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The Editorial objective is to report developments and advanced techniques of particular interest to the professional aircraft accident investigator. Opinions and conclusions expressed herein are those of the writers and are not official positions of the Society. The Editorial Staff reserves the right to reject any article that, in its opinion, is not in keeping with the ideas and/or objectives of the Society. It further reserves the right to delete, summarize or edit portions of any aritcle when such action is indicated by printing space limitations.

The wealth of material presented at the 1985 Seminar has lead to two significant departures from normal Proceedings publication. First, a large group of articles on the subject of the U.S. Federal Aviation Administration/National Aeronautics and Space Administration Controlled Impact Demonstration (CID) have been grouped together and will be presented as a special edition of the *Forum* subsequent to these **Proceedings.** Second, due to the large number of illustrations used in the papers submitted for publication, some have been deleted to remain within publication limits. The editors have attempted to retain those illustrations which were essential for explanation of the text.

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The Jerome F. Lederer Award

Nominations for the 1987 Award will close on March 31, 1987.

The award is given for outstanding contributions to technical excellence in accident investigation. Not more than one award will be made annually and presentation is at the ISASI Seminar. The recipient is selected by the ISASI Awards Committee.

Any ISASI member may submit a nomination for this award. It must be sent to the Chairman of the Awards Committee, and must include a statement describing why the nominee should be considered. This statement should be sufficiently descriptive to justify the selection but no more than one typewritten page in length.

This award is one of the most significant honors an accident investigator can receive, and so considerable care is given in determining the recipient. Each ISASI member should thoughtfully review his or her association with professional investigators, and submit a nomination when they can identify someone who has really been outstanding in increasing the technical quality of investigation.

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Individual membership is available to persons who are, or have been actively engaged in the investigation of aircraft accidents, civilian or military, or in the promotion of air safety. The initiation fee is $35.00 and the first year's annual dues are $50.00 for a total of $85.00 U.S.

Corporate membership is available to firms engaged in air transportation, in the manufacture of aviation products or providing services that are aeronautical in nature. Submit a letter to the President of ISASI and forward the sum of $400.00 U.S. to provide an initiation fee of $100.00 and the first year's dues of $300.00.

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THE JEROME F. LEDERER AWARD

1985

presented to

Dr. John Kenyon Mason

for

Outstanding Contributions to Technical Excellence in Accident Investigations

Mr. Jerome (Jerry) F. Lederer, at right, presents the award to Dr. Mason at ISASI's banquet dinner at the Marriott's Mountain Shadows resort.

The International Society of Air Safety Investigators has awarded the Jerome F. Lederer Award to Dr. John Kenyon Mason, Professor of Forensic Pathology, University of Edinburgh. This award is given for Outstanding Contribution to Technical Excellence in Accident Investigation. The award was presented at the Society's 16th Annual Seminar in Scottsdale, Arizona on September 5, 1985.

Professor Mason's interest in traumatology began in 1955 when he was asked to form a Department of Aviation and Forensic Pathology for the Royal Air Force. The need for this stemmed from the large number of unexplained fatal accidents for which it was felt there might be medical causes; it was also realized that little was known of the cause and significance of many types of aviation trauma.

From the beginning, Professor Mason was motivated to free the forensic pathologist from the confines of the post mortem dissection to being an active accident investigator working closely with the law enforcement officers, engineers, etc. The pattern which evolved included a visit to the site, a personal examination of safety equipment and the crash environment, a study of the relevant past medical histories and an in depth autopsy examination of the fatal casualties. The pathology of trauma could thus be regarded essentially as an aspect of preventive medicine which could be applied to all forms of violent accident death.

The work was first applied to military aviation and was then extended to private flying. Later commercial aviation was included, and disasters were being investigated on a world wide basis. Professor Mason has personally investigated on site over 250 fatal aircraft accidents which included 20 major catastrophes.

The work in traumatology has basically followed four inter-related streams:

a) The morbid anatomy of trauma;

b) The assessment and development of safety equipment - Mason was intimately associated with the development of the military ejection seat and did much work in the field of private aviation;

c) Accident reconstruction - in which particular attention was paid to establishing patterns of fatal injury in passengers so that the type of accident could be diagnosed;

d) Establishing the causes of the accident — the main emphasis has been on toxicological causes and on the interpretation of the role of disease discovered in aircrew.

Major examples of the application of these principles included the passenger safety considerations in the Stockport Disaster in 1967, the discovery of a bomb following the loss of the Comet IV over the Mediterranean in 1967, the elucidation at Lagos of the Nigerian Airways aircraft believed to have been shot down but which crashed, in fact, as a result of pilot error, and the discovery of an acute heart attack in the Captain of the Trident which crashed at London Airport in 1972. The integration of the identification process with the actual accident investigation made an important contribution to these and other disaster investigations.

The system of comprehensive, on the spot investigation of aviation fatalities has been adopted world wide and is strongly endorsed by the International Civil Aviation Organization. The concepts developed by Professor Mason have been a strong influence on the development of investigative techniques.

The Constructive Uses of Aviation Catastrophies And Other Undesired Events

By Jerry Lederer

The title of this presentation could have been Emerson's well known quotation "Learn from the mistakes of others because you won't live long enough to make them all yourself." Accident investigation specializes in uncovering mistakes that result in catastrophies, tragedies, mishaps, incidents or other undesired events so that they will not be repeated. While we investigate the mistakes of others, our mistakes are monitored by associations of airmen, by the media, by the lawyers. This is a good system of checks and balances.

An undesired event may have various shades of meaning. A fatal accident involving, say, a business pilot, may be a catastrophe to the family of the deceased, a tragedy to his friends, a reflection on his airmanship, a challenge to the investigator, an incident to the media, a financial loss the the insurance company, a relief to his competitors, and business for the mortician and the legal arena, with an underlying expectation for the improvement of safety.

Lord Beaconsfield, better known as Disraeli, the great British prime minister of the last century, was asked in Parliament about the difference between a catastophe and a tragedy. Pointing to his powerful political opponent, Mr. Gladstone, he replied, "If Mr. Gladstone were to fall into the Thames River, and drown, that would be a tragedy; if he were rescued, that would be a catastophe!"

As a supplement to this talk, I'd like to propose to ISASI that the next agenda include two controversial subjects that have yet to be adequately addressed. One subject concerns probable cause or causes. These are usually of a promixate nature. Probably cause or causes are based on a provable evidence. I do not question that. But from the point of view of accident prevention, in a generic sense, the root causes should also be explored. Lawyers are pretty adept at digging this up. Root causes involve management, human factors, personal, and management pressures that are difficult to prove as direct basic causes of a loss but may be of more importance than proximate causes for accident prevention.

Management Involvement

The late Prof. Kenneth Andrews of the Harvard Graduate School of Business Management stated in a lecture on "Morale and Safety" at a Flight Safety Foundation Seminar in 1964 that "every accident, no matter how minor, is a failure of organization" (except for acts of God). This means management. In recent years the NTSB has occasionally recommended improvements in management to prevent accident from recurring, but rarely if ever has management been stated as a root cause. Of course, one reason for this is that the Captain has final cockpit management authority. But he is subject to higher management policies. How many accident investigative bodies have an expert on management on their staffs? Management is one of many human factors.

The importance of other human factors is being recognized. Human factor specialists are being added to the investigation staffs. It will be interesting to see how their studies on human factors are handled in the reports, not only the more provable physiological factors such as fatigue as those of a psychological nature such as emotional factors. It is difficult to prove what goes on in a person's mind but as the possible root cause of aberrant behavior that results in an undesired event, root causes should be pursued.

Politics and Safety Recommendations

The second subject for future seminars relates to safety recommendations arising from an accident or incident investigation. I would like to see ISASI involve itself with the promulgation and follow through of safety recommendations from a political standpoint. For instance, in this country safety regulations are required to have the approval of the Office of Management and Budget (OMB). The battle for funds is a political exercise. Pressures by trade associations and airmen organizations are also involved.

The FAA and DOT and similar organizations in other countries have established financial criteria and cost benefit policies for safety regulations. I would like to see the economic aspects of safety recommendations and research debated at ISASI meetings. I was the first to propose that there are economic limits to aviation safety. This was in a talk I gave in 1938 at Norwich University. What bothers me is the seemingly arbitrary position taken by bodies such as OMB. One of the constructive uses of a recent catastrophe, the Delta loss at Dallas in July, was to show that the OMB made a wrong decision in deferring funds for research and development of doppler radar to depict windshear.

I urge ISASI to address in a formal way the problems of determining root causes of aviation accidents and to start examining the process by which safety recommendations and research are processed, delayed, or denied. One of the most important objectives of an accident investigation is to recommend safety measures to avoid the repetition of an undesired event be it an incident or a catastrophe.

I shall now deal briefly with several specific instances in which a catastrophe or tragedy, or a near catastrophe led to constructive safety lessons. These examples will be of an historical nature on the assumption that this audience of professionals is probably familiar with lessons learned from undesired events that have ocurred in your generation of activity.

ICARUS

Let's begin with ancient Greece. The accident report covering the flight accident which led to the death of Icarus is a fitting start for air safety. Icarus had been instructed by his father, Daedalus, to fly in formation with him on their escape from Crete lest Icarus fly too close to the sun. Icarus, succumbing to the euphoria of flight, flew too close to the sun. The probable cause was that the wax which held his feathered wings together melted, causing his fall and death.

His failure to obey instructions resulted in the first reported aviation accident and stressed the importance of two fundamental safety precepts: Obey the captain's orders, and fly by the book.

A recent review of this accident suggest that the probable cause should be questioned. Instead of blaming the radiant heat of the sun for causing structural failure, it may have been due to the rapidly decreasing temperature of the air with altitude that resulted in the cold embrittlement of the wax holding the feathers together and therefore structural failure.

Otto Lillienthal and Crash Survival

A catastophy in 1896 led dirctly to the invention of the Wright Flyer, the world's first powered airplane to accomplish a successful flight, at Kill Devil Hill, North Carolina, Dec. 17, 1903. This catastophe, the fatal glider crash of Otto Lillienthal, also presaged the immense effort to promote air-crash survival that Hugh De Haven began in 1941.

The great German gliding pioneer, Otto Lillienthal, who had made some 2500 glider flights, protected himself from serious or fatal injury in a crash landing by attaching a hoop made of willow wood to his glider. The hoop surrounded his body to help absorb the impact of a crash. Unfortunately, he had not installed the hoop on the day of his fatal crash, August 19, 1896. He died the next day. His last words were "Sacrifice must be made." This tragedy was probably the most constructive in aviation history. It led to the invention of the airplane.

The Wright Brothers had been observers of aviation development since their boyhood days. The death of Lillienthal challenged their dormant interest in action.

But Lillienthal did more than inspire the Wrights to solve the problems of flight. They adopted his philosophy of crash survival. One reason for the placing of the elevator and associated structure of their Wright Flyer ahead of the pilot instead of to the rear with the rudders was to provide protection in the event of a crash. It proved itself in a small way on the first attempt at flight, Dec. 14, 1903, three days before the successful flight of Dec. 17. Wilbur, the pilot, overplayed the elevator control on take off. The ship climbed steeply, stalled and ploughed into the sand. The forestructure took the impact. (Fig. 3A,B)The damage was easily repaired in time for the successful flight three days later. Damage to the main structure might have been serious without the protective forestructure. It may have saved Orville's life five years later as we shall see.

At this point I should mention another safety feature of the first Wright airplane. The 12 HP engine that the Wrights degined and built in six weeks for their Wright Flyer was installed to the right side of the pilot instead of on the center line. One reason for this placement was to protect the pilot from the engine falling on his body in the event of a crash landing. My information comes from a book "The Wright brothers: An Authorized Biography" by Fred Kelly. The Technical authenticity of this book has been questioned.

My neighbor George Russel, a grandnephew of the Wright Brothers, spent his college vacations with Orville Wright. He was present while Orville reviewed every page of the galley proofs, so I feel safe in assuming the validity of these observations on crash survival.

The first great catastophe in powered flight, a fatality, occurred on Sept. 17, 1908 at Ft. Meyer, VA. Orville Wright piloted this first airplane ordered by the U.S. Army. His passenger was Lieutenant Thomas E. Selfridge. The blade of a newly installed propeller developed a longitudinal crack at a flight height of some 60 feet. After some gyrations, the airplane dove in at an angle of about 45 degrees, left wing striking first, then tumbling onto the skids in front. The skids along with the front central surfaces and the supporting structure were crushed. Lt. Selfridge suffered a fatal fractured skull, Orville was stunned, suffered a broken thigh and other injuries. The crash energy absorbed by the forestructure probably protected him from much more serious injury and possible death.

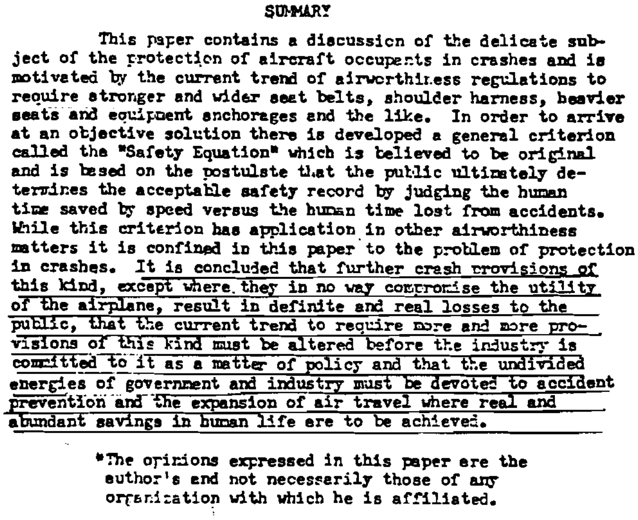
Orville has survived an earlier serious accident at Huffman Field near Dayton, Ohio in 1904. When the wind for which he had been watching was of sufficient strength and on the nose of his plane, he started his take-off run down the wooden tracks. Just as he reached the end of the track and about to lift, the wind suddenly stopped. The airplane crashed. Orville narrowly missed a severe blow to his head by the broken spar of the top wing. This was the first windshear accident. So far as I know, nothing new was learned, but I thought the first windshear accident would be of interest. Here again, the forestructure possibly spared serious injury to Orville.

Other early suggestions on crashworthiness were not taken seriously. In 1910, a British magazine, ARO, published the design of an airplane from the standpoint of crash survival. (Fig. 1) In 1928 at the First National Aeronautical Safety Conference, in N.Y., sponsored by the Guggenheim Fund for the Promotion of Aeronautics and the National Safety Council, Charles Lindbergh, in a talk on pilot training, suggested that "a great deal of attention should be given to designing a training plane for possible crash." In1929, Jimmy Doolittle, in a talk on "Problems In Flying" said "a feature to which insufficient attention is given is designing and constucting an airplane so that it crashes well."

Crash survival as a distinct discipline remained unrecognized by designers until the advent of Hugh De Haven. Designers concentrated on improving flight performance, not crashworthiness. De Haven's constructive interest in crash survival arose from a catastrophic event in which he was one of the principals. He had enlisted in the Royal (Canadian) Flying Corps before we entered WWI. On a training flight in Texas, he was the only survivor of a mid-air collision. During the many months he spent in the hospital, he pondered about the ability of the human body to absorb the energy of a crash. Over the years he collected numerous accounts of humans who had survived falls from great heights. He realized that a body could survive an enormous impact if the load were adequately distributed and/or if a means to absorb the energy of a crash were provided to protect the person, i.e., the safe packaging of a person in an energy absorbing enclosure.

In early 1941 he came to me with letters of introduction from two very prominent individuals in aviation at that time, Franck S. Tichner, Publisher of Aero Digest, a leading aviation magazine, and Gill Robb Wilson, a WWI pilot and president of the National Aeronautical Association. They thought I should listen to his ideas on crash survival. A that time I was Director, Safety Bureau, of the Civil Aeronautics Board, in charge of all civilian aviation accident investigation and the promulgation of Federal Air Regulations, including airworthiness.

Must the Airplane be Designed for Crashes?



SUMMARY

This paper contains a discussion of the delicate subject of the protection of aircraft occupants in crashes and is motivated by the current trend of airworthiness regulations to require stronger and wider seat belts, shoulder harness, heavier seats and equipment anchorages and the like. In order to arrive at an objective solution there is developed a general criterion called the "Safety Equation" which is believed to be original and is based on the postulate that the public ultimately determines the acceptable safety record by judging the human time saved by speed versus the human time lost from accidents. While this criterion has application in other airworthiness matters it is confined in this paper to the problem of protection in crashes. It is concluded that further crash provisions of this kind, except where they in no way compromise the utility of the airplane, result in definite and real losses to the public, that the current trend to require more and more provisions of this kind must be altered before the industry is committed to it as a matter of policy and that the undivided energies of government and industry must be devoted to accident prevention and the expansion of air travel where real and abundant savings in human life are to be achieved.

*The opinions expressed in this paper are the author's and not necessarily those of any organization with which he is affiliated.

Figure 2

De Haven convinced me that the human body could withstand enormous fores if the forces are adequately distributed and if the airplane were designed to protect its occupants from many death dealing or injury producing forces. His clippings and reports on survival from high falls were very persuasive.

He wanted our investigators to supply him with detailed information on crash survival and injury producing aspects in their accident investigations. It was not easy to convince them of the value of this project or to use the forms he supplied. The human body was considered by both investigators and designers to be too fragile to survive a severe crash. In the end we gave De Haven much useful information. The endorsement of the CAB provided support and encouragement for De Haven's ideas. He was able to enlist the cooperation of the National Research Council and State Police organizations. The Cornell University Medical School in New York provided him with office space and other resources. Col. John Paul Stapp's courageous high speed sled test provided experimental proof of De Hven's theories on the ability of the body to withstand high forces (at least 40 g's) when properly supported.

The engineering community remained unenthusiastic about designing for crash survival. One chief engineer declared "we build our airplanes to fly, not to crash." The chief engineer of another large company later prepared an elaborate dialectic study to refute mathematicaly (Fig. 2) the weight and other problems required by design for crash survival were not acceptable. It was an uphill fight. But in time De Haven's concepts were accepted by designers, not only in aviation, but for other forms of public transportation, especially automobiles. Much of the research was done nearby here when Howard Hasbrook moved the Aviation Crash Injury Research project from New York to Phoenix.

A near catastropic crash brought Howard Hasbrook into De Haven's orbit. De Haven had asked me to help him search for a highly motivated assistant.

One day in 1949, Howard came into my FSF office in New York carrying one arm in a sling, his head massively bandaged. He had narrowly escaped death in a crop dusting accident and was now very much interested in dedicating himself to aviation safety. Here was the kind of high motivation that De Haven sought. Hasbrook became an extremely valuable assistant to De Haven. Some of his investigations and reports are of classic and historic significance, such as the first thorough investigation of an airline crash from the standpoint of occupant death and survival.

Important strides have been made in crash survival in civil aviation as a result of research led by Hugh De Haven, by Iver Pinkel at NASA-Lewis, and by Col. John Paul Stapp. This research is being continued by NASA, the FAA and other organizations. It includes crash fire research. The most successful fire research was conducted on helicopter crashes for the US. Army. Investigators might familiarize themselves with the techniqus of crash fire protection developed by the Aviation Crash Injury Research Project not far from here several decades ago. Army experience with these techniques has been remarkable.

So much for impact survival. The prevention or control of fire following a crash is a closely allied problem.

Crash Survival — Fire

The survivability of a crash landing is often threatened and defeated by fire following the crash. Tremendous resources have been allocated to reduce the probability of crash fires. Except for military helicopters, progress has been slow. This audience is probably familiar with the history of crash fire research in the past 40 years. The spectacular research by the NASA-Lewis Research Center and by the Aviation Crash Injury Research Center of the Flight Safety Foundation some 30 years ago, and more recently by the FAA and NASA are well known. It is not generally known that the first full scale crash test to uncover the causes of crash fires took place in 1924, sixty years ago, for the United States Air Mail Service.

This service suffered catastrophic pilot losses. One in every six pilots was killed,usually in forced landings due to weather during this operation from 1918 to 1927. Life expectancy of a pilot was four years. The forced landings were usually survivable if fire did not occur. The airplanes were WWI wood and fabric single engined, Liberty powered (400HP), open cockpit biplanes, designed by De Havilland as a light bomber but ruggedized by the air mail service to withstand the severity of scheduled transcontinental day and night operations. This was the world's first system of continuous airline operation. It laid the foundation of our present magnificent system of air transportation.

The Air Mail Service sent sixteen DH's to the Army Air Service test center at McCook Field, Ohio (now Wright A.F. Base). The airplanes were sent under power down a concrete ramp into a concrete wall. Slow motion films showed the cause of the ignition to be the long hot exhaust manifolds which ran along each side of the fuselage. The 97 gallon fuel tank under 2½ pounds of pressure in the front of the fuselage would break open on impact allowing fuel to pour onto the hot manifolds. The exhaust manifolds were replaced by separate finned aluminum exhaust ports; one for each of the 12 cylinders. These ran cool and were distant from the fuel tank. No fires followed crash tests with this configuration. In 1926 we ordered a set to try, even though I assumed that the Army had already tested them. Our test pilot, Frank Burnside, flew this every day for the six work days per week 60 years ago. He reported no problems and even more power because of reduced back pressure. We ordered 20 sets. Much to my embarrassment, we had to discard them after a few flights because the glare from the exhaust, now in the line of sight of the pilot, blinded him. From this experience I learned that test flights should be made to include the entire operating regime of a vehicle, to suspect assumptions, to consider human factors in design and especially for changes in design. These were constructive results of catastrophies but not the ones we could use. Crash fire catastrophies continue to this day.

Emergency Escape and a Human Factor

About 1935, a DC-3 cash landed at Trammel, Kentucky. The impact forces were low. The occupants rushed to crowd around the main door in back to try to escape.

An Army Lieutenant sitting in front saw that the passengers were unable to open the exit so he kicked his way out through a nearby window. He was the only passenger to survive the fire. I do not recall what happened to the flight attendant or pilots.

The investigators concluded that the other passengers could not open the door because it required the operation of two levers. One of these levers had been operated, the other, not being conspicuous, remained unnoticed and unused. The locking system was redesigned to use only one lever: a design philosophy which has prevailed. This constructive use of a catastrophe has been adopted generically for other emergency equipment.

Flicker Vertigo

About 1955 a friend gave me a book "The Living Brain" by Dr. W.G. Walters. I chanced to read the chapter on Flicker, the effect of flashing light on the brain. Flicker is used as a test for epilepsy, a disease of the nervous system characterized by convulsions and unconsciousness. Not long afterwards I happened to visit the Dutch Aviation Medical Center near Schiphol. There I was told of a recent incident in which the pilot of a small training plane had to be lifted out of the cockpit after he had landed and taxied to the ramp. He had taxied with the sun on his back. The reflection of the sun on the rear of the rotating propeller blades had flickered him into unconsciousness. The Dutch were aware of this phenonomen because flickering lights, at about 15 per second, had been used on captured Dutch members of the resistance movement in WWII. I disseminated this in a Flight Safety Foundation bulletin. Several letters came from pilots who had suffered very distracting effects driving along tree lined roads with the sun shining between the trees creating a flickering effect. Jack Gaty, Vice-President of Beech Aircraft, decribed similar effects while driving under the elevated railroad tracks of New York. The flickering sun shining through the railroad ties above became very annoying at certain speeds. Most important of all, from this standpoint of aviation, was a letter I received from Colonel Jim Wells, U.S. Army, that the Army physicians and psychologists confirmed this hazard and henceforth would require helicopter pilots to be screened for a tendency toward flicker vertigo caused by rotating helicopter blades above. Flashing on navigation lights reflected by nearby clouds may also create similar nervous disturbances. It remins one of many physiological factors for investigators to keep in mind.

Sensory Illusions

Sensory illusions in flight are now a well known hazard. It was a topic for hangar flying until about 1950, when it became a subject of scientific curiosity and analysis by Captain Prosper Cocquyt, Chief Pilot of Sabena Airways. It is an interesting tale.

In 1930, Sabena suffered two catastrophic losses in the new night airmail service, for reasons unknown. Visibility was good with an overcast sky that obscured the horizon. Captain Cocquyt investigated both accidents. In one of these he was astounded by the relaxed appearance of the dead flight mechanic, who was found with his hands in his pockets, obviously not expecting an accident. This perplexed him for years.

When Captain Cocquyt was grounded by the Germans in World War II, he enrolled for courses in psychology and physiology at the University of Brussels. He applied his new knowledge to the mysterious accidents he has investigated, did some experimental night flying after the war to develop a well founded theory on "The Sensory Illusions of Pilots". However his ideas were not taken seriously in European aviation circles at that time.

In 1949, KLM invited me to talk to their pilots on safety problems. Captain Cocquyt was in the audience. He introduced himself to me after the lecture, told me about his theory, and gave me a copy of his manuscript on sensory illusions. I had it translated from French to English, circulated it among experienced pilots and aviation psychologists in this country for criticism and found vindication of Cocquyt's ideas. (Fig. 3)

We disseminated these concepts. Cocquyt was internationally acclaimed. Other pilots and human factors specialists extended Cocquyt's ideas to produce other excellent studies and articles about sensory illusions. An excellent article in my opinion is "When Seeing Is not Believing" by Capt. Barry Schiff of TWA. It appeared in the British aviation safety periodical "Flight Safety Focus" of June 1978. It covers visibility, runway and approach lighting, sloping runways and includes Boeing's research of factor that adversely influence a pilot during visual straight-in approaches at night. Schiff's article appeared originally in the AOPA "Pilot".

Before concluding the lessons learned from several past aviation catastrophies, I'd like to say a word about future accident investigations.

I feel that an investigator should ask himself whether the accident might have been averted by flight data recorders used routinely to seek out inadvertant departures from good practice. Several airlines are routinely using flight data recorders this way under a joint management/pilot agreement that removes the threat of management spying on aircrews. Incidentally, the first Flight Data Recorders were mounted on the first Wright airplane in 1903. It registered time, engine RPM and distance through the air.

Playback procedures are quite common in the world of sports when team members review their actions by watching films. It is a form of valuable Monday morning quarterbacking applied to aircraft operations. This also calls for more than the current parameters required by the FARs flight data recorders in the United States. Many airlines record well over one hundred parameters on their flight data recorders. In the playback, only the deviations from good pratice, if any, are disclosed to a carefully selected pilot-monitor. He informs the crew involved. If a pattern develops, he informs management to adjust the training procedures.

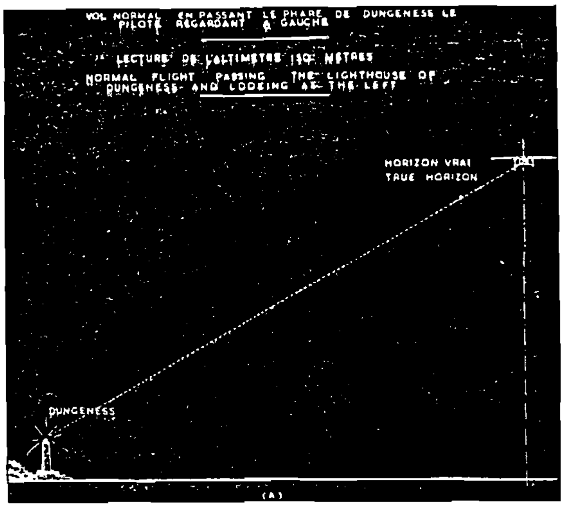
Electrons Leave Evidence

Dr. Carol Roberts of the NTSB, in a recent lecture on "Accident Recorders — An Important Key to Safety" dwells on the need for recording data in the new electronic cockpit. She quotes Rimson's observations on fly by wire accidents:

- Malfunctioning electrons will not be found in the wreckage;
- Computer systems rarely have physical evidence of malfunctions;
- Computer controlled systems often restore themselves after a malfunction.

In the lifetime of many of you here, passengers will be flown ballisticlly over long distances, London to Hong Kong in one hour.

If one of these ships should be lost for reasons unknown, the fleet, each costing very much more than today's transports, would probably be grounded until the mystery is solved, if ever.



Mes expériences

Il y a déjà plus de vingt ans que je me suis rendu compte que les illusions d'optique pourraient être la cause de nombreux accidents d'aviation.

Un premier accident survint à un avion de notre Société, le 11 septembre 1930. L'avion postal de nuit, un trimoteur Fokker VII, ayant comme équipage un pilote et un mécanicien, fit demi-tour quelques minutes après avoir quitté l'aérodrome de Croydon à cause de la mauvaise visibilité et s'écrasa sur l'aile droite, à proximité de cet aérodrome, en prenant feu aussitôt.

Quelques mois plus tard, le 9 janvier 1931, un deuxième

Figure 3

An answer to this would be the use of telemetry to provide the investigators with a continual stream of essential information. Telemetry worked wonderfully well in the space program. On Apollo, the moon landing project, about 48,000 bits of information per second were transmitted to ground control. Without telemetry the loss of Apollo Six, an unmanned launch, would probably have remained unsolved; the Apollo program would have been stifled by conjecture. Apollo Six experienced pogo (vertical vibration), loss of about 35 square feet of the skin, and other malfunctions. Apollo Six disappeared and was never seen again. By the use of informtion supplied by telemetry and simulation, the cause of the trouble was traced in a few weeks to a wiring error. The industrialization of space will require an extension of your activities beyond our atmosphere.

Concluding Remarks

While tracing the historical background of a few of the hundreds of items which concern the aviation accident investigtor, I have suggested that boundary of investigation be formally expanded to include root causes of undesired events as well as the probable causes. This would include policy dictated by management or government policies, mental and emotional factors. In addition I suggested that investigators consider the potential of flight data recorders for the evidence of accidents for the detection of unsafe crew practices before they result in the need for an accident investigation. The industrialization of space will call for the investigation of undesired events in that area. ISASI should accept that challenge.

The files of investigative bodies such as the NTSB probably contain much data on root causes. Because of their hypothetical and perhaps amorphous nature they do not meet the criteria or provable evidence required for an official report, Nevertheless they may be more significant for accident prevention than the usual probable causes. The NTSB is gradually feeling its way into this area. The article "Subtle Pilot Mental Incapacitation" in the USAF magazine "Flying Safety" of August 1983 supports these observations.

I have also suggested that ISASI address the problem of formulating safety recommendations from a holistic standpoint: economic, political, socital, timing, in accordance with the goal set by law "to operate with the highest possible level of safety" indefinite as this may be. Irving Pinkel, when at NASA expressed this concept in better words:

> "Every industry is obliged to improve its safety record where it can. Those who insist on ignoring the smaller safety problems, about which nothing can be done yet, are mostly evading the issue. Most safety measures adopted by an industry deal with the small portions of the total hazard. Over the years the steady improvement that results is significant. If each step is discouraged because it doesn't solve the whole problem then nothing is accomplished."

As an aside to this presentation, I'd like to point to the establishment of the first course in civilian aircraft accident investigation, in 1948. When World War II started I was Director of Safety of the Civil Aeronautics Board in charge of Federal air safety regulations and the investigation of civil aviation accidents. Most of our technical staff were reserve officers in the miltiary services. They were called to duty leaving me with three trained investigators out of 22. We carefully recruited new personnel who were not subject to the draft and trained them the best we could, mostly on the job. Private flying for the most part was grounded so we were not as busy as in peacetime. The new investigators worked out well. One of them was Joe Fluet, the Founder of ISASI!

However I promised myself that I would experiment with a formal training course after the war. The Air Corps let us use Mitchel Field resources. The course was for the training of state aviation officials primarily but others attended. You may be interested in the diploma (Fig. 4).

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Examination of Electrical Wiring and Equipment In Aircraft Accident Investigation

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Abstract

There will normally be a great deal of information for the accident investigator which may be gleaned from the remains of aircraft wiring and equipment which survives an accident and/or fire. Unlike standard 60 Hz. building wiring systems, aircraft wiring systems have known electrical specifications, and carefully documented installation and maintenance procedures.

Inspection of wiring and equipment will help to determine the type of damage (electrical or other), the status of the equipment at the time the damage occurred, and the condition of the equipment at the time the damage occurred.

Introduction

Electrical equipment, wherever used, is designed according to a set of basic principles. The first requirement is usually safety, followed by reliability and efficiency. In portable or transportable applications, weight and volume begin to play a significant role in the final hardware specifications.

Circuit analysis and logic design usually are applied initially to establish the basic requirements of the final system. A schematic diagram is produced and analyzed to assure that the system, when built, is capable of working as planned. After the system performance has been simulated, and compatibility with other systems has been determined, the hardware selection begins.

Hardware design is constrained by several fundamental principles of electrical theory. First, electrical conduction generates heat in the conductors and at contact points; second, electrical potentials will cause currents in undesirable locations if appropriate insulation is not used; and third, insulation materials will degrade, melt or burn if exposed to excessive heat. The production of heat and dissipation of heat are normal in electrical equipment operation, and designers must coordinate material selection and environmental conditions with operating requirements. The equipment must be designed to meet all expected requirements without damage to that equipment or to its surroundings. The equipment is also expected to fail safe when an anticipated catastrophic failure occurs.

The accident investigator becomes involved with the equipment after something catastrophic has occurred. The cause of the accident must be determined from the remains of the aircraft and other available evidence. Examination of the electrical equipment is often an important part of the overall investigation. Thge investigator must, in addition to understanding electrical circuits and the principles of electrical equipment design, also be able to recognize damage patterns and know the conditions necessary for such damage patterns to be created. The accident investigator is always at a disadvantage, in that the investigator may be the only electrical expert available to interpret damage to equipment that was designed by hundreds of engineers with the aid of as many specialists.

The purpose of this paper is to physically describe, categorize and establish a basis for analyzing the common forms of physical damage caused by electrical heating which may be found in electrical equipment after an accident. Problems with operational logic or improper installation are important, but too diverse for discussion in a single presentation.

Thermal Characteristics of Electrical Equipment

There are several, often conflicting, sets of terminology applied to the thermal ratings of electrical equipment. There are current ratings, voltage ratings, volt-ampere ratings, wattage ratings, horsepower ratings and temperature rise ratings, with a specified ambient temperature. There are nominal, minimum, maximum and absolute maximum values for most of these variables. Each of these ratings is determined by analyzing the thermal behavior of the equipment, taking into account variations in environmental conditions during operation. Interpretation of the ratings requires an understanding of the temperature dynamics of electrical equipment in operation. Any analysis of termperature dynamics must begin with the principle of conservation of energy. As a formula:

heat energy generated = heat energy stored + heat energy removed

There are several approaches to the problem of writing the differential equations which make a mathematical statement of the above equation. In the most general case, the equipment will consist of several different materials in close proximity or in actual contact. The heat is generated in some of the materials and conducted by others. Heat will generally be stored in all of the materials. The equations for a complete description of the equipment temperatures are nonlinear and high order differential equations. Solution of these equations is possible only through simulation techniques, and the results are often unsatisfactory. The solution is only as accurate as the model, and the tolerances in manufacturing are often great enough to invalidate the results of a precision simulation. Environmental conditions also are variable and not subject to accurate prediction.

The basic equation above is used in several ways. It may be used to express envelope conditions. That is, the total heat energy generated by a piece of equipment is equal to the total heat energy added to the stored energy in the equipment plus the total heat energy removed by the cooling system. It may also be used as an incremental equation describing an arbitrarily small volume within a single material within the piece of equipment.

Ziegler and Nichols [1] proposed that a first order approximation could be used for higher order systems, with a possible time delay to allow for higher order effects. This method has been used in many applications to model higher order systems when analytic solutions of 2% to 5% accuracy are required. Since field meaurements are seldom more accurate, the model is satisfactory for a large number of applications.

For analysis of temperature versus time, the equation is first differentiated to describe the power balance. The equation follows:

$$\text{power generated} = \frac{d(\text{heat energy stored}) + \text{power removed}}{dt}$$

This equation is used as a basis for many analytic procedures. The particular applications determine the appropriate simplifying assumptions.

Short Time Exposure of Conductors to Overcurrent

One of the most common applications of this equation yields the maximum possible conductor temperature after the conductor has been subjected to a constant current for a short period of time. This application is based on the assmption that no heat energy is carried away by cooling during the short time involved. The equation becomes:

$$\text{power generated} = \frac{d(\text{heat energy stored})}{dt}$$

For a round wire, the power generated is:

$$\text{power generated} = \frac{r\,l\,i^2(T + T_i)}{A\,(20 + T_i)}$$

where: r = the resistivity of the conductor at 20 degrees centigrade;
T_i = the "inferred absolute zero" for the conductor resistivity;
l = the length of the conductor;
A = the cross-sectional area of the conductor;
i = the current in the conductor; and
T = the centigrade temperature of the conductor.

The rate of change of stored energy in the conductor is:

$$\frac{d(\text{heat energy stored})}{dt} = \frac{sAlp\, d(T + T_i)}{dt}$$

where: s = the specific heat of the conductor material; and
p = the density of the conductor.

Rearranging:

$$\frac{d(T + T_i)}{di} = \frac{ri^2(T + T_i)}{sPA^2(20+T_i)}$$

which is easily solved to establish a relationship between time and current for a particular temperature or time and temperature for a particular current. The article of fusing current-time in the Standard Handbook for Electrical Engineers[2] is one application of this equation.

A general solution for the equation is:

$$\frac{ri^2T}{sPA^2\,(20 + T_i)} = \ln \frac{T+T_i}{T_0+T_i}$$

where: T_0 = the initial centigrade temperature of the conductor.

