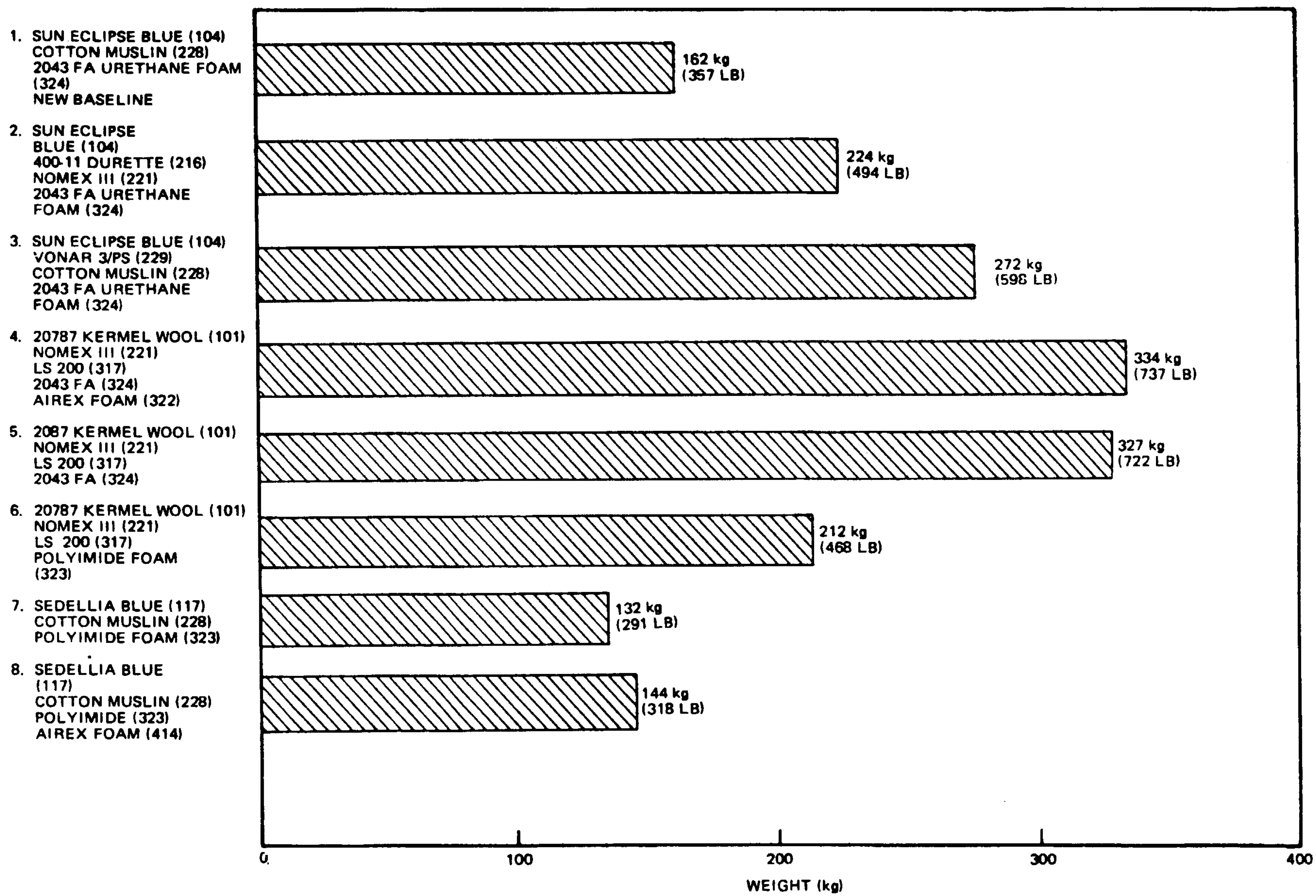

FIGURE 2. WEIGHT ESTIMATE PER 100 CUSHION SETS (BOTTOM AND BACK)

serves as a flotation element. In configurations No. 6, 7, and 8, the polyurethane foam is replaced with a polyimide foam. Because this latter foam is still under development, costs of cushions made with this new foam are represented by a wide range of values.

Full-scale burn tests have been conducted on seat bottoms and seat back cushions constructed for each of the eight seat assemblies. One set of eight has been subjected to a 73.6 kW radiant heat source.

Another set of eight seat assemblies has been subjected to the heat of a pan of burning fuel. The test results are given in Tables 6 and 7.

A survey of the burn test results indicates that Configuration 6 demonstrated superior properties to the baseline and was chosen for cost evaluation. The chief superiority is in the significant "Total Weight Loss" column where Configuration 6 produced the lowest value of all configurations for both types of test subjected to radiant heat and to burning fuel. This low production of the products of combustion is reflected in photometer readings which indicate superior visibility. Temperature measurements have proved somewhat superior, and production of toxic gases is on a par with the other configurations. Figure 1 indicates higher material and labor costs than for baseline cushions. The weight associated with Configuration 6 is 31 percent greater than the baseline weight but is less than that of the majority of the other configurations.

TABLE 6
RESULTS – FULL SCALE FLAMMABILITY TEST OF AIRCRAFT SEAT PROTOTYPES
HEAT SOURCE – 73.6 kW RADIANT ENERGY

SEAT NO.	PHOTOMETER (AVERAGE) (%)	CHX (%)	CO (%)	CO_2 (%)	O_2 (%)	CUSHION TEMPERATURE (AVERAGE) (°C)	CEILING TEMPERATURE (AVERAGE) (°C)	VENT AIR OUT (°C)	TOTAL WEIGHT LOSS (kg)
1 BASELINE	24	0	0	2	19.9	450	270	50	14.5
2	52.5	0	0	0.5	20.5	210	141	50	7.7
3	40	0	0	0.5	20.5	215	162	50	11.6
4	37.5	0	0	0.5	20.5	220	155	50	8.6
5	30	0	0	0.5	20.5	240	134	50	8.9
6	57.5	0	0	0.5	20.5	275	120	40	3.9
7	62	0	0	0.5	20	790	123	40	5.7
8	47.5	0	0	0.5	20.5	275	120	40	4.8

TABLE 7
RESULTS – FULL SCALE FLAMMABILITY TEST OF AIRCRAFT SEAT PROTOTYPES
HEAT SOURCE – FUEL PAN WITH ONE LITER JET A FUEL

SEAT NO.	PHOTOMETER (AVERAGE) (%)	CHX (%)	CO (%)	CO_2 (%)	O_2 (%)	CUSHION TEMPERATURE (AVERAGE) (°C)	CEILING TEMPERATURE (AVERAGE) (°C)	VENT AIR OUT (°C)	TOTAL WEIGHT LOSS (kg)
FUEL PAN ONLY	35	0	0	0.5	20		82	50	–
1 BASELINE	23.5	0	0	2.5	18.5	675	313	75	14.5
2	21	0	0	1	19	375	150	55	5.1
3	22.5	0	0	1	19.5	275	121	50	6.1
4	25	0	0	1	20	100	86	45	3.7
5	27.5	0	0	1	20	85	86	50	2.0
6	30	0	0	1	20	77.5	75	45	0.8
7	30	0	0	1	20.5	138	74	50	1.1
8	17	0	0	1	20	315	89	40	2.8

Safety Concept P2: Anti-misting kerosene (AMK)

Turbine-powered aircraft crashes in which fuel is released from ruptured wing and fuselage tanks can occur in such a manner that the fuel assumes the form of a fine mist. Random ignition sources can turn this mist into a fireball that might envelop the aircraft as it comes to rest.

Suppression of the tendency of the turbine fuel to form this fine mist is the purpose of Safety Concept P2. Such anti-misting fuels have been achieved by addition of a relatively low concentration of polymers having very high molecular weight. In the concept offered here, it has been assumed that the AMK must be degraded (subjected to some mechanical shearing process) to render it suitable for an aircraft engine system.

The factors which influence the AMK concept cost parameters are:

1. Degrader installation (twin-engine aircraft)
   One degrader per engine – weight = 2 × 4.536 = 9.072 kg (20 lb)
   Miscellaneous structure and plumbing – weight = 2 × 4.536 = 9.072 kg (20 lb)
   TOTAL = 18.14 kg (40 lb)

2. Cruise fuel flow increase is 0.06%.
   An estimate of 7.46 kW (10 horsepower) will be used at cruise for degrading fuel.

3. The fuel cost increase is based on \$4.409 per kg (\$2.00 per pound) of additive material plus 1.057 cents per liter (4 cents per gallon) increase for processing and fuel delivery equipment cost.

Safety Concept S1: Additional cabin emergency exits

The sizes and numbers of cabin emergency exits for a transport aircraft are regulated by FAA. In this effort, a study was made of the characteristics resulting from the addition of extra cabin emergency exits. The cost and effectiveness studies were carried out for two and four additional emergency exits which are identified as Safety Concepts S1-1 and S1-2 respectively. In these concepts, the added exits are supplied with "Jet Escape Doors." This door is floor flush, with an escape slide, and it is hinged at the floor line. It is an FAA Type III door. The weight penalty is about 136 kg (300 pounds) per door, including door, hinges, emergency slide, and fuselage doublers.

WORLD AIR TRANSPORT STATISTICS

Basic considerations are as follows:

- Safety concepts will be implemented in future aircraft.
- Concept costs will depend on the total numbers of the future world fleet of transport aircraft.
- Concept benefits will depend on the numbers of future aircraft accidents.
- The number of future aircraft accidents will depend on the numbers of future aircraft flights.
- The number of future casualties will depend on the numbers of future aircraft passenger and crew loads.

Thus, a world air transport statistical survey was carried out for the years 1960-1979 inclusive. From this basic data, projections were made for the years 1980-2005 and are presented in Appendix D. The conclusions of this statistical study are summarized in the plots of Figures D-1, D-2, and D-3.

CONCEPT COST

In this study, the concepts developed have been assessed using arbitrary measures that are intended to gauge the cost benefits. This particular section of the report covers the cost measure (or the sacrifices).

The cost data presented in Tables 8 and 9 were derived in accordance with the simplified assumptions shown below.

1. All cost data are expressed in constant 1980 dollars.

2. Cost data represent budgetary and planning estimates are intended only for the purpose of examining differences among the concepts and are not intended for pricing purposes.

3. Costs are based on the assumption that concepts are applied only to fleet-entry airplanes. This negates the requirement to examine retrofit and modification alternatives.

4. Costs are representative of those which could be experienced with a current state-of-the-art twin-engine commercial air transport.

TABLE 8
DELTA AIRPLANE COSTS FOR GIVEN FLEET SIZE

CONCEPT NUMBER	CUMULATIVE AIRCRAFT COSTS (MILLIONS OF CONSTANT 1980 DOLLARS)				
	NUMBER OF AIRCRAFT				
	100	200	300	400	500
C2 (SEAT MATERIALS) CONFIGURATION 6	1.101	2.201	3.302	4.402	5.503
P2 AMK	6.030	10.351	14.279	17.981	21.534
S1-1 2 EMERGENCY DOORS	17.421	25.695	32.874	39.503	45.732
S1-2 4 EMERGENCY DOORS	41.519	58.940	77.440	92.474	106.849

TABLE 9
DELTA FUEL COSTS FOR GIVEN FLEET SIZE

CONCEPT NUMBER	ANNUAL FUEL COSTS (MILLIONS OF CONSTANT 1980 DOLLARS)				
	NUMBER OF AIRCRAFT				
	100	200	300	400	500
C2 (SEAT MATERIALS) CONFIGURATION 6	0.266	0.533	0.799	1.065	1.332
P2 AMK	20.702	41.404	62.106	82.808	103.510
S1-1 2 EMERGENCY DOORS	0.706	1.412	2.118	2.824	3.529
S1-2 4 EMERGENCY DOORS	1.598	3.195	4.793	6.39	7.988

5. The cost impact caused by fuel does not account for the unpredictable annual increase in the price of fuel, exclusive of inflationary effects.

6. Cost data are presented for fleet sizes varying from 100 to 500 airplanes.

7. Cost data are limited to the nonrecurring and recurring costs required to implement the proposed concepts, and the impact on fuel cost in the category of operating cost.

8. Fuel costs are based on using the airplane at a block distance of 800 n mi, annual productivity of 1,000,000 n mi, and a fuel cost of $0.26 per liter ($1.00 per gallon).

9. Maintenance labor and materials were not considered to be so significant as to warrant detailed examination.

10. The representative transport selected was assumed to be configured as a 185-passenger carrier.

11. Raw materials, purchased parts, and equipment were priced with no advantage in cost assumed for larger quantities.

12. Flight test costs for aircraft implemented with these concepts were considered to be common to the costs associated with the aircraft development and were therefore excluded from this analysis.

Airplane delta costs for the proposed candidates for safety improvements were derived on a discrete basis that involved use of industrial engineering techniques. This means that proposed modifications to the baseline airplane such as structure, equipment, propulsion and fuel system, etc., were all viewed as separate issues for each proposed candidate or concept. This required technical inputs describing the changes and their impact on the weight statement. However, the estimates were not based on the traditional dollar-per-pound approach but rather on man-hours required to accomplish tasks associated with changes. The weight data provided an insight as to the impact of changes in raw materials and fuel.

The cost elements considered in developing the airplane costs are tabulated below:

- Design Engineering
- Sustaining Engineering
- Fabrication Labor
- Planning Labor

- Assembly Labor
- Inspection Labor
- Tooling
- Special Equipment
- Sustaining Tooling Labor
- Raw Materials and Purchased Parts

With the exception of purchased materials, parts, and equipment, all labor estimates were considered to be based on in-house experience. In developing these estimates, the following key assumptions were made:

1. Labor costs include a direct labor rate, overhead, G&A, and a reasonable return on investment.
2. Direct labor rates were varied by organization function.
3. Technologies were assumed to be available and off the shelf.

The effects of safety concepts on the airplane nonrecurring and recurring costs are contained in Table 8 as a function of fleet size. Both types of costs are combined into a single value with no assumptions made about breakeven points. The impact of weight changes on fuel costs is contained in Table 9, as well as any changes that occur to alter fuel consumption as a result of various types of safety concepts.

In developing costs for the escape doors, each type of door was broken down into three primary areas for which labor costs were developed and segregated. These door elements were the door, jamb, and panel. The slide and miscellaneous hardware were excluded because they were considered to be purchased parts, and those costs were developed in the materials category. All labor, however, was calculated as fabrication and assembly labor. Tooling was estimated based on the location of the door in its specific area of the fuselage; and if commonality existed with any other door, it was considered in the estimate. Fuel cost deltas reflect the impact of the delta door weight, with credit given for fuselage structure removed.

Estimated cost impact of the introduction of new seat materials is reflected only in the delta procurement cost of the new seats plus the impact of the delta weight on the fuel usage. Since seat structure was not involved, it has been assumed that installation costs for seats will remain constant and should be excluded from the analysis.

With respect to the anti-misting kerosene concept, the estimated cost impact has included procurement of a degrading device (which was assumed to be developed, and hence procured as an off-the-shelf item) and its installation, including fabrication and assembly of miscellaneous structure and plumbing to accommodate the device. The total impact of weight per aircraft caused by the anti-misting device and miscellaneous hardware is 18 kg per airplane. However, the degrader is expected to result in an increase of cruise fuel flow of 0.06 percent, estimated on the basis that 7.46 additional kW will be used at cruise for degrading the fuel. This is in addition to the fuel increase expected as a result of the delta weight. A fuel cost increase of $0.02 per liter has been factored into the estimate, based on an assumed additive material cost of $0.91 per kg plus $0.01 per liter processing and fuel delivery equipment cost.

CONCEPT EFFECTIVENESS

Available time permitted the study for concept effectiveness to be carried out for Concept S1 only. This is the concept which calls for the addition of extra cabin emergency exits. Two variations of this concept (Concepts S1-1 and S1-2, two and four exits, respectively) were investigated to provide information on the influence of higher quantities of exits. The results of this study are dependent on the accuracy of the basic assumptions and estimates.

The effectiveness of these two concepts was estimated by evaluating their Crashworthiness Index (CI_X)

where: $$CI_X = \frac{\Delta_A}{\left(1 - \frac{\Delta_F}{F}\right)\cdot\left(1 - \frac{\Delta_S}{S}\cdot\frac{1}{10}\right)\cdot\left(1 - \frac{\Delta_A}{A}\cdot\frac{1}{4}\right)\cdot\left(1 - \frac{\Delta_{TUF}}{TUF}\right)}^{*}$$

X = The safety concept identification number

F = Total number of fire fatalities

Δ_F = Change in the number of fire fatalities due to the incorporation of a safety concept. (A decrease in the number of fatalities is positive.)

S = Total number of injuries

Δ_S = Change in the number of injuries. (A decrease in the number of injuries is positive.)

A = Total number of aircraft accidents.

*Make the lesser of $\frac{\Delta_F}{F}$ and $\frac{\Delta_{TUF}}{TUF}$ equal to zero

Δ_A = Incremental number of accidents to aircraft with improved crashworthiness due to the safety concept under examination.

TUF = Time of Useful Function, i.e., the time span, usually in seconds, during which a passenger is in control of his actions and can take purposeful steps to evacuate the cabin and its hostile environment.

Δ_{TUF} = Change in the TUF of the cabin occupants due to the installation of a safety concept.

The weighting factor of 1/10 was associated with the Serious Injury Factor, Δ_S/S, by virtue of the hypothesis that 10 serious injuries are equal to one fatality in estimating the value of a safety concept.

