A STUDY OF NASA AERONAUTICS SAFETY RESEARCH PROGRAMS, 1980 - 1989

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CHAPTER 1

INTRODUCTION

When people think of NASA, the National Aeronautics and Space Administration, they usually think of Space, the "S" in NASA. Yet the first "A" in NASA stands for aeronautics. This study concerns NASA's efforts to make the aircraft safer for people who fly them and fly in them.

At 9:34 on a January night in 1990, Avianca flight 52 crashed at Cove Neck, NY while attempting to land at Kennedy Airport after an eight hour flight from Medellin, Colombia. At least 72 of the 161 people on board were killed (Pusey & Swanson, 1990, p. 3A). This was the United State's first air transport accident of 1990.

Although air travel grew safer during the decade of the 1980s (Ott, 1990), the year saw 1989 with an unusually high number of 31 fatal commercial passenger airline crashes (Worldwide Fatal Accidents, AW&ST, 1990), and the more than 2,000 people who died in commercial airplane crashes in 1985 made it the worst year on record (Chandler, 1986). Probably because of increased awareness of these tragedies due to the ease of communications, people want something done to improve aeronautics safety.

Those early adventurers who first fought gravity by flinging themselves skyward in various contraptions generally put no one in danger but themselves. But now the skies are crowded with planes of all sizes carrying more of us around the globe. The public wants to know what is being done to make travel safer and more comfortable. What about wind shear and microbursts? Icing? Lightning? Is the plane crashworthy and fireworthy?

A USAir Flight 405 crashed on departure from New York's LaGuardia airport in March 1992 because of ice on the wings. The National Transportation Safety Board (NTSB) ruled the "probable cause of this accident was the failure of the airline industry and the Federal Aeronautics Administration" to provide flight crews with proper guidelines to deal with icing conditions ("Fatal Plane Crash," 1993, p. 7A).

Deicing fluid was applied at the gate and again after a delay. But during another delay of 35 minutes before takeoff, light snow and sleet fell. On the attempted takeoff the plane failed to become airborne and crashed into the bay at the end of the runway. The accident killed 27 of the 51 people on board. (Fatal Plane Crash Blamed on Icy Wings, February 18, 1993, p. 7A). The article did not state whether USAir was using Type I ethylene glycol deicing fluid, or the longer lasting Type II deicing fluid. A study by the NASA Lewis Research Center in 1989 found that Type II fluids may not need a holdover time limit (Reinmann, 1989).

An ABC World News Report on September 2, 1978 is another case in point. Jules Bergman, ABC's science reporter, reported on the midair collision between a small four-seat Cessna 172 and a Pacific

Southwest Airlines Boeing 727 in San Diego, CA. Mr. Bergman quit reporting and, in a sharp commentary, accused the two Cessna pilots of murder and further stated that all little airplanes should be banned from the skies! Mr. Bergman's solution would hardly have solved the problem, but that report was one of many in which the public became aware of the growing problem with aeronautics safety. The communications industry has tremendous power to inform the public accurately - - or to mislead.

In fact, the National Transportation Safety Board study showed that the airliner overtook and collided with the Cessna, that the Cessna was almost dead center in the airline pilot's and copilot's windscreen for the time from 170 seconds to 10 seconds before collision ("Aircraft Accident Report: Pacific," 1979). Even though Mr. Bergman's initial conclusion was incorrect, the public again heard a respected voice highlighting problems with aeronautics safety.

The San Diego collision, the American Airlines DC-10 crash in Chicago (Collins, 1986), the Delta Airlines L-1011 crash in Dallas (Chandler, 1986) and many other accidents widely reported in the popular press have led to a heightened public awareness of these problems and a perceived need for more research in aeronautics safety.

The Aircraft Owners and Pilots Association (AOPA) sends each member an Aviation Fact Card each year, and although aimed at its membership of mostly general aviation (GA) pilots, its data and comparisons are relevant to this study. Because most aircraft are general aviation, one would expect the greatest number of fatalities come from general aviation. For 1991, a fairly typical year, general aviation had 746 fatalities compared with 196 for air carrier aircraft, or roughly four to one GA over air carrier (Aircraft Owners and Pilots Association, 1993). Since some air carrier aircraft can carry up to 500 passengers, one accident can slant the figures for any given year. For example, in 1990 there were 736 GA fatalities and only 83 air carrier accidents, for a nine to one ratio (Aircraft Owners and Pilots Association, 1992). Probably a better figure is rate of accidents, and the GA fatality rate was 1.35 per 100,000 hours flown to 0.22 for air carrier aircraft in 1991 (Aircraft Owners and Pilots Association, 1993), and 1.39 per 100,000 hours GA fatality rate in 1990 to 0.20 for air carriers (Aircraft Owners and Pilots Association, 1992). More than six times as many people were killed in GA accidents in 1991 as in air carrier accidents. Of course, in 1991 there were 41,150 highway deaths or 94.2 percent of the total transportation deaths (Aircraft Owners and Pilots Association, 1993).

Obviously, aircraft accidents are not new. The first man to fly was Francois Pilatre de Rozier who, along with the Marquis d'Arlandes, made the first manned flight in an aircraft, a Montgolfier hot air balloon on November 21, 1783. On June 15, 1785, de Rozier was killed in an attempt to cross the English channel in a composite hot air and hydrogen balloon (Taylor & Mondey, 1983). The NASA film, Man's Reach, states that in their studies of flight, the Wright brothers found that Otto Lilienthal, one of the true aeronautics pioneers, was killed in what is now called a stall-spin accident.

Nor is aeronautics research new. Congress created the National Advisory Committee for Aeronautics (NACA) on March 3, 1915, and the first government sponsored facility for the study of aeronautics was Langley Field, which opened on June 11, 1920 (Anderson, 1978). The NACA role in aeronautics research was not so much for aeronautics safety as it was to make aircraft fly higher, faster, and farther. For that matter, the NASA book, Fifty Years of Aeronautical Research, published in 1967, devotes only the last seven paragraphs to aeronautics safety research. However, the stall/spin problem has been studied from the beginning of the NACA, and aeronautics safety has been an unstated goal of many aeronautics research programs.

Aeronautical safety research has been and is still being studied by various governmental agencies, colleges and universities, and private and public organizations. The National Aeronautics and Space Administration (NASA), the Federal Aeronautics Administration (FAA), the aeronautics arm of the Department of Transportation (DOT), and the National Transportation Safety Board (NTSB) are the principal government agencies concerned with aeronautics safety research. The NTSB alone acts only retroactively, getting into the act after an accident occurred.

Some of the universities famous for their aeronautics safety research activities are Massachusetts Institute of Technology Department of Aeronautics and Astronautics, Ohio State University, Princeton University, Wichita State University, Purdue University, and Johns Hopkins University. The Flight Safety Foundation is one of the few non-profit independent organizations that

> serves the public interest by actively supporting and participating in the development and implementation of programs, policies and procedures affecting safety (Rozelle, 1988, inside front cover).

NACA became the National Aeronautics and Space Administration or NASA October 1, 1958 as a result of the National Space Act of 1958. This author believes that NASA's role in aeronautics safety research has changed direction and increased over the years. To examine why this has happened is one of the goals of this study. Three NASA centers are concerned principally with aeronautics research. They are the NASA Langley Research Center in Hampton, Virginia, NASA Lewis Research Center in Cleveland, OH, and the NASA Ames Research Center at Moffett Field, CA. All three of these NASA centers conduct some research on aeronautical safety related problems. Other NASA centers also conduct research that sometimes touches on aeronautics safety. For example, NASA's Johnson Space Center conducted research concerning a toxicokinetic study of Halon 1301 exposed subjects (New Initiatives Office, 1988). Halon is used in fire extinguishers on the Space Shuttle, but it is also a fire suppressant used in most other aircraft fire extinguishers.

The year 1989 was general aviation's safest. “The fatal accident rate per 100,000 hours dropped to 1.40 in 1989 from 1.49 in 1988 and from 1.723 in 1984” (“Last Year.” 1990, p. 12). During a March 1990 discussion in Reno, NV, Russell Watson, the education and training director for Cessna Aircraft corporation, concurred with the need for a study of NASA aeronautics safety programs for the general aviation community. General aviation's safety record, improving each year, is so good that according to Mr. Watson, “just a few accidents could put a good bump” on the downward trending curve.

To summarize the aeronautics safety "problem," several situations, events, and needs are apparent. Some of these are incongruous at the very least. Over the past decade the skies have become safer, if one accepts the statistics, yet more and more people are concerned that the opposite is true. Even though more people are concerned about aeronautics safety, more people fly more often.

> In 1978, the major airlines carried 275 million passengers, according to the Air Transport Association. By 1988, that number had skyrocketed to 455 million (Nather, 1989, p. 28A).

Consequently, the crowded skies and congested airports create more delays and more chances for accidents. Fewer pilots are being trained but more pilots are being hired without the same training and experience of the past. But experience and better training, superior equipment and improved facilities require commitment, time, money, and research. One would think the federal government would be planning at this moment to alleviate the problems. However, this was not the case. The national transportation policy, outlined by Transportation Secretary Samuel K. Skinner, called for a reduction in federal funding of the aeronautics system (Fotos, 1990). All of the above implied a crisis in the skies.

NASA's aeronautics safety research programs in the years 1980 through 1989 constitute the scope of this study. The primary sources of information will be the annual center research and technology reports, NASA technical publications, and NASA special publications on research conducted during those years.

Statement of the problem

Because of the rising public interest in aeronautics safety, the probable need for further aeronautics safety research, and the lack of information on any NASA Aeronautics Safety programs, a developmental descriptive study of such programs was deemed necessary and timely. Mary Sandy, who was the public affairs officer for NASA's Code R, the Directorate of Aeronautics in NASA's Office of Aeronautics and Space Technology when this study was started, said such a study was needed and would be useful for NASA and others concerned with aeronautics safety research.

Purpose of the Research

The purpose of this study was to analyze NASA aeronautics safety related research programs for the years 1980 through 1989.

Objectives

The objectives of this developmental descriptive study were as follows:

1. To identify NASA aeronautics safety programs for the years 1980 through 1989;

2. To classify them as to environment or meteorological factors; the machine, the aircraft and related equipment; human factors including operations and training;
3. To trace the development of NASA Aeronautics Safety Research Programs by comparing programs for the years 1980 through 1989;
4. To summarize each research program;
5. To determine if NASA aeronautics safety research programs have increased in numbers and scope over the years 1980 through 1989; and
6. To compare each program by applicability.

CHAPTER II

REVIEW OF THE LITERATURE

Historical Review of Aeronautics Safety

Even before true manned flight began, dangers of “the sport” were obvious. Many individuals were killed and injured “flying” with “wings” usually fashioned from feathers. In 1503, “G. B. Danti survived his attempt to fly at Perugia using inadequate wings,” (Taylor & Mondey, 1983). In 1507 John Damian broke a thigh bone in an effort from a wall at Stirling Castle in Scotland (Taylor & Mondey, 1983). Called tower jumpers, these people measured their successes only by the falls they survived. Many men and women died in balloons and parachutes during the late 1700s and 1800s.

Heavier-than-air powered flight is acknowledged to have begun with a flight of 12 seconds by Orville Wright on the morning of December 17, 1903. Lieutenant Thomas Etholen Selfridge of the U.S. Army Signal Corps was the first person killed in a powered airplane September 17, 1908. He was a passenger of Orville Wright at Fort Myer, VA. Orville Wright was injured (Taylor & Mondey, 1983). Press coverage brought no public outcry for aeronautics safety.

The Air Commerce Act of 1926 “imposed on the Secretary of Commerce and the Department of Commerce the duty of promoting and fostering the development of commercial aeronautics in the United States” (Wells, 1989). This Act, among other things, defined air commerce and set into effect such things as licenses and inspections of aircraft and pilots.

All students of aeronautics history are aware of the “fact” that American pilots in World War 1 were not allowed parachutes because Congress thought that pilots would unnecessarily abandon expensive airplanes if pilots were issued parachutes. In the television series “Wings,” on the A&E cable channel, Eddie Rickenbacker is quoted as seeing Frank Luke jumping to his death from his blazing airplane, even though he had no parachute. There was no real interest in aeronautics safety, except among those who flew. But then, only daredevils flew.

No real call for aeronautics safety was made until 1931. At 10:47 a.m. March 31, 1931, the famous football coach Knute Rockne of Notre Dame was killed in the crash of a TWA Fokker F-10A (Maisel, 1991, pp. 1B, 10B). The wooden tri-motor transport in which he was a passenger “dived out of a leaden sky” (Maisel, Mar. 31, 1991, P. 1B). The airplane broke up during a thunderstorm and crashed into a hillside in Baazar, Kansas. The press reports blamed the breakup on the fact that the airplane was built of wood (Pyle, 1992). That crash led to the end of the use of wooden aircraft in airline service. It is debatable whether there was a public or a press outcry on the need for safety in the skies.

In 1934 military pilots were used for air mail service after President Roosevelt canceled all air mail contracts on February 9, of that year. The President and Postmaster General Farley were under pressure from people and aeronautics groups who felt that the previous Postmaster General Walter Folger Brown had not been fair in the handling of air mail contracts. The belief was that there was collusion between Brown and the bigger airlines. Taking a drastic step, the President canceled all air mail contracts and pressed army pilots into flying the mail. The army and its planes and pilots were not up to the task. The army pilots flew less than one half of the previous route mileage and had to contend with severe winter weather. In the first week five pilots died in crashes, and six others were injured (Wells, 1989). The army flew the air mail from February 19, 1934 to May 31, 1934, and before the death and destruction were over and new contracts were awarded, the Army Air Corps had lost twelve pilots and had sixty-six forced landings (Pyle, 1992).

> The entire fiasco put a damper on commercial aeronautics growth in the United States for several years and opened the Roosevelt administration to severe public condemnation. Furthermore, it clearly showed how budget limitations had seriously affected the quality of training which the army could offer its pilots (Holms, 1981, p. 162).

The next big push for aeronautics safety came after a midair collision between a TWA Super Constellation and a United DC-7 over the Grand Canyon that killed 128 people in 1956. The result was the Federal Aeronautics Act of 1958. President Eisenhower cited the Grand Canyon midair collision and other midair collisions in asking for "a system of traffic management which will prevent, within the limits of human ingenuity, a recurrence of such accidents" (Wells, 1989).

Air tragedies seem to precede legislation or rule changes. Aeronautics safety rule making has always been retroactive - not proactive. The midair collision between an Aeronaves De Mexico DC-9 and a Piper PA-28-181 over Cerritos, CA on August 31, 1987 is one of the latest to spur tougher rules ("Aircraft Accident Report," 1987). In this accident a private aircraft entered a Terminal Control Area (TCA) without permission and collided with an Air Mexico DC-9. As a result of the accident all aircraft operating within thirty nautical miles of a TCA must have an operating Mode C encoding altimeter that provides air traffic control with altitude as well as position information. It is unfortunate that accidents rather than reason bring about changes in the airspace system.

The original United States aeronautical testing agency was the National Advisory Committee for Aeronautics or NACA, formed by Congress on March 3, 1915 with an initial outlay of $5,000 (Sandy & Martin, 1990). The first test facility was started in July 1917 at Langley Field in Virginia. The facility included a wind tunnel similar to the one built by Gustave Eiffel with a test section about five feet in diameter. The first decade of the NACA and the Langley facility, 1917-1927, saw much outstanding work on calibration and instrumentation that made the NACA a world leader in aeronautical research (Anderson, 1978).

The second decade, 1928-1937 at Langley, began on an upsurge of interest. Lindbergh had crossed the Atlantic in 1927, and the whole world became interested in aeronautics. By 1937 the world and aircraft had changed. Now the best airplanes were all metal monoplanes, with enclosed cockpits and retracting landing gear. And suddenly the world was threatened by the Axis powers (Anderson, 1978).

The years of World War II saw another revolution in aircraft - from the end of biplanes and fabric covering to the turbine or jet powered aircraft. After the war a Bell XS-1, flown by Air Force Captain Charles (Chuck) Yeager, first flew faster than the speed of sound on October 14, 1947. In 1948, the British first flew the first turboprop airliner, and in 1949, the DeHavilland Comet became the first turbojet propelled transport (Anderson, 1978).

The NACA became the National Aeronautics and Space Administration on October 1, 1958 as the result of the Space Act of 1958. This change, brought about as a reaction to the Russian Sputnik satellite launched in 1957, put the first “A” in NASA “aeronautics” out front as the need for research intensified.

Two other well-known federal agencies involved in aeronautics safety research are the Federal Aeronautics Administration, or FAA, and the National Transportation Safety Board, the NTSB. A good example of the type of FAA aeronautical safety studies is the Colangelo and Russell study on injuries to seat occupants of light airplanes. The authors studied 55 light airplane accidents trying to find the role of the seats in injuries to occupants. The findings concluded that large accelerations tend to damage seats and cause injury (Colangelo & Russell, 1989).

The NTSB is best known for accident investigations and reports, but the NTSB also produces frequent statistical compilations on aeronautics accidents. A 1989 NTSB statistical report studied 361 general aviation accidents. The probable cause or a related factor was that these aircraft used visual flight rules (VFR) into instrument meteorological conditions (IMC) in all the accidents (NTSB,1989). It is this researcher's belief that safety research after the fact is very important, but for aeronautics safety education, it is like studying lawn mower safety by counting missing fingers and toes.

Although NASA, the FAA, and the NTSB are probably the best known national aeronautics safety research organizations, other federal agencies and facilities are involved in aeronautics safety research. The Sandia National Laboratories in Albuquerque, New Mexico in 1989 analyzed the packaging and transporting of radioactive materials in air transports and the effects in a crash. (McClure & Luna, 1989).

The Aeronautical Systems Division at Wright-Patterson Air Force Base in Dayton, OH is also involved in aeronautics safety research, as is the Army Aeronautics Systems Command at Fort Eustis, Virginia. The Office of Technology Assessment in Washington, DC also studies safety policies, regulations, and technologies of the government in terms of insuring safety in commercial aeronautics (OTA, 1988). And Vladislav Mazur of NOAA's National Severe Storms

Laboratory in Norman, OK had an article in the Journal of Geophysical Research (1989) on “Triggered Lightning Strikes to Aircraft and Natural Intercloud Discharges.”

The popular press is always involved after the fact in air crashes. Crashes make good copy, and the press always seems to have the cause immediately, or within a few days. This is not to say that it is all headline grabbing. In 1977 the National Geographic magazine had a 27-page article titled, “The Air-Safety Challenge” (Long, 1977). The Dallas Morning News won a Pulitzer prize for its in-depth study of the crash of a business jet on April 4, 1986, in Bowie County, TX. “The Final Flight of 50 Sierra Kilo” was an excellent study in what should not have happened (Hanners, 1988). But is that not what aeronautics safety is all about? Accidents should not happen.

CHAPTER III

SUMMARIES OF THE STUDIES DONE

Along with NASA Headquarters in Washington, DC, nine NASA research field centers are located throughout the country. They include:

Ames Research Center, Moffett Field, California
Langley Research Center, Hampton, Virginia
Lewis Research Center, Cleveland, Ohio
Goddard Space Flight Center, Greenbelt, Maryland
Kennedy Space Center, Kennedy Space Center, Florida
Jet Propulsion Laboratory, Pasadena, California
Johnson Space Center, Houston, Texas
Marshall Space Flight Center, Huntsville, Alabama and
Stennis Space Center, Bay St. Louis, Mississippi.

In order to conduct the study of NASA's aeronautical research programs over the past ten years, it was necessary to identify the programs conducted at the NASA aeronautics research field centers. Langley, Ames, and Lewis are NASA's aeronautical research centers. The other centers may conduct research with applications to aeronautics but not specifically related to aeronautics safety. Thus, the Annual Research and Technology Reports for NASA's aeronautics centers for the period 1980-1989 were studied to identify programs for the survey. Once the aeronautics safety research programs were identified, the following procedures were followed:

1. Identified aeronautics safety research programs from NASA Center's Annual Research and Technology Reports.
2. Classified research programs broadly into three elements
    Human - human factors, operations, and training;
    Machine - structures, instrumentation, stability and control;
    Environment - meteorological factors, storm hazards.
3. Cross referenced programs, as necessary, with other events:
    NTSB reports
    FAA studies
    Air tragedies
    Congressional studies
    Popular press outcries (*le problem du jour*)
4. Summarized research programs
5. Tabulated summaries in chronological order

The Environment

The environment, through which aircraft fly, can be benign or vicious. Almost anyone who has more than a little experience as a pilot, air crew member, or passenger in aircraft can remember a flight where the weather provided an exciting trip. This writer has a vivid memory of a flight from Washington National Airport to Roanoke, VA on Christmas Eve in 1959. In those days Piedmont Airlines still used the Douglas DC-3, a 25 - year old design. The night was snowy, cold, and generally miserable with a low ceiling and poor visibility, and the passengers were more than a little apprehensive. The unpressurized DC-3 flew below 10, 000 feet, and the turbulence was more than enough to keep the air sickness bags working. The flight from Washington National Airport to Charlottesville, then on to Roanoke along the Blue Ridge Mountain chain in stormy weather, usually meant bumpy rides. Passengers were not encouraged when the copilot kept coming into the cabin to check for ice on the wings. And there was ice! The passengers could see it, and the writer saw it.

In the 1980s airliners were pressurized for higher flying, but icing and turbulence were still problems. Most weather occurs below 10, 000 feet, but turbulence called clear air turbulence occurs at the altitudes where airliners and business jets fly. Icing is a possibility whenever aircraft fly in visible moisture. Icing detection systems as well as anti-ice and deicing systems are discussed in the section on machines. Clouds and rain are examples of visible moisture. Other possible weather hazards include microbursts, a weather phenomenon undefined before the 80s, and lightning in and near thunderstorms. Heavy rain was a known hazard, but a hazard of unknown magnitude.

Also, a problem caused by aircraft themselves had to do with wing tip vortices. They are an effect of lift generation in which a horizontal vortex of air streams back from the wing tips. The heavier the aircraft the stronger the vortices, and a following aircraft flying into wing-tip vortices can be uncontrollable, with many fatal crashes having occurred from such vortex encounters. NASA's researchers studied all these problems during the decade of the 1980s.

A tragic accident occurred at D/FW airport at Dallas, Texas the afternoon of August 2, 1985 when Delta Airlines Flight 191 encountered a microburst in a thunderstorm penetration on its landing approach. The accident killed 137 people (Chandler, 1986, front cover flap). This set off many studies as new questions arose:

- How can microbursts be detected?
- How should the pilot fly the aircraft if a microburst is encountered?
- Can microburst wind shear be characterized?
- Can computer codes be produced to simulate microbursts?
- Was heavy rain a contributing cause?

Heavy Rain

NASA began studying the effects of heavy rain on airfoil performance in 1982, and in 1985 Langley Research Center conducted a wind tunnel study on the effects of heavy rain on a small-scale airfoil. Some aircraft crashes with heavy loss of life may have been caused by the weight and airflow obstruction of water on the wings of the aircraft. The Pan American Flight 759, which crashed in Kenner, LA on July 9, 1982, may have been due to a microburst with windshear and/or heavy rain, although at that time the term “microburst” was not in the lexicon of aeronautics and meteorology at that time.

