

NASA'S AVIATION **SAFETY** RESEARCH AND TECHNOLOGY PROGRAM

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NASA's Aviation Safety Research and Technology Program is a broad-based multidisciplinary effort aimed at solving those operational problems where new knowledge or understanding is required.

The field of aviation safety and operating problems provides a continuing challenge to raise the levels of our knowledge and understanding of the aircraft operating environment. As aircraft design, operational boundaries, human roles, and social and economic constraints change, so do the nature and relative importance of operating problems. What may have been an economic nuisance yesterday, may well become a safety problem today or tomorrow. The task of the research planner is not only responding to identified problems, but also in trying to anticipate where the next serious problem area will be, is difficult and formidable. Funding for solutions to tomorrow's problems is difficult to justify, and public impatience for rapid solutions to difficult problems involving highly complex disciplinary and system interactions is often unreasonable. Nevertheless, safety research and technology is an exciting area, carrying with it the satisfaction of achieving in part perhaps the most important goal of all reduction of suffering, misery, and loss.

INTRODUCTION

Safety is difficult to define, but can be thought of as the absence or control of factors which can cause injury, loss of life, or loss of property. Aviation safety is challenged by the practical necessity of comprising inherent factors of design, environment, and operation. If accidents are to be avoided, these factors must be controlled to a degree not often required by other transport modes. The operational problems which challenge safety seem to occur most often in the interfaces within and between the design, the environment, and operations, where mismatches occur due to ignorance or lack of sufficient understanding of these interactions.

Aircraft operating problems accompanies the first success of flight, and have been aviation's constant companions ever since. As aviation's role in public transportation has become firmly established, more and more attention has been devoted to ensuring the reliability, and therefore the safety, of flight. The travelling public has come to expect a very low risk associated with air travel. A recent issue of Flight International (Ref. 1) places the chances of a passenger being killed before arriving at his destination at three in a million. One might quibble somewhat with the data used in arriving at this figure, but the essential point is well made; air transportation is safe indeed. Why then, pursue improved levels of safety? Surely because survival and expansion of air travel demands the lowest operational risk commensurate with the economic well-being of the air transport system. It is in the best interests of the aviation consumer and the aviation engineer and operations communities to ensure the lowest practical risk.

The Nature of Operating Problems:

Operating problems arise most frequently when a new aircraft design is put into service, when a new air or ground operating environment is entered, or when operating procedures are changed. By far, the majority of these types of operational problems can be solved by straightforward engineering methods, calling upon established bases of knowledge, or by modifications in operating techniques or procedures. Examples of this class of problems include such things as hydraulic system malfunctions, abnormally high material deterioration rates, localized vibratory stress failures, avionics malfunctions, terminal area procedural problems, flight crew task loading, etc.

There is another class of operating problems, however, that is characterized by an elusiveness of cause or by a lack of sufficient understanding of how the airplane and its equipment will be operated and of the requirement placed upon the airplane and its equipment as it interacts with the environment. Solutions to these problems have generally required an expansion of knowledge or understanding of not only the nature of the problem, but also of the effects of employing different solution options with a view towards avoiding the creation of another problem. Research serves this purpose well by laying down the basis for development of new materials, system's processes, operating techniques, and design practices which establish a satisfactory safety margin or risk level. Very often an old problem which has been "solved" through research reappears, due to a change in aircraft type or change in operating environment. The new situation has uncovered a subtlety which necessitates a "finer scale" view of the earlier understanding. Additionally, there are situations where an improvement in

design, materials, or procedure undertaken for efficiency improvement or environmental benefit subtly introduces a new vulnerability to hazard, affecting the safety margins previously established. Examples of this class of operating problems include, for instance, gust loading and wind shear, wake vortex interaction with encountering aircraft, engine performance degradation, composite structures integrity, flight crew workload, aircraft crashworthiness and fire-worthiness, and lightning hazard effects.

