DOT/FAA/TC-16/31

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

A Study into the Structural Factors Influencing the Survivability of Occupants in Airplane Accidents

September 2016

Final Report

U.S. Department of Transportation
Federal Aviation Administration

United Kingdom Civil Aviation Authority

NOTICE

This research was carried out at the request of the United Kingdom Civil Aviation Authority and the United States Federal Aviation Administration. This activity has been carried out in cooperation with the Federal Aviation Administration and the UK Civil Aviation Authority under the auspices of the International Cabin Safety Research Technical Group whose goal is to enhance the effectiveness and timeliness of cabin safety research.

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-16/31		

4. Title and Subtitle	5. Report Date
A STUDY INTO THE STRUCTURAL FACTORS INFLUENCING THE SURVIVABILITY OF OCCUPANTS IN AIRPLANE ACCIDENTS	September 2016
	6. Performing Organization Code
7. Author(s) R.G.W. Cherry & Associates Limited	8. Performing Organization Report No.
9. Performing Organization Name and Address R.G.W. Cherry & Associates 33 Star Street Ware, Herts, SG12 & AA United Kingdom	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Transportation Administration Office of Aviation Research and Development Washington, DC 20591	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code ANM-115

15. Supplementary Notes

The Federal Aviation Administration William J. Hughes Technical Center Aviation Research Division COR was Allan Abramowitz.

16. Abstract

This study has been carried out at the request of the United Kingdom Civil Aviation Authority and the United States Federal Aviation Administration. An earlier study carried out for the United Kingdom Civil Aviation Authority (1996 covering years 1969-1991 inclusive) addressed structural issues that might influence the survivability of occupants in airplane accidents (survivability factors). This current study reanalyzed these survivability factors to include more recent accident experience (1992 to 2011 inclusive) and the addition of the Asiana accident in San Francisco in 2013. The study was primarily based on a quantitative and qualitative analysis of past accidents. The quantitative analysis was performed using Monte Carlo models developed specifically for this study.

17. Key Words	18. Distribution Statement
Structural factors, aircraft accidents, survivable aircraft accidents, survivability factors, aircraft accident injury/ fatality rate, crashworthiness	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	64	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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LIST OF ACRONYMS

AAIB	UK Air Accidents Investigation Branch
CAMI	Federal Aviation Administration, Civil Aerospace Medical Institute
CFR	Code of Federal Regulations
CSRTG	Cabin Safety Research Technical Group
CIAIC	Comisión de Investigación de Accidentes e Incidentes de Aviación Civil - Spanish Accident Investigation Authority
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
ICAO	International Civil Aviation Organization
MEC	Main Equipment Center
MLG	Main Landing Gear
NLG	Nose Landing Gear
NTSB	National Transportation Safety Board (USA)
PA	Public Address
PSU	Passenger Service Unit
TSB	Transportation Safety Board of Canada
UK CAA	United Kingdom Civil Aviation Authority

EXECUTIVE SUMMARY

This study has been carried out at the request of the United Kingdom Civil Aviation Authority and the United States Federal Aviation Administration (the Authorities). An earlier study carried out for the United Kingdom Civil Aviation Authority (1996 covering years 1969-1991 inclusive) addressed structural issues that might influence the survivability of occupants in airplane accidents (survivability factors). This current study was aimed at reanalyzing these survivability factors to reflect more recent accident experience (1992 to 2011 inclusive) and the addition of the Asiana accident in San Francisco in 2013. The study was primarily based on a quantitative and qualitative analysis of past accidents. The survivability factors analyzed in this study were:

- Rearward facing seats
- Seat/floor strength
- Head strike adequacy
- Distortion of door frames (door jamming)
- System Crashworthiness
- Structural strength of cabins (ditching/impact resistance, etc.)
- Equipment retention
- Infant seats
- Exit operability
- Occupant restraint (adequacy of seat belts)
- Strength of overhead stowage
- Strength of production breaks
- Emergency and evacuation issues (this survivability factor was only addressed qualitatively)

Accidents were selected for analysis that met the following criteria:

- The accident occurred over the period 1992 to 2011 inclusive.
- The accident involved a western-world built passenger or passenger/cargo turbojet/turboprop aircraft configured with twenty seats or more operating in revenue service.
- The accident was impact related (i.e. it involved the transmission of impact forces into the aircraft structure).
- The accident database contained textual information on the accident based on official accident reports.
- The accident was survivable and did not result from acts of war, terrorism or sabotage.

Using these criteria 115 accidents were identified, 71 involving fatal or serious injuries and 44 accidents involving minor or no injuries. Additionally, the Asiana 777 accident in San Francisco in July 2013 was also included in the study.

Of the 116 accidents selected for analysis, 29 were found to have insufficient information to be analyzed quantitatively and 44 did not result in fatal or serious injuries making quantitative analysis inapplicable. The remaining 43 were subjected to quantitative analysis. One hundred and two (102) accidents had sufficient information to allow a qualitative assessment to assess the relevance of the survivability factors. This qualitative analysis and the conclusions from the quantitative analysis are summarized in section 5 of this report.

The quantitative analysis was carried out using Monte Carlo models developed specifically for this study.

This analysis suggests that only 8 of the 13 survivability factors were likely to yield any mitigation of occupant injuries by their improvement, with the rearward facing seats and seat/floor strength factors predominating. The model predictions for these two survivability factors suggests that mitigation of each of these has the potential to reduce the total number of injuries that might be incurred, in accidents to airplanes configured to the latest airworthiness requirements, by approximately 7% and the number of fatalities by approximately 5%.

The head strike adequacy survivability factor features relatively highly in the quantitative analysis, even when consideration is given to the incorporation of the latest airworthiness requirements, including 16 g seats.

There were many instances where airframe distortion resulted in door jamming and/or equipment becoming unrestrained in the passenger cabin.

The survivability factor system crashworthiness was identified as an issue in 8 accidents. These issues include landing gear separation, and fuselage damage leading to the failure of various systems to operate as designed. Public address and interphone systems were also found to be adversely affected directly or indirectly as a result of the crash sequence.

While the survivability factor infant seats did not feature highly in the quantitative analysis, this is perhaps attributable to the proportion of infants on the airplane being relatively low. However, it would appear evident that infants do not have the same level of protection afforded to adult occupants.

It would appear that the proportion of impact injuries reduces with increasing size of airplane. In particular, impact accidents to wide body airplanes are likely to result in a lower proportion of occupants sustaining injuries than smaller airplanes. However, there were insufficient data to come to any firm conclusions regarding differences in survivability between narrow body and regional airplanes or between turbojets and turboprops.

While it is likely that 16 g seats have provided a positive benefit in injury reduction, there are currently insufficient accident data to quantify the degree of improvement that is likely to have been achieved.

1. INTRODUCTION

This study has been carried out at the request of the United Kingdom Civil Aviation Authority (UK CAA) and the United States Federal Aviation Administration (FAA)[1].

In 1996 the UK CAA published a study carried out by RGW Cherry & Associates Limited which analyzed the structural survivability factors influencing the survivability of occupants in airplane accidents (reference 1).

This study is aimed at reanalyzing the structural survivability factors, identified in the above study, to reflect more recent accident experience.

2. TERMINOLOGY

The definitions shown below are used in this study. In some instances the definitions are not necessarily those currently used by the industry. However, they are likely to be those used in the investigations into most of the accidents analyzed in this study.

Accident Scenario

> For this study an accident scenario is defined as: that volume of the aircraft in which the occupants are subjected to a similar level of threat.

Fatal Injury (Source: NTSB, ICAO)

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

Fatality Rate is the proportion of occupants sustaining fatal injuries.

Injury Rate is the proportion of occupants sustaining serious or fatal injuries.

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

> "An injury which is sustained by a person in an accident and which:
> (a) requires hospitalization for more than 48 hours, commencing within seven days from the date the injury was received; or
> (b) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); or
> (c) involves lacerations which cause severe hemorrhage, nerve, muscle or tendon damage; or
> (d) involves injury to any internal organ; or
> (e) involves second or third degree burns, or any burns affecting more than 5 per cent of the body surface; or
> (f) involves verified exposure to infectious substances or injurious radiation."

Survivable Accident

[1] UK CAA and the FAA are referred to as the Authorities going forward.

There are several definitions of a survivable accident, most of which are similar in concept to that contained in the “Aircraft Crash Survival Guide” published by the U.S. Army Research and Technology Laboratories:

> “An accident in which the forces transmitted to the occupant through his seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations and in which the structure in the occupants’ immediate environment remains substantially intact to the extent that a liveable volume is provided for the occupants throughout the crash sequence.”

However, definitions of this kind are not adhered to in this study for the following reasons:

1. For any particular accident, survivability potential may vary significantly dependent on occupant location.
2. The definition is subjective; therefore, categorization will vary dependent on the analyst’s assessment of the environment to which the occupants are subjected.
3. While for a particular accident scenario, the hazardous environment to which occupants were subjected may have been non-survivable, this does not infer that improvements would not have resulted in survivors.

For these reasons, the following definition of a survivable accident is used in this study:

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

This definition of a survivable accident excludes accidents in which there were no survivors and no potential for survival, such as in-flight break-up, collision with high ground, etc.

3. ANALYSIS METHODOLOGY

3.1 OVERVIEW

The earlier UK CAA study (reference 1) involved the analysis of a “representative set” of 42 survivable accidents[2] that occurred over the period 1969 to 1991 inclusive. The representative set of accidents was selected to be typical of all survivable accidents over the period of the study, in terms of the proportion of occupants sustaining fatal injuries and the proportion of accidents by type (e.g. cabin fire related, ditching etc.). A representative set of accidents was used in the study to reduce the number of accidents that needed to be analyzed in depth. However, since the time of the earlier study, the accident rate has reduced markedly with a consequential reduction in the number of accidents per year. Therefore, for this study all accidents meeting the accident selection criteria defined in section 3.2 have been analyzed.

The primary purpose of the analysis was to assess the likely effects, both qualitatively and quantitatively, on injury rate and fatality rate that might be afforded by the improvements to the survivability factors defined in section 3.3.

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[2] See Section 2 - Definitions

3.2 ACCIDENT SELECTION

The study is based on an analysis of accident data contained in the Cabin Safety Research Technical Group (CSRTG) Accident Database (reference 2) supported by accident reports and other official data (e.g. National Transportation Safety Board Survivor Reports). Survivable accidents were selected for analysis, from the CSRTG Accident Database, based on the following criteria:

1. The accident occurred over the period 1992 to 2011 inclusive.
2. The accident involved a western-world built passenger or passenger/cargo turbojet/turboprop aircraft configured with twenty seats or more operating in revenue service.
3. The accident was impact related (i.e. it involved the transmission of impact forces into the aircraft structure).
4. The accident database contained textual information on the accident based on official accident reports.
5. The accident was survivable in accord with the definition given in section 2.
6. The accident did not result from acts of war, terrorism or sabotage.

Using these criteria results in the number of accidents contained in the CSRTG Accident Database of:

71 accidents that involved fatal or serious injuries
44 accidents involving minor or no injuries

Additionally, the Asiana 777 accident in San Francisco, July 2013, has also been included in the study in accord with the request from the FAA, making a total of 116 accidents to be analyzed. Of the 116 accidents selected, 29 were found to have insufficient information to be analyzed quantitatively, and 44 did not result in fatal or serious Injuries making quantitative analysis inapplicable. The remaining 43 were subjected to quantitative analysis. The 116 accidents are listed in appendix A.

3.3 SURVIVABILITY FACTORS

All survivability factors were subjected to qualitative analysis. One hundred and two of the selected accidents had sufficient information to allow a qualitative analysis to be made. Survivability factors 3.3.1 to 3.3.12 have been considered on a quantitative basis. The survivability factors have been ordered to correspond with section 5.

The following survivability factors have been agreed with the Authorities as being those to be analyzed in the study.

3.3.1 Rearward Facing Seats

Rearward facing seats may have the potential to reduce head or leg injuries to occupants. Quantitative and qualitative assessments are made for this survivability factor.

3.3.2 Seat/Floor Strength

Failures of seat structure, seat rails, or floors can result in injuries or fatalities to occupants. Quantitative and qualitative assessments are made for all cabin occupants (passengers and cabin crew). Additionally, qualitative assessments are made for the flight crew.

3.3.3 Head Strike Adequacy

Injuries which have resulted from head strike of the seated passenger or cabin crew member within the striking radius of the head. (reference Title 14 Code of Federal Regulations (14 CFR) § 25.785). Quantitative and qualitative assessments are made for this survivability factor. Additionally qualitative assessments are made for the flight crew.

3.3.4 Distortion of Door Frames (Door Jamming)

This survivability factor addresses difficulties experienced in opening passenger doors due to distortion of doors, door frames or surrounding structure resulting from impact damage. Quantitative and qualitative assessments are made for this survivability factor. Additionally, cockpit doors and windows are also considered qualitatively.

3.3.5 System Crashworthiness

This survivability factor relates to any adverse effect to safety resulting from impact loads being transmitted to airplane systems including engine controls and landing gear. Quantitative and qualitative assessments are made for this survivability factor.

3.3.6 Structural Strength of Cabins (Ditching/Impact Resistance, etc.)

Structural issues arising from failures in the structural integrity of the cabin that may have a direct adverse effect on occupant survival or impede evacuation. For certain accidents this may result in the entry of fire into occupied areas but may also provide an escape route. Quantitative and qualitative assessments are made for this survivability factor.

3.3.7 Equipment Retention

Occurrences where items of equipment in a passenger or crew compartment become unrestrained, causing injuries or an impediment to evacuation. Quantitative and qualitative assessments are made for this survivability factor.

3.3.8 Infant Seats

Instances where infant injuries might have been mitigated by the use of dedicated infant seats affording a similar level of protection to that which is provided for other passengers. Quantitative and qualitative assessments are made for this survivability factor.

