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Designing for Aircraft Structural Crashworthiness

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This report describes structural aviation crash dynamics research activities being conducted on general aviation aircraft and transport aircraft. The report includes experimental and analytical correlations of load-limiting subfloor and seat configurations tested dynamically in vertical drop tests and in a horizontal sled deceleration facility. Computer predictions using a finite-element nonlinear computer program, DYCAST, of the acceleration time histories of these innovative seat and subfloor structures are presented. Proposed application of these computer techniques and the nonlinear lumped mass computer program KRASH to transport aircraft crash dynamics is discussed. A proposed FAA full-scale crash test of a fully instrumented radio-controlled transport airplane is also described.

Introduction

AVIATION crash dynamics research has a history (Fig. 1) dating back to the pioneering work of Hugh DeHaven in the 1940s. Having survived a midair collision and the ensuing crash that took three lives, DeHaven initiated research into crashworthiness wherein he did on-site investigations of aircraft accidents to identify components and/or subsystems contributing to injuries and/or fatalities. Results from this research produced design guidelines that are still pertinent even today.[1]

The AG-1 crop-dusting aircraft, built by Fred Weick at Texas A&M College, incorporated a number of original crashworthiness features based upon the principles espoused by DeHaven.[2,3] These features are still found in today's production agricultural airplanes.

Another milestone in the progress of improved structural crashworthiness of aircraft is the first series of airplane crash/fire tests conducted by the National Advisory Committee for Aeronautics (NACA) Lewis Research Center in 1952. These tests demonstrated some mechanisms which initiate postcrash aircraft fires.[4] In 1964, the Federal Aviation Administration (FAA) conducted two full-scale crash tests of transport airplanes at the Flight Safety Foundation facility in Phoenix, Ariz. One of these tests used a Douglas DC-7 and the other a Lockheed L-1649. The tests were performed with these objectives in mind: 1) to obtain crash environmental data, 2) to study fuel containment, and 3) to collect data on the behavior of various components and equipment aboard the airplane.[5,6] After nearly a 20 year hiatus, the FAA is proposing another full-scale transport crash test to be conducted in cooperation with NASA. This proposal involves crashing a remotely piloted Boeing B-720 into the ground to simulate a survivable crash landing.

Since the late 1950s, the U.S. Army has been investigating aircraft accidents, studying crash injuries, and conducting crashworthiness research (Fig. 1). These efforts culminated in the Army's Crash Survival Design Guide published in 1967.[7] The Design Guide is used as a tool for aircraft engineers and designers and represents a major milestone toward improved crashworthiness in military aircraft. By requiring that Army aircraft be built to the Design Guide requirements, helicopter crash fires have been virtually eliminated and the overall crashworthiness of the Army aircraft fleet has been substantially improved. The Army Flight Safety and Helicopter Crash Testing Program (Fig. 1) validated selected crashworthy design concepts.[8] The Army's interest in crashworthiness continues to this day. The Design Guide was recently updated on the basis of the latest research results, a crashworthy utility helicopter (Blackhawk) has been put into production, and the production of a crashworthy attack helicopter is imminent.[9,10]

Advanced materials, in particular graphite-epoxy composites, are being considered by the Army for future helicopter weight-saving designs. The Army has embarked on a program to build an all-composite airframe helicopter, which still requires that the crashworthiness requirements applicable to metal aircraft be applied in the design stage.[11]

In 1972, NASA embarked on a cooperative effort with FAA and industry to develop technology for improved crashworthiness in general aviation aircraft. The effort included analytical and experimental structural concept development and involved full-scale crash testing.[12] Prior to 1972, little full-scale crash testing of general aviation airplanes had been done, except for some high-wing, single-engine tests performed by NASA in 1952 and a crash test program involving two TC-45J twin-engine airplanes performed by Aviation Safety Engineering and Research (AVSER) in 1964-65 for the U.S. Army.[13,14] The NASA Langley full-scale three-dimensional crash simulations are examining the response of the structure, seats, and anthropomorphic dummies to realistic crash deceleration pulses. Definitive data that cannot be obtained by investigating field accidents, such as the impact attitude and velocity, crash forces, and dummy accelerations are being obtained in these crash tests.

The general aviation crash dynamics program is currently being expanded to include commercial transport aircraft. It is recognized that there are significantly fewer accidents of transport aircraft than of either general aviation airplanes or military helicopters; however, in a single transport accident, the lives of several hundred passengers and crew are jeopardized.

