OVERVIEW OF SAFETY RESEARCH

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SUMMARY

Aircraft safety is reviewed by first establishing a perspective of air transportation accidents as a function of calendar year, geographic area, and phase of flight, and then by describing the threats to safety and NASA research underway in the three representative areas of engine operational problems, meteorological phenomena and fire.

The aircraft engine operational safety discussion addresses engine rotor burst protection, where both experimental and analytical efforts are underway, and aircraft nacelle fire extinguishment where experimental studies are being carried out to examine the effectiveness of various candidate remedies (for example, application of dry chemicals).

NASA meteorological research is focused on the aircraft-weather interface, both by fine-scale characterization of weather phenomena, and by providing warning or protection against weather hazards. Studies underway are described in the areas of severe weather wind shears and turbulence, clear air turbulence, and lightning.

The present NASA fire program emphasizes fire impact management through fire resistant materials technology development. A description is given of the ongoing five-year FIREMEN Project whose objectives are to identify better fire safety materials for the aircraft interior and to improve the understanding of fire dynamics, test methodologies, and toxicity reduction schemes.

INTRODUCTION

Safety is a subjective term, with many definitions. It includes concepts of risk exposure, risk taking, and risk management. It defies unique interpretation but can be thought of as the absence or control of factors which can cause injury, loss of life, or damage to or loss of property. The meaning of acceptable safety, on the other hand, varies with the situational and time frameworks, and with the individual's perception of risk coupled with his willingness to be exposed to risk and the degrees of exposure. Starr in reference 1 discusses the differences in acceptable risk levels, depending upon whether it is a "voluntary" or "involuntary" risk. These concepts hold high significance for those involved in improving safety and operational efficiency in air transportation. They explain, in part, the vast differences in air transport, general aviation, and auto fatal accident statistics, and suggest reasons for the intense public scrutiny of the typical air transport accident, whereas general aviation and auto accidents receive considerably less attention.

To establish a perspective, consider transportation fatalities for 1977. Of a total 50 856 transportation fatalities, air transport accounted for 654 or 1.3 percent. General aviation suffered 1395 fatalities or 2.7 percent of the total. Another view of air transport safety is given by the fact that in 1977, out of about 5 million U.S. Air Carrier take-offs and landings, only six fatal accidents occurred.

Figure 1 shows the cumulative picture of jet hours and hull losses. Between 1959 and 1977, 300 jet hulls have been lost, world-wide. U.S. carriers account for one-third of the total losses but log slightly more than one-half of the world-wide 142 million cumulative flight hours. Figure 2 shows the cumulative hull loss rate for the same period. As of the end of 1977, U.S. air carriers averaged 1 hull loss per 779 000 hours, slightly less than one-half the loss rate of the rest of the world. Table I shows hull loss rates by geographical area. The dramatic improvement in losses for Australia and South Pacific areas is evident, as is the steady improvement in U.S. operations. These regional figures are interesting, because they raise questions concerning the differences in operational facilities, training, maintenance, regional weather and operating environment, human factors, navigation, and communications. The common denominator is that the same U.S. equipment predominates in each region. Table II is an estimated cost of commercial jet accidents. Note that neither injury liability nor third party damage is included. Although aviation is a highly safe mode of transportation, operating problems, incidents, and accidents continually point the way for safety improvements.

Aviation Safety and Operating Problems Research is itself the subject of conferences similar to this one which are held about every 5 to 6 years. The most recent took place at NASA Langley Research Center in 1976 (ref. 2). This research is a broad topic, infused in disciplinary and project effort, as is evident from the safety considerations noted in many other papers presented during this Conference.

The NASA research program in Aviation Safety derives from identification of operating problems which erode safety margins and from lessons learned through accident analysis by National Transportation Safety Board (NTSB) and Federal Aviation Administration (FAA). The vast bulk of NASA aeronautics funds is spent on keeping aircraft flying efficiently and reliably, with improved performance. Accidents and incidents suggest research and development actions necessary for improving understanding and knowledge of the natural environment and the physical and the operational environments. About 5 percent of the budget is devoted to research on safety and operational problems. Of this segment, about three-fourths is oriented towards avoiding accident-enabling situations; this effort includes aviation meteorology, vehicle systems, operational systems, and human factors. The remaining one-fourth is directed at maximizing occupant survival in case an accident occurs and includes crashworthiness and crash fire research.

Figure 3 shows the distribution of fatalities by phase of jet transport operations. About 80 percent of fatalities occur in the terminal phases, either during approach and landing, during take-off or take-off aborts, or because of loss of control while on the runway. In these cases, the aircraft speeds are lower than during en route operation, so chances for survival of an accident are correspondingly higher; the bulk of our safety effort is directed at preventing accidents and maximizing occupant survival in terminal operations phases.

The remainder of this paper will present a brief overview of three representative operating problems and safety research efforts:

(a) Aircraft engine operational safety
(b) Aviation meteorology research
(c) Fire technology

AIRCRAFT ENGINE OPERATIONAL SAFETY

The aircraft turbine engine and its associated fuel and control systems, contain considerable kinetic and chemical energy which must be controlled in order to preserve adequate safety margins. Engine structural failure and inflight fires are events which, although rare, demand preventive and survival attention.

Engine Rotor Burst Protection

NASA Lewis Research Center has been exploring engine rotor failure and fragment control since the late 1960's with the objective of providing a basis of understanding upon which engine rotor integrity can be improved and fragment control schemes can evolve.