3.3.9 Exit Operability

Difficulties in the operation of cabin doors which result from impact loads being transmitted into the door operating mechanism. This excludes door jamming which is addressed by the survivability factor - distortion of door frames (see section 3.3.4). In this study exit operability has been limited to the operation of the door itself and does not include the operation or usability of the slide. Exit operability is considered compromised only if the door mechanism is damaged by the impact forces. Quantitative and qualitative assessments are made for this survivability factor. The inability to latch the door open is only considered qualitatively.

3.3.10 Occupant Restraint (Adequacy of Seat Belts)

The study addresses instances where passenger seat belts or cabin crew harnesses have failed to provide adequate protection of the occupant. This excludes instances where injuries were sustained due to seat belts not being secured. Quantitative and qualitative assessments are made for this survivability factor. Additionally, qualitative assessments are made for flight crew harnesses.

3.3.11 Strength of Overhead Stowage

The detachment of overhead bins can result in an impediment to the evacuation of passengers and cabin crew as well as the obvious risk of inflicting injury. Quantitative and qualitative assessments, for this survivability factor, are made for all cabin occupants (passengers and cabin crew). Any release of contents from the overhead stowage has also been considered on a qualitative basis.

3.3.12 Strength of Production Breaks

Fuselage ruptures which might occur at a production break and limit the passenger or cabin crew space remaining, possibly allowing entry of fire (but providing an escape route) or the ability of the occupants to rapidly evacuate the aircraft. Quantitative and qualitative assessments are made for this survivability factor.

3.3.13 Emergency and Evacuation Issues

This survivability factor relates to issues arising that have a detrimental effect on the satisfactory execution of emergency and evacuation drills. This includes issues experienced by passengers when carrying out an evacuation. This survivability factor is only considered qualitatively due to the inaccuracies that would be incurred in a quantitative assessment.

4. QUANTITATIVE ASSESSMENT OF SURVIVABILITY FACTORS

Quantitative evaluations of the likely change in occupant survivability due to improvements in survivability factors are based on assessments of the reduction in fatality rate and injury rate[3]. These assessments are made by the use of Monte Carlo models developed specifically for this study. The principles of the models are described in appendix B.

Two master models have been developed; each supported by a sub-model for each of the survivability factors. One of the master models relates to the injuries sustained in the actual accident and the other to the injuries that might have resulted had the aircraft been compliant with

[3] Injuries include both Fatal and Serious Injuries.

the latest standards of occupant survivability as defined in 14 CFR Part 25. These improvements include the following areas:

- 16 g Seats
- Seat blocking layers,
- Improved flammability and burnthrough resistance of Thermal Acoustic Insulation materials
- Floor proximity lighting/marking
- Reduced heat release of cabin interior materials
- Improved access to Type III exits
- Smoke detection in toilet compartments
- Additional fire extinguishers in passenger compartments
- Landing gear design

The inputs to the models are based on the 43 accidents analysed (see section 3.2).

The outputs from the models are shown in figure 1, figure 2, figure 3 and figure 4. The vertical axis of the graphs represents the proportion of fatalities or injuries estimated to be saved by the associated survivability factor. Therefore, a value of 0.06 on the Injury Reduction Chart suggests that 6% of injuries might be saved by the survivability Factor. The top of the yellow band represents the best estimate, or 50 percentile value of the model outputs. The 90 percentile range of the model output is indicated by the top of the blue band to the top of the white band.

4.1 REDUCTION IN INJURY RATE – ACTUAL ACCIDENT

The assessment of the injury rate reduction, for each survivability factor, based on the actual accident, is illustrated in figure 1.

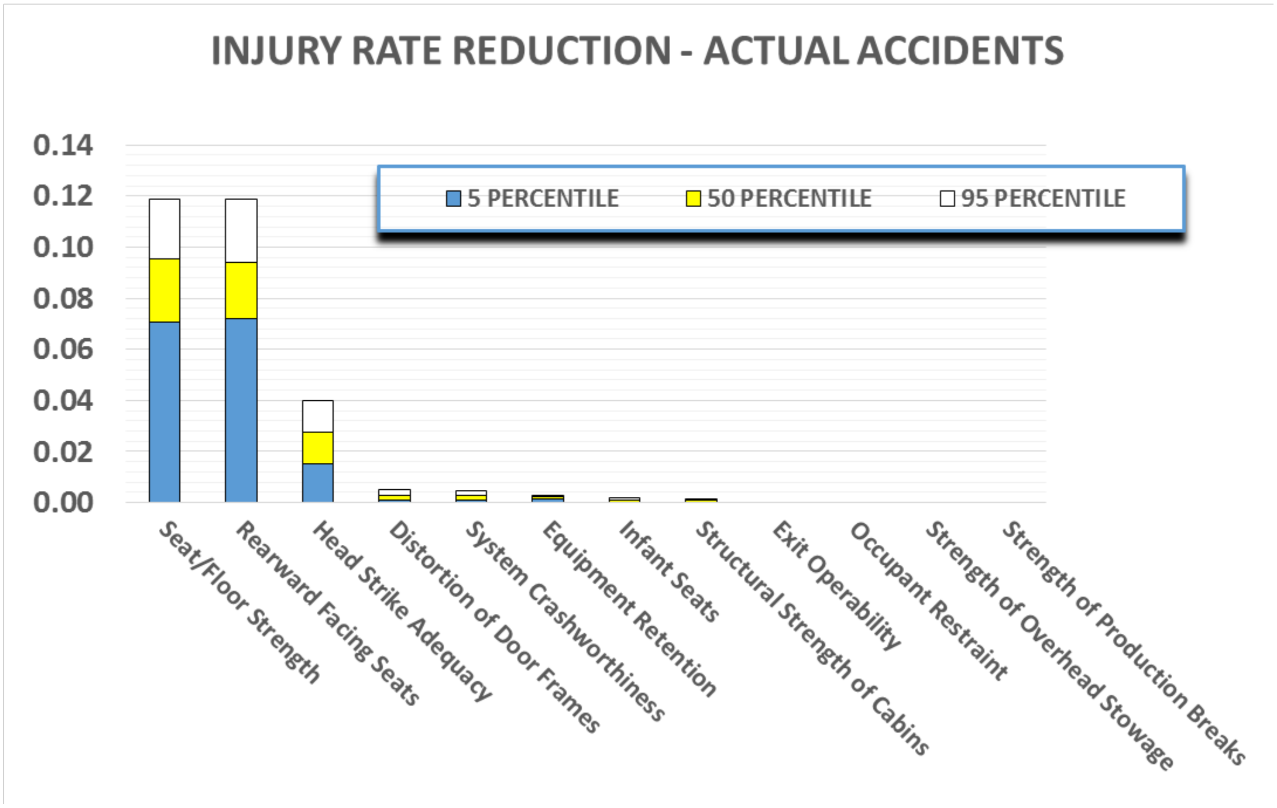

Figure 1. Model Output showing improvement in Injury Rate for each Survivability Factor - based on the Actual Accidents

4.2 REDUCTION IN FATALITY RATE – ACTUAL ACCIDENT

The assessment of the fatality rate reduction, for each survivability factor, based on the actual accident, is illustrated in figure 2.

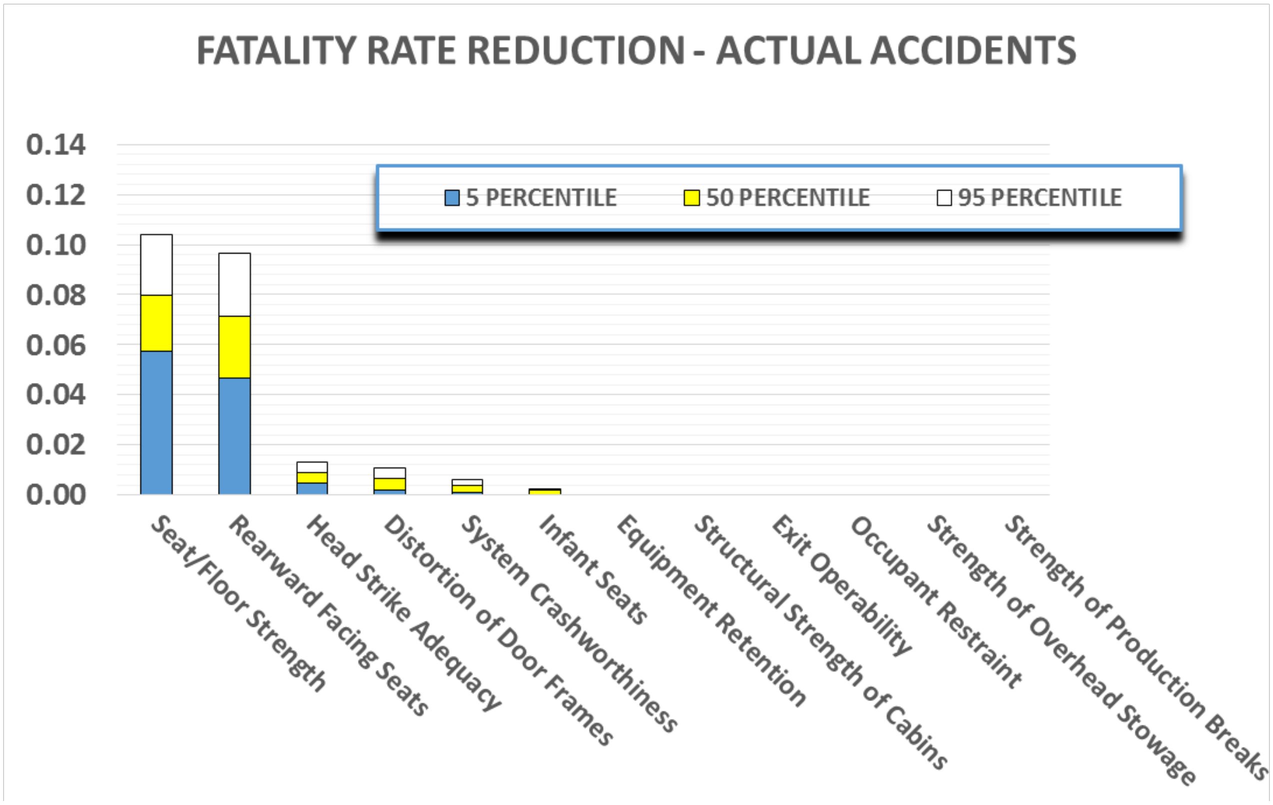

Figure 2. Model Output showing improvement in Fatality Rate for each Survivability Factor - based on the Actual Accidents

4.3 REDUCTION IN INJURY RATE – LATER REQUIREMENTS

The assessment of the injury rate reduction, for each survivability factor, had the airplane been configured to the latest requirements, is illustrated in figure 3.

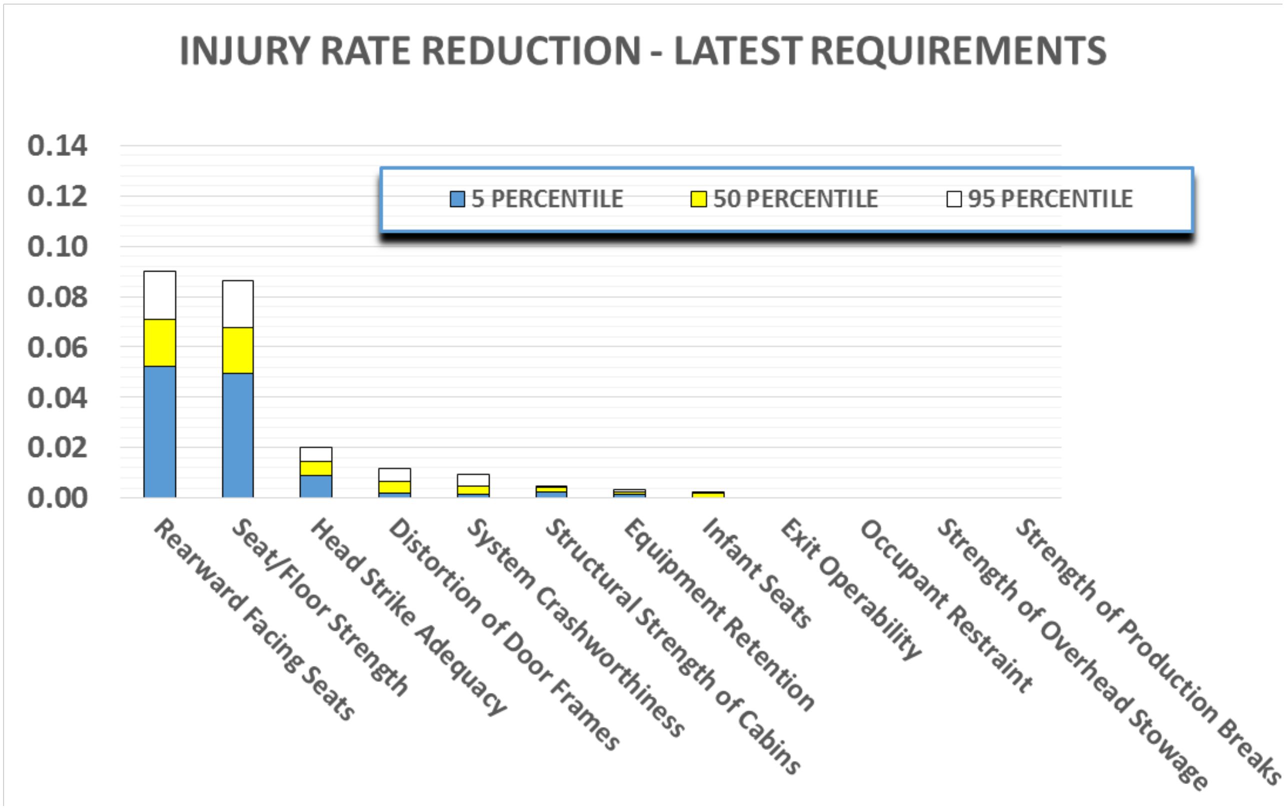

Figure 3. Model Output showing improvement in Injury Rate for each Survivability Factor - based on assessments for Latest Requirements

4.4 REDUCTION IN FATALITY RATE – LATER REQUIREMENTS

The assessment of the fatality rate reduction, for each survivability factor, had the airplane been configured to the latest requirements, is illustrated in figure 4.

