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DEVELOPMENT OF CRASH-RESISTANT AIRCRAFT FLAMMABLE FLUID SYSTEMS

PART I

DELINEATION OF THE PROBLEM

FOR LIMITED DISTRIBUTION

by

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FOREWORD

The investigation described in this report was conducted at the Federal Aviation Agency's Technical Development Center, Indianapolis, Ind., in partial fulfillment of certain tasks under U. S. Army Transportation Research Contract 21X2040 709-9062 P 5030-07 S 44-019, Subtask 127AV, Project 9-89-02-000 dated December 11, 1956.

SUMMARY

Investigations, on-the-scene studies of aircraft accidents, and some helicopter drop-crash tests have been made in an effort to establish the severity of crash impact for which crash-resistant flammable fluid systems, installed in fuselages of fixed- and rotary-wing aircraft, should be designed. In addition, it was desirable to establish other basic considerations which, of necessity, must be observed in locating and installing such systems in aircraft if a firm, reliable level of protection against crash-fires is to be attained. Studies also have been made to determine the contribution of post-crash fire to aircraft accident fatality rates.

These investigations, studies, and tests reveal that post-crash fire is a major factor contributing to higher fatality rates during aircraft accidents, and that a crash-load factor in the order of 35 may be considered likely under severe but survivable crash conditions.

There are certain particular locations in the aircraft where fuel tanks should not be located unless means for affording them substantial protection against damage in crashes is provided. Fuel tanks located in the outboard portions of wings provide a certain level of protection against the hazards of crash-fires by virtue of location.

The design of crash-resistant fuel tanks for internal fluid pressure loads resulting from squashing conditions is now known to be feasible. Crash-resistant fuel cells should be equipped with accessories and components which will not tear the cell and which are capable of sealing the fuel inside the cell in the event of any appreciable movement of the cell with respect to its structural cavity or with respect to adjacent cells during crash conditions.

INTRODUCTION

Considerable progress toward the improvement of crash safety in aircraft is being made by the combined efforts of a number of organizations. The Technical Development Center (TDC) of the Federal Aviation Agency is engaged in a program to develop crash-resistant flammable fluid systems for helicopter and smaller type, fixed-wing aircraft. The objective is to develop criteria for designing crash-resistant, flammable fluid systems for fuselages of aircraft that will not rupture in survivable-type crashes, that is, in those types of accidents and crashes in which the occupants normally can be expected to survive the crash impact. Until such time as all the characteristics of a survivable crash are positively established, it is necessary to concentrate the maximum effort on severe but survivable types of accidents which are experienced most frequently.

The flammable fluids are fuel, oil, and hydraulic fluid. The confinement of these fluids in a crash would prevent the formation of a readily combustible mixture and, in addition, would isolate the flammable fluids from the many possible ignition sources. The fuel constitutes the great bulk of these flammable fluids. The major crash-fire hazards, therefore, generally are associated with the fuel, and it has been concluded that efforts toward a solution of the crash-fire problem should be concentrated mainly on the fuel tanks.

Work on the development of crash-resistant fuel tanks for wings of aircraft has been in progress a number of years and the results obtained to date are presented in several Technical Development Reports.[1 2 3] In the present program efforts are being confined to the flexible, nonmetallic-type tank which appeared to possess the most merit in preventing the spillage of fuel in crashes in the previous work on wing fuel tanks.

The success of the present program depends upon the determination of certain fundamental facts concerning crashes. These are:

1. The attitudes in which fixed-wing aircraft and helicopters normally strike the ground in severe but survivable-type crashes.

[1] R. L. Field, Melvin F. Miller, and George L. Pigman, " An Investigation of the Crash-Fire Problems in Transport Aircraft Fuel Tanks," Technical Development Report No. 134, January 1951.

[2] Richard N. Motsinger, Melvin F. Miller, and Robert J. Schroers, "Some Physical Properties of a Number of Proposed Constructions of Materials for Nonmetallic Crash-Resistant Aircraft Fuel Tanks," Technical Development Report No. 220, December 1953.

[3] Charles V. Bennett and Robert J. Schroers, "Impact Tests of Flexible Nonmetallic Aircraft Fuel Tanks Installed in Two Categories of Simulated Wing Structures," Technical Development Report No. 291, January 1957.

2. The magnitude of load factor which is associated with such crashes.

3. The impact angles which are associated with crashes of this type.

4. The magnitude and direction of the crash loads which should be employed in the design of crash-resistant, flammable fluid systems.

5. The feasibility of providing crash-resistant fuel tanks in the fuselages of rotary-wing aircraft, especially in those cases where fuel tanks, of necessity, must be located in close proximity to heavy, concentrated masses such as engines, rotor mast, cargo, and so forth.

6. The limitations which must be observed with respect to the installation of those systems if a practical and reliable level of protection against post-crash fire is to be provided.

7. It also was desired to know the benefits in terms of reduced fatalities of occupants which might accrue through the use of crash-resistant, flammable fluid systems.

The program to develop crash-resistant flammable fluid systems is divided into four parts as follows:

Part I - A study of aircraft accidents, existing accident reports, and accident investigation data to obtain certain fundamental facts pertaining to the attitudes and severity of impact experienced by aircraft, particularly helicopters, in severe but survivable-type accidents.

Part II - Crash testing of rotary-wing and possibly a few fixed-wing aircraft equipped with experimental fuel cells to establish proper design criteria for crash-resistant fuselage fuel tanks for such aircraft.

Part III - Establishment of specifications for and the development of prototype production components and accessories for crash-resistant fuel tanks and creation of a commercial source of supply for such components and accessories.

Part IV - Crash-proof testing of a number of helicopters equipped with crash-resistant flammable fluid systems to substantiate unquestionably the validity of the design criteria and specifications derived in Parts I, II, and III.

This report covers the work performed under Part I of the program. The report is divided essentially into two major parts; the first pertains to fixed-wing aircraft, the second to rotary-wing aircraft.

DISCUSSION

General.

The results of studies, tests, and investigations conducted in connection with this program show that many factors contribute to the occurrence of occupant fatalities during aircraft accidents. Some of these factors are post-crash fire; failure of seats, belts, and floor tie-down structure; dangerous structural arrangements in cockpit and cabin areas; flying debris, magnitude, direction, and duration of impact loads; occupant position, and so forth. Because of these and many other factors, it has not been possible to establish a positive definition of a survivable crash.

Statistical studies have been made to determine the frequency of post-crash fires and to compare injury rates for the fire and nonfire accidents. The results of one study[4] of serious, scheduled air carrier accidents involving fixed-wing aircraft, which occurred during the period 1938 to 1951, are shown in Table I. The results of this study, conducted by the Civil Aeronautics Board, show that crashes not followed by fire were fatal to 60.8 per cent of the airplane occupants. In accidents followed by fire, the fatality rate increased to 84.6 per cent, an increase of approximately 25 per cent. A similar study[5] has been made of rotary-wing aircraft accidents and the results of this study are summarized in Fig. 1. These data indicate that the fatality rate was 38.8 per cent greater in helicopter accidents in which post-crash fire occurred than in those accidents in which such fires did not occur. The study points out that although fire occurred in only 8.7 per cent of the helicopter accidents, 60.4 per cent of all the fatalities were caused by these fire accidents.

These statistical studies show that post-crash fire is a major factor contributing to higher injury rates in aircraft accidents. This report is intended to supply information pertaining to inertia loads applied as well as structural and fuel system damage normally suffered in crashes, and to define the fundamental design conditions which must be considered in providing crash-resistant fuel tanks in aircraft.

Fixed-Wing Aircraft.

Impact Angle, Attitudes, and Severity of Crash Impact.

Early in the program, a meeting was held of representatives of organizations who, by virtue of their work in connection with improving safety in aircraft, might be able to help provide the fundamental information needed pertaining to aircraft crashes. This meeting was attended by representatives of the Civil Aeronautics Board (CAB), National Advisory Committee for Aeronautics (NACA), Aviation Crash Injury Research of Cornell University (AvCIR); Transportation Corps, Department of the Army; Directorate, Flight Safety Research, Department of the Air Force; the FAA Technical Development Center, and the FAA Office of Flight Operations and Airworthiness. The following describes the information which was presented at the meeting and the conclusions which were reached.

[4]Summary of Fatalities in Scheduled Air Carrier Operations from 1938 through June 1951 (unpublished), Civil Aeronautics Board, Washington, D.C.

[5]Charles V. Bennett and James V. Burkhard, "A Summary of Crash Fire and Injury Rates in Helicopter Accidents," Technical Development Report No. 313, June 1957.

The findings of Aviation Crash Injury Research of Cornell University showed that the original ground impact generally occurs with the airplane longitudinal axis yawed within 30° of the line of flight. This is true particularly in accidents occurring during takeoff and landing phases of flight (one of the most common types of accidents) which normally are associated with high forward velocity compared to the sinking variety. In addition, the longitudinal attitude of the airplane generally is within plus or minus 15° of level, except in stall accidents where the nose-down attitude is as much as 45° from level attitude. It was pointed out that transport airplanes involved in very serious but survivable crashes often hit the ground at velocities as high as 150 knots. Substantial structural damage is incurred in such crashes, and ripping and tearing action would be expected to be a big factor in determining whether or not fuel systems have any reasonable chance of remaining intact.

Results obtained from full-scale crash tests of transport-category aircraft conducted by the NACA[6] show that, in the vicinity of the floor structure, such aircraft experienced load-factor components of 20 for a duration of 0.20 to 0.30 second, acting simultaneously along the vertical and longitudinal axes of the aircraft. Superimposed on each of these was an additional load factor of approximately 25, but for a duration of only 0.03 second. These crashes were considered to be survivable to occupants provided seats of proper design were installed. It also was shown that the response of the fuel in a fuselage tank to the load impulse involved would be a function of the natural frequency of the contained fluid. As a result of this work, it appeared that a load factor of approximately 35 was applicable to the design of crash-resistant fuel tanks.

Based on the information obtained from the impact testing of wing fuel tanks at this Center, it was believed that a comprehensive interpretation of the NACA data possibly could be made with respect to the selection of a load factor for fuel cell design purposes. The results of this testing, in which the duration of impact load was approximately 0.05 second, indicated that the maximum fluid ram pressure developed inside the fuel tanks corresponded to about one-third of the pressure which would have been developed had the full effect of the impact load on the structure been transmitted to the fluid. Consequently, it was concluded that in actual crashes, the fuel is not capable of following faithfully impact loads of very short duration, and it was believed that the fuel would respond to roughly one-fifth of the short period (0.03 second) load factor of 25, or 5. On the other hand, the fuel should be subjected essentially to the full effects of the base pulse of 20g for a duration of 0.20 to 0.30 second. By adding the two load factors 5 and 20, load-factor components of 25 acting along the vertical and longitudinal axes are obtained. Because these load-factor components may be experienced simultaneously along both axes, these components should be added vectorially to give a resultant load factor of 35 for fuel tank design purposes.

[6] I. Irving Pinkel and Edmund G. Rosenburg, "Seat Design for Crashworthiness," NACA TN 3777, October 1956.

TDC personnel who had been studying damaged aircraft at the scenes of crashes reported that average, crash-load factors in the order of 20, acting along the longitudinal axis of the aircraft, had been estimated. These accidents definitely were of the survivable type and there was some evidence indicating that crash-load factors for the design of fuselage fuel tanks should be somewhat higher, possibly 35. The data obtained were meager and did not constitute sufficient evidence which would enable TDC personnel alone to establish firm conclusions on a load factor applicable to the design of crash-resistant, fuselage fuel tanks.