Long Term Exposure of Conductors to Current At Any Level

The long time exposure, or "steady state" condition is described by setting the time rate of change of temperature to zero, and equating heat energy generated to heat energy carried away by the cooling system. The equation becomes:

$$\text{power generated} = \text{power removed}.$$

The power generated is the same as that in the short term application, and the power removed is described according to the heat removal process involved, and the physical attributes of the insulation. The steady state temperature is usually assumed to be proportional to the generated power, at least to a first approximation.

Temperature Trajectories of Conductors

For insulated conductors, the heat is carried from the conductor through the insulation material. Using the termal conductivity linear model, the heat energy removed becomes:

$$\text{heat energy removed} = k\,(T - T_a),$$

where: T_a = the ambient temperature of the area surrounding the wire. Adding this term to the equation for short term exposure yields:

$$\frac{d(T + T_i)}{dt} = \frac{ri^2(T + T_i)}{sPA^2(20+T_i)} + k(T-T_a)$$

This equation has the solution:

$$T(t) = A + (T_0 - A)EXP(F{*}t)$$

where A and F are functions of the geometry, the material parameters and the current.

Temperature Trajectories For Convection Cooled Machines

The temperature trajectories for air cooled machines may also be treated as first order thermal systems if sufficient data are available for developing a reliable model. When forced air cooling is used, the highest temperature encountered within the machine usually will be nearest the air outflow port, beause the temperature of the cooling air rises as it passes through the machine. The heat energy removed is:

$$\text{heat energy removed} = f(i,V,T_a)(T - T_a),$$

where: V = the flow rate of the cooling air.

The complexity of f depends upon the desired accuracy and the amount and precision of available data. An overly complex version may not be as accurate for extrapolation as a simple model, if the range of available data for parameter identification is limited. Also, models for convection cooled systems are strongly dependent on some air flow for valid results. In a first order model, if air flow is set to zero, the model topology must be changed, since some heat flow paths will be reversed in direction. In general, convectively cooled systems must be individually modeled, and parameter identification must be undertaken if temperature dynamics must be known.

For a recent study of a direct current air-cooled generator, the following terms were used in conjunction with the general energy balance equation to produce satisfactory predictions of generator temperature dynamics under a variety of test conditions. Note that each term may be normalized to the thermal storage constant associated with the rate of change of stored energy.

$$\frac{d(\text{heat energy stored})}{dt} = \frac{Jd(T - T_i)}{dt}$$

$$\text{power generated} = \frac{Ri^2(T = T_i)}{(20+T_i)} + B_i$$

And

$$\text{heat energy removed} = (c1V + c2i)\; T - T_a),$$

where: J = the "equivalent thermal inertia" of the machine,

R = the armature circuit resistance at 30 degrees Centrigrade, and

B = a brush loss constant.

The equations developed above are extremely important to an investigaor who is concerned with electrical equipment which has been found at an accident site. With them, an investigator is often able to determine the set of circumstances required to produce an observed damage pattern.

Classes of Electrical failure Caused By Excessive Heat

Insulation failure cannot be covered in a single paper. There are failures related to mechanical damage, chemical reaction, radiation exposure and heat exposure. There are several references available [3] describing the general field of insulation selection and application. In aircraft, the insulation characteristics will be a part of the equipment documentation. When an insulation failure is suspected, the type of damage must be identified. If the damage is not related to heat exposure, the electrical investigator should refer the analytic work to a different specialist. If the damage is caused by heat exposure, then the electrical investigator should work with another specialist to determine whether or not the heat senergy could have come from electrical current. The minimum temperature which could have caused the observed damage must be determined. The minimum time of exposure to that temperature which could have caused the damage must be determined. After this information has been extracted from the damaged insulation, then the time-temperature characteristics are used to determine the time-current range which could have produced the damage.

The aircraft documentation provides access to wiring details, fuse specifications, circuit breaker specifications, and switching arrangements. Available fault current may be determined for all reasonable combinations of generator, inverter or battery connections which may have an effect on the conductor under study. Time-current curves for all fuses and breakers may be obtained and compared to the proposed time-current conditions needed to produce the observed damage.

Conductor Fusion

Most aircraft conductors are made of copper, which melts at a temperature of 1083 degrees, C. As indicated in the previous section, a lower bound of time-current exposure required to reach this melting point from an ambient temperature 40 degrees C, has been published [2] for decades. Normally, fire temperatures reach the melting point of copper only when there is sufficient air motion for a high temperature to develop, which often happens when fuel is burning. In building fires, melted copper is most often related to electrical arching or severe overcurrent. In aircraft fires, fuel and high air velocities can easily melt copper. Other sources of confusion come from metallurgical/chemical reactions between the copper and the structural aluminium in the aircraft.

Figure 1. Fusing Characteristics for Copper

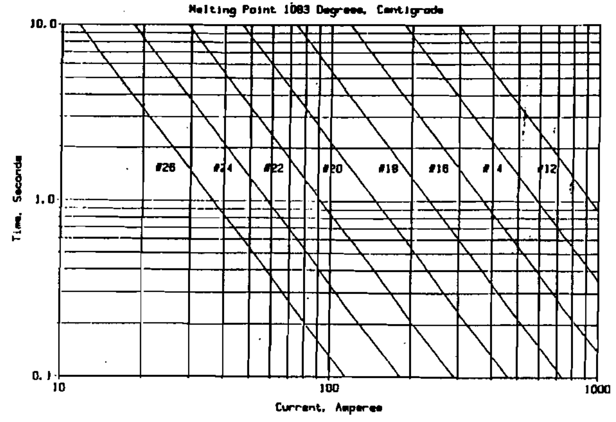


Figure 2. TIME v. TEMPERATURE

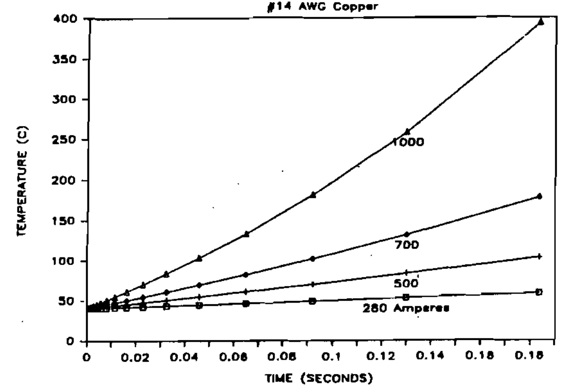


Figure 3. Generator Model

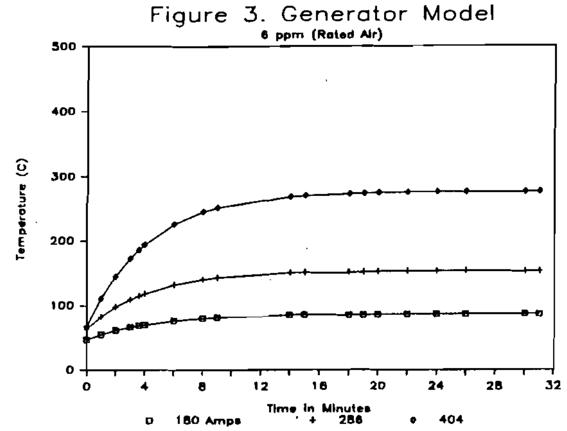
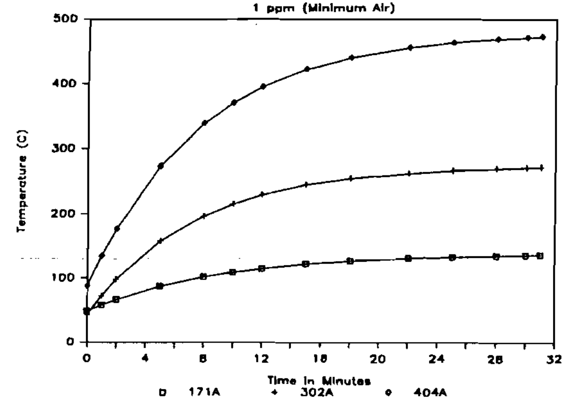


Figure 4. Generator Model



When an investigator is confronted with melted copper conductor, any conclusions must be carefully drawn. Before the cause of melting can be determined, several questions must be answered. Was the melted copper found in an isolated area where nearby equipment shows less heat exposure? Could the conductor have been energized? If energized, was the available supply sufficiently robust to produce the necessary current for the necessary time? Should the circuit protection have allowed the delivery of the required current for the required time? If arcing is suspected, can a return path for the electric current be identified?

The time-current study related to determining the source of insulation damage may be useful in this analysis, if there is reason to suspect that the primary protection (fuse or circuit breaker) was inoperative, and that the current was controlled only by a secondary device of higher rating.

Conclusions

The extensive documentation in an aircraft accident investigation may be used by the electrical expert to determine in some detail just exactly what was in the aircraft immediatly prior to the accident. Physical inspection of the equipment after the accicent, together with the documentation, enables the electrical investigator to analyze the circuits, calculate the expected currents, and determine whether or not an electrical failure could have been responsible for a particular incident. A large number of plausable explanations can usually be reduced to a very few possible explanations.

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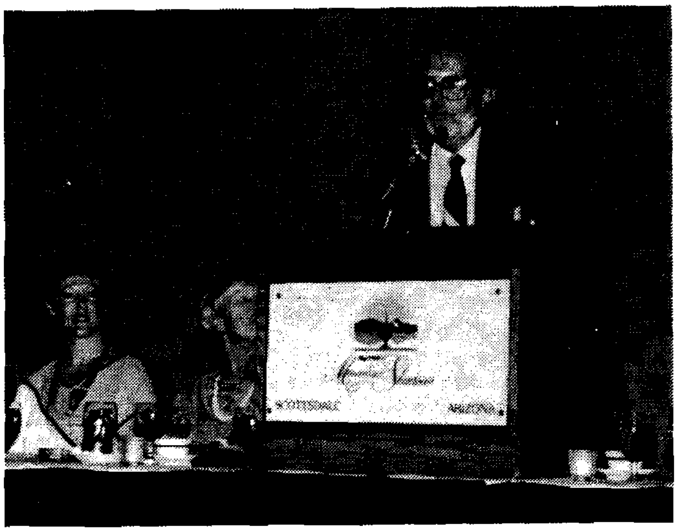

Introductions by Dave Hall, Seminar Committee Chairman.

Fracture Mechanics for Use In Aircraft Crash Reconstruction

by Paul F. Packman[1]
Angela A. Steffan[2]

Abstract:

This paper provides an introduction to the field of fracture mechanics and outlines some of the ways in which fracture mechanics concepts can be applied to aircraft crash reconstruction. Fracture mechanics uses the concept of a critical defect in a component under load, and calculates the size of the defect at the time of final catastropic crack propagation. Examination of the failed part to determine the size of the defect, and using fracture mechanics, one can then estimate the magnitude and direction of loads which were necessary to cause final failure. These loads can be evaluated in terms of the ability of the structure under normal or abnormal circumstances to put these loads into the particular component. The analysis can further demonstrate whether the defect observed on the fracture surface was causal or was present in the material and yet played no significant role in the failure of the component. Several examples and simple calculations are presented and discussed.

Introduction

Fracture mechanics provides the accident investigator with a brief introduction to a large existing body of knowledge that may be of help in evaluating and reconstructing some of the causes of accidents — namely those associated with failure of structural components.

Fracture mechanics is an analytical tool used to predict the behavior of materials in the presence of cracks. In order to use this technique a crack must be already present in the material analyzed. It develped primarily becuase of the need to understand how small cracks in high strength materials could drastically reduce the strength and load carrying behavior of high strength steels. For example, the presence of a crack less than an eighth of an inch long in an ultra high strenth quenched and tempered steel can result in failures at gross tresses less than or equal to the yield strength of the material.

Historial Overview

Fracture mechanics was developed by A.A. Griffith in the 1920's. Using a glass plate with a flaw present in the center of the glass under an applied tensile load, Griffith determined the stress at which the crack drew catastrophically. However, this analysis was not used by the engineering profession until the early 1940's when failure of the World War II Liberty Ships occurred.

In a span of ten years, seven Liberty ships and nine T-2 tankers had broken completely in two as a result of brittle fracture. The majority of the fractures occurred in hatch corners or square cutouts. Design changes were made to the hatch corners and square cutouts using the fracture mechanics analysis and this led to a reduction in the number of incidences of failures of the Libery ships.

In the mid 1950's the crack was used as a concept for failure for design analysis on the British Comet, the Rockwell B-70 aircraft, and U.S. built rocket motor cases. Later in this period, Paul Paris developed a fatigue crack growth analysis based on the fracture mechanics technique.

The late 1960's saw the fracture mechanics technique used extensively on the F-111 aircraft. Flaws detected in the F-111 wing structure led to an Air Force fracture mechanics program. This program led to the development of Military Specification A-8444[1] which has as its objective to "protect the safety of flight structure from potentially deleterious effects of material, manufacturing and processing defects" by providing "damage tolerance design requirements" to aircraft.[1]. In 1970 the B-1 aircraft was the first design ever to use this fracture mechanics design requirement.

The fracture mechanics analysis is not limited to aircraft or ships. Pipelines, off-shore structures, automobiles, oil field equipment, electronic equipment, nearly everything that can be designed using any type of material is now designed with the possibility of failure in mind.

The fracture mechanics concepts have come a long way from Griffith's analysis of a cracked glass plate. Originally the concept dealt primarily with the determination of a critical stress in a material. Now engineers design with fracture in mind, assuming that defects are already present in the materials and include careful inspection procedures to prevent the catastropic failure of the design.

Fracture Mechanics Design

In 1978 the Federal Aviation Administration came out with an advisory circular for all civil aviation. FAR Part 25[2] introduces the concept of a damage tolerant structure, i.e. a structure having a flaw present in the material shall not be considered unsafe. Therefore engineers began to design strctures considering the fact that defects, undetected by normal inspection procedures, could be present in the material without causing catastrophic failure of the structure.

The engineers based their designs on a simply fracture mechanics concept:[3]

$$K = \alpha\sigma(\pi a)^{1/2} \quad (1)$$

where: σ = applied stress = (applied load)/(cross-sectional area)
a = length of crack present in the part
π = 3.1416
α = material and geometric constant

The constant (K) in this equation is called the Stress Intensity Factor and acts as a measure of the intensity of stress (load) in a part with a crack of length (a) present in the material. At fracture:

$$K_c = \alpha\sigma(\pi a)^{1/2} \quad (2)$$

σ_f = applied stress at fracture
K_c = critical stress intensity factor or facture toughness

where fracture toughness is defined as the ability to carry a load in the presence of a notch or crack at the point of fracture of a material.

The critical stress intensity factor is determined for materials using fracture testing techniques. Some values of K_c for some materials under specific testing conditions include:[4]

Material	**K_c**
High Strength Aluminum Based Alloys	40 ksi-(in)$^{1/2}$
High Strength Steels (4340)	155 ksi-(in)$^{1/2}$
High Strength Titanium Based Alloys	124 ksi-(in)$^{1/2}$
Boron Fiber Epoxy Composites	64 ksi-(in)$^{1/2}$
Cast Iron	9 ksi-(in)$^{1/2}$
Ceramics	5 ksi-(in)$^{1/2}$
Glass	1 ksi-(in)$^{1/2}$

Examples Using Fracture Mechanics Concepts

The following examples will now be presented to show the effective use of fracture design and analysis.

1. Landing Gear Strut
2. Helicopter Hub
3. Environmental Affects on Helicopter Lug

Landing Gear Strut

Landing gear struts are "fracture critical" components due to the amount of force they have to sustain during take-off and landing maneuvers. In this example a crack of length 0.4" is present in the strut (figure 1). The configuration of the strut can be modeled as a cylinder under tension loading for purposes of the fracture mechanics analysis (figure 2). Using equation (2) and the following information, the critical fracture stress can be calculated.

Given: $\alpha = 0.4''$
$\alpha = 1.3$ (figure 3)
K_c for 2024 Aluminum = 28 ksi-(in)$^{1/2}$
K_c for 7075 Aluminum = 32 ksi-(in)$^{1/2}$

2024:

$$K_c = \alpha\sigma_f\,(\pi a(^{1/2}$$

$$28 \text{ ksi-(in)}^{1/2} = 1.3\sigma_f\,(\pi\,(0.4))^{1/2}$$

$$\sigma_f = 19.3 \text{ ksi}$$

7075:

$$32 \text{ ksi-(in)}^{1/2} = 1.3\sigma_f\,(\pi\,(0.4))^{1/2}$$

$$\sigma_f = 22.1 \text{ ksi}$$

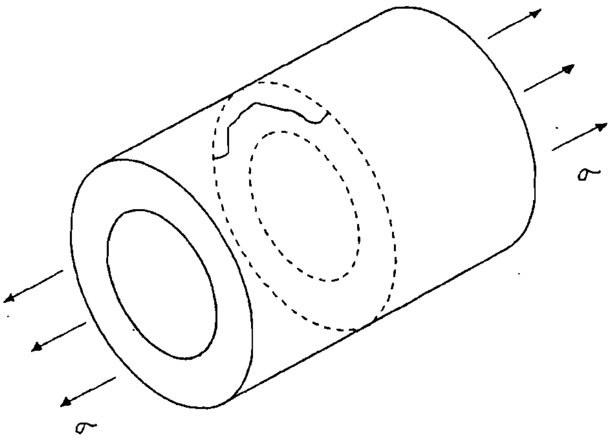

Figure 2: Cracked Cylinder Under Tensile Loading For Landing Gear Strut Analysis

The higher strength material (2024) has a lower fracture stress than the lower strength aluminum (7075) under the same loading conditions. Therefore an increase in the strength of a material does not necessarily improve the overall design of the part in particular when a defect is present in the component.

Helicopter Hub - Leak Before Failures

This example relates to a Sikorski rotor head attachment fitting failures. A Navy Sikorski with a fitting filled with high pressure oil for a blade folding process crashed outside Tuscon, Arizona while on a flight from San Diego to Pensacola Naval Rework Station due to a leak in the hub. It was never thought that a *cracked* hub caused the leak. Since the blade folding device was never operated, the leak was never detected.

In this situation, the hub can be equated to a pressure vessel with a part-thru crack of length 0.15" subject to internal pressure, P (figure 4). In this example, the stress intensity factor is calculated using:[5]

$$K = 1.12\,\sigma\,(\pi a / Q)^{1/2} \quad (3)$$

where: a = depth of the crack partially through the thickness (figure 5)
Q = flaw shape parameter (figure 6)

Given: a = 0.15"
= P(radius to outside of vessel) / (thickness of vessel)
Q = 1.1 (figure 6)

Then:

$$K = 1.12\,\sigma\,(\pi a / Q)^{1/2}$$
$$K = 1.12(24 \text{ ksi})\,(\pi(.15'')/1.1)^{1/2}$$
$$K = 17.6 \text{ ksi-(in)}^{1/2}$$

If the critical stress intensity is K_c = 40 ksi-(in)$^{1/2}$, then the hub will not fail since $K < K_c$.

If the crack depth increases to a = 0.25":
then, $K = 22.7$ ksi-(in)$^{1/2}$

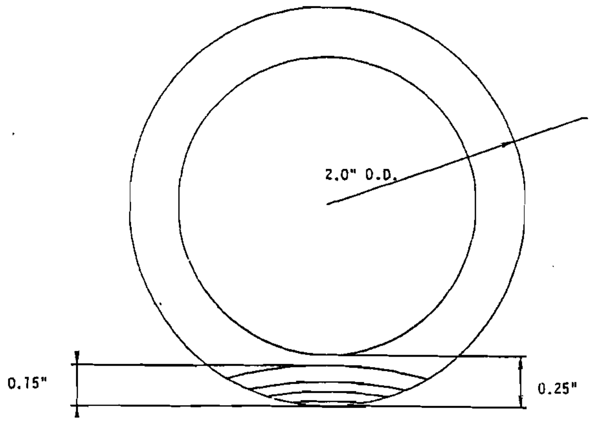

Figure 5: Part-Thru Crack Present In Cylinder Subjected to Internal Pressure. Cross-sectional View.

Again the hub will not fail. However, the fluid will leak from the cracked hub. This situation is called leak-before-failure criteria since the cracked part continues to operate with the leak without causing catastrophic failure of the part. Eventually the crack will grow to such a depth so that the part will fail. In this case the crack grew to the critical crack depth and the helicopter crashed.

Environmental Effects on Cracked Helicopter Lug

In some cases, failures do not occur primarily due to wear or misuse of the component. Environmental conditions contribute to failure of materials, especially stress corrosion.

Stress corrosion cracking occurs when a corrosive agent comes in contact with a material and the agent speeds up the deterioration process of the material. Its fracture mechanics analysis is determined using a specific critical stress intensity factor, K_{scc}. Comparing these values to K_c it is seen that:

$$K_c = \alpha\sigma_f (\pi a)^{1/2}$$
$$K_{scc} = \alpha\sigma_{f(scc)} (\pi a)^{1/2} \quad (4)$$
$$K_{scc} < K_c$$
$$\sigma_{f(scc)} < \sigma_f$$

For example,

4340 Steel $K_c = 155$ ksi-(in)$^{1/2}$

Under corrosive conditions: $K_{scc} = 10$ to 112 ksi-(in)$^{1/2}$

The example to be considered is failure of a lug under stress corrosion conditions (figure 7)

Conditions:

300M Steel
$K_c = 56$ ksi-(in)$^{1/2}$
$K_{scc} = 18$ ksi-(in)$^{1/2}$
$a = 0.3''$ (part-thru crack)
$D = 2.0''$
$Q = 1.3$

$$K = 1.12\,\sigma\,(\pi(a) / Q)^{1/2}\, f(a/D) \quad (5)$$

$f(a/D) = 2$ is a constant relating fracture consequences surrounding a hole present in a part. It is found using the Bowie solution in Figure 8. The stress concentration around the hole is much greater than at any other portion in the part.

By substitution of the above values into Equation (5):

$$K = 1.12\,\sigma\,(\pi\,(0.3) / (1.3))^{1/2}\,(2)$$

$$K = 1.9 \text{ ksi-in}^{1/2}$$

at K_c: $\sigma_f = 29.3$ ksi

at K_{scc}: $\sigma_f = 9.4$ ksi

If the applied critical stress from the design requirement is 15 ksi, then the failure stress due to stress corrosion is closer to the applied critical design stress than the stress due to tensile overload (K_c) it can be speculated that stress corrosion played a significant role in the failure of the lug.

Conclusion

It has been shown from these examples that fracture mechanics is valuable to both the designer and the accident investigator. The calculation of the critical stress intensity factor, the fracture stress or the critical crack length can help determine the cause of failure in a component. The technique has been extremely useful in the aircraft industry and is now being used extensively in other areas of design. It is hoped that is use will make the work of the accident investigator a little easier.

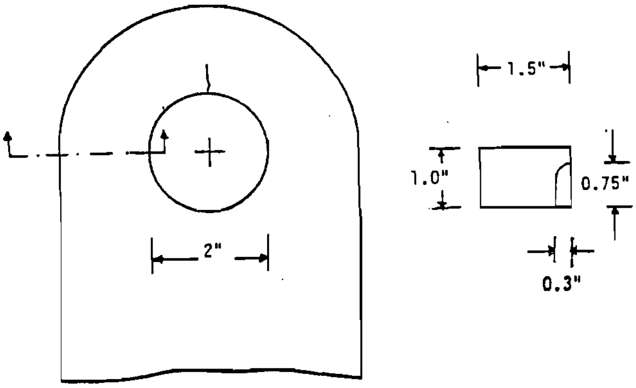

Figure 7: Cracked Lug Under Stress Corrosion Cracking Conditions

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Investiating New Technology Aircraft Accidents

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Abstract

Many of the techniques used in the past, to investigate aircraft accidents, may not be suitable for the new technology aircraft. These aircraft are characterized by cathode ray tubes and microprocessors. While more sophisticated digital flight data recoders may give more definition to flight parameters, it remains the responsibility of the investigtors to make use of other information sources to verify DFDR dta, and to provide a more compelte accident picture. The wide use of control display units and electronic flight instrument presentations will provide the investigator with a different range of problems. The author will develop the data circuit track and potential methods to deal with the new range of problems caused by this new technology.

Present Accident Investigation

The investigation of aircraft accidents has followed a well worn trail of traditional methods. Large aircraft accident investigation has been characterized by the investigating authority establishing specific expert groups such as, structures, powerplants, systems, operations, air traffic control, flight data recorder, cockpit voice recorder, crash survivability, witness, and weather. Special groups are added as needed, such as aircraft performance, human performance, and maintenance records, etc.

Of particular interest in the preparation of this paper was the methods utilized by the systems groups to arrive at the configuration of the aircraft during it's final few minutes of flight. Classical methods of investigative technique include documentation, tear down, and repower. The first task of the systems group is the documentation of the aircraft cockpit. All switches, controls, and indicators, are closely studied, in an undisturbed fashion, in an attempt to record the last position or configuration of the aircraft. Tear down of certain components such as motors, drives or actuators provide useful information about the potential operation of the systems. Power up of such components as motors or electrical continuity checks may also provide valuable information to the investigator. Even light bulb filaments may be studied to verify whether certain warning or cue lights were in the on or off position.

With the introduction of the new technology aircraft, the methods of traditional accident investigation may change drastically. The newer aircraft that are being built abound in cathode ray tubes (CR), microprocessors, and computers. Many of the current generation of accident investigators are alarmed at the loss of information which may occur in transitioning from the "steam guages technology," to the "glass cockpit technology."

ENIAC — A Page From History

With the introduction of the first electroni digital computer in 1946 at the Moore School of Electrical Engineering, University of Pennsylvania, a new era was ushered in. The Electronic Numerical Integrator and Calulator (ENIAC) occupied 1500 square feet, weighed 30 tons, and contained 19,000 vacuum tubes. Since that time computation speed, total weight, and power required have been vastly improved. The use of computer technology in commercial aviation reached wider applications the Inertial Navigation System (INS) was introduced for long range navigation.

Like many of the early computer systems, older INS's used magnetic core memory as the principle means of storage of information. The cores are strung on grids of wires and may be magnetized in one direction or the other to represent a number or word in hexadecimal or octal. The number of core memory plates identifies the address method. Eight memory plates correspond to the use of 8-bit words or one byte. Sixteen memory plates correspond to the use of 16-bit words. Core memory is not suitable for storage of large amounts of data and requires relatively large amounts of electrical energy. One of the advantages of core memory is that power may be removed and then restored without the loss of memory, provided that the ground potential is not changed. During the investigation of the Air New Zealand accident in the South Antartic, the core memory of the INS provided valuable information to the investigators.

Newer forms of memory are a development of the semiconductor indusury and the application in the aviation industry has dramatically increased with the high capcity semiconductor memory chips. These chips have the ability to store several thousand bits within a single integrated circuit. Memory may be random access memory (RAM) in which memory cells may be accessed for writing or for reading, or memory may be read-only memory (ROM) which may be accessed for reading but cannot be altered. Many exceptions to this general statement are apparent when one starts to examine the actual application of the memory chip such as ROM memory in various computers. An example of this nature is the electrically erasable programmable (EPROM) semi conductor memory. This chip will accept new information for storage but has only a limited number of cycles of information change that can be accepted before a chip must be replaced. Another type of chip is the prorammable chip (PROM) which is deliverd without data and is progammed by the user. Other differnces exist in RAM memory chips. To the investigator who knows the type of memory in use in various subsystems may mean the difference between little information or a lot of information.

The B757 As An Example of New Investigative Information

The B757 in spite of it's glass cockpit image has traditional flight instruments such as horizon, altimeter, and airspeed indicator located on the standby instrument panel. The standard cockpit voice recorder (CVR) is augmented by the Digital Flight Data Recorder (FDR) which records some 44 parameters on magnetic tape. Listed below is one air carriers DFDR parameters:

Lateral acceleration
Captain/copilot EFIS switch position
Captain/copilot ADC switch position
Captain/copilot IRS switch position
Captain/copilot FMC switch position
EICAS computer switch position
Vertical acceleration
Thrust reverser deployment or intransit rt and lt
EPR rt and lt
Aileron position rt and lt
Rudder position
Elevator position rt and lt
Air ground switch
GMT

Magnetic heading
Aircraft ID
Vertical speed
Pitch attitude
VHF mic key rt, lt and ctr
HF key rt and lt
Roll attitude
Derated Thrust -2
Leading edge slat extend, retract, partial or fail
Trailing edge flap position rt and lt
Calibrated airspeed
Pressure altitude
Horizontal stabilizer position

A Maintenance Control and Display Panel (CDP) directs very special test information into a Built In Test (BITE) unit to be stored in EPROM memory. After every landing event BITE interrogates six computers controlling autoflight, thrust management, and the flight management systems. The MCDP will store, in nonvolatile memory, up to thirty faults. The memory chips in this system have a capacity of 99 flight histories and may all be retrieved for review. This can be an invaluable tool if system malfunctions are suspected.

The Flight Management Computer (FMS) is the heart of the new technology aircraft, managing navigation and performance information for most efficient operation. Present FMS memory systems are hard disks with four-megabit capacity. Later this year bubble memory will replace the disk system in the updated system. The bubble memory will have an eight-megabit storage capacity and will process data at twice the speed of the disk memory. Bubble memory construction consists of using magnetic material in which a small space or bubble of magnetization is electrically pulsed to store data. This type of memory is nonvolatile and will retain data in spite of a power loss.

Data Track In A Digital System

The data track through one of the digital systems can best be described simply as origination to processor to bus to processor to end user. The processors change the data to a digital format with certain address information. Other processors capture data with the appropriate address and convert the digital signal into information that may be used in many ways. The digitized information is carried as a 32 bit word along the digital data bus (a set of wires twisted to protect from magnetic interference).

Protection Of Memory Units

Critical to the preservation of digital information is the proper handling of the electronic components. Manufacturers identify electrostatic discharge sensitive (SDS) black boxes with warning labels. The only vulnerable place on the box is the pin connectors at the back of the box. Unless you are grounded to the airframe or have the same ground potential as the black box, touching the pins can cause irrepairable damge to the microchips. When a black box is removed one of the first precautions is to cover the pin connectors with a dust cover. Circuit boards must be protected by placing them in a special conductive bag that screens it from electrostatic discharge.

Conclusion

It was not the purpose of this paper, nor is it within the capability of the author to intricately describe the workings, or advantages and disadvantages of the various forms of computer memory in common usage in the newer technology aircraft and retrofit equipment. What is important for the accident investigator to recognize is that many forms of memory exist in computer applications in aircraft. Some of the memory states are nonvolatile and will yield post accident information provided the accident investigator understands the precautions of handling the equipment. Obviously the most knowledgeable resource is the equipment manufacturer. Not only can they assist in outlining protective measures to prevent loss of memory, they can assist in retriving information that may be present.

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Light Bulb Filament Impact Dynamics Study

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M. Vermij (M02592)
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Introductions

The analysis of aircraft light bulbs is a tool that can be used by aircraft accident investigators to infer the states of various systems at the moment of impact. This analysis is especially valuable for systems associated with failure warning lights. Since the state of aircraft light bulbs ('on' or 'off') prior to impact often yields valuable information regarding the pre-crash electrical, mechanical, and operational status of the aircraft, it is important that light bulb analysis be performed as early as possible in the course of an investigation. This can save valuable time and facilitate early development of the accident scenario.

A number of papers have been written on the subject of automotive headlights with respect to impact damage; however, few similarities exist between automotive headlights and aircraft annuciator lights. A mid-study progress report on this project was presented at the 1983 International Society of Air Safety Investigators Conference. Now that the study has been completed, an accident investigation manual on light bulb analysis has been written and is expected to be incorporated into the manual of the International Civil Aviation Organization. A complete report on this study, as well as the manual, is available through the Aviation Safety Engineering Branch of the Canadian Aviation Safety Board.

Light bulbs in aviation applications can be categorized by their function as follows:

a) indication
b) caution and warning
c) spatial illumination
d) local illumination
e) signal beacon

Although there are many different types of bulbs used in aircraft today, annunciator panels and caution and warning indicators frequently employ type 327 miniature light bulbs. General Electric was found to be the most common manufacturer and the major portion of this research project involved the impact testing of over 400 General Electric type 327 (GE-327) light bulbs under known conditions.

Bulb Terminaology

Figure 1 illustrates a GE-327 light bulb with the elements of the bulb identified as follows:

"A" Base
"B" Glass Envelope
"C" Contact Posts
"D" Support Posts
"E" Mounting Bead
"F" Tungsten Filament

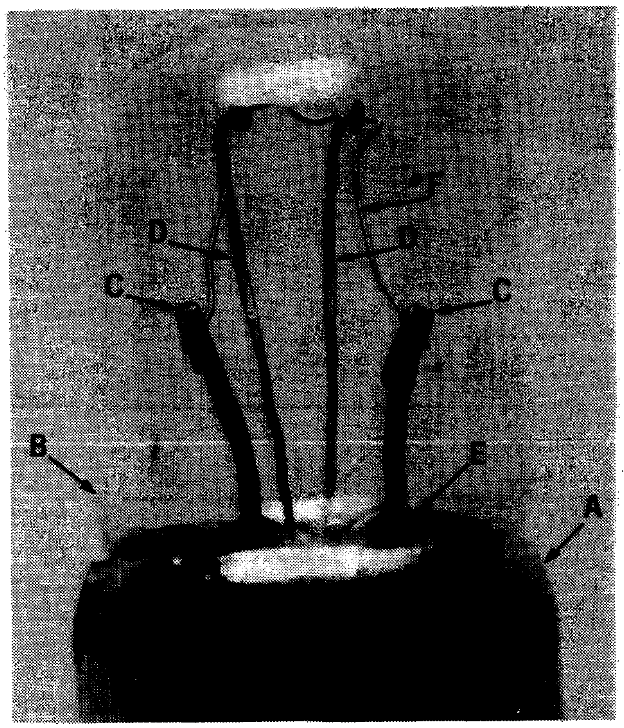


Figure 1

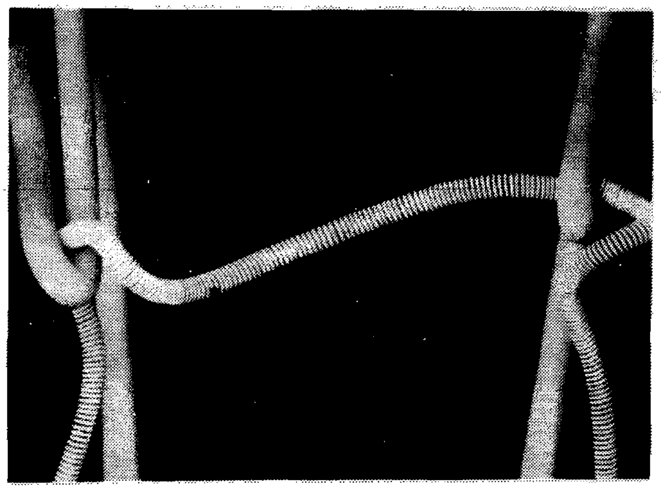


Figure 2

Virtually all aircraft lights contain a very small coiled tungsten filament, which is rather difficult to observe in any detail below 30X magnification. The scanning electron microscope (SEM) has become an important analytical tool for the examination of miniature aircraft lights because of its ability to examine objects over a wide range of magnifications (X20 to X20,000) with extremely good depth of field. Figure 2 shows an SEM image illustrating the coiled tungsten filament as it passes through its two support posts. Since each type of light bulb may have a different arrangement of internal components, the type of bulb becomes an important factor in light bulb analysis. For example, some smaller lights contain a shorter, coiled-coil filament, which typically is able to endure larger impacts without exhibiting damage. As well, support posts are not used in all bulbs. Support post movement at impact typically causes filament damage that would not have occurred in an unsupported bulb type.

Filament Lamp Manufacture

Since most of the damage incurred by light bulbs in aircraft accidents is directly associated with the filament, a short review of the filament manufacturing process is in order. The tungsten filament is generally manufactured by a powder metallurgy process. The tungsten is received at the lamp factory as a fine fibrous wire that consists of body centered cubic crystals that have been elongated and deformed during the various heat treatments and drawings functions. A technique called flashing is used to heat the filament above its recrystallization temperature to promote crystal growth. The main purpose of flashing is to create long interlocking grain boundaries to improve sag resistance. However, there is a trade off. Long interlocking grains produce a weaker filament than a fine grained microstructure. In order to prevent grain boundaries from forming in planes perpendicular to the wire axis, dopants are added in extremely small quantities. As the wire is drawn to smaller diameters, it becomes more ductile at room temperatures. Figure 3 shows the voltage versus temperature relationship for the GE-327 bulb. Ductile to brittle transition temperatures generally range from 500 to 650 degrees K, while recrystallization temperatures can vary from 1300 to 2300 degrees K.

This ductile-brittle transition temperature allows for the difference between 'hot' and 'cold' filament behaviour. Figure 3 reveals that it does not take much voltage for a filament to reach its transition temperature. This is an important consideration because of instrument panels which have a 'dim' select position for night flying and hence operate the lights on reduced voltages. In most cases, even in the dim position, the bulb will still be operating above its transition temperature.

Filament Operations

The GE-327 light bulb, and most of the lights found in aircraft annunciator panels, operate on 28 volts direct current (dc), and operate in a vacuum environment. With burning time, tungsten oxides gradually deposit on the inner glass envelope and a dark silver color is often evident on older bulbs. When operating on dc, present theory suggests that the resulting unidirectional magnetic field causes tungsten ions to migrate to preferred crystal planes. This electromigration causes the filament surface to develop jagged, saw-tooth irregularities, which are commonly referred to as notching (see Figure 4). DC notching will drasticaly reduce the life of bulbs compared to their longevity on alternating current (ac) and hence is a major consideration in light bulb analysis. The more advanced the state of notching, the more susceptible the filament is to impact damage. This type of notching does not occur when operating on ac because, under the influence of cyclically reversing current, the net migration is essentially zero. Some ac notching does, however, occur in the coils near the support posts and contact posts where thermal gradients exist. Notching (ac or dc) does not occur in the coils directly adjacent the posts because the local filament temperature in these areas does not reach recrystallization due to the heat sink effect of the posts.

