Brace for impact! A thesis on medical care following an airplane crash
Postma, Ingri
Chapter 10

Analysis of biomechanical aspects of non-fatal injuries in a major airplane crash

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Analysis of Biomechanical Aspects of Non-Fatal Injuries in a Major Airplane Crash
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Abstract

Introduction
Although the number of fatal air accidents has dramatically decreased since the beginning of commercial air travel, they still occur often enough to justify measures intended to reduce the fatality and injury rates. Survivability studies are a means to assess the effectiveness of current occupant safety measures and identify areas where improvements can be made. In this pilot study of the Flight TK-1951 crash on February 25, 2009, near Amsterdam Airport Schiphol, the injuries sustained by the survivors and the documented structural damage of the aircraft were analysed to determine the most likely cause of the injuries.

Methods
All medical data on the injuries of the survivors and the structural damage of the airplane fuselage, seats, and interior were gathered and documented. A team of specialists evaluated the injuries to explain the injury mechanism involved in relation to the damages that occurred. Four cases were chosen to be presented in this pilot study.

Results
Some of the significant injuries found in the 4 cases were: head injuries related to impact from dislodged objects, spinal fracture and chest injuries related to forward flailing, lumbar spine fractures resulting from high vertical loads, facial fractures and pulmonary contusions resulting from impact onto the seat back in front, and leg injuries resulting from vertical load applied by the disrupted floor.

Conclusions
This pilot study identifies 4 areas where improvements could be made to reduce injuries. These are 1. Insufficiently secured equipment can cause head injury; 2. Insufficient vertical energy absorption by the seat can result in lumbar and thoracic spinal compression injuries; 3. Lack of upper torso restraint can permit forward flailing resulting in spine and chest injuries; 4. Floor deformation can cause an increase in severity of the lower leg injuries by applying extra vertical load. Previous comprehensive studies of relevant accidents have identified many of the same injury causation factors as prevalent in other crashes.
Introduction

The number of flights and air travellers has increased rapidly since the start of commercial air traffic. Also, the size of the aircraft and therefore the number of passengers on board have increased to meet the growing demand for air travel. After a steady decrease in the rate of fatal air accidents up to the 1970’s, the accident rate continues to decline, but at a much slower rate. (1) Fortunately, most (73%) serious airplane accidents are survivable, and in those accidents, 76% of the occupants survived, according to a National Transportation Safety Board (NTSB) study that examined accidents in the period 1983 – 2000 (2) While airliner crashes are relatively rare events (a worldwide average of 2.5 accidents per year in which at least one person is fatally injured during the period from 2002 to 2011), benefit analyses indicate that steps to prevent or mitigate fatalities and serious injuries that could occur, are worthwhile. (3-5)

In 1988, the United States implemented improved safety standards for seats and restraints in aircrafts, with the goal of reducing deaths and injuries. (6) These standards require that seat system strength and occupant protection be evaluated using dynamic testing with Anthropomorphic Test Devices (ATDs), as is done to ensure automobile safety. This test method provides a realistic loading condition and permits direct evaluation of injury risks. The evaluations consist of two tests, one simulating a crash where the forces are horizontal, and the other where a combined vertical and horizontal load is applied. The seats must accommodate a significant amount of floor distortion without failure, since floor distortion is common in survivable crashes. The seat and restraint system must be designed to limit the load transmitted vertically to the spine, which is usually accomplished by allowing some amount of vertical deflection in the seat. Loads transmitted to the head must also be limited, which can be done by controlling the force required to fold the seat back in front of the passenger, or by use of a shoulder strap or inflatable restraint to prevent or reduce the velocity of head impact. These standards were initially applicable to newly designed aircrafts, but this implementation approach resulted in a smaller percentage of the fleet having the improved seats than desired (64% in 2004). In 2009, the standards were applied to all newly produced airliners, to accelerate implementation. (7) Similar requirements have been adopted by the European Union.