Uncontained engine failures are rare events (fig. 4) and remain somewhat centered about 1 per million flight hours. However, the damage wrought by a fragment (fig. 5) is awesome, can reduce the operational margin of safety to near zero (fig. 6) or in the extreme case can be fatal. In U.S. air carrier service, uncontained rotor bursts vary about a mean of 20 to 25 occurrences per year (fig. 7), and not surprisingly, tend to occur more during the high power operation of take-off and climb (fig. 8).

In cooperation with the Naval Air Propulsion Test Center, NASA-built spin facilities (fig. 11) are used to obtain empirical information on rotor failure and fragment impact on containment rings of various high strength materials. Figure 10 is a typical high-speed photographic sequence of a T-58 rotor, scored to control fragment size, failing, and impacting a test containment ring. Analysis of this type of data permits evaluation and screening of various containment ring materials and designs.

Concurrent with this empirical effort is an analytical program at the MIT Aeroelastic and Structures Research Laboratory, designed to develop theoretical procedures for predicting large-deflection elastic-plastic transient structures to cope with rotor burst fragment attack. Earlier efforts have concentrated on containment/deflector (C/D) structures whose axial dimensions are comparable with those of the attacking fragments, and hence the associated structural responses are essentially two-dimensional. Recent research efforts have concentrated on analysis of C/D structures whose axial dimensions are much larger than those of attacking fragments; hence, the associated structural response to be analyzed is essentially three-dimensional. A series of computer programs have been developed which can predict C/D ring response from an assumed fragment attack, or conversely yield loading parameters of a fragment attack from given ring deflections and behavior.

A NASA-sponsored workshop "An Assessment of Technology for Turbojet Engine Rotor Failures" was held at MIT (ref. 3) on March 29-31, 1977 where this NASA program was presented along with results of other foreign and domestic government and industry programs. As engines grow larger and fragment energies continually increase, the problem of insuring adequate safety margin remains with us.

Aircraft Nacelle Fire Extinguishment

Modern jet aircraft engine nacelles contain various piping, tubing, etc., carrying pressurized oil, fuel, and hydraulic fluids. Large volumes of air induced from outside the engine or bypassed from the compressor section ventilate the nacelle space to insulate the hot engine surfaces from the adjacent structure, manifolds, and fairings. Failures of piping due to various causes have occurred and sometimes result in sprays which contact the hot surface, ignite, and burn vigorously in the local air streams. Extinguishing such fires is difficult, and must be rapid and effective to prevent major structural damage or loss of the aircraft. An "effective" extinguishant should be able to initially reduce the fire and to continue to suppress reignition until the fuel flow can be stopped or the hot ignition surface is cooled.

Figure 11 shows an inflight nacelle fire, surrounded by pictures of a small nacelle fire research rig at Ames Research Center designed to examine methods of applying effective fire control. A stream of Jet A fuel is channelled via capillary tubes to a glowing hot surface located in the base of an open trough over which is flowing a stream of air. At the upper left, air flows at 20 m/sec over a stainless steel surface heated to 800° C while Jet A fuel flows onto the surface. At double the airspeed (center left), a very energetic and practically invisible blue flame exists over the test surface. A set of thin parallel rods welded to the surface retain the fuel in intimate contact with the surface while several metal projecting strips act as flame holders for globules of fuel that evaporate and burn on the hot surface.

At predetermined burning conditions for the particular flammable liquid (e.g., Jet A, Jet B, JP 4, etc.), a dry chemical extinguishant is injected in a single, 1-second burst typically knocking the flames down (bottom photograph) and continuing for several seconds or longer to suppress the reignition of the flowing air-fuel mixture contacting the heated surface that was initially capable of igniting the fuel. The dry extinguishant fuses on the hot metal surface, and insulates the fuel from it and thus prevents reignition. In the upper right photograph, the glowing thermocouple leads and red hot surface are still visible through the extinguishant cloud being thinned by the air flow.

The ongoing experiments conducted with Ames nacelle fire simulator are providing new insight into better techniques of controlling hot-surface-ignited fires.

AVIATION METEOROLOGY RESEARCH

Aircraft encounters with bad weather situations continue to produce accidents, incidents, and disruptions to schedules which are frequently surrounded by circumstances which prompt investigators and analysts to question the inevitability of the event.

Bromley of the FAA (ref. 4) reports that statistics for 1975 on delays for periods $\geq$30 minutes show that weather is a significant causal factor affecting the efficiency of air transportation. (See fig. 12.) These FAA data are representative of the past 5 years and show weather parameters as mutually exclusive categories. The percentage of weather-caused delays has varied from 65 percent to 90 percent, with the total number of these delays being >30 000 per year for each year of the 5-year period.

McLean of NTSB (unpublished) cites air carrier statistics showing unexpected encounters with clear air turbulence as the major cause of accident, characterized mostly by injuries to crew or passengers when seat belts have not been used. Factors associated with severe storms account for the most fatalities in air carrier operations, both en route and in the terminal area. Low visibility, due to fog on the ground, has caused fatal errors in judgment on landing and was a major factor in the Tenerife accident.

The Federal government alone spends about $2/3 to $3/4 billion annually on meteorological operations and supporting research, $1/4 billion of this specifically on aviation. FAA, U.S. Coast Guard, NASA, and the military services support meteorology research specifically directed at aviation operations, while National Oceanic and Atmospheric Administration (NOAA) provides basic weather research, data collection, analysis, and dissemination services.

