DOT/FAA/AR-99/57

Office of Aviation Research
Washington, D.C. 20591

CAA Paper 99003
Civil Aviation Authority
London, England

Fuselage Burnthrough Protection for Increased Postcrash Occupant Survivability: Safety Benefit Analysis Based on Past Accidents

September 1999

Final Report

U.S. Department of Transportation
Federal Aviation Administration

Civil Aviation Authority
London, England

NOTICE

This report is available at the Federal Aviation Administration William J. Hughes Technical Center's Full-Text Technical Reports page. www.tc.faa.gov/its/act141/reportpage.html in Adobe Acrobat portable document format (PDF).

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-99/57		

4. Title and Subtitle	5. Report Date
FUSELAGE BURNTHROUGH PROTECTION FOR INCREASED POSTCRASH OCCUPANT SURVIVABILITY: SAFETY BENEFIT ANALYSIS BASED ON PAST ACCIDENTS	September 1999
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Ray Cherry and Kevin Warren	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
R.G.W. Cherry & Associates Limited 20 Bull Plain Hertford Hertfordshire, SG14 1DT England	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research Washington, DC 20591 Civil Aviation Authority London, England	Final Report
	14. Sponsoring Agency Code ANM-100

15. Supplementary Notes

The FAA William J. Hughes Technical Center COTR was Richard Hill.

16. Abstract

The objective of this analysis was to assess the potential benefits, in terms of reduction of fatalities and injuries, resulting from improvements in fuselage burnthrough resistance to ground pool fires. The process employed for assessing benefit is considered to give reasonably accurate and consistent results within the limitations imposed by the available data. The methodology gives a reasonable assessment of the tolerance on the predicted levels.

Fire hardening of fuselages will provide benefits in terms of enhanced occupant survival and may be found to be cost beneficial if low-cost solutions can be found. The maximum number of lives saved per year in worldwide transport aircraft accidents, over the period covered by the data, was assessed to be 12.5 for the aircraft in its actual configuration and 10.5 for the aircraft configured to later airworthiness requirements.

17. Key Words	18. Distribution Statement
Postcrash, Burnthrough, Benefit analysis, Fuel fire	This document is available to the public through the National Technical Information Service (NTIS) Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	169	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The objective of this analysis was to assess the potential benefits, in terms of reduction of fatalities and injuries in worldwide transport aircraft accidents, resulting from improvements in fuselage burnthrough resistance to ground pool fires. The process employed for assessing benefit is considered to give reasonably accurate and consistent results within the limitations imposed by the available data. The methodology gives a reasonable assessment of the tolerance on the predicted levels.

The International Cabin Safety Technical Group's Survivable Accidents Database was used to identify past worldwide transport aircraft accidents and extract detailed data for those accidents where fuselage burnthrough was an issue in the survivability of the occupants. Each of these accidents was analysed in depth to assess the number of lives and injuries that would be saved by a fire-hardened fuselage.

Seventeen accidents to Transport Category aircraft were identified during the period from 1966 to 1993 where occupant fire injuries were sustained, and fire penetration of the passenger cabin occurred as a result of ground fires. Each accident was divided into scenarios where it was assessed that there was a similar level of threat to the occupants. A mathematical technique was used to model each accident scenario and a Monte Carlo simulation was used to predict a high, median, and low value for the benefits assessed.

A range of burnthrough protection times was used, and results are presented for protection times from 30 seconds up to 8 minutes. Eight minutes was chosen to encompass the highest level of protection thought to be practical. The reduction in the structural strength of the fuselage as a result of a pool fire appears to have a limited effect on occupant survival. If this is confirmed it is likely to result in a greater opportunity to find cost beneficial solutions to hardening aircraft against pool fires.

The analysis was carried out for the aircraft standards at the time of the accident and assessed for the aircraft if it were configured to the latest airworthiness requirements.

Fire hardening of fuselages will provide benefits in terms of enhanced occupant survival and may be found to be cost beneficial if low-cost solutions can be found. The maximum number of lives saved per year, over the period covered by the data, was assessed to be 12.5 for the aircraft in its actual configuration and 10.5 for the aircraft configured to later airworthiness requirements.

The variation of benefit with degree of burnthrough protection is approximately an exponential curve with a horizontal asymptote suggesting limited improvement beyond the four to eight minutes additional protection points.

The assessed benefit derived from this study is similar in magnitude to that determined from using a representative set of survivable accidents, giving confidence in the results. Costs have not been assessed to ascertain the cost per life saved for possible methods of enhancing the fire penetration of aircraft. However, the relationship between benefit and additional burnthrough protection, derived from this study, will assist in carrying out such an analysis.

The prime fire penetration route is via the fuselage skin and no evidence could be found to suggest that alternative routes contribute significantly to occupant survival.

Aircraft configured to the latest cabin safety requirements are likely to exhibit limited enhanced protection against large external pool fires since major penetration of the fuselage skin is likely to result in the rapid progression of fire throughout the passenger cabin.

It is not considered likely that the rate of fatalities and injuries per year caused by fuselage burnthrough will change markedly for the near future.

1. INTRODUCTION.

This report contains the method and results of a benefit analysis carried out on fuselage hardening for burnthrough protection against large ground pool fires.

A number of past accidents have been identified which are considered to have involved fire penetration of the passenger cabin with a consequential threat to occupant survival. For each of the accidents identified, the assessed benefit in terms of the reduction in number of fatalities and injuries has been derived assuming improvements to the fire hardening properties of the aircraft fuselage. Section 9 of this report contains the definition of terms used in this study.

2. OBJECTIVES.

The objective of this study was to assess the potential benefits, in terms of reduction of fatalities and injuries, resulting from improvements in fuselage burnthrough resistance to pool fires by:

- Using the International Cabin Safety Research Technical Group's Survivable Accidents Database to identify and extract detailed data for those aircraft accidents where fuselage burnthrough was an issue in the survivability of the occupants.
- Analysing each accident in depth to assess the number of lives and injuries that might be saved by a fire-hardened fuselage.
- Assessing the benefits in the context of all survivable aircraft accidents.

3. METHOD.

3.1 SELECTION OF ACCIDENTS.

Survivable or potentially survivable accidents on scheduled or nonscheduled passenger carrying transport aircraft were selected for inclusion in the analysis based on the following definition of a burnthrough accident:

"An aircraft accident where the fuselage skin was penetrated by an external fire while live occupants were on board."

This definition would exclude instances where the fuselage was consumed by fire after the evacuation period was complete and those accidents where the fuselage burnt through from the inside.

For the purposes of this analysis, the definition of a survivable accident is:

"An aircraft accident where there were one or more survivors or there was potential for survival."

Only survivable or potentially survivable accidents, in which there were fire injuries, were selected for analysis. Accidents in which there were no fire related injuries were not analysed since there could be no benefit to be gained from a fire-hardened fuselage.

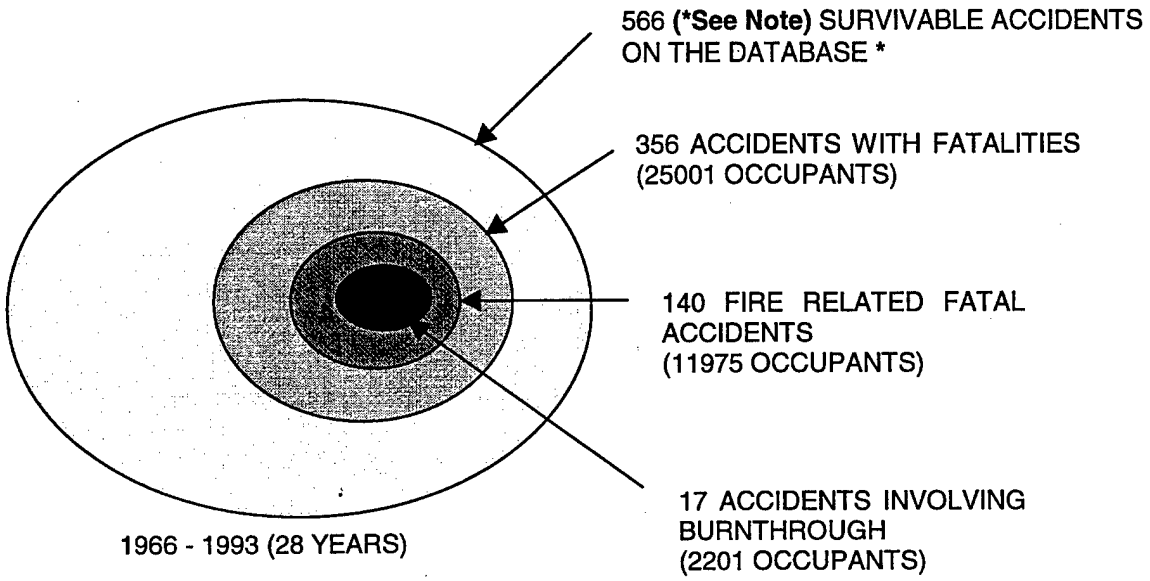
The accidents were selected using the Survivable Accidents Database of the International Cabin Safety Research Technical Group and from information contained in reference 1.

Where accident information did not explicitly state that burnthrough had occurred, it was necessary to make the assumption that a pool fire existing outside an intact portion of fuselage would burnthrough, given the nature of the intensity of the fire.

Seventeen accidents were identified as listed in table 1. The relationship between this subset and all fatal accidents on the database is shown in figure 1.

TABLE 1. LIST OF BURNTHROUGH ACCIDENTS IDENTIFIED

Date	Location	Aircraft
14-Sep-1993	Warsaw	A320
01-Feb-1991	Los Angeles	B737
31-Aug-1988	Dallas	B727
26-Jun-1988	Habsheim	A320
22-Aug-1985	Manchester	B737
30-Aug-1984	Douala	B737
07-Dec-1983	Madrid	B727
13-Sep-1982	Malaga	DC10
07-Oct-1979	Athens	DC8
17-Dec-1978	Hyderabad	B737
15-Mar-1974	Teheran	Caravelle
30-Jan-1974	Pago Pago	B707
22-Jan-1973	Kano	B707
20-Dec-1972	Chicago	DC9
18-Apr-1972	Addis Ababa	SVC10
08-Apr-1968	Heathrow	B707
16-Feb-1967	Menado	L188



Note: This does not represent all survivable accidents over the time period considered.

FIGURE 1. RELATION OF SELECTED DATA TO WHOLE DATABASE

3.2 ACCIDENT SCENARIOS.

The severity of hazard in an accident can vary markedly throughout the aircraft. Experience has shown that considering occupant injuries on a "whole" aircraft basis can be misleading when assessing the effects of survivability factors. It is therefore necessary to divide the aircraft into "scenarios."

A scenario is defined as:

"That volume of the aircraft in which the occupants are subjected to a similar level of threat."

A similar level of threat need not necessarily result in the same level of injury to occupants. The extent of injury sustained can vary with numerous factors including age, gender, adoption of the brace position etc. Furthermore, the threat to occupants can vary over relatively small distances. For example, a passenger may receive fatal injuries because of being impacted by flying debris, and a person in an adjacent seat may survive uninjured. Dividing accidents into scenarios provides a more meaningful basis on which to analyse accidents than considering the whole aircraft due to the marked variation in survival potential with occupant location.

The flight deck and flight attendant areas are generally considered as separate scenarios. The flight deck often has the potential for greater impact damage, and crewmembers usually have full harness restraints. Furthermore, sliding cockpit windows in the area provide a nearby method of egress. The flight attendant areas are normally considered as a separate scenario from the

passenger cabin due to the significant differences in seating, restraint systems, and exit availability.

For these reasons all analytical work carried out during this study has been based on carrying out assessments for each scenario.

3.3 SURVIVABILITY CHAINS.

A mathematical model, known as a Survivability Chain, has been developed such that the overall effect on survivability may be determined from improvements made to survivability factors, taking into account injuries that may be sustained by occupants. A Survivability Chain is derived for each scenario in each accident.

A scenario where injuries are sustained due to impact and subsequent fire has been modelled using two levels in the Survivability Chain.

An example of the model and the effects of improvement in injuries and fatalities resulting from changes to fuselage fire hardening are shown in figure 2.

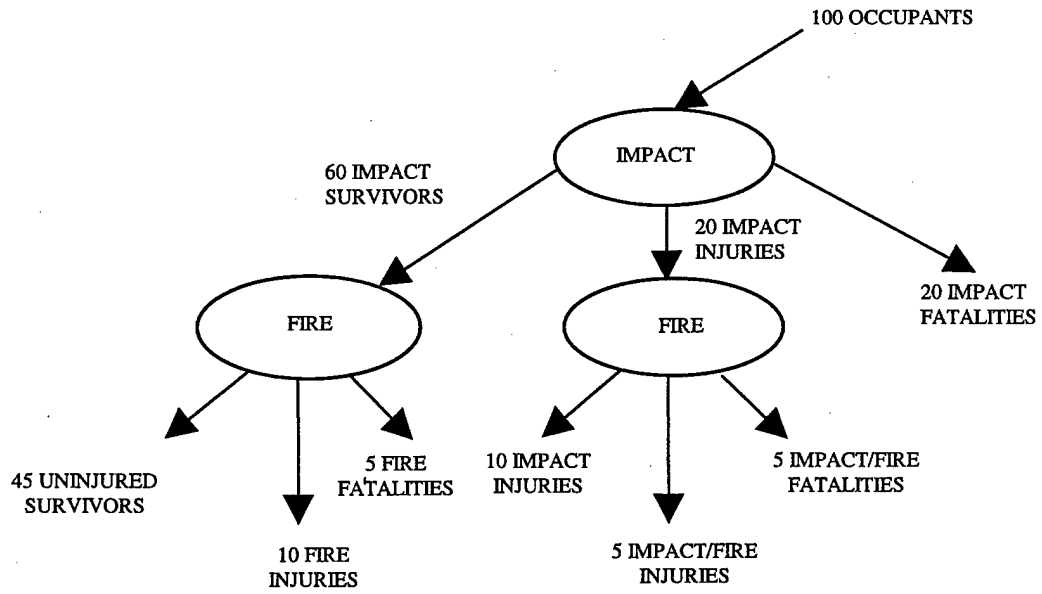


FIGURE 2. EXAMPLE SURVIVABILITY CHAIN

There are therefore:

- 45 uninjured survivors.
- 25 injuries, 10 as a result of the impact, 10 as a result of the fire, and 5 seriously injured as a result of the impact and fire.

- 30 fatalities, 20 as a result of the impact and 10 as a result of the fire (5 of whom sustained nonfatal injuries from the impact).

If improvements were made to fuselage fire hardening, such that it was assessed there were now only 2 fatalities and 6 seriously injured of the 20 impact injured occupants and only 2 fatalities and 7 seriously injured of the 60 impact survivors, then the survivability chain becomes as shown in figure 3.

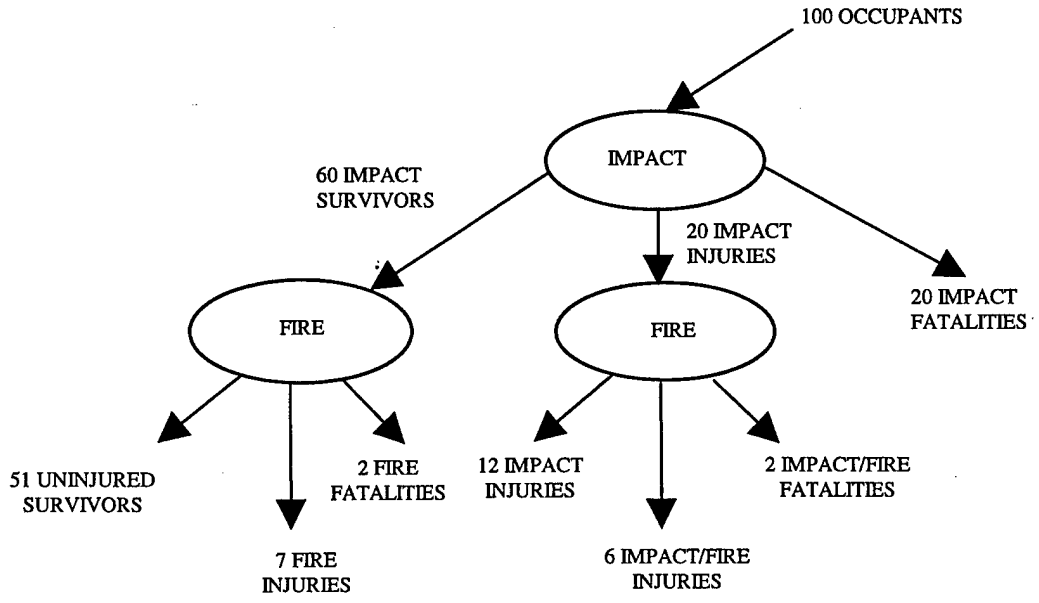


FIGURE 3. EXAMPLE OF SURVIVABILITY CHAIN SHOWING POSSIBLE IMPROVEMENTS IN SURVIVABLITY AS A RESULT OF FUSELAGE FIRE HARDENING

Hence the improvement to the fuselage fire hardening results in:

- 51 uninjured survivors.
- 25 serious injuries, 12 as a result of the impact, 7 as a result of the fire, and 6 as a result of the impact and fire.
- 24 fatalities, 20 as a result of the impact, and 4 as a result of the fire (2 of whom sustained nonfatal injuries from the impact).

The overall situation is summarised as follows:

	Survivors	Injuries	Fatalities
Prior to Improvement:	45	25	30
Post Improvement:	51	25	24

3.4 STATISTICAL MODELLING.

Software has been developed to use this model in a mathematical representation of an accident using Monte Carlo Simulations. This simulation enables an assessment to be made of the change in numbers of survivors, injuries, and fatalities resulting from predictions of the range of improvements that may be possible from changes to a survivability factor.

For each scenario, a numerical assessment is made of the effect on the number of fatalities and injuries because of changes to fire hardening of the fuselage. The assessment results in a prediction of the highest, median, and lowest number of fatalities and injuries that could reasonably be expected from the change.

From the example described in section 3.3, the best (or median) assessments were made of the improvement in the number of fatalities and injuries resulting from enhanced fuselage burnthrough protection. When making this determination an assessment would also be made of the maximum and minimum number of fatalities and injuries that are likely to result from a change in the fuselage fire hardening.

It is then assumed that there can be 100% confidence that the fatalities and injuries will lie in the range from the maximum to the minimum. The software makes random selections over the range 0% to 100% to arrive at a particular number of fatalities and injuries.

From this, a re-evaluation of the number of survivors may be made using the Survivability Chain generated for the accident scenario. This is then compared with the actual number of survivors of the accident. The iterations are then carried out many times to generate a distribution. From this distribution the 2½, 50, and 97½ percentile values are selected to represent a range of the likely improvement in fatality rate for fire-hardened fuselages.

This simulation process is described in detail in appendix A.

It is recognised that the models are not perfect representations of an accident nor are the statistical assessments totally accurate. However, they will provide a better assessment of the likely impact of improvements to fuselage fire hardening than would otherwise be derived from a simple estimate of the resultant change in number of survivors.

3.5 LATER REQUIREMENTS.

Assessments of the improvements in fatality rate were carried out for the accidents based on the aircraft standard, and operating requirements, at the time of the accident. Each accident was then reanalysed taking into account the improvements that might have been made to numbers of fatalities and injuries if the aircraft had been configured to the latest requirements.

The benefit information, relating to aircraft configured to the latest requirements, was entered onto a separate computer database and the statistical analysis described in section 3.4 repeated.

The later requirements used to reassess the accidents were:

- Floor proximity lighting/marking
- Seat blocking layers
- Fire hardening of cabin interior materials
- Improved access to type III exits

3.6 VARIATION OF BENEFIT WITH BURNTHROUGH TIME.

The benefits of a fire-hardened fuselage will depend on the extension to burnthrough times provided. Since this study does not make any assumptions about how the burnthrough protection is achieved, it was necessary to employ a range of burnthrough times and repeat the analysis for a number of different values.

It was difficult to assess from the accident rationales exactly when the burnthrough penetration occurred; therefore the assessments were based on incremental burnthrough improvement times.

The process of assessing high, median, and low values for fatalities and injuries was repeated using the following increases in fuselage burnthrough times; 30, 120, 240, and 480 seconds.

The statistical model was run for each of the protection times and for both the actual aircraft configuration and the aircraft configured to later certification and operating requirements.

3.7 ACCIDENT ANALYSIS METHODOLOGY.

The assessments were carried out by two analysts. Each of the accidents was analysed by analyst 1. After the assessment was complete, there was a discussion between the analysts on each accident. Analyst 1 then made a revised assessment and analyst 2 made another, independent assessment. The results from these assessments were combined by using the largest extremes of the predicted number of fatal injuries and taking the average of the medians as shown in figure 4. This technique was used to reduce the effect of any bias either analyst might have had in making his assessment.

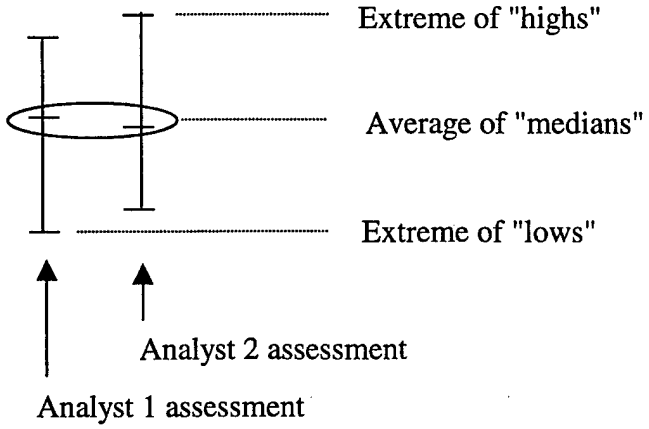


FIGURE 4. COMBINING TWO INDEPENDENT ASSESSMENTS

4. RESULTS.

All of the results contained in this section of the report are based on the assumption that the 17 accidents identified are the only fatal burnthrough accidents that have occurred over the period. Subsequent sections of this report discuss the validity of this assumption and the most likely benefit to be achieved from enhancements to fuselage burnthrough protection.

4.1 BENEFIT DEFINITIONS.

The following definitions are used for the benefits assessed by this analysis.

An improvement in fatality rate is defined as:

"The reduction in the number of fatalities divided by the total number of occupants aboard."

An improvement in injury rate is defined as:

"The reduction in the number of serious and fatal injuries divided by the total number of occupants aboard."

In order to derive the total number of lives saved in all survivable accidents in which there were fatalities, the fatality rate must be multiplied by the total number of occupants, i.e., 25001. (Refer also to figure 1.) In order to derive the number of lives saved per year, the total number of lives saved must be divided by the number of years the data encompassed, i.e., 28. A similar process is adopted for deriving the total number of injuries from injury rate.

4.2 BENEFIT BASED ON THE AIRCRAFT STANDARD AT THE TIME OF THE ACCIDENT.

The high, median, and low prediction of effect on fatality rate was based on 9999 iterations of all burnthrough-related accidents identified on the database using the method described in section 3. These predictions were based on the aircraft configured to the standard at the time of the accident and took no account of the improvements offered by the introduction of later requirements.

The values shown in table 2 represent the incremental change in fatality and injury rate predicted for all survivable accidents in which there were fatalities (25001 occupants, refer to figure 1).

TABLE 2. FATALITY RATE IMPROVEMENT FOR AIRCRAFT IN ACTUAL CONFIGURATION

Additional Burnthrough Protection Time	Median Improvement in Fatality Rate	Median Improvement in Injury Rate*
30 seconds	0.00279	0.00315
2 minutes	0.00568	0.00484
4 minutes	0.00751	0.00841
8 minutes	0.00764	0.00952

*Note that injury rate includes fatal and serious injuries.

These results are summarised in table 3 for the best estimate (median) of number of lives saved over the period 1966 to 1993 and the average per year. They are also displayed graphically in figures 5 and 6.

TABLE 3. POTENTIAL LIFE SAVING FOR THE SEVENTEEN AIRCRAFT IN ACTUAL CONFIGURATION

Additional Burnthrough Protection Time	Median Lives Saved	Median Lives Saved Per Year
30 seconds	69.6	2.5
2 minutes	142.1	5.1
4 minutes	187.7	6.7
8 minutes	191.0	6.8

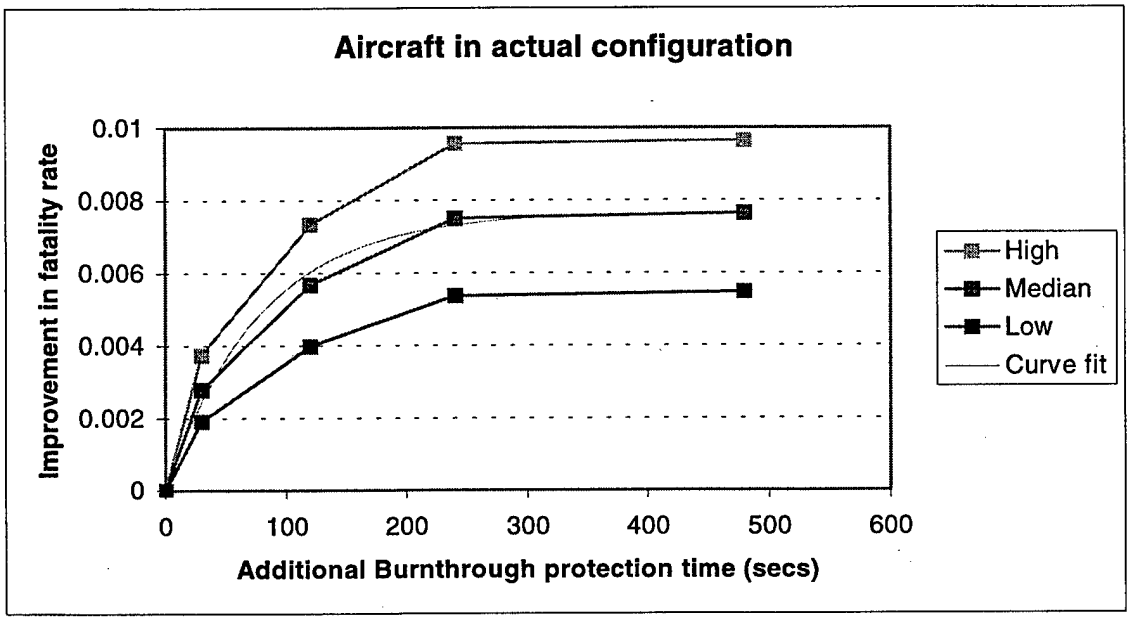


FIGURE 5. VARIATION OF IMPROVEMENT IN FATALITY RATE WITH ADDITIONAL BURNTHROUGH PROTECTION TIME FOR THE SEVENTEEN AIRCRAFT IN ACTUAL CONFIGURATION

The graph is shown overlaid with a least squares exponential curve fit for the median line having the formula $0.0077(1-e^{(-0.013t)})$ where t is the additional burnthrough protection time in seconds.

It should be noted that the coefficient 0.0077 is the horizontal asymptote and represents the maximum assessed improvement in fatality rate with a perfectly fire-hardened fuselage.

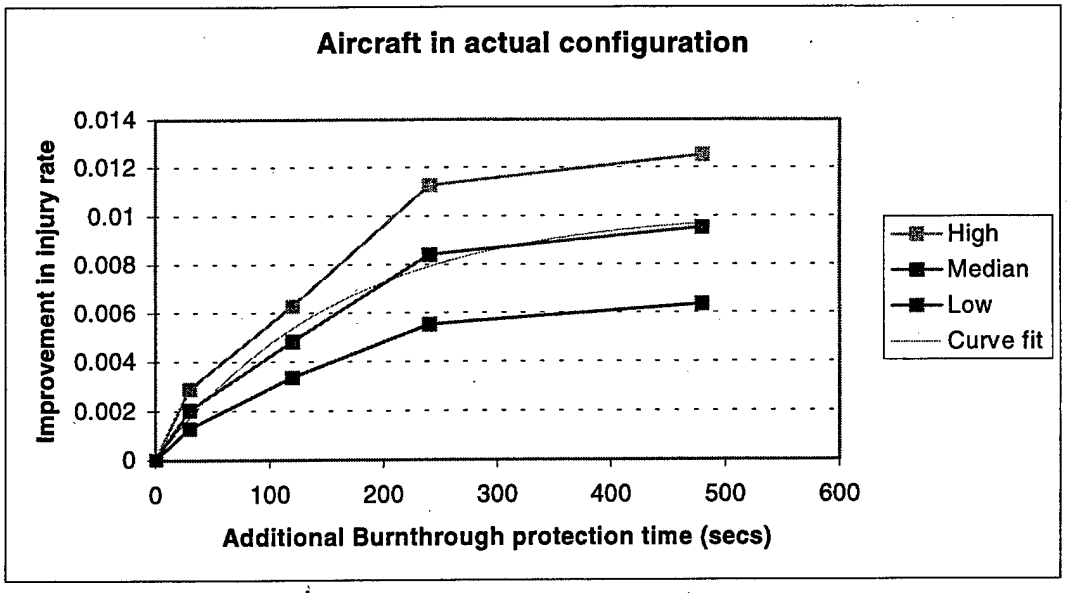


FIGURE 6. VARIATION OF IMPROVEMENT IN INJURY RATE WITH ADDITIONAL BURNTHROUGH PROTECTION TIME FOR THE SEVENTEEN AIRCRAFT IN ACTUAL CONFIGURATION

The graph is shown overlaid with a least squares exponential curve fit for the median line having the formula $0.0102(1-e^{(-0.0063)})$ where t is the additional burnthrough protection time in seconds.

It should be noted that the coefficient 0.0102 is the horizontal asymptote and represents the maximum assessed improvement in injury rate with a perfectly fire-hardened fuselage.

4.3 BENEFIT BASED ON AN AIRCRAFT STANDARD APPLICABLE TO LATER REQUIREMENTS.

The high, median, and low prediction of impact on fatality rate was based on 9999 iterations of all accidents on the database using the method described in section 3 assuming that the aircraft were configured to the later requirements standard.

The values shown in table 4 represent the incremental change in fatality and injury rate predicted for all survivable accidents in which there were fatalities (25001 occupants, refer to figure 1).

TABLE 4. FATALITY RATE IMPROVEMENT FOR THE SEVENTEEN AIRCRAFT CONFIGURED TO LATER REQUIREMENTS

Additional Burnthrough Protection Time	Median Improvement in Fatality Rate	Median Improvement in Injury Rate*
30 seconds	0.00266	0.00250
2 minutes	0.00457	0.00466
4 minutes	0.00618	0.00782
8 minutes	0.00636	0.00852

*Note that injury rate includes fatal and serious injuries.

These results are summarised in table 5 for the best estimate (median) of number of lives saved over the period 1966 to 1993 and the average per year. They are also displayed graphically in figures 7 and 8.

TABLE 5. POTENTIAL LIFE SAVING FOR THE SEVENTEEN AIRCRAFT CONFIGURED TO LATER REQUIREMENTS

Additional Burnthrough Protection Time	Median Lives Saved	Median Lives Saved Per Year
30 seconds	66.5	2.4
2 minutes	114.2	4.1
4 minutes	154.6	5.5
8 minutes	159.1	5.7

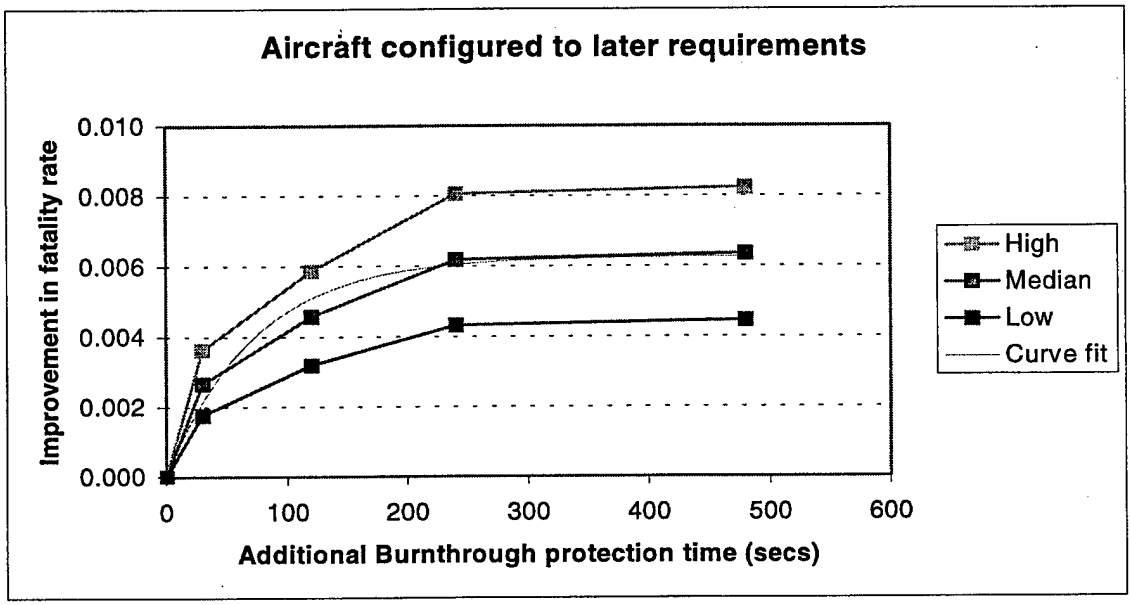


FIGURE 7. VARIATION OF IMPROVEMENT IN FATALITY RATE WITH ADDITIONAL BURNTHROUGH PROTECTION TIME FOR THE SEVENTEEN AIRCRAFT CONFIGURED TO LATER REQUIREMENTS

The graph is shown overlaid with a least squares exponential curve fit for the median line having the formula $0.0063(1-e^{(-0.014t)})$ where t is the burnthrough protection time in seconds.

It should be noted that the coefficient 0.0063 is the horizontal asymptote and represents the maximum assessed improvement in fatality rate with a perfectly fire-hardened fuselage.

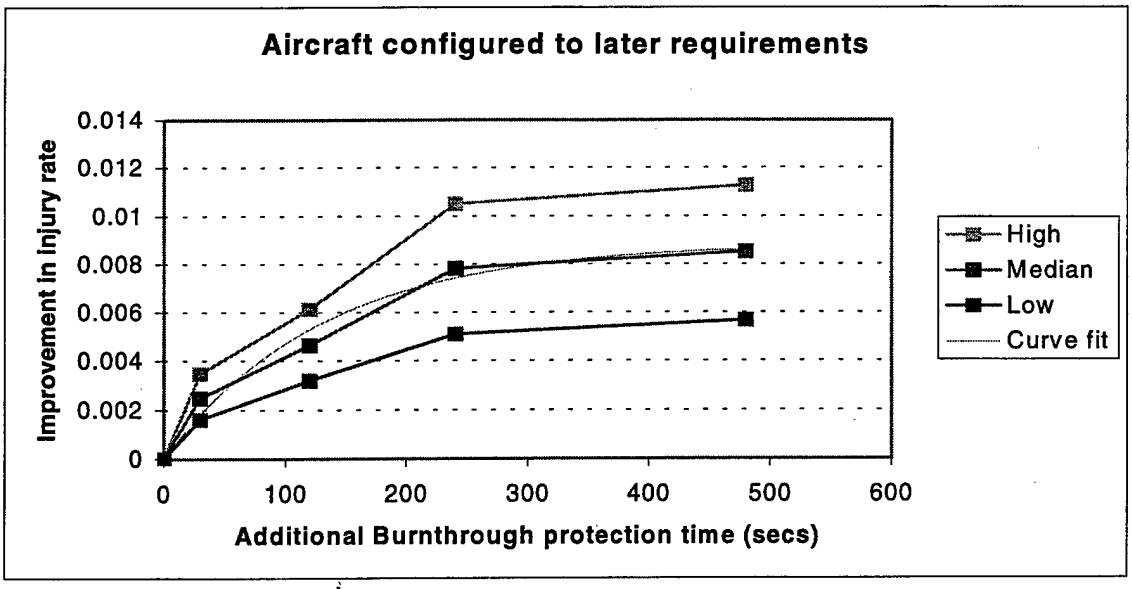


FIGURE 8. VARIATION OF IMPROVEMENT IN INJURY RATE WITH ADDITIONAL BURNTHROUGH PROTECTION TIME FOR THE SEVENTEEN AIRCRAFT CONFIGURED TO LATER REQUIREMENTS

The graph is shown overlaid with a least squares exponential curve fit for the median line having the formula $0.0088(1-e^{(-0.0076t)})$ where t is the burnthrough protection time in seconds.

It should be noted that the coefficient 0.0088 is the horizontal asymptote and represents the maximum assessed improvement in injury rate with a perfectly fire-hardened fuselage.

5. ANALYSIS.

5.1 NUMBER OF BURNTHROUGH ACCIDENTS.

Seventeen accidents were identified as matching the selection criteria in section 3.1 and were considered appropriate to use for the benefit analysis.

It was considered likely that there are other accidents where burnthrough was an issue but because there is little or no data available, they cannot currently be identified. If other burnthrough accidents have occurred, then the derived benefit would increase. This is because the incremental change in fatality rate and injury rate is derived from the total number of occupants in survivable accidents - which is a constant for the period considered. Therefore, the results contained within section 4 can be considered as the minimum level of benefit achievable. From a study carried out of the Survivable Accidents Database, it is assessed that of the worldwide fire related fatal accidents (currently 140 on the Database) only 54% have sufficient data to assess whether burnthrough occurred. If the accidents not having available accident data have a similar benefit potential to those that do, then it is likely that the levels actually realised will be approximately 1.84 times (1/0.54) those contained in section 4 of this report.

Application of this factor to the benefit derived from the accidents studied results in the assessed median lives saved shown in table 6.

TABLE 6. BEST ASSESSMENT OF MEDIAN LIVES SAVED FOR VARYING IMPROVEMENTS IN BURNTHROUGH PROTECTION TIME

Additional Burnthrough Protection Time	Median Lives Saved per Year
30 seconds	4.4
2 minutes	7.6
4 minutes	10.1
8 minutes	10.5

The factor of 1.84 may be applied to all of the benefit assessments based on the 17 accidents in order to obtain an assessment applicable to all accidents.

5.2 COMPARISON BETWEEN FATALITY RATE AND INJURY RATE.

Examination of the results in tables 2 and 4 shows that the potential improvements to injury rate can be less than the improvement in fatality rate. Injury rate includes serious and fatal injuries and might be expected to improve at a greater rate than fatality rate alone.

This apparent anomaly is because the general reduction in injury severity allows for fatally injured occupants to move into the seriously injured category and potentially increase their numbers if insufficient seriously injured move into the minor or no injury category. By way of example, consider the fire hazard presented to the 60 impact survivors shown in figure 2. If the five fire fatalities were reduced to two by the introduction of some enhanced cabin safety feature, then there would be an obvious reduction in the fatality rate. However, if this resulted in the number of seriously injured occupants increasing to 13 (those previously sustaining fatal injuries now being seriously injured), the total number of serious and fatal injuries would remain at 15. There would therefore be no change in injury rate.

5.3 COMPARISON WITH PREVIOUS STUDIES.

5.3.1 Comparison With Cabin Water Sprays.

The benefit analysis that was carried out on cabin water sprays (reference 1) in 1991 concluded that

"... today cabin water sprays would save on average 14 lives per year world-wide."

This benefit should be compared with the assessed 10.5 lives saved per year for enhanced burnthrough protection times of eight minutes derived in this study.

5.3.2 Comparison With a Representative Set of Survivable Accidents.

As part of a separate study (see reference 2) a representative set of survivable accidents has been derived. This set of 55 accidents has been selected such that it has similar attributes to the entire population of survivable accidents. Within this set, there are four burnthrough accidents. From this study it is assessed that these four accidents have the potential for 62 median lives to be saved from 1967-1995 an additional eight minutes of protection time for an aircraft configured to the latest requirements. Over the twenty-eight-year period involving a total of 356 survivable accidents this equates to (356/55) x (62/28) = 14 lives per year.

