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William J. Reals

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THE USE OF AVIATION PATHOLOGY AND AVIATION MEDICINE AS PROOF OF LIABILITY AND DAMAGE

WILLIAM J. REALS*

and

JOHN F. REALS**

The first fatal aircraft accident in the United States (and possibly the first in the world) in which investigation of trauma was made occurred at Ft. Myer, Virginia, in 1908. The United States Army was flight testing the Wrights' airplane "The Wright Flyer" with Orville Wright serving as pilot and Lt. Thomas Selfridge, a member of the United States Army Evaluation Board, as passenger and observer. The aircraft crashed at low altitude when a propellor blade separated in flight, damaging struts and braces, causing a wing failure.¹

Lt. Selfridge was severely injured in the accident and was dead on arrival at the Ft. Myer post hospital. Wright survived the crash, suffering a fracture of the leg. The surgeon's report on the Selfridge fatality on file at the Armed Forces Institute of Pathology (AFIP) in Washington, D. C., states that Lt. Selfridge was killed as a result of falling on his head and sustaining a fracture of the skull.² Lt. Henry "Hap" Arnold, later General Arnold of World War II fame, apparently learned from the Selfridge accident, since a famous photograph shows him seated in the rebuilt Wright Flyer, wearing a protective football helmet.³ This is the first re-

* B.S. 1944, M.D. 1945, M.S. 1949, Creighton Univ., Professor of Pathology and Chairman, University of Kansas School of Medicine—Wichita.

** B.S. 1971, Wichita St. Univ.; J.D. 1974, Washburn Univ.; Attorney at Law, Wichita, Kansas.

¹ AEROSPACE PATHOLOGY 1 (J. Mason & W. Reals eds. 1973) [hereinafter cited as AEROSPACE PATHOLOGY].

² See W. REALS, MEDICAL INVESTIGATION OF AVIATION ACCIDENTS 2 (1968).

³ *Id.* at 3.

corded instance in which the study of aircraft accident trauma resulted in the application of protective devices, since lap-belts also were added to the airplane.⁴

I. INTRODUCTION

The investigation of an aircraft accident calls upon the expertise of many disciplines ranging from engineering to the human behavioral sciences. The forensic pathologist is a key investigator in these cases, as are forensic scientists, and aero-medical experts. The medical aspects of the accident investigation may require the participation of pathologists, toxicologists, odontologists, anthropologists, and psychiatrists as well as others.

The objectives of the medical and pathological investigation of an aviation accident begin with the identification of the victims, both from a civil aspect, i.e., insurance, estate, workmen's compensation and liability, and also the criminal aspect, such as willful sabotage, false identification of victims, homicide and suicide, as well as accidents due to skyjacking. It is important next to reconstruct the crash sequence, including the distribution of the victims' bodies on the ground or in the aircraft, and to catalog in detail the injury patterns. In addition, there should be correlation of the sequence of the disintegration of the airplane both in the air and later on the ground. Next, there should be a determination of medical facts which may have been major or minor factors in causing the crash. These include the crew's possible physical defects such as cardiovascular disease, neurological or respiratory diseases, and other illnesses. Levels in the blood of chemicals such as alcohol, drugs, and carbon monoxide, as well as lactic acid, should be determined. In agricultural spraying accidents, insecticides may be a factor since they are highly poisonous. Medical and psychiatric background evaluations should be reviewed through the family physician or flight surgeon. These steps should be taken as to all members of the crew, and selected passengers should have the same type of background study done.

The investigation will elicit information of value for better structural design to minimize injury or death in future crashes. The Civil Aeromedical Institute of the Federal Aviation Adminis-

⁴*Id.*

tration in Oklahoma City is a repository of such information, as is the Flight Safety Foundation in California. There should then be collection and preparation of material for teaching purposes. The Armed Forces Institute of Pathology is a central laboratory for toxicology and aerospace pathology for both civil and military aviation. Information from the investigation will be of help to industry in aircraft design, the development of escape devices, and restraints for both passengers and crew. In addition the information will be of value to both pilot and aircrew and of course to accident investigators who are active in air safety. These include air safety technicians, physicians, aviation medical examiners, and flight surgeons.

