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Accident Analysis and Prevention 35 (2003) 571–577

ACCIDENT ANALYSIS & PREVENTION

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# Analysis of injuries among pilots involved in fatal general aviation airplane accidents

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Received 5 January 2002; received in revised form 4 March 2002; accepted 8 March 2002

## Abstract

The purpose of this study was to analyze patterns of injuries sustained by pilots involved in fatal general aviation (GA) airplane accidents. Detailed information on the pattern and nature of injuries was retrieved from the Federal Aviation Administration's autopsy database for pilots involved in fatal GA airplane accidents from 1996 to 1999. A review of 559 autopsies revealed that blunt trauma was the primary cause of death in 86.0% ($N = 481$) of the autopsies. The most commonly occurring bony injuries were fracture of the ribs (72.3%), skull (55.1%), facial bones (49.4%), tibia (37.9%) and pelvis (36.0%). Common organ injuries included laceration of the liver (48.1%), lung (37.6%) heart (35.6%), and spleen (30.1%), and hemorrhage of the brain (33.3%) and lung (32.9%). A fractured larynx was observed in 14.7% of the cases, a finding that has not been reported in literature until now. It was observed that individuals who sustained brain hemorrhage were also more likely to have fractures of the facial bones rather than skull fractures.



*Keywords:* Aircraft accidents; Injuries; Autopsy; Crashworthiness

## 1. Introduction

Civil flights (non-military) in the United States (US) are classified as either general aviation (GA) or air carrier operations. GA activities include recreational flying, flight instruction, agricultural operations, sightseeing, and business travel (Li and Baker, 1999). The aircraft involved in GA flying may be piloted by a variety of people with a valid pilot license and medical certificate, but belonging to a wide range of age groups. The aircraft could be airplanes, helicopters, balloons, or gliders.

Each year, the National Transportation Safety Board (NTSB) records about 2000 GA crashes, which claim about 750 lives (National Safety Council, 1997). There has not been any significant decline in these numbers in the past decade. Between 1990 and 1996, GA accounted for 93% of all aviation crashes and 78% of all aviation fatalities. The fatal crash rate per 100,000 flight hours for GA is more than eight times that for air carriers and has also not improved in the past decade (National Safety Council, 1997). It is a widely held belief that the inherent diversity of flight activities, aircraft types and pilot characteristics makes the task of GA safety a difficult and challenging one.

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Investigation into an aircraft accident, while primarily aiming to determine the cause of the accident, also aims to determine the cause and nature of injuries sustained by the occupants. While the former aids in preventing the recurrences of accidents, the latter serves manifold purposes. An analysis of injuries sustained in an aircraft accident assists in determining the mechanism of injury, whether they were preventable, and if preventable, what aspects of the aircraft design or environment caused those injuries. This information eventually guides future issues of crash survivability and helps establish crashworthiness design standards (Desjardins et al., 1979).

Crash survivability and crashworthiness issues generally have received much more attention in military aviation than GA operations and have distinctly influenced crash dynamic patterns and most probably altered injury patterns as well (Shanahan and Shanahan, 1989). Research into correlates of pilot fatalities in GA reveals that the most important correlates are variables related to impact forces. Research also indicates that aircraft fire is an important factor threatening occupant survival in air carrier crashes (Davis et al., 1997; Krebs et al., 1996; Li and Baker, 1993; Pane et al., 1985) and that about 20% of aviation deaths are preventable given the use of better restraint systems (Li and Baker, 1997; Lillehei and Robinson, 1994). A recent study comparing injuries across various categories of aircraft observed that

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PII: S0001-4575(02)00037-4

there were fewer injuries to the upper body in accidents involving fixed wing than the rotary wing aircraft (Chalmers et al., 2000). Li and Baker (1999) found a case fatality ratio of 22% for GA crashes compared to 4% (Davis et al., 1997) for major airlines and 17% for commuter aircraft and air taxi (Li and Baker, 1993). These findings underscore the need to improve the crashworthiness of GA aircraft as the differences in the kinematics of the aircrafts is unlikely to explain these differences (Li and Baker, 1999).

