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16. Abstract

A number of factors operating within pilots may impair their ability to operate aircraft in a safe manner, thus accounting for some of the 83 to 87 percent of pilot "causes" of general aviation accidents. Aircraft accident investigators should be attuned to characteristics of the accident, witness statements, and autopsy and laboratory findings that may suggest partial or complete incapacitation in the pilot. Incapacitation may be brought on by a medical condition which may be revealed at autopsy or be inferred only from medical history. Spatial disorientation is a subjective evaluation only and a form of incapacitation rated as the third most frequent "cause" of fatal general aviation accidents. Lack of oxygen--hypoxia--is a constant threat to incapacitate in aircraft operating at high altitudes. Toxicological factors such as alcohol, drugs, and gases (e.g., carbon monoxide) should always be sought in fatal aircraft accidents by obtaining blood, urine and other specimens for laboratory analyses. Aerial application pilots may be incapacitated by the poisonous materials they apply, especially the cholinesterase-inhibiting insecticides. The finding of therapeutic drugs in the blood or other specimens from accident victims, or of tablets, pills, etc., at the scene, may point to underlying medical conditions that may impair pilot performance. The author discusses these principles and illustrates them briefly with cases to make accident investigators and others aware of the importance of medical and toxicological factors in aircraft accidents.

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MEDICAL AND TOXICOLOGICAL FACTORS IN AIRCRAFT ACCIDENTS*

The National Transportation Safety Board (NTSB) has determined that the pilot is a "cause" of accidents in about 83 percent of nonfatal accidents and 87 percent of fatal accidents.** Because of this, aircraft accident investigators and those reviewing the findings in aircraft accidents should pay particular attention to information that indicates the competency of pilot performance. A number of factors within the pilot may impair his or her ability to operate the aircraft in a safe manner. The pilot may suffer varying degrees of partial incapacitation up to total incapacitation at which point he/she loses all ability to effect control of the aircraft. When complete incapacitation occurs in the single-member-crew situation, the condition most likely results in a severe nonsurvivable accident. Frequently the flight pattern, communications, in-flight breakup, or other conditions will lead the investigator to suspect incapacitation.

Incapacitation may be brought about by a number of conditions. Medical conditions such as heart attacks, strokes, seizures, hypoglycemia, etc., can lead to partial or complete incapacitation and should always be considered by the accident investigator. Any thorough investigation should rule out significant preexisting disease. This is done by having an autopsy performed. However, investigators must realize that the trauma to the occupant in an aircraft accident may be of such a degree that the tissues cannot be adequately examined; that the pathologist may do only a cursory and thus incomplete examination on a highly traumatized or burned body; and that in many cases a thorough examination may fail to reveal an incapacitating condition--a condition that can only be indicated by a thorough medical history. This is illustrated by a personal experience.

A 30-year-old man was stunt flying, practicing for an air show. He broke off a maneuver at about 2,500 feet. The aircraft descended and struck the ground at a 35° angle; the aircraft was demolished, and the pilot was killed. The accident investigator at the scene told me that if the pilot was not incapacitated he did not know whether or not he would be able to explain the accident. A thorough autopsy on a relatively intact body failed to reveal significant disease. Thus, the autopsy was negative in terms of revealing any conditions that may have been incapacitating. On the other hand, crash injury investigators, on questioning a number of persons who knew the pilot, found that he had had trouble when trying to keep up a jogging program,

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**Average figures calculated by the authors from NTSB Aircraft Accident Reports, U.S. Civil Aviation, 1970 through 1975.