NASA Langley conducted wind tunnel tests in the 4 by 7 Meter Tunnel using a model wing airfoil section of a Lockheed L-1011 wide body aircraft. A water spray manifold was located 25 feet in front of the airfoil section, and the water spray simulated a heavy rain environment. On a tour of the facility in 1985 we were told the rain rates simulated in the experiment were up to 40 inches per hour. When questioned about the 40 inch-per-hour rate, Langley personnel explained it had been hypothesized that such seemingly impossibly high rain rates, were indeed possible. Up to that time rain gauges were used for determining only the amount of rain, not the rate. We were told that the first time a true rain-rate meter was tested in what was called an “ordinary thunderstorm,” rates of 40 inches per hour were recorded over short periods of time. The airspeeds for the runs were between 112 and 159 feet per second. For maximum rain rates, the tests showed a 20 percent reduction of lift.

The NASA researchers were worried that scaling effects and the two-dimensional air/water environment used in the wind tunnel tests could be a problem in extrapolating the wind tunnel heavy rain effects to the heavy rain effects on full scale airfoils. Langley researchers, however, did suggest that full size airplanes would experience lift loss at much lower rain rates than those simulated in the wind tunnel.

In 1988 Langley researchers, using the Aircraft Landing Dynamics Facility (ALDF) Rain Simulation System (RSS), tested a full-scale airplane wing section in simulated heavy rain. The ALDF/RSS is 500 feet long, 44 feet wide, and has three 10 inch diameter irrigation pipes supported 40 feet above the ALDF track. With 1590 nozzles expelling 4000 gallons of water in 20 seconds, a rain rate of 40 inches per hour, ± 10 percent, was achieved over an area 15 feet wide and 500 feet long. Rain rates of 2, 10, 30, and 40 inches per hour were possible. Lift and drag tests were made with speeds of 100 knots to 170 knots and angles of attack from 6° to 20°.

The wing section was a 10-foot chord NACA 64-210 equipped with leading edge slats and double slotted flaps. The angle of attack range was 7.5° to 19.5° with simulated rain rates of 9 to 40 inches per hour. At 40 inches per hour, the maximum lift was reduced 15 to 20 percent and the stall angle decreased by about 6°. The LDRF/RSS results correlated well with the small scale wind tunnel tests showing that the scaling effects were not as large as expected.

Microbursts/Windshear

Although rain was present at the time of the Delta Flight 191 accident at Dallas, rain did not cause the crash (Bach & Wingrove, 1986, p. 65). The Delta crash was caused by wind shear in encountering a microburst. Wind shear is any abrupt change in the wind direction or speed, either horizontally or vertically. An airplane is assumed to be flying in a body of air that is homogeneous.

However, that assumption is often not true, and the wind shear near mountains or near thunderstorms can be strong enough to be extremely dangerous. After the Delta Dallas crash, nearly everyone studied wind shear in a microburst. Newly developed technology made it possible to reconstruct the winds encountered by Flight 191.

With the newer digital flight-data recorders (DFDR), sufficient data became available for use in conjunction with Air Traffic Control (ATC) radar data to determine the winds. Using the computer program SMoothing for AirCraft Kinematics, or SMACK, developed at Ames to support the National Transportation Safety Board (NTSB), the microburst/wind shear winds encountered by Delta Flight 191 were reconstructed (Bach, 1981, p. 31). The SMACK program combines and processes data from digital flight recorders and air traffic control radar systems to provide an accurate "reconstruction of aircraft position, velocity, and attitude during the critical moments" of an accident or incident (Bach, 1981, p. 31).

In 1986 Langley researchers conducted a general study on microbursts. They recognized the importance of microbursts as a causal factor in aircraft accidents and the goal of the study was "to define the probability distribution of wind shear severity in microbursts in order to predict exceedance probabilities and other statistical characteristics" (McKissick, 1986, p. 38). Such information would be important in establishing alert/warning criteria for airborne systems.

The researchers used data from 219 microbursts and compared probability of distributions of wind shear magnitudes by using the three parameter Weilbull distribution. The results indicated that the

Weilbull distribution was a valid statistical tool in defining “the probability distribution of wind shear severity in microbursts” (McKissick, 1986, p. 38).

Researchers from Langley's Windshear Research Program used the large amount of data and extensive analysis by numerous investigators to model a microburst. The collected data and analysis included atmospheric conditions just prior to and during the event. Information on rain, hail, and the outflow propagation rate was available. The “information was used to initialize the model, which then generated the full-scale output of microburst parameters” (Bowles, 1987, P. 59). The model, when compared with the DFW atmospheric information, showed excellent agreement. The DFW microburst “propagated from a diameter of zero to approximately 6 miles over a period of 7 to 8 minutes ” (Bowles, 1987, p. 60).

In 1988 Ames researchers, again using the Delta Flight 191 data and serving as part of the National Transportation Safety Board (NTSB) study of the accident, developed a multiple ring vortex model that could be used in flight simulators to better understand the control problems in microburst encounters (Schultz & Wingrove, 1988, pp. 88, 89).

Langley Research Center also conducted two microburst-wind shear studies in 1988. The first was to increase the fidelity of analytical models of wind shear for use in training and research simulators by investigating and characterizing the aerodynamic effect of wind shear. Like the Ames study, this was three-dimensional to determine the effect of spatial variation of the wind field on an airplane’s aerodynamic characteristics. The researchers developed a modified vortex-lattice computer program using a method of characterizing the aerodynamic effect in the form of wind shear aerodynamic coefficients (Vicroy, 1988, p. 69). The results indicated that there may be a significant amount of control authority required to counteract wind shear forces and moments in a microburst environment due to spatial variation in the wind field. These forces and moments were not factored into research and training in use at that time (Vicroy, 1988, p. 69).

The second study, a logical follow on, evaluated the "piloting factors and performance of a candidate set of wind shear recovery techniques in a piloted simulation environment " (Hinton, 1988, p. 70). This program used three techniques for recovery implemented as flight director guidance algorithms in the Visual/Motion Simulator. A math model for a Boeing 737-100 was used, and 252 data runs were made by three research pilots. Each run had a wind shear encounter soon after takeoff. The results showed that maximum recovery performance would include reduced pitch to reduce climb rate, the use of the smallest acceptable climb angle, and later in the encounter, increased pitch to the stick-shaker angle of attack. "Stick-shaker activation must be delayed as long as possible" (Hinton, 1988, p. 70). Flight-path-angle based guidance showed the most promise.

In 1989 Langley researchers conducted a study to determine if a forward-look sensor could be an aid to escape a microburst encounter or to recover from a microburst encounter. This research studied the possible safety benefits from a sensor that would alert the crew to a microburst ahead of the aircraft and indicate how far ahead must the sensor see the microburst. The Visual/Motion

Simulator, programmed as a Boeing 737, was used. Three escape strategies were implemented as flight director guidance.

The base-line strategy, used at that time by flight crews, was to "rotate to an initial pitch of 15° then control sink rate; to track the glide slope to a preset altitude at full thrust to preserve airspeed, then to fly level until exiting the shear, and manage the flight path angle to avoid obstacles and unnecessary climb" (Hinton, 1989, p. 83). Reactive and forward-look detection and warning were used in the simulated encounters. A total of 455 microburst encounters were flown using NASA and air carrier pilots. The wind shear models used were a numeric model of the Dallas/Fort Worth microburst and an advanced analytical model.

The results indicated, that with reactive warning only, there was little if any difference in the three strategies. With forward-look warning, the advanced strategies showed improvement over the baseline, but minimum altitudes were similar. With a 10 second forward-look detection, recovery performance was much improved. The greatest improvement in microburst recovery comes when recovery is initiated early (Hinton, 1989, p. 83).

Clear Air Turbulence

In the early 1980s there were several instances where air transport aircraft in cruise would encounter momentary severe turbulence. Severe turbulence is defined as "turbulence that causes large, abrupt changes in altitude and/or attitude. It usually causes large variations in indicated airspeed. Aircraft may be momentarily out of control" (AIM 1992, § 7-23). The FAA says Clear Air Turbulence can occur at altitudes above 15,000 feet, but Ames Research Center studied occurrences at cruise altitudes above 30, 000 feet.

A 1982 Ames study analyzed a clear air turbulence incident of a DC-10 cruising at 37,000 feet near Hannibal, MO in April 1981. The DC-10 apparently encountered a series of discrete horizontal vortices that appeared "to be a type of air motion, called 'cat's eye' vortices" (Bach, 1982, pp 45, 46). These vortices were hypothesized as being associated with unstable shear layers in the jet stream probably caused by a local storm front. The researchers used the computer program SMoothing for AirCraft Kinematics or SMACK developed at Ames to support the National Transportation Safety Board (NTSB) to simulate the desired winds. The necessary time-history data came from the DC-10s digital-flight data recorder and ATC radar data.

Ames researchers, in a continuation of the NASA/NTSB Clear Air Turbulence study, concluded in 1983 that severe clear air turbulence encounters usually occur at altitudes of 34,000 to 40,000 feet and are associated with strong wind shears in the jet stream or strong mountain waves down wind from the mountain range. Pilots trained in mountain flying are aware of the possibilities of severe to extreme turbulence in rotors, strong vortex wind whorls, which may or may not be marked by clouds. The "severe encounters result from a breakdown of wind shear layers into (Kelvin-Helmholtz) vortex arrays" (Wingrove, 1983, p. 17). The results of the study suggested vortex possibilities to 1,000 feet in diameter, spacing about 3,000 feet, and wind whorl speed above 60 feet per second.

By 1984 the most likely altitudes for encountering clear-air-turbulence, or at least the most recent encounters, were at altitudes from 37,000 to 39,000 feet. The analysis indicated "the airplanes encountered vortex arrays which were generated by destabilized wind shear layers associated with strong temperature near the tropopause" (Wingrove, 1984, p. 30). The vortices were thought to be caused by lower-level barriers as the previously mentioned mountain range, or line of thunder storms. The encounters occur in a lee wave about 10 to 14 miles downwind of the barrier. A severe turbulence encounter can cause changes of angle of attack (∝) from -5° to 10° and force ranges of -1 g to + 2 Gs.

In 1986 Ames reported that extreme clear-air-turbulence was caused by vortex arrays in the tropopause. Since modern airliners and business jets operate at higher altitudes and spend more time in the region of the tropopause, they have a greater possibility of encountering severe/extreme turbulence. Some of the cases of dangerous high altitude turbulence studied were Pan Am Boeing 747s over Greenland in January, February, and November of 1985, a United 747 near Hawaii in March 1986, and a Sabena DC-10 over upstate New York in April 1986. By 1986 the NASA team of scientists and engineers had "identified the strength, size, and spacing parameters of vortex arrays, thereby providing a means to study the effects of these severe wind hazards on operational safety" (Wingrove & Bach, 1986, p. 84).

The Douglas Aircraft Company, under contract to Langley Research Center's Advanced Transport Operating Systems (ATOPS) office, conducted a wind turbulence model study in 1982. The goal was to evaluate state-of-the-art turbulent gust modeling techniques for simulating the flight of large transports. Ground-based flight simulators are used extensively in pilot training, but NASA uses them for research. Ground-based flight simulators have become more sophisticated, and for use in handling and ride-quality research, they must be ultra realistic. Because flight testing is so expensive, ground-based simulators are a necessity. In real life, atmospheric turbulence affects ride quality, handling, pilot work load, and pilot performance.

Computer code for six well-known turbulence-generation models was produced along with documentation. Included were "example gust time histories, probability distributions, power density spectra, and tabulated statistical properties" (Bowles, 1882, pp. 49, 50). This allowed for direct comparison with actual atmospheric turbulence and comparisons among the models. One finding was that in some turbulent gust models, turbulent energies were less than expected from previous research. In 1985 Langley conducted an in-house study to model wind gusts statistically. It used an autoregressive integrated moving average (ARIMA). This method was tested on gust components measured during flights of Langley's F-106B into thunderstorms during Langley's Storm Hazard Program.

NASA Storm Hazards (Lightning) Research

Langley's Storm Hazard Program began in 1980 and studied the characteristics of lightning strikes and their effects on aircraft.

Lightning strikes are not unknown occurrences for aircraft, but they seldom cause damage because most aircraft are made of metal. However, more aircraft and aircraft parts are being made of advanced composite materials, and lightning could become a greater problem. In 1843 Michael Faraday in England found that the electrical charge on a conductor stays on the outside of the conductor (Miller, 1977). Thus if lightning strikes a metal airplane, it could attach and move across the aircraft structure, then detach but always stay on the outside of the airframe. With nonconducting composite structures, the results may not be the same.

The NASA-owned F-106B was used to fly in the vicinity of and to penetrate thunderstorms thus hoping to sustain direct lightning strikes. It was configured with numerous sensors mounted on the noseboom, fuselage, wing, and empennage to detect electromagnetic fields present during the lightning strike process. A shielded recording system was located in the missile bay of the former USAF fighter. The recording instrumentation included:

> a wideband (6 MHz) video recorder for overall lightning strike phenomenon and a transient waveform recorder modified to capture 1.3 milliseconds of data at a 10-nanosecond resolution The sensors were derived from designs developed for nuclear electromagnetic pulse measurements (Dove, 1980, p. 21).

Fisher and Plumer of General Electric, in their 1977 book, Lightning Protection of Aircraft, attempted to

> present under one cover the current state of knowledge

> concerning the potential lightning *effects* on aircraft and the means that are available to designers and operators to *protect* against these effects (Fisher & Plumer, 1977, p. iii).

The authors summarized studies by Plumer and Hourihan of GE, Anderson and Kröninger of South Africa, Perry of the British Civil Aeronautics Authority, Trunov of the USSR National Research Institute for Civil Aeronautics, and an earlier study by Newman and Robb. In summary, those studies indicated that an aircraft was most likely to be struck by lightning if it was:

- in the vicinity of a thunderstorm,
- the air temperature was near 0° Celsius,
- the aircraft was at altitudes of 5,000 to 15,000 feet,
- and, it was climbing or descending near an airport (Fisher & Plumer, 1977, pp. 57, 58, 70).

In a briefing for this writer in 1981, Bruce Fisher the project engineer, said that the first flight tests were flown in thunderstorms at altitudes from 5,000 to 15,000 feet where the temperatures were near 0° C, but the aircraft received few lightning strikes. He concluded that the reason for the different history of lightning strikes was that an aircraft flew through those altitudes climbing from or descending to airports. At cruise altitudes pilots usually avoided thunderstorm cells, changing course to go around them.

The F-106B took its first lightning strikes during flight tests at NOAA's National Severe Storms Laboratory at Norman, Oklahoma. The NOAA laboratory supplied measurements from its ground based Doppler radar. The lightning flights were flown by research pilots Perry Deal of NASA and Maj. Jerry Keyser, an Air Force pilot on temporary assignment to NASA. The first “hit,” as Major Keyser described it, was like looking at a six to eight inch diameter headless snake which came from right to left, struck the noseboom and “spiraled down the left side of the fuselage and was gone” (Aeronautics Travel Times. 1981, p 47). The second occurred that afternoon when Perry Deal was the pilot. Hitting the noseboom, the strike “split into streamers down both sides of the aircraft,” (Weather Advisory, 1981 p. 47) one attaching to the top of the left wing and the other attaching below the right wing. On inspection after the flight, it was found that the second strike attach points traveled down the middle of the F-106B's delta wing. The attach points near the middle of the wing came as a surprise to the researchers. They did not think of the middle of the wing as an attach point zone. A possible problem was the wing skin is not as thick in that area, and that is where fuel tanks are located.

The attach points were likened to rough but shiny spots that looked as if they were made by “the twist of a knife point”(Weather Advisory, 1981, p 47). Mr. Fisher said at the attach points the aluminum skin was melted and quickly re-solidified. He also said the lightning attach points were pit marks about the size of the head of a pin. Mr. Fisher said the new low power avionics and increased use of advanced composites made the lightning tests necessary. Lightning strikes on aircraft have not been a major safety problem, but in the years from 1964 to 1971, two accidents were recorded with no fatalities (Aeronautics Travel Times, 1981, p 49).

Nine strikes were sustained in Oklahoma. The initial three strikes showed a more active electric field compared to the magnetic field expected by the researchers (Fisher, 1980, p. 21). During the same thunderstorm season, eleven flights were made in Virginia using ground based storm measurements from NASA Wallops Flight Center. In all there were 68 storm penetrations with only 10 direct hits.

For all lightning strikes, measurements were taken of lightning's:

- electromagnetic properties
- X-ray emissions
- nitrous oxide concentrations
- optical properties
- and turbulence environment.

The NASA Storm Hazards Program ended in 1986. In the seven years of operation, the NASA F-106B withstood 714 direct lightning strikes, with twenty four coming in 1986. During the test period, higher strike rates came at colder temperatures aloft. Only 98 strikes came at altitudes below 20,000 feet, where most commercial and military strikes had been reported. Most of these may have been cloud to ground strikes. Mr. Fisher said the principle reason for the history of low-altitude strikes was that aircraft flew through those altitudes on climb-out and descent, but avoided thunderstorm cells at cruise altitudes. At higher altitudes most strikes were triggered by the presence of the aircraft.

The electromagnetic measurements have provided data to establish a statistical basis for peak rate changes in the current change and electric flux density between the altitudes of 15,000 feet and 40,000 feet. "The peak of rate current change was found to be several times larger than previous design criteria" (Fisher, 1986, pp. 89, 90). The onboard camera data showed that the entire exterior surface of the F-106B may be susceptible to direct lightning attachment. Lightning attachment zone concepts will need to be changed for future designs (Fisher, 1986, p. 90). This would alter the lightning protection design considerations for future aircraft (Fisher & Pitts, 1987, p. 22).

The six years of flight tests of the full scale F-106B through thunderstorms suggested some possible lightning leader attachment points that were not expected. This was suspected from flight tests but not previously confirmed. Lightning Technologies Incorporated, under contract to NASA, used test techniques established by the Society of Automotive Engineers Lightning Technologies to check for these possibilities. A ten percent scale F-106B was mounted on a dielectric stand that allowed three degrees of attitude adjustment. The model was coated with conductive paint and was positioned approximately midway between a rod electrode suspended above the model and a ground plane beneath the model (Fisher & Pitts, 1988, p. 21).

A rod tip electrode represented the tip of a lightning leader and the ground plane represented the diffuse region of opposite polarity charge. Simulated lightning leaders were attached at many nonextremities, such as wing leading edges, engine inlets, fuselage top and even the canopy. The implications arising from these tests is that new delta or highly swept wing airplanes will need lightning protection over the complete exterior. This would be especially significant for composite designs (Fisher & Pitts, 1987, p. 21).

Sacrificial Lightning Rods

One spinoff from the Severe Storm Hazard program was the development of sacrificial lightning rods to protect aircraft from static discharges and lightning strikes. If one walks along most any flight line, a variety of static discharge devices would be seen protruding from the trailing edges of wings and flight controls. With the proliferation of insulating composites, the Faraday shield of an all metal structure is lost. Low power requirements of modern computer controlled systems, controls, and avionics made protection from electrical spikes necessary. Lightning strikes can be damaging or destructive to composite structures. The damage can be holes caused by burn-through or delamination of layered composites.

The NASA Langley-developed lightweight graphite composite sacrificial tip “can reduce lightning-strike damage to composite parts of aircraft and to dissipate the harmful electrical energy” (Bryan, 1986, p. 97). The tip is made from highly conductive unidirectional graphite fibers in an epoxy matrix. The rods are 0.8 centimeters in diameter and 14 centimeters long. They are tapered from approximately the last 2.5 centimeters to about half the major diameter at the tip. Mounting is on the trailing edges of wings, control surfaces, empennage, winglets, and the most aft parts of the fuselage. The device was successfully tested on the NASA-owned F-106B Aircraft.

The invention is owned by NASA, and information on license for commercial development may be obtained from NASA's patent counsel at NASA Johnson Space Center.

Wake Vortices

Everything that develops dynamic lift by means of lifting surfaces, such as wings, or rotors blades, trail behind them a horizontal wake in the form of a vortex. Everything - - from a butterfly, to the president's helicopter, to the Space Shuttle flying down to a landing - - develops wing tip vortices. The strength of the vortex is a function of the lift generated. Behind heavy wide-body aircraft the wing-tip vortices are horizontal tornadoes. This form of turbulence initially was called prop wash, and when props gave way to jets, the phenomenon not only was still there, but this type of turbulence became stronger and more dangerous as the aircraft increased in size and weight. NASA, in cooperation with the FAA, has studied wake turbulence for years. Studies have shown that peak vortex tangent speeds of nearly 300 feet per second have been recorded (TAB/AERO Staff, 1992, p. 191). Pilots are taught that the wing tip vortices trail behind the aircraft and drop about 500 to a 1,000 feet below it. Near the ground the vortices tend to move laterally at a speed of two to three knots. The vortices dissipate down wind of the aircraft. It was usual for air traffic control to keep a flight separation of about three to five minutes behind heavy (greater than 300,000 pounds) aircraft.

The Airman's Information Manual (AIM) says that “the probability of induced roll increases when the encountering aircraft’s heading is generally aligned with the flight path of the generating aircraft” (TAB/AERO Staff, 1992 7-45, p. 192). This writer once flew into a “wingtip vortex” on a stupid impulse to experience the effect. After the four-place Cessna 172 rolled uncontrollably left 90 degrees and then back level with no control input, my curiosity level dropped to zero. Needless to say, pilots are also taught to stay away from wing tip vortices.

Previous flight tests by NASA and FAA flight tests showed that wing tip vortices could be broken up and totally alleviated at a three nautical mile separation distance by oscillating the ailerons. In this study NASA conducted tests using a scale model Boeing 747 in the Langley Vortex Research Facility that demonstrated the effectiveness of lateral-control oscillations on wake vortex alleviation. The tests demonstrated that lateral-control, aileron, oscillations with flight spoilers upraised reduced rotary motion significantly after a two mile separation. During the tests both ailerons and spoilers were oscillated asymmetrically through their full range corresponding to about a 1/4 cycle per second frequency. Periodically changing the spanwise distribution and inducing spoiler turbulence produced an extremely complex wake. Visual data analysis provided insight into the flow dynamics that contributed to the rapid decay of the wake.

FAA Air Traffic Control terminal instrument flight rules (IFR) require a separation from heavy transports of four to six nautical miles. Wing tip vortex alleviation at two or three miles could reduce separation and thus reduce delay time significantly.

The Machine

NASA conducted many studies in the 80s that were aimed at making the aircraft safer for the flight crews and their passengers. Some studies were to help make aircraft safer in weather such as low visibility or icing conditions, both in the air and before takeoff. Other research was to help make the aircraft easier and thus safer to fly. NASA conducted research on new control systems and new instrumentation in the 80s. Research on damage detection and damage resistant systems was also conducted. NASA also tested antimisting fuel additives, crashworthy and fireworthy structures, and an explosive emergency egress system.