VOLT	AMP (mA)	RESISTANCE (ohms)	RESISTIVITY (u ohm cm)	TEMPERATURE (kelvin)
0.0	0.00	73.0	5.66	300
2.0	10.56	189.4	14.68	651
4.0	13.36	299.4	23.30	942
6.0	16.14	371.8	28.61	1129
8.0	18.82	425.1	32.94	1263
10.0	21.33	468.8	36.33	1372
12.0	23.63	507.8	39.36	1468
14.0	25.78	543.1	42.09	1554
16.0	27.83	574.9	44.56	1631
18.0	29.76	604.8	46.88	1703
20.0	31.60	632.9	49.05	1769
22.0	33.39	658.9	51.06	1831
24.0	35.94	667.8	51.75	1852
26.0	37.62	691.1	53.56	1900
28.0	39.21	714.1	55.34	1960
30.0	40.78	735.7	57.01	2010

NOTE: BASED ON FILAMENT LENGTH OF 29.3cm CALCULATED FROM ROOM TEMP. RESISTANCE AND .0017cm DIA. TEMP. VS RESISTIVITY FROM E-230 PHYSICS HAND BOOK 56th EDITION.

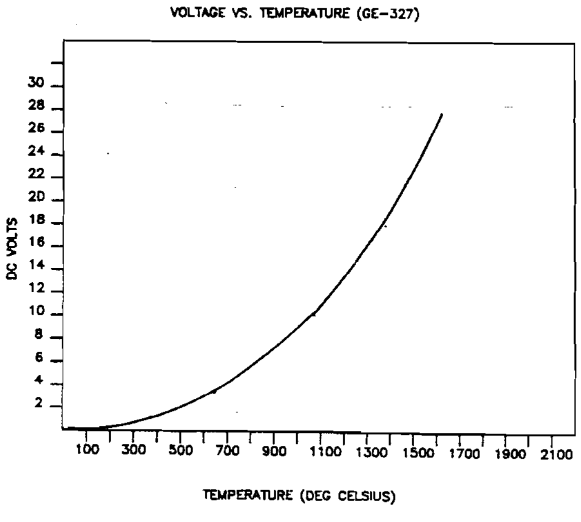


Figure 3

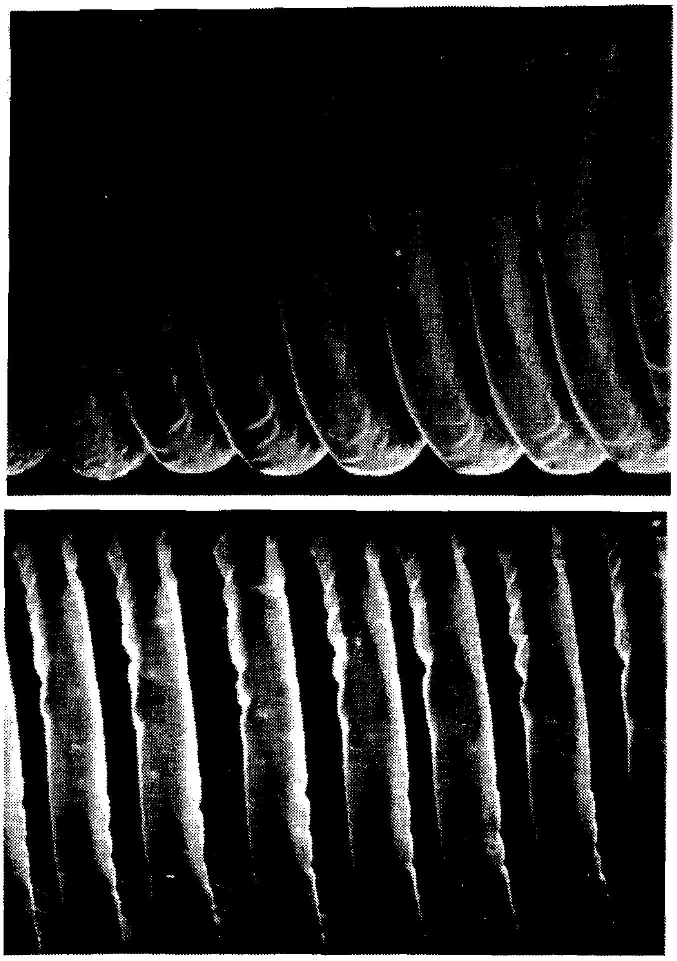


Figure 4a,b

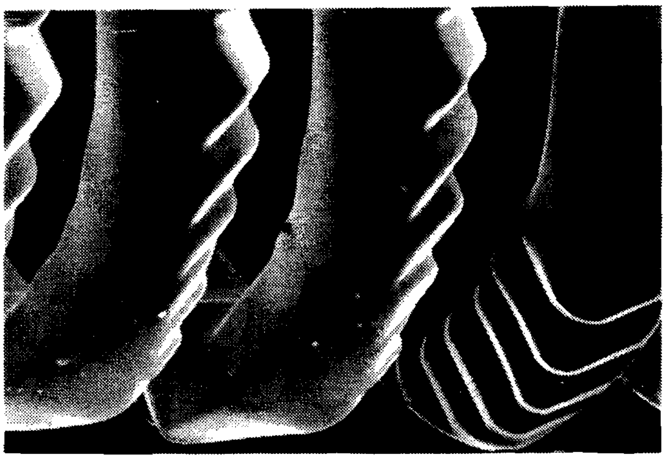


Figure 4c

Another important observation to be noted as a filament ages is the distortion of the filament shape, particularly around the support posts and contact posts as shown in Figure 5. This general deformation due to age must not be confused with impact deformation caused during a crash.

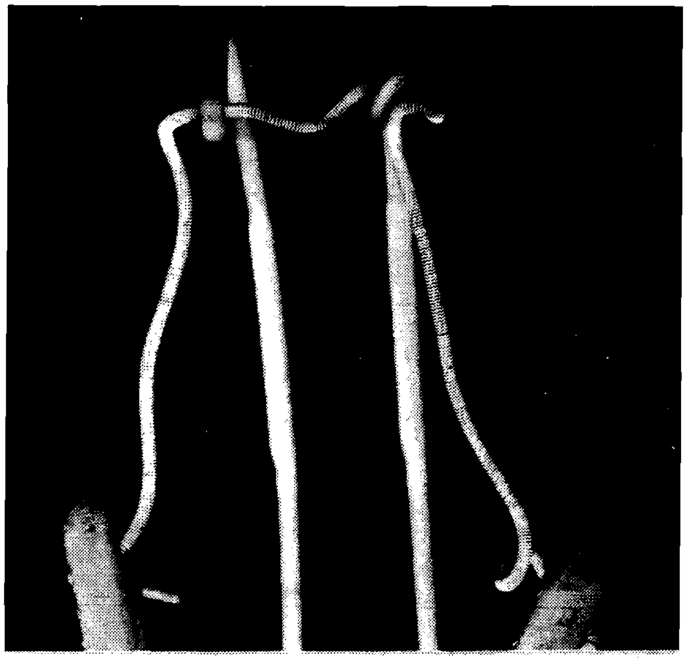


Figure 5

Resonance Testing

As a result of high speed cinematography tests conducted to observe the behaviour of the light bulbs' internal components during an impact, it was discovered that support post movement had a large effect on the deformation of the filament. If the support posts attain their natural frequency during an impact, the resulting filament deformation can be quite dramatic. The support posts for the GE-327 bulb have two major resonance modes, at approximately 1300 hertz and 1550 hertz. These two frequencies cause the supports and, consequently, the filament to oscillate violently.

Figure 6a illustrates the results of a cold filament vibrated at a support post resonant frequency until fracture finally occurred.

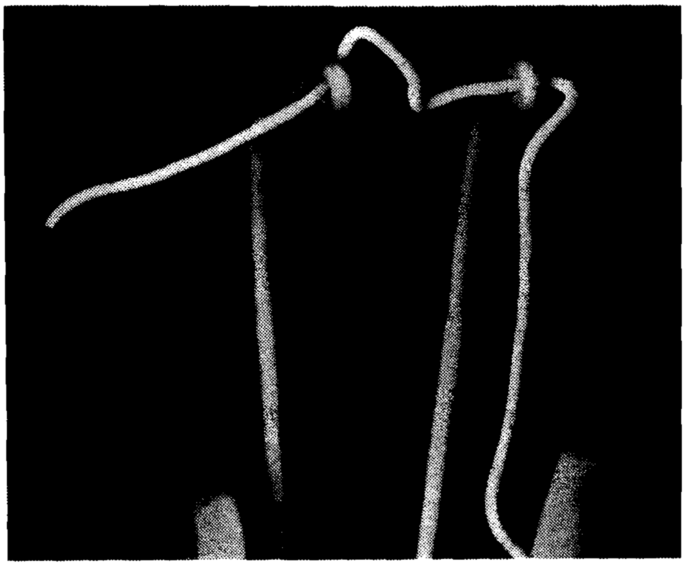


Figure 6a

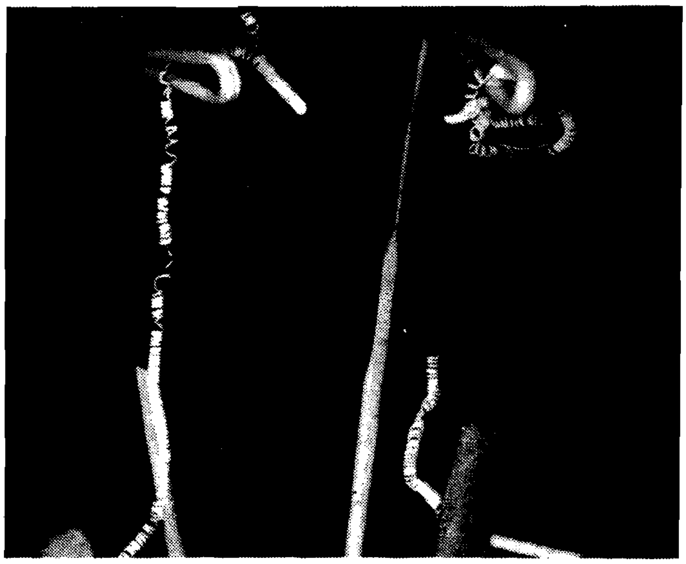


Figure 6b

Figure 6b illustrates the type of filament damage resulting from a hot filament, which was also vibrated at a natural frequency. The acceleration level required to fracture a filament (either hot or cold) decreased as filament age increased. New filaments, for example, could not be damaged when cold, at the maximum g level of the shaker table (-100 g) whereas a 5-10 g vibration level fractured a 210 hour aged bulb instantaneously. Even at this age, however, filaments were able to withstand maximum shaker table acceleration without showing any signs of damage when the frequency of excitation was not a natural frequency of the system. These g levels stated for the vibration tests cannot be compared directly to impacts produced by the laboratory impact machine or the impacts experienced during actual crashes because the vibration tests are continual sinusoids. An impact transient would require much higher g levels to cause the same damage.

Impact Test Program

The major test apparatus used in the light bulb study consisted of a one meter high drop impact tester (Figure 7), which produced

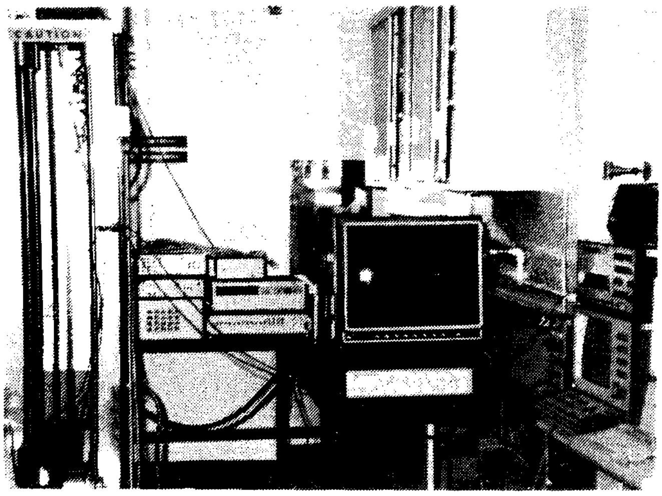


Figure 7

up to 400 g over 0/7 milliseconds half-sine pulse. This type of impact machine subjected the light bulbs to an inertial impact, as opposed to a direct impact. A direct impact would be, for example, when the headlights of a car 'directly impact' an oncoming car. The tail lights in this example would experience an inertial impact. Direct impacts generally cause glass envelopes to break and foreign materials may make direct contact with the filament and damage it. Should the glass envelope break, the filament will instantly oxidize when exposed to the atmosphere and burn out. In most aircraft accidents the glass envelopes of caution and warning lights remain intact.

The light bulb mounting fixture designed for impact testing housed four type GE-327 light bulbs. The bulbs were tested in the horizontal position with the plane of the supports in line with the direction of impact. This orientation provided for the maximum response and any other orientation would require higher g levels to cause impact damage. Filament damage was categorized as general deformation, local deformation, and/or fracture. General deformation was defined as general distortion of the filament while the individual turns remained tightly and regularly coiled. Local deformation was defined as uncoiling or expansion and contraction of the filament coils (stretch).

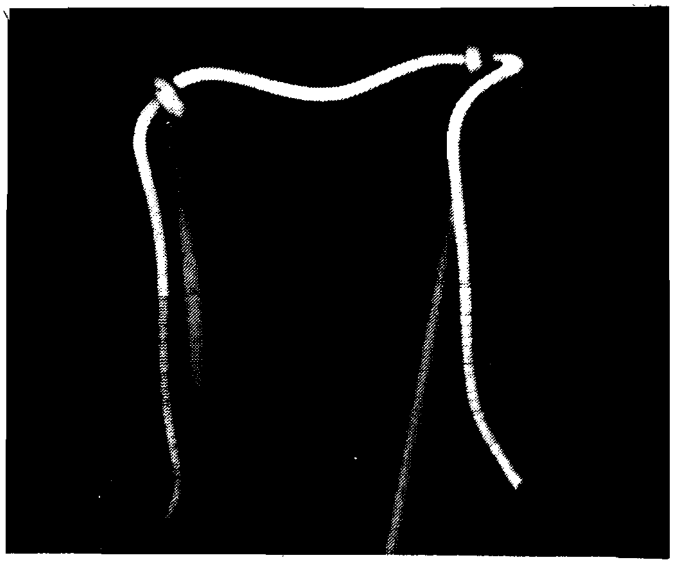


Figure 8a

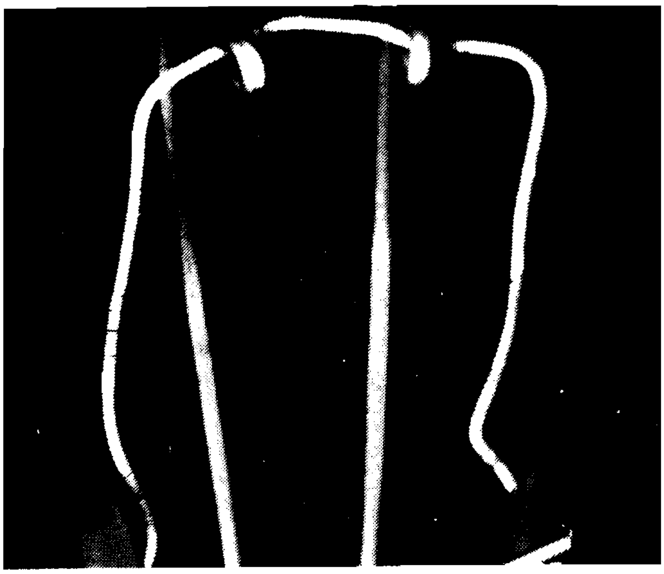


Figure 8b

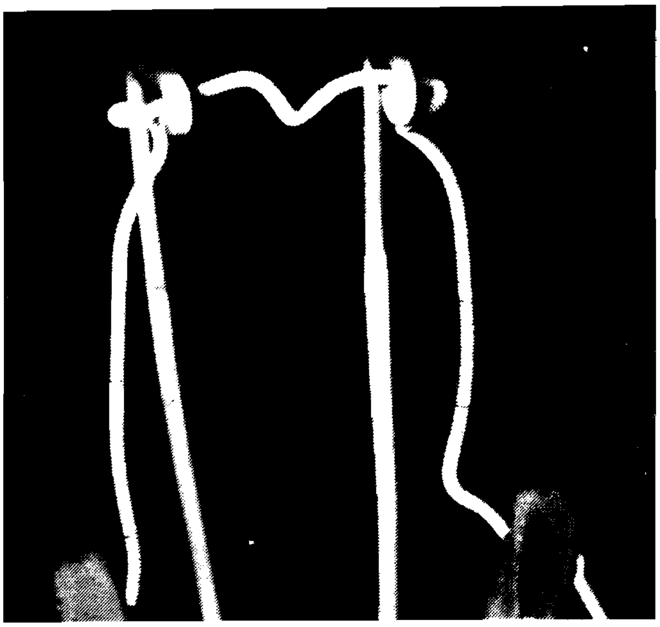


Figure 8c

Figure 8(a-d) shows the results of typical cold filaments of varying age that have been subjected to approximately 300 g over 1.0 milleseconds half-sine pulse. Figure 9(a-d) shows the results of typical hot filaments of varying age that were subjected to approximately the same impact conditions. As discovered in the resonance vibration tests, the older the filament, the more susceptible it was to impact damage for both hot and cold bulbs. Tests showed that new cold bulbs could withstand relatively high impacts, while new hot bulbs would begin to show general and local deformation at those same impacts. The minimum duration of the impact pulses produced by the drop test machine was not short enough to cause excitation of the bulbs' support posts. Since the impact machine was not designed for producing such short durations that would cause resonance, some tests were carried out using a hammer to directly impact a fixture. This produced an impact of short duration, which in turn excited the support posts of the light bulb at

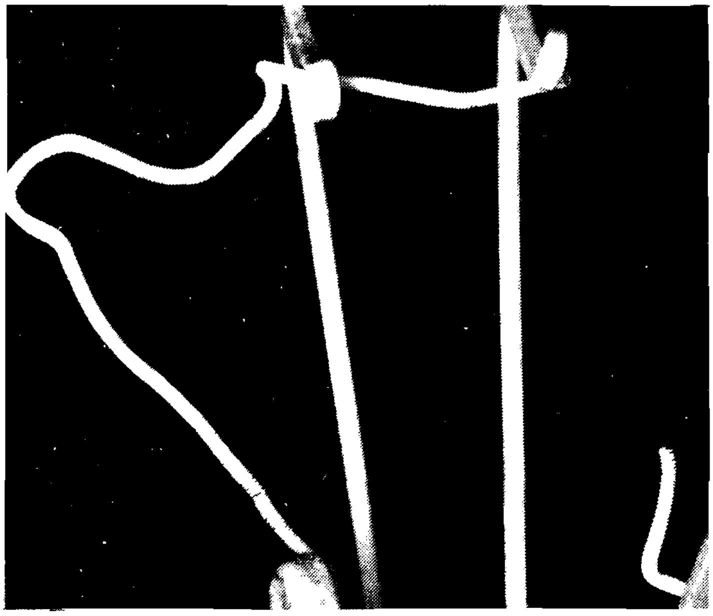


Figure 8d

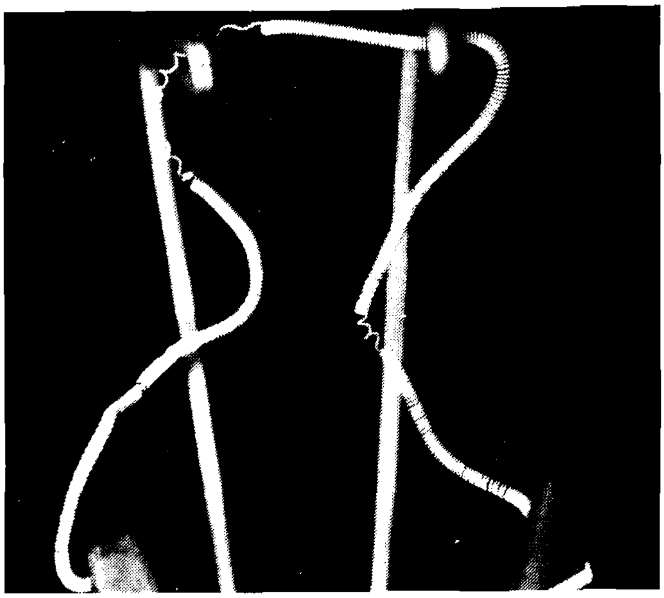


Figure 9b

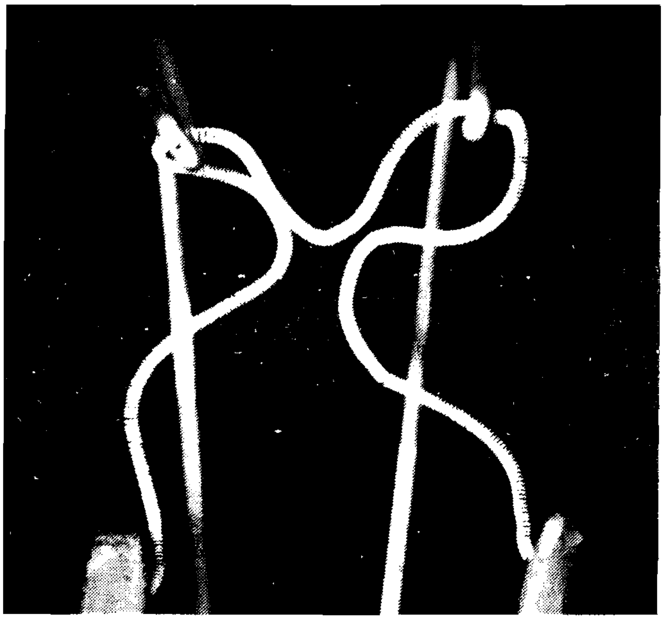


Figure 9a

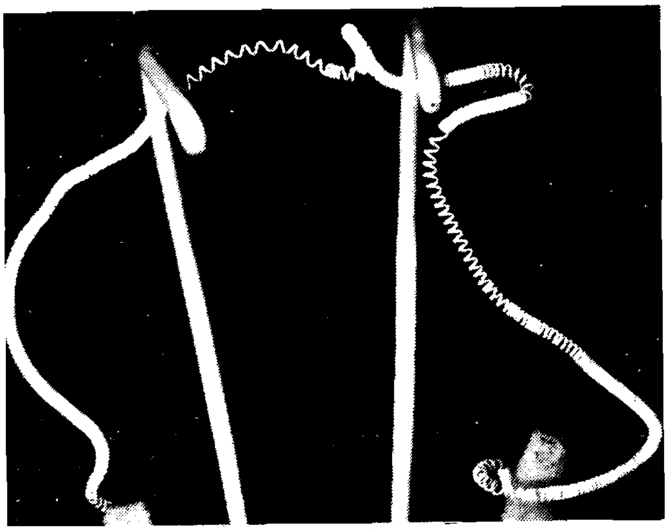


Figure 9c

their natural frequency. Figure 10(a-d) shows the results of testing of bulbs in both hot and cold conditions subjected to an impact of short duration such that the support posts attained resonance. Notice that a small amount of both local and general deformation is evident in the cold impacted bulb aged 0 hours (Figure 10c).

Impact Test Summary

New hot filaments exhibited no local deformation except in the higher g ranges (approximately 3000 g). Typically, new hot filaments only deformed while remaining tightly coiled. Aged hot filaments showed increased local deformation which eventually led to failure (fracture). Of the cold bulbs tested on the impact machine, none showed significant evidence of local deformation.

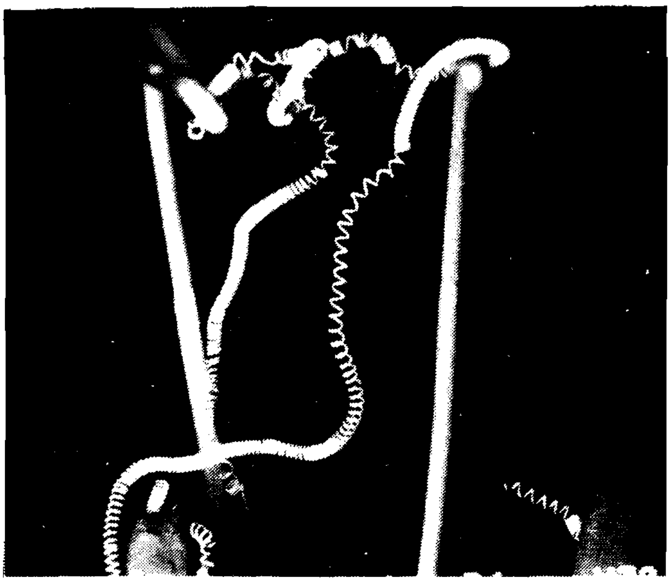


Figure 9d

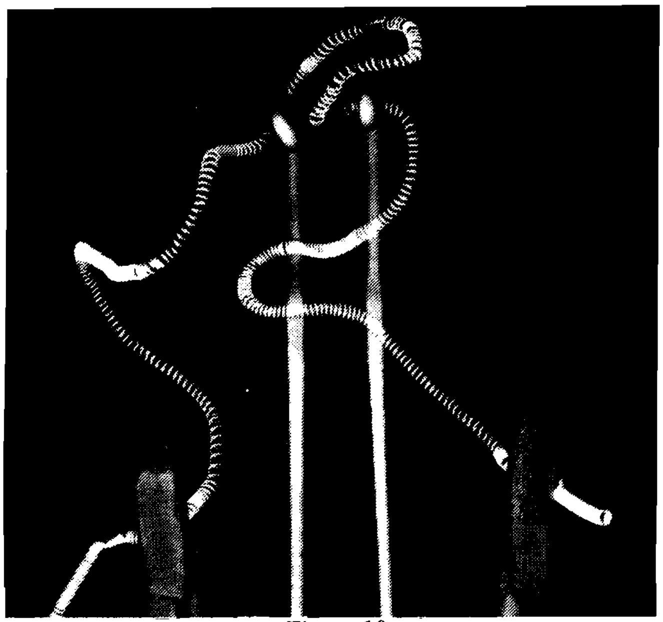


Figure 10a

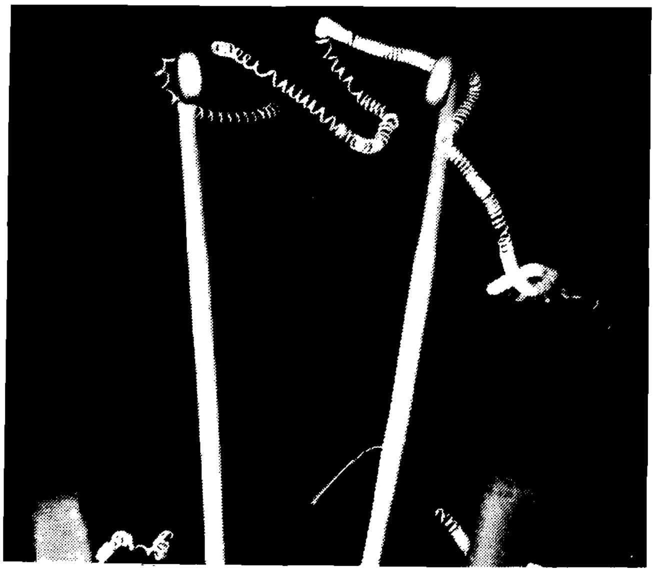


Figure 10b

High g level test of new cold bulbs resulted in some general deformation that was not directly distinguishable from general deformation produced from hot bulbs tested at low g levels. With increasing age, cold bulbs tended to fracture without showing signs of general or local deformation. Local filament deformation occured in cold bulbs when resonance was achieved at high g level, and the bulb was relatively new. This local deformation was likely the result of the support posts 'whipping' the filament around during impact and was typically confined to small areas. Cold local stretch was not observed in older bulbs and is not expected to occur for these type bulbs except possibly in the areas where the filament has not recrystallized (heat sink areas) or where the filament is less notched. This cold local deformation at high impacts was not directly distinguishable from hot local deformation due to low g impacts. This demonstrates the necessity of examining a group of light bulbs known to have been subjected to essentially the same impact forces, performing a comparative analysis, and acquiring some knowledge of the local impact forces involved in the crash.

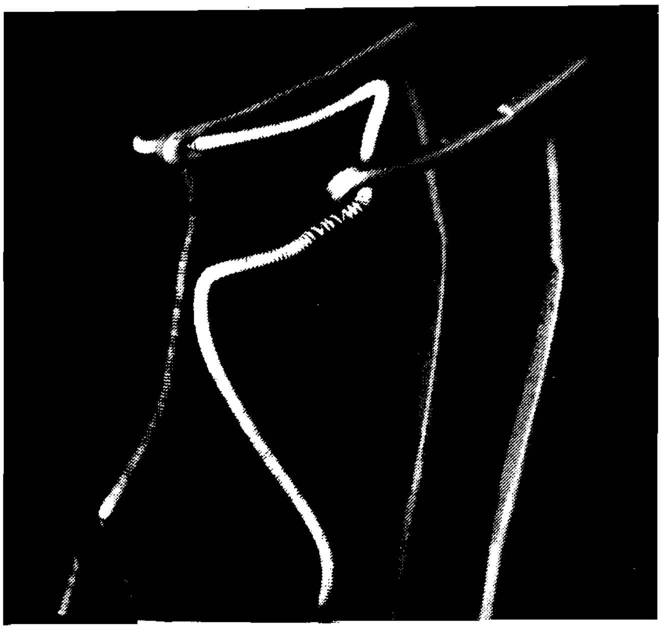


Figure 10c

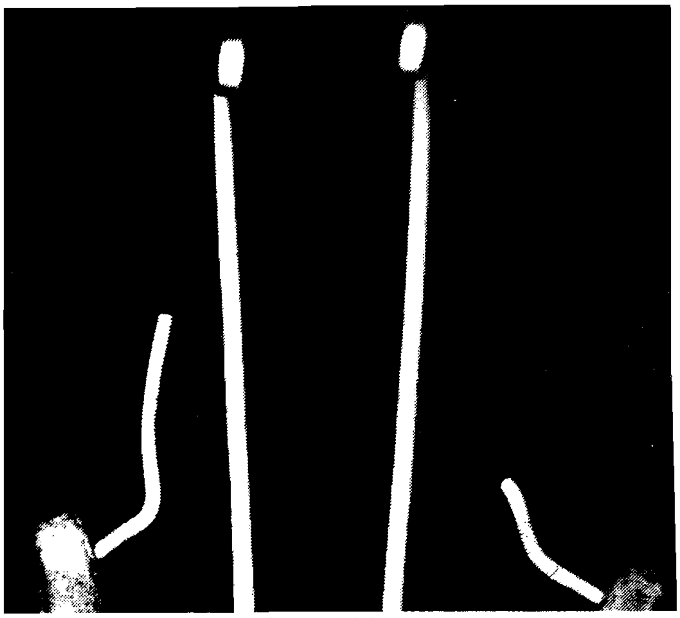


Figure 10d

Fracture Analysis

The terms 'ductile' and 'brittle' fracture cannot readily be applied to light bulb anlysis. These terms have been developed from the relatively slow tensile test in which, if the material elongated more than 10% it was considered ductile and fractured in traditional 'cup-cone' fashion. Less than 10% elongation was considered brittle and was generally associated with a granular type of fracture. A fracture in a filament subjected to impact is far from being 'slow'. The high rate of fracture gives rise to a 'brittle' appearance as a result of the materials strain rate sensitivity. Even though the tungsten may be operating above its brittle-ductile transition temperature, fractures due to impact will typically reflect the characteristics of a traditional 'brittle' fracture. Fracture surface characteristics are largely a function of filament temperature and microstrucutre. Recrystallization and the development of de notch-

Figure 11a

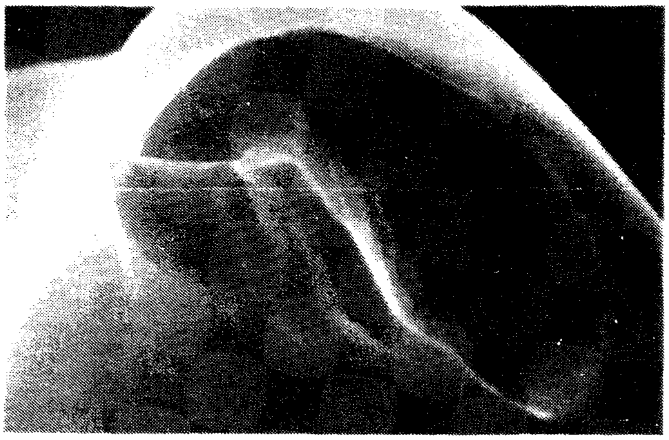


Figure 11b

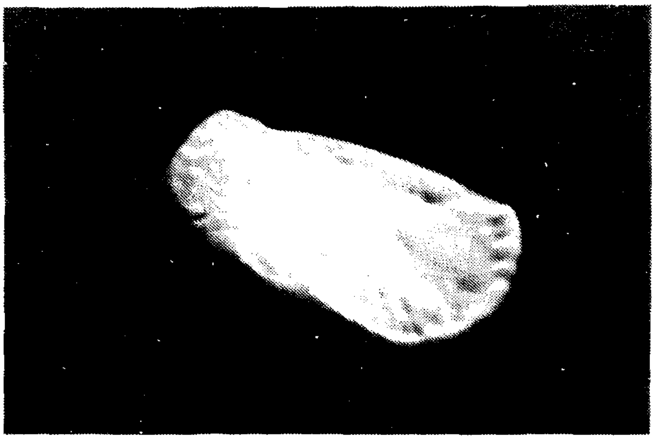


Figure 11c

ing cause the microstructure to continually change, not necessarily in a uniform manner. Because of the non-uniform microstructure development it is not uncommon to observe different fracture characteristics in the same bulb. Figure 11a shows a fracture surface typical of a cold break in an unnotched filament, while figure 11b shows a cold fracture in a notched filament that appears smooth and featureless.

When a hot filament is subjected to severe impact, the ductile state of the filament allows it to deform and uncoil without necessarily breaking. As the hot filament stretches, the probability of the filament crossing together and shorting itself out increases. Very often, the failure mode during a hot impact is burn-out due to this shorting. The fracture does not necessarily occur at the point of contact, but usually somewhere in the length of filament that was short circuited. Figure 12a shows a hot filament (aged 210 hours) that was subjected to approximately 1700 g half-sine impact over 1.4 milliseconds. Fracture did not occur until a few seconds after impact, when the bulb was observed to glow brighter than normal and then burn out. Figure 12b shows in detail the fracture area which is characerized by an 'aneurysm' effect or widening of the filament near the final fracture. This widening is also evident in bulbs that have failed due to excessive voltage, such as when an entire system gets shorted and bulbs see high voltages. Bulbs fractured due to high voltage alone however, do not exhibit the filament deformation found as a result of impact.

In some cases of severe impact, the filament fractures in many locations and, in the case of a cold bulb, results in numerous small

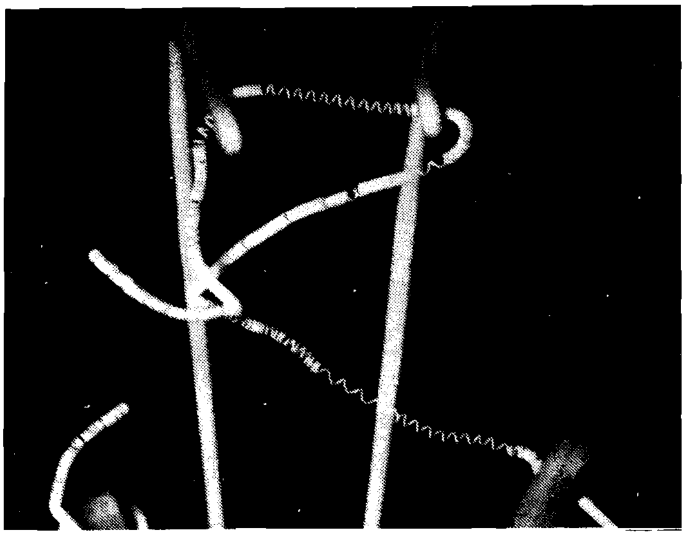


Figure 12a

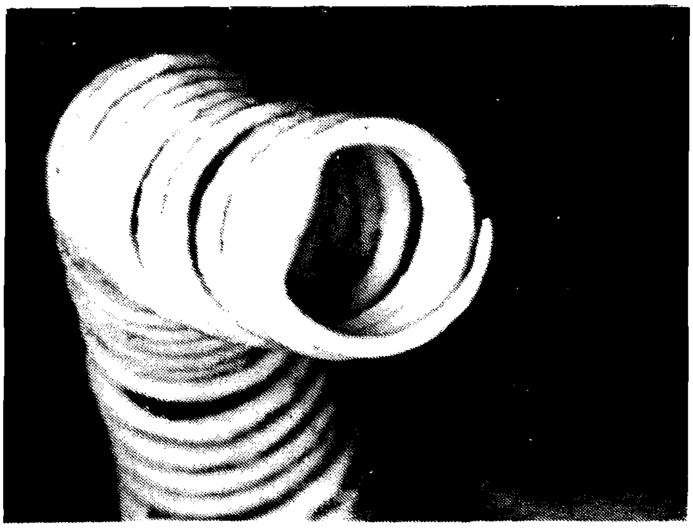


Figure 12b

segments of filament, sometimes only a few coils in length. Examination of the segments reveals no sign of local deformation. In the case of a hot filament, although it still fractures numerously, some local deformation is usually evident and hot segments of filament may often adhere or fuse to the inner glass envelope.