Two primary factors contributing to fatalities in transport accidents are trauma (impact forces) and fire. The total

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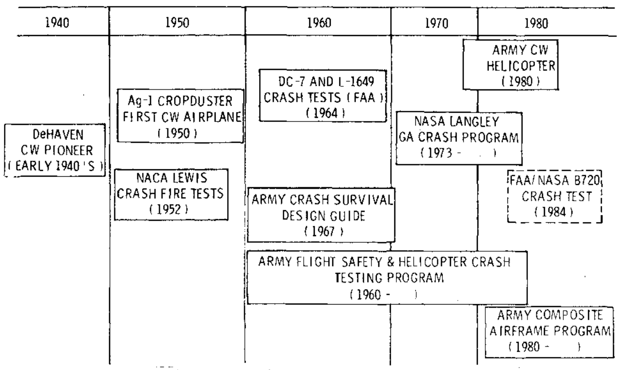

Fig. 1 History of aircraft crash dynamics research.

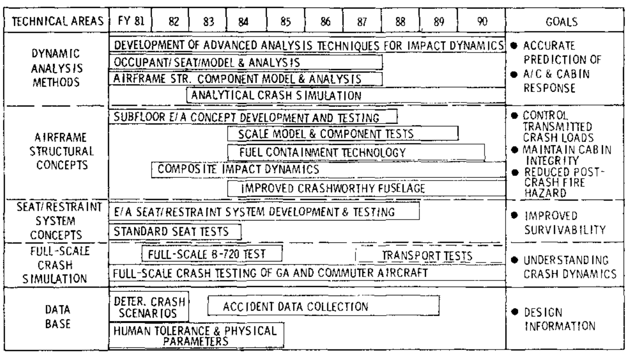

Fig. 2 Aircraft crash dynamics technical program.

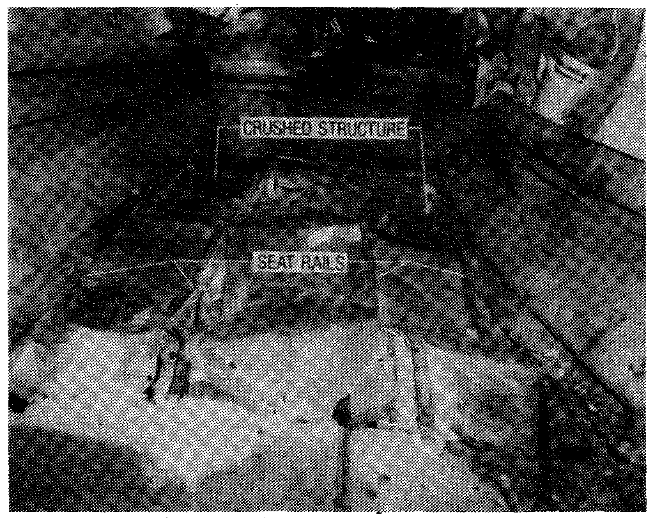

Fig. 3 Cabin floor of crashed airplane.

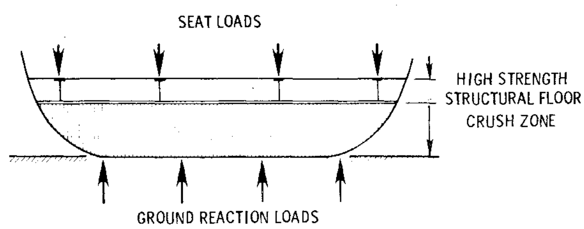

Fig. 4 Lower fuselage design philosophy.

worldwide financial loss for commercial jets between 1952 and 1980 due to accidents is estimated at $3.83 billion.[15] These estimates include 354 hull losses at $2.11 billion, hull damage at $660 million, and 13,169 liability cases (fatalities only) at $1.06 billion.

The initial effort in this program is focused on a definition of a meaningful research program based in part on a careful study of all worldwide transport accident data in 1958-1979. These data have revealed that approximately 80% of fatal commercial transport accidents occur on or near the ground during either approach, landing, or takeoff operations. The aircraft during these operations is typically below normal cruise speed and it would appear that the potential for survivability could be enhanced through applied crashworthiness technology in the design of the airplane.

General Aviation Crash Dynamics Program

In 1972, the FAA, NASA, and industry embarked on a cooperative effort to develop technology for improved crashworthiness and occupant survivability in general aviation aircraft. The effort included analytical and experimental verification of structural airframe and seat configuration modifications to limit the loads transmitted through the airframe and seat subsystem to the occupant. The methods and concepts developed in the general aviation crash dynamics program will be examined and evaluated to determine their applicability to the transport crash dynamics program. The current research efforts in the general aviation program are expected to make possible future aircraft design concepts having enhanced survivability under specified crash conditions with little or no increase in weight and acceptable cost. A research program intended to accomplish this objective is defined by the five technical areas indicated in Fig. 2. A summary of the pertinent technical accomplishments performed in four of these technical areas—full-scale crash simulation, airframe structural concepts, dynamic analysis methods, and seat/restraint system concepts—are discussed in the following sections. The five technical areas indicated in Fig. 2 are also applicable to transport crash dynamics including the data base technical area. Under the transport crash dynamics program accident data pertinent to crash dynamics are being examined as a data base to identify fruitful areas of crashworthiness research and to define transport crash scenarios.