NASA Aviation Safety Research:

NASA's Aviation Safety Research and Technology efforts address the latter class of operational problems, where solutions require a new level of knowledge or understanding of the hazard and its enabling factors. The output of these programs is directed at providing an upgraded technology base upon which manufacturers and operators may draw to reduce risk through design and operation. Better understanding of problems and solutions can also strengthen the rationality of standards setting and regulatory activity aimed at maintaining low risk levels. Public confidence in transportation systems grows as reliability and dependability increase and as risk decreases. Coupled with reasonable fares, high reliability, dependability and safety of operation will increase patronage with obvious benefits to the industry and the public alike.

One can always identify more research needs than there is funding to support. Prioritization is difficult because of the "reactive" nature of operational problems research. The "probable cause" of accidents frequently provides clues to research needs. Incidents, if recognized early and as significant, can cause remedial action that can

hopefully prevent a catastrophe. Accidents often impart an urgency for a solution which is inimical to thorough, necessary research; therefore, compromises must frequently be arrived at in planning the safety research program.

Inputs to NASA's research program planning come from formal and ad hoc advisory panels and communities, from requests and recommendations from other government agencies, and from the industry. These are considered along with NASA staff recommendations in view of resources, manpower, expertise, and facility availabilities in finalizing program plans. Presently, the NASA Office of Aeronautics and Space Technology Aviation program comprises research in meteorological hazards to aircraft operation, wake vortex research, engine rotor fragment containment research, fire research, crashworthiness investigations, aircraft ground operations research, and investigations of the man-vehicle interface. The program is coordinated as broadly as possible, both domestically and internationally.

A comprehensive status report on all elements of the Aviation Safety and Operating Problems Research programs in NASA is clearly beyond the scope of this survey paper, but a report of significant recent progress in several of these areas will be offered as representative of NASA's current program. References are cited throughout and at the end of the paper as sources for more complete information on these topics. However, Reference 2 provides an indepth review.

HAZARDS AND OPERATING PROBLEMS IN THE NATURAL ENVIRONMENT

NASA and its predecessor, the NACA, have for many years studied aircraft operational problems associated with the variability of natural atmospheric parameters. Most of this effort has been targeted on achieving a better understanding of atmospheric processes or to describe them in functional terms of use of the designer, operator, and forecaster. While we share this research responsibility with the FAA, the military services, and the National Oceanographic and Atmospheric Administration (NOAA), our efforts generally derive from an identified operating problem or hazard which affects the design or operation of the flight vehicle. NASA's Office of Applications supports a major effort in Atmospheric Science, but the emphasis of our aviation-oriented meteorology research lies in civil aircraft operating problems associated with turbulence and wind shear, lightning hazards, fog, and radiation hazards.

Clear Air Turbulence Characterization and Prediction:

Turbulence research addresses problems of operation both in the atmospheric boundary layer and at higher altitudes. Representative of this work are efforts to characterize Clear Air Turbulence, or CAT, for use in reliably forecasting its occurrence and to guide development of CAT detection instrumentation. Obtaining accurate, reliable correlations between CAT occurrence and synoptic conditions is fundamental to further understanding of CAT.

A goal of a recent research task was the development of discriminant functions, with synoptic-scale parameters as variables, capable of predicting the areas and altitudes of stratospheric CAT. Also, predictive methods indicating the intensity of the expected turbulence were investigated. The data used in the program were obtained from turbulence experienced with the XB-70 and YF-12A aircraft and 69

synoptic-scale parameters determined from rawinsonde data. A full description of the discriminant function analysis used as the primary analysis tool is contained in Reference 3. The results of this research indicate that there is, indeed, a relationship between selected combinations of synoptic scale parameters of the upper troposphere and lower stratosphere and stratospheric CAT. The relationship is verified only for occurrence, not intensities. Nevertheless, the results are encouraging in offering promise of more reliable forecasting of CAT which should, in turn, enhance safety by providing warning and avoidance information.