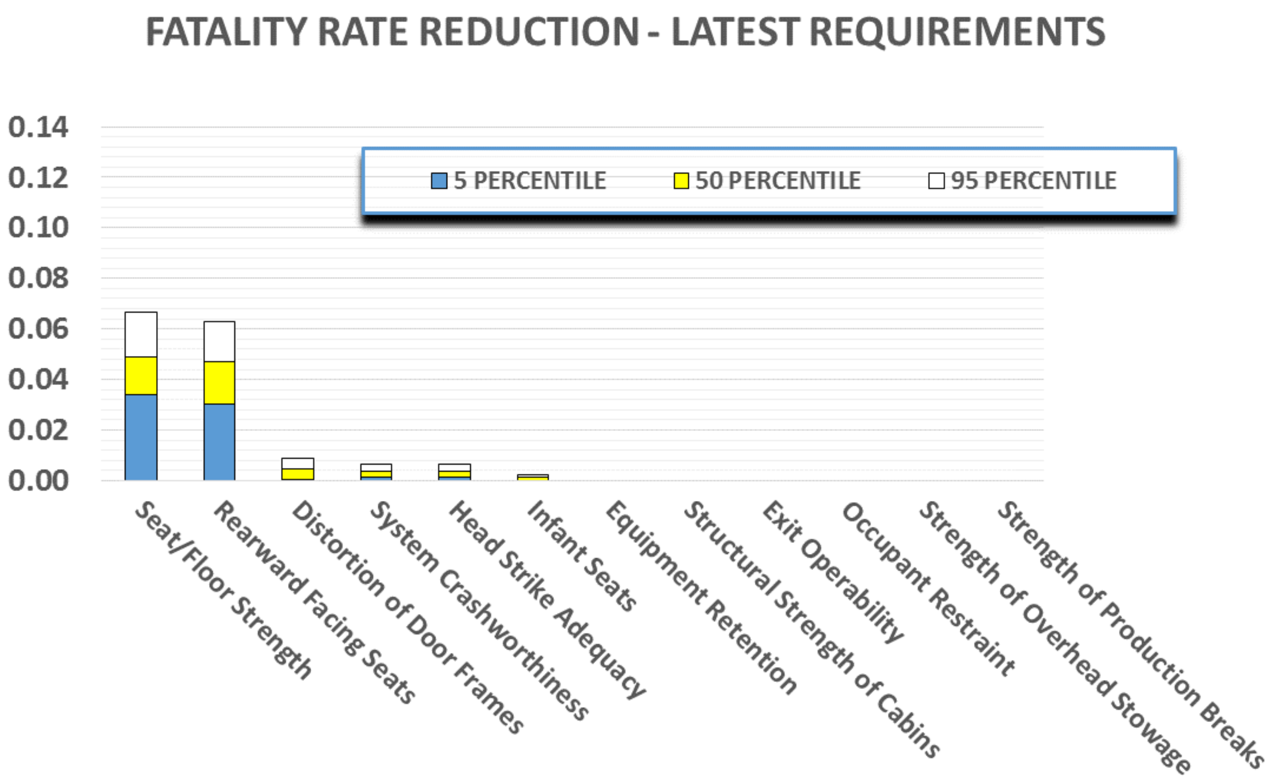

Figure 4. Model Output showing improvement in Fatality Rate for each Survivability Factor - based on assessments for Latest Requirements

5. QUALITATIVE & OVERALL ASSESSMENT OF SURVIVABILITY FACTORS

Sections 5.1 to 5.13 summarize the quantitative and qualitative assessments made for each of the survivability factors.

5.1 REARWARD FACING SEATS

The quantitative analysis shows that the rearward facing seats survivability factor ranks in the top two of all the survivability factors considered in this study. This was also the case in the earlier study carried out for the UK CAA (reference 1). When the mitigation provided by later requirements (primarily 16 g seats) is taken into account this survivability factor is assessed to reduce the total[4] number of injuries by approximately 7% and the number of fatalities by approximately 5%.

The relative importance of this survivability factor, in impact related accidents, might be expected given that rearward facing seats provide better support for the back, neck and head as well as mitigating injuries resulting from flailing limbs.

Reference should also be made to sections 5.3 - Head Strike Adequacy and 5.10 - Occupant Restraint (Adequacy of Seat Belts).

[4] Inclusive of Injuries resulting from fire and water

For the vast majority of airplane accidents analyzed the cabin was configured with forward facing passenger seats. Only one instance was found where the airplane was configured with rearward facing seats (business class seats) and no injuries were sustained that were pertinent to this survivability factor.

The Canadian TSB comment contained in the accident report (reference 3) relating to the A340 accident in Toronto in August 2005 is perhaps germane to this survivability factor:

> *'One of the cabin crew, seated in the same general area as the crew and passengers who incurred serious impact injuries, was not injured. This cabin crew's seat was aft-facing; the other seats were forward-facing.'*

5.2 SEAT/FLOOR STRENGTH

The quantitative analysis shows that seat/floor strength ranks in the top two of the survivability factors considered in this study. This was also the case in the earlier study carried out for the UK CAA (reference 1). When the mitigation provided by later requirements (primarily 16 g seats) is taken into account this survivability factor is assessed to have the potential to reduce the total[5] number of injuries by approximately 7% and the number of fatalities by approximately 5%.

Twenty seven (27) of the accidents analyzed involved damage to seats, seat rails and floors with a direct adverse effect on the survivability of occupants. The following extracts from accident investigation reports illustrate the significance of this survivability factor:

The TSB[6] Investigation report into the accident to a Boeing 737 in August 2011 at Resolute Bay (reference 4) states:

> *"The survivability of the occurrence was related to the extent of damage sustained by the occupants' restraint systems. Occupants whose seats separated from the fuselage early in the breakup sequence sustained more severe injuries, consistent with forceful contact with the ground. Occupants whose seats remained largely intact, upright, and partially attached to the left portion of the cabin floor, throughout or until late in the crash sequence, generally sustained less severe injuries, consistent with less forceful contact with injurious surfaces. All of the survivors belonged to this latter group."*

The CIAIC[7] Investigation report into the accident to a CASA 235 in August 2001 at Malaga (reference 5) states:

> *"On impact the seats of the front rows, 2 rows on the right and 5 rows on the left, broke away from their fixings on the cabin floor due to the supporting structure being cut up on final impact with the embankment and with the concrete and asphalt platform of the highway. Those seats were displaced and piled up in the front part*

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[5] Inclusive of Injuries resulting from fire and water
[6] Transportation Safety Board of Canada
[7] Comisión de Investigación de Accidentes e Incidentes de Aviación Civil - Spanish Accident Investigation Authority

of the passenger cabin, and obstructed the opening of the two front exits from inside."

The NTSB[8] Investigation Report into the accident to a Fokker F28 in March 1992 at La Guardia (reference 6) states:

"Nineteen of the 28 seats had separated from the cabin floor and were scattered throughout the wreckage."

In instances where seat/floor strength was an issue, six involved failures of cabin crew or cockpit crew seats. The accident to the Boeing 737-500 in Denver on the 20th December 2008 (reference 7) resulted in both the pilots' seats fracturing in overload. The seat pan on the aft-facing flight attendant jump seat, mounted on the forward bulkhead between the cabin and the cockpit was also broken in the impact. The NTSB reported that fatigue cracks had weakened the seat frame, although the flight attendant was not seriously injured.

In another example, the TSB[9] report (reference 3) for the accident to the A340 in Toronto in August 2005, where the Captain sustained back injuries, describes how:

"…..both seats [flight crew] experienced high vertical forces during the event. The captain seat was displaced from its normal position. The floor of the seat base had fractured, allowing the chair to detach from the base. The nut attaching the centre screw to the bottom of the base on the first officer seat had pulled through the retainer. The force necessary to pull the nut through the retainer was mathematically calculated. It was determined that a vertical acceleration of a minimum of 16 g was likely reached before the seat broke. The seats were designed to withstand 5.7 g vertically and 9 g longitudinally."

5.3 HEAD STRIKE ADEQUACY

Head strike adequacy is a survivability factor that features relatively highly based on the quantitative analysis; ranking third in terms of injury rate reduction.

The Asiana accident, in July 2013, to a Boeing 777, which was configured with 16 g seats, having additional impact absorption in the seatback, illustrates that this feature does not provide complete protection from head injury in all accident scenarios. The NTSB report, reference 8, states

'……….consequence of the left lateral impact forces appears to be the multiple skull fractures sustained by passenger 11C, a 45-year-old male, who was the only surviving passenger to sustain skull fractures. An examination of the airplane's seating configuration provided insight into how he sustained these injuries. Like the other B-zone passengers, passenger 11C had only a lap belt for restraint, but he was the only passenger who had no seat directly in front of him with a seat to his left front (seat 10B). It is likely that the combined forward and lateral forces acting

[8] National Transportation Safety Board – United States of America Accident Investigation Authority
[9] Transportation Safety Board of Canada

on his body and the absence of a seat back in front of him allowed passenger 11C's head to strike the back of the very stiff inboard armrest of seat 10B. Any marks from this strike on the armrest were obscured by the postimpact fire. However, passenger 11C's skull fractures included the left frontal skull, left temporal bone, left orbital roof and wall, the very areas that would be expected in such a strike scenario. Thus, it is highly likely that passenger 11C's serious head injuries were caused by striking the inboard armrest of seat 10B. The NTSB concludes that the dynamics of the impact sequence in this accident were such that occupants were thrown forward and experienced a significant lateral force to the left, which resulted in serious passenger injuries that included numerous left-sided rib fractures and one left-sided head injury……The NTSB is aware of at least one technology—air bag seatbelts—that is already in service on some commercial airplanes and could potentially mitigate the type of injury sustained by passenger 11C. Therefore, the NTSB recommends that the FAA conduct research that examines the injury potential to occupants in accidents with significant lateral forces, and if the research deems it necessary, implement regulations to mitigate the hazards identified.'

Head injuries might be mitigated when passengers adopt the brace position. However accident experience suggests that this cannot be relied upon to mitigate injury. In the Toronto A340 accident (reference 3), where the aircraft was configured with 16 g seats, the aircraft left the runway and the occupants were subjected to longitudinal forces. A number hit their heads on the seat back in front and/or the cabin side wall. One of the findings in the Canadian Accident Investigating Authority report states:

"Brace commands were not given by the cabin crew during this unexpected emergency condition. Although it could not be determined if some of the passengers were injured as a result, research shows that the risk of injury is reduced if passengers brace properly."

Regarding an emergency landing of a Boeing 737 aircraft at Barcelona in November 2004, following a birdstrike on take-off, the Spanish Accident Investigation Authority report (reference 9) states:

"As the occurrence was completely unexpected none of the passengers assumed the 'brace' position as drawn on the Safety On Board card. Most grabbed their seat arm rests or the seat back in front, while trying to protect their heads. Some passengers reported that their heads were slammed against the side wall panels and tray table during the impact sequence."

The New Zealand Accident Investigation Report (reference 10) on the accident to a DHC-8 in June 1995 describes the substantial impact. The report states:

"Many of the head and facial injuries were sustained early in the impact when restrained seat occupants were thrown forward onto the back of the seat in front of them[10]. These injuries often caused minor concussion which in some passengers

[10] It is not known whether the DHC-8 was configured with 16 g seats.

caused a brief period of unconsciousness or confusion; this together with exit obstruction or entrapment, delayed emergency exit from the aircraft onto the hillside after the aircraft came to rest."

Brace positon was also highlighted as an issue in the accident to an Airbus A320 which ditched into the Hudson River in January 2009 (reference 11). The report stated:

"Of the four passengers who sustained serious injuries, three received their injuries during impact. The two female passengers who sustained very similar shoulder fractures both described assuming similar brace positions, putting their arms on the seat in front of them and leaning over. They also stated that they felt that their injuries were caused during the impact when their arms were driven back into their shoulders as they were thrown forward into the seats in front of them. The brace positions they described were similar to the one depicted on the US Airways safety information card."

Both the issue of the brace position and the wearing of seatbelts are also considered in section 5.13 Emergency and Evacuation Issues.

5.4 DISTORTION OF DOOR FRAMES (DOOR JAMMING)

Distortion of door frames (door jamming) is in the top four of the survivability factors addressed in this study. There were 12 instances identified where airframe distortion caused difficulties in opening, or prevented the opening of one or more doors. This included passenger exit doors and cockpit entry doors. Of the 12 instances identified, 6 involved the cockpit door and 6 involved the passenger exit doors.

In the accident to the Fokker F27 at Sharjah, in February 2004, reference 12, escape for the survivors was prevented by door distortion. The accident report states:

"There were four survivors initially found in the fuselage section however one died on the way to hospital. A witness, who was on the scene very quickly, stated that the main fuselage was still intact when he arrived and he could hear people inside requesting help. Attempts were made to gain access to these passengers through the front door but it would not move as it appeared to be crushed and fire prevented access to the cabin through open sections of the fuselage. The fire intensified very quickly forcing rescuers away and it quickly engulfed that section of the fuselage. A photograph taken approximately 10 minutes after the accident showed the cabin totally engulfed. There may have been more survivors if immediate access to the cabin had been achievable. The survivors could not remember any details of their seating position although it was most likely that they were seated in the middle section of the main cabin behind the wing."

The NTSB Report for the accident to the Boeing 707 at Cove Neck in January 1990 (reference 13) states:

"The left forward overwing emergency exit hatch was found in place and could not be opened because of fuselage distortion."