TABLE 7. COMPARISON WITH REPRESENTATIVE SET

Assessment of Lives Saved per Year From This Study	Assessment of Lives Saved per Year Based on the Representative Set of 55 Accidents
10.5	14

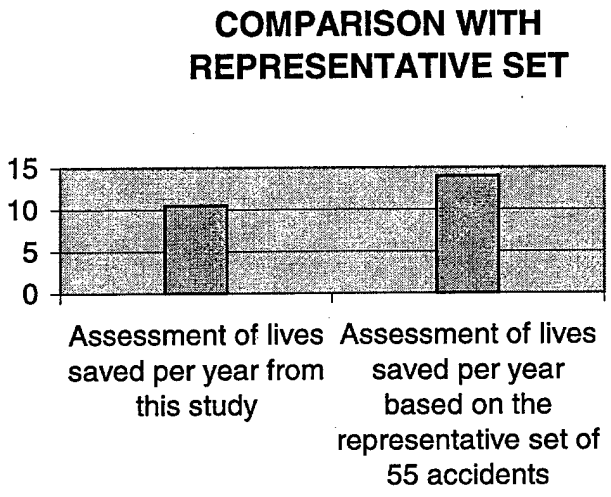


FIGURE 9. BAR CHART SHOWING COMPARISON BETWEEN THE RESULTS FROM THIS STUDY AND THAT DERIVED FROM THE REPRESENTATIVE SET

The similarity of the two values suggests that the prediction of benefit, taking into account the accidents for which data are not available, is reasonably accurate.

5.4 FIRE ENTRY PATH.

During the accident analysis, the fire entry path was identified, where possible, in order to gain an understanding of the susceptible areas of the fuselage.

A summary of fire burnthrough areas is presented in table 8. The median number of lives saved were included so that an assessment may be made of the contribution of each fire entry area to the overall life saving capability.

TABLE 8. FIRE ENTRY AREAS

Date	Location	Fuselage Skin	Doors	Windows	Cargo Hold	U/C Bay	Equipment Bay	Median Lives Saved*
14-Sep-93	Warsaw	Y	?	?	?	?	?	1
01-Feb-91	Los Angeles	Y	N	N	?	?	?	0
31-Aug-88	Dallas	Y	N	N	N	?	?	1
26-Jun-88	Habsheim	Y	N	N	?	?	?	3
22-Aug-85	Manchester	Y	N	Y	N	N	N	40
30-Aug-84	Douala	Y	?	?	?	?	?	0
07-Dec-83	Madrid	Y	?	?	?	?	?	0
13-Sep-82	Malaga	Y	N	N	?	?	?	22
07-Oct-79	Athens	Y	N	N	?	?	?	6
17-Dec-78	Hyderabad	Y	?	?	?	?	?	0
15-Mar-74	Teheran	Y	N	N	?	?	?	13
30-Jan-74	Pago Pago	Y	N	?	?	?	?	9
22-Jan-73	Kano	Y	N	?	N	?	?	52
20-Dec-72	Chicago	Y	?	?	?	?	?	7
18-Apr-72	Addis Ababa	Y	N	N	?	?	?	7
08-Apr-68	Heathrow	Y	?	?	?	?	?	3
16-Feb-67	Menado	Y	?	N	?	?	?	11

* = For 8 minutes additional protection with aircraft configured to later requirements
Y = Conclusive that burnthrough occurred
N = Conclusive that burnthrough did not occur
? = Insufficient information to determine whether or not burnthrough occurred

While conclusive data pertaining to each of the possible burnthrough routes is not available in most cases, it is evident from table 8 that the fuselage skin is the prime entry route for pool fires.

5.5 SENSITIVITY.

5.5.1 Sensitivity to Burnthrough Protection Time.

The improvement in fatality rate has been shown to vary with burnthrough protection time in an exponential manner. It can be seen that the assessed benefit can increase significantly with burnthrough protection time. An additional burnthrough protection time of 2 minutes approximately doubles the improvement in fatality rate compared with an additional 30 seconds of burnthrough protection time.

5.5.2 Sensitivity to Number of Burnthrough Accidents.

An assessment has been made of the sensitivity of the number of lives saved per year to the contribution made by any one accident.

The accident, which contributed the highest number of lives saved by burnthrough protection at 8 minutes (the longest time assessed), was in Kano on 22 January 1973. This accident contributed a median saving of 52 lives. If this accident is removed from the analysis the median number of lives saved per year reduces by 1.9, i.e., 5.7 reduces to 3.8. While this is a significant reduction,

the value still is just on the edge of the range assessed by this analysis prior to applying the correction factor of 1.84 as discussed in section 5.1 of this report. If information were available for all burnthrough accidents then the deletion of one accident would have less of an effect.

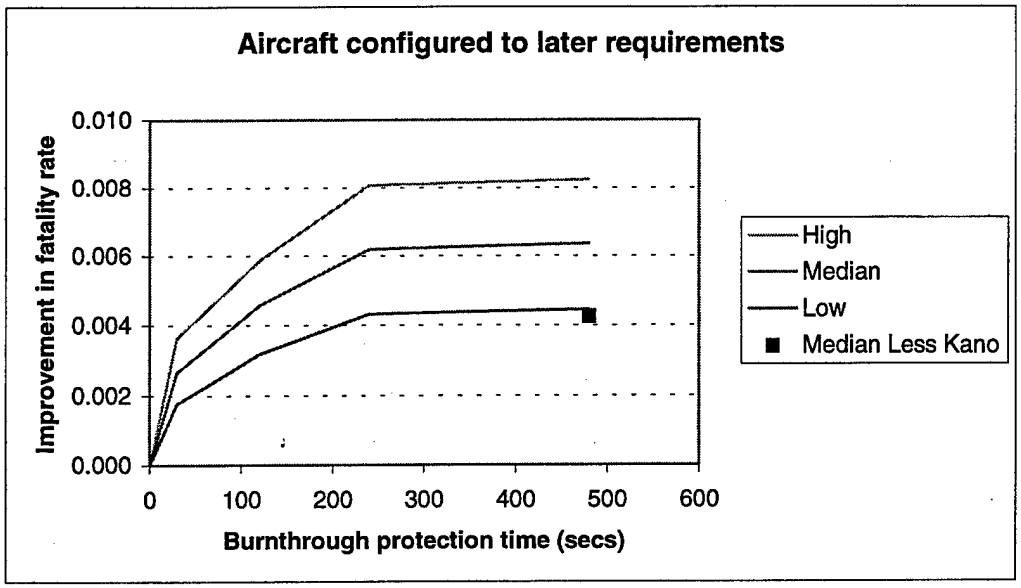


FIGURE 10. REDUCTION IN MEDIAN IMPROVEMENT WITH HIGHEST CONTRIBUTING ACCIDENT REMOVED

6. DISCUSSION.

6.1 METHODOLOGY.

The mathematical and statistical models developed from previous studies for the analysis of accidents is considered an extremely useful tool, especially when analysing accidents with limited data. The technique of assessing a range of improvements as well as a best estimate provides a prediction of both the most likely benefit to be gained and its potential range.

A precise time for burnthrough could not be determined for any of the accidents. Hence, rather than using absolute values for burnthrough time, assessments were made for the potential benefit of increasing burnthrough time, by 30 seconds 2, 4, and 8 minutes. From studying the accidents, it became apparent that improvements in burnthrough time greater than 8 minutes would have no further life saving potential. However, this comparatively high value was chosen in order to get an indication of the maximum achievable benefit providing the technology was available to produce this degree of fire hardening.

Consideration was given to using a standard value for assessing the likely number of lives to be saved for each second in improvement of burnthrough protection time. However, when considering each accident it became apparent that it would be incorrect to adopt this methodology. For example, consider an accident where the pool fire develops to the extent that at some time during the evacuation an exit is rendered unusable due to being engulfed in fire. In this instance, there would be a step change in the egress rate at the time of loss of the exit. The

analyses were therefore carried out by making unique assessments for each accident scenario and the number of occupants that might escape for discrete improvements in burnthrough penetration times.

6.2 RESULTS.

The potential benefit in terms of reduction in fatality rate and reduction in injury rate was assessed for each of the accidents listed in table 1. As can be seen from figure 1, of the 140 fire-related fatal accidents occurring during the period covered by this study, only 17 were identified as involving burnthrough. It has been assessed that the benefit derived from the accidents studied should be multiplied by a factor of approximately 1.84 in order to obtain the corresponding figure for all accidents. If this factor is applied to the assessed benefit for an additional 8 minutes of burnthrough protection time, then the benefit becomes 10.5 lives saved per year.

Injury rate and fatality rate are defined in section 9. It should be noted that in this context, injuries include fatalities and serious injuries. From table 2, a comparison of the injury rates with fatality rate shows that the potential improvement in injury rate is not greatly different from the improvement in fatality rate. Whilst improvements in burnthrough time are likely to reduce the number of fatal injuries, the serious injuries may for some accidents actually increase. This is because the occupants that would be saved from fatal injuries may still sustain serious injuries. Hence, for some accidents there may be no improvement in injury rate (fatal plus serious) but an improvement in fatality rate.

The assessment of fatality rate and injury rate was carried out for varying increases in burnthrough time for each accident. A similar benefit assessment was carried out as if the aircraft had been configured to the standards required by the latest cabin safety requirements. The results of these assessments are presented graphically in figures 5 through 8 for varying increases in burnthrough time. Also shown in these figures is the assessed 95-percentile range in benefit using the methodology previously described. For each of these assessments, a curve of best fit has been derived for the median, or best estimate, of the improvement in fatality rate or injury rate. This curve of best-fit tends to take the form of an exponential relationship between improvement in burnthrough time and improvement in fatality/injury rate

$$\text{improvement in fatality/injury rate} = A\,(1-e^{-Bt}).$$

Where A = the asymptote of the equation representing the maximum possible improvement in fatality/injury rate attainable, and B = a constant that represents the magnitude of the change in improvement in fatality/injury rate with improvement in burnthrough time.

If the factor of 1.84 is applied to the derived values contained in section 4.2, then for an increase in burnthrough protection time of 8 minutes the assessed number of lives saved per year is 12.5 based on aircraft configured to the standard at the time of the accident. The equivalent reduction in number of injuries is 15.6 per year.

For the assessment based on aircraft configured to the latest requirements the derived values for an additional 8 minutes of burnthrough protection time is 10.5 lives saved per year. The equivalent reduction in number of injuries is 14.0 per year.

The assessed change in benefit, both in terms of reduction in number of fatalities and injuries, between the actual aircraft configuration and what is predicted for an aircraft configured to later requirements is not as pronounced as might be expected. This may be because, major penetration of the aircraft skin is likely to result in rapid progression of fire throughout the passenger cabin. In this respect, the later requirements result in less benefit in protecting from large external pool fires than they do for smaller external fires or for internal cabin fires.

By way of comparison, the assessment carried out for cabin water sprays (see reference 1) suggested that water sprays would save in the region of 14 lives per year worldwide. Hence, enhanced burnthrough protection has the potential to save in the region of (10.5/14) approximately 75% of what was assessed for cabin water sprays. However it is likely that techniques for improving the fire penetration resistance of fuselages would impose less costly changes to the aircraft than would cabin water spray systems.

A comparison has also been made between the predictions of benefit from this analysis and those derived from a study of a representative set of survivable accidents as described in section 5.3.2. The results compare reasonably well as shown in figure 9.

An inspection of the data relating to median lives saved for an additional 8 minutes protection time shows that certain accidents make a significant contribution to the overall benefit assessment. For example, the Kano accident contributed a saving of 52 lives. In order to assess the significance of accidents with these high levels of potential benefit, the improvements in fatality rate were assessed for all of the accidents excluding Kano. The subsequent derived rate, whilst significantly reduced, approximated to the lower band of the prediction for improvement in fatality rate. On this basis, it is considered that the results of this study are realistic and reasonable.

The structural strength of the aircraft exposed to a pool fire did not appear to have a significant effect on occupant survival. Although there were limited data available, only two accidents (Los Angeles and Manchester) were positively identified as involving structural collapse. Structural failure occurred at 18 minutes for Los Angeles and hence was not a factor in occupant survival. As previously discussed, it is assessed that there is limited benefit to be gained beyond 8 minutes. There is insufficient data available to ascertain the time that structural collapse occurred for the Manchester accident. Confirmation that structural strength is not a factor in burnthrough accidents is important. If confirmed, changes intended to fire harden the fuselage do not need to take into account the residual structural strength.

Whilst for almost all accidents the data available on the fire penetration route is extremely limited, it is evident that the fuselage skin is by far the most significant path, as might be expected. This is illustrated by the data contained in table 8. Whilst other areas of the fuselage (windows, doors, etc.) may have been penetrated by the fire, it is considered unlikely that they contributed significantly to occupant survival.

There is insufficient data to determine whether the frequency of occurrence of burnthrough accidents has changed significantly during the period covered by this study. However, if there has been any change in rate of occurrence, it is unlikely to be significant when compared to the benefit that may be derived from improving the fire hardening of the aircraft. This is not surprising since the factors contributing to the probability of occurrence of a pool fire have probably not changed significantly. Furthermore, the fire resistance of fuselage skins would be much the same in the current world fleet as it was 30 years ago. On this basis, it is likely that burnthrough accidents will occur at a similar annual rate (per number of flights) for the immediate future.

6.3 COST BENEFIT.

The cost benefit will, of course, relate to the solution adopted for protection of the cabin from external pool fires. Since the benefit has been derived in terms of fire penetration time, an assessment of the cost of each potential solution may be readily calculated. Since it is unlikely that changes in the fuselage skin material will be cost beneficial, then other solutions must be sought. Some work has been carried out by the Federal Aviation Administration and by Faverdale Technology showing the difference between various thermal acoustic insulation materials. If it can be confirmed that structural strength is not a significant factor then solutions such as this are likely to show great potential for being cost-effective. It may be argued that additional benefit may be gained by enhanced flammability standards for cabin floors. However, any enhancement in flammability standards of cabin floors to improve the survivability of occupants in pool fires would require a further study of its effectiveness and feasibility.

7. CONCLUSIONS.

- Fire hardening of fuselages will provide benefits in terms of enhanced occupant survival.
- The assessed reduction in fatalities and injuries from enhanced aircraft fire penetration resistance is shown in the following table:

	Reduction in Fatalities Per Year	Reduction in Injuries Per Year*
Based on Aircraft Standard at Time of Accident	12.5	15.6
Based on Aircraft Configured to the Latest Requirements	10.5	14

*Injuries include fatal and serious injuries

- The rate of improvement in benefit appears to vary exponentially with minimal improvement beyond the 4 to 8 minute additional protection point.

- The assessed benefit derived from this study is similar in magnitude to that determined from a study of a representative set of survivable accidents, thus providing some confidence in the results.

- The prime fire penetration route is via the fuselage skin and no evidence could be found to suggest that alternate burnthrough routes contribute significantly to occupant survival.

- Aircraft configured to the latest cabin safety requirements are likely to exhibit enhanced, but relatively limited, protection against large external pool fires.

- It is not considered likely that the rate of fatalities and injuries per year caused by fuselage burnthrough will change markedly for the near future.

- The reduction in the structural strength of the fuselage as a result of a pool fire appears to have a limited effect on occupant survival. If this is confirmed, it will result in a greater opportunity to find cost beneficial solutions to hardening aircraft against pool fires.

- Costs have not been assessed to ascertain the cost per life saved for possible methods of enhancing burnthrough protection of aircraft. However, the relationship between benefit and additional burnthrough protection, derived from this study, will assist in carrying out such an analysis.

8. REFERENCES.

1. Civil Aviation Authority Paper 93010, Cabin Water Sprays for Fire Suppression. Design Considerations and Safety Benefit Analysis Based on Past Accidents, August 1993.

2. "Cabin Safety Research Prioritisation," R.G.W. Cherry & Associates Limited, Hertfordshire, England.

9. DEFINITIONS.

Accident Scenario

"That volume of the aircraft in which the occupants are subjected to a similar level of threat."

Burnthrough Accident

"An aircraft accident where the fuselage skin was penetrated by an external fire while live occupants were on board."

Fatal Injury (Source. ICAO)

"An injury resulting in death within thirty days of the date of the accident."

Fatality Rate

"The total number of fatalities divided by the total number of occupants aboard."

Improvement in Fatality Rate

"The reduction in the number of fatalities divided by the total number of occupants aboard."

Improvement in Injury Rate

"The reduction in the number of serious and fatal injuries divided by the total number of occupants aboard."

Injury Rate

"The total number of serious and fatal injuries divided by the total number of occupants aboard."

Serious Injury (Source. ICAO Annex 13, Eighth Edition, July 1994)

"An injury which is sustained by a person in an accident and which:

(a) requires hospitalisation for more than 48 hours, commencing within seven days from the date the injury was received; or

(b) results in a fracture of any bone (except simple fractures of fingers, toes, or nose);or

(c) involves lacerations which cause severe haemorrhage, nerve, muscle or tendon damage; or

(d) involves injury to any internal organ; or

(e) involves second or third degree burns, or any burns affecting more than 5 percent of the body surface; or

(f) involves verified exposure to infectious substances or injurious radiation."

Survivable Accident

"An aircraft accident where there were one or more survivors or there was potential for survival."

APPENDIX A—STATISTICAL MODELLING

Software has been developed to represent a mathematical simulation of an accident using Monte Carlo Simulations. This enables assessments to be made of the likely range in numbers of survivors resulting from improvements in survivability factors.

Stage 1 of this process is shown diagrammatically in figure A-1. The in-depth analysis of accident details results in the generation of a survivability chain, or series of parallel survivability chains for accidents with several accident scenarios. In this study an assessment has been made of the effect on number of fatalities as a result of improvements to cabin burnthrough times. The assessment results in a prediction of the highest, mean, and lowest number of fatalities that could reasonably be expected from the improvements.

Stages 2 and 3 of the process are shown in figures A-2 and A-3.

Figure A-2 illustrates the principle for assessing the effect on survivability of variations in the effectivity of improvements to survivability factors. From the rationales, the best (or median) assessment is made of the number of fatalities and injuries that would result in improvements to cabin burnthrough time. However, when making these determinations the analysts will also determine a maximum and minimum number of fatalities and injuries that are likely to result from the improvements.

It is then assumed that there can be 100% confidence that the fatalities will lie in the range from minimum to maximum according to the distribution shown in figure A-2. The software has been developed so that random selections may be made over the range 0% to 100% to arrive at a particular number of fatalities and injuries.

From each random selection a re-evaluation of the number of survivors may be made using the survivability chain generated for the accident scenario as shown in figure A-3. This is then compared with the actual number of survivors of the accident. Thus improvements in survivability, and hence survivability rate may be generated. The formula employed is

$$S_F = \frac{S - S_B}{T}$$

Where S_F = the assessment of the increase in survivability rate

S = the reassessed number of survivors due to the improvements for all accident scenarios

S_B = the actual number of survivors for all accident scenarios

T = the total of all occupants for all accident scenarios.

Stages 2 and 3 are repeated a number of times, typically 10,000, which builds up a statistical distribution of values for the improvement in injury rate. Refer to figure A-4.

Stage 4 of the process is simply to determine the 2½, 50, and 97½ percentiles from the resulting distributions to ascertain a mean and likely range for the prediction.

Whilst it is recognised that the models are not perfect representations of an accident nor are the statistical assessments totally accurate, they will provide a better assessment of the likely impact of improvements to survivability factors than would otherwise be derived from a simple estimate of the resultant change in number of survivors.

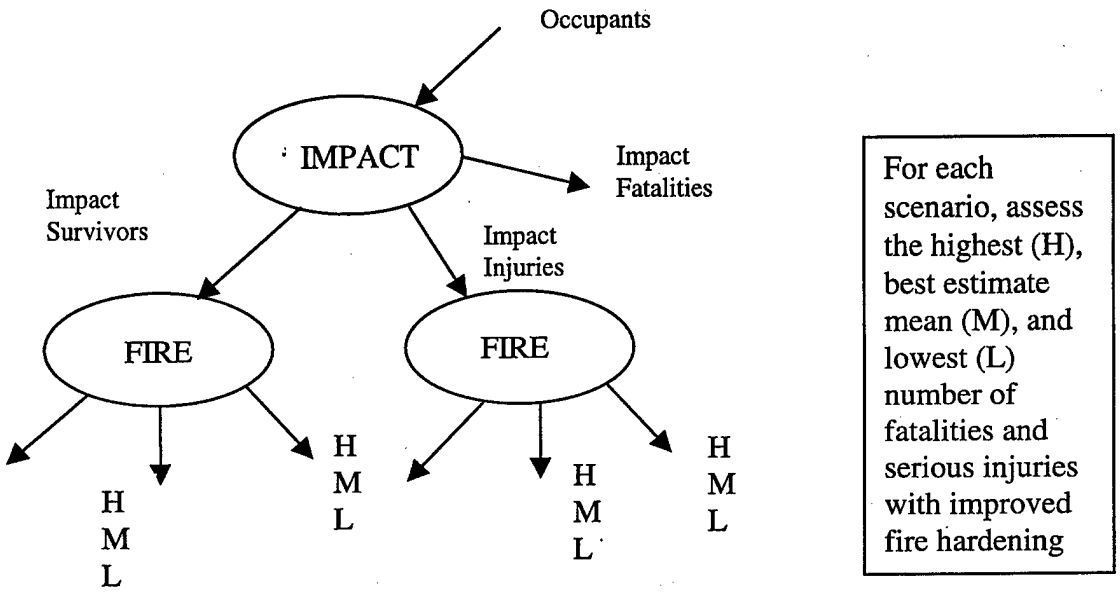


Figure A-1. Statistical Modelling Process, Stage 1

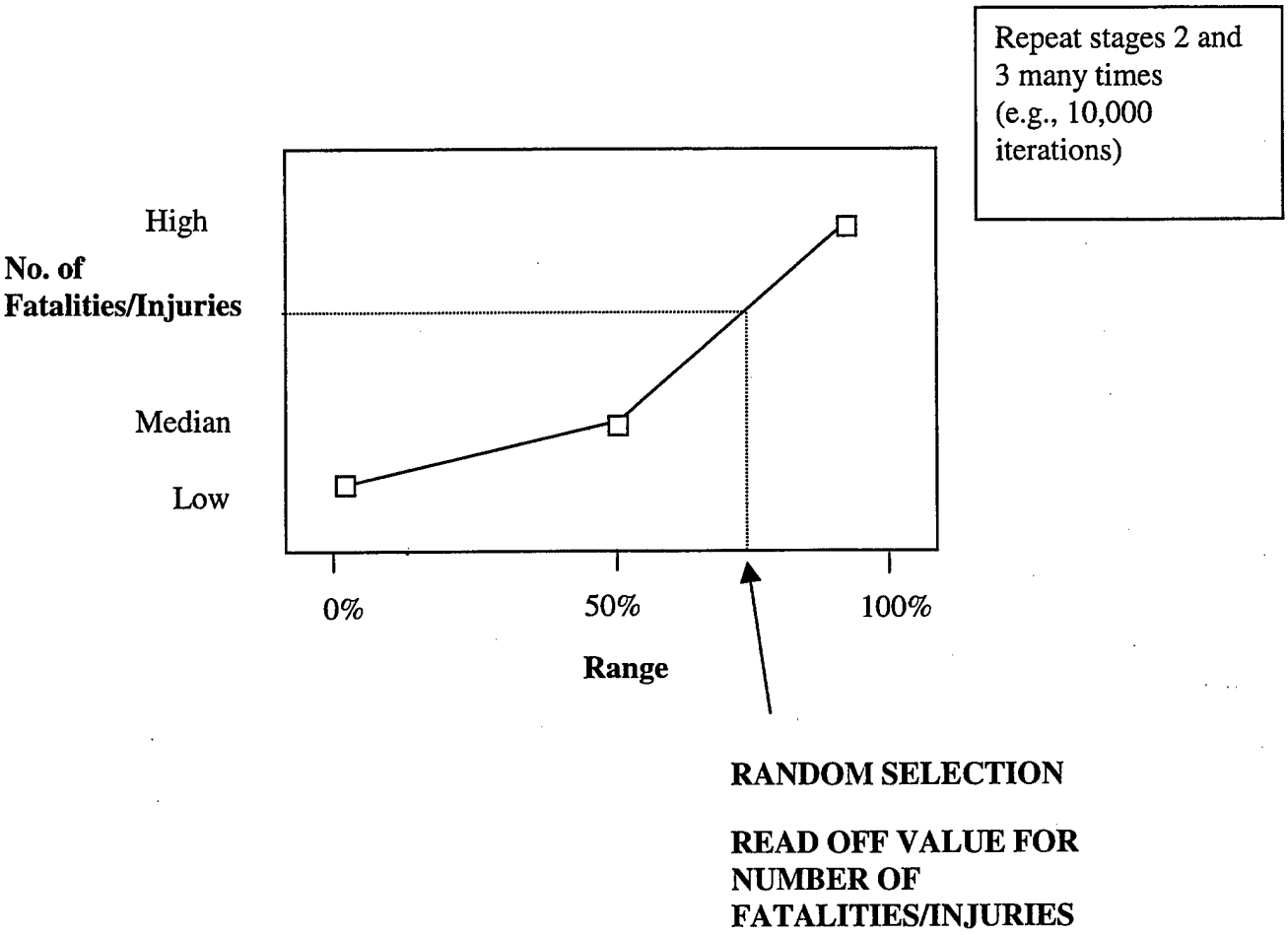
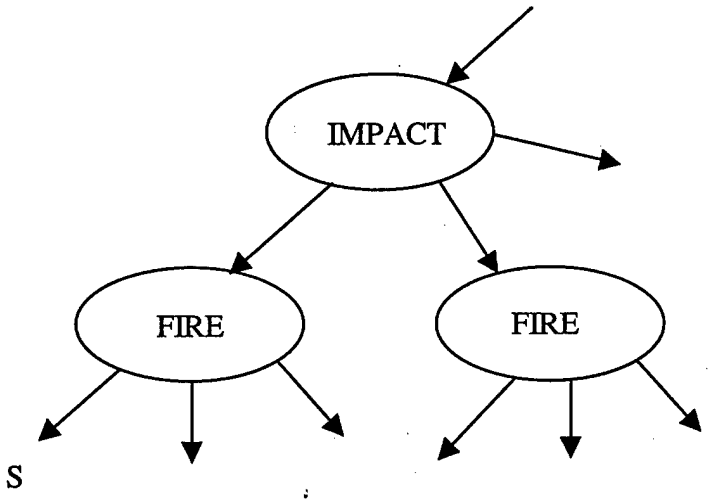


Figure A-2. Statistical Modelling Process, Stage 2



Reassess number of uninjured survivors

Evaluate injury rate improvement using:

$$S_F = \frac{S_B - S}{T}$$

Where:

SF = the assessment of the decrease in injury rate

S = the reassessed number of uninjured survivors for all accident scenarios

S_B = the actual number of uninjured survivors for all accident scenarios

T = Total number of all occupants for all accident scenarios

A similar technique is used for fatality rate improvement.

Figure A-3. Statistical Modelling Process, Stage 3

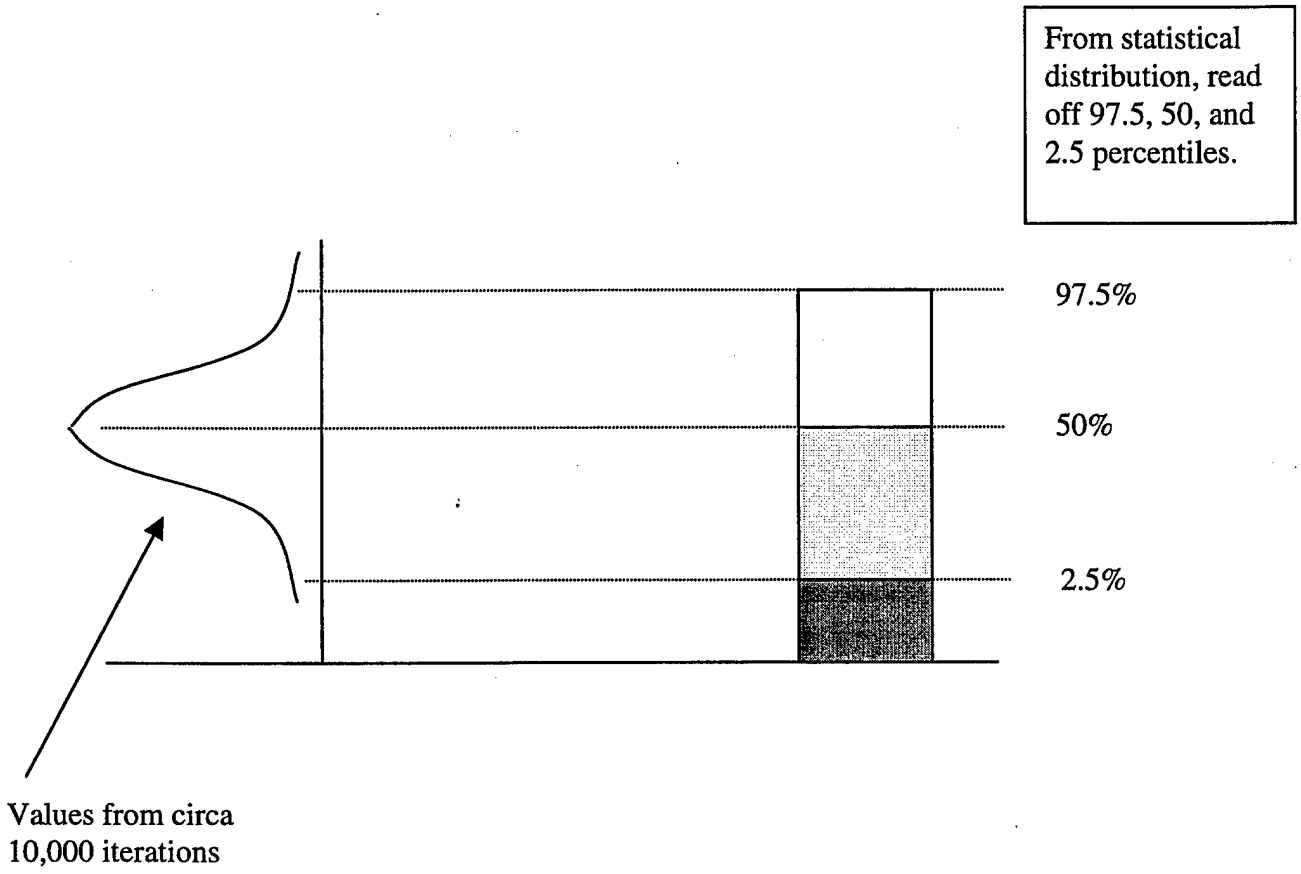


Figure A-4. Statistical Modelling Process, Stage 4

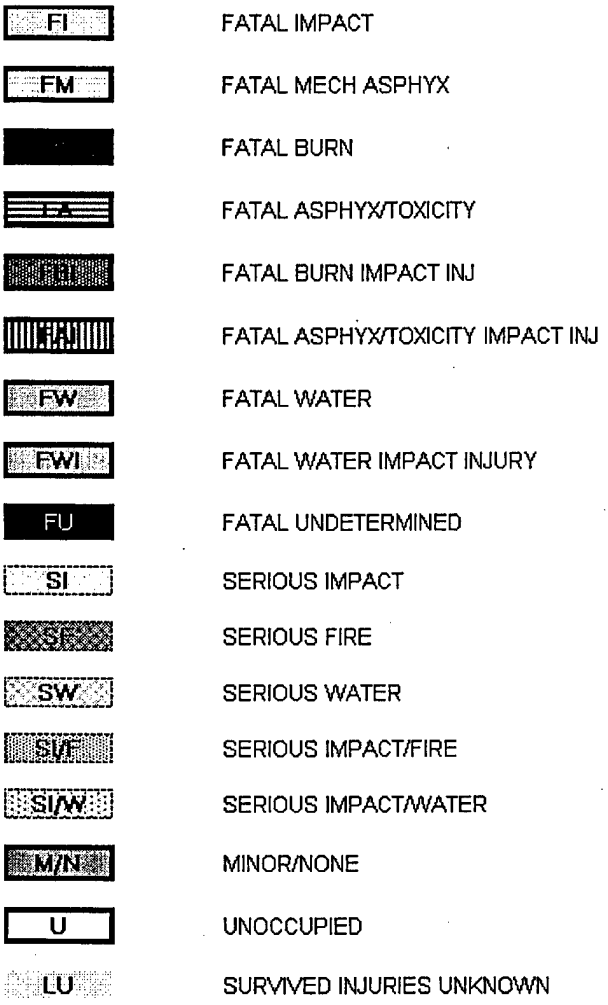
APPENDIX B—ACCIDENT RATIONALES 1 TO 7

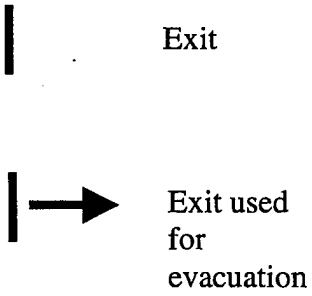
The rationale for each accident that was analysed appears in this appendix. Each accident is presented with the following sections:

- Description of the accident reproduced from the Survivable Accidents Database.
- A description of the fire penetration mechanism using relevant extracts from the database together with any assessments and assumptions made.
- A diagram showing the location of occupants and scenario boundaries.
- Survivability chains for each scenario.
- Effect of later requirements.
- Effect of a fire-hardened fuselage.

The accidents are presented in reverse chronological order.

Key to injury location diagrams:





AIRCRAFT:	**L188**	**DATE OF ACCIDENT:**	**16th February '67**
REGISTRATION:	**PK-GLB**	**LOCATION OF ACCIDENT:**	**MENADO INDONESIA**

1. Description of Accident

RESUME

On 16-Feb-67 Lockheed Electra L-188C registered as PK-GLB was on approach to Mapanget Airport, Menado, Indonesia.

The pilot-in-command adopted an awkward approach technique and the aircraft landed heavily 3 ft short of the runway manoeuvring area and some 156 ft short of the runway threshold. The undercarriage collapsed, the aircraft skidded, caught fire and came to rest on the runway.

The aircraft was destroyed by fire.

There were 8 crew and 84 passengers aboard. 22 passengers suffered fatal injuries. 12 passengers suffered serious injuries. 8 crew and 50 passengers escaped with minor or no injuries.

IMPACT

Examination at the site of the accident revealed that the aircraft first struck the ground with its right main landing gear which collapsed rearward and inboard. Marks on the manoeuvring area indicated that the propellers struck the ground in the order 4-3-2-1 and were all torn off from their respective engines. Impact of the left main landing gear was quite severe and the left wing failed, spilling fuel. The aircraft skidded on its belly along the runway and came to stop on the runway.

FIRE

As the aircraft skidded along the runway, fuel spilling from the left wing caught fire and when the aircraft came to a stop it was ablaze. The heat of the engine and also the heat produced by the friction between the aircraft body and the ground, could all have ignited the fuel.

Due to the inadequacy of the fire fighting equipment the aircraft was burnt out.

EVACUATION

The crew consisted of a pilot-in-command, co-pilot, flight engineer, flight radio operator, 3 air hostesses and a steward.

According to the crew, just after the aircraft came to a full stop the co-pilot instructed the flight engineer and the cabin attendants to open the forward main entrance door but unfortunately they did not succeed in opening this door from the inside. Meanwhile smoke and fumes began to penetrate the first class cabin (aft). The cabin attendants advised all passengers to proceed forward in order to escape from the right hand forward emergency exit and cockpit sliding windows. One of the cabin attendants tried to open the overwing emergency exits but was advised by another crew member not to open them because of fire outside the window. During

that same time the flight crew attempted to open the forward main entrance door from the outside; however, they did not succeed either. Survivors evacuated from the aircraft through the right forward emergency exit and cockpit sliding windows.

Passengers who tried to escape from the rear service door, but were unable to open it quickly were trapped in the burning wreckage.

AIRCRAFT FACTORS

The aircraft was a Lockheed Electra L-188C registered as PK-GLB. The aircraft was airworthy and maintained in accordance with the approved maintenance specifications. There was no evidence of failure or malfunctioning of the aircraft or its components prior to touchdown that could have led to the accident.

The type of fuel used was not stated in the accident report.

The cabin was fitted with a main entry door at the front on the port side with a service door opposite. There was an overwing exit above each wing. At the rear there was an entry door on the port side with a service door opposite.

ENVIRONMENTAL CONDITIONS

The accident occurred at 05:21 hours GMT in daylight. The prevailing weather conditions before and at the time of the accident were reported to be overcast with light showers over the airfield. The 05:00 hours weather report was: wind southerly and about 2 kt, visibility 2 to 3 km, cloud 3/8 at 900 ft and 4/8 at 2000 ft.

INJURIES TO OCCUPANTS

There were 8 crew and 84 passengers aboard. 22 passengers suffered fatal injuries. 12 passengers suffered serious injuries. 8 crew and 50 passengers escaped with minor or no injuries.

Casualties were primarily caused by fire and not impact. All those passengers who apparently tried to escape from the rear service door, but were unable to open it quickly were trapped in the burning wreckage.

2. Fire Penetration Mechanism

As the aircraft skidded along the runway, fuel spilling from the left wing caught fire, and when the aircraft came to a stop it was ablaze. Further, it was reported that smoke and fumes began to penetrate the cabin from the aft end first.

It is therefore concluded that the ignited, spilt fuel lay predominantly under the rear of the fuselage and burnt through the lower skin in that area. Once burnt through, smoke and then flames would have penetrated the passenger cabin through the floor at the aft end of the fuselage.

Based on the above it is assessed that the prime burnthrough route was through the rear lower fuselage skin. However there was insufficient information to be conclusive about detailed burnthrough areas.

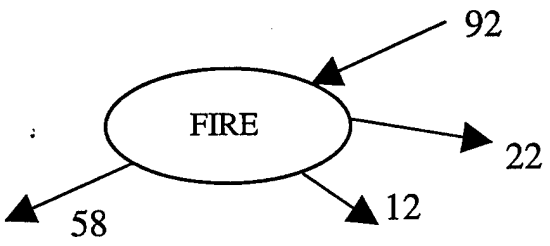
3. Location of Injuries and Scenarios

Due to the lack of detailed information on the location of occupants during the accident, it has been necessary to consider this accident as one scenario containing the whole aircraft.

4. Accident Scenarios and Survivability Chains

This accident is considered as one scenario.

Scenario 1 contains the whole fuselage. Fire entered at the rear and propagated forward. The scenario contains the 4 flight crew, 4 cabin crew and 84 passengers.

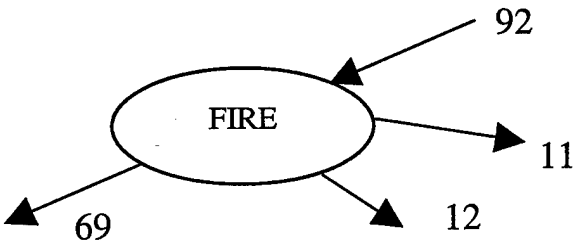


SCENARIO 1

5. Effect of Later Requirements

For Scenario 1, it is assessed that later requirements would have improved flammability standards such that the occupants would have had additional time to escape. It is assessed that 11 fatalities would have escaped with non-fatal injuries and further that 11 seriously injured would have escaped with minor or no injuries.

The survivability chain for Scenario 1 therefore becomes:



SCENARIO 1

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with more time to make their way to the forward exits.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	60	12	20
M	63	15	14
L	73	12	7

For 2 minutes protection:

	S	I	F
H	62	12	18
M	70	14	8
L	80	12	0

For 4 minutes protection:

	S	I	F
H	64	12	16
M	83	9	0
L	92	0	0

For 8 minutes protection:

	S	I	F
H	64	12	16
M	84	8	0
L	92	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	69	13	10
M	75	12	5
L	87	5	0

For 2 minutes protection:

	S	I	F
H	69	15	8
M	80	11	1
L	92	0	0

For 4 minutes protection:

	S	I	F
H	69	16	7
M	86	6	0
L	92	0	0

For 8 minutes protection:

	S	I	F
H	70	19	3
M	88	4	0
L	92	0	0

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	8	6
2 minutes	14	10
4 minutes	22	11
8 minutes	22	11

AIRCRAFT:	**B707**	**DATE OF ACCIDENT:**	**8th April '68**
REGISTRATION:	**G-ARWE**	**LOCATION OF ACCIDENT:**	**HEATHROW**

1. Description of Accident

RESUME

On 8-Apr-1968 BOAC B707 registered as G-ARWE was taking off from London (Heathrow) airport.

Approximately one minute after take-off the No. 2 engine failed and a few seconds later caught fire. The fire did not go out and the aircraft was manoeuvred for the quickest possible return. During the approach, the No. 2 engine fell away from the aircraft. The aircraft made a successful landing but fuel released on the port side caught fire.

An emergency evacuation was initiated using exits on the starboard side as the fire and smoke spread from the rear forwards. The assist means did not perform well and as a result the crew lost valuable time during the evacuation.

Of the 11 crew and 116 passengers aboard, 1 crew member and 4 passengers suffered fatal injuries. 38 passengers suffered serious injuries. 10 crew and 74 passengers escaped with minor or no injuries.