II. AVIATION PATHOLOGY

Aviation pathology, essentially an exercise in correlating autopsy findings with the total environment of a fatal aircraft accident, was probably first used on an organized basis by the German Air Force in the Second World War.⁵ Although the Luftwaffe pointed the way, very little post-war progress was made until the stimulus of the outstanding contribution to the interpretation of the Comet aircraft losses made by the Farnborough workers was published in 1955.⁶

Major credit for appreciation of the potential of this work must be given to the then Directors of Pathology in the United States Air Force and Royal Air Force—Colonel Frank M. Townsend, USAF, MC and Air Commodore William P. Stamm—who simultaneously set up Departments of Aviation Pathology at the Armed Forces Institute of Pathology, Washington, D.C. and at the Royal Air Force Institute of Pathology at RAF Halton, in England.⁷ The work of these two Institutes, and later that of the West German Air Force at Furstenfelbruck, in military accidents focused attention on the need to conduct human-factors investigations in all fatal accidents, civilian as well as military.

Accident investigation must be carried out within the legal

⁵ DEPARTMENT OF THE AIR FORCE, GERMAN AVIATION MEDICINE IN WORLD WAR II 616 (1950).

⁶ Armstrong, Fryer, Stewart & Whittingham, *Interpretation of Injuries in the Comet Aircraft Disasters—An Experimental Approach*, 1 LANCET 1135 (1955).

⁷ See Dept. of Defense Directive No. 5154.11 (Nov. 14, 1955).

framework of the state in which the accident occurs; many of the laws of the states were enacted long before the days of mass air transportation. A coroner or medical examiner generally has jurisdiction over the bodies of the victims and his permit or authorization must be attained before the pathologist can perform autopsies. The National Transportation Safety Board (NTSB) can invoke its powers⁸ to secure autopsies on the bodies of those killed in aviation accidents, including aircrew members, if permits for autopsy are not readily given, or when it is not possible to contact the local authorities promptly.

Most fatal general aviation accidents and all airline accidents are fully investigated. As a result, there are numerous reports in the medical literature which contribute to the understanding of human factors in all types of aviation accidents. These reports and findings are being utilized with increasing frequency in the courts of the United States.

In addition to the investigative benefits accruing in individual accidents, aviation accident investigation opens new vistas for research in general forensic pathology. Recently, great strides have been made in toxicology due to the development of new analytical equipment,⁹ and the way is open for similar advances in histochemistry and biochemistry. It is in these fields that the more subtle ante-mortem changes are likely to be demonstrated at autopsy. Evidence of these changes in the future will be a part of court actions involving questions of time of death and survivorship.

The three areas in which pathologists seek information as to the cause of death in an aviation accident are: (1) environmental factors; (2) trauma; and (3) pre-existing disease. Findings recorded in the autopsy protocol in these areas may have great bearing on the course of lawsuits involving aviation accidents. Each of these will be discussed in turn.

A. Environmental Factors

The environmental factors which may be a cause of aviation accidents include the altitude, the speed of the aircraft, and re-

⁸ See 49 U.S.C. § 1903(b)(5) (1976).

⁹ The most notable advance has been the development of gas chromatography, a technique for separating and detecting traces of volatile chemicals using a stationary column of resin and a moving stream of air.

sulting G-forces. In addition, toxic substances such as carbon monoxide, alcohol, or drugs may be a factor. High and low temperature, noise, and stress are rarely factors but should be considered in the evaluation of the accident.

1. *Altitude and Hypoxia*

At 18,000 feet altitude above sea-level, half of the atmosphere is below the aircraft and the pilot and the partial pressure of oxygen is insufficient to support life except for brief periods.¹⁰ Pressurization of the aircraft or oxygen life support systems including breathing masks are essential for flights above 10-12,000 feet. Present day general aviation aircraft now operate in the upper atmosphere and carry the necessary supplemental oxygen systems. Any failure of the system can result in hypoxia, confusion, inability to control the aircraft, unconsciousness, and eventual impact with the terrain. Franks and his co-workers in Canada have demonstrated that elevated lactic acid levels are found in the brain tissue of fatalities from hypoxia or hypoxia-induced accidents.¹¹ In an otherwise unexplained accident, lactic acid elevation may indicate a need for evaluation of the aircraft's oxygen system by life support equipment experts.

2. *Toxins*

Carbon monoxide is a colorless, tasteless, odorless gas which results from incomplete combustion and is a product of internal combustion engines. When combined with hemoglobin in the human blood cells due to inhalation it forms a substance—carboxyhemoglobin—which poisons the red cell by preventing it from combining with oxygen during respiration.¹² Cabin heater mufflers which utilize the heat from aircraft engine exhaust systems have caused accidents in the past by venting carbon monoxide (CO) from broken or cracked exhaust pipes into the cabin through the heater.¹³ The presence of elevated blood CO levels of about ten percent may indicate that the accident was due to pilot incapacitation. It should be noted, however, that smokers have a higher CO

¹⁰ See generally H. RANDEL, *AEROSPACE MEDICINE* 338 (1971).

