AVIATION ACCIDENTS, ROLE OF PATHOLOGIST

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Definition

Aviation pathology is the application of traumatic pathology to flight safety. It has been defined by Mason as the comprehensive study of aviation fatalities, whereby the medical history of the casualty and the findings at autopsy can be correlated with the environmental factors, the structural or other damage to the aircraft, and the use or abuse of equipment, so that a complete picture of the accident may be formed. The objective of investigating fatal aircraft accidents is to find their causes and prevent similar accidents occurring in the future through thorough and complete investigations using a multidisciplinary team approach and multifactorial parameters.

History

The first documented application of aviation pathology in powered aircraft in the USA was the death of an army lieutenant in 1908 at Fort Myer, Virginia, during army testing of the Wright Flyer, with Orville Wright at the controls and Lt Thomas Selfridge as a passenger. The plane crashed at low altitude due to a faulty propeller. Orville survived with a simple fracture. Selfridge died of craniocerebral trauma from a skull fracture.

The German Air Force during the 1930s developed a basic scientific approach to the investigation of air crashes in World War II at the Aeromedical Research Institute in Berlin. They were also the first to incorporate protective headgear. In the USA during the 1940s, John Stapp contributed significant insight into human tolerance in short-term decelerations in a variety of sled experiments. A series of commercial air transport mishaps involving the British Comet in the 1950s and the role of the pathologist in determining causal factors led to the concept of "packaged crew and passengers" and the origins of aviation pathology as practiced today.

Principles

The pathologist is primarily concerned with the pathology and human factors in the mishap and is often able to implicate a contributory or proximal cause of the accident. This contribution to the mishap investigation occurs in seven main areas:

1. demonstration of disease in the pilot, which may be causative, contributory, or incidental to the mishap
2. circumstantial medical evidence, such as a history of psychiatric illness
3. toxicological evidence: alcohol, carbon monoxide, or drugs
4. mechanical defects manifesting as toxicological evidence, e.g., fumes in the cockpit
5. sequence of events in the mishap
6. whether the emergency was anticipated or occurred without warning
7. questions relating to survivability.

Aerospace pathology is a subset of forensic pathology and is typically practiced by forensic pathologists who also have operational qualifications such as in flight surgery or diving/undersea medicine. Operational experience and knowledge of the mission and operating procedures applied to the pathology findings and ancillary laboratory studies have enhanced our understanding of flight human factors. Following the Comet disasters, the Joint Committee on Aviation Pathology, involving the military safety centers and Armed Forces Institute of Pathology (AFIP) in the USA and Departments of Aviation Pathology in the military services of Canada and the UK was established in 1955 with the Secretariat located at the AFIP in Washington, DC, to serve as a forum for the exchange of information and ideas. Today, much of that effort is pursued in the forums of the Aerospace Medical Association and various North Atlantic Treaty Organization (NATO) working groups.

Concepts

Aircraft accidents are not random events but recurring themes with epidemiological patterns, often with specific pattern injuries identified with specific aircraft. There are unique characteristics of the flight environment that allow an investigation to focus on discoverable causes in engineering, human factors, and flight operations. In general, mishap investigation boards composed of multidisciplinary specialists pursue clues in the accident investigation to reconstruct the events based on comprehensive assessments of the aircraft and wreckage, flight operations, maintenance, crew and passengers, life support and protective equipment, and mission profile based on indepth coordinated inquiries. The format usually follows standards and recommended practices outlined in Annex 13 (Aircraft Accident Investigation) of the International Civil Aviation Organization (ICAO), based in Montreal, Canada.

Organization of Mishap Investigation Boards

The US National Transportation Safety Board (NTSB) is responsible for investigating commercial aviation and transportation accidents in the USA and involving US carriers or aircraft overseas. The Federal Aviation Administration (FAA) has a similar responsibility in general aviation. The NTSB is an independent federal agency created in 1966 that serves as the overseer of US transportation safety with intermodal responsibilities, including railroad, highway, pipeline, marine, and civil aviation transportation. The mission of the NTSB is to determine the probable cause(s) of accidents through direct investigations and public hearings; and secondarily, through staff review and analysis of accident information, evaluations of operations, effectiveness, and performance of other agencies, special studies and safety investigations, and through published recommendations and reports to Congress. The Human Factors Group has a twofold responsibility. The first responsibility is to develop information that may assist in determining the probable cause(s) of the accident by assessing the psychological, physiological, and pathological aspects of crew performance. The second responsibility is to develop survivability factors, which include information on the crashworthiness of the aircraft's structures, seat, and restraint systems, operability of escape systems, emergency training of crew members and the effects of postcrash fire on the ability of occupants to escape from the aircraft. Similar agencies exist throughout the world. The US military has similar responsibilities relative to military aircraft mishaps. Each service has its own infrastructure, including a service safety center, to participate and review mishap investigation findings.

In mishap investigation boards (MIBs), the organization is focused on causal factors in a hazards management program involving 11 primary areas:

1. operations
2. structures
3. power plants
4. human factors
5. aircraft systems
6. witnesses
7. air traffic control
8. weather
9. flight data recorder
10. maintenance records
11. evacuation, search and rescue, firefighting.

