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A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion

December 1999

Final Report

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16. Abstract

The International Cabin Safety Research Technical Group's Survivable Accidents Database was used to identify past worldwide transport aircraft accidents and extract detailed data for those accidents where explosion 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 might be saved if the fuel tanks were protected with nitrogen inerting systems.

The objective of this analysis was to assess the potential benefits, in terms of reducing fatalities and injuries, resulting from three methods of aircraft fuel tank inerting. The methods analyzed were ground nitrogen inerting in centre fuel tank only, ground nitrogen inerting in all fuel tanks, and onboard nitrogen inerting in all fuel tanks.

Thirteen accidents to transport category aircraft were identified during the period from 1966 to 1995 that may have involved a fuel tank explosion. A mathematical technique was used to model each accident scenario and a Monte Carlo simulation was used to assess a high, median, and low value for the total achievable benefits.

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EXECUTIVE SUMMARY

The objective of this analysis was to assess the potential benefits, during an aircraft ground fire, in terms of reducing fatalities and injuries, resulting from three methods of aircraft fuel tank inerting:

- Ground nitrogen inerting in centre fuel tank only.
- Ground nitrogen inerting in all fuel tanks.
- Onboard nitrogen inerting in all fuel tanks.

The International Cabin Safety Research Technical Group's Survivable Accidents Database was used to identify past worldwide transport aircraft accidents and extract detailed data for those accidents where explosion was an issue in the survivability of the occupants. Only accidents in which a fuel tank explosion occurred, but was not the prime cause of the accident, were selected since this latter category of accidents has been the subject of a separate study carried out by the Aviation Rulemaking Advisory Committee—Fuel Tank Harmonization Working Group. Each of these accidents was analysed in depth to assess the number of lives and injuries that might be saved if Nitrogen Inerting Systems were used.

Thirteen worldwide accidents to transport category aircraft were identified during the period from 1966 to 1995 that may have involved a fuel tank explosion. A mathematical technique was used to model each accident scenario and a Monte Carlo simulation was used to assess a high, median, and low value for the total achievable benefits.

The best estimate (median) of the number of lives saved per year, based on an analysis of the period covered by the data for the three methods of inerting, is assessed to be

- Ground nitrogen inerting – centre tank only 0.3
- Ground nitrogen inerting – all fuel tanks 2.4
- Onboard nitrogen inerting – all fuel tanks 6.0

The predicted potential number of lives saved per year is relatively small compared to other survivability factors. One of the reasons that nitrogen inerting may not be effective, in terms of saving lives in the 13 accidents analysed, is that in many cases, fuel tanks were ruptured when the aircraft impacted the ground. Any nitrogen in the fuel tanks is likely to have escaped with the spilled fuel. The system is only effective when the fuel tanks are not significantly ruptured.

1. INTRODUCTION.

This report contains the method and results of a benefit analysis carried out on nitrogen inerting systems intended to provide a degree of protection against fuel tank explosions. Nitrogen inerting systems provide nitrogen to fuel tank ullage, displacing the air, and preventing an explosive atmosphere from developing in the fuel tanks.

A number of past accidents have been identified which are considered to have involved fuel tank explosions with a consequential threat to occupant survival. Accidents where the prime cause was fuel tank explosion have been excluded since they have been the subject of a separate study [1] carried out by the Aviation Rulemaking Advisory Committee (ARAC)—Fuel Tank Harmonization Working Group. The ARAC is an industry commitee commissioned by the Federal Aviation Administration (FAA) to study and advise on potential industry regulatory changes for the Office of Rulemaking. The accidents addressed in this study are those where a fuel tank explosion has occurred postimpact or ground fire.

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 resulting from the use of nitrogen inerting systems. The assessment of benefit has been made for three different methods of inerting:

1. Ground nitrogen inerting in centre fuel tank only.
2. Ground nitrogen inerting in all fuel tanks.
3. Onboard nitrogen inerting in all fuel tanks.

Section 9 contains the definition of terms used in this study.

The methodology utilised is aimed at providing an indication as to the order of benefit likely to be achieved. Since the frequency of occurrence of fuel tank explosions is relatively low, there are insufficient data available to determine precise values. However, a range of benefit has been assessed in which the absolute value is likely to lie.

Certain assumptions have been made in the analysis of data, as described in paragraph 5.1.

2. OBJECTIVES.

The objective of this study was to assess the number of injuries and lives that might be saved per year from ground and onboard nitrogen inerting of aircraft fuel tanks in transport category survivable accidents where a fuel tank explosion occurred but was not the prime cause of the accident.

3. SELECTION OF ACCIDENTS.

The accidents were selected using the Survivable Accidents Database of the International Cabin Safety Research Technical Group. Issue 9, the latest compilation of this database, contained 364

accidents involving fatalities. Of this number 146 were fire-related accidents and 82 contained detailed textural information from accident reports.

The first step in identifying accidents that might have involved fuel tank explosions was to search the database text for the following characters:

- EXPLO—representing exploded, explosion, etc.
- BALL—representing fireball
- ERUPT—representing phrases such as the fuel tank erupted
- BLEW—representing phrases such as the fuel tank blew up
- BLOW—representing phrases such as the fuel tank was thought to have blown up

Forty-six fire-related accidents were identified that contained at least one of these words. The textural information in the database was studied in detail and 31 of the accidents were eliminated as not being likely to have involved a fuel tank explosion.

One accident identified by this process also formed part of the ARAC study described in reference 1, involving eight fatalities on a Boeing 737 on the 11th May 1990. This has therefore not been included in the group for this analysis. The reason for the remaining accidents forming part of the ARAC study not being identified is that they do not form part of the Survivable Accidents Database. This is primarily because either they were considered nonsurvivable or they are outside of the period covered by the database.

The resulting 14 identified accidents that may have involved a fuel tank explosion are shown in table 1.

TABLE 1. LIST OF ACCIDENTS INITIALLY IDENTIFIED BY CHARACTER SEARCH

Date	Location	Aircraft
14-Sep-1993	Warsaw, Poland	A320
21-Dec-1992	Faro, Portugal	DC10
14-Feb-1990	Bangalore, India	A320
15-Nov-1987	Denver, CO	DC9
29-Mar-1979	Quebec, Canada	F27
4-Apr-1977	New Hope, AL	DC9
20-Nov-1974	Nairobi, Kenya	B747
7-Jun-1971	New Haven, CT	CV580
28-Dec-1970	St Thomas, VI	B727
27-Nov-1970	Anchorage, AK	DC8
2-Oct-1970	Silver Plume	M404*
08-Apr-1968	Heathrow, London, England	B707
20-Nov-1967	Greater Cincinnati Airport, KY	CV880
5-Mar-1967	Monrovia, Liberia	DC8

Note: Asterisk (*) refers to an aircraft with reciprocating engines.

The 14 accidents, shown in table 1, were studied further and one accident was eliminated from the list because it involved an aircraft with reciprocating engines which did not fit the criteria of this study. This revised list with the 13 accidents is shown in table 2. It may be seen that each accident has been classified into three categories. YES indicates that the accident did involve a fuel tank explosion. PROBABLE indicates that the accident in all probability involved a fuel tank explosion. POSSIBLE indicates that the weight of evidence suggests that the accident involved a fuel tank explosion but from the data currently available this cannot be confirmed as being the case.

TABLE 2. ACCIDENTS IDENTIFIED AS LIKELY TO HAVE INVOLVED FUEL TANK EXPLOSIONS

Identification No.	Date	Location	Aircraft	Fuel Tank Explosion	Category
1	14 Sep 1993	Warsaw, Poland	A320	Centre	Yes
2	21 Dec 1992	Faro, Portugal	DC10	Centre and Wing	Probable
3	14 Feb 1990	Bangalore, India	A320	Wing	Yes
4	15 Nov 1987	Denver, CO	DC9	Centre	Yes
5	29 Mar 1979	Quebec, Canada	F27	Wing	Yes
6	4 Apr 1977	New Hope, AL	DC9	Centre/Wing	Possible
7	20 Nov 1974	Nairobi, Kenya	B747	Centre and Wing	Yes
8	7 Jun 1971	New Haven, CT	CV580	Centre/Wing	Possible
9	28 Dec 1970	St Thomas, VI	B727	Centre/Wing	Probable
10	27 Nov 1970	Anchorage, AK	DC8	Wing	Probable
11	8 Apr 1968	Heathrow, London, England	B707	Wing	Yes
12	20 Nov 1967	Greater Cincinnati Airport, KY	CV880	--	Possible
13	5 Mar 1967	Monrovia, Liberia	DC8	Centre and Wing	Probable

Notes: 1. -- refers to location of explosion unknown
2. / refers to either one

4. METHOD.

4.1 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, and 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 forward 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, where sufficient data are available, the analytical work carried out during this study has been based on carrying out assessments for each scenario.

4.2 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. In this case, the survivability factor is amelioration of fuel tank explosions by nitrogen inerting. Where sufficient data were available, each accident was divided into scenarios.

An example of the model and the effects of improvement in injuries and fatalities resulting from nitrogen inerting of fuel tanks are demonstrated in figures 1 and 2. Figure 1 gives a typical survability chain for a survivable accident scenario.

This figure is interpreted by first examining the total number of people affected by each hazard (impact, fire) which is reflected by an arrow at the top of the hazard (in this case 100), and the results of that hazard are then interpreted by examining the arrows at the bottom of each hazard, which when read in a “clockwise manner” are fatalities, injuries, and survivors.

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).

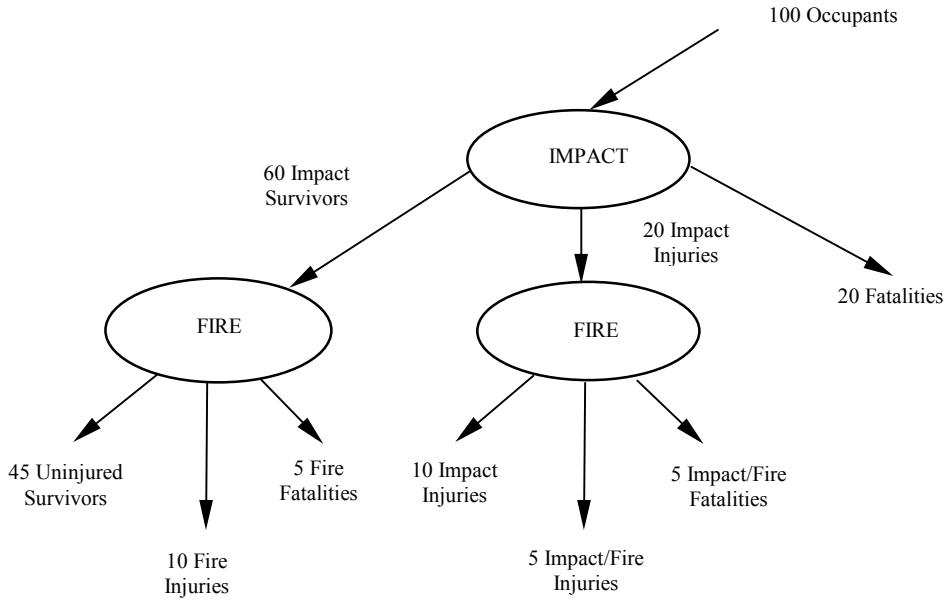


FIGURE 1. EXAMPLE SURVIVABILITY CHAIN

If nitrogen inerting was used in aircraft fuel tanks such that 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 2.

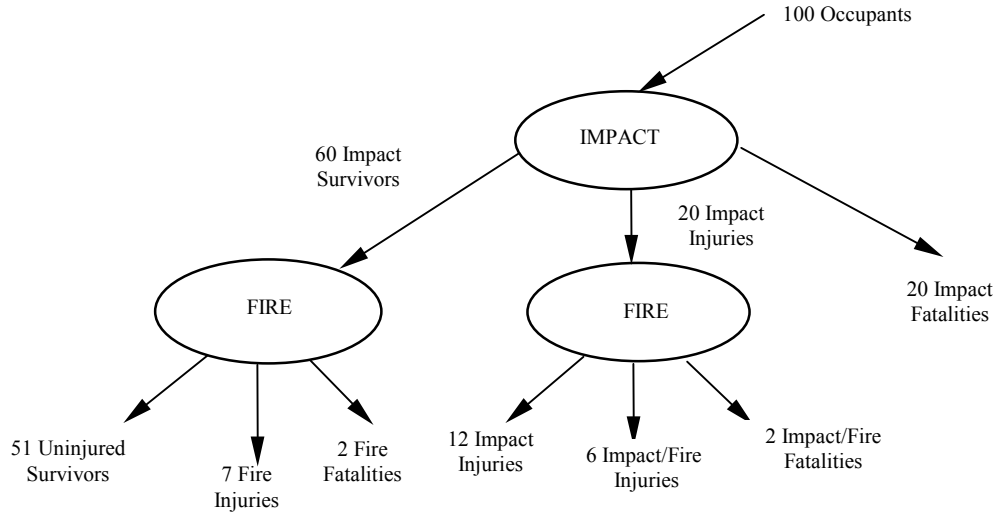


FIGURE 2. EXAMPLE OF SURVIVABILITY CHAIN SHOWING POSSIBLE IMPROVEMENTS IN SURVIVABILITY AS A RESULT OF NITROGEN INERTING

Therefore, the results in improvement through nitrogen inerting of fuel tanks are

- 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

Hence, in this example the assessment would be that there are six lives to be saved as a result of nitrogen inerting of fuel tanks. The analysis of each accident and the rationale for the benefit assessment is presented in appendix A.

4.3 STATISTICAL MODELLING.

As in the example described in section 4.2, the most likely (or median) assessments were made of the improvement in the number of fatalities and injuries resulting from nitrogen inerting on fuel tanks. 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.

It was assumed that there could be 100% confidence that the fatalities and injuries will lie in the range from the maximum to the minimum.

Data from the survivability chains in each scenario in each accident was used as the input to the Monte Carlo simulation software package. The software was developed to evaluate the number of survivors, injuries, and fatalities resulting from predictions of the range of improvements that may be possible from changes to a survivability factor. This simulation process is described in detail in appendix B.

The software model made 9999 iterations of random selections over the range 0% to 100% to arrive at a particular number of fatalities and injuries. Results are presented for the 2.5, 50, and 97.5 percentile points from the resulting distributions.

The numerical assessment and Monte Carlo simulations were repeated for each of the three different methods of nitrogen inerting considered.

5. ANALYSIS AND RESULT.

5.1 ASSUMPTIONS.

The assumptions made in this report are based on the following:

1. Any ground inerting system would prevent fuel tank explosion in accidents occurring on takeoff or immediately after takeoff (unless fuel tanks are severely ruptured and nitrogen lost).

2. Ground inerting would not have prevented fuel tank explosion occurring at the end of a flight.

3. All fuel tank explosions would have been prevented by the use of onboard inerting systems (unless fuel tanks are severely ruptured and nitrogen lost).

4. For ground inerting, it is assumed that the fuel levels are such that adequate nitrogen may be carried in centre or wing tanks to prevent tank explosion during takeoff.

5. In some instances, from the data available, although an "explosion" occurred, it was not possible to be sure that the fuel tank exploded. In these cases it was assumed that the explosion was attributable to the fuel tanks.

6. Any benefits to be gained from cabin safety improvements resulting from later requirements are small in comparison to the threat rendered to occupants from fuel tank explosions.

5.2 OVERALL BENEFIT DERIVATION.

5.2.1 Results.

Table 3 lists the assessed median number of lives that could be saved if nitrogen inerting systems were employed in the accidents that have been identified where explosions were involved.

TABLE 3. ASSESSED MEDIAN BENEFIT ON ALL 13 ACCIDENTS ANALYSED

				Benefit		
				Ground Inerting		Onboard Inerting All Tanks
Identification No.	Date	Location	Aircraft	Centre Tank	All Tanks	
1	14 Sep 1993	Warsaw, Poland	A320	No benefit	No benefit	1 life saved
2	21 Dec 1992	Faro, Portugal	DC10	No benefit	No benefit	27 lives saved
3	14 Feb 1990	Bangalore, India	A320	No benefit	No benefit	No benefit
4	15 Nov 1987	Denver, CO	DC9	2 serious injuries saved	2 serious injuries saved	2 serious injuries saved
5	29 Mar 1979	Quebec, Canada	F27	--	No benefit	No benefit
6	4 Apr 1977	New Hope, AL	DC9	No benefit	No benefit	15 lives saved
7	20 Nov 1974	Nairobi, Kenya	B747	5 lives saved	21 lives saved	21 lives saved
8	7 Jun 1971	New Haven, CT	CV580	No benefit	No benefit	12 lives saved
9	28 Dec 1970	St Thomas, VI	B727	No benefit	No benefit	2 lives saved
10	27 Nov 1970	Anchorage, AK	DC8	No benefit	15 lives saved	15 lives saved
11	8 Apr 1968	Heathrow, London, England	B707	No benefit	5 lives saved	5 lives saved
12	20 Nov 1967	Greater Cincinnati Airport, KY	CV880	--	No benefit	No benefit
13	5 Mar 1967	Monrovia, Liberia	DC8	No benefit	No benefit	3 lives saved

Note: -- refers to no centre tank fitted

Table 4 presents the high, median (best estimate), and low predictions of the effect on the total number of fatalities and injuries based on 9999 iterations across the 13 explosion-related accidents identified on the database using the method described in section 3.

TABLE 4. SUMMARY OF MONTE CARLO SIMULATIONS ON PREDICTED REDUCTION OF FATALITIES AND INJURIES FOR THE ACCIDENTS STUDIED

	LOW	MEDIAN	HIGH
REDUCTION IN FATALITIES			
Ground nitrogen inerting – centre tank only	2	5	8
Ground nitrogen inerting – all fuel tanks	32	41	50
Onboard nitrogen inerting – all fuel tanks	82	101	120
REDUCTION IN INJURIES (Fatal and Serious Injuries)			
Ground nitrogen inerting – centre tank only	1	3	4
Ground nitrogen inerting – all fuel tanks	4	27	45
Onboard nitrogen inerting – all fuel tanks	48	85	117

5.2.2 Number of Fire-Related Accidents.

Thirteen accidents were identified as matching the selection criteria in section 3 and were considered appropriate to use for the benefit analysis. Figure 3 illustrates the relationship of these 13 accidents with respect to the 364 fatal accidents in the Survivable Accidents Database.

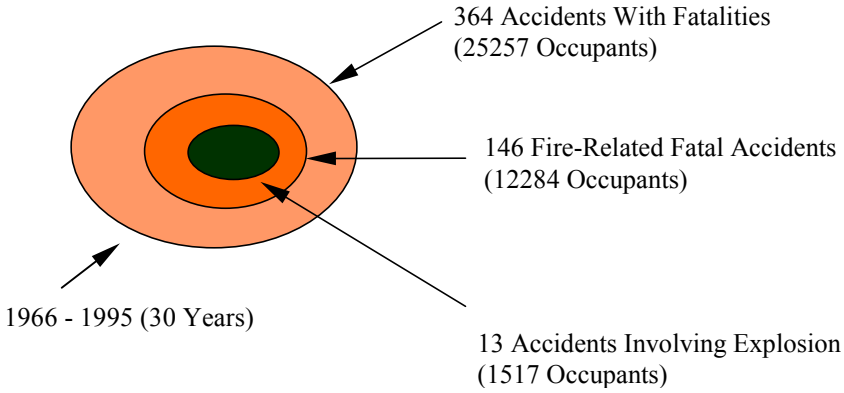


FIGURE 3. BREAKOUT OF FIRE AND EXPLOSION-RELATED ACCIDENTS

It is considered likely that there are other accidents where explosion was an issue but because there are little or no data available they cannot currently be identified. If other explosion accidents have occurred then the derived benefit would increase. From a study using the data from the Survivable Accidents Database, it is assessed that of the worldwide fire-related fatal accidents (currently 146 on the database) only 82 accidents (56%) have sufficient data to assess whether explosion 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 1.78 times (1/0.56) those contained in table 4.

Therefore, applying this factor to the benefit derived from the accidents studied results in the assessed median lives saved as shown in table 5 below.

TABLE 5. SUMMARY PREDICTED REDUCTION OF FATALITIES AND INJURIES (WITH FACTOR INCLUDED)

	LOW	MEDIAN	HIGH
REDUCTION IN FATALITIES			
Ground nitrogen inerting – centre tank only	4	9	14
Ground nitrogen inerting – all fuel tanks	57	72	89
Onboard nitrogen inerting – all fuel tanks	146	180	214
REDUCTION IN INJURIES (Fatal and Serious Injuries)			
Ground nitrogen inerting – centre tank only	2	6	7
Ground nitrogen inerting – all fuel tanks	7	48	80
Onboard nitrogen inerting – all fuel tanks	85	151	209

Table 6 presents the reduction of average fatalities and injuries per year over the 30 year period 1966 to 1995.

TABLE 6. SUMMARY PREDICTED REDUCTION OF FATALITIES AND INJURIES (WITH FACTOR INCLUDED) PER YEAR

	LOW	MEDIAN	HIGH
REDUCTION IN FATALITIES			
Ground nitrogen inerting – centre tank only	0.1	0.3	0.5
Ground nitrogen inerting – all fuel tanks	1.9	2.4	3.0
Onboard nitrogen inerting – all fuel tanks	4.9	6.0	7.1
REDUCTION IN INJURIES (Fatal and Serious Injuries)			
Ground nitrogen inerting – centre tank only	0.1	0.2	0.2
Ground nitrogen inerting – all fuel tanks	0.3	1.6	2.7
Onboard nitrogen inerting – all fuel tanks	2.9	5.0	7.0

Figure 4. Shows the reduction in fatalities due to the three different nitrogen inerting methods considered together with the 95 percentile range for the prediction.

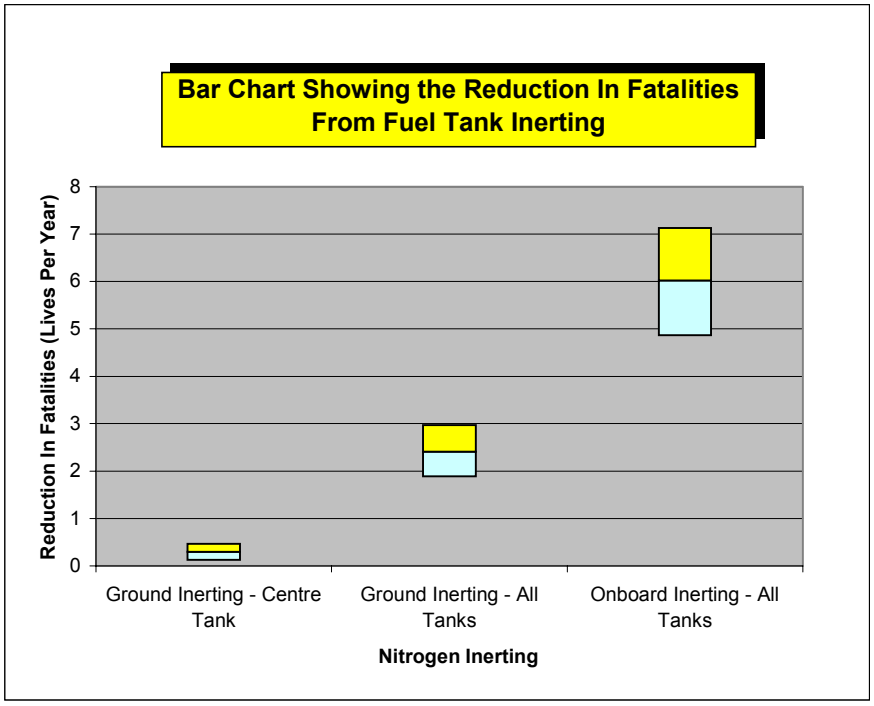


FIGURE 4. NUMBER OF LIVES SAVED PER YEAR

Figure 5 shows the reduction in number of injuries due to nitrogen inerting systems together with the 95 percentile range for the prediction.

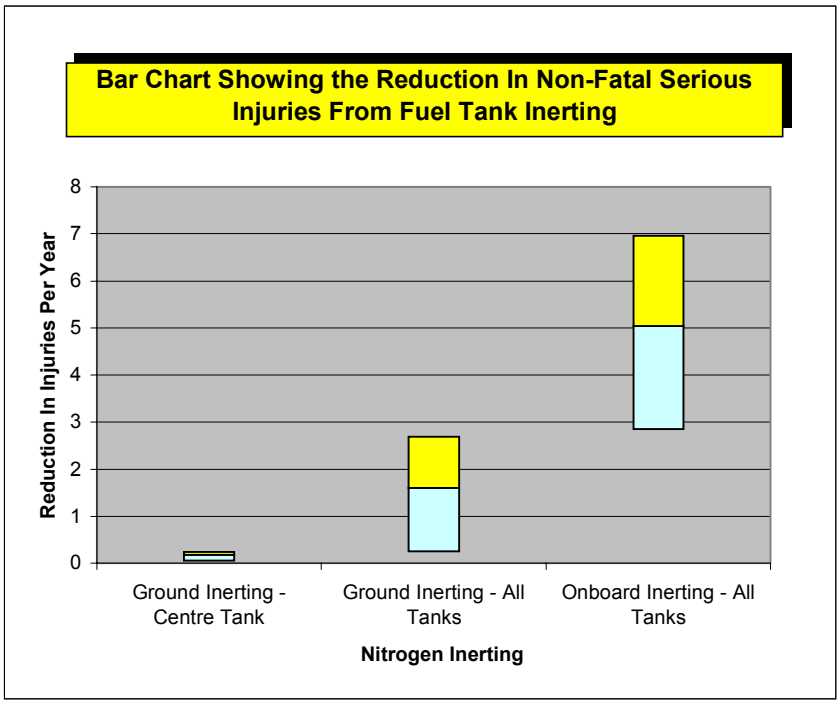


FIGURE 5. REDUCTION IN FATAL AND SERIOUS INJURIES PER YEAR

5.3 PHASE OF FLIGHT AND LOCATION OF FUEL TANK EXPLOSION.

Table 7 shows the phase of flight and location of fuel tank explosion for each accident analysed. Five of the accidents happened in the takeoff phase. Eight accidents occurred in the approach and landing phases which means ground inerting would not have provided any benefit.