CAT Detection:

Several years ago, as part of the U.S. Federal Coordinator's Program for Meteorological Research, NASA undertook an investigation of laser technology as applied to the program of CAT detection and warning. The goal was to examine the feasibility of developing an airborne laser-Doppler system (LDS) for operational use, and to determine whether CAT could be measured far enough ahead of an airplane sufficiently well to be considered practical. Theoretical studies to determine feasibility and to define preliminary design requirements were conducted in 1968-69. The results of these studies led to the design and development of a breadboard pulsed CO₂ laser Doppler system during 1970 to 1972. This breadboard system was flight tested in 1972 and 1973 aboard NASA's CV990. A special forward looking fairing was designed and built for the portside emergency door of the aircraft, which permitted the laser beam to be transmitted forward along the heading of the aircraft. Receiving backscatter light from micron-sized aerosol particles in the atmosphere, the system measures this signal, comparing it with the transmitted beam,

processes the information, and relays it to the displays and recorders. Since the CAT warning must extend over many miles, the laser beam must be highly stable and have large coherence lengths. Two series of successful flight tests were conducted. Some modifications were made to the hardware between the two tests that increased the signal-to-noise performance of the system by about 15 dB.

The feasibility of the LDS as a CAT detector was demonstrated, and some clouds not shown on the aircraft weather radar were detected by the LDS. While turbulence detection ranges were disappointingly short (5 to 6 n. mi. vs 16-20 n. mi.), it is believed that system sensitivities and signal-to-noise (S/N) ratios can be improved to achieve near-theoretical performance. In the coming year we plan to conduct a series of ground based tests with the system incorporating hardware improvements made since the flight test series. These ground tests will lead to a flight test data of mid-1977 for further onboard evaluations.

MAT Program:

Another effort, begun about five years ago, is the Measurement of Atmospheric Turbulence (MAT) program employing a B-57B aircraft with a nose boom incorporating low inertia flow vanes (α & β) and Statoscope (P). The objective of this program is to obtain detailed measurements of the time histories of the components of atmospheric turbulence of all kinds (e.g., jet stream, low altitude, clear air, mountain wave, storm, etc.) using the same aircraft instrumentation and data reduction procedures for all measurements. This program has yielded homogeneous turbulence data which is required in order to

determine the adequacy of the von Karman model at lower frequencies, and to determine a value for the integral scale, L, associated with this model.

Data samplings have been completed between sea level and 50,000 feet (15.2 km) altitude. A total of 60 data runs were taken in 46 flights (30 in eastern U.S., 16 in western U.S.). Instrumentation is being removed from the B-57B preparatory to its installation in a B-57F airplane for sampling between 50,000 and 65,000 feet (15.2 km and 19.8 km) during January-June 1977. Early preliminary results of data analysis indicate that the von Karman description of atmospheric turbulence power spectra is good for the vertical component, but that for the horizontal component, a second power rise is evident at very long wavelengths. Finally, the results of a recently completed study are providing new knowledge concerning the degree of "rounding" of the knee of the von Karman model introduced by nonhomogeneity.

Lightning:

Lightning strike hazards to safe aircraft operation have been the object of NASA study for nearly two decades. In the 1960's attention was focused on prevention of fuel vapor ignition by lightning, and on the behavior of stainless steel and titanium "wet wing" structural panels when struck by lightning. Out of this work evolved design principles which avoided the hazards presented to the fuel tank by "hot spots" and metal spalling behavior. Present design practices in lightning protection center primarily about the avoidance of direct effects of burning, blasting, and physical deformation of skins and structural elements. Both the military services (Ref. 4) and the FAA (Ref. 5) have published specifications which provide guidance to the designer for avoiding direct hazards.

There is currently increasing evidence of troublesome electromagnetic effects due to lightning, involving both permanent damage and temporary malfunction of equipment.