Recently, there has been a series of accidents with Boeing 737 aircraft incorporating seats meeting the new safety standards. These are Continental Flight 1404 in
Denver, Turkish Airlines flight TK-1951 in Amsterdam, American Airlines Flight 331 in Jamaica, and Aires Flight 820 in San Andres. (8) Although the impact scenarios differed somewhat, they were similar in that the fuselage broke into sections but maintained a survivable volume in the majority of those sections. The outcome of these accidents was also remarkably similar, in that most, if not all of the passengers survived. An analysis of these accidents could provide insight into the effectiveness of the new safety standards and identify areas where further improvements to crash safety could be developed. Therefore, in this pilot study the injuries sustained by the surviving victims of Turkish Airlines flight TK-1951 that crashed on February 25 2009 near Amsterdam Airport Schiphol were analysed. This study focuses on the causation of the injuries that occurred, such as inertial loading and contact with the interior. Based on these analyses, recommendations will be provided for improving the protection of aircraft occupants during an impact.

Figure 1. Arial view of wreckage and structural damages

A. Arial view of the plane; B. Floor deformation in the front part of the plane; C. Deformation to the back of seat; D. Front cross tube is bent.
Methods

Figure 2. Injury severity distributions throughout cabin

Data Collection

Of the 135 passengers and crew members on board the aircraft, 9 died. The 126 surviving occupants were all evaluated in hospital. Their medical data, consisting of type of injury, diagnostic imaging, and treatment methods, were gathered for
this study. The injuries were coded using a standardised injury coding system, the Abbreviated Injury Scale (AIS; update 1998). The AIS is an anatomically based, consensus derived, global severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale. The AIS characterizes the severity of injury as 1 Minor, 2 Moderate, 3 Serious, 4 Severe, 5 Critical, and 6 Maximal. (9) The overall injury level of each occupant was determined by calculating the Injury Severity Score (ISS). (10) This score is the sum of the squares of the maximum AIS values for the 3 body areas where the most serious injuries have occurred. Autopsies were only conducted on the fatally injured cockpit crew, but the results were not available for this study.

After the crash, an international team of experts, called the Survivability Group, led by the Dutch Safety Board (DSB), carried out detailed measurements of the damage that occurred in the interior of the aircraft. Specialists from NTSB, Boeing, the U.S. Federal Aviation Administration (FAA), and the Dutch Cabin Crew Union (VNC) were team members. The team noted the general condition of interior components such as the seats, overhead baggage compartments (overhead bins), walls, and emergency exits. Measurements were taken to determine the amount of deformation that had occurred in the seat frames and aircraft floor. The condition and length of all seat belts was also documented. The belts were also inspected for evidence of loading indicated by "witness marks," which is a crease across the webbing made as the webbing adjuster bar was forced into the fabric by the belt tension. For such measurements, no standard protocols were available; the methods used were developed and specified at the scene by the Survivability Group. The measurements were documented in tables and photographs which were made available for our analyses. The DSB also collected the seating arrangements by checking the passenger list from the airline and by asking the passengers about their seat and the people seated around them. These data were made available for the purpose of this study. It should be noted that the medical records consulted for this study are not publically available. Also, the Survivability Group data and the seating arrangement information consulted for this study have not been publically released by the DSB. This study’s protocol was approved by the ethical review board of the Academic Medical Centre, Amsterdam, the Netherlands.

Data Analysis
A team consisting of medical doctors with a special interest in trauma, trauma surgeons, engineers in injury biomechanics, and engineers in aircraft design
reviewed the data of structural damage and injuries to the occupants. These data were then compared with each other to explain possible injury mechanisms. The confidence in the determinations were ranked using the National Highway Traffic Safety Administration (NHTSA) terms for confidence: Certain, Probable, and Possible. After reviewing a substantial number of the cases, 4 cases were selected that were considered illustrative for this crash. The facts concerning these 4 cases and the consensus of the reviewers with regard to injury causation are presented in the results section.

