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Transport Aircraft Crash Dynamics

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LOCKHEED-CALIFORNIA COMPANY
BURBANK, CALIFORNIA

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16. Abstract

A review and evaluation of transport airplane accident data for the 1964-1979 period is presented. Included in the results are (1) formulation of candidate crash scenarios, (2) the identification of the involvement of structural systems and subsystems in transport airplane accidents, (3) a review of existing design criteria and philosophy, and (4) conclusions and recommendations for future R&D effort.

The accident is organized in relation to pertinent accident types including undershoot, overrun, ground collision, obstacle impact, stall, wheels-up or retracted landing, swerve and gear collapse. Ground-to-ground and air-to-ground crash scenarios are presented. Current state-of-the-art procedures are used in the analysis of a current airplane configuration for selected accident conditions. Available structure and occupant modeling techniques are assessed with regard to transport airplane crash dynamics modeling requirements. The revised U.S. Army Crash Survival Design Guide, as well as other design criteria and previous full-scale crash tests are evaluated with regard to transport airplane applicability. A proposed integrated crash dynamics analysis and test program for transport airplanes is presented along with conclusions and recommendations based on the results of the overall study. Included is a description of an "accident data base" computer program developed in this study.

17. Key Words (Suggested by Author(s))

Crashworthiness, Transport, Aircraft, Crash Dynamics, Occupant Survivability, Post-Crash Fire, Crash Design Full-Scale Test, Analysis, Math Model

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FOREWORD

This report was prepared under contract by the Lockheed-California Company under contract NAS1-16083 sponsored by the Federal Aviation Administration and NASA Langley. The report describes the effort performed from January 1980 through August 1981. The work was administered under the direction of Dr. R. Thomson (NASA), L. Vosteen (NASA), and C. Caiafa (FAA).

The Lockheed California Company effort was performed by Gil Wittlin with support from M.A. Gamon, D. Shycoff, T. Gualdone and R.W. Smith. The Lockheed effort was performed within the dynamics and vibrations group, supervised by J.E. Wignot.

SUMMARY

The results of a review and evaluation of transport airplane accident data are presented. Included in the study are: 1) formulation of candidate crash scenarios, 2) the identification of the involvement of structural systems and subsystems in transport airplane accidents, 3) a review of existing design criteria and philosophy, and 4) conclusions and recommendations for future R&D effort.

The accident review and evaluation encompasses the period from 1964 through 1979. The data is organized in relation to pertinent accident types including undershoot, overrun, ground collision, obstacle impact, stall, wheels-up or retracted landing, swerve, and gear collapse. An accident data base computer program, developed during the study, is described. Ground-to-ground and air-to-ground candidate crash scenarios are presented. Selected accident conditions are analyzed utilizing current state-of-the-art procedures. A review and evaluation of available structure and occupant modeling techniques including modal, hybrid and finite element methods are performed. The involvement of various structure and systems with regard to occupant safety in an accident is determined from the accident data. The revised U.S. Army Crash Survival Design Guide, as well as previous test programs, are evaluated with regard to transport airplane applicability. A proposed integrated transport crash dynamics analysis and test program for transport airplanes is presented along with conclusions and recommendations based on the results of the overall study.

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1. INTRODUCTION

1.1 Background

In the last decade there has been a substantial effort toward improving the crashworthiness capability of vehicles used in air and ground transportation. The FAA has sponsored an extensive effort oriented toward the development and experimental verification of an analytical method for crash analysis in the general aviation airplane industry (reference 1). NASA Langley has an ongoing effort involving crash testing several low-wing, twin-engine airplanes, investigating energy absorbing concepts, and developing analytical methods for future crash design application (reference 2). The Department of Transportation has sponsored crash-oriented programs related to the automobile and railroad industries. The U.S. Army Ft. Eustis Directorate is active in crash design aspects for rotary-wing aircraft. The U.S. Army Crash Survival Design Guide (reference 3), a comprehensive document pertinent to the subject of crash design philosophy, requirements, and techniques, has been recently revised into five volumes (reference 4).

The increased usage of modern day wide-body jet transports, which carry large numbers of passengers, has brought crash survivability aspects of transport airplanes into the limelight recently. While changes may ultimately be required in some crash design requirements (reference 5), they should be made on a rational basis, taking into account that the airplane systems reflect structure interaction that can vary depending on the crash environment.

The FAA has been responsible for many structural crashworthiness programs oriented toward large transport aircraft. However, these programs were performed primarily during the period 1964 to 1969. Figure 1-1 describes the nature of some of these programs. Two of the programs shown in figure 1-1 (references 6, 7) involved full scale crash tests of transport airplanes.

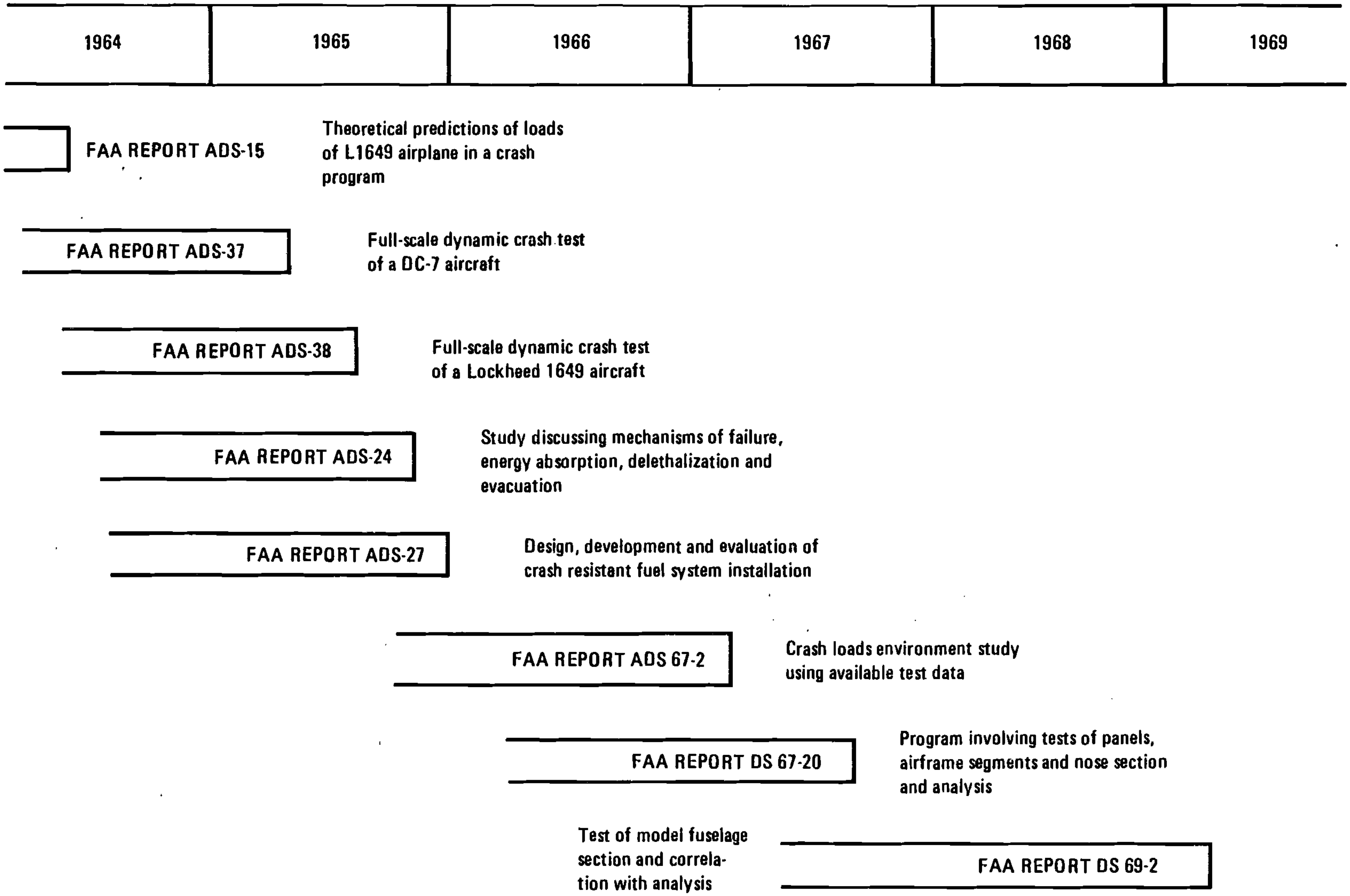

Figure 1-1. - FAA sponsored large transport structural crashworthiness programs, 1964-1969.

While each of the programs shown in figure 1-1 contributed in different areas, the results have not been consolidated into a form which leads to probable crash scenarios, complete assessment of occupant potential for survival, and procedures by which designers can comply with crash dynamics requirements in an efficient and economical manner. Since 1969 there has been considerable additional information in such areas as:

- Compilation of National Transporation Safety Board (NTSB), International Civil Aviation Organization (ICAO) and airframe manufacturer accident reports.
- Analytical techniques applicable to crash dynamics
- Assessment of occupant potential for survival
- Full scale crash test procedures and instrumentation requirements
- Structural load-deformation characteristics

1.2 Transportation Industry Accident Record

Before an evaluation of accident data is performed, it is important to put the subject "Transport Airplane Crashworthiness" into proper perspective. While improvements in airplane design which reduce occupant injuries/fatalities in crashes may be forthcoming, Transport Air Carrier travel is currently a safe mode of transportation. Figures 1-2 and 1-3, obtained from NTSB published data, (reference 8) show that air carriers accounted for less fatalities than any of the other major travel modes. Air carrier fatalities were less than 0.7 percent of all transportation fatalities in 1979. In 1980 air carrier fatalities decreased to 14. On the basis of fatalities per mile traveled air carriers compare very favorably with the other major transportation industries; namely, automobiles and light airplanes. For example, table 1-1 (reference 9) shows that between 1978 and 1980 the fatality rate per 10,000 aircraft hours reduced to .026 from .088 for U.S. air carriers. For the same period of time the general aviation statistics showed a decrease from 2.17 to 1.57 from 1978 to 1979 and then an increase to 1.64 fatal accidents per 100,000 aircraft hours, in 1980.

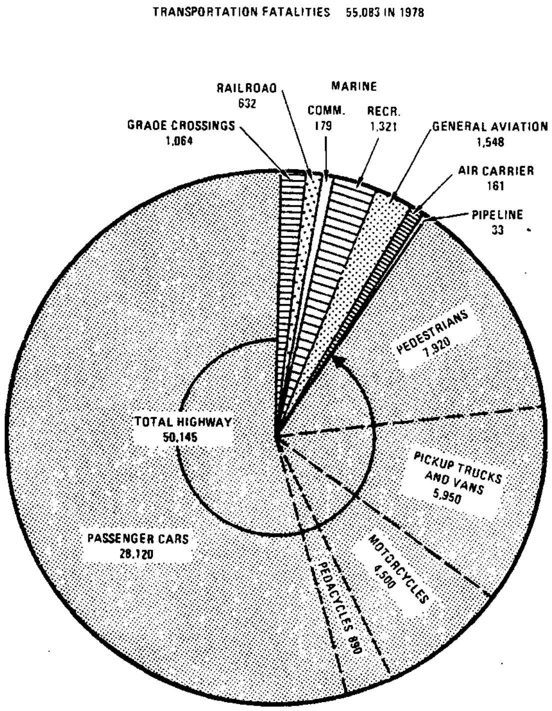

Figure 1-2. - Transportation fatalities, 1978.

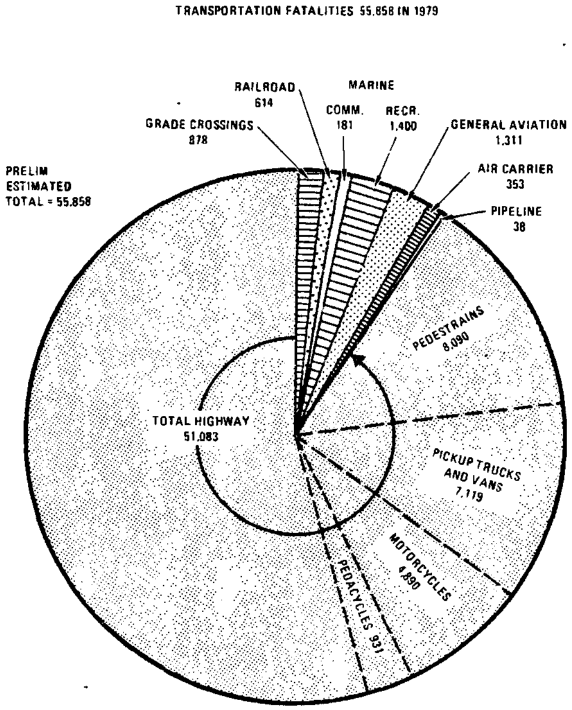

Figure 1-3. - Transportation fatalities, 1979.

TABLE 1-1. - COMPARISON OF GENERAL AVIATION AND U.S. AIR CARRIER ACCIDENT STATISTICS 1978-1980 (REFERENCE 9)

	1978	1979	1980
General Aviation			
No fatal accidents	795	682	677
No fatalities	1709	1382	1375
Fatal accidents/10,000 aircraft hrs.	2.17	1.57	1.64
U.S. Air Carriers			
No fatal accidents	6	6	2
No fatalities	161	355*	20**
Fatal accidents/10,000 aircraft hrs.	.0885	.083	.026

*343 involved in two wide-body accidents
**None involving jet transports

Since, however, the modern day wide-body airplanes carry more passengers each flight than any other air or ground mode of transportation, there exists for any individual accident the potential for substantial loss of life or injuries. This fact indicates that regardless of the existing safety record, a need exists for being able to quantify current crash dynamics performance so that this capability can be maintained or improved upon. This is particularly important when consideration is given to the increasing usage of advanced materials which could have an impact on future airplane designs.

1.3 Program Objectives

The program features are shown in figure 1-4. Four major tasks are identified. These are:

I. Formulation of Candidate Crash Scenarios

II. Identification of Structural Systems and Subsystem Involvement

III. Review of Existing Design Criteria and Philosophy

IV. Conclusions and Recommendations for Future R&D Effort

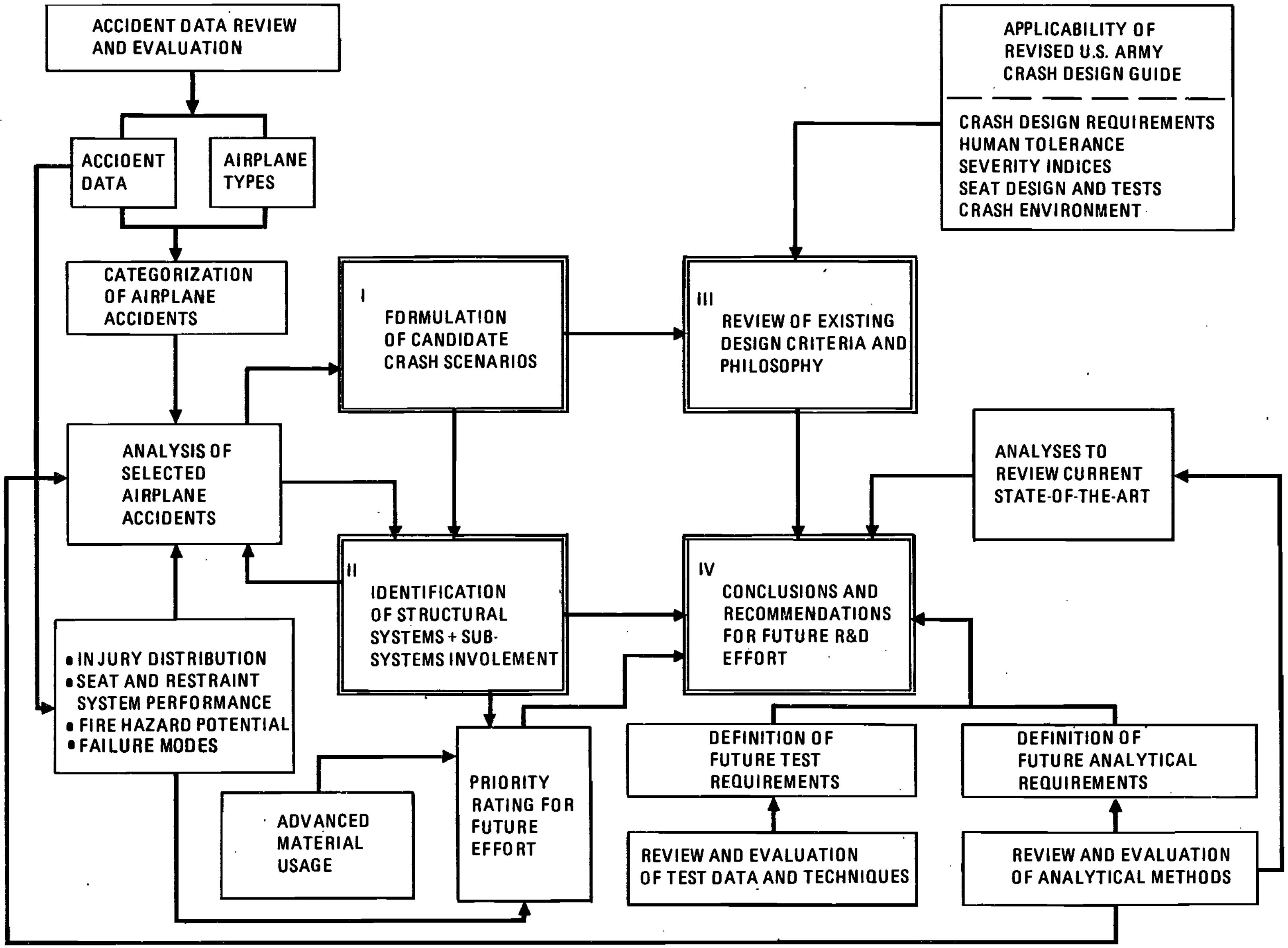

Figure 1-4. - Program features.

The task of formulating candidate crash scenarios involves:

- Review and evaluation of accident data
- Establishment of accident categories
- Development of candidate crash scenarios
- Analysis of selected accident conditions

The task of identifying structural systems and subsystems in accidents includes:

- Injury distribution
- Seat and restraint system performance
- Fire hazard potential
- Structural failures
- Contributions to injury

The task of the review of existing design criteria and requirements includes:

- Crash design requirements for military, Department of Transportation (DOT) - Highway Vehicles, Railroads and Aircraft
- Evaluation of human tolerance and applicable severity indices
- Applicability assessment of the revised U.S. Army Crash Survival Design Guide

The final task of formulating conclusions and recommendations for future R&D effort is based on the initial three tasks as well as:

- Review and evaluation of current test data and techniques
- Review and evaluation of current analytical methods and requirements
- Recommendation for future tests and analyses

The evaluation of future testing and analysis encompasses firm recommendations of types of analyses and tests to fully evaluate proposed crash scenarios so that future airplane crash design requirements can be established on a rational basis.