The phases of the investigation are generally divided into five categories: (1) preliminary evaluation; (2) data collection; (3) data analysis; (4) conclusions; and (5) recommendations. Safety investigation concepts are based on a number of analytical systems: HW Heinrich's accident sequence influence, Bird and Loftus' updated domino sequence, management oversight risk tree (MORT), and multilinear events sequencing (MES). Heinrich's influence involves a domino principle of five factors: (1) ancestry and social environment; (2) fault of person; (3) unsafe act and/or mechanical or physical hazard; (4) accident; and (5) injury, each with underlying accident causes. Bird and Loftus' updated domino sequence expands on Heinrich's influence with more management parameters focused on people, equipment, material, and environment. Five factors are identified: (1) lack of control in management; (2) basic cause(s)/origins; (3) symptoms of immediate cause(s); (4) incident; and (5) people/property/loss. More recently, MORT and MES systems have been advocated as more effective analytic approaches. NTSB tends to use events and causal factor charting focused on identified systematic factors, contributing and direct factors. In these charting systems, events are occurrences, not a condition, and are precisely described, and quantified where possible and sequenced.

Litigation Focus

From a litigation perspective, aircraft accident investigation is divided between human and machine factors. Human factors include intoxication, cardiovascular pathology, carbon monoxide poisoning, hypoxia, depth perception in darkness and monocular vision, visual illusions, spatial disorientation and vertigo, operational errors, and design-induced crew error. Machine factors are focused on impact based on speed, direction of travel, angle of impact, and altitude and wreckage distribution based on scene documentation and momentum mechanics. Accident reconstruction is not equal to aircraft reconstruction but is based on the sequence of failure. Witness marks are probative evidence and include crush damage, wreckage capture position, primary and secondary impact marks, puncture and rotational marks, and smearing. Varieties of witness marks include paint transfers, paint scratches, bends, gouges and indentations, scratches and scoring, imprint transfers, and crushing. Explored airframe and system failures include propulsion, fuel system, control system, structural and mechanical failures, fatigue and corrosion, electrical systems, design, and complex automated flight controls. Identified human errors include: (1) pilot error; (2) inadequate planning; (3) failure to plan before the flight; (4) inadequate use of checklists; (5) operations outside the norm (flight activities exceeding the safety specifications of that aircraft defined by airspeed, attitude, altitude, and G load tolerance); (6) operation with imperfect systems; (7) operation of a system incorrectly; (8) flying into bad weather; (9) operating when fatigued; (10) flying under the influence (both alcohol and drugs: illicit, prescribed and over-the-counter); (11) operating when not proficient; (12) flight crew errors; (13) air traffic controller errors; and (14) maintenance personnel errors.

Survivability Concepts that are Key to Analysis

Survivability is usually assessed by three parameters: (1) tolerable crash forces; (2) occupiable space; and (3) postcrash environment. Relative to these parameters the machine is evaluated according to the acronym CREEP, where C stands for container crashworthiness, R for restraints, E for environment, E for energy absorption, and P for postcrash environment. There are usually a number of concurrent investigations in a mishap investigation: the medical examiner/coronial inquiry, the safety investigation, and, if required, a criminal investigation. Each of these concurrent investigations has different goals and rules of discovery. The primary goals of the medical examiner or coroner are to determine the identification of the casualties, their cause of death and give an opinion on the manner of death. These are statutory death certificate requirements. As previously stated, the safety investigations are to determine the probable cause of the accident and identify correctable safety issues. A criminal investigation, usually pursued in the USA by the Federal Bureau of Investigation, is to identify culpability and pursue punitive measures.

Forensic Principles

For the pathologist, aviation accidents are often multiple-casualty incidents that require the seven basic questions in any forensic investigation to be addressed: (1) who? (2) what? (3) where? (4) when? (5) how? (6) by whom? and (7) why? In most cases, the most labor-intensive activity is the identification of the casualties for legal certification of death.

Identification

Casualty identification falls into three categories for legal certification: (1) positive; (2) presumptive; and (3) by exclusion. Positive identification is based on unique characteristics of the individual identified by pre- and postmortem comparisons of fingerprints, palm prints, footprints, dental comparisons, DNA profiling, and radiographic superimpositions. These methodologies are the preferred means of identification and in investigations usually involve two or more methodologies. Forensic odontology is the most available methodology since dentition often survives when there is otherwise significant biological degradation through decomposition, autolysis, fragmentation, and incineration. Computer dental identification databases have substantially improved the successful outcome of positive dental casualty identifications. However nuclear and mitochondrial DNA casualty identification is considered the "gold standard" for positive identifications and is frequently successful when other methodologies are inconclusive or not available. This is especially true with fragmented, commingled, and incinerated remains. In the absence of databases containing these DNA profiles or the specimens for such analysis, a presumptive template is necessary, either from personal effects such as toothbrushes and hair samples, or a family genealogical tree must be created based on DNA testing and profiling. This usually requires a conscious decision to DNA-test most, if not all, recovered individual specimens so that commingled remains can be separated and reassociated. In many aircraft mishaps there is considerable fragmentation, incineration and commingling of casualty remains. Recovery, separation, identification and reassociation of these remains usually involves a variety of disciplines. DNA profiling, now considered the gold standard for casualty identification provides the means to identify a single body from composite bodies where separated commingled remains are wrongly reassociated and assigned an identification. Comprehensive DNA testing of recovered specimens may be necessary to avoid misidentification. The expectation of success in this endeavor by the families of the deceased as well as the public makes this aspect of casualty identification expensive in time, labor, and cost. Presumptive identifications are based on class versus unique individual characteristics and include visual identification, personal effects, anthropometrics, serology, and medical conditions. Identification by exclusion requires a closed population in which all other variables have been eliminated.