While lightning-induced effects are suspect in some causes of lost aircraft, they are more certain to have caused curtailment of operations or reductions in safety margins. Earlier vacuum tube electronics were relatively immune to lightning-induced transient voltage surges; however, the newer generations of modern, solid-state microcircuitry are increasingly vulnerable to upset or damage from the indirect effects of lightning seen as electromagnetically induced surges. As modern aircraft become more and more dependent upon reliable operation of critical electronic systems, it becomes evident that new knowledge and understanding of lightning indirect effects is essential to safe operation.

NASA, through contractual efforts with General Electric, developed a simulated lightning test and measurement system known as Transient Analysis. This system permits the investigation of specific electromagnetic effects of lightning without hazard to the aircraft being tested. The Transient Analysis technique is fully described in Reference 6.

NASA's Dryden Flight Research Center has developed and demonstrated a digital fly-by-wire flight control system in an F-8 aircraft. Industry is moving toward incorporating even more digital computer and control electronics in new aircraft designs. The indirect effects of lightning very clearly have the potential of presenting a hazard to the safety of flight, and this hazard may be particularly acute for digital systems. While most practical digital fly-by-wire systems would include multiple redundant control circuits, there may be situations wherein the high level electromagnetic interference produced by lightning could interfere with all of the channels of a

fly-by-wire system at once, yielding what is in fact no redundancy at all.

Thunderstorm Gust Fronts :

The thunderstorm is one of the most destructive natural phenomena, producing intense rain showers, hailstones, and tornadoes. Another, but often unrecognized, destructive product of the thunderstorm is the sudden, intense wind surge or gust front that develops at the surface. These gust fronts, or "straight line winds" can be a major hazard to aircraft flying at low levels or on approach to landing. The danger of these gust fronts is the sudden onslaught of high winds as far as 20 Km ahead of the parent storm cell. During frontal passage, wind speeds may increase from a relative calm to 60 knots in five minutes or so, and then decrease just as suddenly. Such gust front occurrences can constitute a major hazard to low-flying aircraft, especially on approach to a landing.

A challenge for aviation meteorologists is to be able to predict the occurrence, intensity, and position of these gust fronts using readily available rawinsonde, satellite, radar, and surface observations. Currently, most observations are obtained on time and space scales much larger than the gust front itself, the cold outflow of which is usually about 10 Km long, 2 Km deep, having a lifetime of up to about an hour. Several past efforts in predicting gust fronts involved relating large scale parameters to small scale events, but the results were inconclusive and disappointing, demonstrating the lack of a sufficiently complete understanding of the complex mechanisms of the gust front. Knowledge of the gust front structure is therefore of prime importance to achieving confident prediction. Only a high density surface observation network can resolve the surface features of a

gust front, Data on its vertical structure is lacking. Tower measurements have the drawback of limited height and fixed position. Aircraft measurements are costly. Radar and other remote sensing concepts may offer promise, but have not been applied to this problem to any great extent.

NASA has tried therefore, to overcome some of these limitations by employing numerical modelling to obtain more information on the structure and mechanism of the gust front phenomenon. Our model is a non-hydrostatic high resolution, two-dimensional primitive equation model, described fully in Reference 7. The model includes sound waves, but they are strongly damped by a high frequency filter, leaving the gravity waves virtually untouched. A fine resolution grid was used to resolve small scale features. The model is very stable computationally. The chief limitation was the short time step necessitated by the non-hydrostatic degree of freedom. The effect of evaporative cooling in producing a vigorous downdraft was parameterized by an arbitrary local cooling function. This function was applied to produce a steady downdraft of cold dense air to drive the cold outflow and associated gust front. The result is a good simulation of the gust front with the capability to examine its structure in some detail for predictive purposes, and NASA and other meteorological research agencies are now using the model as an effective tool to determine the behavior of gust fronts.

AIRCRAFT GROUND OPERATING PROBLEMS

For many years, NASA has conducted research on problems associated with improving the control of aircraft during takeoff roll and landing touchdown and rollout operational phases. This research has included attention to runway pavement design, tire tread design, landing gear loads, and the tire/surface interface under all weather conditions.