Icing Safety Research

Icing Detection Systems.

Since flight became a mode of transportation considered to be dependable, the hazards of airframe icing have held great importance to those who fly. The formation of ice on aircraft surfaces is a serious problem causing numerous accidents each year. Aircraft icing can exist whenever there is visible moisture and the air temperature is at or below freezing. Thus in the colder months, it would be rare to fly and not encounter clouds capable of producing ice. For general aviation aircraft, the rule of thumb has always been to avoid icing conditions, and if ice begins to accrete, flee (Horne, 1993, p. T-11). However, by the time ice is detected, in the old traditional manner of looking out the window, the situation may already be dangerous.

For an icing detector to be useful to a pilot and for useful research, it should do more than indicate the presence of ice on an aircraft. The instrument should measure icing intensity in terms of rate and amount of ice accretion and indicate the liquid water content of clouds. NASA and private industry have been studying the problem and developing ice detection systems for decades. The most successful commercial ice detector is manufactured by Rosemont in Burnsville, MN. The system uses a small vibrating probe located under the nose of the aircraft. Ice accretions of as little as 0.02 inches can be detected (Horne, 1993, p. T-11). BFGoodrich Aerospace's Jet Electronics and Technology subsidiary developed and flight tested The SWPlus stall warning and contamination system. It uses sensors on the wings and horizontal stabilizer to detect ice and identifies performance degradation on takeoff and approach (McKenna, 1993, p. 40).

The Federal Aeronautics Administration (FAA) proposed in the early 1980s that Instrument Flight Rules (IFR) certified helicopters be required to have ice warning devices. Information from PIPEPS, pilot reports, on icing conditions could be supplemented by using Mode S transponder automated down-link of icing data from commuter and air taxi aircraft. Such information is necessary for general aviation safety.

<u>NACA Ice Warning and Rate of Icing Meter Update</u>. In 1981 Lewis Research Center researchers updated the National Advisory Committee for Aeronautics (NACA) ice warning and rate-of-icing instrument. The new instrument is lighter, simpler, and reduces workload of the pilot. Lewis developed a simplified ice detector and accretion meter using a microprocessor that calculates and digitally displays a readout on ice accretion rate, the total accumulated ice, and the cloud liquid-water content. The instrument has a high degree of reliability and can be easily self tested in flight. The system's icing detector and accretion meter used a pitot-static system and an ice collecting element that contains small holes. When icing occurs, the small holes are plugged by the ice, thus changing the impact pressure in the pitot-static system. The time rate change in the pitot-static pressure is used to measure the rate of ice accretion. The NASA - developed meter is low cost, light weight and inherently reliable (Perkins, 1981, p. 16).

<u>Microwave Ice Accretion Meter (MIAM)</u>. The Microwave Ice Accretion Meter (MIAM) developed at Lewis was selected in 1982 for the <u>Industrial Magazine</u>'s IR-100 award. The MIAM measures the thickness of ice actually forming on an aircraft surface where most ice accretion meters use probes projecting from the surface, and surface ice must be inferred. "The MIAM detects the onset of icing, continuously monitors ice thickness, and displays ice thickness and accretion rate" (Ide, 1982, p. 2). The system uses a microwave surface wave guide mounted flush with the surface that changes

resonant frequency with ice accretion. The frequency shift is measured by using a microprocessor that converts a DC voltage proportional to ice thickness. The microprocessor also computes the time rate change in thickness to obtain accretion rate. The system works on aircraft components either on the ground or airborne and mounts on helicopter blades.

The MIAM, in a strange change of name for an ice detection instrument, is now called MIAMI for Microwave Ice Accretion Measurement Instrument. Ideal Research and Development Corp. flight tested the prototype system on a Cessna 303 in 1985. Ideal now plans to adapt the MIAMI system for use in "detecting ice, snow, frost and slush on wing surfaces on the ground and to monitor deicing fluids" (Hughes, 1993, p. 41).

Ultrasonic Icing Detector. In 1985 Langley researchers studied the feasibility of using pulsed-echo ultrasonic sound to detect ice on an airfoil. Initially, the tests were conducted using refrigerated ice on an aluminum surface. The test frequency was 5 MHz, and both compression and shear waves were studied. The ultrasonic waves reflection was detected at the aluminum and ice interface and at the ice and air interface. The ice thicknesses tested were four to six millimeters. The speeds of sound for the compression and shear waves were calculated. It was concluded that an ultrasonic ice detection system was feasible, and using electronic signal processing, the growth rate of ice buildup could be determined (Smith, pp. 20, 21).

Ground Deicing Fluids. In 1989 NASA's Lewis Research Center and Boeing conducted a joint test program using the Icing Research Tunnel (IRT) to evaluate types I and II deicing fluids used by the Association of European Airlines (AEA). Several other experimental fluids were tested as possible replacements for the Type II deicing fluids used at that time.

Deicing fluids are used to prevent snow or freezing rain from sticking to wings and other aircraft surfaces which can cause catastrophic losses in aerodynamic performance at takeoff. Several air tragedies occurred due to ice build up in the past few years. The Association of European Airlines had found that type II deicing fluids lasted longer than type I fluids. The object of the Lewis/Boeing tests was to see if the type II deicing fluids degraded aircraft performance when the aircraft takes off with deicing fluids on its wings. AEA type I fluids are propylene glycol similar to ethylene glycol used by the United States airlines for snow and ice removal prior to takeoff. "AEA type II fluids are non-Newtonian (Thixothropic) fluids whose viscosity varies inversely with the shear applied to the fluid" (Reinmann, 1989, p. 121). They are gels when at rest, but become more liquid, i.e., less viscous, when the air moves across the wing. Thus these thixothropic fluids flow off the wing at takeoff.

There were two models used during the testing program. The first was a 0.091 - scale three-dimensional half model of a Boeing 737 - 200, and the other was a 0.18 - scale two dimensional airfoil section at the 65 percent span, also a Boeing 737 - 200.

Wind Tunnel test objectives were as follows: (1) correlate wind tunnel

> and flight test measurements of the aerodynamic effects of deicing fluids; (2) evaluate fluid effects at higher angles of attack than could be safely in flight; (3) expand flight test results for parametric variations of temperature, airfoil configuration, and fluid formulation; (4) contribute to the data base for establishing aerodynamic acceptance standards for ground deicing fluids; and (5) obtain data that contribute to a physical understanding of the lift loss mechanism. Current type I and type II fluids and eight new type II fluids were tested (Reinmann, 1989, p. 121).

The IRT tests obtained data on lift, drag, and pitching moment through stall; surface static pressures; initial film depth; fluid film depth during takeoff; video recordings of fluid flow off; and boundary layer velocity profiles.

It was found that one of the new type II fluids was much better than the original type II fluids and did not degrade takeoff performance any more than type I fluids. The AEA airlines adopted the new type II fluids, and one U. S. air carrier had adopted the new deicing fluid at the time of publication of the 1989 Annual Report . Some other major U. S. airlines were testing the new type II fluids for possible use the following winter. In 1992 only Northwest Airlines and United Parcel Service were using Type II fluids, and they only started in 1992, three years after the NASA study on type II fluids. There have been eight takeoff accidents due to ice and snow contamination since 1882 (McKenna, 1993, pp. 38, 39).

The NTSB ruled that the USAIR Flight 405 plane crash at LaGuardia Airport in New York on March 22,1992 was caused by ice on the Fokker F-28's wings at the time of takeoff. The NTSB ruled on

February 17, 1993 that the "probable cause of this accident was the failure of the airline industry and the Federal Aeronautics Administration" to provide flight crews with proper guidelines to deal with icing conditions ("Fatal plane crash," 1993, p. 7A).

After deicing fluid was applied at the gate, the plane was deiced again after a delay, but there was another delay of 35 minutes before takeoff. During this time, light snow and sleet fell. On the attempted takeoff, the plane failed to become airborne and crashed into the bay at the end of the runway. Twenty seven of the fifty one people on board died in the accident ("Fatal plane crash," 1993, p. 7A).

The debate over the relative efficiencies of Type I and Type II deicing fluids continues. The AEA De/Anti-icing task force say that Type II fluids are more efficient because they adhere longer to the surfaces, and hold over time is not an issue. The FAA, on the other hand, insists on a 20 to 45 minute time limit for Type II deicing fluids (Sparaco, 1993, p 34, 35).

Research also continues. Some issues remaining are whether Type II fluids cause runway friction degradation and whether high wind velocity and jet blast accelerate the degradation of Type II fluids. Another problem is defining weather conditions. "Extreme weather" could degrade all deicing fluids faster. Icing sensors could be a partial answer to the problem (Sparaco, 1993, p. 35).

Icing Effects on Stability and Control. When ice accretes on an aircraft, the performance is degraded sometimes to the point where the aircraft crashes. Three things happen: lift is decreased, drag increases, and the aircraft weight increases. Current icing protection systems decrease aircraft efficiency to some degree, and future high efficiency aircraft may require that icing protection be provided for only the most critical components.

It was necessary to develop analytical and experimental methods for predicting changes in aircraft handling and performance for:

- enhanced design of aircraft,
- relaxed-stability advanced control systems,
- simulator software,
- analysis of failure modes,
- certification criteria,
- and improved operational safety.

Normally, performance degradation was determined using flight testing or icing tunnel testing. Both methods are time consuming and expensive. Computational Fluid Dynamics (CFD) analytical prediction could lead to increasingly efficient and cheaper alternatives to the icing tunnel and artificial/natural icing tests.

> Emphasis is currently being placed on the prediction of airfoil performance degradation due to leading-edge ice accretions by using both thin-layer Navier-Stokes and interactive boundary-layer codes (Shaw, 1985, p. 7).

The computational and experimental programs compared results of thin-layer Navier-Stokes predictions and measurements of artificial leading-edge ice accretion on a NACA 0012 airfoil. With the assumption of turbulent boundary layer growth downstream from the stagnation point, prediction and experimental data agreed closely. “However, predicted and measured velocities at two points within the separation-reattachment zone downstream of the ice accretion differed” (Shaw, 1985, p. 7). It was theorized that the differences were caused by either ice shape definition, grid characteristics, or turbulence modeling. All three possible areas that may have caused the differences were investigated. Later use of interactive boundary-layer approach cut execution times by an order of magnitude.

To provide a validating data base, an experimental program was conducted to map in detail flow field on airfoils with leading-edge ice accretions. “Little or no quantitative data existed that would be useful for such engineering analyses” (Shaw, 1986, p. 15). Lewis conducted two flight research test programs using the NASA Lewis DeHavilland Canada DHC-6 Twin Otter. Clear air flight tests with artificial ice shapes on the horizontal stabilizer measured static stability changes. As might be expected, the longitudinal control forces were weakened, and the static longitudinal stability was reduced. Dynamic flight maneuvers were made in natural icing conditions with data obtained by using a Kohlman data acquisition system. Noted was an 8 - 9 percent degradation, in cruise, due to icing in the “primary elevator control power derivatives ” (Shaw, 1986, p. 15). Thus the longitudinal stability was reduced. There was greater degradation in the takeoff and landing approach configuration.

Further analysis was planned to help determine the limitations of methods used to identify the icing-caused parameters that degrade flying qualities.

In 1988 Langley Research Center also attempted to quantify the effect of ice on aircraft stability and control by comparing flight test results with analytical predictions and wind tunnel data. This research was in support of the National Aircraft Icing Technology Plan and consisted of two parts. The first "was to determine the accuracy with which the aircraft stability and control derivatives could be estimated" (Batterson, 1988, p. 62). The second "was to determine longitudinal stability and control derivatives for the aircraft both in clean and 'artificially' iced conditions" (Batterson, 1988, p. 62).

To form a basis for stability and control derivatives, 45 maneuvers were flown at the same flight conditions. The artificial ice was "a strip of plastic molded into a generic ice shape seen in flights and in the Lewis Research Center Icing Research Tunnel" (Batterson, 1988, p. 62). Over 200 maneuvers were flown by NASA's deHavilland DHC-6 Twin Otter during four flights in December 1987. "Flight data were analyzed using the modified stepwise regression algorithm developed at Langley Research Center and previously reported in NASA TP-1916 " (Batterson, 1988, p. 62).

The results show significant differences between the derivatives for the iced and uniced machines. It was concluded that the effect of ice accumulation is quantifiable and can be applied in the preliminary design phase of aircraft.

Icing Computational Fluid Dynamics (CFD). During the 80s a major part of almost any research program was the development of analytical methods for designing and predicting the performance of ice prediction systems. Increasingly, computers were put to use in an analytical role, and more powerful computers became available. The icing researchers were now developing algorithms, computer codes, and analytical models that would predict where and how much ice would form on an aircraft and how ice would affect aircraft aerodynamics(Reinmann, 1990). Through the 1980s, computer code and analytical model development made possible:

- ice protection system design/analysis,
- droplet trajectory prediction,
- ice accretion prediction,
- prediction of aerodynamic changes due to ice,
- fundamental experiments on physics of ice,
- and experiments to determine if codes accurately predict experimental results.

Using a Cray 2 supercomputer at the Numeric Aerodynamic Simulator (NAS) located at Ames Research Center, icing researchers completed the “first Navier-Stokes computations showing 3D nature of iced-wing flow field” (Reinmann, 1990). The significance of that milestone was the potential for predicting aero-performance loses caused by ice on modern wings. This was a necessary step in the direction of “predicting response of complete aircraft to icing encounters” (Reinmann, 1990).

Deicing systems

Mention ice to an old high time pilot, and he will probably offer several stories of “almost” crashes, or even some survival tales. Ice on flying surfaces increases drag, and adds weight, while decreasing lift. All aircraft that fly in cold weather must have protection or should stay out of icing conditions. Advanced aircraft of the future will need anti-icing or deicing systems that are low power, lightweight, and reliable. The 1980s research in icing took many forms, from icing detection, to ground deicing, anti-ice systems to deicing systems. Lewis Research Center in Cleveland, OH, the NASA center with the longest history in icing research, has the oldest and largest refrigerated icing wind tunnel in the world.

Lewis Icing Research Tunnel (IRT). The Icing Research Tunnel (IRT) started operations in 1944, with the first test run on June 9, that year. The unique heat exchanger built for the Altitude Wind Tunnel (AWT) and the IRT addition was designed by Mr. Carrier of the Carrier Corporation and has never failed in test operations (Reinmann, 1990). It is still the largest direct-expansion unit in the world with a 21,000 ton capacity at 40° F (ASME, 1987). Lewis Research Center also has a deHavilland DHC-6 Twin Otter research aircraft for flight through natural icing clouds or man-made icing clouds.

To resolve questions concerning validity of data in the Lewis Icing Research Tunnel, Lewis researchers in 1988 ran validation tests because the free-stream turbulence levels are different in flight and in wind tunnels. Turbulence intensity for smooth air flight conditions was less than 0.1 percent. It was found to be 0.5 percent in the IRT even with the cloud-making sprays turned off (VanFossen, 1988, p. 69).

A NACA-0012 airfoil with a 533 cm (21 inch) chord was used for the IRT and flight tests. The flight airfoil was mounted on Lewis' DHC-6 Twin Otter. The rough airfoil was made by attaching 2 mm hemispheres to the airfoil using four patterns. Different airspeeds and angles of attack up to 6° were used. The results were presented as Frossling numbers that are dimensionless heat transfer coefficients divided by the Reynolds number. Flight and wind tunnel data at Reynolds number 1.2 million demonstrated no measurable difference between flight and wind tunnel data when no icing cloud was present. At a Reynolds number of 2.4 million and with the spray nozzle atomizing air on, there still was no measurable difference in flight and IRT data (VanFossen, 1988, p. 70). The data obtained were incorporated in the NASA Lewis LEWICE ice growth ice prediction code.

At a briefing for NASA Aerospace Education Specialists on September 7, 1990, John J. Reinmann stated the NASA aircraft icing technology research purpose: to "improve aircraft safety through development of advanced ice protection concepts and development/validation of advanced icing simulation methodologies." The total NASA icing program encompasses:

- ice protection systems,
- computer modeling,
- helicopter test techniques,
- icing tunnel tests,
- icing physics,

- and flight research.

General Aviation Deice Systems. In 1980 Lewis Research Center conducted a program to develop and evaluate deicing systems for general aviation (GA) aircraft. GA aircraft include those that are usually not pressurized, and as a result, do not fly above the weather. In icing conditions they either do not fly or have some sort of anti-icing or deicing system or systems. Ice protection in the form of deicing for GA aircraft has meant pneumatic boots on wing leading edges and the leading edges of empennage and propeller surfaces. Some modern GA airfoils, such as the Whitcomb designed GAW-1 airfoil, have larger leading-edge radii, and the effectiveness of pneumatic boots on these airfoils is unknown.

Other ice protection concepts that may be suitable for present or future GA aircraft were in the development stage in 1980. One, "oozing antifreeze," had been used on large aircraft for many years. Another proposed ice protection system was ice phobics, or materials on which ice does not tend to accrete or even adhere (Reinmann, 1980, p. 5).

The test systems were installed on the leading edge of a NACA 64-215 airfoil modified with an enlarged leading edge radius similar to the Whitcomb airfoils. The tests were made in the Lewis Icing Research Tunnel. The oozing liquid antifreeze ice protection system was especially effective. The Goodrich Company, TKS, Ltd. in the United Kingdom, and the University of Kansas Department of Aerospace provided support for this research.

Electrothermal Deicers. In 1983 the University of Toledo, under contract to Lewis Research Center, developed a computer analysis code to predict the performance of electrothermal deicers as a part of NASA's rotorcraft and aircraft safety programs. Electrothermal deicers would be useful on laminar flow surfaces because they would not affect the surface shape or smoothness. Periodically, electrothermal deicing systems heat certain aircraft surfaces, such as the leading edges of the wing and horizontal stabilizer, to remove any accreted ice. As a rule, energy requirements for deicing systems are significantly less than for anti-ice systems. At the time of this study helicopter rotor blade deicing systems were being developed by many helicopter manufacturers (Lewis, 1983, p.18).

Pneumatic Deicer for Helicopters. The year 1984 saw a research program to develop a prototype pneumatic deicer for helicopter rotor blades. Support for this research program was provided by the B.F. Goodrich Company (BFG) and the U.S. Army. Helicopters, by the very nature of their flight envelopes, fly below 10,000 feet where bad weather and icing conditions often exist in the cold seasons of the year. Until this program, electrothermal deicers were the only types in use on helicopters. The large power consumption and cost of electrothermal deicers led to the need for an alternative. The light weight pneumatic deicers in use on many airplanes offered a simpler alternative using less energy.

BFG, a manufacturer of deicing boots for airplanes, and NASA Lewis Research Center conducted a development and test program from 1981 to 1984 using the Lewis Icing Research Tunnel, and the U.S. Army assisted by conducting feasibility flight tests using a UH-1H Huey helicopter. The flight test evaluation included structural load surveys, tests of performance and handling, and rain erosion tests. Actual icing tests were made by flying behind a helicopter icing spray system, and limited flight tests were made in natural icing conditions. Artificial icing tests were also flown using the hover spray facility in Ottawa, Canada. During the test period the prototype system was modified and improved.

Pneumatic deicer boots do change the leading-edge shape of the rotor blade. The aerodynamic penalties of these changes can lead to degraded performance and possible changes in handling quality. The prototype deicing boot demonstrated acceptable performance and handling penalties. As on airplanes, "pneumatic deicers for helicopter rotors offer an attractive, low cost, mechanically simple alternative to electrothermal deicers" (Lewis 1984, p. 12). However, the development of an Electro-expulsive deicer at Ames Research Center eclipsed the pneumatic deicer system.

Electromagnetic-Impulse Deicing System (EIDI). Another deicing system developed at Lewis and reported in 1984 was an Electromagnetic-Impulse Deicing System (EIDI) for use on general aviation, transport aircraft, and possibly helicopters. The NASA Lewis sponsored EIDI system program was managed by Wichita State

University, in cooperation with the following industry consortium members:

Beech Aircraft Company,
Cessna-Pawnee Division,
Gates Learjet Corporation,
Cessna-Wallace Division,
LearFan Ltd.,
Boeing Commercial Aircraft Company,
McDonnell Douglas Company,
Simmonds-Precision,
and Rohr Industries.

The array of interested aeronautics industry companies indicated the magnitude of the icing problem.

The electromagnetic-impulse deicing system was developed as an alternative to pneumatic and electrothermal deicing systems then in use. Electrothermal deicing systems have high power requirements, and the simpler pneumatic deicing systems cannot be used with any laminar flow wing airfoils because the airfoil shape must remain constant.

The electromagnetic-impulse deicing system (EIDI) was developed, tested, refined, and proved during 1983 and 1984. The flight tests were conducted using the NASA Lewis DC-6 Twin Otter fitted with a glove on a three-inch extension on the leading edge. The glove contained four EIDI coils. The system had potential uses on a wide range of aircraft including general aviation, commuter, air transport aircraft, and possibly even helicopters.

The EIDI system uses an interaction of magnetic fields and eddy currents that creates “an impulsive force on the skin of several hundred pounds for less than a millisecond” (Lewis, 1984, p. 12). “. . a small amplitude, high-acceleration movement of the skin acts to shatter, debond, and expel the ice” (Lewis, 1984 , p. 12). In other words, the aircraft skin is "thumped" with enough force to knock off the ice.

A major advantage of the EIDI system is a very low power requirement, no more than an aircraft's landing lights. There is no need for ducting or engine hot gas bleed requirements, nor is there any aerodynamic penalty as with pneumatic systems. The electromagnetic-impulse deicing system weight was equal or less than the current systems in use at the time, and the maintenance would be minimal as there are no moving parts.

In 1985 Ames Research Center announced a research program to develop a low cost, lightweight, low power deicer for helicopter rotor blades A major problem for helicopters was a lack of all weather capability due to their sensitivity to rotor blade icing. Airplanes have used deicing devices for decades, but the weight and power requirements made helicopter manufacturers and operators reluctant to add icing protection to existing helicopters.

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Electro-Expulsive Deice System (EEDS). At Ames in 1985 an electro-expulsive deicing system, invented by Leonard A. Haslim, was light enough and had such a low power requirement it became useful for helicopter deicing protection.

> The electro-expulsive deicer boot is readily bondable onto almost any substrate, and requires no mechanical moving parts or pneumatic inflation to effectively shed ice from aircraft surfaces. The new deicer takes the form of an elastometric boot that cyclically, expulsively, expands and throws off any accreted ice (Haslim, 1985, p. 15).

The thin 20-50 mils, about 1/50 inch polyurethane elastomer deicing boot, normally lies flat against the surface. The low temperature rubber includes unbonded sections that have high-voltage ribbon conductors embedded in knife-like slits in the rubber. When a bank of capacitors is discharged, a large pulse of electrical energy is discharged into the ribbon conductors inducing a large repulsive force that expands the elastomer strip and cleans any ice off the surface. About 3,000 amperes are discharged in a few milliseconds. The force is in excess of 75 Gs, enough force to knock off frost (Haslim personal interview). After the pulse, the elastic properties of the rubber cause it to rebound to the flat relaxed position.