Forensic Procedures and Resources

Following the identification process, which may involve an assembly-line multidisciplinary approach in mass casualties with significant coordination and information technology input, documentation of

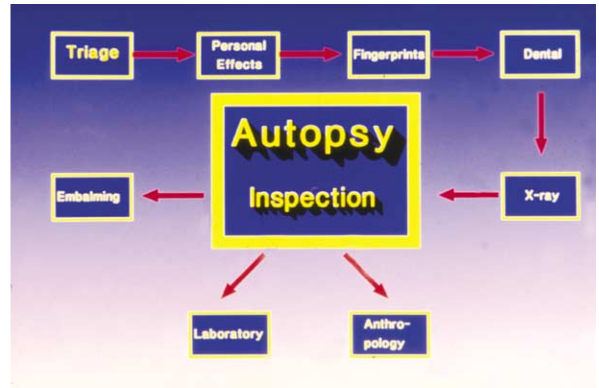

Figure 1 Diagram of medicolegal flow chart for mass-casualty incidents through autopsy and embalming.

the injuries and any preexisting medical conditions through comprehensive medical evaluation is pursued (Figure 1). This medical assessment involves radiographic, autopsy, and ancillary laboratory studies prior to the remains being released for embalming or cremation and final disposition to the next of kin. Resources for these mass-casualty medicolegal investigations often exceed those of the local jurisdiction and may require regional or national assets such as the temporary mortuary facilities of disaster mortuary operational response teams under Federal Emergency Management Agency or military resources such as the Dover (AFB; Air Force Base) Port Mortuary. Frequently, expertise is also available from resources such as the American Academy of Forensic Sciences (AAFS) or the National Association of Medical Examiners (NAME). Resources are often measured by the quality of appropriate facilities, including refrigeration units, radiographic capabilities, and adequate utilities and security. These are often deciding factors as to where this aspect of the investigation is completed relative to the crash site. Where possible, these two geographic requirements are colocated. The complexity of such activities requires the creation, practice, and use of a disaster plan with a coordinated command and control infrastructure.

The autopsy is a primary tool in developing the information for answering most of the forensic questions and must be supported by extensive photographic, histological, toxicological, radiographic, and diagrammatic representations of the findings, as well as the trace evidence analyses, DNA profiling, and physical anthropology studies that may be required. In general, the autopsy procedure follows that of any other forensic inquiry but usually requires additional procedures to document specific regional injuries. These procedures include a layerwise back-of-the-neck dissection (Figure 2), potential selective