The Canadian TSB statement, contained in the accident report (reference 3), relating to the A340 accident at Toronto on 2[nd] August 2005 is also relevant to this issue:

> *Approximately one door width forward of the R4 door was a permanent fold in the outer fuselage skin, indicating that the location was subjected to a substantial bending force. The deformation of the fuselage was very likely transmitted to the door frame and would explain the difficulty experienced opening exit R4.*

In the accident to the Boeing 757, at Girona, in September 1999 (reference 14), Door 3L was not used as excessive handle loads were encountered consistent with damage caused by fuselage distortion.

The BAe 146 accident at Stord Airport, Sørstokken Norway, in October 2006 (reference 15) resulted in both forward main exits becoming unusable; one due to fuselage distortion, the other was inaccessible due to the fuselage resting against the local terrain. The door to the cockpit could not be opened, also due to fuselage distortion. Two passengers and one cabin crew member were fatally injured in the subsequent fire, although the aircraft cabin was undamaged and they were seen to be moving around in the cabin after the aircraft came to rest. The bodies of two of the three fatalities were found adjacent to the forward left main passenger entry door and the cockpit door. The translation of the Norwegian Accident Investigation Board Report for this accident (reference 15) states:

> *"The forward left cabin door was impossible to open, probably because it was mechanically jammed.*
>
> *The forward right cabin door was blocked as a consequence of being pressed against the terrain.*
>
> *"The cockpit door was blocked as a consequence of fuselage deformations."*
>
> *"The pilots should normally have evacuated via the cockpit door, but it could not be opened. This was most probably due to the aircraft having been deformed by impacts, so that the reinforced door had jammed and thus could not be opened using force. The AIBN considers that such reinforced cockpit doors may lessen pilots' chances of safe evacuation. In this context the reinforced door that became compulsory after the terrorist actions in the USA on 11 September 2001 has thus led to negative consequences. After two unsuccessful attempts to open the cockpit door the commander had to give up and the pilots reached safety via the left cockpit window instead. In retrospect, it is difficult to assess the effect if the pilots had managed to open the cockpit door. One consequence might have been that the flames from the cabin could have broken through into the cockpit, thus making the situation worse. Another possibility is that the cabin crew members and the passengers right at the front of the cabin might have evacuated via the cockpit door and the cockpit window."*
>
> *"Information from the survivors indicates that the evacuation of the aircraft started immediately. The position of the door handle on the right forward door shows that*

someone had tried to open the door. This was unsuccessful because the door was blocked by the terrain outside. The left forward door could not be opened either when the commander tried it (from outside). There are grounds for supposing that problems with the opening the cabin door in combination with the early outbreak of the fire at the forward end of the cabin, explains why all those who died were sitting in the forward half of the cabin."

In four of the accidents analyzed the cockpit door could not be opened, or was difficult to open due to distortion. There were cases noted also where fuselage distortion led to higher than normal door handle loads. In these cases the inability to open the cockpit door hindered communication between the cockpit crew and the cabin crew.

5.5 SYSTEM CRASHWORTHINESS

Although system crashworthiness ranks in the top 5 of all survivability factors considered in the study it is unlikely to yield significant benefits. The quantitative analysis, for aircraft configured to the latest requirements, suggests that improvements could result in a reduction of 0.4% in fatalities and 0.5% in injuries.

System crashworthiness was identified as an issue in 8 accidents. These issues can be grouped into two categories; landing gear separation, and fuselage damage leading to the failure of various systems to operate as designed following an impact accident.

5.5.1 Landing Gear Separation

There were two examples of Main Landing Gear (MLG) separation found in the accidents analyzed in this study. The accident to the Boeing 777 at Heathrow on the 17th January 2008 (reference 16) resulted in a Serious Injury and the accident to the DC10 in Fukuoka on the 13th June 1996 (reference 17) resulted in two fatalities caused by the direct impact of the landing gear strut on the fuselage.

In the Heathrow case, the UK Air Accident Investigation Report (reference 16) states:

'….as the aircraft continued the ground slide the right MLG moved aft allowing the shock strut to contact the truck beam. This resulted in the separation of the forward portion of the truck beam together with two wheels. This piece then struck the right side of the fuselage causing damage within the cabin and leading to the passenger (serious) injury.'

The report recommended that the requirements for landing gear emergency loading conditions be updated to include combinations of side loads. This has been accepted by the FAA for the design of future transport category aircraft, becoming effective from 1 December 2014.

5.5.2 Various Systems

Reference should be made to section 5.13 regarding the crashworthiness of public address (PA) and interphone systems.

In two of the accidents, Girona Boeing 757 on the 14th September 1999 (reference 14) and Schiphol Boeing 757 on the 24th December 1997 (reference 18), damage to the Nose Landing Gear (NLG) area, termed 'the doghouse', beneath the cockpit, resulted in loss of a number of systems, including failures of cabin PA and interphone, engine controls and flight controls. For the Girona accident, which resulted in a fatal injury to one passenger, the technical report by the Accident Investigating Authority (reference 14), stated that:

> *"…the injuries suffered in the accident and most of the aircraft damage resulted from the high-speed ground run over very significant obstacles. Had the engines remained at forward idle thrust after the landing, it was likely that the aircraft would have come to rest on the runway or, at worst, run off at relatively low speed. The disabling of spoilers, thrust reversers and the wheelbrake antiskid system due to MEC (Main Equipment Centre) damage would have been undesirable, but probably not critical, and damage was likely to have remained limited to the NLG support structure and MEC areas and the MLG tyres. Thus the uncommanded forward thrust increase caused by interference of the displaced doghouse with the powerplant control cables was responsible for converting the consequences of the accident from relatively benign to potentially catastrophic.*
>
> *It appeared that a similar effect of uncommanded forward thrust increase had probably occurred in a previous case of B757 NLG overload[11]. The report on the accident to PH-TKC (Schiphol) showed that the aircraft had travelled almost 3 km along the runway after landing and then for 100 metres in soft ground before coming to rest. The long ground run occurred in spite of an apparently abnormally high energy absorption by the wheelbrakes, as indicated by the brake fire that occurred. There were thus strong indications that forward thrust on at least one engine had been above idle. This was fully consistent with the reported damage to the control cables for No 1 engine, which was similar to that in G-BYAG's (Girona) case. Extensive MEC damage and electrical power supply loss also resulted in PH-TKC's case.*
>
> *The failure mode of the NLG support structure was very similar in both cases and it appeared likely that it would be closely reproduced in any situation where the B757 NLG experienced a rearward and upward overload. It is therefore recommended that the FAA require the B757 aircraft manufacturer to take measures aimed at preventing potentially hazardous effects on aircraft systems as the result of overload failure of the nose landing gear leg or its support structure. In particular, the measures should aim to prevent uncommanded forward thrust increase."*

There were five cases where fuselage damage resulted in loss of engine control, including propellers and thus the crew was unable to shut the engines down following impact, leading to difficulties in evacuation.

---

[11] Reference 18

5.6 STRUCTURAL STRENGTH OF CABINS (DITCHING/IMPACT RESISTANCE, ETC.)

The structural strength of cabins (ditching/impact resistance, etc.) survivability factor was noted as an issue in several accidents. However, as previously found in the UK CAA study (reference 1), the quantitative analysis suggests little or no potential improvement from this survivability factor.

Perhaps of note was the aircraft ditching of the A320 in the Hudson River on the 15th January 2009 (reference 11), in which a non-structural beam was pushed up through the cabin floor. The Accident Report contains the following statement:

> *"The FR65 vertical beam had punctured through the cabin floor in front of the direct-view jumpseat about 11 inches forward of the seat pan and 19 inches left of the lavatory wall.*[12] *The passenger floor crossbeam web and lower flange in this area were bent in the aft direction. The left-side passenger floor support strut was sheared above the FR65 attachment point and was fractured below the floor crossbeam. The right-side passenger floor support strut was sheared close to the FR65 and crossbeam attachment points. The center passenger floor support strut was missing at the upper attachment angles on the floor crossbeam. The cargo floor structure was completely missing in this area."*

There were three cases of engine propeller debris entering the fuselage and one of uncontained engine failure where shrapnel entered. While these occurrences involved fatal and serious injuries, they are not included in the quantitative analysis since it is considered that strengthening the aircraft structure would not be feasible for high energy debris impacts such as these.

There were two examples of landing gear separation with the gear subsequently striking the fuselage - Heathrow Boeing 777 on the 17th January 2008 (reference 16) and Fukuoka DC10 (reference 17). However these are more appropriately addressed under the survivability factor system crashworthiness and are discussed more fully in section 5.5.

Fuselage ruptures of any kind, associated with a pool fire accident, will tend to allow fire into occupied areas but may also provide an escape route for occupants. An earlier study carried out for the FAA (reference 19) considered this issue and concluded that:

> *"Based on the results derived from the model it is considered that Fuselage Breaks have a net adverse effect on occupant survival."*

5.7 EQUIPMENT RETENTION

The quantitative analysis suggests that improvements to the equipment retention survivability factor are unlikely to yield significant benefits in terms of fatality or injury reduction. However, there were 15 accidents where equipment retention issues were identified; these included galley

[12] According to Airbus, the FR65 vertical beam is a nonstructural beam installed between the passenger and cargo floors at the aircraft center line to support the cargo liner. The beam is designed to be held in place by two quick-release, removable pins. Removing the pins and rotating the beam down allowed maintenance personnel to access the waste water tank. The beam does not carry loads during normal operation and is designed to carry longitudinal loads up to 1.5 G aft in the event of a crash.

carts being unrestrained, PSUs being displaced, oxygen masks and battery packs for exit door lights being released, light lenses separating, and video monitors detaching.

There were five in-flight upset events. Four were caused by turbulence and one by a TCAS maneuver. These resulted in 2 fatalities and 33 serious injuries. Injuries resulted from unrestrained galley carts and passenger/cabin crew impacts.

The report by the Japanese Aircraft Accident Investigation Commission on the accident to the DC10 in Fukuoka on the 13th June 1996 (reference 17), described the release of ovens and galley containers blocking the aisle and the cockpit door during the impact sequence preventing the cockpit crew from assisting in the evacuation.

In another accident, to a Boeing 737 at Burbank California on the 5th March 2000, the forward service door slide inflated inside the cabin while the aircraft was still moving, blocking the aisle from the passenger cabin to both forward exit doors.

The NTSB report for the Boeing 777 accident in San Francisco on the 6th July 2013, (reference 8), contains the following statement:

> *"'…..the flight attendants reported a second impact that was much more severe than the first. Flight attendants R1 and R2A reported that the second impact caused the slide/rafts attached to their doors to come free and inflate inside the cabin, pinning them in their seats. Most of the flight attendants reported items flying throughout the cabin and oxygen masks and ceiling panels falling down."*

In the accident to the Boeing 737-800 at Schiphol on the 25th February 2009, there were head injuries consistent with the occupant being struck with significant energy. In several places throughout the aircraft the PSU or oxygen panel had fallen from their original location on the bottom of the overhead bin. It is possible that these objects are the source of some head injuries. Improving the attachment of the PSU was the topic of NTSB safety recommendations. The NTSB observed that in several (4) survivable 737 accidents from 2008 to 2010 most PSU's had fallen.

The UK Air Accidents Investigation Branch (AAIB) reported in the accident at Heathrow to the Boeing 777 on the 17th January 2008 (reference 16), that:

> *"Oxygen masks has deployed from their PSUs at 13 locations; of these ten were missing the PSU door covers and the nylon hinges having fractured. On the three remaining units the door covers had remained attached and hinges from the latches … the exit signs light lenses were found to have detached from Door 3L and 3R … in the Business economy section, nine of the 32 seat back video monitors had separated."*

The AAIB Report also makes the following Recommendation (2009-098):

> *"It is recommended that the Federal Aviation Administration and the European Aviation Safety Agency, review the qualification testing requirements applied by manufacturers to cabin fittings, to allow for dynamic flexing of fuselage and cabin structure."*

In the accident to a B747 in Bangkok (23rd September 1999) it was reported that five ceiling panels dislodged, one falling and blocking the aisle. Three passengers reported being struck by dislodged PSUs.

The Investigation Report for the accident to a Boeing 757 in Girona on the 14th September 1999 (reference 14) stated:

> *"An appreciable number of PSUs displaced. In most cases the associated oxygen masks deployed and were hanging down. Nineteen of the PSUs were found unlatched and hinged open to the extent allowed by the lanyard. In one case (Seat Row 9R) one of the composite hinges had fractured and the PSU remained attached by the other hinge and the lanyard, with its lower corner having dropped around 56 cm (22 inch). In three cases (Seat Rows 27R, 30R and 41R) both hinges had fractured and the PSU remained hanging on the lanyard, with the lower edge having dropped around 84 cm (33 inch)."*
>
> *"Additionally, the battery pack for the aisle exit sign just forward of Door 3 detached and was found hanging on its lead by Seat Row 30R. The pack, which weighed 2 kg, dropped to around 69 cm (27 inch) below the level of the PSU covers. The similar pack for the Door 3R exit sign also detached and was found hanging on its lead in front of the door 53 cm (21 inch) below ceiling level."*

The accident to the Boeing 747 in New York (reference 20) on the 20th December 1995 resulted in a serious injury to a cabin crew member due to inadequate equipment retention. The NTSB Accident Report contains the following statements:

> *"The two carts that came loose injured the R4 flight attendant and blocked the R4 exit."*
>
> *"The Safety Board could not determine whether the primary latching mechanisms were engaged on the carts that were released from the aft galley. However, the bending in the secondary latches indicated that those latches were engaged, but were not adequate to secure the carts. The Safety Board was unable to calculate the inertial loads imposed on N605FF during the crash sequence because of the malfunctioning FDR. However, the condition of the seats and the comments of the various occupants suggest that the airplane did not experience the loads specified in 14 CFR 25.561(b). Because the crash forces were not severe enough that the latch material should have failed, the Safety Board concludes that the material or installation of secondary latches in the galleys of N605FF was inadequate. Consequently, the Safety Board believes that the FAA should develop certification standards for the installation of secondary galley latches; then use those standards to conduct an engineering review of secondary galley latches on all transport-category aircraft. Further, the FAA should require changes to existing installations as necessary to ensure that the strength of secondary latches and their installation are sufficient to adequately restrain carts."*

5.8 INFANT SEATS

Of the accidents analyzed, there were very few issues noted relating to infant seats and hence the Infant Seat survivability factor. In most cases there was no mention of infant serious injuries or fatalities. The quantitative analysis suggests that infant seats do not feature highly in terms of injury reduction, as was the case in the study carried out for the UK CAA (reference 1). However, the reason for this is perhaps that the proportion of infants on the airplane is likely to be relatively low. What was not determined from this study is whether the current provisions for infants affords a similar level of protection during the impact sequence to that provided for adult occupants.