Full-Scale Crash Simulation

Full-scale free-flight crash tests were conducted in the Impact Dynamics Research Facility, Langley Research Center, in which deceleration histories and structural deformation modes were measured in 24 fixed-wing and two helicopter crash tests.[16-22] A comparison was also made between accident field data for a twin-engine airplane and a controlled full-scale twin-engine airplane crash test.[23] These test data indicated that the impact loads (g forces) measured in the cabin area in the vicinity of the seats and in the dummy pelvic region were, in most cases, above human tolerance levels, even though the livable volume and integrity of the cabin area had been maintained.[24] The need for more uniform and controlled "crushing" of the subfloor and vertical stroking load-attenuating mechanisms for seats became apparent from these full-scale crash simulations.

Airframe Structural Concepts

The cabin floor of a twin-engine aircraft involved in a fatal accident is shown in Fig. 3.[23] The floor undulations were the result of crushing and overturning moments exerted by the seated occupants as the front legs of the seats applied compressive loads to the floor while, at the same time, the rear legs experienced a tensile loading. The intersections of the longitudinal beams and the lateral bulkheads in the floor provided "hard points" or columns which are very efficient load paths from the underbelly of the airplane to the seat rails.

The airframe structural design philosophy developed under the general aviation program is illustrated in Fig. 4. The concept is simply to provide an integral stiff upper floor [approximately 5 cm (2 in.)] to maintain the structural integrity between the floor and seat and to prevent seat rotation (either transverse or longitudinal) and not allow the floor panels and floor beams to separate. The lower subfloor is designed to provide a uniform crush zone and various structural subfloor concepts have been developed in which the floor beams and lateral bulkheads were modified.[25] One such concept which features corrugated floor beams with notched corners at the intersections of the beams with the lateral bulkheads, is shown in Fig. 5 along with an unmodified airplane section. These airplane sections are approximately 120 cm (47 in.) long by 107 cm (42 in.) wide and represent the first passenger row location behind the pilot and the copilot.

Static crush test results are shown in Fig. 5 for the two subfloor sections. The unmodified subfloor section exhibits much higher initial crush loads (15 kip) than the modified subfloor (10 kip). The unmodified subfloor also experienced loss of structural integrity between the floor panels and floor beams by buckling (sudden decrease in load) and tearing of the floor structure. The same amount of work (area under the load deflection curve) is involved in the two static crushes, but the work is much better controlled in the modified section. Dynamic tests were also conducted on the modified and unmodified sections and a dynamic analysis was performed for comparison with the experimental data. The static crush data of the corrugated beam with notched corners were used as input to the analytical model in the form of nonlinear spring elements representing the corrugated beams. The dynamic test was a vertical drop test onto a concrete surface with an impact velocity of 7.3 m/s (24 ft/s). The results are presented in Fig. 6 and show the lower floor accelerations provided by the modified subfloors. The agreement between theory and experimental data (pelvis mass acceleration) for the modified corrugated beam subfloor is excellent.

Dynamic Analysis Methods

An analytical simulation of a vertical drop test of a full aircraft section, shown in Fig. 7, was used as a vehicle to assess various nonlinear computer programs for crash analysis. The aircraft section, the first passenger row position behind the pilot and copilot, is approximately 120 cm (47 in.) in length and 107 cm (42 in.) in width. This specimen is a complete cabin section in contrast to the subfloor sections discussed in the previous section. The aircraft section was dropped vertically (and guided by guide posts) to impact symmetrically at 8.5 m/s (28 ft/s). This vertical impact velocity represents the vertical sink speed measured in a −15 deg pitch (0 deg angle of attack) full-scale crash test at 27 m/s (60 mph). A comparison of fuselage floor outboard vertical accelerations are given in Fig. 8 for three nonlinear structural analysis computer programs. Two of these programs, ACTION and DYCAST, are finite-element representations and the program KRASH is a lumped-mass representation of the structure. Details of these computer programs, their capabilities, and developmental assumptions can be found in Refs. 26-29. The results of this comparison indicate a good analytical representation of the first major plastic buckling load by all three programs; however, the DYCAST computer program is seen to follow more closely the second and third peaks both in magnitude and duration. The KRASH computer program, however, is significantly more economical to execute.[26] KRASH has also been used to analyze four full-scale, single-engine, aircraft crash tests.[27,31] For these reasons, both DYCAST and KRASH will be developed further and evaluated for use in transport crash dynamics analyses.