The Accident Factor, Δ_A/A, introduces the concept of the number of aircraft and the vacancy factor of these aircraft which would benefit during their accident involvement from the installation of the proposed safety concept. A weighting factor of 1/4 was assigned to this factor to avoid duplication of benefits already accounted for in the fatality and serious injury factors.

The estimates for Δ_F, Δ_S, and Δ_A were accomplished by examining each accident described in Appendices B and C and passing judgement on the influence of additional emergency exits on passenger egress patterns. The rate of passenger egress was obtained from the evaluation of the reports of actual evacuations given in the Generalized Approach Flight Mode Scenario work of Section 3.

The Time of Useful Function (TUF) was not found to be altered by the addition of emergency exits.

The computations of the Crashworthiness Index for Safety Concepts C2, P2, S1-1 and S1-2 (pages 27-32) were carried out for the accidents listed in Table 1 and described in Appendices B and C. The results produced the following:

CI_{C2} = 11.03 CI_{S1-1} = 11.73

CI_{P2} = 15.16 CI_{S1-2} = 12.28

These CIs were computed based on the premise that the safety concepts in question were incorporated in the aircraft of the 33 accidents of Table 1 at the time of the accident.

The more appropriate value of CI should be computed on the basis of effectiveness estimates projected into the future when the concept is installed in the existing world fleet and/or the new airliners coming off the assembly line.

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APPENDIX A

POSTCRASH FIRE ACCIDENT DATA BASE

This appendix contains the data base resulting from a review of impact survivable post crash fire accidents. They appear in Tables A-1, A-2, & A-3.

The reference source of this data is given in the last column of Tables A-1, A-2 and A-3. These abbreviations stand for the following.

A = ARB = Aircraft Review Board
C = CAB = Civil Aviation Board
D = DAC = Douglas Aircraft Company File
I = ICAO = International Civil Aviation Organization
N = NTSB = National Transportation Safety Board
R = REF = Reference (No.)
FAA-AM = Federal Aviation Administration - Aviation Medicine

TABLE A-1
POSTCRASH FIRE – SURVIVABLE – APPROACH – ACCIDENT

NO	DATE M D Y	AIRCRAFT	LOCATION	AIRLINE	PASSENGERS AND CREW: TYPE OF FLIGHT	TOTAL*: T	TOTAL*: N/M	TOTAL*: S	TOTAL*: F	FIRE: F	FIRE: MODE OF FUEL RELEASE	FIRE: AIRCRAFT DAMAGE	FIRE	REF.
1-1	11 8 65	B 727	N. CONSTANCE, KY	AMERICAN	P	62	0	4	58	29	W	DESTROYED BY IMPACT AND FIRE	AIRCRAFT SLID 104 m (340 FT) THROUGH SCRUB TREES. STOPPED AT LARGE TREES. INTENSE GROUND FIRE AT IMPACT	C 1-0031
1-2	11 11 65	B 727	SALT LAKE CITY, UT	UNITED	P	91	9	35	43	43	RUPTURED FUEL LINE	FUSLAGE DESTROYED BY FIRE	HARD LANDING 102 m (335 FT) SHORT OF RUNWAY. MAIN GEAR SHEARED, INTENSE FUSELAGE FIRE. SLID 865 m (2838 FT) ON FUSELAGE BOTTOM	FAA AM 70-16 C 1-0032
1-3	4 [illegible] 66	DC8	TOKYO, JAPAN	CPA	P	72	0	8	64	37	W	AIRCRAFT DESTROYED BY IMPACT	IMPACT APPROACH LIGHTS 14 3. IMPACT SEAWALL. CAUGHT FIRE ON RUNWAY	I 1970-6
1-4	4 7 66	DC8 52	AUCKLAND, NZ		T	5	0	3	2	0	W, E	FLIGHT DECK, 1, 3 AND 4 ENGINES SEPARATED	RIGHT WING TIP STRUCK GROUND. FIRE IN RIGHT WING ROOT NO. 2 ENGINE FIRE SPREAD TO REAR FUSELAGE	I 1968-10
1-5	4 22 66	L 188C	ARDMORE, OK	AMERICAN FLYERS	P	98	0	14	84	?	T	DESTROYED BY IMPACT AND FIRE	STRUCK HILL 2.4 km (1 1/2 MILES) FROM AIRPORT	R(1)
1-6	[illegible] 3 67	DC8	MONROVIA, LIBER	VARIG	P	90	16	23	51	40	W	DESTROYED BY IMPACT AND FIRE	IMPACT 1836 m (6023 FT) SHORT. 259 m (850 FT) SLIDE EXTERNAL FIRE ENTERED CABIN AT EMERGENCY EXIT DURING SLIDE	I 1969-15
1-7	11 20 67	CV 880	CONSTANCE, KY	TWA	P	82	0	13	69	0	W	DESTROYED BY FIRE	IMPACT TREES 2852 m (9357 FT) SHORT OF RUNWAY. SHED RIGHT WING. FUSELAGE WAS BROKEN UP	R(1)
1-8	4 28 68	DC8	ATLANTIC CITY, NJ	CAPITOL	T	4	2	2	0	0	E, T	DESTROYED	OFF RUNWAY LANDING, STRUCK DITCH, FAILED LANDING GEAR AND PYLONS, FIRE	R(1) N 1-0009
1-9	6 13 68	B 707	CALCUTTA, INDIA	PAN AM	P	63	49	8	6	?	E, T	SEVERE FIRE DAMAGE	IMPACT TREE 274 m (900 FT) SHORT OF RUNWAY. SHED 4 ENGINES IN GROUND SLIDE	R(1)
1-10	8 2 68	DC8	MILAN, ITALY		P	95			13	?		DESTROYED AFTER IMPACT		D FILE
1-11	12 27 68	CV 580	CHICAGO, ILL	NORTH CENTRAL	P	45	15	3	27	?	W	DESTROYED BY IMPACT AND FIRE	AIRCRAFT STALLED AT 282 m (925 FT) ALTITUDE, AIRCRAFT STRUCK HANGAR UPSIDE DOWN	R(1)
1-12	8 8 70	CV 990	ACAPULCO, MEX	MODERN AIR	C	8	0	8	0	0	W	DESTROYED BY IMPACT AND FIRE	STRUCK TREES, APPROACH LIGHTS, BUILDING. STOPPED 183 m (600 FT) SHORT OF RUNWAY.	N TAPE R(1)
1-13	10 10 70	L 382B	WRIGHTSTOWN, NJ	SATURN	C	3	0	0	3	1	T	DESTROYED	IMPACT TREES, GROUND 1667 m (5470 FT) SHORT OF RUNWAY FIRE AND EXPLOSION FOLLOWED IMPACT	R(1)
1-14	6 7 71	CV 580	NEW HAVEN, CONN	ALLEGHENY	P	31	0	3	28	28	W	WINGS AND ENGINES SEPARATED	IMPACT 3 BUILDINGS 1490 m (4890 FT) SHORT OF RUNWAY. FUSELAGE INTACT. FUEL SPILL. SERIES OF EXPLOSIONS	R(1)
1-15	5 18 72	DC 9-31	FT. LAUDERDALE, FL	EASTERN	P	10	7	3	0	0	W	DESTROYED BY IMPACT AND FIRE	HARD LANDING ON RUNWAY. GEAR DAMAGE, FIRE AT LEFT AND RIGHT WING ROOTS, FUSELAGE EXTR ENGULFED IN FLAMES	N 72-31
1-16	12 8 72	B 737	CHICAGO, ILL	UNITED	P	61	7	11	43	22	T	WING AND FUSELAGE DAMAGE BY IMPACT AND FIRE	LANDING 2.4 km (1 1/2 MILES) SHORT, IMPACT WITH HOUSES, SHED BOTH ENGINES. INTENSE FIRE IN CABIN CENTER SECTION	R (1) N. 73-16
1-17														
1-18	12 29 72	L 1011	N. MIAMI, FLA	EASTERN	P	176	17	60	99	14	T, W (LT WING)	AIRCRAFT DESTROYED BY IMPACT	29 km (18 MILES) SHORT OF RUNWAY IN MUD UNDER 25 cm (12 IN.) WATER FUSELAGE DISINTEGRATED. CABIN FIRE FROM SPRAYED FUEL	N. 73-14
1-19	7 23 73	FH 227B	ST. LOUIS, MO	OZARK	P	44	0	6	38	0	W	ALL SEATS, 3 SEATBELTS FAILED	IMPACT 3.5 km (2.3 MILES) SHORT. OUTER AND CENTER WING SECTIONS SEPARATED FROM AIRCRAFT. MAIN GEARS BROKE OFF	R(1) N. 74-5
1-20	7 31 73	DC 9-31	BOSTON, MASS	DELTA	P	89	0	1	88	44	E, T, W	DESTROYED BY IMPACT AND FIRE	STRUCK SEAWALL 914 km (3000 FT) SHORT. WING AND FUSELAGE FRAGMENTED AND CONSUMED BY FIRE	N 74-3
1-21	11 27 73	DC 9-32	CHATTANOOGA, TENN	DELTA	P	79	75	4	0	0	E	SUBSTANTIAL	STRUCK LIGHTS AND DIKE 239 m (785 FT) SHORT. LEFT WING AND LEFT GEAR SEPARATED. FIRE AT LEFT WING ROOT AND ENGINE	N 74-13
1-22	12 17 73	DC-10	BOSTON, MASS	IBERIA	P	167	163	4	0	0	T	LEFT FUSELAGE SIDE FIRE	IMPACT LIGHT PIERS AND EMBANKMENT. NO. 1 AND NO. 3 ENGINES AND PYLONS SEPARATED. RUPTURED LEFT WING TANK FED FIRE	N 74-14
1-23	1 30 74	B 707	PAGO PAGO, SAMOA	PAN AM	P	101	0	5	96	95	W	4 ENGINES SEPARATED	STRUCK TREES AND GROUND 2550 m (8365 FEET) SHORT. SEVERE WING AND FUSELAGE FIRE. ONLY 1 TRAUMA FATALITY	N 74-15
1-24	9 11 74	DC 9-31	CHARLOTTE, NC	EASTERN	P	82	1	10	71	39	W	WING BROKE IN SECTIONS FUSELAGE BREAKUP	IMPACTED TREES AND GROUND 5.3 km (3.3 MILES) SHORT. FIRE IN CABIN DURING SLIDE OUT. THERMAL FATALITIES	N 75-9
1-25	6 24 75	B 727	JAMAICA, NY	EASTERN	P	124	0	12	112	26	W	DESTROYED BY IMPACT AND FIRE	IMPACT APPROACH LIGHTS. LEFT WING DAMAGED. FIRE ERUPTED. IGNITION SOURCES: ENGINE WINGS, FRICTION	N 76-8
1-26	3 4 77	DC8 63	NAIMEY, NIGERIA	ONA	C	4	0	2	2	0	E, W	SUBSTANTIAL IMPACT AND FIRE	IMPACT CONCRETE POST 503 m (1650 FT) SHORT, AIRCRAFT ROLLED BACK, CAUGHT FIRE. TRAUMA INJURIES ONLY	D. FILE
1-27	9 29 77	DC8-62	KUALA LUMPUR, MAL	JAL	P	79	3	42	34	26		DESTROYED BY IMPACT AND FIRE	IMPACT TREES 8 km (5 MILES) SHORT. AFT FUSELAGE BROKE OFF. FRONT SECTION EXPLODED IN FLAMES	D. FILE

*T = TOTAL
N/M = NONE/MINOR INJURIES
S = SERIOUS INJURIES
F = FATALITIES

E: ENG
T: TANK
W: WING

A: ARB
C: CAB
D: DAC
I: ICAO
N: NTSB
R: REF

TABLE A-2

POSTCRASH FIRE – SURVIVABLE – LANDING – ACCIDENT

NO	DATE M D Y	AIRCRAFT	LOCATION	AIRLINE	TYPE OF FLIGHT	PASSENGERS AND CREW: TOTAL* T	N/M	S	F	FIRE F	FIRE: MODE OF FUEL RELEASE	AIRCRAFT DAMAGE		REF.
2-1	7 11 61	DC8	DENVER, COLO	UNITED	P	114 + 8	64 + 8	33 + 0	17 + 0	17 + 0	E, W	NO. 2 AND NO. 4 ENGINES TORE LOOSE	NO. 4 ENGINE FUEL SPILL FIRE SPREAD TO FUSELAGE RIGHT SIDE. NO. 2 ENGINE CRUSHED UNDER LEFT WING	FAA-AM 70-16
2-2	1 1 64	B 720	JFK	AMERICAN	P	12	12					MAIN LANDING GEARS FAILED RR WARD	SMALL FIRE NO. 3 ENGINE EXTINGUISHED BY AIRCRAFT EQUIPMENT	R (1)
2-3	8 26 64	B 707	KANSAS CITY, MO	TWA	P	138	138					LANDING GEARS SHEARED FROM AIRCRAFT	FRICTION INDUCED SMALL FIRE IN AFT FUSELAGE EXTINGUISHED BY AIRCRAFT EQUIPMENT	R(1) I: 1-0043
2-4	2 13 65	B 707	FRESNO, CA	PAN AM	T	4	4	-				NO. 1 ENGINE POD DRAGGED ON RUNWAY	FIRE IN NO. 1 ENGINE EXTINGUISHED BY AIRCRAFT EQUIPMENT	R(1)
2-5	3 26 65	B 707	SAIGON, VIET NAM	PAN AM	P	170	170	–		–		NO. 4 ENGINE CONTACTED RUNWAY	ENGINE FIRE WAS EXTINGUISHED WITH AIRCRAFT EQUIPMENT	R(1) N (1-0049)
2-6	6 14 65	DC8	SANTIAGO, CHILE		P	7	7	-		-		TIRES, WHEELS, BRAKES, LEFT MAIN GEAR	SMALL LANDING GEAR FIRE	R(1) N (1-0039)
2-7	7 1 65	B 707	KANSAS CITY, MO	CONTINENTAL	P	66	66	-	-	-		SLID OFF END OF RUNWAY	FIRE AFTER IMPACT	R(1)
2-8														
2-9	2 13 66	B 720	DALLAS, TEX	BRANIFF	P	128	128	–	–	–		NORMAL LANDING	NO. 1 ENGINE BURST INTO FLAME. EXTENSIVE DAMAGE TO LEFT WING AND NO. 1 ENGINE PYLON	R(1) A: SUMRY
2-10	3 21 66	CL-44	NORFOLK, VA	FLYING TIGER	C	6	5	1	–	–	W	LEFT WING SEPARATED FROM AIRCRAFT	AIRCRAFT ROLLED ON BACK AND SLID ON RUNWAY. BURST INTO FLAMES	R(1) N(1-0013)
2-11	1 23 67	CV-640	SAN JUAN, PR	CARIBBEAN ATLANTIC	P	28	28	–	–		W	RIGHT WING ENGINE AND AND MAIN GEAR SEPARATED	SMALL FIRE AT RIGHT WING SEPARATION. EXTINGUISHED BY GROUND EQUIPMENT	R(1) N (1-0047)
2-12	4 25 67	B 707	SAN FRANCISCO, CA	TWA	T	3	3	–	–	–		3/4 NOSE GEAR STRUT GROUND AWAY	MINOR FIRE AFTER LANDING	R(1)
2-13	4 23 68	DC8	QUITO, ECUADOR	BRANIFF	P	164	164	–	–	–			OVERRAN RUNWAY AT 18-22 KTS. ENTERED DITCH. FIRE IN NO. 2 ENGINE AFTER IMPACT	R(1) A: SUMRY
2-14	4 28 68	DC8	ATLANTIC CITY, NJ	CAPITOL	T	4	2	2	-	–	E, T	FAILED LANDING GEAR AND PYLONS	STRUCK DITCH AND CAUGHT FIRE	R(1) N(1-0009)
2-15	6 13 68	B 707	CALCUTTA, INDIA		P	63	25	10	6	?		DESTROYED BY FIRE	FIRE AFTER IMPACT	N (TAPES)
2-16	5 1 69	CL44	ANCHORAGE, ALASKA	MOBIL OIL	C	4	2	2	0	0	W	WINGS SEPARATED	HARD LANDING, BOUNCED, INVERTED FUSELAGE. AIRCRAFT BURNED AND WAS DESTROYED	N: 3-3871
2-17	7 5 70	DC8-63	TORONTO, CANADA	AIR CANADA	P	109	0	0	109	109	E	SHED NO. 4 ENGINE, SHED NO. 3 ENGINE AND WING	HARD LANDING, BOUNCED, GO AROUND. CLIMB TO 914 m (3000 FT). EXPLOSION. RIGHT WING SEPARATED	A: SUMRY
2-18	12 28 70	B 727	ST. THOMAS, VI	TRANS CARIBBEAN	P	55	42	11	2	2	T	FORWARD AND AFT FUSELAGE BREAK	HARD LANDING, 2 BOUNCES. OVERRAN RUNWAY. LEFT WING ROOT FIRE. 2 THERMAL INJURY FATALITIES	N: 72-8 R(1)
2-19	6 23 73	DC8-61	JFK	ICELANDIC	P	128	120	8	0	0	E	SHED NO. 1 ENGINE	HARD LANDING, TAIL FIRST LANDING, FIRE AT NO. 1 PYLON. EARLY SPOILER DEPLOYMENT	N: 73-20
2-20	10 28 73	B 737	GREENSBORO	PIEDMONT	P	95	95	0	0	0	E, W	SHED RIGHT ENGINE. RUPTURED WING TANK	OVERRAN RUNWAY, 3 LANDING GEAR COLLAPSED. SMALL FIRE NOT NEAR FUEL SPILL	N: 74-7
2-21	1 16 74	B 707	LAX	TWA	P	55	52	3	0	0	HYDRAULIC FLUID	NOSE GEAR FAILURE	FIRE IN BAY UNDER FLIGHT DECK. FIRE DESTROYED COCKPIT AND CABIN INTERIOR. EVACUATION INJURIES ONLY	N: 74-10
2-22	10 12 74	L-188	IVISHAK, ALASKA	FAIRBANKS AIR SERVICE	C	3	3	0	0	0	?	AIRCRAFT BURNED AND WAS DESTROYED	HARD LANDING 18,927 LITERS (5000 GALLON) CARGO OF DIESEL FUEL	R(1)
2-23														
2-24	4 5 76	B 727	KETCHIKAN, ALASKA	ALASKA	P	50	38	11	1	0	W	FUSELAGE INTO 3 SECTIONS. SHED GEARS AND LEFT WING	OVERRAN RUNWAY. FIRE ERUPTED AT IMPACT. DESTROYED BY IMPACT AND FIRE	N: 76-20
2-25	4 27 76	B 727	ST.THOMAS, VI	AMERICAN	P	88	32	19	37	19	W	WING AND FUSELAGE PARTS SHED DURING SLIDE	OVERRAN RUNWAY. RIGHT WING TIP HIT HILLSIDE. FIRE AT RIGHT WING ROOT. CABIN AND COCKPIT FIRE	N: 77-1
2-26	4 4 77	DC9-31	N. NEWHOPE, GA	SOUTHERN	P	85	1	22	62	24	W, STATION PUMPS	5 FUSELAGE SECTIONS	HIGHWAY LANDING. STRUCK TREES, POLES, GAS STATION, VEHICLES. FIRE IN MID AND AFT FUSELAGE. POWER LINE SHORT	N: 78-3
2-27	3 3 78	DC8	SANTIAGO, SPAIN	IBERIA	P	222	170	52	0	0	W	3 FUSELAGE SECTIONS. AIRCRAFT TOTAL LOSS	OVERRAN RUNWAY INTO RAVINE. IMPACT CONCRETE DITCH. LEFT WING FIRE 10 MINUTES AFTER IMPACT	I: TAPE D: FILE

