Safety Regulation Group

Civil Aviation Authority

CAA PAPER 2002/01

A Benefit Analysis for Enhanced Protection from Fires in Hidden Areas on Transport Aircraft

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Report prepared by R G W Cherry and Associates

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Executive Summary

The purpose of this Analysis is to evaluate the potential benefit, in terms of lives saved, from enhanced protection from fires within hidden areas in the aircraft cabin. For the purposes of this study, a "hidden area" is defined as any area inside the pressure shell, which is not readily accessible to the crew other than a dedicated cargo area.

An assessment has also been made of the benefits to be accrued as a result of enhancements to the flammability standards of Thermal Acoustic Liners attached to the fuselage skin.

The methodology of the assessment has been based on a Mathematical Risk Model. In order to validate the results of the Risk Model, a determination has been made of the number of lives that might be saved from enhanced protection from fires in hidden areas based on an analysis of past accidents.

The assessment of benefit has been based on data for the world fleet of Western-built aircraft over the period 1991 to 2000.

Based on the developed Mathematical Risk Model, it is assessed that the number of lives to be saved from enhanced protection from fires within hidden areas in the aircraft cabin would be **52** per year. The 95-percentile range is 16 to 97 lives per year.

Whilst there are limited data available on hidden fire accidents the assessment of benefit over the period 1991 to 2000, of **48** lives per year, based on an analysis of past accidents, gives confidence in the model predictions.

It is assessed that the number of lives to be saved from improvements in the flammability standards of Thermal Acoustic Liners is approximately **34** per year over the period 1991 to 2000.

1 Introduction

The purpose of this Analysis is to evaluate the potential benefit, in terms of lives saved, from enhanced protection from fires within hidden areas in the aircraft cabin. These enhancements are assumed will prevent the propagation of a fire that is driven solely by an ignition source, the materials concerned and small amounts of contamination. Hidden areas are defined as any area inside the pressure shell, which is not readily accessible to the crew, other than a dedicated cargo area.

An assessment has also been made of the likely benefit that might accrue as a result of enhancements to the flammability standards of Thermal Acoustic Liners.

The benefit has been assessed by the use of a Mathematical Risk Model. In order to validate the results of the Risk Model, a determination has also been made of the number of lives that might be saved from enhanced protection from fires in hidden areas, based on an analysis of past accidents.

2 Objectives

The objectives of the Analysis were to:

1 Derive the number of lives to be saved from enhanced protection from fires within hidden areas in the aircraft cabin.

2 Derive the number of lives to be saved from improvements in the flammability standards of Thermal Acoustic Liners.

3 Assumptions

The assumptions used in the Analysis are as follows:

1 Hidden areas are defined as any area inside the pressure shell, which is not readily accessible to the crew, other than a dedicated cargo area.

2 The enhancements to protection against fires in hidden areas will prevent the propagation of a fire that is driven solely by an ignition source, the materials concerned and small amounts of contamination, to the extent that there will be no resultant fatalities.

3 The probability, or rate of occurrence, of a hidden fire is constant for all aircraft and is constant with flight time.

4 Hidden Areas Benefit Analysis based on a Mathematical Risk Model

A Mathematical Risk Model has been developed to assess the benefit from enhanced protection from fires within hidden areas in the aircraft cabin. The Model is based on the "Monte Carlo Simulation" methodology, and utilises distributions derived from data on in-service aircraft, accidents and incidents. Monte Carlo Simulation is a method where variables are randomly chosen based on their probability of occurrence. The variables are then combined to determine the required output – in this case the lives to be saved from the enhanced protection from fires in hidden areas. By running the Model many times a distribution of the predicted lives to be saved is generated.

The overall structure of the Model and the output from each step are described in paragraph 4.1. The sources used for deriving the data used in the Model are shown in the Bibliography.

4.1 Model Structure

The structure of the model is shown in Figure 1. An explanation of each step is given in paragraphs 4.2 to 4.9.

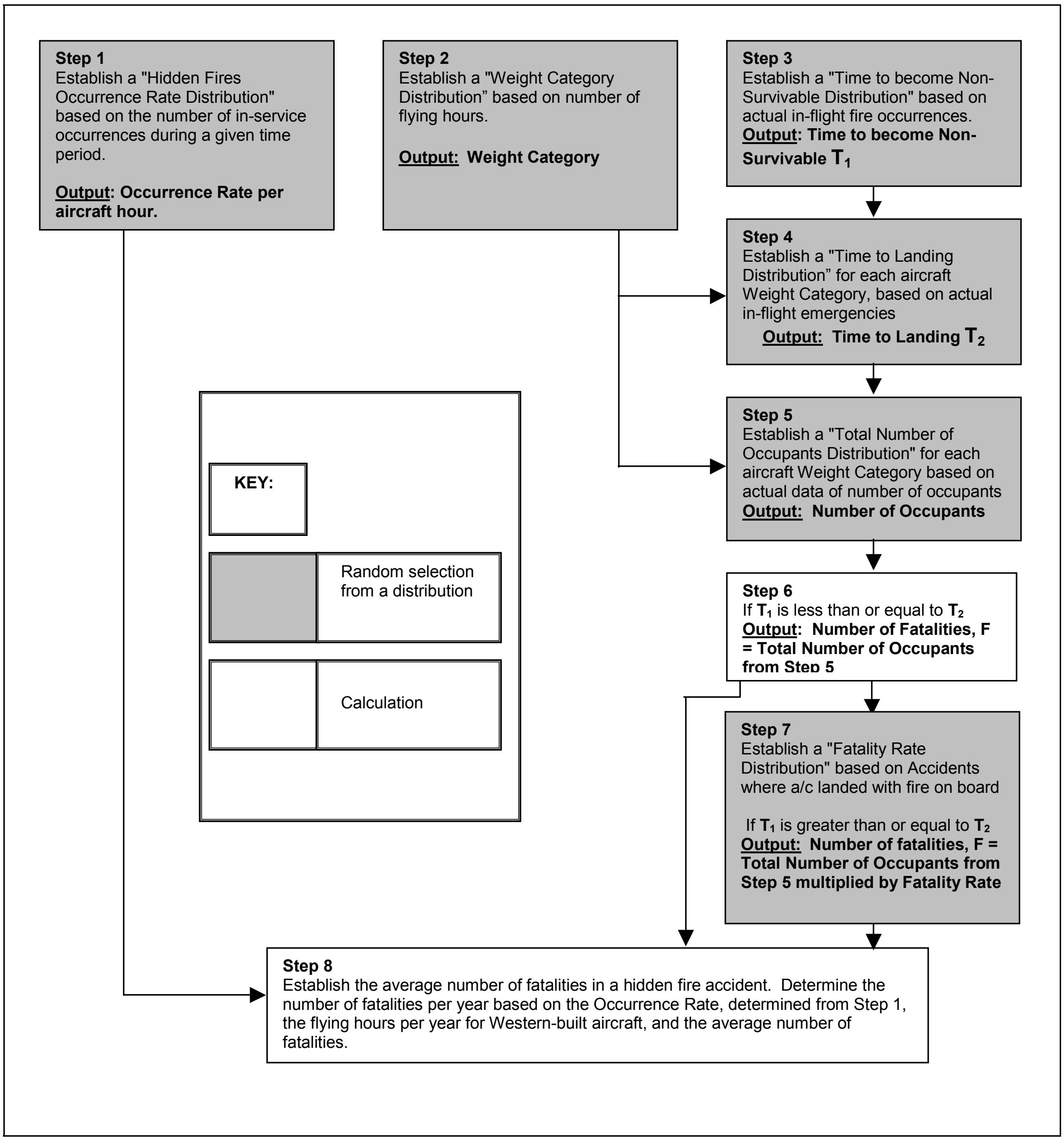

Figure 1 Model Structure

4.2 Step 1 – Hidden Fires Occurrence Rate

The selection criteria for the accidents and incidents were:

1 The accident or incident occurred during the period 1981 to 2000.

2 The accident or incident involved a hidden area fire that could not be controlled by the crew and had the potential to destroy the aircraft.

3 The aircraft involved was a passenger carrying Western-built turbojet or turboprop, which was Type Certificated for more than 30 seats.

4 The fire started at some point between the initial take-off roll and the end of the landing roll.

Many additional incidents were identified where smoke and/or fire were experienced in flight. These however either failed to propagate or were extinguished by the actions of the crew. These incidents were therefore not included since they did not meet selection criterion 2.

The accidents and incidents identified are shown in Table 1 with further details given in Appendix 1. It should be noted that Occurrence Number 8 occurred on pushback and hence does not meet criterion number 4. It is included in Table 1 since it is a significant hidden fire accident, however it has not been included in the data used for the Risk Model.

Occurrence Number	Date	Operator	Aircraft Type	Location
1	08-Aug-00	Air Tran	DC9-32	Greensboro NC, USA
2	29-Nov-00	Air Tran	DC9-32	Atlanta GA, USA
3	04-Sep-93	Dominicana	B727	Santo Domingo, Dominican Republic
4	02-Sep-98	Swiss Air	MD-11	Peggy's Cove, Nova Scotia, Canada
5	24-Nov-93	SAS	MD-87	Copenhagen, Denmark
6	17-Apr-88	Continental Airlines	B737-200	Cleveland, Ohio, USA
7	02-Jun-83	Air Canada	DC9-32	Cincinnati International Airport, USA
8	26-Nov-95	Alitalia	MD-82	Turin, Italy

Table 1 Hidden Fire-related Occurrences

Although all potential data sources were examined, it was considered possible that not all accidents and incidents that occurred prior to 1991 had been revealed. However, the data available to the analysts and the FAA was such that there was confidence that all occurrences had been revealed over the period 1991 to 2000 inclusive. Hence only accidents and incidents over this period were used in the analysis. As may be seen from Table 1, there were 5 hidden fire occurrences over this period - numbers 1 to 5 inclusive.

During the period 1991 to 2000, Western-built turboprops and turbojets are assessed to have accumulated 331,140,000 flight hours (see Appendix 2).

The suggested average rate of occurrence would therefore be 5 divided by 331,140,000 or 1.51 x 10^{-8} per flight hour. However, the actual intrinsic rate of occurrence may be different from this simply due to statistical variation. The confidence level in any rate of occurrence may be established, based on five occurrences in 331,140,000 flight hours, by using the χ^2 Distribution. This relationship between confidence level and occurrence rate is shown in Figure 2.