Unfortunately, aircraft accident reports published by the NTSB are strikingly devoid of information on the nature of crash forces involved in accidents, the description of integrity of the structure, and analysis of restraint systems. In fact, several studies have indicated that this information has not been available in a large percentage of accident reports (Li and Baker, 1999). Nonetheless, autopsy reports do contain information on the nature and extent of injuries sustained by the occupants that can provide valuable insights into the pattern and mechanism of injuries in fatal aircraft accidents. Autopsy reports for US civil aviation accidents are maintained at the Civil Aerospace Medical Institute (CAMI), which is a branch of the Federal Aviation Administration in Oklahoma City, OK.

To date few studies have been conducted to examine the types of injuries sustained in fatal GA accidents. As stated earlier, analysis of injuries can guide crashworthiness design standards. However, to be effective, crashworthy design standards need to be constantly updated to represent accurately the current crash environment, both in the military and civil environment. This can only be accomplished by an accurate and timely information gathered and analyzed from crash investigations and injury patterns. The purpose of the present study, therefore, was to analyze the nature and severity of injuries in GA airplane accidents and their relation, if any, with aircraft and environmental factors.

## 2. Method

Autopsies are performed on pilots involved in fatal civil aviation aircraft accidents in the US by the local medical authority under whose jurisdiction the accident occurred. These reports are then forwarded to the Medical Statistical Section at CAMI. We analyzed these autopsy reports for pilots involved in fatal fixed wing airplane accidents operating under Code of Federal Regulations (CFR) Title 14, Part 91 from 1996 to 1999. A total of 559 autopsies of pilots involved in 498 accidents were analyzed. For the corresponding period, there were 1121 fatal GA accidents, which yield an autopsy-reporting rate by local medical authorities of about 44%.

The autopsy report contained information on the age of the pilot, type of aircraft and a description of injuries classified according to the body region/organ system. The available information in the database was used without any modification to the nature or severity of injuries. The corresponding accident database maintained by the NTSB was used to access information on aircraft and environmental factors.

## 3. Results

### *3.1. External cause of death/primary cause of death*

The autopsy database has two fields, one for the primary cause of death as attributed by the medical examiner performing the autopsy and the other for the secondary cause of death, if any. Blunt trauma, implying polytrauma was attributed as the primary cause of death in 86.0% ($N = 481$) of the cases. The next highest were thermal burns (3.9%, $N = 22$) and drowning in 3.6% ($N = 20$) of the cases. Exsanguination and inhalation of smoke and toxic gases were each responsible for 2.0% ($N = 11$) of the cases. Cardiovascular (1.1%, $N = 6$), asphyxia (0.2%, $N = 2$), hypoxia (0.1%, $N = 1$) and suicide (0.1%, $N = 1$) were cited as the primary cause in other autopsies. The primary cause of death was undetermined/not available in 0.8% ($N = 4$) cases.

### *3.2. Nature of injuries*

#### *3.2.1. Bony and organ injuries*

The five bony injuries that were present in most of the autopsies are shown in Fig. 1. Fracture of the ribs was the most common (72.3%) followed by fracture of the skull (55.1%), facial bones (49.4%), tibia (37.9%), and pelvis (36.0%). The most commonly occurring organ injuries are shown in Fig. 2. These included lacerations of the liver

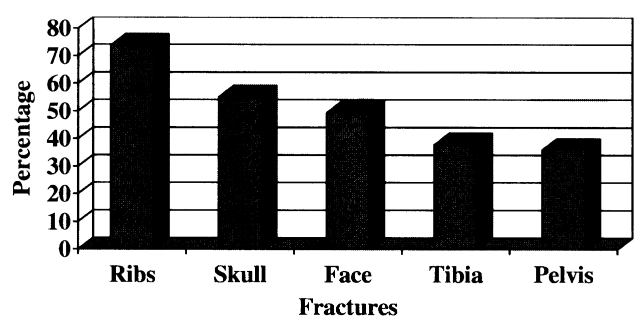



Fig. 1. Percentage of common bony injuries present in autopsy reports.