¹¹ Franks & Anderson, *The Value of Post-Mortem Lactate Analyses in Aircraft Accident Investigation*, in *AGARD CONFERENCE PROCEEDINGS* (1970).

¹² See H. RANDEL, *supra* note 10, at 271.

¹³ See *AEROSPACE PATHOLOGY*, *supra* note 1, at 198.

level than non-smokers, and this habit must be considered in evaluating an elevated CO level. In the past, CO intoxication caused by defective heaters has been the basis of numerous lawsuits against aircraft manufacturers.

When the issue is survivorship or determination whether the pilot was alive at the time of impact, CO analysis can be helpful. A level of CO above ten percent may indicate that the individual was alive during a post crash explosion and fire; in the case of a husband and wife killed in a common accident, the individual with the highest CO level presumably lived the longest time in the fire, thus establishing the sequence of death for estate and other purposes.

3. Alcohol

Tests for blood alcohol should be performed on aircrew members in every aviation fatality. Alcohol is a toxic substance in its effect on the central nervous system, but has become a socially acceptable drug, widely used and abused in our society. It obviously cannot be ingested before or during flight by the pilot if he is to control a complex modern day aircraft at high altitudes and great air speeds. Moreover, Federal Aviation Regulations forbid ingestion of alcohol within eight hours prior to flight.¹⁴ Decreased oxygen tension and hypoxia accentuate the effect of alcohol on the higher centers in the brain, a condition not experienced on the ground at normal atmospheric pressure.¹⁵

Post mortem blood alcohol levels done soon after death, if 1.0 mgm/ml or higher, are evidence of legal intoxication,¹⁶ and may indicate the principal reason for loss of aircraft control and subsequent crash. There are numerous well-documented instances of drunken flying in general aviation accidents.¹⁷ It has not been found in any major air transport accident, thanks to both Federal Air Regulations and the self-imposed discipline of airline pilots.

Blood alcohol levels done post mortem can be introduced as evidence in court so long as there is proper procedure in obtain-

¹⁴ 14 C.F.R. § 91.11 (1978).

¹⁵ See Harper & Albers, *Alcohol and General Aviation Accidents*, 35 AEROSPACE MEDICINE 462 (1964).

¹⁶ The concentration of alcohol in the blood which will establish intoxication as a matter of law may vary from state to state, but is generally set by statute.

¹⁷ See H. RANDEL, *supra* note 10, at 598.

ing the sample, performing the test, and recording the results, much as in automobile accidents in which alcohol is a factor. Pathologists usually secure blood from the heart by needle aspiration prior to autopsy incision, in order to prevent contamination by fuel or other chemicals that may be on the body as a result of the crash. The blood specimen thus obtained can be analyzed for carboxyhemoglobin, carbon monoxide, alcohol, and other licit or illicit drugs which may have a bearing on the accident. Other drugs found may include antihistamines, tranquilizers, and many others. Medical consultation will be needed in such cases to assess the role of these therapeutic agents in the accident. Cyanide gas may also be present in blood specimens. It is produced by the burning of plastic materials such as headliners in aircraft cabins and causes asphyxiation since cyanide also poisons the red cell preventing normal oxygenation.

Speed, G-forces, temperature noise, and stress are also environmental factors, but will not be discussed here since there are no precise post mortem means for determination of their effect. Consultation with a flight surgeon or aviation medical examiner is recommended in each accident in which there may be litigation to discuss the possible role of these factors.

B. Trauma

Trauma in aviation accidents so overshadows other aspects of catastrophic crashes that the worth of an investigation is often questioned because the cause of death appears to be so obvious. In fatalities resulting from an accident, however, it is not enough for the pathologist to state simply that the cause of death was multiple crushing injuries. Scientific investigation requires identification and description of the exact cause of the injury that resulted in death. It is only by this careful examination and description that design engineers can learn to prevent future injuries. The aviation pathologist must conduct a careful, detailed study, employing inductive reasoning and utilizing closely related techniques such as biochemical and toxicological analysis, color photography, dental examinations, and portmortem X-rays. All of these findings will be of great value when offered in court as evidence as to the cause of death and also to detail injury patterns.