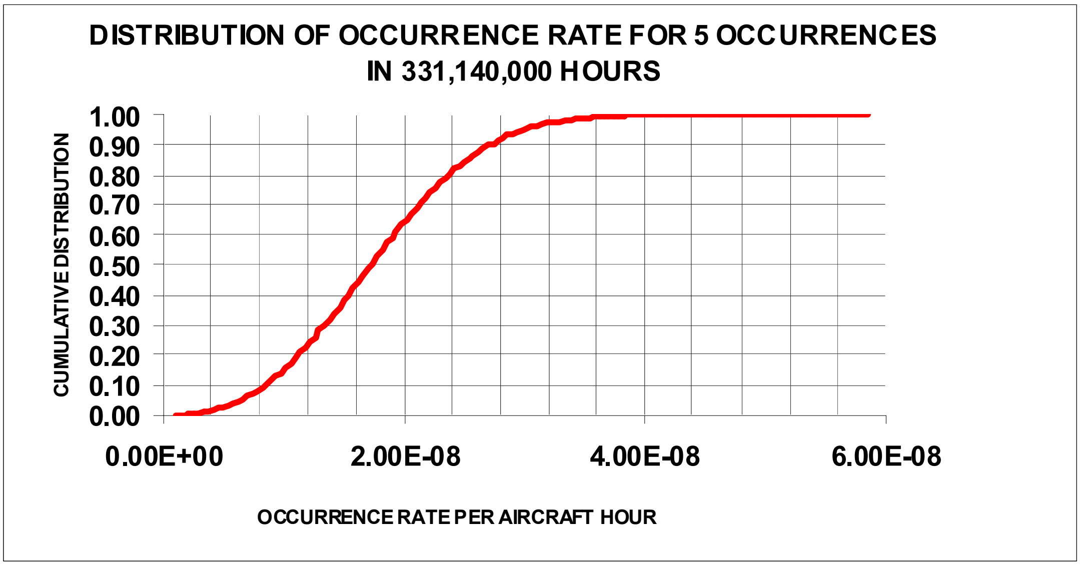

Figure 2 Distribution of Rate of Occurrence of Uncontrollable Hidden Area Fires

By way of comparison, it may be seen from Table 1 that seven of the accidents and incidents occurred during the period 1988 to 2000. During this period, it is assessed that Western-built aircraft accumulated 401 million flight hours (see Appendix 2). This equates to a rate of 1.75 x 10^{-8} per flight hour which compares favourably with the average rate of occurrence, based on the five occurrences, of 1.51 x 10^{-8} per flight hour.

4.3 **Step 2 - Weight Category**

Since, as may be seen from Figure 1, Steps 4 and 5 of the model are dependent on aircraft size, it is necessary to generate a distribution of aircraft by Weight Category (see Section 10 - Definitions) based on their relative percentage of flight hours. Based on the data contained in Appendix 2, the percentage of flight hours accumulated by Western-built aircraft during the period 1991 to 2000 were determined for each Weight Category. For Weight Category B, only aircraft that were type certificated with more than 30 seats were included in the analysis. Table 2 shows the resultant distribution of aircraft by Weight Category based on their relative percentage of flight hours.

Weight Category	Percentage of Flight Hours
B	16.8 %
C	52.3 %
D	12.4 %
E	18.5 %

Table 2 Distribution of Aircraft by Weight Category based on Flight Hours

4.4 Step 3 - Time to Become Non-Survivable - T_1

The Time to become Non-Survivable is taken from the first indication to the crew of the presence of a hidden fire, to it becoming catastrophically uncontrollable. The Time to become Non-Survivable was assessed from the data contained in the Bibliography, numbers 1, 8 and 9. Only accidents where accurate times could be established were used.

Date	Location	Aircraft type	Time to become Non-Survivable (minutes)
26-Jul-69	Biskra, Algeria	Caravelle	26
11-Jul-73	Orly, Nr. Paris, France	B707	7
03-Nov-73	Boston, USA (Cargo flight)	B707	35
26-Nov-79	Jeddah, Saudi Arabia	B707	17
02-Jun-83	Cincinnati International Airport, USA	DC9-32	19
28-Nov-87	Mauritius, Indian Ocean (Cargo flight)	B747	19
02-Sep-98	Peggy's Cove, Nova Scotia, Canada	MD-11	16

Table 3 Hidden Fires - Time to Become Non-Survivable

The data contained in Table 3 was used to generate a cumulative distribution of Times to become Non-Survivable. The Weibull Distribution was assumed since this is a three variable distribution and will approximate to other classical distributions (e.g. Normal, Log-Normal). The curve of best fit was derived which yielded the following parameters of the Weibull distribution:

γ = 0 minutes

η = 23 minutes

β = 2.1

The Weibull Distribution appropriate to these values is:

$$P = 1 - e^{-}\{\frac{T_1}{23}\}^{2.1}$$

Where P = probability of survival time T_1

And T_1 = Time to become Non-Survivable (minutes)

This distribution is shown in Figure 3.

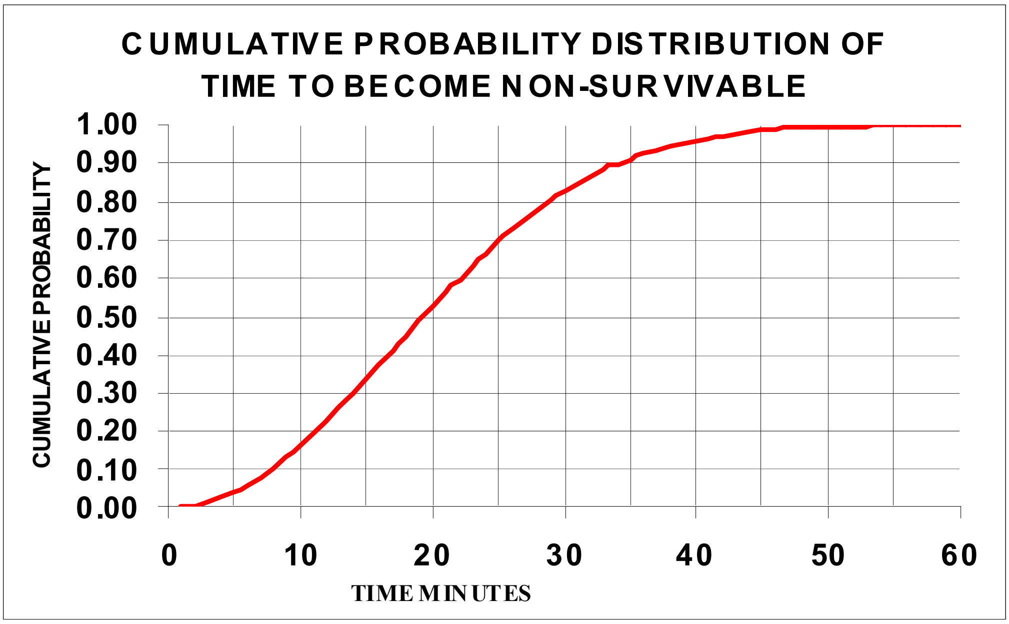

Figure 3 Cumulative Probability Distribution of Time to Become Non-Survivable

4.5 **Step 4 – Time to Landing - T_2**

The time from the crew declaring an emergency to the time of subsequent landing was determined from occurrences contained in the Bibliography, numbers 3 and 12. All emergencies were considered since the nature of the threat is not likely to significantly influence the distribution of time to landing.

Cases considered included situations where the aircraft diverted, continued on to the destination airfield, or returned to the departure airfield.

Since the distribution of Time to Landing is likely to vary significantly with aircraft size, data were collected for aircraft in Weight Categories appropriate to the determinations made in Step 2. The distributions of Times to Landing are shown in Figure 4, Figure 5, Figure 6 and Figure 7 for each of the four Weight Categories.