Incandescence Time Tests

Quite often in aircraft accident investigation, the question arises as to the time required for a light bulb to reach incandescence following application of electrical power. Scenarios have been suggested in which a light bulb that is initially off can become incandescent during the impact sequence, and consequently exhibit hot characteristics to indicate that it was on prior to impact, when in fact, it was not. If the time required for the bulb to fully illuminate is greater than the time required for the major part of the impact sequence then the above scenario is not possible. For the GE-237 bulb, illumination time was found to be about 48 milliseconds and the time to extinguish was about 50 milliseconds. When an aircraft impacts the ground at relatively high speed and steep angles, the impact sequence is relatively short and the possibility of a false light bulb indication diminishes. If, however, an aircraft initially strikes some trees and some part of the aircraft becomes damaged, caution and warning lights could be triggered. The aircraft could subsequently contact the ground with impact forces severe enough to cause damage to these light bulbs, which could mislead investigators as to the pre-crash status of the aircraft.

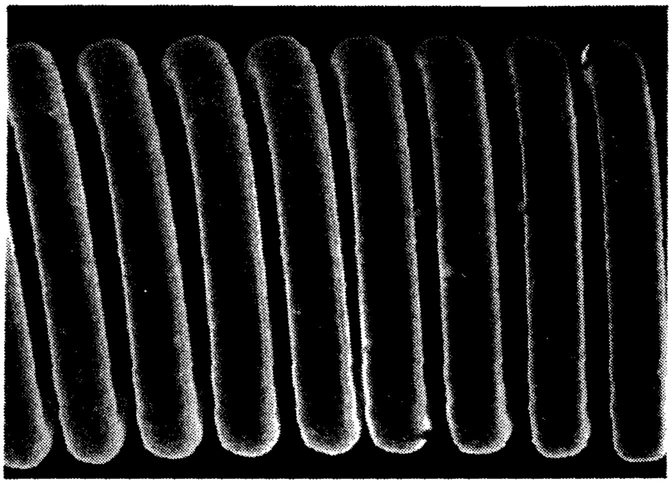


Figure 13

Some Points on 'G' Levels

Basic kinematics states that if an aircraft is travelling at a certain velocity before impact with the ground and stops in a certain distance, a 'g' level or decceleration level may be calculated. The velocity of the aircraft just prior to impact determines its kinetic energy at the moment of impact. This kinetic energy defines the maximum energy that can be dissipated in the crash. However, the g level is not necessarily proportional to the velocity of an aircraft prior to impact. If a penny is dropped onto a steel floor from a height of one meter, it can experience several thousand g (but of extremely short duration). The same penny dropped from the same height onto a pillow, while attaining the same final velocity, will experience a few g (but of long duration). The g level calculated in aircraft crashes using general kinematics principles gives the investigator a feel for the overall g level and time duration of the accident. However, it is important to realize that individual parts of an aircraft, instrument panels for example, can and will experience far different g levels than those calculated by the general kinematics equations, as the complex structure crushes under impact. An accelerometer mounted in the nose of an aircraft may see spikes of several thousand g while one in the tail sees g levels orders of magnitude smaller. Kinematic analysis of the accident yields the average g level of the center of gravity of the aircraft, a third entirely different number. On occasion, the g level of the accident is calculated via kinematics, and then it is extrapolated to state that 'therefore, every component on the aircraft saw a maximum g of such and such'. Such a statement would be incorrect. This study has demonstrated that a relatively new bulb must experience approximately 1000 g to exhibit observable damage. This does not mean that the overall g level of the accident need be 1000 g (i.e., as calculated by kinematics), but only that the bulb at some point in the crash saw 1000 g for sufficient duration to cause damage. It is these high g level spikes that occur for a few milliseconds during the crash that cause filament damage. Finally, stating a g level without a time duration attached to it can be misleading.

Summary

The types of damage which convey useful information relating to the state of light bulbs at impact are:

1) general deformation of the filament
2) local deformation of the filament
3) fracture of the filament
4) filament/glass fusion
5) burnout
6) oxidization (due to glass envelope breaking or developing a leak)

The two most significant factors that affect filament damage are dc notching and impact severity. Impact transients of short enough duration cause resonance of the bulbs' internal components (support posts) and thus a higher than normal response and greater filament damage. Of the two aging mechanisms (dc notching and evaporation), dc notching was found by far to be the predominant life influencing factor. Filament age, as reflected by the severity of notching, reduces the strength of a filament in both a hot and cold state.

New filaments when cold can withstand higher g levels than when hot, as hot filaments begin to show deformation at approximately 1500 g (over 1.5 milliseconds). As the filament ages, it becomes increasingly fragile until eventually even normal handling can fracture an extensively aged filament. New GE-327 bulbs showed no signs of local deformation even to 3000 g (1.0 milliseconds). As the bulbs were aged, local deformation became increasingly evident in all hot impact tests. Fracture eventually occured at impact in many cases due to filament contact with itself and shorting occurring. When tested cold, bulbs of any age showed no significant signs of general or local deformation throughout the non-resonant impact test range until final fracture. In the high g level resonance range, local deformation was evident in relatively new cold bulbs, but was confined to small areas. Aged bulbs, when tested cold, typically fractured before deformation could occur. Cold local deformation typically occurs because the filament is whipped by the support posts; hence it is not expected to be found in any bulbs which are configured with unsupported filaments (except coiled-coil type bulbs in which the primary coil can stretch cold).

When analysing light bulbs, it is essential to examine as large a group as possible, which is known to have been subjected to essentially the same impact forces. If, for example, a bulb is discovered exhibiting severe filament deformation characteristic of a hot filament, other bulbs of similar age exhibiting no deformation become evidence of an 'off' indication.

To avoid misleading representations of the aircraft status, it is necessary to estimate the time of the accident impact sequence.

Traditional methods of stopping distance, speed, and attitude prior to impact can provide a reasonable time estimate, which can then be compared to the illumination and/or decay times of lights previously stated. The times stated comprise only the illumination time and therefore do not take into account the triggering sensor mechanism and linkage delays, etc. The illumination time stated is the minimum time that a system could possibly activate a light, but the overall total system reaction time should be considered and may be considerably longer.

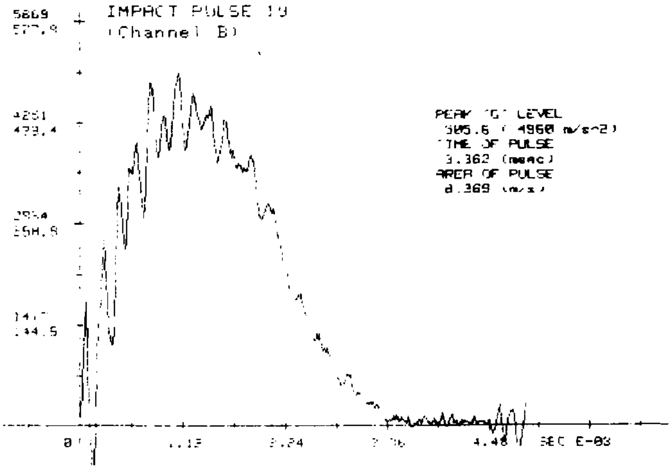
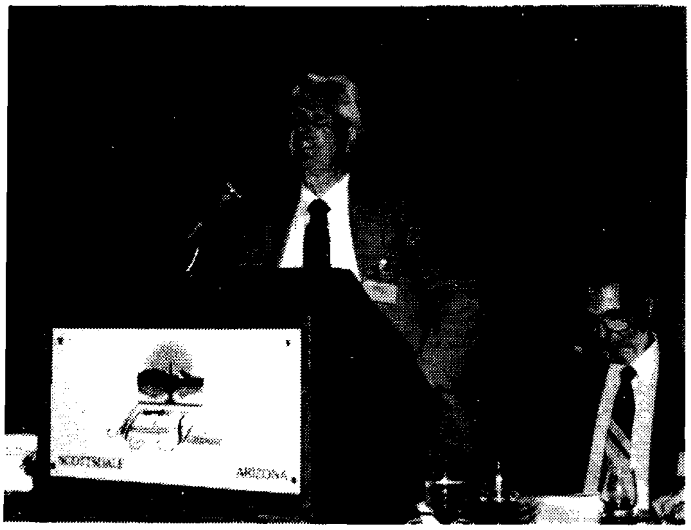


Figure 16

Mike Poole

Michael R. Poole, P. Eng., graduated from Carleton University in Ottawa, Canada in 1981 with Bachelors degree in Mechanical Engineering. He then worked as a Design Engineer for the Van Dusen Commercial Development Corporation in the design and construction of a remote controlled 19 foot diameter prototype of a unique heavy-lift lighter-than-air vehicle. Following this, Mike spent a year with Pratt and Whitney Canada as an Experimental Test Engineer before securing a research consultant contract to study light bulb filament impact dynamics for the (now) Canadian Aviation Safety Board. He is currently involved in a 15 month follow-up contract entitled "Instrument Impact Dynamics Study".



Opening remarks by Charles (Chuck) R. Mercer, Vice President, ISASI.

ADDITIONAL INFORMATION
FIGURES 1-16

FIGURE 1 — Components of the 327 light bulb identified as per text.

FIGURE 2 — Coiled tungsten filament passing through two support posts as viewed in the scanning electron microscope.

FIGURE 3 — Voltage - temperature relationship for GE-327 bulb.

FIGURE 4 — Filament surface characteristic of low burning time (a), approximately 100 hours burning time (b), and high burning time (c).

FIGURE 5 — General distortion of the filament shape, particularly near the support and contact posts as a result of the normal ageing process.

FIGURE 6 — Results of a cold filament vibrated at a support post resonance until failure (a), and a hot filament vibrated until failure (b).

FIGURE 7 — Test equipment used in the light bulb study.

FIGURE 8 — Test 66; all filaments impacted at 3262 G for 1.0 msec at 0 volts. a) aged 0 hours; b) aged 48 hours; c) aged 85 hours; d) aged 144 hours.

FIGURE 9 — Test 64; all filaments impacted at 3507 G for 1.0 msec at 28 volts. a) aged 0 hours; b) aged 48 hours; c) aged 85 hours; d) aged 144 hours.

FIGURE 10 — Bulbs subjected to impact in the resonance range. a) Test 8; aged 0 hours; impacted at 4000G for .3 msec at 28 volts. b) Test 120; age 210 hours; impacted at 4000G for 0.4 msec at 28 volts. c) Test 12; aged 0 hours; impacted at 4000G for .3 msec at 0 volts. d) Test 121, aged 210 hours; impacted at 3700G for 0.4 msec at 0 volts.

FIGURE 11 — Cold fractures in an unnotched filament (a), notched filament (b), and a hot fracture (c).

FIGURE 12 — Hot filament subjeted to severe impact (a), and resulting fracture area (b).

FIGURE 13 — New filament exhibiting some of the drawing marks from manufacturer.

FIGURE 14 — Burn out due to old age.

FIGURE 15 — Filament surface that oxidized when the glass envelope was broken during impact, exposing the filament to the atmosphere. The particles labelled 'c' were found to be largely comprised of silicon, a derivative of the glass envelope.

FIGURE 16 — Typical acceleration-time curve as processed by computer.

Rotor Blades "Then and Now"

Bob Orr
Boeing Vertol
M00591

This paper will cover accidents caused by rotor blade failues and other significant incidents associated with rotor blade failures. These accidents and failures are associated with four helicopter models produced by the Boeing Vertol Company and its predecessors, the Vertol Aircraft Corporation and Piasecki Helicopter Corporation.

The helicopters are the HUP, H-21, 107/H-46 and the CH-47/234 models. All of these models have tandem rotor systems containing three rotor blades forward and three rotor blades aft. A total of 2824 helicopters of the models noted above were built during the period of 1950 thru 1984; this fleet has accumulated approximately 6,450,000 flight hours thru 1984. When these helicopters were first produced, they all utilized rotor blades using a steel spar for the primary structural member and the fairing elements for the rotor blade were wood, fiberglass and/or metal. Later in the late 1970's and early 1980's, a fleet retrofit program introduced the composite rotor blade into the 107, CH-46 and Ch-47/234 fleet. To date, approx 535 helicopters have been retrofitted with or have had composite rotor blades installed at the time of helicopters delivery. Of the 38,700,000 rotor blade hours experienced listed here we have a breakdown of 36,850,000 blade hours for the metal rotor blades and 1,850,000 blade hours for the com posite rotor blades.

So much for the statistics; let us now look at the accident history associated with these rotor blades. In Figure 1 we see that the first accident occurred in late 1958 on a HUP model helicopter. The rotor blade spar failed and the helicopter was a strike. There were three fatalities associated with this first accident.

In Figure 2, the H-21 series helicopter during the period of 1955 thru 1968 sustained three major rotor blade accidents with three helicopters stricken and eight fatalities. There was one incident where a rotor blade spar was found fractured thru 50% of the spar cross section.

In Figure 3, which covers the CH-47/234 series helicopters for the period 1961 thru 1984, we have a total of nine incidents. There were eight accidents with seven helicopters stricken and 94 fatalities. There was one incident in which a 9-inch crack was found in a blade spar following a precautionary landing.

In Figure 4, the CH-46/107 series helicopters during the period 1964 thru 1984 had a total of 14 incidents, resulting in ten accidents and 35 fatalities. There were 10 helicopters stricken as a result of these incidents.

In the next chart, Figure 5, we will take a look at the fracture/separation locations. The results are very consistent in that 78% of all the failures with respect to the rotor blades' spanwise locations occurred in the inboard sections of the rotor blade. This portion of the blade is the most highly loaded section. A review of the fracture origin locations with respect to its surface position on the spar, indicates that 78% of the origins are on the bottom surface of the rotor blade. This is very consistent in that the lower surface of the spar is under a tension type loading at all times while the rotors are turning.

Figure 6 addresses the causal factors for the rotor blade failures, i.e., what was the initiating factor? The most significant factors were mechanical damage and in 12 out of 15 mechanical damage incidents, the mechanical damage was associated with the manufacturing process. Second highest was six cases of corrosion; one of which was fretting corrosion. The (5) remaining cases were pitting corrosion. The local yielding or overstress cases were a direct result of excessive flapping of the rotor blades. The other failures were two unknown; one was a loss of a compressive stress layer which we could not determine the reason for. Last but not least was an improper adhesive mixture, which resulted in the loss of an entire leading edge deicer cap, which resulted in separation of the rotor blade due to a large mass unbalance on the rotor system.

Going back to charts, Figure 3 and 4, you will note that the large number of rotor blade accidents were concentrated in the late 1960's and early 1970's and, of course, the question arises, what actions were taken to try to reduce these type of accidents. There were, of course, following each accident, a number of actions taken to try to combat the specific cause for that specific accident. These are what we would call the near term fixes. there was also, as the number of accidents continued to increase, a program to determine what the long term corrective action should be to combat this high number of rotor blade accidents. In the area of near term fixes, we approached both the field use and the manufacturing processes of the blades as areas to improve. In the field, one of the first steps taken was to institute a worldwide x-ray defraction program to identify those rotor blades which may have sustained a loss of residual stress in the spar due to excess flapping. In the early days we did not identify how significant this ground flapping could be and as a result of the x-ray defraction program we were able to eliminate a number of blades which had earlier on sustained buckling stresses due to excess flapping. In conjunction with the defraction program, we revised the manuals to be sure that ground flapping was identified as a signficant problem and must be reported. We also improved the startup and shutdown prcedures on the aircraft because you can sustain serious flapping problems during the start-up and shutdown period, if you do not exercise the controls in the proper manner.

Another major field activity was a program of eddy current inspections and also an inspection called MLF (Magnetic Leakage Field). They basically are an eddy current inspection of the rotor blade spar and sockets, which is performed by traversing a coil over the entire surface of the rotor blade. This was to detect cracks during the crack's early stage of development.

For the field later on in the early 1970's we went to an x-ray program to identify the cracks as they were developing. I might add that in all of these field inspections, we never uncovered a rotor blade with a crack due to an eddy current test and we never uncovered thru the x-ray program a crack which prevented an accident. We did have one accident in which the blade had been x-rayed but the crack was not detected during the x-ray review.

As far as improvements implemented at the manufacturing level, there were several major steps taken to reduce the number of accidents. One of the items was an improved vacuum melt steel rather than an air melt steel to assure ourselves that we had the cleanest steel possible for the spar. In order to combat the corrosion problems, we went through several iterations to improve the sealing processes. The corrosion almost always involved the heel of the spar where the fairings were bonded to the steel spar and that's the area where the corrosion developed and that's where our biggest job was in developing sealing processes. In order to combat the manufacturing defects identified as the lap, which occurs in the steel spar during the forming process, we went thru several very extensive programs where the spar tubes were ultrasonically tested during the manufacturing stage. Also there was a program where we subjected the spars to a magnetic perturbation program during the manufacturing process and again these processes were repeated when the rotor blades came in for overhaul.

This is just a quick sketch of what can be considered the major near term steps taken to reduce the incident of rotor blade accidents.

In the area of long term improvements there were three major steps and these steps did in fact have a significant impact on reducing the rate of rotor blade accidents. In fact, our last major rotor blade accident with fatalities occurred in 1974. We're hoping that record will continue to stand. The first improvement was in the case of the CH-47 which was the development of a new improved rotor blade from an aerodynamic standpoint; this was called the cambered airfoil blade, commonly referred to as the droop snoot blade. The first step was to increase the wall thickness of the spar on the new rotor blade in an effort to reduce the effect of ground flapping on the rotor blade. They also redesigned the socket by relocating the incident pin hole. Instead of the pin being in a vertical plane, it was placed in the horizontal plane so that the bolt passed thru the neutral axis of the blade spar. I might add that with respect to the 47B/C cambered airfoil blade, there has not been a rotor blade failure with this configuration which resulted in an accident.

The second long term fix that was implemented with the rotor blades and has had a significant impact in reducing accidents was the ISIS (Integral Spar Inspection System). See Figure 7. This is a method for detecting cracks in the rotor blade spar and socket. The system operates by maintaining a differential air pressure between the spar and socket interior and the outside air pressure. This is accomplished by installing an airtight bulkhead near the tip of the blade and sealing between the root end and the socket threaded area of the blades. Then a visual indicator and an evacuation valve are placed at the socket incident bolt location. The cavity that is created is evacuated of air to reduce its pressure below that of normal atmosphere. If a crack develops in the rotor blade during operation, the visual indicator will change color. Between flights an inspection of this indicator will tell the crew that the aircraft can no longer be operated and the rotor blade must be changed out. This system was developed in 1969 and was retrofitted to the fleet beginning in the 1972 time frame. From the initial installation of ISIS thru 1980, we have had nine confirmed rotor blade removals in which the overhaul depots confirmed a crack in the spar. There were many removals for black ISIS indicators but the large majority of these removals were due to a system reliability problem and not associated with cracks in the rotor blades. there was one accident involving an H46 which occurred in 1973 in which a rotor blade with ISIS installed failed. This failure was due to the loss of the entire leading edge of the rotor blade due to a bonding problem. This failure occurred outside of the ISIS protection area.

Fracture/Separation Surfaces

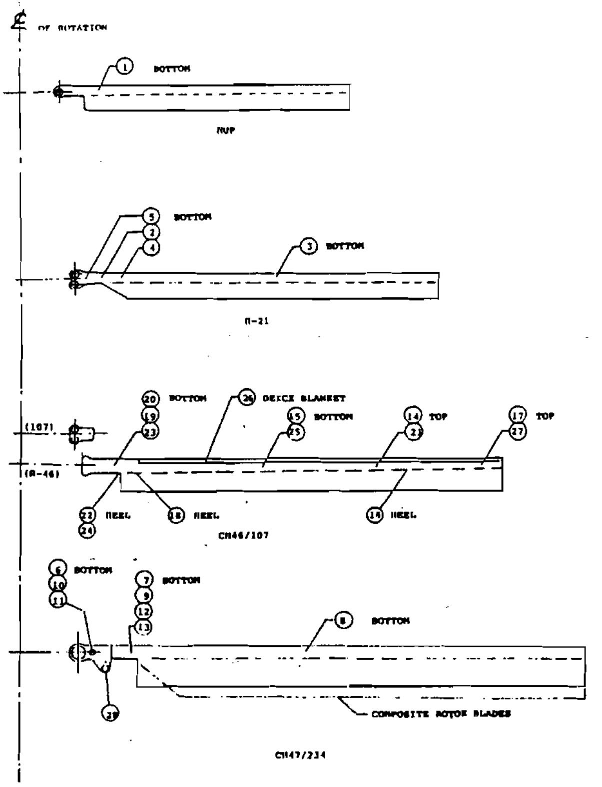


Figure 5

NUMBER	ACCIDENT	INCIDENT	MECHANICAL DAMAGE	CORROSION	OVERSTRESS	OTHER
1	X	-		PITTING		
2	X	-	ROLLING FORMING INCIPIENT CRACK			
3	-	INSP.				UNKNOWN
4	X	-		PITTING		
5	X	-	MACHINING NOTCH			
6	X	-	MACHINING BURR			
7	-	P/L			LOCAL YIELDING (FLAPPING)	
8	X	-	ROLL FORM LAP			
9	X	-			LOCAL YIELDING (FLAPPING)	
10	X	-		FRETTING		
11	X	-				LOSS OF COMPRESSIVE STRESS
12	X	-	ELECTRIC ARC BURN			
13	X	-			LOCAL YIELDING (FLAPPING)	
14	X	-	ROLL FORM LAP			
15	X	-	BULLET HOLE			
16	-	INSP.	DENT			
17	X	-	ROLL FORM LAP			
18	X	-		PITTING		
19	-	P/L	ROLL FORM LAP			
20	X	-	ROLL FORM LAP			
21	-	INSP.	ROLL FORM LAP			
22	X	-				UNKNOWN
23	X	-	ROLL FORM LAP			
24	X	-		PITTING		
25	X	-		PITTING		
26	X	-				IMPROPER ADHESIVE MIX
27	-	INSP.	EXCESSIVE GRIT BLAST			
28	X	-	REPAIR WELD SHRINK CRACK			

CASUAL FACTORS INITIATING FACTORS

INSP - FOUND DURING INSPECTION
P/L - FOUND AFTER PRECAUTIONARY LANDING

Figure 6

The final long term fix in the rotor blades, which has a significant impact on the safety of the blade, was the introduction of the all composite rotor blade into the CH-46/107 and CH-47/234 fleet. Figure 8 shows a typical composite rotor blade. These composite blades were not developed as a direct result of the accident but rather were developed for a multitude of reasons, such as, increased reliability, improved maintainability, safety, survivability, foreign object damage tolerance; all of these go to produce a blade which increases the operational effectiveness of the overall aircraft system. With respect to accidents, that is the safety aspect of the composite blade.

In preparing for this paper, I went back into the history of the development of the composite rotor blade. There are many papers stating that various personnel or firms were first into the arena with composite rotor blades. I would like to put Boeing Vertol's name in that arena. Composite rotor blades at Boeing Vertol go back to the days of the Piasecki Helicopter Company. The first reference I could find in the company history was, that in 1955 Piasecki began analytical studies with the Air Force for the development of what was referred to in those days as a "plastic" rotor blade. By 1957, Piasecki, now called Vertol, was building and testing plastic rotor blade sections and in 1958, design work began on a plastic rotor blade for the H-21 rotorcraft. This design effort was shortly changed after its implementation to be a plastic blade for the CH-47 aircraft. By 1963, a set of plastic rotor blades for the Chinook helicopter had been fabricated. They had completed all of their bench testing and were sent to Wright-Patterson AFB and were whirl tower tested for 150 hours, this included overspeed testing. In 1966 work began on the AGB (Advanced Geometry Blade). This was a blade which was developed for the optimum flying characteristics taking full advantage of the manufacturing capability of plastics.

Composite construction allows the engineer to vary the shapes of the blade along the length of the blade to develop the optimum shaped rotor blade and that was one of the major objectives of the AGB program. In the 1968-1971 time frame, the AGB was flown on CH-47 aircraft, both the glass and boron blades were flown with fiberglass blade on one rotor head and boron rotor blade and the other rotor head. By the early 1970's, design work was started on the UTTAS composite blade. Work was also begun on the heavy lift helicopter composite rotor blade and design work started on the CH-47 composite rotor blade. By 1974, the UTTAS composite rotor blade was flying and in 1975, design work began on the H-46 composite rotor blade. In 1975, the heavy lift helicopter composite rotor blades were ready to fly but that program was subsequently cancelled by the government.

In 1976 the composite blades for the H-46 program entered into their flying program and by 1978 the H-46 rotor blades were ready for retrofit into the fleet. Also, in 1978 the H-47 rotor blade was ready to fly. The difference between the start of design work and delivery of the H-46 and H-47 rotor blades lies in the fact that the U.S. Navy in procuring the composite rotor blade wanted a blade which was totally interchangeable with respect to physical characteristics with the existing metal blade in all facets except for the material with which it was manufactured. It is a blade which looks identical to and retrofits onto the aircraft with no change in performance. The H-47 blade, which the Army elected to buy is a rotor blade, which reqires modification for retrofit and is a rotor blade with significant changes in its operating characteristics in addition to the change in material, i.e., it was a blade with a much wider cord, increased performance and these rotor blades were not ready for retrofit to the Army until 1981.

The accident story on the retrofitted composite rotor blade to date is one accident involving the composite rotor blade. This involved a CH-47 aircraft in which a rotor blade damper bracket failed. At the time of rotor shutdown, as the blades coasted down to their stop position due to non-restraint by the damper, the rotor blade struck the aircraft fuselage. The aircraft sustained an extensive amount of damage. This rotor blade bracket was a cast stainless steel bracket which was bonded and strapped to the rotor blade spar. The corrective action for this accident which had identified a repair weld in the bracket casting as the causal factor was to change the bracket to an all composite bracket, which is not bonded and strapped to the spar of the rotor blade. This blade can now be truly considered an all composite rortor blade except for weights and pin fitting bushings.

The story on the composite rotor blade is certainly an exciting one. It has gone well beyond Boeing Vertol's wildest expectations, not only from the safety standpoint but from the impact that it has had on the operation and the reliability of the aircraft. To give you an example, Figure 9, of a few statistics on the CH-46 composite rotor blade. It is our fleet experience up to the beginning of this year 1985. Note the number of delivered blades that initial fleet installation was in 1978 and to date the high time rotor blade in 2572 hours. The significant reduction in the maintenance manhours per flight hour of the composite is in the order of 90%. The mean time between failure for the blade goes from 135 hours in the metal to greater than 3,000 on the composite rotor blade. In the area of mean time between failure to depot, i.e., blade removed for cause sufficient to return to depot, there have been no returns to depot. All of the rotor blades have been repaired at the field level. These are some of the points about the composite rotor blade that makes it such a significant improvement over the metal rotor blade.

Composite rotor blades are not the only item at Boeing Vertol which is having an impact from a composite standpoint on a helicopter. Figure 10 shows the Model 360 aircraft, presently under development at the Boeing Vertol Company. It is planned that in 1986 this aircraft will be flying. This aircraft will have an all composite airframe, composite rotor blades, composite rotor hubs, composite synch shafting, composite aft vertical shaft, composite transmission covers and composite landing gear. This really tells the story of where Boeing Vertol is going in the coming years with respect to composite construction It is certainly going to have, we believe, a significant impact on the helicopter world in decades to come.

Head table, left to right: Dave Hall; Donald D. Engen, Administrator, Federal Aviation Administration; Jerry Lederer and wife Sarah; Robert D. Rudich, ISASI Vice President.

Crash Injury Investigation: Past, Present - And Future?

By A. Howard Hasbrook, F.As. M.A.; P. E.

The concept of investigating an aircraft accident to determine the cause of injury and death — and reasons for survival — was born quite inadvertently during World War I when two RCAF training planes collided in mid-air; one of the four occupants survived. That survivor was Hugh Dehaven, a United States citizen who had volunteered for duty in the Royal Canadian Air Force. At that time, life or death in a crash was considered to be a matter of luck, but DeHaven didn't believe in luck.

His study of the wreckage — after a long period of hospitalization — and his questioning of the reasons for his survival resulted in the later formation of a small research group at Cornell University Medical School in New York City. This group, called Crash Injury Research, operated on a small grant from the National Research Council during the late thirties, under direction of DeHaven and Dr. Eugene BuBois (who was head of Preventive Medicine at Cornell). They organized the group, with two additional staff members, to investigate and catalog injuries (and their causes) that were occurring routinely in severe but survivable light plane accidents. They hoped that some *pattern* of injury causation might appear; a pattern that might be amenable to corrective — and preventive — measures through engineering redesign.

This writer joined DeHaven and DuBois in 1950, after surviving an almost non-survivable crop duster accident. By this time, DeHaven had established some gross body tolerance criteria through study of hundreds of aircraft accident reports that had been supplied primarily by a few dedicated accident investigators of the Pennsylvania State Aeronatucis Department and the Civil Aeronautics Administration. The research project also had studied numerous free fall cases involving persons who had either accidentally fallen or intentionally jumped from buildings or other high structures such as bridges or smokestacks. These research efforts paid off in a limited way by demonstrating that the human body could withstand much higher dynamic loads without serious injury than had been previously thought — provided the loads were of very short duration (measured in milliseconds) and were distributed over relatively large areas of the body, thereby producing pressures of low magnitude per unit area. These crash injury investigations — and subsequent crash injury analyses — demonstrated that dynamic loads exceeding 40g could be survived with little or no injury provided the force of deceleration could be distributed over a large area of the body through use of strong, properly positioned, safety belts and upper torso restraint systems such as a shoulder harness. Delethalization — a word coined by this writer in the early fifties — also became a descriptive term for providing non-lethal structures in the cockpit and cabin areas; padded or "soft" structures or components that could be struck by the human body without resulting in fatal penetrating wounds or application of concentrated loads on vulnerable body areas such as the skull or chest.

Although the early crash injury research work at Cornell concentrated on light plane accidents, this writer initiated similar investigative efforts in the air carrier (airline) field early in 1952. The first such accident to be fully investigated from the crash injury point of view was a Northeast Convair crash at New York's La Guardia Airport in January of that year. This crash involved relatively low magnitudes of crash force, but produced numerous injuries because of seat attachment failures. These failures were caused by distortion of the aircraft's belly and floor structure, as the aircraft struck shallow water during its approach to the runway.

Subsequent crash injury investigations of airline accidents such as the National DC-6 crash at Elizabeth, New Jersey, the American Airlines Convair 240 accident at Springfield, Missouri, and the Venezuela Airline DC-7 crash at New York's Kennedy Airport served to demonstrate the need for a new and comprehensive engineering look at ways and means of keeping seats (and their occupants) in place in the intact areas of the cabin, and protecting them from "flying objects" such as loose fire extinguishers, baggage, galley equipment and other rigid, sharp and/or heavy objects.

It is interesting that manufacturers of air carrier aircraft — Convair, Lockheed, Boeing and Douglas — became highly receptive at an early date to the need for designing for survival in survivable accidents, as compared to the lukewarm responsiveness of the general aviation manufacturers. Improved tie-down of seats to basic air frame structure, stronger seat belts, more flexible seat structure — to permit some flexing of floor structure wihout seat detachment — delethalized seat-backs and arm rest units, baggage containers, and recessed serving trays and better emergency exit markings all helped to reduce fatality rates in subsequent survivable aircraft accidents involving airline aircraft designed for "crash safety".

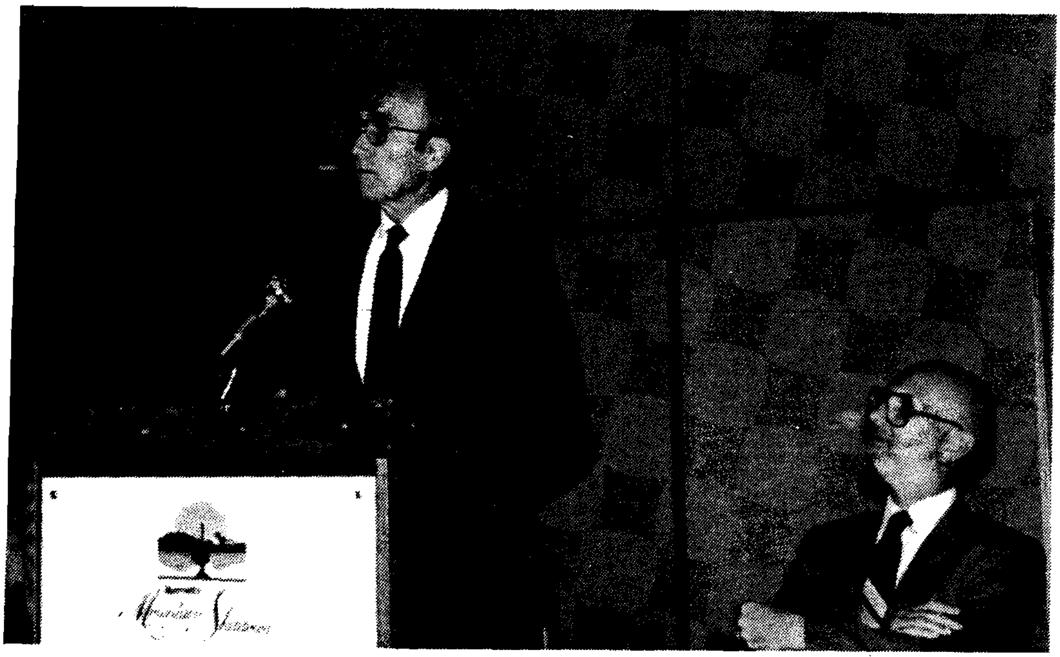
It has been suggested by some that this receptive attitude on the part of the air carrier aircraft manufacturers was due in part to *airline* company management pressure, not only from a humanitarian point of view, but also in relation to foreseeable, potential, heavy financial losses which could accompany product liability suits, if the known "state of the art" of crash safety design was not incorporated into new airline aircraft. Unfortunately, no such consumer pressure was available in the general aviation field even though crash injury data from hundreds of general aviation accident cases had been accumulated and analyzed by Cornell researchers by 1960. However, despite the availability of these data it was not until 18 years later that the Federal Aviation Administration finally mandated the installation of upper torso restraint systems for front seat occupants of general aviation aircraft manufactured after 1978 (I shudder to think of the number of people who have died unnecessarily of head and chest injuries in survivable accidents because of those 18 years of bureaucratic lethargy). Unfortunately, this 1978 mandate has no retroactive provision — thus hundreds more people will lose their lives unnecessarily in future accidents involving aircraft that were manufactured prior to 1978 without shoulder harness installed.

And this brings me to recent times; as an aviation safety consultant, research pilot and accident investigator, I have had numerous occasions to conduct detailed studies of many F.A.A. and N.T.S.B. accident reports relating to severe but survivable (but not necessarily survived) crashes involving general aviation aircraft. And I must say with great sorrow that too few of these reports met the minimal requirements of a properly conducted crash *injury* investigation. Data on aircraft pitch, roll and yaw angles at impact; terrain angle; depth, width and length of ground gouges and slides; flight path angle, and other essential data — as covered in an ISASI paper I presented some years ago in San Francisco — were all missing in their entirety. When such data is missing it is most difficult — and sometimes impossible — for even an experienced analyst to determine the magnitudes, durations and directions of crash load application on the aircraft and its occupants during an impact. Without such data from accidents involving modern aircraft, the F.A.A., N.T.S.B., and industry engineers cannot make meaningful *recommendations* for steps to improve crash safety design in future aircraft.

Likewise, photographic coverage of most of the reviewed reports was inadequate and amateurish, with too few pictures (many of which were out of focus or poorly lighted); in many cases, there were no shots of the interior of the cockpit or cabin, nor of the structural failures associated with seat and/or restraint system separation. Also, in no case, were there data describing distances of rearward collapse of forward structure, nor of direction and distance of movement of the occupants, nor reference to the kinematics (movement) of the aircraft and of the occupants during the principal impact — and subsequent deceleration.

To not have had crash *injury* investigative procedures included in the investigation of these severe but survivable aircraft accidents is a sad commentary on the past years of work by many dedicated researchers.

This, then, is the primary reason for the establishment of the ISASI Crash Injury Investigator Award which bears this writer's name. It is our hope that this award will spur renewed effort throughout the worldwide accident investigative community to obtain and report *crash injury* data that will be the foundation for improved crash safety design in future air carrier, general aviation, and military aircraft.



FAA Administrator Donald D. Engen, banquet guest speaker.

The Social Psychological Aspects of Pilot-Error Accidents: Male vs. Female

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St. Mary's College

Abstract

Regardless of a pilot's sex, aviation requires, attracts, and/or selects out the personality type of a person who is courageous and adventuresome. One who is oriented toward demonstrating competency, skill, and achievement; one who finds pleasure in mastering complex tasks; one whose manifest sexual orientation is decidedly heterosexual. Performance studies suggest an equivocal quality from overvaluation of the female, to equity between males and females, to the females success being attributed to a temporary cause, such as unusual effort, thereby having lower expectations about her future promise. In this study data from the files of the National Transportation Safety Board have been analyzed to observe the number of pilot-error accidents incurred for the years of 1972 through 1981. If both females and males have no difference in performance based on the equivocal nature of the research, then the data would tend to indicate similarities of accident rate and type. The data indicate a greater proportion of female pilots are having pilot-error related accidents compared to male pilots. In comparing the two genders threre also is a difference in age, certification, and accident cause.