Considerable effort has also been expended in developing a good mathematical simulation of occupant, seat, and restraint system behavior during a crash. The FAA-funded computer program SOMLA is a three-dimensional seat, occupant, and restraint system program with a finite-element seat and an occupant modeled with 12 rigid segments joined together by rotational springs and dampers at the joints.[32]

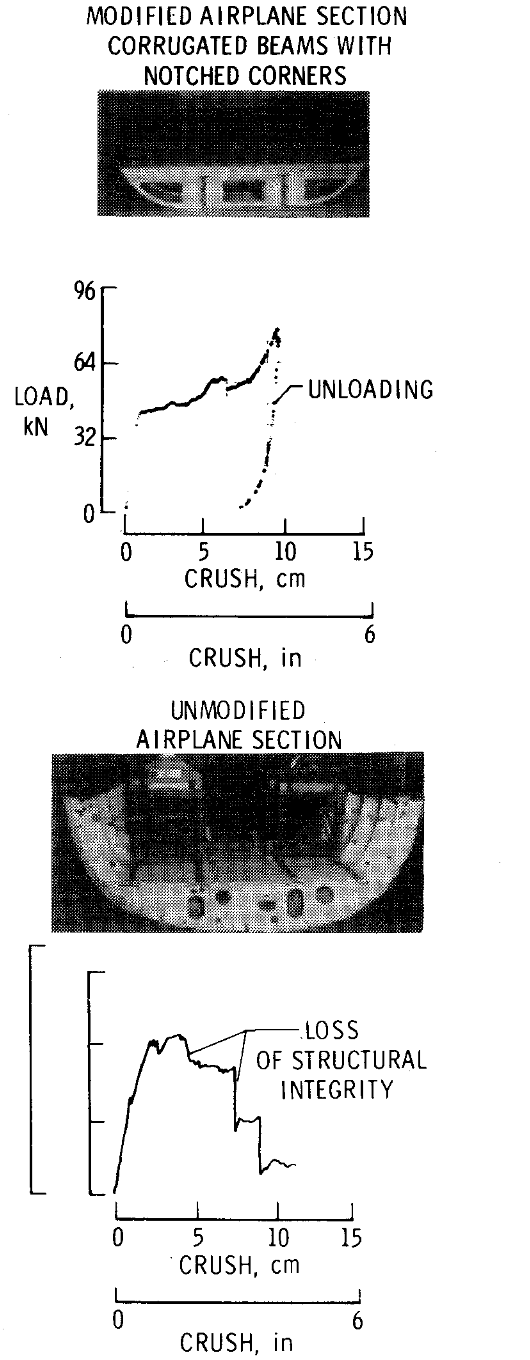

Fig. 5 Static tests of load-limiting subfloor structures.

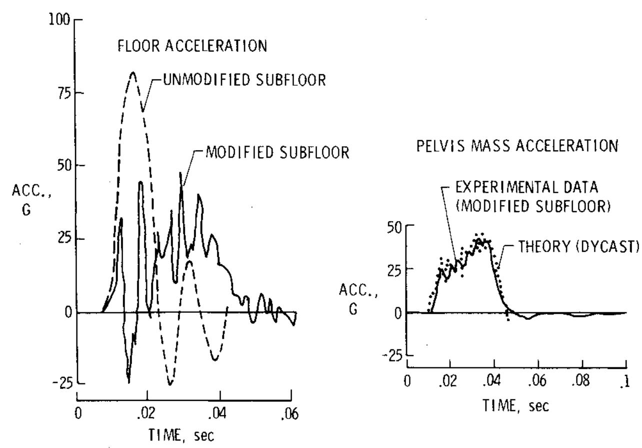

Fig. 6 Dynamic tests and analysis of load-limiting subfloor structures.

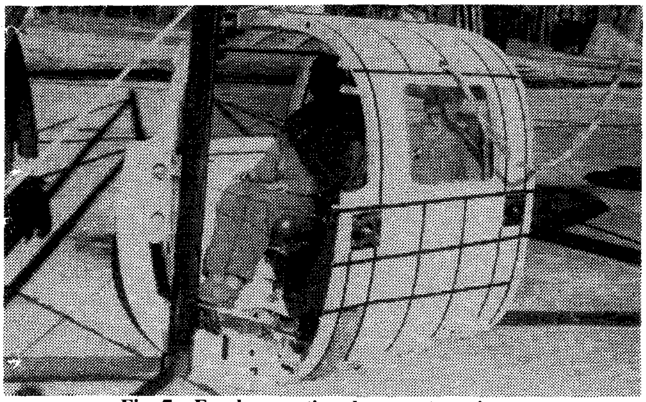

Fig. 7 Fuselage section drop, test specimen.