Additionally, NASA has explored ways of reliably measuring runway slipperiness in functional terms useful to a reliable prediction of stopping distance.

Representative special facilities and equipment supporting this research and the Landing Dynamics Facility at Langley Research Center, the Research Runway at Wallops Flight Center, the Powered Ground Test Vehicle, and various slipperiness-measurement vehicles, including the Diagonal Braked Vehicle.

Major programs currently under way include investigations of air cushion landing systems concepts, determination of mechanical and frictional properties of tires, continued investigation of runway slipperiness, antiskid control research, takeoff/landing simulator development, and tire materials research.

AIRCRAFT FIRE TECHNOLOGY

Modern jet transport aircraft operating at weights double that and more of older piston engine airplanes provide an increased likelihood of crash-impact survival for their occupants. Modern structural designs, including stronger floor and improved seat retention, subjected to decelerative loads of a landings crash or aborted takeoff, absorb much of the impact that the occupant would otherwise sustain. However, the large amounts of onboard fuel and its potential for being spilled and involved with a multitude of ignition sources make post-crash fire a continuing potential threat to occupant survival in a crash. The large amount of organic materials aboard the modern aircraft constitute another potentially ignitable "fuel" which can produce toxic gas and smoke during pyrolysis. While three catastrophic inflight fires have occurred in jet transports within recent years, most in-flight fires are of small

magnitude, are detectable early, and can usually be controlled. Nevertheless, the potential for catastrophe remains, and further attention to preventing, detecting and quenching is essential. Ramp fires are a relatively recent problem, where aircraft with ground power connected may be left unattended for periods of time awaiting scheduling turn-arounds. If they are connected by passenger corridors to the ground terminal, the potential for further fire spread is broadened.

Opportunities to improve fire safety are easily identified with the use of "logic trees" framework, and NASA is sponsoring research in close coordination with FAA, the military services, and the aircraft industry to effect an improved fire safety level. Overall fire safety and survivability for both military and civilian aircraft can be increased by preventing ignition of combustible substances. This is a major factor in considering survivability and vulnerability of close support military combat aircraft. Survivability has been achieved in some instances by ignition suppression of the ballistic incendiary threat and by protection of the fuel system with low density foams and composites, preventing the fuel from coming into contact with the ignition source. NASA research in these areas was described by Parker during the AGARD Propulsion and Energetics Panel Meeting on Aircraft Fire Safety in Rome in April 1975.

NASA's program of fire research and technology is deeply entwined with activity in other agencies and departments. Industry involvement is high, and cooperation between all parties in attacking the fire problem is unusually good. NASA and FAA have entered into an Interagency Agreement which specifies respective roles of the two agencies in fire research. NASA's research takes cognizance of the various factors contributing to aircraft fire and survivability.

Our goals are to improve the understanding of fire dynamics in ramp, postcrash, and in-flight situations; to support the development of improved test methodology; to provide materials technology that will yield properties which cooperate to resist ignition, to insulate, and to exhibit low outgassing levels of smoke and toxic by-products; to explore means of reducing ignition and fire build-up rate; and to provide basic research and technology support to other agencies. This basic program is augmented by a 5-year program called FIREMEN (Fire Resistant Materials Engineering) which is aimed at evaluating new materials concepts in real aircraft applications, improving test methods, and exploring processing and fabrication problems in order to accelerate the application of fireworthy technology.

CRASHWORTHINESS RESEARCH

Crashworthiness Design Technology:

A joint NASA-FAA program was begun three years ago to develop an upgraded reliable technology upon which crashworthiness design of aircraft can be based. This program has three objectives:

- *Development of analytical methods,
- *Definition of a survivable crash envelope,
- Improved seat and restraint systems.

The organization of this program divides the respective responsibilities of the two agencies, and NASA's portion of the joint program has three program elements;

- Full-scale crash simulation testing,
- *Non-linear crash impact analysis,
- Crashworthy design concepts.