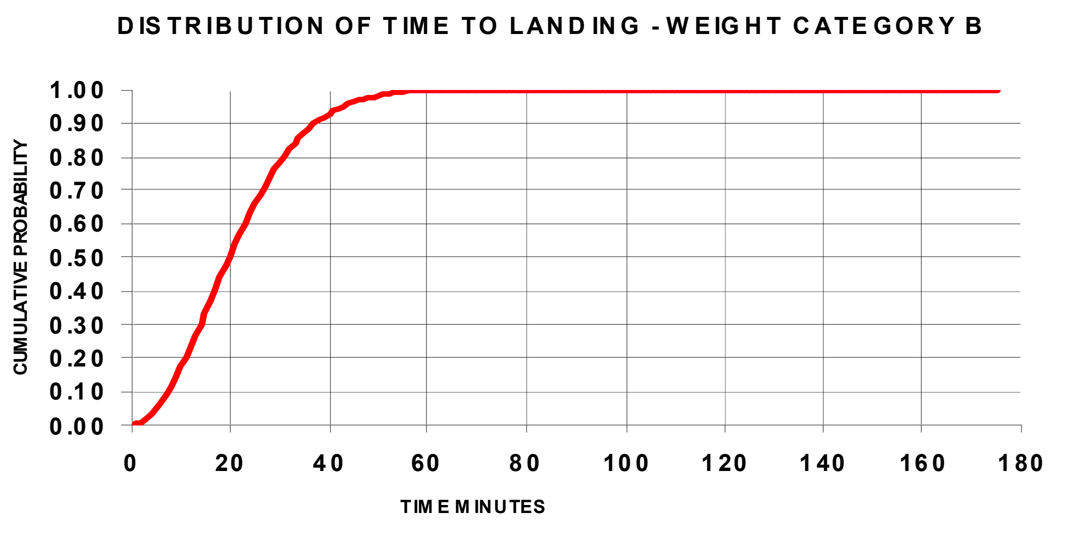

Figure 4 Distribution of Time to Landing for Weight Category B Aircraft

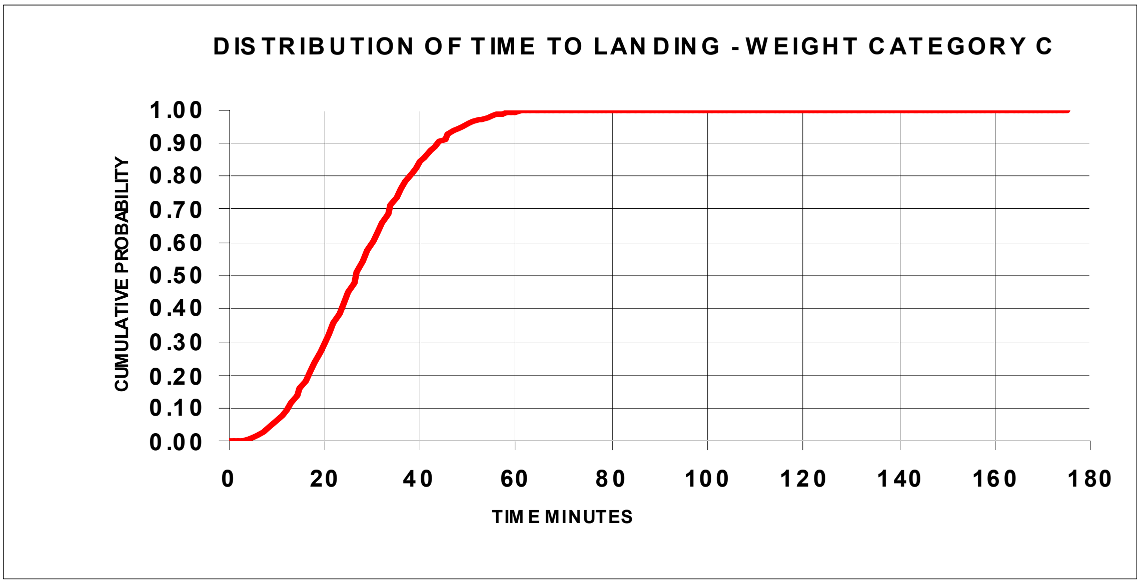

Figure 5 Distribution of Time to Landing for Weight Category C Aircraft

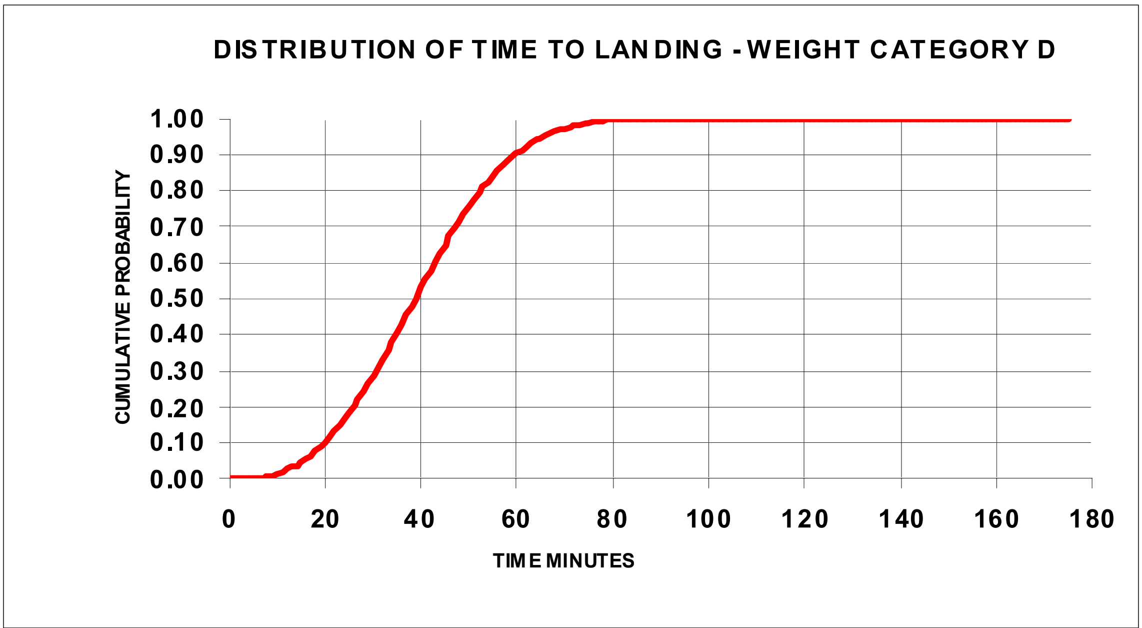

Figure 6 Distribution of Time to Landing for Weight Category D Aircraft

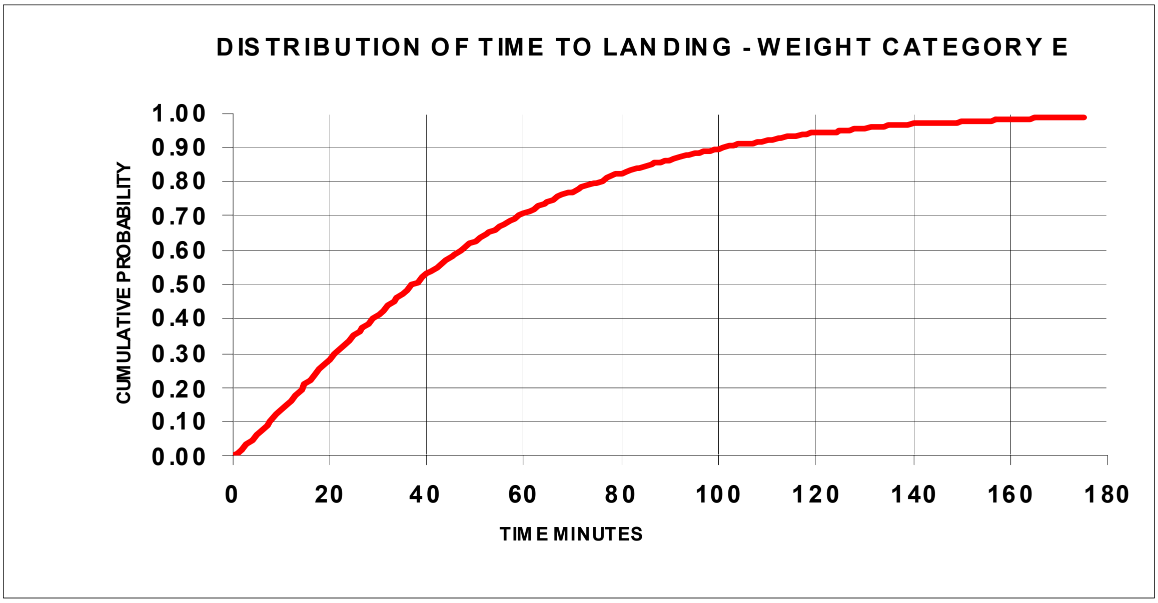

Figure 7 Distribution of Time to Landing for Weight Category E Aircraft

4.6 Step 5 – Total Number of Occupants

Data from the Cabin Safety Research Technical Group Accident Database (Bibliography, number 9.1) was used to determine the distribution of the total number of occupants by each of the four Weight Categories. The total number of occupants is inclusive of passengers and crew. These distributions are shown in Figure 8. There are 593 data points for Weight Category B aircraft Type Certificated for more than 30 seats, 545 in Weight Category C, 160 in Weight Category D and 138 in Weight Category E.

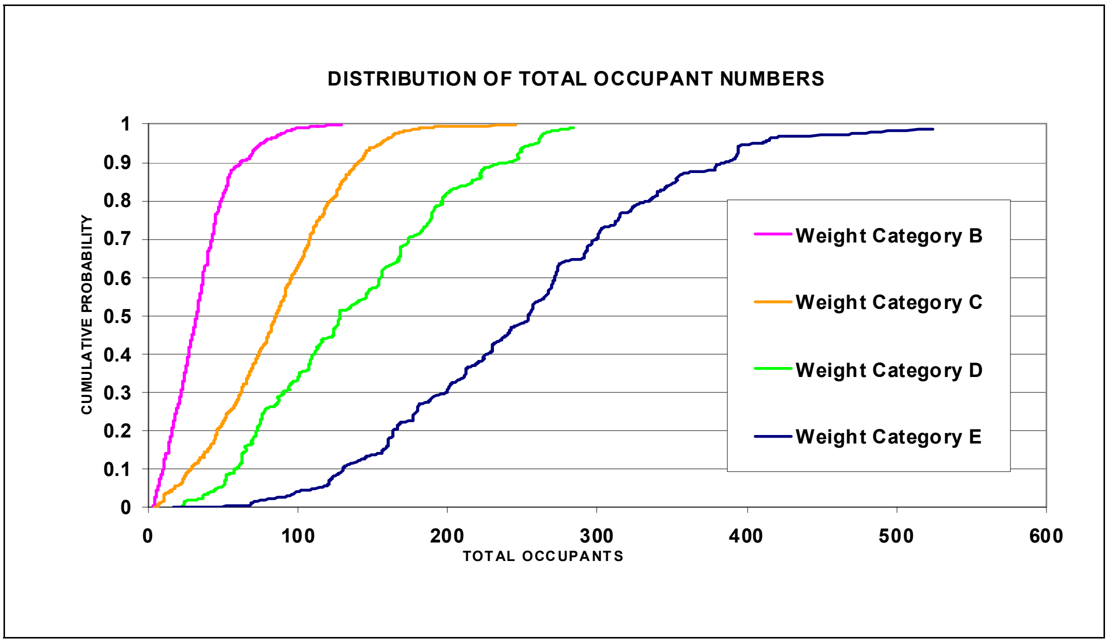

Figure 8 Cumulative Probability Distribution of Total Number of Occupants by Aircraft Weight Category

The average numbers of occupants by Weight Category, based on these data, are shown in Table 4.

Weight Category	Average Number of Occupants
B	34
C	85
D	136
E	250

Table 4 Average Number of Occupants by Aircraft Weight Category

4.7 **Step 6 - Number of Fatalities – Time to Become Non-survivable is Less Than Available Time to Land.**

Step 6 of the model is simply a calculation. The Time to Landing, T_2 (Step 4) is compared with the Time to become Non-Survivable, T_1 (Step 3). If T_1 is less than T_2 the number of Fatalities F is set to the Total Number of Occupants derived in Step 5. If T_1 is greater than or equal to T_2, the number of fatalities is derived from Step 7 as described in paragraph 4.8.

4.8 **Step 7 - Number of Fatalities – Time to Become Non-survivable Exceeds Available Time to Land.**

If Time to become Non-survivable, T_1 is greater than Time to Landing, $T_{2,}$ then there is sufficient time to land the aircraft before the fire becomes uncontrollable. However, in accidents of this type there are still often a substantial number of fatalities. A study was made of accidents where the aircraft landed with a serious fire on board. For each accident the proportion of occupants sustaining fatal injuries, the Fatality Rate, was derived (see Glossary). The accidents studied and the Fatality Rate appropriate to each are shown in Table 5.

Accidents where fires originated from cargo areas were included as well as those where the fire started in occupied areas. A distribution was derived of the Fatality Rate based on these data.

Date	Location	Aircraft Type	Fatality Rate
26-Jul-69	Biskra, Algeria	Caravelle	.95
06-May-70	Mogadiscio International Airport, Somalia	Viscount 785	.17
11-Jul-73	Orly, Nr. Paris, France	B707	.92
19-Aug-80	Riyadh, Saudi Arabia	L1011	1
02-Jun-83	Cincinnati International Airport, USA	DC9-32	.5
24-Nov-93	Copenhagen, Denmark	MD-87	0
17-Apr-88	Cleveland, Ohio, USA	B737-200	0
04-Sep-93	Santo Domingo, Dominican Republic	B727	0
08-Aug-00	Greensboro NC, USA	DC9-32	0
29-Nov-00	Atlanta GA, USA	DC9-32	0

Table 5 Accidents involving an in-flight fire where the aircraft reached an available airfield

Having established a Fatality Rate from the distribution, the number of fatalities is derived by multiplying the Rate by the number of occupants determined from Step 5.

4.9 **Step 8 - Number of Fatalities per Year**

From Steps 6 and 7 the number of fatalities could be determined for each iteration of the model. The resultant distribution of fatalities is shown in Figure 9.

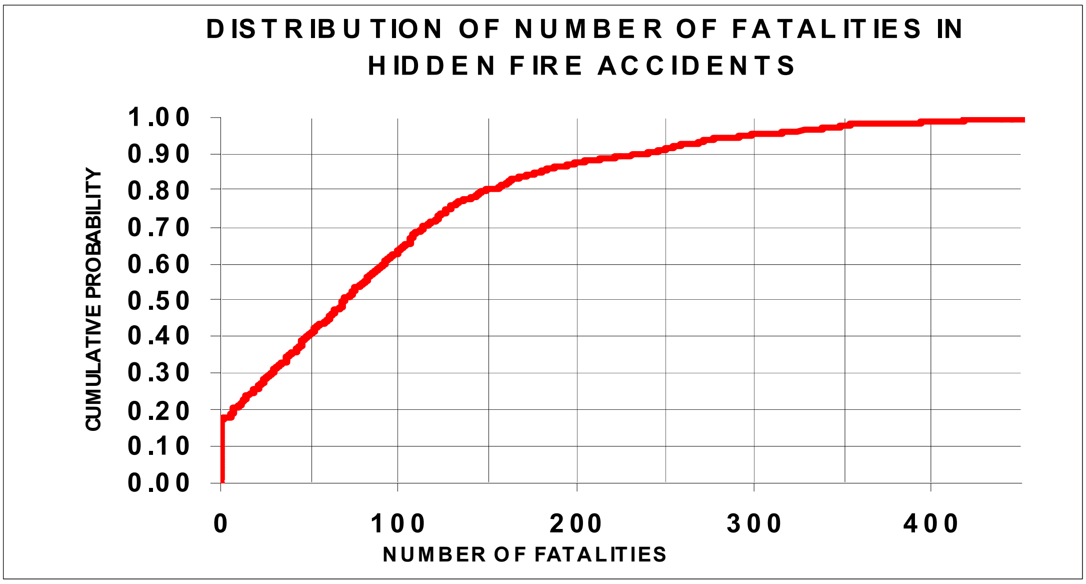

Figure 9 Distribution of Number of Fatalities in Hidden Fire Accidents

It may be seen from Figure 9 that approximately 17% of hidden fire accidents are assessed to result in no fatal injuries. The average number of fatalities per accident is assessed to be 92.8.