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N/M = NONE/MINOR INJURIES
S = SERIOUS INJURIES
F = FATALITIES

E: ENG
T: TANK
W: WING

A: ARB
C: CAB
D: DAC
I: ICAO
N: NTSB
R: REF

TABLE A-3
POSTCRASH FIRE – SURVIVABLE – TAKEOFF – ACCIDENT

NO.	DATE M D Y	AIRCRAFT	LOCATION	AIRLINE	TYPE OF FLIGHT	PASSENGERS AND CREW TOTAL* T	N/M	S	F	FIRE F	FIRE MODE OF FUEL RELEASE	AIRCRAFT DAMAGE		REF
3-1	11 23 64	B 707	ROME, ITALY	TWA	P	73	12	13	48	48	FUEL LINE AND WING	NO. 4 NAC CABIN CENTER AREA	IMPACT WITH STEAMROLLER. NO. 4 NAC FUEL LINE FIRE, WING TIP FIRE, 2 CABIN EXPLOSIONS	FAA AM 70-16
3-2	9 8 67	B 707	FRANKFURT, GERM.	PAN AM	P	174	173	1	0	0	W	NO. 3 ENGINE, PYLONS, FLAPS, AIL	RIGHT WING FIRE FROM LEAKING TANK	A: SUMRY R(1)
3-3	11 6 67	B 707	ERLANGER, KY	TWA	P	36	34	1	1	1	W	FUSELAGE FORWARD OF WING ROOT, ENGINES 1, 2 AND 3	OVERRAN RUNWAY BY 128 m (421 FT) RIGHT WING FAILED INBOARD OF NO. 4 ENGINE, FIRE AT RIGHT WING AND NO. 3, NO. 4 ENGINES	N: 1-0029
3-4	11 22 67	B 707	HONOLULU, HAWAII	BOAC	P	52	51	1	0	0	T	WING AND LANDING GEAR	NO. 1 ENGINE DISINTEGRATED. FIRE UNDER RIGHT WING	R(1) A: SUMRY
3-5	3 21 68	B 727	CHICAGO, ILL	UNITED	C	3	2	1	0	0	T		OVERRAN RUNWAY, COLLIDED WITH DRAINAGE DITCH, FUEL SPILL GROUND FIRE, EVACUATION INJURY	N: 1-0023
3-6	4 8 68	B 707	LONDON, ENG	BOAC	P	127	84	38	5	5	E, W	NO. 2 ENGINE PORT WING	NO. 2 ENGINE FAILED, CAUGHT FIRE, PORT WING TANKS EXPLODED	R(1) A: SUMRY
3-7	12 27 68	DC9 15	SIOUX CITY, IOWA	OZARK	P	68	65	3	0	0	STARBD W	WINGS, TAIL CONE, VENTRL STAIR OPENING	OVERRAN RUNWAY, AIRFRAME ICING, FUEL SPILL, NO FIRE	N: 70-20
3-8	6 24 69	CV 880	MOSES LAKE, WASH	JAL	T	5	0	2	3	3	W	DESTROYED ON IMPACT AND FIRE	NO. 4 ENGINE HIT RUNWAY, OVERRAN RUNWAY, ROUGH TERRAIN, BREAK UP, FIRE	R(1)
3-9	10 16 69	DC8 63F	STOCKTON, CA	SEABOARD WORLD	T	5	5	0	0	0	E	NOSE AND LEFT GEAR, NO. 2 ENGINE SEPARATED	OVERRAN RUNWAY, CROSSED 3 DITCHES, FIRE NO. 2 PYLON, LEFT WING EXPLOSION, LARGE FIRE	N: 1-0058 R(1)
3-10	4 19 70	DC8	ROME, ITALY	SAS	P	65	53	12	0	0	T	DESTROYED	NO. 1 ENGINE DISINTEGRATED, PUNCTURED CENTER WING TANK, FUEL SPILL, FIRE, EXPLOSION	R(1)
3-11	6 9 70	DC8F	BANGOR, MAINE	TRANS CARIBBEAN	P	217	215	2	0	0		RIGHT MAIN GEAR	2 RIGHT GEAR TIRES BLEW, RIGHT GEAR FIRE, 2 SERIOUS EVACUATION INJURIES	N: 1-0029 R(1)
3-12	7 19 70	B 737	PHILADELPHIA, PA	UNITED	P	61	60	1	0	0			NO. 1 ENGINE FAILED, OVERRAN RUNWAY, SUBSTANTIAL DAMAGE, NO FIRE	R(1)
3-13	8 24 70	L 188	HILL AF BASE, UT	UNIVERSAL	C	3	2	1	0	0	?	FORWARD FUSELAGE BROKE	LIFT OFF, AIRCRAFT PITCHED DOWN, IMPACTED RUNWAY, ENGULFED IN FLAMES	R(1)
3-14	11 27 70	DC8-63F	ANCHORAGE, ALASKA	CAPITOL	P	229	133	49	47	46	W	LEFT WING AFT CABIN RIGHT WING	OVERRAN RUNWAY, STRUCK FENCE, ILS STRUCTURE, DITCH FUEL SPILL, INTENSE GROUND FIRE	N: 72-12
3-15	11 30 70	B 707	TEL-AVIV, ISRAEL	TWA	C	3	3	0	0	0	W	BOTH AIRCRAFT DESTROYED BY FIRE	LANDING GEAR AND WING IMPACTED KC97 AND STRUCK GROUND OFF RUNWAY	
3-16	1 21 72	DC9	N. ADANA, TURK		T	5	1	3	1					
3-17	11 8 72	DC8	MOSCOW, RUSS.	JAL	P	76	0	15	61	?	W	DESTROYED BY IMPACT AND FIRE	TAIL FIRST IMPACT, THEN LEFT GEAR, NO. 1 ENGINE, NO. 2 ENGINE, LEFT WING TIP	D: FILE
3-18	12 20 72	DC9-31	CHICAGO, ILL.	NORTH CENTRAL	P	45	26	9	10	10		FUSELAGE GUTTED BY FIRE	COLLIDED WITH CV 880, LOST RIGHT GEAR, FAILED NOSE AND LEFT GEAR AT TOUCHDOWN, AFT FIRE, FUSELAGE GUTTED	N: 73-15
3-19	6 20 73	DC8	BANGOR, MAINE	ONA	P	261	258	3	0	0		RIGHT GEAR - TIRES AND WHEELS	RIGHT GEAR FIRE DAMAGED RIGHT GEAR, RIGHT WING, AND RIGHT SIDE OF FUSELAGE. EVACUATION INJURIES ONLY	N: 74-1
3-20	11 20 74	B747	NAIROBI, KENYA	LUFTHANSA	P	157	78	20	59	?		DESTROYED BY IMPACT AND FIRE	CRASHED TAIL DOWN IN FIELD	R(1)
3-21	11 12 75	DC 10	JFK	ONA	P	139	137	2	0	0	W	CONSUMED BY FIRE	NO. 3 ENGINE DISINTEGRATED, FIRE ON AIRCRAFT RIGHT SIDE, MAIN GEAR COLLAPSED, WING FUEL SPILL, FUSELAGE FIRE	N: 76-19
3-22	2 16 76	B 727	DENVER, COLO	CONTINENTAL	P	120	119	1	0	0	E	ENGINE	ENGINE SECOND STAGE BLADE FAILED. BLADE CUT FUEL INLET LINE	N: TAPE
3-23	11 16 76	DC9	DENVER, COLO	TEXAS INTERNATIONAL	P	86	84	2	0	0		CABIN INTERIOR	OVERRAN RUNWAY, 26 LIGHT STRUCTURES, 2 DITCHES, FAILED LEFT GEAR SUPPORT STRUCTURE, FUEL SPILL, LEFT FUSELAGE FIRE	N: 77-10
3-24	3 27 77	B 747	TENERIFE, CANARY	KLM	P	248	0	0	248	198	W			
3-25	3 27 77	B747	TENERIFE	PAN AM	P	396	36	34	326	192				N WASH N DATA
3-26	10 2 77	DC8	SHANNON, IRELAND		P	159	142	17	0	0				N: WASHN DATA
3-27	3 1 78	DC10	LAX	CONTINENTAL	P	200	167	31	2	2	W	LEFT SIDE OF AIRCRAFT	OVERRAN RUNWAY, LEFT GEAR FAILED, LEFT WING TANK FAILED. FIRE AT LEFT ENGINE, FUSELAGE RIGHT WING AND ENGINE	N: 79-1
3-28	6 26 78	DC9	TORONTO, CANADA	AIR CANADA	P	107	59	46	2	0		FUSELAGE BROKE IN 2 PLACES	OVERRAN RUNWAY, INTO 16 m (51 FT) RAVINE WING FUEL SPILLS. NO FIRE.	H 80002
3-29	2 9 79	DC9												

*T = TOTAL
N/M = NONE/MINOR INJURIES
S = SERIOUS INJURIES
F = FATALITIES

E: ENG
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W: WING

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C: CAB
D: DAC
I: ICAO
N: NTSB
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APPENDIX B

ACTUAL SCENARIOS OF POSTCRASH FIRE ACCIDENTS

The accident data base of Appendix A was surveyed to determine those accidents for which substantial records were in hand. These accidents numbered about thirty-five. The actual accident and fire scenarios of these thirty-five were extracted from the records and assembled in this appendix. A list of these accidents is given in Table 1 of this report (Section 3).

ACCIDENT #1-1 N. Constance, KY.: B727 : 11-8-65

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
62	0	4	← 58 →	

Nose gear, 2 main gears and tail skid in retracted and locked position. First impact made by right wing with a tree top. Terrain up slope was 9.6°. Aircraft slid 104 m (340 ft.) relatively intact thru scrub trees. Impacted and came to rest amidst a group of larger trees. Nos. 1 and 3 engines separated from fuselage during final impact sequence. Passengers stunned by impact trauma.

Flame at rear of cabin

Aircraft exploded.

Intense ground fire completely destroyed aircraft cabin forward of tail.
Heavy rain started to fall.
Fatalities were attributable to severe trauma, fire or both.

ACCIDENT # 1-2 SALT LAKE CITY, UTAH: B727: 11-11-65

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
91	11	33	——	43

Rate of descent during final approach exceeded 10.16 m/s (2000 fpm.) Indicated airspeed at ground impact was 123 KTS. The aircraft impacted the ground 102 m (335 ft) short of runway. The touchdown was violent. The flight recorder noted a vertical deceleration of 4.7g. Both main landing gears sheared off. Lower fuselage impacted the runway with aircraft slightly nose up. 2-3 seconds after impact, there was a muffled explosion. Initial fire occurred near the tail of aircraft in vicinity of engines. Fire broke out in the right aft section of the cabin (aft of wing T/E). The source of this fire was a fuel line supplying thru aft mounted engines from the wing tanks. This line was ruptured when the right main gear strut was driven up into the fuselage near wing T/E. The fuel from this line, still under pressure, was ignited either from broken generator leads or friction sparks. The resulting fire quickly burned through the cabin floor like a blow torch.

During the final swerve, the fire advanced up the fuselage. When the aircraft stopped, it was engulfed in flame to an area forward of the wing.

Several passengers in aft section of the aircraft left seats and moved forward. They were thrown off their feet during the final swerve. Cabin lights went off and smoke accumulated rapidly.

ACCIDENT #1-2 (Cont'd)

The aircraft skidded for 27 seconds on its belly and nose gear for 853 m (2800 feet) beyond the impact point. About 90 seconds elapsed between impact and the escape of the majority of the survivors. All six of the regular exits were used in escape (4 overwing, forward left door and the mid cabin galley service door). The junior stewardess seated in the center jump seat in the forward section could not press her way to the galley door through the crowd of passengers heading toward the forward boarding door. The senior stewardess was blocked from reaching the forward boarding door by passengers already crowded into the area. The 2nd officer pushed his way into the cabin, opened the forward main door and deployed the slide. The rear stairwell could not be opened.

11 passengers exited the forward main door.
9 passengers exited the galley door
24 passengers exited the overwing exit windows.

The serious impact injury survivors were located in the forward part of the aircraft. Burns involving more than 50% of the body surface were found in all 41 bodies remaining on board after the fire was extinguished. No signs of mechanical trauma was evident in these bodies.

ACCIDENT # 1-6 MONROVIA, LIBERIA : DC-8 : 5-3-67

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
90	16	23	11	40

Aircraft passed over power line 10.4 m (34 ft. 2 in.) above ground level. Aircraft impacted ground 134 m (440 ft.) beyond power line and 1836 m (6023 ft) from the runway threshold.

DESCENT ANGLE = 4.5^{0} DESCENT RATE = 5.84 m/s (1150 ft/min) approx.

The ground slide was about 259 m (850 ft.)

The first ground contact was on both main and nose wheel gears. After a roll of 11 m (36 feet), the right gear entered a hold and the undercarriage failed.

The aircraft caught fire externally during the slide.

Fire entered the fuselage through the overwing emergency exit which came open.

The fire divided the cabin at row 15.

The fire spread more rapidly toward the rear than the front.

From seat row 13 forward, there were 17 passengers and 14 crew members.

Eleven passengers and eleven crew members escaped through the front passenger door, left side.

The pilot in command and navigator escaped through the left side cockpit sliding window.

Six passengers from seat row 11, who subsequently died, did not evacuate through the front section with the others.

ACCIDENT #1-6 (CONT'D)

The cabin staff in the front section were unable to gain access through the cabin to the rear due to the fire at row 15 rendering movement through it impossible.

In the section rear of seat row 13, there were 54 passengers and 5 crew members. Ten passengers and 5 crew members escaped through the left side rear passenger door.

The majority of the 44 passengers aft of seat row 13 who did not survive were capable of movement after the crash. Most of the bodies were found with heads directed to the rear of the aircraft, pyramided between the last 3 rows of seats.

Miscellaneous

Cabin lights failed after first impact rendering evacuation more difficult.
Fwd life raft compartment door opened and partially obstructed the forward left hand door.
The contents of the fwd galley were all over the floor.
Fwd right hand passenger door was never opened.
Aft cabin, forward life compartment came open and permitted the life raft to fall and hit crew member in seat 28D.
Closet in forward cabin broke loose and fell across the aisle.
Crew folding seat at the left aft passenger door broke.
Seat belts broke at seats 2C and 25B.
Confusion and crowding the narrow aisle existed in the darkness.
Egress was difficult due to the number of obstructions and the presence of dense smoke and fumes.
The crash rescue crew reached the scene of the accident in 7 minutes and 40 seconds. They attacked the fire at the front but were too late to save the rear or to assist in passenger evacuation.

ACCIDENT #1-15 FT. LAUDERDALE, FLA.: DC9-31 : 5-18-72

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
10	7	3	0	0

At 61 m (200 ft) altitude, aircraft flew into a wall of water. There was a severe downdraft, associated with the wall of water. The high sink rate resulted in a hard touchdown. Aircraft made contact with the runway on the right main gear. After roll of 4.6 m (15 ft.), the left main gear contacted the runway. The right main gear with a section of the rear sparweb separated from the aircraft at impact. The left main landing gear was pushed up and to the rear but remained attached to the left wing. The nose gear remained in the down and locked position.