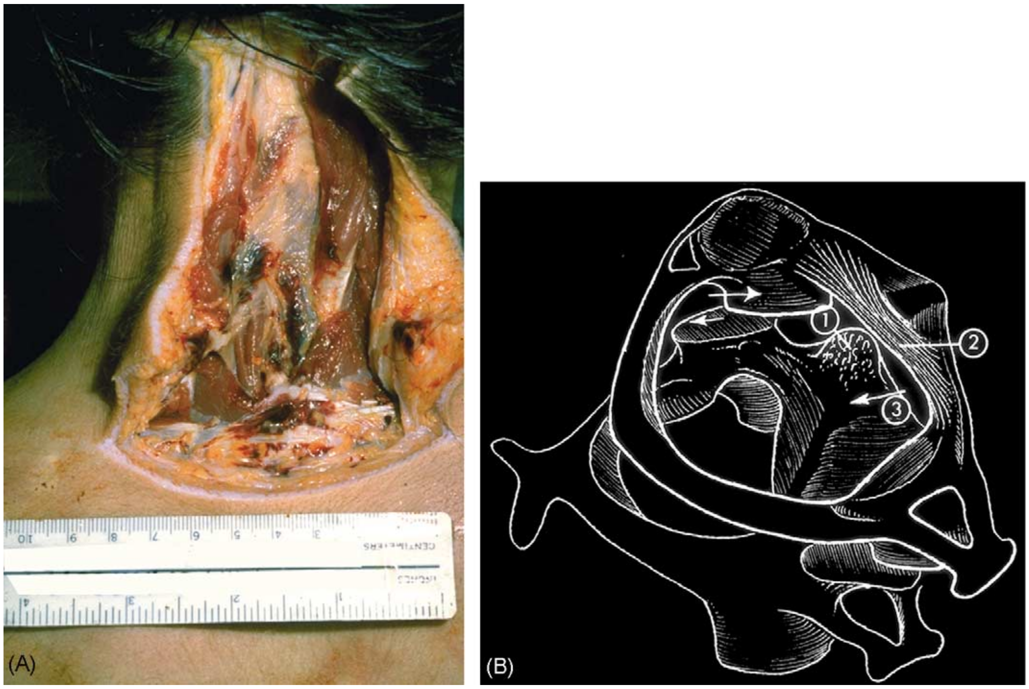

Figure 2 Back-of-neck layerwise dissection at autopsy to disclose cervical injuries. 1, lateral ligaments of the atlanto-occipital synovial membrane; 2, transverse ligament; 3, posterior atlanto-occipital membrane (a broad ligament).

angiography, examination of the spinal cord, and surgical exploration of select extremity injuries, especially those thought to be control surface-induced.

Injury Analysis and Reconstruction

Injury analysis is based on the documented gross and histological findings at autopsy supported by radiographic and toxicological evidence and is classified according to acceptable parameters into penetrating injuries, blunt-force trauma, thermal injuries, asphyxiation, drowning, hypothermia, gunshot wounds, and blast injuries. Injuries have characteristics that reflect applied force magnitude, direction, frequency, or interval, and are important in interpreting mechanism, instrumentality, time of injury, and time of death. In aviation accidents, this injury analysis is critical to reconstructing the sequence of events and human–machine interactions impacting on survivability. Crash force assessments include system trauma biodynamics and are usually characterized relative to applied force (G_z, G_x, G_y), system tolerance, and documented findings. The AFIP uses anatomical markers identified at autopsy to define likely tolerance parameters and compares that to physical evidence at the scene and crash force calculations to interpret survivability. These anatomical markers of quantifiable applied force have been developed over time and with experience and validated against data from completed mishap investigation reports (Table 1). These autopsy markers are force approximations and should be compared and validated against engineering data developed during the investigation and reflect the interdependent multidisciplinary requirements of such medicolegal death investigations. The most useful systems for evaluation include the vertebral column, cardiovascular system, and pelvis.

Table 1 Armed Forces Institute of Pathology (AFIP) morphological markers of crash forces

Observation	***g** force*	*Axis*
Vertebral fractures	15–30	G_z, G_x
Pulmonary contusions	25–30	G_x, G_y
Rupture of atlantooccipital membrane	30–35	G_z, G_x
Laceration of aorta	50+	G_x, G_z
Transection of aorta	80+	G_x, G_z
Skull fractures	50+	G_x, G_z, G_y
Pelvic fractures	100+	G_z, G_x
Fragmentation	350+	G_x, G_z, G_y

Reconstruction of the mishap sequence is possible through documented injury pattern comparisons linked to physical evidence at the scene, modeling, and “black box” data. Emphasis must be on injury patterns and specific injuries directly related to:

1. impact forces
2. time, duration, and direction of applied forces
3. cockpit or cabin configuration

4. nature of the accident and subsequent occurrences
5. occupant kinematics in the accident, particularly relating to restraint systems.

Each body portion has a tolerance, or a range of tolerances, to injury. In all, 70–80% of deaths and injuries in accidents result from head contact with structures. These kinds of statistics have driven the injury pattern analysis into two main categories: (1) diagnosis; and (2) injury prevention. In diagnosis, similarity and deviations in different accidents and in multiple casualties from the same incident become the sought-after pattern for analysis. In injury prevention, it is repetitive injury, for example, head injuries from cyclics, a control device in helicopters, in helicopter crashes, helmet loss or life support or restraint injuries; and modification of injury by environment and/or equipment.

Investigative Template

A series of questions often used by investigators to provide a basis for interpreting investigation results provides a useful template for analyses, conclusions, and if appropriate, recommendations:

1. Why did certain casualties die?
2. To what feature of the accident or of the aircraft can be attributed the escape of the survivors?
3. Would any modification of the aircraft or of its equipment have improved the chance of survival of those killed or reduce the severity of survivor injuries?
4. Would the incorporation of such modifications have a detrimental effect on any of the survivors' chances?
5. Is there any indication that the main or any subsidiary causes of the accident might have been medical in nature?

Patterned Injuries

Particular injury patterns deemed critical to this analysis include control surface injuries, restraint injuries, incapacitating injuries, penetrating injuries, such as those from intrusions, life support equipment injuries, flail injuries, and craniocervical injuries in ejections with or without helmet use. Radiographs of the casualty as recovered and while dressed as well as those obtained after undressing and cataloging of clothing, personal effects, gear, and equipment on the body may demonstrate possible causal interactions. Particular emphasis should be placed on the craniocervical segment, extremities, and the thoracoabdominal region.

Control surface injuries are specific skeletal and soft-tissue injuries of the hands, forearms, and distal lower extremities attributed to impact against aircraft control levers and pedals such as the stick, yoke, and rudder pedals (Figure 3). These injuries usually contain trace evidence supporting the interpretation. The importance of this series of injuries, assuming sufficient forces to create them, is to exclude in-flight crew incapacitation scenarios.