that he occasionally became weak and tremulous, and that, at work while seated at a desk, he had been noted to be pale and tremulous and to have said something about tachycardia (fast heart rate). Medical information on this pilot in the Certification Branch of the FAA Civil Aeromedical Institute showed that he did not reveal, nor did his examining physician find, any condition that disqualified him from flying. However, records in one hospital showed that he had indicated he had "always" had heart trouble, and records in another hospital revealed an electrocardiogram that showed a condition of atrial fibrillation (the basic cause of the fast heart rate) and treatment that converted his heart back to a normal rate. In a physician's office was a printed record indicating that the pilot's condition of tachycardia occurred as often as several times a week and that he occasionally passed out with it. It was then obvious that this acrobatic pilot had a heart condition that on occasion led to loss of consciousness. Such a condition could not be discerned by autopsy examination but was only revealed by the medical history. The most probable cause of the accident was that the pilot in doing his maneuvers set off the condition of atrial fibrillation in his heart. The heart then became an inefficient pump unable to supply enough blood and thus oxygen to the brain to maintain consciousness, the pilot passed out, and the plane flew itself into the ground. Of course, a major reason for the medical certification of pilots is to eliminate from flying those with a medical condition that will significantly reduce the safety of flight. Accident investigators should always try to rule out such conditions by obtaining autopsies. But investigators should be cognizant of the shortcomings of autopsy procedures and aware that even in the most common form of incapacitation--sudden heart attack, collapse, and death--a pathologist most often cannot say unequivocally that death was due to the heart attack. Ancillary medical information such as the findings of medications and medical history may be of paramount importance in discerning what may have happened to the pilot.

A second broad area of incapacitation is what I term physiological incapacitation. Spatial disorientation (or "pilot vertigo") is probably the most common manifestation in this category and is a "cause" in 16 percent of fatal accidents coded by the NTSB. Spatial disorientation is a failure of the pilot to perceive his/her attitude, motion, and speed in relation to the earth; it most frequently occurs when visibility of orientating references outside the aircraft, such as the horizon or ground, is impaired by clouds, fog, snow, rain, etc., or by darkness. All persons, under laboratory conditions with vision obscured and subjected to linear and/or angular acceleration, can be made to experience bothersome disorientation as a function of the semi-circular canals and associated vestibular sensory apparatus in the inner ear. The same type of disorientation occurs in flight and may markedly impair the pilot's ability to maintain the aircraft at a safe operating attitude and speed. Indeed, spatial disorientation is coded by the NTSB as the third most common "cause" of fatal aircraft accidents. I like to think of spatial disorientation as part of a triad, using NTSB terms: "initiated flight into adverse weather"; "continued VFR flight into adverse weather"; and "spatial disorientation." Spatial disorientation appears to be a factor in at least 35 percent of fatal weather-related aircraft accidents (1) and is frequently associated with in-flight breakup in the absence of thunderstorms and turbulence. Accident investigators and those reviewing accident data should be acquainted with this condition which takes so many lives in general aviation.

Hypoxia, that is, lack of sufficient oxygen, is undoubtedly the most serious physiological threat to flight safety in aircraft operating above 15,000 feet but is of considerably less significance in most civil general aviation accidents. However, there have been well-publicized cases of aircraft flying at high altitudes for a considerable time before they crashed. In such an event the first suspicion is that there is a failure of the cabin pressurization system or oxygen supply resulting in in-flight unconsciousness and possibly death in the pilot (and passengers). For the most part there is no way of determining by autopsy whether an accident victim suffered hypoxia. Military accident investigators usually try to obtain and analyze brain tissue for lactic acid which, if elevated, may indicate metabolic changes reflecting the hypoxic condition. Similar toxicologic determinations are not made on the victims of civil aircraft accidents, and, for most civil aviation accidents, if the investigator is to invoke hypoxia as a cause of the accident, he/she must base this on the operating altitude of the aircraft and findings in pressurization or oxygen equipment. A point to consider, however, is that an older pilot or one with constricted coronary or cerebral arteries may be more susceptible to the effects of hypoxia, because of reduced blood flow through the heart or brain, than a person who does not have these changes, so that autopsy findings may be consistent or supportive as part of other findings in the accident-causing milieu.

Toxic factors represent a third broad category of causes of pilot incapacitation, and they are frequently involved as a cause or factor in civil aircraft accidents. Such toxic factors can come from cargo carried in the aircraft, toxic gases resulting from fire or defective equipment, alcohol or drugs consumed by the pilot, legitimate medications taken by the pilot, etc. To monitor such factors in civil aviation a forensic toxicology unit was established some 13 years ago in the Aviation Toxicology Laboratory of the FAA Civil Aeromedical Institute in Oklahoma City. This unit prepares and maintains a supply of toxicology kits in all FAA and NTSB offices where aircraft accident investigators are based. Everything a physician or pathologist needs in order to collect and return blood, urine, gastric contents, tissues, and other biologic samples to the laboratory is contained in one of these "tox boxes." A small amount of ice in this styrofoam-lined container will preserve specimens in a satisfactory condition (for analysis) for 3 days even in hot weather. Currently, specimens for toxicological analyses are received from about 65 percent of pilots killed in aircraft accidents. Accident investigators should make a conscientious effort to see that specimens are collected from accident victims and that specimens are sent to the FAA laboratory, where analytical procedures designed primarily to serve accident investigation can be used and where personnel are alert to the significance of findings to the accident and thus avoid the difficulties encountered when laboratories not versed in forensic procedures attempt to evaluate an occasional specimen. Reports of toxicological analyses are part of all accident records and are available to all persons who seek to review such records.