Shortly after touchdown, the exterior of the fuselage aft of the wing trailing edge was engulfed in flames emanating from the aft section of both wing root areas. The aircraft skidded on the runway surface for a distance of 853 m (2800 ft). The aircraft departed the right side of the runway and skidded on the adjacent soft dirt surface for another 46 m (150 ft).

All crew members and passengers exited the aircraft through the forward main entry door.

Total egress time was approximately 30 seconds. The first of 3 crash trucks was at the scene, applying foam within 40 seconds of the accident occurrence and the fire was extinguished within 2 minutes.

ACCIDENT #1-16 CHICAGO, ILL.: B737 : 12-8-72

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
61	7	11	18*	25*

*estimated

The aircraft crashed into a residential area 2.4k m (1 1/2 miles) short of the runway. Aircraft was in a wings level, nose high attitude. Aircraft first penetrated the upper branches of a 6 m (20 foot) tree. The descent angle from the initial tree contact to the final impact site was about 4.5^{0}.

The aircraft impacted trees, houses, utility pole cables and garages before it came to rest across the foundation of one of the destroyed houses.

The fuselage was destroyed by impact and fire except for the aft portion of the coach section, the empennage and the left side of the cockpit. Cabin lights went out after the impact. The left main gear was found almost fully retracted. The right main gear was completely separated from the aircraft. The nose gear had been retracted at impact but was torn loose from its mount.

Both engines were separated from the aircraft.

The first witnesses at the crash site stated that the structure on both sides of the aircraft was burning and that white smoke was emanating from the fire.

The fire was very intense around the center section of the fuselage and thick black smoke obscured part of the fuselage.

ACCIDENT #1-16 (Cont'd)

The first fire fighting units were on the scene within 3 minutes of the crash.

Only survivor in the fuselage section forward of the wing was the flight attendant who occupied the aft facing jumpseat at the left forward entry door. She was seriously injured when her seat collapsed and she was trapped by aircraft and house debris.

No first class section seats were recovered intact.

There were 17 survivors in the coach section.

Ceiling panels and hat racks with their contents fell on the passengers and in the aisle of the coach section during impact. Seats dislodged from row 12 to 15 and obstructed the aisle. Six survivors escaped through breaks in the fuselage. Nine passengers and 2 flight attendants exited through the rear service door.

Elevated carbon monoxide levels were found in:

27% of the fatalities in the first class section and

76% of the fatalities in the coach section.

Elevated hydrogen cyanide levels were found in the captain and in six fatalities in the coach sections.

Carbon monoxide and hydrogen cyanide are some of the toxic products of the thermal decomposition of materials such as wool, cotton, paper and plastics.

Deaths of most occupants were attributed to burns. Trauma deaths were described as "multiple injuries" and "extreme/partial body destruction." Several deaths were described as "associated with carbon monoxide/cyanide.

ACCIDENT #1-18 NEAR MIAMI, FLA. : L1011 : 12-29-72

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
176	17	60	85	14

While the aircraft was in a left bank of 28^0, it crashed into the Everglades at a point 30k m (18.7 miles) from Miami. The impact area was flat marshland covered with soft mud under 12 to 25 cm (6 to 12 inches) of water. The left outer wing structure impacted the ground first, followed immediately by the No. 1 engine and then the left main landing gear. After impact, a flash fire developed from sprayed fuel. Some of the burning fuel penetrated the cabin area, causing 14 passengers to suffer various degrees of burns on exposed body surfaces.

No complete circumferential cross section remained for the passenger compartment of the fuselage, which was broken into four main sections and numerous small pieces. The entire left wing and left stabilizer were demolished.

The left main gear and nose gear and portions of their attach structure were separated from the airplane and extensively damaged. The right main gear remained in place in the down and locked position.

The No. 1 and No. 3 engines separated from their attach structure. The No. 2 engine remained in place, relatively undamaged.

Most of the survivors were located in the vicinity of the cockpit area, the midcabin service area, overwing area and the empennage sections. These sections were located at the far end of the wreckage path.

ACCIDENT #1-18 (Con't)

In contrast, most fatalities were found in the center of the crash path. Crushing injuries to the chest were predominant causes of death.

Due to the excessive distintegration of the cabin, this accident was not considered survivable. A survival factor worth noting is that the seat incorporated energy absorbers in the support structure.

ACCIDENT #1-21 CHATTANOOGA, TENN : DC9-32 : 11-27-73

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
79	75	4	0	0

The aircraft first struck approach lights 488 m (1600 feet) short of the runway threshold. The aircraft continued to descend, striking additional approach lights. It struck a dike 239 m (785 feet) short of the runway threshold.

The left wing separated from the aircraft.

The ground fire erupted at the dike. The fire died out before the firefighting equipment arrived.

The fuselage with the right wing and empennage attached came to a rest 76 m (250 feet) to the left of the runway and 137 m (450 ft) beyond the runway threshold. The left engine came to rest on the runway threshold. The landing gear had been fully extended. The three gear assemblies were separated from the aircraft.

As the aircraft decelerated, a hole appeared in the floor in front of two flight attendents in the rear cabin jumpseats, through which they were sprayed with mud, debris and fuel. The cabin lights went off.

A flash fire erupted in front of the 2 flight attendants and lasted momentarily. The fire extended from the floor to 15 inches above the attendants head.

ACCIDENT #1-21 (cont'd)

When the aircraft stopped, a fire erupted at the fuselage joint to the left wing root and also near the left engine attach point. However, the fire was dying and was extinguished in less than 1 minute by crash units.

Heat and soot damaged the coach section near rows 37 and 38. Head rest towels were burned, seat back trays were deformed, and plastic covers and bags were melted.

The passenger in seat 38C saw flames near the cabin floor. His hair was singed and his polyester suit was melted in places.

There were patches of dense smoke in the cabin. Baggage in the rear baggage compartment was melted and damaged. Fuel was found in puddles in the baggage compartment.

The smoke in the cabin during evacuation came from the rear baggage compartment and tail cone fires.

Numerous tears in the lower fuselage skin allowed fuel vapor from ruptured fuel lines of the left wing to enter the cargo compartment. Fractures in the cabin floor allowed fuel vapors to enter the main cabin. The ignition of the vapors was probably caused by any one of several electrical sources.

The immediate availability of the four overwing exits and the main boarding door allowed passengers to evacuate promptly. The galley service door was not usable due to debris. The tail cone door could not be used because of structural deformation caused by impact.

ACCIDENT #1-22 BOSTON, MASS. : DC-10-30 : 12-17-73

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
167	163	4	0	0

The aircraft struck approach light piers 152 m (500 feet) short of runway. The aircraft then struck an embankment. The right main gear was sheared. The aircraft veered off the runway and skidded to a stop about 914 m (3000 feet) from the runway threshold. The left main gear had separated from the aircraft. The nose gear failed rearward and was embedded in the fuselage. The centerline gear rotated aft and was embedded in the fuselage. The No. 1 engine and pylon assembly remained intact and in place. The No. 3 engine separated from the right wing and remained under the right wing.

The aircraft caught fire while it skidded along and off the runway.

At the end of the ground slide, fire was burning under the left wing around the left engine and along the left side of the fuselage. Fuel from the ruptured left wing fuel tank was feeding the fire. Firemen extinguished the fire and spread a protective foam cover over the leaking fuel.

Some emergency lights did not illuminate. The battery packs were depleted.

ACCIDENT #1-23 PAGO PAGO, SAMOA: B707 : 1-30-74

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
101	0	5	1	95

The aircraft contacted tree tops, 3865 feet short of runway. After 72 m (236 feet), the first impact with the ground occurred. The aircraft continued through jungle vegetation, struck a 1 m (3 foot) high lava rock wall and stopped 942 m (3090 ft) short of runway. During the slide through the vegetation, the landing gear outboard ailerons, outer wings, parts of flaps, all four engines and more separated from the aircraft.

The aircraft stopped when right wing hit the MM transmitter. The lower fuselage structure was severly damaged from the nose to the rear pressure bulkhead. The wreckage path was 236 m (775 feet) long.

Fire was evident during the last 107 m (350 feet) of wreckage path. Survivors said that the impact forces were slightly more severe than a normal landing. No damage to the cabin interior was reported. Large fires were seen outside the right side of the aircraft. One person opened an overwing exit on the right side; flames came in and he closed it. Four surviving passengers exited the left overwing exits. The surviving copilot escaped through a hole in the cockpit wall with the assistance of 2 cockpit crewmembers.

Some passengers rushed toward the front and rear of the cabin before the aircraft stopped. The survivors did not hear instructions regarding escape from the aircraft after the accident. The forward and rear entry doors were not opened or used for escape. The rear galley service door was not opened.

ACCIDENT #1-23 (con'd)

All fatally injured persons but one, died of smoke inhalation and/or massive burns. Post mortem examination revealed significant levels of carbon monoxide and hydrogen cyanide. The third officer who survived the crash died later from traumatic leg and arm injuries and severe burns. Most of the survivors suffered burns after they escaped from the cabin.

The fuselage from the aft pressure bulkhead forward through the cockpit area was gutted by fire. Both wings and all fuel tanks which remained with the aircraft were burned and melted. The No. 4 main wing tank had ruptured and was extensively damaged by fire.

This was a survivable accident. The survival problems stemmed from post crash fires.

1) The cabin crew did not open the primary emergency exits, (may have been overcome by smoke).

2) The passenger reaction to the fire threat, (passenger may have crowded against the doors).

3) Passenger inattentiveness to the pretakeoff briefings (should have moved to the nearest exit instead of the door of entry).

ACCIDENT #1-24 CHARLOTTE, N.C. DC-9-31: 9-11-74

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
82	1	10	32	39

Aircraft landed 5.3 km (3.3 miles) short.

The right wing tip broke three limbs 8 m (25 feet) above the ground. The left wing struck and sheared a cluster of pine trees. Left main gear struck ground, 34 m (110 ft) past initial impact. Right main gear struck ground, 35 m (115 ft.) past initial impact. Aircraft final descent angle = 4.5^{0} Aircraft bank angle = 5.5^{0} left wing down. Left wing contacted ground, 60 m (198 feet) past initial impact. Left wing hit trees, broke sections, 168 m (550 feet) past initial contact.

Ground fire began. Right wing sheared off. Fuselage continued thru wooded area with severe break up and came to a stop in a ravine, 303 m (995 ft) past initial contact.

Nose gear was separated from fuselage. No fire damage. Right gear was separated from fuselage. Considerable fire damage. Left gear was separated from fuselage. Minor fire damage.

This was a partially survivable accident. Only a small section of cabin near the tail retained structural integrity.

In most cases, the occupant restraint system failed.

Fire occurred in the cabin during the breakup of the aircraft and burned until extinguished by the fire dept in about 8-10 minutes after crash.

ACCIDENT #1-24 (cont'd)

Seven passengers died of burns only. One passenger died of smoke inhalation. Twenty-five passengers died of burns and smoke inhalation. Thirty-two died of impact trauma. Six died of combined factors.

One survivor stated that half of his burns were caused by double-knit garments which melted and adheared to his skin and could not be removed. All survivors in the rear of the cabin were thrown out or escaped through holes in the fuselage. The surviving passenger and two crew members in the forward area escaped through a cockpit window.

The forward cabin entry door was blocked by a fallen tree. The forward galley door was blocked by the ground. The overwing escape windows were destroyed by fire. The auxiliary exit in the tail of the aircraft was usable.

ACCIDENT #1-25 JFK B727: 6-24-75

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
124	0	12	87	25*

*EST

Outboard section of left wing was severed by approach towers 8 and 9. The aircraft rolled into a 90^0 left bank between towers 9 and 10. Left wing contacted ground at tower #10. Three large outboard sections of left wing were located here. Left wing released fuel.

Fire erupted from numerous ignition sources: hot engine components, electrical wiring in A/C, approach light system, street light system and many friction sources. The fuselage collapsed and disintegrated. When the fuselage disintegrated, the cabin floor, and seat anchors failed. Occupants became unrestrained and unconfined. Collisions caused multiple extreme impact injuries.

Near complete destruction of aircraft fuselage. Almost all seats were torn from their support structures were mangled and twisted and scattered over 183m (600 feet) of aircraft slide. Almost all seatbelts remain attached to seats and fastened.

Twelve survivors had been seated in the rear portion of cabin which remained relatively intact.

The aft flight attendants escaped unaided because their restraint systems did not fail. They sustained fractures, contusions, and abrasions especially over the pelvic area where their seatbelts restrained them.

ACCIDENT #1-25 (cont'd)

The fire departments rapid response (6 minutes) prevented fatal burns to 9 passengers, some of whom were found lying in pools of fuel. Each of the surviving passengers sustained burns which varied from first to third degree over 30 to 70 percent of the body. The two forward flight attendants died of multiple extreme impact injuries.

ACCIDENT #2-1 DENVER, COLO. : DC-8 : 7-11-61

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
122	72	33	0	17

The aircraft made a normal touchdown. The airplane veered off the runway to the right. Both main landing gears were sheared off and the aircraft slid on its belly across several hundred feet of open ground.

The aircraft came to a sudden halt when it struck a truck at the edge of an 46 cm (18 inch) concrete abutment. No. 4 engine tore free at impact and tumbled to a point about 18 m (60 feet) forward of the right wing.

Flames followed a path of spilled fuel from the engine to the aircraft and soon the right side of the fuselage was enveloped by a ground-fuel fire. Smoke from the fire evaded the cabin through opened right window exits.

The No. 2 engine tore free and lay crushed under the left wing. Fire developed, due to fuel spill, at the fuselage left side and prevented the use of the left window exits. This fire was of limited extent for the first 5 minutes after the aircraft stopped.

The deceleration forces were mild until the aircraft struck the taxiway.

During evacuation, the principal environmental hazard was smoke. The chimney effect drew smoke thru the right window exit and out the aft galley door. The smoke concentration was heaviest in the aft cabin.

Fire invaded the cabin through the right window exits after 98 passengers had escaped and 16 others were incapacitated by smoke.

ACCIDENT #2-1 (Cont'd)

Forward Section

The second officer left the cockpit and opened forward entry door. Second officer and senior stewardess deployed the slide. First officer (escaped from cockpit window) and held bottom of slide. Junior stewardess decided not to open forward galley door. Senior stewardess helped several passengers thru right window exits. Left window exits were not opened due to wing fire. Second officer re-entered the aircraft. Breathing was difficult. He led several stragglers to the forward door.

Second Class

The junior stewardess did not attempt to open the rear boarding door. It was blocked with cabin debris. Deformation of the floor due to impact with the truck would have prevented its use in any case.

The senior stewardess opened the aft galley door on the right side. Slide was inflated after slight delay. The senior stewardness and passenger exited aircraft and aided passengers descending the slide.

The junior stewardess assisted passengers just inside the galley door. About 20 persons used the slide until it was destroyed by fire.

The evacuation slowed due to the hesitation of many passengers to jump 2 m (6 1/2 feet) to the ground.

After a warning that the aircraft was going to explode, the junior stewardess jumped to the ground. From 15 m (50 feet) away she turned and saw 5 or 6 more passengers exit.

ACCIDENT #2-1 (cont'd)

Passenger evacuation record

forward boarding door	32
right overwing exits	26
aft galley service door	40
TOTAL	98

Evacuation was completed 3 to 5 minutes after the aircraft came to a halt. The first fire equipment arrived just after the evacuation was complete.

Survivor Injuries

First Class:

All 38 first class passengers survived.
Only 7 had serious injuries.
First degree burns of face and hands were common.
No smoke inhalation injury.
Most burns occurred outside the A/C.
Window exits produced more injury than main door exits.

Second Class

44 out of 61 passengers survived.
19 were treated for smoke inhalation.
16 were treated for burns.
Most of the fatalities were at the end of the line going aft. No signs of impact trauma were noted in the fatalities.

ACCIDENT #2-17 TORONTO, CANADA : DC-8-63: 7-5-70

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
109	0	0	0	109

Aircraft made a hard landing. The aircraft bounced back into the air. The No. 4 engine was shed. The pilot attempted to go around and climbed to 914 m (3000 feet). Explosion occurred in the right wing tank. Right wing and No. 3 engine separated from A/C. The aircraft crashed and was non-survivable.

ACCIDENT 2-18 ST. THOMAS, V.I. : B727 : 12-28-70

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
55	42	11	0	2

Approach was normal.

Touchdown was followed by a rebound 15 m (50 ft) above runway. Aircraft touchdown very hard & aircraft became airborne again aircraft touched down for 3rd & last time.

Right wing tip settled to the runway. Aircraft veered off the runway and continued parallel to runway. Aircraft went thru a chainlink fence. Landing gear and right wing tip struck concrete sidewalk, aircraft passed over sidewalk and crashed into a truck. Aircraft continued up incline of a hill and began to break apart as it stopped 91 m (300 ft) beyond the runway.

Explosion occurred in the left wing root followed by a small fire in same area.

Passenger evacuation began. 46 passengers and all the crew escaped the A/C. The fire became intolerable. The fuselage had broken into 3 sections. Engines 1 & 3 were intact and in place. Engine 2 was found under the empennage. Engine fuel lines were intact. Nos. 2 & 3 valves were intact and open.

One fatality was trapped by debris between 2 seats in Row 22. The other fatality was found on the ground in the area of the aft fuselage break.

Forward Section

The galley door was opened by two flight attendants and the slide was inflated. 12 occupants escaped thru the galley door.