The full-scale crash simulation testing is being conducted at the Langley Research Center's Impact Dynamics Facility, the former Lunar Landing Research Facility. It has been modified for free-flight crash testing of full-scale aircraft structures and structural components under controlled test conditions (Ref. 8). The test vehicles are suspended pendulum fashion from beneath the bridge of the facility, swung and released just prior to impact to simulate free-flight crash conditions at impact.

The objective of the analytical effort is to develop the capability to predict the non-linear geometric and material behavior of sheet stringer aircraft structures subject to large deformations and to demonstrate this capability by determining the plastic buckling and collapse response of these structures to impulsive loadings. Two specific finite-element computer programs are being developed with attention focused on modeling concepts applicable to large plastic deformations of realistic aircraft structures:

- Plastic and Large Defelction Analysis of Nonlinear Structures (PLANS): This computer program for static finite-element analysis is capable of treating problmes which include bending and membrane stresses, thick and thin axisymmetric bodies, and laminated composites (Ref. 9).
- Analysis of Crash Transients in Inelastic Or Non-linear Range (ACTION): A non-linear dynamic finite-element computer program is being extended at Langley to more realistic aircraft sheet stringer structures. Membrane elements have been added to the initial truss and frame simulation capability to predict the transient response of frames with and without sheet coverings.

These programs are currently being evaluated in comparison with experimental results on some simplified structures.

The development of structural concepts that improve the energy absorption characteristics of a structure is key to improving occupant survivability in a crash. Langley is investigating effects of modification of structural assemblies, changing the geometry of its elements, or adding specific energy absorption devices to help dissipate kinetic energy.

AIRCRAFT WAKE VORTEX HAZARD RESEARCH

Aircraft wake vortices have been recognized for many years as a major operating problem to contend with as traffic densities in the terminal area have increased to the extent that aircraft separations are limited by vortex upset considerations. There is ample documentation of the hazards associated with vortex encounters which have resulted in upset of the following aircraft at close distances.

The potential hazard of vortices was recognized well over a decade ago, but not until 1972 was a substantial joint program mounted between the FAA and the NASA to investigate means of reducing the operational restrictions imposed by vortex presence. NASA's research in wake vortex alleviation and support to FAA in developing ground-based vortex warning concepts is broad-based.

AVIATION SAFETY REPORTING SYSTEM

The Federal Aviation Administration implemented an Aviation Safety Reporting Program in May 1975, for the purpose of identifying discrepancies and deficiencies in the national air transportation system. The program permits

anyone using and working in the system to report, in a convenient manner, problems or other situations critical to system safety. FAA recognized the need for a "third party" to receive, process, and analyze safety reports in order to insure anonymity to the person or persons providing the information. It has been generally hoped that this procedure would encourage voluntary, timely reporting of potential safety problems by reducing the risks of potential organization or peer-group harassment of the reporting individual. The **FAA** requested NASA's participation as the "third party" in the process, based upon the success of a NASA Human Factors research effort begun in 1974 (Ref. 10). NASA subsequently designed the present Aviation Safety Reporting System (ASRS) and has been operating it since it went "on line."

Reference 11, NASA Release 76-52, contains a complete description of the ASRS, its background, management, staffing, and procedures for reporting.

The ASRS is designed to act as an early warning system. Its purpose is to collect reports which may provide valuable safety information, to extract the safety-related data, and to inform those who can act positively on the information hopefully before an accident occurs. As a so-called "clearing house" for the collection and dissemination of data, the ASRS is organized to detect longer term trends of events which individually may not appear significant, but which collectively may suggest unsafe tendencies.

While the ASRS is being operated by NASA for the **FAA's** use in maintaining air transportation system safety, it will also function as a part of NASA's ongoing research in aviation safety. Thus the ASRS will gather descriptive data while NASA's Aviation Safety Program will continue to perform analytical and experimental studies of problems in the operational environment.

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