Injury Dynamics in Aircraft Accident

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Introduction

THE importance of crash injury analysis in aircraft accidents was recognised since the beginning of aviation in Wright brothers' aircraft accident in 1908. Orvile Wright with Lt Thomas Selfridge were involved in an aircraft accident in the year and Lt Thomas died due to head injury. Since then a number of full scale studies including crash tests of aircrafts were carried out to formulate guidelines for engineering design and life support system for crash survival. But even with modern safety measures incorporated in aircraft design there are cases wherein death/serious injury of the occupants have occurred under potentially survivable accident conditions. This proves that present day application of established crash safety norms in aircraft design leaves much to be desired.

Knowledge of interaction of the aircraft and the occupant during the dynamic phase of crash is a prerequisite in the understanding of injuries. The study of injury dynamics helps the medical investigator to pin point the cause and also the mode of death. In addition, it renders valuable information for aircraft designer.

Impact Forces

The forces encountered in aircraft accidents are generally abrupt accelerations of short duration usually less than 1 sec. These forces cause mechanical damage resulting in injuries.

The major components of impact forces during crash are usually along the longitudinal axis (Gx) of the aircraft or vertical (Gz). In rolling and slewing crashes the maximum forces in lateral (Gy±) and rearward (Gx−) axes are approximately 75% and 50% of the maximum forces in the forward axis (Gx+). The magnitude and duration of impact forces depend upon impact speed, impact angle and structural strength of the aircraft. With steepening angle of impact 22°–27° the horizontal component of forces in relation to long axis of the aircraft rises more than the vertical component[4]. In belly-landing the vertical component of force will greatly exceed the longitudinal forces.

Studies have shown that for better attenuation of forces, the basic design of the aircraft should be such that the cockpit area does not collapse below 40g. and complete structure around 60g. The attenuation of energy in air crash will depend upon the configuration and structural strength of the aircraft (Pressurised, low wing aircraft can attenuate energy better than unpressurised high wing aircraft and maximum energy attenuation occurs around centre of gravity). The energy attenuation is caused by crumpling of structure or plowing into the ground or by localised strikes against obstruction.

Human Tolerance to Abrupt Accelerations

Human body can tolerate considerable forces while striking a relatively large smooth surface. But tolerance is very limited when body is impaled against narrow rigid fixtures, sharp edged instruments and controls etc. Research workers over the past years have subjected innumerable animals and human volunteers to determine the human tolerance to decelerations. The human g tolerance depends upon various factors like :—

(a) Magnitude and duration

(b) Rate of onset (jolt)

(c) Direction of application (body orientation)

(d) Surface area exposed to force

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In aircraft accidents wherein accelerations of very short duration of O.1 sec or even less are encountered, only the overall change in velocity is the criteria (determining factor) and not the peak g[5]. For higher rate of onset the tolerable limit and duration decrease considerably. Body orientation (direction of force) plays important part in human g tolerance values. The human g tolerance at various body orientation assessed from the experimental studies and analysis of accidents are categorised as tolerable, injurious and fatal[8] (Table 1).

Aircraft Crash Injuries and Dynamics

Whenever the impact forces transmitted to the occupants are more than the human 'g' tolerance, serious injuries and fatalities would occur. The correlation of the injuries to the aircraft environment and analysis of use/abuse of restraint system will help the medical investigator to reconstruct the sequence of events. The crash injuries are classified as follows :—

(a) Crushing injuries
(b) Contact injuries
(c) Decelerative injuries
(d) Injuries due to post crash complications.

Except for those accidents in which the aircraft totally disintegrates, accident severity is not the sole determinant factor or either probability of serious injuries or the final outcome. The basic causes and mechanism of these injuries is discussed below :—

TABLE I

Human tolerance limits to short duration acceleration on basis of research by Col. Strap and associates (Restrant System Consisted of a Special Research Model harness with 1.7'' nylon shoulder harness with 3'' wide chest band, 3'' nylon lap belt straps, an Inverted "V" shaped thigh strap and special 40 G buckle and fittings.)