This study will take an expanded look at the data of the National Transportation Safety Board files over the ten year period from 1972 through 1981, and expand the pilot-error accidents to include fatalities, serious injuries, minor injuries, and no injuries while taking gender into consideration.

With the onset of governmental programs and changes in societal attitudes, a dramatic shift in women's educational and vocational attainments over the past deade has taken place. Bachelor's degrees in engineering in 1970 were 1% female; by 1980 women earned 10%. Similarly over the same period, doctorates earned by women in the physical sciences has risen from 4.5% to 10.6%, in life sciences from 12.8% to 23.4% and in psychology from 23.5% to 40.8%. In medicine, the increase has been from 8.5% to 23% (Babladelis, Deaux, Helmreich, Spence, 1983). In aviation, women obtaining certificates has increased from 4.4% in 1972 to 6.2% in 1981.

Population figures for certificated pilots in the United Staes from 1972 through 1981 has grown from 750,869 to 764,182, an increase of 1.8%. The female pilot population has grown from 33,001 to 47,721, an increase of 44.6%, while the number of male pilots has actuallly decreased from 717,868 o 716, 461 (minus .2%).

Looking at the General Aviation Female population by certificate in 1972 through 1981, there is a steady increase from students, up approximately 32.5%, privates up 46.4%, commercial up 85.5% and Airline Transport Pilot Certificates up 458.2%. This shows not only an increase in certification, but an upgrade continuation at an ever increasing rate. In comparison, the General Aviation Male population by certificate 1972 through 1981 has leveled off or decreased in all except those obtaining the Airline Transport Pilot Certificate, which was up 85.4%.

Performance studies suggest that casual attributions may serve as a key link between observed performance and subsequent evaluations (Feldman, Summers and Kiesler, 1974; Deaux, 1976, 1979; Frieze, Persons, Johnson, Ruble, Zellman, 1978). Their results indicate that performance of males and females may be explained differently on the basis of gender alone. For males successes tend to be attributed to stable, personal attributes of the individual's ability, while female successes tend to be attributed to unstable causes, such as effort or luck. These sex-based attributional patterns may be due to different assumptions concerning the capacities of the males and females. That is, if males are expected to be competent, their successes are consistent with expectations and are, therefore, attributed to something stable about them. In contrast, if a woman is expected to do poorly on a masculine task, her success is then attributed to a temporary cause, such as unusual effort, thereby maintaining a low expectation about her future promise (Ruble, Cohen, Ruble, 1984).

Total Population of Certified Pilots

FEMALES	**1972**	**1981**	**Change**
Student	17,054	22,591	+ 32.50%
Private	13,391	19,602	+ 46.38%
Commercial	2,196	4,101	+ 86.75%
Airline Transport	101	584	+478.22%

MALES	**1972**	**1981**	**Change**
Student	164,424	157,321	- 4.32%
Private	308,022	308,960	+ 30%
Commercial	194,032	164,479	-15.24%
Airline Transport	37,613	69,727	+85.38%

Another study showed that women performing a masculine task well were rated as more deserving of a reward than equally performing males. These results may be interpreted as undervaluation of the male performance, and overvaluation of the female performance, or some combination of the two effects. If we expect men to do better than women, and they perform equally, we may undervalue the men's achievements since they exhibited a smaller discrepancy between expected and actual performance. Alternatively, we may give greater credit to the women for harder work. This latter interpretation seems to be preferred by some researchers (Rose, 1978; Rose and Stone, 1978; Taynor and Deaux, 1973).

Still other studies suggest that stereotypes are less likely to affect social judgments and predictions when speciic behavioral information about the target person is provided (Borgida, Locksley, Brekke, 1981; Locksley, Borgida, Brekke, Hepburn, 1980). Thus specific performance information may attenuate the effects of sex stereotypes on evaluations of competence (Ruble et al, 1984). In one study, for example, students were given a case description of a situation in which a male manager and female manager each performed successfully (Hall and Hall, 1976). Ratings of the manager's performance revealed no differences in the evaluation of males and females, indicating that biases were reduced when objective behavioral data were provided to the rater. In aviation, McCloy and Koonce (1981), with specific objective testing conclude there is no difference in overall performance and skill between the genders after training, but also stated that females may take more trials to reach this performance criteria.

Character attributes, on the other hand, are also important in determining impressions about competence. Attributes of female pilots have been looked at by Novello and Youssef (1974). They found that males and females have similar patterns on achievement, exhibition, autonomy, intraception, dominance, change, and heterosexuality. Female pilots deviate from the United States adult female norms in the same pattern as United States adult male pilots do, but to a greater degree.

Research also suggests that the majority sex in an occupation may be viewed as the appropriate or best suited sex (Albrecht, 1976; Krefting, Berger, Wallace, 1978). The major determinant of occupational sex typing appears to be the current distribution of males versus females in a job category (Deaux and Lewis, 1983; Krefting et al, 1978; Mahoney and Blake, 1981; Shinar, 1975).

Additional research supports the value of distinguishing between biases based on sex and biases based on personal characteristics (Fransesco and Hakel, 1981; Hansson, O'Connor, Jones, Mihelich 1980). These studies found a bias favoring masculine characteristics regardless of the sex of the job candidate. Since the roles assigned to men almost invariably carry with them more prestige and greater social and economic power than those assigned to women (Babladelis, et al, 1983), it would seem likely that the masculine character be in the field of aviation.

These previously mentioned articles are the impressions of our society. We all form impressions about individuals successes and failures of performance and character attributes. These impressions have a poweful effect as described by Jones, Rock, Shaver, Goethals, and Ward (1968), becoming a primary effect in our heirarchy of judgments. It becomes a memory of past performances. The performer with a descending success rate, was consistently judged to be more intelligent and was expected to out perform those with either ascending or random patterns. This memory for past performance was uniformly distorted in favor of recalling more success for the descending performer and less success for the ascending and random performers.

Looking at the performance of pilots from the standpoint of pilot-error accidents incurred by males and females, the assumption is there would be no difference, based on the past research indicating equivocal observations.

Method

Purpose of Study

The purpose of this study is to analyze the entire General Aviation data base from the years of 1972 through 1981 for pilot-error related accidents with regard to the differences between the males and females

Sample

The entire population of General Aviation pilots was 42,597 males and 1,004 females, who had accidents and who had them recorded in the files of the National Transportation Safety Board, Washington, D.C. Of that number 37,862 males and 976 females had pilot-error related accidents.

Data Analysis

The data was programmed and managed by the University of Minnesota, Minneapolis, Minnesota.

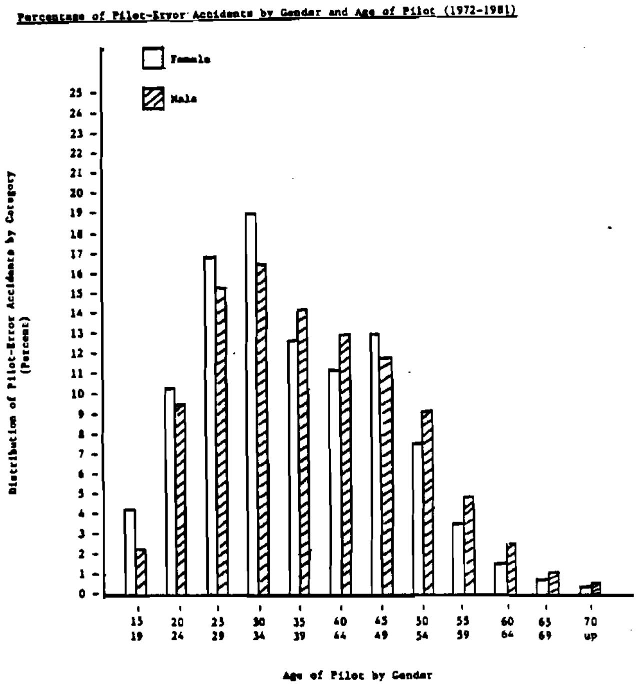
Results

The following tables report a breakdown of data using the factors of 1) age of pilot, 2) certificate of pilot, 3) king of flying, 4) degree of injury of pilot, 5) total time of pilot, 6) time in type of aircraft, 7) phase of operation by degreee of injury, 8) broad cause factor, 9) specific cause factor for pilot error accidents in years from 1972 through 1981.

It was found overall that a significantly higher proportion, $X^2(1,N=38,829) = 33.95$, p .001, of females (96.3%) made pilot-error related accidents than males (91.9%)

Age of Pilot

It is interesting to note that younger females and older males had more accidents than those in other categories. The highest percentage within both groups are between the ages of 25 and 35.



Graph 1

Type of Certificate

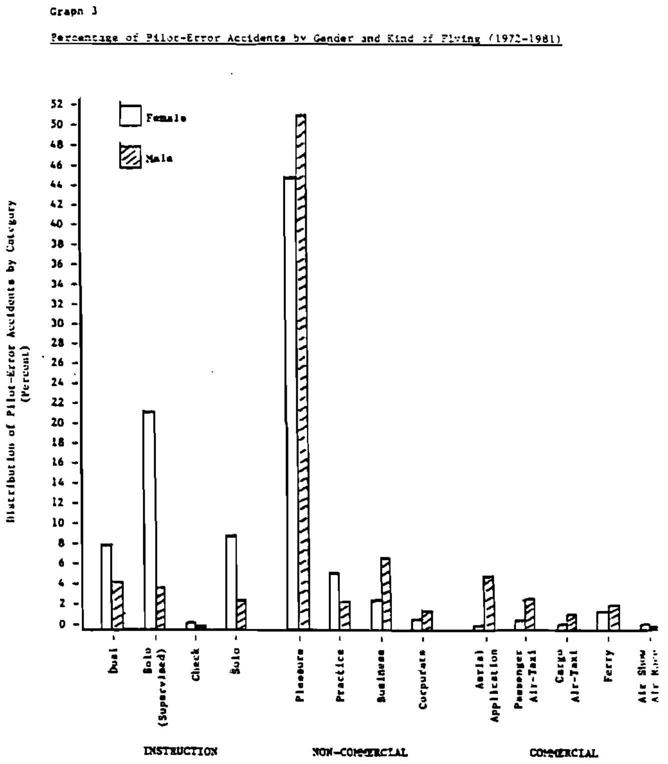
Graph 2 indicates the type of certificates of the males and females involved in pilot error accidents. Most of the accidents by females were by Private pilots (39.5%) followed closely by Student pilots (35.0%). Most of the accidents by males was at the Private level (41.6%). The second group of males having accidents were those having Commercial certificates (26.6%). An interesting note is that with both males and females the third larest category of those having accidents was in the Commercial-Certificated Flight Instructor category with females (13.2%) having a slightly higher percentage than males (12.6%).

Kind of Flying

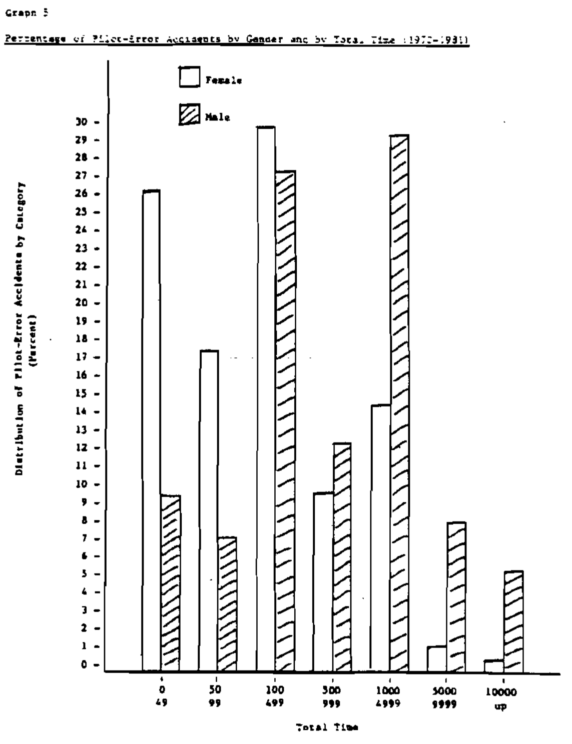
As indicated in Graph 3, the highest rate of pilot error related accidents for both males and females are occurring in non-commercial pleasure related activities (females 44.3% and males 50.7%). A noticeable high proportion of accidents by females are also, however, occurring in Instructional solo (supervised) (21.5%) and solo (9.3%).

Degree of Injury

When the factor of pilot-error accidents by gender and degree of injury was considered, it was found that with both males (58.4%) and females (65.5%) the greatest percentage of accidents resulted in NO injury. However, males (17.4%) have significantly more fatalities as reported by Vail (1985) compared with females (8.7%)



Graph 3



Graph 5

Total Time

Graph 5 shows the percentge of pilot-error related accidents by the total time of pilot certification for females and males. Females with the most accidents had from 0 to 499 hours. Males on the other hand with the greatest number of accidents had from 100 hours to over 10,000 hours.

Type of Aircraft

Graph 6 shows the percentage of pilot-error related accidents by the time in type of aircraft for females and males. Most accidents by both females and males were made by those with from 0-49 hours in any type of aircraft. Females with 0-99 hours are making the most pilot-error accidents. On the other hand, males who are making the most accidents have from 100 to over 10,000 hours.

Both genders were then looked at in pilot-error accidents by aircraft damage. For both most accidents resuled in substantial damage (males 72.5%, females 83.5%). A higher percentage of accidents by males (26.4%) compared to females (15.9%), resulted in the aircraft being destroyed.

Phase of Operation

The Phase of Operation is broken down into fatal, serious, minor and no injury by gender.

Females have the greater percentage of no injury accidents in the entire landing phase including, approach (VFR), level off, touch down and roll (45.3%) in comparison to males (31.0%). Males have the second highest percentage of Inflight-no injury (12.7%, females 6.4%); Inflight-fatal (11.7%, females 4.3%); and Takeoff-no injury (11.2%, females 6.7%).

Graph 7 is the percentage of pilot-error accidents by gender by phase of operation. Females have most of their accidents in the landing phase (63.0%), compared to males (42.4%). Next most common accidents for females are in the taxi phase (7.5%), compared with males (.1%). Males made a higher percentage of their accidents in the Takeoff (18.6%) and Inflight 35.0%) phases compared to females (12.8% and 16.2% respectively).

The Broad cause factor by pilot-error accidents by gender indicates, of all accidents by females where one cause was pilot error, 15.7% were when the female was Pilot-In-Command, in comparison to 14.9% when the male was Pilot-In-Command. The second largest category was Miscellaneous Acts conditions with 7.6%, where 33% was due to overloading failure, and 13.4% due to fuel mismanagement. The males, in comparison, had 8.3% of their total accidents because of Miscellaneous Acts. Seventeen point one percent (17.1%) of these were due to overloading failure, 14.2% due to fuel mismanagement, and (9.1%) due to material failure. The remaining percentages were caused by environmental or aircraft systems.

The Specific cause factor identified by gender in accidents due to pilot error shows females with the greatest percentage of their accidents caused by improper level off (28.4%), compared to males (9.3%), followed by improper recovery from bounced landing (17.8%), compared to males 4.6%), and failure to maintain directional control (17.9%), compared to males (11.3%).

Males had a higher percentage of their accidents (20.2%) due to inadequate preflight preparation and/or planning, than did the females (12.3%); the higher percentage due to failure to obtain-/maintain flying speed (18.9%) compared to females (10.0%), the higher percentage of failure to maintain direction control (11.3%), compared to females (17.0%), and the higher percentage of fuel mismangement (10.3%) compared to females (9.0%).

Discussion

This study looked at the performance of pilots from the number of pilot-error accidents they have made. It was hypothesized that both males and females would have no difference, based on the equivocal nature of performance in past research, but in fact, there is a difference.

The overall analysis from the data indicated that the females have more of their pilot-error related accidents at a younger age, with a lower level of certification, with fewer hours in both total time and time in type of aircraft, and more probably in the landing phase of operation by not being able to handle the aircraft properly. In comparison, the males have more of their pilot-error related accidents at an older age, with a higher level of certification, with more hours in both total time and time in type of aircraft, in takeoff, and in the inflight phases of operation. Also a higher percentage of males than females had accidents based on their personal judgment of the situation, whereas females were based more on skill of handling the aircrft, thus rejecting the hypothesis that males and females are equal.

The study by McCloy and Koonce (1981), shows no difference in overall performance and skill between the genders after training to criteria performance, but the study also states that females may take more trials to reach this performance. Could this study's data, when looking at pilot-error accident performance, led to the conclusion that more females than males receive inadequate training to meet criteria performance? Or could there be a difference in the reporting of accidents? Are both genders equally conscientious in reporting accidents?

In analyzing the overall differences, it appears that the females are having most of their accidents at the inexperienced end of the scale in comparison to the males, who are having most of their accidents at the experienced end of the scale, indicating differences in success periods. Therefore are we in error in looking only at the genders at the lower end of the experience scale when making decisions as to the appropriateness of the occupation of aircraft pilot for females and males. And does the pressure of society on females to conform reduce the self-confidence and result in slowing down their rate of learning compared to males who are, by society, encouraged to take risks as a way of developing self-confidence? There could also be differential directions of youthful play, which affect the cognitive and motor abilities.

In the interest of civilian aviation safety, because of the increase of female pilots, and the lack of knowledge about why there is a differnece in causes of pilot-error related accidents between the genders, I recommend a sampling on a national scale to test for the above mentioned factors.

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Early Polish Works In The Field of Aircraft Safety Years 1926-1939

Leszek Duleba
Professor of the Technical University in Warsaw

I am an aeroplane designer (constructor as we say) and my goal was to give to my aeroplanes such properties as to avoid accident. The best years of my creative work have passed. I began my professional career more than a half century ago. For many of you those times are almost prehistorical ones, nearer to antique Ikar or the first flight of brothers Wright than to contemporary jet aeroplanes. But I will remind you of those difficulties which we have encountered in those times.

The problem of safe flying has four aspects:

1. Airworthiness requirements — the book which is written with blood and lives of those who had dared to fly aeroplanes of new, unknown properties.
2. Aircraft design and construction — task of aircraft designers, workshopmen, pilots. It consists in giving to a new aeroplane type such properties that it can be flown safely, it is easy to be flown, it can perform its task.
3. Ground safety facilities. The whole personnel of aerodromes, aeroports, radar, radio, etc.
4. Aircraft exploitation. Ground maintenance, engineers, pilots, flight mechanics, etc.

I was mainly engaged in the second point — aeroplane design in Aeroplane Experimental Works RWD (first letters of names of first designers in this workshop). Rogalski — died some years ago working at Grummann. Wigura — lost his life in an aeroplane accident in 1932 just after having won the first famous victory in "Challenge International des Avions de Tourisme". Drzewiecki is living in Canada.

At the time of our first constructions (1925-1930) we noticed four main causes of accidents, especially among young, inexperienced pilots in aero-clubs:

1. Involuntary stalling and spinning.
2. Difficulties in maneuverability at low speeds (take off and landing).
3. Difficulties at take off and landing when minimum safety speed is elevated.
4. Damage of engine in flight.

Our first aeroplanes (JD-2, WR-1, PS-1, RWD-1, -2, -3, -4, -5, -7) were not free from those disadvantages.

When minimum safety speed is high for an unexperienced pilot (say 55-54 mph). If he notices an obstacle at take off or landing he has little time for new decisions and for avoiding obstacles. He has tendency to lower the speed and often he stalls the aeroplane.

For discarding those two disadvantages we reached out for slots, a new device at those times, which in our country was known only from literature, so it was necessary to do some investigations in wind tunnel. The first test was made with a slot on straight guides on pulleys. It was not very efficient. Improvement was only in stalling, even at very elevated angles of incident it was no fall of lift coefficent, but no increase too, so no amelioration in minimum speed.

Next experiments were with curved tracks and slight turn of slate. We found a very efficient shape with big augmentation of lift coefficient with increase of angle of incidence. The slot opened very gently: from the angle at which the movement begins the slot opens gradually with increase of incidence and softly stops at the end of movement.

It was used at RWD-6 aeroplane built for the 3rd Challenge International de Tourisme 1932. We achieved V min = 35.6 mph, V max = 134 mph and take off to 26 ft. obstacle - 364 ft., landing from 26 ft. - 344 ft. with an engine Armstrong-Siddeley Genet Major 160 HP 0_u = 607 lb.

These achievements were possible thanks to very good maneuverability at low speed. RWD-6 has had only plain ailerons but with long span, of course these were differential ailerons with large differentiation. For RWD-5 it was +10 to -23 degrees, at the end of the movement the down aileron even withdrew some degrees.

RWD-9 built in 1934 for the 4th Challenge had much smaller ailerons to leave more space for flaps. Ailerons were with slots between wing and aileron and at low speed with open leading edge slots and flaps the ailerons were doubled by interceptors on the wing just behind the outer leading edge slot. We have achieved V min. = 33.6 mph, V max = 175 mph and take off to 26 ft. obstacle - 250 ft., landing from 26 ft.-242 ft. with an engine Polish Skoda GR-76o 217 hp, 2 = 1740 lb. (max T-O weight 2050 lb.), Q_u= 510 lb. (max 820 lb.).

These outstanding performances of start and landing were attainable only for very experience pilots. These aeroplanes were rather expensive with powerful engines and complex construction. For aero-clubs and sanitary transport we designed, in 1934, the RWD-13 aeroplane without flaps, with leading edge slots only before ailerons. The engine was only 130 hp (Gipsy Major or Polish PZInz). Of course performances were much weaker V min. = 42 mph, V max ‡ 131 mph. It was known in Europe as the safest personal light aeroplane. Its sanitary version received in 1938 the first prize as the best and safest light sanitary aeroplane at the International Challenge of Sanitary Aviation in Esch - Luxemburg.

The short and easy landing of these aeroplanes was secured by large deflecting of its landing gears. For RWD-9 it was 20 inches. It was possible to descend with minimum safety sped (for RWD-9 36 mph = 52.8 ft. sec. and sinking speed circa 16 ft. sec. - slope is 1:3.3 - 18° - to touchdown without change of flight parameters before impact.

For short take off and higher level speed it was easy to put on a more powerful engine. But it was against economy of exploitation. For aero-club aeroplanes we chose rather not elevated speed and larger wing area. Wing loading was for RWD-6 - 9.6 lb. sq. ft., RWD-9 - 10.1 lb. sq. ft., RWD-13 - 11.4 lb. sq. ft., for primary drainer without flaps RWD-8 - 7.7 lb. sq. ft., for small transport aeroplane RWD-11 - 21.7 lb. sq. ft. with V max = 190 mph.

These club-aeroplanes were not destined to take off and land in a strong wind (more than 40 ft. sec.), but in normal conditions they were very easy and safe. Once a non-experienced pilot flying an RWD-8 primary trainer found himself in a very thick mist being near the ground. He reduced revolutions and speed but suddenly he felt hits at the undercarriage. He throttled down the engine, the aeroplane stopped and he saw that he was standing on a field covered with beetroots like children's heads. The aeroplane was undamaged. Similar accident involved a Fokker F VII 3m of Polish Airlines "Lot". In a steep climb in thick mist at the foot of the Carpathian Mountains it struck a slope, the pilot cut out engines and astonished passengers asked why it was complete calm. Nobody was hurt, only landing gear broken. These were advantages of slow flying, you all know very well what happens when a DC-10 strikes a hill. But without the DC-10 (or similar aircraft) I could not be here and speak to you. Nevertheless for a club aeroplane and primary trainer for beginners I prefer low wing loading and low landing and take off speed.

In further develpment we looked at the nose wheel. This type of undercarriage has all proprieties (but weight and drag) beter than the classic one with two wheels before center of gravity and third point — wheel or skid — at the tail. The nose wheel offers a more comfortable position on the ground by rest and rolling, easier landing with side wind, better directional stability during take off, landing and rolling, shorter take off and better braking. It is only an additional weight (mass) and drag (if not retractable). It is difficult on the soft, muddy ground.

In 1937 we built the first in Poland aeroplane with nose wheel. It was an experimental aeroplane — a modification of not used prototype RWD-9. After the first trial with a self aligning wheel without shock asorber and improvement to a wheel actuated by rudder bar, with rubber shock absorber and forward inclined axis of adjustment (steering axis) we received an aeroplane about which the test pilot said: "I drive this aeroplane on the ground like a motorcar". We have got all advantages above mentioned correct turns at 20 mph, radius of turn 25 ft. (span of aeroplane 38 ft.). Unfortunately the aeroplane for which this experiemnt was made could not be flown. The outbreak of the Second World War in 1939 stopped our works. We missed completion by three months.

This areoplane (RWD-18— was thought out as a personal five-seater with maximum range of 1100 miles. At such a range and possibility of flights over uninhabited areas it was necessary to be safe in case of damage of an engine. So we applied two engines (150 HP each). It was the first touring aeroplane in Poland with two engines.

At those times we encountered phenomena which were new for us and dangerous.

In 1932 Jerzy Drzewiecki M. Sc. designer and test pilot demonstrated the maximum speed of RWD-6 aeroplane. At a speed near 140 mph and about 30 ft. above the aerodrome he lost the wings, and the fuselage crashed to the ground. It was a real miralce that the severely injured pilot survived this accident. But the cause of accident was unknown. We thought that it was the mechanism of shift of tailplane which failed. The sudden displacement of the tailplane produced a violent rise of wing incidence ad force on them till the rupture. A similar accident occurred involving another pilot with the same aeroplane. He wanted to change the positon of tailplane, he pressed the knob which locked the lever, the level slipped. It was at low speed and not near the gorund so there was no accident. (From that time we always use for tailplane mechanism a self-braking device like wheel with nut and thread). After change of the mechanism the aeroplane flew and won the international competition. Only during the race the pilot has had some difficulties with ailerons: at the highest level speed even with ailerons deflected to the stops, the aeroplane was inclining to one side and pilot was obliged to throttel down and reduce speed. We have thought that it was a torque moment of the engine being rather big for such a small areoplane.

But some days later the winners of the first prize lost their lives during flight in a stormy weather. The wings broke out in the same manner as in the accident to Drzewiecki. Then we found in the newest literature the description of the torsional instability of the wing. After measuring the rigidity of the wing and making some computations we found that the critical speed was just at the highest level speed.

The covering of the whole wing with plywood gave no results (in the original aeroplane only the front part of the wing, before the single spar supported with a single strut was plywood covered). The wing became much stiffer but the torsion axis was moved back. It was necessary. And then it was all right.

In 19365 we built a liaison aeroplane type STOL. IN 1937 during the test of diving speed the pilot could not pull out the aeroplane and escaped by parachute. The tailplane was broken in the air. Perhaps flutter. We made the tailplane much stronger and more rigid but in second test the same result. Pilot jumped out with parachute, tailplane lost in air. After a long investigation the cause was found: an intermediate lever of the elevator controls was too near the fuselage girder tube. During a dive the fuselage was deforming and the lever was blocked in the position of dive. It was impossible for pilot to pull out; aeroplane overpassed the admissible speed and the tailplane broke out. A small change of the position of the lever cured the aeroplane.

In 1936 we met for the first time the flutter of the wing. We built a passenger aeroplane (for nowadays and executive) RWD-11: eight-seater with two engines of 200 HP each, retractable landing gear, wooden low wing, fuselage from steel tubes, maximum level speed 190 mph. The pilto observed that near 185 mph the ends of the wings began to vibrate and with increase of the speed the amplitude raised. The frequency of vibrations was high, the ends of wing looked like mist. The flutter was fortunately "kid" owing to good damping of wooden construction: with constant speed the vibrations were constant too. They raised only with raising speed. We had no instruments for investigation of those vibrations. To measure the frequency at the ground we used a gramophone with a white carton instead of disk onto which a pencil fixed to the vibrating wing was drawing a wavy line. We thought about two remedies: to put a counterweight at the leading edge (or before) of the end of the wing, or to put the counterweight in the nose of the aileron. It was a slotted aileron with the axis of rotation at 23% of its chord. Bringing the center of the mass of the aileron to the rotation line removed the vibrations.

And then came the Second World War. For what we could not find any remedy.

Professor Leszek Duleba, Warszawa, Poland

Born 1907, received degree of master of technical science in 1932. From 1932 to 1939 - designer in Experimental Aviation Works RWD. At the same time I was Adjunct Professor of Warsaw Technical University and Treasurer of The Society of Polish Graduated Aviation Engineers. During that period some 20 prototypes were constructed with my participation. Our airplane RWD-7 held the international records of speed and altitude for airplanes of II class tourist mass till 280 kg.

In 1933 airplane RWD-5 was the first airplane of mass less than 450 to cross the Atlantic from St. Louis - Africa to Maceio - Brasil, beating the record of distance for airplanes of this class. In 1932 and 1934 the airplanes RWD-6 and RWD-9 won international competition — Challenge International de Tourisme first, second, seventh, eighth and fifteenth place between 33 competitors.

During the war service in Polish Airforces in France and England in 1941 directed to Turkey for organization of Turkish Airplane Factory, THK, in Ankara as a chief-designer. Five types of airplanes and 5 types of gliders were designed and built and serial production of primary trainer miles - Magister was organized.

From 1947 to 1961 — chief designer in Polish Airplane Factory. From 1961 to 1967 — adviser of PZL. From 1947 to 1977 — lecturer of Aircraft Construction in Warsaw Technical University, Politechnika Warszawska. In 1958 granted with a title of Professor. From 1977 — Professor retired.

Analysis of Flight Data Recorder Information

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Summary

The analysis of data from a flight recorder, whether it be digital or analog, requires a thorough knowledge of the limitations and potential for error. Recorder limitations are defined generally by the range, accuracy, resolution, and sampling rate of each parameter. On the other hand, potential sources of error may be varied and numerous. In some instances, an error may be acute and quite apparent, while others are subtle and barely discernible. This paper will describe ways in which flight data recorder information can be distorted and methods whereby misinterpretation can be avoided.

I. Introduction

The National Transportation Safety Board (NTSB) and its predecessor the Civil Aeronautics Board have been charged with the task of reading and analyzing flight data recorders from accident/incident flights for the past quarter century. The Board, during this period, has amassed a considerable amount of experience in this very specialized area of accident investigation. This experience has shown the flight recorder to be an invaluable investigative tool. Experience has also shown that recorders have limitations and a potential for error that can have a significant influence on their analysis.

This paper will present some examples of the error potential and limitations of flight recorders and provide methods whereby misinterpretation can be avoided.

II. Error Potential

1. Oscillographic Flight Data Records (FDR)

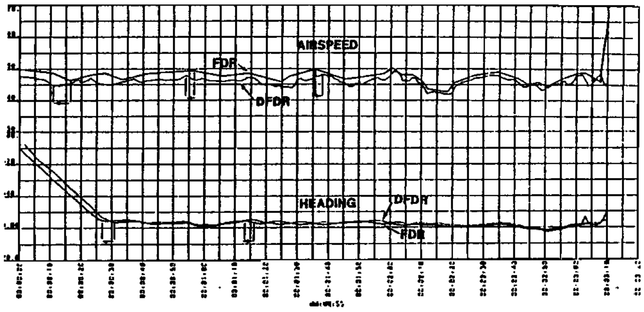
The FDR is currently in use by about 70 percent of the U.S. air carrier fleet and is limited to those aircraft certificated before September 30, 1969.[1] The minimum requirements for an FDR are set forth in ARINC 542, issued September 10, 1958.[2]

This type flight recorder scribes a continuous and permanent record of altitude, airspeed, heading, vertical acceleration, and microphone keying on a metal foil recording medium. The foil movement provides the timing base (0.1 inch per minute), and the styli scribe an analog record of the aforementioned parameters as the foil moves from one spool to the other. Data samples are taken at the minimum rate of one per second for altitude, indicated airspeed, and magnetic heading; vertical acceleration samples are take at a minimum rate of 10 per second. To assure proper timing at readout, a binary scribe makes a mark at 1-minute and 15-minute intervals to record any variations in foil speed. One model, however, was certificated without this feature.

Timing errors can have a very subtle and damaging effect on the accuracy of FDR data. The foil movement is not constant but is subject to short periods (less than a minute) where speed is greatly reduced, and other periods where it is accelerated as the foil slack is taken up. This, of course, causes short-term timing errors within the time span defined by the timing marks.

This type of error occurred in the initial readout of the FDR from the Air Florida accident in Washington, D.C.[3] In this case, it was not until the FDR's microphone keying data was compared to the same transmission recorded on the cockpit voice recorder (CVR) that a 3-second timing disparity was detected. Incidentally, the recorder involved did not record minute marks and was not required to do so.

The Controlled Impact Demonstration (CID) where a Boeing 720 [4] was remotely piloted into the lake bed at Edwards AFB on December 1, 1984, also provided a very good example of a short-term timing error. The 720 comparison of the data recorded on the FDR and the digital records demonstrates this problem quite clearly. The plot of the digital and the FDR data in Figure 1 shows a clear match between the two recordings for airspeed and heading for the last 50 seconds. Then the data begins to show timing disparities in some cases as large at 4 seconds. A similar match in the data can be made if the data is shifted so as to align the first seconds of the plotted data. Clearly in this instance the minute marks recorded by the FDR were inadequate to detect the short term timing variations.



Arrows indicate direction FDR data must be shifted to align with DFDR data.

Figure 1.

Since the FDR produces an individual recording of each recorded parameter, it is necessary to establish a correlation of one parameter to the other. This, of course, is another source of error. This error potential was clearly demonstrated during the readout of the FDR from the Kenner, Louisiana, windshear accident (clearly stamped preliminary) and hurriedly sent to the accident site. During this preliminary readout, the interpretation of the FDR data was based on witness statements and impact marks gleaned from the investigators at the site via a number of phone conversations. As is often the case, this early information proved to be inaccurate and sketchy at best. As a result, an aberrant portion of the altitude and airspeed traces were originally attributed to ground effect as the aircraft skimmed the surface before climbing into a line of trees, as reported by witnesses.

No mention was made of undamaged power lines that would have been in the line of flight had this really occured. This misinformation then lead to an incorrect interpretation as to where the end of the respective traced occurred. The "g" trace exhibited a clear spike that could only be attributed to impact. Therefore, the ends of the aberrant altitude and airspeed traces, were also assumed to end at impact, and were aligned with the "g" impact spike. Subsequent integration of the vertical "g", plus accurate impact information, clearly showed impact with the trees occurred at the beginning of aberrant altitude and airspeed data and not at the end — a 5-second disparity.

The accuracy of the recorded values for the respective parameters should always be treated as suspect until it can be validated. This is necessary since the sensors producing the recording may exhibit some calibration drift over time. Therefore, calibration must be checked against known values such as runway elevation, headings, etc., before it can be incorporated into the readout. Of course, when possible a recalibration of the recorder is also recommended.

Investigators should keep in mind that the accuracy of FDR scribes and altitude and airspeed sensors are examined only during periodic maintenance checks which may not occur for years. Therefore, the investigator must gather all available evidence and weigh that against the FDR data before progressing with any aircraft performance evaluations.

Airspeed and altitude parameters are also subject to errors caused by ground effect and position error. Although these errors can have a significant effect they can also yield useful information. For example, the point of rotation or touchdown can usually be identified on the altitude trace as a decrease or dip. This bit of information has been known and used for years by investigators, but to the uninformed, it could be misleading. The more subtle, but no less significant, effect of position errors must also be identified and accounted for. Of course, to evaluate a potential position error the investigator must gather information from other sources such as the cockpit voice recorder, wreckage and the aircraft manufacturers flight manual containing the position error corrects. Unfortunately, accidents have an uncanny way of occurring in regimes of flight never explored by the manufacturer, for obvious reasons. Therefore, in some instances, additional testing may be in order and, when this is not possible the use of theoretical calculation and sound engineering judgment may be all that is left to the investigator.

Investigators should also be aware that to read an FDR requires an element of interpretation that can have a marked effect on the data. There is enough latitude in FDR data to make it impossible for anyone to read the same foil twice and produce exactly the same values at precisely the same times. This is not to say that the same conclusions could not be drawn. Reader interpretation is a factor that must be taken into consideration during any analysis of FDR data.

Misinterpretation of the data can also occur. This was the case in the preliminary readout of the Kenner, Louisiana, windshear accident mentioned earlier. This situation resulted from misinformation coupled with a very unusual recording but was resolved through the eventual retrieval of very accurate data from the accident site and aircraft performance calculations. Armed with this additional information, a corrected version that became the basis for a number of windshear studies was produced.

2. Digital Recorders (DFDR)

All air carrier aircraft certified after September 30, 1969, must be equipped with a digital flight data recorder that meets the specification in ARINC 573.[1,6] In addition, a digital replacement for the FDR has come into service in recent years.

The DFDR (ARINC 573 models) records digital data on 1/4 inch magnetic tape. This data is formatted into frames and subframes. A subframe is comprised of 64 12-bit words recorded every second. A group of 4 subframes comprises a frame. Each subframe has a unique (Barker Code) 12-bit synchronization (sync) word identifying it as subframe 1, 2, 3, or 4. The data is in sync when successive sync words appear at 64 word intervals. Each data parameter (e.g., altitude, airspeed, heading) has a specifically assigned word number within the subframe.