NASA aviation meteorology research centers around the aircraft-weather interface. It addresses both the need to provide sufficiently fine-scale characterization of weather phenomena such as wind fields at all flight levels, severe storms, lightning, icing, and turbulence; and the need for providing warning or protection against weather effects such as clear air turbulence (CAT), wind shear, lightning strikes, and icing. Three efforts illustrate this research

Severe Weather Conditions

The local gust front (fig. 13) created by the rain-cooled outflow from a severe thunderstorm is a familiar phenomenon. The downdraft impinges upon the surface of the earth and spreads radially outward and thus generates substantial wind speed variation and large wind shears near its leading edge as well as at its core. This developing gust front may extend beyond 15 to 20 km from the storm and poses a serious danger to aircraft operating in its vicinity. Several accidents over recent years have been attributed to encounters with downdrafts or the outflowing gust front.

NASA has been interested in determining the feasibility of predicting conditions under which wind and turbulence environments dangerous to aircraft operations exist. Extensive ground measurements of atmospheric boundary-layer behavior using instrumented towers and laser Doppler systems have been made (ref. 5). Recently, Aeronautical Research Associates of Princeton (ARAP), under contract to NASA, have applied an axisymmetric atmospheric boundary-layer numerical turbulence model to the gust front situation. This model is used to reconstruct wind and turbulence profiles which may have existed at low altitudes at the time of aviation accidents. The predictions obtained are consistent with available flight recorder data, but neither the input boundaries nor the flight recorder observations are sufficiently precise for these case studies to be interpreted as verification tests of the model predictions. The results do provide a physically consistent set of wind and turbulence profiles which may be used to help understand those meteorological conditions which may lead to low-level wind shear and turbulence profiles, as well as providing a set of profiles for use in flight simulation studies which have proved hazardous in the past (ref. 6). The ARAP computer model solves the velocity, temperature, and turbulence distributions in the atmospheric boundary layer. It is based on using invariant modeling for closure of the dynamic equations of the ensemble-averaged single-point, second-order correlations of the fluctuating velocities and temperatures. The model appears to give a good representation of the physical dynamics associated with a local downdraft. Simulated trajectories flown through these model results demonstrate the types of problems that pilots could encounter.

Preliminary results indicate the most important variables to be the temperature decrement and the altitude from which the downdraft originates. Surface roughness and velocity of the storm cell may also be expected to have a strong influence on the winds close to the surface.

Clear Air Turbulence (CAT) Characterization and Warning

Unexpected encounters with turbulence in clear air continue to account for the majority of transport nonfatal accidents. Injuries to flight and cabin crew members as well as to passengers could be avoided or reduced if CAT could be reliably forecast or predicted as to extent and intensity.

CAT occurrence is associated with mountain waves, with shear layers attendant to the jet stream, and with instabilities in the atmosphere's temperature lapse rate. Under the guidance of the Federal Coordinator for Meteorology and Supporting Research, NASA and other agencies have worked for several years to characterize CAT in functional terms so that its occurrence and geographical extent could be understood and reliably forecast from analysis of measurable parameters (ref. 7). Forecasting accuracy has improved substantially in recent years, and has allowed more frequent warning of CAT areas; seat belt usage has also prevented many injuries. However, unexpected CAT encounters still occur so that in-flight detection and warning remains a highly desired capability. As an adjunct of the CAT characterization program, NASA has also been engaged in exploring laser technology applications to the airborne CAT detection problem. This effort has been described at previous Langley Conferences on Aircraft Safety and Operating Problems in 1971 and 1976 (refs. 8 and 9). Since that time, additional system improvements have been made and airborne evaluation (fig. 14) of the upgraded system is scheduled to be completed during the next CAT season, January to March 1979.

A companion effort in airborne CAT detection was undertaken last year as a result of the discovery, during astronomical observation flights aboard the NASA C-141 Kuiper Airborne Observatory, of a correlation between atmospheric water vapor concentration variations and the existence of CAT. A simple prototype infrared radiometer and signal microprocessor detects these water vapor anomalies which seem to be associated with CAT presence. Figure 15 shows the system installation aboard the NASA Lear Jet where it is undergoing flight validation and concept validation. By mid-Spring, 1978, assessment of the promise of this concept as a practical candidate airborne CAT detection system should be possible.

Lightning Hazards Research

NACA and NASA research publications since the 1920's have included reports on various aspects of atmospheric electrical phenomena. Of these, the greatest concern to safe flight operations is undoubtedly lightning. Following the 1963 Elkton, Maryland, accident whose probable cause was determined to be ignition of fuel vapors by a lightning strike, NASA began a series of efforts to determine, in quantitative terms, the effects of lightning strikes on aircraft fuel systems, nonaluminum metals and nonmetallics, and induced effects within aircraft electrical systems which increasingly employed microcircuit elements. In addition, nonelectrical damage to aircraft structure from shock waves emanating from lightning strokes was assessed. Data, knowledge, and understanding from these and other efforts was summarized in a reference publication issued last November entitled "Lightning Protection for Aircraft." (See ref. 10.) NASA in partnership with USAF and other government agencies plans to continue its research on lightning and its effects in order to better characterize the air-to-aircraft strike, to assess effects on advanced control systems, and to explore means of protecting nonmetallic structural elements.

Other Recent Meteorology Efforts

Brief mention must be made of two other related efforts in meteorology operations supported by NASA's Manned Space Flight and Applications Offices.

The Kennedy Space Center, concerned about lightning strike hazards to ground and spacecraft launch operations, has developed a Lightning Detection and Ranging (LDAR) System (ref. 11). The system operates in the frequency band of 30 to 50 Mhz and uses a central receiving station with four outlaying receiving stations, each some 8 km from the central station. The LDAR system locates the position of electrical discharges in the atmosphere by processing the time of arrival of the pulsed radio frequency (RF) radiation emitted by the lightning discharge. LDAR is a near real-time system with a capability of detecting ten data points per second and recording these on digital tape. It affords a means of providing lightning hazard information to aircraft flights within a radius of up to 160 km of the central station. In addition, refueling and other ramp operations could benefit from the safety assurance afforded by LDAR's precise tracking of lightning activity.