In the accident to the DC9 at Charlotte on the 2nd July 1994 (reference 21), an "in-lap infant'' sustained fatal injuries. The NTSB report stated that:

> *"A 9-month-old female infant, who was unrestrained in her mother's lap in seat 21C sustained fatal injuries. The mother was unable to hold onto her daughter during the impact sequence. The impact forces in this area were calculated to have been within human tolerances.' Additionally an 18-month old infant, lying across seats 18E and F sustained serious injuries whereas her mother seated adjacent to the infant, sustained only minor injuries"*.

The importance of securing of seatbelts and confirmation by the cabin crew is illustrated by the accident to the MD88 in Groningen on the 17th June 2003, (reference 22). Seat belts were not checked by the cabin crew and a passenger travelling with a two year old infant did not receive a child restraint. She consequently fastened her seat belt around herself and the child. The Dutch Accident Report states:

> *"the fact that seatbelts were not checked and that no child restraint was provided for the child could have been more serious if the deceleration forces would have been higher"*.

5.9 EXIT OPERABILITY

The quantitative analysis carried out in this study on exit operability suggests little or no potential improvement from this survivability factor. No instances were found where the door mechanism was damaged by impact forces.

However, difficulties in exit operation were noted in 14 accidents; most of the issues were difficulties associated with locking the doors open for an evacuation. In some cases this was due to the orientation of the fuselage after the aircraft came to rest.

For the A320 accident in the Hudson River on the 15th January 2009 (reference 11) it was reported that door 1R was opened normally. However, the flight attendant stated that door 1R started to close during the evacuation, intruding 12 inches into the doorway and impinging on the slide/raft. She stated that she was concerned that the slide/raft would get punctured, so assigned an "able-bodied" man to hold the door to keep it off the slide/raft. She stated that he held the door while occupants evacuated under his arm. Difficulties were also reported with door 1L as the slide/raft did not inflate automatically and the manual inflation handle was used to inflate the slide.

In the Boeing 737 accident at Barcelona on the 28th November 2004 (reference 9), it was reported that door 1R opened normally but did not lock in position, the slide inflated but was folded halfway down.

In the accident to an RJ85 at Gothenburg on the 10th March 2006 problems were also reported in locking the rear left door in the open position, resulting in difficulties in evacuation.

The accident to the MD83 at Manchester on the 27th April 1995 is a further illustration of difficulties encountered with door gust locks. With no immediate danger, the captain decided to disembark the passengers normally via the main entry door. The door gust locks were difficult to engage and the airstairs would not deploy. The crew tried to close the door; however, the door gust lock would not disengage. Evacuation was carried out via slides on the three remaining doors resulting in minor injuries.

Reference should be made to section 5.4 regarding other issues associated with exit operation.

5.10 OCCUPANT RESTRAINT (ADEQUACY OF SEAT BELTS)

The occupant restraint (adequacy of seat belts) survivability factor relates solely to instances where restraint systems were adversely affected by impact loads and does not take into account injuries incurred due to seat belts not being fastened.

5.10.1 Passenger Restraint

No passenger seat belt failures resulting in serious injury or fatalities were identified. However, there were some instances where passengers were not wearing seat belts at the time of the event. In one accident (Chicago Boeing 727, 9th February 1998), two seat belt attachments *'became unhooked at impact*', the cause was unknown and the passengers sustained only minor injuries. In other cases some passengers had difficulties in releasing their seat belts, particularly if the aircraft had come to rest in an inverted position.

5.10.1.1 Securing of Seat Belts

Of the five in-flight upset events identified, four were the result of turbulence and one was a TCAS maneuver event where the seat belt sign was 'ON' at the time of the upset. These events resulted in 2 fatalities and 33 serious injuries. Those passengers who were fatally and seriously injured were considered likely to have not been wearing seat belts. Unfortunately, serious injuries also resulted to passengers with seat belts fastened when they were struck by unrestrained galley carts or other passengers.

The importance of passengers securing seatbelts, and confirmation by the cabin crew, is illustrated in one of the accidents reviewed. The NTSB report for the Boeing 777 accident in San Francisco on the 6th July 2013, (reference 8), contains the following statement:

> *'….none of the passenger seat units were ejected from the airplane…. had the two ejected passengers been restrained, they likely would have survived the accident.'*

5.10.1.2 Upper Torso restraint

The frequency and extent of injuries sustained from the lack of upper torso restraint is not an issue specifically addressed in this study. However, it is a feature of other survivability factors – notably rearward facing seats[13]. The issue is illustrated by the injuries sustained by passengers in the accident to a Boeing 737 at Schiphol on the 25th February 2009. A presentation given by Richard DeWeese of the FAA CAMI (reference 23) in relation to this accident contained the following comment:

> *'Spinal injury of the flexion/distraction type, at T11/T12, with a compression fracture at the anterior corpus and continuation into the posterior column resulting in distraction. This was probably caused by the occupant flailing forward with the seat belt acting as a fulcrum. Injuries of this type were often observed in car crashes before the introduction of the 3 point shoulder restraint.'*

5.10.1.3 Brace Position

This issue is addressed in section 5.3.

5.10.2 Flight Crew Restraint

Failures of the flight crew restraint system were noted in the accident to the Boeing 737-500 in Denver on the 20th December 2008 (reference 7). The aircraft departed from the side of the runway during an attempted take-off in strong and gusty crosswind conditions. Both the pilots' restraints fractured at the harness anchor points in an upward direction consistent with overload. The NTSB Report for this accident (reference 7) states:

> *"Both pilot seats in the accident airplane failed during the accident sequence. Postaccident examination of the seats revealed that both seats' crotch-restraining-strap attachment points were fractured in an upward direction and that both seat height adjustment mechanisms had failed in a downward direction, "bottoming out" during the impact sequence. These failures indicate that the pilots' seats experienced both upward and downward crash forces in excess of their structural capabilities. Both pilots complained of back injuries after the accident, and medical records indicated that the captain sustained multiple lumbar and thoracic spinal fractures. In 1988, the FAA adopted a regulatory amendment (to 14 CFR Part 25) that required more stringent crashworthiness standards, including 16-G dynamic tests, for transport-category airplane seats. In 2005, the FAA issued a final rule (Amendment 121-315) that required that all transport-category airplanes with earlier type certifications be equipped (retrofitted) with passenger and flight attendant seats that meet the 16-G dynamic impact requirements (as codified in 14 CFR 25.562) by October 27, 2009. Seats installed in the cockpits of those airplanes are not required to meet those crashworthiness standards. The cockpit seats in the accident airplane were designed to meet the structural requirements of 14 CFR*

[13] See Section 5.1

25.561,100 which specified that the seat must withstand static forward loads of 9 G, static downward loads of 6 G, and static upward loads of 3 G"

5.11 STRENGTH OF OVERHEAD STOWAGE

The strength of overhead stowage survivability factor does not feature in the quantitative analysis since no instances were found in the accidents analyzed of overhead stowage detachment resulting in occupant injuries. However, 21 of the accidents reviewed contained reports of the collapse of overhead bins and/or the release of luggage from them, 9 of these involved the release of luggage from the bins, and 13 involved the collapse of overhead bin structure.

There was insufficient information to be specific about modes of failure but, as might be expected, increasing severity of impact and associated fuselage disruption was more likely to result in the collapse of the overhead bins.

5.12 STRENGTH OF PRODUCTION BREAKS

In the accidents analyzed, insufficient information was contained in the accident reports to determine the location of the production break relative to any fuselage ruptures. Therefore, no potential improvement could be identified from the strength of production breaks survivability factor. The UK CAA study (reference 1) also suggested that this survivability factor ranked "lowly".

See also section 5.6 regarding fuselage ruptures.

5.13 EMERGENCY AND EVACUATION ISSUES

While the emergency and evacuation issues survivability factor is not related to the airplane structure and was not originally included in the issues to be addressed, notes were made during the review of the accident reports of the salient issues identified in this respect. This survivability factor is not assessed quantitatively in terms of the potential improvement in injury and fatality rate.

The accident review highlighted the injuries sustained in conducting an emergency evacuation. If there was no immediate danger and the crew could wait for assistance and use on-board airstairs, or airport equipment to disembark the passengers, there were fewer injuries. In cases where the slides were used there were instances of fatalities and serious injury as well as minor injuries.

There were 11 events that involved difficulties in the emergency briefing for the passengers. These included the briefings being given in languages not understood by some of the passengers: Barcelona Boeing 737 (28^{th} November 2004), Pusan Boeing 767 (14^{th} April 2002), Fukuoka DC10 (13^{th} June 1996).

Examples of passengers not having clarity of understating of exit operation include:

- Pensacola MD88, 6th July 1996, in which a passenger stated that he would have liked guidance on when to operate the overwing emergency exit.

- Groningen MD88, 17th June 2003, where passengers at the emergency overwing exits did not receive a briefing regarding their operation.

Five instances were identified where passengers took carry-on bags with them in the emergency evacuation. Passengers did suggest a 'leave luggage' command should be included in the evacuation command.

In one accident, East Granby MD83 on the 12th November 1995, passengers were told to remove their shoes before jumping on the slide. This resulted in a build-up in the aisles of discarded shoes which provided a potential obstacle for those still evacuating.

However, the most frequently occurring issue during evacuations was difficulties in communication, both between the cockpit and the cabin, and between different areas of the cabin. There were 21 examples of communication difficulties, these included public address (PA) or cabin interphone system failures. The cabin crew will often wait for the cockpit crew to initiate the evacuation. The locked cockpit door results in reliance on the PA/interphone system to achieve this, and sometimes the only option is to shout through the door. Delays in communication can result in confusion for both passengers and crew, and have a significant effect on the initiation, and therefore successful, outcome of the evacuation. Additionally, there were examples of lack of communication from the cockpit crew of an emergency situation, preventing the appropriate preparation of by the cabin crew, such as telling the passengers to adopt the 'brace' position.

There have been several studies which have highlighted the non-availability of interphone and PA systems in post-crash situations. A study carried out for EASA (reference 24) makes the following recommendation (8):

> *"Given the importance of the availability, during emergency situations, of the service interphone, PA system and evacuation alert system (if fitted), it is proposed that the integrity of the power supplies to these systems should be improved."*

The study carried out for EASA also states in relation to PA Systems:

> *"In 1995, the TSB published a document entitled A Safety Study of Evacuations of Large, Passenger-Carrying Aircraft.*[14] *Twenty-one occurrences involving emergency evacuations were reviewed. In 8 of the 21 occurrences, the aircraft's PA system was inoperable or inaudible following the accident. As a result, cabin crew and/or passengers did not hear the initial command to evacuate and/or did not hear other emergency instructions. The onset of these evacuations was delayed, placing the safety of passengers and crew at risk. One of the recommendations resulting from this safety study is as follows:*
>
> > *The Department of Transport review the adequacy of power supplies and standard operating procedures for PA systems in an emergency for all Canadian operators of large passenger aircraft. (A95-04)"*

---

[14] Reference 25

And in relation to Interphone Systems:

> *"With the current requirements, the failure of the interphone system is likely to occur as a result of the loss of electrical power on the aircraft, either as a result of the flight crew being required to switch certain power buses off in an emergency or as a result of engine failure or crash impact.*
>
> *Accident/incident experience demonstrates that there is a significant risk of system failure or intentional power disconnection affecting the operability of the interphone system, as listed below:*
>
> > *- In-flight: the failure of battery bus in flight (B737-300 accident at Auckland Airport, B737- 33V near Lyons), damaged wiring (B737-436 incident in Clacton), and loss of main electrical supply (EMB-190 incident overhead Edinburgh and Avro 146-RJ100 incident at Edinburgh Airport)*
> > *- Post-impact: loss of main electrical supply – shut off or damaged following impact (Paris B737-20023, Hua Lien MD-90-30, Bangkok B747-438 and Toronto A340 accidents)*

6. THE INFLUENCE OF AIRCRAFT SIZE AND CONFIGURATION ON OCCUPANT SURVIVAL

6.1 AIRPLANE CATEGORY

An indication of the survivability in an airplane accident may be measured by the occupant injury and fatality rate. Figure 5 shows the proportion of occupants sustaining fatal and serious impact injuries, based on the accidents selected for analysis in this study, for wide body, narrow body and regional airplanes. It should be noted that these data exclude occupant fatal and serious injuries from causes other than impact, e.g., fire.

