General Aspects in Aircraft Accident Investigation

LtCol. Dr. Francisco Rios Tejada
Spanish Armed Forces Technical Investigation Board
C.I.M.A. Arturo Soria 82
28027 Madrid. SPAIN

E-mail: frios@saludalia.com

INTRODUCTION

Mishap description and investigational procedures play a key role in understanding what areas failed in the accident sequence of events and provides us the correct tools to address appropiatte recomendations, in order to prevent future similar situations that leads to incidents or accidents.

Wiegman and Shappel (26) described years ago a practical and comprehensive model of human factors which can be applied to every accident. The so named HFACS or Human factors Accident Classification System model followed the causative models described by previously by Reason (17) and later by AGARD WG-23 (19). Nowdays it constitues a handy taxonomical tool to identify and determine causal facts related to active or latent conditions capable to lead to the accident.

The investigation of and aircraft accident is always a difficult task, in where a great number of factors might be involved and where sometimes part of the clues are hidden or missing (5,6). It is like an enormous puzzle where we have to engage all the pieces according to the info provided by meteo, engines, cell, avionics, forensic, human factors etc..., but we have very often a big challenge, some of the pieces of the puzzle are missing, deteriorated, bleached, burned, or even artificially misplaced, and we have to figure out , what are they and where to fit them.

From a biodynamic and impact point of view, the investigational accident proccess should target the preventive measures resulted from the detailed study of the crash forces involved and the type of injuries produced. The analysis of the patterns of injuries sustained by the aircrews are critical and any information concerning the type and nature of injuries involved in a fatal accident must be part of the investigation.

Results of autopsies reveal most of the time that blunt trauma is the primary cause of death in more than 75% of the fatal cases, followed by bony injuries of the ribs, skull and facial bones. Very often all injuries appear and head injuries results as the leading cause of death (2,10,27).

A recent paper pointed out the relevance of the investigation of injuries produced in the survivors, equally subjected to a mechanism of injury that can be easily study and theoretically reproduce in the survivor patient (11).

Paper presented at the RTO HFM Lecture Series on "Pathological Aspects and Associated Biodynamics in Aircraft Accident Investigation", held in Madrid, Spain, 28-29 October 2004; Königsbrück, Germany, 2-3 November 2004, and published in RTO-EN-HFM-113.

A report of the factors associated with pilot fatalities in aircraft crashes in Alaska mentioned that the most frequent ones are (15):

- crashes involving postcrash fires
- flight in darkness or IFR conditions
- No restraints

A review of the aircraft accidents occurred in the Spanish Armed Forces showed that head and blunt trauma were the major causes of death, due to the decelerative forces originated during the impact.

AIRCRAFT ACCIDENT BOARD OF INQUIRY

There are a quite large variety of approaches, depending of the country, legal systems, military, civilian, number and qualification of the members, links with other bodies, etc.. These differences will play a key role in the involvement of the physician in the current investigation.

As an example the investigation board in the Spanish Military is composed by a president with the rank of Brig. General, pilot who represents and signs the reports of the board, a secretary that use to be a full Colonel and basically in charge of the administrative arrangements. There are a pilot representative of each Service plus the Civil Guard, an Aeronautical Engineer, a Physician, a Lawyer, and a Photographer.
Our experience demonstrate that the role of the lawyer in supporting us in all the interfaces with the judge and final review of the report according to legal standards has been very fruitfull and in our understanding necessary (19).

The role of the physician board member must be supported in a deep knowledge of the especialty of Aviation Medicine in order to understand the physiological and pathological factors involved and experience in the investigation itself. In that way provide assistance in the medical, physiological and psychological aspects of the human factors involved. Also can direct or advise if timeframe provided the possibility to be on time in the crash site, in aspects such survival rescue, and egress.

The physician especialist in aerospace medicine will gather data related to the medical history of the victims, dental records and eventually whatever available tool for identification purposes.

Also the physician will be able to identify potential site hazards and let be aware of bloodborne pathogens, composite material, chemicals, compressed gasses or even explosives such an unfired ejection seat or ammunition unexploted.

The physician will be the main advisor of the coroner in correlating the factors causing accident and injury with the safetry aspects of aircrafty design, restrain system , personel equipment, and existing operational and safety regulations, practices and conditions with other board members.

Also along with the technical personnel will evaluate the life support equipment and protective systems that it could be implicated in the cause of the injury.