TABLE 7. FLIGHT PHASE AND FUEL TANK EXPLOSION LOCATION OF ACCIDENTS IDENTIFIED

Identification No.	Date	Location	Aircraft	Phase of Flight	Location of Fuel Tank Explosion
1	14 Sep 1993	Warsaw, Poland	A320	Landing	Centre
2	21 Dec 1992	Faro, Portugal	DC10	Landing	Centre and Wing
3	14 Feb 1990	Bangalore, India	A320	Final Approach	Wing
4	15 Nov 1987	Denver, CO	DC9	Takeoff	Centre
5	29 Mar 1979	Quebec, Canada	F27	Initial Climb	Wing
6	4 Apr 1977	New Hope, AL	DC9	Landing	Centre/Wing
7	20 Nov 1974	Nairobi, Kenya	B747	Initial Climb	Centre and Wing
8	7 Jun 1971	New Haven, CT	CV580	Approach	Centre/Wing
9	28 Dec 1970	St Thomas,VI	B727	Landing	Centre/Wing
10	27 Nov 1970	Anchorage, AK	DC8	Takeoff	Wing
11	8 Apr 1968	Heathrow, London, England	B707	Takeoff then landing	Wing
12	20 Nov 1967	Greater Cincinnati Airport, KY	CV880	Approach	--
13	5 Mar 1967	Monrovia, Liberia	DC8	Approach	Centre and Wing

Notes: 1. -- refers to location of explosion unknown
2. / refers to either one

5.4 PROBABILITY OF FUEL TANK EXPLOSION IN RELATION TO THE SIZE OF AIRCRAFT.

An attempt has been made to ascertain whether the size of aircraft influences the probability of fuel tank explosion. Table 8 shows the number of fire-related accidents from the database involving fatalities by weight category. Weight categories are defined in terms of maximum takeoff weight (MTOW) as follows:

A = less than 12,500 lb
B = 12,500 - 100,000 lb
C = 100,000 - 250,000 lb
D = 250,000 - 400,000 lb
E = greater than 400,000 lb

TABLE 8. DISTRIBUTION OF ACCIDENTS BY WEIGHT CATEGORY

	WEIGHT CATEGORY					
	A	B	C	D	E	Total
Fire-Related Accidents	3	60	79	30	16	188
13 Accidents Observed	0	2	6	3	2	13
13 Accidents Expected	0.2	4.1	5.5	2.1	1.1	13
χ^2	0.21	1.11	0.05	0.41	0.72	2.51

The number of accidents in each weight category, for the 13 accidents considered as involving, or likely to have involved, fuel tank explosions are also shown in table 8. These are designated as "13 Accidents Observed." If the size or weight of the aircraft had no influence on the risk of fuel tank explosion, then they would be distributed similarly to the entire population of fire-related fatal accidents. The row entitled "13 Accidents Expected" shows the distribution of accidents that might be expected if this were the case. It should be noted that there is not a marked difference between the actual number of accidents by weight category and what might be expected if the probability of explosion was to be totally independent of aircraft size.

A χ^2 "goodness of fit" test has been performed on the distribution of explosion-related accidents by weight category to ascertain whether weight or size is of any significance in the probability of fuel tank explosion.

A χ^2 value of 2.51 has been determined with 4 degrees of freedom.

Based on this, no significance can be attached to the hypothesis that fuel tank explosions are related to aircraft size. This does not mean that aircraft size has no influence on the risk of explosion but merely that insufficient evidence exists to support such a hypothesis.

6. DISCUSSION.

6.1 ACCURACY OF PREDICTIONS.

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 nitrogen inerting than would otherwise be derived from a simple estimate of the resultant change in number of survivors.

6.2 ASSUMPTIONS.

With reference to section 5.1, certain assumptions had to be made in this analysis due to the lack of precise data for some accidents. It was assumed that the nitrogen inerting systems would perform their intended purpose, which is to prevent fuel tank explosions. In most accidents, this assumption may be slightly optimistic based on the following:

1. In some instances, the fuel tanks may have been punctured, during impact with the ground, in such a way that nitrogen escaped thus rendering inerting ineffective.

2. An explosion reported in the aircraft accident report may not be as a result of a fuel tank explosion. Past accidents show that statements and descriptions of the event from the survivors or from eyewitnesses may not be 100% accurate. Some explosions could have come from the aircraft oxygen system as a result of a postcrash ground fire.

6.3 RESULTS.

The predicted potential number of lives saved per year is relatively small, compared with other survivability factors. One of the reasons that nitrogen inerting may not be as effective, in terms of saving lives on the 13 accidents analysed, is that in many cases, fuel tanks were ruptured when the aircraft impacted the ground. Any nitrogen in the fuel tanks is likely to have escaped together with the spilled fuel. The system is only effective when the fuel tanks are not significantly ruptured.

7. CONCLUSIONS.

The potential benefit in terms of reduction in fatalities and injuries per year for survivable accidents where an explosion was an issue in the survivability of occupants is assessed for three different inerting methods. As can be seen in table 6, the best estimate (median) of number of lives saved per year, over the period covered by the data, is assessed to be

- Ground nitrogen inerting – centre tank only 0.3
- Ground nitrogen inerting – all fuel tanks 2.4
- Onboard nitrogen inerting – all fuel tanks 6.0

Due to the relatively small number of accidents identified involving postcrash fuel tank explosions, the likely range of this prediction is comparatively large. The assessed 95 percentile range for the number of lives saved is as follows:

- Ground nitrogen inerting – centre tank only 0.1 to 0.5
- Ground nitrogen inerting – all fuel tanks 1.9 to 3.0
- Onboard nitrogen inerting – all fuel tanks 4.9 to 7.1

Assessments were also made of the potential benefit in terms of reduction in fatal and serious injuries. The best estimate (median) of the number of reductions in fatal and serious injuries per year, over the period covered by the data, is assessed to be

- Ground nitrogen inerting – centre tank only 0.2
- Ground nitrogen inerting – all fuel tanks 1.6
- Onboard nitrogen inerting – all fuel tanks 5.0

No specific analysis has been carried out on the proportion of fuel tank explosions attributable to centre and wing tanks due to the lack of precise data. However, for the accidents where clear

statements were made as to the source of the explosion, three were considered to have involved the centre tank and four involved the wing tanks.

No evidence can be found to relate the probability of postcrash fuel tank explosions with the size of aircraft.

8. REFERENCES.

1. Service History/Fuel Tank Safety Level Assessment – Aviation Rule Making Advisory Committee, 14 July 1998.

9. DEFINITIONS.

Accident Scenario

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

Fatal Injury (Source: ICAO)

An injury resulting in death within 30 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 7 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—ACCIDENT DETAILS AND ASSESSMENT

This appendix contains, for the accidents analysed, a detailed description (Screen 3 text from the Survivable Accident Database), scenarios, survivability chains, and assessment of potential benefits in terms of reduction of fatalities and injuries if nitrogen inerting systems were used.

A.1 CASE 1

Date:	**14-Sep-1993**	Flight Phase:	**Landing**
Aircraft:	**A320**	Tank Type:	**Centre**
Location:	**Warsaw**	Fuel Type:	**JA-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 fitting 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 onboard.

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 20°C.

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 monoxide 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 carbon monoxide haemoglobin was found, and in the opinion of the person who performed the autopsy intoxication with carbon monoxide in the environment of the high temperature was the cause of the death.

The injury profile was as follows:

21 spine injuries, 8 head injuries, 8 chest injuries (broken ribs), 4 abdomen contusions, 5 broken limbs, 1 burns and 9 others (56 in total).

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Photographs taken at the scene of the accident indicated that the centre fuel tank exploded; a large hole was created in the cabin floor at the location of the central fuel tank.

This accident is divided into four separate scenarios, as shown in figure A-1.

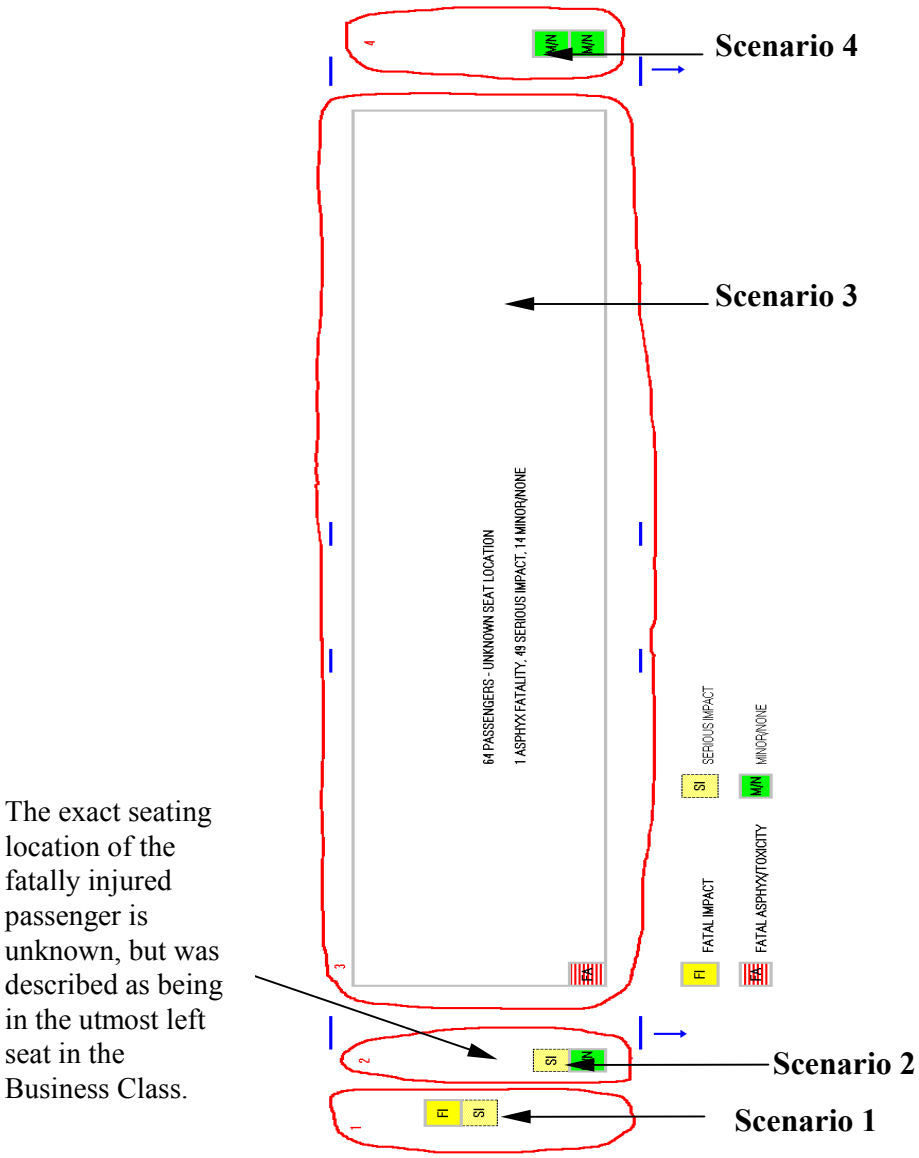
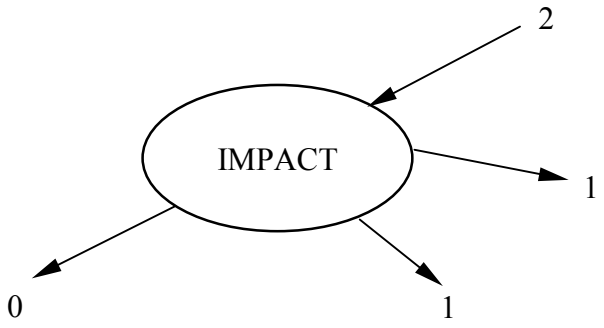


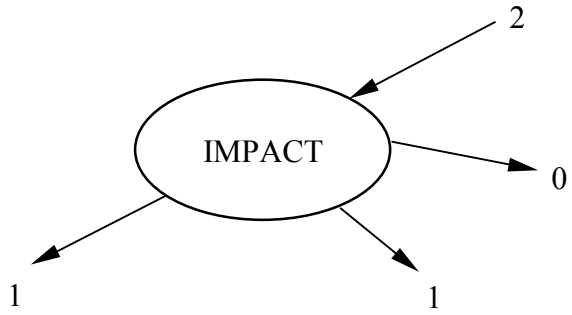
FIGURE A-1. LOCATION OF INJURIES AND SCENARIOS

Scenario 1 contains the flight deck area where 1 flight crew died and the other sustained serious injuries from the impact.



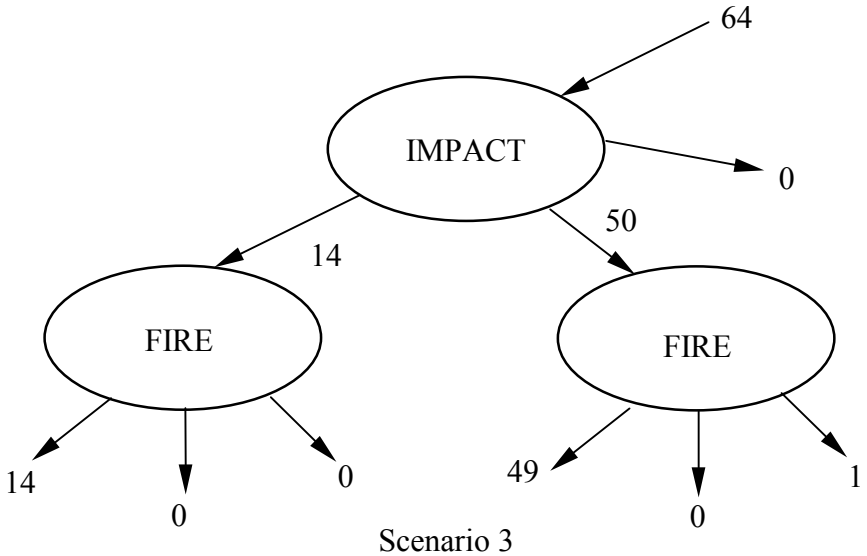
Scenario 1

Scenario 2 contains the forward flight attendant area where only the chief steward sustained serious injuries from the impact. This scenario contains two flight attendants.



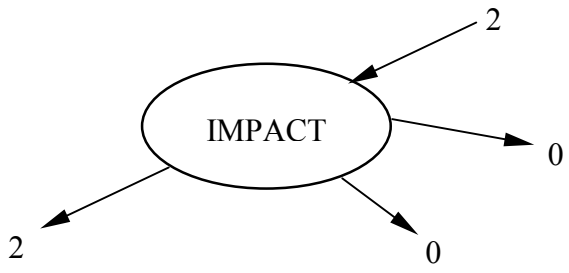
Scenario 2

Scenario 3 contains the whole passenger cabin. This has been used because of limited detail on passenger locations during the accident. This scenario contains all 64 passengers. From the injury profile, apart from the fatally injured passenger, it was assessed that the 49 passengers received serious injuries as a result of the impact.



Scenario 3

Scenario 4 contains the rear flight attendant area where the two flight attendants received minor or no injuries from the impact.



Scenario 4

(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

Scenario 1

It was concluded that ground nitrogen inerting in the centre fuel tank would not have affected the situation in Scenario 1 as all injuries were sustained as a result of the impact.

Scenario 2

It was concluded that ground nitrogen inerting in the centre fuel tank would not have affected the situation in Scenario 2 as all injuries were sustained as a result of the impact.

Scenario 3

The accident occurred during the landing phase. Any nitrogen in the centre fuel tank would have vented in flight, and therefore it would not have prevented the centre fuel tank explosion.

Scenario 4

It was concluded that ground nitrogen inerting in the centre fuel tank would not have affected the situation in Scenario 4 as all injuries were sustained as a result of the impact.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

Scenario 1

It was concluded that ground nitrogen inerting would not have affected the situation in Scenario 1 as all injuries were sustained as a result of the impact.

Scenario 2

It was concluded that ground nitrogen inerting would not have affected the situation in Scenario 2 as all injuries were sustained as a result of the impact.

Scenario 3

The accident occurred during the landing phase. Any nitrogen in the fuel tanks would have vented in flight, and therefore it would not have prevented fuel tank explosions.

Scenario 4

It was concluded that ground nitrogen inerting would not have affected the situation in Scenario 4 as all injuries were sustained as a result of the impact.

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

Scenario 1

It was concluded that onboard nitrogen inerting would not have affected the situation in Scenario 1 as all injuries were sustained as a result of the impact.

Scenario 2

It was concluded that onboard nitrogen inerting would not have affected the situation in Scenario 2 as all injuries were sustained as a result of the impact.

Scenario 3

The fatally injured passenger was killed from intoxication by carbon monoxide and subjection to high temperature following injury during the initial impact.

It was assessed that onboard nitrogen inerting may have prevented the fuel tank explosion, or delayed it long enough for passengers with additional time to go back and remove the immobilised passenger who was seated near to the forward passenger door. Alternatively, the passenger may have succumbed to the fire penetrating the cabin caused by the external fire fed by the ruptured wing tank.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	**Serious Injuries**	**Fatal Injuries**
High	**14**	**49**	**1**
Median	**14**	**50**	**0**
Low	**14**	**50**	**0**

Scenario 4

It was concluded that onboard nitrogen inerting would not have affected the situation in Scenario 4 as all injuries were sustained as a result of the impact.

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 1 (i.e., 1 - 0).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – none.
2. Ground nitrogen inerting in all fuel tanks – none.
3. Onboard nitrogen inerting in all fuel tanks – 1 life saved.

A.2 CASE 2

Date:	**21-Dec-1992**	Flight Phase:	**Landing**
Aircraft:	**DC10**	Tank Type:	**Centre and Wing**
Location:	**Faro**	Fuel Type:	**Unknown**

DESCRIPTION OF ACCIDENT

RESUME

On 21-Dec-1992 a Martinair DC-10-30CF registered as PH-MBN was approaching Faro Airport, Portugal. After a flight of 2 hrs and 17 minutes the flight was cleared to descend to Faro.

At an altitude of 303m and 140kts speed the approach became unstable and at 177m the first officer switched the autopilot from CMD (command mode) to CWS (control-wheel steering). One minute later it was switched from CWS to manual and the airspeed began falling below approach reference speed. About 3-4 seconds short of touchdown elevator was pulled to pitch up and engine power was increased. When the no.3 and 5 spoilers extended, the aircraft had a 25deg. bank, left wing up. The right main gear contacted the runway with a 900ft/min descent rate at 126kts, +8.79deg, pitch up, +5.62deg roll and 1,9533G. The right wing separated while the aircraft slid down the runway. The aircraft came to rest 1100m from the Runway threshold and 100m to the right of the centreline and caught fire.

There were 13 crew and 327 passengers on board. 2 crew and 54 passengers suffered fatal injuries.

IMPACT

A sudden and unexpected wind variation in direction and speed (windshear) occurred in the final stage of the approach. Subsequently a high rate of descent and an extreme lateral displacement developed, causing a hard landing on the right hand maingear, which in combination with a considerable crabangle exceeded the aircraft structural limitations. The fuselage broke into 4 main sections.

Seat rows 1 to 10 - This section (1) came to rest on its left side at 70 deg. There was no fire.

Seat rows 11 to 19 - This section (2) corresponds to the transverse rupture of the cabin due to the longitudinal twisting moment of the fuselage.

Seat rows 20 to 27 - This section (3) corresponds to where, upon first strike, fire propagated in from the right wing.

Seat rows 28 to 41 - This section (4) contains the cabin which structurally resisted the crash most and where evacuation was possible.

FIRE

On impact a fire started on the right wing and propagated into the cabin from the right side. The forward fuselage section (1) contained no fire. The mid-forward section (2) ruptured partly as a result of fire based explosions while the aircraft was off the runway. The mid-rearward section (3) corresponds to where, upon first strike, fire propagated, coming from the right wing. The rear section (4) allowed evacuation for 4 minutes before an explosion relit the fire in the mid section which consumed the whole section.

EVACUATION

There were 13 crew and 327 passengers aboard. The cabin was configured for 336 seats (24 first class and 312 economy class).

In the forward section (1) passengers and crewmembers exited through holes in the cabin walls, since none of the 4 exits were operational. L1 and L2 were half buried in the ground and R1 and R2 were unused since they were almost vertical.

In the mid-forward section (2) the passengers and crewmembers exited exclusively through a fuselage break, mainly through the left side. Most of the passengers who were aware of having been ejected (94%) were sitting in this section, which records also the greatest number of ejected passengers for the total survivals (37%).

In the mid-rearward section (3) an explosion occurred soon after the aircraft came to a halt. 61% of the people seated in this section died. Of the survivors, 52% claim not being aware of how they managed to get out of the aircraft. The remaining survivors claim to have exited through ruptures, either in the fuselage walls or in the cabin floor. Only 2 passengers state having used the emergency exit on the left wing (L3) which was burst open by the explosion. The R3 exit was not used. Among the fatalities, there were 2 flight attendants. Some passengers witnessed that the flight attendants vanished surrounded by a fireball when the explosion happened.

In the rear section (4) evacuation was carried out, in less than 4 minutes, through the 2 rear exits (R4 and L4) before an explosion re-lit the fire in the mid section which spread to the rear section. From the total number of occupants in this section, 97.6% survived. Most of them recall having come out through rear exits, though they cannot state which side it was. The L4 exit opened spontaneously before the aircraft came to a halt. The escape slide was partially deployed. Most of the passengers used this exit, being immediately covered by the firemen's foam. The R4 exit was opened by the R4 stewardess and the escape slide partially deployed. The 2 rear stewardesses decided to suspend evacuation through this exit due to the flames outside.

According to the R4 stewardess, after the "Fasten Seatbelts" sign came on she considered the flight was turbulent and was threatening. She looked across to the L4 stewardess and then the "No Smoking" sign came on. She did not hear the undercarriage come down. She looked across again at the L4 stewardess and saw her in the brace position. The R4 stewardess then consciously took the same position. She remained in this position and waited to land. Suddenly

she heard a bang and from the overwing position saw a jumble of loose objects coming towards her and also some light partitions. She saw an orange-yellow coloured light near exits R3 and L3.

She turned her face away to the right, looking at the exit, and kept the door handle in view, at the same time keeping her left hand on her seatbuckle. When the aircraft came to a stop she released her belt in one movement and opened the R4 exit. The handle position was in AUTO but she did not see the slide or hear the noise of a slide inflating. When the exit was open she saw a dark, black hole and saw a glow. The next moment the L4 stewardess appeared and told her to assist. Passengers came to the exit and especially the women needed pushing to get them out. During the evacuation the L4 stewardess told her that there was no slide. The L4 stewardess pulled the manual inflation handle but it came off in her hand. Since the R4 stewardess did not know the height that the passengers had to jump nor the surface on which they came down, she decided to stop evacuating through this exit and to divert the passengers to the L4 exit. She knew this exit was open and since the aircraft was banked left, in her opinion, she thought the height there was smaller.

Up to that moment she did not have time to look into the cabin. All the time she had been yelling "Get out, get out". Looking past the passengers she saw a glow which she associated with a fire. The glow came closer. Through the L4 exit she saw foam coming in which gave her a safe feeling and she knew that she had done well to get passengers to that exit.

Eventually it quietened down and she started pushing the last passenger out. She directed some more passengers out past the coffee bar and saw the L4 stewardess having problems with a woman who could not jump out. The L4 stewardess drew the attention of the R4 stewardess to a man who was walking in the aisle 5 to 6 rows away. It was an old man stumbling to an exit. The R4 stewardess walked to the man and saw a big hole in the cabin. She got the impression there was nobody left in that part and that nothing else was left of the aircraft. She then left through exit L4 and noticed that there was no slide. She met the R4 stewardess and walked away from the aircraft.

According to the L2 stewardess, before landing, the captain told her that it was advisable that everybody took their seats. She passed this on to her colleagues. She took her seat at position L2 which was rearward facing. She left the airshow on so that the passengers could follow the airspeed and altitude during approach. The main reason for this was that she did not want anybody to stand up. Because of the bad weather she assumed the brace position.

She heard and felt a hard bang or explosion, which she immediately related to the aircraft touching the concrete. Just in front of her a ceiling panel came adrift and a luggage bin opened. She saw more things coming adrift and heard another bang. She saw a spout of fire coming up towards the cabin and enter the cabin on both sides of the window next to position 24K. There were 2 fireballs which disappeared again then no fire. When nothing more fell down and the rolling movement had stopped, she saw fire about 2 seat rows away over the whole width of the cabin.

She immediately called “Get out” although she did not see anybody in the chaos which existed. She tried to make it clear to the passengers that they had to leave. However she was trapped and could not release her seatbelt. With the assistance of a passenger she got free. The L2 exit turned out to be below her and above her she saw a hole through which people were clambering to get outside. She climbed on a row of seats and got out amongst the passengers.

AIRCRAFT FACTORS

The aircraft was a DC-10-30CF registered as PH-MBN and operated by Martinair of Holland.

The cabin was fitted with 4 passenger entry doors along each side. One of which was located above the wing.

ENVIRONMENTAL CONDITIONS

The accident occurred in heavy rain. Wind was between 200 deg and 160 deg at between 29 and 21 kts, gusting to 34 kts.

INJURIES TO OCCUPANTS

There were 13 crew and 327 passengers on board. 2 crew and 54 passengers suffered fatal injuries. The 2 crew fatalities were positioned at exits R3 and L3 where the fire entered the cabin.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

The centre section left wing emergency exit (L3) was burst open by the explosion. It is assessed that the centre fuel tank had exploded and created this explosion from inside the cabin. The fire in the mid-rearward section only lasted for a short while before another explosion relit the fire which spread and consumed the whole rear section. The explosion that relit the fire in the mid-rearward section possibly came from the left wing fuel tank, since the left wing was still attached to this section.

This accident is divided into six separate scenarios, as shown in figure A-2. Scenarios 3 to 6 are bounded by the fuselage ruptures.