It was apparent that the several organizations, working independently in different but somewhat related fields, essentially had arrived at the same general conclusions; namely, that a load factor of 35 was reasonable and should be applied to the design of crash-resistant fuselage fuel tanks. The importance of installing fuselage fuel tanks at a substantial distance above bottom fuselage skin and/or in a position which is protected as much as possible from scraping action with the ground also was recognized.

Studies of actual crashes and of accident reports conducted by TDC in connection with this program showed that crash-load factors may vary greatly in different sections of the fuselage of larger aircraft during crash impact. To substantiate this statement, the observations made in connection with two typical aircraft accidents are presented. In a B-25 accident, the nose of the fuselage was squashed back to the wing front spar, but in the rear of the cabin, a microphone still was hanging on its hook and seat cushions still were in place in the seats. A DC-6 airplane which crashed at Elizabeth, N. J., struck the ground in a nose-down attitude at approximately 15° at approximately 145 mph. All occupants in the forward part of the airplane suffered fatal injuries, but during the initial impact with the ground, occupants in the aft end of the fuselage apparently were hardly more than jostled. From a study of accidents such as these, it is clear that aircraft structure is able to absorb tremendous amounts of energy in crashes, and whereas one location may be subjected to high decelerations, another location even a relatively short distance away may be subjected to greatly reduced, if not negligible, deceleration. Injury of any occupant primarily from the effects of deceleration probably depends on whether or not the occupant is seated in an area of severe impact. Likewise, the deceleration to which a fuel tank may be subjected probably is pretty much a function of its proximity to areas of direct impact. While greater impact loads usually occur in the forward sections of aircraft, severe impact loads may occur anywhere along the fuselage as far back as the areas adjacent to the tail. If crash fires are to be prevented, fuselage fuel tanks, regardless of position along the fuselage, should be designed to a load factor of 35. This is considered to be the most logical conclusion that can be made until such time as more precise data are available on the distribution of inertia loads along the fuselages of large aircraft during crash conditions.

Crash-load factors in the structure of smaller, lighter aircraft also may vary to a considerable extent during crash conditions. Table II presents the load factors obtained in six drop-crash tests of small helicopters. It is believed that the load-factor variation in small fixed-wing aircraft will be comparable. Generally, ignoring the effects of seat design, occupants in small aircraft more often than in large aircraft will be subjected to the maximum decelerations which are experienced by the structure of the aircraft. This is true primarily because of the relatively small size and greater rigidity of the structure. Similarly, fuel tanks in general also will be subjected to the maximum decelerations experienced by the aircraft. If occupants are to be spared the hazards of fire in severe but survivable-type crashes, fuselage fuel tanks in smaller aircraft possibly should be designed to somewhat higher load factors than the tanks in large aircraft, regardless of position along the fuselage. For smaller aircraft, it is concluded that the load factor be not less than 35.

A crash condition in which a resultant load factor of 35 is experienced is described above as one for which fuselage fuel tanks should be designed. Actually, this load factor is the resultant of two components of 25g each acting simultaneously along the vertical and longitudinal axes of the aircraft. Also, as stated previously, aircraft may strike the ground with the longitudinal axis yawed as much as 30° from the line of flight. For a load-factor components of 25 acting in the direction of the longitudinal axis, and with the airplane yawed to one side as much as 30° at instant of impact, the load-factor component in the lateral direction is equal to 25 tan 30°, or approximately 14.

It is not intended that precise basic loading conditions which should be used for the design of crash-resistant fuselage fuel tanks be presented in this report. However, based strictly on the above reasoning, which is quite limited in scope considering the many crash attitudes and gyrations which may be experienced by fixed-wing aircraft during crashes, it appears that a load-factor component in the order of 14, acting in the lateral direction, may be applicable for the design of such tanks.

Damage to Fuselage Structure.

During impact and subsequent scraping along the ground, severe damage may be experienced by forward and bottom fuselage structure. The extent of damage which may be experienced in severe but survivable-type accidents, as shown by NACA tests, AvCIR, and TDC crash studies, is discussed below.

In the case of low-wing airplanes, crushing damage to forward structure may extend from the nose as far back as the plane of the wing front spar. In the case of high-wing and midwing airplanes, the damage may extend considerably beyond this plane. Damage of this kind to both of these types of airplanes may occur even though crash-load factors sometimes may be quite low. Damage to bottom fuselage structure in high-wing aircraft may be extremely severe because the fuselage does not have the protection inherently afforded by strong, center-section wing structure located low in the fuselage.

Often, in the case of low-wing aircraft, this wing structure not only provides considerable protection to the lower portion of the fuselage, but also appears to minimize damage to the aft fuselage structure which may result from scraping and grinding action with the ground.

The condition of the ground on which an aircraft crashes may be an important factor in the degree of fuselage structural damage that is experienced. Soft ground is considered to be worse than hard ground. In soft ground the fuselage apparently tends to dig in more and scoop dirt, thereby imposing severe shearing loads on the lower structure. This can result in almost complete disintegration of whole lower fuselage areas. A typical example of this is the case of a Convair 240 airplane which crashed at Springfield, Mo. Apparently the aircraft landed quite hard on a thin layer of wet, soft ground and skidded to rest in approximately 250 yards. Bottom fuselage structure, including parts of the cabin floor, was torn away. It would have been impossible for any fuel tanks located below the floor line to remain intact in the accident. In this case, damage to the lower fuselage structure occurred even though a wing center-section structure was present to help protect the fuselage. However, other accidents quite similar to this one have occurred in which relatively little damage was done to the lower fuselage areas, and little if any damage would have occurred to the fuel tanks had they been located there.

Insofar as size of aircraft is concerned, it appears that the lower fuselage structure of large aircraft tends to suffer relatively more damage from ripping and tearing action with the ground than smaller aircraft. Smaller aircraft which strike the ground in more or less a flat attitude, as large transports often do, have been found to suffer much less serious damage to the lower structure. For this reason, the problem of achieving effective crash-resistant fuselage fuel tanks in smaller aircraft, whether high- or low-wing type, may not be as difficult as in large aircraft, but it is believed that the advantage lies with the low-wing types.

Damage to Wing Structure.

In survivable accidents, it has been found that wing structure may suffer extensive damage without harmful effects to the aircraft occupants. Direct impact forces may be encountered anywhere along the span of the wing, and these forces generally result in failure of the wing at inboard locations. For this reason, it is highly desirable that, whenever possible, fuel tanks be located in outboard rather than inboard portions of the wing. For present multiengine airplanes, using reciprocating engines, fuel tank positions outboard of the nacelles would be most desirable. Placing the fuel containers in outboard portions of the wings also is highly desirable because of its remoteness from the cabin. If a fuel tank in this location is ruptured, more time generally is available for rescue and evacuation of the occupants.

Experience has indicated that high-wing aircraft experience less damage to the wing structure in crashes than low-wing aircraft because the wing tends to stay away from the ground in the high-wing-type aircraft. In low-wing aircraft, the fuel tanks may be kept off the ground to some extent by virtue of wing-dihedral and low-slung nacelles.

Limitations Which Must be Observed with Respect to Placement of Crash-Resistant Fuel Tanks.

Lower fuselage structure of high-wing, transport-category aircraft is highly susceptible to severe damage even in crashes of moderate impact. In these cases, it appears that fuel tanks, regardless of strength, located low in the fuselage (below the floor line) of such aircraft, have little chance of remaining intact and consequently, cannot be expected to have a high degree of protection against crash fires.

In the case of low-wing, transport-category aircraft, because of scraping and grinding action with the ground, and in spite of the protection which is afforded by the wing center-section structure, it is mandatory that fuel tanks be located well above lower fuselage skin and/or in a protected position such that exposure of the tank to scraping and grinding action with the ground is unlikely. If at all possible, the tanks should be located above the floor. The importance of providing a high degree of protection for the tanks is magnified by the fact that fuel from a ruptured tank in this area can spread quickly to all portions of the fuselage, and if ignited, the ensuing fire may cause a great loss of life in accidents which otherwise might be relatively minor.

While inherently it may be somewhat easier to achieve crash-resistant fuselage fuel tanks in smaller aircraft as compared to large aircraft, it is necessary, nevertheless, that the fuselage tanks in smaller aircraft be located and/or given protection such that they will not be exposed to scraping action with the ground. Again it appears most desirable to install them above the floor line.

If tanks are located in fuselages such that they may be squashed, the tanks must be designed not only for internal fluid ram pressure loads caused by the crash impact but also for squashing loads, if they are to be crash-resistant. This is discussed in further detail later.

The serious structural damage which generally occurs to forward fuselage areas indicates that fuel containers should be positioned as far to the rear of the fuselage as possible, and in no case should a tank be located forward of the plane of the wing front spar. This is true in the case of low- and high-wing, small and large aircraft.

Information obtained from the Department of the Air Force indicates that landing gears installed in lower fuselage structure of modern Air Force aircraft may constitute a hazard to the integrity of fuselage fuel tanks. Air Force experience dictates that fuel tanks should be located in a position such that they are not vulnerable to damage if landing gears fail and are pushed upward into the fuselage. The location of wing fuel tanks with respect to landing gear structure also should receive careful consideration. The landing gear should be placed such that in the event of its failure, the gear will not penetrate a fuel tank.

Rotary-Wing Aircraft.

Impact Angle, Attitudes, and Severity of Crash Impact.

As in the case of fixed-wing airplanes, studies show that the majority of rotary-wing aircraft accidents occur during the takeoff and landing phases of flight. Unlike the fixed-wing airplane crashes, rotary-wing airplane crashes often are preceded by low, forward ground speed and thus, the initial load is applied primarily in the vertical direction.

Records of 342 serious damage accidents experienced by one branch of the military services included only 97 records which contained detailed information pertaining to impact angle and impact attitude. Impact angle refers to that angle between the ground and the path of the descending aircraft, whereas impact attitude refers to the amount of tilt of the body axes of the aircraft. Data on impact angles for these accidents showed that approximately 35 per cent involved an impact angle of 90° (vertical descent) and that approximately 68 per cent crashed at an angle of 60° or greater. The impact attitude in approximately 50 per cent of these 97 accidents was longitudinally and laterally level. The remainder of the 97 accidents were reported as occurring with some combinations of aircraft attitude as nose high, nose low, and banked, and one was inverted. Unfortunately, these records did not contain information which would permit the determination of the magnitudes of the impact loads experienced in these accidents.

In order to obtain some information on the magnitude of crash-load factors, on-the-scene studies of seven helicopter accidents were made. The results of these studies are sumarized in Table III. From the table it may be seen that the crash-load factors varied from 2 to 60. These must be considered approximate values. It also may be seen that in five of the accidents the impact angle was vertical (90°). In addition, telephone contacts with on-the-scene investigating officers of the military services involving eight more accidents also were made which provided additional valuable information on impact angles, attitudes, and velocities, although no information on the magnitude of the impact loads was obtained. The information obtained from these investigators and their reports are summarized in Table IV. In three of these accidents the impact angle was 90° and one was 6°. In the remaining four accidents the angle was unknown.

Failure to flare or premature flare in the landing phase of flight is one of the most frequent causes of accidents. About 80 per cent of the serious accidents, involving one smaller type helicopter in wide use by the military services, were of this kind.