Unlike the FDR or even some models of its digital replacement, the DFDR does not produce the data but merely records it. Therefore, any data errors are the fault of the flight data acquisition unit (FDAU) or the individual sensor. Timing, however, is one area where the DFDR's performance can affect the accuracy of the data. If sync is lost through some malfunction of the DFDR (e.g., loss of power), there is no foolproof way of knowing how many seconds have elapsed until sync is regained. The frame counter required by ARINC 717 [7] and GMT, when recorded, can often provide the timing reference to bridge the sync loss. Any additional check can be obtained by comparing the DFDR microphone keying times to a second recording such as the cockpit voice recorder (CVR) or the air traffic control (ATC) tapes.

The errors generated by the FDAU are generally very obvious but can at times be very subtle and as a result difficult to identify. An example of a very obvious FDAU error occurred a number of years ago. The data from an undamaged DFDR could not be synchronized using normal playback methods. A feature of the Board's readout station called "super sync," which permits sync to be achieved after only one sync word is read, produced evidence that some valid data was recorded. An octal dump of the data then revealed that every other sync word was being written incorrectly. The FDAU, which produces the sync words, was not generating the least significant bit correctly. This bit was manually corrected and the data eventually retrieved.

A faulty sensor is one of the more common errors associated with digital recorders. As with the FDR sensor, calibration can drift between maintenance checks. An example of sensor error that affected the altitude pressure transducer can be seen in Figure 2. In this case the data reduction algorithms were based on the standard calibration for this particular sensor. Unfortunately, this sensor no longer matched the standard. In this case, the error was large and easily detected.

Figures 2.

The values recorded by the DFDR bear little resemblance to the engineering units produced in the data printouts. The actual recorded values range from 0 to 4095 (decimal) and, therefore, must be converted mathematically to engineering units. The conversions at times involve complex algorithms that are often designed for a specific parameter and a given make and model aircraft. The conversion algorithms for a given parameter may also differ from one operator to the next. These conversion algorithms and their coefficients are also subject to changes if an operator elects to implement any recommended modifications. Therefore, it is a never ending task for the Board to keep up with the current list of changes. When an accident occurs, the Board asks the operators and/or airframe manufacturers to supply information for the algorithms in use. It generally takes a day or two to gather this information, so the first printouts produced are stamped "preliminary" and treated as such.

As you can well imagine, an incorrect algorithm or coefficient can alter the value of the engineering units. An accident involving one of the new digital ARINC 542 [2] replacement recorders clearly demonstrated the effects of an incorrect conversion value (see Figure 3). This was the first time this model recorder was read out by the Board's laboratory. The accident involved a Boeing 727 that struck a light pole shortly after takeoff. The runway used was far too short for the aircraft's performance.In the initial readout, the conversion algorithms and coefficients for altitude, airspeed, heading and vertical acceleration for a Boeing 727 from a different operator were used. The readout produced values for all the parameters that seemed correct, matching all the conditions and circumstances. The airspeed values were of particular interest in trying to determine if the crew rotated the aircraft early. A check of the dip in the altitude trace normally associated with rotation, and the corresponding airspeed, did indeed show an early rotation. This finding appeared to fit the circumstances. A crew faced with a rapidly approaching blast fence might be inclined to rotate early. However, all the evidence did not support this conclusion. The dip in the altitude trace showed what appeared to be a normal rotation and liftoff. Early rotation tends to elongate and deepen the dip in altitude. This coupled with the fact that this was a new recorder whose characteristics were unknown, at least to the Board's staff, increased the suspicion that the airspeed might have been incorrect. Checks with the recorder manufacturer and operator were inconclusive, but the airframe manufacturer provided correct coefficients, which, in turn, showed that the aircraft rotated at the proper speed.

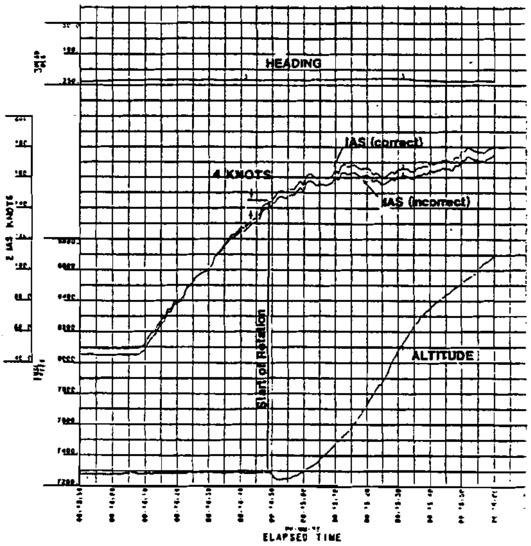


Figure 3.

In this case, the error was subtle but significant. In other instances the error maybe very obvious. In either case, there may be some delay in producing the final version of the printout as operator and manufacturers are queried to obtain the correct conversion coefficients and algorithms.

In the examples cited, the problems were discovered by comparison with information gathered during other phases of the investigation or with other recorded parameters and a thorough knowledge of expected airplane performance. This shows that flight recorder data should not be used or read out in isolation. Therefore, there is no substitute for a complete investigation. Recorders are one of many tools used in the investigation. The field phase of the investigation should not be shortchanged because the investigator thinks the recorder will have all the answers. The recorded data must always be checked and verified against the physical evidence if it is to be used to its fullest potential.

IV. Limitations

In addressing flight recorder limitations, discussions will be limited to those parameters currently being recorded, and not to deficiencies in the number of required parameters. The Board has made its position well known in this regard through its safety recommendtions to the Federal Aviation Administration.[1]

The range over which a parameter is recorded can at times produce an incomplete and, therefore, inadequate record. As an example, most recorders do not record airspeed below 40 knots and some ARINC 542 [2] models do not start until 80 knots. This, of course, presents a severe limitation to the investigator during takeoff accidents, which is compounded when longitudinal acceleration data is not available.

In a recent accident involving a rapid descent, the range of the digital air data computer (DADC) was exceeded, resulting in a distortion of the recorded values for both airspeed and altitude. In this case, the maximum rate of descent that the DADC could handle was 24,000 feet per minute. The altitude and airspeed values suppied to the DFDR showed a constant rate of descent and a steady airspeed when the rate of descent exceeded 24,000 feet per minute. The cockpit display reverted to manual mode presenting raw pitot static values. These parameters first became suspect when examined in relationship to other parameters such as pitch, roll and vertical acceleration. A subsequent engineering simulator study and a bench check of a DADC confirmed the original suspicion.

The accuracy of a parameter could limit the scope of an investigation. If the recorded values cannot be verified it may not be possible to pursue a performance analysis. For example, altitude recorded by ARINC 542 [2] recorders is only required to be accurate to within +100 at sea level and +700 feet at 50,000 feet. If the recorded values cannot be verified against other factual evidence, then how much confidence can investigators have in the data This, again, points up the need for a thorough field investigation.

The resolution of a recorded value can provide misleading results to an investigator if he or she is not careful. A prime example of this surfaced during the investigation into the first fatal L-1011 accident. [8] The stabilizer position sensor, a sychro, could not provide adequate resolution to record the relatively small movements of this aircraft's flying tail. The problem with the stabilizer position sensor had been identified before the accident and a modification developed, However, the accident aircraft had not been modified.

The low sampling rates of some parameters has hampered investigations since digital recorders were first introduced. Parameters such as control wheel and column positions, engine pressure ratios, and vertical acceleration, to mention a few, have sampling rates that are inadequate for proper analysis. During the CID test, vertical acceleration was sampled at 16 times a second. In Figure 4,

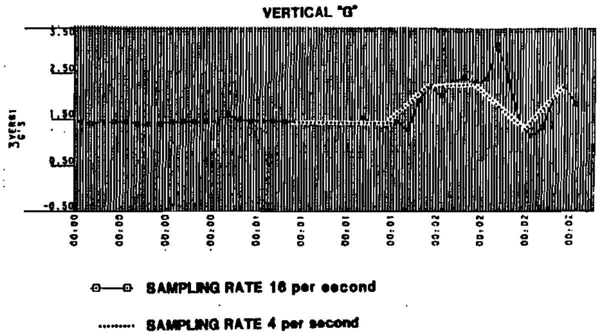


Figure 4.

it can be seen that if the required sampling rate of 4 per second had been applied the peak "g" at impact would not have been recorded.

Sampling rates for engine data are a particular problem. The required sampling of one per 4 seconds precludes an accurate time history of engine performance during dynamic situations such as rejected takoffs or engine failures. Three engine aircraft present an even worse situation where no engine performance is recorded for 1 second. An overrun accident clearly demonstrated this point. As the investigation progressed, the question as to when and what engines were placed into reverse arose. An examintion of the N_1 and thrust reverser data proved to be inconclusive. Fortunately, this aircraft was equipped with a very extensive AIDS[2] package that survived the impact. The throttle lever position data recorded once per second yielded the necessary data.

V. Conclusions

Flight data reorders are a very useful investigative tool. As with all investigative tools or techniques, they have their limitations and are subject to error. It is only through a thorough knowledge of these limitations and errors that a proper and full analysis can be conducted.

The flight recorder data cannot and should not be used in total isolation. The accident investigation must provide the factual information against which the flight recorder data can be measured. Without this corroborating information, flight recorder data will remain unvalidated and can never be utilized to its full potential.

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[1] NTSB Safety Recommendations A-82-64 through -67, July 13, 1982.

[2] Aircrft Integrated Data System

Readout and Data Processing of the Fairchild Digital Flight Recorder

Presented By:
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A review of the design/technical features of the Fairchild Digital Flight Recorder (DFR) and it's accompanying options such as a Data Monitor and Storage (solid state) memory for exceedance recording will be presented. Special emphasis will be on the types of equipment and methods used in readout and data processing.

The DFR uses fully automatic calibration equipment equipment including business type mini-computers for test, calibration, repair and readout. This equipment is also suitable for accident investigative reproduction of the complete 25 hours of recorded data, or portions thereof.

The different data recording formats, used by Fairchild, and interface methods to existing data processing systems will be reviewed.

New data-recording methods and some new equipment developments will be discussed.

Recovering all the recorded data from a Digital Flight Recorder (DFR) often becomes a challenge to the accident investigators.

Digital Flight Recorders are noticeably different in their mechanical designs. Presently nearly all of them use, as a storage medium, magnetic recording tape of 1/4" width (6.25 mm). However, substantial differences exist in the methods of data encoding and where and how it is written onto the magnetic tape.

For retrieving this recorded information, often to the last fractional second, and to be certain about the validity of this obtained data, an understanding of the recorder's peculiar design functions is desirable.

Data Recovery Methods

Fairchild's Digital Flight Recorders use, for data storage, the same well known tape transport as the Fairchild Cockpit Voice Recorder (CVR). The survival record of the CVR over the past 20 years and its familiarity to the investigator eliminates the need for further details at this point. For recovering the recorded data, two methods are used, depending on the damage to the recorder during the accident.

Readout Method 1: Functional Recorder

The DFR is still operational; considerable fire and liquid exposure may have existed. Figure 1 displays two functional DFRs, the burned left unit is from the FAA anti-misting fuel crash (Sept. '84).

Readout Method 2: Damaged Recorders

The recorder is physically damaged or was submerged in liquids or exposed to a severe and prolonged fire. In those events, the tape media must be extracted for readout. Figure 2 shows extensive impact damage to a recorder and submergence in jet-fuel. Figure 3 shows a CVR with most severe impact damage ever seen, no fire.

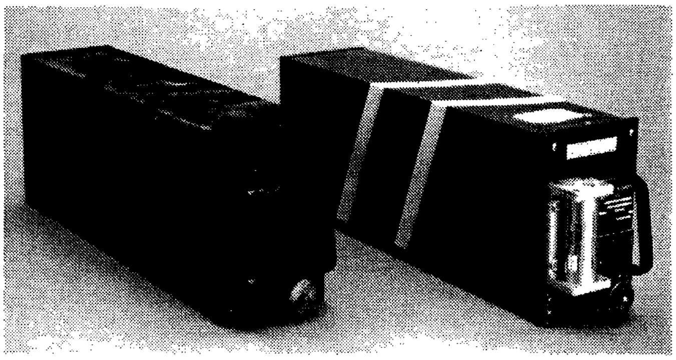


Figure 1

Data Recovery Set-Up

In the endless-loop tape configuration the tape moves only in the forward direction. All 6 tracks are recorded in the same direction. Access to the recorded data is through a front panel ATE-connector for readout or copy. Damaged recorders require the removal of the tape and, depending on it condition, some preparation for playback is needed. Commonly, rewinding the tape and cleaning it and bringing it into proper orientation for playback are steps preceding the actual data readout process. Figure 4 reveals the endless loop tape transport prior to tape removal. Figure 5 presents a removed DFR Tape, 450 feet long prior to cutting it. The last recorded (the end) data is on the outside of the reel. The oxide surface is outwards.

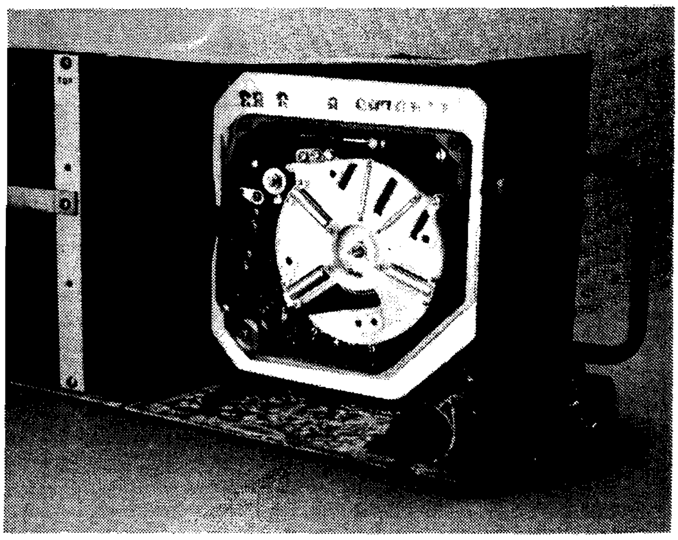


Figure 4

Data Readout Equipment

For data readout in either method, 3 basic equipment elements are required:

1. A tape playback unit. Either the DFR, or a tape reproducer.
2. Data bit synchronizer for reliable bit recovery.
3. Computer with Read-Software.

DFR Calibration and Service Equipment

A complete line of calibration and service equipment is available for the Fairchild DFR line. This equipment is all computer controlled and provides a fully automatic calibration verification. This equipment is also usable for accident investigation, however, for extensive data printout it is comparatively slow. Figure 6 shows such a set-up. On the left top is the Aircraft Simulator (ACS), below, the Read Data Unit (RDU), the APPLE IIe computer is on the right. The Scope is optional and the printer is not shown.

Special Readout Equipment

Additional equipment is available for readout of damaged recorders and for making data copies. See Figure 7 for set-up of tape copy and readout equipment with interconnection to a data processing system.

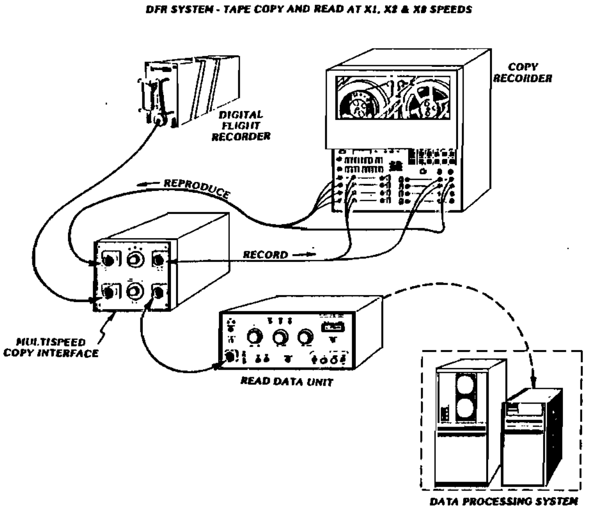


Figure 7

1. **The Tape Reproducer** for the DFR tape is shown in Figure 8. It operates at speeds of 1 times (.36 IPS 9.1mm), 2 times and 8 times playback speed. Also, a tape speed of 1 7/8 IPS (4.5 cm/sec) is provided for playback of Cockpit Voice Recorder tapes. The complete head assembly is exchangeable in this tape player. A 4-track head assembly is used for CVR applications. The output signal is the same as from the DFR (600 mV PP at 1 times speed) with 6 tracks in parallel.
2. **A Copy Recorder** (Figure 9), which is an instrumentation type recorder, for making analog tape copies of the DFR tapes. A general purpose Instrumentation Recorder is used for re-recording the DFR tape data in its analog signal format; all data is thereby re-recorded verbatim, including bit errors and data losses during power up and down. This results in a true tape copy, not a simple copy of the readable digital data only. This recorder has an IEEE-488 bus input; tape movement is controlled by the readout computer.
3. **The Read Data Unit (RDU)** (Figure 10) is required for data readout of all Fairchild DFR Models as well as for data playback, from the Copy Recorder or the Tape Reproducer. This unit contains internal circuitry for amplifying, filtering and shaping the tape playback signals. Further, an internal oscillator follows the tape speed variations and thereby provides a timebase for proper recovery of the recorded binary 1 and 0 data bits.

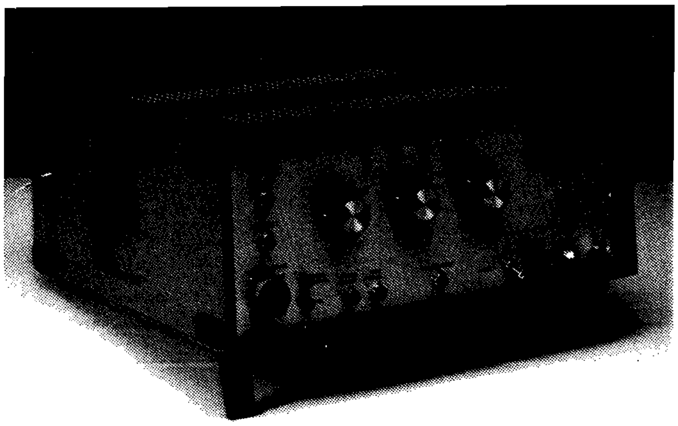


Figure 10

The output signal is digital, *DATA serial* and *CLOCK of 0 degree* to interface to external computers. Selection for playack of either one of 6 DFR tracks and a display of the active recording track are on the front panel. An optional card permits interface to existing main frame computers in the ARINC 717/573 format. An internal reformatter is used in this option, whereby ARINC 542 data will be reformatted to 64 word ARINC 717 format with 0 value words in between. The RDU operates on playback speeds of 1 and 2 times from the DFR, and one, 2, and 8 times from the Copy Recorder or from the tape reproducer. The RDU produces a test data pattern for set-up and provides also a serial output in Harvard Bi-phase at 1 and 2 time speed.

4. **Mini Computer** (Figure 11) shows the APPLE IIe computer used for calibration, maintenance and data readout. The printer is not shown. Software is provided as part of Fairchild's service support. Formula packages are available on floppy disk for service and readout. Programming language used is BASIC. Full program listings are provided.

Tape Track Format

All DFR configurations use a 6 track tape format. Separate heads are used, one for record and one for playback. This allows for continuous readback of the recorded data with a 3 second delay after recording. See Figure 12.

Recording Format on the Tape

Depending on the DFR Configuration and the type of aircraft where it is installed, the recorder produces a data stream of a different bit rate. Three different formats are used in the various DFR configurations.

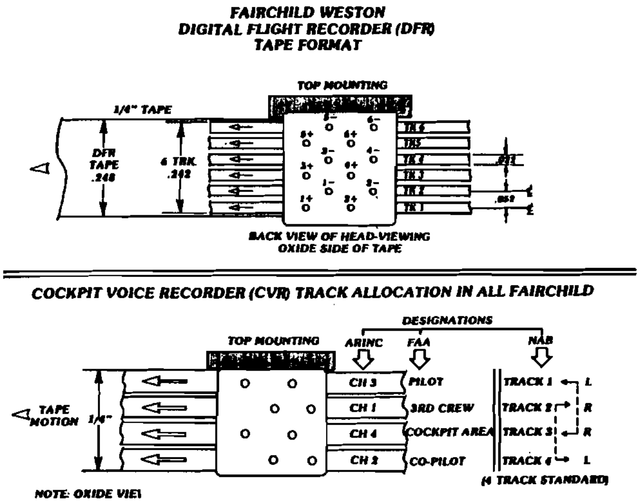


Figure 12

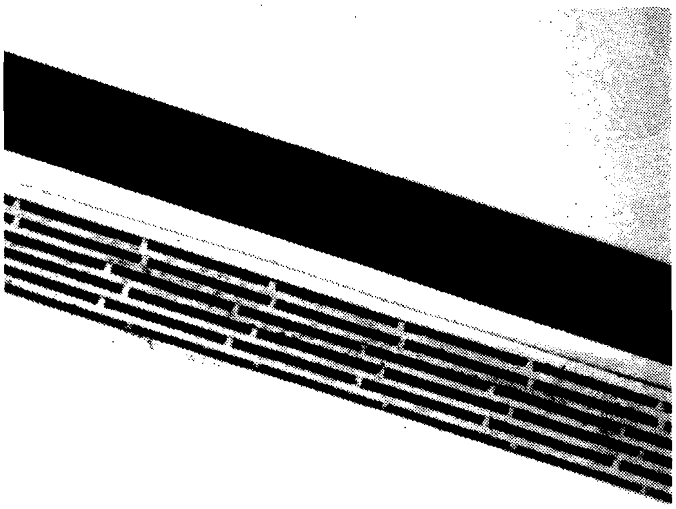


Figure 13

17M700-XX	ARINC 542 with inputs for Pneumatic Altitude and Airspeed. (1 format, 10 words per second)
17M800-XX	ARINC 717/573 inputs from external FDAU. (1 format, 64 words)
17M900-XX	ARINC 542/573/717 Combination Recorder (2 formats, 10 or 64 words)
17M903—XX	CombinationARINC 542/573 with additional analog parameter inputs in the ARINC 542 expanded parameter mode with up to 24 parameter inputs. (2 formats, 32 or 64 words)

Fairchild recorders store only active data bits without adding "filling bits". Consequently,the recording format varies from the 5 parameter installation to the 64 parameter DFR application.

1. **ARINC 542 Format:**
An actual recording is shown in Figure 13. The Magnasee process was used. The recording shows 1 second data bursts separated by a blank word. Data is recorded sequentialy on the 6 tracks. The data rate is 10 words of 12 bits or 120 bits/second, the Harvard Bi-phase encoding techniques is used, resulting in 664 flux reversals per inch. See Figure 14. Further explanation of WORD length and BIT values are given in Figure 15.

The readout software gives formulas for converting the recorded digital values back to engineering units, see Figure 16. An actual printout is shown in Figure 17. Printing is at a rate of 1 line for each second.

2. **ARINC 542 Expanded Format**
DFR modifications to include additional parameters as proposed by the FAA in 1984 are possible. Additional data words are recorded. (Figure 18) A total of 32 data words per second are recorded and additional analog input hardware is installed. Since late 1984 these recorders have been in use, not necessarily with all the optional parameters connected in the aircraft. Recorded bit rate is 32 words at 12 bits × 384 bits per second. Recorded in Harvard Bi-Phase code this results in a recording density of 2,128 flux reversals per inch.

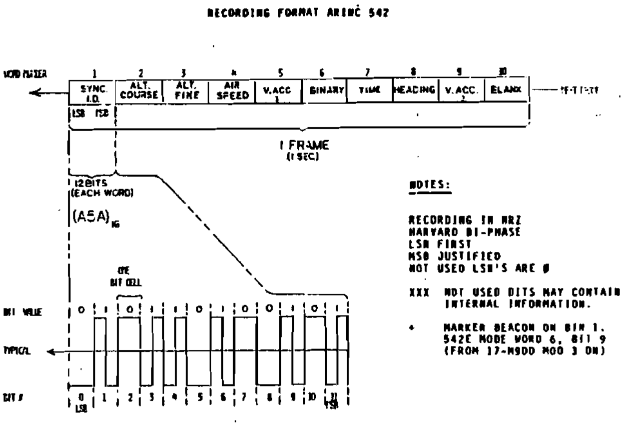
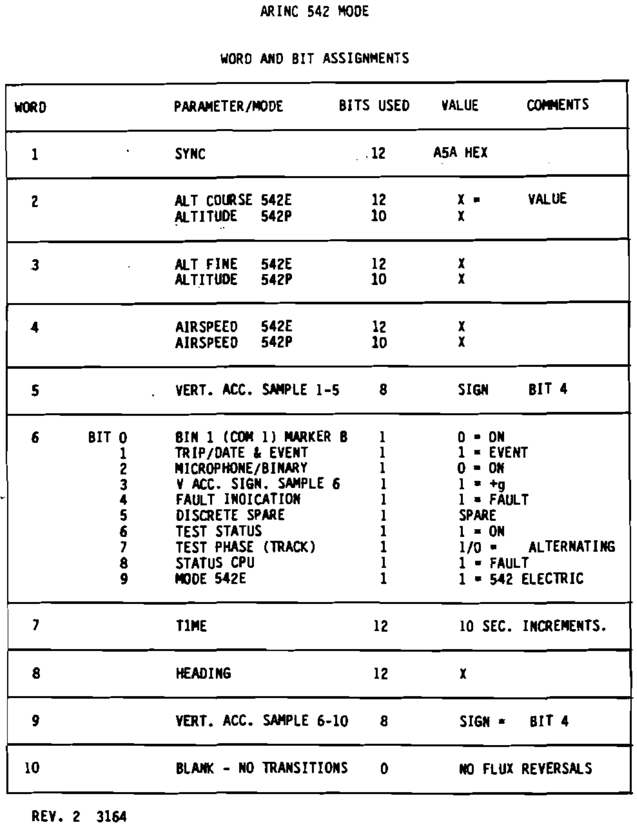


Figure 14

3. **ARINC 573/717 Format**

These systems employ an external FDAU as presented in Figure 19. The data rate is 64 words of 12 bits equal to 768 data bits per second. The FDAU encodes the data in Harvard Bi-phase. This encoding method is very inefficient for magnetic recording at these higher bit rates. The data is therefore re-encoded into a more efficient Group Code Recording (GCR). Four data bits are converted to 5 unique recording bits (refer to Figure 20). This is a code used widely in data processing systems and which allows the use of error detection methods. This GCR code results in a 40% reduction in the recording density on the tape. The recorded format is 768 bits X 5/4 × 960 bits/sec which results in a tape packing density of 2,660 flux reversals per inch.

The playback signal, as it comes from the tape, is in analog form (prior to its processing by the RDU to a digital signal).During DFR power interruptions, violent maneuvers, multiple impacts or just prior to instant of impact, the data is often not readable by automatic means to the last bit. Manual data recovery methods can be used for such short sections. A computer type analog data monitor program, which performs like a pen-recorder, is



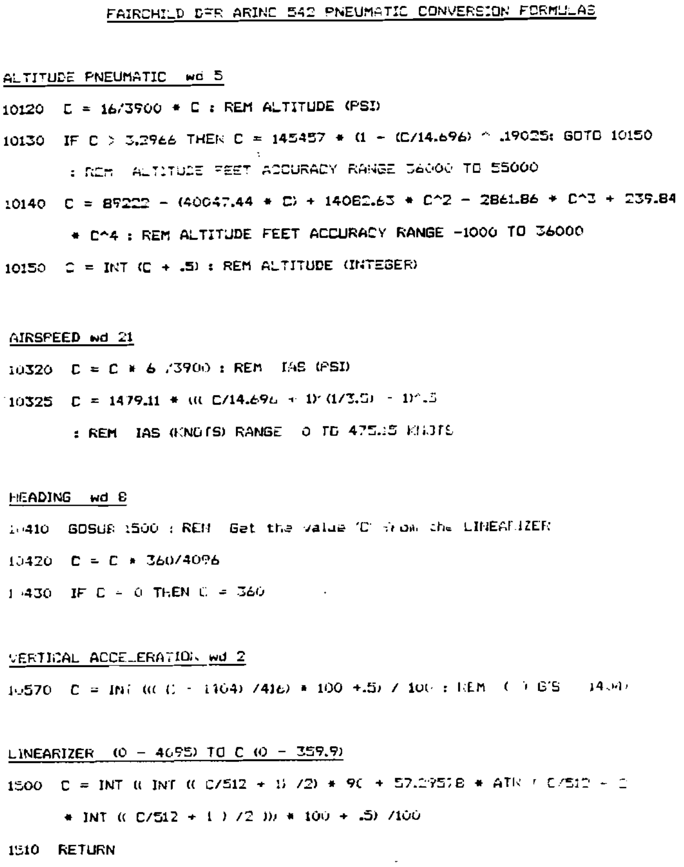
ARINC 542 MODE

WORD AND BIT ASSIGNMENTS

WORD		PARAMETER/MODE	BITS USED	VALUE	COMMENTS
1		SYNC	12	A5A HEX	
2		ALT COURSE 542E ALTITUDE 542P	12 10	X = X	VALUE
3		ALT FINE 542E ALTITUDE 542P	12 10	X X	
4		AIRSPEED 542E AIRSPEED 542P	12 10	X X	
5		VERT. ACC. SAMPLE 1-5	8	SIGN	BIT 4
6	BIT 0	BIN 1 (COM 1) MARKER B	1	0 = ON	
	1	TRIP/DATE & EVENT	1	1 = EVENT	
	2	MICROPHONE/BINARY	1	0 = ON	
	3	V ACC. SIGN. SAMPLE 6	1	1 = +g	
	4	FAULT INDICATION	1	1 = FAULT	
	5	DISCRETE SPARE	1	SPARE	
	6	TEST STATUS	1	1 = ON	
	7	TEST PHASE (TRACK)	1	1/0 =	ALTERNATING
	8	STATUS CPU	1	1 = FAULT	
	9	MODE 542E	1	1 = 542 ELECTRIC	
7		TIME	12	10 SEC. INCREMENTS.	
8		HEADING	12	X	
9		VERT. ACC. SAMPLE 6-10	8	SIGN =	BIT 4
10		BLANK - NO TRANSITIONS	0	NO FLUX REVERSALS	

REV. 2 3164

Figure 15



```
FAIRCHILD DFR ARINC 542 PNEUMATIC CONVERSION FORMULAS

ALTITUDE PNEUMATIC  wd 5

10120  C = 16/3900 * C : REM ALTITUDE (PSI)

10130  IF C > 3.2966 THEN C = 145457 * (1 - (C/14.696) ^ .19025: GOTO 10150

        : REM  ALTITUDE FEET ACCURACY RANGE 36000 TO 55000

10140  C = 89222 - (40047.44 * C) + 14082.63 * C^2 - 2861.86 * C^3 + 239.84

        * C^4 : REM ALTITUDE FEET ACCURACY RANGE -1000 TO 36000

10150  C = INT (C + .5) : REM ALTITUDE (INTEGER)


AIRSPEED wd 21

10320  C = C * 6 /3900 : REM  IAS (PSI)

10325  C = 1479.11 * ((( C/14.696 + 1)^(1/3.5) - 1)^.5

        : REM  IAS (KNOTS) RANGE  0 TO 475.15 KNOTS


HEADING  wd 8

10410  GOSUB 1500 : REM  Get the value 'C' from the LINEARIZER

10420  C = C * 360/4096

10430  IF C = 0 THEN C = 360


VERTICAL ACCELERATION wd 2

10570  C = INT ((( C - 1104) /416) * 100 +.5) / 100 : REM  ( [illegible] G'S  14.4)


LINEARIZER  (0 - 4095) TO C (0 - 359.9)

1500  C = INT (( INT (( C/512 + 1) /2) * 90 + 57.29578 * ATN ( C/512 - 2

       * INT (( C/512 + 1 ) /2 ))) * 100 + .5) /100

1510  RETURN
```

Figure 16

used (Figure 21 Top Line). The lower line represents 1 and 0 data bits as based on manual visual bit analysis.

The underlying reason for using multiple data recording formats is to always record on the tape the lowest amount of data bits necessary to store all the information. This results in a higher data reliability and less sensitivity to mechanical forces as they often occur during the final seconds of an accident. Further it was our design goal to improve recorder reliability and reduce its complexity even if this required more intelligent readout equipment.

Bit and Frame Synchronization

Large computer systems cannot accept data in a one bit by one bit sequence. Further, pre-processing of the data is required, the sync-word has to be found in the data stream by external hardware and the computer needs to be fed one complete 12 bit DFR word at the time. A Frame Synchronizer performs this function and provides a parallel data word interface to the computer system. Several commercial units are available. Figure 22 shows the EMR (Schlumberger) Type EXPERT, which is used by some agencies. The RDU is still required for bit synchronization preceeding the frame synchronizer.

The APPLE computer set-up does not require an external frame synchronizer. This function is accomplished in a software program. However, this will slow down the computer noticeably. The resulting printout of ARINC 717 data is, therefore, 1 line very 4 seconds as shown in Figure 23.

Special Readout Equipment

For DFR system verifiction and fast on board analysis, Fairchild provides its customer with a Portable Data Display Unit (PDDU), Figure 24. This unit contains all readout functions in a small suitcase; the bit synchronizer is in the base of the recorder. A small computer with LCD screen and a compact printer provide output. A mini-cassette or ROM provide for reprogramming. The computer unit can be removed and extended severl hundred feet and readout can be observed in the cockpit in actual engineering units, octal or decimal. Understandably, this PDDU has become a very popular service unit. Newer versions contain large nonvolatile memories for storing data and for data transfer to the maintenance computer for later readout. See Figure 25.

Future DFR Development –

Solid State Memory Options - Data Monitor and Storage (DMS)-

Some operators use the flight recorder for obtaining data on hard landings and engine performance. Fairchild is developing a solid state memory addition to the DFR, which monitors all data going to the tape and stores those predefined events and exceedances. This DMS option consists of one plug-in circuit card, containing a large memory with battery back-up for a 30 day period. Data access is very fast, just seconds. Total memory capaity in the ARINC 717/573 format is for 572 subframes, or 143 events of 4 subframes (4 seconds each). This is equal to 9.5 minutes of flight time. The data storage time is twice as long in the ARINC 542 mode. Readout and transfer is accomplished with the PDDU (refer back to Figure 25).

Cockpit Voice Recorder With Data Inputs

Helicopters record rotor speed data on the Cockpit Voice Recorder (CVR). An external data encoder module Rotor Speed Encoder (RSE) is used for this purpose (Figure 26). A 4600 Hz precision tone is phase encoded (180° phase change) providing for continuous and highly accurate rotor speed recording. Tachometer inputs from 0 to 6,000 Hz or digital data with a data rate of up to 768 bits per second may be recorded. This tone is superimposed on the radio channel without effecting the voice information.

DMT Time Link

A special development for the FOKKER F50/F100 is currently in progress. The FDAU will generate an encoded time tone burst which is recorded by the CVR.

AMT Options for CVR

A plug-in GMT timebase for all Fairchild CVRs is in development. A battery powered clock will be used to record GMT signals on one of the radio channels. The time mark will be audible at 30 second intervals, or the 4,500 Hz tone burst may be decoded for its GMT contents. A decoder will be available from Fairchild.

Combination Voice and Data Recorder

A Combination Voice and Data Recorder (CVDR) has been developed in accordance with the SAE specification 8039 and the FAA TSO C-111.

This CVDR records 2 separate tape tracks for the vice channels of 30 minutes duration each. Two more tracks are used for digital data with up to 198 analog inputs and 4 discretes and internal GMT-Time (Figure 27).

Data of the last 30 minutes is stored continuosly. Older data, up to 8 hours, is segmented and one set of all parameters is stored each 16 seconds. The most recent recorder calibraton data is also retained on the tape to further enchance its accuracy. Installation of a CVDR (Figure 28) in a business type aircraft is in process.

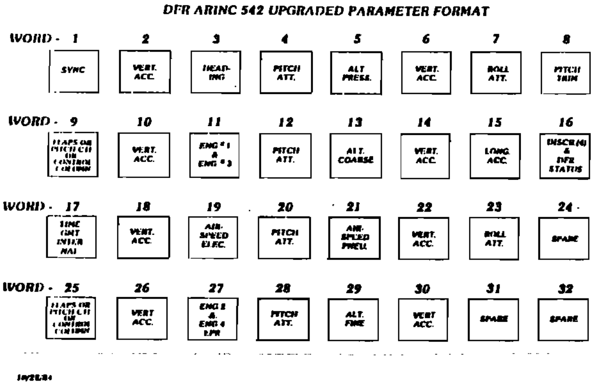


Figure 18

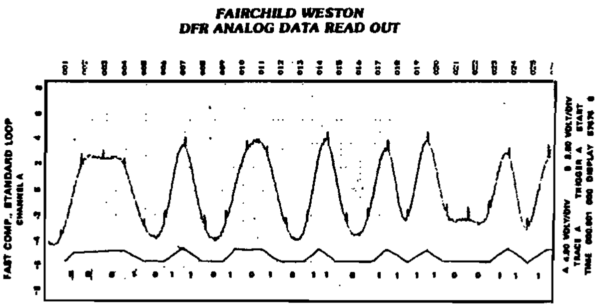


Figure 21

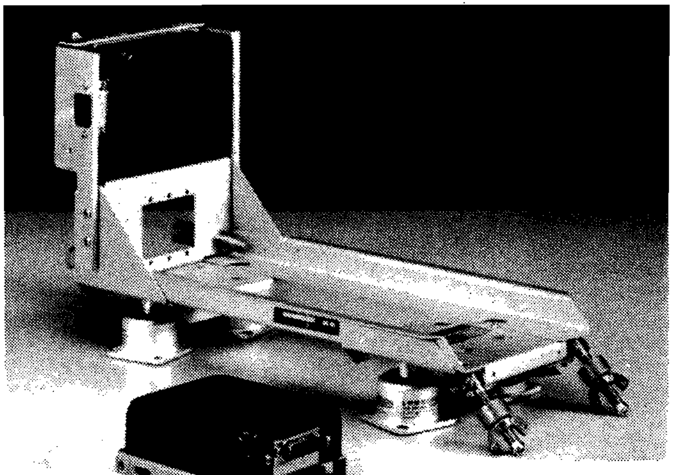


Figure 24

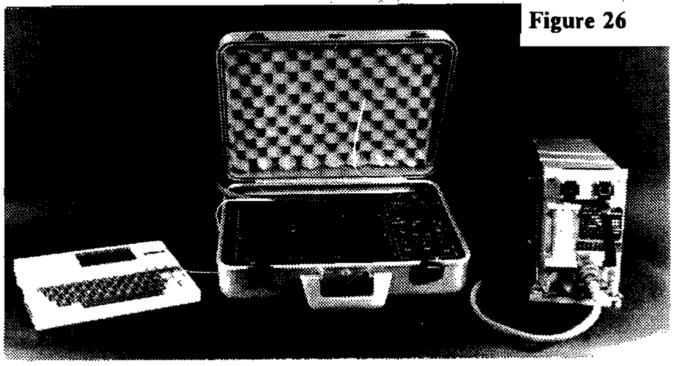


Figure 26

Barry J. Hawkins, International Sales Manager

Mr. Hawkins has been active in the development and marketing of aircraft systems for over 25 years. As International Sales Manager, he is responsible for world-wide sales of Fairchild Cockpit Voice Recorders and Digital Flight Recorders for Fairchild Weston Systems, Inc.