Rarely a pilot may encounter something in the environment that may impair his or her ability to function. For example, in flight, a physician pilot was partially incapacitated by the fumes when the cork in a can of previously opened ether dislodged in his medical bag at altitude. He safely landed his aircraft. A large cargo aircraft was lost and its crew of three were killed when a bottle of nitric acid leaked onto packing materials giving rise to heat, smoldering fire, and fumes which impaired respiration and vision of the crew. A small jet cargo pilot taxiing toward the runway for takeoff became extremely short of breath and returned to the ramp. His cargo consisted of meat maintained in a frozen state by dry ice: solid carbon dioxide. In the enclosure of the aircraft cabin the carbon dioxide was mounting in concentration and could have asphyxiated the pilot had he not aborted his flight. Lithium-sulfur dioxide batteries have been removed from aircraft as a source of power for emergency locator transmitters because of a tendency to explode or leak sulfur dioxide into the cabin. Sulfur dioxide potentially could incapacitate occupants. Careful investigation of all factors associated with an accident should give clues that would lead to suspicion of a rare event as illustrated by these cases.

Five to seven percent of the exhaust gases of an internal combustion engine is carbon monoxide, and, when the engine exhaust is used as a source of cabin heat, a cracked heat exchanger can introduce this toxic gas into the cabin where it is breathed by the aircraft occupants. Carbon monoxide combines with the hemoglobin of blood to form carboxyhemoglobin, reducing the blood's ability to carry oxygen. A heavy smoker possibly may have up to 10 percent carboxyhemoglobin. At 20 percent carboxyhemoglobin, a person may experience tightness around the head, and headache. At 30 to 35 percent he/she may experience nausea and vomiting and shortness of breath. At about 45 percent he/she will become unconscious, and at 65 to 70 percent death will occur. The value of a routine determination of carbon monoxide on all aircraft accident victims can be illustrated by an accident in which three occupants were flying at night and, under frequent guidance from air traffic control, were avoiding some rain clouds. Communication with air traffic control ceased and within 2 minutes the aircraft disappeared from the radarscope and crashed. Investigators sent routine blood samples from two occupants to the laboratory and noted that there had been fire at the crash site. The laboratory found 40 to 45 percent carboxyhemoglobin in these victims. Without so stating in the report, the laboratory surmised the victims were trapped in the aircraft in a postcrash fire (the most common cause of elevated carboxyhemoglobin levels in accident victims). Later, autopsy information available to the laboratory revealed that all occupants of the aircraft were partially decapitated by the impact. Realizing that such injuries would have caused instantaneous death (and thus cessation of respiration) and that the carbon monoxide accumulation must have occurred in flight, the laboratory so informed the investigators, who went back to the wreckage and found and verified a defective heat exchanger.

Of course carbon monoxide is frequently found in aircraft accident victims who are alive and breathing in an environment where there is fire and smoke; that is, they survive the impact but die in the postcrash fire. This happens in both large air carrier aircraft and small aircraft. Toxicological examination of specimens, combined with autopsy information to elucidate the extent of trauma, is needed to assess the relative importance of the trauma and the toxicants in the demise of the occupants. Human factors investigators in large passenger aircraft attempt to gather such information in reconstructing the large-aircraft postcrash survival scenario. Whenever the carboxyhemoglobin (indicating a significant level of carbon monoxide) is above 10 percent in any aircraft accident victim, a determination is made of the hydrogen cyanide in the specimen. It is well accepted that in fire environments there are gases other than carbon monoxide and, depending on the materials burning, there may be hydrogen cyanide, hydrogen sulfide, hydrogen bromide, hydrogen chloride, hydrogen fluoride, acrolein, formaldehyde, sulfur dioxide, and other toxic and irritating gases. In a number of large-aircraft accidents where lives were lost, significant levels of hydrogen cyanide have been found in the blood of victims (2). What an accident investigator should remember is that, although an aircraft occupant's body may be charred, an autopsy should be done. The victim could have died of natural or unnatural causes before the crash; the victim could have died of impact injuries and thus have been a passive figure in the fire; the victim could have received considerable injury in the impact and died of inhaling smoke; or the victim could have escaped injury by the impact but died as a result of exposure to the smoke and fire. The autopsy to determine the extent of impact injury, and examination of respiratory passages which are frequently blackened by soot deposits on their surfaces, combined with the laboratory determinations of carbon monoxide and hydrogen cyanide, can aid the investigators in reconstructing the time and dynamics of the deaths.