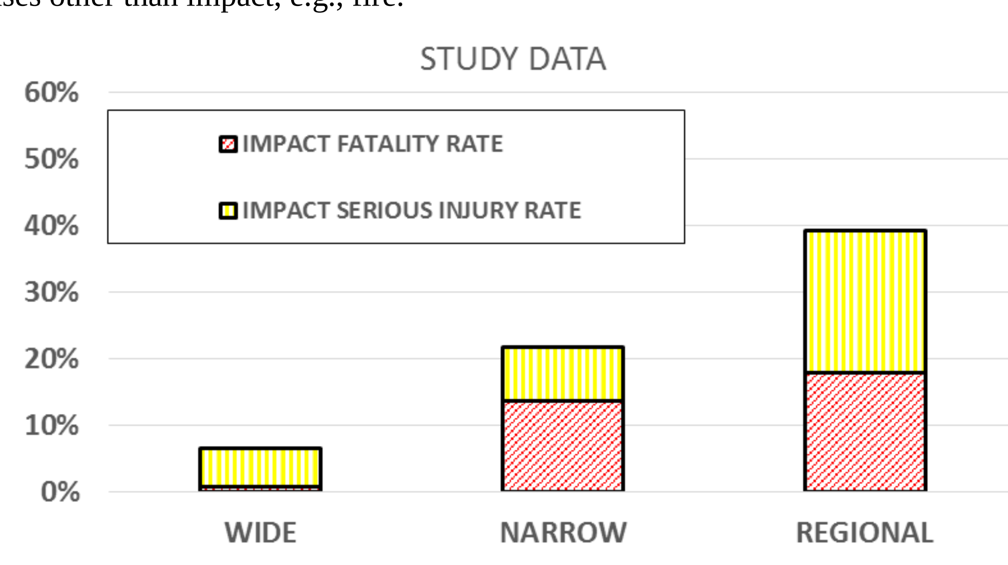

Figure 5. Proportion of Occupants sustaining Fatal and Serious Impact Injuries – by Airplane Category based on the Study Data

The actual number of fatalities and serious injuries are shown in table 1.

Table 1. Number of Occupants sustaining Fatal and Serious Impact Injuries – by Airplane Category based on the Study Data

STUDY DATA	TOTAL OCCUPANTS	IMPACT FATALITIES	IMPACT SERIOUS INJURIES	TOTAL INJURIES
WIDE	4607	34	262	296
NARROW	2193	300	174	474
REGIONAL	168	30	36	66

Figure 5 shows that the larger airplanes have a better survival rate than the smaller airplanes. In order to gain more confidence in any conclusions derived from the data analysed, additional accident information was added to the data set. The accident data used was based on an earlier study carried out for the Authorities (reference 26). This additional data was for nine accidents that occurred over the period 1985 to 1990. The number of occupants, impact fatalities and impact serious injuries for all data (study data and the additional data) are shown in table 2.

Table 2. Number of Occupants sustaining Fatal and Serious Impact Injuries – by Airplane Category based on the Study Data supplemented with Additional Data

WITH ADDITIONAL DATA	TOTAL OCCUPANTS	IMPACT FATALITIES	IMPACT SERIOUS INJURIES	TOTAL INJURIES
WIDE	5057	237	331	568
NARROW	2738	500	344	844
REGIONAL	206	30	40	70

Figure 6 shows the proportion of occupants sustaining fatal and serious impact injuries, based on the accidents selected for analysis in this study and the additional data.

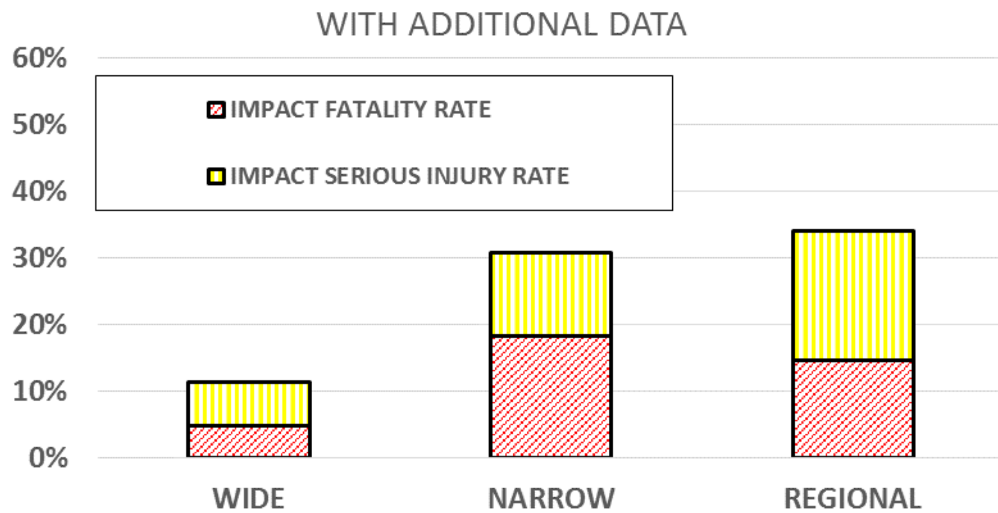

Figure 6. Proportion of Occupants sustaining Fatal and Serious Injuries – by Airplane Category based on the Study Data plus other Accident Data

It would appear from figure 5 and figure 6 that the wide body airplanes have a lower proportion of fatal and serious impact injuries than the narrow body and regional airplanes, suggesting that accidents to the larger airplanes are likely to be more survivable. While it is also likely that narrow body airplanes have a lower proportion of injuries than regional airplanes, there are insufficient data to be conclusive in this respect.

6.2 AIRPLANE WEIGHT CATEGORY

The accident data from the study were organized into weight categories based on the airplane maximum take-off weight. These weight categories are shown in table 3 – Airplane Weight Categories.

Table 3 – Airplane Weight Categories

Weight Category	Maximum Take- off Weight
A	less than 12,500 lb
B	12,500 to 100,000 lb
C	100,000 to 250,000 lb
D	250,000 to 400,000 lb
E	greater than 400,000 lb

Table 4. Number of Occupants sustaining Fatal and Serious Impact Injuries - by Airplane Weight Category based on the Study Data supplemented with Additional Data

WITH ADDITIONAL DATA	TOTAL OCCUPANTS	IMPACT FATALITIES	IMPACT SERIOUS INJURIES	TOTAL INJURIES
D & E	5127	318	335	653
C	2533	404	306	710
B	341	45	74	119

Figure 7 shows the proportion of occupants sustaining fatal and serious impact injuries based on the accidents selected for analysis in this study and the additional data referred to in section 6.1.

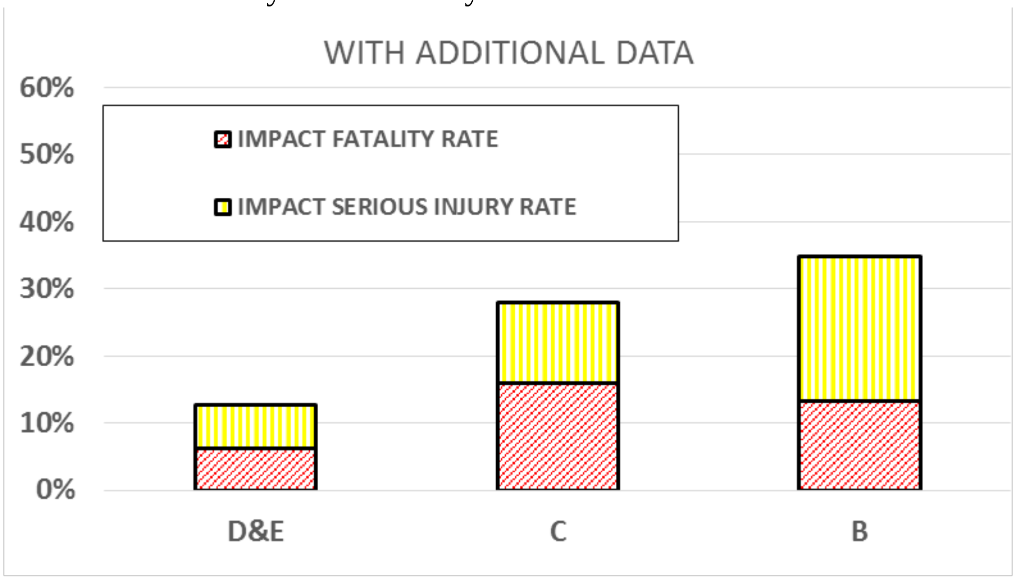

Figure 7. Proportion of Occupants sustaining Fatal and Serious Impact Injuries - by Airplane Weight Category based on the Study Data plus other Accident Data

As was suggested by the division of accidents by airplane category the larger airplanes are likely to be more survivable.

6.3 TURBOJETS V TURBOPROPS

The accident data was also subdivided into turbojets and turboprop airplanes. However, there were insufficient data on turboprop airplanes to derive any conclusions regarding differences in occupant survivability. For completeness the pertinent data are presented in table 5.

Table 5. Number of Occupants sustaining Fatal and Serious Impact Injuries – for Turbo jets and Turboprops based on the Study Data supplemented with Additional Data

WITH ADDITIONAL DATA	TOTAL OCCUPANTS	IMPACT FATALITIES	IMPACT SERIOUS INJURIES	TOTAL INJURIES
TURBOJETS	7778	733	656	1389
TURBOPROPS	223	34	59	93

6.4 SUMMARY

While it would appear evident that larger airplanes exhibit better occupant impact survivability than the smaller airplanes there are insufficient data to derive any further conclusions regarding the influence of aircraft size and configuration.

7. ASSESSMENTS OF THE LIKELY IMPROVEMENTS TO OCCUPANT SURVIVABILITY AFFORDED BY 16 G SEATS

It was the intention that, as part of this study, an evaluation of the benefits that have been afforded by 16 g seats would be carried out. This was to be done by considering accidents in two categories – those where it can be confirmed that the aircraft was configured with 16 g dynamic seats, and those where it can be confirmed that 16 g dynamic seats were not fitted. However, only 4 accidents involving fatalities were identified where it could be confirmed that the airplane was configured with 16 g seats. These 4 accidents resulted in 10 impact fatalities and 70 serious impact injuries. The data sets are too small to carry out meaningful assessments of the improvements likely to be afforded by 16 g seats. Therefore, with the current accident experience, confirmation of the benefits resulting from the installation of 16 g seats cannot be determined.

However, in a previous study carried out for the FAA (reference 26), to assess the likely benefits that might accrue from 16 g seats, it was concluded that:

> *"The re-evaluation of the benefit, based on currently available data, for 'fully compliant dynamic seats' over the period 1984 to 1998 approximates to:*
>
> *Reduction in Fatalities = 45*
> *Reduction in Serious Injuries = 40"*

This assessment suggests a life-saving potential for 16 g dynamic seats, for U.S. registered aircraft, operating under 14 CFR Part 121, to be in the region of 3 (45÷15) lives per year. However, the accident rate has improved markedly since this time as suggested by the study carried out for the FAA (reference 27). A further study carried out for EASA (reference 28) also provided an evaluation of the potential benefits that might be afforded by 16 g seats.

In summary, while it is likely that 16 g seats have provided a positive benefit in injury reduction, there are currently insufficient accident data to quantify the degree of improvement that is likely to have been achieved.

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APPENDIX A - ACCIDENTS SELECTED FOR ANALYSIS

The 116 Accidents selected for analysis are shown in the Table below. Accidents that did not result in serious or fatal injuries are shown in grayscale in the columns headed Total Fatalities and Total Serious Injuries.