There are definite relationships between injury patterns and the

aircraft, that is the man/machine interface.¹⁸ The first factor in order of importance is the magnitude of the impact forces, which can be quite high, followed by the time, duration, and vector of these forces. Design of the cabin and/or cockpit will have a relationship to injury patterns, particularly in the case of pilots who may impact the instrument panel. The nature of the accident is important; for example, a stall, spin, or disintegration in the air will have a far different injury pattern than an accident in which the aircraft makes a hard crash landing. Following is a discussion of the kinematics of the occupants in the accident, particularly relating to the restraint system, that is, the seatbelt and/or shoulder harness.¹⁹

Trauma in aircraft accidents is the result of varying causes.²⁰ First is the high-speed and high-impact trauma of accidents involving turbojet aircraft, usually multi-engine, and propeller-driven aircraft of the multi-engine class but of lower air speed and lower terminal velocity.²¹ Second is trauma from general aviation accidents, that is, those involving small single-engine and multi-engine aircraft weighing less than 12,500 pounds.²² Third are injuries resulting from helicopter or rotary wing aircraft accidents, glider accidents, and parachute accidents resulting either from emergency escape from an aircraft or sport parachuting.²³ In-flight bird strikes are also a cause of severe injury, and have caused aircraft accidents with multiple casualties.²⁴

The forces to which the body is exposed in aircraft accidents can range to explosive forces or impacts of several hundred "G's" which result in severe injury and destructive trauma. A careful examination may offer some evidence of the stresses to which the body was exposed before and during the crash. Thus, an inflight fire, explosion, gunshot wound, cabin decompression, or disintegration of the aircraft due to a mid-air collision may be reflected on

¹⁸ McMeekin, *Patterns of Injury in Fatal Aircraft Accidents*, in *AEROSPACE PATHOLOGY*, *supra* note 1, at 86.

¹⁹ *Id.*

²⁰ Reals, *Air Disasters—Trauma*, in *FORENSIC MEDICINE* at 876 (C. Tedeschi, W. Eckert & L. Tedeschi eds. 1977).

²¹ *Id.* at 877.

²² *Id.* at 879.

²³ *Id.* at 882-83.

²⁴ *Id.* at 885.

the surface of the body by specific marks or foreign material marks or imbedded metal in the body. The human remains available to examine may consist of a small one millimeter fragment scraped from a vertical stablizer edge or an intact body with no major external injuries. Tissue fragments may be identified microscopically as to their human origin, may be tested for blood groups, and for the presence of abnormal chemical constituents and/or poison. They may be examined by an anthropologist for determination of sex, race, and age if there is an intact bone available, and examination by postmortem X-rays for the presence of foreign material which might include a bullet fragment or a part of a bomb. Teeth recovered should be examined by an oral pathologist or forensic dentist. Teeth often survive an intense fire, and may be the only means of identification.

Injuries to specific areas of a relatively intact body may be helpful in identifying a possible hazard in the cabin or cockpit area which resulted in a fatal or severe injury in an accident which should have been survivable. Thus, a head wound to the pilot may indicate that an overhead radio box or dial impacted the head and caused severe skull damage. The utilization of helmets by military operational crews indicates the importance of having a complete analysis of injuries in order to prevent similar future injury and death. The Selfridge accident mentioned earlier in this paper²⁵ is a classic example of human factors analysis, but the lesson learned by Lt. Hap Arnold was forgotten until the early 1950's when jet aircraft entered the inventory of the Air Force and Navy, when flying helmets were developed as protective devices.

The injury pattern may also be helpful in determining the attitude of the aircraft on impact. In a nose down situation, for example, the injuries may differ from those where there is a horizontal impact. Head and perineal injuries may indicate a horizontal attitude of impact while chest, head, and abdominal injuries may be found in most nose down impacts.²⁶ This may also be the case where a plane impacts with its wheels up and parallel with the ground. Such an impact results in the forces being transmitted up the spinal columns of those passengers and crew who are in a sitting position. It may also explain why passengers may not have

²⁵ See text accompanying note 1 *supra*.

²⁶ See Reals, *supra* note 20, at 880.

been able to leave a plane which did not explode and burn for a time after impact: the passengers or crew may have been disabled with spinal fractures and injuries to the spinal cord, or may have ruptured aortas due to the severe impact forces. In aircraft crash landing in forests or in built up areas, severe crushing injury is often seen in the cockpit crew, since there is little protection available to this section of the plane against impact forces from collision with walls, houses, and trees. The main fuselage, however, may remain intact after the cockpit is crushed, and if the passengers are properly braced they may escape from the wreckage without a scratch if no explosion and fire ensues.

Cargoes on commercial and industrial aircraft may also create hazardous conditions which may be a factor in the crash injuries. Agricultural spraying and crop dusting pilots may suffer possible intoxication from the chemicals which they are spreading. These chemicals may slow reaction times on the part of the pilot if he has a critical decision to make. Such agricultural chemicals can be readily identified from post mortem blood samples.