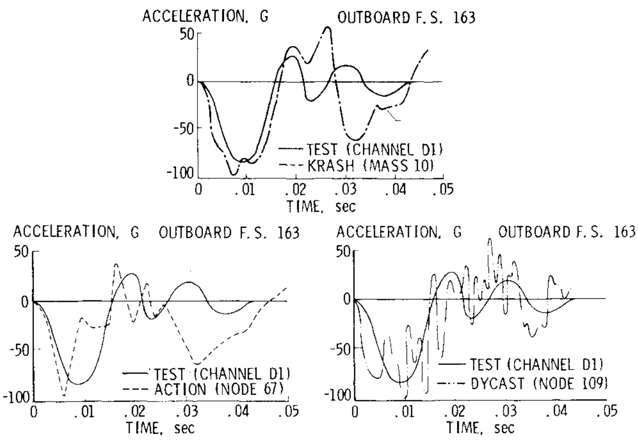

Fig. 8 Comparison of fuselage floor outboard vertical accelerations.

The finite-element seat model consists of beam and membrane finite elements capable of modeling rigid body behavior. SOMLA was used previously to model a standard seat and dummy occupant in a NASA light aircraft section vertical drop test. During this simulation, the seat model was replaced with a nonlinear spring damper system. A discussion of SOMLA, its computer input requirements, and additional experimental/analytical comparisons can be found in Ref. 32. To explore the possibility of incorporating a dynamic finite-element seat model in SOMLA, the ceiling-supported load-limiting seat and occupant were modeled using DYCAST as shown in Fig. 9. The occupant model was restricted to two body masses with a c.g. location in the pelvic region. The seat was modeled using beams, axial rods, and nonlinear springs [representing the wire-bending energy absorbers (E/A)]. The comparison with the test data in Table 1 and Fig. 9 shows excellent agreement. Consequently, the occupant/restraint system model of SOMLA is being integrated with the dynamic finite-element DYCAST program for increased versatility.

Seat Restraint System Concepts

The need for a stroking seat mechanism and a seat-attached restraint system became apparent in the assessment of the full-scale and component crash test results. Wire-bending load-limiting seat legs and seat attachment devices (ceiling supported) were developed.[33,34] Dynamic tests of prototype seats were conducted at the FAA Civil Aero Medical Institute (CAMI) on test sleds. The CAMI sled is linearly accelerated along rails to the required velocity and brought to rest by wires stretched across the track in a sequence designed to provide the desired impulse loading to the sled. A Hybrid II 50th percentile dummy instrumented with accelerometers loaded the seats and restraint system as deceleration of the sled occurred. Figure 9 shows the position of the dummy and seat after such a sled deceleration with the sled pulse showing a maximum deceleration of 34 *g* and a pulse duration of 0.066 s. The seat is tilted 30 deg from the vertical and is yawed 10 deg. The change in velocity is from 12.75 m/s (42 ft/s) to rest. Note the decrease in acceleration from the 34 *g* sled pulse to a 23 *g* pelvic acceleration. Floor-mounted load-limiting seat designs have provided up to 50% acceleration reductions in similar sled tests. An unmodified (nonstroking seat) configuration, however, exhibits dynamic amplification factors as high as 1.5 due to seat rigidity and the motion of the occupant relative to the seat.[33]

Transport Crash Dynamics Program

In 1979, the FAA, NASA, and industry embarked on a cooperative effort to develop technology for improved crashworthiness and occupant survivability in transport aircraft. The effort includes analytical modeling and experimental component and full-scale testing to corroborate structural concept development and to characterize advanced material crashworthiness. The technology developed under the general aviation crash dynamics program discussed above may provide a foundation to advance the crash dynamics technology of transport aircraft, recognizing that transport airplanes have different and unique structural features. These features include fuel containment, multi-occupant seat and floor behavior, composite structure crash response, and multi-occupant egress. The transport crash dynamics technology is expected to make possible future transport aircraft designs having enhanced survivability under specific crash scenarios with little or no increase in weight and acceptable cost.

Accident Data Base

In the first phase of the transport program, it was essential that industry and government examine collectively the accident data base on transport aircraft to identify and define fruitful areas of crashworthiness research (Fig. 2, data base). Many crashworthiness design features have as their foundation an accident data base identifying the specific aircraft structure and subsystems which contribute to injuries and fatalities. For many years, emphasis in accident investigation was placed on determining the cause of the accident with little or no consideration being given to crashworthiness as it relates to injuries and/or fatalities. Within the past 15 years, the lifesaving and injury-minimizing benefits of crashworthy design were realized within the aviation community and in particular by the U.S. Army. With this realization, design philosophy evolved based on accident data, whereby safety features which would reduce injuries/fatalities in a crash were incorporated early in the aircraft design stages. Having a similar objective, three identical transport accident study contracts were awarded to Boeing Commercial Aircraft Company, Lockheed-California Company, and Douglas Aircraft Company (Long Beach). The specific tasks in these three contracts are summarized as follows:

1) To review and evaluate transport aircraft accident data and then define a range of survivable crash conditions or crash scenarios that may form a basis for developing improved crashworthiness design technology.

2) To identify structural features and subsystems that influence injuries/fatalities in the crash scenarios defined in task 1.

3) Define areas of research and approaches for improving transport crashworthiness.

