LS-208

INJURY PREVENTION IN AIRCRAFT CRASHES: INVESTIGATIVE TECHNIQUES AND APPLICATIONS.

GENERAL CONCEPTS AND OBJECTIVES.

Francisco Rios Tejada MD, PhD
Major SPAF, MC
CIMA. Arturo Soria 82, 28027 Madrid. SPAIN

INTRODUCTION.

For years an ongoing biomedical and crash injury field aircraft investigation and research have been conducted by a large variety of agencies taking advantage of the current experience developed from the automobile industry.

Accidents were investigated to reveal any of the wide range of human factors such as underlying illness, use of medications or drugs, fatigue, physical stresses, psychological and psychosocial stresses, types and extension of injuries received, causes of impact injuries, emergency escape from the aircraft, smoke and fire as related to survivability, environmental conditions and a number of other biomedical conditions that may have contributed to the crash or be related to occupant injury or survival.

A detailed analysis of injury sustained in aircraft impact would contribute to an understanding of the mechanisms involved and to know the design limitations of the human body to an impact and its survivability. While many similar injuries can be inflicted in a variety of ways, there are certain characteristic findings which suggest likely mechanisms of injury. For example, compression fractures of vertebral bodies in the low thoracic and lumbar spine typically occur as a consequence of forces acting approximately parallel to the long axis of the spine. Similarly, a typical finding in light-aircraft accidents involves blunt trauma applied to the head affecting the face predominantly and typically resulting from striking the head against a control wheel, instrument panel, console or other cockpit structure. These face and head injuries suggest

Paper presented at the AGARD AMP Lecture Series on "Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications", held in Farnborough, UK, 24-25 November 1997, and Madrid, Spain, 1-2 December 1997, and published in LS-208.

mechanisms that occur independently of seat performance unless the back of a forward seat serves as a contact point for a rear passenger.

Aircraft medical investigation techniques related to aircraft accidents have been identified as an area of major concern by AGARD, and a monographic symposia was dedicated in 1992 to various aspects related to human factors, occupant injury, dynamic response, data analysis, injury and aircraft prevention and accident pathology. The Technical Evaluation Report (TER) of this conference recommended future education and training programmes dealing with specific topics related to accident investigation (1).

In 1990, 819 persons died in 2180 aviation crashes in the United States (2). Data regarding epidemiologic studies of pilot-related factors are needed to identify various risk factors of aircraft crashes (accident or incident). Those studies are of paramount relevance, but they must be done in conjunction with developments in crashworthiness research (3). Many accident investigators have reported that 70% to 80% of all deaths and injuries in crash decelerations are from face and/or head injuries caused by body flailing and head striking surrounding structures (4). Survival of an aircraft accident depends to a great extent on providing a crash-resistant container for the occupants, that is, an occupiable area that will withstand crash forces without crushing, collapsing, or disintegrating, and features such as the deformation of aircraft cockpit and cabin structures, the state of integrity and probable function of seats and restraint systems, probable impact of occupants against aircraft structures and the correlation of injuries with the direction and severity of impacts. Direct consequences of the investigation should lead to specific changes that may improve crashworthiness of the respective aircraft and in addition, significant operational lessons were drawn, and which, by application of what was learnt, led to greater safety (5).

According to Shanahan (6) any effort in order to improve in-flight escape systems and better occupant protection against crash injury requires not only a thorough knowledge of the environment to which an occupant may be exposed in the event of an ejection or crash, but also an understanding of how much force a human can be expected to withstand in a given situation.

Personnel involved in the process of aircraft investigation must have an understanding of the basic principles of crash survivability.

A. Coordinate systems:

1. The aircraft and aircrew have corresponding coordinate axes, Roll (x), Pitch (y) and Yaw (z).
2. Force and acceleration are vector quantities and have both magnitude and direction.
3. Any applied force may be broken down according to its components directed along each of the three perpendicular axes.