A system was developed by NASA for the NOAA to provide a low-cost prototype data handling system to transmit meteorological data gathered from wide-body jet aircraft flying remote routes to ground users via synchronous meteorological data relay satellites. The Aircraft to Satellite Data Relay (ASDAR) project, after successful intensive in-house and airline tests, will continue under evaluation for a year (ref. 12). The routine updating of en route weather over remote areas of the world is made possible by this system and safer operations should result.

FIRE TECHNOLOGY

Successful egress from a crashed airplane can be hindered or made impossible by fire, while in-flight fires must be dealt with directly and promptly to insure survival. Statistics and studies dealing with aircraft accidents present evidence of aircraft occupants surviving crash impact, only to succumb to the associated fire or its effects (fig. 16). Although three catastrophic in-flight interior fires have occurred in turbine-powered transport operations, by far the majority of in-flight interior fires have been of small magnitude, were detected early, and have generally been controlled with minimum damage to life or property. The potential for catastrophe remains, however, and it is essential that continuing attention be focused on preventing, detecting, and extinguishing the in-flight fire.

Because aircraft fires are complex phenomena, it is helpful to structure approaches to dealing with fire within the fire dynamics logic tree, shown in figure 17. Fire safety is insured by either preventing ignition in the first place or, failing that, to manage or control the impact of the fire. Preferably, it is desirable to prevent the fire from occurring, by isolating fuels from ignition energy sources, by making materials ignition resistant, or by modifying jet fuel so that ignition of spilled fuel does not take place during the critical crash period. The impact of fire, on the other hand, can be controlled by limiting burning rate responses of materials, by providing thermal barriers, by suppressing fire through extinguishing schemes, or delaying fire build-up until occupants can be evacuated (ref. 13).

NASA's present fire program emphasizes fire impact management through fire resistant materials technology development. The extensive use of organic materials in aircraft interiors (fig. 18) provides opportunities for material fire response rate modification, to either prevent the involvement of these materials or to limit their rate of reponse so that more time is available for occupants to evacuate a survivable crashed airplane. To this end, NASA is seeking fire safety improvements in materials used in ceiling panels, enclosure panels, sidewall panels and windows, thermoplastic moldings, seat fabrics and cushion materials, and floor panels (fig. 19). This materials technology is being developed concurrently with improving our understanding of fire dynamics, test methodologies, and toxicity reduction schemes. The effort is closely coordinated with FAA and DOD fire research and development. This work is incorporated in a 5-year project designated as FIREMEN (FIre REsistant Materials ENgineering). Begun in 1976, FIREMEN will be completed in 1981 at which time it is expected that advanced, low-toxicity, low-smoking, fire-resistant material candidates will have been thoroughly evaluated not only from a fire safety point of view, but also from the very real aspects of basic materials availability, processability, long-term stability, and economics. The results will provide industry with hard data by which engineering judgments on design and selective employment of promising materials can be made.

The technical basis for the FIREMEN program lies in materials modification or synthesis (fig. 20). The flammability of materials can be decreased by post-manufacture treatment with fire retardant chemicals or by synthesis of new polymers with fire resistant behavior built into the material structure itself. Both methods are attractive for certain applications; however, the respective fire performance boundaries, weight and economic costs, must be clearly understood in order to extract the optimum benefits offered.

Additive treatments can be economically attractive and offer good protection from exposure to short duration, moderate heat flux level. However, it has been found that prolonged exposure to externally generated heat (as in a fuel-fed fire or electrical short, in itself not involving the treated materials) can pyrolize the flame treatment chemicals which in themselves become the source of smoke and incapacitating gases. In addition, when all the treatment chemical is pyrolyzed, the basic material is left unprotected and rapidly becomes involved in the fire (ref. 14).

Polymer synthesis, on the other hand, is based upon developing compounds with high char yields when exposed to external heat fluxes. For a given polymer class, the reduction of flammability is generally accompanied by a reduction of smoke and incapacitating gases. The cost and weight are somewhat higher than currently used organics, and both availability of basic monomers and processability of some of the polymers is somewhat limiting to a more vigorous application of these concepts.

Nevertheless, candidate wall panels (fig. 21), seat fabrics and cushion materials have been constructed and tested and show improved fireworthiness. Long-term stability, durability, and other practical design considerations are currently being evaluated.

CONCLUDING REMARKS

NASA aircraft operating problems and safety research effort continues to respond to needs of the aeronautical community. Expanding the basic understanding and knowledge of physical, chemical, environmental, and operating environments where safety margins are impacted is the key to safe, reliable, and efficient design and operation of transport aircraft.

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TABLE I.- HULL LOSS RATE

[By geographical area; data obtained by M. W. Eastburn of American Airlines]

Area	1960	1965	1975	9 Mos. '77
World	1/144 000	1/265 000	1/ 410 000	1/ 464 000
Australia/South Pacific .	--	1/335 000	1/2 360 000	1/3 110 000
U.S.	1/165 000	1/354 000	1/ 674 000	1/ 711 000
Europe	1/274 000	1/310 000	1/ 410 000	1/ 460 000
Canada	--	1/306 000	1/ 535 000	1/ 709 000
Africa	--	1/244 000	1/ 136 000	1/ 189 000
Asia	--	1/131 000	1/ 144 000	1/ 168 000
Central & South America .	1/ 13 000	1/ 48 000	1/ 141 000	1/ 162 000
World excl. U.S.	1/125 000	1/203 000	1/ 286 000	1/ 339 000