Since no fire occurred during or after the crash, it can be assumed that all injuries were a result of the forces applied to the occupant by the impact of the crash or occurred during evacuation. If the cabin crew are aware that an impact is imminent, passengers are instructed to “brace,” an action that includes placing the head and upper torso against the interior feature just forward of the occupant (typically a seat back). This action can reduce the relative impact velocity with the interior and therefore reduce the impact-related injuries. None of the occupants were aware that the airplane was about to crash, so it can be assumed that no one in the airplane had adopted a “brace position”.

Results

Setting and Conditions of the Accident
This crash involved a Boeing 737-800 that impacted a ploughed farm field during its final approach to Amsterdam Airport Schiphol. The plane was severely damaged but did not catch fire. The airplane fractured in three parts: an rear section including the tail, a large centre section, and a forward section containing the cockpit. The front fracture was between rows 7 and 8, just forward of the wing, and the rear section fractured at row 29, the last seat row. Figure 1A gives an overall view of the aircraft damage. The forward section sustained the most extensive damage to the interior.

The data from the Flight Data Recorder (FDR) consisted of various speeds, roll angle and accelerations, and were of such quality that the initial conditions of the aircraft just before first contact with the ground were fairly accurately known; however, horizontal and vertical velocity at impact were not cited in the DSB final report (8). It is likely that these parameters could be derived from an analysis of the entire FDR data set. Available FDR data do show that the plane was pitched up 22 degrees
and rolled 10 degrees to the left when it contacted the ground. Examination of the ground contact scars and aircraft wreckage indicates that the rear of the aircraft contacted the ground first. FDR data, ground contact scars and the final position of the wreckage provided sufficient information for the DSB to create an animation of the likely sequence of events that occurred during the crash. This animation shows that the initial contact transmitted enough force to the tail of the aircraft to cause the horizontal stabiliser to separate immediately and for the entire fuselage section after row 29 to separate at some point in the crash. The animation also shows the aircraft pitch forward rapidly after the tail touched the ground, causing the nose to hit with sufficient vertical force to break the fuselage just ahead of the wing. The floor of this section deformed significantly, exhibiting an accordion pattern of failure, shown in Figure 1B, indicative of significant forward loading.

Summary of Injuries
Of the 135 passengers and crew, 9 suffered fatal injuries, and 120 had injuries ranging from minor to critical; 15 with an injury severity score (ISS) greater than 15, 21 with an ISS between 8 and 15, and 84 with an ISS of 8 or less. The severity of the injuries sustained as a function of the seat location is provided in Figure 2. Most fatalities and seriously injured occupants were seated in the front section of the aircraft. Most passengers with minor injuries were seated in the middle section (main cabin). It should be noted that under the category of minor injuries there were some occupants who had been unconscious for a short duration. These minor injuries could have resulted in fatalities if there had been a post-crash fire because these occupants may not have been able to evacuate in time.

Cases
Because of privacy issues, no exact seat location, gender or age is provided. The location of the occupant is noted as forward, centre, or rear section, of the plane since the impact environment differed significantly in each of these sections. A summary of the mechanism of every injury is presented in Table 1.

Case 1: forward section; ISS 29
Main injuries: Nose fracture, (AIS 1); Orbital fracture left (AIS 2); Pulmonary contusion,
bilateral (AIS 4); Humeral fracture, left (AIS 2); Forearm fracture, open right (AIS 3); Femur fracture, proximal right (AIS 3); Tibia fracture, distal left (AIS 3). Figure 3.