A study of all available accident reports plus discussions with military helicopter flight safety personnel revealed that the upper limit of impact velocity possibly should be associated with the maximum rate of descent which may be attained in a helicopter during certain controlled, vertical, autorotative conditions of flight. For example, this rate for the Bell H-13 helicopter is approximately 2,600 feet per minute (fpm).

The results of some free-fall drop tests conducted at this Center involving three H-13 simulated structures constructed by TDC for this purpose and three Sikorsky HO5S-1 aircraft are presented in Table II. The H-13 simulated structure and HO5S-1 helicopter are shown in Figs. 2 and 3, respectively.

The aircraft were dropped intentionally from heights of approximately 30 feet in order to produce impact velocities in the order of 2,600 fpm. A drop height of 30 feet theoretically results in an impact velocity of 2,634 fpm. The actual descent velocities and resulting load factors experienced by the structures and by two anthropomorphic dummies seated in two of the HO5S-1 helicopters are shown in the table. The positions on the structures at which these load factors were measured are defined in Figs. 4 and 5. Although some variation of the peak load factors experienced by different parts of the structure is shown by these data, it is considered significant that no extreme variations were measured. This is in direct contrast to the previously discussed crash-load factor variation estimated for large fixed-wing aircraft. Based on the data obtained in the six drop-crash tests, it appears that because of aircraft size the load factor variation in small aircraft may not be nearly so great as in larger aircraft. The absence of large variations in crash-load factors experienced at different structural locations indicates that an average of these load factors, shown in Table II, represents reasonably the over-all load factor experienced by the aircraft.

The average of the three impact velocities experienced in the HO5S-1 drop-crash tests (see Table II) is 2,240 fpm and this is associated with an average load factor of 32. Corresponding data for the H-13 simulated helicopter structures show an average load factor of 32 for an average impact velocity of 2,243 fpm. The achievement of such close agreement in tests of this kind is surprising, but the data are interesting in another respect. The HO5S-1 helicopter is of stressed skin construction whereas the H-13 simulated structure is fabricated completely of steel tubes. These data, though limited, indicate that both types of structure apparently tend to respond in essentially the same manner to a given configuration of crash impact.

In an effort to appraise the meaning of these structural crash-load factors in terms of human survival, load factors experienced by two anthropomorphic dummies while seated in the helicopters of Tests Nos. 2 and 3 were recorded. The load factors suffered by the dummies are presented in Table II and the time history of the pertinent accelerations are shown in Figs. 6A and 6B.

High-speed movies of the tests show that dummy No. 1, seated in the left front seat and which was restrained by both a seat belt and shoulder harness, deflected downward as the deceleration forces increased. This action subjected the seat pan to loads which buckled the floor structure on which the seat was mounted. Following the downward movement, the dummy rotated violently rearward, its head snapping in that direction. The loads imposed by the rearward movement of the dummy and seat resulted in failure of the collective-pitch, control-torque tube behind the seat, but the seat back did not fail. The dummy seated in the right front seat (dummy No. 2), which was restrained by a seat belt only, followed the same kinematic pattern as dummy No. 1, except that its movements were more violent. This resulted in failure of the right-side support for the back rest of the right seat as the dummy rotated backward to a nearly horizontal position. The differences in inertia loads imposed on the two dummies can be attributed partially to the fact that the left side of the helicopter was crushed more than the right side and partially to the fact that dummy No. 1 was restrained by both a seat belt and a shoulder harness. A maximum vertical load factor of 26 for a total duration of 0.025 second and a rate of onset of 1,333g per second was sustained by dummy No. 1 in the upper pelvic region. A load factor of 36 for a duration of 0.020 second and a rate of onset of 2,000g per second was sustained vertically in the chest of dummy No. 2. In test No. 3, dummy No. 1 again was seated in the left front seat and restrained by both a seat belt and shoulder harness. For this test, a 4-inch-thick sheet of Styrofoam was substituted for the seat pad under the dummy. Dummy No. 2 was seated in the right front seat and placed in the "knee-chest" position which is considered to be good practice in the event of an impending crash. It was restrained by a seat belt only. Results of the test indicated that the vertical loads in the pelvic region of dummy No. 1 were reduced from those of the previous test as the Styrofoam crushed under the applied loads, thereby increasing the time of deceleration for this dummy. The load factor perpendicular to the spine of dummy No. 2 was above 45.

The load factors experienced by the dummies, when judged by the human tolerance data obtained by the NACA,[7] are considered to be survivable by humans although some injuries would be expected. The fact that survivable load factors were experienced by the dummies simultaneously with average vertical load factors of 28 and 39 on the structure indicated that the design of flammable fluid systems to withstand load factors of 35 is justified. In addition, information received from the representative of a major helicopter manufacturer reflecting their studies of approximately 120 wartime accidents involving one of their model helicopters showed not only that the principal impact loads were applied in a near vertical direction, but that there were survivors in all accidents where seat failure did not occur, and that load factors estimated to be in the order of 35 were experienced in many of the accidents.

From a review of available helicopter accident investigation data, it is concluded that the predominant crash-load factors imposed in the majority of accidents occur more in a vertical than in a longitudinal direction.

While the impact angles of rotary-wing aircraft in the majority of accidents probably are high, there are accidents in which the impact angles are low; that is, the longitudinal component of velocity at impact

[7]Gerard J. Pesman and A. Martin Eiband, "Crash Injury," NACA Conference on Airplane Crash-Impact Loads, Crash Injuries and Principles of Seat Design for Crash Worthiness, April 17, 1956.

is higher than the component of velocity in the vertical direction. Discussions with flight safety personnel of the Department of the Army indicate that this condition is experienced in crashes which are preceded immediately by low-altitude, high-speed flight, and in landing approaches where normal autorotative procedures are employed. The ratio of vertical-to-longitudinal inertia loads experienced in crashes of this type is unknown. It is recognized, however, that crash tests being conducted to substantiate the adequacy of crash-resistant fuel tank design criteria for helicopters must take longitudinal impact loadings into account adequately.

In an effort to select a reasonable crash configuration which would simulate this type of crash, some data on actual flight-path velocities, flight-path angles, and fuselage attitudes versus height above the ground of four different model helicopters making normal autorotative landings to a panel were obtained by means of a Fairchild flight analyzer camera. The data obtained are shown in Figs. 7, 8, 9, and 10. A summary of information derived from these figures for an arbitrarily assumed height of 50 feet above the ground is presented in Table V. From this table it may be seen that the flight-path angles, fuselage attitudes, and velocities along the flight path vary appreciably among the four helicopters involved. These angles and velocities do not represent the only ones which can be experienced by these helicopters during autorotative landings. In any case it is believed that the angles and velocities associated with a point 50 feet above the ground can be used to establish exploratory test conditions for these helicopters to be crash tested for the explicit purpose of simulating this type of crash. The vertical drop-crash test condition will simulate the type of accident in which impact angles are high.

In the case of the H-13 helicopter, for example, and referring to Table V, one test condition would be a forward speed of 2,610 fpm and a rate of descent of 1,440 fpm which results in a flight or impact angle of approximately 29°. Fuselage attitude could arbitrarily be 0°. The second test condition would be an impact angle of 90° and a vertical rate of descent of approximately 2,600 fpm.

Damage to Basic Structure.

Damage to the H-13 simulated helicopter structures and the HO5S-1 helicopters in this Center's drop tests is described in Table II. From the standpoint of damage to the structures only, it can be stated definitely that these crashes would be survivable to occupants.

Of particular interest is the amount of squashing of lower fuselage structure that was obtained in the HO5S-1 tests. In the area of the fuel cell which is located under the two rear seats, the bottom structure was displaced upward 4.75 inches. The depth of the structural cavity for the fuel cell is approximately 16 inches. Therefore, about one-third of the height of the fuel cell cavity was compressed out of existence during the impact. When a fuel cell having a tensile strength of approximately 140 pounds per inch of width was installed, rupture of the cell occurred immediately upon impact and fluid from the ruptured tank flooded the cabin interior in the form of mist and solid fluid. However, in two tests in which self-sealing fuel cells having a tensile strength of approximately 860 pounds per inch of width were used, failure of the cells did not occur. In these two cases, one-third of the height of the structural cavity and consequently, approximately one-third of the volume of the fuel cell, were displaced upward and outward by the crash impact. This describes the type of action which a successful squash-resistant tank must be able to withstand without rupture under squashing conditions.

In Tests Nos. 1, 2, and 3, Table II, which involved the HO5S-1 helicopter, the gross weight of the helicopter in each case was approximately 2,700 pounds. The average peak load factor for 0.01 second in Tests Nos. 1 and 2 was 28. In Test No. 3, it was 39. The peak load imposed on the bottom fuselage structure in Tests Nos. 1 and 2 therefore was 2,700 times 28 or 75,600 pounds. In Test No. 3, it was 2,700 times 39 or 105,300 pounds. The total area of bottom fuselage structure exposed to these loads was in the order of 55 square feet, or 7,900 square inches. Therefore, the load intensity on the bottom fuselage structure in Tests Nos. 1 and 2 is calculated to be approximately 9.6 pounds per square inch, while in Test No. 3 it was 13.3 pounds per square inch. In all three cases the total displacement of bottom fuselage structure as mentioned above was 4.75 inches. This information is presented because it constitutes the type of basic data which will be vitally necessary in connection with future attempts to design squash-resistant fuel tanks for helicopters.

Drop-crash tests on the HO5S-1 helicopters and H-13 simulated helicopter structures indicate that the fuselage structure obtains very little shock-absorbing protection from the landing gear structure. The tests involved hydraulic-strut-type and solid-steel-tube (nonenergy-absorbing) type landing gears. In the case of the hydraulic struts, the struts were unable to absorb the sudden onset of the crash impact and snapped off immediately at points of attachment to the fuselage. Very little of the kinetic energy of the falling aircraft was absorbed. The same was true of the solid gear. This gear reduced the falling velocity only about 4 feet per second out of a total falling velocity of 40 feet per second even though the gear, which was very rugged, failed completely during the impact.

The rotating rotor blade has been found to present a hazard to fuel tanks in some accidents. The rotor blade is quite flexible and is highly susceptible to damage, particularly in the rollover type of crash. In an accident, the blades tend to break into small pieces and fly in all directions except for the spar which generally is metal, and deforms and continues rotating, thereby becoming a potential source of damage to the fuel tanks. In one accident in which the crash-load factor was very low (1.5 to 2), little damage was sustained by the structure in contacting the ground. In the subsequent rollover, the blades, except for the spar, disintegrated and the tip of the spar punctured an externally mounted fuel tank and a destructive fire resulted. The use of crash-resistant fuel tanks, which consist of an outer metal shell and an inner flexible bladder cell, should help to minimize the type of tank damage.

Limitations Which Must Be Observed with Respect to the Placement of Crash-Resistant Fuel Tanks.

