FAA Aircraft Safety Development Program

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The authority for, goals of, and establishment of the Federal Aviation Agency aircraft safety development program are described and related to the present safety records of air carrier and general aviation aircraft. Specific problem areas such as postcrash fire prevention, crashworthiness, powerplant fires, bird hazards, inflight recording, and flight performance are listed, and the current research and development programs in each area are described. The results of recently completed projects are listed and future safety programs are briefly described.

THE Federal Aviation Act of 1958 outlines the responsibilities of the Federal Aviation Agency in aeronautical research and development. Basically, they are "development work and service testing as tends to the creation of improved aircraft, engines, propellers, and appliances," and "prescribing and revising from time to time: 1) such minimum standards governing the design, materials, workmanship, construction, and performance of aircraft. . . ." The FAA aeronautical safety research and development goal may be simply stated: to provide improvements that will prevent or avoid accidents, and in case accidents do occur, to improve survivability. Secondary goals include increased economy, reliability, and utility. The responsibility for carrying out these obligations rests within the Aircraft Development Service.

The FAA and its predecessor organizations have a long history of work and solid contributions in the field of aircraft safety. The original work on fuel dumping was done by FAA in 1938 and on powerplant fire protection of transport airplanes in 1939.[1] Other specific accomplishments of the past include: the development of high rate discharge (HRD) powerplant fire extinguishing systems, the concept of smooth nacelle inner surfaces to eliminate flame-holding pockets, a reliable method of evaluating aircraft fire extinguishing systems, and the development of crash resistant fuel cells for some military helicopters and specifications for cells and fittings.

Establishment of the Program

First let us take a brief look at the over-all U. S. civil aviation safety record as measured in terms of its opposites, accidents and accident rates, since the development program must be directed toward their reduction. Accident statistics and trends in the U. S. indicate slow but steady improvement in the safety record of both general and commercial aviation. In the post-World War II boom in general aviation, when many aircraft were being introduced into service and extensive training done, aircraft accidents were causing nearly four deaths a day (1384 in 1948). Now the average has dropped to fewer than 2.5 fatalities per day (858 estimated for 1962), while aircraft usage has recovered from the Korean action doldrums and climbed to within 10% of the postwar peak. (Figure 1 indicates the trend.) Approximately 10% of all general aviation accidents are fatal and this ratio has remained about the same since 1938.

As shown in Fig. 2 the number of fatal air carrier accidents per year has remained almost constant during the past ten years. Approximately 15% of the total air carrier accidents involve fatalities. During this period air carrier service has doubled, causing the fatal accident rate to drop to one-half what it was 10 years ago, or just over 1 accident per 100 million airplane miles.

The causes of general aviation and air carrier accidents are shown in Fig. 3. Note that piloting and weather were the two largest categories of causal factors in both air carrier and general aviation accidents (more than one cause assigned in some cases). Detailed study of the individual cases has emphasized the need for the improvement programs described in the following sections.

The safety development programs of the FAA have been established within the framework of the statutory limits previously given and with the funding authorized by the U. S. Congress. It has been directed to the solution of problems brought out by operational experience and many detailed analyses of the accident records just outlined. It has been put into specific form following public discussion and the recommendations of experts both in government and in industry. Finally, it has been examined in the light of work being done by NASA, the military services, and the industry to avoid either duplication or gaps.

The program is being accomplished through the studies and tests done at the FAA National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey, and through contracts with industry, research organizations, and others. Before discussing some of the projects it is well to mention to the NAFEC facilities devoted to the conduct of FAA in-house work in aeronautics. They are located on a 53-acre site and include: equipment safety test laboratory, blower facility, fire test cells, 5-ft fire facility, standards and calibration laboratory, buildup and instrumentation laboratory, air gun impact facility, catapult and track, helicopter test pad, and aircraft drop test facility.

The Program

Present programs are described briefly under general program areas.

Crashworthiness

The term "crashworthiness" encompasses the principle of keeping the occupants alive, conscious, and mobile so that successful evacuation from the aircraft can be effected. The key to crashworthiness lies first, in maintaining the integrity of the passenger cabin floor structure so that improvements in occupant restraint and cabin delethalization can be used, and second, in facilitating egress.