4) Identify test techniques, analytical methods, etc., needed to assess and evaluate the crash response of transport aircraft.

The data base for this study began with a review of the 993 transport accidents which had occurred in the years 1958-1979 and the establishment of a selection process. First disregarded were those accidents in which the structural airframe played no significant role, such as in flight turbulence accidents or maintenance personnel accidents on the ground. Next to be

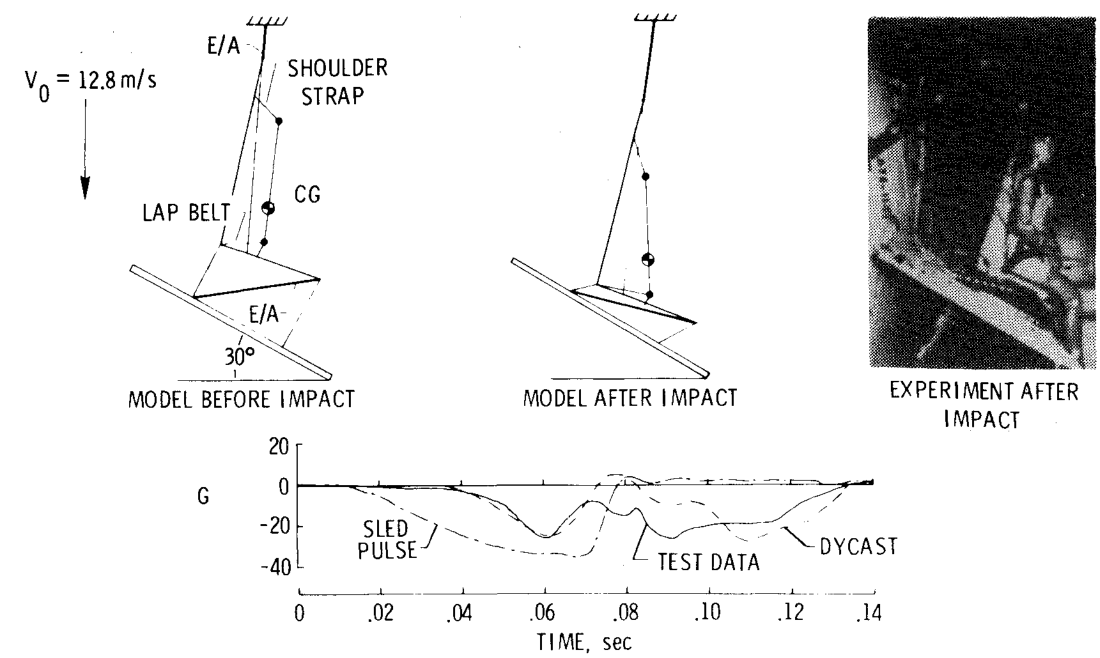

Fig. 9 Analytical and experimental pelvis acceleration in load-limiting seat.

disregarded from the accident data base were the more severe, nonsurvivable midair collision accidents. In an objective, but somewhat unavoidably subjective manner, a combined total of 176 "survivable" accidents remained to form the data base. The criteria that were generally applied in the selection process included: 1) at least 15% of the cabin volume was maintained, 2) the trauma forces were estimated to be within human tolerance levels, and 3) at least one survivor was identified. In a few isolated cases the one-survivor condition was waived when it was felt that the trauma forces had been within human tolerance levels but that a fire hazard existed. The distribution of accident data is illustrated in Fig. 10. The three transport manufacturers generally examined different accidents, but some accidents were examined by all three manufacturers as indicated in the figure by the cross-hatched area, some by two of the three as indicated by the hatched areas, and other accidents solely by one manufacturer (primarily the accidents involving its own aircraft).

Some preliminary survivable accident scenarios are evolving from the studies and are being used in defining classes of accidents. The scenarios consist of four different accident conditions:

1) A hard landing involving high sink speed with gear collapse, wheels-up airplane attitude, and some swerve. The ranges of forward speed and sink speed are 65-82 m/s (126-160 knots) and 3-10 m/s, respectively. The airplane attitude is symmetrical with ≤ 15 deg pitch, on the runway or within 200 m of the runway.

2) A collision with an obstacle on the ground (ditch, light poles, vehicles, etc.) with gear down, level airplane attitude, and swerve. The ranges of forward speed and sink speed are 31-51 m/s (60-100 knots) and ≤1.5 m/s, respectively. The airplane is in a symmetrical, level, attitude on the runway or within 500 m of the runway.

3) A severe impact on the runway with gear down, high angle of attack, and ranges of forward speed and sink speed of 57-103 m/s (110-200 knots) and 1.5-10 m/s, respectively. Airplane attitude is: pitch 0-5 deg, roll ±5-45, yaw 0-10 deg, on runway.