As a result of the tests discussed above, and from studies of actual accidents, it is quite evident that locations in almost any part of the helicopter, except directly under or possibly immediately adjacent to the engines or other highly concentrated heavy masses, apparently are suitable for the placement of fuel tanks provided the tanks are designed, protected and installed so as to be crash-resistant. In the tests involving the H-13 simulated helicopter structures and HO5S-1 helicopters, the engine mounts in all cases broke at low inertia loads and the engines then plunged downward to strike the ground. In the one case where recorded data were obtained (see Table II), the engine struck the ground with a load factor of 58. The engine and rotor component masses attached to it weigh approximately 800 pounds, and therefore, any fuel tank located beneath it would be subjected theoretically to squashing, penetration, and tearing loads in the order of 46,000 pounds, a very severe load. As a general rule, it appears that fuel tanks should not be located directly beneath or adjacent to highly concentrated heavy masses unless (1) the structures supporting the masses are capable of supporting them without failure under applied crash-load factors, (2) the supporting structure, in failing, will prevent the masses from falling on or impinging against the fuel tanks, or (3) it can be demonstrated that the masses, in falling on or impinging against the tank, will not damage it to such an extent that any appreciable amount of fuel is lost from the tank.

As a result of these crash tests, evidence has been obtained which shows that fuel tanks located low in helicopter fuselages, but not exposed to possible damage by highly concentrated heavy masses, can be crash-resistant. These fuselage areas are subject to severe squashing loads in crashes and originally it was considered impractical to try to provide crash-resistant tanks in them. Crushing of lower fuselage structure and squashing of the fuel cells was experienced in the three drop-crash tests on the HO5S-1 helicopters. In Tests Nos. 2 and 3, as mentioned above, the fuel cells did not fail and it is now recognized that the design of squash-resistant fuel tanks is feasible. A special design criterion will be required to solve the fuel tank squashing problem. Until this criterion is available, it is concluded that fuel tanks should not be located in positions where they will be subject to squashing loads.

Flammable Fluid System Components and Accessories.

Some cases were noted where crash fires were fed by broken fuel lines even though the fuel tanks apparently were intact after the crash. Fires from such sources can build up to large magnitudes but more slowly than if failure of the fuel tanks occurred, thereby permitting more time for evacuation. However, such fires can spread to the fuel tank and result in rapid destruction of the aircraft.

Crash-resistant fuel tanks should be equipped with components and accessories which will not detract from their crash resistance. In crashes, forces exist which tend to move the tanks in any direction relative to each other. The amount of shifting and resultant tearing of tanks by the components and accessories can be expected to increase with the severity of the crash.

A guiding concept for the design of components and accessories for crash-resistant fuel cells has been established. Under this concept, a crash-resistant fuel cell, employing the desired types of components and accessories, is visualized as having the ability to unhook, unsnap, or uncouple itself from adjacent tanks and from surrounding structure during crash conditions and roll free of the damaged structure with the fuel sealed inside the cell. This obviously is an objective which cannot be fully attained. Nevertheless, it is the basic objective aimed at in the design of components and accessories for crash-resistant fuel cells.

It is believed that this concept should apply only to those components and accessories which are associated directly with the fuel tanks themselves. The major fire hazard is considered to be the fuel tanks where the great bulk of the flammable fluid is carried. If these tanks can be kept from rupturing and if fuel can be kept from spilling from them through tank components and accessories, a high degree of crash-fire protection for aircraft will be achieved.

CONCLUSIONS

The following conclusions are made, based upon investigations, on-the-scene studies of aircraft accidents, and some helicopter drop-crash tests:

1. A crash-load factor in the order of 35 is considered likely in aircraft under severe but survivable crash conditions.

2. A load factor of 35 is recommended for the design of crash-resistant flammable fluid systems installed in fuselages of fixed- and rotary-wing aircraft. Systems designed to this load factor and properly located, protected, and installed should effect a substantial reduction in the occurrence of crash fires.

3. The fatality rate in crashes of fixed- and rotary-wing aircraft when such crashes are followed by fire is approximately 25 and 39 per cent greater, respectively, than in crashes not followed by fire.

4. While attitudes and flight-path angles of fixed- and rotary-wing aircraft vary widely in actual crashes, these can be reduced to a small number for crash-resistant flammable fluid system design purposes.

5. With certain limitations, almost any location in helicopters appears to be suitable for the placement of crash-resistant flammable fluid systems.

6. Fuel tanks located in outboard portions of the wings of fixed-wing aircraft provide appreciable protection against the hazards of crash fires

by virtue of location. On the other hand, inboard portions of the wings are prone to suffer severe damage more often than outboard portions. For this reason, it is highly desirable that whenever possible, no fuel tanks be located in inboard portions of the wings.

7. Fuel tanks in fuselages of fixed- and rotary-wing aircraft should be located and/or protected such that exposure of the tanks to scraping action with the ground is unlikely. Also, they should be located and installed so that they are not readily susceptible to severe damage from other causes in crashes. Relatively speaking, large fixed-wing aircraft suffer much more damage to bottom fuselage structure than smaller fixed-wing aircraft and helicopters.

8. Fuel tanks in fixed-wing aircraft should not be located forward of the plane of the wing front spar.

9. The design of crash-resistant fuel tanks for squashing loads, heretofore thought to be impossible or at least impracticable, now is recognized as being feasible.

TABLE I

SUMMARY OF FATALITIES
IN SCHEDULED PASSENGER AIR CARRIER OPERATION

1938 through June 1951

	Domestic				International			
	Fire in Crash		No Fire in Crash		Fire in Crash		No Fire in Crash	
Year	Fatal-ities	Occu-pants	Fatal-ities	Occu-pants	Fatal-ities	Occu-pants	Fatal-ities	Occu-pants
1938	10	10	15	26	--	--	19	19
1939	8	12	--	--	14	16	--	--
1940	35	41	10	10	--	--	--	--
1941	34	35	10	30	--	--	2	27
1942	54	65	17	19	--	--	--	--
1943	20	22	10	10	14	15	--	--
1944	24	24	32	47	--	--	17	31
1945	20	20	45	99	--	--	27	44
1946	52	97	28	73	52	62	--	--
1947	164	170	--	--	--	--	18	18
1948	55	56	43	115	30	31	--	--
1949	43	61	61	78	--	--	--	--
1950	51	58	58	58	--	--	--	--
1951	116	146	--	--	--	--	40	40
	686	817	329	565	110	124	123	179
Per Cent	84.0		58.2		88.7		68.7	

Combined Domestic and International
Scheduled Passenger Air Carrier Operation

1938 through June 1951

	Fire in Crash		No Fire in Crash	
	Fatal-ities	Occu-pants	Fatal-ities	Occu-pants
	796	941	452	744
Per Cent	84.6		60.8	

TABLE II

RESULTS OF SOME DROP-CRASH TESTS OF SIKORSKY HO5S-1 HELICOPTERS AND SIMULATED H 13 HELICOPTER STRUCTURES

TEST NO AND HELICOPTERS	IMPACT ANGLE ATTITUDE AND VELOCITY	LOAD FACTOR APPLIED IN VERTICAL DIRECTION TO STRUCTURE (HIGHEST VALUE HAVING A DURATION OF 0 01 SECOND) (COORDINATES DEFINED ON FIG 4)		AVERAGE VERTICAL LOAD FACTOR ON STRUCTURE	LOAD FACTORS ON DUMMY PILOTS: DUMMY IN LEFT FRONT SEAT	LOAD FACTORS ON DUMMY PILOTS: DUMMY IN RIGHT FRONT SEAT	COMMENTS ON STRUCTURAL DAMAGE
1 HO5S-1 (SEE FIG 4)	IMPACT ANGLE 90 LATERALLY AND HORIZONTALLY LEVEL 2100 (FT /MIN)	C-8 FIREWALL RIGHT SIDE B-8 FIREWALL RIGHT SIDE C-6, BEHIND FRONT SEAT RIGHT SIDE B 6, BEHIND FRONT SEAT RIGHT SIDE C 2, BEFORE FRONT SEAT RIGHT SIDE B 2, BEFORE FRONT SEAT RIGHT SIDE	26 0 18 0 26 0 28 0 43 0 28 0	28	-	- -	LANDING GEAR SHEARED OFF AT FUSELAGE ATTACHMENTS SEAT FAILED AT FLOOR ATTACHMENT SEAT PAN FAILED TAIL BOOM FAILED AT JUNCTURE TO TAIL ROTOR ENGINE MOUNT (FORGING) FAILED BOTTOM OIL LINE FITTINGS CRUSHED FUEL CELL SURROUNDING STRUCTURE OPENED FUEL CELL FAILED AND FILLED COCKPIT WITH FLUID SPRAY (TENSILE STRENGTH OF FUEL CELL MATERIAL, 140 LB /IN OF WIDTH) FUSELAGE BOTTOM STRUCTURE CRUSHED UPWARD 4 75 IN PLEXIGLAS FAILED IN MOST WINDOWS FLOOR BUCKLED UPWARD OIL TANK DID NOT FAIL HYDRAULIC FLUID SPRAYED FROM BROKEN LANDING GEAR LIVING SPACE WAS NOT DECREASED SUBSTANTIALLY POWERPLANT OBSERVATION WINDOWS SHATTERED FUEL AND OIL LINES WERE NOT DAMAGED EXCEPT WHERE EXPOSED TO CRUSHING THE CRUSHING ALLOWED THE COMPLETE DRAINAGE OF THE OIL RESERVOIR DOORS WERE THROWN CLEAR OF THE HELICOPTER UPON IMPACT
2 HO5S-1	IMPACT ANGLE 90 LATERALLY AND HORIZONTALLY LEVEL 2200 (FT /MIN)	B-4 FRONT SEAT CENTER A-6 AFT SEAT FOOTWELL RIGHT CENTER A 6 AFT SEAT FOOTWELL LEFT CENTER C 8, FIREWALL RIGHT CENTER B-7, AFT SEAT CENTER C-9 ENGINE CENTER B-8, FIREWALL RIGHT SIDE E 8, FIREWALL RIGHT SIDE C 6, BEHIND FRONT SEAT LEFT SIDE B 6, BEHIND FRONT SEAT RIGHT SIDE	29 3 21 7 32 5 20 4 46 7 58 0 26 0 24 5 24 0 17 5	28*	HORIZONTAL ACCELERATIONS OF CHEST TWO PULSES OF 10G EACH AND ONE OF +10G VERTICAL ACCELERATIONS OF UPPER PELVIC REGION TWO PULSES OF 25G AND ONE OF +2 5G	HORIZONTAL ACCELERATIONS OF CHEST POSITIVE PULSES OF 5, 10, 30, AND 5G TWO NEGATIVE PULSES OF 2G EACH VERTICAL ACCELERATIONS OF CHEST NEGATIVE PULSES OF 34 AND 27G POSITIVE PULSE OF 3G	STRUCTURAL DAMAGE WAS IDENTICAL TO TEST NO 1 EXCEPT AS FOLLOWS FUEL CELL DID NOT FAIL (TENSILE STRENGTH 860 LB /IN OF WIDTH) (SELF SEALING MATERIAL) FUSELAGE BOTTOM STRUCTURE AGAIN CRUSHED UPWARD 4 75 IN RIGHT FRONT SEAT BACK FAILED REARWARD THE ATTACHMENT FROM THE OIL RESERVOIR TO THE ENGINE WAS CRUSHED AND AGAIN ALLOWED COMPLETE DRAINAGE OF OIL
3 HO5S-1	IMPACT ANGLE 90 LATERALLY AND HORIZONTALLY LEVEL 2400 (FT /MIN)	B 1, BEFORE INSTRUMENT CONSOLE CENTER B 4, FRONT SEAT CENTER A-6, AFT SEAT FOOTWELL RIGHT CENTER C 8, FIREWALL RIGHT CENTER C 8, FIREWALL LEFT CENTER B-7, AFT SEAT CENTER C 2, BEFORE FRONT SEAT RIGHT SIDE B 6 C 6 BEHIND FRONT SEAT RIGHT SIDE C 2 BEFORE FRONT SEAT LEFT SIDE C 8, FIREWALL RIGHT SIDE	77 5 40 0 25 8 43 0 46 8 33 8 40 0 34 0 31 0 34 0	39	ACCELERATIONS NOT AS HIGH AS IN TEST NO 2 FOUR-INCH-THICK SHEET OF STYROFOAM WAS SUBSTITUTED FOR SEAT PAD UNDER DUMMY	45G PERPENDICULAR TO SPINE, DUMMY WAS PLACED IN KNEE-CHEST POSITION	STRUCTURAL DAMAGE WAS IDENTICAL TO TEST NO 1 EXCEPT AS FOLLOWS FUEL CELL DID NOT FAIL (TENSILE STRENGTH 860 LB /IN OF WIDTH) (SELF-SEALING MATERIAL) FUSELAGE BOTTOM STRUCTURE CRUSHED UPWARD 4 75 IN BACK OF RIGHT FRONT SEAT DID NOT FAIL AS IN TEST NO 2 BECAUSE THE PILOT DUMMY WAS PLACED IN A BENT-OVER-FROM THE-WAIST" POSITION