IMPACT

The aircraft made a smooth touchdown and the Captain brought the aircraft to halt normally. There was no impact.

FIRE

When the aircraft came to a stop, the fire, which had continued to burn near the No. 2 engine position, increased in intensity and the fuel tanks in the port wing exploded. The accident investigation established that the fire continued to burn because of an omission to close the fuel shutoff valve after the engine caught fire. After the aircraft came to rest, the captain ordered a fire drill on the remaining engines. Before this could be carried out, there was an explosion from the port wing which increased the intensity of the fire and blew fragments of the wing to the starboard side of the aircraft. The captain then ordered immediate evacuation of the flight deck. The engine fire shutoff handles were not pulled and the fuel booster pumps and main electrical supply were not switched off. There were more explosions and fuel, which was released from the port tanks, spread underneath the aircraft and greatly enlarged the area of the fire.

EVACUATION

There were 5 flight crew and 6 cabin crew and 116 passengers aboard.

The cabin crew opened the emergency exits as the aircraft came to a stop and started rigging the escape chutes (this involved positioning a bar behind clips on the cabin floor). The passengers commenced evacuation from the two starboard overwing exits, and shortly. afterwards, when

the escape chutes had been inflated, from the rear starboard galley door and then the forward starboard galley door.

However, because of the spread of the fire under the rear of the fuselage, the escape chute at the rear galley door soon burst and following the first explosion, the overwing escape route also became unusable.

The starboard overwing exits were the first utilised: 18 passengers escaped by these exits under the direction of the Chief Steward before he stopped their further use because of the smoke and flames which enveloped the starboard wing area following the main explosion.

Nobody left the aircraft by the forward port overwing exit.

The starboard rear galley door's chute was rigged, inflated, and found to be misaligned. One of the stewards climbed down to straighten it. Only 5 passengers and 1 steward escaped down this chute before the sparks and flames spreading from the port side burst it. 5 passengers jumped through this doorway after the chute became unserviceable.

The starboard forward galley door's escape chute was delayed in being put into operation, due to difficulty getting the chute retaining bar into its clips. After this initial delay, the main body of passengers evacuated the aircraft rapidly by this route. The evacuation tended to slow down as passengers, both injured and otherwise, began to collect round the bottom of the chute and in front of the starboard wing. The captain left the aircraft by this exit during a gap between the passengers disembarking. When it appeared that all the passengers had left the aircraft, the remaining cabin crew members also used this escape route.

The port forward main door was also used. The chute did not inflate at first, after it as deployed, and the flight engineer climbed down and straightened it out at the bottom; it almost immediately caught fire and burst. 1 passenger escaped jumping from this doorway after the chute collapsed. 3 flight crew members egressed through the cockpit windows.

The evacuation took place in an orderly manner, but when the rear galley door and starboard overwing exits became unusable, some momentary confusion resulted among those passengers who had to revise their escape routes. Conditions in the cabin were quite good in the early stages. But they deteriorated rapidly when the explosion occurred. As the evacuation progressed, dense black smoke advanced forward up the cabin from the rear as the fire took deeper and deeper hold. Smoke eventually reduced visibility to zero in the forward galley area. The captain stated it was completely overpowering. There was some difficulty in helping passengers at the rear of the aircraft, which was the first part of the fuselage to be overwhelmed by the fire. it was in this area that the stewardess was last seen alive attending to the passengers who ultimately succumbed.

The evacuation of passengers had been largely completed by the time airport Fire and Rescue Service began to provide assistance. The fire service prevented the fuel in the starboard tanks from catching fire but the rear fuselage and port wing was burned out.

AIRCRAFT FACTORS
The aircraft was a B707-465 registered as G-ARWE, operated by BOAC.

The cabin was fitted with a main entry door at the front with a service door opposite. There were 2 overwing exits above each wing. There was an entry door at the rear port side and a service door opposite.

ENVIRONMENTAL CONDITIONS
The weather conditions were clear and fine at the time of the accident.

INJURIES TO OCCUPANTS
Of the 11 crew and 116 passengers aboard, 1 crew member and 4 passengers suffered fatal injuries. 38 passengers suffered serious injuries. 10 crew and 74 passengers escaped with minor or no injuries.

4 of the passengers and one stewardess were overcome by heat and smoke in the rear of the aircraft and did not escape.

38 passengers sustained injuries during the evacuation.

2. Fire Penetration Mechanism

After the aircraft had come to a stop on the runway, there was an explosion from the port wing which increased the intensity of the fire and blew fragments of the wing to the starboard side of the aircraft. This would have spread the external fire over the outer surface of the fuselage.

There were more explosions and fuel, which was released from the port tanks, spread underneath the aircraft at the rear and greatly enlarged the area of the fire. Internally smoke was observed as coming from the rear of the cabin and spreading forward.

The spread of fire under the rear of the fuselage combined with the outer surface fire would have rapidly burnt through the fuselage skin, initially at the rear of the cabin.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin. However there was insufficient information to be conclusive about other burnthrough areas.

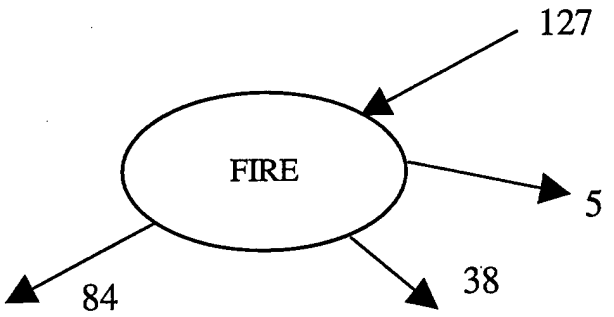
3. Location of Injuries and Scenarios

Due to lack of detailed information on the location of the occupants during the evacuation, this accident has been taken as one scenario containing the whole aircraft.

4. Accident Scenarios and Survivability Chains

This accident is considered as one scenario.

Scenario 1 contains the whole fuselage. It was not subjected to any impact, but the fire entered at the rear and propagated forward. The scenario contains the 5 flight crew, 6 cabin crew, and 116 passengers.

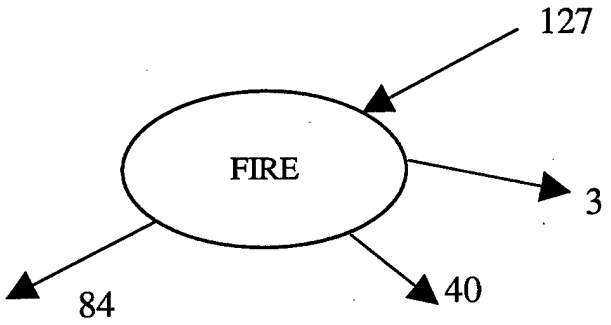


SCENARIO 1

5. Effect of Later Requirements

For Scenario 1, it is assessed that later requirements would have improved flammability standards such that the occupants would have had additional time to escape. It is assessed that two of the fatalities would have escaped with non-fatal injuries.

The survivability chain for Scenario 1 therefore becomes:



SCENARIO 1

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with additional time to make their way to the available exits.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	84	38	5
M	87	38	2
L	89	38	0

For 2 minutes protection:

	S	I	F
H	84	39	4
M	92	35	0
L	100	27	0

For 4 minutes protection:

	S	I	F
H	84	41	2
M	100	27	0
L	116	11	0

For 8 minutes protection:

	S	I	F
H	84	41	2
M	108	19	0
L	127	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	84	40	3
M	86	40	1
L	89	38	0

For 2 minutes protection:

	S	I	F
H	84	40	3
M	92	35	0
L	100	27	0

For 4 minutes protection:

	S	I	F
H	84	41	2
M	100	27	0
L	116	11	0

For 8 minutes protection:

	S	I	F
H	84	42	1
M	108	19	0
L	127	0	0

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	3	2
2 minutes	5	3
4 minutes	5	3
8 minutes	5	3

AIRCRAFT:	**SVC10**	**DATE OF ACCIDENT:**	**18th April '72**
REGISTRATION:	**5X-UVA**	**LOCATION OF ACCIDENT:**	**ADDIS ABABA**

1. Description of Accident

RESUME

A Super VC10 was taking off from Addis Ababa on 18-Apr-1972. Just prior to decision speed the nosewheel tyre hit a jacking pad that has fallen from a Cessna 185 a few hours earlier. The tyre burst and the crew initiated an aborted take-off but were unable to stop the aircraft before the end of the runway.

The aircraft slid down an embankment at the end of the runway and struck a steel lattice tower which ruptured the fuel tank. The spilling fuel ignited and the aircraft broke into three sections as it came to rest.

Survivors evacuated the aircraft through the fuselage breaks as the left emergency exits were jammed by impact damage and the right side exits were blocked by fire. 10 people had to walk away from the aircraft between streams of fuel which subsequently caught fire and trapped them.

Of the 11 crew and 96 passengers aboard, 8 crew and 35 passengers suffered fatal injuries.

IMPACT

After the nosewheel tyre burst the aircraft continued down the runway, veering slightly to the right as it did so. A few seconds later the No.1 rear main tyre failed. After crossing a storm drain located at the end of the runway both undercarriage bogies were damaged and the No.2 rear and No.3 front tyres burst. The aircraft became momentarily airborne as it left the lip of the embankment on which the runway was laid. As it did so, the left outer wing of the aircraft struck a steel lattice tower which ruptured the No.1A fuel tank and severed electrical cable looms in the leading edge of the wing. The aircraft fell heavily on to the ground below the runway level and broke up immediately on impact into three major portions, namely the tail empennage with the engines attached; the centre section and wings; and the forward part of the fuselage. After sliding a short distance the aircraft came to rest.

FIRE

Fire initially broke out when the left outer wing struck the lattice tower and the No.1A fuel tank was ruptured. The released fuel was ignited either by sparks generated as a result of the wing hitting the tower or by arcing due to disruption of electrical cable looms. There was evidence of burning on the ground from the point of impact with the tower to the final resting position, indicating that the fire trailed behind the aircraft for the whole distance.

According to the statements of survivors, fire appears to have started almost immediately after impact towards the rear and underside of the main cabin. There the heat was described as being intense at floor level.

Fire also broke out immediately after impact on the right side by the wing root. This prevented the emergency exits on that side being used. Fire eventually consumed the main cabin area, the forward fuselage, the left wing and the right wing root. The tail unit together with the engines were unburnt though extensively scorched.

EVACUATION

The crew consisted of a Captain, First Officer, Navigating Officer, Flight Engineer and 7 cabin crew. There were 96 passengers aboard.

In the main, the evacuation of the aircraft by the passengers and crew was self effected. Considerable selfless assistance was rendered by members of the cabin staff and also some of the passengers, some of whom died as a result of their efforts in this respect when they would have otherwise survived. The evacuation was facilitated considerably by the fortuitous fracture of the left forward fuselage, allowing relatively easy egress. Had it not been for this fracture casualties may well have been greater, as the left emergency exits were jammed by impact damage and the right side exits were blocked by fire.

Those who managed to get clear of the aircraft to the left side found their way blocked by a barbed wire fence. This forced most passengers and surviving members of the crew to walk down the slope alongside two main streams of fuel flowing from the aircraft. This fuel subsequently caught fire, trapping a number of people, believed to be about 10 in number.

AIRCRAFT FACTORS

The aircraft was a Super VC10 registered as 5X-UVA, operated by East African Airways and had been maintained in accordance with an approved maintenance schedule.

The aircraft was constructed in 1966 and went into service with East African Airways Corporation in that same year, having been issued with both a United Kingdom and an East African Certificate of Airworthiness.

[This series aircraft can be configured for up to 187 passenger seats.]

The fuselage was fitted with 2 doors at the front and rear and 2 overwing emergency exits above each wing.

ENVIRONMENTAL CONDITIONS

A weather observation made shortly after the accident gave the following information: wind 9 knots, temperature 21C, visibility 7-10km.

INJURIES TO OCCUPANTS

It appears that all those on board survived the impact, but some subsequently succumbed to the effects of the fire.

33 occupants were fatally injured by fire before evacuating. 10 cabin occupants succumbed to fire following evacuation.

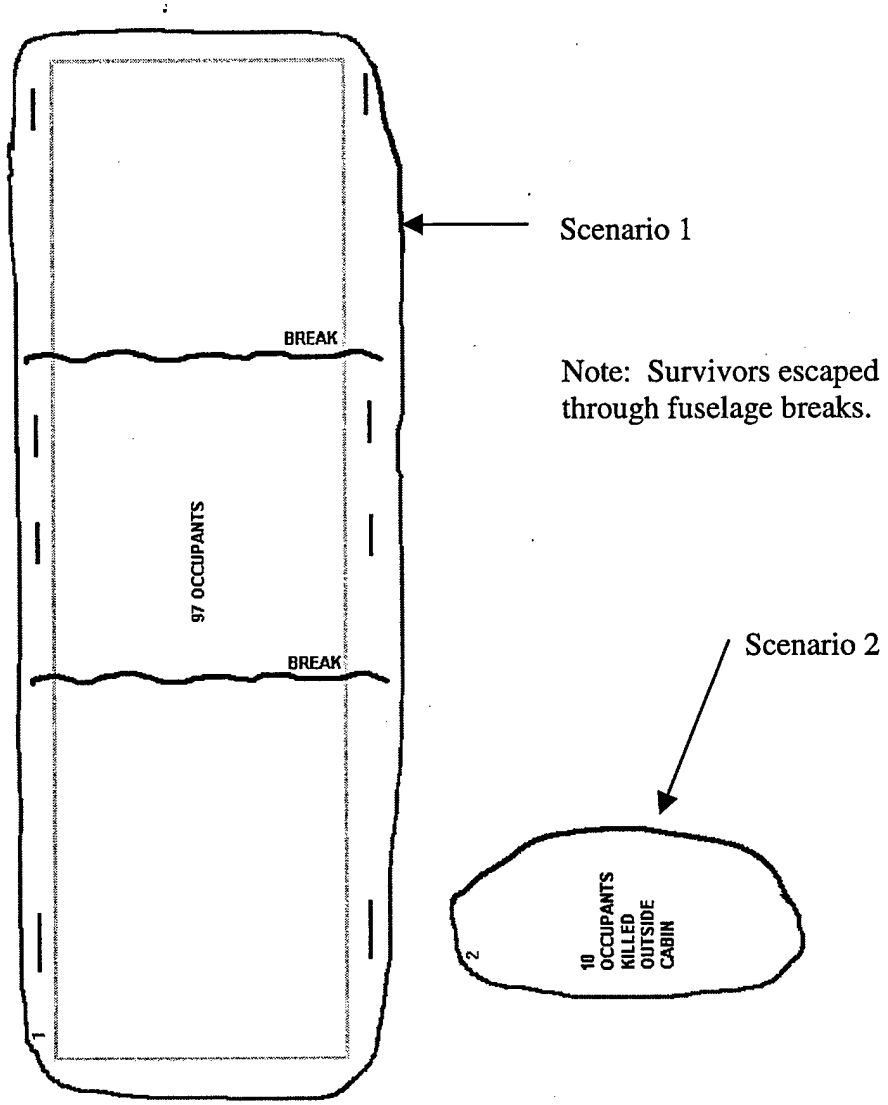
2. Fire Penetration Mechanism

According to the statements of survivors, the fire appears to have started after impact towards the rear and underside of the main cabin. There the heat was described as being intense at floor level. This would be characterised by a burnthrough of the lower fuselage skin allowing the fire to enter under the cabin floor and propagate into the passenger cabin.

Fire was also able to enter the cabin directly through fuselage breaks at either end of the wing root.

Based on the above it is assessed that the prime burnthrough route was through the rear underside of the fuselage skin. However there was insufficient information to be conclusive about detailed burnthrough areas. The fire also entered through fuselage breaks.

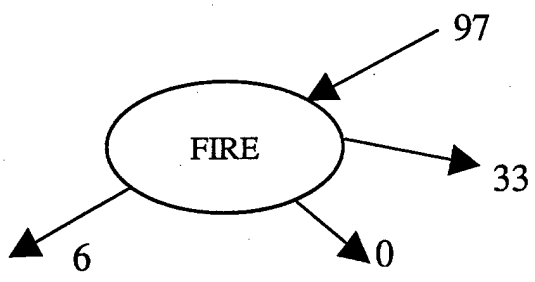
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

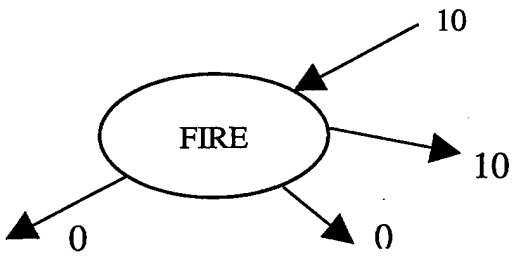
This accident is divided into two separate scenarios.

Scenario 1 contains the main cabin area. Evacuation was carried out through a fuselage break because the left exits were jammed and the right exits were blocked by fire. The scenario contains the 97 occupants including crew and passengers.



SCENARIO 1

Scenario 2 contains 10 occupants who evacuated the aircraft but became trapped between two streams of burning fuel.

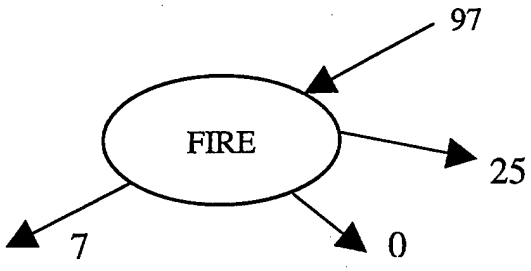


SCENARIO 2

5. Effect of Later Requirements

For Scenario 1, it is assessed that later requirements would have improved flammability standards such that the occupants would have had additional time to escape. It is assessed that an additional eight occupants would have successfully evacuated.

The survivability chain for Scenario 1 therefore becomes:



SCENARIO 1

It is assumed that later requirements would not have affected the situation in Scenario 2 in which all fatalities occurred outside the cabin environment.

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with more time to make their way to the fuselage break. Fire would also have entered through the breaks in the fuselage which would not be affected by a fire-hardened fuselage. It is therefore assessed that ten occupants would still have succumbed to fire even with perfect fuselage fire hardening.

Due to insufficient detail on serious injuries, they have been assigned to zero throughout this accident.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	64	0	33
M	69	0	28
L	77	0	20

For 2 minutes protection:

	S	I	F
H	64	0	33
M	79	0	18
L	87	0	10

For 4 minutes protection:

	S	I	F
H	64	0	33
M	79	0	18
L	87	0	10

For 8 minutes protection:

	S	I	F
H	64	0	33
M	79	0	18
L	87	0	10

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	72	0	25
M	74	0	23
L	88	0	10

For 2 minutes protection:

	S	I	F
H	72	0	25
M	79	0	18
L	89	0	8

For 4 minutes protection:

	S	I	F
H	72	0	25
M	79	0	18
L	89	0	8

For 8 minutes protection:

	S	I	F
H	72	0	25
M	79	0	18
L	89	0	8

Scenario 2

It is assessed that a fire-hardened fuselage would not have affected the situation in Scenario 2 in which all fatalities occurred outside the cabin environment.

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	5	2
2 minutes	15	7
4 minutes	15	7
8 minutes	15	7

AIRCRAFT:	**DC9**	**DATE OF ACCIDENT:**	**20th December '72**
REGISTRATION:	**N954N**	**LOCATION OF ACCIDENT:**	**CHICAGO**

1. Description of Accident

RESUME

A North Central Airlines DC-9-31 was taking off under poor visibility in fog. A Delta Airlines Convair CV-880 was taxying across the runway at the same time due to poor air traffic control. The DC-9 collided with the tail of the CV-880 and as a result was unable to climb and landed back on the runway. The undercarriage collapsed and the aircraft caught fire.

There were 4 crew and 41 passengers aboard. 9 passengers failed to escape the cabin fire because they could not locate the exits in dense smoke and poor lighting conditions.

IMPACT

After the collision, the captain decided that his aircraft could not maintain flight, at which time he took control and flew the aircraft back onto the runway.

The nose and main undercarriage collapsed and the aircraft came to a stop upright with the fuselage resting on the runway.

Passengers described the collision as being a slight bump. The subsequent touch down of the aircraft and the crash slide were described as being comparable to normal landing. Deceleration forces were described as being very slight with some side-to-side motion. None of the passengers reported being propelled into the seat in front of them.

FIRE

Shortly after impact, the DC-9 was engulfed in flames around the aft section of the aircraft and the fuselage was subsequently gutted by fire.

Smoke developed very rapidly which reduced the ability of the occupants to find emergency exits routes and made a co-ordinated crew response extremely important.

The control tower saw a flash but could not see the aircraft burning.

The first fire trucks were reported at the scene within 2 minutes. At the time of their arrival all survivors were already out of the aircraft and had moved away from the wreckage.

Firefighters extinguished the fire in 16 minutes.

EVACUATION

The crew consisted of a captain, first officer and 2 stewardesses. There were 41 passengers aboard.

The accident occurred at night. The cabin lights went out as the aircraft came to a stop and the emergency cabin standby lights were powered by rechargeable 2.5 volt nickel-cadmium batteries which produced a low light intensity when combined with the dense smoke. The extreme darkness reportedly made the location of emergency exits very difficult.

After the aircraft came to a stop smoke began to enter the cabin almost immediately. Some passengers stated that initially there was some pushing and shoving, but generally there was very little panic. Passengers reported having to get lower and lower toward the floor in order to breathe. The smoke was very dense, according to survivor accounts.

One stewardess was seated in the forward jump seat and the other stewardess was seated in seat 15B. After impact and during the slide, the rear stewardess opened the left forward overwing exit at row 12. After the aircraft had stopped, she exited and called to the passengers to follow. 4 passengers followed her out through the exit.

The forward stewardess opened the main entry door after the aircraft stopped. The escape slide deployed but did not inflate because the lanyard was wrapped around the neck of the inflation bottle. The stewardess stated that she was then pushed out of the aircraft. From the outside she called out to the passengers and assisted them down to the ground.

The first officer escaped from the aircraft through the sliding window on the right side of the cockpit. He went around the nose of the aircraft to the main entry door and from the ground he assisted passengers escaping through that door.

The captain entered the cabin through the cockpit door and called to the passengers to come forward. He then went outside through the main entry door. From a position outside the aircraft, he assisted passengers down to the ground. Then, re-entering the aircraft, the captain assisted other passengers through the main entry door. The rest of the survivors deplaned through the main entry door.

Most of the passengers indicated that their biggest obstacles in evacuating the aircraft were smoke and the lack of emergency lighting. Also the supervision of the evacuation by the flight and cabin crew members from a position outside the aircraft delayed egress of some of the passengers.

A passenger opened the right forward overwing exit through which he made his escape.

The rear tail cone emergency exit was not used. The galley exit door and the two aft overwing exits were not opened.

The 9 passengers remaining were found in the following locations by firemen:

- 1 male passenger in the tail cone aft of the pressure bulkhead
- 1 male passenger in the rear rest room
- 1 female passenger in the cockpit
- 1 male passenger halfway in the cockpit

- 5 female passengers (including 1 invalid) seated along the left side of the cabin area.

The 4 passengers who left their seats apparently attempted to find an exit but were unable to do so.

AIRCRAFT FACTORS

Aircraft N954N was a McDonnell Douglas DC-9-31, owned and operated by North Central Airlines, Inc. The aircraft was certificated, maintained and equipped in accordance with approved company procedures and FAA regulations. The aircraft had 22,000 lbs of Jet A aviation kerosene on board.

The aircraft was manufactured as serial number 47159 on 27-Dec-1967.

The fuselage was fitted with a main entry door at the front port side with a service door opposite. There were two overwing exits above each wing. The rear tail cone was also fitted with an emergency exit.

ENVIRONMENTAL CONDITIONS

The accident occurred in fog at night with a visibility of 1/4 mile.

INJURIES TO OCCUPANTS

9 of the 10 fatally injured passengers failed to escape from the aircraft. They received no traumatic injuries but succumbed instead to the effects of smoke inhalation or burns or both. Of the passengers who had left their seats, 2 were found in the cockpit area and 2 were found in the aft section. They apparently attempted to find an exit but were unable to do so in dense smoke and poor lighting conditions. 5 others remained in their seats.

The 10th fatally injured passenger succumbed 5 days later.

13 passengers and 2 crew were injured.

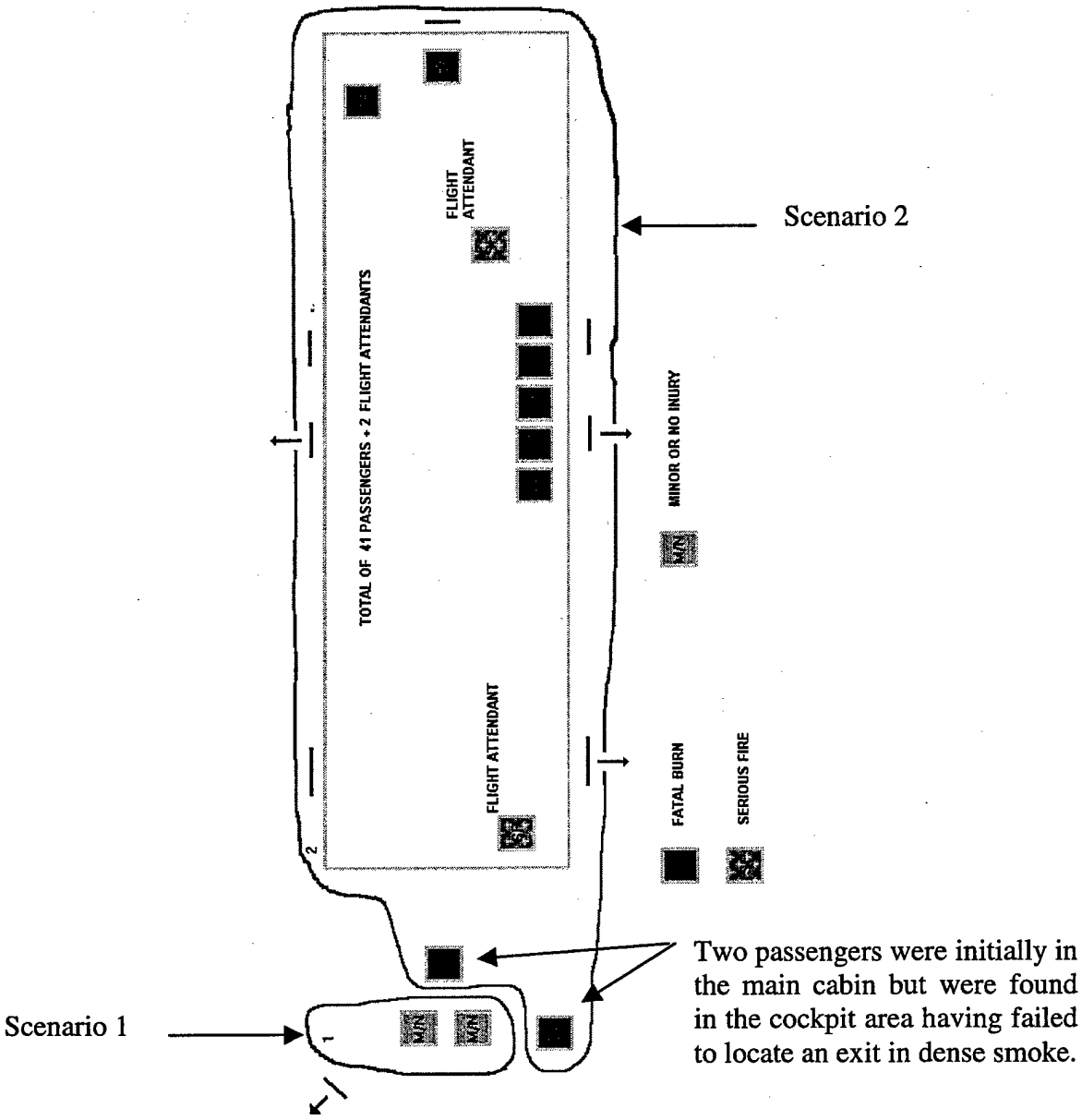
2. Fire Penetration Mechanism

The subsequent touch down of the aircraft and the crash slide were described as being comparable to normal landing. Deceleration forces were described as being very slight with some side-to-side motion. None of the passengers reported being propelled into the seat in front of them. It is therefore assumed that the fuselage was not ruptured by the impact forces.

Shortly after impact, the DC-9 was engulfed in flames around the aft section of the aircraft and after the aircraft came to a stop smoke began to enter the cabin. It was the smoke that dominated the evacuation time rather than flames. It is therefore assumed that the lower surface of the fuselage had burnt through rapidly and that smoke from under the cabin floor propagated into the passenger cabin and hindered attempts to locate the available exits.

Based on the above it is assessed that the prime burnthrough route was through the lower aft fuselage skin. However there was insufficient information to be conclusive about detail burnthrough areas.

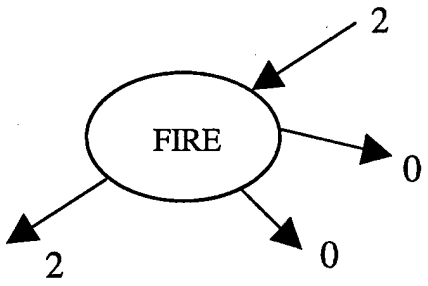
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

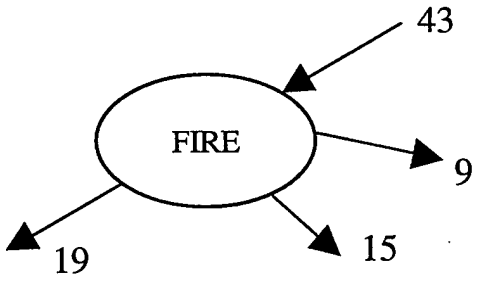
This accident is divided into two separate scenarios.

Scenario 1 contains the flight deck area and two flight crew. It was subjected to the fire but the occupants escaped with minor or no injuries.



SCENARIO 1

Scenario 2 contains the main passenger cabin, which suffered internal fire and had only three of the seven exits available for egress. It includes all passengers and flight attendants. Smoke was very dense and hampered attempts to locate open exits.



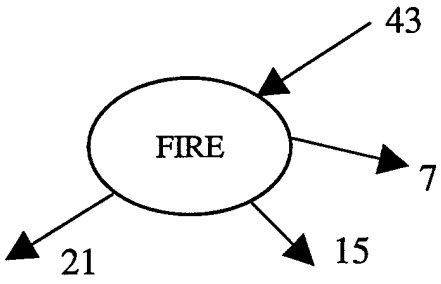
SCENARIO 2

5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation in Scenario 1 in which there were no injuries sustained.

For Scenario 2, it is assessed that floor proximity lighting would have enabled two of the nine fatalities to find an available exit, i.e., the two passengers found in the cockpit who walked past the open main entry door.

The survivability chain for Scenario 2 therefore becomes:



SCENARIO 2

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as no occupants sustained injuries.

Scenario 2

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with more time to locate the available exits.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	19	15	9
M	22	15	6
L	24	15	4

For 2 minutes protection:

	S	I	F
H	19	15	9
M	25	14	4
L	31	12	0

For 4 minutes protection:

	S	I	F
H	19	15	9
M	29	14	0
L	43	0	0

For 8 minutes protection:

	S	I	F
H	19	15	9
M	39	4	0
L	43	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	21	15	7
M	23	16	4
L	25	18	0

For 2 minutes protection:

	S	I	F
H	21	15	7
M	28	13	2
L	31	12	0

For 4 minutes protection:

	S	I	F
H	21	15	7
M	38	5	0
L	43	0	0

For 8 minutes protection:

	S	I	F
H	21	15	7
M	41	2	0
L	43	0	0

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	3	3
2 minutes	5	5
4 minutes	9	7
8 minutes	9	7

AIRCRAFT:	**B707**	**DATE OF ACCIDENT:**	**22nd January '73**
REGISTRATION:	**JY-ADO**	**LOCATION OF ACCIDENT:**	**KANO, NIGERIA**

1. Description of Accident

RESUME

On 22-Jan-1973 an Aila B707 registered as JY-ADO was landing in poor visibility at Kano airport, Nigeria.

The aircraft touched nosewheel first steady and heavy with main wheels barely in contact with the runway. The nosewheel entrenched itself then collapsed. The main gear contacted later in rapid deceleration, pierced the main wings and the aircraft collapsed along the runway centreline. A fire broke out and after a prolonged pause the passengers and crew evacuated.

Of the 202 occupants aboard, 176 suffered fatal injuries as a result of the fire.

IMPACT

As the undercarriage collapsed, indications are that the right hand main landing gear truck beam separated shortly after touchdown and the right hand main landing gear oleo dug through the tarmac surface. All four right hand main landing gear wheel rims were bent and broken, in varying degrees, indicating an unusually high loading during initial touchdown on the right hand main landing gear.

Inspection of the right hand main landing gear trunnion and wing box structure during the investigation indicated that the right hand main landing gear separated in an aft direction. There was no evidence to indicate that the right hand wing tanks opened up during the landing gear separation sequence.

At approximately 1100 feet from the runway threshold there is evidence that No. 1 and 2 engines dug heavily into the runway. Evidence indicates that the left hand outboard wing separated shortly after engine contact. There are indications that the No. 3 and No. 4 engines, the right hand outboard flap, aft fuselage and right hand horizontal stabiliser also contacted the runway.

The aeroplane proceeded down the runway in a shallow swerve to the right crossing the runway right hand edge approximately 2300 feet from runway threshold. The aeroplane continued on across a grassy strip coming to rest across a drainage ditch opposite the 3500 foot mark and 500 feet to the right of the runway centreline. The aeroplane had turned approximately 140 degrees to the right as it came to rest.

FIRE

The left hand outboard wing separation occurred at a point just inboard of the No, 1 engine strut. Shortly thereafter a severe fire occurred on the left hand wing which continued as the aircraft slid, until it came to rest on a grassy strip over a drainage ditch.

The fuselage forward of the aft pressure bulkhead and the wings were almost completely destroyed by fire.

EVACUATION

There were 3 flight crew, 8 cabin crew and 191 passengers aboard.

Once the aircraft came to a stop, the cockpit windows were opened and the crew exited to assist passengers out of the cabin.

There was a prolonged pause when nothing seemed to be happening to evacuating passengers, then an overwing exit was activated and a mass of passengers came through, in doing so they crushed a steward to death. This movement of a bulk of passengers from post-impact lethargy to safety coincided with the spread of fire.

Interviews with the surviving flight stewards indicated that a mass of people in the galley area prevented opening the galley door. Further statements verified the fact that four of the stewards were near the forward end of the passenger cabin and one steward was near the aft entry door at the time the aircraft impacted the runway. The steward who was stationed in the aft cabin section stated that he was unable to open the aft left hand entry door and escaped from the right hand aft galley exit. The stewards at the forward end of the cabin indicated that fire entered the cabin as the left hand forward entry door was opened and they escaped through the fire. Investigation at the scene revealed that both station 990 emergency exits were still in place after the fire had been extinguished.

None of the cabin crew spoke the language of the passengers.

AIRCRAFT FACTORS

The aircraft was a Boeing 707 registered as JY-ADO and operated by Aila Royal Jordanian Airlines.

The cabin was fitted with a passenger entry door at the front on the port side and a service door opposite. There were 2 overwing emergency exits above each wing and 1 each side near the wing trailing edge (Stn 990). There was an entry door at the rear on the port side and a service door opposite.

ENVIRONMENTAL CONDITIONS

The visibility along the runway was around 200 to 400 metres.

INJURIES TO OCCUPANTS

There has been no report available to the accident investigators to indicate that autopsies were performed. Therefore, the official cause for passenger deaths is not known. It appears that fire was the major cause of fatalities.

1 crew member and 175 passengers suffered fatal injuries.

10 crew members and 16 passengers suffered serious injuries.

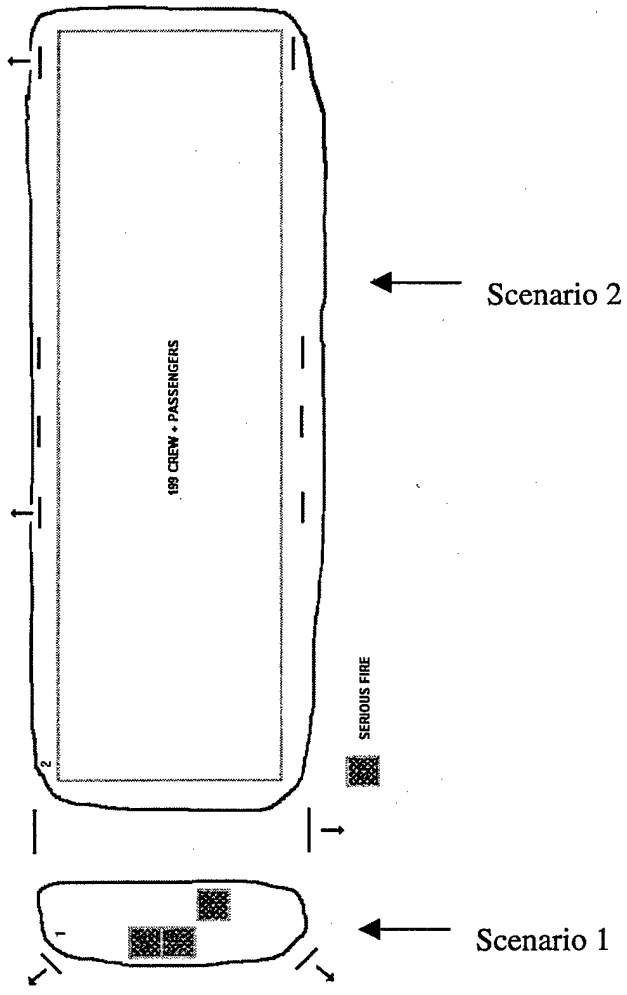
2. Fire Penetration Mechanism

The stewards at the forward end of the cabin indicated that fire entered the cabin as the left-hand forward entry door was opened.

In addition there was extensive fire on the port wing, which can be assumed to have propagated into the cabin by burning through the fuselage side in that area. None of the port overwing exits had been opened.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin in the port wing root area. However there was insufficient information to be conclusive about detailed burnthrough areas. Fire also entered through the opened port forward entry door.

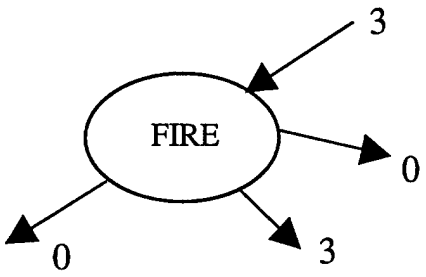
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

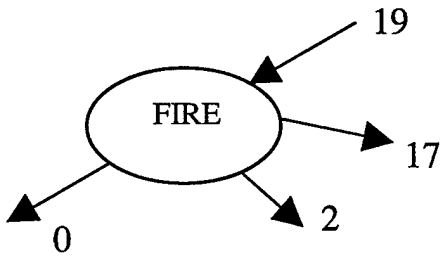
This accident is divided into two separate scenarios.

Scenario 1 contains the flight deck area and the three flight crew. The occupants were able to escape through the cockpit windows.



SCENARIO 1

Scenario 2 contains the main passenger cabin, which suffered internal fire and had only three of the ten exits available for egress. It includes all passengers and flight attendants. Many fatalities were found crowded in the galley area and overcome by smoke.



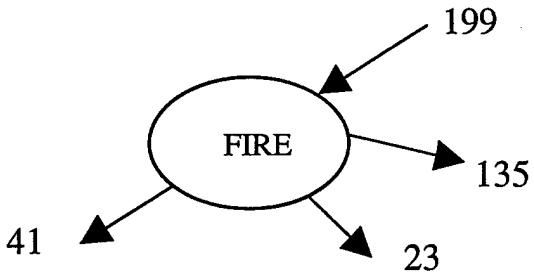
SCENARIO 2

5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation in Scenario 1, which contained only the flight deck area.

For Scenario 2, it is assessed that later requirements would have improved flammability standards such that the occupants would have had additional time to escape. It is assessed that an additional 41 occupants would have evacuated and 41 of the seriously injured would have escaped with minor or no injuries.

The survivability chain for Scenario 2 therefore becomes:



SCENARIO 2

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as all occupants already had access to the cockpit windows for evacuation and were only injured when they re-entered the cabin in order to assist passengers.