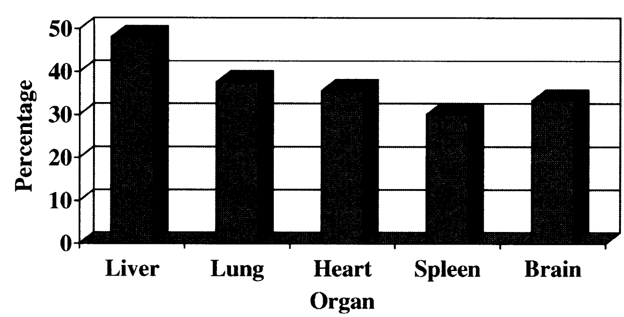



Fig. 2. Percentage of common organ injuries.

Table 1
Injuries to the head and neck region[a]

| Type of injury | Percentage | Number |
|---|---|---|
| Brain injury (all categories) | 61.4 | 343 |
| Cervical fracture | 19.9 | 111 |
| Facial bone fracture | 49.4 | 276 |
| Head laceration | 26.3 | 147 |
| Laceration face | 38.5 | 215 |
| Larynx fracture | 14.7 | 82 |
| Skull fracture | 55.1 | 308 |

[a] The numbers and percentages represent the number of autopsies with the above injuries.

(48.1%), lung (37.6%) heart (35.6%), and spleen (30.1%), and hemorrhage of the brain (33.3%) and lung (32.9%). It was observed that individuals who sustained brain hemorrhage and laceration were also more likely to have facial bone fractures [$\chi^2$ ($N = 559,1$) = 7.415, $P < 0.025$] and [$\chi^2$ ($N = 559,1$) = 25.810, $P < 0.001$], respectively. These relationships remained when cases involving only mandible fractures ($N = 39$) were excluded from the analyses. Surprisingly, there was no statistically significant relation between skull fracture and brain hemorrhage. Fracture of the ribs was significantly associated with laceration of the liver [$\chi^2$ ($N = 559,1$) = 61.847, $P < 0.001$], laceration of the lung [$\chi^2$ ($N = 559,1$) = 44.593, $P < 0.001$], laceration of the spleen [$\chi^2$ ($N = 559,1$) = 23.618, $P < 0.001$], kidney laceration [$\chi^2$ ($N = 559,1$) = 16.194, $P < 0.001$], and diaphragm rupture [$\chi^2$ ($N = 559,1$) = 20.913, $P < 0.001$].

### *3.2.2. Traumatic injuries by body region*

Tables 1–6 tabulate significant injuries to various body regions. In the autopsy database, different categories of injury patterns exist for a single organ such as laceration, rupture, hemorrhage etc. Injuries of varying severity to a single organ (e.g. laceration, rupture, hemorrhage) have been combined to make more meaningful patterns.

Table 2
Injuries to the thorax region[a]

| Type of injury | Percentage | Number |
|---|---|---|
| Aortic injury (all categories) | 41.9 | 234 |
| Heart injury (all categories) | 47.2 | 264 |
| Lung injury (all categories) | 58.0 | 324 |
| Rib fracture | 72.3 | 404 |
| Sternum fracture | 28.4 | 159 |

[a] The numbers and percentages represent the number of autopsies with the above injuries.

Table 3
Injuries to the abdomen[a]

| Type of injury | Percentage | Number |
|---|---|---|
| Abdominal laceration/hemorrhage | 24.0 | 134 |
| Kidney laceration | 11.3 | 63 |
| Liver injury (all categories) | 52.9 | 296 |
| Pelvis fracture | 36.0 | 201 |
| Spleen injury (all categories) | 32.8 | 183 |
| Urinary bladder (all categories) | 7.8 | 44 |

[a] Values are based on the number of autopsies with the above injuries.

Table 4
Injuries to the spine[a]

| Type of injury | Percentage | Number |
|---|---|---|
| Cervical fracture | 19.9 | 111 |
| Lumbar fracture | 1.6 | 9 |
| Sacral fracture | 1.8 | 10 |
| Thorax fracture | 27.2 | 152 |

[a] Values are based on the number of autopsies with the above injuries.

Table 5
Injuries to the upper extremities[a]

| Type of injury | Percentage | Number |
|---|---|---|
| Clavicle fracture | 16.1 | 90 |
| Humerus fracture | 23.6 | 132 |
| Radius fracture | 20.0 | 112 |
| Ulna fracture | 21.3 | 119 |
| Upper extremities fracture | 17.6 | 96 |
| Wrist fracture | 10.2 | 57 |

[a] Values are based on the number of autopsies with the above injuries.