But the main role it will be to make a thorough investigation of the fatal and non fatal injuries sustained to determine their causes and to recomend ways of preventing or minimizing future similar ocurrences.

CRASH SITE

Emergency medical care must be the first priority for the rescue team deployed to the crash site, but we should not forget that potential survivors are the most valuable witness of the accident and record of the names, relatives, police and hospitals where they have been admitted are extremely valuable. Inmediatly after, the medical investigation must start, but keeping all the safety measures around the accident site according to the instructions provided by the rescue teams, fire figthers and security forces. The site always is a hazarous place, and tyres, composites, batttery acids, oxygen equipment and compressed gases, radioactive material (Torium associated to FLIR), ammunition, explosives (ejection seat), weaponery, unknown load and biological tissues and fluids from the victims, are some of the potential hazards for the investigation team (18).

ICAO provides especific recommendations regarding prevention and custody of the remains that should be left as undisturbed as possible in order to preserve the information to the investigators. It is recommended that rescue workers during the access procedures to the victims and survivors do make as little damage as possible to the cabin remains or even record the ultimate stage of the cabin and position of the victims before removal and loss of information due to the on site work. Position of the switches and instruments are important and never must be remove or alter. Also the fracture surfaces of broken parts should be kept in the laying position until expertise analysis and adequate record (photography or video) is finalized.

Major components (engines, ejection seats, hydraulic partss, cabin displays) should not be dismantled in the field without direction of appropiate engineer expert, preferebly the engineer member of the board.

During aircraft recovery effort where human fragmentation occurred, especific authorization of the judge (different procedures can be applied country by country) it should be necessary for the coroner to manage the disposition of the human remains that may be located as wreckage is moved. Close collaboration with the coroner is particuraly necessary.

Special attention must be paid to the life support equipment involved such flight clothing and protective garments, smoke hoods, oxygen delivery systems, helmet and mask, G-protection suit and appropiate restrain systems.

In the case of a mass casualty situation preliminary evaluation of the location and nature of the disaster, number of casualties and availability of resources should be performed in conjunction to careful documentation of injury patterns and accurate identification of data that can be associated to the victim, plus biological sampling for further positive identification procedures.

COLLECTION OF DATA

Collection of evidence are paramount and actually the AGARD AR-361, discussed the directions and procedures used by various NATO countries in order to collect and interchange data coming from the investigation in order to reach a potential common file. In that way a human factors approach were depicted and a new approach described in order to identify failures or conditions that precede active failures. Later on, Shappel and Weigman established a system to understand why the mishap occurred and how it might be prevented from happening again in the future. A version of the domino theory of the Reason model where published describing the levels at which active failures and latent/conditions may occur within complex flight operations (19,26).

A major adjucnt in the collection of data and further positioning of the remains are the diagraming of the wreckage, by using either polar, tear drops aand grids diagrams. Each one is ideally suited for high vertical velocity of impact, scatter pattern along the main flight path vector or a more widely dispersed pattern, respectively.

Extensive on site photography play a key role in documenting and record pieces, victims position, instruments, life support equipment and other portions of the aircraft deemed important for the investigation.
Aerial photography is a great adjunct to the identification and accurate positioning of the elements of the aircraft and a major help to detailed reconstuction of the diagrams.

Information collected and examination of damage should be used for appropiate adquisition of key accident information such, angle of impact, airspeed at impact, attitude at impact, evidence of inflight fire, evidence of ground fire, in-flight structural failure, aircraft configuration and integrity of impact, whether the power plant was producing thrust, if and when ejection or bailout was attempted, phase of flight at impact (recovery, stall, spin, inverted..), evidence of mid-air collision, evidence of fuselage or cockpit intrusion and evidence of inflight incapacitation (1,3,4).

MEDICAL INVESTIGATION

The physician investigator will be in charge not only of the in site investigation but the so called off-site investigation related to the human factors involved. It will be required to interview survivors, witnesses or other individuals who might have been connected professionally to the mishap.

In addition to that the medical investigator will be responsible for determining if illness, sudden or subtlte incapacitation or medication were causal or contributing factor (22).

The medical investigation includes a full review of the crew members medical records and full professional records, including up to date physiological training (altitude physiology, night vision training, spatial orientation and centrifuge training) (9).