The measure of a crashworthy structure is the ability of its elements to retain over-all integrity while deforming under load, absorbing energy, and transferring load to adjacent structure. This capability lies outside the range of normal

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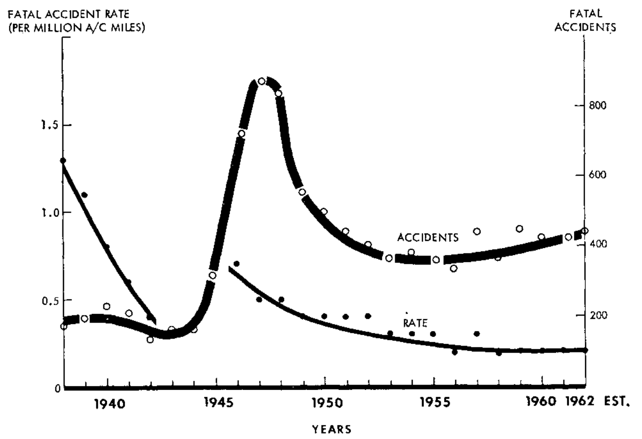

Fig. 1 General aviation: accidents and rates, 1938–1962.

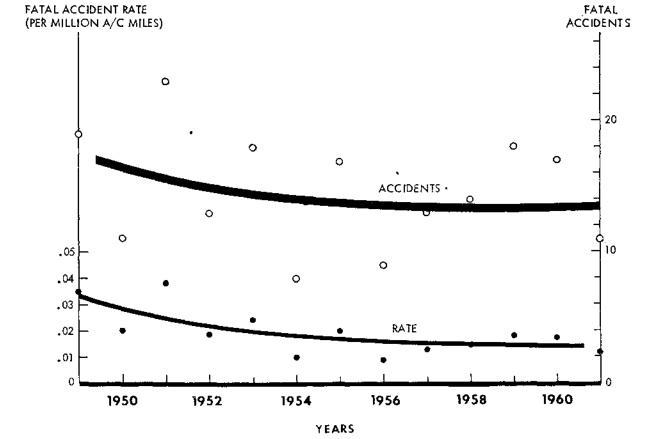

Fig. 2 U.S. air carriers: accidents and rates, all operations, 1949–1961.

design stress levels and in some structures is a virtue beyond the required functional design.

In the same sense that safety and economy tend to be mutually exclusive when carried to the extreme either way, so are crashworthiness and efficiency of structures. Crashworthiness is one of the elements of safety, and efficiency is an element of economy. As with the safety and economy, the goal should be the optimum balance between practicably attainable crashworthiness and efficiency. This requires a continuing evaluation of the cost in efficiency of crashworthy structural concepts.

Another project directed toward advancing the goal of crashworthiness involves a study of crashworthy structural design concepts incorporated in existing fuselage designs and a comparison with their service records to evaluate and catalog service-proved concepts. This study will be followed by an experimental testing of promising concepts.

The envelope within which this effort will be oriented will be more clearly defined by data collected in the crash testing of two transport aircraft early in 1964. The Flight Safety Foundation, under contract to FAA, will instrument and crash, simulating takeoff and landing accidents, a Constellation and a Douglas DC-7 to measure crash loads, study crashworthiness, and study the mechanism of fuel spillage.

Another large area of productive effort lies ahead in the general category of dynamic testing. The FAA is currently developing specifications for a facility to provide this much needed service to the aviation industry. Such a facility may be used to develop improved seats, belts, seat attachment and support structure, cargo pallets and restraint systems, galleys, etc.

Postcrash Fire Prevention

Postcrash fire has been an ever-present problem which increases in seriousness as the trend to increased speeds and fuel capacity continues. The supersonic transport (SST) may take off with 50% of its weight in fuel. This presents a tremendous problem under crash landing conditions.

The crash fire problem is being attacked in two ways at present; improvements in fuel containment, and the minimization of ignition sources. Since fuel containment is a simpler approach than the elimination of the many ignition sources, it is being pursued most vigorously. The FAA has done work on this in the past.[2] The force envelope within which fuel containment effort is being expended is generally that encompassing occupant survival without fire.