The next year, 1986, Ames expanded the possibilities for the electro-expulsive deicer boot to fixed-wing aircraft. The boot was usable for most any aircraft surface subject to icing. With the relaxed thickness of 1/50 inch, no detrimental effects on surfaces with turbulent air flow would be expected. In 1986 an application for patent was made on the electro-expulsive deicer system (Haslim, 1986, p. 31).

The system was developed for helicopter rotor blades, but the U. S. Navy recognized the possibilities of the system for high-performance aircraft. NASA and the U. S. Navy flight tested the system on a F/A-18 Hornet aircraft the next year, 1987. In 1988 Haslim was named NASA inventor of the year (Fenrick, 1989, p. 1). The Ames/Haslim-developed Electro-Expulsive Deicing System (EEDS) was tested on the engine inlet of a Navy F/A-18 Hornet aircraft by the Naval Air Test Center, Patuxent River, MD. Several F/A-18 engines (F-404) had been lost due to severe foreign-object damage when accreted ice broke away from the sharp inlet lip and were ingested by the engine. The Navy had lost five engines and the Canadians had lost 26 engines on their F/A-18 aircraft due to ice ingestion (Haslim, 1988, p. 63-65).

The Naval Air Systems Command provided all funding for the program. The EEDS system was installed on the engine inlet lip of a F/A-18 Hornet aircraft and flown behind an Air Force NKC-135 icing spray tanker aircraft. The EEDS system not only pulverized any accreted ice, it also acted to protect the aircraft from rain and sand erosion (Haslim, 1988, p. 63). When pulsed every three to five seconds, the system performed superbly as an anti-icing system as well as a deicing system. The system was also adaptable for civil transport aircraft. Northwest Airlines was preparing to test the EEDS system on a Boeing 727, and American Airlines was interested in a retrofit for its MD-80 aircraft (Haslim, 1989a , p. 4).

EEDS Sea Trials. The interest in the electro-expulsive deicer system EEDS expanded rapidly with the Naval Air Systems Command Naval Air Test Center, Patuxent River, MD, the U.S. Marines, the U.S. Air Force, and the McDonnell Douglas Corporation all being involved.

By 1989 the Naval Sea Systems Command was involved in expanding the possibilities for the EEDS. The system by now had been tested on an engine inlet of a F/A-18 by the U.S. Navy and on Lewis Research Center's Twin Otter. The U.S. Air Force selected the EEDS for B-1B engine inlet icing protection. In a spinoff of the aircraft deicing system, the U.S. Navy initiated steps to retrofit critical areas of ships with EEDS. Dozens of lives were lost each year from sea-ice related accidents. Sea-ice accumulation reduced safety and effectiveness, caused instability and poor visibility. Ice mass can sink a ship from weight alone. An Aegis-guided missile Cruiser can rapidly accrete 1.5 million pounds of sea-ice even in moderate icing conditions (Haslim, 1989a, p. 4). Personnel doors, vertical launch hatches, and superstructures of Navy ships could be protected from ice using EEDS. A sample of EEDS was tested in the Arctic Simulation Chamber at Point Loma, CA.

Ames, in cooperation with the state of Alaska, tested EEDS in the Bering Sea aboard the largest ship in the Alaska Fish and Wildlife protection program. The test lasted for eight days at sea from Kodiak to the Pribiloffs. The success of the tests led to a joint Ames and Alaska project. The Governor of Alaska made the project a priority and authorized the use of state government vessels to develop the EEDS to enhance the safety and utility of Alaskan fishing vessels. The Navy, seeing the results, intended to retrofit vulnerable areas of its LCAC (Landing Craft Air Cushioned) hovercraft, and personnel and missile launch hatches on Aegis guided missile Cruisers (Haslim, 1989b, p. 7).

Though lightweight, easily retrofittable, and requiring low power at low cost, the EEDS was nowhere mentioned as a useful system on general aviation aircraft.

Control Systems

Decoupled and Coordinated Control Systems.

The control system used by airplanes has not changed since World War I. Roll is controlled by differential acting ailerons on the outboard portion of the trailing edge of the wings. Pitch is controlled by an elevator on the trailing edge of the horizontal stabilizer or by moving the whole of the stabilator; and the yaw control is the rudder. The ailerons and elevator are combined into one pilot control, the stick or yoke, where the pilot pulls or pushes the stick to control pitch and moves the stick left or right, or turns the yoke left or right to control roll. Power, or throttle, is controlled by moving lever(s) or push rods forward or backward with forward always meaning more power.

Here a problem may arise. Moving any one control affects everything else. Adding more power causes the speed to increase and the airplane to climb. Introducing a bank in the airplane causes a turn, but the airplane starts to lose altitude unless the airplane is pitched upward. When an airplane's pitch is changed, the airspeed changes also. Increasing pitch lowers the airspeed. The controls or the effects are coupled. When an airplane encounters wind shear, rapid changes take place in airspeed and altitude. Wind shear has been of significant consequence in many accidents during the final approach phase of flight.

Wind shear is a term that has become a part of the lexicon of most well read people in the last few years. Many airline accidents have had wind shear listed as a cause. The accident that prompted this study was that of Eastern Airlines Flight 66 at Kennedy airport in 1975. Langley researchers studied the effect of independent or decoupled control of the flight path angle, pitch angle, and forward velocity. They used a decoupled longitudinal control system to provide constant gains to implement changes in thrust, elevator position, and symmetric spoilers (Miller, 1980, p. 12).

NASA Langley's fixed-base simulation of the NASA modified Boeing B-737 Terminal Configured Vehicle (TCV) was used for the simulations. The TCV name was later changed to the Transport Systems Research Vehicle, or TSRV. Many people suggested the term "terminal" was too final to use with aircraft. Three research pilots flew the simulations based on a typical twin-engined jet transport using conventional controls and the advanced TCV control system. The simulations, using typical Kennedy Airport wind shear data, resulted in crashes about half the time due to stall when the research pilots pitched at too high an angle of attack. When the decoupled control system was used, the pilots were always able to complete the landing safely. The decoupled control system could be used with any airplane using servo driven actuators (Miller, 1980, p. 12).

In 1981 Langley researchers continued the 1980 study of the positive effects of decoupling the longitudinal control system for air transport aircraft landing in conditions of wind shear. Decoupling the longitudinal control system effectively reduces the pilots pitch control authority. As before, the control system uses constant gains to avoid onboard computation. Changes in thrust, elevator position, and symmetric spoilers were combined to provide independent or decoupled control of the flight path angle, pitch angle, and forward velocity (Miller, 1981, p. 21).

Using the fixed base simulation of the NASA Terminal Configured vehicle, the decoupled system was tested against a conventional control system and the advanced TCV control system. The simulated wind shear conditions were similar to those that occurred at the time of the crash of Eastern 66 at Kennedy Airport in 1975. The conventional control system and the advanced TCV control systems pitched at too high angles of attack and crashed about half the time without the decoupled controls. Using the decoupled system, the stall was avoided, and each landing using the decoupled controls was successful. There was no evidence that the pilot's performance was degraded due to reduced pitch authority (Miller, 1981, p. 21).

Coordinated Elevator and Thrust Control. In 1982 Boeing Commercial Airplane Company, under contract to Langley, studied the effect of coordinating the pitch and power controls. In the longitudinal axis, the lack of control coordination between the elevator or pitch control and throttle control "results in undesirable activity of these controls and in flight path/speed coupling errors" (Hueschen, 1982, p. 49). This lack of coordination can cause inadequate stability in some portions of the flight envelope.

Boeing also designed and used piloted simulation to verify an integrated elevator/thrust control system called Total Energy Control System, or TECS. A common generalized flight path/speed control algorithm coordinated control for all longitudinal modes of the autopilot/autothrottle and the flight management system.

> The system design philosophy uses thrust to control the total energy of the aircraft and elevators to control the distribution of that energy between flight path and speed objectives (Hueschen, 1982, p. 49).

Thus, TECS eliminates speed and flight path deviations since uncoordinated control of either speed or pitch often affects the other.

The hardware and software requirements of the coordinated system are simpler than in a conventional control system. This could lead to savings in engineering development, certification and flight tests, as well as equipment costs. Maintenance would be reduced over a conventional system, and performance would be improved. In wind shear conditions such as those causing the Eastern Airlines flight 66 crash at Kennedy airport in 1975, the Total Energy Control System (TECS) could be a life saver.

Advanced Controls for Light Twin Engine Aircraft. As a flight instructor, this writer attends a biannual Certificated Flight Instructor (CFI) Recertification Course to update and renew his certificate. A course instructor always reminds the CFIs that light twin engine aircraft are not so safe if an engine fails. Loss of an engine cuts the aircraft's climb rate by 80 percent. The extra speed of the air over the wing caused by an operational engine increases lift, and if the engine quits, some lift as well as thrust are lost. In such an engine-out condition, if the propeller is windmilling and the landing gear and flaps are down- -or for that matter, any one of the above- -a light twin cannot remain airborne (FAA, 1978, p. 1).

An engine failure is a major cause of fatal accidents for light twin engined aircraft. In 1983 Langley researchers conducted a piloted simulation study as the first phase of research to help solve the problem. The simulation aerodynamic model was a generic light twin engine airplane. The data for the simulation came from tests in Langley's 30-60 foot wind tunnel and flight data from two NASA owned aircraft. Langley's General Aviation Simulator (GAS) motion-based simulation cockpit had three degrees of motion and an out-the-window terrain board based visual simulation.

The first step explored the effects on engine out controllability and handling characteristics. Although the control input forces were found to be substantial, control was possible. The greatest difficulty was found to be the mental task of determining the “dead” engine. Multi-engine flight training teaches pilots to reduce drag by immediately identifying the inoperative engine and feathering the propeller as quickly as possible. This puts a high workload on a pilot who is now in a high stress environment. When the engine failure happens close to the ground, a fatal blunder can occur when the pilot feathers the wrong propeller. Most pilots in the study committed this type of blunder in the simulation.

A goal of this study was to evaluate automatic control systems to reduce the pilot workload in engine-out situations. With reduced workload it was expected that potentially fatal blunders would be reduced. In 1984 Langley researchers continued the research on engine-out safety problems for light twin aircraft. This study simulated the effect of total pressure sensors in the slipstream to compensate for the asymmetric power caused by the loss of an engine. The automatic trim system would sense any thrust differential and change the rudder, aileron, and elevator trim tab positions for the optimal trim condition. The aerodynamic simulation was developed using data from wind tunnel tests and qualitative flight tests using two NASA aircraft. The piloted simulation of a generic light twin was conducted in the Langley General Aviation Simulator. Research pilots reported reduced pilot workload and easier controllability using the automatic trim system. The system would be most useful and beneficial on takeoff where doing the proper thing quickly under high stress conditions can be the difference in life or death (Stewart, 1984, pp. 9, 10).

Advanced Instrumentation

The advances in display technology and in microprocessors created a revolution in aircraft display technology in the 1980s. The terms "glass cockpit" and Electronic Flight Instrumentation System (EFIS) became reality and common during the decade. Cathode ray tube (CRT) and other advanced display technologies became standard in the industry. At the beginning of the decade, there were electronic versions of the Attitude Director Indicator (ADI), and Horizontal

Situation Indicator (HSI), the electronic ADI or EADI and EHSI. At the end of the decade, there were Primary Flight Displays (PDF's) and Flight Management Systems.

"Follow Me" Box Display for General Aviation. General aviation has always had an accident rate greater than air transport aircraft. Langley, in 1981, attempted to improve GA flight safety by developing a simplified method for precise enroute navigation or terminal area control of general aviation aircraft by integrating microprocessors with advanced displays to provide a pictorial path-in-the-sky display format (Adams, 1981, p. 26).

The usual pictorial display of flight path information in the terminal area is an extended line from the aircraft symbol to be followed by the pilot. The "Follow Me" box provided simplicity with more information along with providing a target equivalent to a flight director signal. The "Follow Me" box's three dimensional shape provided very sensitive indications of small displacement errors. If you could see the top, bottom, or sides of the box, then you were off course. Roll information was provided by the square shape of the box, and the box location provided pitch and heading information.

All information for the control of the aircraft was provided by the box symbol. The pilot tried to fly into the box. By shortening the distance, the box was in front of the aircraft, for tighter control of the aircraft. The two box format was tested and documented in a general aviation context both in simulators and flight tests. Using a "Follow Me" box located four nautical miles ahead of the aircraft, a pilot was offered relative ease in finding and following the correct flight path. A final approach box located 300 meters ahead of the aircraft provided precise control of a curved, descending final approach to a 30 meter decision height (Adams, 1981, p. 26).

Possibly because of NASA's decision to do away with its general aviation program, this effort to improve the safety of GA aircraft was not continued (Czaplyski, 1993, p. 68). By 1989 Langley was again concerned with GA safety and the fact that GA and air taxi operations comprised 74 percent of all air traffic operations (Wallace, 1993, p. 67). This time the goals were to develop new flight control and display systems and to reduce initial training and recurring practice requirements (Stewart, 1989a, p. 19).

<ins>Highway in the Sky (HITS), & "Ez Fly" System</ins>. As mentioned before, GA has always been the least safe way to fly. Part of the problem has been the low time experience of most general aviation pilots. Also, many general aviation pilots do not fly regularly, and recent experience is necessary for proficiency. Researchers using Langley's General aviation Simulator (GAS) developed new flight control and display concepts to make flying more user friendly and intuitive. The pictorial display was a Highway In The Sky, or HITS, at first complete with a road and lane markings, a horizon line, and even telephone poles along the right side. The telephone poles were an altitude cue. The reason for the highway was the belief that for GA to recover and thrive, flying must use the same motor skills as

those used in driving (Wallace, 1993, p. 66). It sounds like a video driving game, but it worked. And no quarters were needed!

The test subjects ranged from NASA research pilots to nonpilots. With no practice to emphasize instinctive reactions, each pilot flew two runs using HITS as a head-up display (HUD).

HUDs are projections, focused at infinity with images or data in the line of sight of a pilot so he can see as he looks forward through the wind screen. The first run used a decoupled fly-by-wire control system called Ez-Fly. The Ez-Fly system has responses that resemble an automobile. Flight director arrows guide the pilot to the center of the “highway” unless displaced by higher priority messages (Stewart, 1989b, 92).

A test subject, on a first attempt without any training, made a takeoff, flew a race track type path through simulated clouds, and made an acceptable landing. Then using the one flight experience, the test subject flew the conventional control system, but using the HITS display, completed about 75 percent of the flight. But it crashed short of the runway. Many nonpilots could fly takeoff to landing with both EZ-Fly and HITS, but most crashed using conventional controls and HITS (Stewart, 1989b, 93).

In the March, 1993 issue of AOPA Pilot, Bruce Holmes, Assistant Director of Aeronautics at Langley Research Center, was quoted as saying a “technical revolution the likes of which we haven’t seen in the history of mankind” might turn around the prospects of general aviation. (Wallace, 1993, p. 65) The EZ Fly/Highway In The Sky display, illustrated in the article, resembled a marriage of the “Follow Me” box and the Highway in the Sky.

Localizer Needle Display Enhancement. Langley Research Center was researching advanced displays in 1980. An enhancement to the localizer needle of the Instrument Landing System was developed as an aid to general aviation (GA) pilots. GA pilots can land as well as airline pilots when the weather is bad and the clouds are low by using an instrument landing system (ILS) approach. For the airline pilot the approach is usually accomplished by the autopilot. For smaller aircraft, the instrument approach is flown manually.

A standard instrument landing system (ILS) is composed of two parts. The glide-slope function tells the pilot whether he is on the correct line and angle to get to the runway at the proper position to land safely. The localizer tells the pilot whether he is on the runway center line. The ILS indicator display presents only deviation in the form of a needle deflection. There is no rate of deviation for either glide-slope or localizer. The lack of deviation rate information increases the pilot workload and decreases tracking performance.

The closer the pilot gets to the runway the more sensitive the ILS display, and often wind shear changes wind speed and direction leading to pilot induced oscillations (PIO) - -the results of which can be a missed approach or a crash.

The required heading changes for maintaining or regaining the localizer are found by trial and error, and they can vary as the aircraft descends into changing winds. The Langley designed pseudo command tracking indicator (PCTI) is an enhancement of a standard ILS display with a rate needle attached to the end of the localizer needle. "The display is configured so as to present raw deviation data, localizer deviation rate, and a pseudo turn command" (Hinton, 1980, p. 18). The farther the localizer rate needle is from the centerline, the greater the turn needed to achieve the center line. In a simulation study, eight pilots flew five approaches with the conventional display and then five approaches using the PCTI. The average rms tracking error using the PCTI was about half the error using the conventional display.

<u>Stall Speed Indicator</u>. Ames Research Center developed a system in 1980 to supply the pilot with a continuous display of indicated stall speed. The stall speed indicator developed at NASA Ames utilized measurements of :

- normal acceleration
- aircraft configuration
- engine power
- atmospheric measurements
- and known aircraft characteristics.

The stall speed indicator, when co-located with the conventional airspeed indicator, gives the "pilot instantaneous information as to his safety margin from stall" (Jackson, 1980, p. 38). It was concluded, that with this system a conventional audible stall warning sensor was not needed on the aircraft. This writer disagrees because it would add to the workload. When tested on a Cessna 402B aircraft, the system gave reasonably accurate stall speeds for normal and accelerated stalls. The differences between actual and indicated stall speeds was usually within two knots and never off more than four knots (Jackson, 1980, p. 38).

Cockpit Display of Traffic Information (CDTI) LaRC

One afternoon years ago on approach to Roanoke, Virginia's Woodrum Airport runway 33, this writer was vectored to a straight-in approach ahead of a Learjet. Since he was in a much slower Beechcraft C-23 Sundowner, the approach controller was asking for more speed and generally trying to hurry things along. Finally, the hand-off to tower was given. "Contact tower now on one-one-eight-point-three." This writer tried again and again but received no acknowledgment. By then he was on about a three mile final and he heard the tower acknowledge the Learjet. Another attempt to contact the Roanoke tower failed, and then a Cessna C-150 two place trainer, lower than the Beechcraft, cut in front turning onto final approach. This was enough, and a go-around was announced with the Sundowner continuing on the runway heading. In a minute or two tower finally acknowledged and apologized for the mix-up. This event convinced the writer it sure would be nice if the pilots knew what the controllers know.

In the 80s decade, there were two NASA developed displays called Cockpit Display of Traffic Information (CDTI). The CDTI developed at Ames Research Center was a 3-dimensional symbolic display. A top view pictorial display with the same name was developed at Langley Research Center.

In 1980 Langley and the FAA, in a joint program, investigated the benefits of a flight crew knowing the positions of surrounding traffic. The traffic display presented an overhead view of aircraft positions, and computers generated previous and expected future flight paths of all traffic, as well as weather and ground runway traffic. The instrument for the display was the electronic horizontal situation indicator (EHSI) found in all air transport type aircraft.

Electronic displays and uplink/downlink data-links were necessary for the Cockpit Display of Traffic Information (CDTI) to be feasible. Thus the system could not be implemented until mode-S transponders became operational. Flight tests were flown using NASA's TCV Boeing B-737 research aircraft. The results showed a substantial increase in the "flight crew's overall situation awareness and provided ample lead time for detecting and resolving conflicts" (Hatfield, 1980, p. 12). Also it was found that monitoring the CDTI did not adversely affect other crew tasks. Other potential benefits noted were a possible increased airway capacity and greater operational efficiency. As this was being compiled in January 1993, the writer could not escape reminders of the mid-air collisions in the time since this research was done. The Cerritos Mid-air collision and the runway collision at LAX, Los Angeles International Airport, when an airliner landed on top of a commuter airplane on its takeoff roll are two examples of accidents that might have been prevented by CDTI.

Cockpit Display of Traffic Information (CDTI) Ames

Ames conducted a series of studies in 1981 to examine the types of evasion maneuvers pilots would make in different conflict situations. The two-dimensional top view cockpit display of traffic information was used to compare pilot intuitive maneuver decisions with those of automatic collision avoidance algorithms. These algorithms were designed to "maximize the minimum miss distance between aircraft" (Ellis & Palmer, 1981, p. 35). Pilots intuitively maneuver to reduce the time to resolve the conflict even if that takes them across the collision course. These conflicting decision patterns enhance the potential of pilot errors.

In 1982 Ames developed a three-dimensional prospective display to show vertical as well as horizontal traffic conflict information. The display shows traffic from a point above and behind a pilot's own aircraft. The pilot's aircraft is shown as a fixed symbol, and the traffic moves around it. In comparing pilot's composite avoidance maneuvers with the perspective display and the mostly horizontal maneuvers of the plan-view display, a bias due to the display appears to affect the chosen avoidance maneuver. Using the perspective display, decisions were made 10 to 20 percent faster. Also, the perspective display reduces the pilot's perception of a collision threat which lessens the number of avoidance maneuvers selected (Ellis & Palmer, 1982, p. 18). One concern was "the fear that its presence might give the pilot greater autonomy and opportunity to question or ignore air traffic control commands" (Stokes & Wickens, 1988, pp. 393, 394). To this writer, this sounds as if the "mushroom" method of management is preferred by air traffic control. Another concern was whether the display would add to the pilot workload and decrease outside scan time.

Traffic Alert and Collision Avoidance System

In 1986 Ames Research Center became the clearing house for the FAA's airborne Traffic Alert and Collision-Avoidance System TCAS. TCAS is a stand alone system that can detect the presence of another transponder-equipped aircraft near enough to be a collision threat. TCAS I provided a visual display showing relative position, distance, and altitude of the other aircraft. The Ames' TCAS II study evaluated the closure rates and flight geometry of the other aircraft relative to itself, and if a collision threat was calculated, issued visual and verbal vertical maneuver information to the pilot. TCAS III will, when implemented, also include lateral maneuvers.

The Ames/FAA program involved close cooperation among avionics manufacturers, airlines, the Air Transport Association (ATA), the FAA, and NASA. TCAS algorithms were provided by MIT's Lincoln Laboratories. ATA supplied the display hardware used, and flight crews were supplied by the ATA member carriers in the FAA's Limited Implementation Program. Ames supplied a full-mission flight and Air Traffic Control (ATC) simulation under a variety of conditions. "The principal independent variable is the amount of information to be provided to flight crews concerning traffic encounters" (Billings & Chappell, 1986, p. 44). The initial data collection was made in early fiscal year FY-87.

1987 saw TCAS coming closer to deployment. Ames Research Center continued the evaluation. The Federal Aeronautics Administration (FAA) developed TCAS in safe, controlled, realistic operational situations where a comprehensive set of conflict scenarios were simulated. NASA, the FAA, and the industry conducted full-mission simulations of the TCAS II system which provides vertical guidance only. The simulations showed "a significant potential for increased safety in flight by reducing the number of unsafe separation situations" (Chappell & Scott, 1986, p. 41). Pilot response time was quicker than the five second design specification, but excessive altitude deviations observed could cause operational problems.