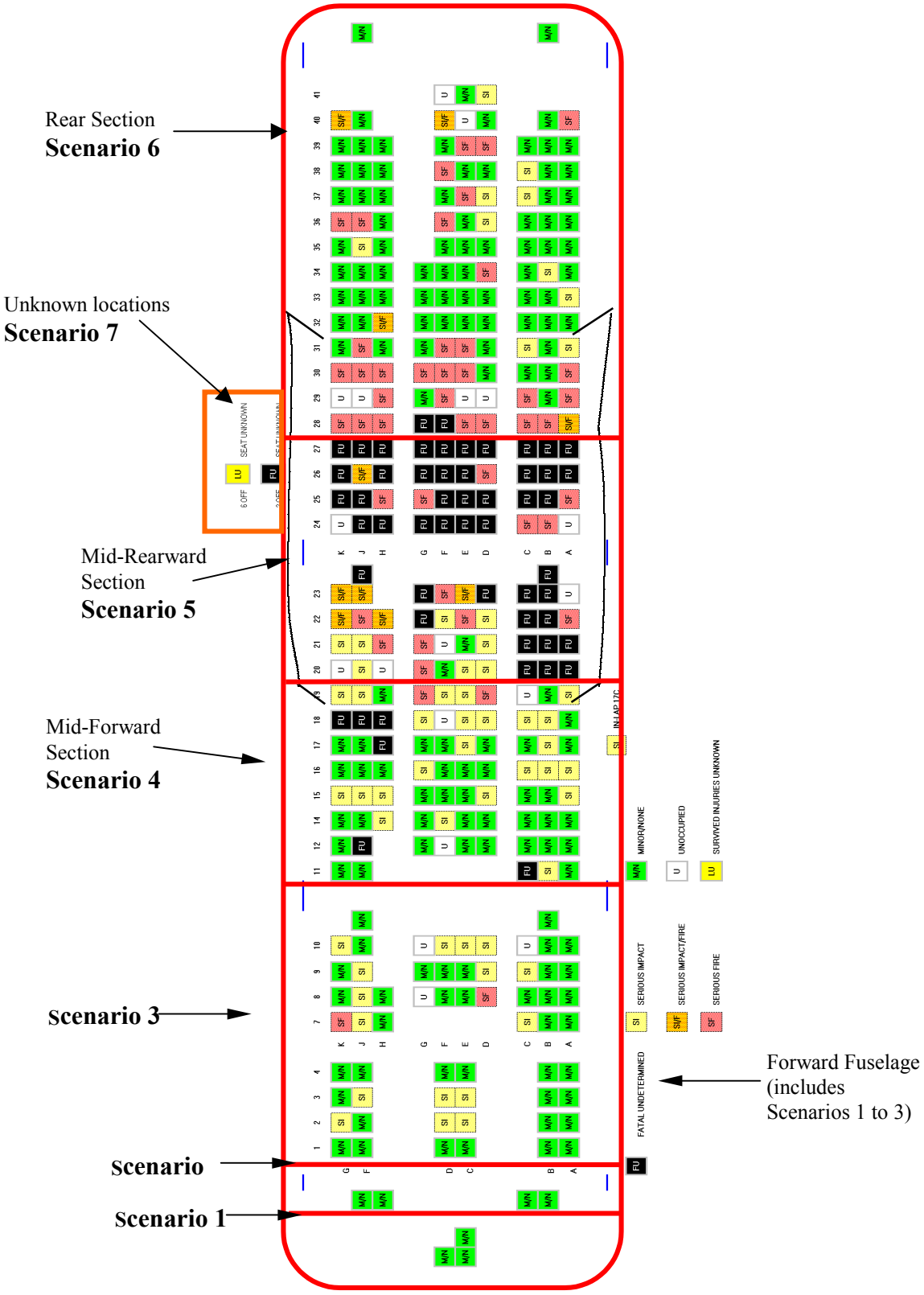
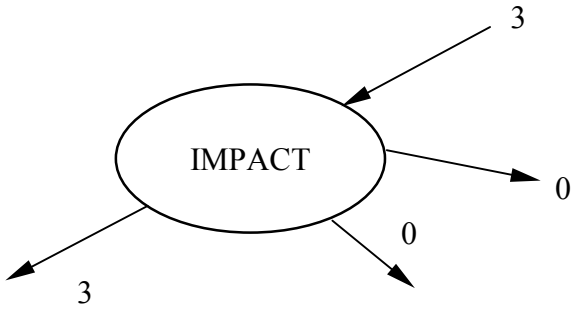


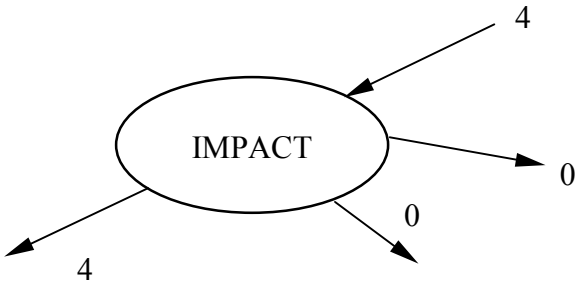
FIGURE A-2. LOCATION OF INJURIES AND SCENARIOS

Scenario 1 contains the flight deck area which was subjected to the impact and was not fire damaged. This scenario contains the 3 flight crew.



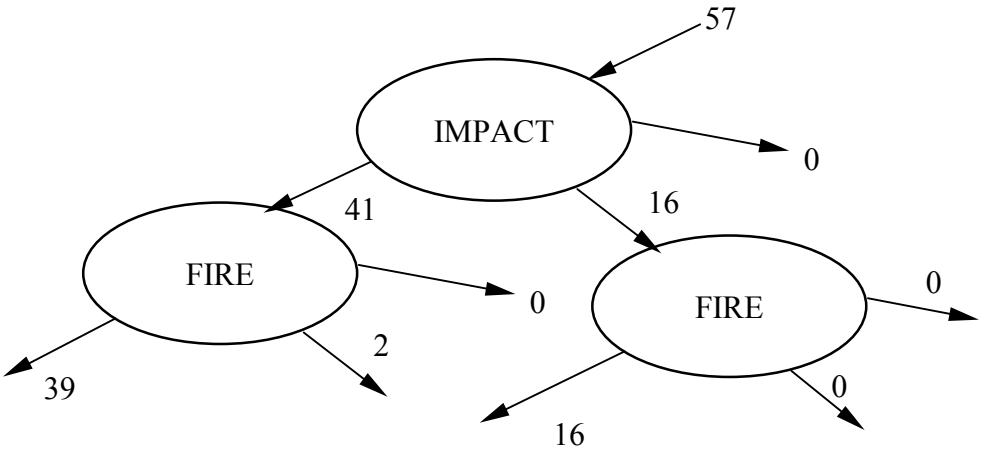
Scenario 1

Scenario 2 contains the forward flight attendant area and encompasses four flight attendants, none of whom sustained serious or fatal injuries.



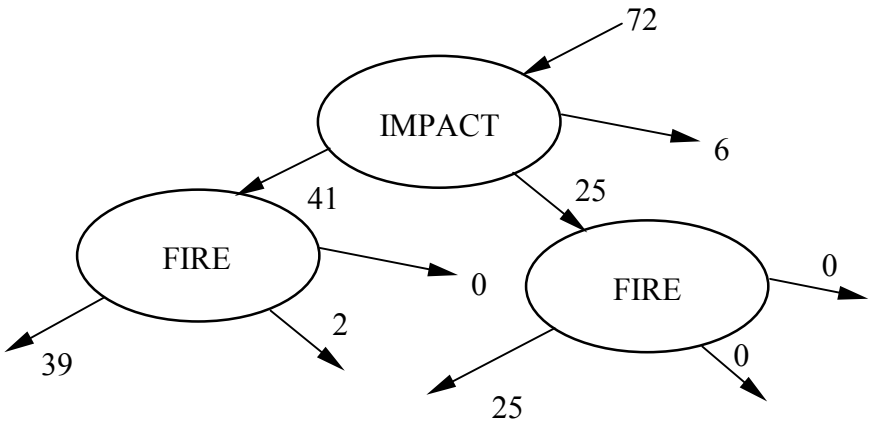
Scenario 2

Scenario 3 contains the forward fuselage, seat rows 1 to 10, which was subjected to the impact and was not fire damaged. This scenario contains 2 crew and 55 passengers. A total of 2 passengers in this scenario sustained serious fire injuries in the accident, presumably the injuries were caused by the fire outside the cabin during the evacuation.



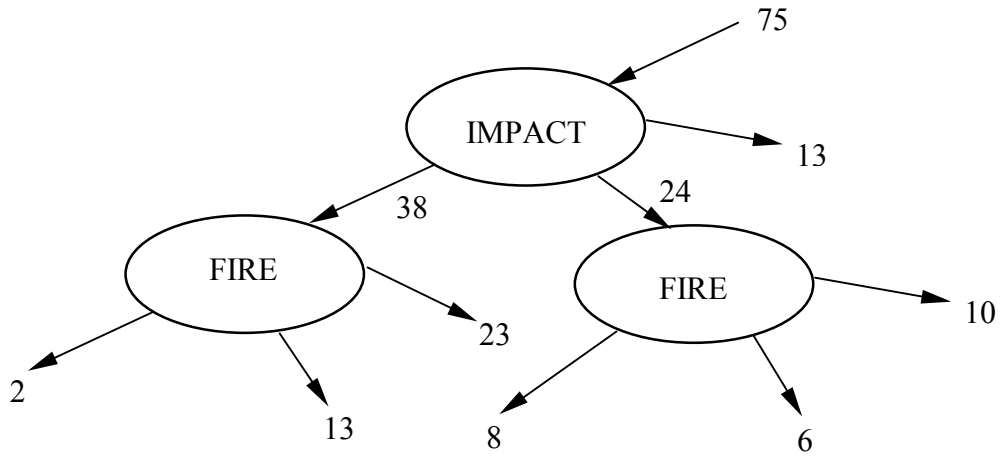
Scenario 3

Scenario 4 contains the mid-forward section, seat rows 11 to 19, which was subjected to the impact and was not fire damaged. This scenario contains 72 passengers. This section contained no fire during the accident, therefore, it is assumed that the 6 occupants were killed by the initial impact. This is also supported by the fact that a large number of the occupants in this section were ejected during the impact. A total of 2 passengers suffered serious injuries from fire but they were located at a fuselage break and it is assessed that either the fire spread locally across the join or they sustained injuries during egress.



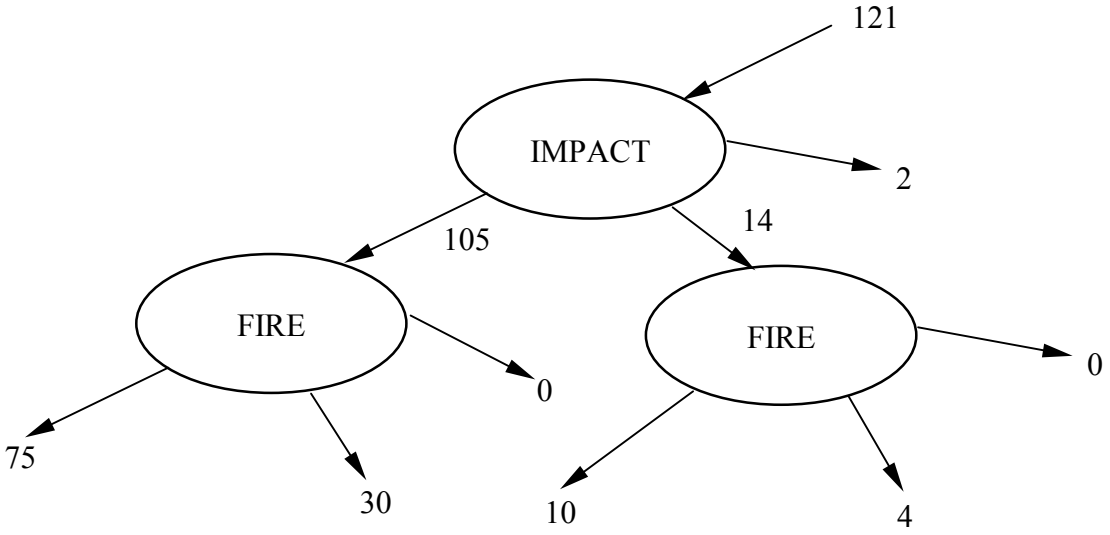
Scenario 4

Scenario 5 contains the mid-rearward section, seat rows 20 to 27, which suffered explosion and fire after the initial impact. This scenario contains 2 crew and 73 passengers. It was reported that some of the passengers died as the fuselage split, and it is therefore assumed that 13 of the undetermined fatally injured passengers, located along the joins, were killed by impact trauma or were thrown out. Of the remaining 33 fatalities, the 2 flight attendants were known to be killed from the fireball. Of the remaining 31 undetermined fatalities, it is assumed that seat rows 21 to 23 suffered impact injuries and then fire death, and seat rows 24 to 26 killed by fire only.



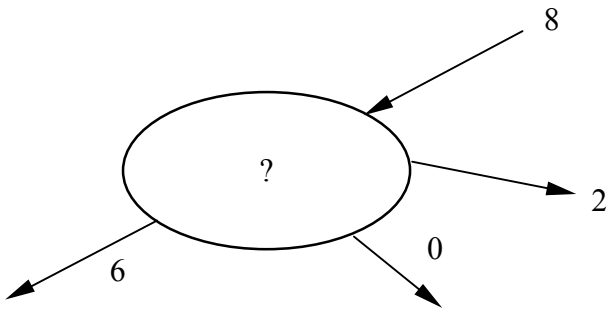
Scenario 5

Scenario 6 contains the rear section, seat rows 28 to 41, and the rear flight attendant area, which was subjected to fire after the initial impact. The scenario contains the 2 crew and 119 passengers. It is assumed that the 2 occupants seated in row 28F and G were killed by impact trauma as the fuselage split into sections.



Scenario 6

Scenario 7 contains the 8 occupants for which seat location and injury was unknown. Absence of information resulted in the following simplified survivability chain. The 6 unknown injuries have been assumed minor or none since they were not significant enough to be reported officially. It is not possible to determine the cause of death for the 2 fatalities.



Scenario 7

(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

Scenarios 1, 2, 3, 4, 5, 6, and 7

It was concluded that ground nitrogen inerting in the centre fuel tank would not have altered the injury patterns for these scenarios as the accident occurred during the landing phase; any nitrogen in the centre fuel tank would have vented in flight.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

Scenarios 1, 2, 3, 4, 5, 6, and 7

It was concluded that ground nitrogen inerting would not have altered the injury patterns for these scenarios as the accident occurred during the landing phase; any nitrogen in the fuel tanks would have vented in flight.

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

Scenarios 1, 2, and 3

It was concluded that onboard nitrogen inerting would not have affected the situation in Scenarios 1 to 3 as there was little or no fire damage in the forward fuselage.

Scenario 4

It was concluded that onboard nitrogen inerting would not have affected the situation in Scenario 4 as there was no fire in this section. It is assessed that the two fire injuries were sustained outside the aircraft.

Scenario 5

Onboard nitrogen inerting in all fuel tanks might have significantly altered the injury pattern in this section. Of the 33 occupants fatally injured by fire in the mid-rearward section, the nitrogen might have prevented the fuel tank explosions or delayed it long enough for the passengers to evacuate. The number of passengers suffering serious injuries due to fire in this section could also have been reduced.

It was assessed that under the worst condition (high assessment) only the fatalities in rows 23 and 24 and the 2 flight attendants might have been saved. The median assessment is that the 6 passengers in rows 24 to 26 on the right-hand side succumbed to the fire that was entering in that area. The low assessment is that all fire fatalities and injuries were eliminated.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	**Serious Injuries**	**Fatal Injuries**
High	**2**	**39**	**34**
Median	**32**	**24**	**19**
Low	**38**	**24**	**13**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 27 (i.e., (13+10+23) - 19).

Scenario 6

Onboard nitrogen inerting in the aircraft fuel tanks would have prevented the fuel tank explosions and hence stopped the fire from spreading to the mid-rearward section. The number of serious fire injury passengers could have been reduced.

It was assessed that under the worst condition (high assessment) only the fire injured in seat rows 28 to 31 might have been saved. The low assessment is that all the fire injured would have suffered lesser injuries. The median assessment is taken the average of the high and the low.

The high, median, and low prediction of the number of injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	**Serious Injuries**	**Fatal Injuries**
High	**96**	**23**	**2**
Median	**100**	**19**	**2**
Low	**105**	**14**	**2**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is zero.

Scenario 7

Due to lack of information, it is not possible to assess any benefits in this scenario.

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – none.
2. Ground nitrogen inerting in all fuel tanks – none.
3. Onboard nitrogen inerting in all fuel tanks – 27 lives saved.

A.3 CASE 3

Date:	**14-Feb-1990**	Flight Phase:	**Final Approach**
Aircraft:	**A320**	Tank Type:	**Wing**
Location:	**Bangalore, India**	Fuel Type:	**JP-A1**

DESCRIPTION OF ACCIDENT

RESUME

On 14-Feb-1990 an Indian Airlines A320-231 registered as VT-EPN was approaching Bangalore Airport, India.

During the final approach, the aircraft descended below the normal approach path and its wheels contacted ground in a golf course area about 2300 feet short of the runway and impacted an embankment at the boundary of the golf course. The aircraft thereafter hopped over a ditch and a road adjacent to it and landed on an area outside the boundary wall of the airport. The aircraft was destroyed as a result of impact with ground and subsequent fire.

There were 7 crew and 139 passengers aboard. Both flight crewmembers, 2 flight attendants and 88 passengers suffered fatal injuries. 1 flight attendant and 21 passengers suffered serious injuries. 2 flight attendants and 30 passengers escaped with minor or no injuries.

IMPACT

The aircraft initially touched softly on the golf course ground on its main wheels at a distance of approximately 2300 feet short of the beginning of the runway. The aircraft then bounced and remained in the air for about 230 feet and thereafter touched the ground on its main landing gear followed by its nose landing gear. At this stage, the right engine also touched a raised portion of ground. Immediately after this, the aircraft hit an approximately 12 feet high embankment leading to separation of both the engines, undercarriage and extensive damage to the front fuselage. The aircraft wings had, on impact, cut off trees over the embankment. The aircraft in this condition hopped over an adjacent ditch and road covering a distance of approximately 26 feet and fell down in a grassy and rocky area approximately 150 feet from the airport boundary wall.

Breaks in the fuselage were large enough to facilitate escape for a few passengers.

The lower portion of front fuselage ahead of the wings was severely damaged by impact with the embankment. The rear fuselage behind the wings, however, remained in shape. On the right hand wing there were ruptures and openings on the front and rear spar near the root from where fuel leaked.

Severe longitudinal/circumferential crumpling was observed aft of the centre wing box. About 11 feet aft of the wing rear spar there was a fuselage fracture about 9 inches wide extending from just above the window line to the lower belly on the left hand side. On the right hand side this was not observed.

The right hand half of the cockpit shell remained with the front and side windscreens in position. The outer skin of the fuselage surrounding the windscreens did not show any evidence of wrinkling, crumpling or cracks, particularly around the right hand sliding window. Even on the inside the sliding window framework was firmly intact. The window handle appeared to be intact with the release button in the pressed position.

Main and nose landing gear structure sheared from their attachments and dragged forward along with the aircraft. Some portions of these components fell in the trail of the wreckage. Bogey beam of both the main undercarriages along with supporting structure suffered extensive damage. Nose wheel strut and its supporting structure disintegrated.

Due to openings in the starboard wing spar, all the fuel had leaked away and this fuel mainly supported the fire. However, in the port wing tank, fuel was still present and approximately 200 litres were retrieved. It appeared that the fuel contained in the port wing did not support the fire.

FIRE

As the aircraft came to rest a huge fire engulfed the forward fuselage. There was extensive fire in the front fuselage area ahead of the wings and practically the whole of the fuselage along with other structure were consumed by fire. Few half burnt and damaged portions of fuselage containing forward doors, forward cargo hold door and right side wing shields were left. The centre fuel tank was open from the forward end and suffered extensive fire damage. Due to the deceleration at impact, the fuel in the tank would have moved forward through the ruptures of the tanks and spread all over the inside bottom portion of the front fuselage. After the aircraft came to a stop, fuel would spill onto the ground. There were a large number of stones in the area where the aircraft came to rest. Rubbing of the structure of the fuselage against these stones could easily cause a spark to start the fuel fire.

One survivor, who occupied seat 12C, stated that he saw the fire coming out of the cabin floor near row 10 or 11. This area would be near the leading edge of the wing root. Another survivor witness, who was sitting at 21A, stated that he saw fire leaping out near the 17th row, right side. This area would be close to the aft end of the wing root.

Seats, cabin floor and galley equipment in the front fuselage were totally consumed by fire. However, in the middle and rear fuselage to where the fire spread from the front side, most of the seats and flooring were burnt.

The top portion of the fuselage shell up to window level was consumed by fire. The rear galley equipment was also exposed to severe cabin fire.

In the tail, both the rear doors and galley, though exposed to cabin fire, were externally in better condition.

With the comparatively low amount of fuel that was available it was rather difficult to explain how the rear passenger cabin was fully burnt up to the rear galley. In all probability, the impact with the embankment and the passage of the fuselage over and rubbing against the embankment may have caused a serious rupture to the bottom surface of the fuel tanks, including the wing tanks. This would have started spilling fuel when the aircraft came onto the ground on its belly and slid forward to come to a stop. Such fuel might have contributed to the damage caused to the floor structure and burning of all internal furnishings. The intense fire due to the fuel may have lasted for a very short period of time which was subsequently supported by the furnishings.

Both front and rear cargo doors were found closed. The front door was partially burnt and damaged. The nature of burns clearly indicated that the fire was initially outside the cargo hold on the cabin side and fire had travelled from the cabin to the cargo hold.

The fire rescue crew did not have a key to open the only gate in the airport perimeter fence near the accident site. As a result time was lost in cutting open the lock and in pushing open the rusty gate. The rescue vehicles could only approach the site at walking speed due to the poor state of the road and terrain. As per eyewitness reports, the Crash Fire Tenders had reached the crash site 10-20 minutes after the occurrence of the accident.

The elderly Rapid Intervention Vehicle had regular starting trouble and was the last vehicle to reach the site of the crash. The fire was extinguished after about 40 minutes when the city fire brigade has also reached the site.

Inspection of the wreckage revealed a hole in the forward spar apparently caused by some force from inside the right wing tank indicative of a post crash explosion from inside the tank.

EVACUATION

The occupants consisted of a pilot-in-command, co-pilot, 5 cabin crew and 139 passengers. The cabin interior was configured to seat 168 passengers.

At the time of commencement of approach ‘No Smoking’ and ‘Fasten Seat Belt’ signs were illuminated.

The usual landing announcement was made by an air-hostess who, along with another air-hostess, also checked the passengers seat belts when the ‘Seat Belt’ sign had been switched on. When the pilot announced ‘Cabin Crew to your stations’, the cabin crew had positioned themselves in their respective seats.

As the aircraft hit the embankment, one air-hostess was thrown out of her seat onto the cabin floor. One who was sitting near the R/H. toilet, hit her head against the toilet wall and was

injured. Another one was alert to the situation and as soon as the aircraft came to a stop she opened the left hand rear door.

According to the statements of some of the survivors, the aircraft made a rough-landing and thud noise was heard three times before the aircraft came to a stop.

An eye witness had seen the aircraft coming to its final rest position and had seen someone thumping against the right hand cockpit window, who he though to be a pilot, before fire engulfed the aircraft.

Upon impacts, many people had impacted the seats in front of them causing various injuries, dizziness and shocks. Some seats in middle to forward section of the cabin had also broken.

Immediately thereafter, smoke started emanating from the front portion of the cabin of the aircraft. One emergency window reportedly opened by itself, and some passengers egressed through that emergency window on their own. However, smoke and heat started spreading backwards inside the cabin. After opening the rear L.H. door, two air-hostesses shouted at the passengers to leave the aircraft immediately, since the smoke starting from the front of the cabin was spreading fast towards the rear.

According to two Air-hostesses the passengers were slow in reacting to their announcement, probably due to shock or injuries. They had to help some passengers to exit out of the aircraft. Some Passengers also helped other passengers to come out of the aircraft.

The two Air-hostesses then went up in the cabin to help other passengers, but due to thick smoke they found it difficult to breathe and thus, had to return and leave the aircraft.

While leaving the aircraft, they saw an Air-hostess with injuries on her face, and in a dazed condition sitting near R.H. Toilet. They helped her exit out of the aircraft.

Upon seeing and hearing about the aircraft crash, a number of people from the surrounding areas had rushed to the spot. Passers-by on the road going round the crash site had also stopped on seeing the aircraft on fire.

Some passengers were seen coming out, in inverted position with head first from underneath the damaged nose portion. They were helped by local people who pulled them out of the wreckage. One person while trying to come out from there was caught up by the fire and was seen dying there.

After coming out of the aircraft, the passengers landed onto marshy area from where they went away to the nearby road. From there the injured passengers were taken to the hospitals.

One passenger after coming out of the aircraft was physically helped by an Air-hostess to the vehicle for removal to the hospital.

There were some minor explosions, because of which, most of the people gathered around the crashed aircraft, kept themselves at a safe distance from the aircraft.

However, some persons, undaunted by the fire, went inside the cabin from rear left-hand door and pulled out the injured passengers until they were prevented by smoke and suffocation.

The passengers seated in row 3E and 4D survived. Similarly passengers seated in 7C, 7D, 7F, 8D, and 8F survived. From witness statements it did appear that an opening may have been created by either the crash or the explosion somewhere around that area for them to escape the fire.

From rows 11, 12, and 13, all the 9 who were seated on the left side of the aisle survived and 1 who was seated at 11D also survived. 6 passengers seated on the right side in these rows all died. It was known that the left hand side emergency exits were opened and these 10 people would have survived coming out of those exits. It was thought most probable that either the right hand emergency exits were not opened by the passengers sitting next to them or they were burnt after exiting the aircraft, as intense fire had been observed on the right hand side wing root area. Also, from the post mortem report it was observed that the passenger seated at 12F had injuries to his forearms, hands and abdomen. It was therefore possible that he was incapable of opening the exit next to him before being burnt to death.

The Officer-in-charge of fire services had reached the site after 8-9 minutes of the crash. On reaching the site he reportedly opened the rear right hand door of the aircraft -from outside. But, by that time, there was no one to come out of the aircraft. He then went around the aircraft and helped 5-6 injured persons lying behind the left wing, near the burning fuselage of the aircraft, to be removed to safe place and then transported to the hospital.

Both the forward doors on port and starboard sides were found closed. Both the rear doors were open. The port side rear door was opened from inside, but the starboard side rear door was opened from outside by rescuers. The escape slide for the rear port door was lying detached from the door in un-inflated condition. As the rear starboard door was opened from outside, it had not deployed the escape slide.

Only 3 out of the 4 overwing emergency exit windows could be found. Handle position of 2 of them suggest that probably they were pulled. The other one was extensively burnt and no indications are available regarding position of handle.

The port overwing escape slide appears to have been deployed but later probably deflated due to fire burns. The starboard overwing escape slide was found packed and partially burnt inside the fuselage indicating that it was not deployed.

It was not possible to know the duration during which the aircraft was burnt and the time that was available to passengers inside the aircraft to escape. From the intensity of the fire the occupants of the forward seats had just a few seconds before the fire engulfed them. As 10 passengers had escaped through the left hand overwing exits, assuming that 5 of them got out

through each exit, it was roughly estimated that fire would have engulfed this region in about 1 minute or slightly less from the time of the third impact.

AIRCRAFT FACTORS

The aircraft was an A320-231 registered as VT-EPN and operated by Indian Airlines.

The cabin was configured with 168 passenger seats.

The aircraft bearing Serial number 079 was rolled out by Airbus Industries, France on the 4th Quarter of 1989. The aircraft was issued Export Certificate of Airworthiness number 15279 dated 22-Dec-1989 by the DGAC, France. The aircraft arrived in India on 24-Dec-1989 and a Certificate of Airworthiness number 1941 was issued to it on 26-Dec-1989 by the Directorate General of Civil Aviation, India in the normal category for 'Public Transport', for carriage of passengers, mail and goods. The Certificate of Airworthiness was valid up to 21-Dec-1990.

The aircraft was fitted with two exits at the front and two at the rear of the passenger cabin. There were two overwing emergency exits above each wing.

ENVIRONMENTAL CONDITIONS

The accident occurred at 13:03 hours Indian Standard Time in daylight.

The prevailing weather conditions at the time of the accident were reported to be: wind variable about 5 kt, visibility 10 km, cloud 3/8 at 2000 ft and temperature 28^{o}C.

INJURIES TO OCCUPANTS

Of the 7 crew and 139 passengers aboard, 4 crew and 86 passengers died in the cabin fire. 2 passengers later succumbed to their injuries in hospital. 1 flight attendant and 21 passengers suffered serious injuries. 2 flight attendants and 30 passengers escaped with minor or no injuries. Post mortem examination of the captain showed that he had died of burns and the consequential shock. There were no fractures of any bones.