Type of Acceleration	Direction of Acceleration	LIMITS		
		Tolerance	Injurious	Fatal
Positive + Gz	Headward	33G @ 500G/sec in optimum position Less than 10G @ 2000G/sec with back hyperflexed	Over 35G @ 400G/sec in optimum position Over 10G @ 2000G/sec in poor position	Over 100G @ 2000G/sec for 0.1 to 0.5 sec
Negative + Gz	Head to feet	16G @ 200G/sec	Over 25G @ 5000G/sec for 0.02 to 0.1 sec	Over 100G @ 2000G/sec for 0.05 to 0.20 sec
Transverse + Gx	Spineward (front to back)	38G @ 1400G/sec for 0.1 sec 50G @ 500G/sec for 0.25 sec 25G @ 1000G/sec for 1.0 sec	60G @ 5000G/sec for 0.1 to 0.5 sec	Over 200G @ 5000G/sec for 0.1 to 0.5 sec
Transverse – Gx	Sternward (back to front)	Over 40G @ 1000G/sec for 0.25 sec	90G @ 5000G/sec for 0.1 to 0.5 sec	Over 200G @ 5000G/sec for 0.1 to 0.5 sec
Lateral ±Gy		9G @ 500G/sec for 0.1 sec		

(*a*) *Crushing within the aircraft structure :* In high speed and near vertical crash, extreme degree of impact forces are imposed on the aircraft and occupants, which cause their disintegration into small pieces. In less severe circumstances skeletal fractures and soft tissue injuries are encountered. Because of the vertical component of the force, head injuries and compressed fractures of spine are very common. The basic cause is the poor crash worthiness of aircraft structure, with the result unattenuated impact energy is transmitted to the occupant through tie down chain system. The occupiable area is not only reduced but broken into multiple pieces. The aircraft parts may act as missiles and lead to secondary injuries. The body parts may get crushed in between the hard surfaces of aircraft leading to crushing injuries. There is no aircraft at present which can give 100% survival potential. To achieve maximum survival potential, the aircraft structure and seat strength including the tie down chain should not be stressed below the human 'g' tolerance.

(*b*) *Lack of restraint* : The restraint system in fighter/fighter trainer aircraft is lap belt, shoulder straps, negative g straps and inertia reel system. The static design strength of 4000 lbs is equal to recommend 40 g shoulder harness[3]. Most of the transport and rotary wing aircraft seats for aircrew are provided with shoulder harness and lap belt where as the passengers are provided only with a lap belt of 2" to 3" width. Due to inadequacy of restraint system and its subsequent failure, the occupant is thrown violently inside the occupiable area and strikes against the injurious environment i. e. projecting controls, knobs, instrument etc. leading to multiple superficial injuries known as contact injuries. The injuries like abrasions, cuts, contustions and fractures are produced by body parts forcefully coming in contact with non-yielding, sharp rigid or abrasive items e. g. aircraft instruments. Impact with broad smooth surface may produce large wounds and skin may be torn from the under structures. Local injury due to belt may be produced, by parting or detachment of the lap belts. When floor breaks up, damage to the lower legs is prominent. However, due to lack of restraint the occupant may be thrown clear outside the aircraft and body parts may intermingle with aircraft parts and or other surrounding structures in vicinity.

Example : In a HT2 aircraft crash, the breaking strength of the harness system was assessed to be 50%

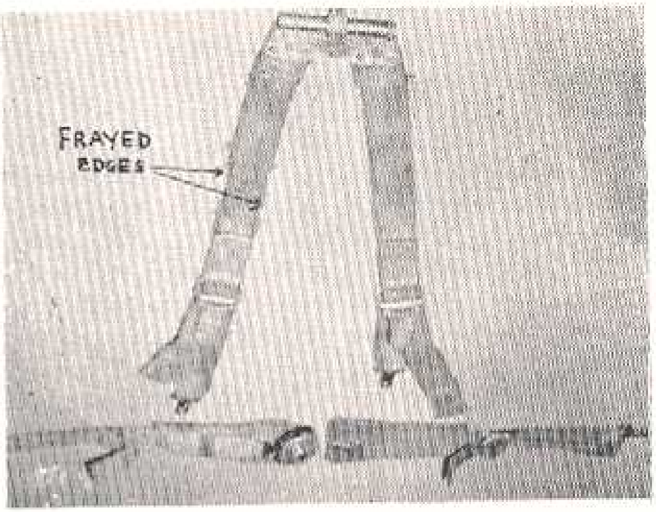

Fig. 1 Old Harness with frayed edges

less as compared to new harness of same type. This harness was soiled with oil, grease and edges were frayed. It was torn and gave way during the accident and lead to multiple fatal injuries in an otherwise survivable crash proved by analysis of crash dynamics. This harness could stand only 10g whereas aircraft seat structure have been stressed upto much higher g (26g). Figs 1 and 2 show old and new harnesses respectively.