TABLE II.- ESTIMATED ACCIDENT COSTS: COMMERCIAL JETS '52 — 9 MOS. '77

[In millions of U.S. dollars; data obtained from M. W. Eastburn of American Airlines]

	U.S.		World excluding U.S.		World	
	Number	Dollars	Number	Dollars	Number	Dollars
Hulls loss	98	599.6	194	977.6	292	1577.2
Est. partial damage . . .	----	282.3	----	219.1	-- ---	501.4
Liability (fatals only) .	2800	522.6	7514	232.9	10 314	755.5
Total		1404.5		1429.6		2834.1

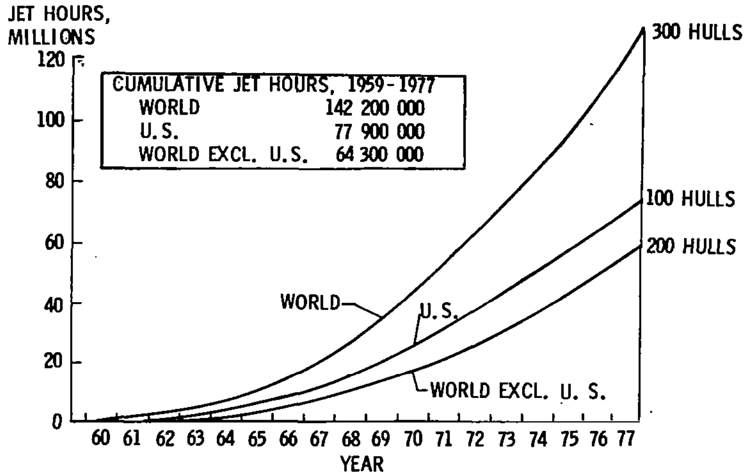


Figure 1.- Air carrier operations. Jet hours - hulls lost (includes 35 destroyed by sabotage and war-like action; 6 U.S.; 29 Non U.S.). Figure obtained from M. W. Eastburn of American Airlines.

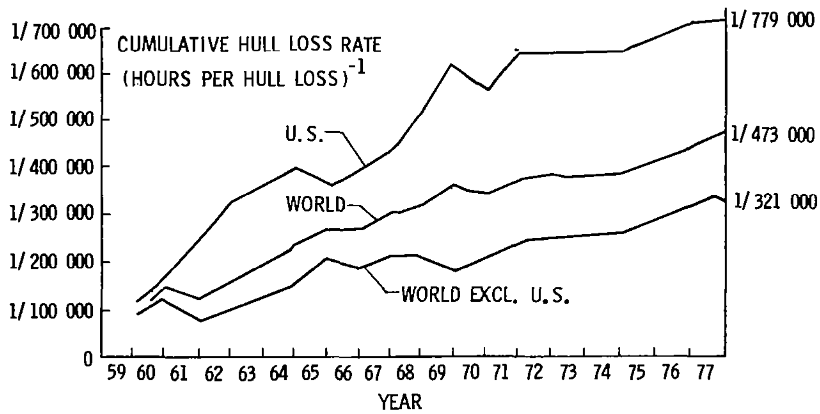


Figure 2.- Air carrier operations. Hull loss rate includes 35 hulls destroyed by sabotage and war-like action. Figure obtained from M. W. Eastburn of American Airlines.

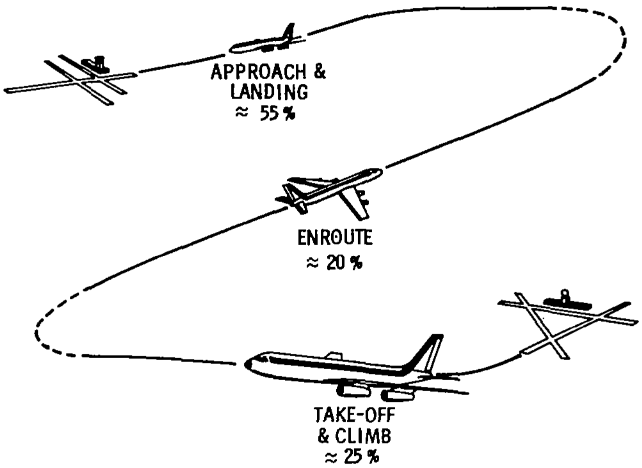


Figure 3.- Distribution of jet transport fatal accidents by phase of flight.

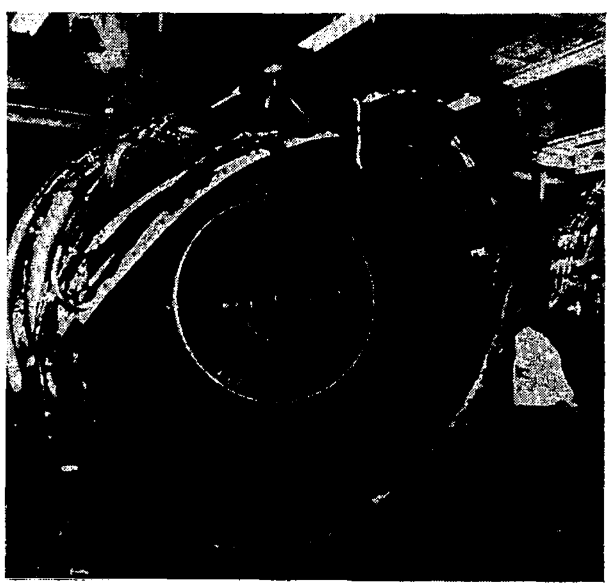


Figure 4.- Engine component failure.