The autopsy of the co-pilot showed that the cause of death was due to burns sustained.

Analysis of the injuries suffered by survivors indicated that 8 persons had burn injuries, 26 persons had face, neck, and head injuries, 8 persons had nasal bone injuries and 16 persons had fractures in other parts of the body. Many cases had multiple abrasions, lacerations, etc.

Of the 90 occupants that died at the accident site, cause of death for 81 was established as shock due to burns sustained. Only in 9 cases burns were not mentioned in the autopsy reports and possibly the burns may have been post mortem.

In 13 individuals only, there was evidence of severe injuries with shock present. This would indicate that 4 of these had sustained both severe injuries with shock as well as burns.

It was seen that 32 persons sustained injuries to lower limbs, 20 sustained injuries to the head and 7 sustained thoracic injuries. It was thought highly probable that at least some of these had died of burns because of physical inability to escape quickly.

It is evident from the seating pattern that most of the fatalities had occurred in passengers occupying the first 10 rows, rows 17 to 20, the cockpit crew and the 2 flight attendants occupying the forward seats. Passengers in the vicinity of the emergency exits and those near the rear door generally managed to escape.

It seemed possible from the injury analysis that the occupants of seats 8A and 8B sustained injuries due to a hard object like a briefcase hitting the head/shoulder.

All occupants of the left side at rows 5 and 6 had sustained multiple injuries including head injury indicating the possibility of some forces causing severe damage in this area or causing failure of these seats.

24 bodies showed injuries to leg/ankle. The possible cause of such injuries could have been the flailing of legs at the time of impact hitting against the bottom bar of the seat ahead. These injuries may have prevented some of these passengers from exiting the aircraft in time.

A large number of fatalities and survivors had face, neck and head injuries. It was thought possible that quite a few of these may have been due to passengers hitting their face/head against the back of the seat in front of them. Such injuries could have been possible if the passenger does not tie the seat belt snugly or the seat in front is not kept in the vertical position prior to landing.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

It was assessed that the centre wing tank was ruptured during the impact sequence and evidence indicates that the right wing tank suffered a postcrash explosion from inside the tank.

There were two main fire entry mechanisms into the fuselage, independent of the wing tank explosion. The fire had initially engulfed the crushed forward fuselage portion of the aircraft and had subsequently spread towards the rear. It was probable that the external fire at the front of the aircraft made its way into the fuselage by way of the spilt fuel laying inside and outside the fuselage and flames propagated through the lower damaged fuselage. From there, the fire would have burnt through the cabin floor. One survivor, who occupied seat 12C, stated that he saw the fire coming out of the cabin floor near row 10 or 11. This area would be near the leading edge of the wing root. This forward fire quickly propagated rearward along the cabin.

At the rear of the fuselage there was some spilt fuel under the keel that fed an intense fire which lasted for a very short period of time. It has been assessed that this fire burnt through locally and

the incoming fire was subsequently supported by the furnishings. A survivor, who occupied seat 21A, stated that he saw fire leaping out near the 17th row, right side. This area would be close to the aft end of the wing root and is consistent with the assessment.

(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

No benefit for any scenario because it was assessed that the centre fuel tank was ruptured and did not explode.

(2) Effect of Ground Nitrogen Inerting in Aircraft Fuel Tanks

No benefit is assessed for any scenario because it was assessed that the centre fuel tank was ruptured and did not explode.

a. The accident occurred in the landing phase and most of the nitrogen onboard would have been vented during flight.

b. The fuel tanks ruptured when the aircraft slid along the ground, so any remaining nitrogen was likely to be lost from the tanks.

(3) Effect of Onboard Nitrogen Inerting in Aircraft Fuel Tanks

No benefit is claimed for any scenario because it is assessed that the ruptures in the fuel tanks, caused as the aircraft slid along the ground, would have resulted in the nitrogen being lost. Furthermore, the intensity of the fire was such that it is considered unlikely that the explosion, which ruptured the front spar of the right wing, would have significantly contributed to the threat to occupants.

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – none.
2. Ground nitrogen inerting in all fuel tanks – none.
3. Onboard nitrogen inerting in all fuel tanks – none.

A.4 CASE 4

Date:	**15-Nov-1987**	Flight Phase:	**Takeoff**
Aircraft:	**DC9**	Tank Type:	**Centre**
Location:	**Denver**	Fuel Type:	**Unknown**

DESCRIPTION OF ACCIDENT

RESUME

On 15-Nov-1987 a Continental Airlines DC-9-14 registered as N626TX was delayed in snow conditions at Stapleton International Airport, Denver while taking off and did not de-ice for a second time.

Following a rapid rotation, control of the aircraft was lost and as a result it crashed off the right side of the runway and came to rest inverted. There was a fireball inside the fuselage for a short time during the impact sequence.

The 2 pilots, 1 flight attendant and 25 passengers were killed. 52 passengers and 2 flight attendants survived and either escaped or were extricated from the aircraft. Some of the passengers were trapped in the wreckage until they could be freed by rescuers.

IMPACT

During the impact sequence the left wing was destroyed, the fuselage separated into 2 sections (at seat row 9) and the empennage separated. The forward fuselage came to rest on its left side and the remainder of the cabin came to rest inverted. The ground was level and snow covered.

There was extensive disruption inside the cabin. The galleys were partly detached and distorted. Luggage bins and seats had become broken and detached. Some floor tracks were missing.

Three major ground scars were found at the accident site. The nearly intact empennage/tail cone section of the aircraft was located approximately 250 feet down from the third scar. It was inverted and coated with soot but showed no signs of thermal damage. The left horizontal stabiliser tip and left elevator tip were missing. Fragments from these components were found earlier along the wreckage path.

The fuselage and right wing were located approximately 200 feet down from the empennage. The forward portion of the fuselage, which had split at station 446, was resting on its left side. The left side was badly damaged. Much of the exterior skin and underlying structure was torn away and found along the wreckage path. The right side of the fuselage was distorted and dented in several places near the forward baggage door. The aft portion of the fuselage was aligned with the forward part of the fuselage and resting inverted. The section of fuselage just aft of the break

was collapsed within inches of the cabin floor. The portion of fuselage just aft of the break was collapsed to the level where the forward part of the engine was resting on the ground.

FIRE

A fireball existed in the fuselage for a short time which started at row 11, moved down the aisle to row 16, and was gone very quickly. The fireball probably resulted from ignition of residual centre fuel tank fuel, extinguishing itself rapidly and did not affect passenger escape. The snow and dirt that entered the cabin during the impact sequence may have prevented the fireball from igniting anything in the cabin.

The moderate snowfall and cold temperature mitigated fuel vaporisation and further prevented a sustained post crash fire.

Several residual fires were evident after the aircraft came to rest but these were quickly extinguished by fire-fighters and caused only minor damage to the airframe.

During the evacuation and extraction of trapped passengers there was dripping fuel but no fire.

Both Crash/Fire/Rescue (CFR) stations were notified of the accident and responded to the scene within several minutes with 5 CFR vehicles and 12 fire-fighters. Numerous structural fire-fighting and rescue units also responded from the nearby city and county. Fire-fighters extinguished several individual localised fires at the root area of the left wing.

EVACUATION

There were 2 flight crew, 3 cabin crew and 77 passengers aboard. The cabin was configured to accommodate 83 passengers.

The flight attendant seated on the left side of the aft jumpseat was positioned in the inverted part of the fuselage near the rear tailcone exit. She tried to remove emergency equipment from the overhead bins which were underneath her feet but failed to do so. She passed two emergency flashlights into the cabin as it was dark. When the tailcone exit had been opened by a male flight attendant and some passengers she sent a 6 year old girl and a couple with a baby first. She was standing on the overhead bins so that people could get by her to get out. Everyone was climbing over her so she got out of the way and exited.

The male flight attendant seated on the right side of the aft jump seat realised that the aircraft was going down and tried to assume the brace position but the force on him was too great and he could not move his hands. He yelled commands “Bend Over, Heads Down” but wasn’t sure he could be heard because the noise was so loud. When the aircraft came to a stop he tried to open the rear tailcone exit but due in back pain realised that he would not be able to open the door alone. He gained the assistance of a few passengers to clear away debris and open the door. They eventually got the door removed, turned it on its side and pushed it out of the aircraft. He estimated that it took 10 minutes to get the door open.

A number of passengers were trapped in the wreckage, some up to 5 hours, before being freed by rescuers.

The three evacuation slides had not been used during evacuation.

Emergency lights were not illuminated in the rear cabin after the aircraft came to rest and during evacuation. Later examination showed that the emergency floor level lighting strip was displaced from the floor and the wires were separated. In the forward cabin, floor path emergency lights reportedly illuminated and remained so for a number of hours after the accident.

The first aid kit could not be removed from its mounting bracket because the aft left bulkhead has shifted forward and jammed the first aid kit in the bracket.

AIRCRAFT FACTORS

The aircraft was a DC-9-14 registered as N626TX and operated by Continental Airlines.

The cabin was divided into first class and coach sections and had a total of 83 passenger seats. The first class section contained two rows of double occupancy seat units for a total of 8 seats. The seats had leather upholstery and were installed at 34 inch seat pitch. The coach cabin had 15 rows of double occupancy seat units on the left of the aisle and 15 rows of triple occupancy seats on the right side of the aisle for a total seating capacity of 75. The coach seats were installed at either 30 or 31 inch seat pitch.

The first class and coach cabins were separated by two cabin dividers, one on each side of the aisle.

An aft facing double occupancy flight attendant jumpseat was mounted on the left rear side of the cockpit bulkhead adjacent to the forward main cabin door. A forward facing double occupancy flight attendant jumpseat was mounted on the aft pressure bulkhead between the two lavatories.

Seat cushion fire blocking was installed on passenger and flight attendant seats.

The aircraft was fitted with 7 emergency exits; 2 cockpit window exits, the main cabin door, the forward galley door, 2 window exits (1 above each wing) and a tailcone exit.

ENVIRONMENTAL CONDITIONS

The accident occurred at 14:16 hours Mountain Standard Time in daylight.

The prevailing weather conditions at the time of the accident were snow precipitation with a temperature of -2^{o}C. Wind was 10 kt.

INJURIES TO OCCUPANTS

Of the 5 crew and 77 passengers aboard, 3 crew and 25 passengers suffered fatal injuries. 11 passengers and 3 crewmembers died of multiple blunt force traumatic impact injuries. 5 passengers died of head injuries and 9 passengers died of traumatic asphyxia.

Survivors' injuries consisted of fractures, closed head injuries, 2nd degree burns, contusions to internal organs and multiple abrasions, contusions and lacerations.

In spite of the brevity of the cabin fireball, 10 survivors and 6 deceased passengers received first or second degree burns.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

The injury location diagram is shown in figure A-3. All fatalities were as a result of the impact, some of the passengers sustained burns to varying degrees. Whilst this accident could be broken into many scenarios for simplicity, the survivability chain has been drawn for all occupants.

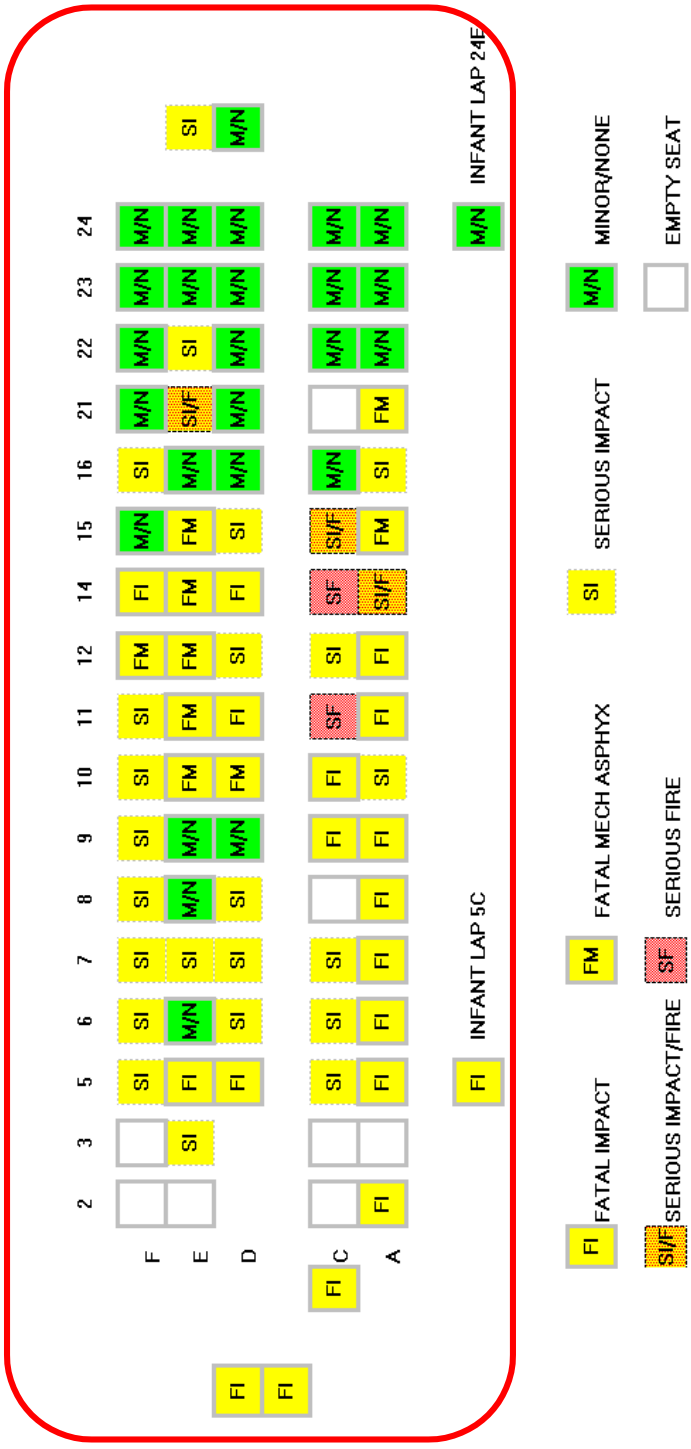
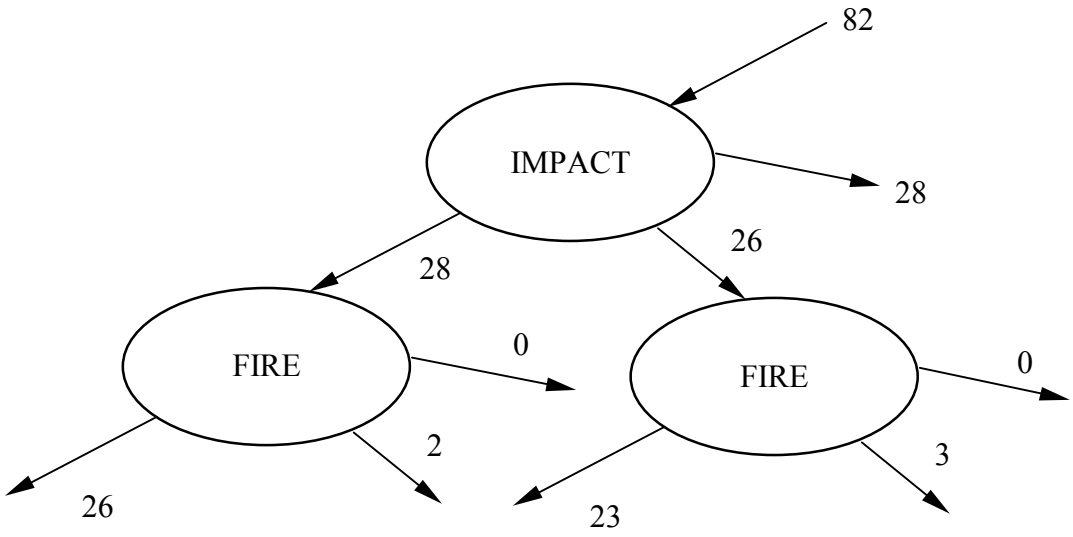


FIGURE A-3. LOCATION OF INJURIES AND SCENARIOS

The aircraft and its occupants were subjected to initial impact followed by postcrash fire. There were 5 crew and 77 passengers onboard the aircraft.



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

Since there were no burn fatalities, ground nitrogen inerting could only have prevented the fireball from the centre fuel tank. Therefore, the 2 passengers seriously injured by fire would have suffered lesser injuries The high, median, and low prediction of the number of injuries resulting from using ground nitrogen inerting in centre fuel only is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**26**	**28**	**28**
Median	**28**	**26**	**28**
Low	**28**	**26**	**28**

Summary

The assessed median number of lives saved by ground nitrogen inerting in the centre fuel tank only is zero.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

The same as for the centre fuel tank.

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

The outcome of this accident would be the same as the ground nitrogen inerting in all fuel tanks.

The high, median, and low prediction of the number of injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**26**	**28**	**28**
Median	**28**	**26**	**28**
Low	**28**	**26**	**28**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is zero.

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – no lives saved but 2 serious injuries saved.

2. Ground nitrogen inerting in all fuel tanks – no lives saved but 2 serious injuries saved.

3. Onboard nitrogen inerting in all fuel tanks – no lives saved but 2 serious injuries saved.

A.5 CASE 5

Date:	**29-Mar-1979**	Flight Phase:	**Initial Climb**
Aircraft:	**F27**	Tank Type:	**Wing**
Location:	**Quebec**	Fuel Type:	**JET-B (wide cut gasoline)**

DESCRIPTION OF ACCIDENT

RESUME

On 29-Mar-1979 a Quebecair F-27B registered as C-FQBL was climbing out of Quebec City Airport.

Shortly after lift-off there was a loud bang from the right engine. The section of the engine from the low pressure compressor forward separated and fell to the ground, including some cowlings. Fire broke out in the engine and wheel well.

The aircraft was seen making a low right hand circuit apparently attempting to make an emergency landing at the airport. With the fire continuing the aircraft flew, at a low airspeed, for 1 min 12 sec, then crashed approximately 4200 feet from the button of the runway.

An intensive fire broke out on impact consuming the flight deck and parts of the wings.

There were 3 crew and 21 passengers aboard. 3 crew and 14 passengers suffered fatal injuries. 6 passengers suffered serious injuries. 1 passengers escaped with minor or no injuries.

IMPACT

Shortly after lift-off, when the aircraft was 40 feet above the runway, there was a loud bang from the right engine as it disintegrated and a severe fire developed. The right engine had separated at the first stage impeller and the forward section of the engine along with the propeller and some cowling had fallen onto the runway.

The captain started the engine failure/fire emergency drill. The crew attempted to raise the landing gear which never came up.

The tower controller noticed the flames from the right engine and advised the aircraft that the right engine was on fire and authorised them to land on any runway.

The aircraft climbed to about 120 feet above the runway and started a right turn, apparently in an attempt to complete a short circuit, remain visual and execute an emergency landing on the airport. The aircraft continued in a right turn at about 100 feet at very low airspeed. The angle of bank then increased and the aircraft started to descend until impact which occurred in a nose-down attitude at approximately 80 kts.

At impact the landing gear was down and locked, flaps were in the takeoff position and the left engine was developing full power.

Initial contact with the ground was made by the right wing tip which scraped the ground for about 21 feet prior to the major impact. During this time the aircraft rotated to the right until the right main gear and right engine stub impacted the ground. The butt of the right wing and centre section of the fuselage then impacted. This was followed by impact of the left engine and propeller group.

During the sequence of impacts the total integrity of the aircraft was destroyed. The aircraft separated into 5 major sections before coming to rest: left and right wings, cockpit area, main fuselage and empennage.

The fuselage failed in a bending overload manner due to inertia loads and the tail section broke free as the separated portion of the fuselage impacted the ground.

The flight deck section was considered non-survivable since the decelerative loads were in excess of the limits of human tolerance.

The passenger cabin area was considered to be generally survivable since most of the impact energy was absorbed in the structural deformation. The 2 most rearward seats were still intact and the aft galley area did not show any impact damage.

All but two of the passenger seats were torn free and ejected out of the cabin section during the latter stages of the crash sequence. The lips of the mounting track failed but the tracks remained attached to the floor structure.

All passengers were thrown out through the forward opening of the fuselage.

FIRE

After the engine separated, an in-flight fire broke out in the engine nacelle. Initially the fire was of high intensity. One witness saw flames extending down the landing gear strut. Surviving passengers stated that as the flight progressed the fire decreased in intensity, confined to the wheel well and trailing flames about 5 to 8 feet to the rear of the nacelle. The intensity of the fire probably decreased after the pilots activated the fire handle shutting off the fluids at the engine firewall, but the fire continued until impact.

The fuel tanks ruptured on impact and a severe fire broke out. The forward section of the fuselage and flight deck area were consumed by fire; parts of both wings were also damaged by fire. The main fuselage, aft of the wings, and the tail empennage were the only sections not damaged by the post impact fire.

Two crash vehicles each with 2 fire-fighters attended the scene along with the local fire services. They found the wreckage completely in flames, except for the rear fuselage. There were

intermittent explosions from the burning wreckage [and it was assessed that one of the secondary explosions in the forward part of the aircraft was ostensibly from a wing tank]. About 55 minutes were required to extinguish the fire.

EVACUATION

There were 2 flight crew, 1 cabin crew and 21 passengers aboard.

All passengers were thrown out through the forward opening of the fuselage.

Two ambulances arrived about 5 minutes after the firefighters and all passengers were evacuated from the site within 25 minutes.

AIRCRAFT FACTORS

The aircraft was an F-27 Fairchild registered as C-FQBL and operated by Quebecair.

The cabin was fitted with a cargo door at the front on the port side. A rear passenger entry door on the port side and an emergency door opposite on the starboard side. There was an emergency exit below each wing.

ENVIRONMENTAL CONDITIONS

The accident occurred on a dark night under an overcast sky with the visibility 1 mile in fog. Temperature was 1^{o}C, wind 230 at 8 kts.

INJURIES TO OCCUPANTS

There were 3 crew and 21 passengers aboard. 3 crew and 14 passengers suffered fatal injuries. 6 passengers suffered serious injuries. 1 passenger escaped with minor or no injuries.

The captain and first officer were killed on impact and subsequently suffered burns in the ensuing fire. The flight attendant died on impact of cerebral haemorrhage and skull fracture. A flailing injury to the right leg was also noted.

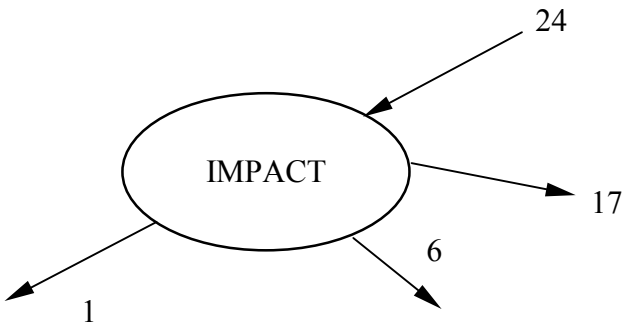
Examination of the fatally injured passengers revealed that they had suffered from severe head injuries including skull fractures. Flailing injuries to limbs were also evident. Only one passenger, who had been killed on impact, suffered from postcrash burns.

It is believed that had more passengers taken the crash position, i.e. heads down with arms over their heads, more passengers may have survived the impact forces of about 9G. The fact that some passengers were wearing seat belts while others were not, did not appear to alter the injury pattern.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to the absence of detailed documentary evidence on the location of injuries, the whole fuselage volume has been taken as a single scenario which includes all occupants.

The aircraft and its occupants were subjected to impact followed by a postcrash fire. It was assessed that the 6 seriously injured passengers received their injuries from impact rather than ground fire, since they all had been thrown out of the cabin. In addition, the main fuselage, aft of the wings, and the tail empennage were not damaged by the postimpact fire. There were 2 flight crew, 1 cabin crew, and 21 passengers onboard the aircraft.



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

Not applicable – no centre tank fitted on this aircraft.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

It is concluded that ground nitrogen inerting would not have affected the situation in this scenario since all of the passengers were thrown out of the cabin through the forward opening of the fuselage. All the victims died from impact injuries.

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

The same as for the ground nitrogen inerting in all fuel tanks.

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – not applicable, aircraft not fitted with centre tank.

2. Ground nitrogen inerting in all fuel tanks – no lives saved.

3. Onboard nitrogen inerting in all fuel tanks – no lives saved.

A.6 CASE 6

Date:	**04-Apr-1977**	Flight Phase:	**Landing**
Aircraft:	**DC9**	Tank Type:	**Centre/Wing**
Location:	**New Hope**	Fuel Type:	**Jet-fuel**

DESCRIPTION OF ACCIDENT

RESUME

On 4-Apr-1977 a Southern Airlines DC-9-31 registered as N1335U was en route from Huntsville Alabama to Atlanta, Georgia.

The aircraft entered a severe thunderstorm, both engines were damaged and all thrust was lost. The engines could not be restarted and the flightcrew attempted an emergency landing on State Spur Highway 92, which bisected New Hope.

As the aircraft hit the ground it struck road signs, utility poles, fences, trees, shrubs, gasoline pumps, 5 cars and a truck. The fuselage broke into 5 major sections and a fire ensued. The aircraft was destroyed.

There were 4 crew and 81 passengers on board. 2 crew and 60 passengers suffered fatal injuries. 1 crewmember and 21 passengers suffered serious injuries. 1 crew member escaped with minor or no injuries.

IMPACT

The flight was routine until the aircraft encountered severe turbulence followed by very heavy precipitation, a lightning strike on the left wingtip and hail. The two engines failed shortly after the hail stopped.

The flightcrew attempted to reach the nearest airfields but could not restart the engines and were forced to choose a highway for an emergency landing.

The aircraft's outboard left wing section contacted 2 trees near the highway. The left and right wings continued to strike trees and utility poles on both sides of the highway and 570 feet later the aircraft's left main gear contacted the highway to the left of the centreline. Almost simultaneously, the outer structure of the left wing struck an embankment and the aircraft veered to the left and off the highway. The aircraft travelled another 1260 feet before it came to rest. As it travelled, the aircraft struck road signs, utility poles, fences, trees, shrubs, gasoline pumps, five automobiles and a truck.

The fuselage broke into 5 major sections:

1. the nose section rearward to fuselage station (FS) 148

2. FS 148 to FS 275 which contained the cockpit bulkhead, forward passenger door, service door and 4 cabin windows

3. FS 275 to FS 579 which contained 12 cabin windows

4. FS 579 to FS 870 which contained the wing centre section

5. FS 870 to FS 1090 which included the engine pylons, APU and aft pressure bulkhead

Additionally, the empennage section had separated at FS 1090.

The first section came to rest inverted and the captain's and first officer's seats were outside the cockpit. The windshield sections separated from the cockpit structure. Although the centre windshields were intact, the outer panes were shattered and the inner panes were cracked. Both clear-view side windows were intact but shattered. The other windows were intact but had been damaged by impact. There was no fire damage.

In the second section, the flight attendant's seat, which was outside the structure and bulkhead, was in good condition. The passenger and service doors were jammed. Several passenger seats were outside the section and all seats showed evidence of compression buckling to the right. The galleys and coat closets were damaged but were generally in place; their contents were scattered about the section. There was no fire damage to this section.