Of the injuries to the head and neck region, fracture of the skull (55.1%) and facial bones (49.4%) were predominant with injuries to the brain in the form of avulsion, laceration, contusion or brain stem transection occurring in 61.4% ($N = 343$) of the cases. As mentioned earlier, these injuries to the facial bones may or may not have had concomitant injuries to the mandible. Injury to the mandible alone was present in 7.0% ($N = 39$) cases. The head was decapitated in 2.9% ($N = 16$) of the cases. Fracture of the larynx was observed in 14.7% ($N = 82$). Fracture of the larynx was significantly related to fracture of the facial bones [$\chi^2$ ($N = 559,1$) = 19.597, $P < 0.001$]. However, pilots who had a cervical fracture were less likely to have a fracture of the larynx [$\chi^2$ ($N = 559,1$) = 10.315, $P < 0.001$].

The thoracic region tended to bear a large brunt of the crash forces. While fractures of the rib bones rank the highest as a single descriptive injury (72.3%), all categories of injuries to the lungs when combined (58.0%, $N = 324$) were also large. Injury to other intrathoracic organs like the heart and aorta were also high (47.2 and 41.9%, respectively).

Table 6
Injuries to the lower extremities[a]

| Type of injury | Percentage | Number |
|---|---|---|
| Amputation above knee/below knee | 7.9 | 44 |
| Ankle fracture | 19.1 | 107 |
| Femur fracture | 33.1 | 185 |
| Fibula | 31.8 | 178 |
| Foot amputation/fracture | 11.8 | 10 |
| Lower extremities fracture | 21.6 | 121 |
| Pelvis fracture | 36.0 | 201 |
| Tibia fracture | 37.9 | 212 |

[a] Values are based on the number of autopsies with the above injuries.

In the abdominal region, as expected based on the anatomical size and location, injuries to the spleen (32.8%, $N = 183$) occurred less often than the injuries to the liver (52.9%, $N = 296$). Fracture of the pelvis was reported in 36% ($N = 201$) of the cases; urinary bladder damage was reported in only 7.8% ($N = 44$) of the cases. Injury to the gastrointestinal system in the form of hemorrhage, laceration or avulsion was reported in 16.4% ($N = 97$) of cases.

The lower extremities appeared to be injured much more than the upper. Cases involving fractures of the tibia (37.9%, $N = 212$), femur (33.1%, $N = 185$) and fibula (31.7%, $N = 178$) were more in number than cases involving fractures of the humerus (23.6%, $N = 132$), radius (20.0%, $N = 112$), and ulna (21.3%, $N = 119$). Amputations of the arm and hand, as well as the lower extremities were also observed.

Injuries to the spine also occurred in several cases. Fractures of the thoracic spine were the highest at 27.2% ($N = 152$) followed by the cervical spine (19.9%, $N = 111$). Fractures of the lumbar spine were reported in only 9 cases (1.6%) and sacral spine in 10 cases (1.8%).

### 3.2.3. *Thermal injuries*

Thermal injuries in the autopsy database have been classified as thermal burns 1 and 2. Thermal burns 1 are burns sustained ante-mortem and were present in 7.7% ($N = 43$) of the cases, whereas post-mortem burns (thermal burns 2), implying those sustained after the pilot had died, were present in 24.3% ($N = 136$) of the cases.