Multiplying this average number of fatalities per accident by the hidden fires occurrence rate derived from Step 1 yields the distribution of number of fatalities per flight hour as shown in Figure 10.

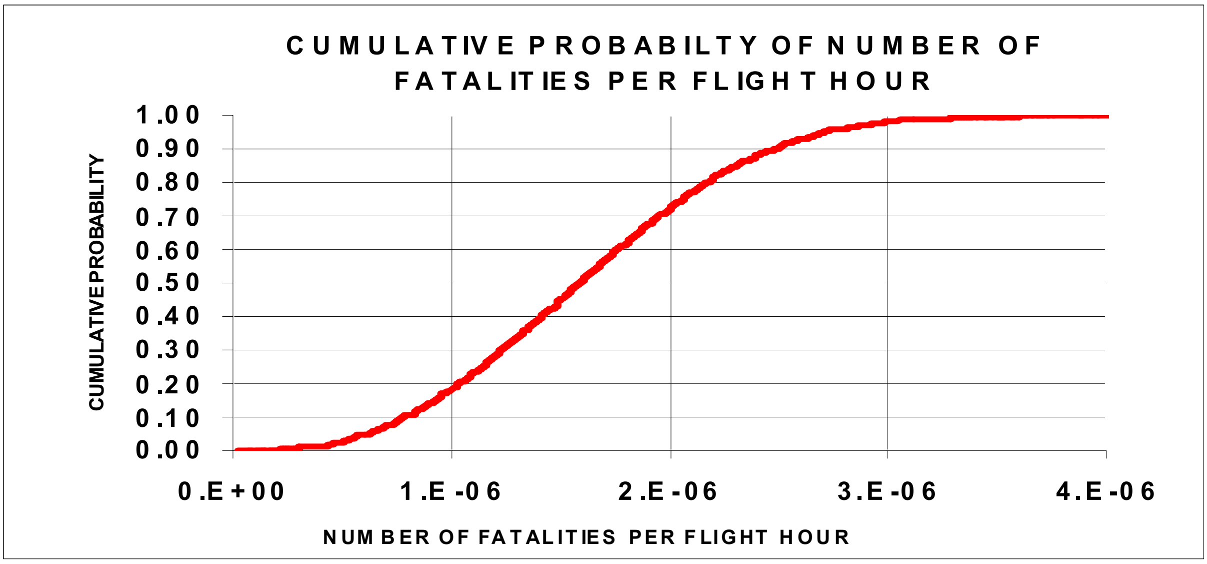

Figure 10 Cumulative Distribution of Number of Fatalities per Flight Hour

For the period considered in this Analysis, 1991 to 2000, the Western-built fleet of turboprop and turbojet aircraft accumulated 331,140,000 flight hours. The average rate of accumulation of flight hours is therefore 33,114,000 per year. Multiplying the distribution shown in Figure 10 by this value results in the probability distribution, of number of fatalities per year, as shown in Figure 11.

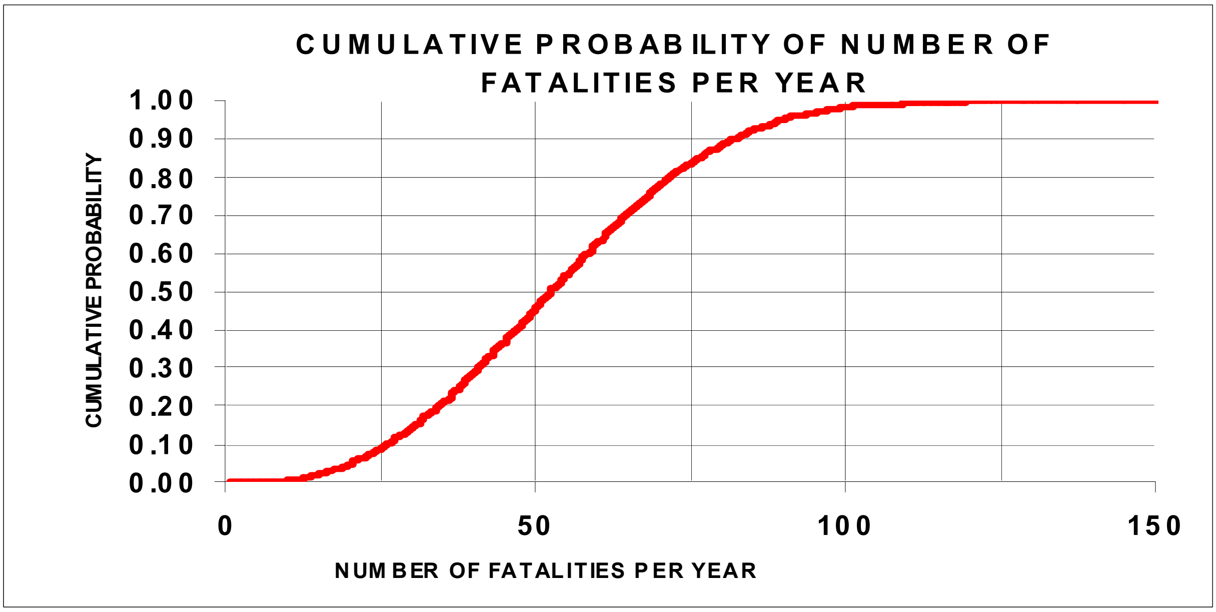

Figure 11 Cumulative Probability Distribution of Number of Fatalities per Year

An assumption of the study is that all lives will be saved by enhancements made to fires in hidden areas. Therefore, based on the data presented in Figure 11 the assessed number of lives to be saved from enhancements to fires in Hidden Areas is as shown in Table 6.

Percentile	Assessed Number of Lives Saved
2½	16
50	52
97½	97

Table 6 Assessed Number of Lives saved from Enhancements to Fires in Hidden Areas

5 Analysis of Past Accidents

5.1 Introduction

In order to validate the results of the Risk Model an assessment was made of fatal accidents to determine the number of lives that might have been saved from enhanced protection from fires within hidden areas.

5.2 Data Sources

The Cabin Safety Research Technical Group Accident Database (Bibliography, number 1) was used as a basis for the selection and analysis of accidents supported by the Bibliography, numbers 2, 5, 6 and 8.

5.3 Accident Selection Criteria

Accidents, involving passenger-carrying aircraft, were selected from the Accident Database over the period 1967 to 1999. The time period considered did not extend beyond 1999 since detailed information is not available for all fire related accidents on the Database for the year 2000. The criteria used for the selection of accidents was as follows:

1 The accident resulted in at least one fatality.

2 The accident was fire related.

3 The aircraft was type certificated with more than 30 seats.

4 The aircraft was a Western-built turbojet or turboprop.

196 accidents were identified from the Database that met all four criteria.

5.4 Hidden Area Fire Accidents

From the 196 accidents selected, 166 were judged to have sufficient information available to make an assessment as to whether the fire occurred post or pre-impact. The categorisation of these accidents is shown in Table 7.

Fire Related Fatal Accident Category	Number of Accidents
Pre-impact fire in Hidden Area - confirmed related to Thermal Acoustic Liners	1
Pre-impact fire in Hidden Area with degree of Thermal Acoustic Liner involvement not confirmed	5
Pre-impact fire in Hidden Area - **not** related to Thermal Acoustic Liners	0
Pre-impact fire in known other area (e.g. engine related)	11
Pre-impact fire in an unknown area	2
Post-impact fire	147
Total	**166**

Table 7 Fire related Fatal Accidents Identified from the Accident Database during the period 1967 - 1999

It may be seen that six of these accidents were hidden fire-related and possibly a further two. The six confirmed as hidden fire related are shown in Table 8. This Table also shows the best assessment of the number of lives to be saved from enhancements to fires in hidden areas – the median value **M**. The maximum number of lives to be saved, **H**, and the assessed minimum, **L**, is also shown in the table. A rationale for the assessed range of lives to be saved is given in Appendix 3.

Date	Location	Aircraft	Fatalities	Assessment of number of lives saved		
			573	H	M	L
26-Jul-69	Biskra, Algeria	Caravelle	35	35	17	0
06-May-70	Mogadiscio International Airport, Somalia	Viscount 785	5	5	0	0
11-Jul-73	Orly, Nr. Paris, France	B707	123	123	100	0
26-Nov-79	Jeddah, Saudi Arabia	B707	156	156	78	0
02-Jun-83	Cincinnati International Airport, USA	DC9-32	23	23	23	23
02-Sep-98	Peggy's Cove, Nova Scotia, Canada	MD-11	231	231	231	231

Table 8 Accidents with Fire in Hidden Areas during the period 1967 - 1999

A simple Monte Carlo simulation was used to assess the total number of lives to be saved and the likely range of this assessment, based on these six accidents. The results of the simulation are shown in Table 9.

Percentile	Assessed Number of Lives Saved
2½	310
50	430
97½	534

Table 9 Assessed Number of Lives saved with Enhanced Protection from Fires in Hidden Areas Based on Six Accidents Occurring During the Period 1967 to 1999

The values shown in Table 9 may be divided by 33 to arrive at a prediction of the number of lives to be saved per year over the period 1967 to 1999. The resultant values are shown in Table 10.

Percentile	Assessed Number of Lives Saved
2½	9.4
50	13.0
97½	16.2

Table 10 Assessed Number of Lives saved per year with Enhanced Protection from Fires in Hidden Areas Based on Six Accidents Occurring During the Period 1967 to 1999

5.5 Comparison with Results from the Risk Model

To compare the results from the Risk Model with those derived from the analysis of past accidents, two factors have to be taken into account:

1 The average number of flying hours per year accumulated by the Western world fleet used in the Model (for the period 1991 - 2000) is higher than the average rate accumulated for the period 1967 - 1999.

2 The accident data used for the study of past accidents was limited to accidents for which data are available. The assessment of benefit would be greater if data were available for all hidden fire accidents occurring during the period 1967 to 1999.

5.5.1 Factor to compensate for accumulated flight hours

Data on the number of flight hours accumulated by the world fleet of aircraft are only available to the analysts for the period 1967 to 2000 for turbojet aircraft. Turboprop flight hours are not complete for the whole of this period. Hence, it has been assumed that the ratio of turbojet flight hours for the periods 1967 to 1999 and 1991 to 2000 are similar to the ratio of the flight hours for turbojet and turboprop aircraft. Any errors in this approximation are likely to be small since, as can be seen from Appendix 2, the majority of flight hours for Western-built aircraft are accumulated by turbojets.

The number of flight hours accumulated by Western-built turbojets over the period 1967 to 1999 is assessed to be in the order of 579,000,000. This equates to an annual average rate of approximately 17,500,000.

The number of flight hours accumulated by Western-built turbojets over the period 1991 to 2000 is assessed to be in the order of 294,000,000. This equates to an annual average rate of approximately 29,400,000.

The ratio of the two annual average rates is **1.68.**

The assessment of benefit based on past accidents would need to be multiplied by this ratio in order to assess the benefit over the period 1991 to 2000.

5.5.2 **Factor to compensate for hidden fire accidents not considered in the analysis of past accidents**

As determined in Section 5.3 the number of accidents selected from the Accident Database that satisfied the selection criteria was **196**.

Of these, **166** accidents had sufficient information available to assess the nature of the fire.

Over the period 1967 to 1999 there were **78** non-fire related accidents on the database and **235** accidents where insufficient data exists to establish whether they were fire related or not.