The third section was inverted and most of the passenger seats separated from their tracks. Many of the seats were scattered around the section. There was no fire damage.

The fourth section was damaged substantially by fire; all of the passenger seats and the cabin floor were consumed by fire. Both wings had separated from the wing centre section.

The fifth section was upright and was damaged substantially by fire. The top of this section was separated and was lying on the ground about 20 feet away from the main portion of the section. Most of the passenger seats had separated from their tracks and were scattered around the section. Some of the seats were substantially damaged by fire.

The landing gears were extended at the time of impact.

FIRE

The aft attendant recalled that the aircraft struck the ground about six times before it came to rest. A fireball erupted after the first or second impact and travelled rearward along the ceiling of the cabin. The fireball extended downward from the ceiling to the tops of the passenger seats. She

saw passengers on fire before the aircraft stopped, but was unable to recall where these passengers were located.

Volunteer firemen who witnessed the crash from a nearby fire station in New Hope responded immediately to the crash scene with 2 firetrucks. The firemen's first efforts were directed toward a fire in a combination grocery store-gasoline station and scattered fires among the automobiles. One firetruck was used to fight this fire while the other truck was used to fight the fire in the mid and aft sections of the aircraft.

Firemen arrived later from the surrounding county fire department and assisted in the firefighting and rescue activities. The fires were extinguished in about 30 minutes.

There was no fire in the fuselage sections forward of the wings.

EVACUATION

There were 2 flight crew, 2 cabin crew and 81 passengers aboard.

According to the CVR, shortly after the aircraft entered the heavy hail and rain, the aft flight attendant announced on the cabin address system that the passengers should keep their seatbelts securely fastened. The aft flight attendant made another announcement concerning the stowage of luggage and instructed the passengers about what to do in the event of an emergency landing.

Several minutes later, when the aft flight attendant was certain that both engines were inoperative, the flight attendants began to brief the passengers on emergency crash landing and evacuation procedures; they demonstrated how to open the exits, and how to assume the brace position on receipt of the flightcrew-activated chime signal, or on command from the flight attendants. Additionally, they instructed the passengers to remove sharp objects from clothing and stow the objects, to check that luggage was stowed securely, and to remove their shoes to prevent damage to the evacuation slides during evacuation.

After the briefings, the forward flight attendant opened the cockpit door to tell the flightcrew that the passengers were prepared for an emergency landing. The first officer immediately told her to sit down, and she returned to the cabin. She noticed that the windshield was shattered. The forward attendant called the aft attendant on the interphone and told her about the situation in the cockpit and they discussed their preparations for an emergency landing and evacuation.

Shortly thereafter, the aft flight attendant saw trees outside the cabin window and she yelled to the passengers, 'grab your ankles'. The forward flight attendant repeated the command, and according to both attendants, the passengers responded as instructed. There were no signals from the flightcrew that landing was imminent. According to the flight attendants, they received no information from the flightcrew about what had happened after the aircraft entered the heavy hail, or how the flightcrew planned to land the aircraft.

After the aircraft stopped, both flight attendants freed themselves without assistance. The forward flight attendant was hanging upside down in her seat, restrained by her seatbelt (the seat had no shoulder harness). After releasing her seatbelt she fell onto debris inside what she thought was the galley area. When she was unable to open the main cabin door, she climbed through an opening in the fuselage and jumped to the ground. She ran to a nearby house to get help. There she saw some of the passengers.

The aft attendant recalled that the aircraft struck the ground about six times before it came to rest. A fireball erupted after the first or second impact and travelled rearward along the ceiling of the cabin. The fireball extended downward from the ceiling to the tops of the passenger seats. She saw passengers on fire before the aircraft stopped, but was unable to recall where these passengers were located. After protecting her hand with her apron because the release lever was hot, she released her seatbelt and stood up. A wall of fire was in front of her, and smoke caused her to cough repeatedly. After trying unsuccessfully to open the rear bulkhead door, she turned and moved forward because the flames had diminished, and walked out of the cabin onto the ground. She then began to pull passengers from the wreckage until an explosion forced her away.

One passenger covered his head with a leather jacket and wedged a pillow between his face and the seatback in front of him just before impact. After the aircraft stopped, he removed the jacket; his head was burned by melted plastic which dripped from the ceiling. He moved forward and exited the aircraft through a hole in the fuselage.

Six of the surviving passengers were seated in the section of the cabin forward of the wings' leading edge. Of these passengers, four were ejected from the aircraft, two of which were ejected with their seats. None of the four were burned although they sustained extensive musculoskeletal trauma. The remaining two passengers were seated in the row nearest the wings' leading edge; they received extensive second-degree burns. One of them said that fire and smoke were around him after the aircraft stopped, and one said that fire erupted during the impacts. Their seats and seatbelts remained intact.

Five of the eight survivors who were seated in the portion of the cabin aft of the wings' leading edge and just forward of the engine intakes said that fire erupted inside the cabin before the aircraft stopped. Almost all of these passengers said that smoke, fire, debris, and bodies hampered their escape. The eight survivors said their seats remained intact. The passengers near the overwing exits opened the right exit but closed it because of fire. The eight passengers were burned severely; three sustained musculoskeletal trauma.

Four of the five survivors in the aft section of the aircraft were ejected with their seats during the impact. The condition of the fifth survivor's seat could not be determined. All of these survivors were burned seriously and three sustained musculoskeletal trauma.

The two survivors from the last row of seats reported that their seats remained intact and that fire was all around them when the aircraft stopped. Both passengers were seriously burned and one sustained rib fractures and lacerations.

Five hospitals were notified of the accident. All of these hospitals implemented emergency plans and were prepared to care for the survivors. The first survivor arrived at Paulding Memorial Hospital in Dallas.

An FAA-designated medical examiner and a nurse arrived at the accident scene, they were the first medically qualified persons on the scene. The medical examiner began triage and co-ordinated the transportation of survivors to hospital.

AIRCRAFT FACTORS

The aircraft was a DC-9-31 registered as N1335U and operated by Southern 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. The rear of the fuselage was fitted with a tailcone entry door and ramp.

ENVIRONMENTAL CONDITIONS

The accident occurred during daylight hours.

Wind was 320 deg at 28 kts gusts 50 kts. Visibility was 0.75 miles in severe thunderstorm and heavy rain.

INJURIES TO OCCUPANTS

There were 4 crew and 81 passengers on board. 2 crew and 60 passengers suffered fatal injuries. 1 crew member and 21 passengers suffered serious injuries. 1 crew member escaped with minor or no injuries.

Post mortem examinations of the flightcrew and passengers were made to determine injuries and to aid in identification. Toxicological examinations of the flightcrew revealed no ethyl alcohol. The tests for drugs were inconclusive because the specimens tested were either unsuitable or insufficient for analysis. The tests for haemoglobin (%), carboxyhemoglobin (gm %), and hydrogen cyanide ug/ml disclosed the following respective levels in the captain and first officer: 14.1 and 8, 0.4 and 5.8, and 0 and 0. Both flightcrew members died of extensive trauma; they were not burned and there was no evidence that they had inhaled smoke.

Twenty passengers died of burns and smoke inhalation; their blood contained various levels of carbon monoxide saturation, the highest level of which was 38 percent. Autopsies revealed no significant injuries although some injuries could have been obscured by the severe burns.

Thirty-one passengers died of extensive traumatic injuries. Most of these injuries consisted of crushing of the upper torso and head. There was no evidence of soot or smoke inhalation in these passengers.

Nine passengers sustained trauma combined with burning or smoke inhalation. In addition to the traumatic injuries, these passengers displayed evidence of smoke inhalation and increased levels of carbon monoxide in the blood. Also, the levels of hydrogen cyanide found in blood samples varied; the highest level was 5.5 ug/ml.

The surviving passengers sustained a variety of serious injuries. Many were burned about the head, face, hands, and lower legs. Three passengers had fractured spines. Arm, hand, and leg fractures were common and most passengers had numerous abrasions and contusions.

Both flight attendants had sprained necks and both had contusions and abrasions of the legs. One flight attendant also had contusions and abrasions on both hands.

The forward fuselage section (from the leading edge of the wing forward) was completely destroyed by impact forces. The forward flight attendant survived because she was in an area of this section that shielded her from numerous impacts with trees and other objects. Most of the survivors from this section were ejected during its fragmentation and destruction, but were seriously injured. Therefore, their survival was fortuitous rather than a consequence of design.

The accident was survivable for those passengers who were seated aft of the wings' leading edges, except for those who were injured too severely to escape unaided. A number of these passengers probably died in their seats from burns and smoke inhalation. For the most part, the survivors' seats and seatbelts in this section remained intact, and about half the survivors were ejected from the wreckage. The ejected passengers were probably burned before they were ejected. The remaining survivors were not incapacitated and, therefore, were able to escape unaided although they were burned in the process.

The feet of a number of the survivors were cut and some were also burned because they had no shoes for protection. In accordance with standard evacuation procedures, the flight attendants had briefed the passengers to remove their shoes to prevent damage to evacuation slides. Because of the lack of information from the flightcrew, the flight attendants had no way of knowing the circumstances associated with the landing and, therefore, had no reason to deviate from standard procedures.

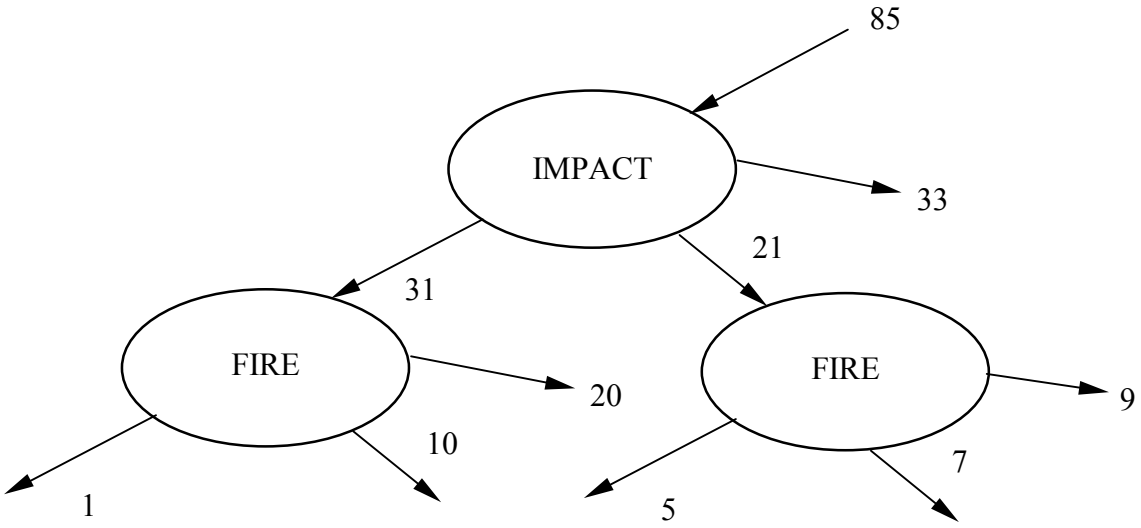
ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

The fireball that erupted inside the cabin after the first or second impact could have been started from the aircraft tanks when the aircraft hit a number of objects on the ground, including a petrol pump. This could have ignited the fuel in the tanks and resulted in an explosion in the form of a fireball. Alternatively, during the impact, after the wings had separated from the wing centre section, fuel could have spilled out from the tanks and ignited in the process. The fireball entered the cabin through the breaks at the wing centre section, from there the fireball travelled rearward and consumed the rear section of the fuselage.

After the aircraft had stopped, the fireball may have started the fire in the cabin and caused a subsequent explosion which had forced the flight attendant away from the fuselage and prevented her from pulling passengers away from the wreckage.

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

The aircraft and its occupants were subjected to impact followed by postimpact fire. There were 2 flight crew, 2 cabin crew, and 81 passengers onboard the aircraft. It was reported that 20 passengers died from burns and smoke inhalation, 31 passengers and 2 crew died from impact trauma, and 9 passengers sustained impact trauma combined with burning or smoke inhalation. Of the 21 surviving passengers, 4 sustained impact injuries, 10 sustained burn injures, and 7 sustained a combination of impact and burn injuries. 1 crewmember suffered serious impact injuries. Therefore, the survivability chain is:



(1) <u>Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only and in all Fuel Tanks</u>

It was concluded that ground nitrogen inerting would not have affected the situation as the accident occurred during the emergency landing phase; any nitrogen in the fuel tanks would have vented in flight. Therefore, it would not have prevented the possible fuel tank explosions.

(2) <u>Effect of Onboard Nitrogen Inerting in all Fuel Tanks</u>

If onboard nitrogen inerting had been used in the fuel tanks, the injury pattern to this accident might have altered. The fireball that erupted inside the cabin at the fourth and fifth sections of the fuselage could have been prevented, and the subsequent explosion delayed, so that extra time might be gained for evacuation.

The high assessment is based on the fact that the fuselage suffered severe disruption and an external fire. Therefore, it is assessed that there were many potential fire entry points to the cabin and consequently a significant fire threat to occupants even if the explosion and fireball were suppressed. Under these conditions, it is assessed that 10 fatalities might have been saved.

The low assessment is based on eliminating the fireball and explosion but that the 9 passengers who sustained impact injuries before being fatally burned may have had reduced mobility and not able to evacuate before fire entered through the fuselage breaks.

The median assessment is based on the average of the high and low assessments.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	**Serious Injuries**	**Fatal Injuries**
High	**4**	**29**	**52**
Median	**4**	**34**	**47**
Low	**4**	**39**	**42**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 15 (i.e., (33+9+20) - 47).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – no lives saved.
2. Ground nitrogen inerting in all fuel tanks – no lives saved.
3. Onboard nitrogen inerting in all fuel tanks – 15 lives saved.

A.7 CASE 7

Date:	**20-Nov-1974**	Flight Phase:	**Initial Climb**
Aircraft:	**B747**	Tank Type:	**Centre and Wing**
Location:	**Nairobi**	Fuel Type:	**JP1A**

DESCRIPTION OF ACCIDENT

RESUME

On 20-Nov-1974 a Lufthansa B747-130 registered as D-ABYB was taking off from Nairobi Airport, Kenya.

The pneumatic system which operates the leading edge flaps had not been switched on and as a result the leading edge flaps remained retracted and the aircraft became airborne in a partially stalled condition.

During the takeoff the crew felt vibration after lift off and suspected engine trouble, subsequently the captain, suspecting wheel imbalance, raised the landing gear. The first officer, who was handling the aircraft, noticed a complete lack of acceleration and had to lower the nose in an attempt to maintain airspeed.

The aircraft lost altitude and the rear fuselage made contact with the ground approximately 1120 metres beyond the departure end of the runway. Parts of the aircraft struck an elevated road 114 metres further on and it started to break up. The main portion skidded an additional 340 metres during which time it turned to the left through 180 deg.

The aircraft was destroyed by the impact and a subsequent fire.

Of the 17 crew and 139 passengers aboard, 4 crew and 55 passengers suffered fatal injuries, 9 crew and 45 passengers suffered serious injuries and 4 crew and 39 passengers escaped with minor or no injuries.

IMPACT

During the rotation phase the acceleration, which up to that time had been normal, ceased abruptly. Very shortly afterwards buffeting or ‘vibration’ was experienced and the captain turned to the flight engineer to ask him if there were any indications of abnormal engine vibration. The flight engineer confirmed that all was normal. On hearing this the captain thought that the vibration might be the result of unbalanced wheels. He therefore checked that a positive rate of climb was indicated and selected ‘Gear Up’. The first officer reported that after becoming airborne he lost all feeling of acceleration such as during normal takeoff and that he had to lower the nose and gradually descend in order to prevent the airspeed from deteriorating.

As the speed decayed the stick shaker operated for 3 seconds. After a 2 second pause the stick shaker recommenced operation and the landing gear warning horn sounded as the first officer closed all 4 throttles when he realised that impact with the ground was imminent.

The first point of impact occurred when the tail of the aircraft grazed bushes and grass located 1120 metres from the departure end of runway 24, and some 33 metres to the south of the extended centre line. The aircraft continued in a partially airborne condition for an additional 114 metres with its tail scraping the ground. It then struck an access road running at right angles to the flight path and protruding to a height of some 8 feet above the surrounding terrain. On impact the tail structure began to disintegrate, but the major part of the aircraft skidded a further 340 metres, during the course of which it turned to the left and came to rest facing in the opposite direction.

The landing gears were found in varying positions and, with one exception, all were detached from the aircraft structure. The nose wheel was down and locked but all 4 main landing gears were in an unlocked condition. The landing gear selector lever was in the up position.

FIRE

As the aircraft came to a stop, fire broke out in the left wing and the separated tail section. Shortly afterwards an explosion in the left inner wing spread the flames to the fuselage.

Fire initially broke out just beyond the raised access road. This was probably caused by severed fuel lines of the port engines and the disruption of the APU from within the rear fuselage. Parts of the aircraft structure that remained in the area were affected, notably the fin and tailplane assemblies. The main fuselage and wings travelled beyond this initial fire outbreak and it was not until it had begun to turn to the left that the left wing burst into flames. Once the aircraft was stationary the fire spread rapidly and the inner left wing exploded. Wing panels were thrown clear of the main wreckage but the fire spread towards the centre fuselage and worked its way forward. The flight crew had opened the top cabin escape hatch creating a chimney effect with the result that the cockpit was destroyed by fire drawn forward from the fuselage.

The centre wing fuel tank did not contain fuel, however it exploded probably due to gases being heated by the surrounding fire. This added to the damage and fire intensity in the forward freight bay area. The forward cabin floor collapsed and the complete left side and roof of the remaining fuselage burnt.

The first fire fighting appliances of the Nairobi Airport Fire Service arrived at the scene a few minutes after the crash and ambulances shortly afterwards. After about 10 minutes the fire had been brought under control.

The majority of the forward fuselage including the cockpit and the left wing were consumed by fire.

EVACUATION

There were 3 flight crew, 14 cabin crew and 139 passengers aboard.

Due to the development of events and the rapid disintegration of the aircraft immediately following initial impact, no evacuation command was heard in the cabin. Accordingly every cabin crew member acted independently on the basis of their instructions at the time of training.

Owing to the rapid sequence of events culminating in the disintegration of the aircraft, the captain was unable to forewarn the cabin staff or passengers or to order the evacuation. When the aircraft came to a halt, he joined the flight engineer in an unsuccessful attempt to open the overhead escape hatch. The flight engineer then tried the crew service door on the right hand side, but was only able to open it some 10 cm. Accompanied by the captain, he then went to the stairway. Finding it to be blocked by debris, the flight engineer jumped down to the lower compartment and crawled out through a hole on the left hand side of the fuselage. Due to injuries sustained to his right shoulder either during the accident or during his subsequent escape he was unable to assist in the evacuation.

The captain in turn jumped down to the lower compartment and crawled out through a hole on the right hand side of the fuselage. He then re-entered the aircraft through the door immediately in front of the right wing (exit R2) and assisted with the evacuation until a severe explosion from the left wing forced him to leave the aircraft. He then aided passengers and crewmembers who had escaped.

The first officer, on seeing that the captain and flight engineer were unable to open the escape hatch, attempted to leave by the stairway. Finding it blocked, he returned to the escape hatch and managed to open it. However, on looking out and seeing flames on the ground apparently encircling the nose of the aircraft he decided against using this exit. Instead he went back and tried without success to open the crew service door. He thereupon returned to the escape hatch and used the emergency escape reel to lower himself from the hatch to the ground. He then assisted passengers to escape until forced to leave the area by two heavy explosions.

Escape from the left hand side of the cabin was impossible on account of the fierce fire that had developed, but evacuation through doors numbered 2 and 3 on the right hand side was accomplished. The automatic action of both these doors and the deployment of both escape chutes functioned correctly.

A number of passengers and some cabin crew were thrown out of the cabin as it disintegrated, and some left through fractured openings after the aircraft came to rest. It was reported that determined efforts to open doors Nos. 1 and 4 on the right hand side of the cabin were unsuccessful. During the evacuation the cabin crew continued to assist passengers to leave the wreckage until forced away by the fierceness of the fire.

Rescue operations were initially commenced by members of the public, who were travelling on the main road to the airport, and who turned off towards the scene as the aircraft crashed. On the

whole, the rescue and fire fighting services were good, the one criticism being that no central command post was set up.

AIRCRAFT FACTORS

The aircraft was a B747-130 registered as D-ABYB and operated by Lufthansa.

The aircraft was fuelled with JP.1A fuel.

The cabin was fitted with 5 passenger entry doors along each side. There was an upper deck crew door port and starboard. The cockpit had overhead escape hatches.

ENVIRONMENTAL CONDITIONS

At the time of the accident the weather was fine and the runway dry. The accident occurred in daylight. Surface weather observations were; visibility 10 km, wind 020 deg at 4 kts.

INJURIES TO OCCUPANTS

Of the 17 crew and 139 passengers aboard, 4 crew and 55 passengers suffered fatal injuries, 9 crew and 45 passengers suffered serious injuries and 4 crew and 39 passengers escaped with minor or no injuries.

The flight crew all survived the crash. The captain suffered haematoma and contusions on the legs, and the first officer sustained multiple bruises and a cut on the head. The flight engineer sustained a dislocated right shoulder.

Four of the cabin crew were killed. Of the ten surviving cabin crewmembers, four were uninjured. None of the remainder suffered from burns, but one had a fracture of the lumbar vertebra, whilst the others suffered bruising and minor injuries. The four cabin crew who were killed were all situated in the vicinity of the two rear doors, and death was caused by multiple fractures.

In the case of the fatally injured passengers, nine cases were due to smoke asphyxiation and of these, all but two had other severe injuries precluding movement and escape. Severe burns were present in the case of twenty others, but as no smoke was present in the lungs, it is presumed that death was caused by other injuries before burning. The remainder suffered from asphyxia and burning, and also had severe multiple injuries.

From Police and Pathological records, those persons killed who suffered from burns, appeared to have been in the forward half of the aircraft, whilst the remainder, including those thrown from the aircraft on impact, were situated in row 35 or further aft, i.e. behind the main wings.

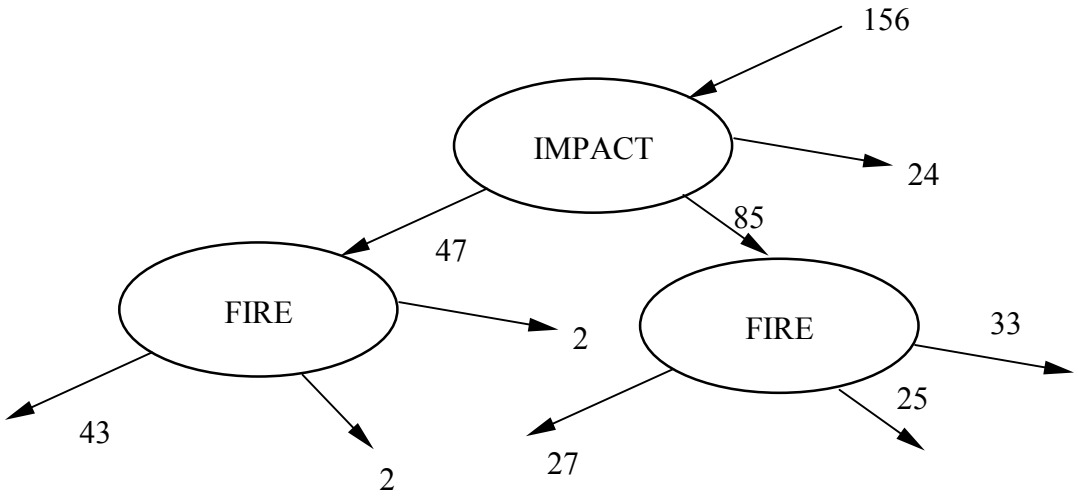
The majority of deaths occurred as a result of impact injuries. Only eleven deaths were as a result of fire, and all but two of these were immobilised by severe injuries and unable to escape.

Survivors had been situated in all sections of the aircraft and almost all of those who were not severely injured were able to leave the aircraft on their own or with help from the crew and other passengers.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to the absence of documentary evidence on the location of passengers, the whole fuselage volume has been taken as a single scenario which includes all occupants.

The aircraft and its occupants were subjected to impact followed by postimpact fire. There were 3 flight crew, 14 cabin crew, and 139 passengers onboard the aircraft. Due to the absence of information on the 45 seriously injured passengers, their injuries have been assessed as in the same proportions as known deaths, i.e., impact : impact and fire : fire = 24 : 33 : 2. This results in 18 injured by impact and fire and 2 injured by fire alone.



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

If ground nitrogen inerting had been used in the centre fuel tank, it would have prevented the postimpact explosion from the centre tank. This may have provided extra time in the forward cabin area, allowing rescuers to assist some of the immobile passengers out. However the explosion from the left wing tank would still have rapidly spread the fire to the cabin, therefore savings would be modest.

The high assessment is based on the fact that the 2 asphyxiated passengers might have been saved and the 33 passengers who suffered severe impact injuries would still have succumbed to the fire.

The low assessment is based on the fact that the 2 asphyxiated passengers might have been saved and that 6 of the occupants who suffered less severe impact injuries (26) would have had the chance to escape. The 7 passengers who suffered severe impact injuries which precluded movement would still have succumbed to the fire.

The median assessment is taken as the average of the high and low assessments.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of ground nitrogen inerting in centre fuel tank only is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**43**	**56**	**57**
Median	**45**	**57**	**54**
Low	**45**	**60**	**51**

Summary

The assessed median number of lives saved by ground nitrogen inerting in the centre fuel tank only is 5 (i.e., (24+33+2) – 54).

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

If ground nitrogen inerting had been used in the aircraft fuel tanks, it would have prevented the postimpact explosions from the left inner wing and the centre tanks. This would have provided extra time for the rescuers to assist some of the passengers out.

The high assessment is based on the fact that the 2 asphyxiated passengers might have been saved and that half (13) of the occupants who suffered less severe impact injuries (26) would have had the chance to escape. The 7 passengers who suffered severe impact injuries which precluded movement would still have succumbed to the fire.

The low assessment is based on the fact that the 2 asphyxiated passengers might have been saved but the 7 passengers who suffered severe impact injuries which precluded movement would still have succumbed to the fire.

The median assessment is taken as the average of the high and low assessments.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of ground nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**43**	**69**	**44**
Median	**45**	**73**	**38**
Low	**45**	**80**	**31**

Summary

The assessed median number of lives saved by ground nitrogen inerting in all fuel tanks is 21 (i.e., (24+33+2) - 38).

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

If onboard nitrogen inerting had been used in the aircraft fuel tanks, it would have had the same result as the ground inerting system.

Therefore the high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**43**	**69**	**44**
Median	**45**	**73**	**38**
Low	**45**	**80**	**31**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 21 (i.e., (24+33+2) - 38).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – 5 lives saved.
2. Ground nitrogen inerting in all fuel tanks – 21 lives saved.
3. Onboard nitrogen inerting in all fuel tanks – 21 lives saved.