Restraint injuries reflect the type and configuration of restraints used, if any, and include abrasion/contusions of the shoulder girdle, abdomen, and pelvis. The presence of restraint injuries supports either an anticipated emergency or normal flight activities. The absence of restraint injuries in one or more persons in a multiple-casualty mishap where the majority of victims reflect these injuries suggests pursuing reasons for the "odd one out" injury pattern. The likelihood of flail injuries consisting of skeletal fractures and soft-tissue avulsions is defined by the safety norms (Figure 4). The margin of safety is determined by the characteristics of the aircraft design, the restraint system, and it is also determined by altitude, air speed, and attitude.

Incapacitation injuries are those that would either likely render the victim unconscious or prevent voluntary escape from the aircraft. This is particularly important in the postcrash environment if the aircraft mishap is otherwise considered survivable based on crash forces and occupiable space.

Thermal injuries are common and often complex, complicated by commingling and fragmentation. Evidence of survival is dependent on the documentation of all potentially fatal injuries and evidence of inhalation-soot in the airways, pulmonary congestion, positive toxicology findings for carbon monoxide and cyanide, as well as other potentially toxic substances. Full-body radiographs are critical. Artifacts commonly encountered include pugilistic body positions, extremity fracture/dislocations, heat amputations, epidural hemorrhages, and comminuted skull fractures. Fires are a common postcrash occurrence so injury analysis must be interpreted relative to survivability parameters. Evidence of life during the fire is dependent on the severity of documented trauma and extensive toxicology studies.

Drowning or water immersion is another relatively common postcrash environment circumstance and is a diagnosis of exclusion. The autopsy should be able to exclude other fatal injuries and perhaps explain why the occupant could not exit the aircraft because of incapitating injuries or entrapment. Hypothermia also plays an important role in immersion fatalities. Autopsy findings in drownings consist of pulmonary edema, hyperinflated lungs, pleural effusions and