Present transports use either all integral tanks or combinations of integral cells and bladder cells. One project presently under way will direct us toward improving the crashworthiness of integral tanks by increasing their ability to contain high internal hydrostatic pressure, particularly in the forward areas, and to reduce the spillage when partial structural failure occurs.

Bladder cell fuel systems are more readily amenable to improvement because of the development of high-strength, relatively light-weight crash-resistant fuel cells and breakaway fittings which can be incorporated into "crash-resistant fuel systems." Another project well under way deals with the exploration of the installational problems, the evaluation of the weight and cost, and the demonstration of the capabilities of crash resistant fuel systems.

Another approach under experimentation which may be considered a form of containment is the gelatination of fuel. The characteristics of gelled fuel are being explored to see if they offer promise for minimizing fuel escape and spray in a crash. If the characteristics are promising, gelling system development will follow.

Ignition suppression is being studied generally as a part of the entire crash fire problem. The first report or crash fire ignition potential[3] has just become available.

A third important part of the attack on postcrash fires involves increasing the time for evacuation. To this end, test projects are under way to improve the resistance of engine installations and cabin interiors to fire.[4] These projects, when combined with improved passenger cabin structural integrity, ignition suppression, and better fuel containment, offer the potential of greatly minimized crash fire hazards.

General Aircraft Improvements

The present U. S. fleet contains more than 80,000 general aviation aircraft. The continuing production of approximately 7000 new aircraft per year is steadily changing the nature of general aviation. Instead of full-time professional pilots and the fair-weather airport pattern pilot, there is an increasing trend by business and professional people toward the use of general aviation aircraft in business and extended

CATEGORIES	AIR CARRIER	GENERAL AVIATION
PILOT FACTORS	55	76
OTHER PERSONNEL	22	6
POWER PLANT	11	7
AIRFRAME	1	1 .
LANDING GEAR	11	7
EQUIP'T. & ACCESSORIES	2	1
AIRPORT TERRAIN	15	11
WEATHER	26	13
MISCELLANEOUS	3	2

Fig. 3 Accident causal factors, U. S. civil aviation, 1960; percentage of total accidents in which category was a causal factor.

pleasure flying. There comes with this trend, owing to vagaries of weather over most of the country, a pressing need for better means of presenting to the latter group of pilots the necessary information on attitude and whereabouts, as well as of providing improved flying qualities. This need has been recognized by the FAA,[5] and an active project termed "Project Little Guy" is under way to improve pilot presentation and cockpit arrangements.

Another aspect of the problem of wider use relates to the increased performance of general aviation aircraft. In past years with slow airplanes, structural breakup in flight was extremely rare. The fast and clean airplane, however, when upset due to inattention, turbulence, or pilot disorientation may accelerate rapidly, and with relatively low-control forces may be broken up by sudden movement of the controls. Despite considerable attention to this problem by FAA, NASA, and industry, well over 100 high-performance general aviation aircraft have disintegrated in flight under conditions of turbulence, weather, etc., and many more have struck the ground in high-speed dives.

The FAA has let two contracts which could lead to the solution of this problem. One is directed toward the development of a beta control system for piston engines so that the propeller drag can be used to control speed, and another is directed to developing a stability augmentation system with warning system and programmed recovery for attitude control. Both approaches will extend the operational usefulness of new high-performance light aircraft, in addition to the safety aspects of the systems.

Bird Hazard to Primary Structure

Following the loss of a transport airplane in November 1962, from the impact of a large bird on the horizontal tail, a project was set up to explore the hazards to primary structure and to determine whether structural components of new aircraft were more or less vulnerable to failure from bird impact than older aircraft structures.

Powerplant Fire Tests

The last comprehensive full-scale fire tests conducted in the U. S. were FAA tests at the Civil Aeronautics Administration Indianapolis Center in 1958 on a Boeing pod with a P&W J57 "straight jet" engine.

Since that time the advantages of the bypass or fan engine have been demonstrated in service, and undoubtedly the fan engine, with increasing bypass ratios, will largely supersede the straight jet for subsonic flights. The fan engine, however, brings with it new problems in fire detection, extinguishment, and protection. There are generally two concentric shells, two flow paths of different velocity and temperature, as well as flow, within the cowling, and new problems of accessory location and exposure. There have been incidents in which steel diffuser housing have been burned; serious consequences, fortunately, have not resulted to date. Other coming propulsion units include a fan-in-wing type with annular nozzle-turbine systems.