The Ames/FAA program continued through 1989 during which Ames researchers and current airline crews conducted experiments that explored:

1. TCAS II with part and full-time traffic display, and with no traffic display, just maneuver information;
2. pilot performance with and without target areas displayed on the vertical speed indicator;
3. pilot execution of the commanded maneuvers in different aircraft performance regimes (Chappell, 1989, p. 53).

Diagnostic Expert Fault Monitoring System

In 1988 Langley researchers developed an onboard fault monitoring and diagnosis system using artificial intelligence to aid crews of air transport aircraft. The prototype, called "Faultfinder," detected and diagnosed failures in engine and hydraulic systems of a generic aircraft. The two-stage system used rules to diagnose known faults and model-based reasoning to diagnose unknown faults.

Using eight accident cases, the faults were reconstructed to produce a simulation of the accident. The expert system used simulations to produce hypotheses of the probable cause. These hypotheses were compared to the actual cause as determined by the NTSB. The system correctly diagnosed seven of eight cases. The first stage diagnosed two of seven test cases, both on turbine blade separation. Stage two correctly diagnosed two fan failures, one each on engine separation, foreign object damage (FOD), and a bearing failure. Multiple hypotheses were given in several cases (Schutte, 1988, p. 78).

Takeoff Performance Monitoring System TOPMS

Several fatal accidents on record have dealt with flight crew attempts to continue a takeoff when the aircraft was not performing properly. The crash of an Air Florida B-737 at Washington National Airport January 13, 1982 and the Delta B-727 crash at Dallas in 1989 are examples. The Air Florida crash was due to the engines being set at less than normal takeoff thrust due to a partially blocked probe creating false high thrust readings (Foushee & Helmreich, 1988, p. 195). At Dallas the Delta crew failed to set the proper flap position. In both cases the crews failed to make a decision to abort when the aircraft could not takeoff. Neither captain recognized there was a problem.

The Takeoff Performance Monitoring System (TOPMS) would provide the crew with information on how the aircraft was performing, “information pertinent to their decision to continue or reject a takeoff” (Middleton & Srivatsan, 1987, p. 57). An algorithm was developed to compute, organize, and send takeoff performance data to the electronic horizontal situation indicator EHSI as a head down display. This navigational instrument could be used for this display during the takeoff phase of a flight. The TOPMS display provided a runway graphic overlaid with predictive and advisory information using symbols and numeric information. The information included:

- current position on the runway,
- current indicated air speed,
- predicted location where decision speed (V1) would be reached,
- predicted location where rotation speed (VR) would be reached,
- balanced field length and ground roll limit for reaching VR,
- predicted stop point for abort from current conditions,
- engine failure flags,
- and an overall situation advisory flag.

The overall situation flag recommended continuation or rejection of the takeoff. One of the abort flags was a familiar red octagonal stop sign (Middleton & Srivatsan, 1986, p. 49).

Thirty two professional pilots evaluated the TOPMS display in Langley's Transport Systems Research Vehicle (TSRV) real-time simulator. The pilots used a rating scale having a range from "1" meaning excellent, to "10" for unsuitable. The criteria for evaluation "included credibility, ease of comprehension, suitability for task, and pilot comments" (Middleton, 1986, p. 49).

A test evaluation consisted of twenty takeoff simulations where the pilot flew, and twenty where the pilot was not flying but was monitoring the takeoff. Test conditions simulated runway conditions that varied from dry to wet to slushy. Used were a range of ambient temperatures, pressure altitudes, and runway lengths. Degraded acceleration performance including engine failure was simulated.

The overall rating was 2.92 where 3.0 was good. Comments and suggestions were being incorporated into a revised display. In an interview in 1987, David Middleton mentioned that the professional pilots had positive comments about the information given but did not like the rejection advisory, especially the stop sign. The pilots felt that the abort decision was theirs to make. The pilots who flew as two-man crews also recommended that the pilot not flying should have primary display monitoring responsibility, and the pilot flying should have a simplified head-up TOPMS display. This was implemented in a follow-up study with 17 pilots whose "ratings and comments were quite favorable" (Middleton & Srivatsan, 1987, p. 57). The head-up display tested in 1987 was a simplified version of the head-down display previously tested. The HUD and head-down display were tested by 17 invited pilots who rated them good to very good. They liked the system because it displayed needed information in a form that made for quick and easy comprehension (Middleton & Srivatsan, 1987, p. 60).

During the TOPMS research program, TOPMS displays were flown by 41 pilots from the United States Air Force, NASA, airlines, Federal Aeronautics Administration (FAA), and industry pilots. The Transport Systems Research Vehicle (TSRV) B-737 simulator was used for all the simulated flights. The general feeling of the evaluation pilots was the display would require low mental effort and would provide critical information for takeoff/abort decisions. The TOPMS system was later flown in the head-down version on board NASA's B-737 (Middleton, 1988, p. 74).

This writer regrets that the TOPMS display, which might have prevented the Air Florida accident in Washington, the Delta accident in Dallas, the Continental accident in Denver, and the USAIR accident in New York, may be dead from a fear of product liability lawsuits.

Crashworthy and Fireworthy Structures Research

Impact Dynamics Research Facility. For several years Langley Research Center has researched crashworthy structures. The most famous program was the general aviation crash tests of the 1970s. The Impact Dynamics Research Facility at Langley Research was originally an astronaut training facility for the Apollo Lunar Program for Lunar landing simulations.. The structure is an A-frame 230 feet high and 400 feet long. For impact dynamics studies, full scale

scale aircraft were supported by cables and swung pendulum-style onto the concrete runway below.

The two cables pivot point was at the 217 foot level and the aircraft were pulled back to a height determined by the test. Just before impact the cables were released by pyrotechnics and the aircraft swung pendulum-style into the ground. It was possible to change the angle of impact from 0° to about 60°. Air speeds varied up to 65 mph by varying the pullback height. With rocket assist, speeds up to 95 mph were possible.

The pitch, roll, and yaw were varied by changing the support cable harness. Data from onboard instrumentation was transmitted to the control room by hard-wire through an umbilical from the crash aircraft, up through the A-frame support structure. Photo data were obtained by still and motion picture cameras mounted above the A-frame, ground cameras, and cameras mounted inside the crash test aircraft.

Analysis of Crash Impact Dynamics. During the series of crash dynamics tests, “a simplified analysis of the complicated crash scenario was developed based on impulse-momentum relationships” (Carden, 1983, p. 67). A triangular acceleration time impulse was assumed, and the analysis and crash test data agreed closely. As a result of the crash dynamics program, the National Transportation Safety Board undertook a program to identify a range of accident scenarios where it may be possible to design for passenger survivability.

Load Limiting Subfloor Structure. Since 1972, Langley Impact Dynamics Research Facility researchers have conducted a full-scale crash test program that included 32 general aviation aircraft, two air transport tests and tests using USAF F-111 escape modules. One of the findings was that forward forces were not the real killer in aircraft crashes. The real killer is the vertical forces on crew and passengers when the aircraft “slaps down” on impact. A human can withstand 45 Gs horizontally, 25 Gs vertically, and 20 Gs laterally (Ethell, 1986). This NASA Langley study involved the design and construction of five load-limiting structures

> “ . . . to dissipate kinetic energy by appropriate structural arrangement, astute shaping of geometry of structural elements, or incorporating clever energy dissipating devices”(Carden, 1980, p. 17).

The structural concepts would replace a currently used subfloor structure. The floor structure itself would still be strong to maintain the aircraft and seat integrity. The subfloor would collapse in a controlled manner to absorb the loads in the event of a crash. One of the more promising modified structural concepts was a ”notched joint” sine-wave shaped aluminum subfloor structure that supposedly reduced vertical loading to 18 Gs (Carden, 1980, p. 17). A sample of this structure is in the possession of this researcher.

Test results of the five specimen structures indicated they performed as hoped with the floor remaining intact throughout the loading. The crush-type structure collapsed at a load level below a standard structure with a uniform magnitude throughout the test.

Later dynamic drop tests were conducted with vertical velocities up to 9 meters/second (Carden, 1980, p. 17).

Vertical Drop Test of Boeing 707 Fuselage Section. In 1983, to "determine structural, seat, and occupant response to vertical crash loads," (Williams, 1983, p. 66) a 12 foot, 5,000 pound, section of a Boeing 707 was dropped vertically at the Langley Impact Dynamics Research Facility. The research was in preparation of the Controlled Impact Demonstration (CID) program. In the CID program a Boeing 720 was flown by remote control to a "controlled" gear up landing on the desert floor at Edwards Air Force Base.

The height was adjusted to give a vertical speed of 20 feet per second. The fuselage section was loaded with seats, anthropomorphic dummies and instrumentation. The drop caused the fuselage beneath the floor to collapse inward approximately two feet. "Bending failures occurred along the centerline of the baggage compartment floor and on both sides of the fuselage about four feet below the floor" (Williams, 1983, p. 67). The upper fuselage, cabin floor, and seats suffered no apparent damage. The crushing of the lower fuselage prevented undue forces to be transmitted to the cabin floor. The vertical pelvic accelerations experienced by the anthropomorphic dummies ranged from 6.5 Gs to 8.0 Gs. These accelerations were well below the accepted value of 25 Gs for neck or back fractures.

<u>Structural Analysis of Jet Transport Controlled Impact Demonstration</u>. In 1986 Langley researchers conducted a study to model jet transport crash dynamics by comparing pre-impact scenarios of the Controlled Impact Demonstration (CID) with actual CID data. Langley worked in cooperation with the Federal Aeronautics Administration (FAA) and Boeing Commercial Airplane Company.

NASA Langley Impact Dynamics Branch and the FAA attempted to "quantitatively assess jet transport airplane crash dynamics using nonlinear dynamic finite element computer codes" (Fasannella, 1986, p. 79). Experimental data came from the FAA/NASA Controlled Impact Demonstration (CID) remotely-piloted Boeing 720 jet transport instrumented with more than 350 crash sensors.

Boeing used a hybrid finite-element airplane crash model DYCAST (DYnamic Crash Analysis of STructures) developed by Grumman under a NASA Langley contract. Three transport fuselage sections were dropped vertically with impact velocities of 20 feet per second from Langley's Impact Dynamics tower. These tests were modeled and analyzed using DYCAST. This was to provide nonlinear subfloor crush springs for the CID model.

It was planned that the CID impact would be fuselage first with wings level. That was not the case. The number one engine on the left wing impacted first, with the aircraft in a thirteen degree yaw to the left. The anomaly was caused by an oscillation in roll. The resulting impact was not as "controlled" as the researchers had hoped. There was a spectacular fire. It lasted only 10 seconds, and because of the antimisting fuel it was only half as hot as a normal fire. The problem was that the "half as hot" was 700° F and a passenger could not be half as dead. The DYCAST prediction of a maximum G loading of 17 near the nose and a minimum of five in the tail area of the B-720 was close, but high in comparison to the CID data. This may have been a result of the rolling motion introduced by the aircraft not impacting with the wings level.

However, NASA Langley researchers were pleased with the agreement between the DYCAST model results and the CID experimental data. They found the model to be useful and valid for assessing the crash dynamics of large transport aircraft.

Crash Tests of All-Composite Helicopter Structures. In 1987 in support of the United States Army's Advanced Composite Airframe Program (ACAP), researchers at Langley's Impact Dynamics Facility tested two fully-instrumented, all composite, full-scale helicopter airframes. One airframe was built by Bell Helicopter Textron, and the other was a Sikorsky Aircraft structure. The experimental utility helicopters used advanced composites in both primary and secondary structures. Primary structures are strength-critical, and secondary structures are stiffness-critical.

The Sikorsky ASAP airframe was dropped vertically with a flight path velocity of 38 ft/sec, 10° right roll, and 10° pitch up attitude. The Bell ASAP airframe had a flight path angle of -57°, a flight path velocity of 48.1 ft/sec, and the same pitch and roll angles as the Sikorsky ASAP. Initial evaluation indicated the survivable load and structural integrity criteria were met (Carden, 1987, p. 92).

Static Response of Composite Floor Sections. Also in 1987, Langley researchers conducted a program to test the crashworthiness of primary composite fuselage structures. Composite materials have been used for years for secondary, or stiffness-critical structures. Primary or strength critical structures of advanced composites may be used in some next generation aircraft. Experimental and analytical studies of the crashworthiness of composite structures were conducted using two circular 6-foot diameter graphite/epoxy subfloor sections with identical skeletal frameworks. One section had a graphite/epoxy skin bonded and riveted to the framework and stringers. The skinned specimen had about one forth the load deflection as the non-skinned frame.

The crash computer program DYCAST (Dynamic Crash Analysis of Structures) was used to predict the load deflection response, and the best correlation for the skinned section did not include out-of-plane or twisting displacements. For the non-skinned frame the best analytical/experimental correlation occurred when the frame bent out of plane but did not twist (Carden ,1987, p. 120).

Fireworthy Structures Research

Fire-Blocking Mechanisms for Seats. In 1982 Ames Research

Center developed aircraft seat cushioning that was fireworthy by the use of fire-blocking mechanisms. Aircraft seats should be as fire resistant as possible while providing maximum fire protection with minimum weight. It was found that aluminized thermally stable fabrics used with urethane foams had low weight and were cost effective. To determine cost effectiveness a full scale model and computer-based algorithm were developed and tested at Douglas Aircraft. The study concluded polyurethane-based cushions with a fire blocking layer were the most desirable (Kourtides, 1982, p. 66). Of course, the most desirable cushioning material would not have any polyurethane. In a fire, polyurethane foam emits lethal hydrogen cyanide gas as well as other toxic vapors.

Fireworthy/Crashworthy Seat Cushioning. In 1986 Ames developed a comfortable aircraft seat with energy absorbing characteristics without using polyurethane foam. Ames researchers invented a crashworthy seat using elliptical spring supports made of graphite-epoxy surrounded by a fire-resistant polyimide belt. “Crashworthy characteristics are imparted to the cushioning by incorporating a layer of energy-absorbing visco-elastic layers between the nested, elliptical strings (sic)” (Haslim, 1986, p. 32). Note: the word “strings” should be “springs.” Not only was the seat fire-resistant and energy-absorbing, it was easy to make and maintain. It was lightweight and structurally strong.

By 1988, the Ames-developed fire-retardant aircraft seat cushioning had been patented. The cushioning was developed for aircraft seating but the concept also attracted interest from the automobile industry. Several airline and automobile companies requested prototypes of the cushioning for evaluation, and three Fortune 500 material companies have applied for manufacturing licenses to produce the cushioning (Haslim, 1989, p. 8).

Lightweight, Fire-Resistant Aircraft Interior Panels.

Prior to 1990 aircraft interiors were built primarily of epoxy resin and fiberglass. It was well known these materials emitted large amounts of heat, toxic gases, and smoke when exposed to fire. In 1983 NASA Ames Research Center, in cooperation with the FAA and several commercial companies, developed aircraft panel face-sheets that were lighter than fiberglass panels used at the time and were more fire-resistant. The research was done in cooperation with:

- Federal Aeronautics Administration (FAA)
- American Cyanamid (resin development)
- Hercules, Inc. (prepreg graphite fiber)
- Douglas Aircraft (decorative film development)
- Lockheed Corp. (decorative film development).

The advanced panel was faced with graphite fiber sheets impregnated with polystyrylpyridine (PSP) resin. The panel was tested and compared to a baseline epoxy glass panel and a phenolic-glass panel. The three panels were subjected to a heat flux of 5 watts per square centimeter. The epoxy glass and phenolic glass panels were destroyed, but the advanced panel showed almost no damage.

Large scale panels were constructed using a modified PSP resin and tested in the FAA's C-133 at the FAA Technical Center at Atlantic City, NJ. The use of the graphite/PSP panels would save approximately 500 pounds in each wide-body aircraft, and reduce fuel by 2.5 million gallons per year for a 300 aircraft wide-body fleet (Kourtides, 1983, p. 49).

By 1989 the FAA enacted requirements that aircraft interiors meet maximum heat-release rate and total heat release of 65 kW/m^2 and 65 $kW\text{-}min/m^2$ respectively. In a cooperative program between Ames Research Center and the FAA, materials similar to the 1983 materials were developed to meet the standards. The materials use graphite fibers and a resin matrix of bismaleimide/vinylpolystrylpyride (VPSP/BMI) at a ratio of 65/35. The newly developed resin cured at 177° C, in the conventional curing equipment (Kourtides, 1989, p. 170).

Antimisting Kerosene

Prevention is probably the best way to protect against fire damage. A fire prevention program spanning the 1980s used antimisting kerosene research. In 1980 Lewis Research Center, the FAA and Pratt Whitney Aircraft Group evaluated Jet A fuel additives to inhibit break up of fuel into tiny droplets or mist in an airplane crash. Jet A is the standard aeronautics jet fuel, and it is kerosene. The fuels with these additives are generically called antimisting kerosenes, or AMK. The misting of jet fuel is the cause of the deadly fires often accompanying airplane crashes. However, these additives do not work in engine combustors. The NASA Lewis role in this study was to help make the jet engines and antimisting kerosenes compatible.

Although several additives were developed and evaluated by the FAA, AMK additive FM-9, developed by the Imperial Chemical Industries and the Royal Aircraft Establishment of Great Britain, was chosen for testing in engine fuel systems. "AMK additives are large polymeric molecules with molecular weights of about 5 million" (Schmidt, 1980, p. 4). These large molecules are very resistant to misting, but cannot be burned in jet engines. They must be broken down or degraded before the fuel can be used in jet engines. To accomplish this the undegraded AMK is subjected to repeated mechanical shear forces to make the fuel compatible with jet engines. This writer was at NASA Dryden Flight Research Center (DFRC) in May 1984, just before the Controlled Impact Demonstration (CID), when Rogers Smith, a NASA research pilot, told him of the problems with degrading the AMK kerosene and of the delay it was causing. The joke around Dryden was that CID should mean "Crash In Desert." This was a prophetic belief.

The AMK fuel would store in the aircraft fuel tanks and then flow through degraders before being introduced in the jet engine combustors. Thus the bulk of the fuel would be in the undegraded form in the event of a crash, and it was hoped this would prevent the tragic conflagrations that too often occur in air transport crashes. Lewis contracted with Pratt & Whitney Aircraft Group of United Technologies Corporation (UTC) to:

- develop methods to degrade AMK,
- and evaluate the effect of degraded AMK on the performance of the fuel system of the JT8D engine.

The results of the test program showed that it should be possible to operate JT8D engine on degraded FM-9 AMK fuel, if practical methods of degrading the AMK could be developed. Additional testing was suggested to determine the long term effects of AMK on fuel systems. This research was four years in advance of the CID program in 1984 (Schmidt, 1980, p. 4).

General Aviation (GA) Safety Research

General aviation is the term applied to all aircraft activity which is not military or scheduled air transport. This activity includes everything from a yellow Piper Cub flown out of a farmer's pasture, to a 22.35 million dollar Falcon 900 that will take a Fortune 500 executive across country nonstop. It also includes non-scheduled air-taxi operations. According to 1990 AOPA figures, general aviation aircraft, after a decade of decline, flew twice as many hours as air carriers, carried almost a quarter of the passengers flown, and used less than ten percent of the fuel. Air carrier aircraft make up less than three percent of the active aircraft in the civil fleet. The decline in general aviation in the 1980s can be shown in the loss of more than 100,000 pilots during the decade and a decline in aircraft shipments from almost 12,000 in 1980 to just over 1,000 in 1990. Statistically, general aviation is a very large part of aeronautics.

During the decade of the 1970s, general aviation aircraft sales experienced a boom, and NASA dedicated a general aviation research program. But in 1981, NASA made a conscious decision to do away with its general aviation program (Czaplyski, 1993, p. 68). NASA general aviation research trailed off to isolated studies as the 80s rolled by. Not only did NASA general aviation programs dry up, but as noted above, the same happened to the U.S. general aviation industry.

When this writer instructs at Certificated Flight Instructor (CFI) recertification courses, interesting discussions arise among flight instructors over why general aviation is dying in this country. Product liability is usually the *cause célèbre* named by most CFIs. Lawyer CFIs in attendance blame insurance companies. CFI insurance people blame lawyers. This writer points to a litigious society and any blame is well described by Walt Kelly's Pogo character. Pogo said, "We have met the enemy, and he is us."

NASA Daniel Goldin, at the Experimental Aircraft Association's National Convention in Oshkosh, committed NASA to giving aeronautics the attention it deserves. He followed up with the establishment of a NASA Aeronautics Advisory Committee Task Force on General aviation Transportation (EAA, 1993, p. 10). General aviation was nearly dead at the end of the 1980s. But maybe like the movie alien E.T., it will revive. As a general aviation pilot, this biased writer has sincere hopes.

Stall/Spin Research. Langley's 20-Foot Vertical Spin Tunnel is the only operational spin tunnel in the United States, and there is only one more in the free world. It operates as a free spin tunnel, is powered by a 1,300 horsepower main drive and has a closed throat annular return. The 25-foot tall test section has 12 sides and is 20 feet across. Tunnel speeds are variable from 0 to 90 feet per second. Spin recovery characteristics are studied by remotely actuating the aerodynamic controls to predetermined positions. Its actuators, like spring loaded mouse traps, move immediately to the anti-spin position. Video or motion picture records are used to record the spin and recovery characteristics.

For ten years, NASA Langley's Stall/Spin Research Program worked to improve the spin resistance of light aircraft. Stall/spin accidents are a leading cause of fatal accidents for general aviation aircraft. The majority of these fatalities occur from an inadvertent stall and resultant "departure from controlled flight" (Stough, 1983, p. 15) at low altitude. In 1980 Langley researchers conducted a study to improve flight safety by predicting potential spin modes using on-line predictions with rotary-balance techniques. The 20 foot spin tunnel at NASA Langley was once the only way to measure "an airplane's aerodynamic characteristics in the rotational flow environment of a spin" (Chambers, 1980, p. 15). The rotary balance used with the mini-computer made it possible to measure aerodynamic forces and moments for a model over the expected range of variables in a spin and immediately predict spin modes. Having the instantaneous analysis greatly speeds up the process of determining "spin modes, recovery control effects, airframe component effects, and parameter sensitivity studies" (Chambers, 1980, p. 15). When used with the spin tunnel tests, a better understanding of an airplane's spin characteristics can be obtained.

Spin Research Rocket System. In full-scale stall/spin studies in 1980, Langley developed a spin recovery system using hydrogen peroxide rockets mounted on the wing tips of light aircraft. The system, tested on a Beechcraft C-23X Sundowner, can retard the spin rate, thus providing recoveries from fully developed spins. It also can increase the spin rate and can generate spins at very high angles of attack. This allows the exposure of all possible spin modes of the aircraft. There may be spin modes encountered at higher angles of attack than those achievable with standard airplane controls. If there is a hidden spin mode, this system is capable of finding it (O'Bryan, 1980, p. 18).

All aircraft tested in the stall/spin program had exits on both the right and left fuselage sides except the prototype Piper Arrow IV. In the event of a non-recoverable spin and the failure of the anti-spin parachute used for recovery, it might have been impossible for the research pilot to exit the airplane. So in 1981, Langley researchers designed an emergency egress system usable in any type of aircraft by allowing designers to create an opening anywhere on the fuselage of the aircraft. "The system is very stable and is activated by predetermined positive actions" (Bement, 1981, p. 23). The system works in the air or on the ground and improves chances for exiting the aircraft in an emergency. It can be used on any aircraft whether military, commercial, or general aviation.