Discussion: The seat remained attached to the seat track, but the aircraft side wall showed significant intrusion, contacting the end of the seat. The cross tubes that support the seat pan were only supported at one end. These tubes were bent down 4.5 inches at the unsupported end, indicating significant vertical loading at this location. The lack of spinal injuries may be explained by the energy absorbed during the seat frame deformation. During dynamic tests run to qualify new seat designs, flexion of cross tubes has been observed to significantly reduce force transmitted to the lumbar spine. However, the amount of permanent deformation at this seat location implies that loading was beyond the load (14 g) applied during dynamic qualification tests.

Overhead bins in this area were dislodged and then later removed by rescue workers. The back of this seat and the one beside it were buckled at about 12 inches up from the hinge, indicating significant loading from above (potentially from the dislodged overhead bin). Figure 1C.

The row in front was completely dislodged during the crash. The seat back in front of this occupant was broken and was bent forward, but did not have blood or other prominent marks. The right seatbelt anchor bolt was pulled out of the seat frame. The seatbelt was still latched and had an obvious witness mark, showing that the seatbelt was worn and loaded during the crash. This failure is consistent with the significant forward loading apparent in this section of the aircraft. It is likely that the attachment failure resulted in ejection of the occupant from the seat, allowing excursion of the whole body forward and to the left, likely hitting the side wall and pushing the seatback in front, forward. The orbital fracture appears as a blowout caused by high intra-orbital pressure; it is likely that was caused by a high velocity impact with the seat in front. The seat is a more likely cause than the side wall, because its softer surface provides an increased contact area associated with this type of injury. The nose fracture is likely to have occurred during this same contact. The pulmonary contusion is most likely due to the impact from the side (wall) and seat in front.

The complex spiral fracture of the humeral shaft on the left is the result of a high energy, direct impact and suggests impact with the side wall and seat frame in front, which probably occurred when the occupant was ejected. Contact with the frame of the seat in front was also the likely mechanism for the transverse forearm fracture on the right.
The complex spiral wedge fracture of the proximal femur on the right side is the result of a high-energy bending load. The most likely fulcrum point was the front cross tube of the occupant’s seat, since forward flailing of the occupant tends to force the femur downward against this tube as would vertical loading if the lower leg was extended forward. Figure 1D shows that the cross tube is bent down more on the left side of the occupant than the right, which may be why there is not a similar injury on the left side.

The left tibia and fibula fracture were the result of a high energy impact, with loss of occupant space, consistent with the downward bending of the seat frame, causing an axial load. This was probably combined with a direct impact caused by contact of the lower leg against the seat in front, when the occupant was ejected.

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**Case 2: forward section. ISS 18**

Main injuries: Kidney contusion, right (AIS 2); Humeral fracture, right (AIS 2); Tibia fracture, distal left (AIS 3); Tibia fracture, distal right (AIS 3, Figure 4A); Spinal fracture, L5 (AIS 3, Figure 4B).

Discussion: The seat assembly was severely damaged and canted forward with the front cross tube nearly at floor level. The floor track under this seat sheared just in front of and behind the seat leg attachments, allowing the entire seat assembly to rotate forward. Occupants in this row were probably thrown forward in their seats as
the seat was pitched forward. The downward motion of the front of the seat relative to the remaining floor would have applied significant axial loading to the occupant’s lower legs and forced the ankles into dorsiflexion. Both lower legs exhibited an almost pure axial loading injury, resulting in a comminuted intra-articular distal tibia (pilon) fracture. A flailing component against the seat in front was less prominent. The left roll of the aircraft could have caused the occupant to be thrown forward in a skew manner forcing the right side against the front row first, causing the greater tuberosity fracture of the right humerus. The seat in front was pushed forward even though it was unoccupied, indicating significant loading by the occupants behind it. The 5th lumbar vertebral fracture shows again an almost pure axial load through all 3 columns. A posterior distraction caused by flailing over the seat belt was not present. The cross tubes under this seat place remained relatively straight, while those on either side were somewhat bent down. This caused the axial load to be almost completely transferred through the lumbar spine, causing the compression burst fracture with great loss of the height of the spinal corpus. The kidney contusion could have been the result of a direct impact, possibly the armrest.