In addition to the shift from straight jet to fan power and other engine types, engine installations have changed markedly. In place of wing-pylon-pod arrangements, aft-fuselage mounting has been employed, and for the current trend to three-engine transports, engines buried in the fuselage are used.

Full-sized and scaled-model fire tests of these engines and installation arrangements have recently begun. Other projects on improved detector and extinguisher arrangements which are essential to a proper understanding of the problems will be conducted in the near future.

Engine Ingestion Problems

In establishing the certification tests for turbine engines the FAA included standards for foreign object ingestion, i.e., birds up to 2–4 lb maximum, and hailstones of 1–2-in. diam. Engines are required to ingest these object without sustaining major structural breakup, and other aspects are evaluated. Power failure could and sometimes did occur, but this was not a cause for disqualification, since the transport aircraft performance standards are based on the assumption of engine failure on takeoff.

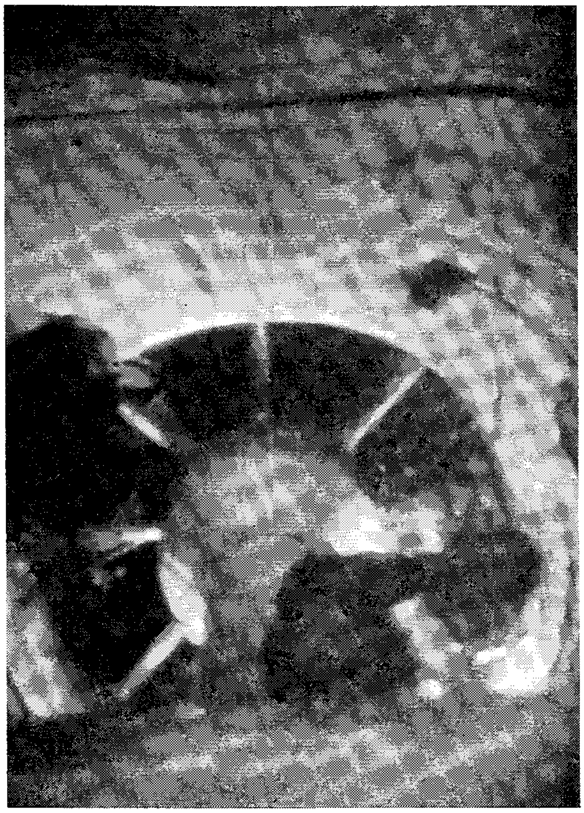

Fig. 4 Starling expulsion from engine inlet.

The tragic accident of a turbo-prop transport at Boston in late 1960 forced a re-examination of the problem since early inspection indicated, and the Civil Aeronautics Board concluded that multiple engine power failure occurred due to the ingestion of birds. The engine manufacturer immediately conducted static test stand runs, and these were followed up by an FAA-funded test program of the engine-propeller combination in a wind tunnel with airspeed as in the actual takeoff condition. Forty tests were conducted, in which a total of 141 starlings and one sea gull were ingested. The average individual weight of the starlings was 80 g (3 oz) and the sea gulls weighed 717 g (2.5 lb).

The conclusions from the latter tests may be summarized as follows:

1) Ingestion of 1–3 starlings did not cause autofeathering, i.e., engine shutdown, but 6–8 starlings caused autofeathering in all cases. The ingestion of 4 starlings produced variable results.

2) Engine power fluctuations increased with the number of birds ingested.

3) The only engine damage that occurred was minor bending of the inlet guide vanes.

4) The tests in the wind tunnel provided information not available from previous static test runs.

5) Through the comprehensive recordings of engine variables and high-speed movies, a much better understanding of ingestion phenomena has been obtained.