Of these **235** accidents it is likely that the number that were fire-related would be:

$$\frac{196}{(196+78)} \times 235$$

or approximately **168**

Therefore, the ratio of the likely total number of fire related accidents and the fire related accidents with sufficient information available to assess the nature of the fire over the period 1967 to 1999 would be:

$$\frac{196 + 168}{166}$$

This is approximately equal to **2.2**

It is assumed that the fire related accidents not having sufficient data to assess benefit would yield proportionate benefit to those where sufficient information were available to make a determination. On this basis, the derived benefit would need to be increased by the ratio 2.2.

5.5.3 Assessed Number of Lives Saved based on an analysis of past Accidents likely to accrue to the world fleet of Western-built aircraft over the period 1991 to 2000

This assessment may be derived by simply multiplying the values of benefit shown in Table 10 by the two factors, 1.68 and 2.2 derived in paragraphs 5.5.1 and 5.5.2. This yields the values of benefit shown in Table 11.

Percentile	Assessed Number of Lives Saved
2½	34.6
50	48
97½	59.6

Table 11 Assessment of Number of Lives Saved Based on an Analysis of Past Accidents Likely to Accrue to the World Fleet of Western-built Aircraft Over the Period 1991 to 2000

6 Assessment of Benefit from Enhanced Flammability Standards for Thermal Acoustic Liners

It is necessary to estimate the contribution that a change to Thermal Acoustic Liner flammability will make. In all the accidents and incidents analysed the fire was in a hidden area and hence was likely to have had a Thermal Acoustic Liner involvement. However, the degree of involvement could not always be established with certainty.

Table 12 shows all 12 Incidents and Accidents analysed in this study (details of which are shown in Appendices 1 and 3).

Each of the occurrences in Table 12 was qualitatively assessed in terms of the degree to which Thermal Acoustic Liners were considered to have significantly contributed to the propagation of the fire. Since Thermal Acoustic Liners would play a part in any hidden fire that presented a threat to the occupied area of the aircraft, the degree to which they constitute a major threat is less readily determined. However, on 4 of the 12 occurrences (one third) shown in Table 12 it appears that Thermal Acoustic Liners were a major factor in fire propagation. It is also feasible that they may have been a major factor in the fire propagation on all 12 accidents. On this basis, it would be reasonable to assume that Thermal Acoustic Liners might have been the major factor in the propagation of the fire in 8 (or two-thirds) of the occurrences. Given that the life saving potential from the eradication of hidden fires in areas that presented a threat to occupied areas was 52, the thermal acoustic liner contribution would be $^{2}/_{3}$ x 52, i.e. in the region of **34** lives per year.

Date	Operator	Aircraft	Location	Qualitative Assessment of the Probability of Thermal Acoustic Liner involvement
26-Jul-69	Air Algerie	Caravelle	Biskra, Algeria	Probable
06-May-70	Somali Airlines	Viscount 785	Mogadiscio International Airport, Somalia	Possible
11-Jul-73	Varig	B707	Orly, Nr. Paris, France	Probable
26-Nov-79	Pakistan International Airlines	B707	Jeddah, Saudi Arabia	Probable
02-Jun-83	Air Canada	DC9-32	Cincinnati International Airport, USA	Probable
17-Apr-88	Continental Airlines	B737-200	Cleveland, Ohio, USA	Probable
04-Sep-93	Dominicana	B727	Santo Domingo, Dominican Republic	Probable
24-Nov-93	SAS	MD-87	Copenhagen, Denmark	Yes
26-Nov-95	Alitalia	MD-82	Turin, Italy	Yes
02-Sep-98	Swiss Air	MD-11	Peggy's Cove, Nova Scotia, Canada	Yes
08-Aug-00	Air Tran	DC9-32	Greensboro NC, USA	Yes
29-Nov-00	Air Tran	DC9-32	Atlanta GA, USA	Probable

Table 12 Assessed Probability of Thermal Acoustic Liner Involvement for Hidden Fire-Related Occurrences

7 Discussion

7.1 Prediction based on the Mathematical Risk Model

The Hidden Fires Occurrence Rate determination, Step 1, is the most sensitive part of the Model. It is a direct linear function of the final assessed benefit values.

Steps 2 to 8 inclusive are the means by which the average number of fatalities in a hidden fire is determined. Any inaccuracies that may exist in this part of the Model have a less significant effect on the final determination of benefit.

7.1.1 Step 1 – Hidden Fires Occurrence Rate

The data set used was taken over a limited period, 1991 to 2000, and is for the world fleet of Western-built aircraft in which significant occurrences are likely to be reported. It may be questionable whether the occurrence involving the DC9-32 in August 2000 involved a fire that could be classified as uncontrollable. However, it was concluded that it should be included in the data set. The rate suggested by taking the longer time period of 1988 to 2000, in which there were seven occurrences, was 1.75×10^{-8} per flight hour. This is greater than that suggested from the five occurrences taken over the ten year period, 1.51×10^{-8} per flight hour. On this basis the rate used in the model may be considered to be somewhat conservative.

The Model is based on the assumption that the Occurrence Rate of Hidden Fires is random with time and is constant for all aircraft types. In practice the probability of occurrence will vary with each aircraft and is likely to vary with flight phase due to changes in aircraft system states. However, the nature of these variations is unknown and hence the model was based on the assumption there is a constant risk of occurrence of a hidden fire with time.

7.1.2 Step 2 – Weight Category

The classification of aircraft by Weight Category was necessary in order to reflect the variations in number of occupants and operational roles of aircraft of different sizes. The number of seats in any particular aircraft and its operational role will vary with operator. Classification by weight is to some extent arbitrary but provides a reasonable basis for accommodating the requirements of the model. The Weight Categories are those used in the Cabin Safety Research Technical Group Accident Database and have been used in previous studies.

7.1.3 Step 3 – Time to become Non-Survivable - T_1

The data available to produce the distribution for Time to become Non- Survivable was limited in that there were only seven data points used. Although information was available on other accidents, the times were approximations. Only times to become Non-survivable that could be established with some precision were used in the Model.

It was assumed that the data was distributed according to the Weibull distribution. The curve of best fit was applied to the data set producing a Weibull distribution with a shape parameter β , of 2.1. This results in a distribution similar to the Lognormal.

The time T_1 will be dependent on the nature of the hidden fire. However, it is not feasible to account for this factor. The Time to become Non- Survivable might vary with aircraft size but there is insufficient information available from the accident record to determine whether this might be the case and the nature of any such variation. As may be seen from Table 3 the longest and the shortest times were recorded on the same aircraft type – a Boeing 707. Whilst no firm conclusions can be derived from this, it suggests that factors other than aircraft size determine the variation in this variable. The assumption made in constructing the Model was that all aircraft and all types of hidden fires had similar probability distributions of Time to become Non-survivable.

7.1.4 Step 4 – Available Time to Landing -T_2

The Model was predicated on the assumption that the probability of occurrence of a hidden fire is constant with time from the start of the take-off roll to the end of the landing roll.

Data was used on times to landing based on information from actual accidents or incidents. Following the declaration of an emergency the aircraft would return to the departure airfield, continue to its destination or divert to another airfield. There are many factors that are involved in the choice of airfield and in practice it is not necessarily the nearest that is chosen by the flight crew.

Distributions of Available Time to Landing were generated for all of the four weight categories. The data suggests that generally the larger the aircraft the longer the time taken to reach an available airfield. This is to be expected since the larger aircraft tend to have longer average flight times and hence are likely to spend longer at large distances from available airfields. The distribution for the largest aircraft, those in Weight Category E, is somewhat different from the other weight categories. No explanation for this could be fully substantiated.

7.1.5 **Step 5 – Total Number of Occupants**

The distributions of Total Number of Occupant Numbers, for each of the four Weight Categories, were derived from quite large populations of data. All available data in the Cabin Safety Research Technical Group Accident Database (Bibliography, number 1) were used over the period 1967 to 2000. Over this period there would be variations in the total number of seats and passenger load factor for each of the Weight Categories. However, it was considered preferable to use all available data rather than to limit the source to the period 1991 to 2000. Any differences that might exist between this latter period and the period 1967 to 2000 are likely be relatively small and make the assessment of benefit slightly conservative.

7.1.6 **Step 6 – Number of Fatalities – Time to become Uncontrollable is Less than Available Time to Land**

Step 6 is a purely mathematical function within the model that uses data derived in earlier steps.

7.1.7 **Step 7 – Number of Fatalities – Time to become Uncontrollable Exceeds Available Time to Land**

If the aircraft is able to land before the fire becomes uncontrollable, it is likely that there will be some survivors. Based on experience of such occurrences a determination was made of the proportion of occupants that are likely to sustain fatal injuries - fatality rate. The distribution of this fatality rate was assessed from a relatively small number of occurrences. It does not take into account the time that the fire had been in existence - which is likely to be a factor in the proportion of occupants sustaining fatal injuries. However, once again any errors in this assessment are not likely to result in large differences in the assessment of benefit because:

1 There is no bias in the model with respect to the time remaining for the fire to become uncontrollable after landing. In some instances the model will generate a large number of fatalities when the fire has been in existence for only a short period of time - on other occasions it will generate a small number when the fire is on the point of becoming uncontrollable at the time of landing. On balance it is likely that the distribution of fatalities will be close to what might be expected had the model catered for the relationship between fatality rate and available time prior to the fire becoming uncontrollable.

2 For aircraft with hidden fires, an approximate assessment is that only one third will reach an airfield before the fire becomes uncontrollable.

3 As stated earlier variations in Steps 2 to 8 have a less significant effect than Step 1 on the final determination of benefit.

7.1.8 **Step 8 – Number of Fatalities per Year**

Step 8 is a purely mathematical function within the model that uses data derived in Steps 1, 6 and 7 and an assessment of the average number of flight hours accumulated per year by Western-built aircraft to determine the benefit from enhanced protection from fires within hidden areas in the aircraft cabin.

7.2 Prediction Based on an Analysis of Past Accidents

The prediction based on an analysis of past accidents suggested a benefit level from enhanced protection from fires within hidden areas in the aircraft cabin that was similar to that derived from the Mathematical Risk Model. Whilst this prediction is not considered to be of great accuracy, due to the limited data on which it is based, it does provide a basis for validation of the model.

7.3 Assessment of Benefit from Enhanced Flammability Standards for Thermal Acoustic Liners

Since almost all hidden areas will contain Thermal Acoustic Liners they will be involved to some degree in any fire that might occur. Many of the hidden area fires considered in this study are likely to have had a significant involvement of Thermal Acoustic Liners. However the extent of this involvement cannot be positively confirmed in most cases.

On this basis the assessment that $^2/_3$ of the life saving potential from enhancements in protection against fires in hidden areas may be assigned to Thermal Acoustic Liners is considered reasonable and probably conservative.

8 Conclusions

8.1 Based on the developed Mathematical Risk Model it is assessed that the number of lives to be saved from enhanced protection from fires within hidden areas in the aircraft cabin would be **52** per year over the period 1991 to 2000 for Western-built aircraft. The 95-percentile range is **16** to **97** lives per year.

8.2 The benefit assessment, derived from the mathematical model, was validated from an analysis of past accidents. Whilst there are limited data available on hidden fire accidents, the assessment of benefit of **48** lives per year over the period 1991 to 2000, gives confidence in the model predictions.

8.3 It is assessed that the number of lives to be saved from improvements in the flammability standards of Thermal Acoustic Liners is approximately **34** per year.