Aerial application pilots are a special case in terms of incapacitating factors in the environment. Many of the materials they apply to crops from their aircraft are designed to kill insects or have a harmful effect on certain types of growing plants. Pilots and other aerial application workers may be poisoned by the very substances they are applying. Such poisoning may occur at any of a number of stages of their activities.

The most dangerous of the materials they apply are the cholinesterase-inhibiting insecticides. Both the carbamate and the organophosphate insecticides inhibit cholinesterase, an enzyme essential for nerve impulse transmission and body activities. Poisoning of workers may be overwhelming, as in a young flagman who spilled some organophosphate insecticide on his arm, absorbed the material through his skin, and almost died 24 hours later.

Or poisoning may be gradual as in a pilot who is exposed to small amounts over a period of time. In the latter instance the effects are cumulative. This can be documented by having the laboratory make blood cholinesterase determinations before and several times during the working season. In a somewhat careless pilot the cholinesterase level may fall to half its preseason value. Some pilots who experience headache, blurring vision, and chest tightness, the early symptoms of insecticide poisoning, may take atropine orally to alleviate these symptoms. Although this treatment may relieve the symptoms, it is dangerous in that the pilot's reserve of cholinesterase remains low and he/she may thereafter be completely incapacitated by additional exposure to insecticide which otherwise would not cause such complete incapacitation.

In all aerial application accident victims, blood should be collected for cholinesterase determinations. Most accident investigators realize this, and it becomes fairly routine that such determinations are made. However, interpretation of the significance of the laboratory determinations is questionable without a preseason value with which to compare. Many operators encourage pilots to obtain preseason and periodic determinations during the course of their work activities.

Pilots may elect to take into their systems chemicals that may alter their mood and impair their performance in flying an airplane. In this respect alcohol is the drug of greatest abuse. Statistical treatment of alcohol values in pilots killed in civil aviation accidents indicates that about 9 percent of the pilots have blood alcohol levels about 0.05 percent, a level that has been determined to affect the ability of a pilot to fly an aircraft. About 20 percent of pilots killed in aircraft accidents have some alcohol in their systems (3).

When low levels of alcohol are obtained certain questions are cogent. Does this level reflect what was truly in the pilot's blood and system, or does the level signify some degree of laboratory error, or was the alcohol perhaps the result of bacterial fermentation that occurred between the time the pilot was killed and the time the blood was analyzed in the laboratory? These are legitimate questions, and those investigating aircraft accidents should be prepared to make some statement as to the significance of such findings. The findings can possibly be corroborated by investigation of the background of the pilot and particularly by defining any drinking history in the 24 hours before the accident. In the laboratory we attempt to add to the validity of the determination by culturing the microorganisms out in any blood sample that has a significant level of alcohol. Once bacteria are obtained they are put into a broth containing sugar and the alcohol obtained is analyzed. If the bacteria are capable of producing alcohol, it is considered that low levels of blood alcohol may not reflect a precrash blood alcohol level, but instead a postmortem artifact of bacterial contamination. Bacteria seldom produce high levels of alcohol so that high postmortem levels of blood alcohol most often reflect high levels of alcohol in the antemortem blood.

Cocaine, heroin, barbiturates, and other habituating drugs are routinely screened for in accident victims, but positive results are unusual. Marihuana is a drug of more widespread use, but it has been difficult for toxicologists to verify intake by identifying the active ingredient tetrahydrocannabinol or a metabolite in postmortem specimens. If a victim is suspected of having smoked marihuana, alcohol swabs may be made of the fingers, lips, and mucous membranes of the mouth. A relatively simple chemical reaction can detect marihuana ingredients extracted into the alcohol, but this test is qualitative and only heightens one's suspicion that the pilot may have been influenced by marihuana. Other evidence in the form of pipes, papers, and marihuana leaf residues may be corroborative. In the exceptional case, specimens from accident victims can be sent to laboratories conducting research on marihuana. Such laboratories in the past have been able to confirm the presence or absence of the active ingredient in the blood of pilots and vehicle operators.