2. ACCIDENT DATA REVIEW AND EVALUATION

2.1 Sources of Accident Data

The sources of accident data for this review are:

a. National Transportation Safety Board (NTSB)

b. International Civil Aviation Organization (ICAO)

c. World Airline Accident Summary - Civil Aviation Authority (CAA)

d. Company accident files

e. Miscellaneous Reports, Articles

The NTSB records were the primary source of information upon which the accident statistics used in this report were compiled. The other data sources were used to augment information obtained from the NTSB. The accidents for 1964-77 were used initially as the reference material since at the time the study was initiated NTSB accident summaries (references 10, 11) were complete for these years. As the study proceeded additional accidents were added to the statistics.

2.2 Accident Data Review

The NTSB 1964-77 accident data was reviewed and categorized with regard to:

- Airplane weight class
- Occupant injury index
  - Fatal
  - Severe
  - Minor/None

- Aircraft damage severity
  - Destroyed
  - Substantial
  - Minor/None
- Operational Mode
  - Takeoff
  - Landing
  - Taxi
  - Inflight
  - Static

Table 2-1 shows the distribution of NTSB reported accidents as a function of operational mode for the time periods of 1964-69 (reference 10) and 1970-77 (reference 11) as well as the full 14 year span. The distribution by mode does not change significantly for the two time periods involved. Approximately

TABLE 2-1. - SUMMARY OF ACCIDENTS BY OPERATIONAL MODE AND PERIOD OF TIME

Operational Mode	1964-69		1970-77		1964-77	
	No.	% Total	No.	% Total	No.	% Total
Static	19	4.3	29	8.5	48	6.1
Taxi	31	7.0	31	9.1	62	7.8
Takeoff	54	12.1	42	12.3	96	12.3
Landing	163	37.9	95	27.8	258	33.0
Inflight	174	39.3	143	42.0	317	40.5
Other	1	0.2	1	0.3	2	0.3
Total	441	100.0	342	100.0	783	100.0

40 percent of the accidents occur inflight followed by landing (≈ 33 percent), takeoff (≈ 12 percent), taxi (≈ 8 percent) and static (≈ 6 percent). The inflight accidents while large in number are predominantly turbulence and maneuver related. Table 2-2 shows the distribution of inflight accidents including the severity in terms of occupant injury.

Table 2-3 shows a distribution of accident occurrence in the proximity of airports. Based on a total of 441 accidents involving 455 aircraft (eight of the 455 aircraft were other than air carrier aircraft) resulting in 447 accident reports in the NTSB accident summary for 1964-69, approximately 50 percent of the accidents occur in the airport. However, these 50 percent account for only 17.6 percent and 21.7 percent, respectively, of the accidents classified as fatal or severe injury. The nearly 36 percent of the accidents that occur at distances of five miles or more from the airport account for 50 percent and 67 percent of the fatal and serious injury accidents, respectively. The large number of fatal and serious injuries associated with accidents which occur 5 or more miles from an airport attest to the fact that

TABLE 2-2. - SUMMARY OF INFLIGHT ACCIDENT TYPE DISTRIBUTION

			1964-77 NTSB Data Injury Index		
Accident Type	Accidents	% Total	Fatal	Serious	Minor
Turbulence	186	58.7	1	185	0
Engine failure	25	7.9	2	3	20
Misc., Unk.	20	6.3	3	15	2
Hail, lightning, evasive maneuver, uncontrolled alt. descent, bird strike	24	7.6	0	18	6
Collision with aircraft	12	3.8	10	1	1
Uncontrolled ground/water collision	11	3.5	11	0	0
Controlled ground/water collision	10	3.2	9	1	0
Fire/explosion	10	3.2	3	0	7
Airframe failure	9	2.8	4	0	5
Collision w/obj., tree, etc.	5	1.6	1		4
Prop./rotor failure	4	1.3	3	0	1
Stall	1	0.3	1	0	0
Total	317	100.0	48	223	46

TABLE 2-3. - SUMMARY OF ACCIDENT OCCURRENCE AS A FUNCTION OF PROXIMITY TO AIRPORT

1964-69 NTSB Data

Location	No. Accidents Injury Index			Total No. of Accident Records	% Total
	Fatal	Serious	Minor/None		
On airport	12	33	180	225	50.34
Within: 1/4 Mile	0	2	3	5	1.12
1/2 Mile	2	1	1	4	.89
3/4 Mile	1	1	1	3	.67
1 Mile	1	1	3	5	1.12
2 Miles	5	2	2	9	2.01
3 Miles	2	2	1	5	1.12
4 Miles	2	0	0	2	.45
5 Miles	3	0	3	6	1.34
Beyond 5 miles	35	101	24	160	35.79
in traffic pattern unknown	5	5	6	16	3.58
miscellaneous	0	4	3	7	1.57
Totals	68	152	227	447	100.

extremely high impact conditions coupled with obstacles and uneven terrain are present in these areas. In addition, these accidents may be characterized by a lack of pilot control to minimize the severity of the crash. For these reasons it appears that the primary concern of the accident data review should be for accidents in the vicinity of airports and generally associated with landing, takeoff and taxi modes, with the inclusion of pertinent inflight and static operation accidents.

Several airplane weight classes (reference 12) are formulated to assist in the evaluation of the accident data. Figure 2-1 depicts these weight classes.

ICAO designations (reference 13) include; category III aircraft (12,000 - 60,000 lbs. max. takeoff), category IV aircraft (60,000 - 600,000 lbs. max. takeoff) and category V aircraft (>600,000 lb. max takeoff). The latter category appears to include the L-1011 and DC-10 airplanes, although their

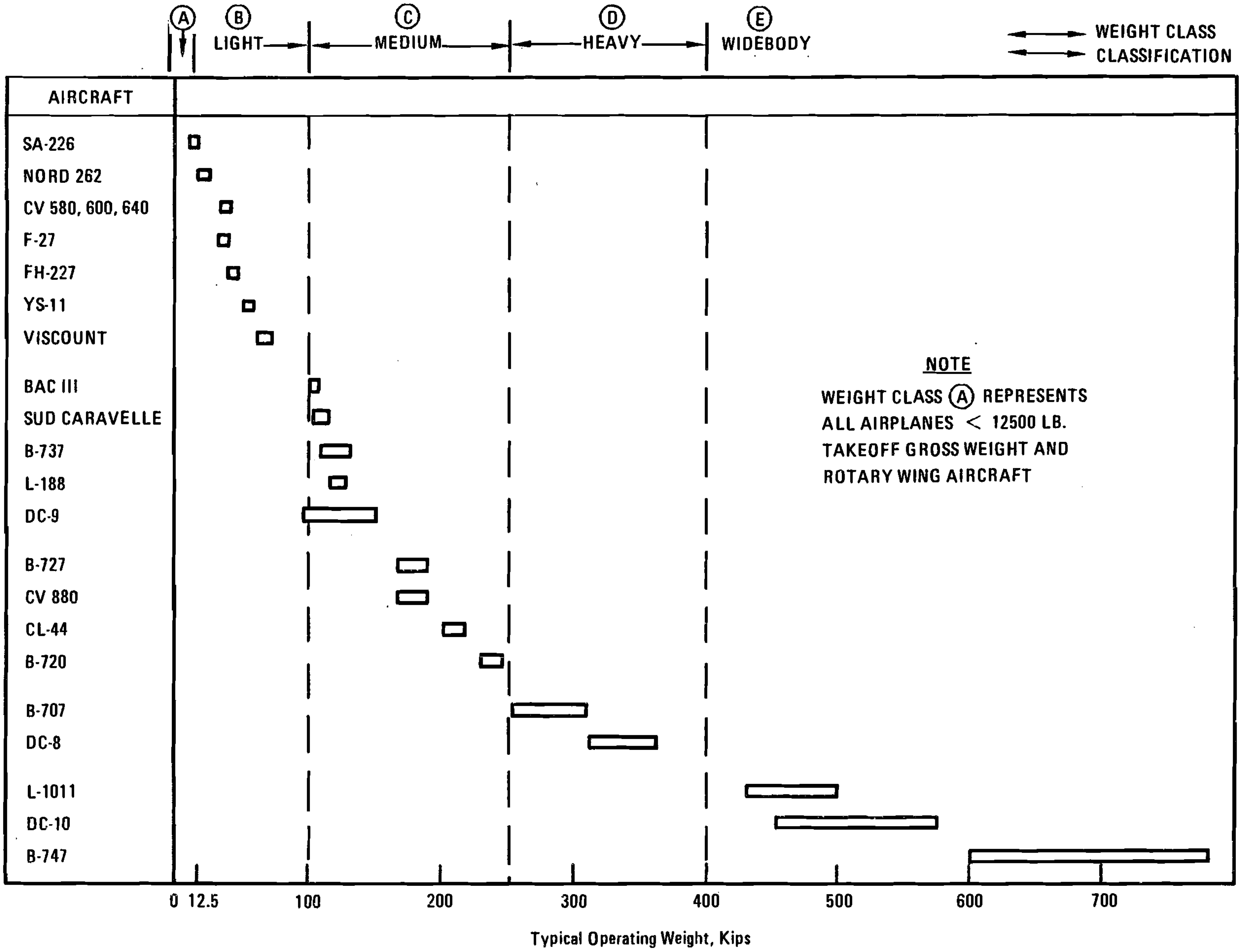

Figure 2-1. - Transport airplane vs takeoff G.W.

maximum takeoff weights are shy of 600,000 lb. The weight classes shown in figure 2-1 approximate the ICAO designations as follows:

"B" class - category III

"C & D" classes - category IV

"E" class - category V

Table 2-4 shows the breakdown, by airplane weight class and injury index, for the period 1964 to 1977 based on NTSB accident reporting. The percentages shown in table 2-4 indicate that fatalities and serious injury accidents represent 15.5% and 41.7%, respectively, of the total. During this 14 year period only 6.4% of the accidents involved widebody aircraft. This low percentage is partially explained by the fact that the influence of these aircraft was not felt until the 1970's.

Table 2-5 shows a summary of accident types as a function of injury index. In addition, the aircraft damage severity and occurrence of post-crash fire are noted. From table 2-5 it can be seen that a large percentage (81.8%) of the fatal accidents occurred in aircraft that were destroyed. A relatively

TABLE 2-4. - SUMMARY OF ACCIDENT INJURY LEVELS AS A FUNCTION OF AIRPLANE WEIGHT CLASS

1964-77 NTSB Data

Airplane* Weight Class	Injury Index				Percentage of Total
	Fatal	Serious	Minor/None	Total	
A	11	12	60	83	10.6
B	34	48	120	202	25.8
C	45	129	91	265	33.8
D	27	105	51	183	23.4
E	4	33	13	50	6.4
Total	121	327	335	783	100.0
Percentage of total	15.5	41.7	42.8	100.0	

*See figure 2-1 for weight class definition

TABLE 2-5. - SUMMARY OF ACCIDENT TYPES AS A FUNCTION OF INJURY INDEX

1964-77 NTSB Data

		Injury Index			
		Fatal	Serious	Minor/None	Totals
	Aircraft Damage				
	Destroyed	99	17	13	129
	Substantial	7	38	314	359
	Minor/None	15	272	8	295
	Post Crash Fire Occurrence				
	Yes	70	21	26	117
	No	47	306	309	662
	Unknown	4	0	0	4
	Primary Type Accident				
I.	Severe Impact	54	12	30	96
	A. Controlled collision	26	5	1	32
	B. Uncontrolled collision	20	2	1	23
	C. Undershoot	4	2	20	26
	D. Stall	4	3	8	15
II.	Moderate-High Sink Speed	9	15	152	176
	A. Hard landing	2	1	27	30
	B. Gear collapse	2	5	40	47
	C. Wheels up	0	1	19	20
	D. Retracted gear	0	0	16	16
	E. Swerve	1	2	34	37
	F. Overshoot	4	6	16	26
III.	System Malfunction	20	40	71	131
	A. Engine malfunction	3	17	34	54
	B. Prop. rotor malfunction	10	7	4	21
	C. Airframe failure	4	5	12	21
	D. Fire/explosion	3	11	21	35
IV.	Collision with	30	9	56	95
	A. Trees	6	0	4	10
	B. Ditches, fence, seawall	2	3	1	6
	C. App. lights, wires	0	3	7	10
	D. Obstacles (bldg., auto)	2	0	24	26
	E. People	5	1	0	6
	F. Aircraft	15	2	20	37
V.	Misc. Unk.	6	44	18	68
VI.	Turbulence and misc. flight occurrences	2	207	8	217
	Totals	121	327	335	783

large percentage (57.9 percent) of the fatal accidents are accompanied by post-crash fire. Of the total number of serious injury accidents, only a small number happened in destroyed aircraft (~5 percent) and aircraft involved in post-crash fires (~6 percent). There are a large number of accidents in which aircraft experienced substantial damage and in which minor, or no, injuries occurred. This type of damage is usually local, such as in the landing gear region.

Table 2-6 shows the distribution of accident types by operational mode (takeoff, landing, taxi, flight, static and other). The distribution is also divided into the severity of injury. There are several categories of accidents noted including:

I. Severe Impact

II. Moderate - High Sink Speed

III. System Malfunction

IV. Collision with Various Items (Aircraft, Obstacles, People, etc.)

V. Miscellaneous Unknown Types

VI. Turbulence and Other Flight Related Items, such as

- Hail
- Evasive Maneuver
- Uncontrolled Altitude Descent
- Lightning
- Bird Strike

From the data in table 2-6 one can observe the relative severity of different accident categories and types.

In the development of crash scenarios many NTSB reported accidents potentially can be eliminated because they

TABLE 2-6. - SUMMARY OF ACCIDENT TYPES BY OPERATIONAL MODE

1964-77 NTSB Data

Primary Accident Type	Takeoff *	Landing *	Taxi *	Flight *	Static *	Other *	Totals (T) X-Y-Z *
I. Severe Impact							(96) 54-12-30
A. Controlled collision	2-0-0	15-4-1		9-1-0			(32) 26-5-1
B. Uncontrolled Collision	2-1-1	7-1-0		11-0-0			(23) 20-2-1
C. Undershoot		4-2-20					(26) 4-2-20
D. Stall	1-2-8	2-1-0		1-0-0			(15) 4-3-8
II. Moderate-High Sink Speed							(176) 9-15-152
A. Hard landing		2-1-27					(30) 2-1-27
B. Gear Collapse	1-1-4	0-2-25	0-0-11		1-2-0		(47) 2-5-40
C. Wheels up	0-0-1	0-1-18					(20) 0-1-19
D. Retracted Gear	0-0-3	0-0-11	0-0-2				(16) 0-0-16
E. Swerve	1-1-7	0-0-25	0-1-2				(37) 1-2-34
F. Overshoot		4-6-16					(26) 4-6-16
III. System Malfunction							(131) 20-40-171
A. Engine Malfunction	1-9-11	0-4-3	0-1-0	2-3-20	4-6-0		(54) 3-17-34
B. Prop/rotor malfunction	2-0-2	1-0-1	0-1-0	3-0-1	4-6-0		(21) 10-7-4
C. Airframe failure	0-5-1	0-0-3	0-0-3	4-0-5			(21) 4-5-12
D. Fire/explosion	0-2-2	0-1-4	0-3-3	3-0-7	0-5-5		(35) 3-11-21
IV. Collision With							(95) 30-9-56
A. Trees	–	5-0-3		1-0-1			(10) 6-0-4
B. Ditches, fence, seawall	1-3-1	1-0-0					(6) 2-3-1
C. App. lights, wires	0-1-2	0-2-4		0-0-1			(10) 0-3-7
D. Obstacles (bldg., auto)	1-0-3	1-0-9	0-0-9	0-0-2	0-0-1		(26) 2-0-24
E. People	2-0-0	1-1-0	1-0-0		1-0-0		(6) 5-1-0
F. Aircraft	2-0-0	0-1-0	3-0-17	10-1-1	0-0-2		(37) 15-2-20
V. Misc. unk.	0-2-5	1-4-8	0-4-1	3-15-2	1-18-2	1-1-0	(68) 6-44-18
VI. Turbulence and misc. flight occurrences	1-0-1	0-4-1		1-203-6			(217) 2-207-8
Totals	17-27-52 96	44-35-179 258	4-10-48 62	48-223-46 317	7-31-10 48	1-1-0 2	121-327-335 783

* X-Y-Z
X = No. of accidents involving fatalities
Y = No. of accidents in which highest injury index is severe injury
Z = No. of accidents in which only minor/no injuries were sustained

(T) = Total no. of accidents

1) pertain to a weight class of airplane which is not FAR 25 regulated

2) are related to an accident which does not involve a crash, and

3) involve impact conditions which do not represent a potentially survivable crash condition

An expanded version of these potential accident types which may be eliminated is shown below

1. Aircraft in weight class 'A'
    a. ≤12500 lb. Takeoff Gross Weight (max.)
    b. rotary wing aircraft
2. Non-crash design related items
    a. Inadvertent inflight accidents resulting in injuries involving:
        - turbulence
        - uncontrolled altitude descent
        - evasive maneuver
        - hail
        - decompression
        - bird strike
    b. Miscellaneous accidents involving:
        - inadvertent door opening
        - onboard equipment failures not related to flight operations
        - nonmoving or "static" operations
    c. Accidents involving injury or fatality as a consequence of not following required safety practices such as:
        - unfastened seat belts
        - airplane boarding/leaving injuries
        - attendant or passenger aisle injuries

d. Accidents involving injuries or fatalities to nonpassenger personnel outside of the airplane such as:

- ground personnel
- people in autos or buildings

3. Unrealistic impact conditions for crash design scenarios

a. Collision with:

- other aircraft
- buildings
- people

b. Accidents in which pilot control of airplane is lost or greatly impaired: *

- sabotage
- inflight structure breakup
- loss of elevator, pitch or rudder control
- loss of major control surface (horizontal stabilizer)

Tables 2-7, 2-8, 2-9 and 2-10 show summaries of the reduced NTSB 1964-77 time period accident data. The accident types noted above for elimination from crash scenarios have been omitted from these summaries. From table 2-7 it is found that the percentage of accidents resulting in fatalities increases slightly to 18.5 percent from 15.5 percent (table 2-5). The percentage of accidents listed as a serious injury reduces significantly to 12.1 percent from 41.8 percent reflecting to a great extent the elimination of flight type accidents which are not directly related to crash design requirements.