## 3.3. *Crash and environmental conditions*

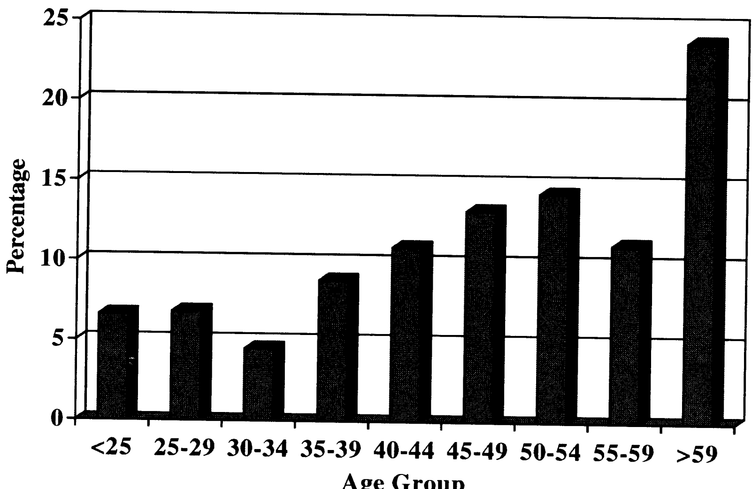
All the aircraft included in this analysis were fixed wing airplanes and over 100 different types of aircraft were included in the database. However, Cessna aircraft was involved in 28.1% ($N = 140$) of the cases, followed by Piper and Beech, with 20.6% ($N = 103$) and 11.6% ($N = 58$), respectively. Table 7 list the various injuries associated with each airplane type. As can be seen from this table, the distribution of injuries was similar across airplanes. Indeed, $\chi^2$-analyses comparing injuries across airplane type did not reveal any significant differences in the distribution of injury patterns across airframes.

Table 7
Distribution of injuries across different airplanes[a]

| | Beech ($N = 58$) | Cessna ($N = 140$) | Piper ($N = 103$) | Others ($N = 197$) |
|---|---|---|---|---|
| Bony injuries | | | | |
| Facial bone | 25 (43.1) | 79 (56.4) | 41 (39.8) | 100 (50.8) |
| Tibia | 22 (37.9) | 56 (40.0) | 36 (35.0) | 74 (37.6) |
| Skull | 30 (51.7) | 78 (55.7) | 53 (51.5) | 110 (55.8) |
| Rib | 42 (72.4) | 103 (73.6) | 65 (63.1) | 144 (73.1) |
| Pelvis | 23 (39.7) | 47 (33.6) | 32 (31.1) | 74 (37.6) |
| Visceral injuries | | | | |
| Spleen laceration | 17 (29.3) | 46 (32.9) | 31 (30.1) | 55 (27.9) |
| Lung hemorrhage | 17 (29.3) | 43 (30.7) | 33 (32.9) | 76 (38.6) |
| Lung laceration | 21 (36.2) | 57 (40.7) | 37 (35.9) | 75 (38.1) |
| Liver laceration | 27 (46.6) | 72 (51.4) | 43 (41.7) | 92 (46.7) |
| Heart laceration | 21 (36.2) | 47 (33.6) | 32 (31.1) | 73 (37.1) |

[a] Values are based on the number of accidents involving each airplane type in which one or more of the above injuries occurred (values shown in parentheses are in percent).

Almost one half of the accidents occurred during either the maneuvering (24.3%, $N = 121$) or cruise (24.1%, $N = 120$) phase of flight. A total of 15.7% ($N = 78$) of the accidents occurred during take off and 5.4% ($N = 27$) during climb phase. Besides these, 13.9% ($N = 69$) accidents occurred during the approach, 7.25% ($N = 36$) during descent, and 4.8 % ($N = 24$) during the landing phase. There was one accident each during the standing and taxiing phases. Phase of flight information was not available in 4.2% ($N = 21$) of the cases. There was no correlation between the nature of injuries and cause of death and phase of flight. Information on the use of shoulder harness was not available in a high percentage of cases (39%) and hence, was not utilized for analysis.



### 3.4. Demographic information

Approximately 95.3% of the pilots in this autopsy database were males. The age distribution of these pilots is given in Fig. 3. Approximately one quarter of the pilots ($N = 133$) were 60 years of age or more. Only 6.6% ($N = 37$) of the pilots were less than 25 years of age. However, there was no relation between age and the distribution of major injuries.

## 4. Discussion

The decelerative forces involved in aircraft crashes can produce a wide range in severity and pattern of injuries (Hill, 1989). Therefore, it comes as no surprise, that the primary mechanism of death in the fatal accidents examined in this study was blunt trauma in 86% of the cases. This finding also corroborates results obtained in earlier studies indicating that a majority of aviation fatalities in both the US (Li and Baker, 1997) and other countries (e.g. Germany, Ast et al., 2001) are due to blunt trauma.