*LOAD FACTOR ON ENGINE NOT USED IN DETERMINATION OF THIS LOAD FACTOR THE LOAD FACTOR OF 58 WAS EXPERIENCED WHEN ENGINE STRUCK GROUND SUBSEQUENT TO MAIN STRUCTURAL IMPACT

TABLE II (CONTINUED)

RESULTS OF SOME DROP-CRASH TESTS OF SIKORSKY HO5S 1 HELICOPTERS AND SIMULATED H 13 HELICOPTER STRUCTURES

TEST NO AND HELICOPTERS	IMPACT ANGLE ATTITUDE AND VELOCITY	LOAD FACTOR APPLIED IN VERTICAL DIRECTION TO STRUCTURE (HIGHEST VALUE HAVING A DURATION OF 0 01 SECOND) (COORDINATES DEFINED ON FIG 5)		AVERAGE VERTICAL LOAD FACTOR ON STRUCTURE	LOAD FACTORS ON DUMMY PILOTS: DUMMY IN LEFT FRONT SEAT	LOAD FACTORS ON DUMMY PILOTS: DUMMY IN RIGHT FRONT SEAT	COMMENTS ON STRUCTURAL DAMAGE
4 SIMULATED H 13 (SEE FIG 5)	IMPACT ANGLE 90 LATERALLY AND HORIZONTALLY LEVEL 1750	G-5, ENGINE MOUNTING BLOCK LEFT SIDE G-5, ENGINE MOUNTING BLOCK RIGHT SIDE A-1, AFT FUEL TANK - LEFT SIDE A-1, AFT FUEL TANK - RIGHT SIDE A-1, AFT FUEL TANK CENTER A-12, FORWARD FUEL TANK CENTER	26 6 33 9 31 8 21 8 31 5 28 8	29	- - -	- - -	LANDING GEAR FAILED AT FUSELAGE JUNCTURE POINTS SEAT PAN FAILED DOWNWARD TAIL BOOM BENT DOWNWARD AFT OF FUSELAGE ATTACH MENT POINTS ENGINE SUPPORTING STRUCTURE FAILED ALLOWING ENGINE TO STRIKE GROUND MAIN FUSELAGE STRUCTURE SUFFERED ONLY NEGLIGIBLE DAMAGE
5 SIMULATED H 13	IMPACT ANGLE 90 LATERALLY AND HORIZONTALLY LEVEL 2400	C-12, FWD , FUEL TANK RIGHT CENTER B 12 FWD , FUEL TANK RIGHT CENTER C 12 FWD FUEL TANK LEFT CENTER B-12, FWD FUEL TANK LEFT CENTER D-1, AFT FUEL TANK LEFT CENTER B-1, AFT FUEL TANK CENTER C-9 FWD FUEL TANK LEFT CENTER A-9, FWD FUEL TANK RIGHT SIDE A-9, FWD FUEL TANK LEFT SIDE G-5, ENGINE MOUNTING BLOCK LEFT SIDE G-5 ENGINE MOUNTING BLOCK RIGHT SIDE C-1 AFT FUEL TANK LEFT CENTER C-1, AFT FUEL TANK RIGHT CENTER	45 0 45 0 32 0 40 0 38 5 32 5 42 2 27 7 10 7 32 5 39 4 36 9 34 9	35	- -	- -	STRUCTURAL DAMAGE WAS ESSENTIALLY IDENTICAL TO TEST NO 4
6 SIMULATED H-13	IMPACT ANGLE 90 LATERALLY AND HORIZONTALLY LEVEL 2580	G-1, AFT FUEL TANK RIGHT CENTER C-1, AFT FUEL TANK RIGHT CENTER C-1, AFT FUEL TANK RIGHT SIDE F-2 AFT FUEL TANK RIGHT SIDE D-2, AFT FUEL TANK RIGHT SIDE B-2, AFT FUEL TANK RIGHT SIDE C-12, FWD FUEL TANK CENTER B-12, FWD FUEL TANK CENTER C-9 FWD FUEL TANK LEFT CENTER A-9, FWD FUEL TANK RIGHT SIDE C-1, AFT FUEL TANK RIGHT CENTER F-1, AFT FUEL TANK RIGHT CENTER	27 0 35 0 22 5 30 0 32 0 32 0 34 0 29 0 33 7 32 0 39 4 40 0	32		- - -	STRUCTURAL DAMAGE WAS ESSENTIALLY IDENTICAL TO TEST NO 4, EXCEPT AS FOLLOWS SEAT PAN DID NOT FAIL NO WEIGHT WAS USED IN THE SEAT

TABLE III

RESULTS OF ON-THE-SCENE STUDIES OF HELICOPTER ACCIDENTS BY TDC INVESTIGATORS

Acci-dent	Helicopter Designation	Load Factor "n"	No. of Occupants	Fatalities	Post-Crash Fire	Impact Attitude	Impact Angle (deg.)	Remarks
1	H-13	*60	2	2	Yes	Slightly nose down, laterally level.	---	Flew into power lines.
2	H-23	18 Vertically	1	0	No	Level	---	Autorotated into tree.
3	H-23	15 Vertically	1	0	Yes	Level	90	Low-level maneuvers.
4	H-23	11 Vertically	2	0	No	Level	90	Struck tree with tail rotor on takeoff.
5	HTL	2 Vertically	2	0	Yes	Level	90	Moving sideward close to ground, rolled over upon striking ground.
6	H-34	--	2	2	Yes	27° nose down	90	Lost ground reference upon attempting to land.
7	47-H	50 Vertically	1	1	No	27° nose down	90	Lost control upon takeoff.

*Parallel to flight-path angle which was in the order of 30° with the ground.

TABLE IV

ACCIDENT DATA RECEIVED FROM ON-THE-SCENE MILITARY INVESTIGATORS

Accident	Helicopter Designation	Phase of Flight in Which Accident Occurred	No. of Occupants	Fatalities
8	YHUL-1	Landing	3	0
9	HSS-1	Landing	3	2
10	H-21C	Landing	3	0
11	H-21C	Cruising - lost reference in flight and crashed into ground.	3	3
12	H-21C	Cruising - lost reference in flight and crashed into ground.	3	0
13	H-21C	Cruising - lost reference in flight and crashed into ground.	3	3
14	H-34	Hovering	3	0
15	H-23	Cruising - lost control in flight and flew into ground.	2	2

TABLE IV (Continued)

ACCIDENT DATA RECEIVED FROM ON-THE-SCENE MILITARY INVESTIGATORS

Accident	Helicopter Designation	Post-Crash Fire	Impact Angle (deg.)	Impact Attitude	Forward Velocity	Descent Velocity (ft./min.)
8	YHUL-1	No	---	Nose down Laterally Level	20-25 knots airspeed	---
9	HSS-1	Yes	90	Level	0	---
10	H-21C	No	6	Level	Airspeed indicator jammed at 50 knots.	500-600
11	H-21C	Yes	90	Level	40 knots airspeed	---
12	H-21C	No	---	---	---	---
13	H-21C	Yes	---	Nose down Right bank	135 knots airspeed	5000
14	H-34	No	90	Level	0	---
15	H-23	Yes	This report has not been received.			

TABLE V

FLIGHT-PATH ANGLES AND VELOCITIES AND FUSELAGE ATTITUDES AT A POINT 50 FEET ABOVE THE GROUND FOR FOUR HELICOPTERS MAKING AUTOROTATIVE LANDINGS TO A PANEL

(1)	(2)	(3)	(4)	(5)	(6)
Helicopter	Flight-Path Angle (deg.)	Fuselage Attitude (deg.)	Velocity Along Flight Path (ft./min.)	Velocity Parallel to Ground (ft./min.)	Velocity Perpendicular to Ground (ft./min.)
		+ Nose-Up		(4) cos (2)	(4) sin (2)
H-13	29	-2 (estimated)	3000	2610	1440
HOK-2	8	+20	5700	5650	795
H-19	7	+10	3200	3175	390
H-21	14	+11	3800	3690	920