Improper restraint in a crash, even at low impact speed, may result in disabling injuries including facial lacerations and bone trauma which will cause secondary effects due to aspiration of blood. There also may be skull fractures. Aspiration of food, chewing gum, vomitus, or dental prosthesis may be seen to have caused strangulation. There also may be basilar skull fractures following impact to the point of the jaw, with subsequent brain laceration, bleeding, and unconsciousness. It is paradoxical that many of these serious injuries can be prevented with a little precaution and/or wearing a helmet.²⁷ Impact of the chest and abdomen often results in explosive ruptures of the heart, lungs, and liver in cases where the body has struck the forward cabin wall or the instrument panel.²⁸ The jackknifing effect of the body over a seatbelt may produce additional injury to the head because of flailing after initial impact. Fractured ankles often are a sign of bracing for impact and are a common complication of forward impact crashes which often explain why the victims did not make an effort to leave the burning plane.²⁹ The high rate of survival in agricultural

²⁷ *Id.* at 882.

²⁸ *Id.* at 880.

²⁹ *Id.*

spray applicator flights or crop dusting flights after accidents is a tribute to the conscientious use of restraining devices, helmets, and the sturdy design of spray aircraft cockpit areas.

C. Pre-Existing Disease

No investigation of an aircraft accident is complete without careful study of the possibility of pre-existing disease as a cause. Coronary artery disease is by far the most common finding in otherwise unexplained accidents. Examples of sudden death in flight resulting in mass casualties are well documented in the medical literature.³⁰ In one case, a pilot had diabetes, severe coronary artery disease, and was taking insulin, but had denied illness at the time of his annual flying physical examination.³¹ All of these are sufficient grounds for denial of a medical certificate for flight by the Federal Aviation Administration.³² Sudden death due to other, rarer lesions such as cerebro-vascular accidents ("strokes") occur very infrequently.

Because of the rigid examination given all pilots by aviation medical examiners designated by the Federal Aviation Administration, individuals who have serious disease such as diabetes or epilepsy, impaired vision or hearing, or any other condition that might render them unconscious or incapable of controlling the aircraft in flight are not allowed to fly. Standards for airline transport pilots are even more rigorous and include, after the age of forty, adequate demonstration by electrocardiogram of freedom from coronary artery disease or its sequelae, myocardial infarction. Fortunately, large air transport aircraft have three pilots in the cockpit, and even in the event of sudden incapacitation of one the other two can assume his functions, thus insuring the safety of the passengers.

Post-crash discovery of coronary artery disease or other pre-existing disease depends upon the thoroughness of the autopsy and the subsequent examination of microscopic sections from the heart muscle and from the major coronary blood vessels. Mason feels strongly that the mere presence of severe coronary artery disease

³⁰ Reals, Mohler, Doyle & Gibbons, *An Integrated Approach to Aeromedical Investigation of Civil Aircraft Accidents*, 39 AEROSPACE MEDICINE 82 (1968).

³¹ *Id.* at 83.

³² See 14 C.F.R. Part 67 (1978).

in a pilot involved in a fatal accident cannot be regarded in itself as the cause of the accident unless there is supporting evidence.³³ The best evidence of all is that of survivors, since there are numerous cases in which aircraft have been landed successfully by co-pilots or even by spouses not licensed to fly. The pathologist, in conjunction with other members of the group investigating an accident, must assess the history of the patient in terms of the probability of the accident having been caused by a pre-existing disease of the pilot.

Interpretation of the findings obviously must take into consideration interviews with the family physician of the dead pilot, with the aviation medical examiner who examined him and issued the medical certificate, and with the pathologist who had the gross and microscopic autopsy findings in his records. The testimony of expert witnesses in this area may be confusing because of differing opinions as to the severity of the disease by pathologists who represent opposing sides in a lawsuit concerning an aviation accident death. Fortunately, death in aviation due to pre-existing disease is relatively rare.

III. CONCLUSION

We have attempted to present a broad outline of the medical and pathological investigation of fatalities resulting from aircraft accidents. The objectives have been given and three areas of search by the aviation pathologist outlined: environmental factors; trauma; and pre-existing disease. In addition, we have discussed the role of toxicology and touched on that of dentistry and anthropology. The final product of the aviation pathologist is a protocol in which he gives his gross observations, microscopic interpretation, reports of toxicological examination, and his diagnosis of the case. Pathology records are frequently introduced in court and need careful explanation to jurors as well as to legal counsel so that they may understand the subtle changes that may occur in the human body as a result of injury. The role of aerospace medicine and aviation pathology is a significant one in the investigation of aviation accidents and its function is to ascertain what human factors caused the injury and death.

³³ AEROSPACE MEDICINE, *supra* note 1, at 79.