4) A severe ground/water impact off the runway with gear up or down, high angle-of-attack collision, and ranges of forward speed and sink speed of 51-103 m/s (100-200 knots) and 1.5-10 m/s, respectively. Airplane attitude is: pitch 0-45 deg, roll ±5-45 deg, yaw 0-10 deg, off runway.

The range of impact conditions for these scenarios are tentative and are given only as an illustrative example in this paper. Until such time as all of the data are finalized, these scenarios and parameter ranges are subject to change.

Fuel Containment

One of the identifiable structural features and subsystems that influence injuries/fatalities in transport accidents is the wing structure fuel tank system. Fuel spillage from a damaged wing structure is one of the primary causes of catastrophic fires and passenger fatalities. The previously addressed accident studies clearly identify mechanisms in which wing structure damage could result in fuel spillage. For example, the main gear could penetrate into the fuel tank area of the wing-mounted engine pylon or the wing structure could fail.

In the area of fuel containment, advanced analytical techniques will be used to study the response of the wing tanks to localized and distributed crash loadings and to study the mean gear and engine pylon failure mechanisms. The nonlinear analytical techniques developed under the general aviation crash dynamics program will be applied to these unique nonlinear transport failure mechanisms. Consideration of advanced composite structural materials and their effect on structural behavior and failure mechanisms must be included in future transport airplane design. The necessary modeling capability for nonlinear dynamic composite structural analysis needs to be developed and verified, first on an element level and then on a more representative aircraft structural component level. Full-scale dynamic testing of instrumented inboard wing tank and fuselage sections subjected to impact (with obstacles) under controlled deceleration and attitude conditions are also anticipated. These full-scale dynamic tests may be conducted at the FAA Technical Center in a newly proposed 68,000 kg (150,000 lb), 77 m/s (150 knots) catapult facility.

Advanced Analytical Techniques for Transport Aircraft

Airframe and Subsystems

The objective of the analytical efforts in crash dynamics is to develop the capability of predicting nonlinear geometric and material behavior of sheet stringer aircraft structures subjected to large deformations and to demonstrate this capability by determining the plastic buckling and collapse response of such structures under impulsive loadings. Two specific computer programs have been developed under the general aviation crash dynamics program and have been discussed previously in this paper. One, called DYCAST, is a finite-element program which focuses on modeling concepts

Table 1 Ceiling suspended seat comparison

Impact parameters: vertical, 12.8 m/s, $g_{max} = 34$, $T = 0.066$ s, 30 deg pitch	Sled test	DYCAST model
Upper E/A stroke, cm (in.)	22.2 (8.75)	22.9 (9.0)
Lower E/A stroke	0.0	0.0
Shoulder harness (total), N (lb)	3251 (73)	3398 (764)
Lap belt, N (lb)	—	5026 (1130)
Accelerations, body axes, *g*		
Forward pelvis	16.0	22.0
Vertical pelvis	25.0	26.0

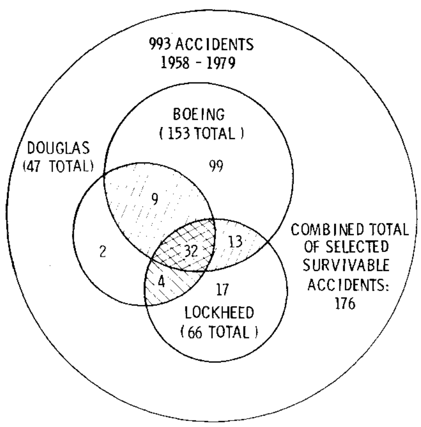

Fig. 10 Selective data base for crash scenarios.

applicable to large dynamic deformations of realistic aircraft structures; and the other, called KRASH, is a versatile lumped-mass computer program which models the gross behavior of the total aircraft structure. Both of these programs have specific strengths and weaknesses depending on the particular nonlinear problem that is being addressed. Both have been evaluated in the general aviation crash dynamics program and will be used to model transport aircraft structure.[26]

Occupant/Seat/Restraint System

As mentioned previously, the occupant/restraint system model of SOMLA is being integrated with the dynamic finite-element DYCAST program for increased versatility. The new program, called DYSOM, will be used to predict the structural response and occupant behavior of fully or partially loaded multioccupant transport seats under specific crash loadings.

Both the structural and the occupant/seat programs will be updated to include advanced material modeling to accommodate the newer composite materials' anisotropic properties in a macroscopic sense. However, much research work needs to be conducted on postbuckling composite behavior characteristics before an adequate representation of composite failure mechanisms can be predicted.

All of these structural predictive methods will be compared with full-scale and component testing of representative transport structure.