Medical exams of the aircrew survivors can add a valuable information regarding their physical status and a battery of test might be considered in order to rule out the event of intoxication (CO poisoning), or being under the influence of sustance intake (cocaine, alcohol, marijuana, amphetamines, opiates and medication), or simply rule out a medical problem (hypoglicemia, anemia, infection) (8,12,14).

Appropiate X-Ray exam should be orderer in the case of trauma. If ejection or bail-out, compression fractures of the spine can be expected and MR and Isotopic studies should be considered. In the event of head trauma full neorological exam must be performed along with the appropiate radiological exam and rule out parenquimatous, epidural or subdural bleeding.

Victims must be identify and appropiate methods for positive identification of them should be used such, dental records comparation, finger and footprints data, presence of previous fractures already recorded and DNA profiles. Presumtive identification are based in techniques such visual apperance, anthropometrics, personal effects, flight manifest, sex , race , age and personal items. Presumtive identification must be consider not always reliable and causiously considered (7,16,18).

Postmortem studies should answered several questions such determination of the cause and manner of death, by establishing the circumstances of the accident. Basic questions such, who is the casualty, what are the injuries, when did these injuries or conditions occur, how did occur, who caused it, where did happen and why did happen (2).

Injury patterns has to be analyzed in relation to the eventual position of the victim in the aircraft. Exam of hands, arms, feet might reflect the character of the control (stick, pedals), and actually colinear fractures of the metacarpals or metatarsals, fractures of the wrist, or distal fractures of the radius and ulna may indicate that the individual was attemting to control the aircraft at the time of the impact (20,23).

Full body X-Ray exams both with equipment and undressed provide important visual documentation mostly in high speed ejection injuries resulting in potential fatal neck or flail injuries. Radiographic exams provide the best evidence and characterization of fractures, dislocations and presence of foreign material (7).

The information collected and subsequent analysis of the data comes not only from the medical sources but from the mishap site, survivors interviews, laboratory results, radiological findings, autopsy outcome, and other sources. All of them must be pieced together in an organized way to produce the proper information, which becomes evidence that is utilized to identify the many causal factors present in the accident (1, 7,13,18,23).

The pattern of injuries sustained at impact might provide an indication or clue of what the subject was performing in such critical moment and subsequent reconstruction of the accident pattern is facilitated.

IMPACT TOLERANCE .

Analysis of crash or impact forces can be very important in determining causes of injury or death. Crash survivability focuses on what happened and why the mishap occurred, but the ultimate goal is to determine the primary cause and adjuvant circumstances in order to prevent similar events (20).

Many accident investigators have reported that 70% to 80% of all deaths and injuries in crash decelerations are from face and /or head injuries cused by body flailing and head striking surrounding structures. Survival of an aircraft accident depends to a great extent on providing a crash-resistant container for the ocupants, that is, occupiable area that will withstand crash forces without crushing, collapsing, or desintegrating, and features such as the deformation of aircraft cockpit and cabin structures, the state of integrity and probable function of seats and restarint systems, probable impact of ocupants against aircraft structures and the correlation of injuries with the direction and severity of impacts. But surviving an aircraft generally involves also tolerable deceleration forces and a non-lethal post-crash environment (1,20).

Factors affecting crash survivability has been clasically classified (1,7,18,20,23) in 5 key aspects:

1. Container related factors.

It is the capability of the airframe to maintain an intact shell around the ocupants and preserve an adequate volume of living space and prevent penetration of external or internal objects.

2. Restrain systems factors.

It is the linking of the occupants to the container in order to secure them avoiding the posibility of striking through the closest estructures of the airframe. Bassically consist of seat belt, shoulder harnesses, seat belt anchorages, and the floor used to prevent the occupants. We should consider the restarint of the cargo and components from being trown loose within the aircraft. Any failure of those systems increase the chance of injury.

3. Environmental factors.

Related to the shape and configuration of potential striking structures within the aircraft. The presence of injurious surfaces that can be avoied and replaced by energy absorbing materials wherever possible. The mishap environment might affect the ability to withstand crash forces or prevent the egress from the aircraft or combustion of products from postcrash fire. In addition self protection can be improved by the use of appropiate clothing garments, adequate underwear, socks, boots, gloves and helmet. The extensive use either for fix wing aircraft or rotary of Night Vision Devices attached to the helmet or even integrated in the helmet is an element of concern due to the added weight and hence deceleration supported.