B. Acceleration.

1. A key consideration in acceleration injury is the body's inertial response to an acceleration which is opposite and equal to the applied acceleration.
2. Acceleration may be described in G units.
3. Crash forces may be thought of as multiples of the weight of objects being accelerated.
4. A crash pulse is the time history of an applied force or acceleration and may be thought of as triangular in shape for this purpose:

$$\text{Peak G} = \frac{v^2}{32.2 \times \text{stop distance}}$$

C. A crash is considered survivable if:

1. The forces transmitted to the occupants do not exceed the human tolerance.
2. The structure around the occupants maintains a livable volume throughout the crash sequence.

D. Crashworthiness assessment:

The overall crashworthiness capability in terms of airframe load factors, crash resistance of seats and fuel systems and emergency egress provisions imply a human tolerance to abrupt acceleration which is function of:

1. Magnitude of the acceleration.
2. Direction of the acceleration.
3. Duration of acceleration.
4. Onset rate.
5. Design and characteristics of the support and restraint systems.

Snow and al.(7) stated that survival and escape from a crashed aircraft, potentially in flames is a question of time, indeed most of the time no more than a few seconds, and this short period of time must be used in identifying the safest exit by overpassing numerous hazards, any of which might endanger the life of the crew or the passengers, i.e., smoke, fire and flames, blocking debris and physical barriers as a consequence of the impact. In addition to these extrinsic factors, their chance of survival is also influenced by physical and mental attributes of their own that may enable, or prevent, effective exploitation of the short time they have remaining.

Several factors might be involved and definitively influence the escape of passengers from a crashed aircraft or any emergency evacuation. These factors (7) may be grouped as:

1. Configurational:
Such as standard features of occupant environment controlling access to exits and evacuation flow rates. Seat size, seating density, number, location, indication and width of exits and cabin structure resistance to impact (seats and pins) could influence design factors.

2. Procedural:
Appropriate regulations regarding training among the aircrew and rescue personnel. New technologies such as virtual reality and advanced fire simulators will help in coping with procedural factors involved in emergency escapes from an aircraft.

3. Environmental:
Special features, such as the production of toxic fumes might greatly influence the evacuation procedures.

4. Biobehavioral:
Human behavior under conditions of extreme

physical and emotional stress should be considered, as well as biological, psychological and cultural attributes of individual passengers which influence agility and behavior. Sex, age, physical condition, experience, careful attention to emergency procedures briefing and mental agility can be taken as key behavioral factors.

OBJECTIVES.

This Lecture Series was developed to fulfill the technical training needs related to Injury Prevention in Aircraft Crashes of AGARD Aviation Medicine personnel involved in the investigation of the medical and pathological aspects of aviation accidents.

Objectives of this course are to:

1. Identify and understand the aspects related to impact effects and the accelerative force involved in an aircraft accident.

2. Provide support and assistance in the analysis of the mechanisms involved in the injury and death of aircraft occupants.

3. Collect and analyze medical and pathological data to support the determination of the factors that may play a definitive or contributory role in the accident.

4. To understand the application of injury analysis data to better research in protection and on scene accident safety escape.

Purpose of this Lecture Series was to address a critical aspect of the investigation related to the factors used in the prevention of potential injuries among the occupants as a consequence of the impact and post-crash fire, heat and toxic fumes.

CONTENTS.

This Lecture Series compiles a review of critical aspects of injury prevention.

First of all, we describe the acceleration vectors involved and how they may have an influence on the aircraft. Secondly, we discuss how the acceleration forces might be tolerated by the aviator as a function of the acceleration onset rate, the G axis direction with respect to the body, the acceleration duration, the acceleration magnitude, the type of seat restraint, the physical characteristics of the aviator/occupant, the secondary impact of body parts with the aircraft, and distribution of force over body parts.