A.8 CASE 8

Date:	**07-Jun-1971**	Flight Phase:	**Approach**
Aircraft:	**CV580**	Tank Type:	**Centre/Wing**
Location:	**New Haven**	Fuel Type:	**Unknown**

DESCRIPTION OF ACCIDENT

RESUME

On 7-Jun-1971 an Allegheny Airlines CV580 registered as N5832 was attempting an instrument approach to Tweed-New Haven Airport, New Haven, Connecticut.

In poor forward visibility, the aircraft struck 3 beach cottages located on the northern shore of Long Island Sound, at a height approximately 25 feet above mean sea level, 4890 feet from the displaced threshold of the runway, and approximately 510 feet to the right of the extended centreline of the runway. The fuselage came to rest 270 feet north of the point of initial impact.

An intense fire ensued immediately upon initial impact and continued to burn to the point of near total destruction of the upper portion of the fuselage and cabin area of the aircraft.

Of the 3 crew and 28 passengers aboard, 2 crew and 26 passengers suffered fatal injuries and 1 crewmember and 2 passengers suffered serious injuries.

IMPACT

The aircraft struck 3 beach cottages located on the northern shore of Long Island Sound, at a height approximately 25 feet above mean sea level, 4890 feet from the displaced threshold of the runway, and approximately 510 feet to the right of the extended centreline of the runway.

The fuselage came to rest 270 feet north of the point of initial impact. The landing gear was in the extended position and the flaps had been extended to 40 degrees.

The forward section of the fuselage, comprising of the cockpit area, was broken open and sustained massive damage due to the impact. The rest of the fuselage remained in one section with the exception of a circumferential fracture and separation at fuselage station 790.

FIRE

There was no in-flight fire. Ignition of spilled fuel occurred simultaneously with the aircraft's initial contact with the buildings and power lines and the consequent fracture of the wing structure which contained fuel.

The fuel spillage and flame propagation continued at an accelerated rate after final impact. Secondary explosions occurred shortly after final impact. Fire damage and near total destruction of the cabin interior occurred within several minutes after final impact.

2 firefighting units arrived at the crash site approximately 5 minutes after the accident occurred. However, upon arriving in the vicinity of the crash site, the firefighters did not see the burning aircraft immediately and directed their efforts to the burning buildings. Subsequently, the firemen noticed the burning aircraft, at which time they diverted their efforts to it.

EVACUATION

There were 2 flight crew, 1 flight attendant and 28 passengers aboard. The cabin was configured for 50 passenger seats.

With the exception of the cockpit area, the fuselage structure remained intact to preclude the infliction to traumatic injuries to the occupants. 1 of the 2 surviving passengers experienced some difficulty in releasing his seatbelt after the impact. He observed that the cabin was dark and that it was smokey at the rear. He had, however, thoroughly familiarised himself with the emergency exit configuration of the aircraft while en-route from London to New Haven. He stated that at one point during the crash sequence, he was thrown forward and his head impacted the seatback in front of him. After opening the right forward overwing exit, he was unable to leave the aircraft by this exit because of flames entering the cabin through this opening. His face and hands were burned. He leapt back and went to the exit window directly across the cabin, found the exit was open and left the cabin through it. The surviving female passenger saw the other passenger leave through this exit and quickly followed him. Both passengers proceeded through an area of fire outside of the aircraft and into a water filled ditch which was located near the aircraft wreckage.

Several witnesses stated that, when they first arrived at the accident site, they heard voices of people inside the aircraft and that several violent explosions occurred shortly after impact. The female surviving passenger also recalled seeing 7 or 8 persons up and moving about the cabin and hearing the sound of a male voice calling, “try to get to the back”.

When the fire was extinguished, 15 of the 27 nonsurviving passengers were near the rear service door. The others were found near the centre and forward cabin sections.

The operation and opening of the rear service door by other than trained personnel requires an ability to see and adhere to the instruction which are affixed near the door handle.

It appears likely that the flight attendant was partially incapacitated due to injury sustained during the impact and was therefore physically unable to operate the rear service door. Historically, difficulty had been experienced in the operation of this door, even under nonemergency conditions. It was considered unlikely that a passenger in the smoke filled darkness of the rear cabin could have read or followed the instructions for opening this door or could have successfully opened it.

Extensive fire damage precluded determination as to which other emergency exits were opened by surviving passengers. The remains of the rear service door disclosed that this door was unopened. The lower latch hooks which secure this door were engaged.

AIRCRAFT FACTORS

The aircraft was a Convair CV 340/440 which had been modified into a CV 580. It was registered as N5832 and operated by Allegheny Airlines. The current airworthiness certificate was issued on 22-Nov-1967.

The aircraft was configured with 50 passenger seats. There was a one class seating arrangement, with 12 forward facing double seat units on each side of the cabin identified as rows 1 through 9 and 11 through 13 longitudinally and A through D laterally. Seat units of row 10 were modified to remove the window seat on each side of the cabin (seats 10A and 10D). A galley unit was forward of row 1 on the right. There was a lavatory aft of row 13 on the right.

The fuselage was fitted with 3 emergency exits down each side (at seat rows 4, 7 and 10) and a service door at the rear on the port side. The service door was equipped with a door mounted evacuation chute.

ENVIRONMENTAL CONDITIONS

The accident occurred during the hours of daylight. Wind was 200 deg at 5 kts. Visibility was 1.75 miles in fog. The ambient temperature was 21^{o}C.

INJURIES TO OCCUPANTS

Of the 3 crew and 28 passengers aboard, 2 crew and 26 passengers suffered fatal injuries. 1 crew member and 2 passengers suffered serious injuries.

The 2 passenger survivors sustained burn injuries to their hands and faces.

Autopsy and toxicological studies showed that all fatalities, except the captain, had died of chemical asphyxiation and thermal injury or a combination of both.

The captain was observed in his seat in the nose section of the burning fuselage and could not be reached by rescuers. The captain's pulmonary tree, unlike that of the passengers, the first officer's and the flight attendant's showed no carbon deposit [i.e. he sustained fatal injuries on impact]. The captain, however, did have severe burn injuries, a skull fracture and rib and collarbone fractures.

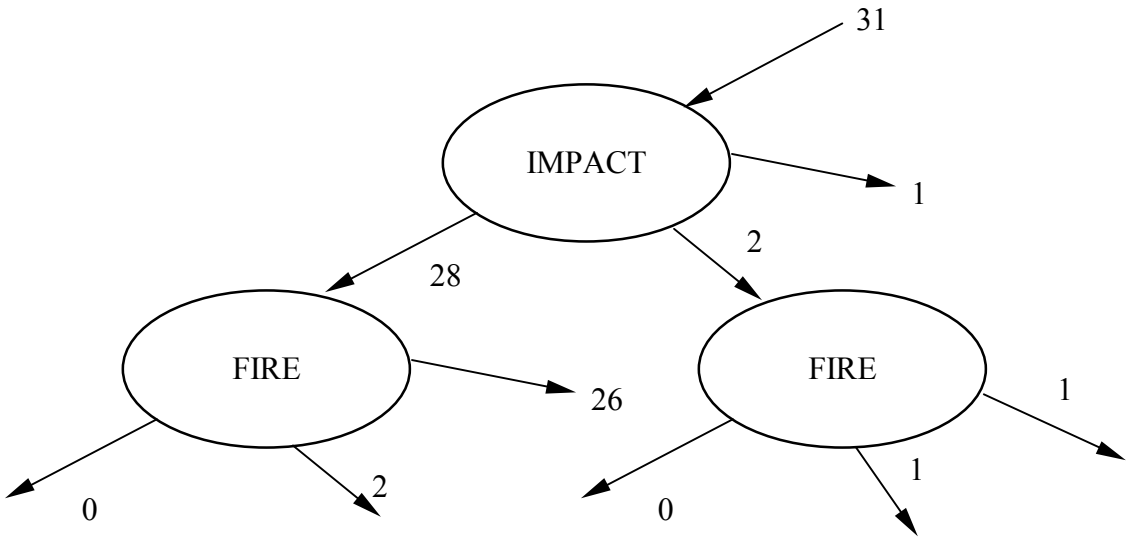
The first officer was rescued from a position on the ground approximately 20 feet in front of the nose section of the burning fuselage. He had sustained massive burn injuries and serious injuries to both legs. The injuries were so critical that amputation of both legs was required later.

The flight attendant who was stationed near the rear door also died of chemical asphyxiation and, in addition, had suffered fractures of the upper posterior rib, fracture of the left clavicle and fracture of the third thoracic vertebra.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to the absence of documentary evidence on the location of passengers, the whole fuselage volume has been taken as a single scenario which includes all occupants.

The aircraft was subjected to impact followed by a postimpact fire. There were 2 flight crew, 1 cabin crew, and 28 passengers onboard the aircraft.



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only and all Fuel Tanks

If ground nitrogen inerting had been used in the aircraft fuel tanks, it would not have altered the accident injury pattern. The accident occurred during the final approach phase, therefore, any nitrogen in the fuel tanks would have vented in flight.

(2) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

If onboard nitrogen inerting had been used in the aircraft fuel tanks, it would have altered the accident injury pattern. The nitrogen could have prevented or delayed the explosions, so extra time may have been gained for rescuers to get the injured occupants out off the wreckage.

It was reported that the fire did not enter the cabin area for about 3 minutes. Several witnesses stated that when they first arrived at the accident site they heard sounds from the occupants in the aircraft.

Five minutes after notification of the fire service the aircraft was smoking heavily, but no significant amount of fire was visible. The cabin area seems to have remained intact until after another explosion (could have come from the wing or the centre tank) severely shook the wreckage. Fire was then visible throughout a major portion of the wreckage.

Although the extent of the reduction cannot be assessed with any accuracy, the explosions were evidently violent and must have accounted for a significant loss of life.

The high and the median assessments are based on the assumption that 15 of the 27 passengers would still have been trapped as they were unable to open the rear service door. Consequently, the remaining 12 may have found the open left overwing exit.

The low assessment is based on the possibility that all fire-related fatalities may have been saved if the tanks had not exploded.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	**Serious Injuries**	**Fatal Injuries**
High	**0**	**15**	**16**
Median	**0**	**15**	**16**
Low	**20**	**10**	**1**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 12 (i.e., (1+1+26) - 16).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – no lives saved.
2. Ground nitrogen inerting in all fuel tanks – no lives saved.
3. Onboard nitrogen inerting in all fuel tanks – 12 lives saved.

A.9 CASE 9

Date:	**28-Dec-1970**	Flight Phase:	**Landing**
Aircraft:	**B727**	Tank Type:	**Centre/Wing**
Location:	**St Thomas**	Fuel Type:	**JP1A**

DESCRIPTION OF ACCIDENT

RESUME

On 28-Dec-1970 a Trans Caribbean Airways B727-200 registered as N8790R was landing at Harry S Truman Airport, Charlotte Amalie, St Thomas, Virgin Islands.

The approach appeared to be normal until touchdown, after which the aircraft ascended to a height of about 50 feet above the runway. The aircraft touched down again very hard, became airborne again and touched down a third and last time about 2700 feet down the 4650 feet runway. Almost simultaneously with the last touchdown, the right wing tip settled to the runway. The aircraft then veered off the right side of the runway, continued along a grass median strip parallel to the runway, passed through the airport perimeter fence, crossed over a paved highway and came to rest against a hillside adjacent to the highway. The fuselage broke into 3 major sections.

A small fire ignited immediately but several minutes elapsed before a general conflagration developed. In the interim, 46 of the 48 passengers and all crewmembers escaped from the aircraft.

Of the 7 crew and 48 passengers aboard, 2 passengers suffered fatal injuries. 2 crew and 10 passengers suffered serious injuries. 5 crew and 36 passengers escaped with minor or no injuries.

IMPACT

The captain recalls none of the events of the flight subsequent to the initial touchdown; however, both other flight crewmembers noted that the captain did not seem to be reacting as he normally would. The first officer, who followed the captain through this bounce with his hands on the yoke, did not think the captain was using sufficient control force. The flight engineer noted “then as we crested the bounce, the captain reached for the speed brake handle, paused for a second, then pulled it back; then returned it just before, or as we touched the second time.”

The second touchdown occurred about 1,500 feet from the threshold according to the tower controller. This touchdown was described as hard both by eyewitnesses and passengers. Two passengers commented: “... so hard it literally shook the stuffings out of the whole plane” and “... extremely violent bone jarring is an apt description - and there was a buckling effect with

noise of grinding metal." Two passengers thought something on the right main landing gear broke on this touchdown.

The aircraft then bounced again, this time to an estimated height of 15 to 30 feet. The first officer noted "the aircraft bounced a second time, the nose over-rotating upwards. It was at this point that I took firm hold of the yoke and pushed forward. As the aircraft reached the crest of the bounce I pulled all the way back on the yoke. The aircraft touched down the third time and stayed on the ground."

Several witnesses verified that the third touchdown occurred about 2,700 feet from the threshold, and that the right wing tip settled and began to drag on the runway immediately after the touchdown. The local controller said that the fire department was called just after this bounce. It was about this time that the captain called for a go-around, according to the other crewmembers, and the flight engineer advised him not to. The captain advanced the thrust lever, and he called for the flaps to be raised to 25°. The flight engineer noted that he tried, first with his left hand and then with both hands, before he succeeded in raising the flap lever to the 25° setting. The aircraft veered off the runway 3,800 feet beyond the threshold, and the first officer helped the captain regain directional control.

At approximately this point in the sequence of events, witnesses recalled hearing "muted popping sounds" or "backfire" noises, and some saw flames extending from the tailpipes of one or more engines. One witness, an aircraft mechanic, stated that the No. 3 engine compressor was definitely stalling as it passed his position. This witness was located approximately 3,800 feet from the runway threshold.

The aircraft then continued, almost parallel to the runway, across the access taxiway to Runway 27 and through a chain link boundary fence at a point 4,950 feet from the threshold of Runway 9. The landing gear and right wing tip then struck a raised concrete sidewalk located about 4 feet beyond the fence. The aircraft passed over the sidewalk and an adjacent highway and crushed a truck thereon that had been hastily abandoned by its driver seconds earlier. The aircraft continued up the incline of a hill immediately east of the highway and began to break apart as it came to a stop.

The airframe sustained extensive structural damage, with 2 complete fractures of the fuselage. The fractures occurred fore and aft of the wing centre section at FS 700 [seat row 9] and FS 940 [seat row 20].

There were 8 known passenger seat failures in the aircraft. However, the frame of only 1 seat unit was found, the others having been consumed by the fire. The seat frame, which was that of a right hand triple unit, was found near the break at FS940. All of the legs of the seat were fractured and the entire seat showed a lateral deformation to the left.

FIRE

As the aircraft came to a stop, an explosion occurred in the vicinity of the left wing root (possibly from the centre or the left wing tank). This was followed by a small fire in the same area. Several minutes elapsed before the fire became intolerable and jeopardised the evacuation efforts.

The crash sequence and impact were observed by several of the permanent firefighting personnel. Response to the crash was instantaneous with equipment arriving on-scene within 1 to 1.5 minutes.

2 fire engines were initially driven up to the access road near the aircraft cockpit and the fire was attacked from that position with a turret nozzle. The firemen were forced to retreat, however, because of the intensity of the fire. Other equipment deployed hand lines from the main road. The fire was not extinguished until the fuselage was virtually consumed.

EVACUATION

There were 3 flight crew, 4 cabin crew and 48 passengers aboard. The cabin was configured for 134 passenger seats.

The forward section contained the cockpit, forward thrift area and intermediate first class area. This section was occupied by the flight deck crew, 7 passengers and 2 flight attendants. It contained the left main entry door and the forward galley door. The latter was located on the right side of the fuselage. Both doors were equipped with inflatable evacuation slides. The galley door was opened by the 2 flight attendants with the assistance of several of the passengers and the evacuation slide was inflated without difficulty. However the slide failed to reach the ground because the forward section of the aircraft was resting on a 17 feet high embankment. Consequently the lower end of the slide was about 6 feet above ground level and at least 1 of the evacuees from that section sustained serious injuries as a result of the 6 feet drop from the bottom of the slide. All 12 occupants of this section successfully escaped through the galley door exit.

The first officer protected his head with his arms when he realised that the crash was inevitable. His seatbelt and shoulder harness were fastened. He recalled that the aircraft impacted the hill with a severe jolt, but recalled no violent body movements. When the aircraft stopped he unfastened his seatbelt and shoulder harness, opened his cockpit sliding window and attempted to move the start levers to the off position. He shook the captain, who appeared unconscious and unfastened his seatbelt and shoulder harness. He then went aft to the forward cabin section and noted that all the occupants had departed. He returned to the cockpit and assisted in the evacuation of the captain.

The flight engineer, after he positioned the wing flap lever to the 25° position, subsequent to the final touchdown, moved his seat sideways against his work table, faced the engineer's panel and grasped the table top tightly with his arms. He placed his head into the corner formed by the

back of the first officer's seat and the flight engineer's panel. On final impact, his arms were forced from the table and flung backwards and the first digit of the fourth finger on his left hand was amputated in the process. His shoulder harness was not fastened. When the aircraft came to rest, he unfastened his seatbelt and moved aft to the forward passenger area. His attempt to open the left main cabin entry door proved futile. He told the flight attendants to leave and surveyed the forward section for remaining passengers. He had intended to proceed to the rear of the passenger section, but the aisle was blocked by a partition which separated the first class and economy section. He returned to the cockpit and assisted the first officer in removing the captain, who appeared to be too stunned to leave the aircraft unaided.

The centre section of the aircraft consisted of that portion of the fuselage from FS 700 [seat row 9] to FS 940 [seat row 20]. It contained 60 seats and was occupied by 19 passengers. The 4 overwing emergency exits were located in this section however none of these were used, as all 19 passengers escaped through the aft break in the fuselage at FS 940. Many reported that they had to crawl across broken seats and other debris to reach the aft break. A drop of 10 to 15 feet was required to reach level ground through the aft break. Many of the evacuees used conduits and cables exposed by the rupture to assist in their descent to the ground.

The aft section extended from FS 940 to the end of the aircraft. It contained 41 seats and was occupied by 22 passengers and 2 flight attendants. The aft main cabin entry and the aft galley service doors were located in this section, on the right and left sides of the fuselage respectively. Also the rear ventral stair was located in the aft section. One of the flight attendants experienced difficulty in opening the aft main cabin entry door. However, with the aid of several passengers, she opened the door and inflated the evacuation slide. The other flight attendant attempted to reach her emergency station at the overwing exits but was unsuccessful due to many obstructions and to passengers attempting to move fore and aft to other exits. She managed to get to the aft break at FS 940 where she directed the escape efforts of aft section evacuees. She recalled considerable smoke and heat in that area as the last passengers made their exit. 12 evacuees of the aft section escaped through the fuselage break and 10 used the slide out of the aft main door. The 2 passenger fatalities were located in the aft section.

AIRCRAFT FACTORS

The aircraft was a B727-200 registered as N8790R and operated by Trans Carribean Airways.

The aircraft had a total passenger seating capacity of 134, apportioned into 3 separate seating areas. The forward thrift area had 21 seats, the intermediate first class area contained 12 seats and the aft thrift area contained 101 seats. Passenger seats were designed for the ultimate inertia forces specified in FAR 25.561, which were: 2.0g upward, 9.0g forward, 1.5g sideward and 4.5g downward.

The aircraft had a total of 4 floor level exits, 4 overwing emergency exits and a ventral stairway exit.

ENVIRONMENTAL CONDITIONS

The accident occurred during the hours of daylight. Wind was 110 deg at 10 kts. Visibility was 30 miles. The ambient temperature was 30°C.

INJURIES TO OCCUPANTS

Of the 7 crew and 48 passengers aboard, 2 passengers suffered fatal injuries. 2 crew and 10 passengers suffered serious injuries. 5 crew and 36 passengers escaped with minor or no injuries.

The cause of the 2 passenger fatalities was attributed to burns. 1 fatality reportedly was trapped by debris between 2 seats in row 22. The body of the other was recovered, free from its seat, on the ground in the area of the aft break in the fuselage. They were father and child.

Although the captain's seatbelt and shoulder harness were secure, he sustained multiple bruises on his head and there were small haematomas on the top midline of his head, behind the left ear and on the posterior midline.

The first digit of the fourth finger on the left hand of the flight engineer was amputated during the impact sequence.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to lack of information on injuries to occupants, figure A-4 is the only data available which shows their seat allocation and exit use in the evacuation. Based on this information the accident is considered as three scenarios.

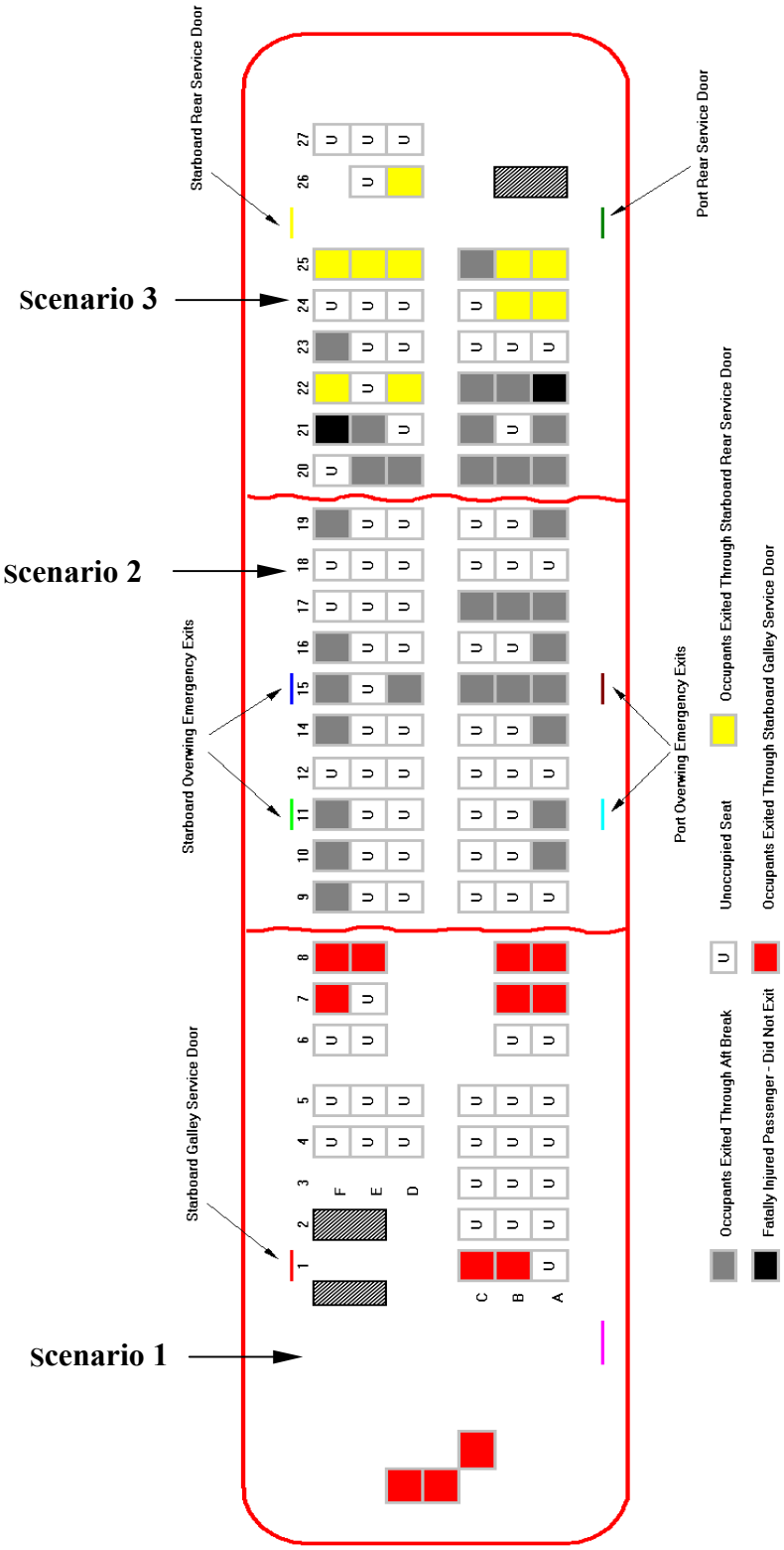
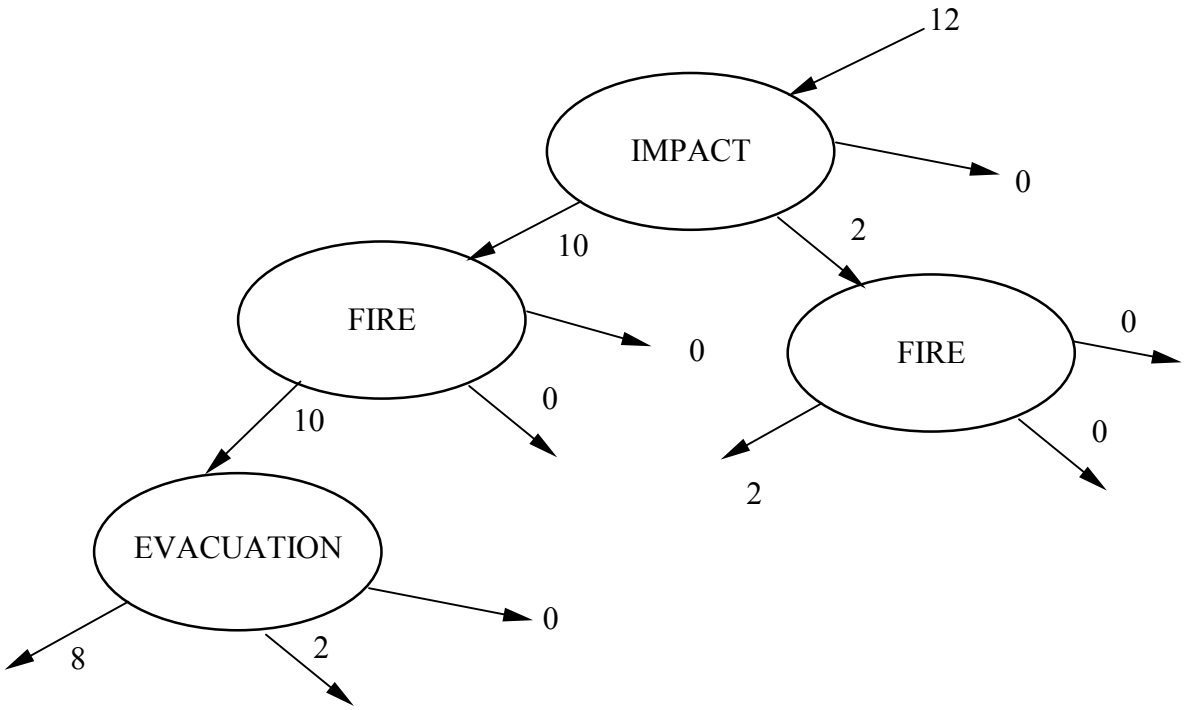


Figure A-4. Occupants Seat Allocation and Exit Use Chart

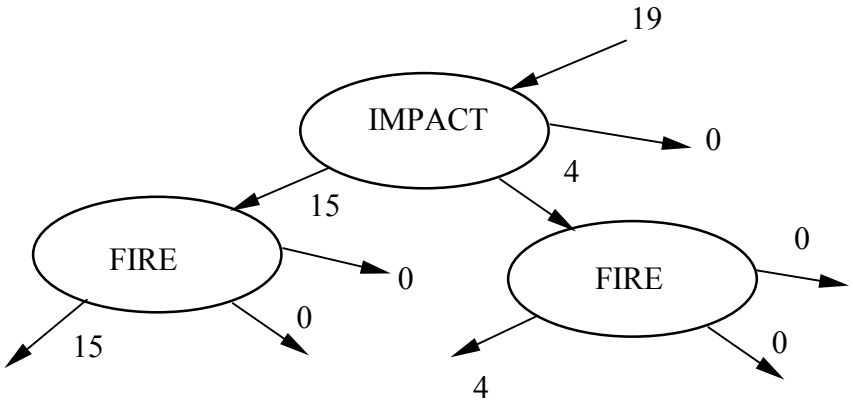
Scenario 1 contains the flight deck area and seat rows 1 to 8. It was subjected to impact and postimpact fire. The scenario contains the 3 flight crew, 2 cabin crew, and 7 passengers. All occupants escaped before a small fire developed into a general conflagration, hence no injuries were due to fire.