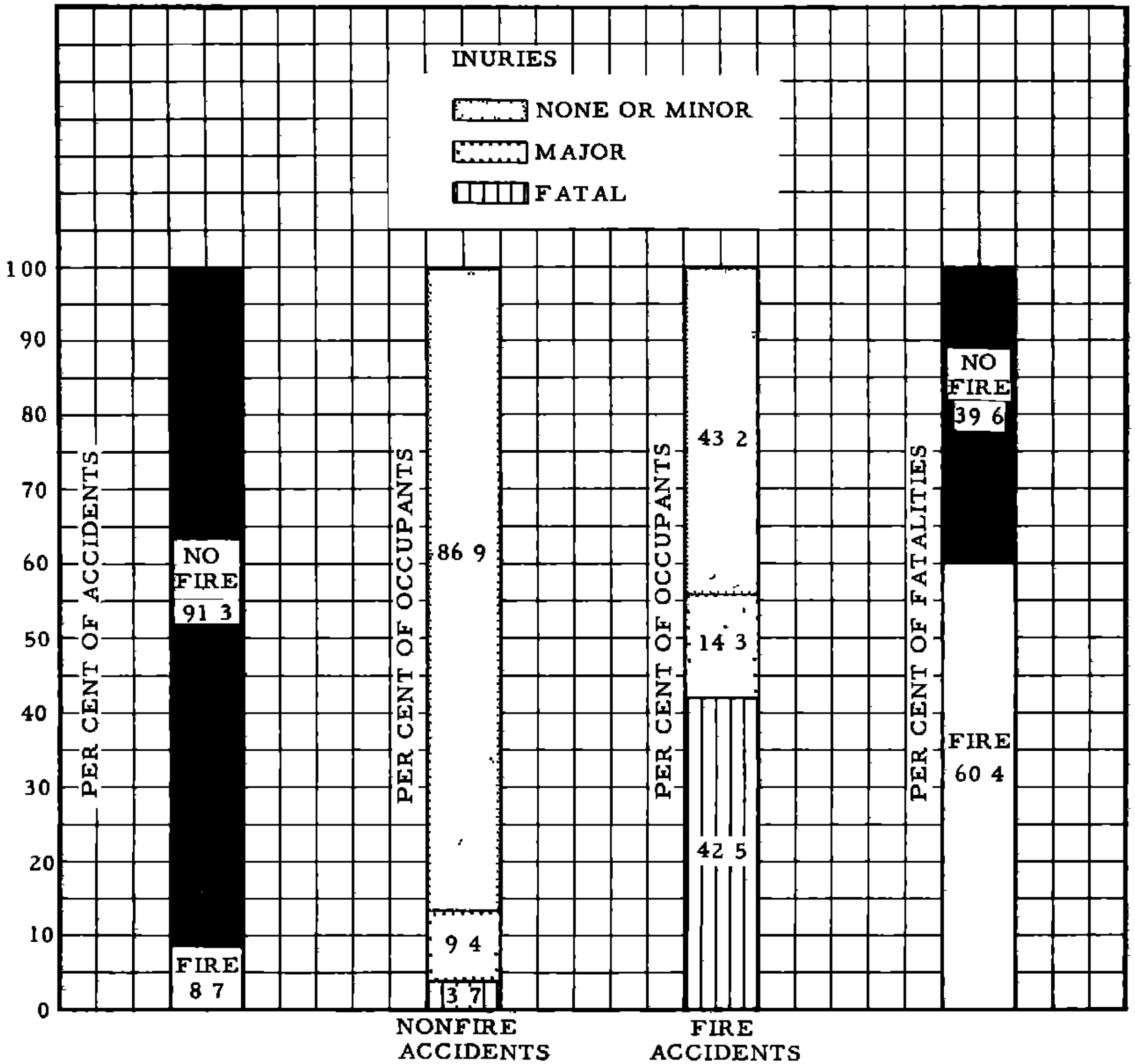

FIG 1 PERCENTAGE DISTRIBUTION OF FIRE AND NONFIRE ACCIDENTS, INJURIES, AND FATALITIES EXPERIENCED IN MILITARY AND CIVIL HELICOPTERS

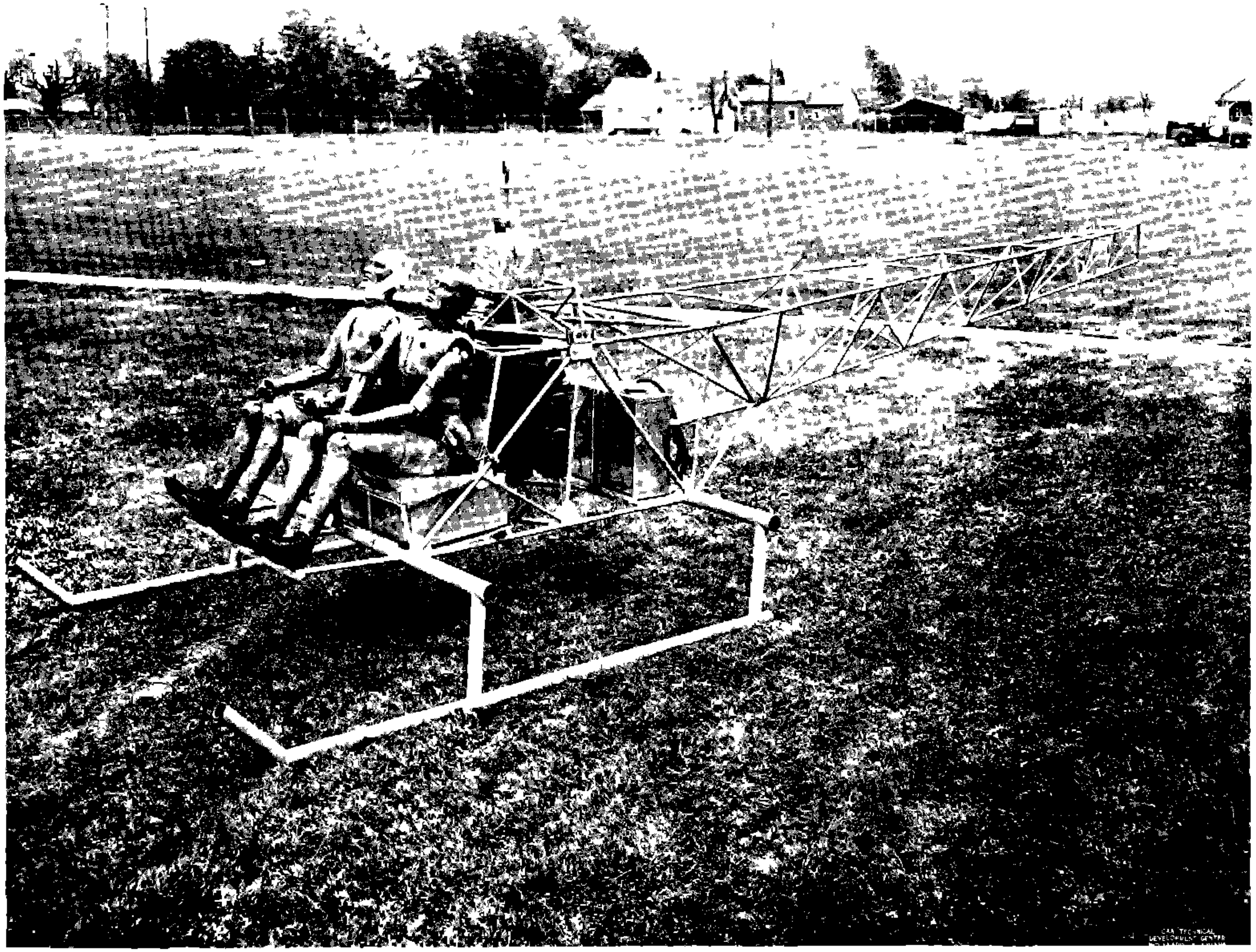

FIG. 2 PHOTOGRAPH OF H-13 SIMULATED HELICOPTER STRUCTURE WITH DUMMIES INSTALLED

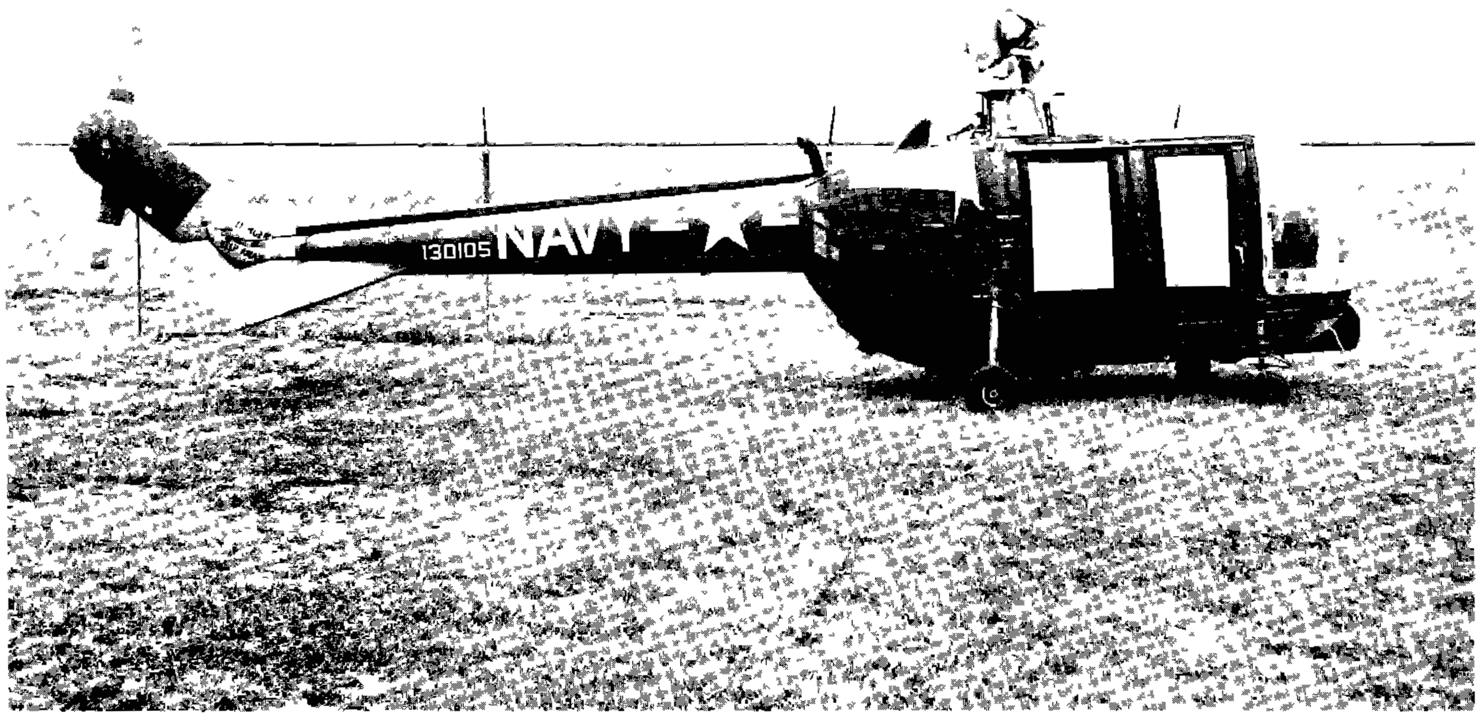

FIG 3 PHOTOGRAPH OF AN HO5S-1 HELICOPTER

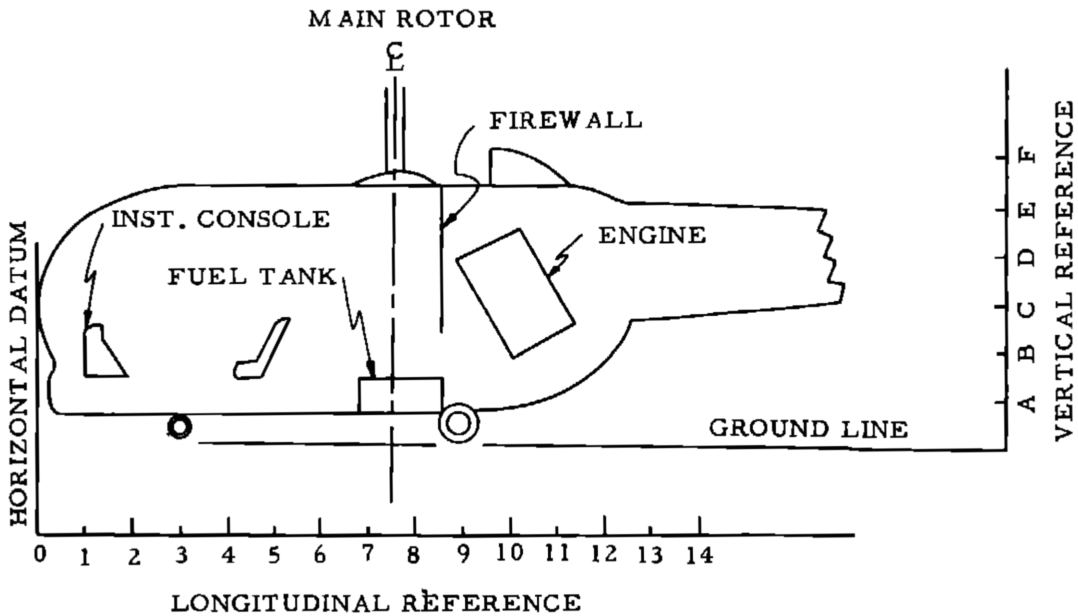

FIG. 4 SIDE ELEVATION REFERENCE FOR ACCELERATION MEASUREMENTS ON HO5S-1 HELICOPTER FULL-SCALE GRID SPACING IS 1 FOOT.