Previously, he was instrumental in the development and marketing of the Fairchild STAN Integral Weight and Balance System. He is the author of a number of technical articles (Interavia, Control Engineering, ISA Journal, etc.) and has presented several papers at ISASI, FLight Safety Foundation, International Society of Aeronautical Weights Engineers and other organizations.

Hans F. Napfel, Director of Engineering

As Director of Engineering for the Equipment Recorders group, Mr. Napfel has overall responsibility and active involvement in all aircraft recordings equipment systems developed by Fairchild Weston Systems, Inc.

He had direct project responsibility for the electrical systems of the Cockpit Voice Recorder, including design and customer coordination and the responsibility for testing programs leading to the approval by the FAA for these recorders.

Mr. Napfel's active involvement in new generation airborne data recording techniques encompassing advance multiplexing analog to digital conversion and computer readout techniques has lead to the development of Fairchild's Digital Flight Recorder which utilizes latest Microprocessor technology.

Mr. Napfel has given several technical papers, is the holder of several patients, including one on a sound head circuit and is a recognized authority on magnetic recording techniques.

The Application of CVR and FDR Data In Human Performance Investigations

By
Phyllis Kayten, Ph.D. and Carol A. Roberts, Ph.D., PE
National Transportation Safety Board

Abstract

This paper examines the use of cockpit voice recorder (CVR) and flight data recorder (FDR) information in the investigation and analysis of the human performance aspects of an aviation accident. The National Transportation Safety Board has investigated several accidents in which the presence of CVR and/or FDR have proved significant to the investigation. In the human performance area, CVRs and FDRs can provide critical insight into the circumstances surrounding an accident, including the judgemental and decision-making procedures as well as the control decisions and inputs made by the flightcrew. Such critical information not only provides a better understanding of the accident factors, but also results in developing principles for enhancing safety.

Introduction

The National Transportation Safety Board (NTSB) is mandated to determine the probable cause of all U.S. civil aviation accidents, and the cause of selected accidents in rail, highway, marine and pipeline transportation. In the aviation mode alone, between 60 and 85 percent of all accidents are not attributable to mechanical, structural, or engine failures. In the past, too many of these accidents were categorized as "pilot error", and little or no further investigation was done to determine the nature of the pilot, or human, error, In November 1983, the Safety Board established a Human Performance Division, whose members were to investigate the human performance aspects of accidents in greater depth. The Human Performance group uses Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR) data regularly, when available, in investigation of the human performance aspects of aviation accidents. Sometimes the data from the CVR or FDR provides a jumping-off point from which the human performance group can investigate further one or more aspects of the system in which the accident occurred. Sometimes the CVR and/or FDR data is used by the Human Performance group to verify or clarify statements or other data gathered by interview or other investigation.

NTSB's Gerritt Walhout (Ref. 1) has discussed human performance investigations and the role of flight recorders in providing essential information:

> "Efforts to learn the reasons [for 'pilot errors'] have been largely speculative until Flight Data Recoders and Cockpit Voice Recorders became available in large transport aircraft . . . Aircraft recorders are essential basic tools of the human performance investigator requiring quality, dependability and state-of-the-art equipment to refine the investigative methodology of human performance investigations.
>
> Despite the best available equipment and the most carefully developed procedures, aircraft operations depend to a great extent on human judgement, vigilance, perceptions, learned behavior and expectations that may exceed the limitations imposed on all of us by the capacity of our senses and the processes by which decisions are made.
>
> The advent of the FDR and the CVR and their installation in large air carrier aircraft has provided the tools needed to examine the underlying causes of these errors. Considerable progress has been made, because of CVR/FDR availability, in explaining the human performance aspects of accidents. Also the potential for more rational recommendations for accident prevention purposes have been recognized."

This paper describes how the Human Performance Group in an NTSB aviation accident investigation makes use of the CVR and FDR data to examine the underlying causes of human errors.

NTSB Human Performance Investigation

In November 1983, NTSB established a Human Performance Division within its Bureau of Technology. Before this human performance issues were investigated by the Human Factors Division. This was divided to form the Human Performance Division and the Survival Factors Division the Survival Factors Division continues to investigate the crash-worthiness of aircraft, assess survivability of accidents, and document crash injuries. The Human Performance Division has thus been able to concentrate on the human performance issues only (and incidentally the human performance investigation is not solely limited to the flightcrew, but includes maintenance personnel, airport control tower personnel, and airline and airport management personnel).

The Human Performance Division presently consists of 6 members, all with advanced degrees in psychology, and with expertise in human factors or human engineering aspects of at least one mode of transportation. We also have an expert in the field of toxicology. Three members of the Human Performance division hold pilot certificates; most have participated in or observed some form of commercial carrier pilot training. A member of the Human Performance division is assigned to every major accident investigated by NTSB, in every mode of transportation; typically a Human Performance division member is present on scene at any accident to which the Safety Board launches a full "go team".

NTSB's Human Performance protocol has been described many times before (Ref. 2,3,4). Basically, we collect factual information on factors that have been shown to affect human performance. These factor have been categorized in six general profile areas: Behavioral, Medical, Operational, Task, Equipment Design and Environmental. Figure 1 illustates the basic investigative scheme. Factural information often overlaps one or more of these basic categories; these categories are used simply as a way of organizing the information for analysis.

Although not a member of the CVR or FDR Group assigned during an NTSB investigation, the Human Performance investigator has access to the data collected from the CVR, after the CVR transcript is prepared, and FDR. The Human Performance investigator listens to the CVR for specific factors, for example, communication patterns (Ref. 5,6), environmental distractions (Ref. 7), compliance with company or FAA regulation or policy. The Human performance investigator works closely with the airplane performance specialist who interprets the FDR data, so the performance of the airplane due to pilot control (or lack of control) is understood. Thus, the CVR and FDR data are input to the Human Performance investigator as basic raw data. Examples of how the CVR and FDR data are utilized follow a brief description of the NTSB laboratory.

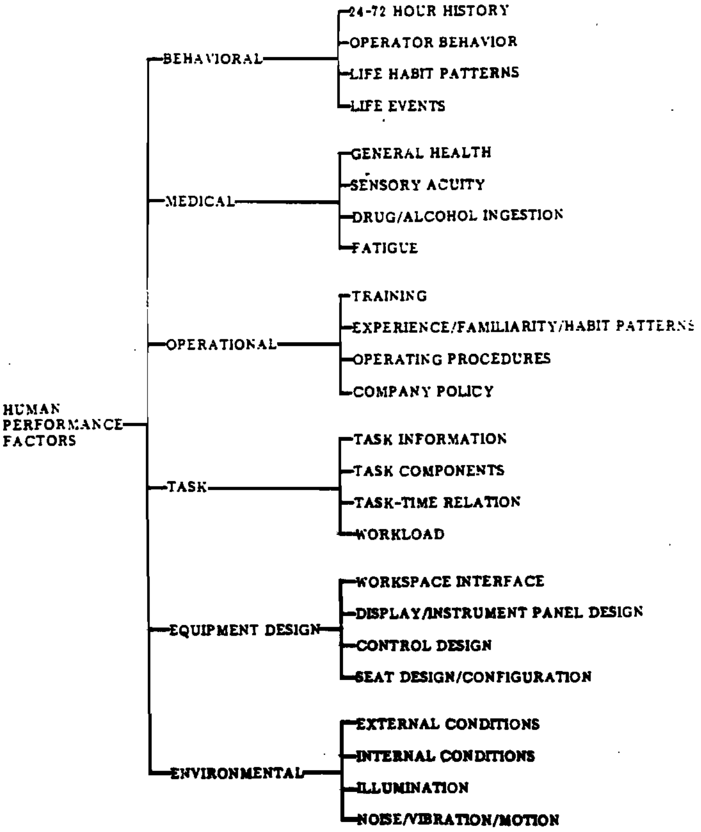


Figure 1

The NTSB Laboratory

The Safety Board operates its own laboratory to provide specialized services and unbiased analyses to accident investiagors, other U.S. Government agencies, and foreign governments upon request.

The Flight Data Recorder Laboratory and the Audio Laboratory retrieve information from flight recorders installed on transport category aircraft involved in accidents or selected incidents. Together, the FDR and the CVR provide a substantive reconstruction of an accident flight.

Any aircraft type certificated after September 30, 1969, that is required to carry an FDR, must be equipped with the expanded-parameter type known as the digital flight data recorder or DFDR (Ref. 8).

After an aircraft accident, the recorders are flown to Washington, D.C., and taken to the NTSB laboratory, where they are examined and read. Readout groups are established for the CVR and the FDR or DFDR. Each of these is headed by an NTSB specialist. Members can include persons from the Federal Aviaton Administration (FAA), the pilots organization(s), the air carrier, the airframe manufacturer, and from other official parties to the investigation, as necessary.

The CVR group has the most sensitive job, since its members make a written transcript of what was said by the flightcrew immediately before final impact. Group members are chosen for familiarity with the crew (for voice identification) and with the particular airplane.

The CVR contains a quarter-inch tape, which cycles repeatedly past the recording heads. As it does so, old sounds are erased and new sounds are recorded. Thus, the recorder retains the last 30 minutes of information. Depending on the quality and intelligibility of the recorded audio, the group may take from 3 days to several weeks to make a timed transcript of the tape.

For every accident, group members painstakingly review each section of the tape. A phrase may be played dozens of times before members agree on what was said. Sometimes, no agreement is reached, and the transcript will record this either as "unintelligible" or "questionable text". As the group listens to the tape, the NTSB specialist can insert, remove, and change various filters. This enables members to hear a section of tape in various ways and decide which combination of filters renders the section most intelligible.

The end product of this effort is a written and timed transcript of the information on the cockpit area microphone channel (including crew conversation, and audio warning device signals) and the radio channels; there are three separate tape tracks for the captain's, copilot's and the flight engineer's radio channels.

Flight data recorders store a time history of the airplane's altitude, airspeed, magnetic heading, vertical acceleration, and crew microphone keying for a minimum period of 25 hours of flight time. In newer aircraft (those type certificated after September 30, 1959), information regarding the position of the flight controls, the amount of engine thrust,and several other parameters crucial to accident investigation is also recorded.

The readout of the FDR or "scratch" recorder must be performed with the aid of an optical microscope. The metal foil recording medium contains engravings of the airplane's altitude and other parameters as a function of time. The metal foil is placed under the microscope and numerical values (X-Y coordinates) are measured from the traces with respect to a selected origin on the foil. These values are fed to the lab's VAX 11/750 computer and are converted to feet of altitude versus time, knots of airspeed versus time, etc.

Numerical values of each parameter from the digital recorder are read directly from the tape into the VAX 11/750 computer (no microscope). The end result of a normal readout is a listing of the data for as much of a given flight or flights as desired (the so-called engineering units printout), as well as a data plot. The group chairman's factual report for an aircraft accident always contains the engineering units printout and a plot. Flight data recorder presentations in Safety Board accident reports are usually in graphical form only.

If circumstances of an accident indicate that aircraft, environmental, or even human performance factors require examination of aircraft performance or engineering simulation, an aircraft performance group is established. An aerospace engineer from the Aircraft Performance Section of the Safety Board's laboratory heads this investigative group. The purpose is to describe and analyze the behavior of an aircraft during the accident sequence and to examine those factors which significantly contributed to any discernible abnormalities.

One of the first things the performance group does is to "correlate" the information from the CVR and the FDR/DFDR. This process involves aligning events in time from the two recorders, and this is done by matching the pilot microphone keying events recorded by the FDR/DRDR with the radio transmission from the airplane as recorded by the CVR (there is no common timing signal on the recordings). Once a match is obtained, the events on the CVR transcript can be appropriately placed on the FDR/DFDR plot to produce a good preliminary sequence of events for the accident. Clock time is obtained from air traffic control tapes. These have a recorded time track, as well as recorded radio transmissions to and from the aircraft (they do *not*, however, contain the very improtant cockpit area microphone information).

Good quality flight recorder information — both voice and data — is essential to the conduct of an aircraft accident investigation. More often than not, FDR/DRDR and CVR data have provided extremely valuable clues to the cause, established the sequence of events in the cockpit and the timing between critical events, and provided the basis for the human performance analysis which, in turn, either uncovers or corroborates the probable cause and contributes to safety recommendations to prevent future accidents.

Human Performance Issues Investigated Using CVR and FDR Data

Pinchneyville, Illinois: On October 11, 1983, Air Illinois Flight 710 was being operated as a regularly scheduled passenger flight between Capital Airport, Springfield, Illinois and Southern Illinois Airport, Carbondale, Illinois. About 2020 central daylight time, Flight 710 departed Springfield with seven passengers and three crewmembers on board. About 1.5 minutes later, Flight 710 called Springfield departure control and reported that it had experienced a slight electrical problem but that it was continuing to its destination about 40 minutes away.

The cockpit voice recorder (CVR) transcript showed that shortly after takeoff Flight 710-s left generator suffered a complete mechanical failure and that in responding to the failure of the left generator, the first officer mistakenly isolated the right generator and the right generator bus bar from the airplance's d.c. electrical distribution system and, thereafter, the right generator disconnected from the right generator bus bar. All subsequent attempts to restore the right generator to the airplane's d.c. electrical distribution system were unsuccessful, and the airplane proceeded toward Carbondale relying solely on its batteries for d.c. electrical power.

The flight toward Carbondale was conducted in instrument meteorological conditions. The cloud bases in the area of the accident were at 2,000 feet m.s.l. with tops at 10,000 feet. Visibility below cloud bases was 1 mile in rain, and there were scattered thunderstorms in the area.

About 2053, while the airplane was descending from its instrument flight rules (IFR) assigned altitude of 3,000 feet, battery power was depleted. Flight 710 continued to descend, turned about 180°, and crashed in a rural area near Pinckneyville, Illinois, about 22 nmi north northwest of the Southern Illinois Airport. The airplane was destroyed by impact forces, and all 10 persons on board the airplane were killed. There was no postcrash fire.

The National Transportation Safety Board determines that the probable cause of the accident was the captain's decision to continue the flight toward the more distant destination airport after the loss of d.c. electrical power from both airplane generators instead of returning to the nearby departure airport. The captain's decision was adversely affected by self-imposed psychological factors which led him to assess inadequately the airplane's battery endurance after the loss of generator power and the magnitude of the risks involved in continuing to the destination airport. Contributing to the accident was the airline management's failure to provide and the FAA's failure to assure an adequate company recurrent flightcrew training program which contributed to the captain's inability to assess properly the battery endurance of the airplane before making the decision to continue, and led to the inability of the captain and the first officer to cope promptly and correctly with the airplane's electrical malfunction (Ref. 9).

The 1983 Air Illinois accident in Pinchneyville is a case in which the CVR provided virtually the only clues to probable cause in the early phases of investigation. The failure in the electrical system caused the DFDR to stop operating in the final minutes of flight. The only relevant information transmitted to air traffic control was at 2021:34, when Flight 710 informed the departure controller that it had experienced a "slight electrical problem", approximately thirty mintues before impact.

The Human Performance investigator, who was not initially sent on scene to the investigation, listened to the CVR recording during the fact gathering phase of investigation. The CVR revealed the following pieces of information:

- By six minutes after the flight departed Capital Airport, the left generator was not functioning and the first officer was unable to restore the functional right generator.
- Although it was after sunset, the captain turned off the navigation and position lights on the airplane.
- With battery power alone, the captain elected to continue to Carbondale when he was 6 minutes from Springfield and 29 mintues from Carbondale (the CVR ran at a continuously reducing speed throughout the entire flight; if generator power had been restored the CVR would have resumed design speed).
- The cew did not follow properly the emergency procedues for failure of both generators in the checklist provided in the Air Illinois Airplane Operating Manual (AOM).

The Human Performance investigation centered around the question, "Why did the pilot continue to Carbondale on battery power alone, when he could have returned to Springfield safely?" The necessary factual information included:

(1) personality/operating style of both crewmembers
(2) training received by both crewmembers
(3) information available to the crewmembers during the flight (i.e., the AOM)
(4) external pressures placed upon the crewmembers
(5) life/habit patterns of the crewmembers, and recent (24-72 hour) history
(6) general and recent health of crewmembers

Friends, roommates, and pilots who had flown with the crewmembers were interviewed to obtain information on the crewmembers' life patterns, recent history and personality and operating style. Air Illinois pilots were asked about pressures placed on pilots to maintain schedules, and about general morale among employees. The Chief Pilot and other pilots were questioned about training given by Air Illinois. The AOM was examined to determine the information available about the electrical system and emergency operation on board the plane. Medical records were examined to determine crewmembers' general health and any medical restrictions. Toxicological reports were examined to determine if crewmembers were under the influence of any drug or alcohol.

The following facts were gathered from these interviews and examinations:

- Two days before the accident, the captain had had 5 hours sleep. The night before the accident, the captain had gotten 10 hours sleep.
- Flight 710 was running 45 minutes behind schedule when it departed Springfield.

- The accident occurred late in the day, and the crew had been on duty almost 10 hours.
- A mechanic and spare parts were not readily available in Springfield.
- A majority of the pilots interviewed stated that the captain ran "a one man operation", and didn't respond well to suggestions from first officers.
- A majority of pilots interviewed stated that the captain was "in a hurry" to make schedules.
- The captain would become angry easily, especially at Air Illinois flight and ground personnel who did not do things according to company, or his own standards.
- Some pilots interviewed said the captain's confidence exceeded his ability, that he hated to stay overnight in Springfield, and overspeeded the airplane, and flew too close to or under thunderstorms to avoid delaying flights.
- Pilots interviewed stated that the company did not exert undue pressure on pilots to make schedules. The company had never questioned or criticized any of the interviewed pilots' decisions to delay or cancel a flight.
- The first officer was very knowledgeable, confident and tactful, and "laid back".
- Air Illinois flightcews had received groundschool training on electrical sytem emergencies which included single and dual generator failures; dual generator failures were simulated on the ground. The pilots flying the HS 748-2A (the accident aircraft) were not in agreement as to the endurance time of the airplane batteries after a dual generator failure.
- The AOM did not provide the endurance time of the airplane batteries in a dual generator failure; it stated only the available battery time was dependent on "the charge state of the batteries and essential loads required for flight conditions."

Based on the information gathered in the human performance investigation, the Safety Board concluded that emergency procedure training provided by Air Illinois was inadequate and that the inadequate training contributed to the captain's imprudent and improper decision to continue to Carbondale. The Safety Board also concluded that the captain's decision to continue to Carbondale was influenced by "self-imposed psychological factors": i.e., "his reluctance to remain overnight in Springfield, his self-imposed determination to adhere to schedule, his demonstrated willingness to assume what he believed to be reasonable risks to adhere to schedule, and, in this case, a misplaced confidence in his knowledge of the airplane and his flying capabilities" (Ref. 9, pg. 54)

The investigation and findings in the Air Illinois accident investigation go far beyond the finding of "pilot error", "improper decision", which might have been the finding without human performance investigation. Human Peformance investigation would not have had a focus had not the CVR provided the basic information from which to expand the factual base of information. The CVR indicated that a problem had been perceived by both crewmembers,that measures had been taken to remedy the problem, that the problem had not been remedied, and that the captain had made the decision to continue. The Human Performance investigation provided the information necessary to explain the crew's inadequate emergency procedures and the captain's improper decision.

Detroit, Michigan: On January 11, 1983, United Airlines Flight 2885, a McDonnell Douglas DC-8-54F, N8053U, was being operated as a regularly scheduled cargo flight from Cleveland, Ohio, to Los Angeles, California, with an enroute stop at Detroit Metropolitan Wayne County Airport at 0152, where cargo for Detroit was unloaded, the airplane was refueled, and cargo for Los Angeles was loaded. At 0249:58, United 2885 called for clearance onto runway 21R and was cleared for takeoff at 0250:03. Visual meteorological conditions prevailed at the time, and the company had filed and been cleared for a standard IFR flight plan.

According to witnesses, the takeoff roll was normal, and the airplane rotated to takeoff attitude one-half to two-thirds of the way down runway 23R. After liftoff, the airplane's pitch attitude steepened abnormally, and it climbed to about 1,000 feet above ground level. The airplane then rolled to the right an descended rapdily to the ground. An explosion and fireball occurred at impact. The airplane was destroyed by impact and by the postimpact fire. The flightcrew, consisting of the captain, the first officer, and the second officer, were killed.

The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's failure to follow procedural checklist requriements and to detect an correct a mistrimmed stabilizer before the airplane became uncontrollable. Contributing to the accident was the captain's allowing the second officer, who was not qualified to act as a pilot, to occupy the seat of the first officer and to conduct the takeoff. (Ref. 10)

Investigators on scene were first alerted that the appropriate crewmembers were not flying the plane by the positions of the bodies found in the wreckage. The second officer was found in a position more likely to be occupied by the first officer (and vice versa). Investigators listened to the CVR for verification that a seat swap had been made. Figure 2 is an excerpt from the CVR transcript, which provided the needed verification.

Excerpt of a Transcript of a Sundstrand V-557 Cockpit Voice Recorder Removed from the United Airlines DC-8 Which Was Involved in an Accident at Detroit, Michigan, on January 11, 1983

Legend

CAM	Cockpit area microphone voice or sound source
-1	Voice identified as Captain
-2	Voice identified as First Officer
-3	Voice identified as Flight Engineer

INTRA-COCKPIT

TIME & SOURCE	CONTENT
0249:16 CAM-1	Are you guys trading?
CAM-2	Do it
CAM-1	Are you guys trading?
CAM-2	Ready
CAM-2	You ready?
CAM-3	Go for it
0249:23 CAM-2	Ready to trade
CAM-3	Oh we're going to trade now?

Figure 2

Human Performance investigation in this case overlapped the Operations Group investigation; a combined Human Performance/Operations Group investigated the following factual details to determine why the crewmembers switched seats, and what the general abilities of the cewmembers were:

(1) company policy with respect to seat-swapping
(2) other crewmember experience with the crew of United Flight 2885 with respect to seat-swapping
(3) the crewmembers' qualifications, experience and operating style
(4) company policy in general with respect to cargo flights, and
(5) recent (24-72 hour) history of the crewmembers.

The investigators interviewed 12 United Airlines flight crewmembers who were familiar with the crew of United 2885. They found that the captain was generous in permitting second officers to fly the airplane. The first officer was described as preoccupied with outside business interest, and he was reported to have volunteered to "work the panel" and allow the second officer to fly on a previous flight. The second officer was described as a competent, professional, conscientous flight engineer.

Examination of personnel records revealed that the second officer had entered DC-8 first officer upgrade training in June, 1979, but his training had been terminated as it was considered doubtful that he could successfully complete the course. The second officer had completed upgrade training for B-737 first officer in March 1980, but after continuing poor performance on check rides, he was removed from line flying. He had again entered special B-737 training in May, 1981, and again received an unsatisfactory proficiency check. Check comments included "basic flaws in scan pattern," "tendency to overcontrol on takeoff and landing," "inconsistency in maneuvers due to getting behind in planning and attitude instrument flying," "slow scan," "excessive control inputs," "attitude could not be better and he is a hard worker, however, he has not made normal progress in his first full (year) as first officer." His command ability is below (average) and has exhibited poor operational judgement both IFR and VFR." In May, 1981, the second officer voluntarily agreed, in writing, to forego bidding any future pilot vacancies on United Airlines and to remain in second officer status for the balance of his flying career.

Most crewmembers interviewed stated that seat swapping occured on a limited basis in freighter or ferry flight operations. There was no evidence that the captain was aware of the second officer's deficiency in flying skills. There was a general consensus among pilots interviewed that there was a greater fatigue factor in cargo versus passenger operations. At the time of departure, the first officer had been active a minimum of approximately 14 hours, and the captain had been active for 19 hours.

On the basis of the factual information gathered in human performance/operations investigation, the Safety Board concluded that the seat swap may have been made because the first officer and captain were fatigued. It also concluded that in the light of the second officer's lack of flying ability, "he may have not been capable of assessing the gravity of the rapidly deteriorating flight conditions on takeoff and might not have been capable of initiating corrective action for the unwanted and unexpected trim. This takeoff was at night and, with the reduced visual cues, required skills such as rapid scan and division of attention — skills at which the second officer was considered to be deficient" (Ref. 10, p. 23)

With regard to the FDR, United Flight 2885 was equipped with a Fairchild model 5424 (foil type) FDR, which became nonfunctional for about 55-60 second beginning approximately 23 seconds after the recorder was turned on, and then became functional again 15 seconds prior to ground impact. Valuable information about the performance of the aircraft at critical periods was lost. To better assess probably aircraft performance, extensive simulation tests were run on a DC-8 simulator at United Airlines Training Center in Denver, Colorado. This is an example of a unique type of human performance investigation, which became necessary because of a *lack* of airplane performance data. Although the human performance group was not formally in existence at the time of this investigation, it represents the type of test and analysis which a human performance participation might be required.

Simulation test revealed that the trim setting indicated by the jackscrews found in the wreckage corresponded with the trim setting which would be common to setting the trim "in the flare" during landing. During interviews with crewmembers, it was reported that the first officer was inconsistent in retrimming after landing, which provided a possible explanation for the trim setting at impact. simulation tests also revealed that the airplane could recover at rotation if immediate nosedown trim were applied along with full forward elevator input. However, once the airplane left the ground and started to accelerate, recovery was improbable. Pilots inexperienced with the DC-8, or lacking in flying skill, would be unable to detect the hazardous situation. The human performance/operations investigation that uncovered the second officer's lack of flying skill supported the simulator findings.

The probable cause of the United 2885 accident was determined with the help of human performance investigative corroboration of the seat-swapping practice, which was verified by data on the CVR. Without the CVR data, the seat swapping could not have been verified, and human performance investigation may not have focused on the prevalence of seat-swapping,and on the possible reasons (i.e., fatigue, generosity of captain) behind the seat swap.

Jamaica, New York: On February 28, 1984, Scandinavian Airlines System Flight 901, a McDonnell Douglas DC-10-30, was a regularly scheduled international passenger flight from Stockholm, Sweden, to New York City, New York, with an en route stop at Oslo. Norway. Following an approach to Runway 4 Right at New York's John F. Kennedy International Airport, the airplane touched down about 4,700 ft (1,440 meters) beyond the threshold of the 8,400-foot (2,560-meter) runway and could not be stopped on the runway. The airplane was steered to the right to avoid the approach light pier at the departure end of the runway and came to rest in Thurston Basin, a tidal waterway located about 600 ft from the departure end of runway 4R. The 163 passengers and 14 crewmembers evacuated the airplane safely, but a few received minor injuries. The nose and lower forward fuselage sections, wing engines, flaps, and leading edge devices were substantially damaged at impact.

The weather was ceiling 200 ft overcast, ¾-mile visibility, with light drizzle and fog. The temperature was 47°F with the wind from 100° at 5 knots. The surface of the runway was wet, but there was no standing water.

The National Transportation Safety Board determines that the probable cause of this accident was the flightcrew's (a) disregard for prescribed procedures for monitoring and controlling of airspeed during the final stages of the approach, (b) decision to continue the landing rather than to execute a missed approach, and (c) over-reliance on the autothrottle speed control system which had a history of recent malfunctions." (Ref. 11)

The investigation of this accident depended heavily upon the onboard recorders. The SAS DC-10 was equipped with a Sundstrand Data Control Model 573 DFDR, a Sundstrand Data Control Model Av-577B CVR, and with an additional recorder that supplemented information from the DFDR, an aircraft integrated data system (AIDS).

Among the recorded parameters were outer marker and middle marker positions, altitude, airspeed, heading, autopilot status, autothrottle status, inertial navigation system (INS) ground speed, thrust reverser position, wheel brake position, and engine fan rotor speed (N1).

Investigators on scene (the human performance investigator did not respond on scene with the go-team) interviewed the crewmembers and found out what their calculated approach and touchdown speeds were. Performance analysis of the DFDR and AIDS data revealed that:

- The airplane crossed the runway threshold about 60 knots faster than the calculated V ııı.
- The airplane touched down on the runway 36 knots above the programmed touchdown speed.
- The airplane touched down about 4,700 ft from the

approach end of the runway, with only 3,700 ft of runway remaining.

- Reverse thrust application reached 90 percent on the Nos. 1 and 3 engines. Reverse thrust on No. 2 engine did not increase past 41%; (No 2 engine N1 showed no increase past 41% from 12 seconds prior to touchdown to the last recorded point.)
- The crew used the autothrottle speed control system (ATSC) throughout the approach for airspeed control.

The CVR revealed that:

- The crew did not follow SAS required airspeed and altitude callout procedures during the ILS approach to JFK. If the airplane was not at the desired approach speed at or below 1,000 ft radio height, the second (nonflying) pilot was required to call out "not stabilized". No callout was made. At or below 500 ft and not at desired speed, the nonflying pilot was required to say "Not stabilized, pull up". No call was made.
- The captain instructed the crew to make a category II approach and set the radio altimeter to category II minimums. Shortly after, the runway visual range increased,and the captain instructed the crew to "go back to normal". (Post-accident examination of the cockpit showed that the radio altimeter bugs were set to the decision height for the category II approach).

Investigators who interviewed the crew found that the airplane had had problems with the ATSC on previous flights, and the crew was aware of the auto-throttle malfunctions. The crew's recollections indicated that neither captain nor copilot were totally aware of the airplane's increasing airspeed during the final approach.

With respect to touchdown location, the captain indicated that a normal touchdown was made at least one-third of the way down the runway; the first officer thought the landing was gentle, and believed the touchdown was halfway down the runway. The systems operator (flight engineer) described touchdown as harder than normal, and thought it had been made within three-eights to halfway down the runway. If the crew had made computations based on the information provided them by the airline, they would have found they needed about 4,200 ft to stop on a wet runway using reverse thrust at normal speed. Inspection of the airport revealed that there were no runway distance markers.

The Human Performance Specialists's participation in this accident investigation consisted of reviewing the CVR, the readout from the AIDS and DFDR, the Operations Group's interviews with crewmembers, and the SAS Training Program for DC-10 aircraft transition. The human performance issues examined were:

- Reliance on automation and failure to monitor performance instruments
- Windshear training
- Crew coordination procedures
- Reverting to previously-learned but inappropriate behavior (habits) during stressful conditions.

The human performance investigator was alerted to the crew's failure to adhere to callout requirements by the CVR. The Board concluded that the airspeed and altitude callouts provide checks and balances between flightcrew members; they would have reinforced each crewmember's perception of the aircraft performance, and enabled each crewmember to better assess each other's situational awareness. As a result of this accident the Safety Board recommended that the FAA:

> Direct air carrier principal operations inspectors to review the airspeed callout procedues of assigned air carriers and, where necessry, to require that these procedures specify the actual speed deviations (in appropriate increments, i.e., +10, +20, -10, -20, etc.) from computed reference speeds. (Class II, Priority Action)(A-84-124) (Ref. 11, p. 50)

In this investigation, the comparison of the data from the DFDR and AIDS, the CVR and the crew interviews provided the critical information that the crew was going faster than they were aware, touched down farther down the runway than they were aware, and did not follow procedures that would have alerted them to these conditions. Based on this information, the human performance specialists examined possible reasons for the crewmember's errors. The conclusion reached were that the crew failed to monitor primary flight instruments and were slow to detect and react to a fault in the auto-throttle system because they over-relied on the automated systems and did not adhere to procedures. Possible training deficiencies were suggested, in the areas of wind-shear compensation, judgement of stopping distances, maximum braking procedures and thrust reversing procedures.

Conclusion

Data from CVRs and FDR/DFDRs have, for over 20 years, has been important, and in many cases critical, in determining probable causes of, and contributing factors to, aircraft accidents. Human performance investigation is not entirely new; the human performance factor in 60-85% of all aircraft accidents has long been an accepted statistic. The Safety Board's, and for that matter, the entire airplane industry's, emphasis on human performance investigation has caused more in-depth investiation of the factors underlying pilot (and other human) error. The Safety Board's Human Performance Division has developed a method for investigating human performance factors, and it regularly makes use of CVR and FDR data. As the Human Performance Division's methods continue to evolve, it will continue to use the recorded information, perhaps more effectively. In the future, it is quite probable that human performance specialists will have input into recommendations for broadened use of CVR and FDR's in air carrier, commuter, and in multi-engine, turbine powered general aviation and corporate airplanes, and in recommending additional or modified data items to be recorded.

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Phyllis Kayten, Ph.D.
Human Performance Investigator
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Phyllis Kayten joined the National Transportation Safety Board in November, 1983, as Human Performance Investigator in the newly formed Human Performance Division of the Bureau of Technology. Since joining the Safety Board, she has investigated on scene the human performance aspects of accidents in all modes of transportation, including major railroad collisions in Minnesota and Colorado (both Burlington Northern Railroad), fatal schoolbus-truck and schoolbus-train collisions in Florida and Montana, pleasure boat sinking in New Mexico, and runway incursions in Minneapolis (MSP) and Chicago (Midway) airports. She has participated in the human performance investigation of the Galaxy Airlines crash in Reno, Nevada, still under investigation by the Safety Board. Presently, she is serving as Human Performance Group Chairman of the Safety Board's Special Investigation of Runway Incursions.

Before joining the board, she was a program director with Ship Analytics, in Centerport, New York, and North /Stonington, Connecticut, where she conducted simulator training research and designed training curricula for cadets at the US Merchant Marine Academy in Kings Point, New York, and for deck officers of major oil companies, including EXXON and MOBIL. Also while t Ship Analytics, she designed the users manuals and user interface for a full bridge shiphandling simulator for the Marine Engineers Benevolent Association in Toledo, Ohio.

Phyllis received her B.A. from Brandeis University in 1972, and her Ph.D. in psychology in 1978 from the State University of New York, Stony Brook. She is a member of the Human Factors Society, American Psychological Association, American Society for Training and Development, and the Society for Naval Architects and Marine Engineers.

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Carol Roberts assumed duties as Chief of the Laboratory Services Division, National Transportation Safety Board, on October 1, 1979. She joined the Laboratory Services Division in July of 1972 as an Electronic Engineer, serving as an aircraft accident investigator in the Flight Data and Cockpit Voice Recorder Laboratories. She received an award for special achievement for her work in establishing and setting up the Safety Board's Digital Recorder Laboratory.

She served as the U.S. representative to the International Civil Aviation Organization's Flight Recoder Study Group, is a member of the Society of Automotive Engineers' Subcommittee on Small, Lightweight Flight Recorders, and headed two Safety Board task forces on computing systems.

She was the Safety Board's Flight Data Recorder Group Chairman for every major wide-bodied jet accident (worldwide) which ocurred between December 1972 (Eastern Flight 401 in the Florida Everglades near Miami) and May 1979 (American Flight 191 at Chicago). She has appeared on network television, including ABCT's *Nightline,* and has done interviews for newspapers and magazines, including the *New York Times* and *OMNI Magazine.*

Prior to joining the Safety Board, Carol was employed by the Harry Diamond Laboratories and the U.S. Naval Research Laboratory, both in Washington, D.C.

She is a registered Professional Engineer in Washington, D.C., and received the BEE (Summa cum Laude), MEE, and Ph.D degrees in Electrical Engineering from the School of Engineering, Catholic University of America, Washington, D.C.

She is a member of the associate teaching staff of the Department of Transportation's Transportation Safety Institute of Oklahoma City, Oklahoma, and a member of the Board of Visitors of the School of Engineering and Architecture, Catholic University of America.

She is married to John P. Roberts, a Process Licensing Engineer for the U.S. Nuclear Regulatory Commission. Both are pilots (Carol holds an Instrument Rating and a Commercial License). They both have had a brief fling at hang gliding; they enjoy flying, traveling, reading, and various forms of polka dancing. Carol thoroughly enjoys Italian opera, John suffers through. She is a member of a number of aviation and engineering associations, including the Institute of Electrical and Electronics Engineers (IEEE), the IEEE Computer Society, Tau Beta Pi, Sigma Xi, and the Society of Automotive Engineers. She is currently Vice Chairman of the Laura Taber Barbour Air Safety Award Board of the Flight Safety Foundation. She was president of the Washington, D.C. chapter of the International Society of Air Safety Investigators from 1977-1979, secretary/treasurer from 1975-1977, a member of the International Council from 1976-1978 and a staff member of *FORUM* from 1975-1978.