The captain and flight engineer suffered serious impact injuries and at least 1 passenger sustained serious injury during the evacuation. It is therefore assumed that 2 passengers were seriously injured during the evacuation when they were using the slide at the forward galley door which was about 6 feet above the ground at the lower end.



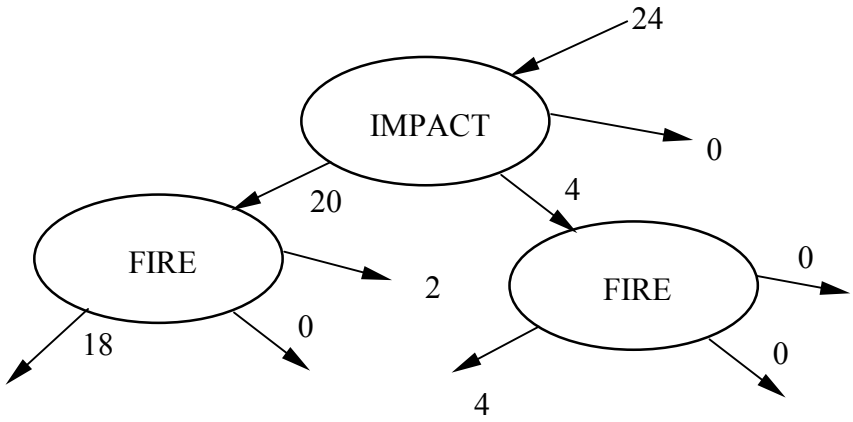
Scenario 1

Scenario 2 contains seat rows 9 to 19 which was subjected to impact and postimpact fire. The scenario contains 19 passengers. All occupants escaped before fire hampered the evacuation; therefore, it is assumed that all injuries were as a result of impact forces. Further, seat failures were reported in this area which is consistent with the impact injuries. There were 8 seriously injured passengers between scenarios 2 and 3 which had a similar number of occupants. It is therefore assumed that half (4) of the seriously injured passengers were in each scenario.



Scenario 2

Scenario 3 contains seat row 20 to the end of the aircraft. It was subjected to impact and postimpact fire. The scenario contains the 2 cabin crew and 22 passengers. 2 passengers suffered fatal burns. Following the same logic of Scenario 2, it is assumed that 4 passengers received serious injuries as a result of impact forces.



Scenario 3

(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

Scenarios 1, 2, and 3

If ground nitrogen inerting had been used in the centre fuel tank, it would not have altered the accident injury pattern. The accident occurred during the final approach phase, therefore, any nitrogen in the centre fuel tank would have vented in flight.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

Scenarios 1, 2, and 3

The same as for the ground nitrogen inerting in centre fuel tank only.

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

Scenario 1

It was assessed that all the seriously injured passengers received their injuries during the evacuation when they were using the slide at the forward galley door, which was about 6 feet above the ground at the lower end. The 2 flight crew received their injuries during the impact.

Since there were no burn fatalities in Scenario 1, no benefits can be claimed from the use of onboard nitrogen inerting.

Scenario 2

It was assessed that all the seriously injured passengers received their injuries during the evacuation at the aft break (FS 940). The aft break was 10 to 15 feet from the ground level.

Since there were no burn fatalities in Scenario 2, no benefits can be claimed from the use of onboard nitrogen inerting.

Scenario 3

If onboard nitrogen inerting had been used in the aircraft fuel tanks, it would have prevented the explosion from the left wing root area which possibly came from the centre or the wing tank. Therefore, the small fire following the explosion may not have started and the 2 fatally injured passengers might have been saved.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**18**	**4**	**2**
Median	**18**	**6**	**0**
Low	**20**	**4**	**0**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 2 (i.e., 2 - 0).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – no lives saved.
2. Ground nitrogen inerting in all fuel tanks – no lives saved.
3. Onboard nitrogen inerting in all fuel tanks – 2 lives saved.

A.10 CASE 10

Date:	**27-Nov-1970**	Flight Phase:	**Take-off**
Aircraft:	**DC8**	Tank Type:	**Wing**
Location:	**Anchorage**	Fuel Type:	**Jet A-1**

DESCRIPTION OF ACCIDENT

RESUME

On 27-Nov-1970 a Capitol International Airways DC-8-63F registered as N4909C was taking off from Anchorage, Alaska.

As a result of a high frictional drag which was caused by a failure of all main landing gear wheels to rotate, the aircraft failed to become airborne during the takeoff run and overran the end of the runway. It continued along the ground and struck a low wooden barrier, the ILS structure and a 12 foot deep drainage ditch before coming to a stop approximately 3400 feet beyond the end of the runway. The aircraft was destroyed in the intense ground fire which developed subsequent to the crash.

Of the 10 crew and 219 passengers aboard, 1 crew member and 46 passengers suffered fatal injuries. 6 crew and 43 passengers suffered serious injuries. 3 crew and 130 passengers escaped with minor or no injuries.

IMPACT

The Captain testified that the aircraft appeared normal, up to approximately 130-135 knots. The speed did not diminish, the acceleration was somewhat decayed or flattened out. He reached V1 and there was no more decay, the acceleration was continuing and at 145 knots the speed flattened out and the acceleration flattened out. The aircraft continued and it appeared that there was sufficient runway to continue the takeoff. At VR the aircraft did not come off the runway and the aircraft overran the end of the runway. It appeared to the Captain that the tail was dragging but he did not see any object in front of him. He then thought that it would be better to come to a stop on the ground rather than becoming airborne. He reduced the power and there seemed to be three different impacts. Each time he could not control any movement. At the last impact the lights went out.

Evidence found on the runway showed progressive deterioration of the aircraft tyres during the takeoff run. The aircraft ran off the end of the runway and continued down the extended centreline of the runway, through the ILS localizer facility, hit a low wooden barrier and struck the far side of a deep drainage ditch. It came to rest in an upright position approximately 3400 feet beyond the end of the runway.

Major structural damage occurred on the second impact, at which time the aft section of the cabin broke open and the right wing tore loose spilling the fuel contained therein.

The fuselage sustained a circumferential fracture near Fuselage Station 1320 [seat row 36]. The tail section came to rest about 30 feet from the main fuselage section and rotated 10 deg anti-clockwise from it.

During the impact sequence numerous interior fixtures including galley equipment, overhead racks and liferafts tore loose from their attachments and obstructed aisles and exits in the passenger cabin. The forward galley exit was completely blocked by loose galley equipment and the ceiling panel which prevented the use of this exit in the evacuation.

FIRE

Although there was no evidence that a fire existed before the aircraft struck the ILS structure, survivors reported that fire broke out on the left side of the aircraft following the first impact and continued throughout the crash sequence.

Major structural damage occurred on the second impact, at which time the aft section of the cabin broke open and the right wing tore loose spilling the fuel contained therein. A large fire then erupted on the right side of the aircraft.

Thousands of gallons of raw fuel which were released when the wing broke loose accumulated in one big pool, reportedly 6 to 8 inches deep, in and around the aircraft.

The interior of the fuselage forward of the rear pressure bulkhead was totally gutted by fire.

The fire destroyed most of the fuselage and much of the wing structure.

A dry chemical unit of the airport fire department arrived on the scene within 3 minutes after the crash occurred and initiated the firefighting and rescue activities. All airport fire units were operating at the scene within 5 minutes after the alert. Several minutes after the accident occurred, 2 fairly large explosions were observed emanating from the left side of the aircraft. Subsequent explosions occurred and hampered firefighting and rescue operations.

Fire and rescue units from the surrounding area also responded and assisted in the firefighting and rescue activities.

EVACUATION

There were 4 flight crew, 6 cabin crew and 219 passengers aboard. The cabin crew were seated at their assigned stations for takeoff. #1 in the rear entryway jump seat by the aisle; #2 in the forward entryway jump seat; #3 in the forward galley jump seat; #4 in the aft galley jump seat; #6 in the flight attendant seat at the jetescape door, right side of aisle in row 9; #7 in the flight attendant seat at the jetescape door left side aisle seat in row 33.

Impact conditions were survivable, as the occupied area of the aircraft remained relatively intact and decelerated forces were not of a magnitude to cause incapacitation trauma that would have prevented escape. However, postcrash fire and explosions caused intolerable conditions which prevented the escape of some of the nonincapacitated occupants.

While the aircraft was still moving forward a passenger opened the left hand overwing exit and fire came into the cabin for a short period of time.

As the large fire erupted on the right side of the aircraft, some of the passengers seated in this area removed their seatbelts and attempted to move away from the fire. The third and final decelerative jolt caught them en-route and threw them forward, injuring some.

Flight attendants reported difficulty in remaining in their fold-down jumpseats during the crash sequence. One forward-facing double seat unit folded from under the attendant while the aircraft bounced over the rough terrain. An attendant who was seated at a rear galley exit stated that during the crash the galley equipment began to come loose and in order to hold it secure she had to loosen her seatbelt and manually hold this equipment in place. Because of the loosened seatbelt she was thrown from her seat and, in fact, knocked unconscious so that she had to be carried from the aircraft by one of the passengers during the evacuation.

The forward galley exit was completely blocked by loose galley equipment and the ceiling panel which prevented the use of this exit in the evacuation. Except for this door, all exits in the forward part of the cabin were opened and used for evacuation. 3 of the 4 overwing window exits were also opened and used.

It was agreed generally that both overhead luggage racks came down on top of the passengers.

The majority of the fatalities had been occupying seats located in an area aft of the wing and forward of the main break in the rear passenger cabin. This area predominantly encompassed seating rows 26 through 35. There were 2 jet escape doors located in this area (row 33); however according to a survivor seated next to the door on the right side, he was unable to open either of them. He exited through the break in the fuselage near row 36. The other survivors from this area, as well as all of the survivors in the forward cabin areas, used the overwing exit, forward jet escape doors and forward entry door.

It should be noted that the fatally injured flight attendant was seated at row 33 on the aisle seat near the left side jet escape door.

The remaining survivors in the aft cabin area either found themselves outside of the aircraft after it stopped or exited through the break in the fuselage. A few survivors used the aft galley exit which could only be partially opened as it was lodged next to a small embankment. The aft entry door was jammed and could not be opened by the flight attendant assigned to that station.

Passengers in 36C, 36E, 36F, 37C and 37D reported being thrown out of the aircraft while still in their respective seats.

The captain stated that after the aircraft stopped he opened his cockpit window and yelled to the passengers who were leaving through the forward entry door to leave the area. He attempted to go back into the cabin through the cockpit/cabin door but it was blocked. He then exited through the left side cockpit window, went back to the main entry door and assisted passengers to get out of the aircraft through this exit. When no other passengers appeared at this door, he proceeded to the right side cockpit window and assisted the co-pilot [first officer] in evacuating the flight engineer and the navigator who had been injured in the crash.

AIRCRAFT FACTORS

The aircraft was a DC-8-63F registered as N4909C and operated by Capitol International Airways, Inc. The aircraft was issued a Standard Airworthiness Certificate, Transport Category on 2-Jul-1969.

The aircraft was carrying Jet-1-A fuel.

The cabin was configured with 219 passenger seats with a minimum seat pitch of 38 inches. A conventional DC-8-63 is configured to carry 250 passengers with 45 rows of seats and a 46th row single seat on the right side. When the aircraft is used for military charter, the configuration is changed to 219 passengers maximum. In order to accomplish this, left-hand side seats in row 4 and complete rows 10, 16, 26, 32 and 40 seat units are removed and the space is divided between the remaining rows of seats. Those seats at the over-wing exits at rows 21 and 23 (which become 18 and 20) and the forward and aft jetescape exits at rows 11 and 38 (which become rows 9 and 33) are not changed during conversion from the commercial to the military configuration. However, the row numbering of the commercial version continues to show throughout the cabin.

The first 4 rows of triple seats are on the left side of the centre aisle only. Opposite them and the forward main passenger entrance are the forward lavatories, coat racks and the forward galley. Seat rows 5 through 8 are triple seats on both sides of the centre aisle, as are rows 10 through 32 and rows 34 through 39. Rows 9 and 33 contain only a double seat unit on both sides of the centre aisle with no seat at either of the outboard positions, in front of the jetescape floor-level exits.

Row 9, right side aisle seat is reserved for the #6 flight attendant. At row 33 the left side aisle seat is blocked for flight attendant #7 to occupy during landings and take-offs. Over-wing exits are at rows 18 and 20. Row 40 contains a triple seat unit on the left side of the aisle and a single aisle seat on the right side. Seats in the rows are lettered alphabetically from A at the left window seat position through F at the right window.

At the forward entry is a double aft-facing fold-down jump seat for the flight attendants; in the forward galley are 2 aft-facing fold-down jump seats, similar to those in the aftgalley; and in the aft entry the double fold-down jump seat is forward facing.

The aircraft was equipped with 4 floor level exits along each side (2 at the front and 2 at the rear). In addition, there were 2 overwing emergency exits above each wing.

ENVIRONMENTAL CONDITIONS

The accident occurred during the hours of darkness. Wind was 060 deg at 6 kts. Visibility was 5 miles.

At the time of takeoff, a very light freezing drizzle was occurring at the airport. The runway was covered with ice with braking action reported as fair to poor.

INJURIES TO OCCUPANTS

Of the 10 crew and 219 passengers aboard, 1 crewmember and 46 passengers suffered fatal injuries, 6 crew and 43 passengers suffered serious injuries, 3 crew and 130 passengers escaped with minor or no injuries.

The majority of the occupants were soaked in fuel when gross amounts entered the cabin.

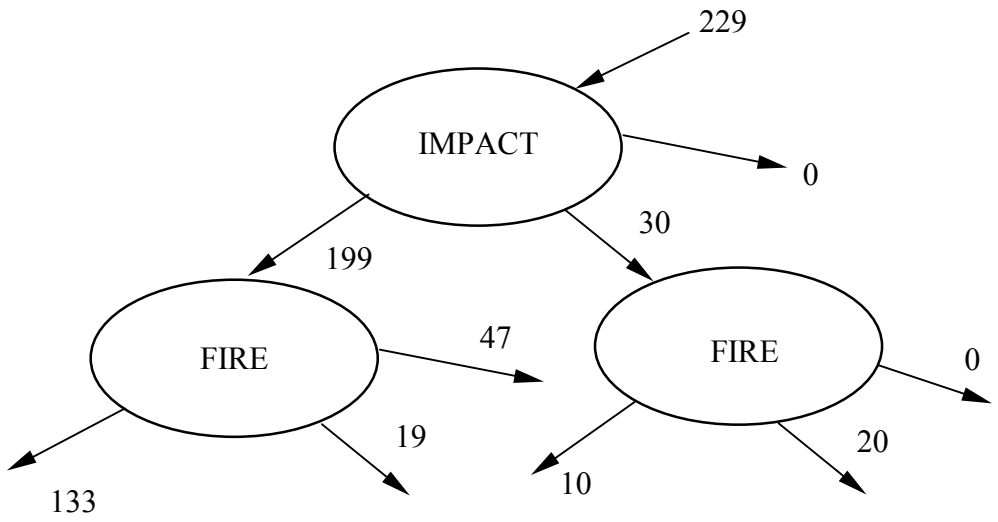
Pathological examination of the deceased disclosed that the primary cause of death was fire with evidence of the inhalation of the products of combustion. There were no traumatic injuries found that would have caused death. In only one fatality was there any finding that would indicate a possible degree of incapacitation due to decelerative forces.

The passengers were predominantly military personnel with a high ratio of healthy, well disciplined occupants and only a few dependants. Had this not been the case the loss of life, most certainly, would have been much higher.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to the absence of documentary evidence on the location of passengers, the whole fuselage volume has been taken as a single scenario which includes all occupants.

The aircraft and its occupants were subjected to impact followed by postcrash fire. There were 4 flight crew, 6 cabin crew, and 219 passengers onboard the aircraft. 1 flight attendant suffered serious injuries during the impact being thrown from her seat. Some (taken as 4) passengers, having got out of their seats and moving away from the fire, were thrown forward and injured during the impact. 5 passengers were thrown out of the aircraft while still in their seats and are assumed to have suffered serious impact injuries. This leaves 34 passengers and 5 crew with undetermined serious injuries. In the absence of detailed information, it is assumed that half of these suffered burns and half were injured by the impact as well as suffering burns. This results in 17 passengers and 2 crew suffering burns and 17 passengers and 3 crew suffering impact and burn injuries.



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

There was no indication from the aircraft accident report that the centre fuel tank had exploded; therefore, any ground nitrogen inerting used in the centre tank may not have altered the injury pattern of this accident. It was assessed that the explosions possibly came from the left wing tank.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

During the impact, thousands of gallons of raw fuel were released in and around the aircraft when the right wing broke loose. If ground nitrogen inerting had been used in the aircraft fuel tanks, it may have only prevented the two fairly large explosions observed emanating from the left side of the aircraft. The two explosions possibly came from the left wing tanks since the left wing was still attached to the main fuselage. The explosions would have increased the speed of the spread of fire on the left side of the aircraft.

The high assessment is based on the fact that there was extensive fuel and fire surrounding the aircraft and there was opportunity for fire to enter the cabin even if the explosions were prevented. In this event, it is assessed that 10 lives might be saved.

The low assessment is based on 20 fatal burn injuries being saved.

Due to lack of detail, the median assessment is taken as the average of the high and low assessments.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of ground nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**133**	**59**	**37**
Median	**133**	**64**	**32**
Low	**133**	**69**	**27**

Summary

The assessed median number of lives saved by ground nitrogen inerting in all fuel tanks is 15 (i.e., 47 - 32).

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

The effect of onboard nitrogen inerting would have been the same as the ground nitrogen inerting in all fuel tanks. Therefore, the high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**133**	**59**	**37**
Median	**133**	**64**	**32**
Low	**133**	**69**	**27**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 15 (i.e., 47 - 32).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – no lives saved.
2. Ground nitrogen inerting in all fuel tanks – 15 lives saved.
3. Onboard nitrogen inerting in all fuel tanks – 15 lives saved.

A.11 CASE 11

Date:	**08-Apr-1968**	Flight Phase:	**Landing**
Aircraft:	**B707**	Tank Type:	**Wing**
Location:	**Heathrow**	Fuel Type:	**Unknown**

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 crewmembers also used this escape route.

The port forward main door was also used. The chute did not inflate at first, after it was 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 the 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

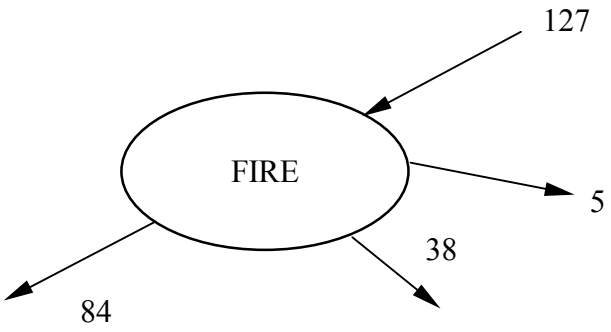
Of the 11 crew and 116 passengers aboard, 1 crew member and 4 passengers suffered fatal injuries, 38 passengers suffered serious injuries, 10 crew and 74 passengers escaped with minor or no injuries.

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.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to the absence of documentary evidence on the location of passengers, the whole fuselage volume has been taken as a single scenario which includes all occupants.

The aircraft and its occupants were not subjected to any impact but fire entered at the rear and propagated forward. There were 5 flight crew, 6 cabin crew, and 116 passengers onboard the aircraft. Because of the extent of the fire on the ground external to the aircraft, it is assessed that all serious injuries suffered during the evacuation were sustained from the fire.



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

There was no indication in the aircraft accident report that the centre fuel tank had exploded, therefore, nitrogen inerting in the centre tank would not have altered the injury pattern of this accident.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

The accident occurred shortly after takeoff. It was assessed that ground nitrogen inerting may have prevented the wing tank explosion, therefore, reducing the intensity and the speed at which the fire spread such that the occupants would have had additional time to escape. The conditions in the cabin were quite good in the early stages, but they deteriorated rapidly when the explosion occurred.

The high assessment is based on the fact that there were other fire entry paths, e.g., the opened port forward main door and probable burnthrough of the left fuselage side. It is, therefore, assessed that 2 passengers would still have succumbed to the fire and none of the serious fire injuries would have been avoided.

The median assessment assumes that all the fire fatalities were saved and that half of the serious injuries would have been avoided.

The low assessment assumes that all the fire fatalities were saved and that all the serious injuries would have been avoided.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of ground nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	**Serious Injuries**	**Fatal Injuries**
High	**84**	**41**	**2**
Median	**108**	**19**	**0**
Low	**127**	**0**	**0**

Summary

The assessed median number of lives saved by ground nitrogen inerting in all fuel tanks is 5 (i.e., 5 - 0).

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

It was assessed that the onboard nitrogen inerting would have prevented the fuel tank explosions, therefore, reducing the intensity and the speed at which the fire spread such that the occupants would have had additional time to escape. It is assessed that at most 2 of the fatalities would have escaped with nonfatal injuries.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	Serious Injuries	Fatal Injuries
High	**84**	**41**	**2**
Median	**108**	**19**	**0**
Low	**127**	**0**	**0**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 5 (i.e., 5 – 0).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – no lives saved.
2. Ground nitrogen inerting in all fuel tanks – 5 lives saved.
3. Onboard nitrogen inerting in all fuel tanks – 5 lives saved.

A.12 CASE 12

Date:	**20-Nov-1967**	Flight Phase:	**Approach**
Aircraft:	**CV880**	Tank Type:	**Unknown**
Location:	**Gt. Cincinnati**	Fuel Type:	**Aviation Kerosene**

DESCRIPTION OF ACCIDENT

RESUME

On 20-Nov-1967 a Trans World Airlines Convair CV880 registered as N821TW was making a final approach to Greater Cincinnati Airport, Covington, Kentucky.

Due to poor visibility in light snow at night, the aircraft flew below published minimums for this approach. The aircraft first struck trees 9,357 feet short of the approach end of the runway and 429 feet right of the extended runway centreline. After several more impacts with trees and the ground, the aircraft came to rest approximately 6,878 feet from the runway and 442 feet right of the extended runway centreline. The aircraft was destroyed by impact and fire.

Of the 7 crew and 75 passengers aboard, 5 crew and 65 passengers suffered fatal injuries. 2 crew and 10 passengers suffered nonfatal injuries.

IMPACT

The crew initiated the final descent, extended 50 deg flaps and performed the final landing checklist.

3 witnesses observed the aircraft crossing the Ohio River Valley just prior to the impact. 1 witness stated that other aircraft she had observed were always higher at this point in the flight. She described the aircraft as lowering faster and with a steeper descent than usual with an attitude approximately 10 degrees nose-down.

The aircraft first contacted small tree limbs, at a point approximately 9,357 feet from the approach end of the runway and 429 feet right of the extended centreline.

A surviving stewardess stated that the first noticeable impact felt like a hard landing. This was followed by a series of bumps and final impact. None of the survivors recalled any increase of engine power or felt any rotation of the aircraft.

The aircraft came to rest 6,878 feet short of the runway and 442 feet right of the extended runway centreline, virtually disintegrated and enveloped in flames.

The primary wreckage area, 2,500 feet from the initial impact point, contained the bulk of the aircraft and was approximately 500 feet long and 200 feet wide, with its centre 6,878 feet from the runway threshold.

No part of the aircraft was found outside the wreckage path or the primary wreckage area and portions of all parts of the aircraft were found in those areas. There was no evidence of preimpact failure of the airframe. All fractures observed were of the overload type. The landing gear was down and locked.

FIRE

There was no evidence of in-flight fire. The aircraft did burn after it came to rest and witnesses reported several explosions after the crash.

Fire fighting equipment responded from the airport and surrounding communities and fires were contained and extinguished by them.

EVACUATION

There were 7 crew and 75 passengers aboard.

[The cabin in this series aircraft could be configured with up to 110 passenger seats.]

Only 1 person, a passenger, was able to give a clear, sequential report of his escape. This man read the emergency information card as instructed and had his seat belt tight. At the first unusual sounds he put his head between his knees and remained in that position until the aircraft movement stopped. Being in a window seat, he was able to crawl out through the fractured fuselage beside his seat and escape serious injury.

AIRCRAFT FACTORS

The aircraft was a Convair CV 880. It was registered as N821TW and operated by Trans World Airlines.

The aircraft was completed on 20-Dec-1960 and received an airworthiness certificate on 8-Jan-1961. The aircraft was placed into service by TWA on 12-Jan-1961.

[The cabin in this series aircraft could be configured with up to 110 passenger seats.]

The front and rear of the fuselage were each fitted with an entry door on the port side with a service door opposite. There was a single overwing emergency exit above each wing.

ENVIRONMENTAL CONDITIONS

The accident occurred during the hours of darkness in an area where snow was falling. Visibility was 1.5 miles in light snow. The ambient temperature was 1°C. Wind was 110 deg at 7 kts.

INJURIES TO OCCUPANTS

Of the 7 crew and 75 passengers aboard, 5 crew and 65 passengers suffered fatal injuries. 2 crew and 10 passengers suffered nonfatal injuries.

Of the 82 occupants of the aircraft at the time of the accident, 60 persons were killed outright, 22 were removed to local hospitals where 10 subsequently died.

Of the 12 survivors, 2 cabin attendants and 4 adult passengers were interviewed shortly after the accident. The physical condition of the remainder precluded interviews at that time but all of the adults subsequently received questionnaires.