4. Energy absortion capabilities.

It is the capability of the airframe to absorb the crash-force energy. The dynamic responses of the estructure of the aircraft during the crash impact determine how forces acting on the aircraft are trasmitted to the occupants. Desirable structures are those that absorb energy, such energy absorbing seats that progressively collapse, and absorbe impact energy at levels within the human tolerance ranges, without storing it to later produce a delayed dynamic overshoot.

5. Postcrash factors

Mainly related to fire and fumes or escape from a ditching aircraft. The control of post-crash is primarily related to aircraft design. Factors that increase the survivavility are the location of fuel cells and fuel lines in relation to electrical and mechanical ignition sources and the resistance of the fuel system components to rupture under conditions of moderate crash forces or airframe distorsion, sufficient emergency exits, breakaway valves applied to fuel lines, wear addequate clothing (cotton, nomex) and avoid synthetics in seats and cushions.

INJURY ANALYSIS

Any injuries found in the occupants must be correlated with the circumstances of the accident. All the information provided will be extremely valuable for potential future recommendations. The analysis of injuries sustained by any aircrew or passengers should intend to examine the nature of the injuries and establish the precise pathogenic mechanism which lead to identifying the cause of the accident. This effort will provide the aircraft with improved aircrew restraint, inertia reels, airbags systems, crashworthy seats, improved egress training and improved egress procedures, which will provide the aircrew and passengers with a level of protection commesurate with the risk of operating aircraft in the military and civilian environment (20,21,25).

The information provided should answered several questions related, such when the injury occur, what was the nature of the forces involved, if the injuries were as a result of the mishap forces or due to post-crash artifacts and if the injuries preexits or occur before or after death.

Injury can be the result of a direct impact against a solid object or indirectly transmitted force, resulting in damage to the bones or soft tissues and internal organs of the body.

Impact injury typically refers to structural disruption of biological tissue as a result of a short duration physical force. The duration associated with impact it is considered less than two seconds.

Sustained injury is associated to a sustained component. Tissues can be stressed in different ways, such compression stress, tension or distraction stress or combination of both compression-tension stress. Another factor to consider is the cross sectional area where it is applied, so that compression-tension stress can be defined by the force per unit area over which it is applied.

The physical basis of injury is associated to strain or degree of deformation produced by stress. The resistance to strain is defined as stiffness or resistance to deform. The strain is measured by the amount of decrease in the dimension divided by the initial value.

We can consider:
- Bending: distorts tissue about cross-axis.
- Torsion: angular distorsionabout the long axis.
- Shear: as a consequence of the structure'slip.

Any part of the body can be subjected to impact and subsequent injury, but depending of the anatomical characteristics of the human structure, composition, mass, elasticity and vital organs affected we can review several patterns associated to body organs, systems and structures (4, 20).

Skeletal injury.

Injuries afecting the limbs are very comon, even if appropiate restraint systems are used, taking into account that arms and lower extremities are not currently restrained. We can classifed according to the particular shape, location and response to an applied force or load.
- Long bones: with tubular structure, capable to absorb energy but subjected to injury mechanisms such spiral or bending fractures.

- Short bones: short and cuboidal bones such carpus and tarsus are subjected to multidirectional motion when under stress. Sometimes fractures are associated to aircraft control gear.
- Flat bones: generally they have a high resistence to deform, they broke under direct impact.
- Irregular bones: such bones of the face, can be afected by multiple forces, generally associated to direct impact against the panel.
- Spine and vertebrae: impact are more frequently associated to bending and longitudinal axis load.

Joints.

Disruption of the joint can lead to dislocation of the attached estructures and unestability of the joint. Forces applied to the joint can produce the distension or rupture of the capsule, ligaments, tendons, sweling and haemorrage.

Abdominal cavity.

The abdominal cavity reacts to an impact as a fluid–filled or hydraulic cavity in which force is wave-transmitted to all organs and structures. Most frequent type of injury is blunt trauma as a result of pressure wave transmission, compression and shear forces.

Chest.

Injury to almost any one structure of the chest can seriously compromise the survivability of the victim. Time and magnitude of the impacting force are critical for the thoracic content. Disruption of the circulatory system including aorta rupture or penetrating injuries use to be fatal.

Head and Face.

Most frequent cause of death in aircraft accidents. Open or close head injuries does not mean higher or lower rate of mortality unless it is associated to brain injury. In addition to that, very often are associated to various injuries in the rest of the body complicated with haemorrhage and lost of circulating volume.