Bibliography

1 Cabin Safety Research Technical Group Accident Database Version 4.3 Issue 16

2 The National Transportation Safety Board Accident Database - located on National Transportation Safety Board web-site at www.ntsb.gov

3 The Federal Aviation Administration Incident Data System - located on Federal Aviation Administration web-site at www.faa.gov

4 The United Kingdom Civil Aviation Authority Mandatory Occurrence Database

5 The International Civil Aviation Organization Accident Database

6 Additional Data supplied by the Federal Aviation Administration

7 The United Kingdom Civil Aviation Authority Data on World Fleet Hours

8 R.G.W. Cherry & Associates Limited - Library of Accident Reports

9 "Interim Air Safety Recommendations" dated 4th December 2000 NTSB Report relating to the Swiss Air Accident of the 2nd September 1998

10 AGARD 1997 Conference Proceedings 587 "A Review of Recent Civil Air Transport Accidents/Incidents and their Fire Safety Implications" - Richard G. Hill, David R. Blake

11 Repubblica Italiana Alitalia MD-82 Cabin Fire Working Paper June 1996

12 The United Kingdom Air Accidents Investigation Branch Bulletins

Glossary of Terms

Fatal Injury (Source: NTSB, 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."

Serious Injury (Source: NTSB, 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 per cent of the body surface; or

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

Weight Category

Weight Category is defined based on aircraft having Maximum Take-off Weights in the following ranges:

Category A = less than 12,500 lb

Category B = 12,500 - 100,000 lb

Category C = 100,000 lb - 250,000 lb

Category D = 250,000 lb - 400,000 lb

Category E = greater than 400,000 lb

Appendix 1 Hidden Fire Accidents and Incidents

Occurrence 1

Date	Source of Information		Aircraft Type
08-Aug-00	NTSB Accident Database Identification DCA00MA079		DC9-32
Operator	**Location**		**Registration**
Air Tran	Greensboro NC, USA		N838AT
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
63	0	0	Not known

Description of Accident

The captain and first officer noticed a smell of smoke shortly after take-off. The crew immediately donned oxygen masks and smoke goggles. The smoke became very dense and restricted the crew's ability to see both the cockpit instruments and the visual references outside the airplane. The cabin crew noticed a smell of smoke, followed by a visual sighting of smoke and sparks in the area of the forward flight attendant jump-seat. The flight crew was able to identify the Greensboro airport and make a successful emergency landing. The airplane was immediately stopped, and an emergency evacuation was conducted on a taxiway.

The Board's initial investigation found extensive heat damage to wires and insulation in the electrical panel behind the captain's seat. The heat was sufficient to blister the primer on the fuselage crown skin.

Four crew members received minor injuries from smoke inhalation in-flight and one passenger received a minor injury during the evacuation; one crew member and 57 passengers were uninjured. The airplane was substantially damaged from the effects of fire, heat, and smoke.

[Greensboro, 08-Aug-00]

Figure 1 Fire in Bulkhead, Spread to Area Above Cabin Ceiling (Overhead)

Figure 2 Fire in Bulkhead, Spread to Area Above Cabin Ceiling (Overhead)

Occurrence 2

Date	Source of Information		Aircraft Type
29-Nov-00	NTSB Accident Database Identification DCA01MA005		DC9-32
Operator	**Location**		**Registration**
Air Tran	Atlanta GA, USA		N826AT
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
97	0	0	Not known

Description of Accident

During initial climb, the flight crew noted numerous circuit breaker trips and illumination of several indicator lights. The crew declared an emergency with air traffic control and requested a return to the airport. The airplane landed safely and cleared the runway onto a taxiway. At some point during the landing rollout and taxi, the flight attendants notified the flight crew of smoke in the forward section of the cabin. An emergency evacuation ensued. The FAA advise that the fire was extinguished by the Fire Brigade.

Examination of the airplane revealed fire damage to an area of the left fuselage below and aft of the forward passenger entry door, and to the adjacent forward cargo and main cabin floor areas. Wiring, ducts, and hydraulic lines located in this area were also burned.

[Atlanta, 29-Nov-00]

Figure 3 Fire in Cheek Area, Spread to Area Above Cargo Compartment

Figure 4 Fire in Cheek Area, Spread to Area Above Cargo Compartment

Occurrence 3

Date	Source of Information		Aircraft Type
04-Sept-93	AGARD 1997 Conference Proceedings 587 "A Review of Recent Civil Air Transport Accidents/Incidents and their Fire Safety Implications" - Richard G. Hill, David R. Blake		Boeing 727
Operator	**Location**		**Registration**
Dominicana	Santo Domingo, Dominican Republic		HI-617CA
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
105	0	0	Approx. 20 mins.

Description of Accident

Approximately fifteen minutes into a thirty minutes flight from San Juan to Santo Domingo, a flight attendant noticed a flight attendant call button lit for the aft lavatory. She checked the lavatory and saw smoke inside. The airplane landed at Santo Domingo and the passengers exited normally through the L1 door as the cabin began to fill with smoke. The flight crew requested a mechanic with a fire extinguisher to check the lavatory. The mechanic opened the ventral stairs and saw fire that he judged to be too big to attempt to fight with a hand held extinguisher. The airplane was destroyed by fire. The fire was determined to have originated in the area of the aft lavatory but the cause was never found.

Occurrence 4

Date	Source of Information		Aircraft Type
02-Sep-98	TSB Aviation Safety Recommendations Report "The Circumstances of Swiss Air Flight 111 accident"		MD-11
Operator	**Location**		**Registration**
Swiss Air	Peggy's Cove, Nova Scotia, Canada		HB-IWF
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
231	231	0	16 minutes

Description of Accident

On 2-Sep-1998, about 2230 local time, a Swiss Air flight 111, McDonnell Douglas MD-11, registered as HB-IWF, crashed into a bay near Blandford, Nova Scotia (the nearest area is called Peggy's Cove). The airplane was a regularly scheduled passenger flight from JFK International Airport, Jamaica, New York to Geneva, Switzerland, operating under 14 CFR Part 129. The flight also operated as Delta flight 111 under a code sharing agreement.

56 minutes into the flight in normal cruise at FL330, the flightcrew issued a 'Pan'-call reporting smoke in the cockpit and requesting emergency vectoring to the nearest airport, which they thought was Boston. The Moncton controller cleared the flight to descend to FL310 and offered Halifax as the closest airport available, which was accepted by the crew. The flight was handed over to Moncon Centre and was vectored for a back course approach to Halifax runway 06. Whilst the airplane was just 30 miles from the threshold, so Moncton Centre vectored the plane for a 360-degree turn to lose some altitude and to dump fuel off the coast. The situation in the cockpit apparently became worse. At this point and about 10 minutes after the first alert message, the crew declared an emergency and reported that they were starting the fuel dump and that they had to land immediately.

There were no more radio communications and the aircraft disappeared from radar approximately 5nm off Peggy's Cove and 35nm from the airport off the Nova Scotia coast. The airplane hit the water 16 minutes later after the alert message.

There were 14 crewmembers and 217 passengers (including 2 children) aboard, all were fatally injured. The plane was destroyed as a result of the accident.

[Peggy's Cove, 02-Sep-98]

Since the aircraft crashed into water, all fire damage occurred in flight. The ongoing investigation (A98H0003) has identified substantial fire damage above the drop-down ceiling in the forward section of the aircraft extending about 1.5 metres forward and 5 metres aft of the cockpit wall.

Occurrence 5

Date	Source of Information		Aircraft Type
24-Nov-93	Cabin Safety Research Technical Group Accident Database - Accident Reference 19931124A		MD-87
Operator	**Location**		**Registration**
SAS	Copenhagen, Denmark		SE-DIB
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
85	0	0	-

Description of Accident

During landing the CA2 cabin attendant, who was positioned in the aft most part of the cabin, noticed that her work lights suddenly lit up brightly and then went out. While taxiing towards the assigned gate she noticed a faint smell of electrical smoke/ fire and immediately informed the CA1 about her observations. The CA1 immediately informed the first officer about the situation.

When the CA2 checked the lavatory on the right hand side, she noticed whitish smoke in front of and above the lavatory door. The CA2 immediately informed the flight deck about her observations via the interphone. The first officer, who answered the call, told the CA2 that they were just about to turn into the parking gate and that he suggested they kept the interphone connection open until the aircraft was parked and the engines were shut down. The first officer repeated all the conversation out loud so that the captain was able to follow developments.

The CA3, who was seated at the over wing exit position, got up and walked to the forward galley where she heard that there was a smell of something burning at the back of the cabin. Consequently she decided to go to the aft cabin and offer her assistance. When she reached the aft rows of seats she sensed a fairly strong smell of burning. When she opened the right-hand lavatory door, heavy smoke build-up was evident and smoke also entered the cabin through the ventilation ducts in the ceiling.

After the aircraft was parked, the crew turned off the generators, shut down the engines and selected emergency power ON. The captain requested the assistance of a fire vehicle over the radio.

[Copenhagen 24-Nov-93]

The ground engineer who met the flight routinely connected the external power supply. While he was doing so the captain, who had opened the sliding window, attracted the engineer's attention and asked him to go to the aft stairway and check for smoke. The ground engineer entered the cabin via the aft stairway to check the aft lavatory and cabin area for the origin of the fire. However, as the engineer only identified lots of smoke and smell of electrical fire in the cabin, he left the cabin and inspected the lower aft cargo compartment, but without actually seeing the flames.

After personally having checked that the cabin was empty, the captain checked the outside of the aircraft and noticed a bright glowing spot on the fuselage in front of and above the right-hand engine. He quickly returned to the cockpit and used the radio to emphasize the urgent need for assistance from fire and rescue services.

At about 3 minutes after the captain's second radio request for assistance, the first fire vehicle arrived and initiated the fire fighting. The full airport fire detachment arrived 3 minutes later. The first of the vehicles from the county fire brigade arrived 3 minutes after that.

The captain remained at the scene until the fire and rescue services arrived so that he could inform the rescue crew that all the crew and passengers had indeed vacated the aircraft.

About 15 minutes after the sounding of full scale alarm the fire was under control and the fire fighting ended a total of about 1 hour and 5 minutes after the captain's second radio call.

Later investigation revealed that factory installed wiring had been pinched and chafed, which led to arcing and ignition of the cabin sidewall insulation material.

The fierce fire that erupted in the aft right-hand side of the cabin destroyed major parts of all of the equipment installed in that particular area. The extreme heat development destroyed the fuselage skin and structure over a large area on the aft right-hand side of the aircraft. Additionally, the entire cabin furnishings, i.e. seats, partition, galleys, lavatories and panelling were severely damaged by smoke and heat. This form of damage extended as far forward as to include the cockpit and cockpit equipment.

The overhead stowage bins on the right-hand side of the cabin has suffered various degrees of damage. From seat row 20 and aft, the bin doors were totally burned away.

[Copenhagen 24-Nov-93]

The seats in rows 21 to 23 were severely heat damaged as they had been exposed not only to heat but also to hot/burning debris falling on them. The right-hand stowage closet and the right-hand galley, which had been exposed to direct fire and very high temperatures, exhibited severe heat deformation mainly around the upper and outboard parts of the units.