The great magnitude of the airflow changes during power fluctuations and surge is indicated by Fig. 4 taken from a 500 frame per sec film strip. Here starlings are being driven *back toward* the inlet due to reversal of air flow associated with compressor surge after having attained an ingestion velocity

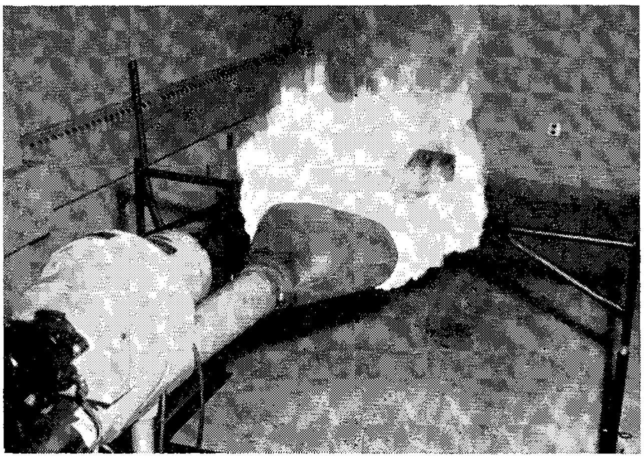

Fig. 5 Fire test of aircraft recorder.

of about 90 fps. In some cases the birds changed direction several times before finally being ingested or expelled. Further steps in this program include the development and test at NAFEC of intakes with reduced possibility of bird ingestion.

Other tests were conducted to determine the effect of ingesting radar chaff, which was insignificant, and the ingestion of fragments of frangible runway markers made of foam plastic. The latter led to overtemperature effects due to air blockage at the inlet. A comprehensive report on the ingestion work to date is now available.[6]

Recorders

FAA has a comprehensive development program in this area. Present work includes further development of the crash recorder, completion of work on cockpit voice recorders, and an evaluation of a maintenance recorder.

Crash Recorder

The aircraft flight performance recorder, generally referred to as a "crash recorder" and required for all turbine transports, has proved to be a valuable tool in incident and accident investigations. The present recorders were designed and tested to withstand crash conditions of 100 g, and 1100°C (2012°F) for 30 min, and to record speed, altitude, acceleration (normal g), and heading against time on tape. Two production recorders employ metal tape and one employs magnetic tape. Figure 5 indicates a heat test of a recorder. CAB information indicates that the recordings have been found usable in 24 out of 28 major accidents. In the remaining 4 cases, either the recorder was not operating or it was destroyed in the crash.

The present FAA development effort, based upon study of past experiences and consultation with CAB and FAA investigators and industry, is intended to provide additional recording channels, easier readout, greater ruggedness against crushing and puncturing loads, better positioning within the aircraft, and locating devices.

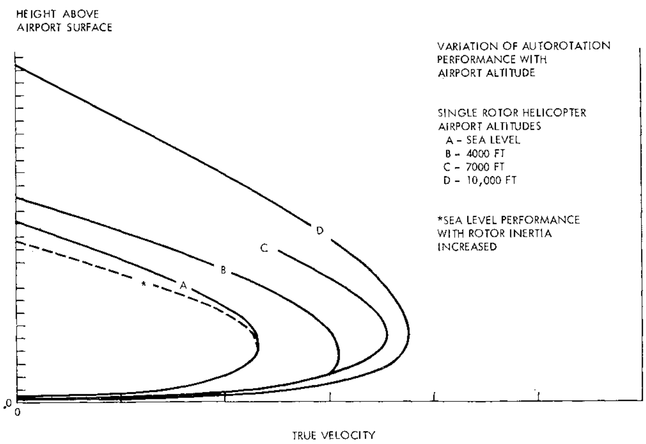

Fig. 6 Helicopter height — velocity diagram.

Voice Recorder

A flight-deck voice recorder may be of value in certain accidents to supplement the information provided by the flight data recorder. Different makes of recorders have been developed with FAA funding. These recorders are intended to record all flight deck crew conversation, continuously "erase" all but the last 30 min of record, withstand the crash conditions listed in the foregoing, and operate for 500 hr without maintenance attention.

Maintenance Recorder

Several maintenance recorders have been developed by industry, and there is considerable interest on the part of maintenance people regarding their use in regular airline operation as a means of keeping an accurate check on many powerplant and airframe variables.

At this time FAA development interest lies in the installation of an available recorder in one of the FAA jet transports with the objective of gaining experience on its usefulness as a maintenance aid.