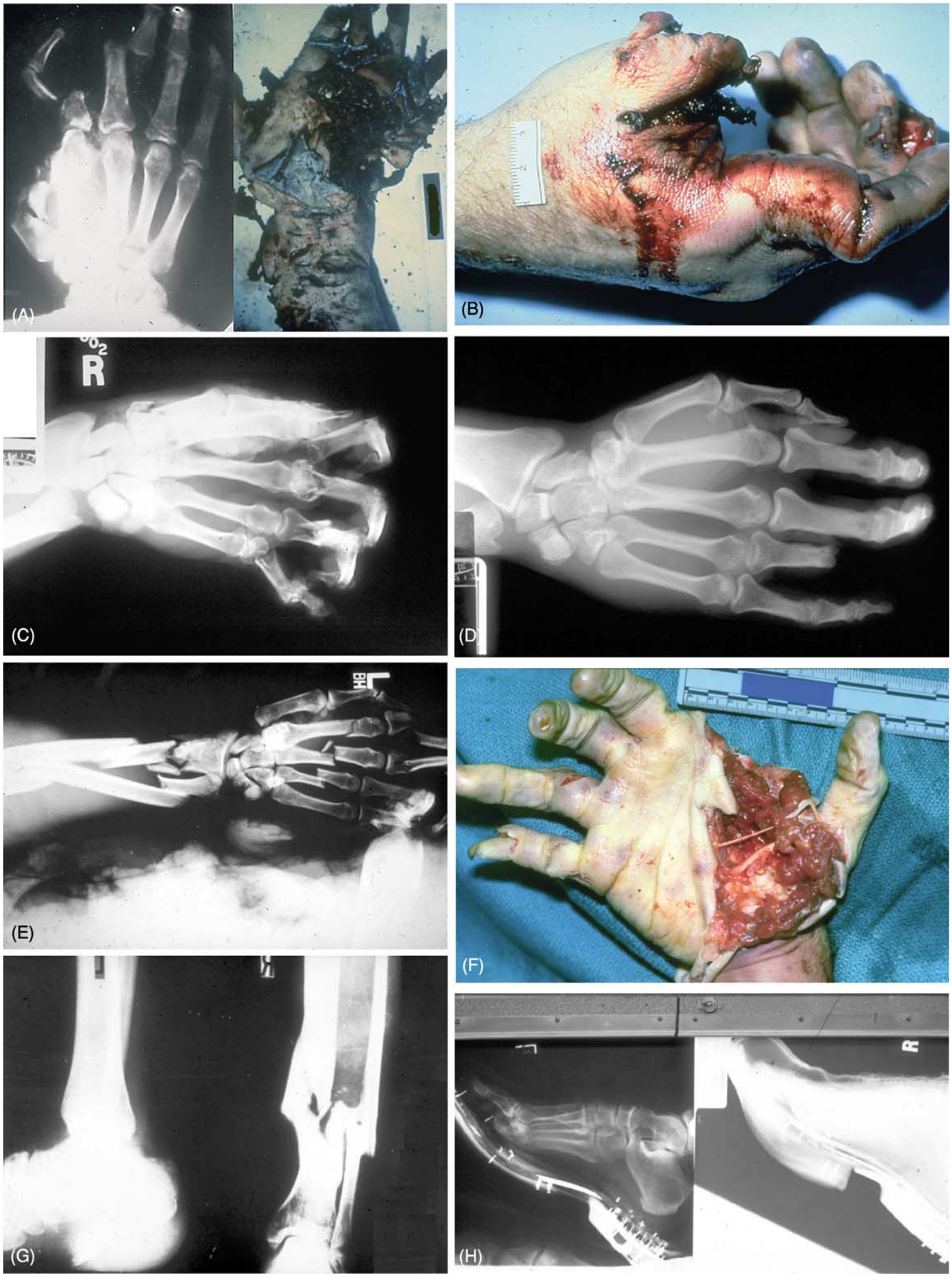

Figure 3 Hand and foot injuries including radiographs – control surface injuries. This series of photographs is of common soft tissue and skeletal injuries encountered on the hands and feet when they are in contact with aircraft controlling surfaces (rudders/pedals for the feet, yoke/control stick for the hands). The fractures are predominantly transverse rather than diagonal and are relatively uniformly spread across the bony structures. The pattern is consistent with the design of the aircraft's control surfaces. Those forces are also transmitted through the extremity to proximal joints/articulation. The most common soft tissue injuries are those to the soft tissues of the thumb and represent the thumb's usual apposition to the hand's other digits. The figures of the feet with boots on show bending of a longitudinal metal plate in the boot and separation of the sole. This finding is indicative of a force transmitted vertically through the foot. The significance of these findings are interpreted as proof of the pilot/aircrew member trying to control the aircraft at impact rather than being incapacitated (unconscious or not at the controls).

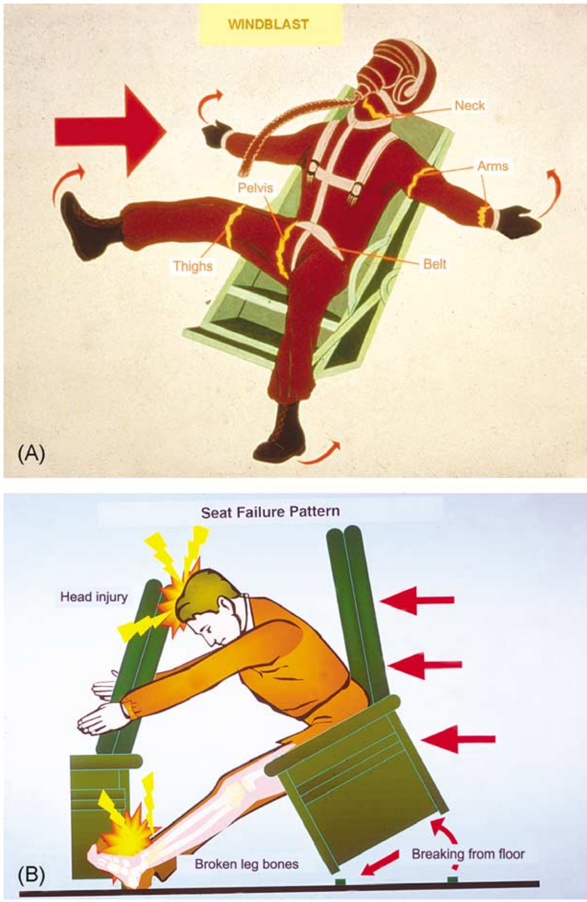

Figure 4 Classical pattern injuries. (A) Flail injuries common during high-speed ejection; (B) shows seated and restrained common injuries.

hemorrhages in the sinuses and middle ears, and possibly air embolism. Air embolism, excluding divers who fly shortly after a diving operation, is most likely found in water-immersed casualties recovered from the depths. In these cases, it is an artifact induced by the recovery ascent. Particularly in cold-water immersions, "dry drowning" may occur from laryngeal spasm.

Computer-assisted analysis of injuries has significantly improved injury analyses. A number of programs exist and allow the data to be tailored to the circumstance. This type of approach to injury epidemiology is being used with greater frequency and success. Studies done based on death certificate data indicate that, despite a reduction in the number of fatalities, the injury patterns were relatively stable. One such recent study showed that multiple injuries were listed as the immediate cause of death in 42% of fatalities, followed by head injury (22%), internal injury of thorax, abdomen, or pelvis (12%), burns (4%), and drowning (3%). Head injuries were most common amongst children. The majority (86%) died at the scene or shortly thereafter on hospital arrival. Blunt-force trauma related to restraint and aircraft design remained the single greatest hazard identified. These kinds of study define persistent parameters of inquiry for injury reduction in design, engineering, and personal protective equipment.