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
20 January 1992	A320-100	PASSENGER	NR STRASBOURG, FRANCE	96	87	5	Collision with Ground on Approach	DESTROYED
22 March 1992	F28-4000 a	PASSENGER	LA GUARDIA, NEW YORK, U.S.A.	51	27	9	Stall on Take-off	DESTROYED
01 July 1992	SAAB SF340	PASSENGER	DEVONPORT, TASMANIA, AUSTRALIA	20	0	0	Loss of Control on Landing	SUBSTANTIAL
30 July 1992	L1011-385-1	PASSENGER	JOHN F. KENNEDY INTERNATIONAL AIRPORT, NEW YORK, U.S.A.	292	0	1	Aborted Take-off	DESTROYED
07 December 1992	MD11-P	PASSENGER	20 MILES EAST OF JAPAN	265	0	0	In-flight Turbulence	MINOR
21 December 1992	DC10-30CF	PASSENGER	FARO, PORTUGAL	340	56	?	Loss of Control on Landing	DESTROYED
05 March 1993	F100	PASSENGER	SKOPJE AIRPORT, REPUBLIC OF MACEDONIA	97	83	13	Loss of Control on Take-off	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
06 April 1993	MD11	PASSENGER	NEAR SHEMYA, ALASKA, U.S.A.	255	2	60	In-flight Upset	SUBSTANTIAL
14 April 1993	DC10-30	PASSENGER	DALLAS/FORT WORTH AIRPORT, DALLAS, TEXAS, U.S.A.	202	0	2	Loss of Control on Landing	DESTROYED
14 September 1993	A320-211	PASSENGER	WARSAW, POLAND	70	2	51	Runway Overrun on Landing	DESTROYED
04 November 1993	B747-409B	PASSENGER	KAI TAK AIRPORT, HONG KONG	286	0	1	Runway Overrun on Landing	DESTROYED
01 December 1993	SD330 300	PASSENGER	UMIUJAQ, QUEBEC, CANADA	13	0	0	Stall on Approach	DESTROYED
07 January 1994	JETSTREAM 4101	PASSENGER	COLUMBUS, OHIO, U.S.A.	8	5	0	Stall on Approach	DESTROYED
01 February 1994	SAAB SF340B	PASSENGER	FALSE RIVER AIR PARK, NEW ROADS, LOUISIANA, U.S.A.	26	0	0	Runway Overrun on Landing	SUBSTANTIAL
02 March 1994	MD82	PASSENGER	LA GUARDIA AIRPORT, FLUSHING, NEW YORK, U.S.A.	116	0	0	Runway Overrun - Aborted Take-off	SUBSTANTIAL
21 March 1994	DC9-32	PASSENGER	VIGO AIRPORT, SPAIN	116	0	3	Collision with Obstacles on Approach	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
26 April 1994	A300B4-622R	PASSENGER	NAGOYA/KOMAKI AIRPORT, NAGOYA, JAPAN	271	264	7	Stall on Approach	DESTROYED
02 July 1994	DC9-31	PASSENGER	CHARLOTTE AIRPORT, CHARLOTTE, NORTH CAROLINA, U.S.A.	57	37	16	Loss of Control during Go Around	DESTROYED
10 August 1994	A300B4-622R	PASSENGER	CHEJU ISLAND AIRPORT, SOUTH KOREA	160	0	0	Runway Overrun on Landing	DESTROYED
22 November 1994	MD82	PASSENGER	BRIDGETON, MISSOURI, U.S.A.	140	0	0	Collision with Another Aircraft	SUBSTANTIAL
27 April 1995	MD83	PASSENGER	MANCHESTER AIRPORT, U.K.	178	0	0	Gear collapse on Landing	MINOR
08 June 1995	DC9-32	PASSENGER	WILLIAM B. HARTSFIELD INTERNATIONAL AIRPORT, ATLANTA, U.S.A.	62	0	1	Engine Non-containment on Take-off	DESTROYED
09 June 1995	DHC8-100	PASSENGER	NR. PALMERSTON NORTH, NORTH ISLAND, NEW ZEALAND	21	4	14	Collision with Ground on Approach	DESTROYED
21 August 1995	EMB120RT	PASSENGER	NEAR CARROLLTON, GEORGIA, U.S.A.	29	8	13	Loss of Control following Propeller Detachment	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
18 October 1995	DORNIER 228-212K	PASSENGER	MALE' INTERNATIONAL AIRPORT, MALE', MALDIVES	8	0	1	Loss of Control on Landing	DESTROYED
12 November 1995	MD83	PASSENGER	BRADLEY INTERNATIONAL AIRPORT, CONNECTICUT, U.S.A.	78	0	0	Collision with Obstacles on Approach	SUBSTANTIAL
13 November 1995	B737-200	PASSENGER	KADUNA AP., NIGERIA	138	11	14	Loss of Control on Landing	DESTROYED
20 December 1995	B747-136	PASSENGER	JOHN F. KENNEDY INTERNATIONAL AIRPORT, NEW YORK, U.S.A.	468	0	1	Loss of Control on Take-off	SUBSTANTIAL
20 December 1995	B757-223	PASSENGER	BUGA, NR. CALI, COLOMBIA	163	159	4	Collision with Ground on Approach	DESTROYED
07 January 1996	DC9-32	PASSENGER	NASHVILLE INTL AIRPORT, TENNESSEE, U.S.A.	93	0	0	Loss of Control on Landing	SUBSTANTIAL
19 February 1996	DC9-32	PASSENGER	HOUSTON INTERNATIONAL AIRPORT, TEXAS, U.S.A.	87	0	0	Wheels up Landing	SUBSTANTIAL
13 June 1996	DC10-30	PASSENGER	FUKUOKA AIRPORT, JAPAN	275	3	18	Runway Overrun - Aborted Take-off	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
06 July 1996	MD88	PASSENGER	PENSACOLA REGIONAL AIRPORT, FLORIDA, U.S.A.	142	2	2	Engine Non-containment on Take-off	SUBSTANTIAL
08 July 1996	B737-2H4	PASSENGER	NASHVILLE METROPOLITAN AIRPORT, TENNESSEE, U.S.A.	127	0	1	Aborted Take-off	MINOR
05 September 1996	B747-400	PASSENGER	IN FIGHT NR OUAGADOUGOU, BURKINA FASO	224	1	9	In-flight Turbulence	MINOR
19 October 1996	MD88	PASSENGER	LAGUARDIA AIRPORT, NEW YORK, U.S.A.	63	0	0	Collision with Obstacles on Approach	SUBSTANTIAL
06 August 1997	B747-3B5B	PASSENGER	NIMITZ HILL, NR AGANA, GUAM	254	228	26	Collision with Ground on Approach	DESTROYED
24 December 1997	B757-236	PASSENGER	SCHIPHOL AIRPORT, AMSTERDAM, NETHERLANDS	213	0	0	Loss of Control on Landing	SUBSTANTIAL
28 December 1997	B747-122	PASSENGER	IN FLIGHT, 870NM ESE OF TOKYO, JAPAN	393	1	18	In-flight Turbulence	NONE
09 February 1998	B727-223	PASSENGER	O'HARE INTERNATIONAL AIRPORT, CHICAGO, ILLINOIS, U.S.A.	122	0	0	Collision with Ground on Approach	DESTROYED
30 March 1998	HS748 SER 2B	PASSENGER	STANSTED AIRPORT, LONDON, U.K.	44	0	0	Engine Non-containment on Take-off	SUBSTANTIAL

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
21 May 1998	A320-212	PASSENGER	IBIZA AIRPORT, BALEARIC ISLANDS, SPAIN	187	0	0	Loss of Control on Landing	SUBSTANTIAL
25 October 1998	ATR42-300	PASSENGER	LUIS MUNOZ MARIN INTL, AP., SAN JUAN, PUERTO RICO	27	0	0	Collision with Ground Equipment	SUBSTANTIAL
03 December 1998	HS748-2A	PASSENGER/CARGO	IQALUIT AIRPORT, IQALUIT, NWT, CANADA	7	0	0	Runway Overrun - Aborted Take-off	DESTROYED
05 April 1999	B737-200	PASSENGER	HASANUDDIN AIRPORT, UJUNGPANDANG, SOUTH SULAWESI, INDONESIA	66	0	0	Loss of Control on Landing	SUBSTANTIAL
01 June 1999	MD82	PASSENGER	NATIONAL AIRPORT, LITTLE ROCK, ARKANSAS, U.S.A.	145	11	45	Runway Overrun on Landing	DESTROYED
22 August 1999	MD11	PASSENGER	HONG KONG INTERNATIONAL AIRPORT, HONG KONG	315	3	50	Loss of Control on Landing	DESTROYED
14 September 1999	B757-204	PASSENGER	GIRONA AIRPORT, SPAIN	245	1	2	Loss of Control on Landing	DESTROYED
23 September 1999	B747-438	PASSENGER	BANGKOK, THAILAND	410	0	0	Runway Overrun on Landing	SUBSTANTIAL

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
07 November 1999	F100	PASSENGER	BARCELONA AIRPORT, BARCELONA, SPAIN	44	0	0	Loss of Control on Landing	SUBSTANTIAL
21 December 1999	DC10-30	PASSENGER	AURORA INTL A/P, GUATEMALA CITY, GUATEMALA	314	16	10	Loss of Control on Landing	DESTROYED
13 January 2000	SD360	PASSENGER	MARSA EL BREGA, LIBYA	41	22	13	Unplanned Ditching on Approach	DESTROYED
30 January 2000	A310	PASSENGER	NEAR ABIDJAN AIRPORT, IVORY COAST	179	169	9	Loss of Control on Take-off	DESTROYED
05 March 2000	B737-300	PASSENGER	BURBANK, CALIFORNIA, U.S.A.	142	0	2	Runway Overrun on Landing	DESTROYED
25 May 2000	MD83	PASSENGER	CHARLES DE GAUILE, PARIS, FRANCE	157	0	0	Collision with Another Aircraft	MINOR
17 July 2000	B737-200	PASSENGER	NEAR PATNA AP, INDIA	58	55	3	Loss of Control on Approach	DESTROYED
31 October 2000	B747-412B	PASSENGER	CHIANG KAI-SHEK AP, TAIWAN	179	83	39	Collision with Ground Equipment	DESTROYED
05 November 2000	B747-200	PASSENGER	PARIS CHARLES DE GAULLE, FRANCE	203	0	0	Loss of Control on Landing	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
15 January 2001	DHC8-300	PASSENGER	CHINMEN SHANGYI AP, CHINMEN ISLAND, TAIWAN	27	0	0	Gear collapse on Landing	SUBSTANTIAL
31 January 2001	B747	PASSENGER	7NM SOUTH OF YAIZU, SHIZUOKA, JAPAN	427	0	9	In-flight Upset	MINOR
07 February 2001	A320	PASSENGER	BILBAO A/P, SPAIN	143	0	1	Gear collapse on Landing	SUBSTANTIAL
11 April 2001	A330-243	PASSENGER	COLOMBO INTL AIRPORT, KATUNAYAKE, SRI LANKA	152	1	3	Emergency Evacuation due to Smoke in the Airplane	NONE
24 August 2001	A330-243	PASSENGER	LAJES, AZORES, PORTUGAL	306	0	2	Total Loss of Engines in Flight	SUBSTANTIAL
29 August 2001	CASA 235	PASSENGER	NEAR MALAGA AIRPORT, SPAIN	47	4	18	Loss of Control on Approach	DESTROYED
24 November 2001	AVRO RJ	PASSENGER	NEAR ZURICH, SWITZERLAND	33	24	5	Collision with Ground on Approach	DESTROYED
06 January 2002	B737-400	PASSENGER	FUERTEVENTURA, SPAIN	88	0	0	Loss of Control on Landing	SUBSTANTIAL
14 January 2002	B737-200	PASSENGER	PEKANBARU, INDONESIA	103	0	1	Loss of Control on Take-off	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
16 January 2002	B737-300	PASSENGER	BENGAWAN SOLO RIVER, SERENAN VILLAGE, CENTRAL JAVA	60	1	13	Unplanned Ditching on Approach	DESTROYED
15 April 2002	B767	PASSENGER	PUSAN, SOUTH KOREA	166	129	37	Collision with Ground on Approach	DESTROYED
07 September 2002	A340	PASSENGER	MADRID, SPAIN	263	0	0	Loss of Control on Landing	SUBSTANTIAL
14 September 2002	B747	PASSENGER	MADRID, SPAIN	373	0	0	Collision with Obstacles on Ground	SUBSTANTIAL
02 November 2002	F27-500	PASSENGER	SLIGO, IRELAND	40	0	0	Runway Overrun on Landing	DESTROYED
06 November 2002	F50	PASSENGER	NIEDERANVEN, LUXEMBOURG	22	20	2	Total Loss of Engines during Go-around	DESTROYED
17 January 2003	F50	PASSENGER	MELILLA, SPAIN	19	0	0	Loss of Control on Landing	DESTROYED
06 March 2003	B737-2T4	PASSENGER	TAMANRASSET, ANTIGUA AND BARBUDA	103	102	1	Loss of Control on Take-off	DESTROYED
17 June 2003	MD88	PASSENGER	GRONINGEN AIRPORT EELDE, NETHERLANDS	149	0	0	Runway Overrun - Aborted Take-off	SUBSTANTIAL

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
22 June 2003	CANADAIR RJ100	PASSENGER	BREST, FRANCE	24	1	4	Loss of Control on Approach	DESTROYED
18 July 2003	A330-342	PASSENGER	REPORTING POINT NOBEN, MANILLA FIR	251	0	2	In-flight Turbulence	MINOR
04 December 2003	DORNIER 228-202	PASSENGER	BODO AIRPORT, NORWAY	4	0	2	Loss of Control on Approach	DESTROYED
25 December 2003	B727-223	PASSENGER	COTONOU, BRUNEI DARUSSALAM	160	138	22	Loss of Control on Take-off	DESTROYED
01 January 2004	MD81	PASSENGER	TOKUNOSHIMA AIRPORT, JAPAN	169	0	0	Gear collapse on Landing	SUBSTANTIAL
05 January 2004	F70	PASSENGER	MUNICH, GERMANY	32	0	0	Loss of Control on Approach	DESTROYED
10 February 2004	F50	PASSENGER	2.6 NM FROM SHARJAH INTL A/P, SHARJAH, UNITED ARAB EMIRATES	46	43	3	Loss of Control on Approach	DESTROYED
09 May 2004	ATR72	PASSENGER	SAN JUAN, PUERTO RICO	236	0	1	Loss of Control on Landing	SUBSTANTIAL
17 May 2004	DHC6-300	PASSENGER	MALE INTERNATIONAL AIRPORT, MALDIVES	17	0	3	Collision with Ground on Take-off	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
18 October 2004	A320-232	PASSENGER	TAIPEI SUNGSHAN AIRPORT, TAIWAN	106	0	0	Gear collapse on Landing	SUBSTANTIAL
04 November 2004	B737-37Q	PASSENGER	MANCHESTER AIRPORT, MANCHESTER, U.K.	?	0	0	Collision with Another Aircraft	SUBSTANTIAL
04 November 2004	B767-204	PASSENGER	MANCHESTER AIRPORT, MANCHESTER, U.K.	?	0	0	Collision with Another Aircraft	MINOR
28 November 2004	B737-406	PASSENGER	BARCELONA, SPAIN	146	0	0	Loss of Control on Landing	DESTROYED
30 November 2004	MD82	PASSENGER	ADI SUMARMO AIRPORT, SOLO, INDONESIA	163	25	55	Runway Overrun on Landing	DESTROYED
01 December 2004	GULFSTREAM IV	PASSENGER	TETERBORO AIRPORT, TETERBORO, NEW JERSEY, U.S.A.	9	0	0	Loss of Control on Landing	SUBSTANTIAL
02 August 2005	A340-313	PASSENGER	LESTER B PEARSON INTL AIRPORT, TORONTO, CANADA	309	0	12	Runway Overrun on Landing	DESTROYED
06 August 2005	ATR72	PASSENGER	23NM NORTH EAST OF PALERMO AIRPORT, ITALY	39	16	16	Loss of Engines resulting in Ditching	DESTROYED
05 September 2005	B737-200	PASSENGER	MEDAN, INDONESIA	117	100	15	Runway Overrun on Take-off	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
08 December 2005	B737-700	PASSENGER	CHICAGO MIDWAY INT AP, CHICAGO, ILLINOIS, U.S.A.	103	0	0	Runway Overrun on Landing	SUBSTANTIAL
10 December 2005	DC9-31	PASSENGER	PORT HARCOURT, NIGERIA	110	108	2	Loss of Control on Landing	DESTROYED
10 March 2006	AVRO RJ85	PASSENGER	GOTHENBURG/LAND VETTER AIRPORT, SWEDEN	32	0	0	Gear collapse on Landing	SUBSTANTIAL
18 March 2006	B737-6D6	PASSENGER	SEVILLE, SPAIN	107	0	0	Gear collapse on Landing	SUBSTANTIAL
27 August 2006	CANADAIR RJ100	PASSENGER	BLUE GRASS AIRPORT, LEXINGTON, KENTUCKY, U.S.A.	50	49	1	Runway Overrun on Take-off	DESTROYED
10 October 2006	BAE 146-200A	PASSENGER	STORD AIRPORT, SORSTOKKEN, NORWAY	16	4	6	Runway Overrun on Landing	DESTROYED
16 November 2006	B757-27A	PASSENGER	99 NM SOUTH OF JEJU ISLAND, SOUTH KOREA	137	0	4	In-flight Upset	MINOR
25 January 2007	F28-100	PASSENGER	PAU, FRANCE	54	0	0	Loss of Control on Take-off	DESTROYED
18 February 2007	EMB170	PASSENGER	CLEVELAND HOPKINS INTL A/P, CLEVELAND, OHIO, U.S.A.	75	0	0	Runway Overrun on Landing	SUBSTANTIAL