Scenario 2

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with more time to use the available exits. Twenty-three occupants evacuated in 60 seconds, i.e., say 11 in 30 seconds. Assuming a constant evacuation rate, it is assessed that an additional maximum of 11 occupants would have escaped for each additional 30 seconds of protection. Further, 1/10 of the occupants who were seriously injured would escape with minor or no injuries for each additional 30 seconds of protection. Because fire also entered through the front main entry door no additional benefit was assigned after 4 minutes of burnthrough protection.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	0	25	174
M	2	28	169
L	3	31	165

For 2 minutes protection:

	S	I	F
H	1	30	168
M	15	34	150
L	28	39	132

For 4 minutes protection:

	S	I	F
H	2	37	160
M	46	29	124
L	89	22	88

For 8 minutes protection:

	S	I	F
H	2	37	160
M	46	29	124
L	89	22	88

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	47	19	133
M	49	22	128
L	50	25	124

For 2 minutes protection:

	S	I	F
H	48	24	127
M	66	24	109
L	84	24	91

For 4 minutes protection:

	S	I	F
H	49	31	119
M	91	25	83
L	132	20	47

For 8 minutes protection:

	S	I	F
H	49	31	119
M	91	25	83
L	132	20	47

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	7	7
2 minutes	26	26
4 minutes	52	52
8 minutes	52	52

AIRCRAFT:	**B707**	**DATE OF ACCIDENT:**	**30th January '74**
REGISTRATION:	**N454PA**	**LOCATION OF ACCIDENT:**	**PAGO PAGO, AMERICAN SAMOA**

1. Description of Accident

RESUME

On 30-Jan-74, B707-321B was making an ILS approach at night to Pago Pago International Airport in American Samoa. The aircraft encountered destabilising wind changes which resulted in an excessive descent rate and as a result the aircraft crashed short of the runway.

A fire broke out and the occupants could not open all the emergency exits. Of the 101 occupants, 97 suffered fatal injuries.

The aircraft was destroyed by the impact and subsequent fire.

IMPACT

Due to destabilising wind changes which resulted in an excessive descent rate the aircraft crashed into trees 3,865 feet short of the runway and then struck the ground.

The undercarriage landing gear was extended at the time of impact.

There was progressive destruction of the aircraft during its travel through the vegetation and as it slid over the ground. The fuselage remained intact except for the forward nose fuselage structure.

Passengers who survived the accident said that the impact forces were slightly more severe than a normal landing. No damage to the cabin interior was reported.

FIRE

Fire was evident during the last 350 feet of the wreckage pattern. The fuselage from the aft pressure bulkhead forward through the cockpit area was gutted by fire and the passenger cabin floor and contents were consumed. From the wing trailing edge forward, the top of the fuselage and the fuselage sidewalls were consumed by fire down to a point about 4 feet above the window line. The interior of the rear fuselage aft of the rear pressure bulkhead was not damaged by fire.

The response of the fire department was hampered by the weather, obstacles across the response route and the uncertainty of whether the fire was from an aircraft or a house. However it is doubtful that any of the occupants remaining in the aircraft were still alive when the fire and rescue personnel arrived at the scene.

EVACUATION

There were 10 crew and 91 passengers aboard. The crew consisted of a captain, first officer, third officer, flight engineer and 6 cabin crew.

Large fires were seen outside the right side of the aircraft. One person opened an overwing exit on the right side of the aircraft; flames came in through the exit, and he closed it. Other survivors opened the left overwing exits, and all the survivors except the first officer escaped through those exits. The wing was described as very hot and several survivors fell into flaming fuel at the trailing edge.

The first officer was assisted in his escape by two other cockpit crewmembers and left the aircraft through a hole in the cockpit wall.

The surviving passengers reported that 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. Most of the survivors suffered burns and other injuries after they escaped from the cabin.

Post accident investigation revealed that the forward and the rear entry doors were not opened or used for escape. The forward door was opened about 2 to 3 inches, but the aft door was closed.

The forward galley service door could not be identified in the wreckage. The rear galley service door was found in place and locked.

It is possible that the flight attendants were overcome by smoke or that they tried to open the exits and did not redirect passengers to alternate exits. It is also possible that the passengers crowded around doors and for that reason the flight attendants were unable to open the exits.

It is unlikely that all of the passengers could have escaped from the aircraft through the 2 left overwing exits. However it is possible that there would have been more survivors had the passengers acted according to preflight instructions and proceeded to the nearest exit, instead of moving toward the main exits through which they had originally entered.

The movement of most of the passengers to the front and rear exits indicates that they either did not comprehend the pretakeoff briefing or they reacted to the emergency without thinking.

AIRCRAFT FACTORS

The aircraft was a B707 registered as N454PA, operated by Pan American World Airways. The aircraft was certificated, equipped and maintained in accordance with FAA regulations.

The aircraft had 117,000 lbs of Jet A-1 fuel aboard.

There were two floor level exits located in the front of the cabin and two floor level exits located in the rear of the cabin. Each door was a plug type that had to be opened inward and then rotated outboard. Each floor level exit was fitted with an automatically deployable and inflatable emergency evacuation slide. Two emergency exits were located over each wing. These exits were not fitted with evacuation slides.

The aircraft was configured as a 146 passenger capacity aircraft with some cargo on board as well.

The first class section contained four rows of two double seat units for a total capacity of 16 passengers. Located forward of the first class section were two galley units and two lavatories on the right side of the cabin and a galley unit, console bar, and two flight attendant jump seats on the left side of the cabin. Each of the jump seats were double occupancy, rear-facing seats fitted with seat belts but no shoulder harnesses. A cabin divider was installed between the first class and economy class sections of the cabin. The economy class section contained twenty rows of two triple seat units one row of two double seat units and two rows of single triple seat units for a total capacity of 130 passengers. At the rear of the economy class cabin there were three galley units, a carry-on baggage compartment, three lavatories and a double forward-facing flight attendant jumpseat. The jumpseat was fitted with seat belts and shoulder harnesses. None of the jumpseat locations afforded a view of the passenger compartment.

ENVIRONMENTAL CONDITIONS

The accident occurred at night, below clouds, in rain. After the crash the rain became heavier.

INJURIES TO OCCUPANTS

Of the 101 occupants, 97 suffered fatal injuries. 9 passengers and 1 crew member survived the crash and fire. 1 passenger died the next day, the crew member and 3 passengers died 3 days after the accident. 1 passenger died 9 days after the accident but at that time 'fatalities' had to occur within 7 days of the accident so it was counted as a survivor. [However for consistency, the current definition of a fatality has been used and hence this passenger has been determined to have sustained fatal injuries.]

Except for the Third Officer, all fatally injured persons died of smoke inhalation, massive 1st, 2nd and 3rd degree burns and complications from those massive burns. The Third Officer survived the crash but died later of traumatic leg and arm injuries and severe burns.

Toxicological examinations of the casualties revealed significant levels of carbon monoxide and hydrogen cyanide which are normal byproducts of aircraft fires.

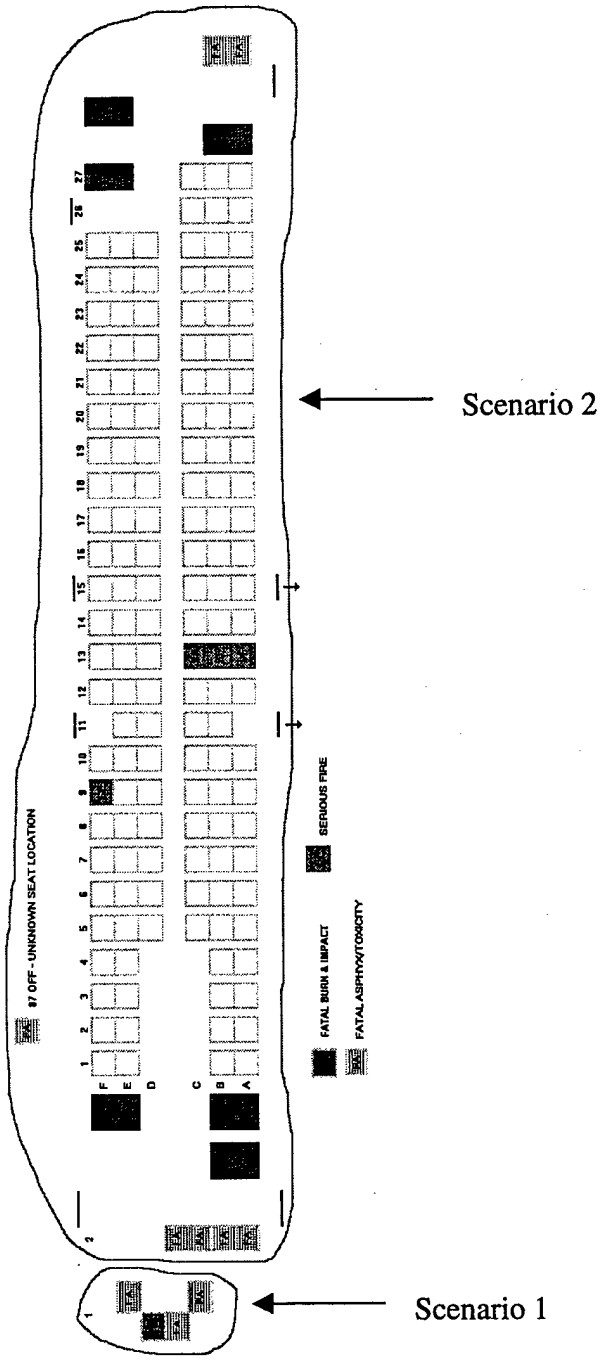
2. Fire Penetration Mechanism

The fuselage remained intact as it came to rest. A fuel-fed fire broke out along the whole of the right-hand side and it can be assumed that this pool of fire burnt through the underside of the fuselage and then entered the passenger cabin from below. Indeed large parts of the right fuselage sidewall were eventually consumed by the flames as was the cabin roof.

The fire services were delayed in their efforts to reach the site and as a result the fire became quite severe. However it was unlikely that there were any further survivors to be rescued.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin lower surface. However there was insufficient information to be conclusive about other burnthrough areas.

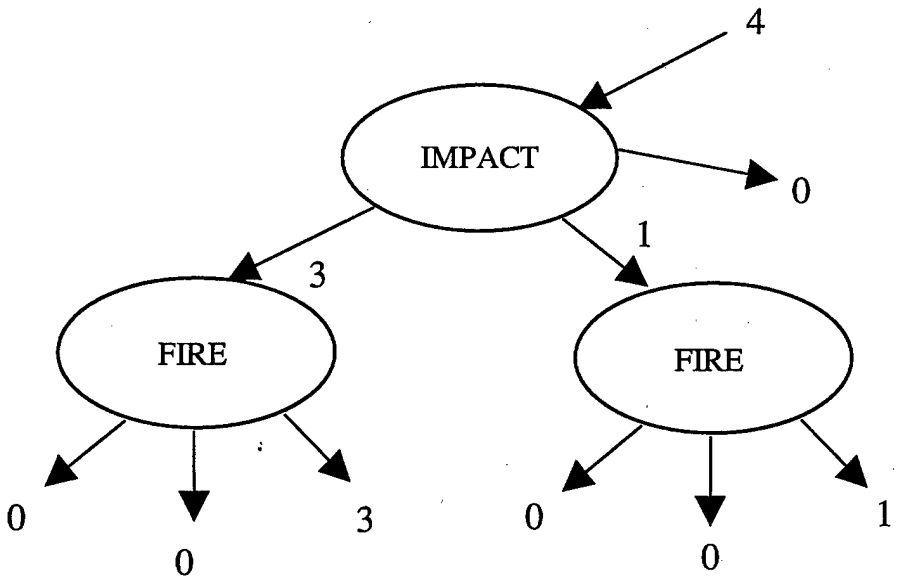
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

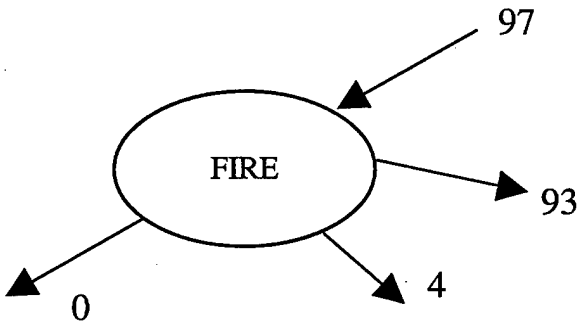
This accident is divided into two separate scenarios.

Scenario 1 contains the flight deck area. It was subjected to the initial impact which was not severe but did create a hole in the forward skin that the third officer used to crawl out from and escape. The scenario contains the four flight crew.



SCENARIO 1

Scenario 2 contains the main passenger cabin, which suffered internal fire and had only the two left overwing exits available for egress. It includes all passengers and flight attendants. Survivor statements indicate that the cabin occupants were moving up and down the cabin trying to locate and open exits. Most were found overcome by smoke crowded near the exits.



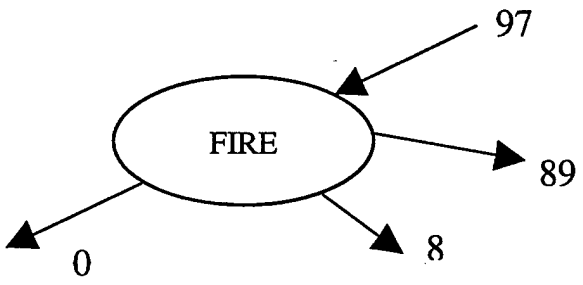
SCENARIO 2

5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation in Scenario 1, which contained only the flight deck area.

For Scenario 2, it is assessed that many were injured outside the aircraft in the external fire and hence later requirements would have only had a modest effect.

The survivability chain for Scenario 2 therefore becomes:



SCENARIO 2

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the flight crew with more time to either help open the forward main passenger door or follow the third officer out of the hole in the cockpit wall. The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	0	0	4
M	0	2	2
L	3	0	1

For 2 minutes protection:

	S	I	F
H	0	0	4
M	1	2	1
L	2	2	0

For 4 minutes protection:

	S	I	F
H	0	0	4
M	2	2	0
L	2	2	0

For 8 minutes protection:

	S	I	F
H	0	0	4
M	2	2	0
L	2	2	0

Scenario 2

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and smoke and provided the occupants with more time to use the available overwing exits or to open the forward entry door. However, little benefit has been assigned due to the panic behaviour of the occupants and because those evacuating had to exit close to the external fire and risked injury outside the cabin environment.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	0	4	93
M	1	8	88
L	2	12	83

For 2 minutes protection:

	S	I	F
H	0	4	93
M	1	8	88
L	2	12	83

For 4 minutes protection:

	S	I	F
H	0	4	93
M	1	8	88
L	2	12	83

For 8 minutes protection:

	S	I	F
H	0	4	93
M	1	8	88
L	2	12	83

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	0	8	89
M	1	12	84
L	2	16	79

For 2 minutes protection:

	S	I	F
H	0	8	89
M	1	12	84
L	2	16	79

For 4 minutes protection:

	S	I	F
H	0	8	89
M	1	12	84
L	2	16	79

For 8 minutes protection:

	S	I	F
H	0	8	89
M	1	12	84
L	2	16	79

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	7	7
2 minutes	8	8
4 minutes	9	9
8 minutes	9	9

AIRCRAFT:	**CARAVELLE**	**DATE OF ACCIDENT:**	**15th March '74**
REGISTRATION:	**OY-STK**	**LOCATION OF ACCIDENT:**	**TEHERAN, IRAN**

1. Description of Accident

RESUME

On 15-Mar-74, a Stirling Airways Caravelle registered as OY-STK was taxying at Teheran/ Mehrabad International Airport, Teheran, Iran.

Shortly before the aircraft was going to initiate a left turn towards the run-up area two loud noises were heard in the aircraft and the right wing dropped to the ground and struck the runway. The aircraft came to a stop 90 m further on and a heavy fire developed.

Evacuation of the aircraft was carried out through exits on the left side of the aircraft.

Preliminary investigation revealed that the right landing gear collapsed due to structural failure of a fitting (lower 'candelabra'). A rupture of the fuel tank resulted and the JP 1 fuel escaping from the tank ignited before the aircraft came to a stop. The source of the ignition was not determined.

There were 4 crew and 92 passengers aboard. 15 passengers suffered fatal injuries.

IMPACT

The aircraft was taxying at the time of the accident and there was no impact.

FIRE

After refuelling at Teheran/Mehrabad International Airport, the aircraft was cleared to taxi for take-off. Due to some construction work it was cleared to back track on the runway to the take-off position. Whilst the aircraft was taxying on the runway, it was requested by the ATC to expedite taxying and to clear the runway on the run-up area close to the runway threshold because another aircraft was on final approach.

Shortly before the aircraft was going to initiate a left turn towards the run-up area 2 loud noises were heard in the aircraft and the right wing dropped to the ground and struck the runway.

The aircraft came to a stop 90m further on and a heavy fire developed.

Preliminary investigation revealed that the right landing gear collapsed due to structural failure of a fitting (lower 'candelabra'). A rupture of the fuel tank resulted and the JP 1 fuel escaping from the tank ignited before the aircraft came to a stop. The source of the ignition was not determined.

EVACUATION

There were 4 crew and 92 passengers aboard.

Evacuation of the aircraft was carried out through exits on the left side of the aircraft.

Evacuation time was thought to be approximately 2 minutes.

AIRCRAFT FACTORS
The aircraft was a Caravelle 10B3 registered as OY-STK and operated by Stirling Airways.

The aircraft was carrying JP 1 fuel.

There was an up-and-over main entry door at the front port side with a service door opposite. Two emergency exits were located over each wing.

ENVIRONMENTAL CONDITIONS
The accident occurred during daylight with little or no prevailing wind.

INJURIES TO OCCUPANTS
There were 4 crew and 92 passengers aboard. 15 passengers suffered fatal injuries.

2. Fire Penetration Mechanism

As the aircraft came to a stop, leaking fuel formed a pool next to the fuselage on the starboard side and ignited.

It can be concluded that with a pool fire on the starboard side of the fuselage, the skin would have been burnt through from underneath after approximately 30 seconds, causing smoke and flames in the cabin. This can be assumed to be during the evacuation period as it was estimated that evacuation took 2 minutes.

With this type of fire, penetration would have been initially through the lower fuselage skin and later into the passenger cabin through the floor. Once smoke was present in the cabin the occupants would have become disorientated and unable to locate the open exits.

Based on the above it is assessed that the prime burnthrough route was through the lower fuselage skin. However there was insufficient information to be conclusive about detailed burnthrough areas.

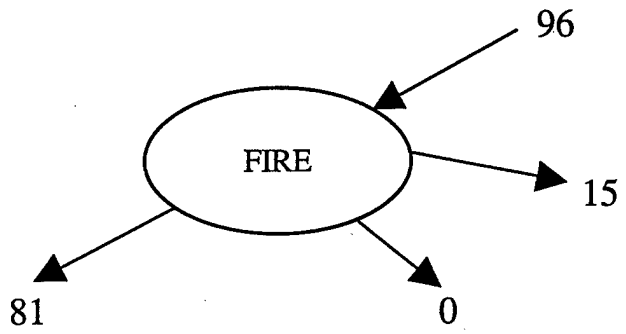
3. Location of Injuries and Scenarios

Because of the absence of documentary evidence on details of the evacuation, the whole fuselage volume has been taken as a single scenario which includes all occupants.

4. Accident Scenarios and Survivability Chains

This accident is taken as one scenario.

Scenario 1 contains the whole aircraft and encompasses 4 crew and 92 passengers.

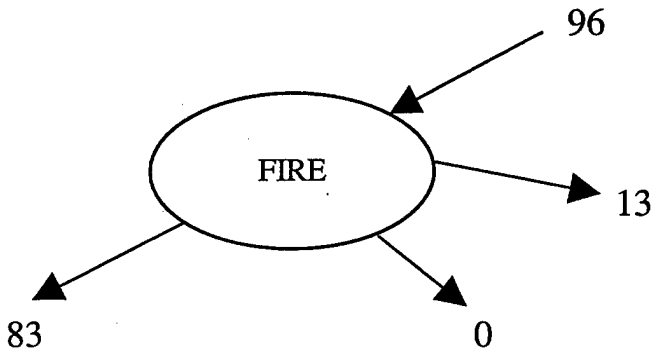


SCENARIO 1

5. Effect of Later Requirements

It is assumed that later requirements would have provided additional time for evacuation such that an additional two occupants would have located open exits and evacuated successfully.

It is assessed that this would result in the survivability chain becoming:



SCENARIO 3

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the passengers with additional time to locate and use the available exits.

In the absence of detail information on serious injuries, these have been assigned to zero throughout this accident.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	81	0	15
M	88	0	8
L	96	0	0

For 2 minutes protection:

	S	I	F
H	81	0	15
M	92	0	4
L	96	0	0

For 4 minutes protection:

	S	I	F
H	81	0	15
M	96	0	0
L	96	0	0

For 8 minutes protection:

	S	I	F
H	81	0	15
M	96	0	0
L	96	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	83	0	13
M	90	0	6
L	96	0	0

For 2 minutes protection:

	S	I	F
H	83	0	13
M	94	0	2
L	96	0	0

For 4 minutes protection:

	S	I	F
H	83	0	13
M	96	0	0
L	96	0	0

For 8 minutes protection:

	S	I	F
H	83	0	13
M	96	0	0
L	96	0	0

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	7	7
2 minutes	11	11
4 minutes	15	13
8 minutes	15	13

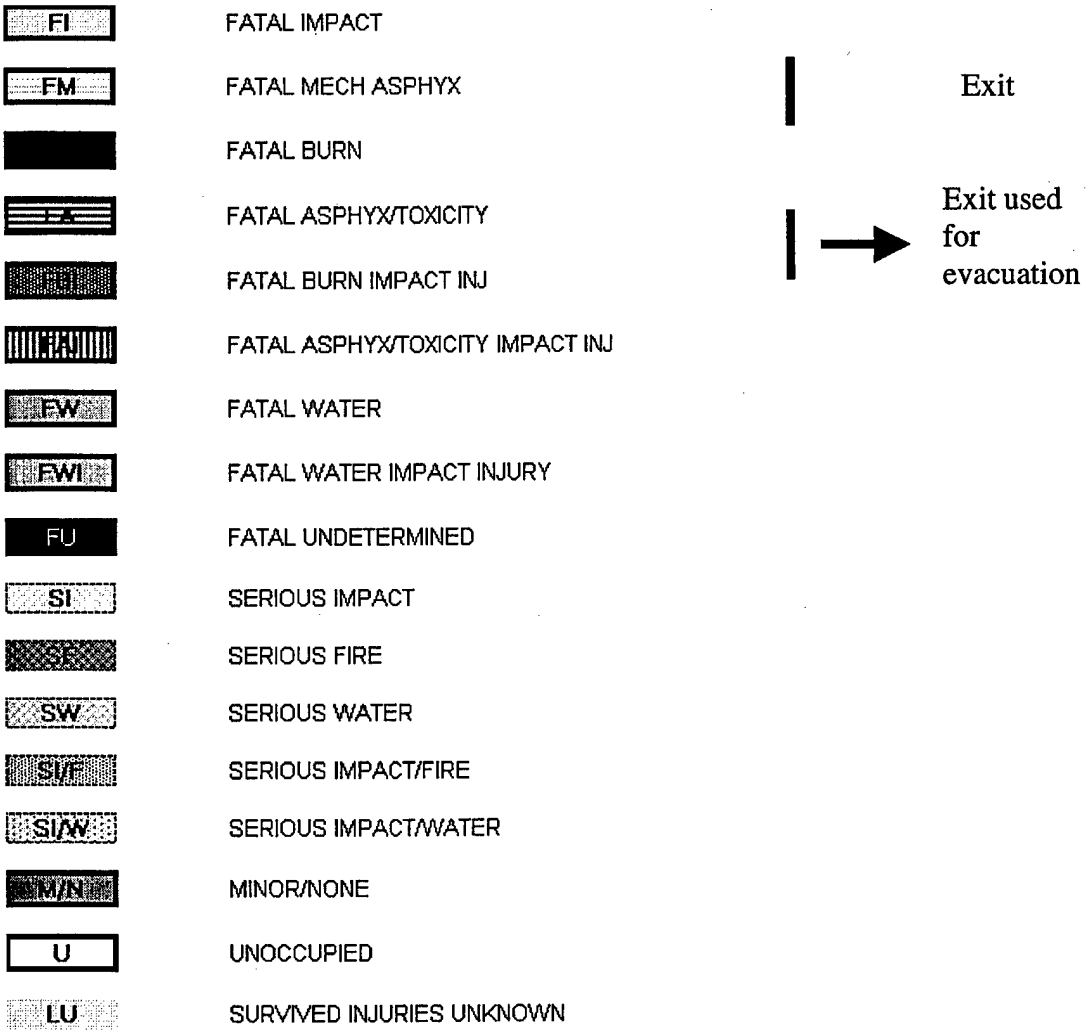
APPENDIX C—ACCIDENT RATIONALES 8 TO 17

The rationale for each accident that was analysed appears in this appendix. Each accident is presented with the following sections:

- Description of the accident reproduced from the Survivable Accidents Database.
- A description of the fire penetration mechanism using relevant extracts from the database together with any assessments and assumptions made.
- A diagram showing the location of occupants and scenario boundaries.
- Survivability chains for each scenario.
- Effect of later requirements.
- Effect of a fire-hardened fuselage.

The accidents are presented in reverse chronological order.

Key to injury location diagrams:



AIRCRAFT:	**B737**	**DATE OF ACCIDENT:**	**17th December '78**
REGISTRATION:	**VT-EAL**	**LOCATION OF ACCIDENT:**	**HYDERABAD, INDIA**

1. Description of Accident

RESUME

Indian Airlines B737 registered as VT-EAL was taking off from Hyderabad Airport on 17-Dec-78. The leading edge devices did not deploy and as a result the aircraft became aerodynamically unstable. The take-off was aborted and the aircraft was flared for a belly landing with undercarriage retracted. The aircraft belly landed in nose up, left wing low attitude, on the centre line of the runway. It slid for 3080 feet, hit a boundary fence, crossed a drain and ploughed in rough terrain negotiating with small boulders and came to rest. Fire broke out on impact.

The aircraft was completely destroyed by fire.

There were 6 crew and 126 passengers aboard, of which 1 passenger suffered fatal burn injuries, 1 cabin attendant and 3 passengers were seriously injured.

3 persons cutting grass near the boundary fence of the airport were killed.

IMPACT

The leading edge devices did not deploy and as a result the aircraft experienced a severe shudder and became aerodynamically unstable. The aircraft did not gain any height and started to sink.

The take-off was aborted and the aircraft was flared for a belly landing with undercarriage retracted. The aircraft belly landed in nose up, left wing low attitude, on the centre line of the runway.

The aircraft slid for 3080 feet, hit a boundary fence, crossed a drain and ploughed in rough terrain negotiating with small boulders and came to rest.

As the aircraft slid into rough terrain it began breaking up, shed the port engine, starboard engine and engine accessories. The rest of the aircraft remained intact.

The ground markings included drag marks at a distance of 7185 ft from the beginning of the runway, indicating first contact of the aircraft. On the right hand side a second drag mark was found at a distance of 7293 ft. A third drag mark was observed at a distance of 7385 ft. It was concluded that the first and second were caused by the port engine and the third by the starboard engine. A centre traverse mark was intermittent and was caused by the fuselage. Debris was found littered alongside the tracks.

ATF spillage could be inferred from the soakage in the overrun area.

The undercarriage was found in the retracted position and appeared to be locked. The main wheels were lying fore and aft instead of one above the other.

FIRE

The fire appeared initially at the trailing edge of the port wing and spread to the starboard side of the aircraft. Fuel from tanks leaked and collected underneath the starboard side and due to wind the fire intensified. At first the right wing became engulfed in fire and later the middle and forward portions of the fuselage. The upholstery of the aircraft was burnt in 2 hours. Witnesses stated that at times the fire subsided and again flared due to bursting of fuel tanks.

The interior of the passenger cabin and cockpit areas were completely burnt out.

Fire fighting operations were not successful because the fire crew could not get close to the wreckage quickly enough. This was partly due to their perception that the aircraft was at the end of the runway where, in fact, it was significantly further into the rough terrain and the crew were not acquainted with the terrain in that area. The fire engines could not get past a drain and had to fight the fire from some distance.

EVACUATION

The crew consisted of a Captain, Co-pilot and 4 cabin crew. There was also a pilot who occupied the observer's seat.

There were 126 passengers aboard.

The Captain said he was unable, due to preoccupancy, to announce emergency and order passenger evacuation. The emergency drill was not adopted and the control tower was not alerted. The fire crew, however, observed the crash landing and proceeded at once to the site.

[The accident report did not state which doors were used in the evacuation.]

AIRCRAFT FACTORS

The aircraft was a basic series B737-200 registered as VT-EAL and operated by Indian Airlines. It was maintained and operated in accordance with airworthiness requirements.

The aircraft was manufactured in 1970 as serial number 20485.Airworthiness Certificate number 1576 was issued on 9-Mar-1971 on the strength of FAA Export Certificate of Airworthiness E9894.

The aircraft was carrying Jet-A fuel.

The aircraft was fitted with a main entry door in the cabin at the front on the port side with a service door opposite. There was an entry door at the rear on the port side with a service door opposite. There was a single overwing emergency exit above each wing.

ENVIRONMENTAL CONDITIONS

On the day of the accident the weather was reported to be: wind 120 deg, 10 knots, visibility 10 km, temperature 23 C.

INJURIES TO OCCUPANTS

There were 6 crew and 126 passengers aboard, of which 1 passenger suffered fatal burn injuries, 1 cabin attendant and 3 passengers were seriously injured.

As a result of the fire, one passenger suffered serious burn injuries all over his body. He was admitted to hospital but died 3 days later.

Other serious and minor injuries were attributed to the impact:

1 passenger received a fracture injury on her tibia and her fibula was injured.
1 passenger suffered a fracture of the bone below his left knee.
1 passenger received a fracture of her left hand.
1 passenger received a fracture of his left leg.
1 passenger sustained a fracture of his left heel bone.
1 stewardess received injury narrowing the space between her 11th and 12th vertebrae.
1 stewardess received incised injury on her forehead.

There were 14 passengers (all male) who received minor injuries.

2. Fire Penetration Mechanism

The fire appeared initially at the trailing edge of the port wing and spread to the starboard side of the aircraft. Fuel from tanks leaked and collected underneath the starboard side and due to wind the fire intensified. At first the right wing became engulfed in fire and later the middle and forward portions of the fuselage.

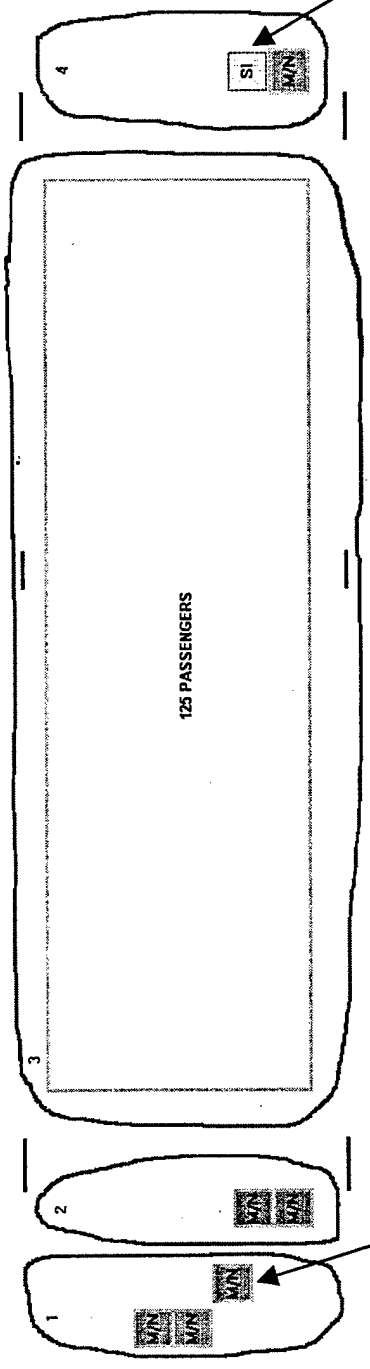
It can be reasonably assumed that the ignited fuel that collected either side of the fuselage would have burnt through the fuselage under surface in the area of the wing root/fuselage junction. There were no breaks in the fuselage due to impact forces.

Once the skin was penetrated, smoke and flames would have entered the passenger cabin through the cabin floor.

As only one passenger was reported to have suffered (and later died of) burn injuries, it can be assumed that the evacuation was nearly completed before the entry of smoke and fire became a threat to the occupants. Details of the evacuation process did not appear in the official accident report.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin. However there was insufficient information to be conclusive about other burnthrough areas.

3. Location of Injuries and Scenarios



Seriously injured flight attendant was arbitrarily assigned to this position. Her location has no effect on this analysis.

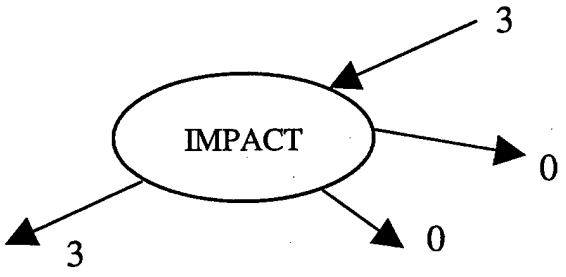
Note: The accident report did not state which doors were used in the evacuation.

Pilot who occupied the observer's seat has been counted as a passenger for the purpose of this analysis.

4. Accident Scenarios and Survivability Chains

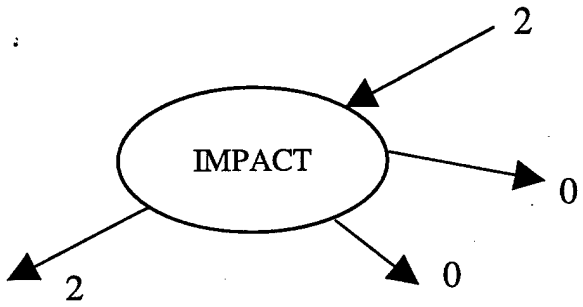
This accident is divided into four separate scenarios.

Scenario 1 contains the flight deck area, which was subjected to the initial impact. The scenario contains two flight crew and a pilot in the observer's seat.



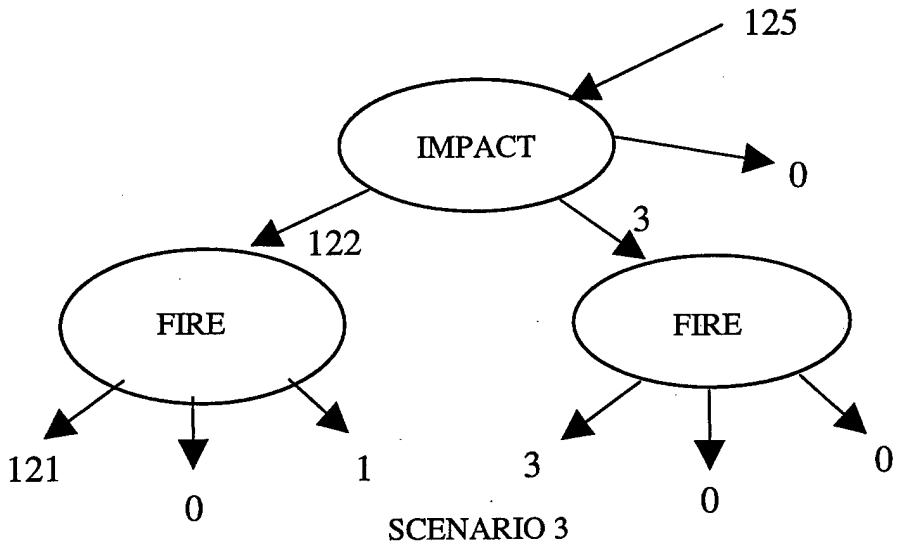
SCENARIO 1

Scenario 2 contains the forward flight attendant area and encompasses two flight attendants.



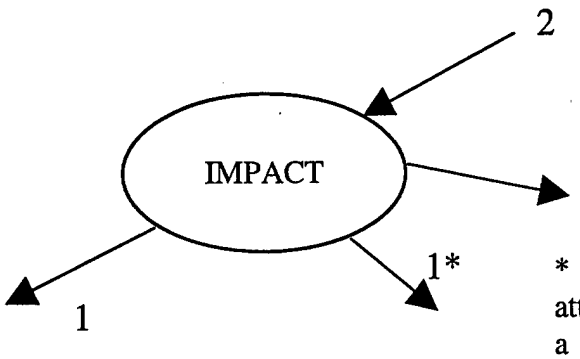
SCENARIO 2

Scenario 3 contains the main passenger cabin, which suffered internal fire after the initial impact. The scenario contains 125 passengers.



SCENARIO 3

Scenario 4 contains the rear flight attendant area and encompasses two flight attendants.



* The seriously injured flight attendant was arbitrarily assigned a seat position. Her location has no effect on this analysis.

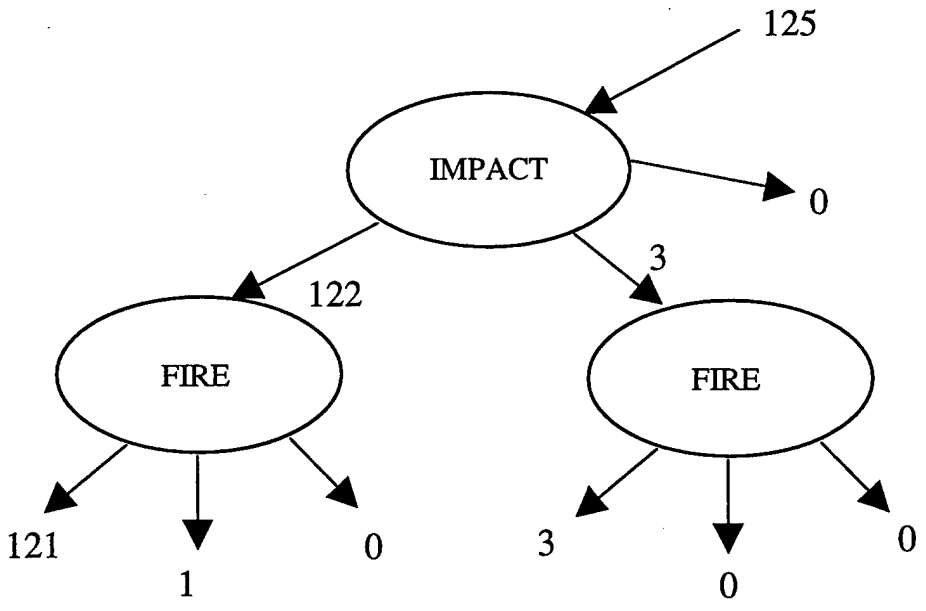
SCENARIO 4

5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation in scenarios 1, 2, and 4 in which all injuries were related to the impact.

For Scenario 3, it is assessed that later requirements would have provided additional time to escape for the only occupant injured by the fire. In this event it is assessed that the injuries would have been less severe and therefore not fatal.

The survivability chain for Scenario 3 therefore becomes:



SCENARIO 3

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as there were no injuries.

Scenario 2

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 2 as there were no injuries.

Scenario 3

It is concluded that a fire-hardened fuselage would have provided sufficient time for the passenger with burn injuries to escape with lesser injuries.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	121	3	1
M	121	4	0
L	121	4	0

For 2 minutes protection:

	S	I	F
H	121	3	1
M	121	4	0
L	121	4	0

For 4 minutes protection:

	S	I	F
H	121	3	1
M	121	4	0
L	121	4	0

For 8 minutes protection:

	S	I	F
H	121	3	1
M	121	4	0
L	121	4	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	121	4	0
M	122	3	0
L	122	3	0

For 2 minutes protection:

	S	I	F
H	121	4	0
M	122	3	0
L	122	3	0

For 4 minutes protection:

	S	I	F
H	121	4	0
M	122	3	0
L	122	3	0

For 8 minutes protection:

	S	I	F
H	121	4	0
M	122	3	0
L	122	3	0

Scenario 4

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 4 as the only injury was related to the impact.

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	1	0
2 minutes	1	0
4 minutes	1	0
8 minutes	1	0

AIRCRAFT: DC8 **DATE OF ACCIDENT:** 7th October '79

REGISTRATION: HB-IDE **LOCATION OF ACCIDENT:** ATHENS

1. Description of Accident

RESUME

On 7-Oct-79, a DC-8-62 was landing at night on a wet runway at Athens Airport, Greece.

After a late and fast touchdown and after ineffective breaking, the aircraft overshot the runway end and the overrun area, fell down a slope of 4 m and caught fire.

Of the 154 occupants, 14 suffered fatal injuries as a result of the fire.

The aircraft was destroyed by impact and fire.