Center Section

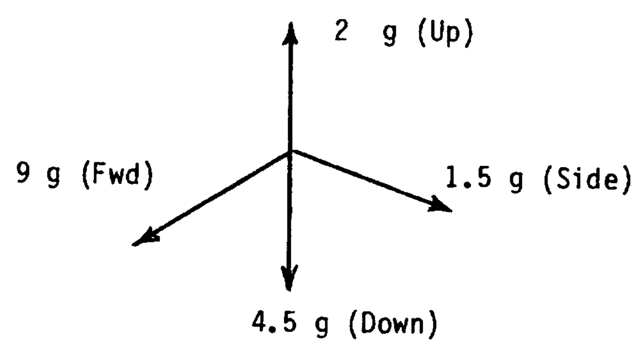
The four overwing emergency exits were located here. All 19 passengers escaped thru the aft fuselage break.

Aft Section

12 evacuees escaped thru the fuselage break. 10 evacuees used the slide at the aft main door. The two passenger fatalities were located here. The aft main door was opened by the cabin attendant and two passengers with difficulty. The aft galley door was not used.

Seat Failures

There were 8 known passenger seat failures. Only one of these seat frames was found. All the legs of the seat were fractured. The entire seat showed a lateral deformation to the left. They were designed for



ACCIDENT 2-19 JFK : DC8-61 : 6-23-73

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
128	120	8	0	0

Aircraft was on a flare just before touchdown. Spoilers were inadvertantly deployed. Aircraft struck the runway, tail first and 6 m (20 feet) short of runway. Aircraft was damaged substantially. The No. 1 engine separated from the aircraft. A fire ignited in the No. 1 engine pylon. The fire was fed by a ruptured fuel line. The crash truck arrived 1 minute after the crash. The fire was extinguished with foam 30 seconds later.

ACCIDENT 2-21 LAX : B707 : 1-16-74

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
65	63	2	0	0

The nose landing gear collapsed on touchdown. The aircraft vertical acceleration measured +4.5 g. The ignition source was the friction generated between the nose wheel tires and the runway surface. Two fractured nose wheel steering hydraulic lines fueled this fire with hydraulic fluid.

Firefighting personnel were unable to place the extinguishing agent directly on the source of the fire. Only evacuation injuries occurred.

All four cabin doors and four overwing emergency exits were opened. The L.A. Fire Department arrived on the scene 6 minutes after the accident. Smoke was coming from all 3 exits and the open cockpit windows.

The fire had erupted thru the entire fuselage. The fire was under control in 25 minutes.

ACCIDENT 2-24 KETCHIKAN, ALAS. : B727 : 4-5-76

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
50	38	11	1	0

The aircraft overran the runway. The left wing hit the antenna support structure. The aircraft then struck large rocks and tree stumps. Fuselage broke into three sections. One break at the wing L/E and one break at the wing T/E. The left wing remained attached to the fuselage. The right wing separated from the fuselage. The nose and main gears separated from their attachments. No. 1 engine separated. No. 2 and No. 3 engines remained attached.

Fire erupted on impact. Flames were concentrated primarily in the cabin and aft of the wing.

The cabin sustained multiple fractures to legs and ribs.
The first officer sustained skull, leg, rib and spinal fractures.
The second officer sustained multiple spinal and rib fracture.
Flight attendant in seat 6C sustained leg and abdominal bruises.
Flight attendant in seat 8C sustained cervical strain and rib fracture.
Flight attendant in seat 22C sustained fuel burns to his skin.
Flight attendant in seat 22D sustained fuel irritation to right eye and singed hair.

10 occupants evacuated the main cabin door.
6 occupants exited holes in the cabin.
The remaining passengers evacuated two overwing exits.
The cockpit crew was trapped in cockpit.
16 seats failed.
Seat legs showed evidence of compression buckling.

ACCIDENT 2-25 ST. THOMAS, V.I. : B727 : 4-27-76

PASSENGERS & CREW				
T	N/M	S	F*	
			I.T.	FIRE
88	32	19	18	19

*estimated (severe impact & severe fire & smoke)

Aircraft overran the runway. Aircraft struck electronic equipment support structure. Aircraft struck a portion of the chain link perimeter-fence.

The right wing tip struck an embankment. The outboard portion of the right wing was torn from the aircraft. The fire erupted immediately after the right wing struck the embankment. The fire emanated from the rupture in the right wing near the fuselage and was fed by aircraft fuel.

The aircraft impacted several automobiles. The aircraft came to rest in a gasoline station against a rum warehouse.

The fuselage broke into three parts during the impact. Black smoke and intense fire penetrated forward and center sections of the broken fuselage as the aircraft slid to a stop.

The first crash vehicle arrived on the scene about 2 minutes after the accident. It fought the fire from a distance of 49 m (160 feet) due to approach and equipment difficulties.

The surviving occupants escaped through fuselage breaks and overwing emergency exits on the left side of the fuselage within 1 to 1 1/2 minutes after the aircraft came to a stop.

ACCIDENT 2-25 (Con't

The three flight crew members escaped thru the first officer's sliding window. Several passenger seats broke loose from their mounts.

Two survivors stated that smoke in the cabin was immediate and affected their ability to breathe almost before they could get out of their seats. It is estimated that passengers could live for no more than 1 minute in the wreckage.

ACCIDENT 2-26 N. NEWHOPE, GA : DC-9-31 : 4-4-77

PASSENGERS & CREW				
T	N/M	S	F	
			I.T.	FIRE
85	1	22	38	24

The aircraft outboard left wing contacted two trees. About 1.3 km (.8 miles) later, left wing again contacted a tree. The left and right wings continued to strike trees and utility poles on both sides of the highway. The left main gear contacted the highway. The outer left wing struck an embankment and aircraft veered left off the highway. The aircraft struck road signs, utility poles, fences, trees schrubs, gasoline pumps, five automobiles and a truck. Total wreckage was 579 m (1900 ft.) long and 90 m (295 ft.) wide. The aircraft struck the ground 6 times before it came to rest. The fuselage broke into five major sections. The fourth section contained the wings. The fifth section contained the engine pylons. The first, second and third sections were forward of the wings and were not damaged by fire. The fourth and fifth fuselage sections had substantial fire damage.

In the fifth section, after the first or second bounce after the aircraft hit the ground, a fireball erupted and traveled rearward along the ceiling. The fireball extended downward from the ceiling to the tops of the passenger seats and some passengers were on fire before the A/C stopped. Four of the five survivors were ejected with their seats during the impacts. All of these survivors were burned seriously.

In the fourth section, the survivors said that smoke, fire debris and bodies hampered their escape. The survivors were severely burned.

In the third section (just forward of the wings L/E), the forward seated passengers received extensive impact trauma. Two passengers seated in the row nearest the wings L/E received extensive second degree burns. Fire erupted during the impacts.

ACCIDENT 2-26 (cont'd)

Twenty passengers died of burns and smoke inhalation. Thirty-one passengers died of extensive traumatic injuries (mostly crushing of the torso and head). Nine passengers died of combined trauma with burning or smoke inhalation.

Seat failures contributed sustantially to impact trauma.

The feet of a number of survivors were cut and some were burned during the evacuation. The flight attendants had evoked this standard crash preparation.

ACCIDENT 3-1

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

Rome, Italy 11/23/64

Ref. Italian Ministry of Civil Transportation

(Post Crash Fire)

Boeing 707, N769TW

DESCRIPTION

During takeoff roll, No. 4 engine EPR dropped to zero and N_2 surged slightly. In addition No. 2 engine reverse light came on. The captain aborted the takeoff. The aircraft veered to the right. Upon crossing a taxiway the No. 4 engine contacted a pavement steam roller and caught on fire and subsequently exploded.

WEATHER AND TIME

The time of the accident was approximately 13.08 local time.

FIRE

Fire was very intense on the right of the aircraft.

FIRE DYNAMICS

Cause of the fire was due to fuel escaping from the air vent at the end of the right wing, and breaks in the fuel lines of the No. 4 engine at the time it collided with the steamroller. The explosion of several fuel tanks, the most violent of which occurred about 20 seconds after the aircraft came to a stop, and the extremely rapid spread of a fire of enormous size, caused the almost instantaneous death of the passengers remaining aboard or on the ground in the immediate vicinity of the aircraft.

FIRE DYNAMICS (Cont'd)

Some parts of the No. 4 engine, the left front wheel, and other fragments of the structure were found along a strip between the position of the steam roller and that of the main body of the wreck. Immediately upon the aircraft's stopping, the fire and the subsequent explosions destroyed and consumed the central portion of the fuselage and the wings. Following the explosion of the No. 3 engine and central fuel tanks, numerous fragments of these tanks were hurled into the surrounding area.

Examination of the fuel tank indicated that the right sector of the overall fuel system burst as a result of an internal explosion, which caused the aft spar to bend under compression. The entire forward part was carried away by the explosion. The boost pump for the left portion of the central fuel tank was totally destroyed by fire.

The feedlines to the No. 3 engine were bent and twisted by the heat all along the section to the fuel pump, where there was one broken connection.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
73	48	13	12	48

ACCIDENT 3-3

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

Erlanger, Kentucky 11/6/67

Ref. NTSB File No. 1-0029
1 CAO 107-AN/81

(Post Crash Fire)

Boeing, 707, N742TW

DESCRIPTION

TWL Flt. 159 crashed while attempting to abort a takeoff. The first officer of the flight heard a loud report from the right side of the aircraft during the takeoff roll. He concluded that his aircraft had struck a Delta Airline DC-9 which was mired adjacent to the runway and attempted to abort the takeoff. The aircraft was extensively damaged by the ground slide and fire.

WEATHER AND TIME

The accident occurred at approximately 1841 E.S.T. The Weather Bureau reported 24 km (15 miles) visibility, temperature 1^{o} C (34^{o} F) dew point -7^{o} C (19^{o} F), wind 190^{o}/5 kt.

FIRE

Ground fire occurred in the area of the right wing separation and the No. 3 and 4 engines. This was a survivable accident, although one of the eleven injured died four days after the accident. The death was not a result of fire after impact.

FIRE DYNAMICS

The aircraft overran the runway and became airborne momentarily. It contacted the ground approximately 20 m (67 feet) further down the embarkment, the landing gear sheared, and the nose wheel was displaced rearward which forced the cabin floor upward approximately 38 cm (15 inches). During a ground slide, the fuselage upper structure ruptured just forward of the wing root, and the right wing failed inboard of the No. 4 engine. Engines Nos. 1 and 2 partially separated and engine No. 3 separated from the wing structure. The right wing area surrounding the break was damaged by ground fire. The fuel shutoff valves were closed by the flight engineer before he departed the aircraft.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
36	1	1	34	1

ACCIDENT NO. 3-7

REJECTED TAKEOFF, AIRBORNE AND TRIED TO LAND ON REMAINING RUNWAY

Sioux City, Iowa 12-27-68

Ref. NTSB File 1-0039

DC-9-15, N974A

(No post crash fire)

DESCRIPTION

An Ozark Air Line Flt. 982 crashed while taking off from Sioux City Airport. The aircraft began its takeoff with the flight crew aware that ice was on the wings. As the landing gear began to retract, the aircraft rolled abruptly and violently to the right to an angle of bank estimated by the flight crew to have reached 90^{o}. After maneuvering the airplane until the right wing came up, the captain discontinued the takeoff. He succeeded in leveling the wings prior to final ground contact. The aircraft came to rest in a grove of trees 360 m (1181 feet) beyond the departure end of the runway.

WEATHER AND TIME

The accident occurred at 071 C.S.T. The surface weather was overcast with visibility of 4.8 km (3 miles), the temperature at -6^{o} C (22^{o}F), dew point was -7^{o} C (20^{o}F), and wing from 20^{o} at 13 knots.

FIRE

There was no fire.

FIRE DYNAMICS

The aircraft was damaged beyond economical repair by ground impact and subsequent slide through trees. The wings were torn and crumpled extensively. The wing fuel cells were ruptured. The leftwing tip and tip extension were separated from the wing. Wreckage examination confirmed that the fuel tanks were ruptured prior to the time the aircraft came to rest. An estimated 8328 liters (2200 gallons) of fuel emptied from the ruptured fuel tanks and a heavy fuel odor permeated the area around the fuselage. Absorption of the fuel by the 56 cm (22 inches) of snow on the ground and reduced vaporization as a result of the -6^{0} C (22^{0}F) temperature were considered major reasons for the absence of fire. The left engine which continued to run, could have provided the ignition source.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
68	0	3	65	0

ACCIDENT NO. 3-8

REJECTED TAKEOFF, AIRBORNE AND TRY TO LAND ON REMAINING RUNWAY

Moses Lake, Washington 6-24-69

Ref. NTSB AAR-80-11

(Post crash fire) (Training flight)

Convair 880

DESCRIPTION

Japan Air Line Training Flt. 90 crashed while executing a takeoff. Shortly after lift-off, the flight instructor reduced power on No. 4 engine to check the trainee's emergency procedures, and the aircraft began to yaw to the right. This yaw continued until the right wing went down and the No. 4 engine pod made contact with the runway. The aircraft slid off the runway. The aircraft slid off the runway into a rough terrain, breaking up and bursting into flames.

WEATHER AND TIME

Weather observations recorded by control tower at the time of the accident were made at 1555 and 1610. Both recorded visibility 105 km (65 statute miles); temperature 23^{o} C (74^{o}F), dew point 3^{o} C (38^{o}F). The 1555 observation showed the wind from 250^{o} at 15 knots and the 1610 observation showed the wind from 280^{o} at 10 knots.

FIRE

Evidence of ground fire was found approximately 518 m (1700 feet) north of where the aircraft left the runway and beyond the point where disintegration of the aircraft began. Upon coming to rest, the wings and the fuselage erupted in flame. The fuselage (except for the empennage) and wings were almost completely consumed by fire.

FIRE DYNAMICS

The fuselage separated at the trailing edge of the wings. The aircraft was completely destroyed by fire except the components scattered along the wreckage path.

All engines were separated during the ground slide. They all were subjected to various degrees of fire damage. The fuel valves were determined to be in normal takeoff positions. No evidence of a pre-impact malfunction or failure of the engine were found.

PASSENGERS & CREWS

Total	Fatalities	Severe	None/Minor	Fire Fatalities
5	3	2	0	3

No photos

ACCIDENT NO. 3-9

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

Stockton, Calif. 10-16-69

Ref. NTSB File No. 1-0058

(Post crash fire)

DC-8-63F, N8634

DESCRIPTION

A Seaboard World Airline training flight overran the departure end of the runway and struck the roadway. The aircraft came to rest 241 m (792 feet) beyond the end of the runway and subsequently was destroyed by fire. This occurred when the captain rejected the takeoff during a touch and go maneuver.

WEATHER AND TIME

The accident occurred at 1545 P.D.T. The weather report at that time showed a visibility of 32 km (20 miles), wind 310^{0} at 12 knots, temperature 21^{0} C (70^{0}F), dew point 12^{0}C (53^{0}F).

FIRE

The post crash fire originated in the area of the No. 2 engine and the pylon separated from the left wing, gutting most of the aircraft.

FIRE DYNAMICS

When the aircraft struck the roadway, the left main nose landing gear collapsed. The aircraft overran slightly left of the runway centerline. There was substantial damage to the aircraft's structure. The left wing was destroyed by fire from the No. 1 engine inboard to the fuselage. There was extensive damage in the right wing root and the inboard leading edge of the

FIRE DYNAMICS (Cont'd)

tank between the fuselage and the No. 3 engine was consumed by fire. No. 2 engine and its pylon separated. No. 1, 3, and 4 fuel control units were in off position; No. 2 engine fuel control was in an intermediate position between off and on. No. 1 and No. 2 engine nacelles contacted the terrain.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
5	0	0	5	0

ACCIDENT NO. 3-12

REJECTED TAKEOFF, AIRBORNE AND TRIED TO LAND ON REMAINING RUNWAY

Philadelphia, Penn. 7/19/70

Ref. ICAO Circular 118-AN/88
& NTSB AAR-72-9

(no post crash fire)

Boeing 737-222, N-9005U

DESCRIPTION

United Air Line Flt. 611 crashed shortly after taking off from the Philadelphia International Airport. After taking off, the crew heard a loud explosion, following which the aircraft veered right. The captain then decided to land on the remaining runway. The aircraft touched down hard on the departure runway and continued off the end and across a blast pad.

WEATHER AND TIME

Weather conditions are not considered to have been a factor in this accident. The temperature was 29^{0} C (84^{0}F), dew point 21^{0} C (69^{0}F), wind 150^{0} 12 knot, and visibility 16 km (10 miles).

FIRE

There was no evidence of fire on any part of the aircraft or on the ground in the impact area.

FIRE DYNAMICS

Part of the aircraft landed in a pond. The left wing sustained major structural damage. The forward trunnion attach fitting of the left landing gear had been fractured resulting in fuel leakage. The lower fuselage

FIRE DYNAMICS (Cont'd)

structure was substantially damaged. The right main landing gear was separated from the aircraft. The left main landing gear was attached to the aircraft by the outboard walking beam attachment.

The nose landing gear had folded aft and was lodged in the electronic and electrical compartment of the fuselage.