Mechanical injuries arising from aircraft crashes, however, may be classified into either acceleration or contact injuries (Shanahan and Shanahan, 1989). Both forms of injury arise from application of force to the body through an area of contact with an accelerating surface. In the case of acceleration injury, the application is more distributed so that the site of force application usually does not receive a significant injury. The site of injury is distant from the area of application and is due to the body's inertial response to the acceleration. A contact injury, on the other hand, occurs when a localized portion of the body comes into contact with a surface in such a manner that injury occurs at the site of contact (the secondary contact). This could occur either by crushing within a collapsing airframe, entrapment within the wreckage, absence or failure of a restraint or being struck by loose objects. A mixed form of injuries may also occur.

The above discussion on the possible origin and mechanism of injury causation in crashes helps in understanding the differing patterns of injuries evident in this data. Fractures of the skull appear to be primarily a contact injury due to collapsing structure, intrusion of high mass items (transmission, engines), flailing of the head and upper torso, or a combination of the above. Surprisingly, no significant relation was observed between skull fractures and injuries to the brain. On the other hand, a statistically significant relation was observed between fracture of the facial bones (excluding the mandible) and hemorrhage of the brain.

Conflicting theories exist on the role of the mid-face in crash dynamics. It is generally believed that the mid-face is designed to absorb impact (acts as a cushion) and protect the cranial structures (Lee et al., 1987). Haug et al. (1994), on the contrary, concluded that the mid facial bones appear to transmit the force of impacts directly to the cranium and result in increased injuries to the cranium. The relationship between facial bone fractures and brain hemorrhage observed in this study appears to support this latter theory. However, injuries to the brain are also possible in the absence of any bony injury to the head and face. Head injury could, in itself, be fatal or severely impair the ability of the injured pilot to escape from the post crash environment and hazards like fire, and hence, deserves utmost attention in any strategy to improve crashworthiness.

Currently there are no regulations mandating the use of flight helmets in GA flying. However, head injuries can often be prevented or their severity reduced by the use of some protective headgear. Helmets by distributing the impact load and preventing skull deformation can increase the skull tolerance to linear acceleration to the 300 G level (Glaister, 1999). Moreover, avoidance of even transient concussion allows the pilot to extricate himself promptly in the event of a post crash fire. However, the issue of full-face protection to minimize the transmission of energy from the mid-face to the brain/cranium needs further research and validation.

Of interest is also the presence of a fractured larynx in 14.7% of the cases. Such a high incidence has not been reported previously in the literature. The positive association between larynx and facial bone fractures and its negative relation with cervical fractures seems to suggest the mechanism of this injury. It is possible that contact injury may be the mechanism of both facial bone and laryngeal trauma, whereas, cervical fracture may be occurring because of a sudden flexion injury, in the process, protecting the larynx from a contact injury.

The thorax was the second most common site of injury observed in this study. Injuries to the ribs, sternum and the intra thoracic contents constitute a large percentage of injuries in these fatalities. Compression of the chest and penetration of viscera by broken ribs and/or the sternum, together with foreign bodies have been considered the primary attributable causes of injury here, but evidence suggests that there may be more complex factors involved. Physiological changes due to acceleration may also induce injury. With the lungs being the most superficial in the thoracic cavity, it comes as no surprise that the lung was found injured in 58% of the autopsies. On the other hand, even though the human heart is relatively safely embedded in the thorax, it is, nevertheless, exposed to various influences during the accident sequence. Jolt like forces acting on the occupant and flailing injuries to the thorax may cause concussions, contusions or cordal compressions to the heart with resulting morphologic and functional alterations (Hill, 1989).

There has always been great concern about the availability and use of a restraint system in an aircraft and the protection it provides. However, this information was not available in 39% of the cases, and hence did not provide enough reliable information for statistical conclusions. Protective effects of shoulder restraints have been reported in studies of commercial aircraft and air taxi crashes (Krebs et al., 1996, Li and Baker, 1993). The restraint system attempts to maintain the occupant within a known volume so that the crash dynamics may be attenuated, and movement of the occupant restricted to avoid secondary impacts with equipment such as displays and controls. Impact protection using air bags is also becoming more common, at least in the automobile industry and appears to have a place in aircrafts too (Li and Baker, 1999). Under appropriate acceleration loads, the bag inflates and provides a soft structure that absorbs energy. Air bags, however, are elements of a restraint system, and do not replace the need for a harness.