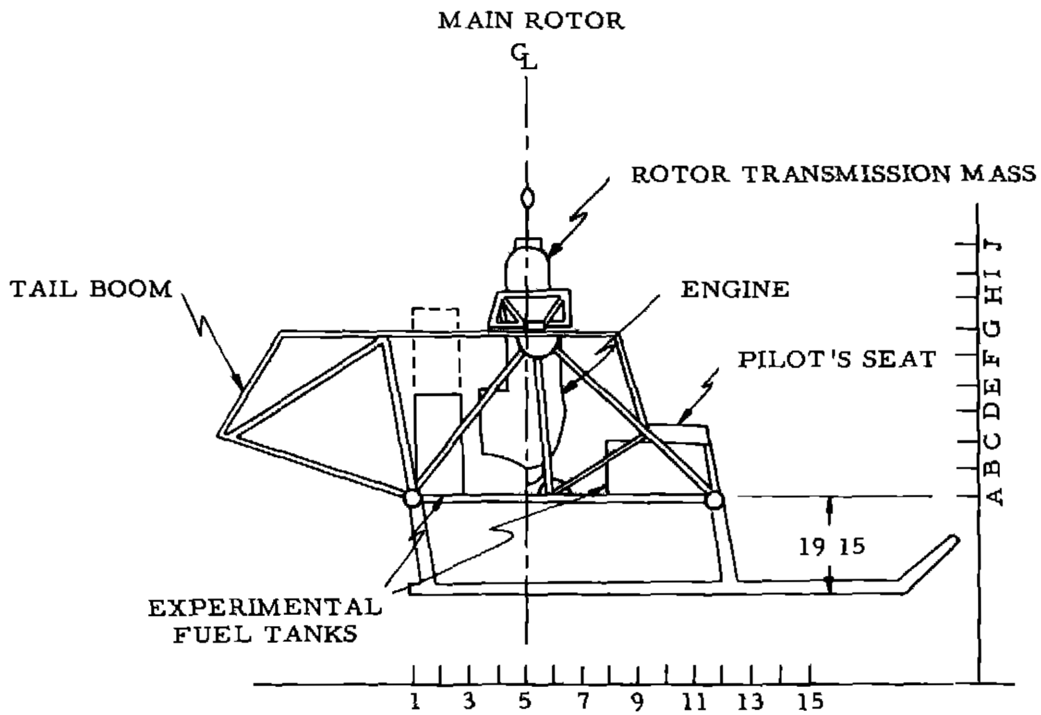

FIG. 5 SIDE ELEVATION REFERENCE FOR ACCELERATION MEASUREMENTS
ON SIMULATED H-13 HELICOPTER
FULL-SCALE GRID SPACING IS 1/2-FOOT