Jurisdiction Issues

The documentation of injury and any preexisting disease is dependent on access to the casualty as well as to the scene and to the victim's medical and dental records. This requirement raises the issue of challenges to jurisdiction and possible conflicts between the NTSB, military services, and the local medical examiner or coroner. In the USA, there are three basic kinds of jurisdictions relative to fatal casualties: (1) exclusive federal; (2) concurrent; and (3) proprietary. In general, there are relatively few exclusive federal jurisdictions (i.e., Dover AFB, Delaware). Most investigations will fall into the concurrent jurisdiction arena where local authorities will have first right of refusal but there is concurrent federal or military interest and participation. In proprietary jurisdictions, the local authority retains control of fatalities regardless of federal or military interests (District of Columbia). Jurisdiction is also defined by the initial port of entry for deaths in international waters or air-space, and/or by treaty agreements such as those existing in NATO.

Preexisting Medical Conditions

Preexisting medical conditions are also an important aspect of the accident investigation and are classified as proximal, contributory, or incidental according to the severity of the documented condition and the overall sequence of events as defined by the safety investigation. In general, there are only three systems whose diseases can kill suddenly: (1) central nervous system (CNS); (2) cardiovascular; and (3) respiratory. These three systems deserve comprehensive pathological assessments. Histological microscopy studies supporting or expanding gross autopsy findings are important to document the presence and significance of these findings and to complement data developed from a review of available medical records, clinical laboratory, and toxicology studies. Radiographic data are particularly important in validating these conditions and should be used as appropriate in the documentation. Access to medical and dental records is mandatory in this aspect of the medicolegal investigation.

This pathology effort of the investigation is widely believed to be more subjective than most observers believe. There are three superimposable interpretative challenges: (1) mimicry; (2) superimposition; and (3) interruption. In mimicry, the results of trauma may closely mimic those of natural disease, for example, pulmonary congestion or intracranial hemorrhage. Superimposition of trauma on natural disease is problematic, especially in cardiovascular pathology and specifically in coronary artery disease. Trauma will also interrupt the course of natural disease so that the precursor condition rather than the endpoint of a disease must be defined. Much of this effort is focused on cardiovascular disease because, numerically, it appears to have a greater significance in relation to aircraft accidents. Aside from coronary artery disease, myocarditis is often identified as a causal factor. Other potentially dangerous conditions demonstrated only on microscopy include encephalitis, pneumonitis, sarcoidosis, and allergic states. Occult disease, such as epilepsy, that becomes discoverable through medical records, witnesses, and/or toxicological studies must also be considered. A more recent preexisting condition reported in passenger morbidity and mortality is pulmonary embolus from deep-vein thrombosis (DVT). Prolonged static positioning on long flights is the proposed contributing factor. Clinical molecular tests such as factor V Leiden may identify those predisposed to DVT.

Toxicology Analysis

Toxicology studies are an extremely important aspect of aircraft accident investigation. Materials from nonfatal mishaps (blood and urine) are routinely analyzed either at the FAA Civil Aeronautical Institute in Oklahoma City or for the US military at the Armed Forces Institute of Pathology in Washington, DC. Similar national reference laboratories exist in all countries. Tissues from fatal aircraft accidents are also analyzed at one of these two agencies and include blood, urine, bile, vitreous humor, gastric contents, and organ specimens. When necessary, similar studies can be carried out on muscle, bone, and hair as well as entomological specimens recovered on the remains. Blood and urine are screened for a variety of substances, including alcohol, carbon monoxide, and a spectrum of acid, basic, and neutral drugs. Confirmatory tests follow any positive blood or urine screening. These studies are then usually followed by specific organ tissue analysis to qualitate and quantitate any chemical substances present. The bulk of this analysis is done by advanced instrumentation, including gas chromatography, mass spectroscopy, high-pressure and capillary liquid chromatography, and a variety of immuno-based methodologies. Therapeutic drug screening may be crucial in these chemical analyses either for identification purposes or for evidence of underlying preexisting medical conditions. In decomposition cases, a spectrum of alcohols, ketones, and aldehydes is present and may generally indicate that low levels of ethanol present could be an artifact. Vitreous humor analysis is useful in this circumstance since it is resistant to decomposition. Drinking and flying, while infrequent, appears to occur more often in general aviation than in commercial or military aircraft mishaps.

Fires are a common postcrash factor and in-flight fires are not unheard of, often resulting in aircraft structural damage contributing to mishap. In fatal crashes, and especially in casualties with thermal injuries, extensive toxicology studies are needed to evaluate the inhalation of fire products, particularly carbon monoxide, cyanide, and other pyrolytic chemicals. Carbon monoxide and cyanide are two substances that, when detected and linked to documented soot in the airways and thermal damage, are clear indications of a survival interval during or after the fire. Extensive chemical analysis for pyrolysis products may characterize a particular etiology or substance hazard. A high index of suspicion may be necessary to focus the chemical inquiry. Fire deaths in aircraft mishaps have not decreased in recent years despite engineering efforts to reduce risk. Fire remains a serious cause of morbidity and mortality in the air and on the ground. Heat, smoke, and toxic gases are potent causes of morbidity and mortality and continue to attract considerable interest in the aviation community. Recently, a number of investigators have questioned the importance of cyanide in fire deaths, especially since cyanide may be produced as well as metabolized in postmortem tissues. Additional future studies will hopefully clarify this issue.