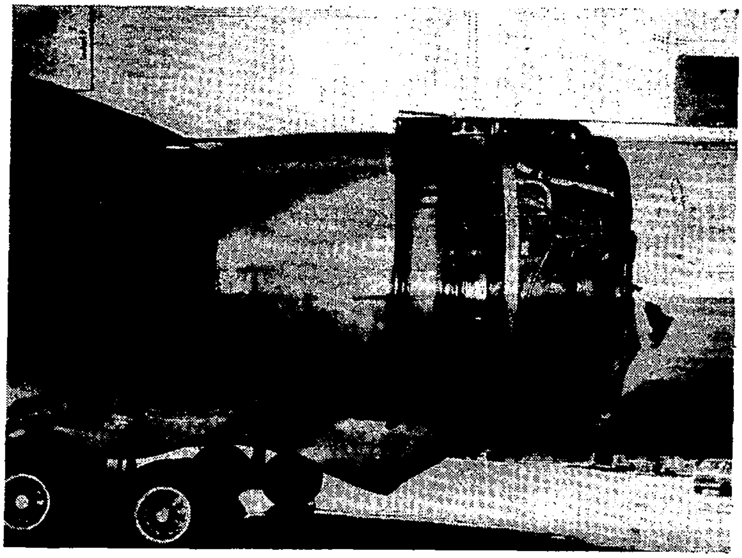


Figure 5.- Uncontained failure of jet engine.

Figure 6.- In-flight engine component failure.

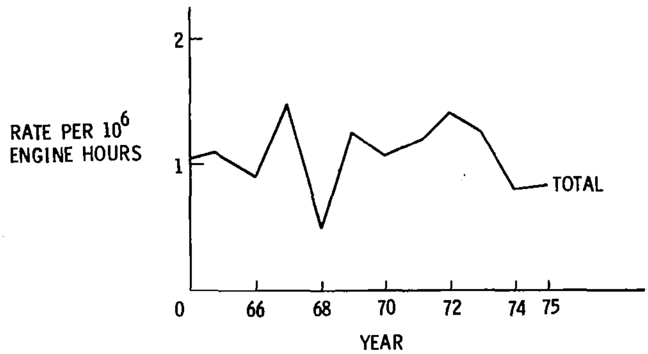


Figure 7.- World-wide noncontainment engine failure rate.

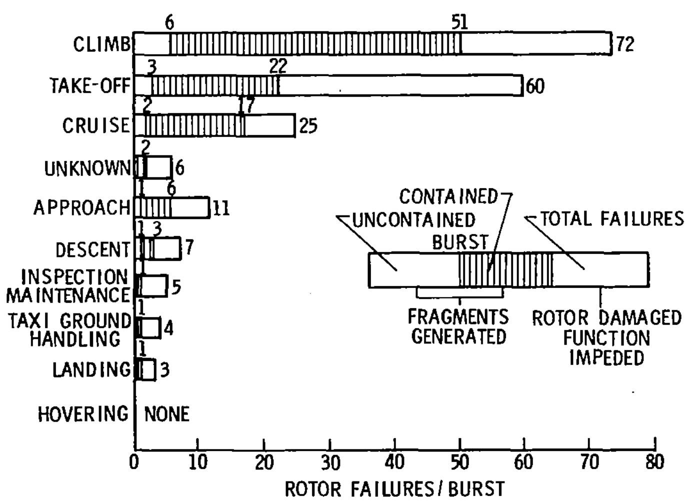


Figure 8.- Flight condition at rotor failure/burst - 1975.

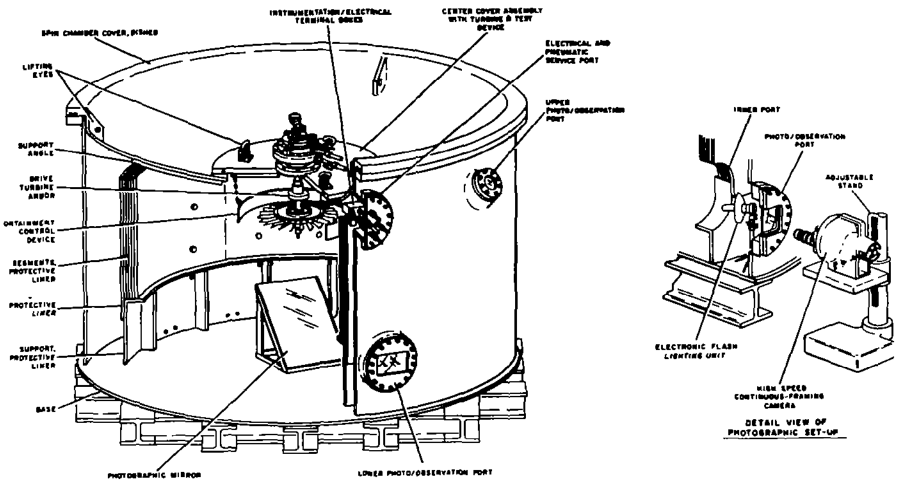


Figure 9.- Spin chamber facilities.