Figure 3. Injuries in Case 1: A. humeral shaft spiral fracture, B. blow out orbit fracture, C. proximal femur fracture
Case 3: centre section ISS 10
Main injuries: Cerebral contusion, right (AIS 3); Retinal laceration left (AIS 1)
Discussion: The overhead panel above this seat was missing. This panel may have contained an oxygen generator or video monitor, both of which are relatively heavy objects. The Passenger Service Unit (PSU) door was open and the oxygen masks were hanging down in this row. There was limited damage to the seatback in front and no damage to the tray table. An AIS 3 cerebrum contusion indicates a high velocity impact that would typically produce high head accelerations. An impact with the seatback producing that level of acceleration would have resulted in significant break-over of the seatback in front, which was not observed here. Therefore, this head injury was probably not caused by contact with the seatback, but more likely from impact of a large object falling from above. This same impact could have also caused the retinal injury.

Case 4: centre section. ISS 9
Main Injuries: Spinal fracture T11 (AIS 2); Spinal fracture T12 (AIS 3, Figure 4C); Sternum fracture (AIS 2, Figure 4D).
Discussion: This row had extra leg room which provided more space for the occupant to flail forward. The seat frame under this occupant was intact, but the overall condition of the seat just after the impact is hard to determine since it was one of several in this area removed by rescue workers. This means that the documented condition of the seat could include damage that occurred as it was extracted. The occupant suffered spinal injury of the flexion/ distraction type, 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.
The sternum fracture was a direct impact injury and could be inflicted by contact with the knees from forward flailing, consistent with T11/T12 vertebrae injuries. The distance to the seat in front makes it unlikely that the sternum could have struck a rigid structure on the back of the seat.

Discussion

In this pilot study we focused on mechanical injuries, which in crashes can be from inertial loading causing indirect acceleration/deceleration injuries, or the
result of direct loading of various body parts against objects in the environment during impact. Contact injuries can be prevented by restraining the occupant and restraining potentially harmful objects. Acceleration injuries can be prevented through energy absorption in crush zones and energy absorbing seats. This discussion elaborates on the injury biomechanics of the illustrative cases in comparison to literature. Several safety items are identified.

**Figure 4:** Injuries Case 2 and 4.

**Loose objects**

In case number 3, it is likely that a loose object struck the occupant’s head causing an injury. The cerebrum contusion (AIS 3) indicates that a high-velocity impact of significant energy occurred. A blow like this to the seat in front would have left evident marks, which were not present. So, a loose object from above is more likely to have caused this injury. We found that in several places in the airplane the PSU or sometimes even heavier objects such as oxygen generators and video
monitors came loose from the bottom of the overhead bins above the occupants and could have swung down with quite some force. Head injury causes a major safety issue in airplane crashes. When a head injury is severe enough to knock an occupant unconscious, they would be unable to evacuate the airplane. In a post-crash fire, this is often fatal. Improving the attachment of overhead objects could greatly improve survivability. In this crash, 60 (48%) of the survivors suffered a head, or face injury. (12)