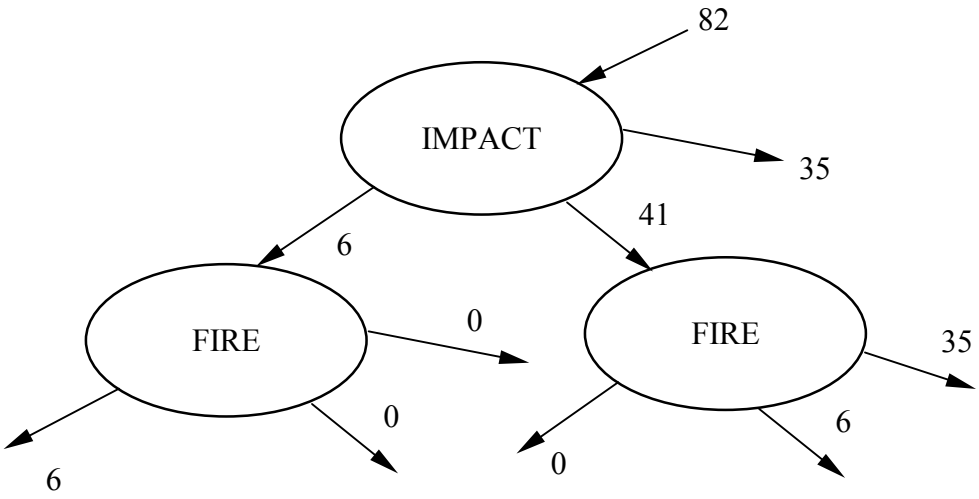
ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to the absence of documentary evidence on the location of passengers, the whole fuselage volume has been taken as a single scenario which includes all occupants.

The aircraft and its occupants were subjected to impact followed by postcrash fire. There were 3 flight crew, 4 cabin crew, and 75 passengers onboard the aircraft. Due to a lack of detailed injuries to occupants, the following assumptions have been made:

- half of the 70 fatalities died from impact – the aircraft impacted trees and ground several times.
- half of the 70 fatalities died from impact and fire.
- 6 occupants received minor or no injuries – 2 cabin attendants and 4 passengers were interviewed shortly after the accident.
- 6 of the seriously injured occupants received impact and burn injuries (physical condition precluded them from being interviewed).

The survivability chain is therefore:



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

It is believed that this aircraft was not one of the final 17 of the 65 CV-880 sold which had an extra centre-section tank to allow operation over longer range. The CV-880 in this accident was completed on 20 December 1960 which would have been built as part of the initial batch of 40 aircraft ordered by TWA and Delta in 1959.

Even if this aircraft had a centre fuel tank, ground nitrogen inerting would not have altered the accident injury pattern. The accident occurred during the final approach phase, therefore, any nitrogen in the centre tank would have vented in flight.

(2) Effect of Ground Nitrogen Inerting in Aircraft Fuel Tanks

If ground nitrogen inerting had been used in the aircraft fuel tanks, it would not have altered the accident injury pattern. The accident occurred during the final approach phase, therefore, any nitrogen in the fuel tanks would have vented in flight.

(3) Effect of Onboard Nitrogen Inerting in Aircraft Fuel Tanks

If onboard nitrogen inerting had been used in the aircraft fuel tanks, it would not have altered the accident injury pattern. From the accident report, the aircraft impacted with trees and ground several times and was virtually disintegrated and on fire. Although there were several explosions after the cash, there was no indication in the accident report as to where they came from. If the explosions did come from the aircraft fuel tanks, there would have been significant disruption of the tanks and the nitrogen gas would have been lost, hence no life saving capability has been assumed.

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – not applicable, aircraft not fitted with centre tank.

2. Ground nitrogen inerting in all fuel tanks – no lives saved.

3. Onboard nitrogen inerting in all fuel tanks – no lives saved.

A.13 CASE 13

Date:	**05-Mar-1967**	Flight Phase:	**Approach**
Aircraft:	**DC8**	Tank Type:	**Centre and Wing**
Location:	**Monrovia**	Fuel Type:	**Unknown**

DESCRIPTION OF ACCIDENT

RESUME

On 5-Mar-1967 a Varig Airlines DC-8-33 registered as PP-PEA was approaching Roberts International Airport, Monrovia, Liberia after a non-stop flight from Rome, Italy.

The flight was conducting a VOR/locator instrument let down and landing approach when it touched the ground in the middle of a small village slightly to the right of the extended centreline of the runway, approximately 6000 feet short of the runway threshold. The aircraft lost its undercarriage, engines and other components during a ground slide of approximately 850 feet and burned.

Of the 19 crew and 71 passengers aboard, the flight engineer and 50 passengers suffered fatal injuries. 16 crew and 7 passengers suffered serious injuries. 2 crew and 14 passengers suffered minor or no injuries.

IMPACT

A descent under visual meteorological conditions at 300 knots IAS at an average rate of descent of about 2000 feet per minute was commenced. After sighting the aerodrome runway lights from vertically overhead, the captain informed the first officer that despite the fact that he had the runway completely in sight he would make in Instrument Flight Rules (IFR) let down and landing approach.

The captain observed that his altitude over FR was about 800 feet, whereas his correct altitude should have been 520 feet. He told his 1st officer "I am a little high and I am descending to 550 feet". During the final phase of flight the second officer observed that the altimeter was still above 500 feet. He then felt the aircraft sinking, he looked at the altimeter and noticed the pointer passed 300 feet in a fast descent and immediately after the accident occurred. The rate of descent in the last 2 seconds of the approach was later calculated to have been at least 1150 feet per minute.

The first point of impact was 6023 feet from the threshold of the runway, 180 feet to the right of the extended centreline with the aircraft coming to rest after a ground slide of approximately 850 feet, the ground slide being parallel to the centreline of the runway.

The first point of impact showed the imprint of both main landing gears and the nose gear. The distance between the nose wheel and the axle of the main gear is approximately 690 inches. These imprints continued for a distance of 36 feet indicating "down and locked position". Thereafter, the undercarriage failed due to the right main gear entering a hole 6ft x 16ft x 4ft deep.

All flight control surfaces and all major components of all aircraft systems were found in the wreckage area indicating no evidence of inflight separation of the aircraft structure or components.

FIRE

Passengers reported that small fires around the base of the seats and aft galley (probably as a result of short circuits in the electrical wiring) occurred but quickly went out.

Fire was noted outside on both sides of the aircraft and some passengers reported that fire was coming in through an open overwing exit, almost completely dividing the cabin at row 15, progressing faster to the rear than to the front part of the fuselage. This was probably due to the fuel spilled behind the aircraft wing.

The length of time required for the fire to completely encompass the aircraft is unknown. It is noted however, from survivors reports, that smoke and fumes were in the cabin, which they described as smelling like burning rubber and kerosene. It is reported that these fumes did not bother their eyes, however there was evidence of suffocation as 1 passenger and 1 crew member were treated in hospital for their condition from inhalation of smoke and fumes.

The time taken for the airport crash trucks and 1 reserve water tender to arrive at the site was thought to have been between 5 and 10 minutes. The 2 trucks were positioned on each side of the aircraft nose section and foam was applied on the fuselage from both sides. The fire crew who were occupied with fighting the fire from the front were unable to take rescue action in the area behind the wing.

When the fire chief arrived shortly after the arrival of the fire crew he ascertained himself by looking through the open front left hand door that nobody could be saved from the front part of the cabin. An eruption of a fuel tank prevented him from looking into the rear cabin at the rear door when he was about to do so. As the small fire crew was fully occupied by fighting the fire it was beyond their physical capabilities to effect rescue.

EVACUATION

There were 9 flight crew (4 off duty), 10 cabin crew and 71 passengers aboard.

During the aircraft slide one of the overwing emergency exit doors fell into the cabin.

Within the fuselage, reports were that the forward liferaft compartment door opened and partially obstructed the forward left hand door. In addition, the contents of the forward galley were all over the floor, indicating that the galley doors opened.

Survivors state that passengers from seat row 13 in the coach section and those in the first class section escaped through the forward left hand passenger door. It is not known if any attempt was made to open the forward right hand passenger door, however it was never opened.

In the aft end of the cabin the forward liferaft compartment door came open and permitted the liferaft to fall to the floor hitting a crew member in seat 28D. The closet just forward of the right hand coat room broke loose and fell across the aisle.

The crew folding seat adjacent to the left aft passenger door broke and dropped the 2 attendants occupying the seat to the floor, obstructing the access way to the door. The seat belts on this seat did not break, however seat belts did break at seats 2C and 25B.

The aft left hand passenger door could not be opened on the first attempt. The crew and passengers report that they tried to open the aft right hand passenger door by the galley, but this door could not be opened either and, in fact, was never opened. The left hand aft passenger door was successfully opened on the second attempt and all survivors aft of coach seat row 15 escaped through this exit. 1 passenger and probably more who did not survive headed toward the front of the cabin after unsuccessfully attempting to escape through the rear of the aircraft.

In the front section from seat row 13 forward there were 14 crew members and 17 passengers. 11 crewmembers and 11 passengers escaped through the front passenger door, left side. 2 other crew members escaped through the left side cockpit sliding window.

In the rear section rear of seats row 13 there were 5 crewmembers and 54 passengers. 5 crewmembers and 10 passengers escaped through the left side rear passenger door.

A number of the passengers who survived from the front section of the aircraft from seat row 13 forward were assisted through the first class section by the cabin staff and evacuated through the forward left hand passenger door. Cabin staff from the front section were unable to gain further access through the cabin to the rear due to fire which divided the cabin at row 15 rendering movement through it impossible. None of the crewmembers stated that they assisted in the further evacuation of those passengers who were still in the aircraft after they had themselves evacuated the aircraft, except 1 crewmember who after evacuating himself through the front left hand door and running 50 yards away from the front of the aircraft returned, after hearing an explosion, and circled around the port wing to see if anyone was getting out of the rear door. He stated that on reaching a point mid-way between the port outer engine and the wing tip he saw that the aircraft, rear of the leading edge of the wing, was circled with flames so he returned to further assist the passengers evacuating at the front left hand door.

In the aft section the 2 flight attendants seated on the folding seat adjacent to the left hand passenger door were rendered ineffective when their seat broke and dropped them to the floor.

Both flight attendants suffered traumatic injuries. A third flight attendant was stunned when struck by a falling liferaft and was pushed out of the aircraft by an unidentified passenger. All 10 surviving passengers aft of row 15 gained access unassisted to the rear left hand passenger door. The statement of several survivors shows that the area near the rear left hand passenger door was not initially blocked by outside fire.

Failure of the cabin lights after first impact rendered evacuation action more difficult.

AIRCRAFT FACTORS

The aircraft was a DC-8-33 registered as PP-PEA and operated by Varig Airlines.

The aircraft was manufactured in 1960 and the Certificate of Registration was issued on 21-Jan-1963.

The cabin was equipped at the front with a floor mounted entry door on the port side and a service door opposite. At the rear there were two floor mounted doors on each side. There were 2 overwing emergency exits above each wing.

ENVIRONMENTAL CONDITIONS

The accident occurred during the hours of darkness in light fog. Wind was 050 deg at 2 kts. Visibility was 5 miles. The ambient temperature was 24°C.

INJURIES TO OCCUPANTS

Of the 19 crew and 71 passengers aboard, the flight engineer and 50 passengers suffered fatal injuries. 16 crew and 7 passengers suffered serious injuries. 2 crew and 14 passengers suffered minor or no injuries.

Among the 39 survivors, 21 needed medial attention for fractures, second degree burns, contusions, lacerations and lung congestion from fumes. 9 crew members and 4 passengers were hospitalised.

Most of the bodies were found severely burned in the aft section of the economy class cabin lying in the debris with their heads in the direction of the rear of the aircraft pyramided between the last 3 rows of seats.

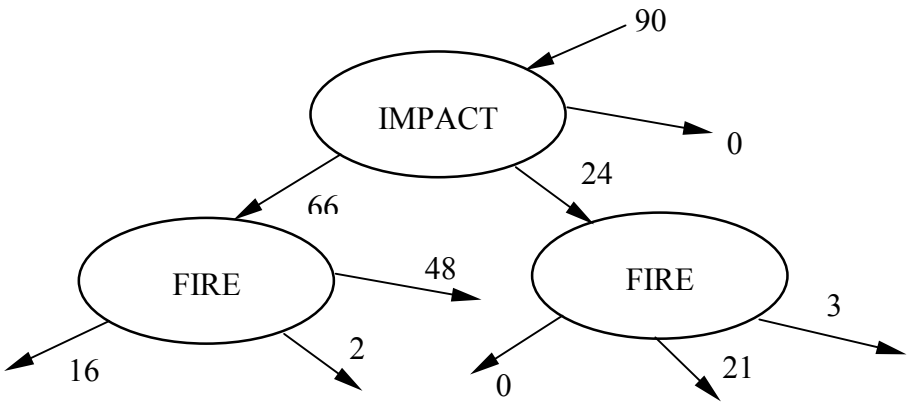
Post-mortem examination of the bodies revealed a few cases of additional fractures that appeared to be ante-mortem and the bodies showed evidence of carbon monoxide poisoning.

A cargo load of movie safety films carried aboard the aircraft largely consumed by fire released large quantities of carbon monoxide. The presence of large quantities of carbon monoxide inside the burning cabin brought stupor, coma and final death to the majority of the 51 persons who died.

ACCIDENT SCENARIOS AND SURVIVABILITY CHAINS

Due to the absence of documentary evidence on the location of passengers, the whole fuselage volume has been taken as a single scenario which includes all occupants.

The aircraft and its occupants were subjected to impact followed by postcrash fire. There were 9 flight crew, 10 cabin crew, and 71 passengers onboard the aircraft. A few occupants (taken as 3) suffered impact injuries before they succumbed to the fire, the rest (taken as 48) died as a direct result of the fire only. Of the seriously injured, 21 reportedly suffered impact injuries and burns, the remaining 2 are assumed to have suffered burns only.



(1) Effect of Ground Nitrogen Inerting in Centre Fuel Tank Only

If ground nitrogen inerting had been used in the centre fuel tank, it would not have altered the accident injury pattern. The accident occurred during the final approach phase, therefore, any nitrogen in the centre tank would have vented in flight.

(2) Effect of Ground Nitrogen Inerting in all Fuel Tanks

If ground nitrogen inerting had been used in aircraft fuel tanks, it would not have altered the accident injury pattern. The accident occurred during the final approach phase, therefore, any nitrogen in the fuel tanks would have vented in flight.

(3) Effect of Onboard Nitrogen Inerting in all Fuel Tanks

It was assessed that the first explosion that was heard by a crewmember, as he was circling the aircraft, could have come from either the centre or the right wing tank. He was in the area of the left wing and only reported hearing the explosion. If the left wing tank had exploded, he would presumably have seen it as well.

It was believed that the eruption of a fuel tank which had prevented the fire chief from looking into the rear cabin at the left rear door could have been the left wing tank since he was on that side. The right-hand rear passenger door was not opened in the evacuation.

If onboard nitrogen inerting had been used in the aircraft fuel tanks, it would have prevented the fuel tanks from exploding. However, the fire entered the cabin through an open overwing exit and divided the cabin. It was several minutes after evacuation started that the explosions occurred.

The high assessment is based on there being considerable fire in and around the cabin even without the explosions. On this basis no fire fatalities would have been saved and no serious fire injuries would have been avoided. In addition, a cargo load of movie safety films, carried aboard the aircraft, was largely consumed by fire releasing large quantities of carbon monoxide. The presence of large quantities of carbon monoxide inside the burning cabin brought stupor, coma, and finally death to the majority of the 51 persons who died.

The low assessment is based on there being a small number of occupants (2 fire fatalities from the front of the cabin and 3 from the rear) still evacuating at the time of the explosions, who may have been helped if the explosions were suppressed. The 2 serious fire injuries may also have been avoided.

Due to lack of detailed information, the median assessment is taken as the average of the high and low assessments.

The high, median, and low prediction of the number of fatalities and injuries resulting from the use of onboard nitrogen inerting in all fuel tanks is as follows.

	Minor/No Injuries	**Serious Injuries**	**Fatal Injuries**
High	**16**	**23**	**51**
Median	**17**	**25**	**48**
Low	**18**	**26**	**46**

Summary

The assessed median number of lives saved by onboard nitrogen inerting in all fuel tanks is 3 (i.e., (3+48) - 48).

OVERALL SUMMARY

Benefit

1. Ground nitrogen inerting in centre fuel tank only – no lives saved.
2. Ground nitrogen inerting in all fuel tanks – no lives saved.
3. Onboard nitrogen inerting in all fuel tanks – 3 lives saved.

APPENDIX B—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 B-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 fuel tank inerting. The assessment results in a prediction of the highest, mean, and lowest number of fatalities that could reasonably be expected from inerting.

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

Figure B-2 illustrates the principle for assessing the effect on survivability of variations in the effectivity of improvements. From the rationales, the best (or median) assessment was made of the reduction in the number of fatalities and injuries that would accrue from fuel tank inerting. 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 inerting.

It was 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 B-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 B-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 survivability rate. Refer to figure B-4.

Stage 4 of the process is simply to determine the 2.5, 50 and 97.5 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 the number of survivors.

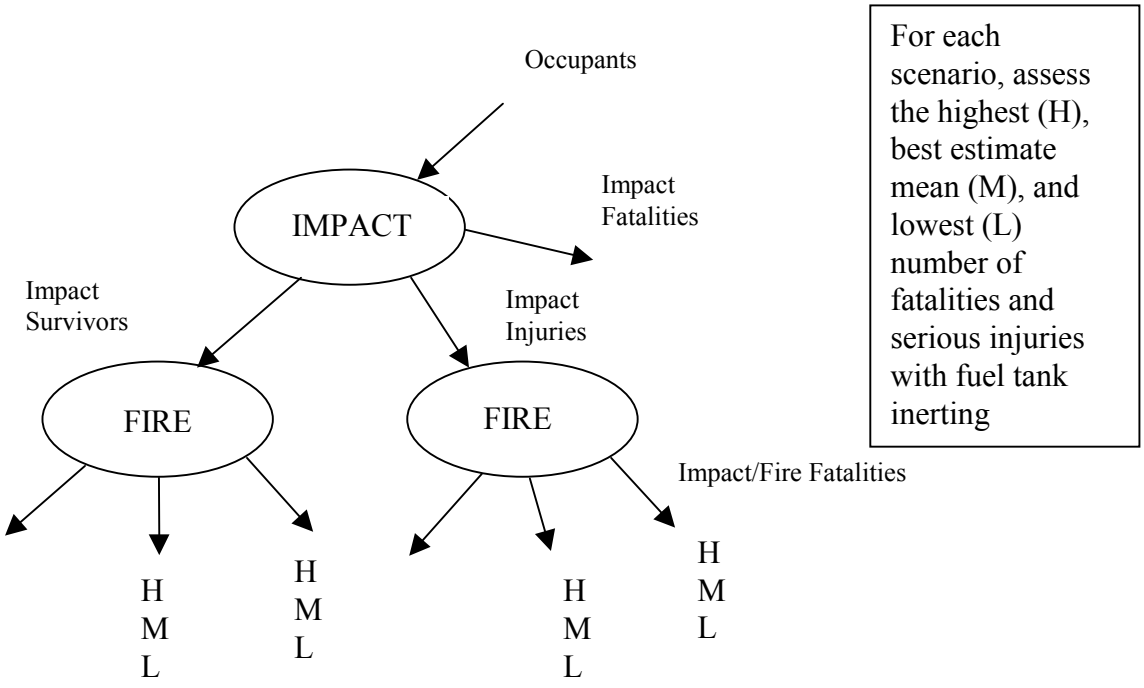


FIGURE B-1. STATISTICAL MODELLING PROCESS, STAGE 1

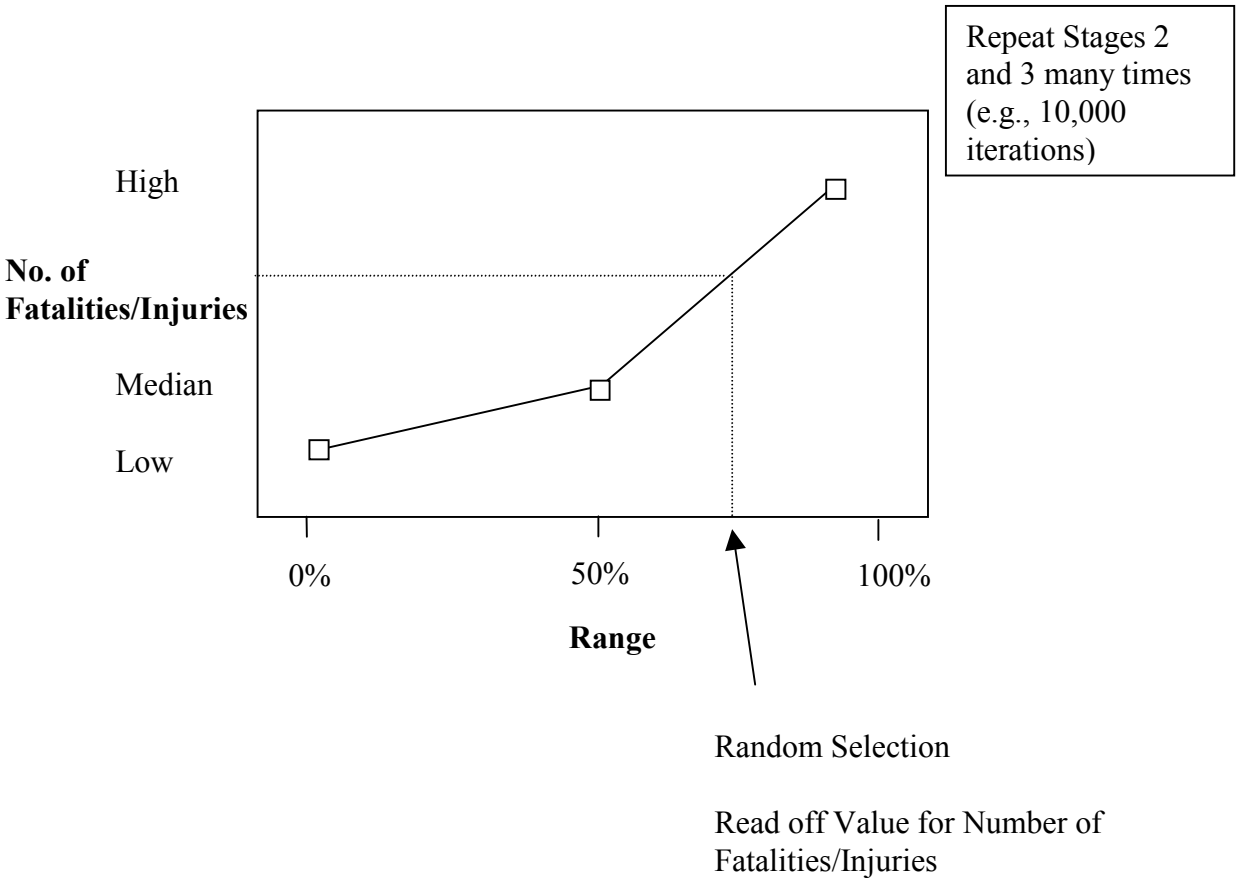
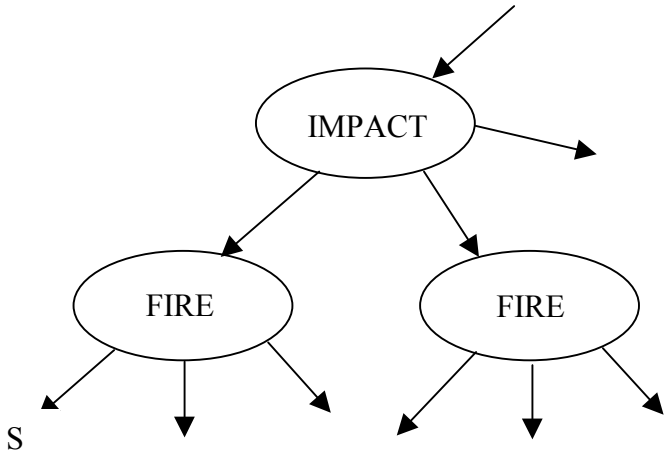


FIGURE B-2. STATISTICAL MODELLING PROCESS, STAGE 2



Reassess number of uninjured survivors

Evaluate injury rate improvement using:

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

Where:

S_F = the assessment of the decrease in injury rate after fuel tank inerting (over all accidents)

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 B-3. STATISTICAL MODELLING PROCESS, STAGE 3

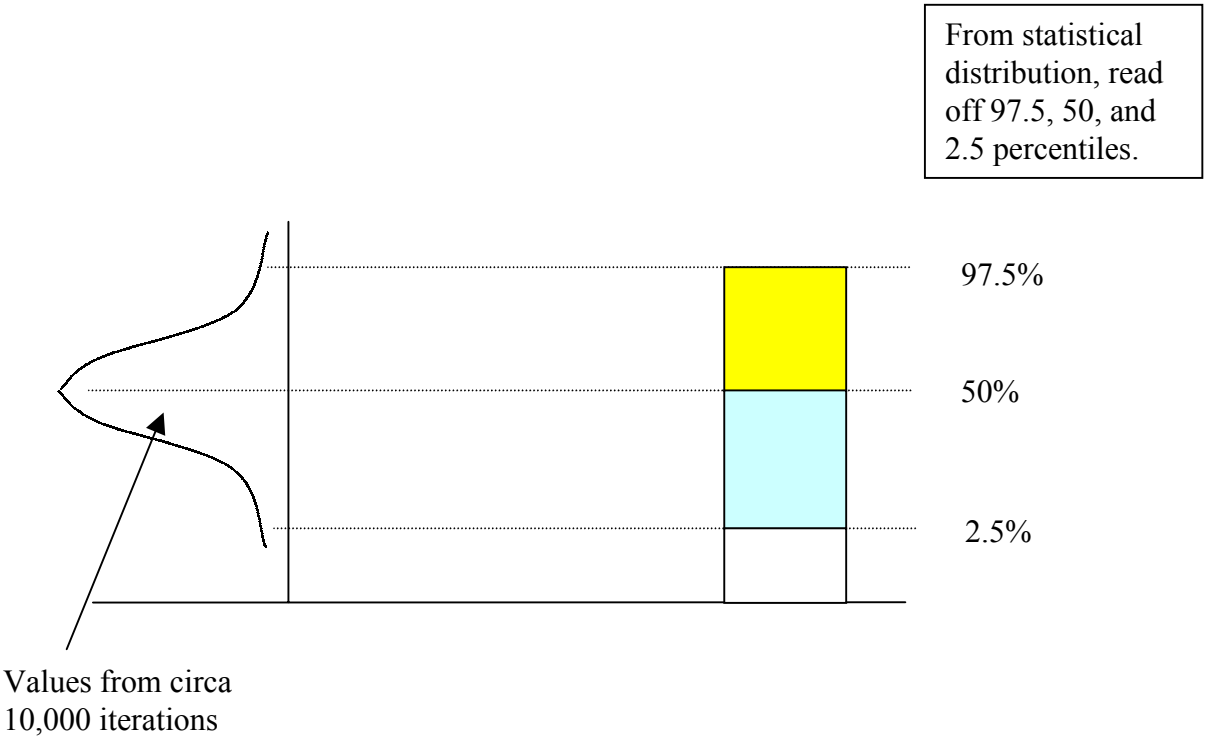


FIGURE B-4. STATISTICAL MODELLING PROCESS, STAGE 4