Of interest to the FAA, which is responsible for the conduct of a program to medically examine and certify pilots, are means of monitoring standards of certification. To this end we maintain a keen interest in autopsy and toxicologic findings in fatal pilot accident victims. For example, in the last year three captains of air carrier aircraft died cardiac deaths while their aircraft were in flight. Each of these pilots, as with all air transport pilots, had undergone a certifying medical examination within 6 months before his death.

One means of monitoring for medical conditions is to examine specimens from fatal pilot accident victims for the presence of drugs. The finding of quinidine in the blood of a pilot probably indicates he or she was being treated for a cardiac arrhythmia. Mood-elevating drugs may reflect some psychiatric problem. Thus, the finding of a drug in an accident may suggest a medical condition that may have disqualified the pilot from medical certification--a condition that may not have been revealed by the pilot undergoing certification examination. Indeed, the withholding of information from the aviation medical examiner could influence the settlement of injury claims and alter the liability of a pilot involved in an accident.

Because therapeutic drugs are used at fairly low doses it is frequently difficult to detect the drug in the specimens submitted for toxicological examination. The thorough accident investigator will look among the pilot's personal possessions for pills, tablets, liquids, ointments, etc., which may suggest the type of drug the laboratory should concentrate on in attempting to identify materials in the postmortem specimens. Not infrequently the drugs found will suggest some condition that can lead to unfolding of a significant medical history. Drugs and disclosure of a medical history could add significance to the autopsy findings. For example, a commercial pilot was flying a large aircraft with passengers aboard. At a critical point in the flight, control was lost, the plane crashed, and everyone aboard was killed. The autopsy revealed markedly diseased coronary arteries, but this finding in itself could not be interpreted as indicating cardiac incapacitation in the pilot. In the pilot's possessions the investigators found a bottle of peritrate, a drug commonly used by persons experiencing recurrent heart pains, and some chemically impregnated paper used for testing the urine for sugar. This latter is suggestive of the pilot's having diabetes mellitus, a condition that accelerates coronary artery disease. Comparison of fracture patterns in the pilot and copilot revealed minor fractures in the pilot's hands, whereas the copilot had large fractures of the arms and both thumbs were fractured, the latter suggesting he had his hands on the controls as the aircraft crashed. The most probable cause of the accident was sudden cardiac incapacitation in the pilot. Of course no one item of evidence was adequate to establish this--it took a combination of autopsy findings and information gathered at the accident scene.

From the foregoing discussion it should be clear that when there is a failure in the man-machine combination that leads to an accident, it is most often the man that fails to perform adequately. Such failures may reflect a physiological, medical, or toxicological incapacitation. In fatal accidents, investigators should insure that the man--the pilot and other occupants--is adequately examined. Such examinations should entail autopsy and toxicological examination of the victims. However, neither of these procedures in itself is adequate. The investigator must combine information gathered from these procedures with other information such as flight characteristics, impact dynamics, fire, weather, medical history, and other ancillary findings at the scene to give each portion of data its most meaningful role in establishing the causes and factors operating to bring about the accident.

REFERENCES

1. Kirkham, W. R., W. E. Collins, P. M. Grape, J. M. Simpson, and T. F. Wallace. 1978. Spatial disorientation in general aviation accidents. Aviation, Space, and Environmental Medicine, 49(9):1080-1086.

2. Kirkham, W. R., D. J. Lacefield, and C. R. Crane. 1979. Toxicological and pathological findings in aircraft accident victims that indicate incapacitation from burning interior materials. Paper presented at the 50th Annual Scientific Meeting of the Aerospace Medical Association, Washington, D.C., May 14-19.

3. Lacefield, D. J., P. A. Roberts, and C. W. Blossom. 1975. Toxicological findings in fatal civil aviation accidents, Fiscal Years 1968-1974. Aviation, Space, and Environmental Medicine, 46(8):1030-1032.

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