IMPACT

Touch down was at approximately 500m from the displaced runway threshold. There was a very short flare phase with the effect that the nose wheel touched down almost simultaneously with the main landing gear. Immediately after touch down the captain selected idle reverse on all 4 engines and took control of the aircraft from the co-pilot. The co-pilot set normal reverse. A few seconds later brake application was initiated which gave an impression of almost normal braking conditions.

At approximately 500-600m before the end of the runway braking efficiency dropped and full braking was applied. In spite of this action braking efficiency dropped to almost nil within seconds. Still the impression prevailed that with reverse deceleration it would be possible to stop the aircraft before the runway end. At approximately 300m before the runway end a first doubt came up about this fact. The captain tried to test directional steering capability by turning the nose wheel slightly to the left. No rotation of the aircraft was felt. In this condition the aircraft was skidding the remaining distance of the runway and with a speed of approximately 20-25 knots overran the runway end.

After rolling over the asphalt overrun area of approximately 65m length, the aircraft fell approximately 4m onto a bitumen road which crossed the runway axis almost rectangularly.

The first impact occurred with the nose wheel within reach of the road. The second impact must have occurred with the afterbody/tail on the end of the overrun area. Approximately at the same time the nose wheel was bent backwards due to the terrain which rises by about 0.5 m. The main landing gear struck the ground between a bank and the road. The aircraft skidded further before coming to a halt, the tail being approximately 76.5m from the end of the runway.

The aircraft was destroyed by the hard impact in the vicinity of the road and by the ensuing fire. The left wing was broken in front of the No. 1 engine. The fuselage was broken in front of the vertical stabiliser. The nose wheel was bent backwards. The right and left main landing gear

were torn off the wing structure with parts of the rear spar bent backwards and twisted by approximately 90° for the left and by approximately 180° for the right.

The aircraft was carrying 40 packages of radio active material for medical purposes. Experts found that the packages were for the most part destroyed due to the ensuing fire. However no leakage of radio active materials occurred into the atmosphere.

FIRE

As soon as the aircraft overshot the runway and stopped outside the airport's boundary, fire broke out at the right main part of the fuselage. The impact forced the right main landing gear to bend backwards by approximately 180° and tore open the fuel tanks of the right wing. Fuel from these tanks started to flow and the fire was extended not only to the aircraft, but to the road at the right side of the aircraft. This meant that access to the aircraft's right side was impossible.

The fire fighting service was in action in approximately 3 minutes and 3 of the fire fighting cars which had turrets began action without any delay combating the fire from the edge of the slope. 3 cars from the US base fire brigade fought the fire at the tail and the right side of the aircraft. Another fire service took over the left side from which passengers were still evacuating.

While the fire had begun to be under control some small explosions were heard, probably from exploding oxygen bottles and fire covered the aircraft completely.

One rescuer equipped with fire proof equipment and smoke mask did not enter the aircraft because he was waiting for a specific order. This was not given because the rescue crew were out of the protective range of the turrets.

The fire was under control within about 25 minutes and extinguished after about 2 hours from the initial crash. A total of 20 fire fighting cars and 75 fire crew took part in the operation.

EVACUATION

There were 3 flight crew, 7 cabin crew and 144 passengers aboard.

As soon as the aircraft came to rest, the captain left the aircraft through the cockpit window in order to assist passengers as they came out of the forward exit. The crew opened the left front and rear doors. The front door opened normally, and the slide worked quickly. The rear door had some difficulty in opening, probably because of deformation, it was opened with some delay. The slide did not deploy.

The crew was giving the appropriate instructions for quick evacuation and passengers were leaving the aircraft normally at the front. However the loss of the PA system meant that no information regarding the use of the exits could be transmitted. As a result confusion was created to the passengers in the central area of the aircraft who could not use the overwing exits due to the external fire.

According to crew and passenger statements, approximately 120-130 passengers left the aircraft through the left front exit. The exit doors and emergency exits at the right side of the aircraft were not used. Overwing exits at the left side were not used either because, according to the flight attendants' statements, there was external fire in that area. The delay in opening the rear door resulted in passengers moving back and forth. The rear of the cabin had more smoke than the front part due to the lack of draught.

The passengers were finally directed to the front door. The front slide failed after it had been used by 40-50 passengers and the passengers were then jumping from a height of 1.70 metres. 11 passengers sustained minor injuries due not only to the height but also to the fact that they were jumping on each other. The evacuation lasted approximately 3.5 to 4.5 minutes. The co-pilot re-entered the aircraft after the last passenger was out to search for passengers. He couldn't see anything because of smoke.

According to witness statement as well as the Swissair boarding cards, the 14 dead persons were seated at the rear part of the aircraft between the 21st and 26th row. It seems that these passengers hadn't tried to leave the aircraft, considering the evacuation had been completed from the rear door, as stated by the flight attendant. 5 of the dead were seated in row 25. Many passengers walked through that area and no one had reported any difficulties in passing through.

It was calculated that the evacuation lasted approximately 3.5 to 4.5 minutes.

AIRCRAFT FACTORS
The aircraft was a DC-8-62 registered as HB-IDE, operated by Swissair.

The aircraft was manufactured as serial number 45919 and delivered on 22-Nov-1967.

The aircraft had 4 exit doors, 2 at the front part and 2 at the rear part of the cabin, 4 overwing emergency exits and 2 sliding windows in the cockpit.

ENVIRONMENTAL CONDITIONS
The accident occurred at night on a wet runway. Wind was 090°, 17 knots. Visibility was 7 km in light rain. The temperature was 18C.

INJURIES TO OCCUPANTS
Of the 10 crew and 144 passengers aboard, 14 passengers suffered fatal injuries.

Fourteen fatalities were found sitting in rows 21-26. The forensic medical postmortem reports testify that the death of 14 passengers was caused by burns of third degree on the whole body.

11 passengers suffered minor injuries during evacuation.

2. Fire Penetration Mechanism

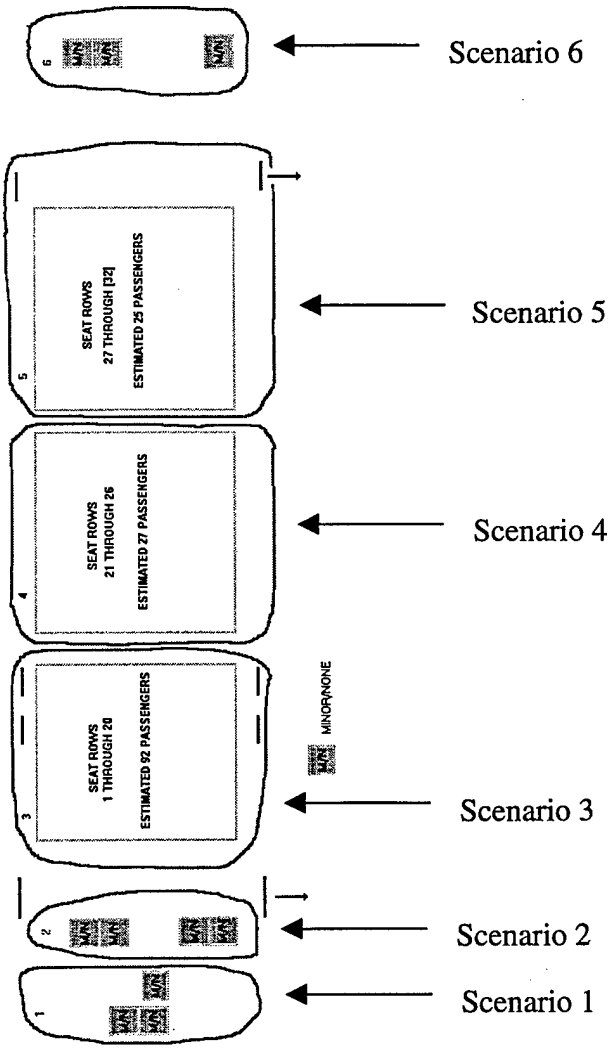
As the aircraft came to a stop, leaking fuel ignited and extended along the entire starboard side of the fuselage. In addition the port overwing exit doors were not opened because the cabin crew saw fire in that area.

It can be concluded that with fire on both sides of the fuselage, the skin would have burnt through after approximately 30 seconds, causing smoke and flames in the cabin. This can be assumed to be during the evacuation period as it was estimated that evacuation took 3.5 to 4.5 minutes. Indeed, fire services were on scene in 3 minutes and saw passengers still evacuating.

With this typical pool fire environment, fire penetration would have been initially through the lower fuselage skin, baggage bay, or undercarriage bay and later into the passenger cabin through the floor. Once smoke was present in the cabin, the occupants would have become disorientated and unable to locate the open exits. It was considered that occupants were not rendered immobile by the impact forces as movement was reported of passengers back and forth during the delay in opening the rear port door.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin. However there was insufficient information to be conclusive about other burnthrough areas.

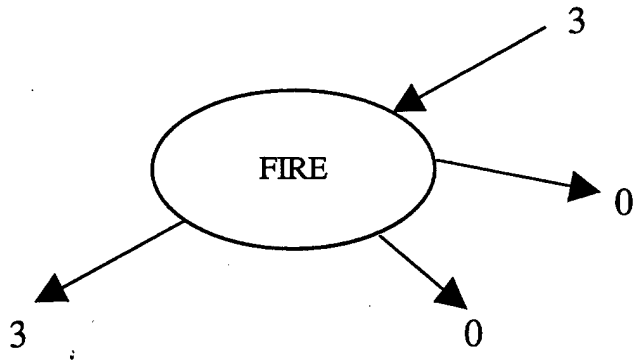
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

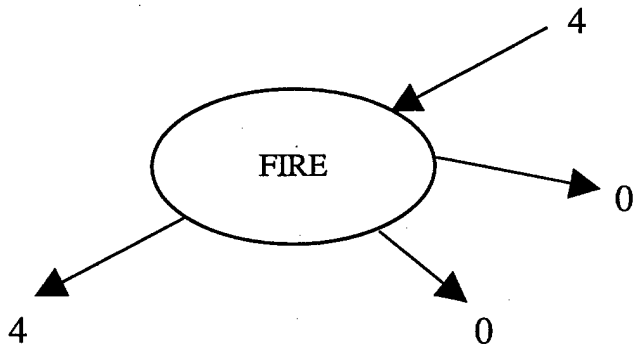
This accident is divided into six separate scenarios:

Scenario 1 contains the flight deck area encompassing the three flight crew who were not injured.



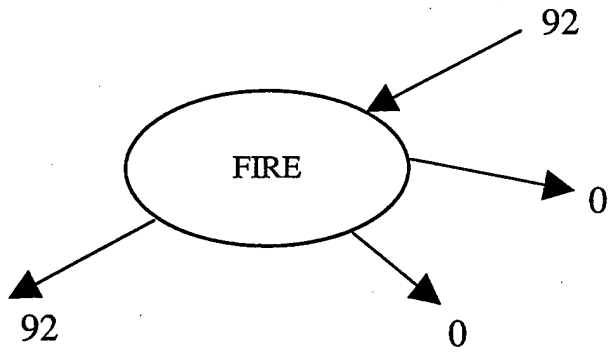
SCENARIO 1

Scenario 2 contains the forward flight attendant area with four flight attendants, all of who escaped uninjured.



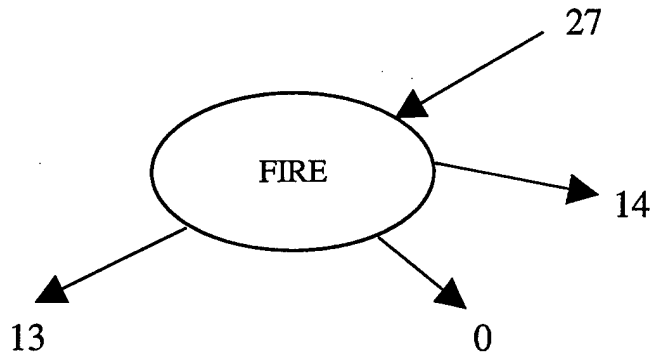
SCENARIO 2

Scenario 3 contains the front section of the passenger cabin from seat row 1 to seat row 20 inclusive. A uniform distribution of passengers was assumed; therefore this scenario contains an estimated 92 passengers, all of whom evacuated without injury.



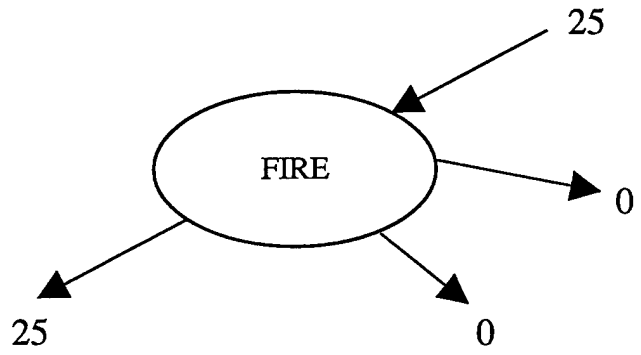
SCENARIO 3

Scenario 4 contains the midsection of the passenger cabin from seat row 21 to seat row 26 inclusive. A uniform distribution of passengers was assumed; therefore this scenario contains an estimated 27 passengers, 14 of whom succumbed to the fire.



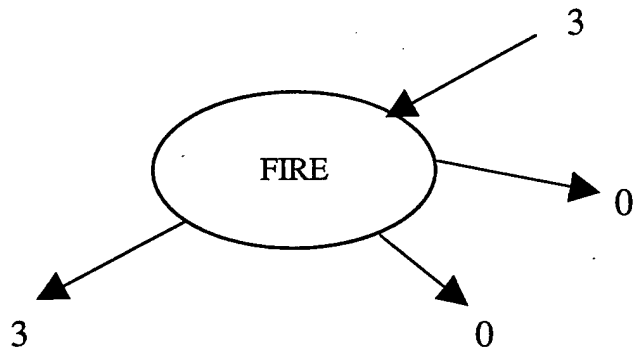
SCENARIO 4

Scenario 5 contains the rear section of the passenger cabin from seat row 27 to the end (taken as seat row 32 with 3 abreast in the tapered fuselage) inclusive. A uniform distribution of passengers was assumed; therefore this scenario contains an estimated 25 passengers, all of whom evacuated without injury.



SCENARIO 5

Scenario 6 contains the rear flight attendant area encompassing three flight attendants, all of whom evacuated without injury.

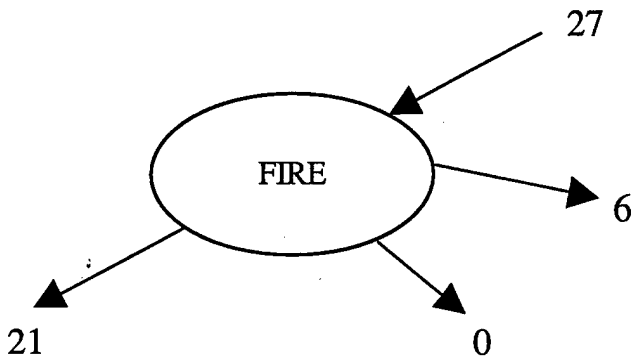


SCENARIO 6

5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation in scenarios 1, 2, 3, 5, and 6 which already had sufficient time for successful evacuation.

For Scenario 4, it is assessed that later requirements would have improved passenger orientation and an additional eight passengers would have been able to locate the useable exits. The survivability chain for Scenario 4 becomes:



SCENARIO 4

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as there was already sufficient time for a successful evacuation.

Scenario 2

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 2 as there was already sufficient time for a successful evacuation.

Scenario 3

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 3 as there was already sufficient time for a successful evacuation.

Scenario 4

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with additional time to use the available exits.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	13	0	14
M	13	4	10
L	14	13	0

For 2 minutes protection:

	S	I	F
H	13	0	14
M	15	6	6
L	18	9	0

For 4 minutes protection:

	S	I	F
H	13	0	14
M	18	4	5
L	24	3	0

For 8 minutes protection:

	S	I	F
H	13	0	14
M	20	4	3
L	27	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	21	0	6
M	21	3	3
L	21	6	0

For 2 minutes protection:

	S	I	F
H	21	2	4
M	23	4	0
L	23	4	0

For 4 minutes protection:

	S	I	F
H	26	1	0
M	25	2	0
L	25	2	0

For 8 minutes protection:

	S	I	F
H	27	0	0
M	27	0	0
L	27	0	0

Scenario 5

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 5 as there was already sufficient time for a successful evacuation.

Scenario 6

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 5 as there was already sufficient time for a successful evacuation.

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	4	3
2 minutes	8	6
4 minutes	9	6
8 minutes	11	6

AIRCRAFT:	**DC10**	**DATE OF ACCIDENT:**	**13th September '82**
REGISTRATION:	**EC-DEG**	**LOCATION OF ACCIDENT:**	**MALAGA**

1. Description of Accident

RESUME

On 13-Sep-82 a Spantax DC-10-30F registered as EC-DEG was taking off from Malaga Airport in Spain.

The pilot aborted the takeoff because of 'vibrations' of unknown origin. The aircraft proceeded off the end of the runway and struck a number of objects, creating sufficient damage to cause fuel spillage, but no fire, as it decelerated.

Approximately 700 feet from the end of the runway, the aircraft crossed a road and struck a house. This impact was quite severe, ripping off the right wing and creating a fireball. The fireball 'followed' the aircraft until it came to rest approximately 1000-1200 feet beyond the runway

Of the 13 crew and 381 passengers aboard, 3 crew and 47 passengers suffered fatal injuries. 40 passengers were seriously injured.

IMPACT

The aircraft proceeded off the end of the runway and struck a number of objects, creating sufficient damage to cause fuel spillage, as it decelerated.

Approximately 700 feet from the end of the runway, the aircraft crossed a road and struck a house. This impact was quite severe, ripping off the right wing. The fuselage was believed to be entirely intact at this point, resting on its belly.

FIRE

A large external fuel fire developed on the right hand side of the aircraft aft of the wing area. The fire size was estimated 25 feet long (fuselage direction) and 50 feet wide. Flames extended 2-21/2 times the height of the fuselage. A much smaller fuel fire formed on the left hand side. The wind speed was 14 knots. The wind vector was forward to aft and at a slight angle with the fuselage centre line, tending to bend the flames away from the fuselage.

There are witness accounts that fire broke in through the tail and dense smoke seeped in probably through a tear in the upper part of the passenger cabin at the height of door 4R.

The aircraft was gutted from the inside-out by fire (the external fuel fire was extinguished by the fire department).

EVACUATION

There were 2 flight crew, 11 cabin crew and 381 passengers aboard.

Slides were deployed for the front emergency exits immediately: L1, L2, and R1. Door R2 was opened later by a passenger (intense fire on that side). After 3 or 4 passengers exited, the slide that served R2 was disabled by fire. Because that landing gear was sheared off, the slides formed a shallow angle and occupants were able to 'walk down the slides'.

Door R3 was not opened due to the intense fire on that side. The stewardess in charge of opening door L3 saw fire on the left side of the plane but decided to open it anyway because she noted the fire was more intense on the right side. The three stewardesses located toward the plane's tail tried to open doors L4 and R4 without success according to witness accounts.

The evacuation took place slowly because the passengers picked up their carried luggage before evacuating. In the third cabin, besides the problems brought about by hand-carried luggage, a bottleneck resulted due to the number of passengers, most of them on the left aisle, that were trying to reach door L3. On top of that, evacuation was carried on with difficulty due to the fire having destroyed the L3 slide.

The lack of visibility, due to the fire and smoke, and the cabin dividers made it impossible to have a view of the plane as a whole, and consequently, three different evacuations were carried out. One from each cabin.

The 91 passengers in the first cabin left the plane through doors L1, R1 and L2. The 122 in the second cabin left through doors L2, L3 and some through R2. The third cabin was occupied by 167 passengers. On these, the 117 that evacuated the plane did so by using door L3 which was affected by the fire through most of the process. The L3 slide was rendered useless. The 47 passengers and three crew members that died occupied the third cabin.

AIRCRAFT FACTORS
The aircraft was a DC-10-30F registered as EC-DEG and operated by Spantax.

The cabin was fitted with 4 passenger doors down each side.

ENVIRONMENTAL CONDITIONS
The accident occurred in daylight. The prevailing weather conditions at the time of the accident were dry, no cloud and wind at 14 kt.

INJURIES TO OCCUPANTS
Of the 13 crew and 381 passengers aboard, 3 crew and 47 passengers suffered fatal fire injuries. 40 passengers were seriously injured.

2. Fire Penetration Mechanism

When the aircraft came to a stop, a large external fuel fire developed on the right-hand side of the fuselage aft of the wing area and a much smaller fuel fire formed on the left-hand side.

The wind direction was forward to aft and at a slight angle with the fuselage centre line, tending to bend the flames of the large fire away from the fuselage side. However, it can be assumed

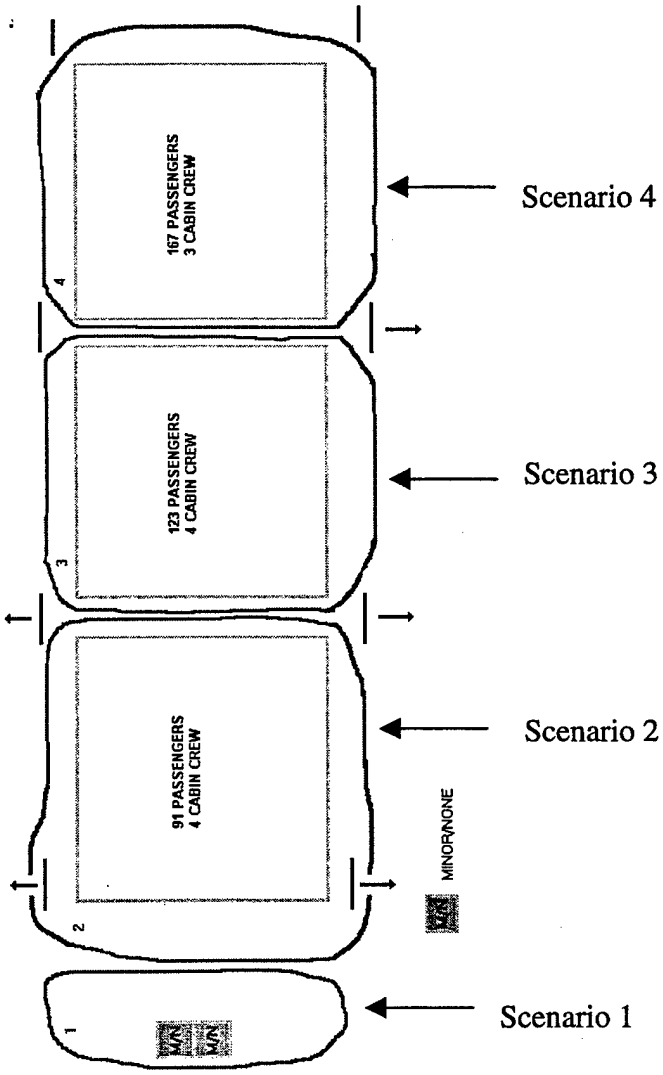
that flames from the smaller fire were being directed onto the fuselage side at the rear of the cabin and would have caused a burnthrough from the left side.

In addition, smoke was seeping in through a tear in the upper part of the passenger cabin at the height of door 4R. It is assessed, however, that there was no immediate burnthrough in this area.

The wreckage was described as being gutted from the inside out by fire. It is assumed that this would have occurred well after the evacuation was complete.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin at the rear on the left side. However there was insufficient information to be conclusive about detail burnthrough areas.

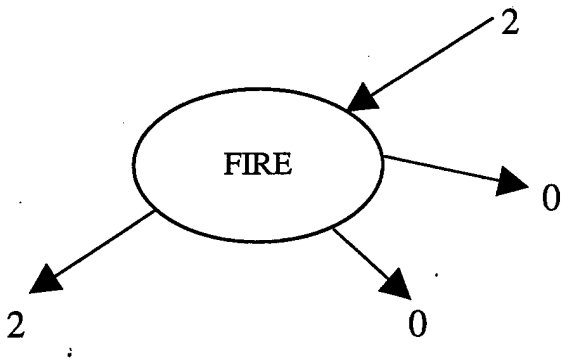
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

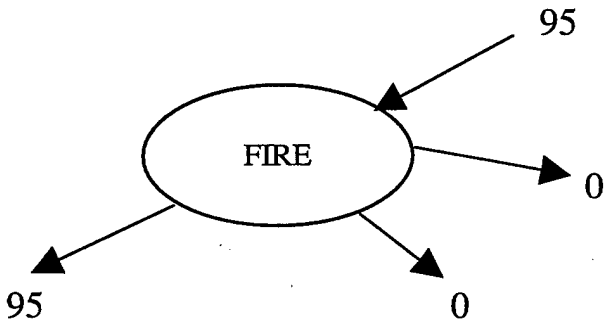
This accident is divided into four separate scenarios.

Scenario 1 contains the flight deck area where all occupants successfully evacuated. The scenario contains the two flight crew.



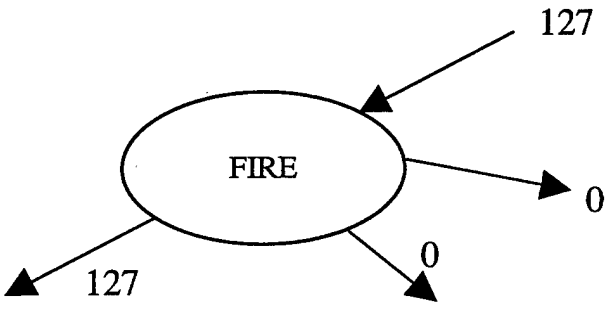
SCENARIO 1

Scenario 2 contains the forward passenger cabin area where all occupants successfully evacuated. The scenario contains 91 passengers and 4 flight attendants.



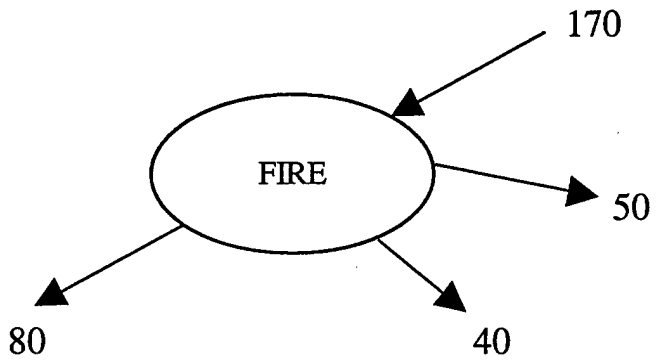
SCENARIO 2

Scenario 3 contains the mid passenger cabin area where all occupants successfully evacuated. To account for all passengers it has been assumed that there were 123 passengers (instead of the 122 quoted in the accident report) and 4 flight attendants in this scenario.



SCENARIO 3

Scenario 4 contains the rear passenger cabin area where 50 occupants did not have sufficient time to make their way to the open L3 exit. The scenario contains 167 passengers and 3 flight attendants.



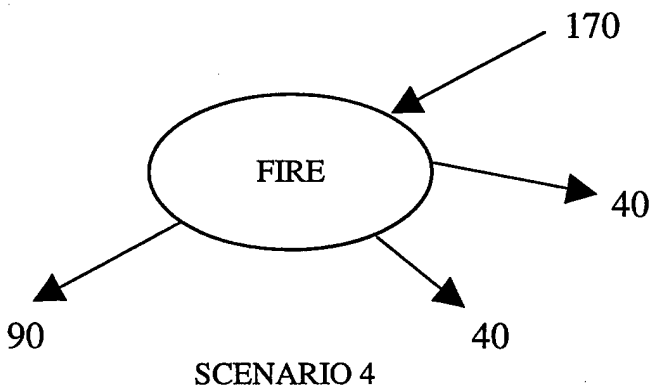
SCENARIO 4

5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation in scenarios 1, 2, and 3 which already had sufficient time for successful evacuation.

For Scenario 4, it is assumed that later requirements would have provided an additional 30 seconds of evacuation time to those in the rear passenger cabin area who only had L3 as an available exit. The evacuation rate on this exit was such that an additional 10 occupants would have been able to evacuate given an additional 30 seconds.

The survivability chain for Scenario 4 therefore becomes:



SCENARIO 4

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as no injuries were sustained.

Scenario 2

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 2 as no injuries were sustained.

Scenario 3

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 3 as no injuries were sustained.

Scenario 4

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the passengers with additional time to make their way to the open L3 exit. It is further assessed that smoke was entering through the tear above door L4 and therefore approximately 10 occupants would still have succumbed even with perfect fire hardening.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	80	40	50
M	84	42	44
L	100	40	30

For 2 minutes protection:

	S	I	F
H	80	40	50
M	93	44	33
L	112	48	10

For 4 minutes protection:

	S	I	F
H	80	40	50
M	104	38	28
L	144	16	10

For 8 minutes protection:

	S	I	F
H	80	40	50
M	111	33	26
L	144	16	10

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	90	40	40
M	94	42	34
L	110	40	20

For 2 minutes protection:

	S	I	F
H	90	40	40
M	102	42	26
L	118	42	10

For 4 minutes protection:

	S	I	F
H	90	40	40
M	112	37	21
L	146	14	10

For 8 minutes protection:

	S	I	F
H	90	40	40
M	115	37	18
L	146	14	10

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	6	6
2 minutes	17	14
4 minutes	22	19
8 minutes	24	22

AIRCRAFT:	**B727**	**DATE OF ACCIDENT:**	**7th December '83**
REGISTRATION:	**EC-CFJ**	**LOCATION OF ACCIDENT:**	**MADRID, SPAIN**

1. Description of Accident

RESUME
On 07-Dec-1983 an Iberia B727-200 registered as EC-CFJ was taking off from Madrid-Barajas Airport, Spain in fog conditions.

As the aircraft reached V1 speed, it collided with a DC-9 which had taxied onto the runway in error due to the poor visibility.

The aircraft spun round, caught fire and was destroyed.

Of the 9 crew and 84 passengers aboard, 1 crew member and 50 passengers suffered fatal injuries. 4 crew and 26 passengers suffered serious injuries. 4 crew and 8 passengers escaped with minor or no injuries.

IMPACT
The DC-9 aircraft was on the flight runway, because the visibility conditions due to fog in the zone through which the aircraft had taxied prevented the crew from obtaining sufficient visual references in order to determine that it was not the correct route which they should have been taking to reach the head of the runway.

At the moment of impact the B727 had just reached Vl and was travelling substantially on the runway axis.

The port side of the aircraft's fuselage on a level with the partitioning bulkhead between the crew and passenger cabins collided with the port wingtip of the DC-9 which had invaded the flight runway.

The effect of this initial impact was to instantly cause the other aircraft to swing round, leaving it practically parallel with, but in the opposite direction to, the B727, which lost its port wing and landing gear. The B727 continued along the runway, swinging round and moving over until it came to a halt at 460 m from the point of impact on the left hand edge of the runway, facing the opposite way to the direction of take-off.

FIRE
Fire broke out on the initial impact due to the breaking off of the port wing and the consequent leakage of fuel, which subsequently destroyed the whole aircraft.

The fire and the smoke generated affected the passengers of the B727 throughout the seconds which passed from when the collision occurred until the aircraft came to a complete stop and its evacuation.

EVACUATION
There were 9 crew and 84 passengers aboard.

The instantaneous fire which broke out on the port side of the aircraft and the plane's subsequent violent swing round incapacitated the victims who were unable to reach the exits.

AIRCRAFT FACTORS
The aircraft was a B727-200 registered as EC-CFJ and operated by the Iberia Company.

The cabin was fitted with a passenger entry door at the front port side, a service door on the starboard side, 2 overwing emergency exits above each wing and service door at either side at the rear. The cockpit had sliding windows on each side.

ENVIRONMENTAL CONDITIONS
The accident occurred during the hours of daylight but in fog.

INJURIES TO OCCUPANTS
Of the 9 crew and 84 passengers aboard, 1 crew member and 50 passengers suffered fatal injuries. 4 crew and 26 passengers suffered serious injuries. 4 crew and 8 passengers escaped with minor or no injuries.

5 people died instantly as a result of the impact of the DC-9's port wing with the B727's fuselage.

The traumatic injuries both of the survivors and of the fatalities were produced as a result of:

(a) The initial impact of the port wing tip of the DC-9 with the part of the B727's fuselage level with the bulkhead separating the crew compartment from the passenger cabin.

(b) The dynamic forces generated by the accelerations at the commencement and end of the aircraft's turn through 180 deg.

The effects of the smoke and fire which broke out on collision, plus the traumatic injuries, incapacitated a large number of victims, preventing them from evacuating the aircraft.

2. Fire Penetration Mechanism

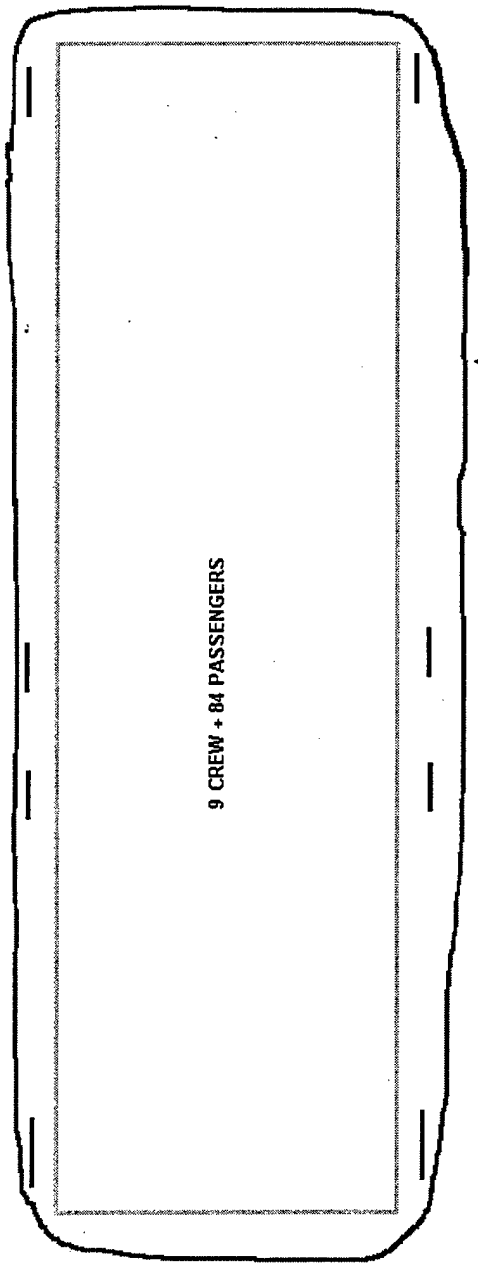
Fire broke out on the initial impact due to the breaking off of the port wing and the consequent leakage of fuel. The fire was instantaneous and on the port side of the aircraft. The fire and the smoke generated affected the passengers throughout the seconds which passed from when the collision occurred until the aircraft came to a complete stop and its evacuation.

It is assessed that some fire and smoke could have entered the cabin through ruptures in the fuselage side caused by the impact. In addition, there was a pool fire around the aircraft as it came to a stop and it is assumed that this fire would have burnt through the fuselage during the evacuation.

The pool of ignited fuel subsequently destroyed the whole aircraft.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin. However there was insufficient information to be conclusive about detail burnthrough areas. It is additionally assessed that fire could have also entered the fuselage through ruptures.

3. Location of Injuries and Scenarios



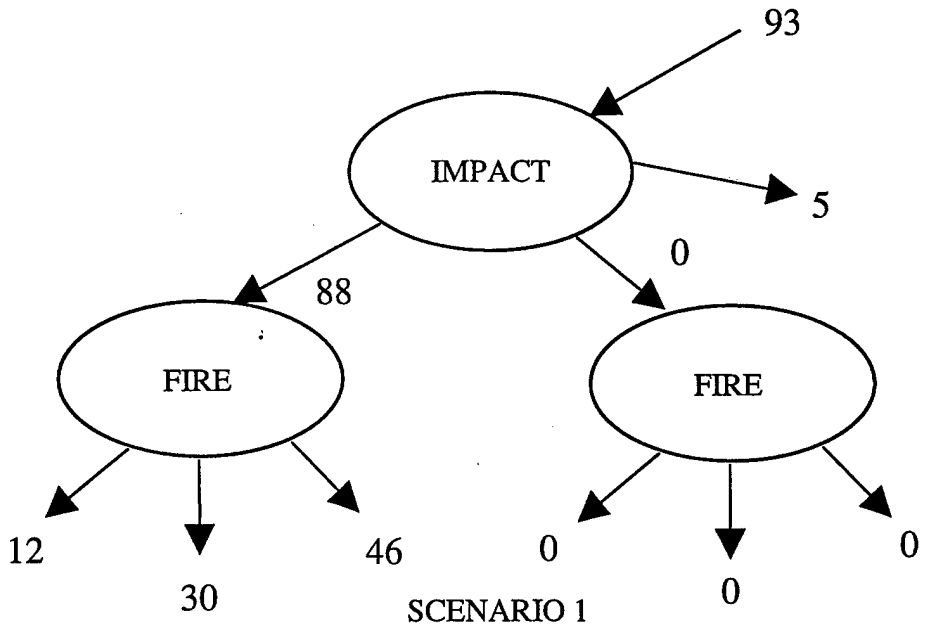
Scenario 1

Note: The accident report did not indicate which of the exits were used for evacuation.

4. Accident Scenarios and Survivability Chains

Due to insufficient documentary detail, this accident is considered as one scenario containing the whole aircraft.

Scenario 1 contains the whole aircraft.



5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation because the occupants who did not evacuate were incapacitated during the violent swing through 180 degrees and were unable to attempt an evacuation.

6. Effect of a Fire-Hardened Fuselage

It is assumed that a fire-hardened fuselage would not have affected the situation because the occupants who did not evacuate were incapacitated during the violent swing through 180 degrees and were unable to attempt an evacuation.

AIRCRAFT:	**B737**	**DATE OF ACCIDENT:**	**30th August '84**
REGISTRATION:	**TJ-CBD**	**LOCATION OF ACCIDENT:**	**DOUALA, CAMEROON**

1. Description of Accident

RESUME
Before take-off the right engine failed with significant damage to the engine and the right wing between the fuselage and the engine pod. Fragments from a high pressure compressor disc perforated the right integral wing tank.

Fuel leaked onto the ground and ignited. Fire destroyed the aircraft.

There was no impact damage.

There were 118 occupants aboard, of which 2 suffered fatal injuries due to fire outside the cabin environment.

2. Fire Penetration Mechanism

There is very little data available on this particular accident, but it may be assumed that once the leaked fuel under the fuselage ignited, the fuselage would have burnt through along the lower surface.

Once the fuselage was penetrated, fire and smoke would have propagated up through the floor and then into the passenger cabin.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin. However there was insufficient information about other burnthrough areas.

3. Location of Injuries and Scenarios

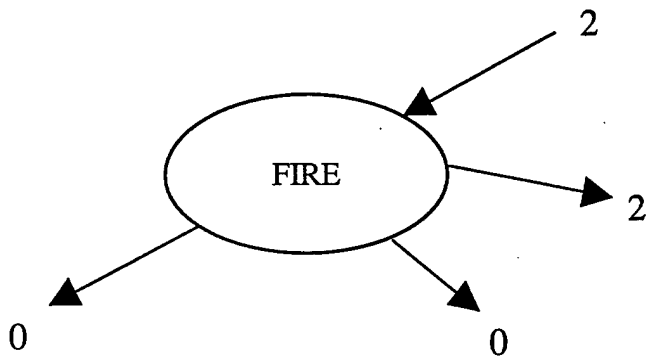
There is insufficient data to identify the location of injuries except for the fact that the two fire fatalities occurred outside the cabin environment.

Therefore the accident is considered as two scenarios, one containing the two external fire fatalities and one containing the remainder of the occupants.

4. Accident Scenarios and Survivability Chains

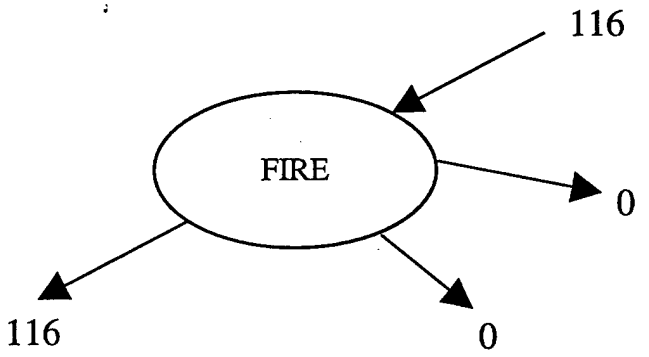
This accident is considered as two separate scenarios.

Scenario 1 contains the two occupants fatally injured outside the cabin environment.