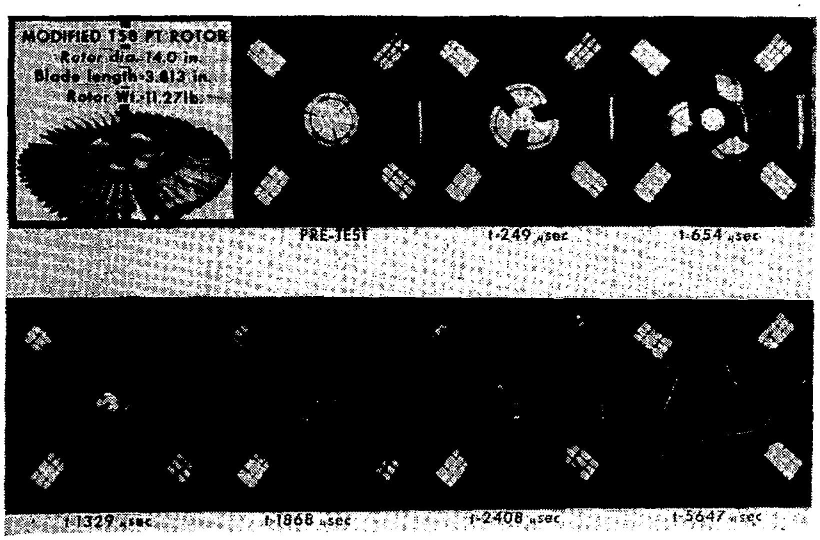
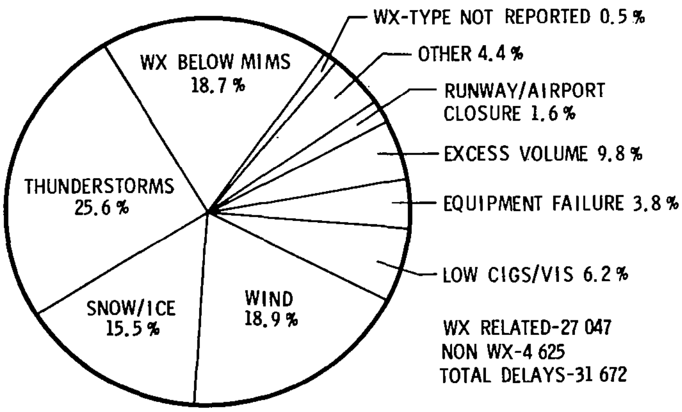


Figure 10.- Bladed rotor fragment generator and bladed rotor burst test results (1 in. = 2.54 cm; 1 lb = 4.448 N).

Figure 11.- Engine in-flight fire extinguishant research.



BREAKDOWN BY CATEGORY OF CAUSES FOR AIR TRAFFIC DELAYS OF 30 MIN OR LONGER DURING 1975.

Figure 12.- Impact of weather on safety and efficiency of air transportation. (Data from Bromley, Bulletin American Meteorological Soc., vol. 58, no. 11, Nov. 1977, pp. 1156 ff.)

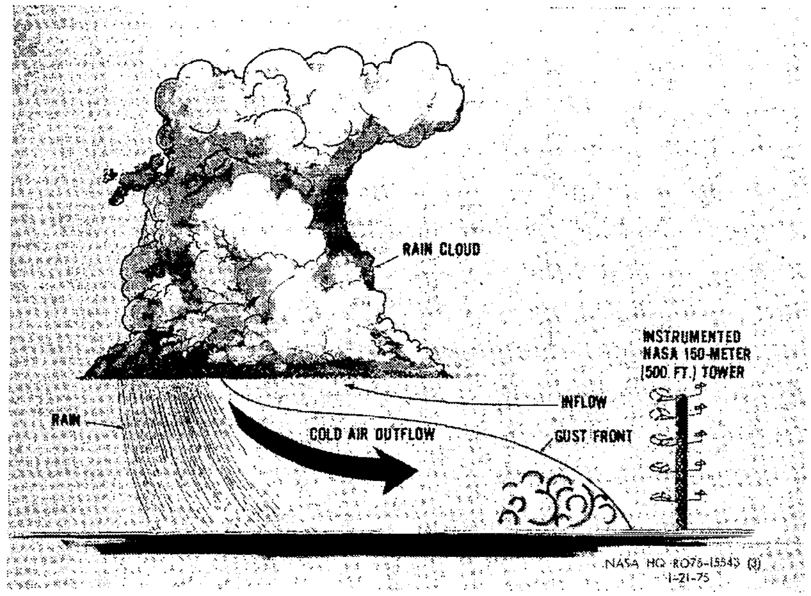


Figure 13.- Thunderstorm gust front technology development.

Figure 14.- CAT research instrumentation on CV990.

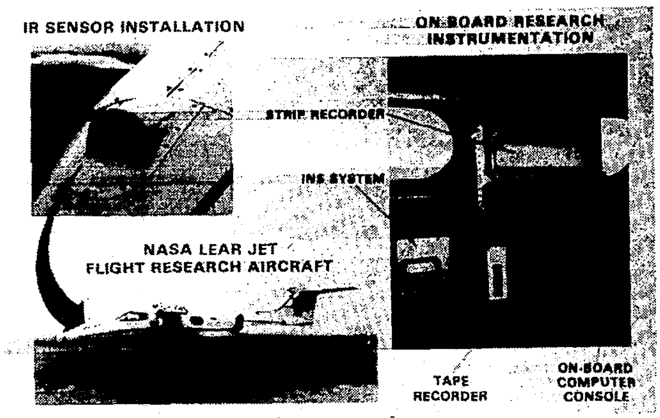


Figure 15.- Clear air turbulence research infrared radiometer detector system.