The system, when activated, creates an opening and automatically ejects the structure. (It is not like an airliner emergency exit where someone must open the exit and then find some place to put the door.) The system was used on the NASA Langley prototype Piper Arrow IV in NASA's stall/spin test research program.

The system, designed so it could be an add-on, cuts the aircraft skin and creates a square opening approximately 76 cm (30 in) on each side. An external frame outlines the area to be cut. The metal is cut using a very small amount of explosive. The needed quantity is less than 11 gm (0.4 oz). The system is actuated by a single pull of a handle (Bement, 1983, p. 24).

The explosion cuts the skin around the window to the floor, and on the Piper Arrow, it also cuts the central stringer. The opening is "neat and smooth" (Bement, 1983, p. 24). The explosive pressure wave hits the external frame jettisoning it. The panel is jettisoned at a speed of 13.7 m/sec. That is 45 ft/sec or about 30 mph. There is a protective internal structure to contain all by products of the explosion including pressure and sound. The explosive pressure expansion is within the 3.8 cm (1.5 in) depth of the Piper Arrow. A wire mesh keeps the pilot window from entering the cockpit. The add-on weight is less than 6.3 kg (14 lb.).

NASA Langley says the explosive is completely insensitive to mechanical abuse, radio/radar transmissions, lightning, and static electricity. No maintenance is required, but the initiators should be replaced every five years. Safe to say of this system, if the pilot wants a door, there will be a door!

Discontinuous Wing Leading Edge. In 1983 Langley flight tested a sharp-discontinuous-wing leading edge that produced a large increase in the stall angle of attack of the outer wing. Thus, there is a significant improvement in aircraft spin resistance (Stough, 1983, p. 15). NASA, industry, and FAA pilots flew one airplane with the discontinuous-leading edge and identified the need to define standards for departure resistance and spin resistance. Spin resistance, as later defined by NASA and reported in Aircraft Spin Resistance Criteria, AIAA Paper No. 87-2562-CP, was, in essence, that the airplane will not spin even after it has stalled and that pro-spin controls are held for seven seconds or until a 360° heading change is reached. The spin tests were conducted using a Grumman American Yankee low-wing two place aircraft and a Beechcraft Be-23X Sundowner. Later tests used the prototype Piper Arrow IV and Cessna C-172.

> The summation of increments in angle of attack, due to maximum pitch control input, center-of-gravity location, power effects, and dynamic effects have been quantified and correlated well with the spinning tendencies (Stough, 1983, p. 15).

When Beechcraft added wing tip extensions with extra fuel tanks to their turbocharged A-36TC Bonanza model, it initially could not pass the FAA stall/spin certification tests. Beech engineers developed “dual vortex generators,” wedge shaped extensions on the

Bonanza wing leading edges that perform like the Langley discontinuous leading edge. A number of Beechcraft Bonanza models were later fitted with dual vortex generators to improve spin resistance.

Stall/Spin Resistance Criteria. Langley researchers in 1986 assisted the General Aviation Manufacturers Association (GAMA) in the development of criteria for spin-resistant airplanes. Non-spin-resistant airplanes develop rapid rolling and yawing motions near and beyond the stall. A spin-resistant airplane would respond to normal control inputs and resist these motions. The criteria were proposed to the FAA in an effort to change FAA's Federal Aeronautics Regulation Part 23 concerning stall/spin criteria for the design of a light airplane. Additional data were provided by data from Langley tests of NASA's Beechcraft C-23X Sundowner, "a representative four-place, single engine light airplane" (Stough, 1986a, p. 11). The NASA/GAMA spin-resistance criteria were proposed to the FAA in May of 1985. These criteria were proposed as an alternative to FAR Part 23 § 200 standards.

> The proposed criteria address these characteristics through assessment of lateral controllability during stalls, stall characteristics during uncoordinated flight, and overall controllability following sustained control abuse (attempted spin entries) (Stough, 1986b, p. 91).

The Beechcraft C-23X Sundowner, when tested with the basic wing, failed twenty two percent of the stall criteria tests and sixty seven percent of the spin entry tests. Using the drooped or discontinuous wing leading edge configuration, all tests were passed which showed the criteria are achievable.

The discontinuous leading edge and spin resistance criteria were developed through a complementary program of wind tunnel model tests, radio controlled model tests, and full scale airplane tests.

Wing leading edge modifications were "developed to improve high-angle-of-attack aerodynamic characteristics" (Stough, 1987, p. 14), and for "improved lateral stability and enhanced spin resistance" (Stough, 1987, p. 14). The technology was applied to the Schweizer SA2037A surveillance aircraft for improved low speed controllability, the prototype Devore 2-place Sunbird, and the OMAC 10-passenger Laser 300.

The spin resistance criteria developed by NASA Langley and the General Aviation Manufacturers Association were accepted by the FAA for certification of the LASER 300 and Sunbird. At the request of NASA and the FAA, selected pilots were familiarized with spin-resistant characteristics using a NASA spin-resistant research airplane.

Emergency Locator Transmitter (ELT) Reliability

Emergency Locator Transmitters were mandated by the U. S. Congress in 1970 with a deadline of 1974 (Likakis, 1986, p. 1). The serviceability and reliability history of ELTs has been poor to dismal. ELTs are supposed to activate if the airplane crashes. But they don't activate when they should and they activate when they should not. A NTSB report based on 1976 and 1977 reports stated ELTs worked as they should in only 10 percent of those accidents where they should have helped (Likakis, 1986, p. 2). Any FAA safety seminar or Civil Air Patrol member will quote false alarm rates above 95 percent, but the FAA, in Attention To ELT's Insurance to Life issued in June 1987, states that in the calendar year 1986, only 5,268 of 46,062 possible ELT signals in the 48 conterminous United States were actually distress signals. So only 88.6 percent of the ELT signals were false.

> Federal Aeronautics Regulation (FAR) 91.52 requires all U.S. registered civil airplanes, except turbojets, agricultural aircraft, helicopters, or trainers used exclusively within 50 miles of home base, and other airplanes used in scheduled operations under FAR 121, other than charter, to be equipped with Emergency Locator Transmitters (ELT) (FAA, 1970, p.1).

The emergency locator transmitters broadcast on the international distress frequencies 121.5 megahertz (MHz) and 243.0 MHz (Geeting & Woerner 1988).

In 1980 Langley researchers tested ELTs in full scale crash test aircraft and in a laboratory test apparatus that simulates crash pulses. The ELT inertia switches, often called "g" switches, have been found to be vibration sensitive. The ELT inertia switches resonant frequencies fall in a range from below 50 Hertz (Hz) to about 200 Hz. This is also the range of frequencies for local structural vibrations known to exist in general aviation (GA) aircraft. It is little wonder then that the ELTs tend to activate so easily in normal operations, but often do not activate in airplane crashes.

The frequency range of crash pulses is usually below 15 Hz. The NASA Langley study suggested a change in the frequency response characteristics of ELT inertia switches to make them sensitive to crash pulse frequencies. An experimental switch was built and tested with the correct resonant frequency response characteristics. The experimental switch was found to have desirable performance characteristics (Carden, 1980, pp. 16,17).

Ultrasonic Nondestructive Evaluation of Aluminum Alloys

Aluminum alloys will fail under low level cyclic stress loads. An increase in the number of fatigue cycles increases the probability of failure. The fatigue life of aircraft and the term "aging aircraft" hit the headlines when an Aloha Airlines Boeing 737 lost a large section of its upper fuselage over the Hawaiian Islands April 28, 1988. This accident led to the first-ever human factors program in maintenance (Foushee, 1989, p. 115). In the Langley study, nondestructive evaluation (NDE) techniques were used in this study, and the acoustic nonlinearity parameter ß´ was determined for fatigued and non-fatigued samples of 2024 aluminum. The fatigued samples showed a 100 percent increase in nonlinearity (Yost, 1988, p. 120). Thus, it would be possible to check for possible catastrophic fatigue during normal maintenance inspections.

Turbine Disk Crack Detector

On July 19, 1989, a United Airlines DC-10, on a flight from Denver to Chicago, was flying over Iowa when it experienced turbine disk failure. Turbine parts flying about severed hydraulic lines causing the loss of control to the tail surfaces. The crew almost made a landing at Sioux City, Iowa. There were 107 deaths.

Six years earlier in 1983, Lewis researchers developed a turbine disk crack detection system that consisted of:

> an eddy current sensor, and its cables within the engine, external connecting cables, and a remotely located electrical bridge and signal analyzer. As the turbine spins the rotor is monitored by the sensor for radial surface cracks emanating from the interblade region of the engine. (Barrenger, 1983, p. 9)

The sensor was placed 2.5 mm (3/32 in) from the downwind side of the first stage turbine disk. The first turbine stage is where cracks tend to occur. The system was tested on a small military engine that had a turbine disk with service-induced cracks. At ground idle the system detected cracks as short as 3 mm (1/8 in). The system performed well when operated in all normal engine operating regimes for over 25 hours, including 35 starts and stops. This writer has to wonder, what if?

The People - Human Factors

"Oh no, it wasn't the aeroplanes. It was Beauty killed the Beast"

(Creelman & Rose, 1933). Really, it wasn't Beauty, either. To paraphrase the familiar National Rifle Association refrain: airplanes don't kill people; people kill people. For the 10 years 1974-1983, 68.8 percent of all air transport accidents had the cockpit crew listed as the probable cause (Nagel, 1988, p. 265). As bad as that seems, commuter and general aviation statistics are more alarming. Pilot error has been identified as a contributing factor in 79 percent of commuter airline fatal accidents and in 88 percent of general aviation accidents. (Ott, 1988, p. 127) As might be expected, machine causes of aircraft accidents have decreased with availability of better systems, powerplants and navigation aids. But strange as it might seem with such improvements making airplanes easier to fly, human error is increasing as the cause of accidents. Billings and Reynard, as quoted by Nagel, called the human problem the last great frontier in aeronautics safety (Nagel, 1988, p. 266).

Man-Vehicle Systems Research Facility

The Ames Research Center Man-Vehicle Systems Research Facility (MVSRF) is a unique national research tool with the objective of studying basic human-factors issues related to human errors in the national aeronautics system. The MVSRF has two full-mission flight simulators. One is a Boeing 727-200 simulator, and the other is the Advanced Concepts Flight Simulator. Both simulators can work independently or interactively in the same airspace, using a simulated Air Traffic Control (ATC) system. Air-to-ground, multiaircraft, and full-mission scenarios can be flown with the capability to study man-to-man or man-to-machine interactions.

> The facility is used to conduct human-factors research on:
>
> 1. Development of fundamental analytical expressions of the functional performance characteristics of aircraft crews.
> 2. Formulation of design criteria and principles for environments of the future.
> 3, Integration of new subsystems into contemporary flight and air traffic control scenarios.
> 4. Creation of new training technologies that will be required by the continued technical evolution of flight systems and the operational environment (Styles, 1984, p. 67).

During the decade of the 80s, the MVSRF studied such problems as cockpit coordination and communications, later called resource management (CRM), automation, and the use of simulators in pilot training.

Aviation Safety Reporting System (ASRS)

The Aviation Safety Reporting System (ASRS) is a continuing program to improve safety by analysis of reports from pilots, air traffic controllers and others involved in aeronautics incidents. ASRS is concerned primarily with the quality of human performance in the aeronautics system. ASRS serves the aeronautics community, the Federal Aeronautics Administration, and the Department of Defense by providing a central focus for collecting, analyzing, and disseminating safety information derived from confidential reports of incidents and situations in the national system (Reynard, 1981, p. 34).

> The ASRS program is unique among aeronautics reporting systems. Its special qualities include the following:
>
> 1. proof of the concept of acquisition, analysis, and use of incident data,
> 2. unique methodology to capture otherwise inaccessible human performance data,
> 3. one-of-a-kind data base of actual incident information as reported by participants,
> 4. proven capability for diverse application to both research and operations,
> 5. ability to actively monitor the aeronautics system,
> 6. capability of effective technology transfer as evidenced by ASRS-type systems in other countries and disciplines,
> 7. the world's largest repository of human performance information,
> 8. consistent support and use of the program by government and industry (Reynard, 1988, p. 56).

The ASRS has operated under a memorandum of agreement with the Federal Aeronautics Administration since 1975.

The ASRS is funded by both the FAA and NASA, but the FAA has no direct role in the program's management. ASRS is managed by the Life Sciences Directorate at Ames and functions as a part of the human factors research in the aeronautics environment. ASRS reports have led to changes in operational procedures. The "sterile cockpit" concept in air carrier operations is an example.

> Incident reporting has proven to be a logical and effective supplement to established accident investigation procedures and other system monitoring techniques. Whereas incidents occur with predictable regularity, and always leave the participants in a position to help investigators if they so choose, accidents often preclude post-event interaction with the flight crew members (Reynard, 1983, p. 32).

What makes ASRS work is its confidential, nonpunitive, and voluntary nature. The data is unique and often is an honest self-appraisal. Issue-specific data are available to NASA, the NTSB, the FAA, and anyone else interested in aeronautics safety. What is not available is information about the person making the report.

By providing a report of an incident or an unsafe condition, the person filing the report is, for the most part, immune from any disciplinary action under Federal Aeronautics Regulations (14 CFR § 91.57). The filing of an ASRS report is "indicative of a constructive attitude" (FAA AC No. 00-46C, § 9. c). For this reason, when this writer instructs at Certificated Flight Instructor Courses for the Texas Department of Aeronautics, ASRS reports are referred to as "CYA" paper.

The ASRS reports are also used to report hazardous conditions. This writer knows of two instances where ASRS reports have had an effect. In Cincinnati, OH Lunken Airport had some taxiway markings which were worn away, and some local pilots believed visiting pilots unfamiliar with the airport could inadvertently taxi onto an active runway. ASRS analysts wrote to the airport manager, and the markings were repainted (Lunken pilots, January 19, 1992). Patrick Shaub, Texas Department of Aeronautics, said in a personal communication that the Austin, TX airport control tower radar would not show the emergency transponder code 7700. That code is supposed to trigger an alert if an aircraft has an emergency. Several calls to the FAA facility had no effect, but after an ASRS report, the situation was resolved.

CALLBACK, a monthly publication distributed to the aeronautics community, is a brief, readable means of sharing important safety data. CALLBACK summarizes some ASRS reports and includes interesting safety tips for pilots and air crews. In a special 1991 Fall edition of CALLBACK, the headline read: "The Bottom line: ASRS works."

Emergency Medical Service Safety Network

The mid-80s saw a high accident rate for EMS helicopter operators. It was estimated that 80 percent of the accidents were pilot error. To identify the primary causes of those accidents, an EMS Safety Network was established with the NASA ASRS being the primary and secondary repository for EMS accident and incident information (Hart, 1987, p. 45).

An in-flight evaluation of EMS flight crews was completed in 1989. The field study investigated pilot workload, pilot decision making, cues for geographical orientation, and communications. EMS pilots gave missions to accident scenes the highest workload ratings, and hospital transfers the lowest. Outbound legs were given higher workload ratings (Battiste, 1989, p. 51).

A preflight risk assessment procedure called SAFE, similar to those used by the U.S. Army and the U.S. Coast Guard, was tested by EMS pilots, hospital personnel , or administrators. For geographical orientation EMS pilots used more cultural and natural features such as lakes, bridges, and cities or mountain peaks than linear features like roads and rivers. Compared to four non-EMS pilots who depended on charts, the EMS pilots relied more on memory. EMS pilots navigate by pilotage and radio navigation while the other pilots also use dead reckoning. Both groups estimated spending more than half (58 percent) of their time on flying, about 25 percent navigating, 15 percent in geographical orientation and 3 percent communicating (Battiste, 1989, p. 52).

Cockpit Resource Management (CRM)

> CRM refers to a broad array of factors associated with effective team performance such as communication, interactional styles, leadership and related characteristics (Foushee, 1989, p. 38).

Many accidents occur when perfectly good aircraft crash, and people die because well-trained air crews fail to perform as well-trained air crews. Three accidents come to mind. An Eastern Airlines Lockheed L-1011 crashed near Miami in 1972 because the crew quit flying the aircraft after becoming distracted by a failed indicator light. A United Airlines DC-8 crashed after running out of fuel near Portland, OR in 1978, again after the air crew became distracted by a failed indicator light. Finally, and possibly the worst case of a crew not flying the aircraft occurred June 26, 1988 near Habsheim, France during a low fly-by at an airshow. The crew of a new Airbus A320, pilot Michel Assetine and co-pilot Pierre Maxières flying manually, managed to defeat all the A320s ultrasafe systems (Gunston, 1992, p. 829). Rescuers recovered four bodies and 30 injured.

Crew Coordination and Communications

Ames researchers identified the extent of air crew coordination problems in the 1970s. NASA took the lead in encouraging and assisting airlines in developing programs that influence air crew performance. An early NASA research program in the CRM area was a flight crew coordination study at Ames in 1981. Its objective was to identify and propose solutions to cockpit coordination and communication problems.

The lack of crew coordination and communications has led to many more aircraft accidents than those listed above. This study was conducted using full-mission simulations. The cockpit voice recordings were analyzed and in-flight errors were recorded. A relationship was found between communication patterns and performance. In general, crews that communicated less made more errors. As a result of this study, the NTSB recommended that the

FAA take steps to ensure adequate flight crew communications (Lauber, 1981, p. 34).

Another result of the study was to conclude full mission simulation can be beneficial to flight training. Line Oriented Flight Training (LOFT) or a simulation of a complete flight better shows crew coordination problems. As a result, the FAA changed its regulations to promote more widespread use of LOFT for training in crew coordination and resource management (Lauber, 1981, p. 34). The military version of LOFT is MOST, or mission-oriented flight training.

In 1982 Ames continued its crew coordination and communication study. The NTSB had observed that in some accident cases subordinate crew members were aware of potential problems but were not assertive enough to the pilot in command. Full missions of Boeing 747 flights from New York to London were simulated. The cockpit voice recordings were content-coded for all categories of communication. The full-mission simulation included all aspects of the actual flight. Visual and motion cues, air traffic control, and weather were realistically duplicated (Foushee, 1982, p. 18). Various simulated malfunctions were used to increase crew workload.

Substantial differences showed up in crew performance related to communication and coordination. The best performing crews showed more cohesion and a higher frequency of acknowledgment for the input of others. A free exchange of information led to better performance. The "management style" of the captain strongly affected the communication process (Foushee, 1982, p. 18). Traditionally, the captain of an aircraft is king, be it dictator or despot, benevolent or not. Assertiveness training was included with CRM training by some airlines as a result of these studies. This writer knows of one incident where a copilot pointed out to her captain that an action he had taken was illegal and possibly dangerous. She was fired by the airline the next day.

By the late 1980s, CRM was accepted by all U.S. air carriers and incorporated into their training programs. Those studies led to development of CRM training programs and techniques like Line-Oriented Flight Training (LOFT). The U.S. Air Force was the first to accept the need for CRM, and Delta Airlines was the last of the airlines to incorporate CRM training. An Ames study in 1988, funded by the FAA and conducted by the University of Texas, evaluated the effectiveness of Cockpit Resource Management (CRM) training programs. Data was collected from multiple organizations on key crew coordination dimensions related to performance and overall safety. The data was collected before, during, and for a period of years after training. The Aeronautics Safety Reporting System and other incident data bases provided by all participating organizations provided long-term trends (Foushee, 1988, p. 38).

Fatigue and Circadian Rhythmicity

In the mid 1980s, Ames research Center undertook several studies to “document the psychological and physiological impact of fatigue and circadian factors on short-haul and international long-haul trips” (Lauber, 1985, p. 31). This research was mandated by

Congress in 1982. Fatigue has often been cited as a contributing cause of aircraft accidents. Previous studies had been of little use because of the difficulty of generalizing laboratory performance and the fact that there were few controlled studies on fatigue. This study examined the performance of 20 crews, 10 rested and 10 just coming off a three-day high density short-haul duty cycle.

The results were as expected in that the post duty crews were significantly more fatigued than the rested crews. But unexpectedly, it was found that the fatigued crews performed significantly better than the rested pre-duty crews. The post-duty crews flew more stabilized approaches, made fewer operational errors, and communicated more. Suggested reasons were that the post-duty crews had more crew coordination due to the recent time working together (Foushee & Lauber, 1985 , p. 31).

In a companion study, researchers continuously monitored air crew's heart rate, temperature, and limb activity before, during, and after flying line trips. The short-haul study included 91 crew members from two airlines on 46 trips that included 821 flights. Researchers looked for sleep decrement, increase in subjective fatigue, mood shifts, and changes in sleep/activity and temperature rhythms. The long-haul trip selection was based on flights per day, layover and trip length, as well as unusual flight times, high workload operations, and multiple time-zone crossings. The physiological record was keyed to time-linked cockpit observer logs of operational events. Background information on lifestyle and personality was combined with information from daily log books in which each pilot's sleep, activities, diet, and mood were recorded. The long-haul study consisted of four crews on six or seven representative trips in eastward, westward, and north-south directions (Lauber, 1985, p. 31).

The study continued into 1986 and NASA's circadian rhythmicity studies were more extensive than ever undertaken before. As a result, NASA was asked to assist in the development of certification criteria for advanced long-haul aircraft (Graeber & Foushee, 1987, p. 44).

By 1988, to better understand how and why pilot performance can be degraded, studies of limited laboratory and simulator research were combined with extensive field studies to objectively study the physiological and behavioral responses of flight crews operating different flight environments. This program was conducted in cooperation with research organizations and airlines in West Germany, the United Kingdom, and Japan. The impacts of fatigue and circadian rhythmicity on flight crew performance of both military and commercial crews were studied. Reasons for the study were the reduction in air crew size and the introduction of highly automated aircraft. Three planned improvements to flight safety were:

- development of guidelines for rule making and certification,
- design of individual coping strategies,
- and operational recommendations to air carriers.

The types of flight operations studied were:

- B-747 and C-141 operations in multisegment international long-haul patterns (Pan Am , British Airways, and USAF),

- B-727 overnight cargo delivery (Federal Express),
- and extended range North Sea helicopter transport with four rotorcraft types (British Airways).

This was augmented with electroencephalography (EEG) sleep data on layovers from flight operations on eastward and westward polar routes through Anchorage.

> Technology transfer to the industry is occurring through interaction with the FAA aircraft certification teams, two U.S. Pacific carriers, and the development with a U.S. manufacturer of a crew alertness support device for long-haul glass cockpits (Graeber, 1988, pp. 41, 42).

Cockpit Rest Periods

The FAA, unions, and two aircraft manufacturers then approved a study of preplanned cockpit napping. An AP report from London, in the Daily Oklahoman January 20, 1989, quoted Dr. Jeffery Bennett, the chief medical officer of the British Civil Aeronautics Authority, as saying, "If asked, any long haul pilot of 20 years experience will say that at some stage he will have woken up and found the whole crew asleep" ("Airline Crews," 1989, p. 2).