SCENARIO 1

Scenario 2 contains the remainder of the occupants.



SCENARIO 2

5. Effect of Later Requirements

Due to lack of data, no assumptions can be made about the effect of later requirements.

6. Effect of a Fire-Hardened Fuselage

As the only fire fatalities occurred outside the cabin environment, it is concluded that a fire-hardened fuselage would have had no benefit in this accident.

AIRCRAFT:	**B737**	**DATE OF ACCIDENT:**	**22nd August '85**
REGISTRATION:	**G-BGJL**	**LOCATION OF ACCIDENT:**	**MANCHESTER**

1. Description of Accident

RESUME

At 0612 hrs G-BGJL, carrying 131 passengers and 6 crew on a charter flight to Corfu, began its take-off from runway 24 at Manchester with the co-pilot handling. About thirty six seconds later, as the airspeed passed 125 knots, the left engine suffered an uncontained failure, which punctured a wing fuel tank access panel. Fuel leaking from the wing ignited and burnt as a large plume of fire trailing directly behind the engine. The crew heard a 'thud', and believing that they had suffered a tyre-burst or bird-strike, abandoned the take-off immediately, intending to clear the runway to the right. They had no indication of fire until 9 seconds later, when the left engine fire warning occurred. After an exchange with Air Traffic Control, during which the fire was confirmed, the commander warned his crew of an evacuation from the right side of the aircraft, by making a broadcast over the cabin address system, and brought the aircraft to a halt in the entrance to link Delta.

As the aircraft turned off, a wind of 7 knots from 250° carried the fire onto and around the rear fuselage. After the aircraft stopped the hull was penetrated rapidly and smoke, possibly with some flame transients, entered the cabin through the aft right door which was opened shortly before the aircraft came to a halt. Subsequently fire developed within the cabin. Despite the prompt attendance of the airport fire service, the aircraft was destroyed and 55 persons on board lost their lives.

The cause of the accident was an uncontained failure of the left engine, initiated by a failure of the No 9 combustor can which had been the subject of a repair. A section of the combustor can, which was ejected forcibly from the engine, struck and fractured an underwing fuel tank access panel. The fire which resulted developed catastrophically, primarily because of adverse orientation of the parked aircraft relative to the wind, even though the wind was light.

IMPACT

There was no disruption to the passenger cabin as a result of impact in this accident.

FIRE

G-BGJL began its take-off from runway 24 at Manchester with the co-pilot handling. About thirty six seconds later, as the airspeed passed 125 knots, the left engine suffered an uncontained failure, which punctured a wing fuel tank access panel. Fuel leaking from the wing ignited and burnt as a large plume of fire trailing directly behind the engine. The crew heard a 'thud', and believing that they had suffered a tyre-burst or bird-strike, abandoned the take-off immediately.

After the aircraft stopped the hull was penetrated rapidly and smoke, possibly with some flame transients, entered the cabin through the aft right door which was opened shortly before the aircraft came to a halt. Subsequently fire developed within the cabin.

Fire was first spotted 10 seconds after the bang. The port engine and wing caught fire. Fuel leaking from the wing ignited and burnt as a large plume of fire trailing directly behind the engine. Upon turning, the fire spread under the fuselage because of wind and totally engulfed the aft fuselage. The aircraft was extensively damaged by fire. Most of the light alloy components in the aft region of the left engine nacelle were melted or burnt away. The left wing lower aft surfaces, large sections of the trailing edge flaps inboard of the engine and the lower surfaces of the flaps outboard of the engine were melted, and the remaining regions of the left inner wing and the main landing gear bay were superficially fire-damaged.

The rear fuselage was extensively burnt between the wing trailing edge and the rear doors; a large part of the left fuselage side between frames 787 and 887 (approximately seat rows 17 to 21) was completely burnt away. The whole of the fuselage aft of the rear cargo door and the tail section had collapsed onto the ground.

Analysis of the wreckage has shown that the fire initially penetrated the skins on the left side in the vicinity of seat rows 17 to 19, below the level of the cabin floor. Having breached the outer skin, the only barrier which prevented the fire gaining access to the cavity formed between the outer skin and the cargo bay side-liner panels, which communicated directly with the cabin interior above via floor level air-conditioning grills, was a 1 inch thick fibreglass wool acoustic insulation blanket contained in a thin plastic bag.

Most of the passenger cabin ceiling and crown skins were burnt and all of the overhead luggage bins were destroyed. The support beams which carried the cabin floor above the rear cargo hold were burnt away in the central aisle area and on the right side of the cabin, allowing most of the cabin floor above the hold to collapse down onto the baggage. Most of the cabin interior fittings and seats in this section of the cabin were destroyed completely or were very extensively damaged. The interior fittings in the centre and forward sections of the cabin were generally less severely affected by the fire. However, there was considerable local variability, particularly in the severity of seat damage. Notably, seats 8C and 9C (left aisle seats just forward of the overwing exits) were completely destroyed, whereas the adjoining seats were relatively intact.

The survivors statement indicated that the smoke suddenly emanated from the rear of the cabin just before the aircraft stopped. Many passengers reported holding their breath as smoke hit them and that one breath of the thick black smoke caused breathing problems and lung pain. A passenger from seat 6A saw a sheet of flame inside the cabin. It seemed to be near the centre of the aircraft and separated the front half from the back. Another passenger from 6B, after seeing foam being sprayed over the fire on the left side of the aircraft, tried to move into the aisle but it was jammed with people and it was difficult to move. On turning he saw flames shooting in through the side windows and up through the floor area. The flames were several feet in length and continual.

The fire station crash alarm was initiated by ATC immediately the fire was observed from the tower. However, many fire crew personnel heard the bang, saw the fire and started to respond before the alarm had sounded.

RIV2 arrived at the scene approximately 25 seconds after the aircraft had stopped. It was positioned on the left side of the aircraft and foam was applied initially onto the left side of the fuselage and then onto the left engine. RIV1 arrived shortly after RIV2, positioned off the nose slightly on the left side, and discharged the whole of its foam along the left side of the fuselage with the intention of protecting passengers, who by then were evacuating from the L1 chute, and cooling the left side of the fuselage.

Approximately 7 minutes into the incident, after it became clear that no more passengers were likely to emerge unaided, a team with breathing apparatus made an entry via the R1 door. Conditions inside the cabin at that time were very bad, with thick smoke and a serious fire in progress at the rear of the cabin. Shortly after entering, an explosion occurred which blew one of the firemen out of the door onto the tarmac. The officer in charge was by that time becoming increasingly concerned about the reducing water supplies, especially with regard to the potential loss of water supplying sidelines deployed within the cabin, and directed that there would be no more attempts to gain entry until there was a reliable supply of water. In the interim, sidelines were used on the exterior only. At about this time a fire was seen to flash briefly along the cabin.

By approximately 11 minutes into the incident, the internal fire appeared to have spread forward throughout the cabin, where breaches in the roof could be seen. J1 was dispatched to replenish with water from the hydrant system: the vehicle was positioned at three hydrants in succession, but no water could be obtained from any of them. This resulted in a delay of about 10 minutes, after which J1 returned to the scene empty. It was then dispatched to the hydrant behind the fire station, where replenishment was successful.

The GMC fire appliances arrived at the aircraft approximately 13 minutes into the incident. Initially, the Station Officer (SO) in charge experienced some difficulty in identifying the officer commanding the airport fire service, resulting in some delay before the water requirements were identified and the transfer of the 1600 gallons of water from the GMC appliances to J2 could begin. Using a sideline from the newly replenished J2 tender, a two man team with breathing apparatus was then able to make an entry via the R1 door using a short ladder, and, for the first time, were in a position to begin addressing the internal fire.

EVACUATION

During the take-off run the commander made the routine call of "eighty knots" which was confirmed by the co-pilot, and 12 seconds later a 'thump' or 'thud' was heard. Believing that they had suffered a tyre-burst or bird-strike, the crew abandoned the take-off immediately, intending to clear the runway. They had no indication of fire until 9 seconds later, when the left engine fire warning occurred. After an exchange with Air Traffic Control, during which the fire was confirmed, the commander warned his crew of an evacuation from the right side of the aircraft, by making a broadcast over the cabin address system; "Evacuate on the starboard side please." As the aircraft's groundspeed reduced through 17 Kt., 10 seconds before it stopped, the purser opened the flight deck door and said, "Say again", seeking confirmation of the evacuation order. The commander repeated, "Evacuate on the starboard side", 8 seconds before the aircraft came to a halt.

The passenger evacuation drill, a non-memory drill was called for by the commander and was read from the Quick Reference Handbook by the co-pilot. Before they were able to complete the drill the commander saw fuel and fire spreading forward on the left side of the aircraft, opened the co-pilot's sliding window on the right side of the flight deck and ordered him to evacuate the aircraft. This the co-pilot did by means of a fabric escape strap secured above the sliding window and he was followed down to the ground by the commander.

The purser and stewardess seated in the left of the forward galley area during the take-off run heard a 'thud' which they too thought was a tyre burst. They were aware that the take-off had been abandoned. There were sounds of distress in the cabin and the purser leaned inboard in an attempt to improve his view and saw passengers standing up. He made a Public Address announcement for passengers " to sit down and to remain strapped in", released his harness and went into the forward part of the cabin. He saw fire outside the aircraft on the left side coming up over the leading edge of the wing and flowing back over the wing's top surface. There was no smoke or fire apparent to him in the cabin at that time.

Passengers in rows 1-3 appear to have been initially oblivious of the fire which issued from the engine after the 'thud'. However, most of those seated aft of row 5, and in particular those aft of row 14 on the left side, were immediately aware of an intense fire. The flames were seen to cause some 'cracking and melting' of the windows, with some associated smoke in the aft cabin before the aircraft stopped. These effects, with the accompanying radiant heat, caused some passengers to stand up in alarm. A male passenger shouted "sit down, stay calm". Similar calls were then made by others seated mainly on the right side of the aircraft. Many sat down, but some found the pressure to move into the aisle irresistible.

After the purser had confirmed the evacuation with the commander he repeated the evacuation call a number of times over the PA system. Then, as the aircraft was coming to a halt, he went to the right front (R1) door to open it and release the inflatable escape slide. The door unlocked normally but as it was moving out through the aperture the slide container lid jammed on the doorframe preventing further movement of the door. After spending a short time trying to clear the restriction he postponed further effort and crossed to the L1 door. He cracked it open, ascertained that the forward spread of the fire was slow enough to allow evacuation from that door, opened it fully and confirmed the inflation of the slide manually. This was achieved about 25 seconds after the aircraft had stopped and coincident with the initiation of foam discharge from the first fire vehicle to arrive. Evacuation began on the left side under the supervision of the No 4 stewardess, who had to pull free some passengers who had become jammed together between the forward galley bulkheads in order to start the flow.

The purser returned to the R1 door, lifted the slide pack in order to close the slide container lid, and cleared the obstruction. He succeeded in opening the door about 1 minute 10 seconds after the aircraft stopped and again confirmed the automatic inflation of the slide by pulling the manual inflation handle. Evacuation was carried out from this exit supervised by the purser. Smoke emanating from the cabin quickly reached the galley area and became rapidly more dense and acrid. When the smoke began to threaten severe incapacitation, the forward cabin crew vacated the aircraft by the slides at their respective doors.

As the aircraft came to a halt and at the instigation of other passengers, a young woman sitting in seat 10F, beside the right overwing exit, attempted to open it by pulling on her right hand arm-rest which was mounted on the exit hatch. Her companion in seat 10E, the centre seat of a row of three, stood up and reached across to pull the handle located at the top of the hatch marked "Emergency Pull". The hatch, weighing 48 lb., fell into the aircraft to lay across the passenger in 10F, trapping her in her seat. With the assistance of a man in row 11 behind the women, the hatch was removed and placed on vacant seat 11D. The passengers in 10F and 10E then left the aircraft cabin through the overwing exit onto the wing followed by other survivors. This exit was open about 45 seconds after the aircraft stopped.

During the latter stages of the abandoned take-off, and just as the aircraft turned towards taxiway link Delta, the right rear door was seen by external witnesses to be open, with the slide deployed and inflated. A stewardess was initially visible in the doorway but the door and slide were obscured by thick black smoke as the aircraft stopped. No one escaped through this door. Two passengers remember seeing one of the two stewardesses from the rear of the aircraft struggling to direct passengers in the rear aisle. Neither rear stewardess survived.

As the aircraft stopped, the aft cabin was suddenly filled with thick black smoke which induced panic amongst passengers in that area, with a consequent rapid forward movement down the aisle. Many passengers stumbled and collapsed in the aisle, forcing others to go over the seat-backs towards the centre cabin area, which was clear up until the time the right overwing exit was opened. A passenger from the front row of seats looked back as he waited to exit the aircraft, and was aware of a mass of people tangled together and struggling in the centre section, apparently incapable of moving forward, he stated "people were howling and screaming".

The smoke quickly moved forward and passengers from seats 6A and 6B, waiting to get into the aisle, said they couldn't see and it became very hot as they entered the aisle to get to the forward exits. Passengers behind them either climbed over seats to get forward, or felt their way down the aisle by way of the seat. People seated in seats 7A and B could not see the exit when they reached it, but had to feel the walls to find a gap. A female passenger from seat 15A who climbed over seats to move towards the front exit was pushed past the exit by a mass of bodies. People all around her were collapsing on the floor. She fell to the ground unconscious just outside the doorway. She revived and pulled herself out.

At least 15 passengers reported going over seats or climbing over other collapsing passengers in the aisles. Of these 15 passenger survivors, at least 11 used the starboard overwing exit to escape, which represents some 44 percent of those who used the congested aisle. Many passengers who ultimately got out the starboard overwing exit, collapsed temporarily within or adjacent to this exit due to incapacitation; e.g. passengers from seats 12D, 14F, 15A and 8B.

With regard to the exits used during the evacuation, some 15-17 used the left forward exit, 34-36 used the right forward exit. Some 27 passengers (including two infants) used the right overwing exit. Survivors indicated hesitation by some to exit the left front on the side of the fire, which slowed evacuation out of the doors.

The first people were out the left front door at 30 seconds from stopping and, out the right front door at 90 seconds from stopping. The overwing exit was opened 45 seconds from stopping. Passengers stopped using the left front door when the right front door was opened due to the presence of fire on the left side. In 3.5 to 4 minutes after stopping, all survivors (except one 14 year old boy from seat 12D found by the fireman 5.5 minutes after their arrival) were off the aircraft. From the statements of the survivors, it is evident that the effects of the fire on the left side of the aircraft rapidly instilled fear and alarm in many passengers, particularly those in the aft/left cabin - i.e. row 14 aft. These effects appear to have been marked heat radiation through the windows together with "cracking, melting and smoking" of the window transparency panels, which motivated some passengers from the aft cabin to enter the aisle and move forward before the purser's 'sit down' announcement on the PA, and therefore before the evacuation call 14 seconds prior to the aircraft stopping.

The left rear door was opened by firemen some time after the fire had been extinguished.

The air and ground movements controllers in the tower had seen the fire and smoke trailing behind the aircraft and had initiated 'full emergency' action. The air controller activated the alarm siren connected directly to the aerodrome fire service station (Manchester International Airport Fire Service - MIAFS), and gave brief details of the emergency to the MIAFS watchroom over the direct telephone link.

Members of the MIAFS heard a bang and saw an aircraft decelerating on runway 24. Black smoke and flames were trailing from the left side of the aircraft and the firemen had already initiated their response when the crash alarm siren sounded.

Two Rapid Intervention Vehicles (RIVs) attended first, one arriving at the aircraft coincident with, the other just after the L1 door had opened and its slide deployed, as passengers were about to start to evacuate. About 30 to 40 seconds later, as two major foam tenders took up position, the R1 door was opened fully and its slide deployed.

Many survivors from the front six rows of seats described a roll of thick black smoke clinging to the ceiling and moving rapidly forwards along the cabin. On reaching the forward bulkheads it curled down, began moving aft, lowering and filling the cabin. Some of these passengers became engulfed in the smoke despite their close proximity to the forward exits. All described a single breath as burning and painful, immediately causing choking. Some used clothing or hands over their mouths in an attempt to filter the smoke; others attempted to hold their breath. They experienced drowsiness and disorientation, and were forced to feel their way along the seat rows towards the exits, whilst being jostled and pushed. Many, even in the forward cabin, resorted to going over the seat backs in order to avoid the congested aisle.

At the start of evacuation from the L1 door, the stewardess stated that passengers seemed to be jammed in the cabin aisle and entrance to the galley (i.e. between the twin forward bulkheads). She cleared the jam by pulling one young passenger forwards and the flow then started. Later she saw a young girl lying on the floor of the forward aisle. She pushed another youth back, pulled the girl forward by her collar and pushed her down the slide. As the passengers came forward through the bulkhead aperture so the smoke built up in the forward galley area. She

recalled feeling a body slump against her legs, bent down and, due to improved visibility near the floor, saw that it was another girl passenger. Her face was black with soot, eyes fixed and dilated with no signs of breathing. The stewardess considered giving her the kiss of life when a fireman down below shouted for her to throw the girl down to him. With great difficulty she lifted her by the waist and threw her onto the chute. After being forced down by the smoke onto her hands and knees, the stewardess felt around for other passengers back as far as the galley cabin entrance. She was considering getting her smokehood when a fireman shouted at her to jump, concerned that she would perish if she delayed. Having been unable to locate any further passengers, she went down the slide.

The Purser stated that, after getting the R1 door open at his second attempt and initiating evacuation from this exit, the smoke began entering the galley area.

Very rapidly the area around the overwing exit became a mass of bodies pushing forward to the exit. People all around were falling and collapsing to the floor. Many passengers who ultimately got out of the right overwing exit, nevertheless collapsed temporarily within, or adjacent to it. The exit was blocked with "people's bodies lying half-in and half-out of the aircraft". A male passenger, from 16C, died after becoming lodged in this right overwing exit. A young boy, from 12D, was pulled out over this man's body by a fireman about 5 minutes after the aircraft stopped. Several of the survivors who used the overwing exit were impeded by becoming entangled in the ditching strap. However, one passenger recalled catching hold of it as she collapsed, to recover consciousness with her head outside the exit.

Of the 24 passengers who escaped from the right overwing (not including the 2 young children and the young boy pulled clear) some 11 passengers (46%) went over the seats as opposed to using the congested aisle to get there.

AIRCRAFT

The aircraft was fitted with 130 passenger seats, two double and one single cabin crew seats. One of the double crew seats was forward of door L1 facing rearwards and the other double aft of door L3 facing forwards. In the forward passenger cabin a pair of full height galley bulkheads were positioned just aft of the two doors, L1 and R1. In the aft end of the cabin a full height stowage unit was located just forward of door R3 with a single crew seat mounted on the rear of it, facing aft.

This configuration was in compliance with British Airways Configuration Modification No 25C211, Drawing No 1-54378 certified by the British Airways authorised engineer as being in compliance with the appropriate regulations on the 20 November 1981.

This drawing specifies a seating pitch of:

	Rows 1-9	Rows 9-10	Rows 10-22
Pitch	30 ins	31 ins	29 ins

In addition, this drawing specified that seats 10A and 10F, should be of a type modified to prevent the seat-backs from hinging forward and row 9 seats should have no recline, in order that access to both overwing exits should not be impeded. The seat backs of row 9, in common with the majority of seats, could be folded forwards to create more room for the upper body of any person moving between rows 9 and 10 to the overwing exits.

The aisle aperture between the twin forward bulkheads in this configuration was 22 inches wide.

The aircraft was equipped with four main cabin doors ('Type I'), two overwing emergency exits ('Type III') and two sliding-window emergency exits on the Flight Deck. Each main door incorporated a slide pack.

The overwing emergency exits were located at either side of row 10 and were intended for ground evacuation of centre cabin passengers, or as the primary exits for use after a sea-ditching. For the latter purpose, these exits were each equipped with a webbing-type escape rope/lifeline, anchored to the upper/forward corner of the aperture, with a snap-hook on the other end for attachment to a lug located on the upper surface of each wing near the trailing edge. These lifelines were some 17 feet in length and designed to provide evacuees with a means of stabilising themselves while on the wing upper surface prior to boarding the rafts. For ground evacuation, arrows painted on the upper surface of each wing were intended to lead evacuees to the trailing edge and down the extended flaps.

On pulling the overwing exit hatch release handle the hatch, weighing 48 lb., pivots inboard about its lower edge and requires lifting to remove it from the aperture to make the exit available.

The Flight Deck had two sliding-window emergency exits for use by the pilots, with two associated webbing-type escape ropes stored in the overhead above the windows.

The cabin crew stations at the forward and aft passenger doors (i.e. left) were each equipped with an interphone and passenger address microphone. The forward cabin crew were also provided with two 'Scott' smokehoods, located in a cupboard stowage facing their bench-seat. One 1.5 Kg capacity Bromochlorodifluoromethane (BCF) fire extinguisher bottle (discharge duration 15 seconds) was also located in a stowage locker facing this seat. The other three smokehoods, for use by the cabin crew, were stored in the overhead 'bin' at row 18 (right). One 1.5 lb. capacity water fire extinguisher was stored in this area of the cabin within the right overhead at row 20. A further two, 1.5 Kg BCF extinguishers were located on the aft wall of the rear right bulkhead. Two megaphones were available for cabin crew use, one stored in the forward left overhead bin at row 2 and the other in the aft right overhead at row 18.

Ten portable oxygen bottles were stored in the cabin overheads; two (for crew use) were located at row 2 right, two units either side of the aisle at row 10 (for passengers) and four units within the overhead at rows 20-21 right, of which three were designated for crew use.

ENVIRONMENTAL CONDITIONS

The accident happened during daylight. The weather recorded at Manchester Airport at 0550 hrs was:

Surface Wind: 270°/5 Kt Visibility: 25 km Cloud :1 okta at 1,400 feet Temperature: + 13 C QNH *:1014 millibars*(Corrected mean sea level pressure setting)

The weather recorded at 0620 hrs was:

Surface Wind: 260°/6 Kt Visibility :1,000 metres in smoke Cloud: 1 okta at 1,400 feet Temperature: + 13 C QNH: 1015 millibars

The Manchester Automatic Terminal Information Service (ATIS), information 'C' was received by the crew prior to starting engines. This gave the surface wind as 280°/6 Kt., variable 240°-320°. When ATC cleared the aircraft for take-off, they passed a surface wind of 250° at 7 Kt. The runway was dry.

INJURIES TO OCCUPANTS

The major cause of the fatalities was rapid incapacitation due to the inhalation of the dense toxic/irritant smoke atmosphere within the cabin.

A marked deposition of carbon particles was found within the trachea of all victims, with some congestion of the mucosa (mucus lining) in 17 cases ("marked congestion" in the case of one passenger) with many instances of "excess mucus". The lungs of all fatalities showed marked general congestion and oedema (fluid), with carbon particles in the air passages, consistent with the inhalation of smoke. There was no evidence of organic disease which could have caused the death of any of the victims.

Blood samples were analysed to determine carboxyhaemoglobin and cyanide levels. In addition, hydrocarbon absorption was measured, including benzene and toluene, these two being the most prevalent volatiles found in all fatalities. Many other minor trace volatiles were found, including acetaldehyde.

Of the 54 occupants who expired on the aircraft, 43 (80%) had cyanide levels in excess of 135 micrograms/100 ml which would have led to incapacitation. Of these, 21 had levels above 270 micrograms/100 ml, the fatal threshold. Forty passengers (74%) had levels of carboxyhaemoglobin in excess of 30% saturation which would also be expected to cause incapacitation. Of these, 13 passengers had levels in excess of 50%, which is generally accepted as the fatal threshold. From information in the accident report and from the AAIB, it was determined that 9 passengers had absorbed less than the incapacitating levels of carbon monoxide and hydrogen cyanide stated above, and died from direct thermal assault. The remaining 48 passengers who died on board did so as a result of smoke/toxic gas inhalation.

One eventual fatality, a 31 year old man from seat 8B had superficial burns over 24 percent of his body, was taken off the aircraft alive 33 minutes after the aircraft stopped. He died after 6 days in hospital because of severe pulmonary (lung) damage and associated pneumonia.

2. Fire Penetration Mechanism

As the aircraft came to a stop, the spilling, ignited fuel collected in a pool under the wing on the left side, directly behind the port engine. The wind direction was such that flames were directed onto the fuselage side and as a result the rear fuselage was extensively burnt. A large part of the left fuselage side approximately between seat rows 17 and 21 was burnt through and allowed fire and smoke to enter the passenger cabin. One passenger reportedly saw flames shooting in through the side windows and up through the floor area.

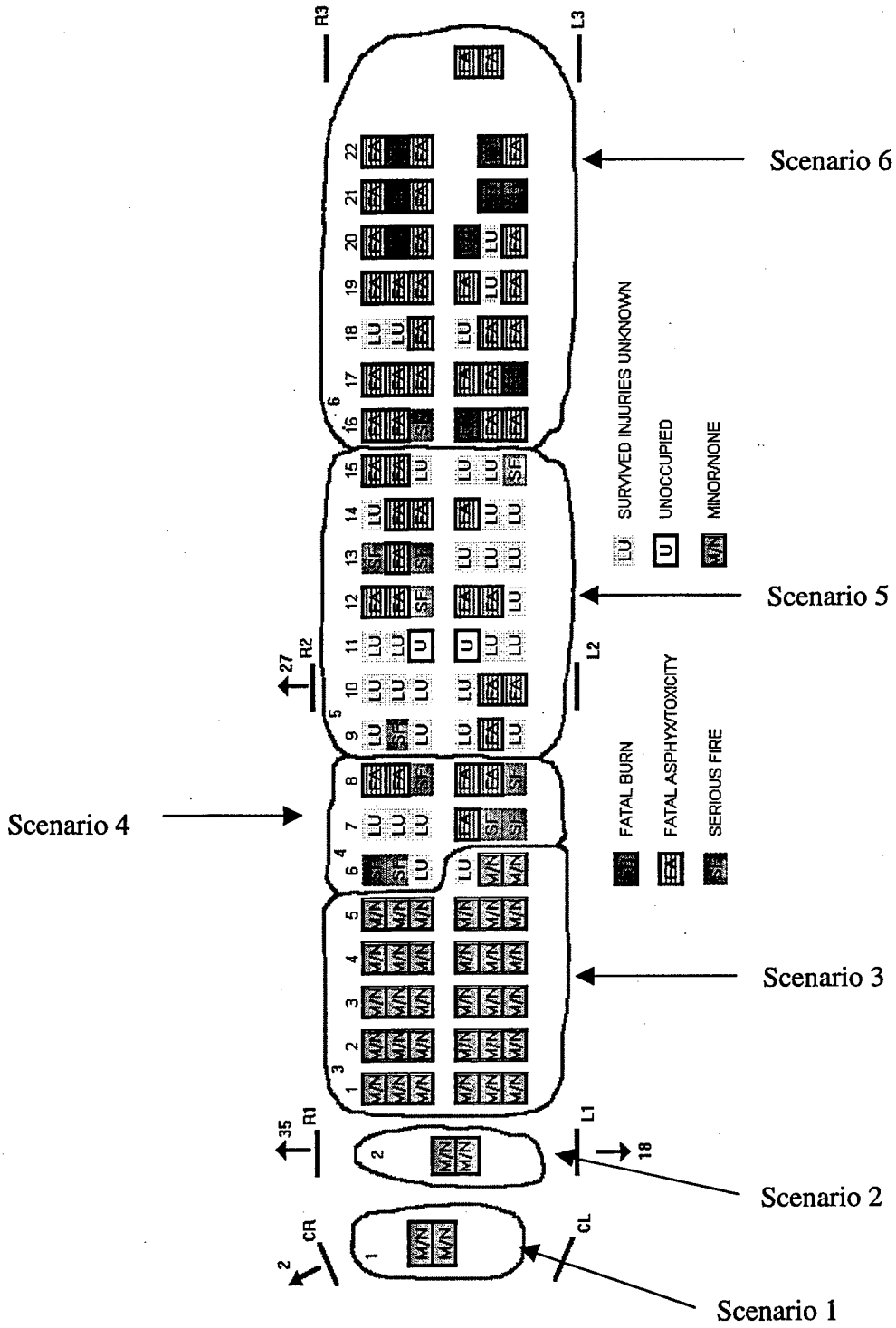
Analysis of the wreckage has shown that the fire initially penetrated the skins on the left side below the level of the cabin floor. Having breached the outer skin, the only barrier to the fire gaining access to the cavity, formed between the outer skin and the cargo bay side liner panels, was a 1-inch-thick fibreglass wool acoustic insulation blanket contained in a thin plastic bag. This cavity communicated directly with the cabin interior above via floor level air conditioning grills.

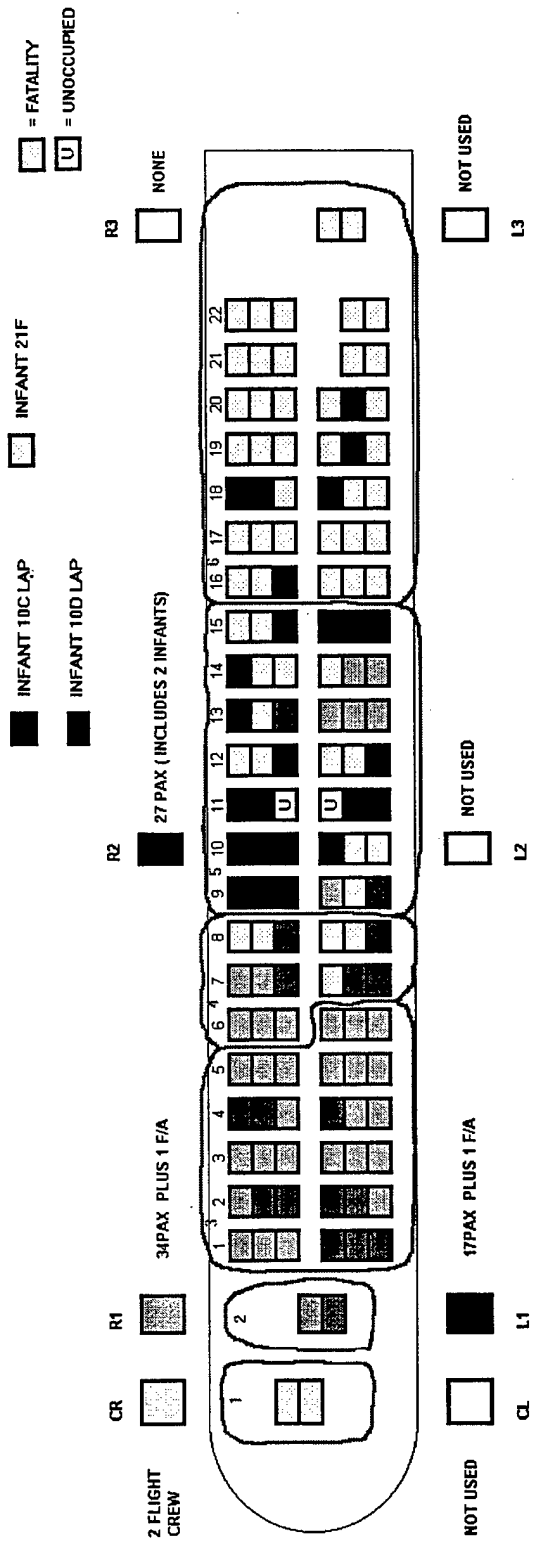
The aft right door was opened shortly before the aircraft came to a halt and this allowed some flame transients to enter the cabin. No occupants were able to use this exit as a means to escape.

As fire and smoke entered the cabin at the rear, it rapidly propagated forward. Many survivors described a roll of thick, black smoke clinging to the ceiling and moving rapidly forward along the cabin. On reaching the forward bulkheads it curled down, began moving aft, lowering and filling the cabin. Some passengers became engulfed in the smoke despite their close proximity to the forward exits and were forced to feel their way out. Others succumbed to the smoke and died of asphyxiation.

Based on the above, it is assessed that the prime burnthrough route was through the fuselage skin and windows on the left side.

3. Location of Injuries and Scenarios

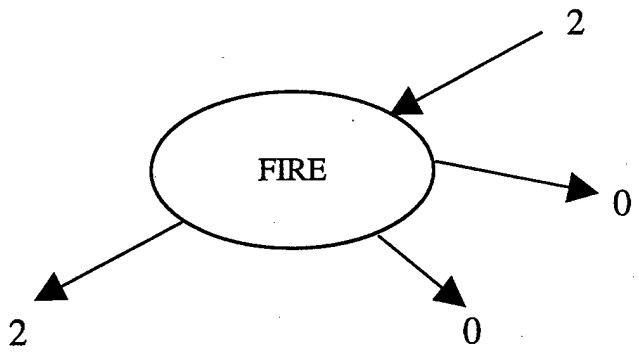




4. Accident Scenarios and Survivability Chains

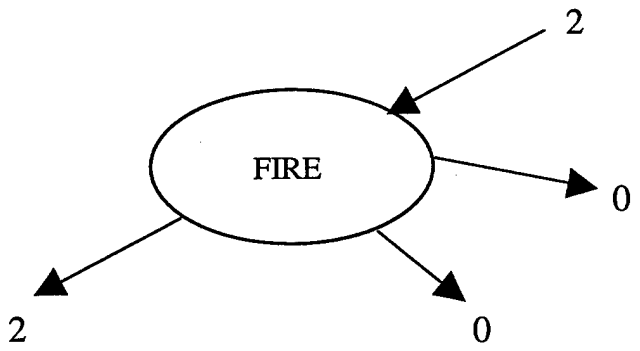
This accident is divided into six separate scenarios.

Scenario 1 contains the flight deck area. It was the area furthest from the point of entry of the fire and therefore had the most time available for evacuation. The scenario contains the two flight crew who exited through the right cockpit window.



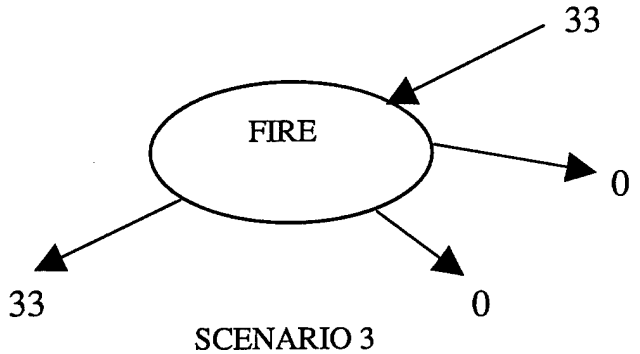
SCENARIO 1

Scenario 2 contains the forward flight attendant area. The flight attendants were initially seated rearward facing and stayed close to their respective exits throughout the whole evacuation period as they directed passengers out. Indeed, they each finally evacuated through their assigned exits when they considered it unsafe to remain. As a result they both survived uninjured.



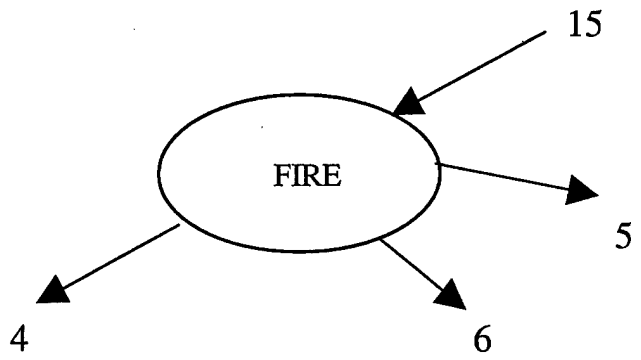
SCENARIO 2

Scenario 3 contains the front section of the passenger cabin from seat row 1 to seat row 5 inclusive and the left side of row 6. This area had both the L1 and R1 exits open and useable. The occupants executed a successful evacuation uninjured. It is assumed that the unknown injuries were minor.



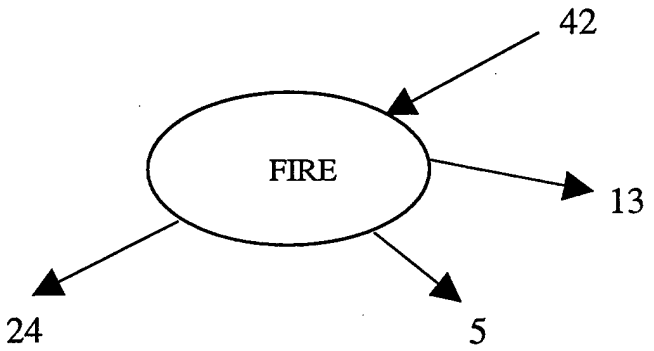
SCENARIO 3

Scenario 4 contains the front section of the passenger cabin from seat row 7 to seat row 8 inclusive and the right side of row 6. Occupants in this area made their way to the L1 and R1 exits. Those further from the exits had a longer exposure to the fire and smoke and were either injured or asphyxiated. It is assumed that the unknown injuries were minor.



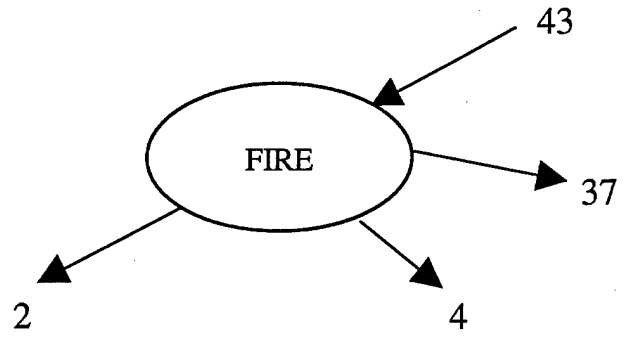
SCENARIO 4

Scenario 5 contains the midsection of the passenger cabin from seat row 9 to seat row 15 inclusive. This area had only the R2 overwing exit open and useable. Those occupants closest to the exits executed a successful evacuation. Those further away had a longer exposure to the fire smoke and were either injured by fire or overcome by smoke and toxic gas. It is assumed that the unknown injuries were minor. The numbers include two infants who were carried out of the aircraft uninjured.



SCENARIO 5

Scenario 6 contains the rear section of the passenger cabin from seat row 15 to seat row 22 inclusive as well as the two rear flight attendants. This area had only the R2 overwing exit open and useable and was the area in which the fire burnt through and entered the cabin. All occupants from this section had a significant distance to travel before reaching the overwing exit. Further, visibility was severely restricted by dense black smoke and location of exits was almost impossible. As a result, most of the occupants either died as a result of burns or were overcome by the smoke and toxic gas. It is assumed that the three unknown injuries next to the point of fire entry were serious and all other unknown injuries were minor. The numbers include an infant who was asphyxiated in the cabin.

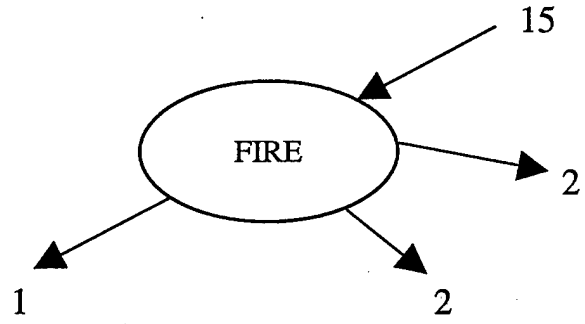


SCENARIO 6

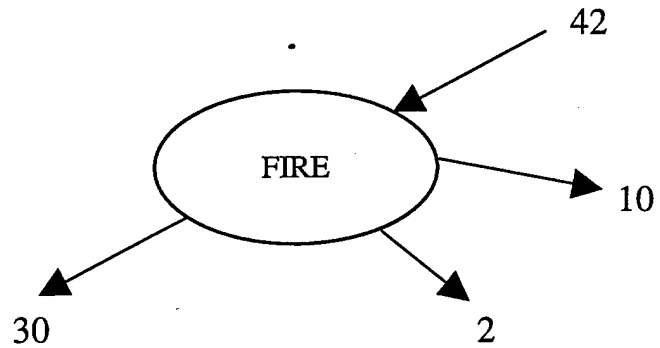
5. Effect of Later Requirements

It is assumed that later requirements would not have affected the situation in scenarios 1, 2, and 3 which already had sufficient time for successful evacuation.