The No. 1 engine was separated from the pylon and lodged beneath the left wing. The engine was deflected in an outboard diretion of approximately 45^{0} and had rotated approximately 90^{0}, such that the bottom of the engine was facing towards the left wing tip. All engine accessories were intact and attached except for a separated fuel filter housing assembly.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
61	0	1	60	0

ACCIDENT NO. 3-14

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

Anchorage, Alaska 11-27-70

Ref. NTSB AAR-72-12
DC-8-63F, N4909C

(Post crash fire)

DESCRIPTION

Capitol International Airways Flt. C2C3/26 crashed and burned following an unsuccessful takeoff attempt. The aircraft failed to become airborne during the takeoff run and overran the end of the runway. It continued along the ground and struck a low wooden barrier, the instrument landing structure, and a 3.7 m (12 foot) deep drainage ditch before coming to a stop. The aircraft was destroyed in the intense ground fire which developed subsequent to the crash.

WEATHER & TIME

The runway was mostly covered with ice with occasional dry spots. A 1707 weather observation reported a visibility of 8 km (5 miles), temperature -4^{o} C (24^{o}F), dew point -5^{o} C (23^{o}F), wind 60^{o}/6 knots.

FIRE

The interior of the fuselage, forward of the RR. pressure bulkhead was totally gutted by fire. The major portion of the left wing and the inboard end of the right wing were also consumed by fire. The forward cockpit area and the aft fuselage was not destroyed. Several minutes after the accident occurred, two fairly large explosions were observed emanating from the left side of the aircraft.

FIRE DYNAMICS

First impact was with the ILS structure at which point structural damage was incurred in the left wing area. Fire broke out on the left side of the aircraft. The second impact was the most severe and was felt as the aircraft traversed the 3.7 m (12 ft.) deep drainage ditch. This initiated gross structural breakup. The aft section of the cabin broke open and the right

FIRE DYNAMICS (Cont'd)

wing tore loose, spilling fuel. A large fire then erupted on the right side of the aircraft. Some passengers removed seat belts and moved away from the fire.

The third (final) jolt injured some of these passengers. This jolt occurred when the aircraft came to a stop.

A narrow trail of ground fire originated at the far edge of the ditch between the depressions left by the right hand engines and continued to the main wreckage site which was 213 m (700 ft.) east of the drainage ditch. A similar trail of ground fire originated on the left side of the aircraft approximately 91 m (300 ft.) east of the ditch and continued to the main wreckage area

Thousands of liters (gallons) of raw fuel formed a big pool 15 to 20 cm (6 to 8) inches deep around the aircraft.

Except for the forward galley door, which was blocked by galley equipment, all exits in the forward part of the cabin were open and used for evacuation. Three of the four over-wing exits were also opened and being used.

Most fatalities were seated in the aft cabin between rows 26 and 35 just aft of the wing. The aft 2 jet escape doors (row 33) were closed and jammed. However, there was a break in the fuselage at row 36 through which several survivors exited. The other survisors from the aft cabin and all the survivors from the forward cabin areas used the over wing exits and the forward entry door. The fatally injured flight attendant was seated at row 33 on the aisle seat near the left side escape door.

The remaining survivors from the aft cabin area exited through the break in the fuselage or through the aft galley exit which could only be partially opened.

PASSENGERS & CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
229	47	49	133	47

ACCIDENT NO. 3-17

REJECTED TAKEOFF, AIRBORNE AND TRIED TO LAND ON REMAINING RUNWAY

Moscow, USSR 11-28-72

Ref. USSR Ministry of Aviation and JAL Report

(Post crash fire)

DC-8-62

DESCRIPTION

During climb after aircraft began takeoff roll, it began to descend sharply, crashed and was subsequently destroyed by impact and post crash fire.

WEATHER AND TIME

The weather is described as cloudy sky, visibility of 4500 m, wind 210^o at 3 meters per second, and temperature -5^{o}C with relative humidity of 96%.

FIRE

The aircraft was engulfed in fire in the process of its destruction after touching the ground. As a result of the fire, a considerable part of the aircraft was burned.

FIRE DYNAMICS

The parts of the aircraft involved in the initial impact were: the tail part, L/H landing gear bogie, No. 1 engine, No. 2 engine and L/H wing tip. The fire on the aircraft appeared to be a result of ignition of fuel which was pouring out of tanks.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
76	61	15	0	?

ACCIDENT NO. 3-18

COLLISION

(Post crash fire)

DC-9-31, N954N

O'Hare International Airport 12/20/72
Chicago, Illinois

Ref. NTSB-AAR-73-15

GENERAL DESCRIPTION

Delta Airline Flt. 954, CV-880 collided with a North Central Airline Flt. 575 on the runway. The DC-9 was destroyed by the impact and fire after attempting a quick takeoff to avoid the crash.

WEATHER AND TIME

The weather at O'Hare airport at the time of the accident was reported as sky obscured, with visibility of 0.4 km (1/4 mile) in the fog. Time was 1800:08.7.

FIRE

Fire broke out almost immediately, and smoke developed very rapidly in the DC-9 after it came to a stop. The fuselage from FS 160 to FS 900 was gutted by fire. The empennage was intact with evidence of fire damage on the vertical and horizontal stabilizers. There was no fire on the CV-880.

FIRE DYNAMICS

DC-9: The right main landing gear and two sections of the right leading edge flap separated from the aircraft. The nose gear and left main gear had failed rearward. Engine disclosed no evidence of abnormal operation or malfunction. The No. 1 (left) emergency fuel shutoff valve was nearly closed, and No. 2 engine emergency shutoff valve was closed. The No. 1 engine was only slightly damaged, but the No. 2 engine was damaged extensively by fire. A 46 cm

FIRE DYNAMICS (Cont'd)

(18-inch) piece of a horizontal rib from the CV-880 vertical stabilizer was lodged against the inlet vanes of the No. 2 engine. When the plane touched down, the remaining landing gear collapsed and the aircraft skidded to a stop. Fire was seen in the aft section of the aircraft. Nine of the 10 fatally injured passengers failed to escape from the aircraft. These passengers received no traumatic injuries but succumbed instead to the effects of smoke inhalation or burns, or both.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
45	10	9	26	10

ACCIDENT NO. 3-19

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND	Bangor, Maine	6-20-73
(Post crash fire)	Ref. NTSB AAR-74-1 File #1-0015	

DC-8-63, N863F

DESCRIPTION

ONA Flt. 4655 blew two landing gear tires while taxiing for takeoff. The captain then rejected the takeoff and brought the aircraft to a stop.

FIRE

Fire broke out in the area of the right main landing gear and severly damaged the right main landing gear system, the right wing, and the right side of the fuselage. The right inboard wing panel and flap assembly were heavily damaged by fire and flying debris. Fire also damaged a small area on the right side of the fuselage near the right wing root.

FIRE DYNAMICS

The fire was ignited by the friction between the metal wheels and the runway pavement. The fire started during the takeoff roll and burned for approximately 5 minutes before it was extinguished.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
261	0	3	258	0

ACCIDENT NO. 3-21

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

(Post crash fire)

Jamaica, New York 11-12-75

Ref. NTSB AAR-76-19

DC-10-30, N1032F

DESCRIPTION

ONA Airways Flt. 032 crashed while attempting to take off. During the takeoff roll, the aircraft struck many sea gulls, and the takeoff was rejected. As the aircraft decelerated, the No. 3 engine disintegrated and caught fire. The NTSB determined that the probable cause of the accident was the disintegration and subsequent fire in the No. 3 engine when it ingested a large number of sea gulls.

WEATHER AND TIME

The time of the accident was 1310 E.S.T. The weather information was: visibility 24 km (15 miles), wind 160^{o} at 8 knots, 3048 m (10000 feet) overcast. (Runway surface was wet).

FIRE

After the birds were ingested and the No. 3 engine had disintegrated, fire erupted on the right side of the aircraft. Occupants in the aircraft who were able to see the No. 3 engine agreed that fire erupted on the right wing as soon as the engine disintegrated and separated. The fire was not extinguished until about 36 hours after the accident.

There were many separated aircraft parts scattered on the runway. These parts consisted of pieces of the No. 3 engine's compressor, fan module, fan thrust reverser and cowling; the main landing gear wheels and tires, and the right, aft centerline landing gear door.

FIRE DYNAMICS

Parts of the No. 3 engine found on the runway were: the lower HPC stator case assembly, the HPC stage 1 and stage 2 discs, the complete fan module, and miscellaneous engine parts including the engine fuel feed line.

The Safety Board concludes that the fire erupted as the engine separated. The most probable ignition source was the raw fuel which released from the main fuel line onto the hot engine at a rate of 567 to 606 liters (150 to 160 gallons) per minute.

As the aircraft was turned onto taxiway 2, the fire continued to burn in the area of the No. 3 engine. After the failure of the right main landing gear, structural loads were transferred to the right wing when the wing hit the ground.

This transfer resulted in an overload failure of the right rear spar and skin at wing station 622 in the area of the No. 3 fuel tank. Fuel released from the wing tank fracture area flowed down to, and pooled against, the fuselage, and continued to feed the fire at the No. 3 pylon location.

Simultaneously with the right main landing gear and wing failures, the No. 3 pylon structure also hit the ground and was displaced inboard, which allowed the remaining parts of the No. 3 engine to penetrate the lower wing skin at the No. 2 fuel tank location; this penetration allowed additional fuel to be added to the fire. Fire fighters were not able to extinguish the fire for about 36 hours because of the fuel accumulation in the storm drain.

PASSENGERS & CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
139	0	2	137	0

ACCIDENT NO. 3-23
REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

Denver, Colorado 11-16-76

(Post crash fire)

Ref. NTSB AAR-77-10
DC-9-14, N9104

DESCRIPTION

Texas International Flt. 987 crashed after rejecting a takeoff. The takeoff was rejected after the aircraft had rotated for takeoff. When the pilot was unable to stop the aircraft within the confines of the runway, it over-ran the runway, traversed drainage ditches, struck approach stanchions, and stopped. (False stall warning)

WEATHER & TIME

The weather was clear, wind from 130° at 7 knots, and the temperature was 4° C (40°F). The time of the accident was approximately 1729.

FIRE: The aircraft was damaged severly by impact and fire.

FIRE DYNAMICS

Fire erupted on the left side of the aircraft after the left main landing gear traversed the ditch and severed the left main landing gear's attaching structure on the left main fuel tank's gear bulkhead. Fuel escaped from this tank, burned, and caused massive damage to the left side of the fuselage and inboard section of the left wing. The cabin interior was damaged heavily throughout by smoke and soot. The fire burned through the left side in the area of the left wing root. The left wing was on the ground; the wing tip separated.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
86	0	2	84	0

ACCIDENT NO. 3-24 & 3-25

COLLISION

Tenerife, Canary Island 3-27-77

Ref. Unpublished NTSB report & Armed Forces Institute of Pathology

(Post crash fire)

B747, N736 & B747, PH-BUF

DESCRIPTION

PAA flight B150, a charter flight from L.A., collided with KLM flight 4805, a charter flight from Amsterdam, on the runway while both were taxiing to prepare for takeoff.

WEATHER & TIME

The accident occurred at approximately 1707. Visibility was reported to be 500 meters.

FIRE

Both aircraft caught on fire immediately. The PAA plane came to an immediate stop but the KLM flight travelled an additional 457 meters. All occupants of the KLM airplane received fatal injuries.

In general, all the KLM bodies were burned and all but approxmiately 10 fatalities from the PAA aircraft were burned.

The fire was not extinguished until 330 on March 28, 1977. Destruction of both aircraft by fire was very complete.

FIRE DYNAMICS

The KLM contacted the PAA initially at a 30 to 40 degree angle with its engine at the upper lounge area. The right wing gear and body then sheared off near the PAA right wing root area. The No. 3 engine broke free and remained within the center section of the PAA aircraft. The right wing of the PAA was destroyed by the KLM body. The fuselage of the KLM then travelled through the PAA aft fuselage, destroying this section and shearing off the empennage. Fire enveloped the entire KLM aircraft immediately. Fire was confined in the PAA aircraft to the right wing and aft fuselage. The fire later progressed to the forward fuselage. A flight attendant who escaped the wreckage noted that the left outboard engine was running and saw fire behind the left wing. She also noted several small explosions.

Two principal areas where thermal fatalities occurred corresponded to the passage of the KLM center fuselage section and areas on either side of the No. 1 engine. Fuel probably spilled from the center wing and left wing tank of the KLM and started the initial fires in these areas.

Engines #3 & #4 of PAA separated. Landing gears of KLM separated.

PASSENGERS AND CREW

	Total	Fatalities	Severe	None/Minor	Fire Fatalities
KLM	248	248	0	0	198
PAA	396	326	34	36	192

ACCIDENT NO. 3-27

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

Los Angeles, Calif. 3-1-78

Ref. NTSB-AAR-79-1

(Post crash fire)

DC-10-10, N68045

DESCRIPTION

Continental Air Lines Flt. 603 overrun the runway following a rejected takeoff. Three tires failed during the takeoff roll. The aircraft slid to a stop.

WEATHER & TIME

Weather report indicated a visibility for 3 miles in rain, temperature 15^{o} C (59^{o}F), dew point 15^{o} C (59^{o}F), wind 140^{o} at 11 knots gusting to 20 knots. The time of the accident was 0925 P.S.T. (The runway was wet).

FIRE

According to passenger statements, fire erupted from the left side of the aircraft before it came to a stop. The fire spread rapidly under the fuselage and damaged the inboard right wing and right engine cowl.

FIRE DYNAMICS

The No. 1 engine was damaged severely when the left main landing gear failed and the left side of the aircraft dropped on the engine and left wing.

The left wing was damaged severly when the left main landing gear collapsed; it caught on fire. The No. 1 engine and pylon assembly had separated and was located just forward of the wing. The engine pod and pylon assembly was badly burned. The fuel tank had not ruptured when the engine pylon separated.

FIRE DYNAMICS (Cont'd)

The outboard flap had separated from the wing. The left wing leading edge had been damaged by fire.

Slats Nos. 5 through 8 were burned on the surface and appeared to be retracted. The slats were still attached to the wing. The lower wing tip skin had broken through, rupturing the fuel tank near the tip. A section of the rear spar web and vertical tang of the lower cap had broken loose at the outboard end of the landing gear fitting, which created a 0.09 sq. m (1 sq.ft) hole in the aft wall of the left compartment of the No. 2 fuel tank.

A trapezoidal portion of the wing rear spar web (about 1/3 sq. m) remained attached to the landing support when the upper and lower auxiliary spar tore off at the flap hinge fitting. This opened up the No. 1 fuel tank.

This was a survivable accident.

PASSENGER & CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
200	2	31	167	2

ACCIDENT NO. 3-28

REJECTED TAKEOFF, AIRCRAFT NEVER LEFT THE GROUND

(No post crash fire)

Toronto, Canada 6-26-78

Ref. H80002
CANADIAN AIRCRAFT ACCIDENT REVIEW BOARD

DC-9-32, 47197

DESCRIPTION

Air Canada Flt. 189 crashed during a rejected takeoff. The No. 3 tire failed and rubber debris damaged the right main landing gear "down & locked" switch. The right gear unsafe light came on in the flight deck. The aircraft failed to stop within the confines of the runway. It continued beyond the overrun area, over the edge of a ravine, and came to rest in the ravine.

WEATHER & TIME

The accident occured at 809 EDT. Weather observations were visibility 3.2 km (2 miles) in fog, temperature $18^{0}C$, dew point $16^{0}C$, wind 140^{0} at 7 knots.

FIRE DYNAMICS - The aircraft broke into three parts on impact, but there was no fire.

Impact forces had ruptured the left main fuel tank. MOT report states that the auxiliary tank leaked fuel, however inspectors on the scene stated that this was not correct. A large amount of fuel was spilled. Although there was no fire, the areas were completed foamed due to fire danger.

PASSENGERS AND CREW

Total	Fatalities	Severe	None/Minor	Fire Fatalities
107	2	46	59	0

APPENDIX C

CRASH CHARACTERISTICS AND ASSOCIATED INJURIES

This appendix contains three sets of tables (TABLES C-1, C-2, & C-3), devoted to the demonstration of a dependency of aircraft occupant injuries to some of the characteristics of three types of accidents.

TABLE C-1	Approach Accidents
TABLE C-2	Landing Accidents
TABLE C-3	Takeoff Accidents

These tables list some 30 accident characteristics for 35 accidents which are among the ones that have better descriptions. It is obvious that considerable emphasis was and will be given to those accidents with large numbers of fatalities as well as serious injuries.

The thirty accident characteristics of each table represent an initial effort to organize the ingredients of an accident. The number of characteristics could easily be expanded to include three times this number to produce a more thorough listing. These characteristics were assembled into seven convenient groups listed below.

A convenient method of describing an accident is by representing it as a chronologically ordered series of events, especially since time is of the essence during the evacuation period. Thus, four of the seven characteristics groups are chronologically arranged. These are the 3rd, 4th, 5th and 6th groups of the following list.