The Dallas Morning News December, 28, 1992 included a Washington Post article reporting the FAA had developed a plan called "controlled rest" to one crew member at a time to take a nap. This came about as a result of NASA crew factors study. The Allied Pilots Association, which is American Airlines pilot's union, criticized the plan as it could lead to longer duty times for pilots ("Study finds," 1992, p. 4A).

Boredom Detection

In 1989 Langley Research Center conducted a related study to develop physiological measures that could be useful in boredom detection. The method used was to detect the pilot's mental states, which are predictive of performance degradation, and then intervene to restore acceptable performance.

Boredom is not a problem in high task load situations like takeoff and landing. This study simulated conditions characterized by "simple repetitive responses with minimal novelty, complexity, and uncertainty" (Comstock, Harris & Pope, 1989, p. 89). An Electrocardiogram (EKG), an electroencephalogram (EEG), and pupil diameter (PD) were used to measure mental state of the test subjects. The task was to monitor an engine fault pictorial with several possible faults. Subjects were to acknowledge the fault with minimal response time.

Physiological measures of the 11 test subjects were monitored over one hour test sessions. "Heart rate variability (HRV), alpha variance (EEG component), and PD each exhibited changes indicative of decrements in subject arousal level" (Comstock, Harris & Pope, 1989, p. 90).

Computational Models of Attention and Cognition

In the opposite vein, where information comes too quickly or from too many resources, humans are limited in their ability to process and respond to multiple information sources. Thus, Ames had an ongoing program to develop and validate computational models of human information processing.

> Aeronautics and space environments impose severe visual, auditory, and decision-making demands in situations where human failure can cause catastrophic results. Information overload has been identified as a major contributor to error in military aeronautics, and in critical monitoring tasks such air traffic control (Remington, 1988, p. 54).

The solution to human limitations in attention and cognitive capabilities requires an optimal allocation of function between man and machine and optimal configuration of multimodal displays and controls. Researchers identified stimuli that control attention and situations in which distraction was unavoidable. Computational models of human information processing were developed (Remington, 1988, p. 54).

Attention and cognitive capacities were investigated as a basis of analysis and model development in the following areas:

- ground control of manned and unmanned space operations,
- helicopter nap-of-the-Earth (NOE) and search and rescue operations,

- and air traffic control and anticipated Space Station proximity control operations.

Also studied were the related areas of collision avoidance, pilot workload, pilot alertness, and pilot error (Remington, 1988, p. 54). Since the era of advanced aircraft controls and instrumentation was common in the late 1980s, Ames studied human factors in these advanced transports.

Effect of Digital Altimetry on Pilot Workload

In 1984 Langley researchers conducted a program to determine the placement and type of display to reduce altimetry errors. One of the most common errors in flying is missing an altitude assignment. All air carrier aircraft and many general aviation aircraft have at least two altimeters, and all air carrier aircraft have at least two crew members. Using different types of display devices and microprocessors, a general effort was made to determine the effects different types and information placement had on pilot scanning behavior and workload.

The NASA Langley fixed-base Full-Workload Simulator was used for the evaluation. Seventy two VOR-DME (VHF omni range/Distance Measuring Equipment) approaches were flown. The scanning behavior and workload of using the counter-drum-pointer altimeter (CDPA) and the digital altimeter were compared. Six pilots used both the CDPA and the DA. Data taken by using the Langley oculometer system ". . was reduced to dwell percentages, average dwell times, transition matrixes, and dwell time histograms" (Harris, 1984, p. 30).

The results showed little difference in the use of either altimeter. The research pilots were generally negative toward the digital altimeter due to a lack of needle motion cues. The research pilots took longer to form a mental picture of altitude using the digital altimeter. There was also more mental arithmetic required to estimate the difference in altitude and assigned altitude. Dr. Cecil Dugger of the Aeronautics and Space Education Department of Oklahoma State University, in a personal communication in February, 1993, pointed out the same problem in using digital watches. More mental arithmetic and the necessity of forming a mental picture are necessary in using a digital watch unless only the absolute time is needed. Analog watches give a mental picture of a time period as well as the time. Analog altimeters indicate an altitude in a range of altitudes. Near an assigned altitude or near the ground, the pilot sees where he is, where he is headed, and where he needs to be. Digital display of altitude does require more cognitive processes of the pilot than conventional altimeter display (Harris, 1984, p. 30).

Advanced Technology Transport Problems

Often problems and benefits of new technology emerge only after extensive pilot experience in actual operations. Two airlines and more than 200 pilots participated in this 1989 study. The principal investigator, Earl Wiener of the University of Miami, attended ground school and made observation flights from the jump seat.

The results show pilots were generally positive but had reservations about safety. Some of the concerns were:

- Pilots believed automation reduces workload in routine operations but workload was increased if the Flight Management System was reprogrammed.
- Pilots were concerned about too much head-in-the-cockpit time.
- Pilots were concerned about degradation of manual flying skills and took active measures to avoid it.
- Pilots believed that crew coordination was especially necessary in advanced transports.
- Pilots were concerned that air traffic control did not take advantage of the advanced navigation and guidance capabilities of the new systems.
- Pilots felt that cockpit automation changed traditional role definitions like pilot flying versus pilot not flying.
- Pilots complained about a lack of clarity of who does what.
- Pilots felt that supervision was more difficult or at least different.
- Pilots often performed tasks assigned to the other pilot, such as the first officer sometimes was more proficient than the captain in the new displays.

A full-mission study was conducted to further investigate the interaction of cockpit automation and crew coordination.

Automation

Microprocessor technology made it possible to highly automate aircraft cockpits, and several technical, economic, and safety benefits of automation should have been evident. It did not always work out that way. Automation is often thought of as synonymous with dehumanization. Images of HAL in the movie 2001 or robots come to mind. Wiener, in Human factors in Aeronautics, states that automation "generally means replacing human functioning with machine functioning" (Wiener, 1988. p. 436). Wiener also states that a considerable amount of time during the early NASA Ames studies on cockpit automation was expended in defining the term. Wiener's definition is that "some tasks or portions of tasks performed by the human crew can be assigned, by the choice of the crew, to machinery." (Wiener, 1988, p. 436) Ames researchers conducted several studies on cockpit automation from 1985 through 1989 to evaluate cockpit automation to determine desirable and undesirable characteristics and features.

Williams, in From Sails to Satellites, states:

> If, some day, the human pilot is removed from the airline flight-deck, it will not be to economize on his salary, but for fear that he might touch something. There are already airliners with flying control systems which override the commands the pilot gives to the system by the forces he exercises on the controls when the machine

> thinks fit - a premonitory view of the monitor monitored (Williams, 1992, p. 163).

Williams also made another point on automation. Writing about navigators, he stated:

> Human navigators have always made mistakes; but experienced ones seem to have some kind of feedback system in their heads which often enables them to sense when something is wrong. Machines have no equivalent sense, and as men become more remote from the navigation they lose theirs. The magnitude of the blunder at the interface is virtually unlimited (Williams, 1992, p. 173).

One can replace the term “navigator” with “pilot” or with almost any other term, and the idea still holds.

Field Studies and Guidelines. Studies were conducted during early line operations of the McDonnell Douglas MD-80 and the Boeing 767. The investigation covered all facets of operations from ground school to line operations. Researchers used questionnaires, rating scales, and interviews. Four airlines participated in the study and the results found wide acceptance of the new cockpit technology. Some specific features were more popular than others, and like a VCR, some features were not understood by the pilots. Thus, there was room for improvement. With the new systems came new requirements for training, and there was the potential for skill loss if automation left less for pilots to do in the cockpit. Automation did not eliminate pilot error, and in some cases the automated cockpit systems lead to different errors (Lauber, 1985, p. 31).

Error Detection. Several factors increased the need for more precise navigation and control. Along with automation changing the traditional role of pilots, there was greater traffic volume and no increase in airport capacity. In 1986 Ames Research Center studied the effects of cockpit automation on human error, workload, and the need for improved performance. Pilot attitude toward automation and their usage patterns were augmented by studies of the Aeronautics Safety Reporting System data base.

The goal was to develop computerized systems to detect errors and either warn the pilot or take autonomous corrective action. Ames also contracted studies for the use of artificial intelligence in crew error detection. For automation to be an asset instead of a liability it must insure maximum compatibility with human pilot capabilities and limitations (Palmer, 1986, pp. 31, 32).

Ames researchers developed a computer program to track crew activity and detect pilot errors. Aeronautics Safety Reporting System data indicated that human error accounted for more than 75 percent of all accidents. Ames researchers believed that properly designed forms of automation could reduce the impact of human error in aeronautics operations. It would be necessary to understand crew errors and understand crew actions for an error-tolerant cockpit to become a reality. A script knowledge-based program for a Boeing 727 tracked crew activity and detected crew errors. An extension of the program predicted consequences of detected errors, and a related study found the application of flight path control was feasible (Palmer, 1987, p. 51).

Error-Tolerant Systems. A necessary component of an error-tolerant system was a pilot model to track pilot actions, infer pilot intent, detect unexpected actions, and alert the crew to potential errors. Thus, pilots would always be riding with a check pilot, an electronic one. The study pursued three alternative ways to track operator activity. They were:

- A rule-based script of flight phases and procedural actions,
- operator function models,
- and Bayesian temporal models (Palmer, 1988, p. 51).

The script based program could detect procedural errors but could not adequately account for procedures that were not normal. A capability to link unexpected actions to normal actions was added. Georgia Tech developed an intent-inferencing system based on an operator function model that was tested on data from a satellite communications system. Search technology developed a prototype for an intent-inferencing system based on Bayesian reasoning. Three models were tested against the B-727 simulator. And the technology developed was used to develop an interactive procedures cockpit display (Palmer, 1988, p. 51).

As a follow up to previous research, in 1989, Ames researchers planned to initiate an experiment to determine how check pilots detect procedural errors and infer pilot intent. The researchers also planned to develop a “smart checklist” that would track pilot actions and include both passively monitored pilot’s executions of procedures and automatic executing procedures (Palmer, 1989, p. 74).

Ames Research Center, under a Small Business Innovation Research contract, planned to "develop and test a procedure execution aid that can compose procedures that are appropriate for the current flight situation and equipment configuration" (Palmer, 1989, p. 75). As a result of this research, Ames researchers planned to develop full-mission simulations for a cockpit procedures monitor and smart checklist in the Advanced Concepts Flight Simulator of the Man-Vehicle Systems Research Facility.

Advisory System for Conflict Detection & Resolution for Air Traffic Control

Ames Research Center developed a system in 1988 for air traffic controllers to detect and resolve a potential conflict between aircraft in the terminal environment. The system used four dimensional (4-D) guidance to accurately predict potential conflicts even when the aircraft are flying complex trajectories. A hierarchy of resolution techniques were "derived from an extensive interview of a controller expert" (Lee, 1988, p. 85).

Using calculated 4-D trajectories based on 4-D guidance algorithms for all aircraft from the present to a look-ahead time that is usually 10 minutes, the system generated aircraft trajectories and potential conflict pairs stored in a global conflict-detection matrix. The pairs with the shortest conflict time were resolved first by altering speed, altitude, or heading. The result was a sequence of time-ordered guidance commands. After the potential conflict was resolved, the aircraft maneuvers to the original flight path (Lee, 1988, p. 85).

CHAPTER IV

SUMMARY OF FINDINGS

A total of 83 NASA aeronautics safety programs was identified during the years 1980 through 1989. The research was accomplished for the most part by researchers from NASA Langley Research Center in Hampton, VA; NASA Lewis Research Center in Cleveland, OH; and the NASA Ames Research Center at Moffett Field, CA. In addition, various contractors, universities, and, in some cases, military personnel and installations were involved.

The research programs were analyzed using four methods in an attempt to compare and contrast the research from the three NASA centers involved with aeronautics safety. The four methods were as follows:

- listing the various programs without repetition of continuing programs, found in APPENDIX A, as per objective 1,
- listing the programs classified by category, found in APPENDIX B, as per objective 2,
- listing the programs compared by year, found in APPENDIX C, as per objective 3,

- and listing the programs compared by applicability to all aviation, air transport operations, or general aviation operations found in APPENDIX D, as per objective 6.

In total, Ames Research Center conducted 27 aeronautics safety research programs during the 80s. Several were multi-year programs such as the individual crew factors program. The Aeronautics Safety Reporting System (ASRS) had been operating for five years before the decade started and is still operating in April 1993. Ames conducted two weather related programs, seven aircraft related programs, and 16 human factors programs.

Langley Research Center researchers conducted by far the most aeronautics research programs. The 43 Langley programs were more than those of Ames and Lewis combined. Langley conducted 12 programs on weather and wake vortex problems, 27 programs related to machine or aircraft, and five programs dealing with human factors.

Lewis Research Center in Cleveland was involved in the fewest programs with 13 programs including 11 related to icing. The other two dealt with powerplant research.

Summary by Objectives

Objective 1: To identify NASA aeronautics safety programs for the years 1980 through 1989 (Appendix A).

The NASA aeronautics safety research programs of the period 1980-1989 were as follows:

NASA Aeronautics Safety Research Programs 1980-1989

- The Environment, weather and turbulence
    - Heavy Rain
    - Microbursts/Windshear
    - Clear Air Turbulence
    - Storm Hazards/Lightning
    - Sacrificial Lightning Rods
    - Wake Vortices
- The Machine, the aircraft
    - Langley 20 Foot Vertical Tunnel
    - Lewis Icing Research Tunnel (IRT)
    - Icing Detection Systems
    - Ground Anti-Icing/deicing Fluids (Types I and II)
    - Icing Effects on Stability and Control
    - Icing Computational Fluid Dynamics (CFD)
    - Deicing Systems
    - Control Systems
    - Advanced Instrumentation
    - Crashworthy Structures Research
    - Fireworthy Structures Research
    - Controlled Impact Demonstration
    - General aviation Stall/Spin Research
    - Emergency Locator Transmitter Reliability
    - Aging Aircraft, NDE Aluminum Structures
- The People, Human Factors
    - Ames Man-Vehicle Systems Research Facility (MVSRF)
    - Aeronautics Safety Reporting System (ASRS)

Cockpit Resource Management (CRM)
Crew Coordination and Communications
Fatigue and Circadian Factors (Jet-Lag)
"Controlled Rest"
Automation
Error/Fault-Tolerant Systems
Emergency Medical Service Safety Problems
Advisory Conflict Detection and Resolution for Air Traffic Control

Objective 2: To classify research programs broadly into three elements (Appendix B).

- the Environment - the air, the medium in which all aircraft fly, including weather and aircraft induced turbulence;
- the Machine - the aircraft, electrical or mechanical systems, its airframe, engines, instrumentation;
- and the people, including everything integrating the humans with the machines they fly.

Objective 3: To trace the development of NASA Aeronautics Safety Research Programs by comparing programs for the years 1980 through 1989 (Appendix C).

Appendix C lists the programs reported in the yearly Research and Technology publications. Note that continuing programs were not always reported each year.

Objective 4: To summarize each research program.

Chapter III contains the summaries of all programs identified for the years 1980-1989.

Objective 5: To determine if NASA aeronautics safety research programs have increased in numbers and scope over the years 1980 through 1989.

Objective 5 was harder to attain than thought at the beginning of the research. For that matter, a valid comparison is impossible, due to the diversity of programs and lack of prioritization. Comparison of aviation safety programs is truly an “apples and oranges” situation. A look at Appendix C shows that the totals show more identified programs in 1989 than in 1980. But the 17 programs for 1989, compared to 13 for 1980, really do not show an increasing commitment by NASA in aviation safety. Safety programs come and go with seemingly little long range planning, direction, or coordination.

Objective 6: To compare each program by applicability (Appendix D).

A comparison of aviation safety research programs by applicability to all areas of civil aviation, air transport operations, and general aviation indicates that all areas were included. There were fewer general aviation programs, but the general aviation program ended early in the decade. The total numbers for the programs were 27 programs applicable to all civil aviation, 35 applicable to air transport operations, and 27 applicable to general aviation safety research.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

NASA and Aeronautics Safety Research

NASA accomplished much in the area of aeronautics safety in the decade of the 1980s, and by almost any measure, aeronautics was a safer activity at the end of the decade than the beginning. But how much safer, because of NASA aeronautics safety research, is arguable. Surely more is known now about microbursts, windshear, and clear air turbulence. More is known about how to build fireworthy and crashworthy aircraft structures. Automation has made aircraft operation navigation incredibly easy, but now NASA is developing error tolerant systems and fault-tolerant controls.

At NASA, there is a noticeable trend toward total automation, with little or no pilot/air crew input or control. The research using the advanced pilot work stations at Ames and Langley Research Centers, for the most part, have the pilot as a systems monitor only.

There is a Catch 22 with automation. Automation should give the pilot more time to become alert to what is happening, but when the pilot does or does not do something in an automated environment, often a blunder results.

As stated earlier, when humans and machines are interfaced and humans are removed from the information loop and control, they usually do not notice problems. But if they do, they do not understand how to resolve the problems. Humans also begin to commit blunders when removed from the information loop. The more experienced humans sometimes notice problems faster and with better understanding. In the future when all aircraft are automated, when and where are pilots going to attain the experience to sense when something is wrong or to know what to do if there is a problem?

There is a joke that in the future the total crew of an airliner will be a "pilot" and a dog. The pilot will be there to feed the dog, and the dog will be there to bite the pilot if he touches anything. The attempt to make aircraft/machines idiot proof has not achieved its objective. The Airbus A320 crash at Habsheim in 1988 and an Airforce B-1B crash in West Texas in 1992, where the crew turned off the terrain-following radar only seconds before the aircraft flew into the side of a mountain, are horrible but good examples.

This writer found no research enhancing the human role in aeronautics safety. What was noticed was a resigned belief that pilots are going to make mistakes, so the trend appears merely to give them less to do and provide systems that safely tolerate the blunders. This may stem from the way pilots are trained from the beginning.

Pilot training is not training in how to think. Pilots are trained to perform a set of operations whether in normal operations or emergency conditions. All operations are devoid of human thought. This type training is to assure quick reaction. Surely, if you are flying a light twin engined airplane and you lose an engine just after takeoff, you are going to crash if you do not quickly clean up the airplane by raising the landing gear and flaps. But you cannot just react. You must still fly the airplane while thinking, not merely reacting. Clear thought and keen pilot attention to the situation, whether it is normal operations or an emergency situation, is essential. The only situation this writer can think of where the pilot must be out of the information/control loop is in a zero ceiling and zero visibility automatic landing situation. There would be no time for the pilot to react or to act positively if something goes wrong close to the ground. Of course, that situation leads to an interesting question. If the human pilot is useless in the worst piloting scenario, why have a human pilot anyway?

NASA as an Aeronautics Advocate

One could conclude that NASA has always been on the cutting edge of technology, but often that is not the case, though not always NASA's fault. NASA's role is R & T, Research and Technology - - not R & D, Research and Development. Any development is the decision of industry. For example, ice detection system technology identified and studied by NASA in the 1980s may prove to be superior to commercial systems. But as this is being written in 1993, it is not in production.

In 12 years presenting educational programs for NASA all over the United States, this writer is asked occasionally why NASA, a civilian agency of government, works with the military. There is an official reason, and a good reason. NASA is the official U. S. Government agency for all aeronautics research, not just civil aeronautics research. The good reason for NASA to be in the "loop" in military research is the greater possibility of getting the benefits of that research into civil aircraft sooner. This writer is convinced that much duplicated research is done by the military and NASA because of secrecy requirements within the military establishment.

Also NASA is answerable to Congress and is funded directly by Congress. Few scientific studies on what research programs should be pursued and funded have come from Congress. Perhaps if NASA had the independence or autonomy, it would be possible to form partnerships to improve safety.

NASA management appears to be unable to push good ideas. The money spent on research is wasted if the products, systems, ideas, or techniques researched are not used. Only by reading trade publications would you know whether NASA does anything in aeronautics, much less aeronautics safety.

Recommendations

NASA aeronautics safety programs have been responsible for research that has made or will make the skies safer for passengers and air crews. NASA should continue its aeronautics safety research and become a more assertive leader in the field of aeronautics safety.

Recommendations for NASA's role in future aeronautics safety programs follow:

1. NASA should establish a task force on aeronautics safety similar to the NASA Aeronautics Advisory Committee Task Force on General Aviation Transportation with government, industry, university, and aeronautics organization participation.

2. NASA should be allowed to pursue development by assisting industry partners for inventions or technologies that would enhance aeronautics safety. This would allow the technology to be placed in service sooner. This development could be in cooperation with the NASA Technology Utilization Office.

3. NASA has developed several ice detectors and deice systems. Several have been developed by private corporations. A lightweight, low cost complete ice detector/deice system should be developed as a cooperative

venture with government, industry, university, and aeronautics organization participation.

4. NASA should join with government agencies and other organizations to press the U.S. Air Force to allow civilian usage of the precise code for navigation using the Global Positioning System (GPS) for enhanced safety in navigation and instrument landings. Then working with private industry, government, university, and aeronautics organizations, an easy-to-use low-cost navigation and instrument landing system should be developed. The system should use Differential GPS, DGPS similar or analogous to the "Pinpoint" system developed by Magnavox and Cue Network Corporation using commercial FM radio stations, or an extension of the marine system being implemented by the U.S. Coast Guard.

5. NASA should seek out promising inventions and developing safety systems with the goal of promoting safety. Not everything good comes from NASA. If there is a "not-invented-here," attitude, it should be changed.

6. A study of the dehumanization of automation systems should be undertaken. Automation takes the pilot/air crew out of the recognition/decision loop. NASA research has been directed at fault tolerant systems or "big brother" type systems to oversee pilot/air crew actions.

7. A study should be made to determine if giving the pilot greater participation in the recognition/decision loop could reduce blunders, incidents, and accidents. All pilot training teaches pilots to react, not think. This is true for any and all situations, whether it is normal operations or emergency situations.

8. A study of the philosophy of accident prevention should be made. It has been shown that as the machines are improved, the pilots/air crews are becoming more of a problem in causing incidents and accidents. If more automation and more information along with less input and control by the pilots and crews are causing problems, possibly there is another way. It may be that there is no possibility of totally eliminating accidents, but accident reduction is definitely possible.

9. A study should be undertaken to identify and compare other fields of human endeavor where accidents have had man-machine interface causes. Possibly in other areas, solutions have been found that could be adaptable to aeronautics.

10. Congress should provide greater support for NASA aeronautics safety programs.

11. Increased NASA aeronautics safety research would be an excellent directional change away from military aerospace research funding and would put displaced workers back on the job.
12. NASA should establish a network on aviation safety research programs conducted throughout the world. This network could have NASA ASRS as the primary repository of this information.

Without doubt NASA has done much in the field of aviation safety. Also, without doubt more research is needed. Much remains to be accomplished. A natural follow up to this study would be an extension concerning actual and planned NASA aviation safety research programs for the decade of the 1990s.