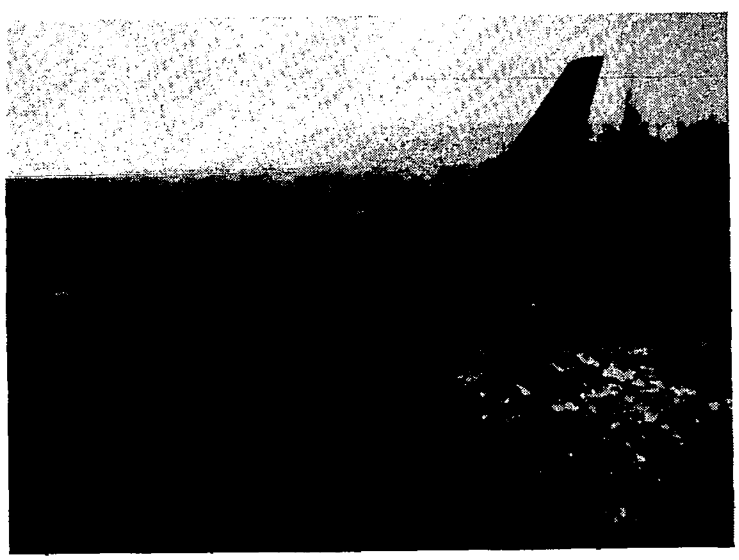


Figure 16.- Fireburned fuselage.

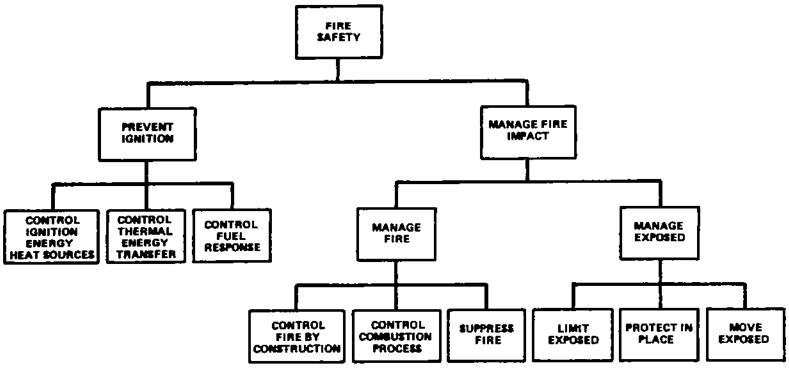


Figure 17.- Aircraft fire dynamics logic tree.

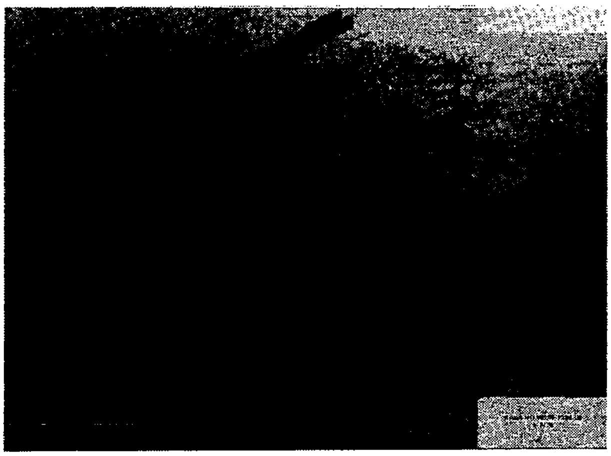


Figure 18.- Representative aircraft cabin interior trim assembly breakdown. Nonmetallic materials.

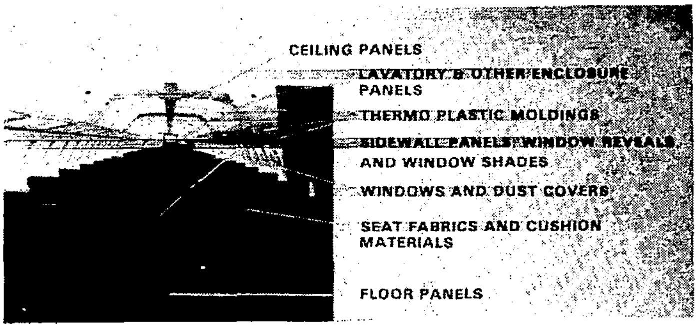


Figure 19.- Improved fire safety in aircraft interior materials.

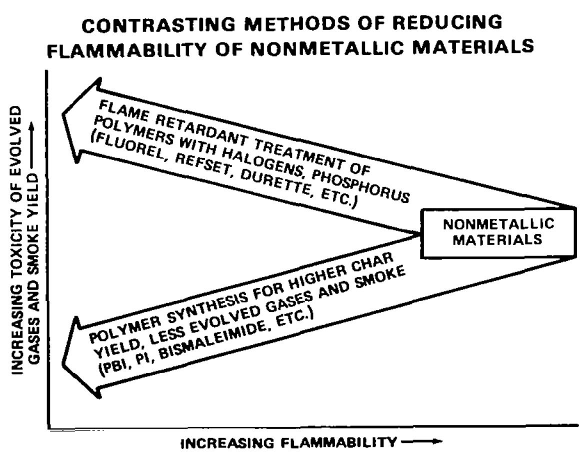


Figure 20.- Aircraft fire safety research.

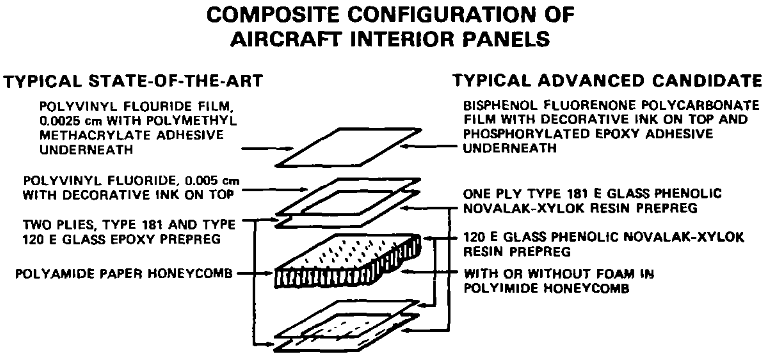


Figure 21.- FIREMEN program.