Also, we discuss the physical and engineering principles which allow an understanding of an impact event and the current available techniques for occupant protection. We analyzed the occupant kinematics and the impact and crash survivability focusing on what happened during the mishap. Also, we review how to evaluate the tolerable deceleration forces and volume occupiable space consistent with life. Applications of physical analysis of crash survivability are discussed in order to determine the impact sequence, the quantity of the deceleration pulses, the extent of aircraft structural damage plus occupant seating to establish the extent and nature of occupants' injuries related to cabin environment. Ejection seats are briefly mentioned as a special case.

Injury assessment should respond to questions such as, when did the injury occur, the nature of the forces that produced the injury and their relationship to mishap forces. Injury types related to thermal, intrusive, impact or decelerative forces are discussed.

The collection of medical information should identify the potential causes which can affect what happens to an individual, the way in which the occupant moves in response to the forces applied (crash dynamics, aircraft/cockpit and life support equipment) which may have a profound effect upon the nature and severity of the injury.

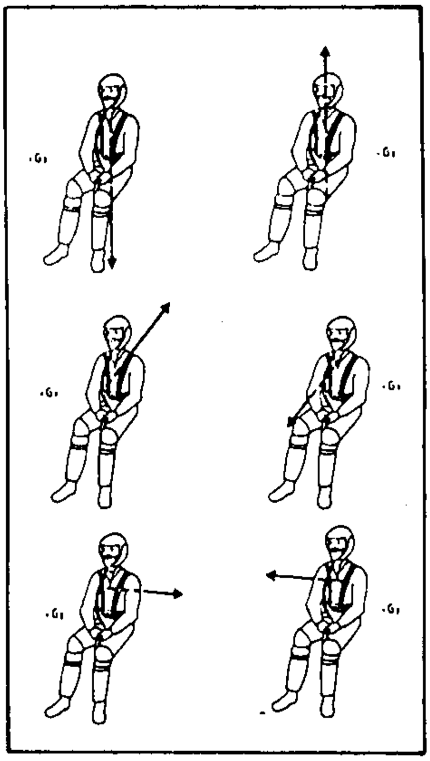
Emphasis is made on the application of injury data to improve aircraft and protective equipment design to control energy dissipation during a crash in order to prevent injury to occupants. On-scene investigation should provide adequate information related to the survivor consideration of escape from the crash aircraft.

FINAL CONSIDERATIONS.

Unfortunately, as it was mentioned in AGARD CP 532, crash survivability is not the most important consideration in the design of an aircraft, and weight and cost do limit the degree of crashworthiness that can be practically incorporated into a design. Nevertheless when tradeoffs are made, it is imperative that developers understand the consequences of proposed compromises and ensure that cost, weight, performance and safety are weighted in their decisions.
According to Green and al.(8) the guiding principle of aircraft design is that it should be accomplished in a way that fits the job to the man rather than the man to the job and to apply the increased knowledge and techniques available nowadays to design the principles that may allow the crew to carry out their duties in the greatest safety and comfort and the passengers to cope easily with any emergency situation.
Finally, as a summary of this LS we should emphazise the relevance of the study and research related to specific mediators of injury. Their analysis is of paramount importance in order to improve airplane design and safety.
As a brief summary of the crash environment aspects we should consider, we describe an outline of the most critical factors involved (9,10):

1. Impact tolerance limits:
We can consider a survival accident, those in which the impact conditions are within human tolerances, and crew and passenger occupiable space remains reasonably uncompromised. In addition, postcrash factors must be such that successful egress is possible.
Factors involved are:
- Tolerable decelerative and impact forces.
- Occupiable space.
- Post crash environment.