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*Accidents of this type in which crash impact conditions are relevant and data is available are included in the study.

TABLE 2-7. - SUMMARY OF ACCIDENT INJURY LEVELS AS A FUNCTION OF AIRPLANE WEIGHT CLASS, BASED ON REDUCED NUMBER OF ACCIDENT CANDIDATES

1964-77 NTSB Data

Airplane Weight Class	Injury Index				Percentage of Total
	Fatal	Serious	Minor/None	Total	
B	22	11	111	144	42.2
C	24	17	78	119	34.8
D	16	9	36	61	18.0
E	1	5	11	17	5.0
Total	63	42	236	341	100
Percentage of total	18.5	12.3	69.2	100	

Table 2-8 presents data which show the distribution of aircraft damage, postcrash fire and primary accident types as a function of the injury index. It is significant to note that, for the reduced list, the 63 fatal accidents are associated with 63 airplanes destroyed and 61 postcrash fires. From table 2-9 it can be observed that the reduced list of accidents shows that of the 105 accidents involving fatalities and/or serious injuries, 55.2 percent occur during landing, 27.6 percent occur during takeoff and 15.2 percent are associated with inflight accidents. Controlled and uncontrolled collisions with ground-water account for 2/3 of the inflight fatal accidents. Table 2-10 shows the distribution of accident types as a function of airplane weight class. The addition of later data will increase the totals of "E" class airplanes. Considering the number of different airplanes in each weight class there is relatively little accident data available for each particular airplane model, especially when considering fatal and/or severe injury accidents.

TABLE 2-8. - SUMMARY OF ACCIDENT TYPES AS A FUNCTION OF INJURY INDEX BASED ON REDUCED NUMBER OF ACCIDENT CANDIDATES

1964-77 NTSB Data

	Injury Index			
	Fatal	Serious	Minor/None	Totals
Aircraft Damage				
Destroyed	63	16	10	89
Substantial	0	25	220	245
Minor/None	0	1	6	7
Post Crash Fire Occurrence				
Yes	61	19	4	84
No	2	23	212	237
Unknown	0	0	0	0
I. Severe Impact				
A. Controlled collision	23	4	1	28
B. Uncontrolled collision	8	2	1	11
C. Undershoot	4	2	18	24
D. Stall	2	1	4	7
II. Moderage-High Sink Speed				
A. Hard landing	2	1	24	27
B. Gear collapse	1	3	38	42
C. Wheels up	0	0	16	16
D. Retracted gear	0	0	14	14
E. Swerve	1	2	26	29
F. Overshoot	4	6	16	26
III. System Malfunction				
A. Engine malfunction	2	9	27	38
B. Prop. rotor malfunction	4	0	3	7
C. Airframe failure	1	3	12	16
D. Fire/explosion	1	3	15	19
IV. Collision With				
A. Trees	6	0	4	10
B. Ditches, fence, seawall	2	3	0	5
C. App. lights, wires	0	3	7	10
D. Obstacles (bldg., auto, etc.)	2	0	10	12
Totals	63	42	236	341

TABLE 2-9. - REDUCED SUMMARY OF ACCIDENT TYPES BY OPERATIONAL MODE BASED ON REDUCED NUMBER OF ACCIDENT CANDIDATES

1964-77 NTSB Data

	Takeoff *	Landing *	Taxi *	Flight *	Totals * (T) X-Y-Z
I. Severe Impact					70 37-9-24
A. Controlled collision	2-0-0	15-4-1		6-0-0	(28) 23-4-1
B. Uncontrolled collision	2-1-1	2-1-0		4-0-0	(11) 8-2-1
C. Undershoot		4-2-18			(14) 4-2-18
D. Stall	0-1-4	2-0-0			(7) 2-1-4
II. Moderate-High Sink Speed					(154) 8-12-134
A. Hard landing		2-1-24			(27) 2-1-24
B. Gear Collapse	1-1-4	0-2-23	0-0-11		(42) 1-3-38
C. Wheels up	0-0-1	0-0-15			(16) 0-0-16
D. Retracted gear	0-0-3	0-0-10	0-0-1		(14) 0-0-14
E. Swerve	1-1-6	0-0-18	0-1-2		(29) 1-2-26
F. Overshoot		4-6-16			(26) 4-6-16
III. System Malfunction					(80) 8-15-57
A. Engine malfunction	1-6-9	0-2-2		1-1-16	(38) 2-9-27
B. Prop/rotor malfunction	2-0-2	1-0-1		1-0-0	(7) 4-0-3
C. Airframe failure	0-3-1	0-0-3	0-0-3	1-0-5	(16) 1-3-12
D. Fire/explosion	0-1-1	0-1-4	0-1-3	1-0-7	(19) 1-3-15
IV. Collision With					(37) 10-6-21
A. Trees		5-0-3		1-0-1	(10) 6-0-4
B. Ditches, fence, seawall	1-3-0	1-0-0			(5) 2-3-0
C. App. lights, wires	0-1-2	0-2-4		0-0-1	(10) 0-3-7
D. Obstacles (bldg., auto)	1-0-1	1-0-2	0-0-6	0-0-1	(12) 2-0-10
Totals	11-18-35	37-21-144	0-2-26	15-1-31	63-42-236
	64 (19%)	202 (59%)	28 (8%)	47(14%)	341(100%)

*X-Y-Z X = No. of accidents involving fatalities

Y = No. of accidents in which highest injury index is severe injury

Z = No. of accidents in which only minor/no injuries were sustained

(T) = Total No. of accidents

TABLE 2-10. - SUMMARY OF ACCIDENT TYPES BY AIRPLANE WEIGHT CLASS, BASED ON REDUCED NUMBER OF ACCIDENT CANDIDATES

1964-77 NTSB Data

	Weight Class				Totals	
Primary Accident Types	B(1) *	C *	D *	E *	(T)	* X-Y-Z
I. Severe Impact					(70)	37-9-24
A. Controlled collision	6-1-1	10-1-0	7-1-0	0-1-0	(28)	23-4-1
B. Uncontrolled collision	3-0-0	2-2-1	2-0-0	1-0-0	(11)	8-2-1
C. Undershoot	1-0-12	2-2-4	1-0-2		(24)	4-2-18
D. Stall	1-0-3	1-1-1			(7)	2-1-4
II. Moderate-High Sink Speed					(154)	8-12-134
A. Hard landing	1-0-6	1-0-12	0-1-5	0-0-1	(27)	2-1-24
B. Gear collapse	0-2-17	0-1-13	1-0-8		(42)	1-3-38
C. Wheels up	0-0-10	0-0-5	0-0-1		(16)	0-0-16
D. Retracted Gear	0-0-11	0-0-3			(14)	0-0-14
E. Swerve	0-1-12	0-1-8	1-0-4	0-0-2	(29)	1-2-26
F. Overshoot	0-2-6	2-3-5	2-1-4	0-0-1	(26)	4-6-16
III. System malfunction					(80)	8-15-57
A. Engine malfunction	1-3-14	1-2-9	0-3-2	0-1-2	(38)	2-9-27
B. Prop/rotor malfunction	3-0-2	1-0-1			(7)	4-0-3
C. Airframe failure	1-1-3	0-0-4	0-1-2	0-1-3	(16)	1-3-12
D. Fire/explosion	1-0-5	0-0-5	0-2-4	0-1-1	(26)	1-3-15
IV. Collision With					(37)	10-6-21
A. Trees	3-0-3	3-0-1			(10)	6-0-4
B. Ditches, fence, seawall	0-1-0	1-2-0	1-0-0		(5)	2-3-0
C. App. lights, wires	0-0-1	0-2-3	0-0-3	0-1-0	(10)	0-3-7
D. Obstacles (bldg., auto)	1-0-5	0-0-3	1-0-1	0-0-1	(12)	2-0-10
Totals	22-11-111	24-17-78	16-9-36	1-5-11	341	63-42-236
	144	119	61	17	341	

*X-Y-Z X = No. of accidents involving fatalities
Y = No. of accidents in which highest injury index is severe injury
Z = No. of accidents in which only minor/no injuries were sustained

(T) = Total No. of accidents

(1)This weight class category includes many aircraft that are equivalent to commuter types.

For the first cut through the data, the following types of accidents are retained in reviewing data for scenarios:

1. Primary accidents involving collisions on the ground with:
   - building and autos, in which only airplane occupants are injured or killed
   - approach lights, wires
   - ditches, fences, seawalls
   - water
2. Accidents as the airplane approaches the ground involving collision with:
   - trees
   - obstacles (building, auto)
   - approach light, wires
   - ditches, fences, seawalls
   - water
3. System malfunctions which result in subsequent crash impact conditions

While these three types of accidents present a difficult assessment of an impact condition they are retained so that as much data as is available will be utilized. Table 2-11 shows a list of fatal and serious accidents which involve secondary collisions with on-the-ground items.

2.3 Validity of NTSB Data Usage

Arrangements were made with the NTSB in Washington, D.C. to obtain NTSB accident reports as well as backup data such as human factors, structures reports and flight recorder data. This information is used to supplement the NTSB reports available in company files. A total of 108 accident reports were available for use in this study.

TABLE 2-11. - LIST OF ACCIDENTS INVOLVING SECONDARY COLLISION IMPACTS

Airplane Weight Class: B, C, D

Injury Index: Fatal

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
B 3-3-72	Landing, f.a.	Prop. failure	Bldg.	No	D	17	34	3	
8-10-68	Landing, f.a.	Undershoot	Trees	Yes	D	35	2	0	
2-16-75	Takeoff, i.c.	Eng. failure	Trees	No	S	2	1	0	
2-8-76	Takeoff, i.c.	Prop. failure	Bldg.	Yes	D	3	0	3	
C 2-24-75	Landing, f.a.	Undershoot	App. lights	Yes	D	112	12	0	
4-5-76	Landing, l.o.	Overshoot	Ditch	Yes	D	1	11	0	
4-27-76	Landing, l.o.	Overshoot	Object	Yes	D	37	20	32	
D 1-30-74	Landing, f.a.	Overshoot	Trees	Yes	D	96	5	0	
3-30-67	Landing, f.a.	Uc	Bldg.	Yes	D	19	0	0	13 non passengers involved
6-13-68	Landing, f.a.	Overshoot	Bldg.	Yes	D	6	0	56	India Government jurisdiction
11-23-64	Takeoff, abort	Swerve	Object	Yes	D	48	11	14	Italian Government jurisdiction

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach
l.o. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail

TABLE 2-11. - LIST OF ACCIDENTS INVOLVING SECONDARY COLLISION IMPACTS (Continued)

Airplane Weight Class: B,C,D
Injury Index: Serious

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
B 2-13-64	Landing, roll	Overshoot	Ditch	No	S	0	3	37	
2-27-66	Takeoff, run	Swerve	Ditch	Yes	D	0	3	13	
C 6-3-68	Landing, f.a.	Undershoot	Runway	No	S	0	1	101	
8-12-69	Landing, l.o.	Overshoot	Auto	No	S	0	3*	119	*Auto occupants
2-11-70	Landing, t.p.	Eng. fail.	Ditch	No	S	0	1	6	
3-31-75	Landing, l.o.	Overshoot	Ditch	No	S	0	1	98	
7-19-70	T.O. i.c. – abort	Eng. fail.	Fence	No	S	0	1	60	
D 4-28-68	Landing, t.p.	Eng. fail.	Ditch	Yes	D	0	2	2	

Operation Mode/Phase

u.c. = uncontrolled collision with ground/water
c.c. = controlled collision with ground/water
i.a. = initial approach
f.a. = final approach
m.a. = missed approach

l.o. = level off
t.p. = in traffic pattern
i.c. = initial climb
g.a. = go-around

Injury Dist.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

The accidents noted in the NTSB records that are most pertinent to crash dynamics are:

- controlled collision with ground/water
- uncontrolled collision with ground/water
- undershoot
- stall
- hard landing
- wheels up
- retracted gear
- gear collapse
- overshoot
- swerve
- obstacle impact or collision

As noted in the previous section, the number of NTSB accidents for the period of 1964-77 to be considered for subsequent crash scenario evaluation was reduced from 783 to 341. Figure 2-2 shows a comparison of the number of occurrences of fatal, serious injury and minor/non-injurious accidents for both the original set of data (783) and reduced set (341) as a function of primary accident types. The trend for both sets of data is consistent. For example:

- Controlled and uncontrolled collisions with ground result in a higher percentage of fatal accidents (≈80 percent) than other types of accidents.

- Accidents involving initial impacts with trees, obstacles, lights, and other hazards result in a moderate percentage of fatal accidents (≈20 percent to 30 percent).

- Air-to-ground type accidents such as stalls and undershoots show a lesser percentage of fatal accidents (≈15 percent to 28 percent) than ground or obstacle collision accident types.

- Air-to-ground type accidents such as hard landing, wheels-up landing, retracted gear and collapsed gear types rarely result in fatal accidents. The percentages range from 0 to 7 percent of the number involved.

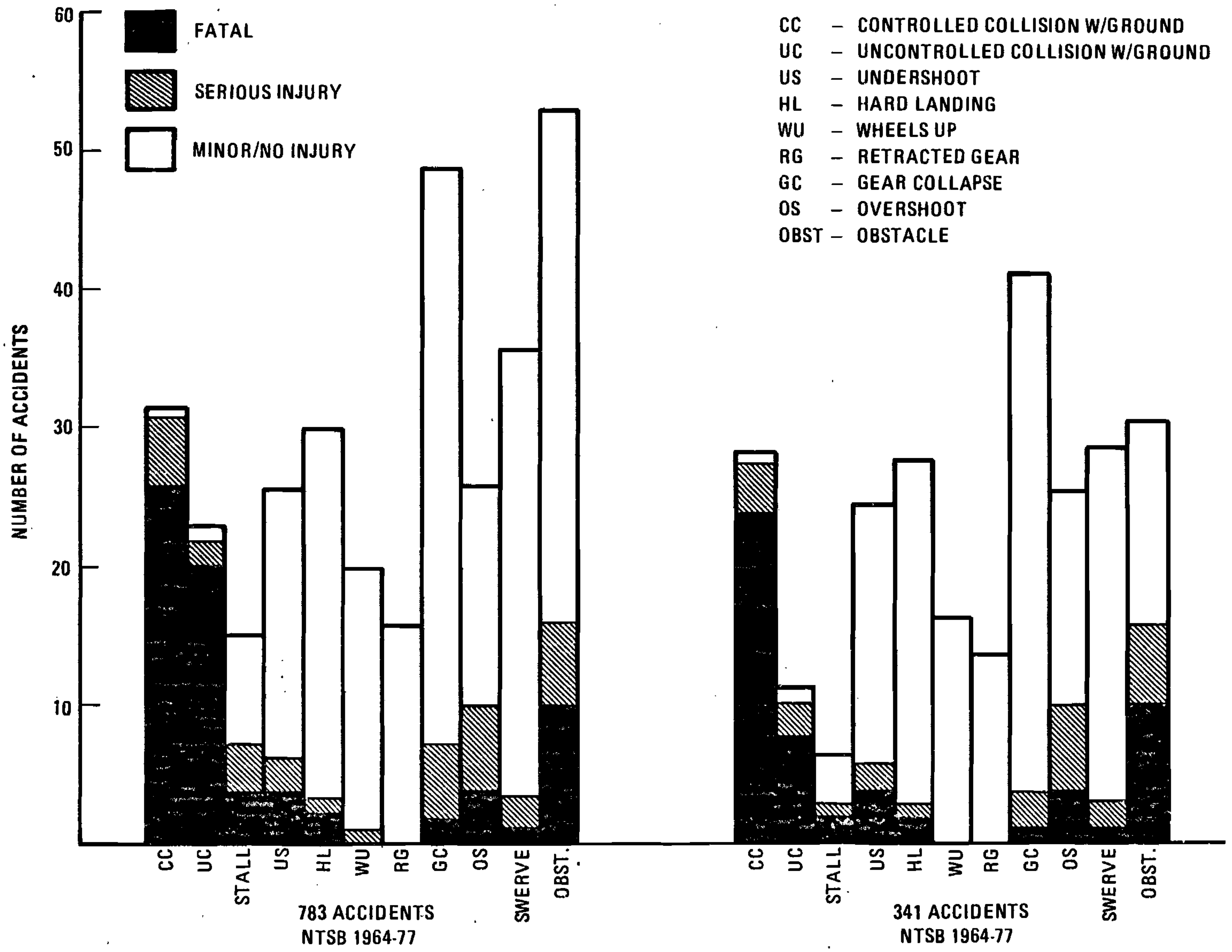


Figure 2-2. - Comparison of NTSB summaries.

- Ground to ground type accidents such as overshoot and swerves have a relatively low percentage of fatal accidents ($\lesssim$15 percent for overshoots and $\lesssim$3 percent for swerves).

Thus, the reduction to a data set of 341 accidents provides a reasonable representation of the overall accident severity as a function of accident types and can be used as a basis for the formulation of crash scenarios. However, before proceeding with the accident data review, it is necessary to determine if the data from NTSB accidents can be an effective representation of the overall worldwide statistics.

The NTSB accident data is used as a basis for formulating scenarios primarily because it is the source which provided the most details about accidents. The NTSB data represents less than 29 percent of the total accidents in the world during the period 1964-77. During this period of time the NTSB summaries include 783 accidents compared to 2707 Worldwide accidents (reference 14). During 1979, an additional 196 accidents were recorded in Worldwide accident summary. The NTSB accident data shows a decline in the number of accidents from an average of 73.5 per year in 1964-69 to an average of nearly 43 per year in 1970-77. This compares to Worldwide statistics of 181 per year and 203 per year, respectively, for comparable periods of time. Figures 2-3, 2-4 and 2-5, obtained from reference 15, reflect differences in U.S. airline operation and Worldwide operations, namely that U.S. traffic is carried by large airlines with long experience, modern aircraft, well-equipped airfields and uniform overall control, whereas foreign operations have a mixture of operators, experience, use older aircraft and fly in less favorable environments.

Since the primary emphasis of this study is long-range future aircraft with responsibility to perform in compliance with FAR25 requirements, the validity of using NTSB data has to be established.