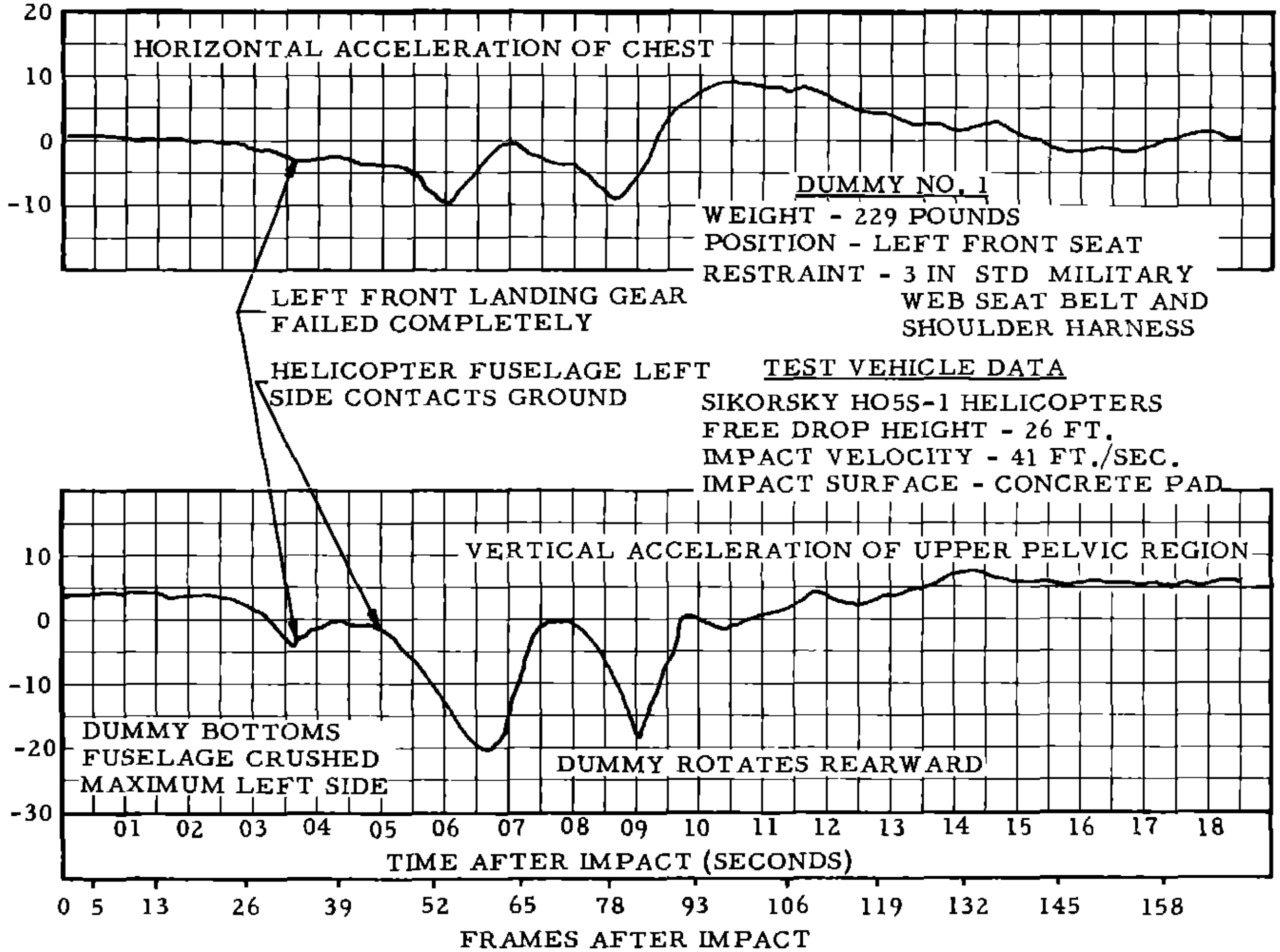

FIG. 6A ANTHROPOMORPHIC DUMMY NO. 1 ACCELERATIONS EXPERIENCED DURING TEST NO. 2

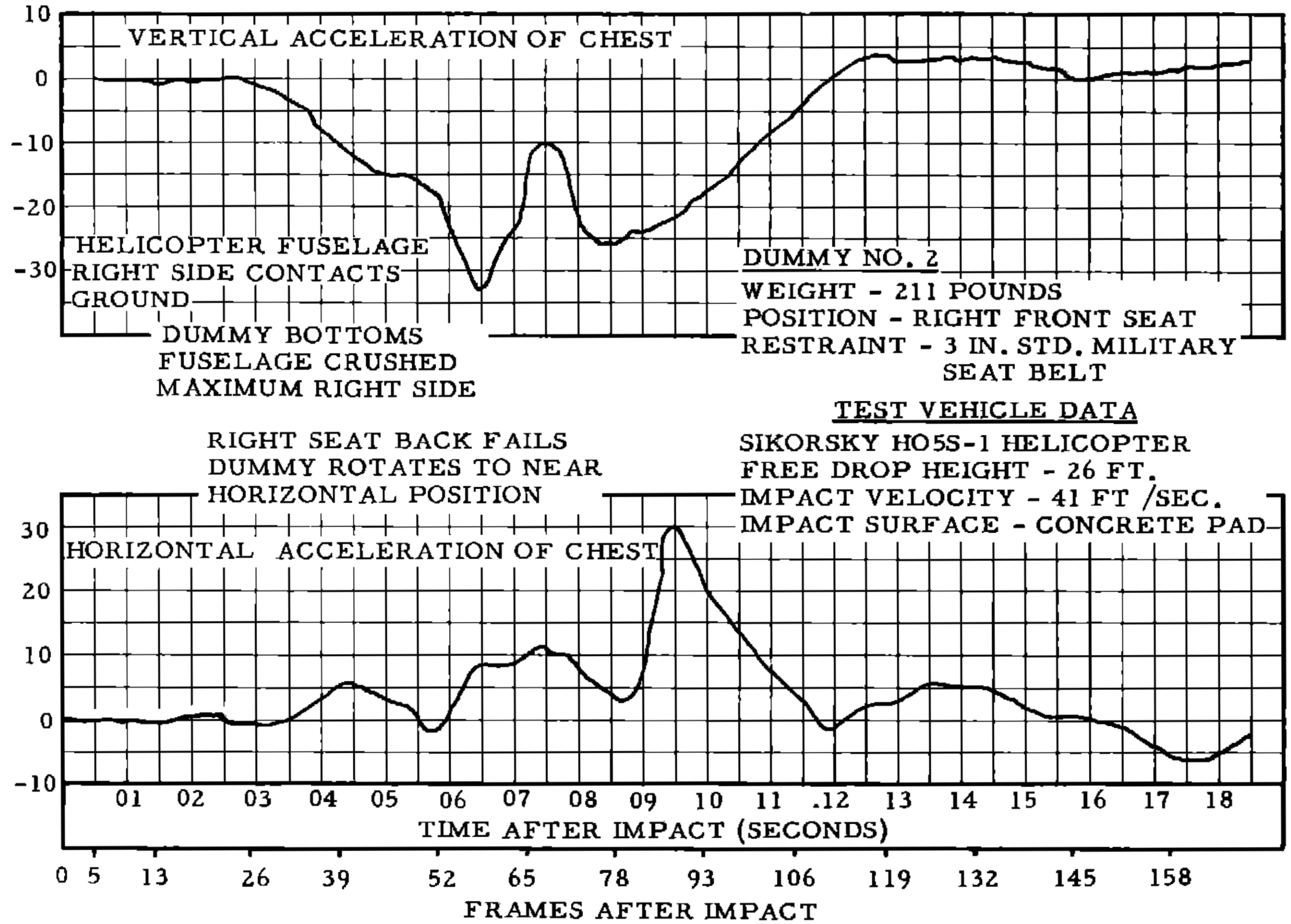

FIG. 6B ANTHROPOMORPHIC DUMMY NO. 2 ACCELERATIONS EXPERIENCED DURING HO5S-1 DROP CRASH TEST NO. 2

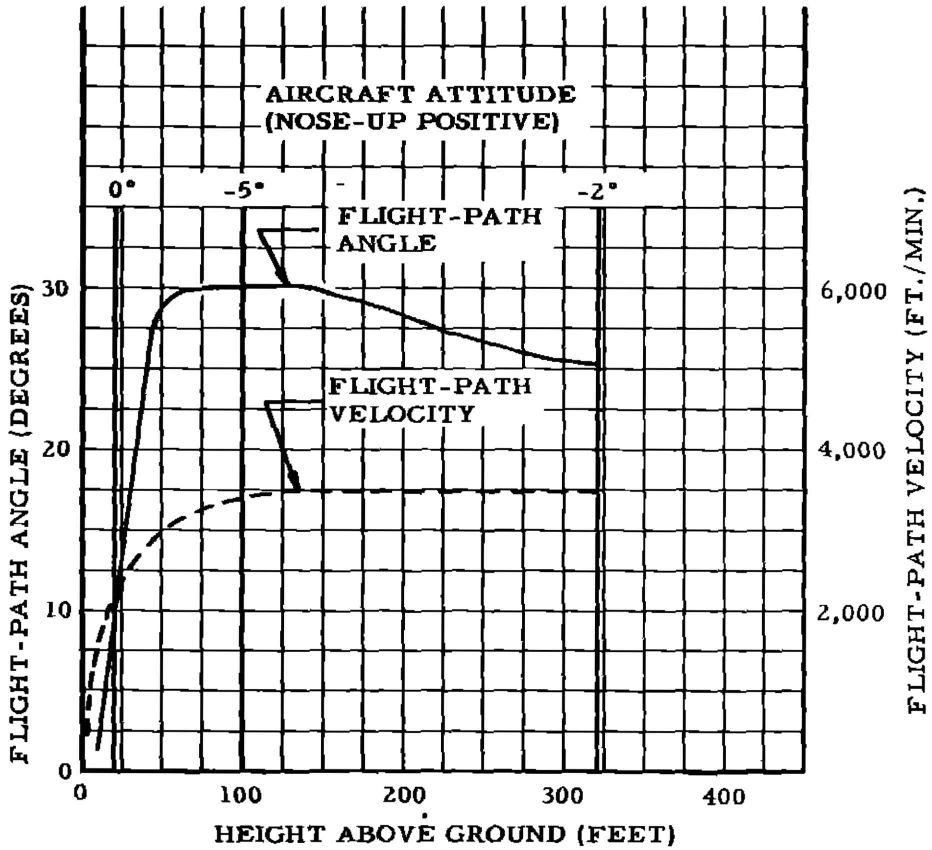

FIG 7 BELL H-13 VELOCITY, FLIGHT-PATH ANGLE, AND AIRCRAFT ATTITUDE VERSUS HEIGHT ABOVE GROUND FOR A NORMAL AUTOROTATIVE LANDING

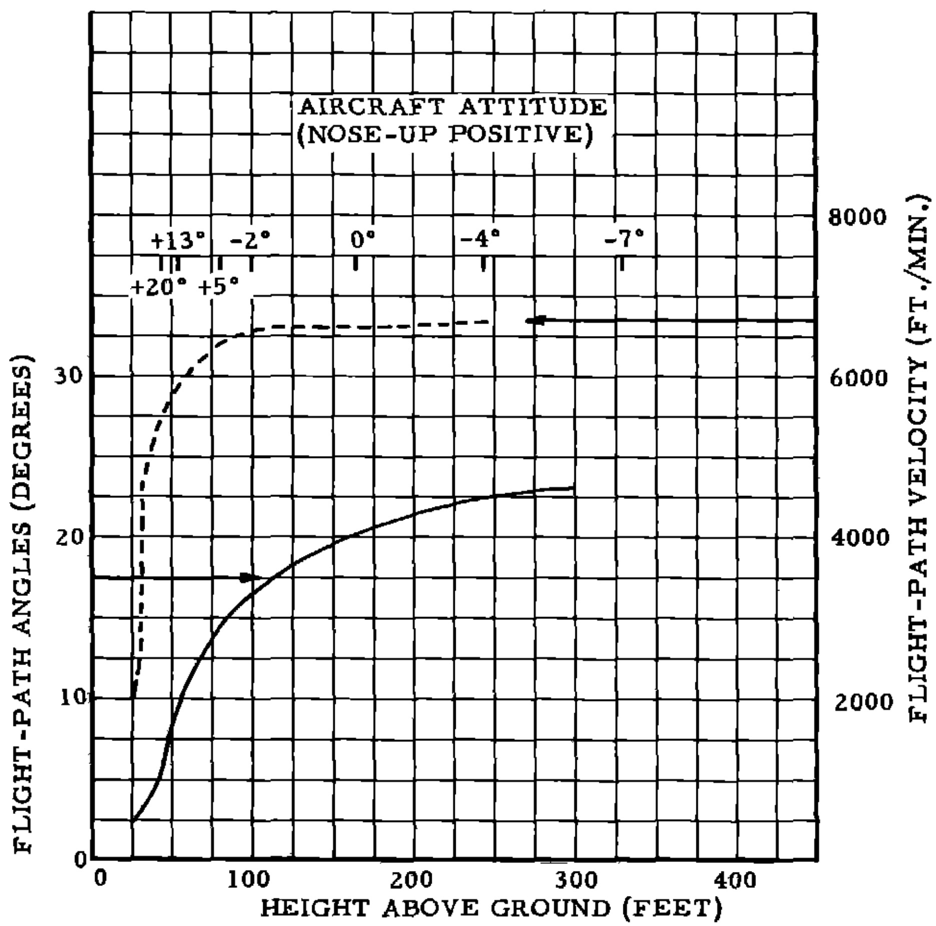

FIG. 8 KAMAN HOK-2 VELOCITY, FLIGHT-PATH ANGLE, AND AIRCRAFT ATTITUDE VERSUS HEIGHT ABOVE GROUND FOR A NORMAL AUTOROTATIVE LANDING

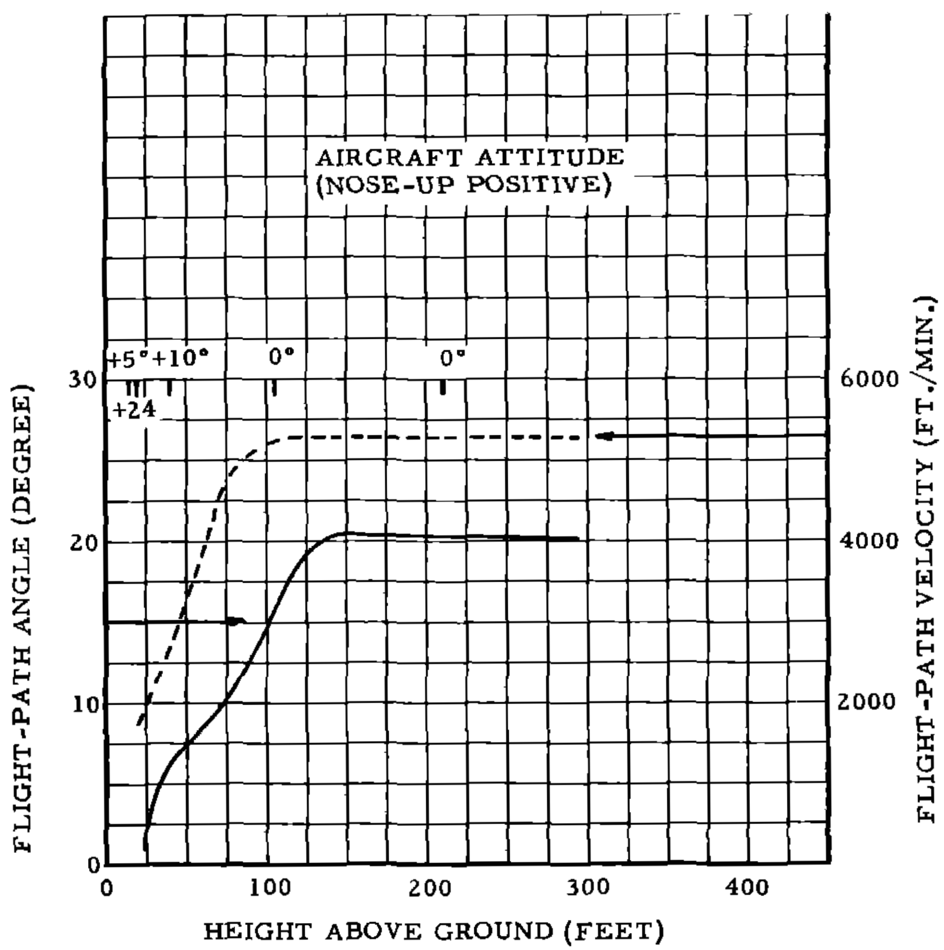

FIG. 9 SIKORSKY H-19 VELOCITY, FLIGHT-PATH ANGLE, AND AIRCRAFT ATTITUDE VERSUS HEIGHT ABOVE GROUND FOR A NORMAL AUTOROTATIVE LANDING

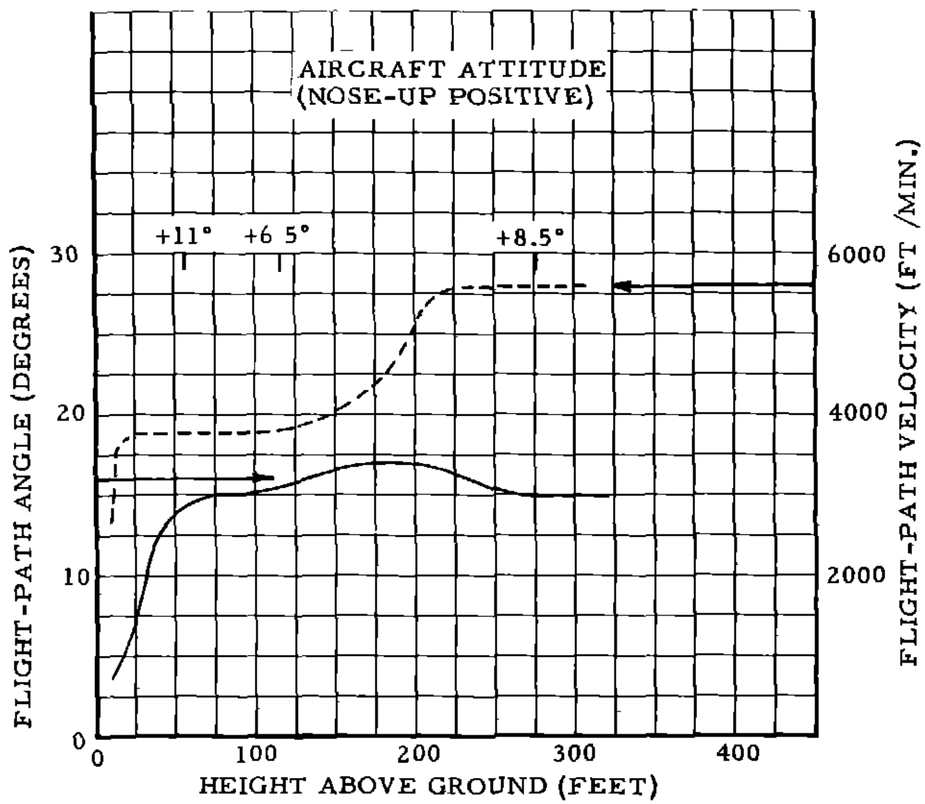

FIG 10 VERTOL H-21 VELOCITY, FLIGHT-PATH ANGLE, AND AIRCRAFT ATTITUDE VERSUS HEIGHT ABOVE GROUND FOR A NORMAL AUTOROTATIVE LANDING