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APPENDIX A

NASA AERONAUTICS SAFETY RESEARCH PROGRAMS LISTED BY CENTER

NASA CENTERS AERONAUTICS SAFETY
RESEARCH PROGRAMS
LISTED BY CENTER

AMES

27 PROGRAMS

ASRS
SIMULATORS IN TRAINING
STALL SPEED INDICATOR
SMACK CODE
COORDINATION & COMMUNICATIONS
CDTI-AMES
REDUCED-VISIBILITY SIMULATION
CLEAR-AIR TURBULENCE
FIREWORTHY SEAT CUSHIONING
FAULT-TOLERANT CONTROLS
DEEP-STALL EXPERIMENT
FIRE-RESISTANT PANELS
MAN-VEHICLE SYSTEMS RESEARCH
ELECTRO-EXPULSIVE DEICE EEDS
OBJECTIVE ASSESSMENT PILOTS
FATIGUE, CIRCADIAN RHYTHM
SHORT HAUL HUMAN FACTORS
AUTOMATION HUMAN FACTORS
TCAS
MICROBURSTS
EMERGENCY MEDICAL SYSTEM
INFORMATION TRANSFER ERROR
ERROR-TOLERANT SYSTEMS
COCKPIT RESOURCE MANAGEMENT
ATTENTION & COGNITION
HUMAN FACTORS -ADV. AIRCRAFT
CONFLICT/RESOLUTION ADVISORY

LANGLEY

43 PROGRAMS

DECOUPLED CONTROLS
CDTI-LaRC
GENERAL AVIATION STALL/SPIN
ELT RELIABILITY
LOAD LIMITING SUBFLOOR
LOCALIZER ENHANCEMENT
ROCKET SPIN RECOVERY
STORM HAZARDS-LIGHTNING
EMERGENCY EGRESS SYSTEM
AUTOPILOT COMPLEXITY TRADEOFF
"FOLLOW ME" BOX DISPLAY
WAKE VORTEX ALLEVIATION
20-FOOT SPIN TUNNEL
COORDINATED ELEVATOR-THRUST
TURBULENCE MODELS
LIGHT TWIN WITH ENGINE INOPERATIVE
LIGHT TWIN, ENGINE OUT AUTOTRIM
DISCONTINUOUS LEADING EDGE
B-707 FUSELAGE DROP TEST
GA DATA USE IN ACCIDENT STUDIES
EFFECT OF DIGITAL ALTIMETRY
HEAVY RAIN WIND TUNNEL
ULTRASONIC ICE DETECTOR
WIND GUST MODELING
SPIN RESISTANCE CRITERIA
MICROBURST PROBABILITIES
CID STRUCTURAL ANALYSIS

LEWIS

13 PROGRAMS

ANTIMISTING KEROSENE
GENERAL AVIATION ICE PROTECTION
ICING PREDICTION/ACCRETION SYSTEM
MICROWAVE ICE ACCRETION METER
TURBINE DISK CRACK DETECTOR
ELECTROTHERMAL DEICER
PNEUMATIC DEICERS HELICOPTERS
ELECTROMAGNETIC-IMPULSE DEICERS
AIRFOIL ICING PERFORMANCE
ICING PERFORMANCE & HANDLING
IRT DATA VALIDATION
ICING TEST ROTORCRAFT
GROUND DEICING FLUIDS

NASA CENTERS AERONAUTICS SAFETY RESEARCH PROGRAMS LISTED

AMES	LANGLEY	LEWIS
	TOPMS	
	PRIMARY FLIGHT DISPLAYS (PFD'S)	
	WINDSHEAR MODEL DFW DATA	
	COMPOSITE HELICOPTER CRASH TESTS	
	GENERAL AVIATION ADVANCED CONTROLS	
	LIGHTNING F-106 B MODEL	
	ICING EFFECTS ON STABILITY & CONTROL	
	WINDSHEAR MODELING	
	WINDSHEAR TRAJECTORY GUIDANCE	
	DATA LINK, ATC-PILOT-ATC	
	DIAGNOSTIC EXPERT SYSTEM	
	ULTRASONIC NDE ALUMINUM	
	ALDF-RSS HEAVY RAIN SIMULATION	
	GA HIGHWAY-IN-THE-SKY, EZ FLY	
	FORWARD LOOK WINDSHEAR DETECTION	
	BOREDOM DETECTION	

APPENDIX B

NASA AERONAUTICS SAFETY RESEARCH PROGRAMS CLASSIFIED BY CATEGORY

NASA CENTERS AERONAUTICS SAFETY RESEARCH PROGRAMS CLASSIFIED BY CATEGORY

AMES

ENVIRONMENT

CLEAR-AIR TURBULENCE
MICROBURSTS

MACHINE

CDTI-AMES
DEEP-STALL EXPERIMENT
ELECTRO-EXPULSIVE DEICE EEDS
FIRE-RESISTANT PANELS
FIREWORTHY SEAT CUSHIONING
STALL SPEED INDICATOR
TCAS

PEOPLE

ASRS
ATTENTION & COGNITION
AUTOMATION HUMAN FACTORS
COCKPIT RESOURCE MANAGEMENT
COORDINATION & COMMUNICATIONS
EMERGENCY MEDICAL SYSTEM
ERROR-TOLERANT SYSTEMS
FATIGUE, CIRCADIAN RHYTHM
FAULT-TOLERANT CONTROLS
INFORMATION TRANSFER ERROR
MAN-VEHICLE SYSTEMS RESEARCH
OBJECTIVE ASSESSMENT OF PILOTS
REDUCED-VISIBILITY SIMULATION
SHORT HAUL HUMAN FACTORS

LANGLEY

ENVIRONMENT

ALDF-RSS HEAVY RAIN SIMULATION
FORWARD LOOK WINDSHEAR DETECTION
HEAVY RAIN WIND TUNNEL
LIGHTNING F-106 B MODEL
STORM HAZARDS-LIGHTNING
MICROBURST PROBABILITIES
TURBULENCE MODELS
WAKE VORTEX ALLEVIATION
WIND GUST MODELING
WINDSHEAR MODEL DFW DATA
WINDSHEAR MODELING
WINDSHEAR TRAJECTORY GUIDANCE

MACHINE

B-707 FUSELAGE DROP TEST
CDTI-LaRC
CID STRUCTURAL ANALYSIS
COMPOSITE LIGHTNING RODS
COORDINATED ELEVATOR-THRUST
GA DATA USE IN ACCIDENT STUDIES
DECOUPLED CONTROLS
DISCONTINUOUS LEADING EDGE
ELT RELIABILITY
EMERGENCY EGRESS SYSTEM
"FOLLOW ME" BOX DISPLAY
GENERAL AVIATION ADVANCED CONTROLS
GENERAL AVIATION STALL/SPIN

LEWIS

MACHINE

ANTIMISTING KEROSENE
AIRFOIL ICING PERFORMANCE
ELECTROMAGNETIC-IMPULSE DEICERS
ELECTROTHERMAL DEICER
GENERAL AVIATION ICE PROTECTION
ICING DETECTOR/ACCRETION SYSTEM
ICING PERFORMANCE & HANDLING
ICING TEST ROTORCRAFT
IRT DATA VALIDATION
MICROWAVE ICE ACCRETION METER
PNEUMATIC DEICERS HELICOPTERS
GROUND DEICING FLUIDS
TURBINE DISK CRACK DETECTOR

AMES

PEOPLE
- SIMULATORS IN TRAINING
- SMACK CODE
- HUMAN FACTORS ADV. AIRCRAFT
- CONFLICT/RESOLUTION ADVISORY

LANGLEY

MACHINE
- HELICOPTER CRASH TESTS
- HIGHWAY-IN-THE-SKY, EZ FLY
- ICING EFFECTS STABILITY & CONTROL
- LIGHT TWIN, ENGINE INOPERATIVE
- LIGHT TWIN, ENGINE OUT AUTOTRIM
- LOAD LIMITING SUBFLOOR
- LOCALIZER ENHANCEMENT
- PRIMARY FLIGHT DISPLAYS
- ROCKET SPIN RECOVERY
- SPIN RESISTANCE CRITERIA
- 20-FOOT SPIN TUNNEL
- ULTRASONIC ICE DETECTOR
- ULTRASONIC NDE ALUMINUM
- TOPMS

PEOPLE
- AUTOPILOT COMPLEXITY TRADEOFF
- BOREDOM DETECTION
- DATA LINK ATC-PILOT-ATC
- DIAGNOSTIC EXPERT SYSTEM
- EFFECT OF DIGITAL ALTIMETRY

LEWIS

APPENDIX C

NASA AERONAUTICS SAFETY RESEARCH PROGRAMS COMPARED BY YEAR

NASA CENTERS AVIATION SAFETY RESEARCH PROGRAMS COMPARED BY YEAR

AMES	LANGLEY	LEWIS
1980 ASRS SIMULATORS IN TRAINING STALL SPEED INDICATOR	1980 DECOUPLED CONTROLS CDTI-LaRC GA STALL/SPIN ELT RELIABILITY LOAD LIMITING SUBFLOOR LOCALIZER ENHANCEMENT ROCKET SPIN RECOVERY STORM HAZARDS-LIGHTNING	1980 ANTIMISTING KEROSENE GA ICE PROTECTION
1981 ASRS SMACK CODE FLIGHT CREW COORDINATION CDTI-AMES	1981 DECOUPLED CONTROLS EMERGENCY EGRESS SYSTEM AUTOPILOT COMPLEXITY TRADEOFF "FOLLOW ME" BOX DISPLAY WAKE VORTEX ALLEVIATION 20-FOOT SPIN TUNNEL STORM HAZARDS-LIGHTNING	1981 ICING DETECTOR/ACCRETION
1982 ASRS CDTI-AMES CREW COMMUNICATION REDUCED-VISIBILITY SIMULATION CLEAR-AIR TURBULENCE FIREWORTHY SEATS	1982 COORDINATED ELEVATOR-THRUST TURBULENCE MODELS STORM HAZARDS-LIGHTNING GENERAL AVIATION STALL/SPIN TESTS	1982 MICROWAVE ICE ACCRETION METER

NASA CENTERS AERONAUTICS SAFETY RESEARCH PROGRAMS by YEAR

AMES

1983
ASRS
CLEAR-AIR TURBULENCE VORTICES
FAULT-TOLERANT CONTROLS
DEEP-STALL EXPERIMENT
FIRE-RESISTANT PANELS

1984
ASRS
FAULT-TOLERANT CONTROLS
MVSRF
SEVERE TURBULENCE

1985
ASRS
ELECTRO-EXPULSIVE DEICE EEDS
OBJECTIVE ASSESSMENT PILOTS
FATIGUE, CIRCADIAN RHYTHM
SHORT HAUL HUMAN FACTORS
AUTOMATION

1986
ASRS
ELECTRO-EXPULSIVE DEICE EEDS
FIREWORTHY SEAT CUSHIONING
TCAS
ERROR-TOLERANT SYSTEMS
MICROBURST
CLEAR-AIR TURBULENCE

LANGLEY

1983
LIGHT TWIN, ENGINE INOPERATIVE.
DISCONTINUOUS LEADING EDGE
B-707 FUSELAGE DROP TEST
CRASH TEST IMPULSE-MOMENTUM
STORM HAZARDS-LIGHTNING

1984
LIGHT TWIN ENGINE-OUT TRIM
DIGITAL ALTIMETRY
STORM HAZARDS-LIGHTNING

1985
HEAVY RAIN WIND TUNNEL
ULTRASONIC ICE DETECTOR
WIND GUST MODELING
STORM HAZARDS-LIGHTNING

1986
SPIN RESISTANCE CRITERIA
MICROBURST PROBABILITIES
CID STRUCTURAL ANALYSIS
COMPOSITE LIGHTNING RODS
TOPMS
STORM HAZARDS-LIGHTNING

LEWIS

1983
TURBINE DISK CRACK DETECTOR
ELECTROTHERMAL DEICERS

1984
PNEUMATIC DEICERS HELICOPTERS
ELECTROMAGNETIC-IMPULSE DEICERS

1985
AIRFOIL ICING PERFORMANCE

1986
ICING PERFORMANCE & HANDLING

NASA CENTERS AERONAUTICS SAFETY RESEARCH PROGRAMS by YEAR

AMES

1987
ASRS
FATIGUE, CIRCADIAN RHYTHM
EMS NETWORK
INFORMATION TRANSFER ERROR
ERROR-TOLERANT SYSTEMS

1988
ASRS
CRM TRAINING
FATIGUE, CIRCADIAN RHYTHM
EMS HUMAN FACTORS
ERROR-TOLERANT SYSTEMS
ATTENTION & COGNITION
ELECTRO-EXPULSIVE DEICE EEDS
FIREWORTHY SEAT CUSHIONING
MICROBURST MODELING
FIRE RESISTANT PANELS
CONFLICT/RESOLUTION ADVISORY
EEDS F/A-18 FLIGHT TESTS

1989
ASRS
ELECTRO-EXPULSIVE DEICE EEDS
EEDS SEA TRIALS
FIREWORTHY SEAT CUSHIONING
EMS HUMAN FACTORS
TCAS

LANGLEY

1987
SPIN RESISTANCE CRITERIA
STORM HAZARDS-LIGHTNING
TOPMS
PRIMARY FLIGHT DISPLAYS (PFD's)
WINDSHEAR MODEL DFW DATA
HELICOPTER CRASH TESTS

1988
GA ADVANCED CONTROLS
LIGHTNING F-106 MODEL
ICING EFFECTS STABILITY & CONTROL
WINDSHEAR MODELING
WINDSHEAR TRAJECTORY GUIDANCE
TOPMS
DATA LINK ATC-PILOT-ATC
DIAGNOSTIC EXPERT SYSTEM
ULTRASONIC NDE ALUMINUM
ALDF-RSS HEAVY RAIN SIMULATION

1989
GA HIGHWAY-IN-THE-SKY, EZ FLY
FORWARD WINDSHEAR DETECT.
TOPMS
BOREDOM DETECTION
ALDF-RSS HEAVY RAIN SIMULATION

LEWIS

1987
ICING RESEARCH TUNNEL IRT

1988
IRT DATA VALIDATION

1989
ICING TEST ROTORCRAFT
GROUND DEICING FLUIDS

NASA CENTERS AERONAUTICS SAFETY RESEARCH PROGRAMS by YEAR

AMES	LANGLEY	LEWIS
1989		
FATIGUE, CIRCADIAN RHYTHM		
ERROR-TOLERANT SYSTEMS		
ADV. TECH. AC. HUMAN FACTORS		
HUMAN FACTORS ADVANCED AIRCRAFT		

APPENDIX D

NASA AERONAUTICS SAFETY RESEARCH PROGRAMS LISTED BY APPLICABILITY

NASA CENTERS AVIATION SAFETY RESEARCH PROGRAMS BY APPLICABILITY

CENTER	DATE(s)	PROGRAM
PROGRAMS APPLICABLE TO ALL AVIATION		
AMES	80 - 89	AVIATION SAFETY REPORTING SYSTEM
AMES	80	STALL SPEED INDICATOR
AMES	81	SMOOTHING FOR AIRCRAFT KINEMATICS (SMACK)
AMES	82	REDUCED-VISIBILITY SIMULATION
AMES	82 - 89	FIREWORTHY SEAT CUSHIONING
AMES	84	MAN-VEHICLE SYSTEMS RESEARCH FACILITY
AMES	85 - 89	ELECTRO-EXPULSIVE DEICE SYSTEM (EEDS)
AMES	85	OBJECTIVE ASSESSMENT OF PILOT PERFORMANCE
AMES	87	INFORMATION TRANSFER-NATIONAL AEROSPACE SYSTEM
AMES	88	COMPUTATIONAL MODELS OF ATTENTION AND COGNITION
AMES	88	ADVISORY SYSTEM CONFLICT DETECTION RESOLUTION
LaRC	80	COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI)
LaRC	80	LOCALIZER DISPLAY ENHANCEMENT
LaRC	80 - 88	STORM HAZARDS (LIGHTNING)
LaRC	81	AUTOPILOT COMPLEXITY/BENEFIT STUDY
LaRC	81	WAKE VORTEX ALLEVIATION
LaRC	83	GA CRASH DATA ROLE - IMPULSE & MOMENTUM
LaRC	84	EFFECT OF DIGITAL ALTIMETRY ON PILOT WORKLOAD
LaRC	85	DEVELOPMENT OF ULTRASONIC ICE DETECTION SYSTEM
LaRC	88	LIGHTNING ATTACHMENT TESTS ON F-106B SCALE MODEL
LaRC	88	QUANTIFYING ICING EFFECTS ON STABILITY & CONTROL
LeRC	81	AIRCRAFT ICING DETECTOR AND ACCRETION METER
LeRC	81, 82	MICROWAVE ICE ACCRETION METER (MIAM)
LeRC	84	ELECTROMAGNETIC-IMPULSE DEICING SYSTEM (EIDI)
LeRC	85	AIRFOIL PERFORMANCE IN ICING CONDITIONS
LeRC	86	AIRCRAFT PERFORMANCE & HANDLING CHANGES IN ICING
LeRC	88	ICING RESEARCH TUNNEL IRT VALIDITY TESTS
PROGRAMS APPLICABLE TO AIR TRANSPORT		
AMES	80	USE OF SIMULATORS IN PILOT TRAINING
AMES	81 - 88	FLIGHT CREW COORDINATION & COMMUNICATION LATER COCKPIT RESOURCE MANAGEMENT (CRM)
AMES	81 - 82	COCKPIT TRAFFIC DISPLAYS (CDTI-AMES)
AMES	82 - 86	ANALYSIS OF CLEAR-AIR TURBULENCE
AMES	83 - 88	ERROR/FAULT-TOLERANT CONTROL - MANAGEMENT/SYSTEMS
AMES	83 - 88	FIRE-RESISTANT AIRCRAFT INTERIOR PANELS
AMES	85 - 89	INDIVIDUAL CREW FACTORS IN FLIGHT OPERATIONS FATIGUE AND JET-LAG STUDY: LONG HAUL & SHORT HAUL
AMES	85	AIRCRAFT AUTOMATION: FIELD STUDIES & GUIDELINES

PROGRAMS APPLICABLE TO AIR TRANSPORT

AMES	86 - 89	TRAFFIC ALERT COLLISION AVOIDANCE SYSTEM (TCAS)
AMES	85 - 88	MICROBURST INVESTIGATIONS
AMES	88	ADVISORY SYSTEM FOR CONFLICT DETECTION AND RESOLUTION FOR AIR TRAFFIC CONTROL
AMES	89	HUMAN FACTORS ADVANCED TECHNOLOGY TRANSPORTS
LaRC	80, 81	DECOUPLED CONTROLS - IMPROVED SAFETY IN WIND SHEAR
LaRC	82	COORDINATED ELEVATOR & THRUST CONTROL
LaRC	82 - 85	WIND TURBULENCE MODELS FOR PILOTED AIRCRAFT
LaRC	83	VERTICAL DROP TEST OF B-707 FUSELAGE SECTION
LaRC	85	AIRFOIL PERFORMANCE IN SIMULATED HEAVY RAIN
LaRC	86	MICROBURST SEVERITY WEILBULL PROBABILITY
LaRC	86	CONTROLLED IMPACT DEMONSTRATION (CID) ANALYSIS
LaRC	86	COMPOSITE LIGHTNING RODS FOR AIRCRAFT
LaRC	86 - 89	TAKEOFF PERFORMANCE MONITORING SYSTEM (TOPMS)
LaRC	87	EFFECTS HORIZONTAL & VERTICAL INFORMATION INTO PRIMARY FLIGHT DISPLAY (PFD)
LaRC	87	VALIDATED WINDSHEAR MODEL, DFW MICROBURST DATA
LaRC	88	WINDSHEAR INFLUENCE VORTEX-LATTICE METHOD
LaRC	88	AIRCRAFT TRAJECTORY GUIDANCE WINDSHEAR ENCOUNTERS
LaRC	88	DIAGNOSTIC EXPERT SYSTEM USING NTSB ACCIDENT DATA
LaRC	88	ULTRASONIC NON DESTRUCTIVE TECHNIQUE, AL FATIGUE
LaRC	88	ALDF- RSS HEAVY RAIN SIMULATION
LaRC	88	ULTRASONIC TECHNIQUE TO DETERMINE FATIGUE STATE SIGNIFICANT ALUMINUM ALLOY
LaRC	89	FORWARD-LOOK WINDSHEAR DETECTION FOR AIRCRAFT
LaRC	89	PHYSIOLOGICAL MEASURES USEFUL IN BOREDOM DETECTION
LeRC	80	ANTIMISTING KEROSENE
LeRC	83	TURBINE DISK CRACK DETECTOR
LeRC	83	HEAT CONDUCTION ANALYSIS ELECTROTHERMAL DEICERS
LeRC	89	GROUND DEICING FLUIDS -LOWER AERODYNAMIC PENALTIES

PROGRAMS APPLICABLE TO GENERAL AVIATION

AMES	83	CONTROLLED DEEP STALL EXPERIMENT
AMES	87 - 89	EMERGENCY MEDICAL SERVICE SAFETY PROBLEMS
LaRC	80	EMERGENCY LOCATOR TRANSMITTER (ELT) RELIABILITY
LaRC	80	GENERAL AVIATION STALL/SPIN RESEARCH
LaRC	80	EMERGENCY LOCATOR TRANSMITTER (ELT) RELIABILITY
LaRC	80	LOAD LIMITING SUBFLOOR STRUCTURE
LaRC	80	SPIN RESEARCH WITH A ROCKET RECOVERY SYSTEM
LaRC	81	EMERGENCY EGRESS SYSTEM FOR AIRCRAFT
LaRC	81	"FOLLOW ME" BOX DISPLAY FOR GENERAL AVIATION
LaRC	81	20 FOOT VERTICAL WIND TUNNEL
LaRC	83	ENGINE-OUT CHARACTERISTICS OF LIGHT TWIN AIRCRAFT

PROGRAMS APPLICABLE TO GENERAL AVIATION

LaRC	83	GA STALL/SPIN DISCONTINUOUS LEADING EDGE
LaRC	84	AUTOMATIC ENGINE-OUT TRIM FOR LIGHT TWIN AIRCRAFT
LaRC	86,87	SPIN RESISTANCE CRITERIA FOR LIGHT GA AIRCRAFT
LaRC	87	CRASH TESTS COMPOSITE HELICOPTERS
LaRC	88	ADVANCED CONTROLS FOR GA AIRPLANES
LaRC	88	REDUCTION PILOT STRESS BY DATA LINK ATC-PILOT-ATC
LaRC	89	HIGHWAY-IN THE-SKY (HITS) AND EZ FLY CONCEPTS
LeRC	80	IMPROVED ICE PROTECTION SYSTEMS FOR GA AIRCRAFT
LeRC	84	PNEUMATIC DEICERS FOR HELICOPTER ROTORS
LeRC	89	NEW ICING TEST CAPABILITY FOR ROTORCRAFT

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VITA

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Biographical:

Personal Data: Born in Roanoke, Virginia, November 13, 1938, the son of Theodore O. and Anna S. Poff.

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