Figure 5 Copenhagen Cabin Burnthrough

[Copenhagen 24-Nov-93]

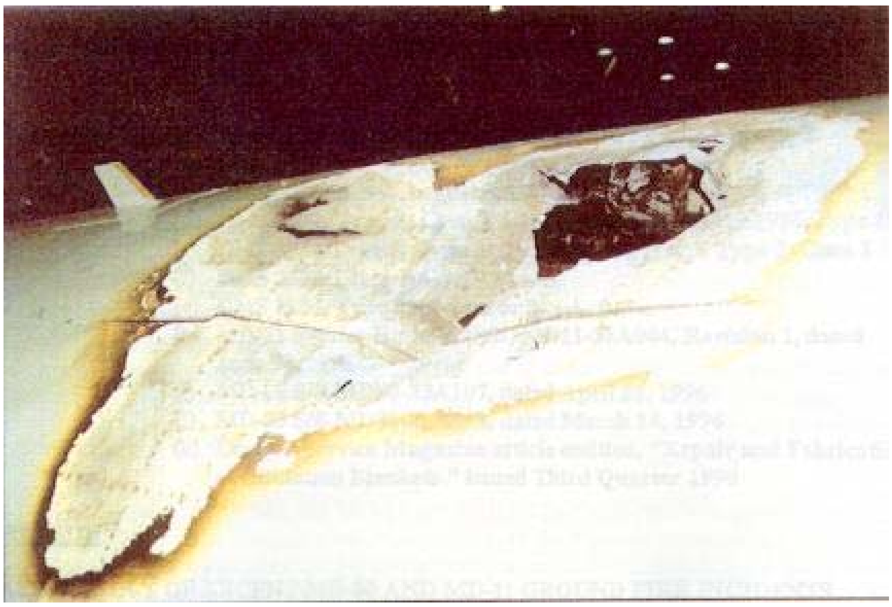

Figure 6 Copenhagen Cabin Burnthrough

Occurrence 6

Date	Source of Information		Aircraft Type
17-Apr-88	NTSB Accident Database Identification ATL88IA147		Boeing 737-200
Operator	**Location**		**Registration**
Continental Airlines	Cleveland, Ohio, USA		N433PE
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
108	0	0	-

Description of Accident

While on final approach smoke and flames developed in the cabin above overhead luggage bins over seats 16 A, B and C. The aircraft was within 2 miles of the runway. Crew declared Emergency, landed, turned off the runway expeditiously, stopped on runway 18, and evacuated. Smoke poured from the opened cabin doors. Examination of the aircraft revealed that a ceiling florescent light fixture shorted internally resulting in the fire. The fire was extinguished by the airport fire department.

Occurrence 7

Date	Source of Information		Aircraft Type
02-Jun-83	Cabin Safety Research Technical Group Accident Database - Accident Reference 19830602A		DC9-32
Operator	**Location**		**Registration**
Air Canada	Cincinnati International Airport, USA		C-FTLU
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
46	23	0	19 minutes

Description of Accident

On 2-Jun-1983 Air Canada DC9-32 registered as C-FTLU was flying from Dallas to Montreal. While en route at 33,000 feet, the cabin crew discovered a hidden fire in the aft lavatory. After attempting to extinguish it an emergency descent and landing was made to Greater Cincinnati International Airport. After the subsequent evacuation a flash fire occurred within the cabin.

Of the 5 crew and 41 passengers, 23 passengers were not able to get out of the aircraft and died in the fire.

The Safety Board concluded the air conditioning packs were turned off at least 4 minutes before the aeroplane landed (almost two complete changes of cabin and cockpit air otherwise would have occurred). There was subsequently virtually no fresh air supply to the cockpit and cabin.

A flight attendant, noting a strange smell, opened the left lavatory door and saw a light grey smoke from floor to ceiling. The in-charge flight attendant then inspected the situation. He saw smoke coming out of the seams where the aft lavatory wall and ceiling meet. He then closed the doors and notified the flight officer. The grey smoke quickly progressed forward in the cabin. Several passengers reported a short interval (estimated by one passenger to be 5 minutes) during which the smoke subsided. When the aeroplane began a steep descent, the smoke got heavier, intensified, increased in density and moved forward. Dense smoke filled the cabin. No open flames were witnessed inside the cabin in flight.

[Cincinnati, 02-Jun-83]

The flight officer came aft to inspect the fire, returned to the cockpit to get his goggles. When he reached the lavatory, the door was hot to the touch. He informed the captain and shortly after, a rapid descent was initiated. Both the pilot and flight officer used smoke goggles and an oxygen mask. Passengers in the rear were instructed and helped to move into seats in the forward section of the aircraft. During the descent, some passengers received evacuation instructions from the flight attendants. Several passengers said that when the flight attendants were walking down the aisles checking seat belts, it would have been impossible to read the briefing cards at that time due to smoke. Most passengers reported the smoke hurt their chest and lungs and caused respiratory irritation. Several passengers kept their heads down while the aeroplane was in flight, saying it relieved some of the symptoms. One man in seat 10E knelt between the seats, keeping his face as close to the floor as possible, and breathing through a wad of tissues he brought on the aeroplane. He didn't have any difficulty breathing; other passengers reported breathing through the paper napkins from their dinner tray, headrest covers, clothing or wet hand towels which were handed out by a flight attendant to passengers in the first several rows. There were no reports of panic on the aeroplane. As soon as the aeroplane stopped, the man seated in 2B undid his seat belt and walked across the passageway to the front of the plane. He was engulfed by a thick cloud of smoke. He could not see anything nor could he feel anyone pushing against him. He heard coughing inside the cabin and sounds of people. Other passengers stated that by the time the aircraft landed, they could not see their hands in front of their faces while seated or standing. Seventeen minutes elapsed after discovery of the fire until the aircraft landed on the runway at Cincinnati. The cabin burst into flames as the last person exited. This occurred 60-90 seconds after the aircraft stopped. The fire spread rapidly forward.

Fire-fighters extinguished the fire 56 minutes after fire fighting began.

Five of the seven passenger exits were used in the evacuation. The left front door was used by seven passengers and two flight attendants. The right front door was used by one flight attendant. Six passengers used the left front window exit, and four passengers used the right front window exit. One passenger exited through the right aft window exit. The captain and flight officer exited through the cockpit windows. The first passenger exited the left forward door 30 seconds to 1 minute after the aircraft stopped. The right front window (R2) was the first overwing exit opened. The survivors who had moved aft to reach the overwing exits found them because they had memorised the number of rows between their seats and the exits, and therefore counted the rows by feeling the seat backs as they moved aft. Some were able to see a dim glow of light as they reached the exit. In one case, the survivor felt a slight breeze across the back of her legs when she reached the rear of an open exit. Two bodies were found further aft. They apparently failed to see the exit. The rear tailcone exit was not used for evacuation.

[Cincinnati, 02-Jun-83]

Figure 7

Occurrence 8

Date	Source of Information		Aircraft Type
26-Nov-95	Repubblica Italiana Alitalia MD 82 Cabin Fire Working Paper June 1996 + NTSB file note 1st December1995		MD-82
Operator	**Location**		**Registration**
Alitalia	Turin, Italy		I-DANM
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
26	0	0	-

Description of Accident

[Initial communication - NTSB file note 1st December 1995]. On 26th November 1995, at Turin, Italy, an Alitalia MD-82 caught fire on pushback. The cabin fire resulted in evacuation of 26 SOB without injury. It is suspected to have begun in the overhead at about station 900. Substantial damage is suspected.

[Transcript from Repubblica Italiana Alitalia MD 82 Cabin Fire Working Paper June 1996]. "The Italian Investigation Team (I.I.T.) at the beginning of the investigation found in the passenger cabin at Station 847 of the Alitalia MD-82 I-DANM the Day-Ray ballast p/n 70-94 and s/n 81818D with the cover on the top broken and with signs of internal burning. Evidences in proximity of the ballast let suppose the I.I.T. that smoke and flames travelled outwards from the rupture of the cover.

Exams and burns in proximity of Day-Ray ballast:

Dust scal flap: burned in different areas (few centimetres)

Outboard and central ceiling panels: partially burned up to the central passenger conduct with drippings on the internal side

Insulation blankets: partially burned

Insulation covering: burned roughly 5 by 1.5 meters

Wires: with some edge fuses

Support rail: smoked

Overhead storage compartment: not interested by flames

To understand better the mechanism of the fire the I.I.T. develops the following Analysis of Propagation of the Cabin Fire on I-DANM regarding the first 10 - 15 seconds of the event:

[Turin, 26-Nov-95]

1 Day-Ray p/n 70-94 fluorescent light ballast s/n 81818D installed on the left overhead storage compartment at Sta. 847 was the ignition source for the fire.

2 When the ballast case suffered violent rupture, smoke and flames travelled outwards from the rupture, the duration of the flames could not have been determined exactly but even a little flame at not more than 1550^{o}F and lasting approximately **less than 2 seconds** would have been sufficient to ignite the insulation covering ORCOFILM AN-43 DMS 2072K TYPE 2 CLASS 1 GRADE A.

3 A horizontal flame (very narrow) ignited the outer covering of the insulation blankets under the support rail of the overhead storage compartment; the other part of the flame (vertical) contacted the support rail, the dust scal and the outboard ceiling panel and, at last, it threaded its way out up to the insulation covering blanket mentioned above and burned it again.

4 Once the insulation covering began to burn, the fire spread within the ceiling panels, the temperature raised quickly and drippings coming from the insulation covering dropped on the outboard ceiling panels that began to burn from inside; as a consequence the adjacent dust seal attached to the edge of the outboard ceiling panel began to smoulder in different areas.

A secondary analysis of cabin fire propagation can be formulated considering that the duration of the flame erupted from ballast is not less than 30 seconds and the flame is directed towards the dust flap and the outboard edge of the outboard ceiling panel.

When the ballast case rupture occurred, a flame was emitted which contacted the ceiling panel dust flap and the outboard edge of the outboard ceiling panel. Even if this flame could be able to burn the dust flap adjacent to the outboard edge of the ceiling panel and contributed to the ignition of the outboard ceiling panel, it is sure that after the burning of outboard ceiling panel this latter ignited the mylar outer covering of the insulation blankets due to its upper position. The fire spread within the ceiling panel very rapidly through the mylar and drippings coming from mylar dropped on the ceiling panels contributing to rise quickly the temperature because the flames involved the ceiling panels and other materials.

I.I.T. knows that some fire extinguishers bottles were discharged in proximity of the station 847 because smoke was observed by crew members in this area. This intervention was unsuccessful because the flames were internal to the ceiling panels. A confirmation to this fact is given by the witness of a cabin flight attendant.

The fire brigades extinguished the cabin fire avoiding further propagation of the flames inside the ceiling panels of the passenger cabin.

Appendix 2 Total Flying Hours for Western-Built Aircraft

1 Total Flight Hours for Period 1991 - 2000 (Hours x 10^3)

Aircraft Weight Category	B*	C	D	E	Total
Western-Built Turbojets	18,820	172,670	41,110	61,310	293,910
Western-Built Turboprops	36,780	440	0	0	37,220
Total	**55,600**	**173,110**	**41,110**	**61,310**	**331,130**

* Weight Category B aircraft with more than 30 seats

2 Total Flight Hours for Period 1988 - 2000 (Hours x 10^3)

Aircraft Weight Category	B*	C	D	E	Total
Western-Built Turbojets	21,490	209,660	49,710	75,080	355,940
Western-Built Turboprops	44,600	770	0	0	45,370
Total	**66,090**	**210,430**	**49,710**	**75,080**	**401,310**

* Weight Category B aircraft with more than 30 seats

Data Source: United Kingdom Civil Aviation Authority World Fleet Hours

Appendix 3 Accidents with Fire in Hidden Areas

Occurrence 1

<table>
<tr><th>Date</th><th colspan="2">Source of Information</th><th>Aircraft Type</th></tr>
<tr><td>26-Jul-69</td><td colspan="2">Adapted from French Republic, Ministry of Transport, Secretariat General for Civil Aviation report on "Accident to Caravelle Air Algerie 7T-VAK on 26th July 1969 at Biskra" dated 27.8.69</td><td>Caravelle</td></tr>
<tr><th>Operator</th><th colspan="2">Location</th><th>Registration</th></tr>
<tr><td>Air Algerie</td><td colspan="2">Biskra, Algeria</td><td>7T-VAK</td></tr>
<tr><th>Total Aboard</th><th>Fatalities</th><th>Serious Injuries</th><th>Time to become uncontrollable</th></tr>
<tr><td>37</td><td>35</td><td>Unknown</td><td>26 minutes</td></tr>
</table>

Description of Accident

An intense in-flight fire in the forward vestibule area caused the crew to make a successful emergency landing in the dark in open country. Emergency exits were opened before touchdown; two passengers exited from these but unfortunately were ingested by the engines. It is assumed that due to the intense fire the remaining passengers were unable to evacuate.