(*c*) *Application of excessive force to the partially restrained body :* The lap belt alone becomes inadequate restraint when the forces applied are otherwise within human 'g' tolerance limits because of heavy

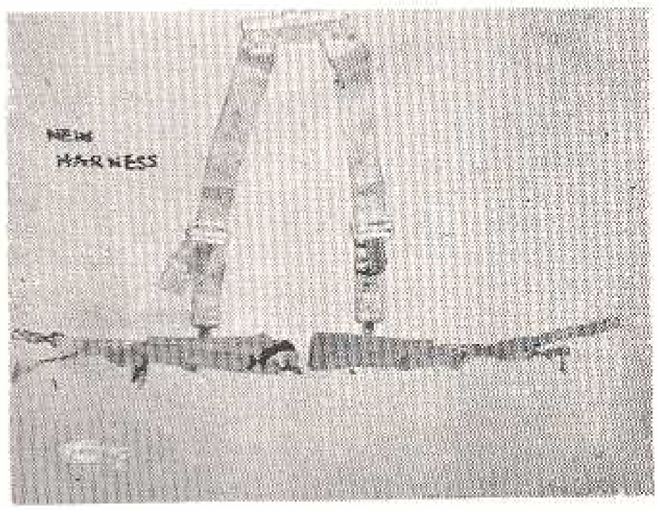

Fig. 2 New Harness

loads imposed. The lap belt itself may act as a injury device due to Jack-knifing and flexion mechanisms. In jack-knifing the upper torso whip-lashes forward and may strike the back of front seat in a transport aircraft. Without proper head protection with helmet, occupant may sustain serious head injuries. In the flexion action both upper torso and the legs undergo flexion and may produce spinal fracture/dislocation. Injuries of lower and uppe-limbs due to flailing could be produced by the aircraft structures in immediate vicinity. This may also lead to bursting injury of urinary bladder in hypogastric area though overlying skin may show only slight ecchymosis. Fig 3 shows the dynamics of injuries produced on lower abdomen and vertebral injuries due to lap belt[9].

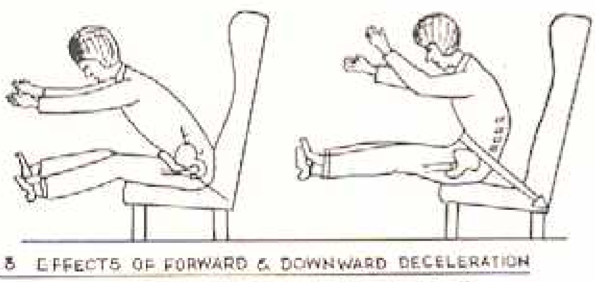

FIG. 3 EFFECTS OF FORWARD & DOWNWARD DECELERATION WHEN BODY IS RESTRAINED BY LAP BELT

Example : In a survivable Helicopter accident, one of the aircrew who had tightened the harness and was rescued with serious injuries survived while the other aircrew who had slackness in harness sustained head injuries and crushing injuries of spleen and eventually died.

(d) Application of excessive force to the adequately restrained body : Keeping the short comings of various types of harness system, the combined harness (shoulder harness and lap belt) will increase the tolerance limits upto maximum but at level of 12-17 vertical ' g ' forces may cause costal cartilage fracture and moderate shock. With use of maximum comprehensive harness, the limit of human g tolerance to transverse accelerations is much higher around 40g.[2]

(e) Striking of the body by inadequately restrained aircraft contents : Bombardment of missiles of various kindsincluding occupant with or without seats, themselves is another cause of injuries in an improperly restrained cargo contents of aircraft. Proper anchorage and lashing of equipment and material is very important and needs to be stressed. There has been instances wherein improper anchorage of a vehicle in transport aircraft lead to fatalities to the passengers in the past which was otherwise survivable accident.

(f) Trapping within the remains of the aircraft : Having survived the forces of impact, it is not uncommon in aircraft accidents for occupants who become incapacitated to extricate themselves from the crashed aircraft and die due to shock, haemorrhage, and asphyxia.