Can be classified in:
- Contact injuries. Required a blow to the head. Direct impact can lead to skull fracture, extradural haematoma or coup contusion. Transmision can produce deformations distant from the site of the impact and result in vault and basilar fractures. Injury wave can be transmitted across and produce contracoup contusion and/or intracerebral bleeding.
- Non contact injuries. Consequence of acceleration but does not need necessarily that the head strike against any object or the head be struck by any unrestrained object. Generally associated to angular accelerations which lead to deformation of the tissue as a result of an external loading force. Surface strains can lead to subdural haematoma or contracoup contusion. Deep strains might lead to concussional syndromes and difuse axonal injury.

Spine.

Response might be different from individual to individual, according to the age, physical fitness, posture (mainly in ejections), and involvement of the musculo-skeletal support of the vertebral column and spinal cord. The motion of the spine is complex and associated to coupled motions, i.e. lateral bending involves rotation about the horizontal and vertical axes as well as the translation perpendicular to the horizontal plane, hence lateral bending may cause a combination of transverse shear in the horizontal plane, rotational shear about the vertical axis and tensile and compressive stresses in the vertebral body. Other mechanisms are associated to hyperextension, hyperflexion with or without compression (7, 20).

Tolerance is not uniform along the spine. Association with stability is key for determining irreversible complications such quadriplegia or paraplegia.

Injuries associated to assisted scape from aircraft are more frequent in the thoraco lumbar hinge (T12-L1), although a significant proportion of injuries also occur at the mid-thoracic level. The combination of axial compressive force and spinal flexion lead to the most frequent one, the anterior wedge fractures. From an anatomical point of view can be classified in (24):

- Anterior wedge fractures.
- Burst fractures.
- Chance fractures.
- Dislocations and fracture-dislocations.
- Rotational injuries.
- Hyperextension injuries.

Injuries also can be classified in four major groups according to the mechanism of production (7):

- Intrusive injuries: Due to loss of occupiable space as a result of the intrusion of portions of the aircraft and /or surrounding objects, such trees, wires, poles etc.. most frequently generates the so called "crush injuries".
- Thermal injuries: Associated to postcrash fires. It is very relevant to distinguish if fire started during flight or after impact and if the resulting thermal injuries were the cause of death or merely an artifact sustained after death. During autopsy procedures it is critical to look for presence of soot in the trachea and rest of the airways. It is rather common to find in bodies exposed to fire artifactual situations not necessarily associated to the cause of death such, pugilistic attitude of extremities, thermal fractures of long bones and skull, epidural haematomas and splitting of soft tissue.
- Impact: The classically described as control surface injuries are non specific and can be seen not only in pilots but even in the passengers, therefore their interpretation must be cautious. Most frequent control injuries are described in hands, carpal, metacarpal, tarsal, and metatarsal bones, associated to lacerations in the palms and soles.
- Decelerative forces: depends on both magnitude and duration force. Experimental human tolerance estimates for 0.1 sec. Decelerations described bellow derived from laboratories and artificial crash-impact research (modified from Naval Flight Surgeon Manual, Pocket Reference to Aircraft Accident Mishap).

Pulmonary contusion	25 G
Nose fracture	30 G
Vertebral body compression	20-30 G
Fracture dislocation of C1-C2	20-40 G
Mandible fracture	40 G
Maxilla fracture	50 G
Aorta intimal tear	50 G
Aorta transection	80-100 G
Pelvic fracture	100-200 G
Vertebral body transection	200-300 G
Total body fragmentation	350 G
Concussion over 0.02 sec.	60 G
Concussion over 0.005 sec.	100 G
Concussion over 0.002 sec.	180 G

RECOMMENDATIONS AND PREVENTION

Direct consequences of the investigation should lead to specific changes that may improve crashworthiness of the respective aircraft an in addition, significant operational lessons were drawn and which, by application learnt, led to greater safety.

Tolerance levels demonstrated by dummies studies can show the effectiveness of the various configurations of restrait systems and resistance of the airframe to deformity and capability to crush.

The documentation and the pathological interpretation of the injuries associated to the aircraft accident determined how they occurred, a key premise in order to establish conclusions and be able to minimize or prevent future similar events.

Data collection and interoperability procedures must be stablished by developping the actual framework provided by STANAG 3531.

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