**Upper-Torso Restraints**

The sternum fracture in case 4 is surmised to have been inflicted from contact with the knees by the occupant flailing forward, consistent with T11/T12 vertebral injuries. Sternal fractures in Motor Vehicle Crashes (MVA) often occur in combination with spinal injuries. (14) We found that 14 occupants in this crash suffered significant (AIS 3-5) chest injury. A shoulder harness or inflatable restraint system (airbag) that keeps the torso upright during a forward impact might have prevented this injury. Flexion distraction type spinal injuries, as first described by Chance and seen in case 4, were often observed in car crashes before the introduction of the 3 point shoulder restraint. (15) The seat belt allows the occupant to flail with the belt acting as a fulcrum, resulting in a flexion at the anterior and distraction at the posterior column (16). In this accident 23 (18%) of the 126 survivors suffered a spinal injury. (12) Six of these injuries were fractures with a flexion and distraction pattern. (Ref: Unpublished data: Spinal Injuries in an Airplane Crash; I.L.E. Postma, et al.) For many seat designs, the introduction of conventional shoulder harnesses may not be possible, as the seats may not have the structural strength to support the restraint, and they are designed to break over to limit head injuries to the passengers rear of the seat. Forces applied by a shoulder strap to the seat back would defeat this function. Inflatable restraint systems are available that can significantly reduce forward flailing without interfering with the seatback’s load-limiting function. (17) However, implementation of technologies to mitigate one injury risk could have the unintended consequence of raising the risk of other injuries. For instance, retinal injuries are described in MVA as a result of a forward flail of the head against the deploying airbag. (18) With a pressure rise, compression and distraction of tissue can cause several types of injury, like orbital blowout fracture or retinal laceration. Studies of MVA show that the use of a shoulder restraint does not seem to decrease the incidence of pulmonary contusion and could even increase thoracic injury by rib fractures along the seatbelt line. (19; 20) Moreover, restraint systems that keep
the occupant upright could increase the risk of head impact injuries from loose objects. (21) Studies also show that airbags and upper torso restraint systems are not effective in preventing upper- and lower-extremity injuries. (22)

**Insufficient Vertical Energy Absorption**

The femur fracture in case 1 resulted from a bending load. After an airplane crash in England, Brownson et al identified the front cross tube of the seat to be a fulcrum on which the femur breaks when the leg is forced down during forward flailing. (23-25) In our study population there were two additional femur fractures that could have been caused by the same trauma mechanism.

The lumbar spine fracture (L5) in Case 2 occurred in a seat place that had little to no vertical energy-absorbing capability. The centre place of a typical triple place seat is well supported by structure, whereas the end places are free to deflect downward as vertical loading increases. This downward deflection is likely to be the reason that Case 1 did not have a spinal fracture, even though that seat place received the same or greater vertical loading as the Case 2 seat place (based on the amount of vertical deformation observed). For the centre place, the only features available to absorb or control energy are the seat pan and seat cushion. Conventional seat cushions tend to amplify loads rather than absorb them, which leaves the energy absorbing function to the seat pan. (26) The deformation observed in the cantilevered seat places in the front of the aircraft were indicative of vertical loading in excess of the 14 CFR Part 25.562 Emergency Landing Conditions, so the frequency of spine injuries in this area of the aircraft is not unexpected. However, in other areas where seat deformation indicated vertical loading was less than in the forward section, there were also many occupants with spinal injuries. Among the 23 thoracolumbar spinal injuries throughout the cabin, 14 had a burst fracture pattern consistent with axial loading of the spine. (Ref: Unpublished data: Spinal Injuries in an Airplane Crash; I.L.E. Postma, et al.) Some of these injuries may have been prevented if the seats had provided more vertical energy absorption.