In an attempt to do this the Worldwide accident summaries were reviewed on the same basis as the NTSB data (tables 2-9, 2-10). The summaries provided in reference 14 were often sketchy and presented difficulties in establishing accident categories associated with many accidents. Thus, the task of summarizing this data was not straightforward. Working within these constraints

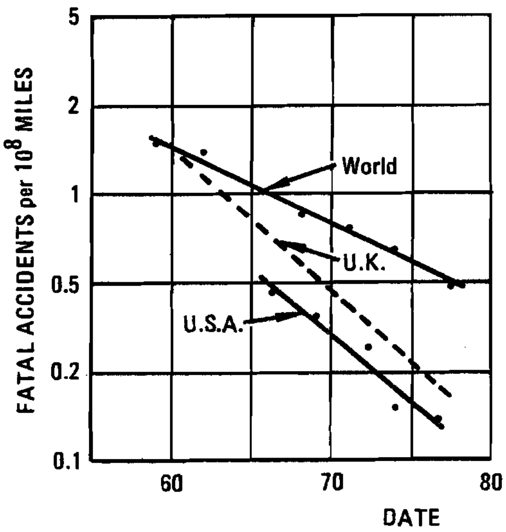


Figure 2-3. - Trend of accident rates as function of miles flown for USA, UK and the world.

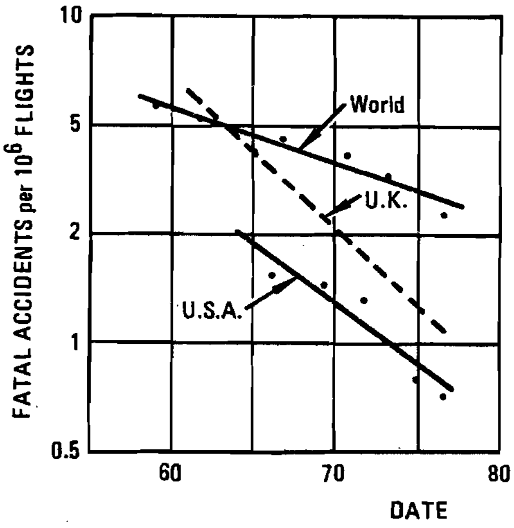


Figure 2-4. - Trend of accident rates as function of flights for USA, UK and the world.

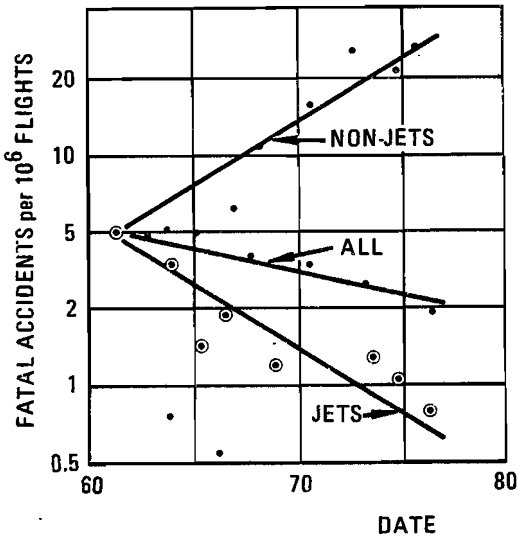


Figure 2-5. Trend of accident rates per flight for jet and nonjets.

and limiting the review to class B, C, D and E airplanes, a total of 726 Worldwide accidents are summarized in table 2-12 similar to table 2-10 for the NTSB data. The Worldwide data is for the period of 1964-1979 (March) and does not include the accidents in the NTSB data file.

A comparison of the two sets of data shows that the totals after removing static and miscellaneous accidents are as follows:

	Number of Accidents			
	Fatal	Serious	Minor/None	Total
NTSB:	63	42	236	341
Worldwide:	156	51	519	726

The Worldwide data shows a percentage distribution of 21.5 percent, 7 percent and 71.5 percent for fatal, serious and minor/none, respectively. The comparable NTSB percentages are 18 percent, 12.6 percent and 69.4 percent, respectively. Since System Malfunction and Collisions with Obstacles often result in secondary accident conditions a comparison of the two data sets on the basis of accidents in which it is anticipated that more defined impact

TABLE 2-12. - SUMMARY OF ACCIDENT TYPES BY AIRPLANE WEIGHT CLASS, FOR WORLDWIDE ACCIDENTS

Worldwide Data (1964 – 1979)*	Aircraft Weight Class											
	B			C			D			E		
Primary Accident Types	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
I. Severe Impact												
A. Controlled collision	49	7	24	6	1	6	3		4			
B. Uncontrolled collision	12	2	7	11	1	1	4		2			
C. Undershoot	5	3	11	4		5	5	1	1			2
D. Stall	12	1	13	1		3	2			1		
II. Moderate-High Sink Speed												
A. Hard landing	1		15			18	1		12			4
B. Gear collapse	3	5	92	1	1	36			11			3
C. Wheels up			27									
D. Retracted gear		8	28		1	14			4			2
E. Swerve	5	2	60	2	1	10	1	1	5			1
F. Overshoot	1	6	30	3	3	19		1	7			5
III. System Malfunction												
A. Engine malfunction	1			1			1					
B. Prop/Rotor malfunction												
C. Airframe failure	1											
D. Faire explosion				1			1				1	
E. Tire/brake									1	1	1	5
IV. Collision With												
A. Trees	7	3	9	1		1	1		1			1
B. Ditches, Fence, Seawall								1				
C. App. lights, wires			1									
D. Obstacles (bldg., auto)	3		11	3		4	1		2			1
E. People												
F. Aircraft												
Totals	100	37	328	34	8	117	20	4	50	2	2	24
	465			159			74			28		

*Through March 1979

X = No. of fatalities
Y = No. of serious injuries
Z = No. of minor/no injuries

conditions would be available is presented. Table 2-13 shows this comparison. The percentage associated with these conditions are as follows:

	Fatal	Serious	Minor/None
NTSB:	20%	9.3%	70.7%
Worldwide:	20%	7%	73%

Figure 2-6 shows a comparison of the worldwide data versus the reduced NTSB summary for injury level versus accident type. While percentage distribution varies somewhat for each accident type comparison the trend of the data is consistent. For example, air to ground type accidents such as controlled and uncontrolled collisions, stall, collision with obstacles and undershoot, still show the highest percentage of fatal accidents. Air to ground type accidents such as hard landing, wheels-up or retracted gear type show little or no fatality occurrence for both sets of data. The Worldwide data shows a higher percentage of fatal accident occurrence for an undershoot accident and lower percentage of fatal accident occurrence for an overshoot occurrence than does the NTSB data. Table 2-14 summarizes the data shown in figures 2-2 and 2-6 for the three sets of data. From the data in table 2-14 it can be observed that air-to-ground accidents (controlled ground collision, uncontrolled ground collision, stall and obstacle collision) show high ratios of fatality level accidents. Other-air-to-ground accidents such as hard landing show a small percentage (<8 percent) of fatality accidents, while wheels-up and retracted gear accidents have not shown any fatal accident. A ground-to-ground accident such as an overshoot, or swerve, fatality occurrence shows percentages of from 3 percent to 9 percent. Fatal accidents as a result of gear collapse which occurs during landing, takeoff and taxi, presumably at low speed, occur less than 5 percent of the time. Undershoot accidents, which show a fatality accident percentage which varies from 16 percent to 38 percent, are a cross between a hard landing and air-to-ground collision. The spread in fatal accident percentage for this accident may be associated with the proximity to the airport at which this accident occurs.

The use of NTSB data upon which to formulate crash scenarios is considered adequate since the data 1) is representative of the accident history, 2) more readily available, and 3) consistent with the trends associated with modern day jet usage.

TABLE 2-13. - COMPARATIVE SUMMARY OF ACCIDENT TYPES BY AIRPLANE WEIGHT CLASS, FOR NTSB AND WORLDWIDE DATA

NTSB 1964-77 Data	Weight Class					
	B	C	D	E		Totals
	*	*	*	*		*
	X-Y-Z	X-Y-Z	X-Y-Z	X-Y-Z	(T)	X-Y-Z
I. Severe Impact					(70)	37-9-24
A. Controlled collision	6-1-1	10-1-0	7-1-0	0-1-0	(28)	23-4-1
B. Uncontrolled collision	3-0-0	2-2-1	2-0-0	1-0-0	(11)	8-2-1
C. Undershoot	1-0-12	2-2-4	1-0-2		(24)	4-2-18
D. Stall	1-0-3	1-1-1			(7)	2-1-4
II. Moderate-High Sink Speed					(154)	8-12-134
A. Hard landing	1-0-6	1-0-12	0-1-5	0-0-1	(27)	2-1-24
B. Gear collapse	0-2-17	0-1-13	1-0-8		(42)	1-3-38
C. Wheels up	0-0-10	0-0-5	0-0-1		(16)	0-0-16
D. Retracted gear	0-0-11	0-0-3			(14)	0-0-14
E. Swerve	0-1-12	0-1-8	1-0-4	0-0-2	(29)	1-2-26
F. Overshoot	0-2-6	2-3-5	2-1-4	0-0-1	(26)	4-6-16
Totals	12-6-78 96	18-11-52 81	14-3-24 41	1-1-4 6	(224)	45-21-158
Worldwide 1964-79** Data						
I. Severe Impact					(210)	115-16-79
A. Controlled collision	49-7-24	6-1-6	3-0-4		(100)	58-8-34
B. Uncontrolled collision	12-2-7	11-1-1	4-0-2		(40)	27-3-10
C. Undershoot	5-3-11	4-0-5	5-1-1	0-0-2	(37)	14-4-19
D. Stall	12-1-13	1-0-3	2-0-0	1-0-0	(33)	16-1-16
II. Moderate-High Sink Speed					(450)	18-29-403
A. Hard landing	1-0-15	0-0-18	1-0-12	0-0-4	(51)	2-0-49
B. Gear collapse	3-5-92	1-1-36	0-0-11	0-0-3	(152)	4-6-142
C. Wheels up	0-0-27	0-0-0	0-0-0	0-0-0	(27)	0-0-27
D. Retracted gear	0-8-28	0-1-14	0-0-4	0-0-2	(57)	0-9-48
E. Swerve	0-8-28	2-1-10	1-1-5	0-0-1	(88)	8-4-76
F. Overshoot	1-6-30	3-3-19	0-1-7	0-0-5	(75)	4-10-61
Totals	88-34-307 429	28-8-112 148	16-3-46 65	1-0-17 18	(660)	133-45-482

X = No. of accidents involving fatalities

Y = No. of accidents in which highest injury index is severe injury

Z = No. of accidents in which only minor/no injuries were sustained

**Thru March 1979 (T) = Total No. of accidents

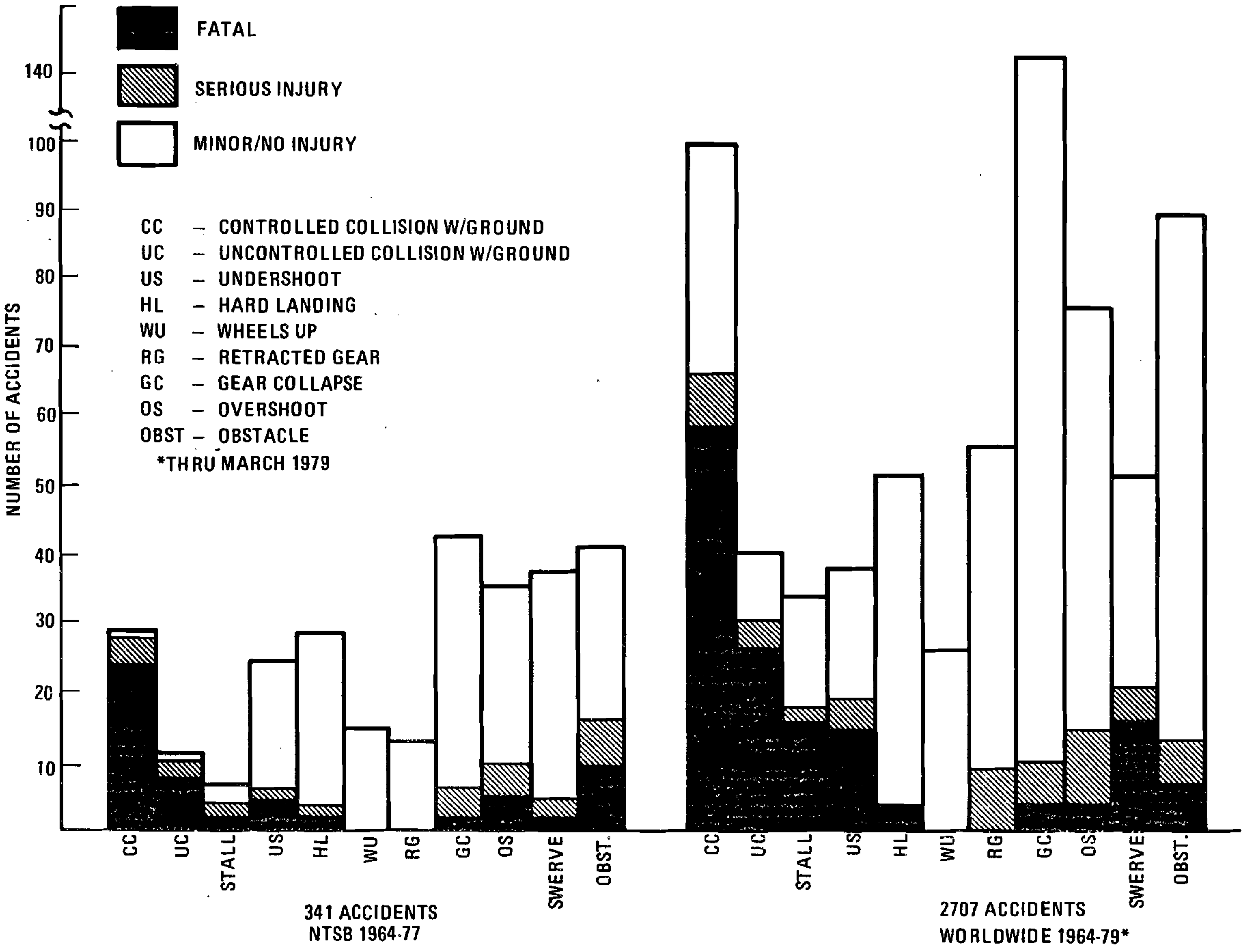


Figure 2-6. - Comparison of NTSB and worldwide accident summary data.

TABLE 2-14. - COMPARISON OF FATAL ACCIDENT PERCENTAGES FOR NTSB AND WORLDWIDE ACCIDENT SUMMARIES

	NTSB 1964 – 77 (783 Accidents)			NTSB 1964 – 77 (341 Accidents)			Worldwide (1964–79)* (2707 Accidents)		
Accident Type	No. Fatal Accidents	No. Total Accidents	% Fatal:	No. Fatal Accidents	No. Total Accidents	% Fatal:	No. Fatal Accidents	No. Total Accidents	% Fatal:
Controlled collision	26	32	81.3	23	28	82.1	58	100	58
Uncontrolled collision	20	23	87	8	11	72.7	27	40	67.5
Stall	4	15	26.7	2	7	28.6	16	33	48.5
Undershoot	4	26	15.4	4	24	16.7	14	37	37.8
Hard landing	2	30	6.7	2	27	7.4	2	51	3.9
Wheels up	0	20	0	0	16	0	0	27	0
Retracted gear	0	16	0	0	14	0	0	57	0
Gear collapse	2	47	4.3	1	42	2.4	4	152	2.6
Swerve	1	37	2.7	1	29	3.4	8	88	9
Overshoot	4	46	8.7	4	26	15.4	4	75	5.3
Collision with obstacle	10	52	19.2	10	37	27	16	51	31.4

*Thru March 1979

2.4 Accident Categories

Based on the preceding discussion and several accidents noted in the data base, preliminary accident categories were established. These categories are shown in tables 2-15 and 2-16. The accident types listed in table 2-15 are concerned with accidents that take place in and around airports and are initiated while the airplane is in ground contact. The accident categories in table 2-16 relate to accidents which are initiated while the airplane is in the air enroute to a ground impact. A review of the accident types indicates that some commonality exists between the various designations in tables 2-15 and 2-16. As a result of further evaluation of the data associated with the accidents the number of potential crash scenarios was reduced to eight as shown in table 2-17.

TABLE 2-15. - GROUND TO GROUND POTENTIAL CRASH SCENARIOS

Designation	Condition or Phase
G1	Aborted takeoff
G2	Taxi
G3	Takeoff run
G4	Gear retraction/collapse
G5	Overshoot
G6	Swerve
G7	Collision with obstacle

TABLE 2-16. - AIR TO GROUND POTENTIAL CRASH SCENARIOS

Designation	Condition or Phase
A1	Hard landing
A2	Controlled collision with ground/water
A3	Uncontrolled collision with ground/water
A4	Undershoot
A5	Stall
A6	Wheel-up landing
A7	Collision with obstacle prior to ground contact

TABLE 2-17. - REDUCED NUMBER OF POTENTIAL CRASH SCENARIOS

Designation	Description
A1	Hard landing
A2	Controlled collision with ground/water
A3	Uncontrolled collision with ground/water
A4	Undershoot
A5	Stall
A7	Collision with obstacle prior to ground contact
G1	Aborted takeoff
G5	Overshoot

The scenarios eliminated and the reasons are given below:

- A6 Wheels-Up Landing: None of the reports reviewed was in this category. A review of the table 2-6 summary shows that in all sixteen accidents of this type no serious injury or fatality was recorded. This condition is covered in FAR 25.561(b) and FAR 25.721(b) and the accident results to date indicate that the criteria are adequate.

- G2 Taxi: A review of the one accident report in this category indicated an unusual situation in which the airplane weathercocked 70° and slid backward down a snow covered 13° embankment and came to rest on a service road. Two of the 121 onboard personnel received vertebrae compression injuries when the airplane slid down the embankment. Of the other 27 Taxi accidents listed in table 2-9 only 1 involved serious injuries.

  Taxi accidents predominantly involve gear collapse at low speed resulting in little damage and no serious injuries or fatalities. Applicable design criteria for this type of failure are covered in FAR 25.721(a).

- G3 Takeoff Run: Of the four cases in this category three involved a rejected takeoff near the end of the run and were transferred to category G1. The fourth accident could have been classified a Controlled Ground Collision or Overshoot. Since it involved a takeoff mode and the airplane had been airborne prior to the accident it was transferred to the A2 category.

- G4 Retracted Gear/Collapse: The only accident report in this current file involved no injury. The total of 44 Retracted Gear or Collapsed Gear Landing and Takeoff Accidents summarized in table 2-9 shows 1 fatal accident and 3 serious injury accidents. The fatal accident is covered as a takeoff abort in category G1. The three other accidents involve one serious injury each out of a total of 167 occupants. However, NTSB reports for these accidents were not available. The NTSB briefs report that two of the accidents involved nose gear failures and the third an undercarriage collapse due to an overload failure during a turn on a wet runway. No other data are available on these accidents.