Helicopter Height-Velocity Diagram

A basic requirement in the civil air regulations for rotary wing aircraft is the ability to make a safe landing following power failure. In helicopters the rate of sink is largely a function of disk loading. The ability to reduce or flare out the rate of sink to an acceptable value just prior to contact is primarily a function of the amount of energy stored in the rotor, i.e., the inertia of the rotor and the magnitude of the usable rotor rpm reduction. Secondary factors in both rate of sink and flare include airfoil shape and blade loading.

In the certification of helicopters there are combinations of height above the landing surface and speed which should be avoided. These are plotted on a diagram referred to as the height-velocity diagram or "dead man's curve." The values shown in such a diagram must be developed through flight testing; however, the question whether or not the height-velocity diagram increased in extent at altitude airports and, if so, how much, has never been answered satisfactorily.

To secure realistic and accurate answers to this problem, the FAA conducted comprehensive tests with a thoroughly instrumented small helicopter. More than 700 autorotational landings were made and accurately recorded by space-time cameras, at airport altitudes of sea level, 4000 ft, 7000 ft, and 10,000 ft (Fig. 6). Further, through the installation of 10-lb weights inside the blade tips it was possible to obtain test data on a rotor aerodynamically identical to, but having an inertia much greater than, that of the basic rotor. This program was conducted with the cooperation of NASA and other organizations so that previous theoretical studies, wind tunnel tests, and other work may be correlated with this testing in order to produce a realistic "mathematical model" to facilitate future predictions of the effect of airport altitude on the height velocity diagram. The report on the initial program is now available.[7]

Slush Drag

As a result of the early experience of jet aircraft operating on slush-covered runways, the FAA established an operating limitation which precluded operation in slush at depths greater than $\frac{1}{2}$ in. Subsequent data, including NASA test rig data, indicated that limitation was unnecessarily restrictive. The FAA conducted a test program to determine the effect of slush depth or performance. References 8 and 9 contain the results of this program. A sound-motion picture is also available.

Laminar Flow Control

The FAA is participating with the Air Force in a full-scale laminar flow demonstration program. Cruise laminar flow will be demonstrated and operating characteristics and maintenance requirements will be evaluated. Flight tests are in progress with a modified B-66 aircraft. This program may provide design, manufacturing, and operational data directly useful in the design of future aircraft.

An interesting by-product of this program is the sonic engine inlet arrangement which may provide additional valuable experience on this method of reducing turbine approach noise.

Noise

The FAA has devoted a great amount of effort to the alleviation of the aircraft noise problem. Special routing of air traffic, flight tests to optimize operational procedures, plus airport design studies to determine compatible land uses are a few of the programs undertaken. NASA, the Port of New York Authority, and airframe and engine manufacturers are doing considerable work. There is specific funding in the FAA SST program for engine noise reduction, and operational acoustic limits have been established.

Because of the continuing seriousness of the problem, FAA development funds are being assigned to direct design improvements in future engines for subsonic aircraft and other noise reduction work.

Other Projects

The FAA aeronautical development program includes two projects of a continuing nature. These are 1) the determination of the concentration and distribution of fire extinguishing agents in powerplant installations, using a gas analyzer device; and 2) the determination of the cockpit visibility or outlook from the pilots' eye position through the windshield, using a special binocular vision camera.

In addition, work is being done on the following: dynamic testing of aircraft seats, airframe icing protection,[10] cargo compartment fire protection, protection against bombs or other sabotage, fuel vent lightning/static protection,[11] thrustmeters, takeoff monitors, accelerometers, helicopter wake turbulence,[12] ozone, concentration measurements at civil operational altitudes,[13] measurement of takeoff and landing flight paths during conditions of low visibility, and others.

Conclusions

As the result of many years of aeronautical safety development work the FAA provided a substantial input to improvements in safety and safety standards.

The present FAA program will yield additional safety gains through better protection against crash fire, crash injury, engine damage and sabotage, and through improved recorders and other equipment. It is providing a better understanding of aircraft performance on takeoff and landing under adverse conditions, and of the flight performance and characteristics of rotorcraft. Future FAA aircraft safety research and development work will bring additional gains in safety.

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