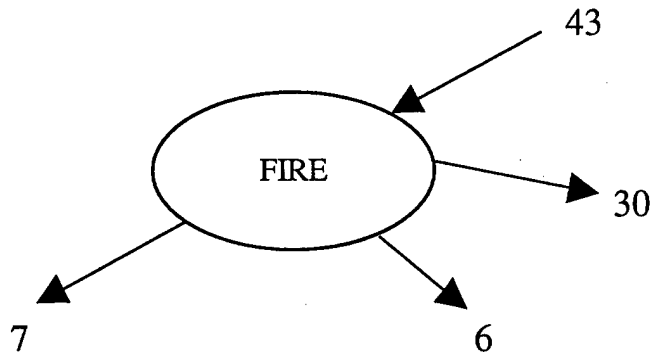
For scenarios 4, 5, and 6 it is assessed that later requirements would have improved flammability standards such that the occupants would have had an additional 30 seconds of time to escape. It is assessed that this would result in the survivability chains for Scenarios 4, 5, and 6 becoming:



SCENARIO 4



SCENARIO 5



SCENARIO 6

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as there was already sufficient time for a successful evacuation.

Scenario 2

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 2 as there was already sufficient time for the flight attendants to direct passengers and then evacuate themselves successfully.

Scenario 3

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 3 as there was already sufficient time for a successful evacuation.

Scenario 4

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the passengers with additional time to locate and use the two forward exits.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	4	6	5
M	5	7	3
L	5	10	0

For 2 minutes protection:

	S	I	F
H	4	6	5
M	7	6	2
L	9	6	0

For 4 minutes protection:

	S	I	F
H	5	7	3
M	9	5	1
L	13	2	0

For 8 minutes protection:

	S	I	F
H	8	6	1
M	11	4	0
L	15	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	11	2	2
M	12	2	1
L	15	0	0

For 2 minutes protection:

	S	I	F
H	11	2	2
M	13	2	0
L	15	0	0

For 4 minutes protection:

	S	I	F
H	11	3	1
M	14	1	0
L	15	0	0

For 8 minutes protection:

	S	I	F
H	14	1	1
M	15	0	0
L	15	0	0

Scenario 5

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with additional time to use the available overwing exit.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	24	5	13
M	27	6	9
L	32	5	5

For 2 minutes protection:

	S	I	F
H	26	5	11
M	31	8	3
L	33	9	0

For 4 minutes protection:

	S	I	F
H	25	12	5
M	34	6	2
L	39	3	0

For 8 minutes protection:

	S	I	F
H	25	12	5
M	37	3	2
L	42	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	31	3	8
M	33	4	5
L	42	0	0

For 2 minutes protection:

	S	I	F
H	31	8	3
M	34	6	2
L	42	0	0

For 4 minutes protection:

	S	I	F
H	31	10	1
M	37	5	0
L	42	0	0

For 8 minutes protection:

	S	I	F
H	31	11	0
M	37	5	0
L	42	0	0

Scenario 6

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided the occupants with additional time to move forward and use the available overwing exit.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	3	5	35
M	4	8	31
L	5	15	23

For 2 minutes protection:

	S	I	F
H	9	4	30
M	17	13	13
L	31	12	0

For 4 minutes protection:

	S	I	F
H	8	4	27
M	20	13	10
L	35	8	0

For 8 minutes protection:

	S	I	F
H	8	8	27
M	20	13	10
L	43	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	8	7	28
M	14	10	19
L	23	12	8

For 2 minutes protection:

	S	I	F
H	11	4	28
M	21	12	10
L	33	8	2

For 4 minutes protection:

	S	I	F
H	10	9	24
M	34	7	2
L	43	0	0

For 8 minutes protection:

	S	I	F
H	10	9	24
M	34	7	2
L	43	0	0

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	12	17
2 minutes	37	30
4 minutes	42	40
8 minutes	43	40

AIRCRAFT:	**A320**	**DATE OF ACCIDENT:**	**26th June '88**
REGISTRATION:	**F-GKFC**	**LOCATION OF ACCIDENT:**	**HABSHEIM**

1. Description of Accident

RESUME

During an airshow on 26-Jun-88, A320 F-GKFC made a level pass at about 30 ft, gear and flaps out, engines almost at idle and 130 passengers on board. After the go-around, the aircraft hit trees at the end of the runway. The right wing broke up and a fire erupted.

All passengers evacuated the aircraft except 3 who suffered fatal injuries as a result of the fire.

IMPACT

The aircraft touched the trees shortly after the end of the runway at 12:45.40; at this time, engine speed was around 83% Nl, the pitch attitude of the aircraft was 14 deg.

The first contact between the aircraft and the trees was made by the rear section of the fuselage, the tailplane, then the engine nacelles and the main landing gear.

The aircraft sank slowly into the forest. The tip of the right wing then the right wing itself broke, finally the aircraft came to rest.

FIRE

As the right wing broke fuel was projected forward and fire immediately broke out and penetrated the cabin as soon as the aircraft came to rest. Fuel flowed under the cabin and as a result fire also raged around the left wing.

EVACUATION

There were 2 flight crew, 4 cabin crew and 130 passengers on board.

As soon as the aircraft came to rest, the stewards stationed at the forward and aft doors, seeing the fire on the right of the aircraft, opened the left doors.

The normal lighting went off and the emergency lighting did not come on due to a design error in its automatic illumination program.

The captain declared that he made several attempts to trigger the evacuation signal; but it seems that this signal did not work, as nobody in the cabin heard it.

The purser wished to broadcast a message via the public address but could not find the handset, which apparently, had been torn from its support, maybe due to the fragility of this support and of the attachment of the electrical lead.

A passenger stated that he had wanted to open the left wing emergency exit but could not reach it. The opening of this exit would have been very dangerous, as fire was raging around the left wing level.

The left forward door was blocked by branches after it had started to open correctly. The escape slide started to deploy partly outside and partly inside the cabin.

The purser, with the help of at least one passenger and an air hostess from another airline (who was in the cockpit as a passenger during the flight), pushed the door. The door opened suddenly and the purser and the passenger fell out of the aircraft and were covered by the escape slide.

The passengers started to panic and push in the front of the cabin. The passenger hostess then started to evacuate the passengers, but the first ones were blocked by branches in the escape slide. The other passengers jumped out beside the escape slide but they very quickly piled up on top of each other again due to the branches.

The hostess then stopped evacuation for a short while so that the passengers who had already jumped had time to extricate themselves. Meanwhile, on the outside, the purser, with the help of another air hostess, tore away the branches from across the escape slide to free the blocked passengers. After a certain time, the hostess herself left the aircraft suffering from the effects of the smoke.

The hostess stationed in the centre of the aircraft at 12D was pushed into the aisle by the passenger in 12F, who was seriously burnt, was then carried forward while at the same time helping a passenger whose clothes were on fire.

She arrived at the left forward door (L1), no doubt after the evacuation of the previous hostess, and took her place.

After the evacuation of the last persons to arrive at this door, she called into the cabin to find out if anyone was still there but did not get any reply; by this time, the smoke, very thick, and flames made any visual inspection impossible. On the order of the captain, who had just evacuated the injured first officer, she then left the aircraft.

The captain then returned to the cockpit to get an antismoke mask with the intention of going through the cabin, but in turn had to leave, before he could don the equipment, suffering from the effects of the fumes.

Note that the cabin attendants either were not able to use the antismoke masks during the evacuation or did not think of doing so. They were, in fact, more occupied in opening the doors as quickly as possible so as to speed up passenger evacuation.

The left aft door was opened without any problems and the escape slide was correctly deployed. The steward ordered the passengers to come toward him to evacuate and at the same time reassured them verbally. This, combined with the absence of smoke at the rear of the cabin, certainly contributed toward the good evacuation via this door.

After several passengers had used the escape slide it was punctured on the branches. The steward asked his colleague to descend to help to receive the passengers. Evacuation continued without panic with spontaneous help from one passenger, especially for the evacuation of an elderly person who had difficulty in moving.

After the last passengers had left the aircraft, the hostess returned to go through the cabin but the flames and smoke had reached the galley; she was able only to shout out in the direction of the cabin.

During the evacuation, the stewards and hostesses could not see what was happening at the other end of the aircraft due to the fire around the left wing. Therefore, after the end of evacuation via their door, they went round the wing toward the front or the rear to see if they could be of any help at the other door.

It has not been possible to determine the time it took to evacuate the survivors.

All passengers were able to leave the aircraft, except three who succumbed to the fire.

AIRCRAFT FACTORS
The aircraft was an A320-100, registered as F-GFKC and operated by Air Charter International.

The aircraft obtained its Certificate of Airworthiness on 22-Jun-1988 and was delivered on 24-Jun-1988.

The aircraft was fitted with two doors at the front and two doors at the rear of the passenger cabin. In addition there were 2 overwing emergency exits over each wing.

ENVIRONMENTAL CONDITIONS
The accident happened in daylight during an airshow. Visibility was 8km and wind was 010 deg at 6 kts.

INJURIES TO OCCUPANTS
All passengers were able to leave the aircraft, except three who succumbed to the fire:

A young handicapped boy in seat 4F who seems to have remained in his seat.

A little girl located at 5C who, according to her young brother (carried away by the flow of the other passengers), had not been able to open her seat belt and was blocked by the back of her seat, which was tilted over onto her.

A woman travelling in seat 10B who, according to her husband, had reached the left forward door; as her body was found near that of the little girl, we can reasonably assume that she went back into the cabin to help the little girl and was overcome by the fumes.

2. Fire Penetration Mechanism

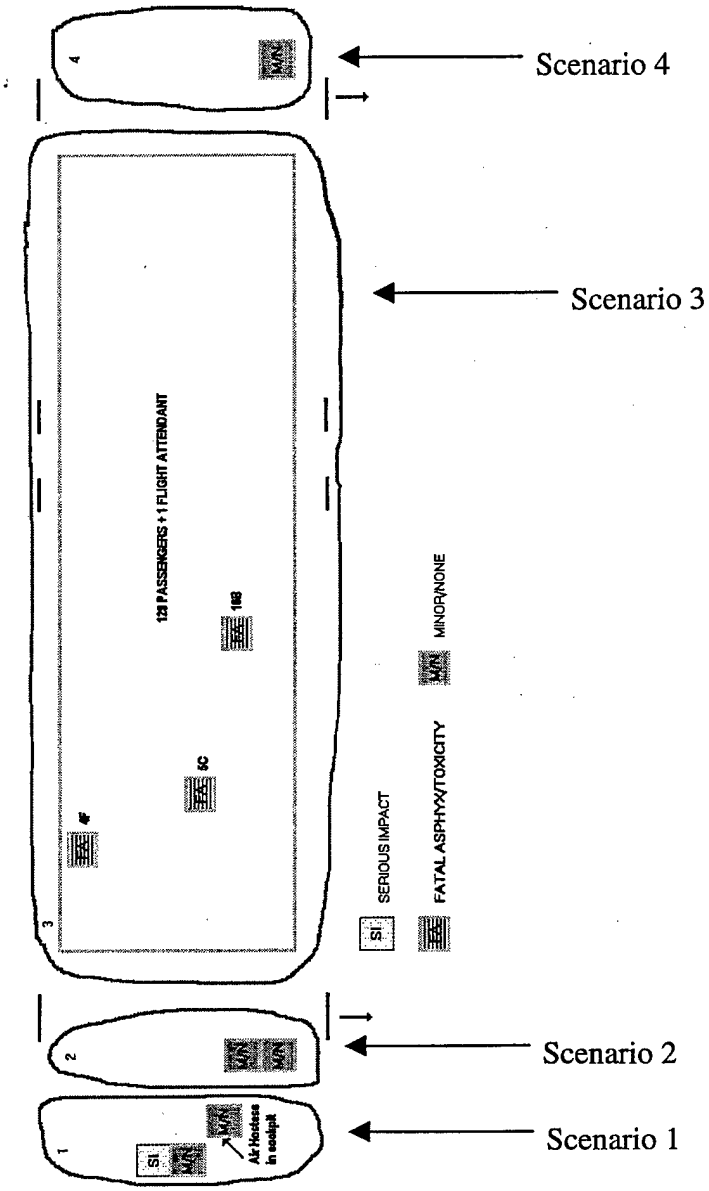
As the right wing broke, fuel was projected forward and fire immediately broke out and penetrated the cabin as soon as the aircraft came to rest. Burnthrough is therefore assumed to be initially from the right side.

Fuel flowed under the cabin and as a result fire also raged around the left wing. It can be assumed that the pool fire under the cabin centre section and left wing root would have added to the initial burnthrough on the right side.

The fuselage was found completely burnt out and this is taken to mean that the fuselage skin had been consumed by the fire mainly after the evacuation had taken place.

Based on the above it is assessed that the prime burnthrough route was through the fuselage skin on the right side. However there was insufficient information to be conclusive about detailed burnthrough areas.

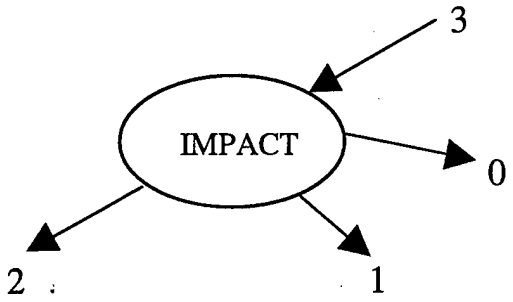
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

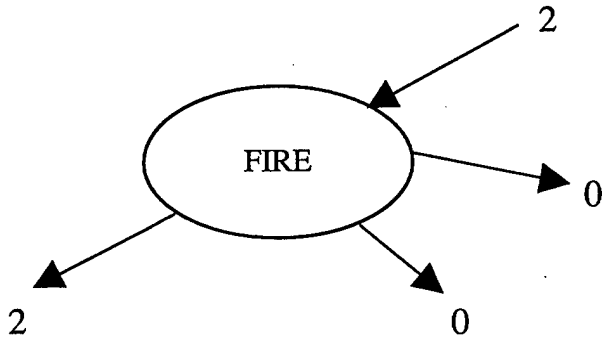
This accident is divided into four separate scenarios:

Scenario 1 contains the flight deck area. It was the area furthest from the point of entry of the fire and the only injury was to the first officer during the impact. The scenario contains the two flight crew and an observer air hostess.



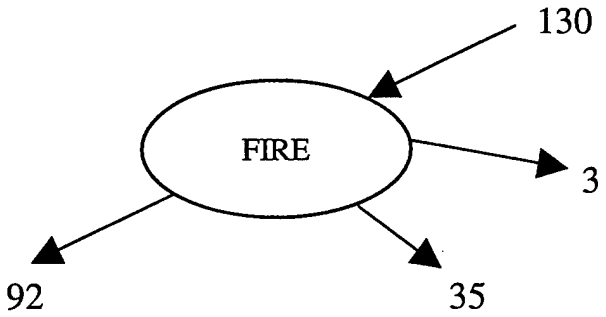
SCENARIO 1

Scenario 2 contains the forward flight attendant area. The flight attendants were seated rearward facing and they both survived uninjured.



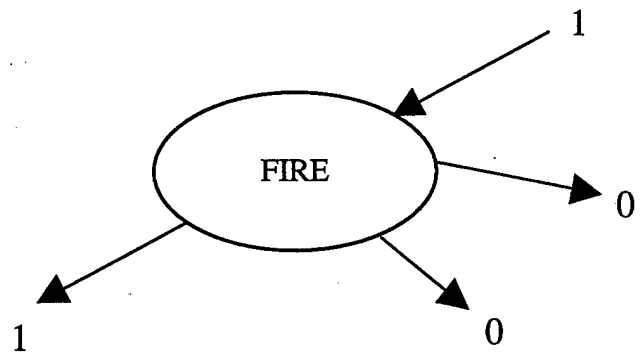
SCENARIO 2

Scenario 3 contains the main passenger cabin in which there were 129 passengers and a flight attendant in 12D.



SCENARIO 3

Scenario 4 contains the rear flight attendant area where there was one flight attendant who escaped uninjured.

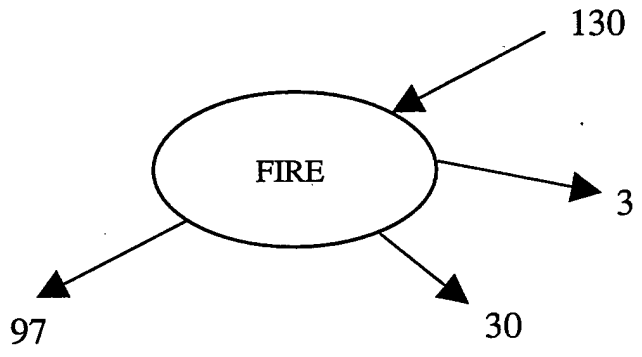


SCENARIO 4

5. Effect of Later Requirements

It is assumed that seat blocking would have been fitted on an aircraft of this age. Further there was no mention of passenger disorientation so no benefit was assumed for floor proximity lighting. It was, however, assumed that later requirements on material heat release would have saved some serious injuries in Scenario 3.

It is therefore assessed that the survivability chain for Scenario 3 becomes:



SCENARIO 3

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as injuries were related to the impact.

Scenario 2

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 2 as there were no injuries.

Scenario 3

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and provided occupants with additional time to go back and assist some of the remaining passengers to safety.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	92	35	3
M	97	31	2
L	99	30	1

For 2 minutes protection:

	S	I	F
H	92	35	3
M	102	27	1
L	107	23	0

For 4 minutes protection:

	S	I	F
H	92	35	3
M	109	21	0
L	122	8	0

For 8 minutes protection:

	S	I	F
H	92	35	3
M	113	17	0
L	130	0	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	97	30	3
M	102	26	2
L	104	25	1

For 2 minutes protection:

	S	I	F
H	97	30	3
M	104	25	1
L	110	20	0

For 4 minutes protection:

	S	I	F
H	97	30	3
M	112	17	1
L	126	4	0

For 8 minutes protection:

	S	I	F
H	97	30	3
M	115	15	0
L	130	0	0

Scenario 4

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 4 as there were no injuries.

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	1	1
2 minutes	2	2
4 minutes	3	2
8 minutes	3	3

AIRCRAFT:	**B727**	**DATE OF ACCIDENT:**	**31st August '88**
REGISTRATION:	**N473DA**	**LOCATION OF ACCIDENT:**	**DALLAS-FW, TEXAS**

1. Description of Accident

RESUME

On 31-Aug-88, B727-232 registered as N473DA was taking off from Dallas-Fort Worth International Airport, Texas. The slats and flaps were not properly configured and as a result the aircraft did not gain altitude after rotation.

The aeroplane struck an instrument landing system (ILS) localiser antenna array approximately 1000 feet beyond the end of the runway and came to rest about 3200 feet beyond the departure end of the runway. The flight was airborne approximately 22 seconds from lift-off to the first ground impact near the ILS localiser antenna. The aeroplane was destroyed by impact forces and the postcrash fire.

The combination of jammed left aft service door and the intense impenetrable fire trapped 12 occupants.

Of the 108 occupants aboard, 12 passengers and 2 crew members were killed by fire, 21 passengers and 5 crew members were seriously injured and 68 passengers sustained minor or no injuries.

IMPACT

The aeroplane struck the instrument landing system (ILS) localiser antenna array approximately 1000 feet beyond the end of runway 18L, and came to rest about 3200 feet beyond the departure end of the runway. The flight was airborne approximately 22 seconds from lift-off to the first ground impact near the ILS localiser antenna.

The fuselage had separated into three major sections: (1) the forward section consisted of the nose forward of fuselage station (FS)-420 [just aft of seat row 1]; (2) the centre fuselage section included the body structure between FS-420 and FS-950c [between seat rows 27 & 28]; and (3) the aft fuselage section extended from FS-950c aft to the end of the No. 2 engine tailpipe.

The forward fuselage section had rotated to the left about 45 deg. The entire lower fuselage structure sustained various degrees of tearing, buckling and general overall distortion. Some sooting was noted in the area between the first officer's side window and the separation.

The centre fuselage section came to rest right side up and was supported by the left wing and right wing centre section.

FIRE

The external fire was initiated when the right wing and tail struck the localiser antenna array. The fire intensified when the aircraft struck the lip of a depression in the terrain. Flames not only impinged on the right side of the fuselage but extended around the fuselage, heating the inboard wing area on the left side. The forward door of the aft cargo compartment was torn off at its hinges, causing a large opening in that area through which fire entered the cargo area before the aircraft came to rest. The fire burned through the floor.

Fire also entered the cabin through the aft break in the fuselage and later through a burnthrough in the centre wing box area.

The left side forward of FS-720e [between seat rows 17 & 18] showed no evidence of fire damage and all passenger windows were intact. However, the left side between FS-720e and FS-950c had sustained varying degrees of fire damage. In the general area of FS-950c, some fuselage structure had been consumed by fire.

The right side of the centre fuselage section between FS-420 and FS-950c also contained fire damage with some fuselage areas totally consumed by fire. All passenger windows on the right side were missing or melted.

The fuselage crown between FS-450 [between seat rows 2 & 3] and FS-680 [between seat rows 13 & 14] from the top of the passenger window line on the right side to the top of the Delta logo on the left side was consumed by fire. Another area of the top fuselage, between FS-720c [between seat rows 16 & 17] and FS-840 [between seat rows 21 & 22], was consumed by fire from the top of the right forward overwing emergency exit door to the fuselage centreline.

The aft fuselage section had rolled to the left and rotated counterclockwise about 45 deg. The aft fuselage skin structure between FS-950c and FS-950e [between seat rows 28 & 29] on the left side was consumed by fire. The aft fuselage skin structure on the right side between FS-950e and FS-1030 [between seat rows 31 & 32] was found laying on the ground alongside the fuselage. The centre aft fuselage section generally sustained various degrees of breakup and fire damage.

The aft cabin floor was completely consumed by fire from approximately station 950d [seat row 28] to station 1130 [just aft of seat row 36] with the exception of the passageway that led to the left-rear door at the galley. Fire damage to other components was also extensive in this area with most major interior components destroyed.

The area forward of station 950d had less severe fire damage to the floor and sidewall areas (continuing through station 740 [between seat rows 18 & 19]). As noted previously, there was a large area of burnthrough on the cabin floor from approximately station 740 to approximately station 720d [seat row 17] on the right side. From this point forward to approximately station 400 [just forward of seat row 1], fire damage to the right side of the interior was significantly more extensive than that of the left side. From station 400 forward, the cabin was free of fire damage.

Damage to ceilings, sidewalls, overhead stowage compartments, closets, etc., was closely correlated to areas of floor and fuselage burnthrough. From station 400 aft, no ceiling panels were in place including areas where the fuselage crown was present as well as the areas that were burned through.

All floor exit level door liners were found. The aft right exit had only the lower portion of the liner present from approximately the top of the escape slide container downward. It was heavily sooted and showed some signs of melting. The aft left door liner was essentially intact with heavy charring and melting over the upper third of the surface. Both of the left and right forward door liners were free of fire damage. The liner on the ventral door was destroyed by fire.

Sidewalls were intact on the left side of the forward cabin from station 380 [forward edge of starboard service door] to the area of the overwing exit. Many of these panels were melted at the upper portion above the window, but were in place and otherwise intact. Sidewall panels on the right side of the cabin in this zone were completely destroyed. Small portions of other right side wall panels were present near the floor toward the aft part of the cabin. Two sidewall panels on the left side at approximately stations 950b and c (immediately forward of the separation in the aft fuselage) were relatively free of fire damage but were heavily sooted.

From station 380 to station 760 [between seat rows 19 & 20] on the left side, there were some large remnants of overhead stowage units hanging from the structure. These were extensively burned and melted, however, they were recognisable as overhead stowage units. No other overhead stowage units were present.

In most areas of the cabin wherever the sidewall and/or ceiling panels were destroyed, the thermal insulation was also destroyed. The following exceptions were noted:

In the aft right corner of the cabin in the sidewall area just forward of and adjacent to the last row of seats.

Some small areas over the overhead stowage bin area along the left side of the cabin between station 380 and 950.

A few sidewall areas on the right side of the cabin near station 720.

The last row triple seats (right side) showed frame burn through and residual cushion fire blocking layer. Up to and including row 28, all seats were missing, with the exception of the triple seat in row 30 left side, which had some cushion fire blocking layer remaining, along with some seat frame structure burnthrough on the seat back cushions. Rows 23 through 26 (right side) were heavily fire damaged, but some cushion fire blocking layer remained. The seat back cushions on 23E, 24E, and 26D were burned through. Seats 27D, E, and F were severely damaged and its common frame was twisted and displaced several feet rearward from the proper position. Rows 26 and 27 (left side) had fire blocking layer present (frame intact), with the exception of seat back 26C which was totally destroyed by fire. Row 25 (left side) was missing (possibly falling down into the hole of the floor area). Rows 23 and 24 (left side) had fire blocking layer remaining, except for row 24A, B, and C, in which the seat back frame were

totally destroyed by fire. Seats 22B and C sustained severe damage to the seat bottoms. The remaining seats in rows 20 through 22 (left side) sustained fire damage to the seat backs, burning through the seat back frame, but the seat bottom cushions in this area had some fire blocking remaining. Rows 20 through 22 (right side) sustained fire damage to the seat back frame with some fire blocking layer remaining, except for row 20, which was pitched forward and bent up on the frame bottom.

Rows 15 through 19 (right side) sustained severe fire damage, with no fire blocking layer remaining. Rows 10 through 14 (right side) were destroyed by fire. Rows 10 through 19 (left side) had some fire blocking layer remaining on the seat back and bottom cushions, with the exception of rows 15 and 17, which sustained lesser amounts of fire damage.

In the first class section, seat row 1 (left and right sides) was intact with little fire damage. Row 2 (left side) had some fire damage to the seat back and bottom cushions with some fire blocking layer remaining. Seats 3A and B were twisted with some fire damage. Seats 4A and B were fire damaged with some cushion fire blocking layer remaining on the seat bottom. Row 3 (right side) was totally destroyed by fire. Row 4 (right side) was missing.

A number of lives were saved by the use of the fireblocking layer on the passenger seats. An exact number of additional survivors could not be determined.

The fire services arrived within 5 minutes of notification, the fire was knocked down within 5 minutes and extinguished in about 40 minutes.

EVACUATION

There were 3 flight crew, 4 cabin crew and 101 passengers aboard.

The investigation found that although the fuselage had separated in several places, the occupiable volume of the cabin was not substantially compromised. Passengers generally stated that impact forces were not severe. Further, the cause of deaths of the passengers in the aft section of the cabin were attributed to smoke inhalation and fire rather than impact injuries. Exit from the aft cabin was hampered by the fire that impinged on the right side of the aeroplane. Exit from the mid and forward cabin was through breaks in the fuselage and through the left side exits, except for the left aft service door which was not opened.

The right forward exit door was lodged in the wreckage. The main entry door (left forward) was open and wedged under the forward fuselage section.

Both overwing exit hatches on the left side were open. The hatch from the forward exit was found inside the cabin and the hatch from the rear exit was found outside the aircraft.

The right side rear overwing exit hatch was not opened, the hatch from the forward right side was found in the cabin.

The rear floor level exit on the right hand side was found not opened.

The left aft service door could not be opened due to deformation of the door frame which resulted from the aeroplane's repeated impacts with the ground.

A flight attendant, while attempting to open the left aft service door, stowed the girt bar on the door as per Delta's flight attendant training procedures which address the difficulty in opening a door following a gear-up landing.

It would have been unlikely for any one person of average strength to open the left aft service door under the circumstances existing at the time of the attempted evacuation.

The aft airstair was not usable because the aircraft was resting on its fuselage and the airstairs could not be lowered. Also the rear pressure bulkhead door to the tailcone was jammed closed due to impact damage.

AIRCRAFT FACTORS

The B727-232 was configured for a three person flightcrew and 149 passengers. The passenger cabin was configured with 12 first class passenger seats and 137 tourist class seats. A double occupancy aft facing flight attendant seat was on the aft left side of the cockpit rear bulkhead; a double occupancy forward facing flight attendant seat was located on the central airstairs door. A single flight attendant seat was in row 32.

The aircraft was delivered to Delta Air Lines in November 1973 in a passenger configuration. It was serial number 20750, line number 992. Fire blocking layers were fitted to passenger seats. This was the first survivable accident following the implementation of floor proximity and fire blocking rules. It can therefore be assumed that floor proximity lighting was also fitted.

The aircraft had a total of four floor level exits and four overwing emergency exits and a ventral stairway exit.

ENVIRONMENTAL CONDITIONS

The weather conditions at the time of the accident were: visibility 10 miles, wind 100 deg at 8 knots and temperature 22C.

INJURIES TO OCCUPANTS

Of the 108 persons on board, 12 passengers and two crewmembers were killed, 21 passengers and five crewmembers were seriously injured, and 68 passengers sustained minor or no injuries.

The cause of death of the 11 passengers and the two flight attendants was determined to be smoke inhalation. Levels of carboxyhemoglobin (COHb) ranged from 15 to 81 percent. Tests for drugs and ethanol were negative in all 13 persons. A 14th fatality was a passenger who had successfully evacuated but later attempted to re-enter the burning aeroplane. This passenger died of severe burns, 11 days after the accident.

2. Fire Penetration Mechanism

The fuselage broke into three main sections; the front, mid, and rear with significant breaks between them. These inter-section breaks were large enough to facilitate passenger egress from the wreckage during the evacuation.

For the front section, fire entered through the inter-section break.

For the midsection, fire was present along the whole of the right side and also extended round, under the fuselage and heated the inboard wing area on the left side. Fire entered through the inter-section breaks at either end and later burnt through in the centre wing box area, presumably as a result of the pool fire underneath.

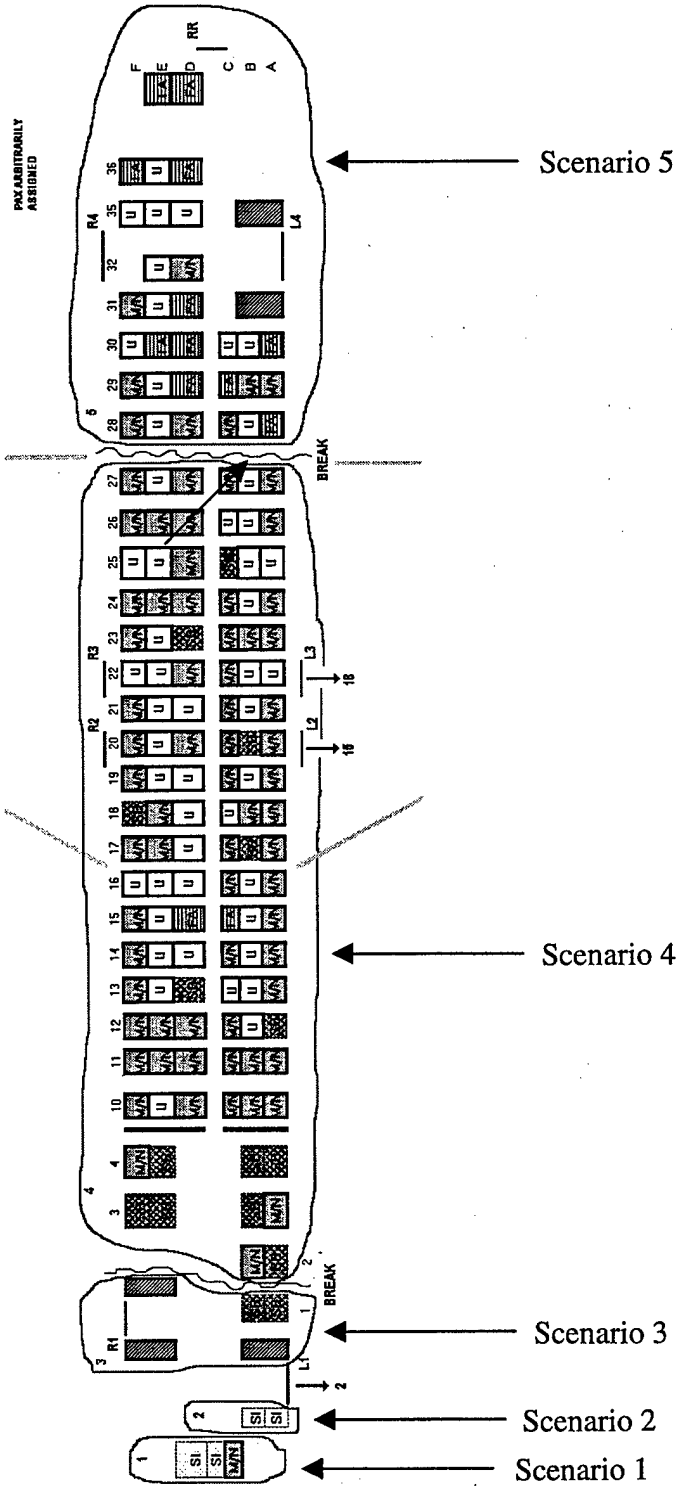
For the rear section, fire entered the rear cargo area when the external door was torn off at its hinges. This fire propagated into the cabin by burning through the floor.

The accident report stated that a number of lives were considered as being saved by the use of the fire-blocking layer on passenger seats. An exact number of additional survivors could not be determined.

The fire services arrived within 5 minutes of notification; the fire was knocked down within 5 minutes and extinguished in about 40 minutes.

Based on the above it is assessed that the prime burnthrough route was in the midsection lower fuselage skin in the wing box area. However there was insufficient information to be conclusive about detail burnthrough areas.

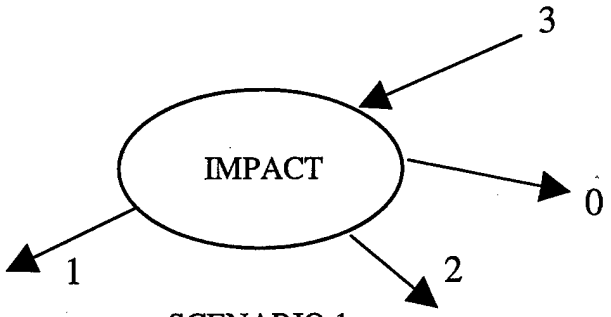
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

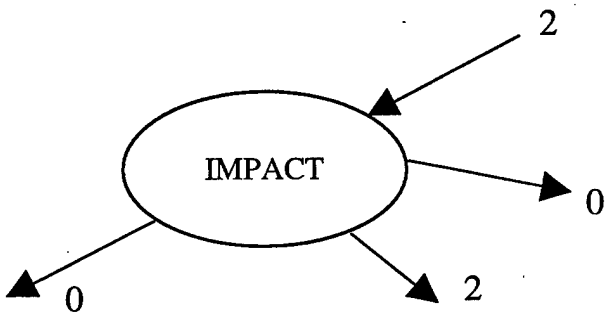
This accident is divided into five separate scenarios.

Scenario 1 contains the flight deck area. It was subjected to the initial impact, which was not severe, and was not fire damaged. The scenario contains the three flight crew.



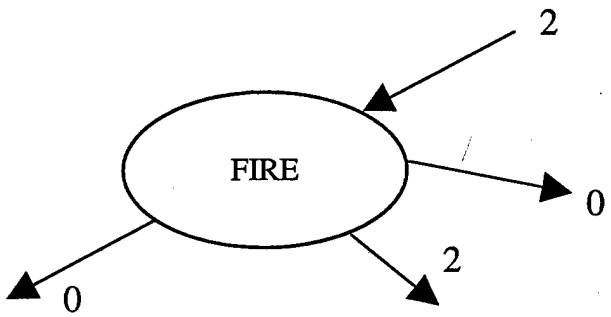
SCENARIO 1

Scenario 2 contains the forward flight attendant vestibule area. It was subjected to the initial impact, which was not severe but was not fire damaged. The scenario contains two flight attendants who both left the aircraft through the L1 exit.



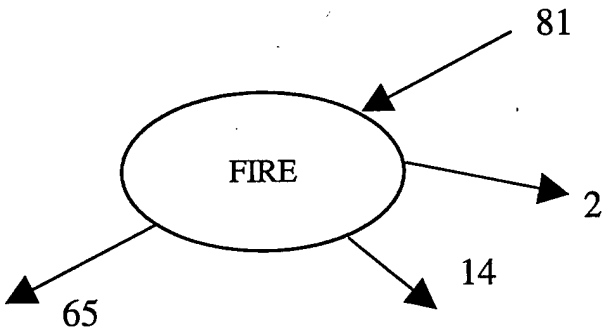
SCENARIO 2

Scenario 3 contains the front part of passenger cabin from the galleys to the inter-section break just aft of row 1. All injuries were sustained in the postcrash fire. Both occupants exited through the break in the wreckage.



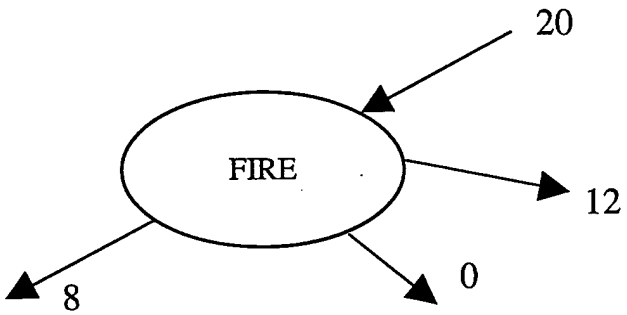
SCENARIO 3

Scenario 4 contains the passenger cabin from the front fuselage break just in front of seat row 2 to the rear fuselage break at seat row 27 inclusive. All injuries were sustained from the external fire which entered the cabin through the breaks in each end and by way of a burnthrough from underneath the centre wing box area. The two overwing exits L2 and L3 were available for egress along with fuselage breaks.



SCENARIO 4

Scenario 5 contains the passenger cabin from the rear fuselage break at seat row 28 to the rear of the cabin. All injuries were sustained from the postcrash fire which entered the cabin by burning through the cabin floor from the cargo area where the cargo door had been torn off. All survivors exited through fuselage breaks.



SCENARIO 5

5. Effect of Later Requirements

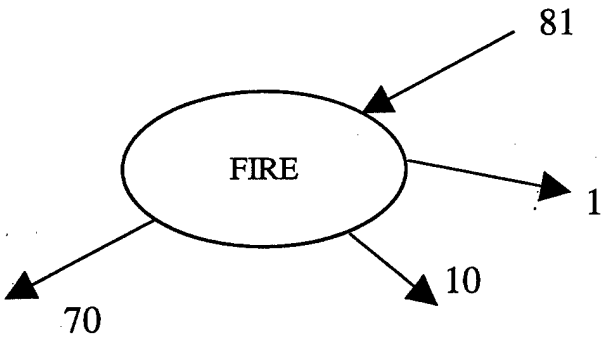
The aircraft seats were fitted with fire-blocking layers.

It is assumed that later requirements would not have affected the situation in Scenarios 1 and 2 in which all injuries were related to impact forces.

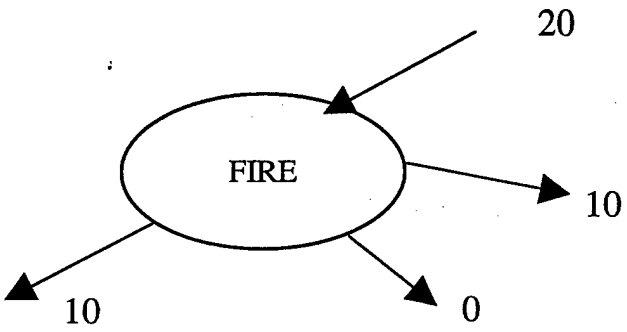
It is assessed that later requirements would have improved flammability standards such that the occupants would have had additional time to escape. Bearing in mind that fire was also entering directly through fuselage breaks, the additional time would have been modest.

In Scenario 3, the fire injuries were seated immediately next to the break (and fire) and so improved flammability standards would not have prevented injury from the direct assault.

The survivability chain for Scenarios 4 and 5 therefore become:



SCENARIO 4



SCENARIO 5

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected injuries in this scenario because the cause of injury was related to impact.

Scenario 2

It is concluded that a fire-hardened fuselage would not have affected injuries in this scenario because the cause of injury was related to impact.

Scenario 3

It is concluded that a fire-hardened fuselage would not have affected injuries in this scenario because fire entered through fuselage breaks and not by burning through the fuselage skin.

Scenario 4

It is concluded that a fire-hardened fuselage would have delayed the entry of fire from the centre wing box area and provided the occupants with more time to use the available overwing exits.

However, fire also entered through breaks at either end, and it is therefore assessed that the additional time would have been modest and would not have varied with additional burnthrough protection time.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	65	14	2
M	70	10	1
L	74	7	0

For 2 minutes protection:

	S	I	F
H	65	14	2
M	70	10	1
L	74	7	0

For 4 minutes protection:

	S	I	F
H	65	14	2
M	70	10	1
L	74	7	0

For 8 minutes protection:

	S	I	F
H	65	14	2
M	70	10	1
L	74	7	0

For an aircraft configured to the standards appropriate to the latest requirements this assessment becomes:

For 30 seconds protection:

	S	I	F
H	70	10	1
M	75	6	0
L	78	3	0

For 2 minutes protection:

	S	I	F
H	70	10	1
M	75	6	0
L	78	3	0

For 4 minutes protection:

	S	I	F
H	70	10	1
M	75	6	0
L	78	3	0

For 8 minutes protection:

	S	I	F
H	70	10	1
M	75	6	0
L	78	3	0

Scenario 5

It is concluded that a fire-hardened fuselage would not have affected injuries in this scenario because fire entered through fuselage breaks and not by burning through the fuselage skin.