1. Passengers and Crew
2. Subsystems
3. Approach and Impact
4. Terrain and Aircraft Slide
5. Fire
6. Evacuation
7. Meteorological Information

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TABLE C-1
CRASH CHARACTERISTICS AND ASSOCIATED INJURIES – APPROACH ACCIDENTS

		PSGR AND CREW				SUBSYSTEMS											APPROACH AND IMPACT		TERRAIN AND SLIDE			
				F			LANDING GEAR								CABIN LIGHTS				RUNWAY			
ACCDT NO.	ACFT	T	S	I.T.	FIRE	LANDING GEAR SEPARATED	UP	DOWN	ENG SEPT'D	WING SEPT'D	WING TANK RUPT'D	FUEL LINE RUPT'D	HYD LINE RUPT'D	SEAT FAIL.	ON	FAILED	CRASH AIR SPEED (KN)	RATE OF DESCENT m/SEC (FPM)	OFF	ON	SLOPED GROUND	LIGHT SUPT STRUCT
1-1	B727	62	4	29	29	–	NOSE 2 MAIN TAIL SKID	–	NO. 1 & 3	–	–	–			–	–	147	3.18 (625)	√		UP 9.6°	
1-2	B727	91	33	0	43	BOTH MAIN GEARS	–	√	–	–	–	FUS		–	–	√	123	10.16 (2000)	√	√	–	
1-6	DC-8	90	23	11	40	R MAIN	–	√	NO. 3 & 4	–	YES	–		–	–	√		5.84 (1150)	√	–	–	
1-15	DC-9-31	10	3	0	0	BOTH MAIN GEARS	–	√	–	–	–	–		–	–	–	135 140	10.16 (2000)	–	√	–	
1-16	B737	61	11	18	25	NOSE & R MAIN	√	–	NO. 1 & 2	–	–	–		YES	–	√	113	7.87 (1550)	√	–	–	
1-18	L-1011	176	60	85	14	L MAIN & NOSE	–	√	NO. 1 & 3	LEFT	–	YES		YES	–	–	195	10.16 (2000)	√	–	–	–
1-21	DC-9-32	79	4	0	0	NOSE & MAIN	–	√	NO. 1	LEFT	–	–		–	–	√	122	4.83 (950)	√	–	–	√
1-22	DC-10-30	167	4	0	0	R, L, NOSE, CENTER			NO. 1 & 3	–	L WING TANK	–		–	–	√	149	5.38 (1060)	√	–	–	√
1-23	B707	101	5	1	95	MAIN & NOSE			NO. 1 2,3 & 4	–	YES	–		–	–	–			√	–		
1-24	DC-9-31	82	10	32	39	NOSE & MAIN			–	LEFT & RIGHT		–		YES	–	–	168	4.06 (800)	√	–		
1-25	B727	124	12	87	25	–			–	LEFT	L WING TANK	–		YES	–	–	123	7.62 (1500)	√	–	–	√
Σ	11	1043	169	263	310																	
NO. OF FIRE FATALITIES						256	54	97	203	78	160	57	0	103		108			310	0		25
NO. OF EVENTS						9	2	5	7	4	4	2		4		5			10	1		3
NO. OF FIRE FATALITIES/EVENT						28.4	27	19.4	29	19.5	40	28.5	-	25.8		21.6			31	0		8.3
AVERAGE																		6.91 (1360)				

T – TOTAL
S – SERIOUS INJURY
F – FATALITY
I.T. – IMPACT TRAUMA
FIRE – FIRE FATALITY

TABLE C-1

CRASH CHARACTERISTICS AND ASSOCIATED INJURIES – APPROACH ACCIDENTS (CONTINUED)

	TERRAIN AND SLIDE								FIRE							EVACUATION					
											IGNITION SOURCE			FUEL VALVE		EGRESS				CREW ASSIST	
ACCDT NO.	VEHICLE	BLDG	EMBANK-MENT	DIKE/WALL	TREES	MARSH LAND	DITCH	GND SLIDE DIST	FIRE	EXPLOS'N	ENGINE	ELEC WIRING	FRICTION SPARKS	CLOSED	OPEN	TOTAL EXITS	EXITS USED*	FUS BREAKS	CABIN DEBRIS	GOOD	POOR
1-1	–	–	–	–	√	–	–	104 m (340 FT)		YES	√	–	–			7	–	–	–		
1-2	–	–	–	–	–	–	–	853 m (2800 FT)		YES	√	√	√			7	6	–	NO	√	
1-6	–	–	–	–	–	–	–	259 m (850 FT)		–	NO. 3 & 4	–	–			8	2	–	YES		
1-15	–	–	–	–	–	–	–	899 m (2950 FT)		–	–	–	√			7	1	–	–		
1-16	–	√	–	–	√	–	–	–		–	√	–	–			6	1	√	YES		
1-18	–	–	–	–	–	√	–	–		–	√	–	–			–	–	√	–		
1-21	–	–	–	√	–	–	–	381 m (1250 FT)		–	√	–	–			7	5	–	YES		
1-22	–	–	√	–	–	–	–	1067 m (3500 FT)		–	NO. 1	–	–			8		–			
1-23	–	–	–	√	√	–	–	165 m (540 FT)		–	√	–	–			8	4	–			
1-24	–	–	–	–	√	–	√	–		–		–	–			7	1	√			
1-25	–	–	–	–	–	–	–	183 m (600 FT)		–	√	√	√			7	–	√			
Σ																					
NOFF	0	25	0	95	188	14	39			72	271	68	68					103	65		
NOE	0	1	1	2	4	1	1			2	9	2	3					4	3		
NOFF/E	0	25	0	47.5	47	14	39			36	30.1	34	22.7					25.8	21.7		
AVG								460 m (1508 FT)								7.2	2.9				

NOFF – NO. OF FIRE FATALITIES
NOE – NO. OF EVENTS
NOFF/E – NO. OF FIRE FATALITIES/EVENT
AVG – AVERAGE

*The numbers of exits used for egress by cabin occupants in these accidents does not reflect the total number of exits usable in all cases.

TABLE C-2
CRASH CHARACTERISTICS AND ASSOCIATED INJURIES – LANDING ACCIDENTS

		PSGR AND CREW				SUBSYSTEMS										APPROACH AND IMPACT			TERRAIN AND ACFT SLIDE			
ACCDT NO.	ACFT	T	S	F I.T.	F FIRE	LDG GEAR SEPT'D	TIRES FAILED	ENG SEPT'D	WING SEPARATED	WING TANK RUPT'D	FUEL LINE RUPT'D	HYD LINE RUPT'D	SEAT FAIL.	CABIN LIGHTS ON	CABIN LIGHTS FAILED	CRASH AIR SPEED (KN)	RATE OF DESCENT m/SEC (FPM)	BOUNCED BACK INTO AIR	RUNWAY ON	RUNWAY OFF	SLOPED GROUND	LIGHT SUPT STRUCT
2-1	DC-8	122	33	0	17	2 MAIN		NO. 4 & 2	–	YES	–	–				NORMAL	NORMAL		✓	✓		
2-17	DC-8-63	109	0	0	109	–		NO. 4	R WING & NO. 3 ENG	–	–	–						YES (914 m)	✓	–		
2-18	B727	55	11	0	2	–		NO. 2	RIGHT	YES	–	–	YES			122	(650)	TWICE (15 m)	✓	✓	YES	
2-19	DC-8-61	128	8	0	0	–		NO. 1	–	–	YES	–	–						✓	✓		
2-21	B707	65	2	0	0	NOSE		–	–	–	–	YES	–			147	(1400)					
2-24	B727	50	11	1	0	NOSE & MAIN		NO. 1	RIGHT	–	–	–	YES									L WING
2-25	B727	88	19	18	19	–		–	RIGHT	R WING	YES	–	YES									YES
2-26	DC-9-31	85	22	38	24	–		–	–	YES	–	–	YES						–	✓		
Σ	8	702	106	57	171																	
NO. OF FIRE FATALITIES						17		128	130	62	19	0	45					111	128	43	2	19
NO. OF EVENTS						2-1/2		5	4	4	2	1	4					2	4	4	1	2
NO. OF FATALITIES/EVENTS						6.8		25.6	32.5	15.5	9.5	0	11.3					55.5	32.0	11	2	9.5
AVERAGE																135	5.33 (1050)					

T – TOTAL
S – SERIOUS INJURY
F – FATALITY
I.T. – IMPACT TRAUMA
FIRE – FIRE FATALITY

TABLE C-2
CRASH CHARACTERISTICS AND ASSOCIATED INJURIES – LANDING ACCIDENTS (CONTINUED)

	TERRAIN AND AIRCRAFT SLIDE								FIRE							EVACUATION					
											IGNITION SOURCE			FUEL VALVE		EGRESS				CREW ASSIST	
ACCDT NO.	VEHICLE	BLDG	EMBANK-MENT	DIKE/WALL	TREES	FENCE	GRND SLIDE DIST	OVERRUN RUNWAY	FIRE	EXPLOS'N	ENG	ELEC WIRING	FRICTION SPARKS	CLOSED	OPEN	TOTAL EXITS	EXITS USED*	FUS BREAKS	CABIN DEBRIS	GOOD	POOR
2-1	YES			√			61 m (200 FT)			–	√	–				8	4	–			
2-17	–									YES R WING		–				12	–	–			
2-18	YES			√		YES		91 m (300 FT)		L WING ROOT		–				9	6	3 SECTIONS	YES		
2-19	–									–		√				12		–			
2-21	–									–		–	HYDRAULIC FLUID			8	8	3 SECTIONS			
2-24	–				YES			YES		–		√				9	3	3 SECTIONS			
2-25	YES	YES	R WING TIP			YES		YES		–		√				9	2	3 SECTIONS			
2-26	YES	YES			YES	YES	579 m (1900 FT)			–	√	–							YES		
Σ																					
NOFF	62	43	19	19	24	45		21		111	41	19	0					21	26		
NOE	4	2	1	2	3	3		3		2	2	3	1					4	2		
NOFF/E	15.5	21.5	19	9.5	8	15		7		55.5	20.5	6.3	0					5.3	13		
AVG							320 m (1050 FT)									8.4	4.6				

NOFF – NO. OF FIRE FATALITIES
NOE – NO. OF EVENTS
NOFF/E – NO. OF FIRE FATALITIES/EVENT
AVG – AVERAGE

*Ref. Note on Page 103.

TABLE C-3
CRASH CHARACTERISTICS AND ASSOCIATED INJURIES – TAKEOFF ACCIDENTS

ACCDT NO.	ACFT	PSGR AND CREW				SUBSYSTEMS										APPROACH AND IMPACT				TERRAIN AND AIRCRAFT SLIDE			
		T	S	F		LDG GEAR SEPT'D	TIRES FAILED	ENG SEPT'D	WING SEPARATED	WING TANK RUPT'D	FUEL LINE RUPT'D	HYD LINE RUPT'D	SEAT FAIL.	CABIN LIGHTS		CRASH AIR SPEED (KN)	STALL	BECAME AIRBORNE	ACFT ICING	RUNWAY		RUNWAY SURFACE	LIGHT SUPT STRUCT
				I.T.	FIRE									ON	FAILED					ON	OFF		
3-1	B707	73	13	0	48	–		–	–	–	NO. 4 ENG	–	–			40		NO		✓	✓		
3-3	B707	36	1	0	1	YES		NO. 1, 2, 3	R WING INBD NO. 4 ENG	–		–	–					YES	–				
3-7	DC-9-15	68	3	0	0	–		–	–	YES		–	–				✓	YES	✓				
3-8	C-880	5	2	0	3	YES		ALL ENGINES	–	YES		–	–					YES	-	✓	✓		
3-9	DC-8-63F	5	0	0	0	L MAIN & NOSE		NO. 1 & 2	–	L WING TANK		–	–					YES		✓	✓		
3-12	B737	61	1	0	0	MAIN & NOSE		NO. 1	L WING *	L WING TANK		–	–					YES	–				
3-14	DC-8-63F	229	49	0	47	–		YES	R WING	YES		–	–					NO	–			ICE	✓
3-17	DC-8-62	76	15	30	31	L MAIN		NO. 1	L WING	YES		–	–					YES	–				
3-18	DC-9-31	45	9	0	10	MAIN & NOSE		–	–	–		–	–		✓			NO	–				
3-19	DC-8-63	261	3	0	0	–	2 R MAIN GEAR	–	–	–		–	–					–					
3-21	DC-10-30	139	2	0	0	R MAIN		NO. 3	–	YES	YES	–	–					–	-			WET	
3-23	DC-9-14	86	2	0	0	L MAIN		–	–	L WING TANK		–	–				FALSE WARN.	–	–				✓
3-24	B747	248	0	50	198	BOTH MAIN		NO. 3	–	YES		–	–					YES	–	✓	✓		
3-25	B747	396	34	34	192	–		–	R WING	YES		–	–					–	–	✓			
3-27	DC-10	200	31	0	2	L MAIN	3 LEFT MAIN	NO. 1	–	L WING TANK		–	–					–	–				
3-28	DC-9-32	107	46	2	0		NO. 3 TIRE	–	–	L MAIN TANK		–	YES (25 g)					–	–			WET	
Σ	16	2035	211	116	533																		
NO. OF FIRE FATALITIES						245	2	282	271	473	48	0	0		10		0			441		47	47
NO. OF EVENTS						10	3	9	5	12	2	0	1		1					5		3	2
NO. OF FIRE FATALITIES/EVENT						24.5	0.7	31.3	54.2	39.4	24	0	0		10					88.2		15.7	23.5
AVERAGE																40							

T – TOTAL
S – SERIOUS INJURY
F – FATALITY
I.T. – IMPACT TRAUMA
FIRE – FIRE FATALITY

TABLE C-3
CRASH CHARACTERISTICS AND ASSOCIATED INJURIES – TAKEOFF ACCIDENTS (CONTINUED)

	TERRAIN AND AIRCRAFT SLIDE								FIRE								EVACUATION					
												IGNITION SOURCE			FUEL VALVE		EGRESS				CREW ASSIST	
ACCDT NO.	VEHICLE	FENCE	EMBANK-MENT	GROUND SURFACE	TREES	DITCH	GRND SLIDE DIST	OVERRUN RUNWAY	FIRE	EXPLOS'N	FUEL SPILL	ENG	ELEC WIRING	FRICTION SPARKS	CLOSED	OPEN	TOTAL EXITS	EXITS USED*	FUS BREAKS	CABIN DEBRIS	GOOD	POOR
3-1	STEAM ROLLER							–	YES	TWO		✓				–	8		–			
3-3	–		✓					✓	YES			✓			✓	–	8		–			
3-7	–			SNOW	✓			✓	NO		8.3 m^3 (2200 GAL)	–				–	7		–			
3-8	–							518 m (1700 FT)	YES			✓				✓			AT WING T.E.			
3-9	–							241 m (792 FT)	YES			NO. 1 & 2				✓	14					
3-12	–							✓	NO			–				–	6		–			
3-14	–	✓				3.7 m (12 FT) DEEP		✓	YES		17 cm (8 IN.) DEEP POOL	✓	✓			–	14	6	YES	✓		
3-17	–						119 m (390 FT)	–	YES			✓				–	14		–			
3-18	CV-880							–	YES			✓				✓	7	3	–		✓	
3-19	–							–	YES			–		GR METAL WHEELS		–	14		–			
3-21	–							–	YES		R WING	✓				–	8		–			
3-23	–							✓	YES		L WING	–				–	7		–			
3-24	–						457 m	–	YES		YES	–							–			
3-25	✓							–	YES	✓	YES	–							YES	✓		
3-27	✓							–	YES			✓				–	8					
3-28	–			SNOW		15 m (50 FT)		✓	NO		YES	–					7		3 SECTIONS	✓		
Σ																						
NOFF	252	47	1	0	0	47		51	532		437	142		0	1	13			242	239		
NOE	4	1	1	2	1	2		8	13		7	9		1	1	3			4	3		
NOFF/E	63	47	1	0	0	23.5		4.4	40.9		62.4	15.8		0	1	4.3			60.5	79.7		
AVG							288 m										9.4	4.5				

NOFF – NO. OF FIRE FATALITIES
NOE – NO. OF EVENTS
NOFF/E – NO. OF FIRE FATALITIES/EVENT
AVG – AVERAGE

*Ref. Note on Page 103.

APPENDIX D

AIRLINE TRANSPORT STATISTICS

This appendix contains world air transport statistics derived from IATA (International Air Transport Association) and ICAO (International Civil Air Organization) sources. The data includes international and domestic operations for the year 1960 through to 1979. the ICAO organization produces the more complete world data base.

The data recorded here pertains only to the following:

1) Total passengers carried per year
2) Total departures per year
3) Yearly world fleet totals.

Projections of these data were made for international and domestic operations (in Tables D-1, D-2, D-3 and D-4) for the years 1980 up to 2005. Plots of these data age given in Figures D-1, D-2 & D-3.

Basic Data

Ref. Aviation Week & Space Technology, September 1, 1980.