- G7 Collision with Obstacle on the Ground: Generally, this involves a collision with an aircraft, parked vehicle or person and these are not likely crash scenarios for which design conditions need exist. Consequently, while there are NTSB reports available, this type of accident was not a scenario candidate in this study.

  The accidents used in the formulation of candidate crash scenarios are shown in Appendix A.

2.5 Accident Data Evaluation

The number of cases in the Lockheed preliminary crash scenario accident file, for which reports are available, totals 108. For each of the accidents, an accident worksheet was completed. The format of the worksheet is shown in figure B-1, appendix B. A computer program was developed for the purpose of storing the accident data from the worksheet for future retrieval and usage as required. A description of the computer program and associated data files is provided in appendix B. Also available are human factor and/or structural data back-up reports for 65 of these accidents. Table 2-18 summarizes the number of occupant fatalities and injuries, as well as the total number involved in the crash scenario accident file. The data includes 108 accident reports and 94 briefs for a total of 202 accident cases. Ten-thousand eight-hundred fifty-three (10,853) occupants were involved in these accidents, of which nearly 20 percent were killed. The ratio of fatalities to total occupants involved is higher for the accident cases in which reports are available,

TABLE 2-18. - SUMMARY OF INJURIES/FATALITIES FOR CRASH SCENARIO ACCIDENTS

Category	Description	Accident Reports (1) F-S-M/NAC	Accident Briefs (1) F-S-M/NAC	Totals (Reports & Briefs) (1) F-S-M/NAC)
A-1	Hard landing	2-30-299/5	0-0-840/22	2-30-139/27
A-2	Controlled collision	818-131-104/27	0-7-127/2	818-138-231/29
A-3	Uncontrolled collision	556-144-189/18	—	556-144-189/18
A-4	Undershoot	286-59-878/9	0-1-670/15	286-60-1548/24
A-5	Stall	118-32-73/7	0-0-13/4	118-32-86/11
A-7	Collision with obstacle	190-160-509/14	9-9-409/17	199-169-918/31
G-1	Aborted takeoff	58-121-1488/17	0-8-916/18	58-129-2404/35
G-5	Overshoot	38-68-932/11	6-4-551/16	44-72-1483/27
Overall totals		2066-745-4472/108	15-29-3526/94	2081-774-7998/202

(1) F-S-M/NAC Denotes: Fatal-serious injury-minor or no injury/number of accident cases

as compared to the accidents in which only briefs are available. This is because reports are generally issued for accidents which tend to have a number of fatalities and/or injuries, while many of the accidents which do not result in a fatality or an injury are summarized in 'brief' form only. If the statistics were based on accidents in which fatalities occur then the ratio will be biased to the high side. Conversely, a ratio based on briefs only would be expected to show lower values. Table 2-19 shows the Fatality Ratio (FR) or the ratio of number of fatalities/total number of passengers developed for each accident category. The average ratio is .2837 and .0042 for reports and briefs, respectively, which is consistent with the aforementioned bias associated with the accident reports and briefs. The average fatality ratio based on the total number of reports and briefs is .1917. Normalizing the fatality ratio by dividing the individual FR by the average FR, one obtains results which show the relative severity of the accident category with regard to occupant fatality. An 'average' accident would have a normalized fatality ratio equal to one. Normalized ratios above one and below one are more and less severe, respectively, than the 'average'.

Of interest is the average distance from the airport that the various accident types occur, which is shown in table 2-20. Figure 2-7 compares the fatality rating given in column 7 of table 2-19 to the distance from the airport in miles. The accident severity is related to the distance from airports at which aircraft accidents occur. Accidents around airports; Hard Landings, Takeoff Aborts, and Overshoots are relatively fatality free. Undershoots which occur at approach velocities but involve terrain with some degree of roughness and contour unpredictability at an average distance of approximately 900 feet shy of the runway, are moderately severe, but less than the average. Stalls, which occur on an average about 1.2 miles from the airport, are severe accidents. The airplane's uncontrolled attitude at impact during a stall contributes to this severity. Collison with Obstacles near the airport are relatively mild. Usually they involve wires and approach lights which damage the airplane but do not inhibit the pilot from making a safe landing. Injuries that result from this type of accident often occur during the evacuation from the airplane. Collisions with Obstacles, generally trees and buildings, are more fatal than the average. This type of accident occurs on an average

TABLE 2-19. - RATIO OF FATALITIES TO OCCUPANTS INVOLVED IN CRASH SCENARIO ACCIDENTS

Category	Description	Accident Reports F-T/NAC(1)	Accident Briefs F-T/NAC(1)	Total (Reports and Breifs) F-T/NAC(1)	Fatality Ratio (FR) for Reports/Total(2)	Normalized Fatality Ratio (FR/FR_{AVG}) for Reports/Total
A-1	Hard landing	2-331/51	0-840/22	2-1171/27	.0060/.0017	.0211/.0089
A-2	Controlled collision	818-1053/27	0-134/2	818-1187/29	.7768/.6891	2.7381/3.5947
A-3	Uncontrolled collision	556-889/18	–	556-889/18	.6254/.6254	2.2044/3.2624
A-4	Undershoot	286-1223/9	0-671/15	286-1894/24	.2339/.1510	.8245/.7877
A-5	Stall	118-223/7	0-13/4	118-236/11	.5291/.5000	1.8659/2.6082
A-7	Collision with obstacle (all)	(190-859/14)	(9-427/17)	(199-1286/31)	(.2212/.1547)	(.7797/.807)
	a) off airport	190-531/9	–	190-531/9	.3578/.3578	1.2612/1.8665
	b) at airport	0-320/5	9-427/17	9-755/22	.0000/.0119	0.0030/.0621
G-1	Aborted takeoff	58-166/17	0-924/18	58-2591/35	.0348/.0224	.1227/.1168
G-5	Overshoot	38-1038/11	6-561/16	44-1599/27	.0366/.0275	.1290/.1435
Totals		2066-7283/108	15-3570/94	2081-10853/202	.2837/.1917	1.000/1.000
Average fatility ratio (FR_{Avg})		.2837	.0042	.1917		

(1) F-T/NAC denotes: Fatal – total onboard/number of accident cases

(2) FR = Ratio of number of fatalities/total number of passengers

TABLE 2-20. - AVERAGE DISTANCE FROM AIRPORT ASSOCIATED WITH ACCIDENT CATEGORIES

Category	Description	Average Distance from Airport (Miles)
A-1	Hard landing	0.00
A-2	Controlled collision	7.80
A-3	Uncontrolled collision	2.70
A-4	Undershoot	.16
A-5	Stall	1.20
A-7	Collision with obstacle (all)	(1.50)
	a) off airport	2.30
	b) at airport	0.00
G-1	Aborted takeoff	.13
G-5	Overshoot	.11

2.3 miles from the airport and has a FR equal to 1.86. Uncontrolled Ground/ Water Collisions occur on an average 2.7 miles from the airport and have a fatality ratio of 3.26. The Controlled Ground/Water Collision accident type occurs at an average distance of 8 miles (excludes one accident approximately 80 miles from the airport) from the airport and has a normalized fatality ratio of 3.59, which is the highest of all the categories.

Many of the accidents included in the review involve nonsurvivable accidents with little or no useful accident description. At this point a category entitled "Impact Nonsurvivable Accidents" was established. Table 2-21 lists these accidents and their previous categories. All 32 accidents for which reports are available, in this category are "wipe-outs," that is, everyone onboard perished. These accidents will not enter into the formulation of crash scenarios. With the elimination of ten (10) miscellaneous accidents the number of accidents upon which the crash scenario data is to be obtained is reduced to 66 from the 108 accidents in which reports are available.

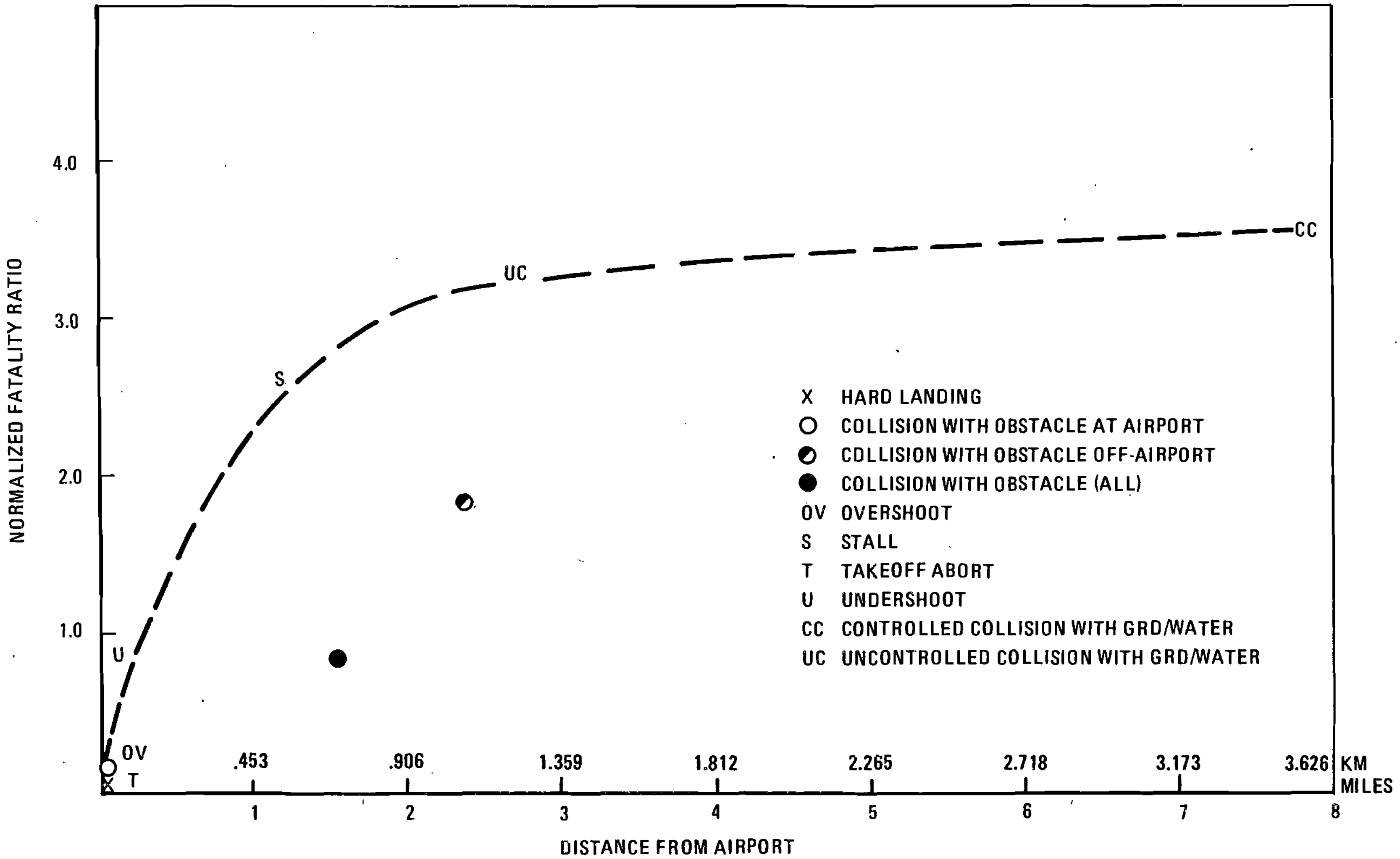


Figure 2-7. - Normalized fatality ratio versus distance from airport for crash scenarios.

TABLE 2-21. - IMPACT NONSURVIVABLE ACCIDENTS

Date	Location	Airplane/Class	Previous Category and Number
2-25-64	New Orleans, La.	DC-8/D	A3-1
7-9-64	Parrotsville, Tenn.	V745/C	A3-2
11-15-64	Las Vegas, Nev.	F27/B	A2-1
12-24-64	San Francisco, Ca.	L-1049/C	A2-2
2-8-65	Long Island, N.Y.	DC-7/C	A3-3
8-16-65	Lake Michigan	B727/C	A2-3
9-17-65	B.W.I.	B707/D	A2-4
10-1-66	Wemme, Ore.	DC-9/C	A2-6
3-10-67	Klammath Falls, Ore.	F-27/C	A3-5
3-30-67	Kenner, La.	DC-8/D	A3-6
6-23-67	Blossburgh, Pa.	BAC111/C	A3-7
12-26-68	Alaska	B707/D	A3-8
1-18-69	Los Angeles, Ca.	B727/C	A3-9
7-26-69	Pomona, Ca.	B707/D	A3-10
11-19-69	Glen Falls, N.Y.	FH227/B	A7-3
9-8-70	JKF, New York	DC-8/D	A5-3
11-14-70	Huntington, W. Va.	DC-9/C	A2-10
3-31-71	Ontario, Ca.	B707/D	A3-11
9-4-71	Alaska	B727/C	A2-11
6-21-73	Miami, Fla.	DC-7/C	A2-12
9-8-73	Alaska	DC-8/D	A2-14
9-27-73	Mena, Ark.	CV600/B	A2-27
11-3-73	Boston, Mass.	B707/D	A3-14
12-15-73	Miami, Fla.	L-1049/C	A2-15
3-13-74	Bishop, Ca.	CV340/B	A2-16
9-8-74	Ionian Sea	B707/D	A3-15
12-1-74	Thiels, N.Y.	B727/C	A5-5
12-1-74	Berryville, Va.	B727/C	A2-18
1-13-77	Alaska	DC-8/D	A5-6
7-6-77	St. Louis, Mo.	L188/C	A3-18
12-13-77	Evansville, Ind.	DC-3/B	A5-7
12-18-77	Kaysville, Utah	DC-8/D	A2-22

3. CANDIDATE CRASH SCENARIOS

Three crash scenario candidates are established on the basis of the review and evaluation of accident data described in section 2. Tables 3-1, 3-2 and 3-3 provide a general description of the candidate scenarios with regard to crash impact characteristics, accident, airplane configuration, hazards and terrain. The candidate scenarios are defined as follows:

1. <u>GGO - Ground to Ground, Overrun</u>

   GG1 - Ground to Ground type accident such as take-off abort or landing overrun which occurs at low forward (avg. 70-80 kts) and sink (<1.5m/sec) speeds with the airplane in a symmetrical attitude. Most of the accidents occur on pavement surfaces or hard ground. To some extent, damage is sustained by the airplane as it traverses a ditch, road or mound. The airplane weight, c.g., gear position and availability of pilot action to control secondary impacts can influence the resultant damage that the airplane might sustain. These accidents can result from pilot misjudgement.

   GG2 - Ground to Ground type accident similar to the GG1 type. In this scenario the hazards and terrain conditions have a much greater influence on the severity of damage the airplane will sustain. These accidents occur within 1000 m. of the runway. The forward velocity range is from 60 - 100 kts. The hazards can include ravines, embankments, lights, poles and vehicles.

2. <u>AGHL - Air-to-Ground, Hard Landing</u>

   AG1 - Air to Ground type accidents such as hard landings and undershoots. The sink speeds, including ground slope effects, average 6 m/sec and the forward velocity is in the range of 126 to 160 knots. The airplane can be characterized to be in a symmetrical nose-up impact attitude. These accidents generally occur on the airport or within 100 meters of the airport. The terrain characteristically ranges from grass to pavement. The airplane configuration is the same as the GG1 scenario configuration except that these accidents occur at landing weights. These accidents can result from pilot misjudgement.

TABLE 3-1. - GROUND-TO-GROUND, OVERRUN CONDITION, GGO

Type	Characteristics	Accident Description	A/P Definition Required	Hazards and Terrains ②
GG1/Ground to Ground (20 accidents)	• Low Sink Speed or ENV. ① ($\leq$1.52 m/sec) • Low Fwd. Vel. { $\leq$T.O. V_R $\leq$ Ldg. T/D (Range 40-130 Kts Avg. 80 Kts) • Symmetrical Impact Conditions Level Attitude • On Runway or Within 500m	• T.O. Abort • Ldg. Overrun	a) Configuration Weight (Ldg./T.O.) CG (Fwd/Aft) Gear Extended Controls Availability (full)	Hazards GG1 (6) Ditch/Storm drain (4) Service Road/Mound (2) each; raised sidewalk fence, light stanchion (1) each; concrete slab, upsloped hill, metal bldg. Terrain (4) Runway/Taxiway (4) Hard dirt (8) Unstated (1) each; grassy dirt, mud/soft, water, sand/water Average Overrun 239m. Range 26.8 – 498m
GG2/Ground to Ground Obstacles (9 accidents)	• Low Sink Speed or ENV. ($\leq$1.52 m/sec) • Low Fwd. Vel. { $\leq$T.O. V_P $\leq$Ldg. T/D (Range 60-100 Kts Avg 74 Kts) • Symmetrical Impact Conditions Level Attitude • Within 1000m. of Runway	• T.O. Abort • Ldg. Overrun	a) Configuration Weight (Ldg/T.O.) CG (Fwd/Aft) Gear Extended Controls Availability (full)	Hazards GG2 (5) Ravine Embankment (3) Lights/Poles (2) each; fence, drainage ditch vehicles (1) each; service station, hill, trees, rocks Terrain (5) Ravine (1) each; grassy dirt, sand, sod, rough Average Overrun 293m. Range 36.6 – 1036m.

① ENV = effective normal velocity

② (X) = number of occurrences

TABLE 3-2. - AIR-TO-GROUND, HARD LANDING, AGHL

Type	Characteristics	Accident Description	A/P Configuration	Hazards and Terrains ②
II. Air to Ground AG1/Undershoot, Hard Landing (11 accidents)	• High Sink Speed or ENV. ① (>3.1 m/sec) (<10 m/sec) Avg ~6 m/sec. • Fwd. Vel. < Final Approach > L.O/TD 126-160 Kts • Symmetrical Impact Conditions ≤ 15° Nose Up • On Runway or Within 100m.	• Hard Landing • Undershoot	a) Configuration Weight (Landing) CG (Fwd./Aft) Gear Extended Control Availability (full)	Hazards None Terrain Impact: (4) Runway, (2) Grassy dirt, (1) Soft ground, (4) Unstated Final: (8) Runway, (6) Grass, (1) Soft dirt Average undershot 64m. Range 6-102m.