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	1	1
2 minutes	1	1
4 minutes	1	1
8 minutes	1	1

AIRCRAFT:	**B737**	**DATE OF ACCIDENT:**	**1st February '91**
REGISTRATION:	**N388US**	**LOCATION OF ACCIDENT:**	**LOS ANGELES, CALIFORNIA**

1. Description of Accident

RESUME

On 1-Feb-91 a Boeing 737-300 registered as N388US was landing at Los Angeles International Airport. It collided with a Fairchild Metroliner that was positioned on the same runway awaiting clearance for take-off.

The aircraft slid to the left side of the runway and into an unoccupied fire station whereupon a fire broke out. An evacuation took place but 20 passengers and 2 crewmembers were fatally injured.

IMPACT

The B-737 remained largely intact as a result of the collision with the Metroliner. The aircraft veered off the runway and into an unoccupied fire station building.

The only parts of the B-737 that separated from the aircraft were the nose cone, nose gear doors and left pitot tube. The impact with the building destroyed the cockpit and damaged the left engine and an area of the left wing leading edge. The top and left sides of the cockpit were crushed inward, and the forward section of the cockpit on the captain's side was crushed in, down, and to the right. Both forward cockpit windshields were cracked. Several propeller slashes were on the lower right side of the B-737 fuselage skin in the area of the forward galley door.

No fuel tank rupture or leakage from the wing or centre tanks of the B-737 was observed. The fuel which was on fire came from the ruptured fuel cells of the Metroliner which was found crushed underneath the B-737.

Several passengers noted that the landing appeared to be routine; however, within a few seconds of touchdown they recalled feeling the aeroplane, move up and down, consistent with heavy brake applications. They noticed 'an orange glow' through the cabin windows on both sides of the aeroplane; flight attendants were heard yelling repeated commands 'get down, stay down'. After the impact with the building, the flight attendants commanded the passengers to release their seatbelts. The two rear flight attendants and several passengers had unbuckled their seatbelts after the first impact and were thrown forward when the aeroplane struck the building.

The R1 flight attendant stated that the 'touchdown felt normal' and that shortly thereafter 'I heard a big metal scrape, and felt like they slammed the brakes real hard'. Within 2 or 3 seconds, the emergency lights came on and he began to shout commands, 'grab ankles, heads down, stay down'. He saw the floor in front of him moving up and down about knee high.

FIRE

After the first impact, and while the aeroplane was still moving, the R1 flight attendant noted that the cabin became 'really warm', and he observed smoke coming from underneath the floor in front of him. He also remembered seeing smoke and fire on top of the valet closet in front of him. He described the smoke as 'very thick'.

On the right side of the fuselage there were a number of small holes burnt through in the lower quadrant and a large hole had burnt through in the lower belly area.

In the forward cargo compartment, the cargo liner on the left side had very little heat damage whereas the right forward corner had heavy fire damage. There was slight fire damage to the cargo liners, the cabin floor, cargo compartment floor and some structure in the area. This area also housed the crew oxygen cylinder, which was found loose. The cylinder contained heavy amounts of soot, except for the area of an attaching strap. The pressure gauge and regulator were extensively fire damaged, and the overpressure and supply lines were broken.

The fire fighters were able to control the fire under the aircraft but fire continued in the cabin.

An area of the top of the B-737's fuselage burnt through in the forward cabin between the first class and coach sections. This burnthrough was from the inside out. Interior fire damage in this area was extensive.

The top of the fuselage was also burned away from just aft of the wing to the aft doors. The fuselage along the floor beams was still attached aft of the wing so eventually the entire tail section drooped to the ground. At this time the fire fighters were able to advance into the cabin and extinguish all remaining fires.

The forward passenger door (L1) was jammed shut, and the lower half of the door was displaced inward approximately 6 inches. There was no fire damage to the exterior of the door. The forward service door (R1) was open. The door was structurally intact, but its interior had sustained significant fire and heat damage. The exterior of the door contained soot near its bottom forward side. The aft passenger door (L3) was open, and both sides of the door were fire damaged. The aft service door (R3) was open. There was no soot on the interior surface of the door, and minor amounts of soot were evident on the exterior.

The most extensive interior fire damage was in the rear of the cabin. All interior materials located at 4 feet or higher were destroyed by the interior fire. The carpet was intact throughout the cabin with the exception of the first class section. The cabin seats contained fire blocking material with Poly-Benizol Iomedizal (PBI). Floor proximity emergency lights were installed in the cabin and based on survivor's statements they functioned during the evacuation. All of the overhead baggage compartments were found detached and melted onto the seats.

EVACUATION

There were 2 flight crew, 4 cabin crew and 83 passengers aboard. The cabin layout had 128 passenger seats.

As the aeroplane struck the abandoned fire station and stopped, the R1 flight attendant departed his jumpseat and went to his exit door. After assessing the area outside the door for fire, he rotated the handle to the open position and attempted to open the door. During this time he said that the smoke got so bad that he could no longer see anything. After forcing the door, he was able to open it about 12 inches and shortly thereafter he was able to open it fully. At that point, a passenger was standing by the door, and he pushed the passenger out of the aeroplane. The distance from the door sill to the ground was about 5 feet. Another passenger then passed the R1 flight attendant and jumped out. The flight attendant then attempted to enter the cabin near row 1; however, the smoke and flames were too intense. Returning to the R1 door, he jumped to the ground.

Several passengers who had been seated in the coach cabin between rows 4 and 13, escaped via the two overwing emergency exits and the R3 service door. Because of the fire, only two passengers were able to escape from the left overwing emergency exit. They crawled along the left wing and jumped from the leading edge of the wing to the ground.

About 37 passengers escaped via the right overwing emergency exit. Their egress was hampered by the passenger seated in seat 10-F who stated that she was very frightened and 'froze', and was unable to leave her seat or open the window exit next to her. The male passenger seated in 11-D climbed over the 10-E seatback and opened the overwing exit; he pushed the passenger seated in 10-F out the window and onto the wing and then followed her. During the subsequent evacuation through the right overwing exit, two male passengers had an altercation at the open exit that lasted several seconds.

The outboard seatback at 10-F adjacent to the right overwing exit was found folded forward after the accident blocking approximately 25 percent of the exit opening. The retaining bolt at the seat's pivot point was sheared. The timing of this occurrence could not be determined.

Passengers who escaped by the right overwing exit made their way across the right wing and slid down the extended flaps. They were directed away from the aeroplane by flight attendants and fire fighters who, they estimated, arrived on scene 1 to 2 minutes after the B-737 struck the abandoned fire station.

Passengers seated around row 10 stated that prior to departure the flight attendant assigned to the R1 position conducted a special oral briefing for the persons seated in and around row 10. Passengers stated that the instructions provided by the R1 flight attendant aided in their evacuation.

Fifteen passengers seated aft of the overwing area who made their way to the rear of the cabin reported using the emergency floor path lighting. All of the passengers stated that the cabin filled with thick black smoke within seconds of the impact with the building.

The L3 flight attendant stated that she slightly opened her door without difficulty before impact with the building; however, the outside of the door was ablaze so she closed the door. She had taken about two steps into the cabin when the building was struck. She did not return to the door. After the final impact, she attempted to make her way to the overwing exits in accordance

with company procedure. Because of the number of passengers moving aft, she was only able to advance forward to the seats at rows 19 and 20 on the left. From there, she directed the passengers to the rear of the cabin.

After the final impact, the flight attendant who was assigned to the R3 door opened the door, deploying the emergency slide, and evacuated about 15 passengers. He then exited and directed passengers away from the aeroplane.

Four of the six exits were used during the emergency evacuation: the R1 forward service door, and left and right overwing emergency exits, and the R3 service door. The L1 exit was damaged subsequent to the secondary impact with the abandoned fire station. The L3 exit was opened by the L3 flight attendant during the slide to a stop between the first and second impacts; however, because of flames along the left side of the aeroplane, she stated that she closed the door and elected not to use it thereafter. Investigators found the door open with the slide deployed. It was determined that ARFF personnel had opened the door well after the accident.

The R1 slide pack did not deploy. It was found below the door in an area where the floor was burned away. The postcrash examination of the girt bar and its two retaining brackets revealed that the bolts that secured the retaining brackets to the floor on the inboard side of the door were bisected (sheared off at floor level). The R3 slide pack deployed as designed when the door was opened by the R3 flight attendant to initiate the emergency evacuation.

AIRCRAFT FACTORS

The aircraft was a B737-300 registered as N388US operated by USAir.

The aircraft was fitted with two doors at the front and two doors at the rear of the passenger cabin. In addition there was an overwing emergency exit above each wing.

The aircraft was manufactured in 1985. Although the interior was partially refurbished in 1989, most of the interior panel were from state-of-the-art materials at the time of original aircraft manufacture. The cabin seats contained fire blocking material with Poly-Benizol Iomedizal (PBI). Floor proximity emergency lights were installed in the cabin.

The cabin configuration was predominantly 3 abreast either side of a central isle. The total passenger capacity was 128.

ENVIRONMENTAL CONDITIONS

The accident happened at night with a visibility of 15 miles. Wind was 260 deg at 6 knots and the temperature was 14C.

INJURIES TO OCCUPANTS

Of the 89 persons aboard the B-737, 20 passengers, one flight attendant and the captain were fatally injured. Autopsies of the 19 passengers and one flight attendant who were removed from the wreckage revealed that they died of asphyxia due to smoke inhalation. One person who evacuated the aeroplane died as a result of thermal burns a few days later. The captain

succumbed to multiple traumatic injuries. In addition, one passenger died of thermal burn injuries 31 days after the accident.

2. Fire Penetration Mechanism

After the first impact and while the aircraft was still moving, the R1 flight attendant observed smoke coming from underneath the floor in front of him. As he was positioned rearward facing in the vestibule area, it is assessed that fire was coming through the floor from the cargo area. It is considered that the observed smoke appeared too quickly for a burnthrough of the fuselage skin to have occurred from the burning Metroliner underneath. It is assessed more likely that fire penetrated into the cargo area through ruptures in the lower fuselage skin.

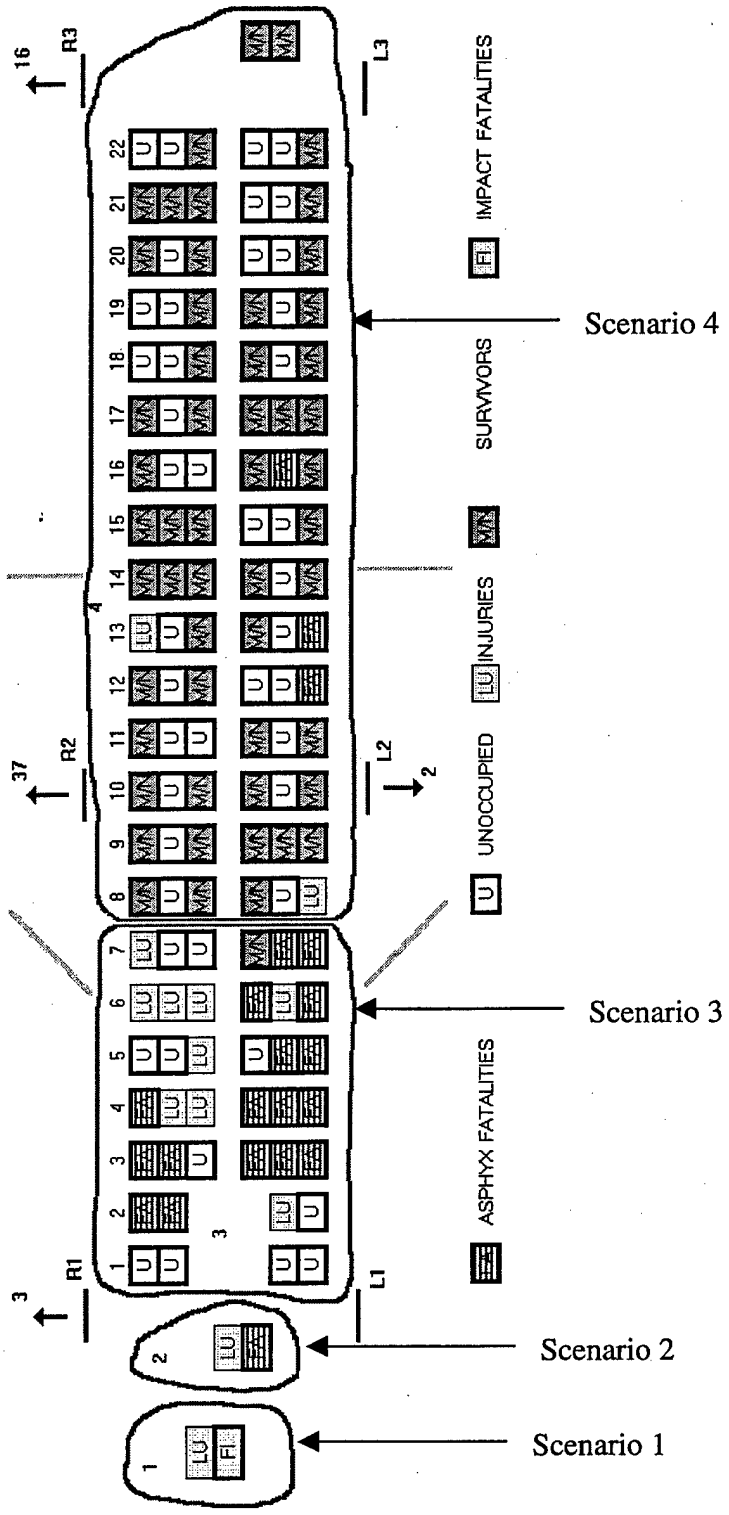
It was stated that there was little damage to the carpet along the length of the fuselage and it is therefore concluded that there was no burnthrough in the rear fuselage. However, the roof in that area burnt through from inside out; hence, it is assessed that once the fire had entered at the front, it then propagated aft along the cabin and accumulated just rear of the main wing.

On the right side of the fuselage there were a number of small holes burnt through in the lower quadrant and a large hole had burnt through in the lower belly area. It is assessed that these penetrations were insignificant compared with the main fire entry path and did not constitute a significant threat to the occupants.

The firefighters were able to control the fire under the aircraft but not the one in the cabin. Later in the sequence of events the top of the fuselage burnt through in the forward cabin area between the first- and coach-class sections from the inside out. Eighteen minutes after the accident occurred, the top of the fuselage also burned away from just aft of the wing to the aft doors which caused the entire tail section to droop to the ground and allow firefighters to advance into the cabin and extinguish all remaining fires.

Based on the above, it is assessed that the prime burnthrough route was through the fuselage lower skin; however, more significant, non-burnthrough fire entry paths were also present.

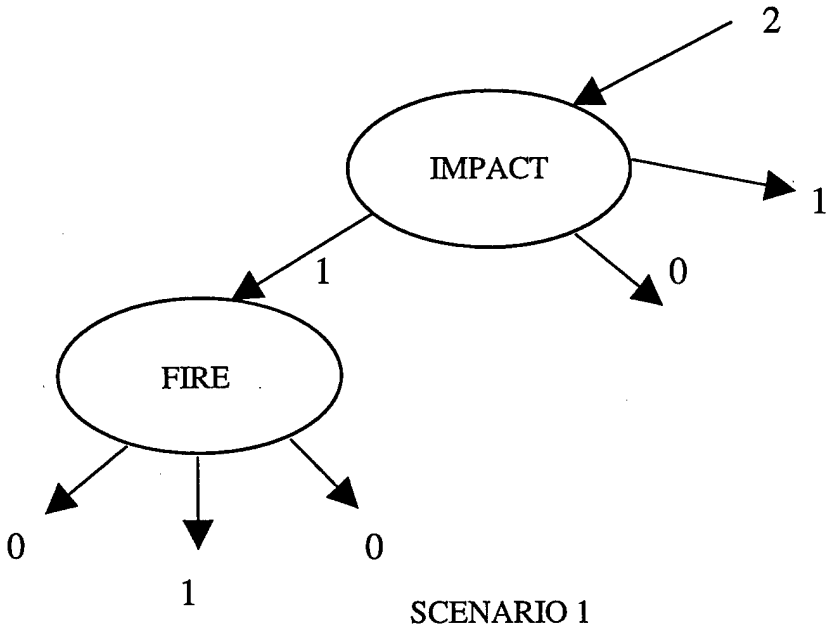
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

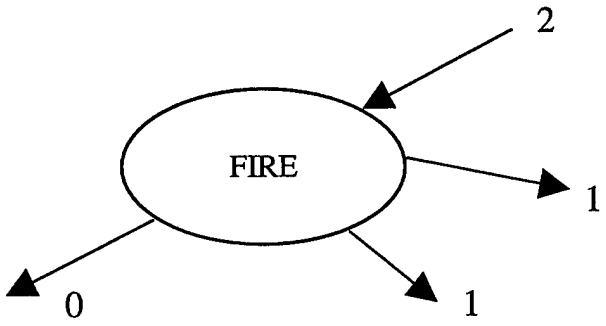
This accident is divided into four separate scenarios.

Scenario 1 contains the flight deck area. It was subjected to substantial impact damage as the aircraft impacted the fire station building and was crushed. The captain sustained multiple traumatic injuries. The unknown injury was assumed to be serious and as a result of the fire.



SCENARIO 1

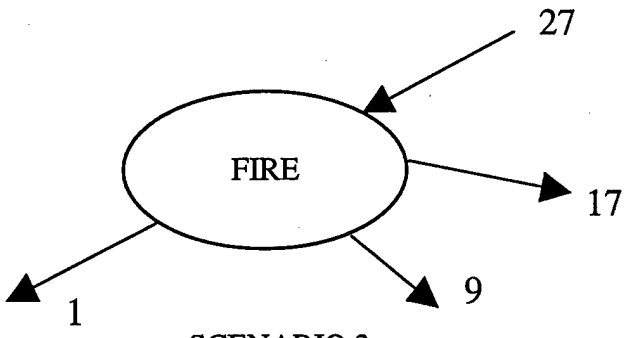
Scenario 2 contains the forward flight attendant vestibule area. This was the area in which fire first penetrated the passenger cabin. Visibility was restricted by very thick smoke. The scenario contains two flight attendants. The unknown injury was assumed to be serious and as a result of the fire.



SCENARIO 2

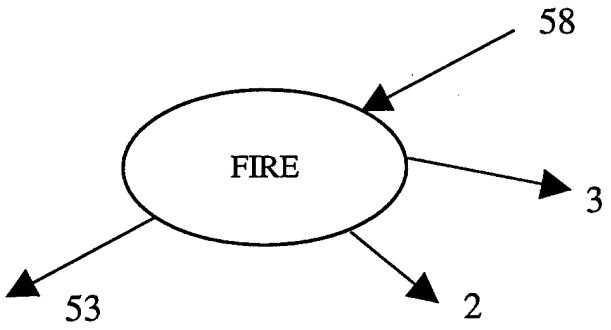
Scenario 3 contains the passenger cabin from seat row 1 in first class to row 7 in the coach section inclusive. This was subjected to dense smoke and fire and R1 & R2 were the only usable exits. It can be assumed that the smoke hindered the occupants' attempts at locating the exits

and as a result many were overcome. This scenario contains 27 passengers. The unknown injuries were assumed to be serious and as a result of the fire.



SCENARIO 3

Scenario 4 contains the passenger cabin from seat rows 8 to the rear of the cabin, including the aft cabin attendant area. This area had the longest time before smoke and fire hampered evacuation. R2, L2, and R3 exits were available for egress. The scenario contains 56 passengers and 2 flight attendants. The unknown injuries were assumed to be serious and as a result of the fire.



SCENARIO 4

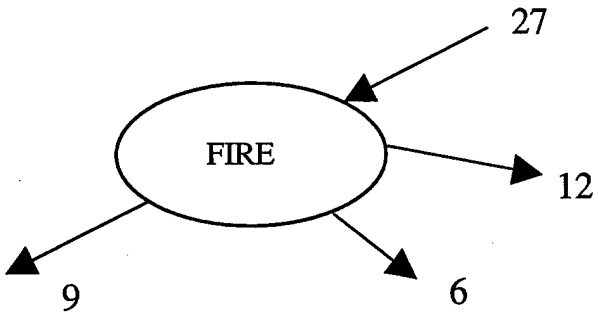
5. Effect of Later Requirements

It is assumed that there would be no change to the number of fatalities for Scenarios 1 and 2 had the aircraft been configured to the standards required by later requirements.

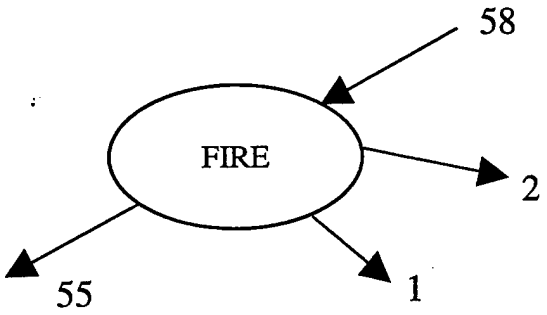
The aircraft was configured with floor proximity lighting and seat fire blocking but did not meet improved flammability standards.

Additional time would be provided to facilitate escape if the aircraft had been configured to these improved flammability standards. Furthermore improved access to Type III exits is likely to have relieved the congestion at the overwing exit. However, due to the intensity of the fire, which was most probably increased in severity by the release of oxygen, the reduction in fatalities resulting from these improvements would have been modest.

The survivability chain for Scenarios 1 and 2 are therefore unchanged, and Scenarios 3 and 4 become:



SCENARIO 3



SCENARIO 4

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected injuries in this scenario because the predominant cause of injury was impact.

Scenarios 2 and 3

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenarios 2 and 3 because it is assessed that fire entered through ruptures in the lower fuselage skin.

Scenario 4

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 4 because it is assessed that fire entered the scenario by propagating along the fuselage from Scenario 3.

Summary

It is assessed that no benefits would be gained by a fire-hardened fuselage in this accident since the prime fire entry path was through fuselage ruptures.

AIRCRAFT:	**A320**	**DATE OF ACCIDENT:**	**14th September '93**
REGISTRATION:	**D-AIPN**	**LOCATION OF ACCIDENT:**	**WARSAW**

1. Description of Accident

RESUME

On 14-Sep-1993 a Lufthansa A320 registered as D-AIPN was landing at Okecie in Warsaw, Poland.

The pilot in the left seat was subject to check but was the pilot flying at the time of the accident. The pilot in the right seat was the instructor who was in overall command of the aircraft.

Okecie tower warned the crew of windshear and so the flight crew increased the approach speed by 20 knots, in accordance with the Flight Manual. A storm front passed through aerodrome area at that time which produced a tail wind and as a result the aircraft touched down too fast. The very light touch of the runway surface with the landing gear and lack of compression of the left landing gear leg (to the extent understood by the aircraft computer as the actual landing) resulted in delayed deployment of spoilers and thrust reversers. Delay was about 9 seconds. Thus the braking commenced with delay and in a condition of heavy rain the aircraft did not stop on the runway.

The aircraft ran off the end of the runway, collided with an embankment and stopped the other side of it. The aircraft caught fire as a result of the impact.

There were 6 crew and 64 passengers aboard. 1 crew member and 1 passenger suffered fatal injuries. 2 crew and 49 passengers suffered serious injuries. 3 crew and 14 passengers escaped with minor or no injuries.

IMPACT

Okecie tower warned the crew of windshear and so the flight crew increased the approach speed by 20 knots, in accordance with the Flight Manual. A storm front passed through aerodrome area at that time which produced a tail wind of approximately 20 knots and as a combined result the aircraft touched down too fast.

After first contact of the right landing gear assembly with the runway the pilot attempted to use wheel brakes, and when they failed to work, demanded the right-seat pilot to assist.

Automatic systems of the aircraft depend on oleo strut compression and a weight-on-wheels switch to unlock the use of ground spoilers and engine thrust reversers. Only when the left landing gear touched the runway were these systems activated. As a result of the light and fast landing the operation was delayed by about 9 seconds. The systems then began to operate; the spoilers deployed to full angle (50 deg), the thrust reverser system began to work and N1 of the engines came to 71%, but the wheel brakes, depending on wheel rotation being equivalent of circumferential speed of 72 kts began to operate only after about 4 seconds.

Deceleration of the aircraft progressed in conditions of heavy rain and with a layer of water on the runway. The aircraft was decelerated with normal performance but on the last 180 metres of runway deceleration decreased by about 30%. Residual length of the runway (left from the moment when braking systems had begun to work) was too small to enable the aircraft to stop on the runway. Seeing the approaching end of runway and the embankment behind it, the pilot tried to turn the aircraft but only managed to deviate the aircraft a little to the right.

The aircraft ran off the end of runway with a speed of 72 kts and having travelled 90 metres its left wing collided with the embankment. The aircraft slid over the embankment, destroying an aerial and stopped right behind the embankment. During this stage the landing gear of the aircraft and the left engine were destroyed.

The bottom part of the fuselage up to the wing area was found significantly deformed, and broken in the wing area.

The radar dome and radar antenna were found detached from the aeroplane and destroyed.

The aft part of the fuselage, from aft doors, was found complete, with minor deformation.

The left main landing gear was detached, the wheel assembly partially burnt and no pressure was found in the tyres. The right main landing gear was partially detached from the fuselage fittings but otherwise complete. Wheels and tyres were not damaged. The front landing gear detached from the fuselage but the wheels and tyres were not damaged.

FIRE

In the collision of the aircraft with the embankment and with the aerial located on it, the fuel tanks of the aircraft were broken and the fuel began to spill on the left side of fuselage. It was most probably ignited because of contact with hot parts of the damaged left engine or with the electrical system of the aerial. It caused a fire on the left wing. The fire spread onto an area of about 600 square metres. Shortly the fire penetrated into passenger cabin, creating smoke at first, and later filling the whole cabin. In 3 minutes from the emergency call, 5 Aerodrome Fire Service cars came to the scene. They managed to extinguish the external fire and successfully evacuated the passengers remaining in the area of danger (and blocking access for the fire services) to a safe distance.

It was impossible to stop the fire inside the aircraft. Neither the foam introduced through the open entrance, nor the attempts to open the emergency exits on the left wing and to break into the cabin were successful. Eventually pouring foam through the broken out cockpit windows gave a positive result. After 2 minutes from the beginning of the activities on the scene, the tank in the middle part of wing blew out. For the next 30 minutes extinguishing of the burning fuselage through the hole created in the roof was continued.

15 minutes after the emergency call four cars of the national fire service came to the aircraft and entered into action.

Calculation of the residual fuel, remaining on board at the moment of impact and the amount drained from the wreckage indicates that about 2900 litres of aviation kerosene JA-1 was burnt in the fire and due to action of the high temperature of oxygen bottles about 12000 litres of oxygen was released, which obviously increased the intensity of the fire.

After the fire had been extinguished, about 6000 litres of fuel were drained from the tanks of the wreckage.

The upper part of the fuselage from the cockpit to the fin and to bottom of the passenger cabin was burnt out, including cabin furniture and equipment. The cockpit was found burnt out.

EVACUATION

There were 2 flight crew, 4 cabin crew and 64 passengers on board.

A successful evacuation of passengers, organised by the 4 cabin crew, in conditions of an aircraft fire, contributed to the rescue of 63 passengers of the 64 on board.

The front and aft passenger doors were found open with escape slides deployed.

During the landing the cabin crew were seated in two pairs, one near to the front entrance and the other near to aft entrance. Only two were available to act immediately. A stewardess from the aft pair, due to breathing difficulties, fainted after opening the door and initialisation of the escape slide and was unable to take part in the further activities, and chief steward (with injured head), who was in the front part of cabin, remained unconscious all the time during passenger evacuation. After regaining consciousness he managed to release the injured pilot blocked in the cockpit, enabling him to leave the aircraft through the open front door. But he was not able to lift the body of the instructor remaining in the cockpit.

The prompt and successful evacuation of 63 persons out of the passenger cabin during increasing smoke and intensive fire was directly due to the behaviour of the cabin crew, in spite of their injuries. The two active cabin attendants played a significant and unquestionable role preventing the panic and organising the movement of passengers to the exits.

The passenger seated in the utmost left seat in "business class" sustained a fracture of the first lumbar vertebra and of both hands. This made him probably unable to leave his seat unaided. In addition, his temporary loss of consciousness during the impact did not allow him to draw the attention of other passengers and cabin attendants.

The situation would have been significantly more severe if the injured persons needed individual direct assistance leaving the wreckage or if the type of injuries required immediate intervention, e.g. because of haemorrhage or need for reanimation. A sufficient number of ambulances did not come to the scene quickly enough and some injured were carried to the airport by casual means of transport (e.g., bus).

AIRCRAFT FACTORS

The aircraft was an A320, registered as D-AIPN and operated by Lufthansa.

The airframe was production serial number 105, manufactured in 1990 with a Certificate of Airworthiness dated 25-Apr-1990.

The aircraft carried JA-1 kerosene fuel.

At the time of the accident the tyre tread depths were low and may have been a factor in the inability of the aircraft to stop within the confines of the runway, especially in heavy rain.

The cabin was fitted with two doors at the front and two doors at the rear of the passenger cabin. In addition there were 2 overwing emergency exits over each wing.

ENVIRONMENTAL CONDITIONS

The accident happened during daylight hours in windshear conditions.

Wind was 150 deg at 12 kts. The ambient temperature was about 20C.

INJURIES TO OCCUPANTS

There were 6 crew and 64 passengers aboard. 1 crew member and 1 passenger suffered fatal injuries. 2 crew and 49 passengers suffered serious injuries. 3 crew and 14 passengers escaped with minor or no injuries.

Of the 2-person cockpit crew, the left-seat pilot survived (injured by impact) and the right-seat pilot was killed outright.

The autopsy of the body of the right-seat indicates that he was killed during the impact due to collision with cockpit interior elements. It was confirmed by extensive damage to the internal organs, namely: rupture of pericardial sac and of the main artery wall, rupture of internal membrane of aorta, perforation of the lungs with broken ribs. Presence of the carbon oxide haemoglobin or alcohol in the blood of the pilot was not stated. During examination of stomach contents and kidney neither drugs nor medicines affecting the capacity or capability to perform pilot duties were discovered.

In the blood of the fatally injured passenger 22.6% of carbonoxide haemoglobin was found, and in the opinion of the person who performed the autopsy intoxication with carbon oxide in the environment of the high temperature was the cause of the death.

The injury profile was as follows:

spine injuries	21
head injuries	8
chest injuries (broken ribs)	8
abdomen contusions	4
broken limbs	5
burns	1
other	9
Total	56

2. Fire Penetration Mechanism

When the aircraft came to a stop, spilled fuel on the left side of the fuselage ignited and spread onto an area of about 600 square metres, including the left wing. With this amount of fire impinging on the fuselage side, it is assessed that it burnt through and penetrated into the passenger cabin from the left side. Smoke was reported as appearing first and later the fire entered, eventually filling the whole cabin.

Only one surviving passenger was identified as suffering burn injury and so it is concluded that the burnthrough occurred toward the end of the evacuation time.

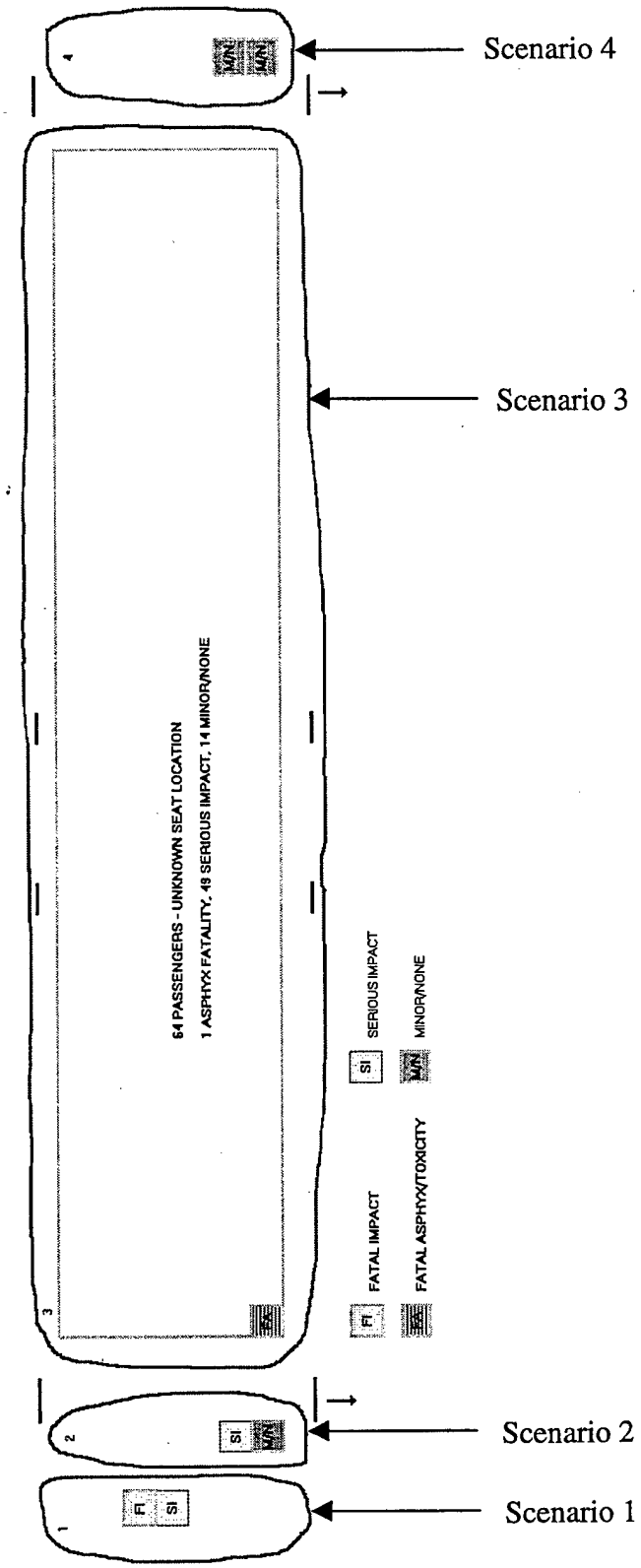
It was stated that the Aerodrome Fire Service cars came onto the accident scene approximately 3 minutes from the emergency call and moved the evacuated passengers away from the aircraft. It is therefore assessed that evacuation had been completed in 2 to 3 minutes.

One passenger was stated as having immobilising impact injuries and it is assumed that this person was the eventual fatality, being overcome by the fire.

The wreckage was described as having a hole burnt through the roof and the upper part of the fuselage burnt out. It is assumed that this was as a result of the intense internal fire burning through from the inside out and the major burning of fuselage skin would have occurred well after the evacuation was completed.

Based on the above, it is assessed that the prime burnthrough route was through the fuselage skin. However there was insufficient information to be conclusive about other burnthrough areas.

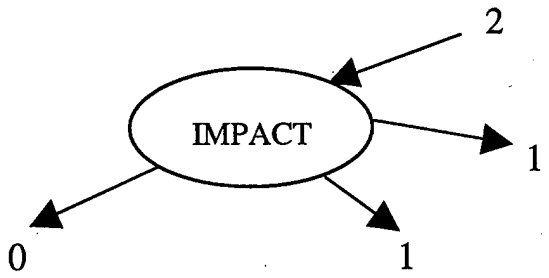
3. Location of Injuries and Scenarios



4. Accident Scenarios and Survivability Chains

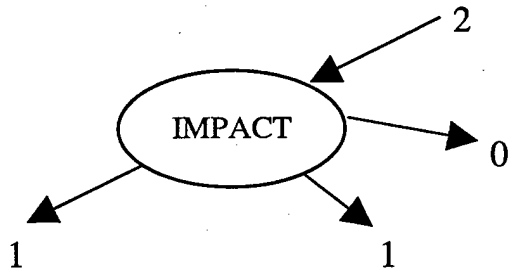
This accident is divided into four separate scenarios.

Scenario 1 contains the flight deck area where all injuries were sustained from the impact. The scenario contains the two flight crew.



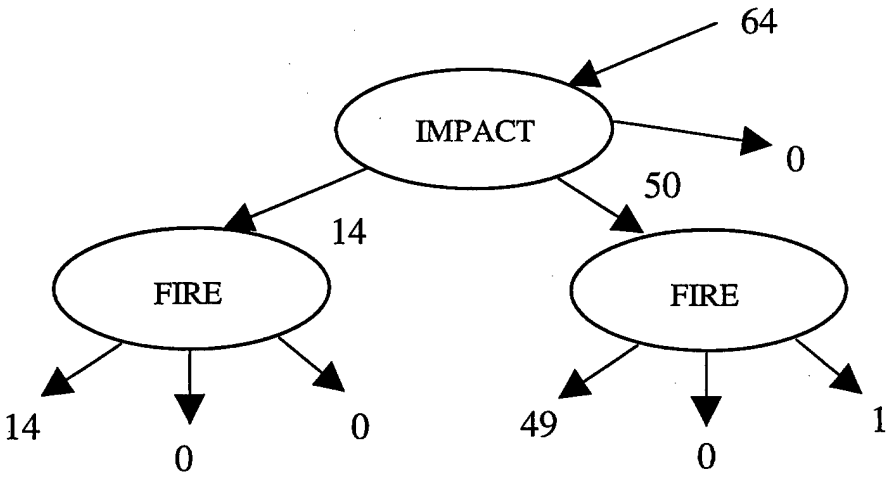
SCENARIO 1

Scenario 2 contains the forward flight attendant area where injuries were sustained from the impact. The scenario contains two flight attendants.



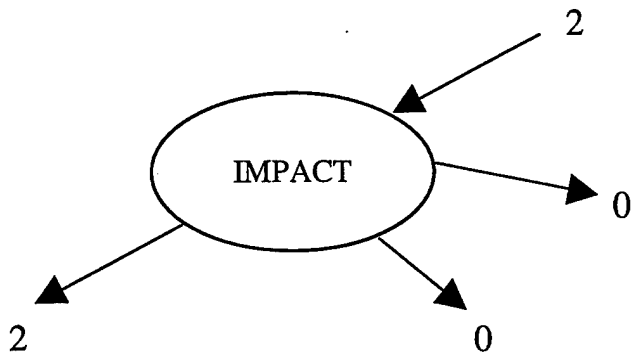
SCENARIO 2

Scenario 3 contains the whole passenger cabin. This has been used because of limited detail on passenger locations during the accident. The scenario contains all 64 passengers.



SCENARIO 3

Scenario 4 contains the rear flight attendant area where only minor injuries were sustained from the impact. The scenario contains two flight attendants.



SCENARIO 4

5. Effect of Later Requirements

The aircraft was manufactured in 1990. It is assumed that lower heat release materials had been fitted and that seat-blocking layers were already installed. Since there was only one fire fatality in this accident, any errors in these assumptions would have a minimal effect on the conclusions of this study.

It is therefore assumed that later requirements would not have affected the situation in any scenario.

6. Effect of a Fire-Hardened Fuselage

Scenario 1

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 1 as all injuries were sustained as a result of the impact.

Scenario 2

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 2 as all injuries were sustained as a result of the impact.

Scenario 3

It is concluded that a fire-hardened fuselage would have delayed the entry of fire and may have provided the passengers with additional time to go back and remove the immobilised passenger who was seated near to the forward passenger door.

The high, median, and low prediction from the use of a fire-hardened fuselage is:

For 30 seconds protection:

	S	I	F
H	14	49	1
M	14	49	1
L	14	50	0

For 2 minutes protection:

	S	I	F
H	14	49	1
M	14	49	1
L	14	50	0

For 4 minutes protection:

	S	I	F
H	14	49	1
M	14	50	0
L	14	50	0

For 8 minutes protection:

	S	I	F
H	14	49	1
M	14	50	0
L	14	50	0

Scenario 4

It is concluded that a fire-hardened fuselage would not have affected the situation in Scenario 2 as all injuries were sustained as a result of the impact.

Summary

The assessed median number of lives saved by a fire-hardened fuselage are:

Burnthrough Protection Time	Aircraft in its Actual Configuration	Aircraft Configured to Later Requirements
30 seconds	0	0
2 minutes	0	0
4 minutes	1	1
8 minutes	1	1