(g) Postcrash complications : The biggest hazard in aircraft crash is fire hazard. The other post crash complications like drowning and toxic hazards are equally lethal. Proper selection of protective clothing for special sorties over the sea and precautions on inadvertent operation of CO_2 fire extinguishers can reduce these hazards.

Conclusion and Recommendations

Due to lack of authentic data on survivable aircraft accidents with recorded crash dynamics and adequate information on use of protective equipment and life support system the feed back from autopsies gets limited. Casesure on record where one occupant survived and other died. In some cases there were serious injuries to few passengers and no injuries at all to others.

(a) For quick retrieval of information for correlation of injuries with aircraft environment during crash, a suppliment form (fig 4) is suggested to be incorporated to Form MS 1956 which is currently in use[1].

(b) Form MS 1956 should also be raised on all major/minor non-fatal survivable accidents in addition to fatal accidents where the occupants sustained injuries, because it will be more useful in such cases to suggest improvements and modifications on following areas of cockpit environment.

(i) Crash worthiness

(ii) Restraint/Life support system

(iii) Delethalisation and prevention of injurious environment

(iv) protective equipment etc.

A/C TYPE :

SEAT No. :

RANK :

NAME :

No. :

AGE :

UNIT :

FLYING EXPERIENCE :

TYPE OF SORTIE :

TYPE OF ACCIDENT

MINOR MAJOR FATAL

SURVIVABLE UNSURVIVABLE

1. This form is to be filled by the Medical Officer (member) of C of I in consultation with the local pathologist conducting autopsy and other members of C of I.
2. Describe factor/cause of injury (numbers) from the list given on the side and place in the appropriate box describing body area and type of injury.
3. Use one form for each occupant.
4. Crash Dynamics should be entered on the reverse graph with brief narrative of accident.

INJURY CAUSATION ANALYSIS

STATE OF BODY AND INJURIES	INTACT	DISINTEGRATED	BURNS	CONTACT INJURY	CRUSHING INJURY	FRACTURES	DISLOCATION	AMPUTATION	CYTOPATHOLOGICAL INJURIES	SHOCK	DROWNED	ANY OTHER
BODY PARTS												
HEAD												
NECK												
BRAIN												
UPPER LIMBS												
VERTIBRAL COLUMN												
SPINAL CORD												
THORACIC CAGE												
LUNGS												
HEART AORTA												
DIAPHRAGM												
LIVER												
SPLEEN												
STOMACH												
KIDNEYS												
URINARY BLADDER												
LOWER LIMBS												
ANY OTHER												

1. Helmet
2. Visor
3. Mask
4. Harness
5. ORB
6. Self Inflicted
7. Arm Guards
8. Leg Guards
9. Head Restraint
10. Seat Pan
11. Leg Restraint
12. Seat Back
13. S. Pack
14. Parachute
15. Anti 'G' Suit Connector
16. Throttle Quadrant (Item carried loose)
17. Canopy Handle
18. O_2 Regulator
19. L.H. and R.H. Console
20. Front Panel
21. Rudder Pedals
22. Rudder Pedestal
23. Cockpit Floor
24. Under Structure of Inst Panel
25. Bulk Head
26. Engine
27. Control Column
28. Canopy Jettisoning Handle
29. Canopy Structure
30. Wind Shield
31. Cabin Window
32. Cabin Locking System
33. Side/Front/Rear Seat
34. Other Pilot/Passenger
35. Cabin Content/Baggage
36. Door Structure
37. Cabin Fuselage
38. Overhead Structure
39. Diagonal Brace Tubing
40. Fire Extinguisher
41. Map Case/ Writing Material
42. Any Test Equipment
43. Survival Equipment
44. Outside Object
45. Special Clothing
46. A/C Engine Propeller
47. A/C Wing
48. Tail Section
49. Nose Wheel
50. Stretchers
51. First Aid Box
52. Fire in Air
53. Fire After Crash
54. Water(Sea/Pond/River)
55. Jungle-Bushes or Trees
56. Co Poisoning
57. Toxic Agent
58. Sabotage
59. Any Other

Fig. 4 Supplement form suggested to be incorporated in Form MS 1956

(c) Indoctrination should be given on the proper use of protective equipment and proper tightening of harness system.

(d) A periodical check on maintenance/replacement of worn out harness, and deteriorated/rusted coupling of the components should be ensured.

(e) Periodic mock-up crash rescue drills should be practiced at flying stations to minimise the chances of fatalities and injuries due to post crash complications.

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