**Floor and Seat Deformation**

Floor deformation and disruption often occur in aircraft crashes and can cause seats spanning the distorted sections to become detached. This occurrence is prevalent enough that current aircraft seat safety standards (the 16-g seat rule) require that seats accommodate some distortion without failure. A benefit analysis of the 16-g seat rule by the U.S. Federal Aviation Administration and the UK Civil Aviation
Authority determined that in some accidents the use of dynamically qualified seats offer no benefit in terms of decreasing injury or fatality if there is extensive floor deformation. (4) In this crash, most seats remained attached, even in cabin areas where the distortion was beyond the level applied in seat qualification tests. However, in addition to creating a seat structural integrity risk, the significant amount of floor distortion and disruption that occurred in the front portion of the cabin also caused a direct injury risk by applying a vertical load to the occupants’ legs. Studies show that pure axial loading on the foot/ankle complex is more likely to result in calcaneal fractures, but with added Achilles tendon tension, distal tibia fractures result. (27; 23) In MVA, Achilles tendon tension is thought to be the result of bracing for impact and braking with the foot pedal. In the case of airplane crash victims, extensive floor deformation could have caused the same injury mechanism. Intra-articular distal tibia fractures, like in cases 1 and 2, can cause significant impairment. Eighteen (14%) surviving occupants of the crash suffered in total 30 lower extremity fractures or ligamentous injuries. A major injury to a lower extremity could prevent an occupant from evacuating the airplane, which in a post-crash fire, could become fatal. In our study population, we found 6 patients with 8 tibia fractures that could have resulted from an axial load, and 3 patients with 4 tarsal fractures (talus, calcaneus and navicular) that were consistent with an axial load. These findings indicate that aircraft floor designs that limit the amount of floor distortion not only reduce the risk that seats will be detached, but can also reduce the risk of leg injuries.

Comparison with Previous Crash Investigation Findings

In 1995 and again in 2009, R.G.W. Cherry & Associates Limited, a consultancy company formed from widely experienced aeronautical engineers carried out a study, on behalf of the European Aviation Safety Agency, on the potential benefits of structural design changes that could improve passenger safety in aircraft accidents. (28) Some of the “Cabin Safety Threats” cited in that report that could lead to injuries are: 1) detached overhead bins and cabin equipment, 2) seat detachment, 3) floor deformation, 4) seatbelt failure, and 5) leg contact with structure resulting in lower-limb injuries. These threats coincide with some of the injury causation mechanisms we identified in this study. Findings from our study and from previous studies of similar accidents (absence of fire and toxic fumes, lack of brace position before impact) suggest that these identified injury risks may be typical for survivable aircraft crashes and are not unique to this specific crash.
Limitations

Although seat and aircraft damage information was available for all locations, lack of autopsy data for the fatally injured did not permit determination of the possible causes of those injuries. The injuries were coded using the 1998 version of the AIS. The injury codes and severity levels of some injuries have changed slightly in the latest (2008) version. Use of the older version does not allow direct comparison of this data set with the latest accident data that utilize the 2008 version. The injury causation findings in this study were deduced from the likely occupant motion induced by the apparent major impact vector and the seat/aircraft damage observed. Advanced computer modelling techniques could be used to analyse the entire crash sequence, and to estimate the acceleration time history for each seat place. This information could be used as an input to detailed aircraft seat/interior/occupant models designed to directly evaluate injury potential. Once calibrated using the documented injuries and damage, these models could show the most likely occupant/aircraft interior interactions that took place throughout the impact sequence and estimate the contact forces. This additional knowledge would increase the confidence level for many of the injury causation determinations.

Conclusions

This pilot study focused on the causes of the injuries sustained during a severe but survivable aircraft crash. While the study focused on some of the most seriously injured passengers, it should be noted that, considering the overall severity of the crash, a significant number of passengers (70%) had only minor to moderate injuries (ISS 0-8). While anecdotal, this statistic is an indication of the level of safety afforded by the current aircraft and seat system designs. In examining the causes of the injuries, four areas were identified where improvements could be made to reduce the risk of some of the observed injuries. These areas are: 1) preventing or reducing the severity of head injuries by improving the security of objects above the head; 2) preventing some spine and chest injuries caused by forward flailing by incorporation of upper torso restraint, such as a shoulder harness, or inflatable restraint; 3) preventing or reducing the severity of lumbar and thoracic spine injuries by increasing the amount of vertical energy absorption provided by each seat; 4) preventing or reducing the severity of some leg injuries by limiting the amount
of floor distortion that occurs during a crash. Previous comprehensive studies of relevant accidents have identified many of the same injury causation factors as prevalent in other crashes. Incorporation of improvements in these areas are likely to require further research to implement and to ensure that they do not introduce any new injury mechanisms.
References
Chapter 10