① ENV = effective normal velocity

② (X) = number of occurrences

TABLE 3-3. - AIR-TO-GROUND, IMPACT, AGI

Type	Characteristics①	Accident Description	A/P Configuration	Hazards and Terrain ②
AG2/Undershoot, Obstacles (4 accidents)	• High/Sink Speed or ENV. (>3.1 m/sec.) (<10 m/sec.) • Fwd. Vel. (< Final Approach > L.O./TD 126 – 160 Kts.) • Symmetrical Impact Conditions $\leq 5^{0}$ Nose Up • 150 to 1200m. off runway	• Undershoot	a) Configuration Weight (Landing) CG (Fwd/Aft) Gear Extended Control Availability (full)	**Hazards** (2) Ravine/Embankment (2) Lights/Poles (1) each; tree, fence, dike, rocks **Terrain** (4) Unstated Average Undershoot 574m. Range 152 – 1175m.
AG3/Air to Ground High Sink Speed (7 accidents)	• Moderate to High (>1.52 m/sec.) Sink Speed or ENV. (<10 m/sec.) • High Fwd. Vel. ≥ Final Approach ≥ T.O. Climb < Descent 110-200 Kts • Symmetrical and Unsymmetrical Impact Conditions pitch (θ) 0 to $+5^{0}$ roll (ϕ) $\pm 5^{0}$ to $\pm 45^{0}$ yaw $\psi = 0$ to $\pm 10^{0}$ flight path $(\Upsilon) = -4^{0}$ to -7^{0} • Occurs On or Off-Airport Runway	• Controlled & Uncontrolled Grnd. Collision • Stall • Collision with Obstacle • Undershoot	a) Configuration Weight (Ldg./T.O.) CG Fwd/Aft) Gear Extended/ Retracted	**Hazards** None **Terrain** (4) Slope/Mountain (1) Runway (1) Marshland (1) Runway/Rough–Rocky Average distance from airport – 10203m. Range 2414 – 20094m.
AG4/High Sink Speed Obstacles (14 accidents) Total: 25 accidents	• Moderate to High (>1.5 m/sec) Sink Speed or ENV. (<10 m/sec) • High Fwd. Vel. [< Final Approach > T.O. Climb < Descent 100-200 Kts] • Symmetrical and Unsymmetrical Impact Conditions Pitch (θ) 0 to $+5^{0}$ Roll (ϕ) $\pm 5^{0}$ to $\pm 45^{0}$ Yaw $(\psi) = 0.$to $\pm 10^{0}$ Flt. Path $(\Upsilon) = -4^{0}$ to -7^{0}	• Controlled & Uncontrolled Ground Collision • Stall • Collision with Obstacle • Undershoot	a) Configuration Weight (Ldg/T.O.) CG (Fwd/Aft) Gear Extended/ Retracted	**Hazards** (8) Trees (8) Bldgs. (2) Lights/Poles (1) each; Ravine/Embankment, Vehicle, Seawall **Terrain** Not Stated Average distance from airport - 4410m. Range – 335 to 9656m.

① ENV = effective normal velocity ② (X) = number of occurrences

3. AGI, Air-to-Ground, Impact

AG2 - Air to Ground type accident such as an undershoot. In this scenario the hazard and terrain conditions have a significant influence on the severity of damage the airplane sustains. These accidents occur from 150 to 1200 m. off the runway. The hazards can include ravines, embankments, lights, poles, trees, fences and dikes.

AG3 - Air to Ground type accidents generally described as a controlled or uncontrolled collision with obstacle or undershoot. Characteristic of this accident are moderate to high sink speeds, high forward velocity and unsymmetrical attitude. These accidents can occur near the airport or as far as several miles from an airport. The terrain can vary from slopes and mountains to marshland. These accidents often occur as a result of the pilot becoming disoriented and unaware of the airplane's position relative to the terrain.

AG4 - Air to Ground type accidents similar to the AG3 scenario. However, in this scenario the hazards and terrain conditions have a significant impact on the structural damage and airplane post-impact behavior. These accidents occur off-airport and up to several miles from the airport. The hazards include trees, buildings, lights, poles, ravines, embankments, vehicles and seawalls.

Table 3-4 provides data associated with the accidents which comprise the candidate crash scenarios described in tables 3-1, 3-2 and 3-3. Included in table 3-4 is a brief description of the accident, terrain and obstacles encountered, the injury factors, occurrences of fire, seat failure, and airplane failures as well as some indication of aircraft location and/or direction. The candidate crash scenarios are the basis of the evaluation of system involvement, structure interaction and fire potential, all of which are described in the following section.

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude Knots M/Sec (Ft./Sec.) Degrees	Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
				Fatal	Serious			
				Type – Ground to Ground, GG1				
1. 4-7-64 JFK, N.Y. B707/O (Surviv.)	0-7-138	160 T/D 82 overrun Landing T/D, Gears Extended	None, no fuel spill	None	3 trauma 4 Unknown	Some identified first class seat failures	• Engine No. 1, 3, 4 separated • Fuselage fwd. severed at FS 600 (at water impact)	Wet runway, crossed an asphalt surface and through a sandy area. Came to rest in shallow water. Overrun~26.8 m. Evac. time = 5 min. G5-1
2. 10-28-73 Greensboro, N.C. B737/C (Surviv.)	0-0-96	139 T/D 80 Overrun Landing T/D, Gears Extended	None, Rt. engine wing tank rupture and fuel spill Fuel drained F.C. away Ambient temp. < vaporization temp. of Jet A fuel	None	None	None stated	• MG's, NG collapsed aft as A/P crossed service road • light panels fell • No. 2 engine separated	Wet runway, crossed service road (all LG's collapsed), developed right skid. Overrun, along centerline - 195 m. G5-3
3. 12-15-72 Miami, Fla. B747/E (Surviv.)	0-0-160	140 T/D 27-70 overrun Landing T/D, Gears Extended	None, no fuel spill	None	None	None stated	• NG collapsed aft, causing damage to fuselage underside and cabin floor	A/P NG ran off runway 37 to left of centerline. Struck concret slab and collapsed. 354 m. overrun G5-8
4. 6-8-68 SLC, Utah B727/C (Surviv.)	0-4-88	126 T/D 52 overrun Landing T/D, Gears Extended	None, no fuel spill	None	4-evacuation	None stated	• RMG collapsed aft • LMG collapsed to side • A/P final position didn't allow aft door to open	Slid off runway, yawing to left, @ 100° angle to the runway. Evac. time = 50 sec to 1 min G5-11
5. 7-9-78 Rochester, N.Y. BAC111/C (Suriviv.)	0-1-76	163 T/D 96 overrun Landing T/D, Gears Extended	None, no fuel spill	None	1 trauma – (elderly woman) (overhead rack)	None stated	• NG sheared (crossing ditch), collapsed into lower fuselage • Overhead service units (27) Door jammed and deformed • MG's separated	A/P crossed a drainage ditch –10.7m wide x 3.1m deep and came to rest 222 m. past the runway. A/P yawed Evac. time - 90 sec. G5-7

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude Knots M/Sec (Ft./Sec.) Degrees	Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
				Fatal	Serious			
				Type – Ground to Ground, GG1 (Continued)				
6. 7-1-65 K.C., Mo. B707/D (Surviv.)	0-1-65	135 T/D 30°-45° yaw 40 overrun Landing T/D, Gears Extended	None, no fuel spilled	None	1 trauma {did not use harness}	o Some " partially (3) loose" Fwd Section o 1 pax seat belt or attachment failed o 1 crew seat cushion restraint	• FS separated fw (FS-600 and aft (FS1060) when impacted road • No. 2, 3, 4 engines separated • door jammed • NLG separated	Hit ILS Antenna, slid over dirt mound and fell onto the road. Mound impact mild. Road impact noticeable. 320 m. overrun. A/P yawed Evac. time = 1.5-2.5 min. G5-10
7. 8-12-69 V.I. DC-9/C (Surviv.)	0-0-119	135 T/D 57 overrun Landing T/D, Gears Extended	None, no fuel spilled	None	None	None stated	• NG collapse aft (sidewalk impact) damage underside • Fuselage nose damage – FS 218 • tire/wheel damage	Encountered raised sidewalk. Came to rest penetrating a metal bldg. (insignificant) 100 m. overrun G5-2
8. 3-31-75 Caspar, Wy. B737/C (Surviv.)	0-1-98	152 T/D 80 overrun Landing T/D, Gears Extended	None, no fuel spilled	None	1-evacuation (helping pax deplane)	None stated	• RMG separated (ditch impact) • No. 2 engine sep. (ditch impact) • LMG partial sep. • NG collapsed aft • door slightly jammed • slide punct. by wire (fence) • debris, obstructions	Struck stanchion and shallow ditch 268 m. overrun Evac. time - 2 to 3 min. G5-4
9. 3-21-68 Chi., Ill. B727/C (Surviv.)	0-1-2	Takeoff rotation, Gear Extended	Yes, wing failure fuel tanks (impact with drainage ditch)	None	1-Evac. (jumped)	None stated	• LG's sheared (ditch) • Left wing damage (ditch) • Aft fusel. separated (ditch) • Lwr fusel. abrasion • No. 1 engine separated	Soft shoulder and mud crossed 1.83 m. deep ditch. 335 m. overrun 45.7 m. to right of the runway edge G1-2

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Knots	M/Sec (Ft./Sec.)	Degrees		Fatal	Serious			
					Type – Ground to Ground, GG1 (Continued)					
10. 10-16-69 Stockton, Ca. (DC-8/D (Suriv.)	0-0-5	130 Abort 80 overrun			Yes, No. 2 engine and pylnn separation (fuel line break)	None	None	Nona stated	• LMG collapsed aft (struck roadbed) • NLG collapsed aft and to right (struck roadbed) • No. 2 engine and pylon separated (80 m. beyond LMG collapse)	Crossed .25 to .31 m. elevated roadway 122 m. beyond runway. Overrun 241 m. Terrain contained 3 ditches at right angles to the runway .91 m. wide and .51 m. deep within 30.5 m. of the runway (with no structural damage occuring) G1-3
11. 12-28-70 V.I. B727/C (Surviv.)	2-11-42	117 T/D 80 Overrun Landing Rollout, Gears Extended		18	Yes, wing root area (Type A fuel used, minimized fire hazard)	2-fire	11-trauma Crew 1-chest PAX 2 spine 1 pelvis	• Pax outboard leg (1) • Seatback in rear direction (2) • Left and fwd directions (8) pax seat attachment • 1 seat pan. • pilot seat adjustment (previous occurrence)	• RMG collapse • Fuselage separated in two places a) fore and aft wing • No. 2 engine separated • NG collapse • Debris	Went through chain link fence, struck raised sidewalk and ended up on a slope where trauma injuries occurred. Ended 91.5 m past the runway 61 m. to the rt. of centerline. Est. 5-10 g's peak, 30° to longitudinal Evac. time - 1 min. A1-2
12. 9-13-72 S.F. Ca. B707/D (Surviv.)	0-0-3	140 Abort 69 overrun Gears Extended			None	None	None	None stated	• Fuselage break fwd of wings • NG separated • No. 2 engine separated • 6-ft. of last wing tip separated	Came to rest in bay water. 274 m. overrun G1-7
13. 6-20-73 Bangor, Me. DC-8/D (Surviv.)	0-3-258	110 Abort Takeoff Rotation, Gear Extended			Yes, RMG wheel rim friction and sparks	None	3-Evacuation (fell from slides)	None stated	• RMG tire and wheel damage • RMG tire deflated during taxi	Wet runway. A/P stopped on the runway. Evacuation time = 3 min. G1-8
14. 11-12-75 JFK, N.Y. DC-10/E (Surviv.) *Bird Ingestion	0-2-137	168 Abort 40 Overrun Takeoff Rotation, Gear Extended			Yes, rt. wing engine disintegrated* and sep. (fuel line break.) Fuel tank integrity lost when A/P left paved surface FC	None	2-Evacuation (fell to ground)	None stated	• Tire and wheel failures • Right engine (No. 3) separated • LMG, centerline gears separated • Overhead rack • RMG collapsed	Wet runway. Stopped on taxiway. A/P came to rest in a storm drain which helped stop fuel and provide oxygen for fire Yawed. Evac. ≈ 1 min. G1-10

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude Knots M/Sec (Ft./Sec.) Degrees	Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
				Fatal	Serious			
Type -- Ground to Ground, GG1 (Continued)								
15. 11-16-76 Denver, Colo. DC-9/C (Surviv.)	0-0-84	157 Abort 120 Overrun Gears Extended	Yes, LMG tank rupture, due to LG collapse	None	2-Minor injuries, req'd hospitalization	None stated	• NG collapse (ditch) • LMG collapsed and severed LG attach structure on fuel tank near bulkhead • Lwr. fuselage structure from radome to nose gear damaged • Door deformed • Left wing tip sep.	A/P struck stanchion, crossed ditch 4.6 m wide X .91 m. deep Total overrun = 320 m. and 122 m. to the right of extended runway Evac. time = 2 min. G1-11
16. 3-1-78 L.A., Ca. DC-10/E (Surviv.)	2-31-167	159 Abort 68 Overrun Takeoff Rotation, Gears Extended	Yes, LMG separated and ruptured fuel tank (at juncture of the two left wing main fuel tanks)	2 – Fire	31-Slide Failures (impact with ground)	None stated	• LMG tires blew • Left wing damaged when LMG collapsed • No. 1 engine and pylon separated	Wet runway. LG failed 30.5 m. off the runway Total overrun - 202.4 m. Evac. time = 4.5 min. G1-12
17. 3-27-74 Alaska DC-8/D (Surviv.)	0-1-230	130 Abort Takeoff Rotation, Gears Extended	Yes, in area of LMG (tires, wheels brakes)	None	1-Evacuation (fell off slide)	None stated	• No. 1 and 2 tires blew	Tires blew. Stopped 122 m. short of departure end. G1-14
18. 5-28-78 Miami, Fla. CV880/C (Surviv.)	0-0-6	160 Abort 71-110 Overrun Takeoff Rotation, Gears Extended	None, no fuel spillage	None	None	None stated	• MG tires failed • NG collapsed	86.9 m. overrun and 3.05 m. to the left of runway centerline G1-16
19 1-16-77 Balt., Md. DC-8/D (Surviv.)	0-7-94	Takeoff Rotation, Gears Collapsed	None, no fuel spillage	None	7-Evacuation (Slide Problems) Windy conditions	None stated	• No significant damage	On the runway Evac. time 1.5 min G1-17
20 7-19-70 Phila, Pa. B737/C (Surviv.)	0-1-60	100 Abort Landing Rollout, Gears Extended	None, Fwd, trunnion attach fitting of LMG fractured and resulted in fuel spillage	None	1-Evacuation (at base of slide)	None stated Aft fwd. facing, Flt. attendant (F/A) Seat was determined to have a deficient harness design. Aft double jump seat F/A's were tossed from side to side during slideout	• Lwr. fuselage • RMG separated • LMG failed but attached • NG folded aft	A/P passed over three threshold lights, through a 1.83 m. chain link fence into a grass field, then impacted two earthen mounds and rubble and came to rest Total overrun - 498 m. Evac. time 45 sec. G1-4

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude Knots M/Sec (Ft./Sec.) Degrees	Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
				Fatal	Serious			
Type – Ground to Ground, GG2 (Continued)								
1. 11-27-73 Akron, Ohio DC9/C (Surviv.)	0-16-10	Landing T/D, Gears Extended	None, No fuel spillage	None	16-Trauma 7-pax in failed seats (seat pan spring over-extension) F/A spinal	• Crew jump seat attach: filtering (1) • Pax seat downward collapse and bending (2) • Pax seat pan spring overextension (11) • F/A seat collapsed (3) • F/A S/B attachment (1)	• Tail section broke off @ aft cabin pressure bulk-head • Cabin floor deformed between rows 11 and 16 • Overhead racks collapsed (major contributor to injury)	Overrun = 146.3 m and came to rest at the bottom of an enbankment G5-9
2. 4-5-76 Alaska B727/C (Surviv.)	1-11-38	135 T/D 76 Overrun Landing T/D, Gears Extended	Yes, a) erupted at break near tail b) right wing separation from fuselage. Fuel spillage, fuel line or wing fuel tank	1- Fire and trauma (85 yr. old woman)	11-Trauma 1 F/A spinal 3 F/A chest 1 F/A head	• Downward bending, compression and deformation • Tore loose at supports (10) 16 failed seats (9 of which inconclusive) rows 6-9 (aft of cockpit	• Fuselage separated into 4 sections (3 breaks) wing LE, TE and cockpit • Rt. wing sep. at root • Left wing separated • NG and MG's separated • No. 1 eng. separated	Wet runway. Crashed into a ravine, area strewn with tree stumps end large rocks Overrun ~ 213.4 m G5-5
3. 4-27-76 V.I. B727/C (Partially Surviv.)	37-19-32	127 T/D 102 Overrun Landing T/D, Gears Extended	Yes, right wing struck embank-ment and ruptured rear fuselage. Fuel spillage	8-Trauma, Burns and smoke inhalation	19-Trauma, Burns and smoke inhalation	• Pax fwd cabin seats broke loose from mounts (several locations) – Frame deformed and legs separated. • Aft facing F/A seat separated from bulkhead	• Fuselage broke into 3 sections (wing L.E. & T.E.) • Wings outbd. sections separated • Fuselage underwing heel beam separated • No. 1 and 2 engines separated	Impacted 1.22 m. embankment at end of runway, ripped across a busy highway, hit cars and service station. Overrun ~ 309.4 m. G5-6
4. 11-6-67 Erlinger, Ky. B707/D (Surviv.)	1-1-34	145 Abort 60 Overrun Takeoff Rotations, Gears Extended	Yes, right wing failed inboard of No. 4 engine.	1-Trauma (probable)	1-Trauma (probable)	None stated	• Floor buckling (Pre-vented door opening) • MG's spearated • NG collapsed • Lwr. fuselage crushed upward 38 CM. NG wheel penetration • Fuselage separation @ F.S. 600 • Wing separation at W.S. 733 • No. 3 and 4 engines separated	Hit brow of hill 128.3 m beyond runway and contacted the ground 20.4 m. beyond embankment G1-1