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
07 March 2007	B737-497	PASSENGER	ADI SUCIPTO AIRPORT, YOGYAKARTA, INDONESIA	140	21	12	Runway Overrun on Landing	DESTROYED
12 April 2007	CANADAIR RJ200-LR	PASSENGER	CHERRY CAPITAL A/P, TRAVERSE CITY, MICHIGAN, U.S.A.	52	0	0	Runway Overrun on Landing	SUBSTANTIAL
16 September 2007	MD82	PASSENGER	PHUKET INTNL A/P, THAILAND	130	90	26	Loss of Control during Go Around	DESTROYED
17 January 2008	B777-236ER	PASSENGER	HEATHROW AIRPORT, LONDON, U.K.	152	0	1	Loss of Control on Approach	DESTROYED
10 June 2008	A310-324	PASSENGER	KHARTOUM AIRPORT, SUDAN	214	30	?	Runway Overrun on Landing	DESTROYED
20 August 2008	MD82	PASSENGER	MADRID BARAJAS INTL A/P, MADRID, SPAIN	172	154	18	Stall on Take-off	DESTROYED
20 December 2008	B737-500	PASSENGER	DENVER INTERNATIONAL A/P, DENVER, COLORADO, U.S.A.	115	0	6	Loss of Control on Take-off	SUBSTANTIAL
15 January 2009	A320-214	PASSENGER	HUDSON RIVER, WEEHAWKEN, NEW JERSEY, U.S.A.	155	0	5	Loss of Engines resulting in Ditching	DESTROYED
25 February 2009	B737-800	PASSENGER	SCHIPHOL AIRPORT, AMSTERDAM, NETHERLANDS	135	9	11	Collision with Ground on Approach	DESTROYED

DATE	AIRPLANE TYPE	OPERATION	LOCATION	TOTAL OCCUPANTS	TOTAL FATALITIES	TOTAL SERIOUS INJURIES	BRIEF ACCIDENT DESCRIPTION	AIRPLANE DAMAGE
07 December 2009	EMB135LR	PASSENGER	GEORGE A/P, SOUTH AFRICA	35	0	0	Loss of Control on Landing	SUBSTANTIAL
12 May 2010	A330-202	PASSENGER	(NR) TRIPOLI INTERNATIONAL AIRPORT, TRIPOLI, LIBYA	104	103	1	Loss of Control during Go Around	DESTROYED
20 August 2011	B737-210C	PASSENGER/CARGO	RESOLUTE BAY, NUNAVUT, CANADA	15	12	3	Collision with Ground on Approach	DESTROYED
06 July 2013	B777-200ER	PASSENGER	SAN FRANCISCO INTL A/P, CALIFORNIA, U.S.A.	307	3	49	Collision with Ground on Approach	DESTROYED

APPENDIX B - MATHEMATICAL AND STATISTICAL MODELLING

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, sex, 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 analyze accidents than considering the whole aircraft due to the marked variation in survival potential with occupant location.

The flight deck and cabin crew areas are generally considered as separate scenarios. The flight crewmembers usually have full harness restraints, and sliding cockpit windows in the area provide a nearby method of egress. The cabin crew 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 is based on assessments carried out for each accident scenario.

SURVIVABILITY CHAINS

A mathematical model, known as a survivability chain (see figure 8) has been developed, that enables an assessment to be made of the overall effect on survivability, from improvements made to survivability factors, taking into account injuries that may be sustained by occupants.

Where sufficient data are available, each accident is divided into scenarios and a survivability chain constructed.

The following is an example of the model and the effects of improvement in injuries and fatalities resulting from changes to survivability factors.

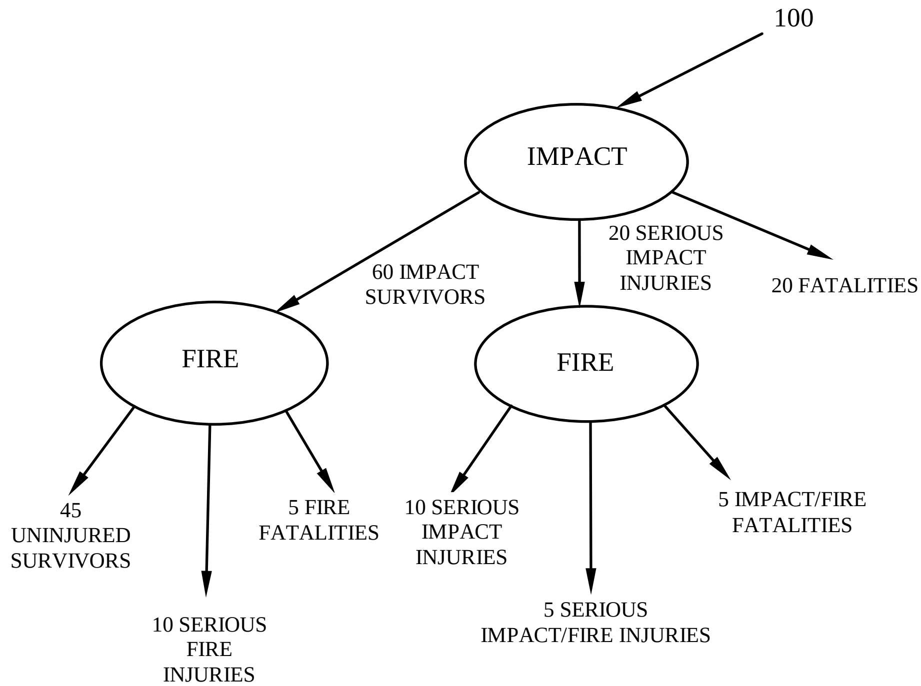

Figure 8. Example of Survivability Chain for an Accident Scenario

In this example, of the 100 occupants in the scenario there are: -

- 45 uninjured survivors.
- 25 serious 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 non-fatal injuries from the impact).

If improvements are made to an impact-related survivability factor, such that there are only 12 fatalities and 16 seriously injured of the 100 occupants, the survivability chain then becomes: -

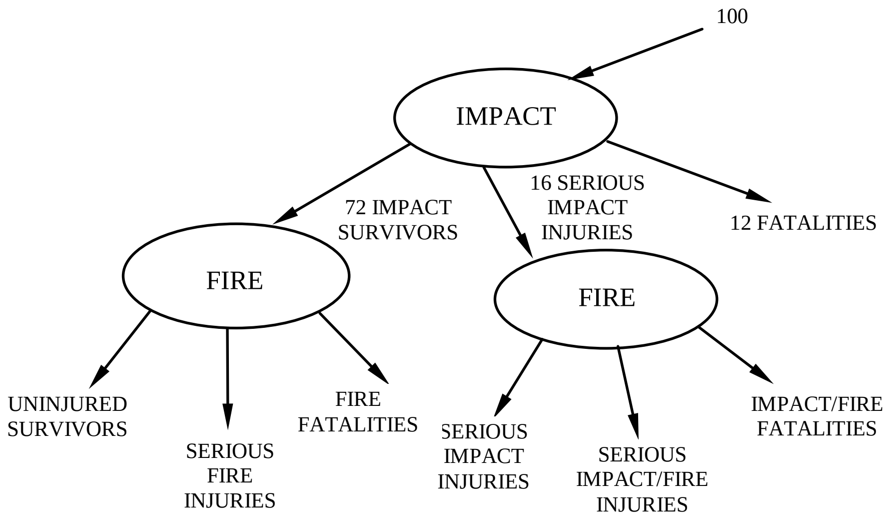

Figure 9. Example Survivability Chain showing possible improvements in an Impact-Related Survivability Factor

It is known from the accident that 5/60ths of those that survive the impact uninjured and 5/20ths of those that sustain injuries from the impact subsequently succumb to death because of the fire. Furthermore, 10/60ths of those that survive the impact seriously injured are seriously injured from fire and 5/20ths of those that sustain injuries from the impact also sustain injuries because of the fire. It is assumed that these ratios are constant for any particular scenario.

On this basis an assessment of the numbers of fatalities and injuries may be made as follows: -

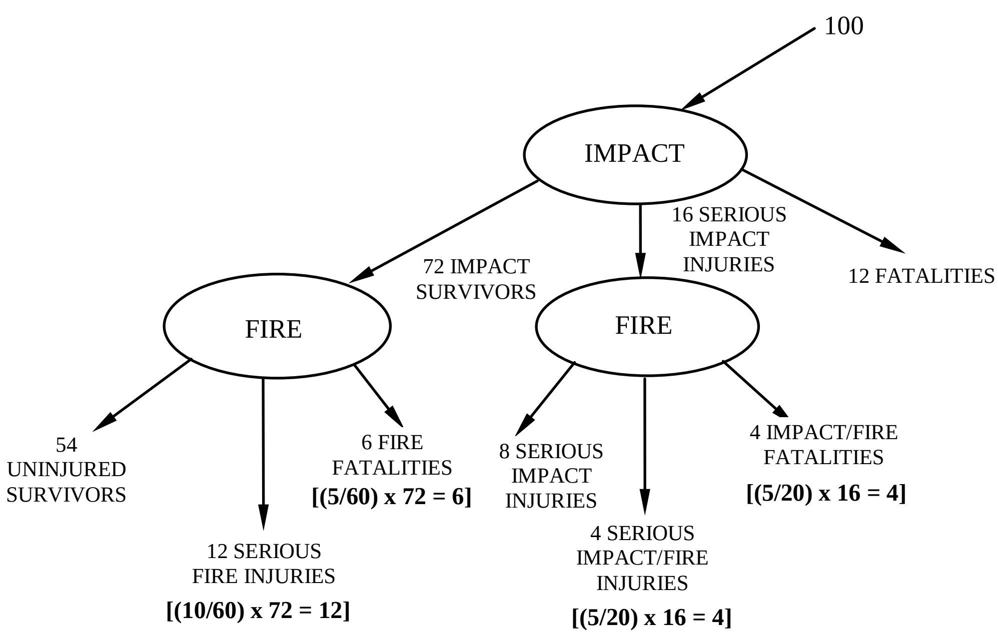

Figure 10. Example of Survivability Chain showing the Overall Improvements in Survivability

Therefore, the improvement to the impact related survivability factor results in: -

- 54 survivors.
- 24 serious injuries, 8 as a result of the impact, 12 as a result of the fire, and 4 seriously injured as a result of the impact and fire.
- 22 fatalities, 12 because of the impact, and 10 because of the fire (4 of whom sustained non-fatal injuries from the impact).

It should be noted that the survivability factor improvement resulted in a reduction in impact fatalities of 8 (20-12) and impact injuries of 4 (20-16). However, the overall situation is as follows: -

	Survivors	Serious Injuries	Fatalities
Prior to survivability factor improvement:-	45	25	30
Post survivability factor improvement:-	54	24	22

STATISTICAL MODELLING

A software package was developed that uses this survivability chain model in a mathematical representation of an accident using Monte Carlo simulations. This enables an assessment to be made of the change in numbers of survivors, injuries and fatalities resulting from predictions of the range of improvements that may be possible from changes to a survivability factor.

For each scenario, a numerical assessment will be made of the impact on number of fatalities and injuries because of changes resulting from the improvement to a survivability factor. The assessment results in a prediction of the highest, mean and lowest number of fatalities and injuries that could reasonably be expected from the change.

From the example described above, the “best” (or median) assessment was that improvements to the survivability factor relating to impact deaths resulted in an improvement in the number of fatalities from 20 to 12. Similarly, the impact injuries reduced from 20 to 16. When making this determination an assessment would also be made of the “maximum” and “minimum” number of fatalities and injuries that are likely to result from the improvement in a survivability factor

It is then assumed that there can be 100% confidence that the fatalities and injuries will lie in the range from the maximum to the minimum. Unless there is evidence to suggest otherwise it will be assumed that the 50-percentile point of the confidence level distribution corresponds to the “best” or median assessment.

The accidents analyzed are likely to be to aircraft with varying standards of fireworthiness. The intention is to determine the benefit likely to be accrued by aircraft compliant with today's standards. Therefore, an allowance will be made for a reduction in fire fatalities and injuries that might result from the improved fire characteristics of cabin materials compliant with the standards introduced by 14 CFR part 25 .

From this a re-evaluation of the resultant number of survivors, serious injuries and fatalities may be made using the survivability chain generated for the accident scenario. This is then compared with the actual outcome of the accident scenario and the improvement in the number of fatalities and serious injuries derived. The software will make numerous iterations of random selections over the range 0 to 100% to generate a distribution of the degree of improvement. From this distribution, the 5, 50 and 95 percentile values are selected to represent the “best” assessment of the improvement and its likely range.

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