1980 - 1994	6100 new passenger jet aircraft 63% short & medium range aircraft
1979	5803 passenger aircraft in 202 passenger airlines of which 5032 were jet aircraft. (3900 or 68% will be retired by 1994)

World traffic increase rates (passengers carried)

1980	5%	
early 1980's	7%	annually
early 1990's	6%	annually

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Aircraft Revenue Departures & Numbers of Passengers

World Air Transport Operations (1975-1979)

ICAO - International and Domestic

	ICAO Yearly Departures	Percent Change		Yearly ICAO Pax	Percent Change	
1975	9672×10^3	+0.7%		435.8×10^6	+2.8%	
1976	9945×10^3	+2.8%		475.1×10^6	+9.0%	
1977	$10,136 \times 10^3$	+1.9%	+2.14%	517.2×10^6	+8.8%	+8.6%
1978	$10,371 \times 10^3$	+2.3%		581.0×10^6	+12.3%	
1979	$10,680 \times 10^3$	+3.0%		639.0×10^6	+10.0%	

	IATA Yearly Departures	IATA Yearly PAX
1975	6258×10^3	317.2×10^6
6	6463×10^3	345.2×10^6
7	6523×10^3	373.0×10^6
8	5892×10^3	372.2×10^6
9	5795×10^3	389.2×10^6
	$30,931 \times 10^3$	1796.8×10^6

$$\frac{\text{ICAO Depart}}{\text{IATA Depart}} \quad \frac{50,804}{30,931} = 1.642$$

$$\frac{\text{ICAO PAX}}{\text{IATA PAX}} = \frac{2648.1}{1796.8} = 1.474$$

$$* \frac{9672}{1.007} = 9604 \times 10^3$$

$$\frac{435.8}{1.028} = 423.9 \times 10^6$$

	IATA		ICAO	
	Yearly Departures	Yearly PAX	Yearly Departures	Yearly PAX
1960		82.4×10^6		121.5×10^6
1		187.5		
2		95.0		
3	4004×10^3	106.5		157.0
4	4062	120.3		
5	4507	141.1		
6	4715	157.9		
7	5476	188.0		277.1
8	5873	208.1		
9	6150	228.9		
1970	6191	241.0		355.2
1	6141	252.5		
2	6547	285.3		
3	6847	313.7		
4	6425	316.9	$*9604 \times 10^3$	423.9×10^3
				1,474xIAT

TABLE D-1 IATA Versus ICAO

Numbers of Yearly Passengers

1960 - 1974

Aircraft Revenue Departures & Numbers of Passengers

World air Transport Operations (1985 - 2005)

ICAO - International & Domestic

	Percent Increase	ICAO	Yearly PAX	Percent Increase	ICAO	Yearly Departures
1979		P	639×10^6		D	10.68×10^6
1980	5%	1.05 P	671	3.0%	1.03 D	11.00×10^6
1981	7%	1.12 P	716		1.06 D	11.32×10^6
2		1.20 P	767		1.09	11.64×10^6
3		1.28 P	818		1.13	12.07
4		1.38 P	882		1.16	12.39
5		1.47 P	939	2.75%	1.19	12.71
6	6.5%	1.57 P	1003		1.22	13.03
7		1.67 P	1067		1.26	13.46
8		1.78 P	1137		1.29	13.78
9		1.89 P	1208		1.33	14.20
1990		2.02 P	1291		1.36	14.52
1	6.0%	2.14 P	1367	2.5%	1.40	14.95
2		2.27 P	1451		1.43	15.27
3		2.40 P	1534		1.47	15.70
4		2.55 P	1629		1.51	16.13
5		2.70 P	1725		1.54	16.45
6	5.5%	2.85 P	1821	2.5%	1.57	16.77
7		3.01 P	1923		1.61	17.19
8		3.17 P	2026		1.65	17.62
9		3.34 P	2134		1.68	17.94
2000		3.53 P	2256		1.72	18.37
1	5.0%	3.71 P	2371	2.0%	1.76	18.80
2		3.89 P	2486		1.79	19.12
3		4.08 P	2607		1.83	19.54
4		4.29 P	2741		1.86	19.86
5		4.50 P	2876×10^6		1.90	20.29×10^6

TABLE D-2 - PROJECTED YEARLY NUMBERS OF DEPARTURES AND PASSENGERS
WORLD AIR TRANSPORT OPERATIONS
1980 - 2005

Aircraft Revenue Departures & Numbers of Passengers

Development of World Air Transport

ICAO - International & Domestic

	IATA Yearly Departures	Percent Change				Percent Change		ICAO Yearly Departures
1960								
1961								
2								
3	4004×10^3	-1.4%	-5.65%				.652 D	6.306×10^6
4	4062	-9.9%					.693 D	6.703
5	4507	-4.4%					.736 D	7.119
6	4715	-13.9%		-5.86%			.781 D	7.554
7	5476	-6.8%	-6.06%				.830 D	8.028
8	5873	-4.5%					.882 D	8.531
9	6150	-0.7%				-5.86%	.937 D	9.063
1970	6191	+0.8%			-2.43%		.995 D	9.624
1	6141	-6.2%					.996 D	9.633
2	6547	-4.4%	-.10%				.997 D	9.643
3	6847	+6.6%					.998 D	9.652
4	6425	+2.7%				-.10%	.999 D	9.662
5	6258	-3.2%		-.10%			D	9.672×10^6
6	6463	-0.9%						9.945×10^6
7	6523	+10.7%	+2.1%					10.136×10^6
8	5892	+1.7%				+2.1%		10.371×10^6
9	5795							10.68×10^6
1980								

TABLE D-3 - Projected Yearly Numbers of Departures
World Air Transport Operations
1963 - 1979

World Air Transport Operations (ICAO - Internat'l & Domestic)

Year	Yearly PAX Total $x10^9$	Yearly Departure Total $x10^6$	Year	Yearly PAX Total $x10^9$	Yearly Departure Total $x10^6$	World Fleet Jet	World Fleet Prop
1960	.12	5.4	1986	1.0	13.1	6300	520
1961	.14	5.75	7	1.075	13.45	6500	500
2	.15	6.0	8	1.15	13.8	6700	460
3	.16	6.4	9	1.41	14.2	6850	400
4	.20	6.7	1990	1.29	14.5	7000	390
5	.225	7.1	1	1.37	14.9	7200	350
6	.25	7.55	2	1.45	15.3	7400	320
7	.28	8.0	3	1.54	15.65	7600	300
8	.305	8.55	4	1.63	16.0	7800	270
9	.34	9.05	5	1.72	16.45	7900	210
1970	.35	9.65	6	1.825	16.8	8100	190
1	.375	9.65	7	1.93	17.2	8300	160
2	.39	9.65	8	2.025	17.6	8500	140
3	.405	9.65	9	2.14	18.0	8700	100
4	.43	9.65	2000	2.25	18.4	8820	60
5	.465	9.7	1	2.375	18.8	9250	0
6	.51	9.9	2	2.50	19.1	9640	
7	.55	10.1	3	2.62	19.6	10,050	
8	.59	10.4	4	2.75	19.9	10,500	
9	.64	10.7	5	2.87	20.25	10,900	
Total	6.875	169.55		36.920	333.00		

TABLE D-4 - Summary of Yearly Numbers of Departures and Passengers
World Air Transport Opertions
1960 - 2005

Total PAX $\frac{1986\text{-}2005}{1960\text{-}1979} = \frac{36.92x109}{6.875x10^9} = \boxed{5.37}$

Total Departures $\frac{1986\text{-}2005}{1960\text{-}1979} = \frac{333.0x106}{169.55x10^6} = \boxed{1.96}$

World Fleet - Present and Future

1979 — 5803 passenger aircraft in 202 airlines
(5032 (86.7%) jet aircraft)
(771 (13.3%) prop aircraft)

1980-1994 — 6100 new passenger jet aircraft added to fleet
3900 passenger aircraft retired

Aircraft Retirement rate $= \frac{3900}{15} =$ 260 aircraft per year

Jet addition rate $= \frac{6100}{15} =$ 407 aircraft per year

1985 World Fleet
(1985-1979)

=(5803-260 (1985-1979)) .867 + 407

= 5031-1353 + 2442 = 6120 jet aircraft
=(5803-260 (1985-1979)) .133
= 772 - 207 = 565 prop aircraft

1990 World Fleet

= 6120-260 (1990-1985) .867 + 407 (1990-1985)
+6120-1127 + 2035 = 7028 jet aircraft
= 565-260 (1990-1985) .133
=565-173 = 392 prop aircraft

1995 World Fleet

= 7028-1127 + 2035 = 7936 jet aircraft
= 392-173 = 219 prop aircraft

2000 World Fleet

= 7936-1127 + 2035 = 8844 jet aircraft
= 219-173 = 46 prop aircraft

2005 World Fleet

= 8844-1127 + 2035 = 9752 jet aircraft
= 46-173 = 0 prop aircraft

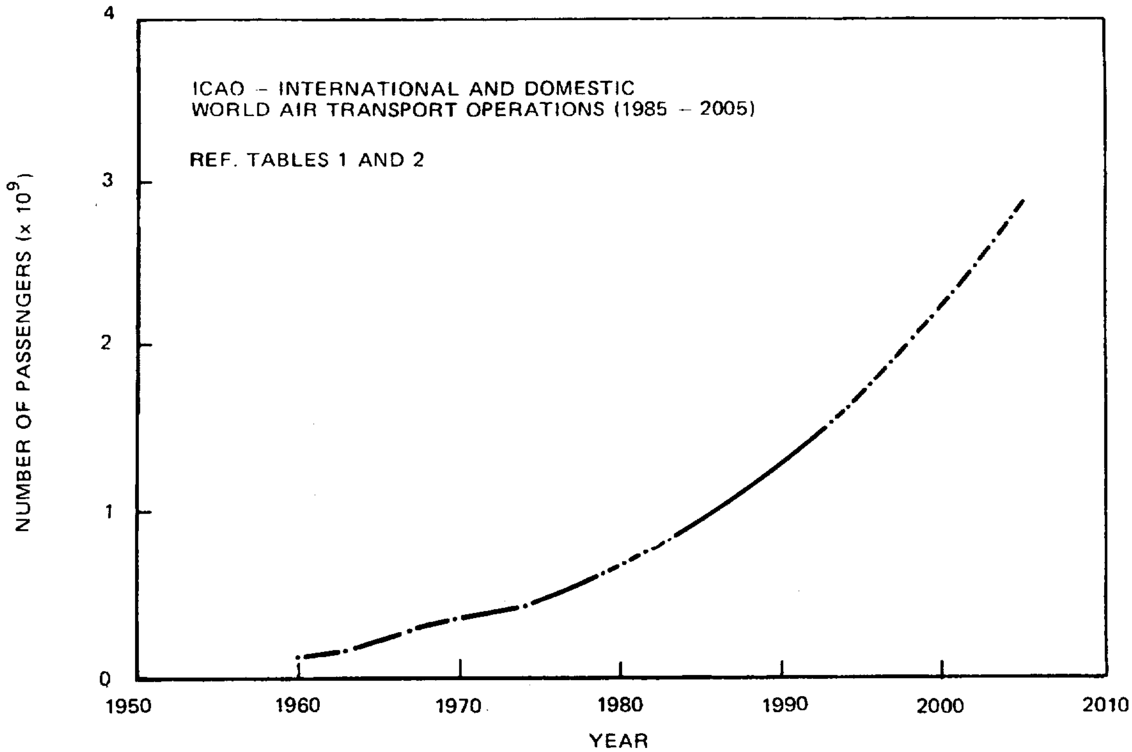

FIGURE D-1. TOTAL YEARLY PASSENGERS

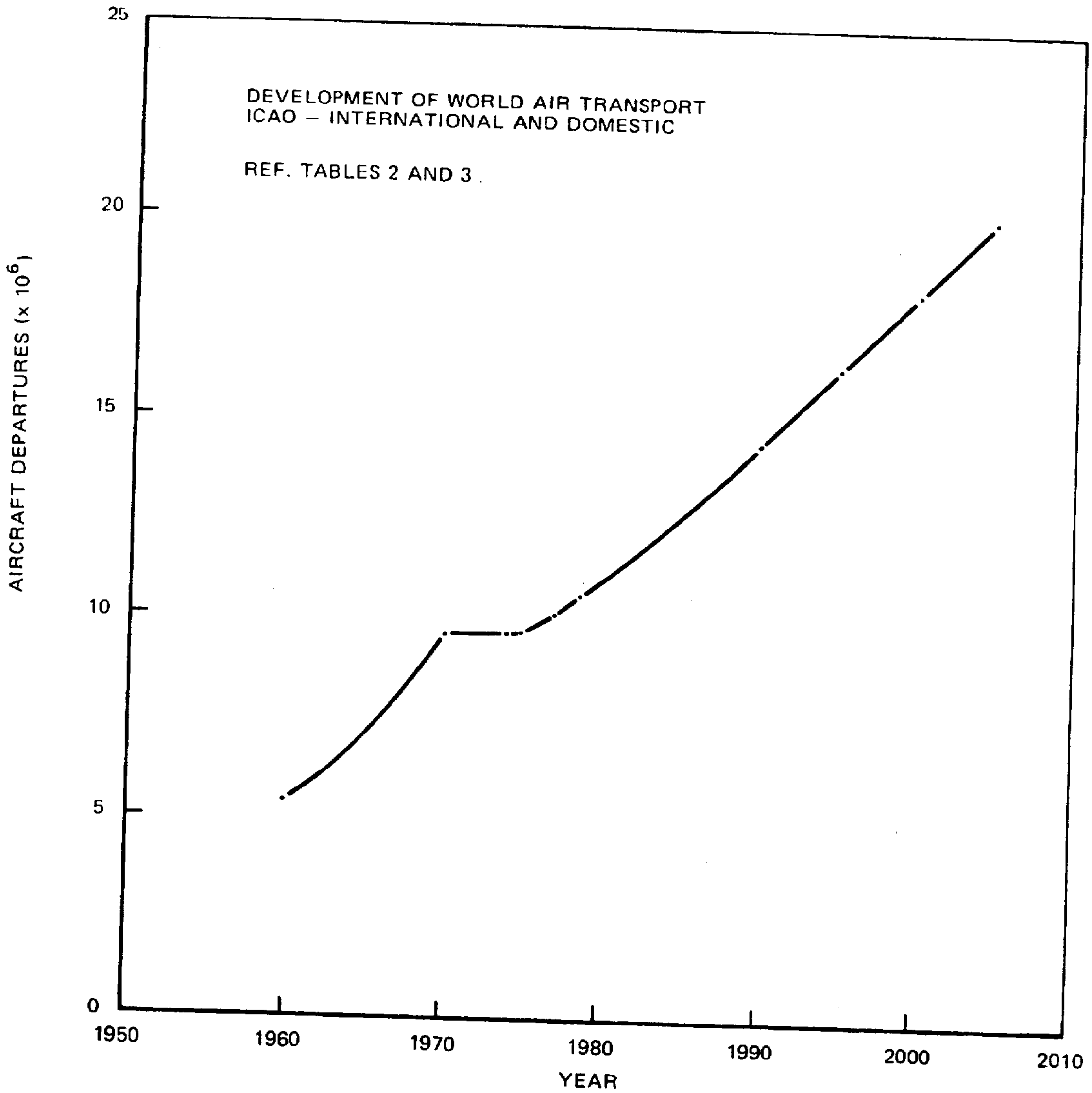

FIGURE D-2. TOTAL YEARLY DEPARTURES

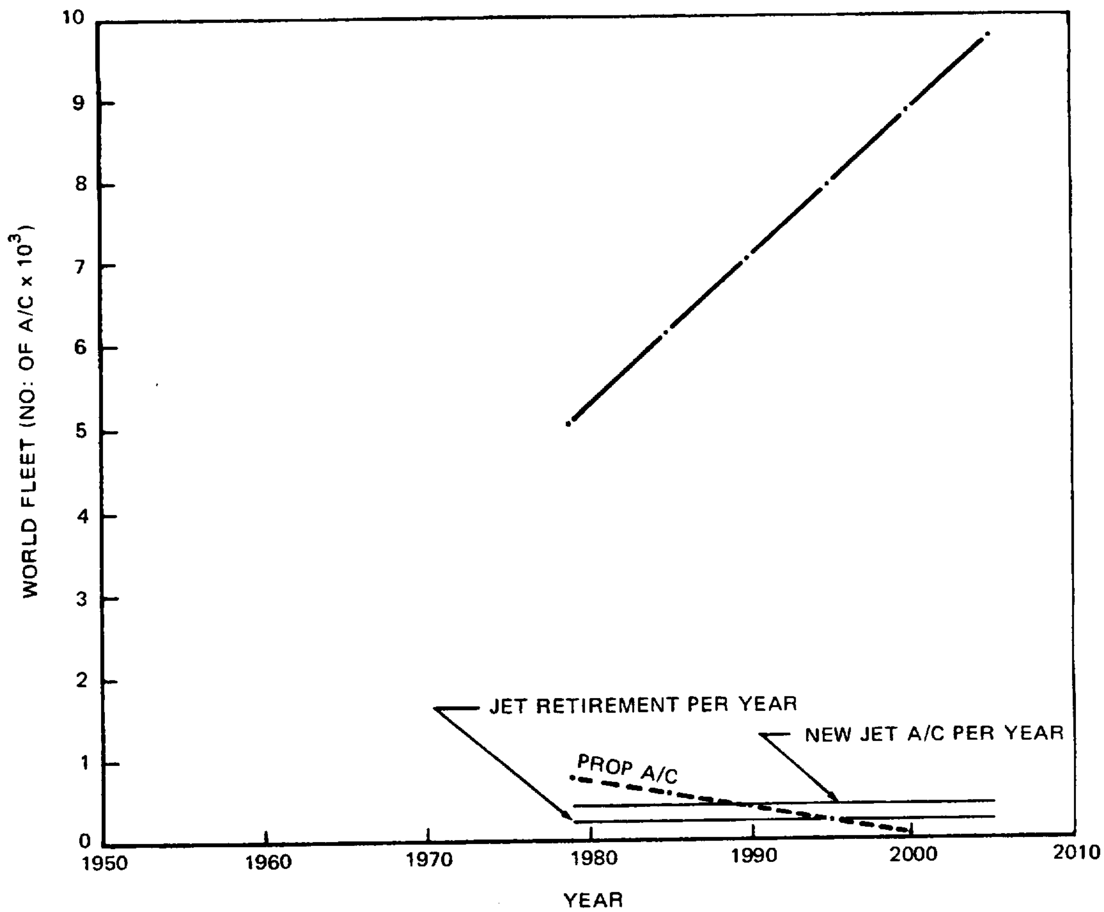

FIGURE D-3. WORLD FLEET