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Data Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Knots	M/Sec (Ft./Sec.)	Degrees		Fatal	Serious			
Type – Ground to Ground, GG2 (Continued)										
5. 8-13-72 JFK/N.Y. B707/D (Surviv.)	0-18-170	154 Abort 70 Overrun Takeoff Rotation, Gears Extended			Yes, fuel tank rupture	None	16-Evacuation (jumped 1.5 m. to 3 m.)	None stated	• Left outbd. wing panel (impact with steel blast fence) • Overhead racks opened, debris fell • Slide didn't inflate	A/P ran off right side of paved surface of the runway. Continued through a steel blast fence. Stopped 36.6 m. past runway and 24.4 m. to the rt. of the runway. Came to rest in sand. Evac. in 5 min. G1-6
6. 8-27-75 Miami, Fla. CL-44/C (Partially (Surviv.)	6-4-0	139 Abort 65 Overrun Takeoff Rotation, Gears Extended			Yes, undetermined (wing intact)	6-Trauma (2 while not using S/B) Occupants ejected	4-Trauma	• Seat tiedowns failed • S/B failed at buckle (2) • Separation of seat pan inboard tube at rivet • Seat frame crushed downward and to side	• LMG collapsed (ditch) • Fuselage wing LE • Cockpit and cabin destroyed. (Crashed into bank of a canal)	A/P left runway into sod, hit approach light structure, through a ditch, over a road and hit an auto. Hit light at 168.8 m past the runway and ditch located 268 m. past runway Total overrun - 305 m. G1-9
7 6-26-78 Toronto, Can. DC-9/C (Surviv.)	2-47-58	149 Abort 70 Overrun Takeoff Rotation, Gears Extended			None, Fuel tanks ruptured and fuel spilled (impact forces)	2-Trauma	47-Trauma 2 crew spine 1 crew head 1 F/A spinal 43 pax more serious injuries in fwd than in rear compt's	• Pax seats pulled from tracks • Pax seats collapsed	• Fuselage broke into three parts (ravine impact) • MG, NG collapsed aft (ravine impact) • Exit door jammed due to floor buckling • Overhead racks collasped • Tire failed • Debris • Water tank	A/P overran 'moist' runway and went over a ravine dropped 15.5 m.(17.4 m/sec) @ 48 knots, 16.5° nose down slight roll. Total overrun 183 m and 19.8 m to the left of centerline. Calculated cg crash forces: (25G resultant) Longitudinal (fwd) 16G, .18 sec. duration. Vertical (down) 19G, .13 sec duration. Evac. time = 50 min. G1-13
8. 12-16-76 Miami, Fla. CV880/C (Surviv.)	0-3-0	160 Abort Takeoff Rotation, Gears Extended			None	None	3-Trauma (serious and minor injuries)	Configured for cargo None stated	• Lwr. fuselage crushed up and aft • NG partially collapsed • Left wing (ILS) • Cockpit crushed	A/P struck ILS antenna structure and came to rest nose down in a drainage canal. 320 m. overrun. 56.4 m. to right of ℄ Grass terrain. G1-15

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Knots	M/Sec (Ft./Sec.)	Degrees		Fatal	Serious			
Type – Ground to Ground, GG2 (Continued)										
9. 11-27-70 Alaska DC-8/D (Surviv.)	47-49-133	159 Abort Takeoff rotation, Gear extended			Yes, left wing root due to ILS structure impact. Right wing tore loose when traversed ditch, spilling fuel	47 burns	49 trauma and burns (Seat belts removed after ditch impact) Majority occupied seats in rear of a/p & fwd of the fuselage break	• Pax seat attachments (6) @ rows 35-36 (area of fuselage separation) • Occupants in seats ejected from aircraft	• Left wing tore loose (ILS structure impact) • Fuselage aft section (ditch impact) • Right wing tore loose • Fuselage fwd. section broke • MLG separated • Overhead racks • Jammed exit door • Cabin debris • Galley equipment	A/P struck low wooden barrier. ILS structure (damaged left wing area) and 3.60 m. deep drainage ditch* (initiated structural break-up). Final jolt came when A/P stopped in rough terrain. 1036 m. overrun *~800 m. beyond runway G1-5
Type Air to Ground, AG1										
1. 9-15-70 JFK, N.Y. DC-8/D (Surviv.)	0-69-87	Touchdown (150-200) Landing Touchdown, Gears Extended	5.02 (16.5)	+2.30 pitch	None, No fuel leaks	None	(11) Unknown* *11 hospitalized	None Stated	• LMG, RMG collapsed • NG separated • Fuselage separated @ wing T.E. • Fuselage buckled • Lwr fuselage crushing • No. 1, 3, 4 engines separated • Debris • Service door jamed	Run impact. Ended off runway Evacuation time = 3 min. A1-1
2. 6-23-73 Jamaica, N.Y. DC-8/D (Surviv.)	0-8-120	Final Approach (129) Landing Touchdown, Gears Extended	4.11 (13.5) (Avg. over last min.)	Nose up Pitch	Yes, No. 1 engine separation and ruptured fuel line led several electrical wires	None	(8) Trauma	• Rear pax seat legs collapsed (4) • F A seats separated from mounting (2)	• LMG, RMG collapsed • Fuselage lwr. skin scraped and buckled • Tail skid crushed up • Overhead racks separated • Debris • No. 1 engine separated • Rear cabin (flour) damaged	Inadvertent ground spoiler deployment. Initial impact 6.1 m short of runway A1-3

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Knots	M/Sec (Ft./Sec.)	Degrees		Fatal	Serious			
Type – Air to Ground, AG1 (Continued)										
3. 1-16-74 L.A., Ca. B-707/D (Surviv.)	0-2-63	Touchdown (130-150) Landing Touchdown, Gears Extended	7.92 (26)	–	Yes, Ruptured hydraulic lines due to NG penetration of fuselage	None	(2) Evacuation (fell from slides)	None Stated	• NG collapsed • Cabin floor damaged by NG Penetration FS312–FS400	4.6 G's on NG. Evacuation time=45 sec. Runway A1-4
4. 5-18-72 Miami, Fla. DC-9/C (Surviv.)	0-3-7	Touchdown (135-140) Landing Touchdown, Gears Extended	10.1 (33.3)	+2.5° Pitch	Yes, Wing root area	None	(1) Trauma (1) Evac. (fall) (1) Trauma or Evac. F/A spine (1) Crew spine (1)	• Down direction (1) • Seat back (1) • F/A Mech. (1)	• RMG separated • LMG collapsed • Tail section separated	Seat Design 9G fwd., 7G down A/C landed on runway and skidded off into soft dirt Egress time = 30 seconds A1-5
5. 6-23-76 Phila., Pa. DC-9/C (Surviv.)	0-36-70	Ldg. go around (118) Landing, Gears Retracted	7.62 (25)	+10-15° Pitch	None, No fuel leaks	None	(36) Trauma	• Compression buckling pilot seat • PAX seats, buckled, separated floor fittings and lateral supports (92-100).	• No. 1 and 2 engines separated • Fuselage tail section separated just off pressure blkhd. • Fuselage damage below cusp line, at rear pressure blkhd., eng, stab.-wing attachments, lwr. skin abraided and frames crushed along entire A/P length • Cabin floor buckled above MLG's	Impacted alongside runway Seats tested to 8.63 g's vertical A3-17
6. 8-7-75 Denver, Colo. B727/C (Surviv.)	0-15-115	T.O. initial climb (126) Takeoff climb, Gears Retracted	5.5 (18)	+7° Pitch	None, No fuel leak	None	(15) Trauma {1 crew 4 F/A 10 Pax} 2 F/A submarined. 2 F/A heads struck unpadded fwd cabin blkhd. 6-pax, spinal 1-F/A spinal	• F/A jump seat pan in downward direction (1) • Crew restraint belts failed (2) • Pax seat tiedown pins • F/A seat mechanism (1)	• Fwd. fuselage split upen circumferentially FS 271-390 and aft at FS 1050-1100 at impact • ceiling panels • overhead racks • debris • door jammed • cabin floor throughuut A/P	50-60 Knot tail wind at impact. Impact occurred 118 m. beyond runway on hard grass terrain. A/P may have encountered updraft (12.8-16.5 m/sec., followed by down drafts (4.6-9.2 m/sec.) Evac. time = 3 to 4 min. A3-16
7. 11-11-65 SLC, Utah B727/C (Surviv.)	43-35-13	Final approach (120) Landing FA, Gears Extended	9.0 (29.5)	Nose Up Pitch	Yes, Ruptured fuel lines supplying No. 2 and 3 engine as a result of RMLG failure.	43 burns and smoke inhalation	(7) Trauma (28) burns and smoke inhalation	None Stated	• MG's sheared on impact • Engine No. 1 separated • Lower fuselage abrasion	A/P hit 102 m. short of threshold. A/P slid 366 m. on nose gear and bottom fuselage (hit an approach light, but not a factor) A4-1

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Fwd. Vel. Knots	Sink Speed M/Sec (Ft./Sec.)	Attitude Degrees		Fatal	Serious			
Type – Air to Ground, AG1 (Continued)										
8. 9-8-70 Louisville, Ky. DC-9/C (Surviv.)	0-0-94	Level off/ TO (123-130) Landing Touchdown, Gears Extended	5.63 (18.5)	–	None	None	None	• 2 pax at attach fitting seat tracks separated • Pax seat compression buckling at row 38	• Fuselage separation -- FS 775-786 (Aft of Wing T.E.) • Keel beam structure buckled • Fuselage buckling at various locations • Cabin floor seperation	A/P landed 47.5 m. short of the runway threshold on MGs-Terrain was grassy dirt. 79.8 m. down the runway indications of of rear fuselage contact. 5% gradient A4-3
9. 11-12-75 Raleigh, N.C. B727/C (Surviv.)	0-1-138	Final approach (147) Landing F.A., Gears Extended	6.5 (21.3)	-2.5°γ	None, No fuel leakage	None	(1) Evacuation	• Seat pan extension • Pax seat legs deformed (2) • Seat back trays • 1st class	• No. 3 engine separated • MG's separated • Overhead racks failed	Landed 86 m. short. A/P slide on the runway and came to rest on grass to the right of the runway. Evac. time = 1 1/2 min. Slight upslope ~1.34° A4-6
10. 1-2-76 Istanbul DC-10/E (Surviv.)	0-1-376	Final Approach (151) Landing F.A., Gears Extended	4.88 (16.0)	+3 to 9 pitch -2.1° roll	Yes, Engine and left wing when engine separated	None	Unstated (1)	None Stated	• No. 1 engine separated • LMG, CG separated	Landed 82 m., short, soft ground Evac. time = 3.5 min. A4-8
11. 8-7-68 Boston, Mass. B727/C (Surviv.)	0-0-83	Final Approach (140) Landing F.A., Gears Extended	6.7 (22)	+9° pitch	None	None	None	None Stated	• MG's collapsed (Gear supt. beam fitting) • Lwr. fuselage skin abrasion and buckling FS 950-rear pressure blkhd.	A/P landed 81 m. short A4-9
Type – Air to Ground, AG2										
1. 1-30-74 Pago Pago B707/D (Surviv.)	98-5-0	Final Approach (142) Gears Extended	7.47 (24.5)	-3.5°Y	Yes, All 4 wing tank fwd. walls ruptured	(1) Trauma (95) Burns and smoke inhalation	(5) Unknown	None Stated	• All 4 engines separated • MGs and NG separated • Lwr. fuselage from nose to fwd. of rear pressure bulkhd. damaged • Wing outbd. of WS 733-820 separated	Landing 1175 m. short through trees A4-4
2. 6-24-75 Jamaica, N.Y. B727/C (Partially Surviv.)	112-12-0	Final Approach (123) Gears Extended	6.83 (22.4)	-4.5°Y (90° roll after contact)	Yes, Erupted after left wing failed and released fuel	(2) Trauma (33) Trauma and Fire 77 (Unknown)	(3) Trauma (9) Burns and smoke inhalation All survivors in in rear which was intact	Mangled and torn loose in all sections • Seat to rail attachments (12)	• Engines 1 and 2 separated • Fuselage disintegrated • Wing outbd. section severed • Cabin floors failed when fusel. disintegrated	Landed 731 m. short. Hit approach light and fence. More severe in forward region. Hit several approach lights, large boulders and a 1.83 m embankment. Rough and rocky terrain. A4-5

γ = flight path angle

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Knots	Sink Speed M/Sec (Ft./Sec.)	Attitude Degrees	Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
						Fatal	Serious			
Type -- Air to Ground, AG2 (Continued)										
3. 11 27-73 Chattanooga, Tenn. DC-9/C (Surviv.)	0-3-76	Final Approach (120) Gears Extended	5.7 (18.7)	Nose down Pitch	Yes, Left wing separation, at root and at left engine attach point Fuel entered cabin through fractures in cabin floor ignition caused by a/c electrical sources timely response by fire fighters	None	(3) Trauma spinal injury 2 crew 1 pax (not in position)	- Pilot seat inboard seat track cracked (floor beneath displaced approx. 2 inches) - 5 pax seats showed impact damage. Seat bottom panel displ downward 2"-3" - Pax seat tracks separated (rows 29 31) (floor distorted upward)	- Left wing separation when dike struck - Eng. #1 separated - MLG's, NG separated - Exit door jammed - Debris hindered evacuation - Cabin floor buckled and fractured - Lower skin torn	A/P struck approach light short of threshold 244 m struck control dike 2.39 m. high Evac. time = 2-3 min. A7 9
4. 12-17-73 Boston, Mass. DC-10/E (Surviv.)	0-3-164	Final Approach (153) Gears Extended	5.33 (17.5)	+5.4^0 Pitch	Yes, Left wing, rupture of interior fuel tank	None	(1) Trauma* (2) Evac (fall trauma) *seat related	Pilot seat moved aft seat support mechanism failed	- Wing fractured - Fuselage separation @ FS 811 - Aft cabin floor buckled - Engines 1 and 3 separated - RMG, LMG separated - Center gear, NG collapsed aft	Landed 152.4 m. short, hit approach light, piers, embankment Evac. time = 2 min. A4-7
Type Air to Ground AG3										
1. 11-8-65 Constance, Ky. B727/C (Nonsurviv.)	58-4-0	147 Landing F.A., Gears Retracted	3.2 (10.5)	+5^0 Pitch 5^0 Roll	Yes, Not stated. Could be engine separation and several lines from fuse. separation	(58) Trauma fire or both	(4) Trauma	None State	- Fuselage broken into 4 parts a) FS130-294 b) FS294-640 c) FS640-1183 - No. 1 and 3 engines separated	9.6^0 slope (ENV = V_{sin} 9.6^0 + 3.2 m sec. = 15.7 m/sec). Occurred 3219 m. from airport. Initial impact by rt. wing with tree. Fire consumed A/P fwd. of tail section A2-5
2. 4-22-66 Ardmore, Okla. L-188/C (Partially surviv.)	83-15-0	150 Landing Approach, Gears Extended	9.9 (32.5)	0^0 Pitch 10^0 Roll -7.2γ	Yes, Right wing separated from fuselage (tree contact). Tank area ruptures - WS 454	(83) Trauma	(15) Trauma and burns	- Tore loose from attachments - Bend fwd. and to the right	- No. 4 engine separated - Right wing separated at WS 514 and at root - FS above floor from FS 200 540 separated - NG, LMG separated - RMG shock strut piston separated - Left wing separated at WS 465	ENV >>10 m/sec (including flt. path and hilly terrain). Fwd. section telescoped Survivors were in mid and aft compartment. Pilot experienced heart attack and A/P flew into hill. A/P proceeded over top of hill and slid down for 244 m. 2414 m. from airplane. A3-4

γ = flight path angle

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Data Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude Knots	M/Sec (Ft./Sec.)	Degrees	Fire Occurrence, Fuel Leakage, Location	Injury Factors Fatal	Serious	Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
					Type -- Air to Ground, AG3 (Continued)					
3. 10-2-70 Silver Plume Colo. M404/B (Partially Surviv.)	30-10-0	128-137	4.88 (16)	31° roll -4°γ	Yes, wings separated, engine separation probably	(30) Fire and impact	(9) Trauma* (1) Burns *Unfastened S/B's and thrown from A/P	• Many seat tiedown failures • Impact forces fwd. and to left. Lack of S/B use noted.	• Wings separated at attach points • Empennage severed from fuselage • Engines were separated	Incline in excess of 28° (ENV >33.6 m/sec) Descended through trees 12876 m. from the airport. Seat design criteria improved since M404 design A2-9
4. 5-30-72 Ft. Worth, Tex DC9/C (Partially Surviv.)	4-0-0	Extreme rt. wing row Landing F.A., Gears Extended			Yes, ruptured wing tank	(3) Trauma (1) Fire	None	None Stated	A/P was destroyed. No further description	Followed in wake of DC-10. Non-survival for cockpit Cabin comp't interity maintained. A/P inverted. Occurred on runway A3-12
5. 12-29-72 Miami, Fla. L-1011/E (Nonsurviv.)	99-77-0	200 Flight, Uncontrolled Descent Gears Extended	8.23 (27)	-28° Roll	Yes, Left wing fuel tanks	(99) Trauma	(63) Trauma (14) Fire & Burns	• Many remained attached to floor structure • Seat separation where floor failed • Bending and facture of legs	• Fuselage completely shattered • Entire left wing and left stabilizer demolished • LMG and NG separated • No. 1 and 3 engines separated	Crashed in Everglades, flat marshland covered with soft mud under 0.15 m. to 0.3 m. of water. Left wing, engine and LMG contacted in sequence. A3-13
6. 8-30-75 Alaska F27/B (Partially Surviv.)	10-20-2	109 Landing F.A., Gears Extended			Yes, in vicinity of left engine	(10) Trauma	(20) Trauma	• Seat leg supports to floor attachments • Supports bent downward	• Floor loss of structural integrity. • Cockpit crushed • Fuselage separated into 4 parts • Left wing separated at nacelle • No. 1 engine separated • MG's and NG separated	High ENV due to steep mountain incline ≈25-30° est. Vsinθ = 78. A/P overturned after impact. Occurred 2414 m. from the airport A3-19
7. 6-24-69 Moses Lake, Wash. CV880/C (Surviv.)	3-2-0	116 Takeoff I.C., Unknown		22° Yaw 37-42° Roll	Yes, Wings and engines separated fuselage erupted into flames	(2) Burn (1) Burn or Trauma	(2) Burn	None Stated	• Tail skid separated • All engines separated • Fuselage separated @ trailing edge of wings	Shortly after T.O. A/P yawed severely to rt. and lost alt., careened off runway, broke up and burned. Reached alt. of 38.1 m. Rocky rough terrain A2-25