Forensic Biochemistry

Biochemical postmortem analysis may be required to substantiate certain physiological conditions suspected beyond those addressed in toxicology studies. Many blood enzymes become unstable with an increased postmortem interval. Nonetheless, more expansive use of the clinical laboratory may be justified depending on the case and particular issue. Specimens used for evaluation include whole blood, serum, bile, urine, cerebrospinal fluid, and vitreous humor.

Scene Investigation

The scene investigation should be part of the pathologist's checklist and is particularly useful when linked to the assigned mishap board flight surgeon or aviation medical examiner, as well as

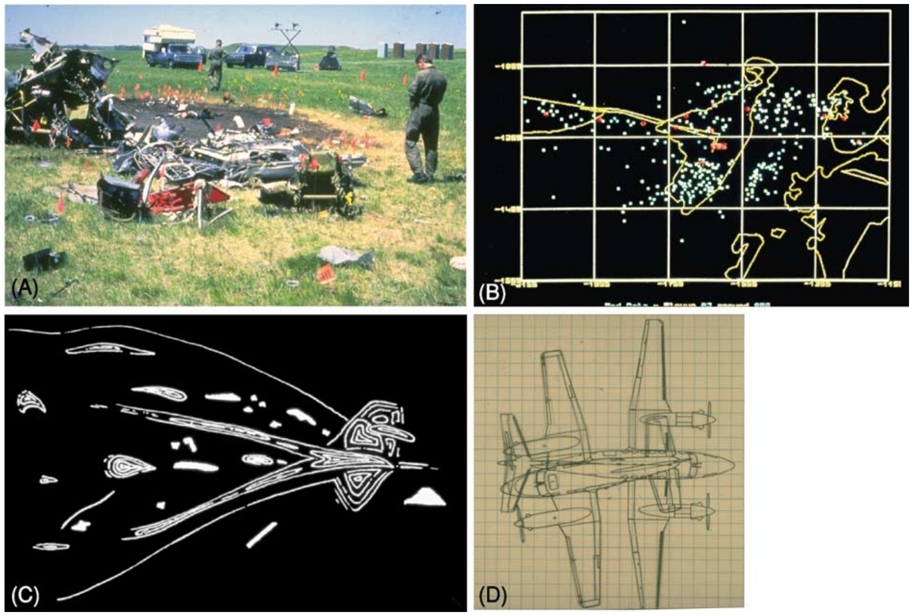

Figure 5 A typical crash site and charting.

other representatives from flight operations, maintenance, or engineering. This provides a broad-based multidisciplinary investigation platform. Furthermore, knowledge of the crash site characteristics is often useful in the subsequent injury interpretations resulting from the pathologist's findings. Recovered body location versus assigned seat locations and aircraft configuration provides insight into the crash sequence and may give clues to trauma etiology. The crash site, once secured, is typically divided into segments and coordinated recovery is correlated with segment and location for biological material, power plant, instrumentation and controls, ordnance, and aircraft structure (Figure 5). Ongoing security is critical as well as protection against hazardous materials. This risk appears greater today with the use of composite materials and is required by OSHA (Occupational Safety and Health Administration) or similar regulations. Access will not be permitted until the crash site and wreckage are rendered safe by explosive ordnance disposal, firefighters, and utility personnel. Heavy equipment is usually needed for wreckage recovery and transportation. This equipment and its operation provide additional hazards. Postcrash fires may delay the recovery of human remains and sifting through the wreckage, prolonging evidence retrieval.

Aerial photography, including infrared color photography, may provide valuable clues to wreckage distribution, witness marks, and impact parameters. Photographic and diagrammatic representations are essential and should be accurate, identified, and comprehensive. Success in these operations is often defined by the location and nature of the crash site and the availability of resources to exploit search-and-rescue and search-and-recovery efforts. In the Arrow Air crash in Gander, Newfoundland, Canada, in December 1985 that killed all 256 persons aboard, including 247 service members returning from the Sinai to Fort Campbell, Kentucky, the crash site on the side of a mountain needed to be excavated in February to recover all the remains and aircraft. This effort required the involvement of the people of Gander, the Royal Canadian Mounted Police, and the US Army with units from Fort Bragg, North Carolina and Fort Campbell, Kentucky, as well as the AFIP. Evaluation of the site also required the use of cadaver dogs, divers to explore Lake Gander, and Canadian military helicopters for surveillance, mapping, and wreckage transport. On-site pathology services proved critical to the successful recovery of all victims.

Summary

Aircraft accident investigations are studies in concurrent and multidisciplinary investigations where a successful outcome is based on cooperation, coordination, collaboration, and comprehensiveness. The medical findings at autopsy and its ancillary laboratory studies provide a critical perspective in the overall accident investigation as to probable cause, level of survivability based on crash forces, occupiable space, and the postcrash environment, and the role of any preexisting condition as a risk factor. A comprehensive medicolegal investigation will provide the data necessary to link those concurrent investigations.

See Also

Body Recovery; **Death Investigation Systems:** Japan; **Falls from Height, Physical Findings:** In Children; In Adults; **Fire Investigation, Evidence Recovery**; **Injury, Transportation:** Air Disasters

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