Rationale of Estimate of lives to be saved

There is insufficient data to confirm that the fire was in a hidden area. However, it was stated to be in the forward vestibule area and hence in all likelihood it was not extinguished because the crew could not access the source. On this basis, the Median prediction of lives to be saved from elimination of fires in hidden areas is taken as half the actual number of fatalities.

<table>
<tr><td>Fatalities in actual accident</td><td colspan="2">35</td></tr>
<tr><td rowspan="3">Estimate of lives saved</td><td>High</td><td>35</td></tr>
<tr><td>Median</td><td>17</td></tr>
<tr><td>Low</td><td>0</td></tr>
</table>

Occurrence 2

Date	Source of Information		Aircraft Type
6-May-70	Ministry of Communications and Transport, Department of Civil Aviation, Accident Report No. 6, (Mogadiscio, dated 22 August 1970)		Viscount 785
Operator	**Location**		**Registration**
Somali Airlines	Mogadiscio International Airport, Somalia		60S-AAJ
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
30	5	9	3 minutes

Description of Accident

A number of the passengers saw the outbreak of fire from under the cabin floor when the aircraft was on short final. The pilots unaware of the fire, experienced complete loss of control of the aircraft at a distance of approximately 2 kilometres from touchdown. The aircraft, however, continued to fly on the correct heading towards the runway and a slight nose-down attitude was corrected by the application of power. The aircraft landed heavily exactly on the centreline and on the threshold of runway 24. The nosewheel hit first and the gear sheared rearwards. The aircraft continued rolling on its main gear with the nose on the ground. It came to rest after nearly 900 metres; the fire then developed quickly and destroyed most of the aircraft fuselage. The majority of the passengers and all the crew were able to evacuate the aircraft timely, however five children perished.

Rationale of Estimate of lives to be saved

It is not known exactly where the fire started however it would appear that the crew was unable to access and extinguish the fire. It is conservatively assessed that any enhancements pertaining to fires in hidden areas are most likely not to have resulted in any life saving.

Fatalities in actual accident		5
Estimate of lives saved	**High**	5
	Median	0
	Low	0

Occurrence 3

Date	Source of Information		Aircraft Type
11-Jul-1973	Cabin Safety Research Technical Group Accident Database, Version 4.3, Issue 16, Accident reference 19730711A		Boeing 707
Operator	**Location**		**Registration**
Varig	Orly, near Paris, France		PP-VJZ
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
134	123	11	7 minutes

Description of Accident

On 11-Jul-1973 a Varig B707 registered as PP-VJZ was descending to Orly, near Paris, France. The aircraft reported a problem with fire on board and requested an emergency descent. This request followed a report by cabin personnel of smoke in the rear of the passenger cabin. In reply to a request by control, the pilot reported total fire which was prompted by the alarming announcement of the chief steward, who stated that the situation was becoming more and more serious, that smoke had invaded the cabin and that passengers were being asphyxiated. At about this time smoke was smelled in the cockpit.

The crewmembers put on oxygen masks and anti smoke goggles but there was so much black smoke in the cockpit that the pilot could no longer see the instruments and the side windows were therefore opened. The captain then decided that, in view of the untenable situation, a forced landing was necessary. This was carried out with the pilots looking at the ground through the side windows.

The aircraft made a forced landing in level ground used for market gardening. The impact was very hard and the aircraft slid on its engines and then on its belly for almost 500 m. The aircraft came to rest having lost all its engines and half of the left wing but the fuselage sustained little damage.

Of the 17 crew and 117 passengers aboard, 7 crew and 116 passengers suffered fatal injuries, 10 crew and 1 passenger suffered serious injuries.

[11-Jul-73 Orly]

Pertinent extract from the Accident Report:

"Although the hypothesis of a fire which originated in the left toilet cannot definitely be excluded, it is more likely that the fire started and developed in the aft right toilet, probably in the washbasin unit."

"It can be assumed that the fire was already propagating in the false ceiling …"

Rationale of Estimate of lives to be saved

It is clear from the accident report that the fire was between the trim and fuselage above floor level and hence it would appear to be in a hidden area. However, precise details of the fire source are not known. Hence, the Median prediction of lives to be saved from the elimination of fires in hidden areas has been set at approximately 80% of the actual number of fatalities.

Fatalities in actual accident		123
Estimate of lives saved	**High**	123
	Median	100
	Low	0

Occurrence 4

Date	Source of Information		Aircraft Type
26-Nov-79	Cabin Safety Research Technical Group Accident Database, Accident reference 19791126A.		Boeing 707
Operator	**Location**		**Registration**
Pakistan International Airlines	Jeddah, Saudi Arabia		AP-AWZ
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
156	156	0	17 minutes

Description of Accident

On 26-Nov-1979, a Pakistan International Airlines (PIA) Boeing B707-300, registered as AP-AWZ, struck the ground while attempting to return to Jeddah Airport, Saudi Arabia. The aircraft was destroyed. There were 11 crewmembers and 145 passengers aboard and all suffered fatal injuries.

At 0105 hours, 21 minutes after take-off the flight crew reported smoke in the cockpit coming from the cabin area. They requested and received ATC clearance to return to Jeddah and to leave their cruising level. An emergency descent was executed while attempting to return to Jeddah. The aircraft struck the ground in a level rocky area at 3300ft, exploded and burned.

An inflight fire started in the aft cabin and rapidly spread throughout the aircraft. The origin of the fire was not determined. Incorrect emergency and smoke evacuation procedures were carried out and smoke incapacitated the flight crew.

Rationale of Estimate of lives to be saved

There is insufficient data to confirm that the fire was in a hidden area. However, in all likelihood it was not extinguished because the crew could not access the source. On this basis, the Median prediction of lives to be saved from elimination of fires in hidden areas is taken as half the actual number of fatalities.

Fatalities in actual accident		156
Estimate of lives saved	**High**	156
	Median	78
	Low	0

Occurrence 5

Date	Source of Information		Aircraft Type
02-Jun-83	Cabin Safety Research Technical Group Accident Database - Accident Reference 19830602A		DC9-32
Operator	**Location**		**Registration**
Air Canada	Cincinnati International Airport, USA		C-FTLU
Total Aboard	**Fatalities**	**Serious Injuries**	**Time to become uncontrollable**
46	23	0	19 minutes

Description of Accident

On 2-Jun-1983 Air Canada DC9-32 registered as C-FTLU was flying from Dallas to Montreal. While en route at 33,000 feet, the cabin crew discovered a hidden fire in the aft lavatory. After attempting to extinguish it an emergency descent and landing was made to Greater Cincinnati International Airport. After the subsequent evacuation a flash fire occurred within the cabin.

The Safety Board concluded the air conditioning packs were turned off at least 4 minutes before the aeroplane landed (almost two complete changes of cabin and cockpit air otherwise would have occurred). There was subsequently virtually no fresh air supply to the cockpit and cabin.

Of the 5 crew and 41 passengers, 23 passengers were not able to get out of the aircraft and died in the fire (for further details on this accident see Appendix 1).

Pertinent extract from the Accident Report:

"Propagation.- regardless of the ignition source, the physical evidence showed that there was an area of intense burning in the lower aft outboard corner of the lowest section of the amenities section, and it also showed that the fire propagated forward from that point. As the fire moved forward from the amenities section, it also burned through the lavatory walls allowing smoke, hot gases, and fumes to rise to the air space between the lavatory shell and the airplane's outer skin and between the aft pressure bulkhead and the lavatory's liner walls."

[02-Jun-83 Cincinnati]

Rationale of Estimate of lives to be saved

The precise source of the fire was not established. however it propagated between the trim panels and the fuselage. As the aircraft successfully landed, even a slowing of the propagation of the fire would have allowed all passengers to successfully evacuate. It is therefore assessed that enhancements to fires in hidden areas would have resulted in all lives being saved.

Fatalities in actual accident		23
Estimate of lives saved	**High**	23
	Median	23
	Low	23

Occurrence 6

<table>
<tr><th>Date</th><th colspan="2">Source of Information</th><th>Aircraft Type</th></tr>
<tr><td>02-Sep-98</td><td colspan="2">Cabin Safety Research Technical Group Accident Database - Reference 19980902A and TSB Aviation Safety Recommendations Report "The Circumstances of Swiss Air Flight 111 accident"</td><td>MD-11</td></tr>
<tr><th>Operator</th><th colspan="2">Location</th><th>Registration</th></tr>
<tr><td>Swiss Air</td><td colspan="2">Peggy's Cove, Nova Scotia, Canada</td><td>HB-IWF</td></tr>
<tr><th>Total Aboard</th><th>Fatalities</th><th>Serious Injuries</th><th>Time to become uncontrollable</th></tr>
<tr><td>231</td><td>231</td><td>0</td><td>16 minutes</td></tr>
</table>

Description of Accident

On 2-Sep-1998, about 2230 local time, a Swiss Air flight 111, McDonnell Douglas MD-11, registered as HB-IWF, crashed into a bay near Blandford, Nova Scotia (the nearest area is called Peggy's Cove).

56 minutes into the flight in normal cruise at FL330, the flight crew issued a 'Pan'-call reporting smoke in the cockpit and requesting emergency vectoring to the nearest airport, which they thought was Boston. The Moncton controller cleared the flight to descend to FL310 and offered Halifax as the closest airport available, which was accepted by the crew. The flight was handed over to Moncton Centre and was vectored for a back course approach to Halifax runway 06. Whilst the airplane was just 30 miles from the threshold, so Moncton Centre vectored the plane for a 360-degree turn to lose some altitude and to dump fuel off the coast. The situation in the cockpit apparently became worse. At this point and about 10 minutes after the first alert message, the crew declared an emergency and reported that they were starting the fuel dump and that they had to land immediately.

There were no more radio communications and the aircraft disappeared from radar approximately 5nm off Peggy's Cove and 35nm from the airport off the Nova Scotia coast. The airplane hit the water 16 minutes later after alert message.

There were 14 crewmembers and 217 passengers (including 2 children) aboard - all were fatally injured. The plane was destroyed as a result of the accident.

[02-Sep-98 Peggy's Cove]

Since the aircraft crashed into water, all fire damage occurred in flight. The ongoing investigation (A98H0003) has identified substantial fire damage above the drop-down ceiling in the forward section of the aircraft extending about 1.5 metres forward and 5 metres aft of the cockpit wall.

Rationale of Estimate of lives to be saved

As the nature of the fire and its source are known it is assessed that enhancements pertaining to fires in hidden areas are most likely to have resulted in all lives being saved.

Fatalities in actual accident		231
Estimate of lives saved	**High**	231
	Median	231
	Low	231