The abdominal organs sustained a wide range of injuries. Hill (1982) has postulated various possible mechanisms for injury to the intra-abdominal organs. Direct compression of the viscera does undoubtedly occur and may remain the primary mechanism of intra-abdominal injury. Shear waves may compress organs if the waves are of sufficient intensity and rotational forces can displace the organs into a position where they may be compressed. The fact that the incidence of lacerations to both the liver and spleen were statistically related to fractures of the ribs seems to suggest that impactment by broken rib edges may be a primary mechanism of injury to these intra-abdominal organs.

Lau et al. (1987) concluded from their automobile studies that by varying steering wheel stiffness, orientation and column angle, resultant abdominal injuries could be reduced from fatal or critical to minor or none, with wheel stiffness being the primary determinant of abdominal injury severity. They also concluded that wheel stiffness, not column characteristics, were the primary determinants of steering system-induced injury. Comparison of injuries sustained to the liver and kidneys during airplane accidents with those sustained in helicopter accidents might provide additional insights into these issues, given the dramatic difference in the types of yoke and control wheels found in these aircraft. However, basic research is still needed to examine the injury-causing potential of various steering wheel characteristics in all aircraft.

Finally, the incidence of ante-mortem burns (7.3%) is also consistent with those reported in the literature. Burns were found to be the primary cause of death in 4.3% of helicopter accidents in the US from 1980 to 1985 (Conroy et al., 1992). Li and Baker (1997) also reported burns as a cause of death in 4% of US aviation fatalities.

A comment should also be made concerning the overall completeness of the autopsy data used in this study. As mentioned earlier, the autopsy reports examined here were from 498 out of a possible 1121 fatal accidents occurring from 1996 to 1999, indicating an autopsy-reporting rate of about 44%. Ast et al. (2001) reported a slightly higher autopsy-reporting rate of 50% in fatal aircraft accidents in Lower Saxony (Germany) for a 15-year period. Aviation authorities in US have expressed concerns about the low percentage of autopsy reports reaching CAMI, despite the existence of federal guidelines that state specific procedures for submitting these reports (Booze, 1989). The findings obtained from autopsies can be essential for reconstructing the accident sequence, as well as assessing crashworthiness issues. Their rates should therefore be increased. Nevertheless, given that the type of aircraft in the GA fleet has remained relatively unchanged in the last two decades, it is reasonable to assume that despite the low autopsy rate, the data reported here is a fair representation of general injury patters.

Basic theoretical principles of crashworthiness would point at three basic strategies at making crashes more survivable. Providing means of attenuating the energy of a crash before it can be transmitted to an individual prevents acceleration injury. This method has been employed to prevent vertebral injuries in crashes of Black Hawk helicopters in the US Army (Shanahan and Shanahan, 1989) by providing energy attenuating landing gear and seats. However, analysis of injuries in the data reported here, suggests that contact injuries may be more of a concern than acceleration injuries. Indeed, Shanahan and Shanahan (1989) reported that contact injuries exceeded accelerative injuries by a ratio of approximately five to one. If potentially fatal injuries to the head (contact injuries) and the extremities (contact/flailing) are to be minimized, there is a distinct need for further development in the areas of improving restraint systems and reducing strike hazards in the cockpit and cabin. Crash activated inflatable restraint systems (air bags) placed strategically within the cockpit and cabin may be one viable option. However, a thorough understanding of potential injury mechanisms as well as the impact-environment in GA operations is required. This will be possible when crash investigators document crashworthiness factors and identify sources of injuries. It is only then that a realistic assessment of the protective mechanism can be thoroughly evaluated.

## Acknowledgements

This work was supported in part by a grant from the Federal Aviation Administration (DTFA 99-G-006). A grant from the RD Birla Smarak Kosh, Mumbai, India was also given to the second author. The views expressed in this article are those of the authors and do not necessarily reflect those of the FAA.

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