A Combination Flight Data Recorder/Cockput Voice Recorder For Both Civilian and Military Aircraft

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Abstract

During the 1978 to 1984 timeframe, two United States Navy (USN) prototype solid state combination Flight Data Recorder/Cockpit Voice Recorder (FDR/CVR) systems were developed, tested, and evaluated (DT&E) for military aircraft. Currently, there are four solid state FDR systems in full scale development (FSD) planned for the F-16, B-1B, T-46A, UH-60A, HV-22, E-6A and F/A-18 aircraft. Between 1980 and 1985, coordinated civilian and military standards (AS 8930 and MIL-STD-2124) for separate and combination FDR/CVR systems were developed. This paper describes a cost effective, combination, nonvolatile, solid state FDR/CVR that meets the minimum requirements of both civilian and military standards. The FDR/CVR system will utilize commercial high density Metal Nitride Oxide Semiconductor (MNOS) and low data rate audio Linear Predictive Coding (LPC) technology. The FDR/CVR system will be proposed as a joint civilian (FAA) military (USN) DT&E project in FY86.

Introduction

Flight Data Recorders (FDR) and Cockpit Voice Recorders (CVR) required by the Federal Aviation Agency (FAA) have been in operation aboard civilian air carrier (Part 121) aircraft for about 25 years. The FDRs store analog or digital data (about six parameters) on metal foil or wire or magnetic tape for periods up to 25 hours wrap-around. The CVRs store analog audio from the cockpit, including radio communcations, intercommunications, and area microphones, for about 30 minutes wrap-around. The newer digital magnetic tape FDRs are capable of storing 50 to 100 parameters. Air carrier FDRs and CVRs are crash-hardened for nondeployable operation, weigh about 30 pounds each and occupy a volume of about 1600 cubic inches. They also have an underwater pinger-locator attached. FDRs and CVRs have not been required by the Department of Defense (DOD) to operate aboard military aircraft until recently. The services (Army, Navy, Air Force, Marine Corps and Coast Guard) have had quasi requirements for FDRs and CVRs, primarily for multiengine fixed wing aircraft. Thus, only a small percentage of military aircraft have been equipped with FDRs and even fewer with CVRs. The U.S. Navy led the way in 1965 with the installation of a deployable, survivable, combination FDR/CVR in its E-2A and C-2A aircraft, followed by installations in P-3B and Marine Corps RC-130 aircraft.

This FDR/CVR system has been used by the U.S. and foreign military air forces for approximately 20 years. The military magnetic tape combination FDR/CVR stores 26 digital aircraft parameters and two analog channels of cockpit audio, including radio communications, intercommunications, and area microphone, for 30 minutes wrap-around. The deployable package, which includes the FDR/CVR and a battery powered, single frequency (243 MH*z*) Emergency Locator Transmitter (ELT) housed in a fiberglass covered polyurethane airfoil, weighs between 10 and 35 pounds and occupies a volume of 1200 to 1800 cubic inches depending on the aircraft installation configuration. It is deployed from the aircraft by either electromechanical or electropyrotechnic release mechanisms triggered by frangible and hydrostatic switches upon crash. Upon deployment, FDF/CVR is survivable over land, floats in water and the ELT automatically transmits an emergency UHF signal for 48 hours.

In 1978 the USN developed and built the first prototype solid state combination FDR/CVR using two million bits (Mbits) of 8Kbit Block Organized Random Assess Memory/Metal Nitride Oxide Semiconductor (BORAM/MNOS) devices. The BORAM/-MNOS chips were the first production nonvolatile memory devices developed jointly by the USN and U.S. Army. This Solid State Flight Data Recorder (SSFDR) stores 175 digital aircraft parameters in 500 Kbits of memory for 30 minutes wrap-around and digital cockpit audio radio communications and intercommunications in 1.5 Mbits of memory for 2.5 minutes continuous or 5 minutes compressed (silence edited) wrap-around. A Continuous Variable Slope Delta Modulation (CVSDM) audio digitizer was used operating of 12 Kilobits per second (Kbits) to get maximum data storage in the allocated memory (1.5 Mbits) and acceptable audio intelligibility. This prototype SSFDR was designed to the 60 cubic inch volume of the deployable magnetic tape FDR/CVR for resting within an existing deployable airfoil package. Successful flight test and evaluation (T&E) was conducted on the 2 Mbit SSFDR in a USN P-3B in December 1979. Details of this DT&E program are published in reference 1.

A second prototype SSFDR was developed and tested by the USN between 1980 and 1984 using 6 Mbits of enhanced 8 Kbit BORAM/MNOS devices. This unit provided the same digital aircraft parameter storage capacity as the 2 Mbit SSFDR, but increased the audio storage capacity to 5.5 Mbits. This, with the 12 Kbps DVSDM, 15 minutes of compressed (silence edited) audio was stored, as required by the military. The 6 Mbit SSFDR was designed for optimum memory packaging density using six one Mbit printed circuit boards (pcb) and one control pcb. This unit was subjected to design environmental qualification testing and survivability testing, which established the test criteria specified in AS 8039 (reference 4). AS 8039 is currently being adopted by the FAA under a proposed Technical Standard Order (TSO-C111).

The military (DOD) is the only organization, to date, utilizing the SSFDR. The USAF will be the first with its Standard Flight Data Recorder (SFDR) on its F-16 fighter aircraft. The SFDR is a crash hardened, nondeployable FDR (no audio) which records about 60 aircraft perameters in 500 Kbits of Electrically Erasable Programable Read Only Memory (EEPROM) MNOS For 15 mintues wrap-around. The SFDR Signal Acquisition Unit (SAU) contains auxiliary memory for maintenance, fatigue, and other monitoring, which makes it an extremely compact and sophisticated Aircraft Integrated Data System (AIDS) (see figure 1). Reference 2 contains a good listing of all deployable and nondeployable FDRs and CVRs, CPLs and ELTs used on both military and civilian aircraft as of early 1983. The USAF SFDR is currently in Full Scale Development, which similar systems for the USN F/A-18, the USA UH-60A helicopter and the USCG helicopters are still in the planning stage.

Two military standards and one civilian standard for the SSFDR have evolved from these prototype development, test and evaluation programs. Two of these, MIL-STD-2124 (reference 3) and AS 8039 (reference 4) were coordinated and developed concurrently.

The Problem With Solid State CVRs

Although the USN prototype SSFDRs both contain cockpit audio recoding capability,none of the current military programs (on going or planned) have chosen to include audio recording. There are several reasons for this. First, the DOD does not have a firm requirement for cockpit audio recording, particularly for single seat fighter/attack aircraft. Secondly, solid state audio recording, using the CVSDM digitizer and relatively low density (8 Kbit) MNOS memory devices, have made it not cost effective. For example, with a 12 Kbps CVSDM, 5.5 Mbits of nonvolatile memory are required to record 7.5 minutes of continuous audio. The minimum audio recording time required by AS 8039 is 15 minutes wrap-around. Thus, to record 15 minutes of continuous audio (no compression) using a 12 Kbps DVSDM, would require 11 Mbits of memory, which is considered cost prohibitive. The third reason for the DOD not implementing CVR audio is subtle and subjective. There is a significant number of aviators or pilots who do not want their radio and intercommunication audio to be recorded. Although it is difficult to identify this group of pilots within the military, it is felt that their numbers are significant and influential on the CVR acquisition decision process. The first obstruction to CVR audio recording can be and has been overcome to some extent by establishing DOD and military operational requirements and specifications. The second obstacle is purely and simply technical and the prime thrust of this paper. The third obstacle can only be resolved by pilot training, understanding and experience.

Memory Technology

The nonvolatile data storage memory medium in current SSFDRs is EEPROM. The list of available nonvolatile memory technologies contains more than EEPROM, but the proposed appraoch offers the optimal cost/performance ratio. The extremely high bit density required in the SSFDR (not to mention the cost) precludes the use of the more traditional wired core memory. Battery back-up has an inherent maintenance penalty and bubble memory has performance limitations at the operational and storage temperature extremes over which the data must survive.

The individual EEPROM devices are 64K (65,536) bits in capacity organized as 8K (8192) x 8 bits. Several vendors are currently shipping military temperature range as well as MIL-STD-883 Level B screened parts. Although there is a good deal of commonality between parts of equal density from different vendors, with rare exceptions no two vendors' 64K devices are totally interchangeable. The reason for this apparent unwillingness to standardize on basic control functions and pin assignment can probably be attributed to the ambition of individual memory suppliers to capture sufficient market share to become the de facto standard. The SSFDR design overcomes this situation by having the ability to adapt, if necessary, to a change in EEPROM vendor without alteration of hardware. Of the EEPROM devices currently available, three technologies have emerged as the most prominent. These technologies are the Complementary Metal Oxide Semiconductor (CMOS), the N-channel Metal Oxide Semiconductor (NMOS), and the Silicon Nitride Oxide Semiconductor (SNOS).

Both the CMOS and NMOS processes are mature in terms of their process development and their application. Each is widely used in the industry to implement everything from simple logic elements to extremely complicated system functions. SNOS, on the other hand, is employed almost exclusively in the fabrication of nonvolatile memory devices. The important feature, which differentiates these three processes, is the charge storage mechanism. The mechanism eployed in the CMOS and NMOS technologies is essentially the same and they are referred to as Floating Gate devices. The term "Floating Gate" refers to that part of the memory cell where the actual electrical charge is stored. The SNOS technology differs in that the stored charge is trapped in a layer of insulating nitride. At the functional level, the single most important difference between these technologies is the fact that the SNOS yields a nonvolatile memory cell that has an erase/write cycle endurance limit, which is inversely proportional to data retention time. There is also a relationship between retention time of the stored data and the duration of the programming pulse that was used to store it. In application terms, this offers a means of trading off retention for endurance while lowering the programming time.

The other (CMOS and NMOS) processes offer endurance and retention limits, which are fixed and independent. A breakdown of EEPROM devices and their associated performance features is shown in table 1.

Non-Volatile Memory Technology Comparison Table

ACRONYM/ COMMON NAME	FULL NAME	ENDURANCE (E) VS RETENTION (R)	DEVICE DENSITY AND ORGANIZATION	OPERATING VOLTAGES	CYCLE TIME (approximate)	I/O and ADDRESS	POWER DISSIPATION (max.)	VENDORS	OUTLOOK
MNOS [illegible]	METAL NITRIDE OXIDE SEMICONDUCTOR BLOCK ORGANIZED Random	$R = \frac{10^{12}\ \text{hrs}}{E}$ e.g. R=1 yr@E-10	32 K bit/device 1024 X 32 bits	+12 to +15v -18 to -20v 0v	Tr= 300 µs/word Tw= 100 µs/word Te= 200 µs/word or 1 ms/device where Tr= read time Tw= write time Te= erase time	serial/mux'd address serial data	400 mw active 30 mw stby	WESTINGHOUSE SPERRY [illegible]	planned in early '90's custom/captive applications
SNOS	Silicon Nitride Oxide Semiconductor	$R = \frac{10^{8}\ \text{hrs}}{E}$ e.g. R=1 yr@ E-10	64 K bit/device byte wide various page sizes	+5v 0v	Tr= 300ns/byte Tw= 1µs/byte Te= 10ms/byte or 100ms/device	parallel address and data	300 mw active 150 mw stby	NCR GI [illegible]	evolved from MNOS above only other technology, with demonstrated R/E relationship
NMOS	N-channel Metal Oxide Semiconductor Floating gate	R= 10^5 hrs E= 10^4 cycles	64 K bit/device byte wide various page sizes	+5v -0v	Tr= 300 ns/byte Tw= 1µs/byte Te= 1µs/byte or 10 ms/device	parallel address and data	900 mw active 250 mw stby	Xicor Seeq AMD	evolved from EPROM technology, currently enjoys largest market share
NMOS	same as above with oxynitride tunneling dielectric	R= 10^5 hrs E= 10^6 cycles	16 K bit/device byte wide	+5v 0v	Tr= 300 ns/byte Tw= 5 ms/byte Te= 5 ms/byte or 10 ms/device	parallel address and data	500 mw active 250 mw stby	Seeq	most recent development
CMOS	Complementary Metal Oxide Semiconductor	R= 10^5 hrs E=10^4 cycles	64 K bit/device byte wide various page sizes	+5v 0v	Tr= 300 ns/byte Tw= 1µs/byte Te= 1µs/byte or 1 ms/device	parallel address and data	5 mw active 0.1mw stby	Hughes [illegible]	

Table 1 - Memory Comparison Table

A reasonable requirement for the nonvolatile memory medium in the SSFDR is that it have an endurance of 5 million erase/write cycles and a minimum data retention period of 6 months. The typical Floating Gate EEPROM offers a minimum of 10 years data retention and an endurance cycle limit of only 4 million. The nitride parts offer a similar retention capability at the 4 million endurance rating but the relationship between endurance and retention may be exploited to optimize them for the high endurance required for the SSFDR. There has been a recent flurry of activity among Floating Gate vendors to provide parts with the endurance exended by one or even two orders of magnitude. If this performance can be reliably and economically achieved, there will be an even wider range of nonvolatile memory suppliers, which will serve to enhance the long term stability of the SSFDR Memory design.

Audio Digitization and Storage

The amount of information necessary to describe an analog signal is strongly dependent on the frequency range of that signal (bandwidth) and on the faithfulness of the reproduction. The greater the bandwidth, the more frequently the signal must be sampled and the more accurate the reconstruction, the greater the range of sampled values. In the digital environment, these factors have a direct impact on the amount of digital data generated and stored for a given signal. Most, if not all of the aircraft sensor parameters being recorded by the FDR have low bandwidth requirements and a typical resolution of 10-12 bits, resulting in a per parameter data rate in the order of 10 to 100 bits per second. An audio signal recorded in a similar manner would generate 1,000 times as much data, principally as a result of the much larger bandwidth of the audio signal, typically varying from 350 to 5000 Hz.

Considerable work has been done in the area of audio processing and several alternatives for this analog to digital conversion exist. These alternatives cover the range from high quality, high bit rate conversion to synthetic, low bit rate systems. A comparison of the various conversion types, bit rates and relative quality is shown in table 2.

Quality	Typical Algorithms	Bit Rate (KBPS)	Complexity of Implementation
Commentary	PCM, APCM, DM, ADM	64	low/meduim
Toll	All of the above plus CVSDM	16-64 12-16	low/meduim
Communication	LPC - voice excited LPC - residual excited APC, ATC	4.8-16	medium/high
Synthetic	Formant coding Phoneme coding Pattern matching LPC-vector quantizer	0.1-4.8	high

Table 2 - Speech Digitization Technique

In general, the technique used to provide commentary and toll quality reproduction can be classified as waveform coding. The acoustic waveform is sampled, digitized and reproduced just as it occurred. The resulting sound has a natural quality because all energy within the set passband, vocal and non-vocal in origin, will be captured. Waveform coders are limited in their efficiency (quantity of digital data resulting from the A to D conversion) by the sampling theorem. This theorem proposes that a continuous analog signal can be represented digitally by sampling at a frequency, which is not less than twice the highest frequency in the sampled signal. Hence a signal of 3 KHz in bandwidth would be digitized into n-bit samples at a rate of not less than 6 KHz, and the data rate would be approximately n x 6 x 3,000,000 bits per second. The practical lower limit of waveform encoding is achieved using a single bit (n=1) sampling technique known as delta modulation (DM). Optimizing this technique into CVSDM results in near toll quality results with sampling rates as low as 12 Kbps.

The other major type of analog to digital conversion is referred to as vocoding (contraction of voice-coding). This class of hardware is generally associated with communication and synthetic quality voice applications, where the accuracy of reproduction is less important than the low digital data rate. The vocoder is dedicated the the reduction of human speech into its least redundant component parts.

There are many different vocoding techniques available but the most promising, and hence widely used, is known as Linear Predictive Coding (LPC).

A key point about the vocoder, especially in a cockpit voice recorder application, is that all sounds are interpreted as though they were spoken sound even if the sound is not human speech. It is only the acoustic energy that has been produced by the human vocal tract that can be accurately reproduced. The early implementations of LPC vocoding reproduced a voice that was quite unnatural, almost robotic in quality. Since that time the structure of human speech has been the focus of considerable study and this theory has been applied to LPC vocoding hardware. It would not be unreasonable to expect that this technique will soon be capable of capturing and reproducing the natural, inflected speech demanded of a cockpit voice recorder.

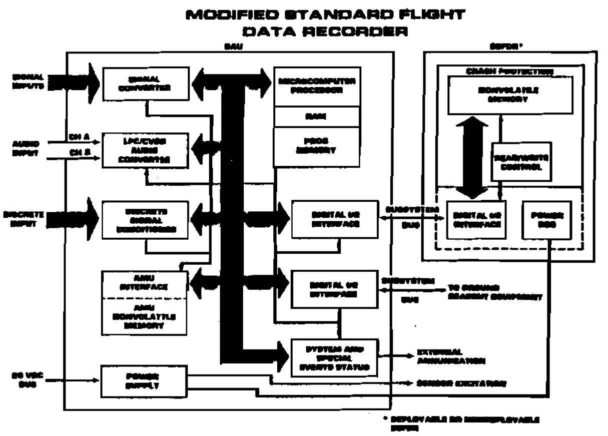

Figure 1

The relatively small amount of data generated by the vocoder is the result of intense mathematical computation on the digitized signal. The digital signal processing hardware, which makes this activity possible in real time, has recently become available in a sufficiently compact and low power configuration to make it usable in an avionics environment.

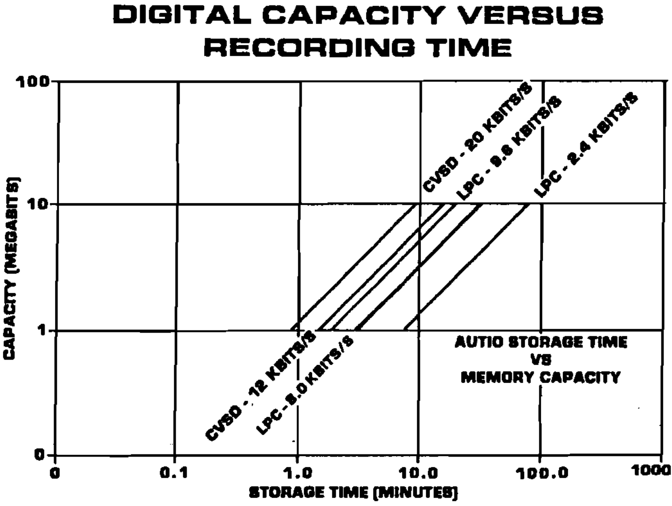

Figure 2

A graph illustrating the relationship between the recording bit rate of various digitization schemes, the digital capacity of the recorder and the recording time is illustrated in figure 2. Typical values for these relationships are shown in table 3 for different quantities of available memory. This data can be used to determine system performance objectives for the cockpit voice recorder. Further information about the relative cost, complexity and versatility of waveform and voice coders is included in table 4.

At the present time, government and industry are actively investigating LPC vocoding with a view to its application in cockpit voice recorders. The reduction in memory for recording a specific time of voice can be up to 80%. The primary trade-offs are in quality of speech and the recording of non-voice cockpit area

MEMEORY AVIALABLE FOR AUDIO (Mbits)	Audio Time (approx.)	
	Cockpit Area 16 KBPS CVSDM	Aircrew Voice 2.4 KBPS LPC
2	1 minute	7 minute
	2 minute	0 minute
4	2 min.	14 min.
	4 min.	0 min.
6	3 min.	21 min.
	4 min.	14 min.
	5 mni.	7 min.
	6 min.	0 min.
8	4 min.	28 min.
	5 min.	21 min.
	6 min.	14 min.
	8 min.	0 min.
10	5 min.	35 min.
	6 min.	28 min.
	8 min.	14 min.
	10 min.	0 min.

Table 3 - Example Audio time apportionment vs memory available

Recording Technique	Complexity	Implementation Cost	Maintenance Cost	Reliability	Versatility
Analog (Tape)	low	low	high	low	lowest
Waveform	medium	medium	lowest	highest	greatest
Vocoder	high	high	low	high	fair

Table 4 - Relative Comparision of Recording Technique

sounds. Waveform coding is presently being used by industry, but is handicapped by the comparatively high data rate and hence large amounts of memory required. Memory density is predicted to quadruple by 1987 and double again by 1989. At these new higher densities, waveform encoding may become the most economically viable technique, but until that time vocoding techniques such as LPC will continue to be evaluated.

The Naval Research Laboratory (NRL) has been most active in the development of LPC algorithms. The first was a 2.4 Kbps and a 9.6 Kbps algorithm documented in reference 5. These algorithms have been implemented in hardware by several electronic firms and laboratories. NRL developed a special 8 Kbps LPC algorithm (reference 6) for the SSFDR/CVR, which is currently being incorporated into a military systems specification. The NRL 2.4 Kbps LPC is now covered by a Federal Standard (reference 7) used for telecommunications.

Audio Intellegibility

As previously mentioned, close attention should be and is paid to the qulaity of audio recorded in a CVR. A system that produces poor or noisy audio on read-out is difficult, if not impossible, to use for aircraft mishap/crash analysis. Many military and civilian CVRs have been found in this condition. Although the military and the National Transportation Safety Board (NTSB) crash analysis laboratories are equipped to do extraordinary things to reconstruct audio on magnetic tape, valuale data is frequently lost from CVRs due to poor quality. Poor recording quality can be caused by several factors. First, the input quality at the microphone may not be good. The speaker's voice may be stressed or not close to the microphone. The microphones may not be of the newer, more effective type, such as the dynamic noise canceling or electret type. Also, there is probably background noise in the cockpit that tends to degrade voice recording intelligibility. Secondly, noise that degrades or obstructs voice intelligibility such as 60Hz and 400 Hz, is, many times, induced into the aircraft intercommunication and radio systems. Last, but not least, the recording quality of the CVR may not be adequate. There are many things that can cause poor magnetic tape CVR operation, such as tape quality, erratic tracking speed, distortion, noise, wow and flutter. Also the moving mechanical parts in magnetic tape CVRs are susceptible to extreme environmental conditions such as acceleration, shock, vibration, temperature and humidity.

Solid state digital audio recording eliminates or reduces many of the conditions that adversely affect magnetic type CVR quality. First, no CVR can eliminate poor audio input. This must be accompished by the speaker using a good quality microphone. Secondly 60 Hz, 400 Hz and other avionics noises can and have been eliminated by analog noise filtering and other techniques prior to digitization. It is from this point on that solid stae CVRs (SSCVR) exhibit a decided improvement in audio quality over magnetic tape. The digitized data is stored in the nonvolatile memory chips, which have no moving parts and are extremely impervious to environmental conditions. SSCVR reliability is predicted to be five times greater than magnetic tape CVRs and survivability is ten times greater than magentic tape CVRs. Testing on the prototype SSCVRs is beginning to confirm these numbers.

The SAE A-4 Subcommittee, on which the USN participated, attempted in AS 8039, section 5.3, to specify audio quality by controlling frequency response, distortion, noise level, wow and flutter. These control parameters are applicable to analog magnetic tape CVRs only. They are meaningless when applied to SSCVR systems. At that time the A-4 Subcommittee had no other way of measuring audio quality. Subsequently the USN developed hardware and software systems that allow generic measurement of recoded digital and recorded analog audio. These tests can be specified as follows:

"Intellegibility requirements for aircraft CVR audio channel recording shall be equivalent to 97% intelligibility of a phonetically balanced word list using consonant-vowel-consonant nonsense words. The intelligibility performance of the CVR shall be measured with all systems installed in the aircraft and accompanied by ambient noise representative of normal flight conditions. The test method used can be any of the following with preference on the Speech Transmission Index (STI):

Articulation Index — ANSI S3.5-1969
Phoentically Balanced World Testing — ANSI S3.2
Speech Tranmission Index – International Standard pending)."

It is anticipated that this or similar wording will be incorporated into the next revision to AS 8039 and MIL-STD-2124.

The SSFDR/CVR System Design

The USN is in the process of conducting a system design analysis and economic (cost— analysis for a combination military/civilian SSFDR/CVR. The USAF SFDR and MIL-STD-2124 will be used as the baseline for the military SSFDR/CVR, and AS 8039 will be used as the baseline for the civilian SSFDR/CVR. Figure 1 shows the SFDR modified to include SSCVR capability. Figure 3 shows another system approach using both CVSDM and LPC for audio recording. This design would provide one channel CVSDN area cockpit recording for approximately two mintue wrap-around and two channels LPC radio and intercommunications recording for 15 to 30 minutes wrap-around.

The USN analyses will identify the functional, physical, environmental and test differences between the military and civilian SSFDR/CVR. These differences are evident upon examination of existing civilian and military specifications. The economic (cost) analysis will establish a minimum cost (nonrecurring and recurring)

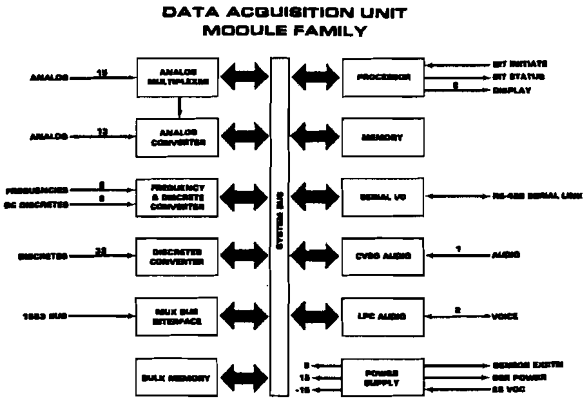

Figure 3

for both military and civilian systems. High cost requirements, component and testing will be identified, with recommended cost reduction areas indicated. These analyses are expected to be complete in October 1985.

Upon completion of the USN analyses and development of a system design specification, one or more prototype SSFDR/CVR units will be procured under a proposed joint USN/FAA program. These prototype systems would be subject to functional, environmental, operational and survivability testing by the USN and FAA. The generic military/civilian SSFDR/CVR design would then be available for multi-source competitive production procurement by the military, aircraft manufacturers and air carriers.

Conclusions

The following conclusions are summarized from the above detailed discussions:

a) Prototype combination Solid State Flight Data Recorders/-Cockpit Voice Recorders (SSFDR/CVR) have been successfully developed, tested and evaluated for use on military aircraft.

b) Although SSFDRs are in full scale development for military aircraft, SSCVRs are not presently included due primarily to the high bit capacity/cost required for digital audio recording using 12 to 16 Kbps CVSDM digital coder/decoder devices and 8 Kbit MNOS nonvolatile memory devices.

c) A reasonably low cost, reliable combination SSFDR/CVR is required and needed for both military and civilian aircraft.

d) The FAA and USN have proposed a joint DT&E program to develop an ADM prototype combination SSFDR/CVR to the minimum requirements of AS 8039, with provisions to include the military requirements of MIL-STD-2124.

e) The EEPROM is the current state-of-the-art high density nonvolatile MNOS device most suited for the SSFDR/CVR.

f) The LPC audio digitizer provides the lowest usable digitizing rate and best audio quality suitable for voice recording.

g) The USN is conducting analyses to develop a SSFDR/CVR system design specification and an economic (cost) analysis. The USN proposed SSFDR/CVR system design is based on the USAF F-16 Standard Flight Data Recorder modified to accept high density, 64 Kbit EEPROM/MNOS nonvolatile memory and using a 2.4 to 8.0 Kbps LPC audio digitizer cockpit voice recording and a 12 to 16 Kbps CVSDM for cockpit area microphone recording. This system will also provide as an option auxiliary EEPROM/MNOS memory for AIDS maintenance/fatigue monitoring.

h) The USN has developed a specification for testing and measuring audio intelligibility recorded into and played back from either a magnetic tape CVR or a SSCVR.

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The Anatomy and Pathology of an Aircraft Accident Lawsuit

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I. Introduction:

It is not unusual for an aircraft accident to end in civil tort action. In cases of death or injury incurred from the accident the forensic pathologist often will have to testify to not only the cause and manner of death but also mechanisms of injury or depth and the interpretations of the patterns of injury. In the accident we wish to discuss a single wing light aircraft, Beechcraft Baron, crashed into a remote desert area west of Tucson, Arizona, in early December 1983 killing the pilot and passenger. About a month-and-a-half later in January 1984, a newspaper reporter attempted to obtain copies of the autopsy report through a medicolegal investigator, and when the office refused to give out a copy, he attempted to obtain it through the medical examiner by subterfuge. No reason for the newspaper's need for the autopsy was given. Eventually a lawsuit was filed against the Medical Exmainer of Pima County and the Office of the Medical Examiner (OME). The statement was made by a representative of the newspaper that the *Arizona Daily Star*, as guardian of the public interest, was going to determine if the Office of the Medical Examiner (OME) was doing a proper job.

II. Circumstances of the Accident:

On December 11,1983, at approximately 3:00 p.m., a certified flight instructor, along with a student, departed Ryan Airfield located near Tucson, Arizona, in a Beechcraft Baron aircraft. The purpose of the trip was to instruct the student in the operation of a twin engine aircraft.

The aircraft was reported missing when it failed to return to the airfield. The crashed aircraft was found at 7:10 a.m. on December 12, 1983. The aircraft crash site was approximately four miles north and seven miles west of the airfield where the flight had originated.

The instructor was found still strapped in the right front seat and pinned in the fuselage wreckage. The student, who was also still strapped in the aircraft, was found in the left front seat of the aircraft. The aircraft was overturned and had extensive damage. Reconstruction experts from the FAA and the Sheriff's Department determined that the aircraft appeared to approach the ground with both engines operative and with the landing gear lowered. They also determined that the craft touched down once and then became airborne again. When the craft touched down the second time, the right wing hit the ground and the aircraft overturned, skidding in an upside-down postiion for several hundred feet, then came to rest in the same upside-down position.

III. Allegations:

Several weeks after the crash, allegations were raised by investigative reporters for the *Arizona Daily Star* that the dead instructor was an agent of the CIA, who had been a potential witness in a trial involving the murder of an Arizona Department of Public Safety narcotics officer who had been shot during an undercover narcotic operation in 1979 by a person named Genaro Celaya. Allegedly, information was developed by the reporters that linked the instuctor to Genaro Celaya. Celaya, the source of the reporters' information, claimed that he had been set up for a "hit" by the CIA. The deceased narcotics agent, John Walker, was supposed to carry out the hit, according to Celaya. Also claimed by Celaya was that Agent Walker, on the very day of the shooting, had been contacted by a CIA agent who wanted Celaya killed. Celaya claimed that the instructor pilot could have provided corroborative testimony for Celaya. Supposedly the pilot, if he were to testify, would link Celaya to a law enforcement officer who initially had introduced Celaya to a DEA agent, who used Celaya as an informant on narcotics trafficking. This same DEA agent had, in fact, been an agent for the CIA prior to becoming a DEA agent. This agent had previously testified that he ceased working for the CIA In 1975. It should be noted that in 1981 Genaro Celaya had been put on trial and convicted of the officer's murder, and there had been no allegations of a CIA operation or a CIA killing during that trial. These claims were being made for the first time in 1983 after the Arizona Suprene Court reversed the 1981 conviction on unrelated grounds. As the date of the retrial of the case approached, Celaya claimed that the instructor was killed by the CIA in order to prevent him from coming forth and testifying at the new trial. It was pointed out to several potential witnesses by the "investigative reporters" that photographs they possessed of the aircraft crash indicated the absence of blood in the cockpit. This fact, they claimed, substantiated their belief that the instructor and the student were murdered by the CIA, that the aircraft crash was staged, and they were then placed in the aircraft in the positions they were found. Photographs of the aircraft crash scene had been furnished by the County Sheriff to the reporters in an attempt to quell this bizarre conspiracy plot alleged by the reporters.

Celaya further alleged that the reason he was to have been killed was that the DEA agent was in reality still a CIA agent and that Celaya had been asked to spy on high-ranking Mexican political figures and report back to the "CIA" agent any infromation concerning politics, criminal invovlement of governmental officials, and drug trafficking. The disclosure of spying in a friendly country would have proved embarrassing to the United States and was the primary reason to have Celaya killed. Another reason was the exposure of the cover of a CIA operative.

IV. Pathological Findings:

The cause of death in each case was listed as massive blunt force trauma with craniocerebral and other internal injuries and multiple fractures. The external examinations of the two bodies showed numerous abrasions, contusions and lacerations of the head and facial areas with lesser involvement of the trunk and extremities. All injuries were antemortem, with blood being found in the cabin. The injuries were consistent with high speed and rapid deceleration impact injuries corresponding with the positions in the inverted aircraft. Toxicological analyses were essentially negative for ethanol and other drugs.

V. The Lawsuit:

The story of the lawsuit extends over a period of four-and-a-half months, beginning with the receipt of a notarized letter from the *Arizona Daily Star*, Star Publishing Company, on January 30, 184, requesting not only the autopsy reports from the aircraft accident on December 11, 1983, but "All documents in the possession of the Pima County Medical Examiner's Office pertaining to any and all deaths in Pima Cunty during the months of November and December 1983 which were found to have been caused by accident, including but not limited to automobile, airplane and industrial accidents." The request was not only for autopsy reports but for all specimens, photographs and investigative reports. The request further stated that, "The material is requested in connection with the preparation of a news story or news stories in the public interest, and therefore, will be used for non-commercial purposes."

The request was given to the Civil Division of the Pima County Attorney's Office for a decision. The request was denied on the basis of ongoing investigations. The attorney's decision was based on previous precedent material in the State of Arizona and is summed up in this brief statement. "Autopsy reports fit the definition of public records but the access to the public is permitted only when the custodian of the records determines, after considering the various factors discussed, that no important or harmful effect on his or her duties will result."[1],[2],[3],[4]

Three days later an article appeared in the *Arizona Daily Star* concerning a special action complaint seeking a court order requiring the County Medical Examiner to provide records on all accidental deaths that occurred in Pima County during November and December 1983. The plaintiff alleged that the Medical Examiner "acted in bad faith and in an arbitrary and capricious manner" by denying an *Arizona Daily Star* reporter's written request for records earlier that same week. In support of its request, the *Star* cited the State of Arizona Public Records Law, which allows citizens to view "public records and other matters . . . at all times during office hours."

The policy for record release had been set over a period of several years by the previous Medical Examiner and remained in effect during the tenure of the new medical examiner. This policy consisted of releasing reports to law enforcement agencies, next of kin of the deceased and to any person or organization who has obtained a notarized release from the next of kin.

The plaintiff, the *Star*, contended that the records were not confidential because the legislature hadn't made any statutory provision for them to be confidential. The *Star* requested a court order requiring the Medical Examiner to fulfill the request and to pay all court costs and attorney's fees. On the 9th day of the suit a court order for initial hearing was set in Superior Court, County of Pima, State of Arizona. Within the next several days the U.S. Attorney's office became an intervenor in the case to protect the interests of confidential material in their cases, particularly cases involving accidents occurring on Indian Reservations.

During the hearings the Medical Examiner explained the necessity to maintain certain confidentiality of these recods, some with highly sensitive material pertaining to families, results of toxicologic studies, and cases with ongoing criminal investigation. After a series of hearings, during which the testimony concerning the confidentiality of these cases was given, the *Star* refused to state reason(s) for its request. The original judge excused himself because he felt he could not give an impartial opinion. A new judge was appointed in April and all further hearings were held in camera.

During the hearings of Chief Medicolegal Investigator for OME handled the interests of the Office, relieving the Chief Medical Examiner to continue his duties. The proceedings involved a detailed case-by-case exclusion or inclusion of testimony from investigating officers and attorneys. After two months of hearings the judge gave his decision that all cases with active investigation going on were to be given to the *Star*, with one exception. The exception was a very sensitive, high profile automobile accident still undergoing investigation; at that time such disclosure would have constituted an unwarranted invasion of privacy. In June the court order was complied with and all cases were given to the *Star*. The OME agreed to cooperate on turning over any specific cases that the *Star* would designate. The Court ordered the *Star* to pay the $10,000.00-plus court costs.

VI. Discussion:

The results of the medicolegal investigations (including the postmortem examination) were never questioned as to the procedures or cause of death. It was only the interpretations of how the deaths occurred that resulted in the demand for the case files. The hearings were long and resulted in much wasted time for the medical examiners, attorneys, investigators and the courts. The decision was not appealed, so a precedent could not be established by the Court of Appeals. In the long run no one really was asking to check the work of the OME, but the newspaper reporter apparently hoped that the OME files might contain some investigative material (non-autopsy) that might lend credence to the conspiracy plot.

VII. Summary:

The cases and subsequent legal action illustrate the potential problems incurred in any medicolegal case. These problems include the thoroughness of investiation, interrelated cases, covert or overt activities, statutes requiring clarification, updating statutes concerning what are public records, and the release of information that is either of a sensitive nature or involves potential, if not actual, criminal or civil cases. It is hoped that this narrative would direct the attention of aircraft accident investigators to examine all old procedures and to develop new laws.

REFERENCES

1. *Mathews v. Pyle,* 75 Ariz.76, 261 P. 2d 893 (1953)
2. *Mathews,* 75 Ariz. at 80, 251 P. 2d at 896
3. *Industrial Commission v. Holohan,* 97 Ariz. 122, 397 P. 2d 624 (1964)
4. *Church of Scientology v. City of Phoenix Police Department,* 122 Ariz. 338, 594 P. 2d 1034 (App. 1979)

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