Proposed Full-Scale B-720 Transport Crash Test

In order to corroborate analytical predictive methods, test crashworthy structural design concepts, and verify the performance of antimisting kerosene additives, the FAA/NASA will conduct a full-scale transport crash test in 1984. The proposed test specimen, an FAA B-720 four-engine jet transport with a 160,000 kg (350,000 lb) takeoff weight will be crash-tested by remote control into a designated impact site. The crash scenario will be one selected from the accident data

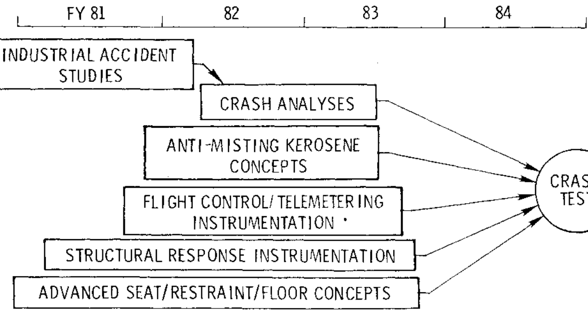

Fig. 11 Full-scale B-720 transport crash test schedule.

studies. Provisions will be made that the structural failure of the inboard fuel tanks take place at the maximum approach crash speed to provide a severe velocity test of the effectiveness of antimisting kerosene. The cabin interior will be fully instrumented and will contain both standard and crashworthy seat designs with fully instrumented anthropomorphic dummies. Crashworthy structural floor features will be assessed during the monitored crash sequence. In addition, pyrotechnic egress device concepts will be evaluated and evacuation slide techniques verified. The B-720 crash test program time chart is given in block form in Fig. 11. The blocks represent major ongoing activities that are a part of the preparation and assessment exercises associated with the full-scale crash test, scheduled tentatively for the summer of 1984.

A set of objectives associated with three different crashworthy research areas have been identified in the proposed B-720 full-scale crash test plan. These three crashworthy research areas are structural airframe and seat response, antimisting kerosene performance characteristics, and cabin fire safety materials testing. They are discussed briefly in the following sections.

Structural Airframe and Seat Test

The objectives of the structural airframe and seat tests are: 1) to define dynamic seat pulse data in the form of acceleration time histories at the seat/floor interface, 2) to measure acceleration time-history data throughout the cabin interior for comparison with nonlinear analytical predictions of structural behavior and to determine the level of injury by acceleration indices, 3) to determine accuracy of current flight recorder data, 4) to assess current and improved seat/restraint system/floor behavior, and 5) to determine structural deformations and failure modes.

Antimisting Kerosene

The FAA and NASA are heavily committed to the research and development of an antimisting fuel additive, which has the potential for precluding the development of the fine mist and associated fireball resulting from fuel spillage. In addition, this additive should exhibit the potential for allowing restoration of the filtration and atomizing characteristics of the fuel, a major requirement for aircraft engine and fuel systems operations.

The proposed B-720 full-scale test utilizing the antimisting additive will afford the participants an opportunity to: 1) evaluate the performance of the additive's in-flight engine burning characteristics, 2) determine the additive's compatibility with aircraft engines, and 3) determine flammability and plume characteristics in a postcrash environment.

Cabin Fire Safety

The overall objectives of cabin fire safety are: characterizing cabin hazards created by external fuel fires and the contribution of interior materials to this hazard, and increasing the survivability and safety of occupants in the event of a cabin fire. The proposed B-720 crash test could provide a test bed to evaluate the effectiveness of interior materials as fire retardants when exposed to a fire in a second-phase fire test with the airplane at rest.

Conclusion

The FAA, NASA, and industry have initiated a transport crash dynamics program to develop technology to define and demonstrate new structural concepts that will enhance passenger and crew survivability by minimizing crash force trauma and the potential fire hazard caused by fuel spillage. This technology will facilitate the integration of crashworthy structural design concepts into transport design methods and will consider airframe, seat, floor, fuel tanks, and landing gear behavior. In addition, the potential of antimisting kerosene additives to reduce the fire hazard are to be determined as well as the additive's compatibility with aircraft engines.

The dynamic nonlinear behavior of structural components will be determined analytically and verified by full-scale and scaled dynamic tests. The nonlinear analytical techniques developed under the general aviation crash dynamics program will provide a foundation for application to metal transport structure. Consideration of advanced composite structural materials and their affect on structural behavior and failure mechanisms will be studied and design tools developed to aid in future transport airplane design.

In the development of transport crash scenarios, a thorough evaluation of accident data will be made to provide a fundamental understanding of occupant injury mechanisms and aircraft structural response. The effort will be a continuing one, with both industry and government participation, and should provide a data base from which a design philosophy can evolve. Close cooperation with other governmental agencies is being maintained to provide data on human tolerance limits concerning the magnitude and duration of deceleration levels, toxicity levels, and heat exposure.

To date, the U.S. Army's experiences indicate that crashworthy design technology has been a most productive art, not only in reducing injuries/fatalities but in achieving these benefits economically. Through the continued research and development efforts of government and industry significant gains can be achieved in reducing transport crash hazards by crashworthy design technology.

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