The specific mediators in crash survival are related to known velocities, stopping distances, ground and airframe deformation and decelerative forces on aircraft must be calculated. These factors classically have been classified in four main aspects:

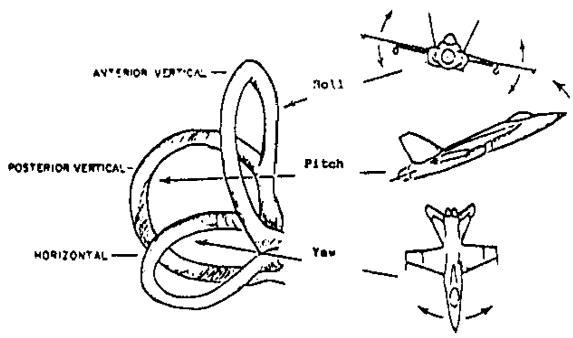


Acceleration classification

- Container.
Related to the aircraft structures needed to provide an intact shell around the occupants.

- Restraints.
Used to prevent the occupants, cargo and components from being thrown loose within the aircraft. Failure of any link in the restraint system results in a much higher chance of injury.

- Environment.
Related to the shape and configuration of potential striking structures within the aircraft.



Aircraft-Human coordinate and attitude directions

- Energy absorption.
The dynamic responses during crash impacts determines how forces acting on the aircraft are transmitted to the occupants.

- Post-crash factors. Generally associated to rapidly developed fires.

2. Injury analysis:

2.1. G forces.
Devoted to the characteristics of the decelerative forces involved. Different G patterns will cause specific results in each organ, from aortic transection to compression fractures.

2.2. Impact injury.
Injuries due to man-machine interaction or as a result of uncontrolled movements during the crash sequence, mostly associated to ejection.

2.3. Intrusive injuries.
Imply a loss of occupiable space due to intrusion of external elements as rotor blades, trees, wires, missiles or mid-air strike.

2.4. Thermal injury.
Differentiation between true thermal injuries and artifactual injuries.

3. Other factors to consider in the investigation:

3.1. Pre-existing disease.

3.2. Toxicology analysis.

3.3. Physiological factors.

3.4. Psychosocial factors.

3.5. Psychological factors.

3.6. Life support equipment.

3.7. Restraint and egress systems.

In conclusion, the analysis of injuries sustained by any aircrew or passengers should intend to examine the nature of the injuries and to establish the precise pathogenetic mechanism which lead to identifying the cause of the accident.
This effort will provide the aircraft with improved aircrew restraint inertia reels, airbag systems, crashworthy seats, improved egress training and improved egress procedures, which will provide the aircrew and passengers with a level of protection commensurate with the risk of operating aircraft in the military and civilian environment.

REFERENCES

1. AGARD CP 532. Aircrafts Accidents: Trends in aerospace medical investigation techniques.

2. National Safety Council. Accidents facts, 1991 Edition. Chicago: NSC, 1991.

3. Li G. Pilot related factors in aircraft crashes: a review of epidemiologic studies. Aviat Space Environ Med. 1994, 65: 944-52.

4. Haynes A L, Lissner HR. Experimental Head Impact Studies. Proceedings of fifth Stapp Automotive Crash and Field Demonstration Conference. Minneapolis, Univ of Minnesota, 1962, pp 158-170.

5. Kirkham WR, Wicks SM, Lowrey DL. Crashworthiness studies: cabin, seat, restraint, and injury findings in selected general aviation accidents. FAA-AM-82-7, 1982.

6. Shanahan DF, Shanahan Mo. Kinematics of US Army helicopter crashes 1980-1985. Aviat Space Environ Med, 1989, 60: 112- 121.

7. Snow CC, Carroll JJ, Allgood MA. Survival in emergency escape from passenger aircraft. FAA AM 70-16, 1970.

8. Green RG, Muir H, James M, Gradwell D, Green RL. Human factors for pilots. Avebury Aviat, 1991.

9. Crowley Js. USARMY Aviation Medicine Handbook. Society of USArmy Flight Surgeons. 1993.

10. Aerospace pathology for the flight surgeon. Division of Aerospace Pathology. Armed Forces Institute of Pathology. Washington DC 20306, 1987.