γ = flight path angle

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Knots	Sink Speed M/Sec (Ft./Sec.)	Attitude Degrees	Fire Occurrence, Fuel Leakage, Location	Injury Factors Fatal	Injury Factors Serious	Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain Obstacle Comments Former Category No.
Type – Air to Ground, AG3 (Continued)										
8. 12-27-68 Sioux City, Iowa DC-9/C (Surviv.)	0-3-6	133-148 Takeoff climb, Gears Retracted		45° Roll	No, ruptured wing fuel cells, fuel leak (Freezing temp)	None	3-Trauma (didn't use available harness in 2 instances)	Attachment (2) partially separated (3)	• Left wing tip from contact with runway • wings torn and crumpled • Fuselage distorted, torn 4 wrinkled	Left wing contact, A/P slid straight and came to rest in tree grove, ~378 meters beyond runway A5-1
Type – Air to Ground, AG4										
1 11-20-67 Constance, Ky. CV880/C (Nonsurviv.)	70-12-0	191 Landing F.A., Gears Extended	9.14 (30)	Level	Yes, not stated	(70) Unknown	(12) Trauma	None stated	Airplane was destroyed, no description given	Struck trees 2865 m. short of runway A2 7
2. 12-27-68 Chicago, Ill. CV580/B (Partially Surviv.)	27-16-2	Landing F.A., Gears Extended		Steep roll Nose Low	Yes, not stated	(27) Trauma	(16) Trauma	pax seats (19) separated from fasteners (seat bolts) directly to floor). Failure direction, up, left and forward	• Tail section sep. aft of blkhd. • All 4 engines sep. • Buckling and twisting of fuselage rows 4-6 • Wings separated	A P struck hangar in inverted position. Fwd. (Rows 1-5) nonsurviv. Rows 6-7 C questionable Rows 8-12 - survivable Occurred 335 m. off the runway A5 2
3. 12-8-72 Chicago, Ill. B737/C (Partially Surviv.)	43-12-0	120 Landing F.A., Gears Retracted	7.6 (25)	Nose high roll -4.5γ	Yes, entire left wing and outer rt. wing area	(43) Unstated	(12) Unstated	• pax seats tore loose at supports. Pax thrown fwd. and to left F A • F/A Seat collapsed	• Both wings separated • RMG separated • NG tore from its mounts • Both engines sep. • Fwd. to mid fuselage disintegrated • Ceiling panels	Initial contact; tail section, rt. wing followed by nose. A P crashed into houses. 1st hit trees in level altitude. Occurred 2414 m. from the airport. 1 survivor in section fwd of wing. 17 survivors in coach section A5-4
4. 7-23-73 St. Louis, Mo. FH227/B (Non Surviv.)	38-6-0	Landing F.A., Gears Extended			Yes, outbd. of nacelle (tree impact)	(38) Trauma	(6) Trauma	• All but 1 seat failed • Failed fwd. and to right (Row 4 7) or left (Rows 8 11)	• Both wings sep. (on impact with tree) outbd. of nacelle • MLG's separated • Fus. sep. aft of cockpit	Crashed in residential area surrounded by trees. Cabin tore open by trees. Occurred 3700 m. from the airport A2-13

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Knots	M/Sec (Ft./Sec.)	Degrees		Fatal	Serious			
Type – Air to Ground, AG4 (Continued)										
5. 9-11-74 Charlotte, N.C. DC-9/C (Partially Surviv.)	71-10-1	129 Landing F.A., Gears Extended		-4.5° γ -5.5° roll	Yes, sheared left wing by tree, probably fuel line severed (No indication of tank rupture)	(32) Trauma (25) Burns and Smoke Inhalation (7) Burns (1) Smoke Inhalation (6) Combination	(10) Trauma and burns	• Pax and crew rest. systems failed when cabin disintegrated	• Left wing broke in sections • Right wing and stabilizer sheared • Fuselage broke up in wooded area • MG's and NG separated	A/P struck ground in open field surrounded by dense woods and underbrush. A/P came to rest in a ravine. Only cabin section near tail retained structural integrity. Occurred 5310 m. from the airport A2-17
6. 4-4-77 Newhope, Ga. DC-9/C (Partially Surviv.)	62-22-1	Normal T/D attitude loss of engine power rolled attitude at impact. Landing T/D, Gears Extended			Yes, a) left wing as A/P struck ground, b) Fuel mist and spillage from right wing WS 127 and 214	(31) Trauma (9) Trauma and burns (20) Burns and smoke inhalation (2) Unk	(22) Trauma and burns	• Impact forces from right to left • Pax and clear seat legs -- track seperation • Pax seats compression buckling of legs to the right • Seats tore loose at attach (10)	• Both wings separated from center section • Fuselage broke into 5 sections a) Nose to FS 148 b) FS 148-275 c) FS 579-870-wing center section d) FS 870-1090, eng. pylons, APU and aft e) FS 1090 empennage • Doors jammed • Left engine pylons separated	A/P landed on highway, hit bldg., truck and autos. Wings struck trees and utility poles. Fwd. section-impact forces nonsurviv. Aft section-impact forces surviv. Occurred 8047 m. from the airport. A2-20
7. 10-20-77 Miss. CV240/B (Partially Surviv.)	6-19-1	Landing F.A., Unknown		-5° γ	None, Out'd wing panels separated, wing structure separated, but low on fuel	(6) Trauma 5-Fwd 1-Mid 0-Aft	(19) Trauma 3-Fwd 11-Mid 5-Aft	• Tore loose from floor • Seat legs bent and deformed to the rt.	• Cockpit structure crashed against trees • Both wing out'bd. sections seperated. • Props separated from engine • Fuselage separated fwd. of bottom leading edge of vertical stabilizer.	A/P crashed in heavily wooded area. Cockpit nonsurvivable Cabin survivable Occurred 8047 m. from the airport A2-21

γ = flight path angle

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Date Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Knots	M/Sec (Ft./Sec.)	Degrees		Fatal	Serious			
Type – Air to Ground, AG4 (Continued)										
8. 12-24-68 Bradford, Pa. CV580/B (Partially Surviv.)	20-12-15	130 Landing F.A., Gears Extended	25	Severe roll -4° γ	Yes, Fracture of right wing outb'd of nacelle, tank rupture	Trauma (Probable)	Trauma (Probable)	• Appear to have torn loose from floor supports	• Engine separated • Wings fractured • Door jammed • Fuselage fractured	• Impacted trees. A/P broke up as it cut the trees and rolled to an inverted position before striking ground. Terrain had avg. up-slope of 1.5°. Occurred 4023 m. from the airport A7-1
9. 1-6-69 Bradford, CV 580 (Partially Surviv.)	11-17-0	134 Landing F.A., Gears Extended	12	-2.5° to -6°} γ Severe roll	Yes, wing fuel tanks ruptured due to tree contact	Trauma (Probable)	Trauma (Probable)	• Cabin seats sep. from their attachments	• Fuselage separated fwd. of wing L.E. (~row 7) • Trees impaled aft fuselage • Left engine sep. • Right wing fractured outb'd eng. and at root	Airplane cut through trees and came to rest inverted. Breakup progressed. Occurred 7563 m. from the airport. A7-2
10. 6-7-71 New Haven, Conn. CV440/B (Surviv.)	28-3-0	105 Landing F.A., Gears Extended	8	-	Yes, Fracture of wing structure inb'd of nacelles. Fuel tank rupture	(26) Burns (2) Burns and Trauma	(3) Trauma, Burns and Smoke Inhalation	None Stated	• Cockpit structure demolished • Both engines separated • Fuselage broke aft of cockpit & fwd. of empennage • Both wings were severed	Airplane hit cottages. Occurred 1609 m. from the airport. A7-5

γ = flight path angle

TABLE 3-4. - CRASH SCENARIO ACCIDENT DATA (Continued)

Data Location, A/P & Class NTSB Rating	Injury Distribution F-S-M/N	Initial Conditions and Airplane Configuration Fwd. Vel. Sink Speed Attitude			Fire Occurrence, Fuel Leakage, Location	Injury Factors		Seat Failures	Airframe, Engine and Landing Gear Failures	Terrain/Obstacle Comments Former Category No.
		Knots	M/Sec (Ft./Sec.)	Degrees		Fatal	Serious			
Type - Air to Ground, AG4 (Continued)										
11. 3-3-72 Albany, N.Y. FH227/B (Partially Surviv.)	18-32-0	117 Landing F.A., Gears Retracted		5° pitch* -5° γ -1.5 roll	None, Fuel spilt from wing tank rupture. Low amb. temp., fuel vapor characteristics and lack of ignition source	Trauma (lack of use of avail. harness and S/B contributed) 1st 4 rows most fatalities 2 Crew Skull, spine, lower leg fractures 14 Pax Crushed rib cages and lower extremity fractures	Trauma (Several had legs pinned under seats) 1 Crew 31 Pax Mostly spinal and lower extremity fractures	• Separated from floor • Seat pan downward collapse • Support structure in lateral and down directions • Bending or fracture of seat legs (just below chassis attach. points) • Floor tracks attach.	• Wing fracture outb'd engine • Fuselage fracture aft of cockpit and fwd. of empennage • Right eng. separation • Cockpit crushed in longitudinal direction • Door jammed	A/P crashed into house and came to rest within confines of the residence. Seat design capability Stewardess Pax 9.0g Fwd. 9.0 6.5g Down 7.5 2.0g Up 4.5 1.5g Side 3.0 Calculated mean G forces Longitudinal 15-25 g's Lateral 5-10 g's Vertical 5-15 g's Occurred 5633 m. from airport. *Impact angle - 10° upward relative to airplane longitudinal axis A-7
12. 7-31-73 Boston, Mass. DC-9 (Nonsurviv.)	88-1-0	130 Landing F.A., Gears Extended	20		Yes, Not stated. Many possibilities including fuel tank or line ruptures	(3) Trauma (85) Trauma and burns	(1) Trauma and Burns	• Tore loose from floor • Leg failures show twisting and tension • Predominant failure direction fwd., right and down	• Fuselage break fwd of empennage • Nose section and cockpit fragmented • Wing separated at Stub • All engines separated • LG's separated	A/P hit seawall with nose approx. 914 m. short of runway approach and flipped. Pilot and Copilot Seat Design 4.5 g's Up 7.5 g's Down 3.0 g's Side 1.2 g's Aft A7-8
13. 2-8-76 Van Nuys, Ca. DC-6/B (Partially Surviv.)	3-0-3	Takeoff IC, Gears Extended			Yes, fuel lines in left wing L.E. ruptured. Fire ignited during rescue by sparks during fuselage cutting operation	(3) Trauma	None	• Tore loose from supports, 6 rows	• Fuselage break at FS 261 of cabin • Lower fuselage skin abrasion • Cockpit crushed • Slides failed • MG's separated • Floor buckled	Crashed 1609 m. short of runway onto golf course and hit building A7-11
14. 12-28-78 Portland, Ore. DC 8/D (Partially Surviv.)	10-23-156	Landing F.A., Gears Extended			No, Fuel spill potential from wing separations .92 m. to 1.53 m. outb'd of fuselage. Fuel tank rupture possibility. Airplane was out of fuel.	(10) Trauma (Fwd. comp't and cockpit)	(23) Trauma (including 2 during evac.)	• Seat attachments to floor track (12) (rows 20-22) • F/A, crew and Pax seats separated from floor attachment	• Floor buckling • Fuselage break aft of cockpit • Heavy damage to fuselage underside • Both wings separated • MG's separated • Slides torn by debris • Tree penetration of fuselage (caused serious injuries)	Crashed 9656 m. short of runway in residential area with trees. First hit trees. Evac. time = 2 min. A7-13

γ = flight path angle

4. STRUCTURAL SYSTEM INTERACTION

4.1 Injury Distribution

The injury distribution, as related to the candidate crash scenarios, is shown in tables 4-1 through 4-4 and graphically illustrated in figures 4-1 and 4-2. The breakdown is by numbers of fatalities, serious injuries and either no or minor injuries as well as percentages of the total for each candidate designation. Fatalities and serious injuries are shown as they relate to modes such as trauma, fire, fire and trauma, and evacuation. A general category of miscellaneous, unknown, or undecided, is also shown. In many accident reports no classification of injury is given. The tabulated data shows that for 29 ground-to-ground accidents, fatalities are less than 4 percent and severe injuries are approximately 9 percent of the total occupants involved in these accidents. The influence of unpredictable hazards, such as ravines and embankments, can be seen in the difference between the GG1 and GG2 statistics; the latter accidents show fatalities and serious injuries reach 12.8 percent and 22.6 percent, respectively, of the total occupants involved in 9 related accidents. One accident of this nature resulted in 47 fire related fatalities and 49 injuries. Otherwise, trauma would be considered the most frequent mode of injury for ground-to-ground accidents.

Table 4-3 and figures 4-1 and 4-2 provide data for the hard landing accidents, which are in the AG1 or AGHL designation. The only fatalities occurred in one accident and were associated with fire and/or trauma. Trauma injuries occur to about 5 percent of the occupants. Another 5 percent of the occupants sustained injuries while the unknown are probably trauma related since no fire occurred.

TABLE 4-1. - SUMMARY OF INJURY DISTRIBUTION

	Candidate Crash Scenarios*						
	GGO		AGHL	AGI			
	GG1	GG2	AG1	AG2	AG3	AG4	Totals
Number of Accidents	20	9	11	4	8 (2)	14 (3)	66
Fatalities	4	94	43	208	287 (157)	493 (196)	1129
Serious Injuries	71	166	170	23	131 (81)	185 (19)	748
Minor/None	1930	475	1168	240	8 (0)	180 (0)	3199
Total	2007	735	1381	472	426 (138)	858 (215)	5879
Fatalities							
Trauma	–	9	–	2	195 ② (99)	197 (41)	403
Burns and/or Inhalation	2	47 ①	–	95 ③	33 (0)	79 (0)	256
Burns and/or Trauma	–	38	43 ③	33	59 (58)	102 (85)	275
Evacuation	–	–	–	–	–	–	–
Misc., Unk., Unident.	2	–	–	77	–	115 (70)	194
Serious Injury							
Trauma	16	82	67	7	99 (67)	123 (6)	393
Burns and/or Inhalation	–	–	28	9	3 (0)	–	40
Burns and/or Trauma	–	68 ①	–	–	29 (14)	36 (1)	133
Evacuation	51	16	5	2	–	2 (0)	76
Misc., Unk., Unident.	4	–	70	5	–	24 (12)	106

( ) Applicable to nonsurvivable accidents

*GGO = Ground to Ground, Overrun
AGHL = Air to Ground, Hard Landing
AGI = Air to Ground, Impact

① All fatalities and 49 injuries occurred in one accident

② 182 fatalities occurred in two accidents

③ All fatalities occurred in one accident

TABLE 4-2. - GROUND-TO-GROUND OVERSHOOT CANDIDATE CRASH SCENARIO INJURY DISTRIBUTION

Accident Scenario	GG1	GG2	GG0
No. of Accidents	20	9	29
Fatalities	4 (0.2)	94 (12.8)	98 (3.6)
Serious Injuries	71 (3.5)	166 (22.6)	237 (8.7)
Minor/None	1930 (96.3)	475 (64.6)	2405 (87.7)
Total	2005	735	2740
Fatalties			
Trauma	0 (0)	9 (1.2)	9 (0.3)
Fire	2 (0.1)	47 (6.4)	49 (1.8)
Fire and/or Trauma	0	38 (5.2)	38 (1.4)
Unidentified	0	0	0
Evacuation	0	0	0
Miscellaneous	2 (0.1)	0	2 (0.1)
Serious Injury			
Trauma	16 (0.80)	82 (11.2)	98 (3.5)
Fire	0	0	0
Fire and/or Trauma	0	68 (9.2)	68 (2.5)
Unidentified	0	0	0
Evacuation	51 (2.5)	16 (2.2)	67 (2.4)
Miscellaneous	4 (0.2)	0	4 (0)

( ) = Percentage of total number of occupants for each crash scenario candidate

TABLE 4-3. - AIR-TO-GROUND HARD LANDING CANDIDATE CRASH SCENARIO INJURY DISTRIBUTION

Scenario	AGHL
No. Accidents	11
Fatalities	43 (3.1)
Serious Injuries	170 (12.3)
Minor/None	1168 (84.6)
Total	1381
Fatalities	
Trauma	0
Fire	0
Fire and/or Trauma	43 (3.1)
Evacuation	0
Miscellaneous	0
Serious Injury	
Trauma	67 (4.9)
Fire	28 (2.0)
Fire and/or Trauma	0 (0)
Evacuation	5 (0.4)
Miscellaneous	70 (5.1)

( ) = Percentage of Total Number of Occupants

Severe impact air-to-ground accidents involve undershoots, collision with ground (either controlled or uncontrolled), and stalls. These are in designations AG2, AG3, and AG4. The total of 26 such accidents (table 4-4) shows that over 56 percent of the occupants receive fatal injuries and over 19 percent sustain serious injuries. Excluding 5 NTSB designated non-survivable accidents, these statistics change to 49 percent and 18 percent, respectively. Fatal injuries in this category are associated with trauma (22.6 percent), burns and smoke inhalation (11.8 percent), burns and/or trauma (11 percent) and unknown but probably burns, trauma or both (11 percent). Similarly, serious injuries in this category are associated with trauma (13 percent), burns and/or trauma (3.9 percent), unknown (2 percent) and

TABLE 4-4. - AIR-TO-GROUND IMPACT CANDIDATE CRASH SCENARIO INJURY DISTRIBUTION

Scenario	AG2	AG3	AG4	AGI	AGI*
No. Accidents	4	8	14	26	21
Fatalities	208 (44)	287 (67.3)	493 (54.5)	987 (56.3)	634 (48.7)
Serious Injury	23 (4.8)	131 (30.8)	185 (21.5)	339 (19.3)	239 (18.4)
Minor/None	240 (51.2)	8 (1.9)	180 (21.0)	428 (24.4)	428 (32.9)
Total	472	426	858	1754	1302
Fatalities					
Trauma	3 (0.4)	195 (45.8)	197 (23.0)	394 (22.5)	255 (19.5)
Burns and/or Inhalation	95 (20.2)	33 (7.7)	79 (9.2)	207 (11.8)	207 (15.9)
Burns and/or Trauma	33 (7)	59 (13.8)	102 (11.9)	194 (11)	51 (3.9)
Evacuation	0	0	0	0	0
Miscellaneous, Undet.	77 (16.4)	0	115 (13.4)	192 (11)	122 (9.4)
Total	208	287	493	987	635
Serious Injury					
Trauma	7 (1.5)	99 (23.3)	123 (14.3)	229 (13)	156 (12)
Burns and Smoke Inhalation	9 (1.9)	3 (0.7)	0	12 (0.7)	12 (0.9)
Burns and/ Trauma	0	29 (6.8)	36 (4.2)	65 (3.7)	50 (3.9)
Evacuation	2 (0.4)	0	2 (0.2)	4 (0.2)	4 (0.3)
Miscellaneous, Undet.	5 (1.0)	0	24 (2.8)	29 (1.7)	17 (1.3)
Total	23	8	185	339	239

* Excluding nonsurvivable accidents.

( ) = Percentages of total for each accident category

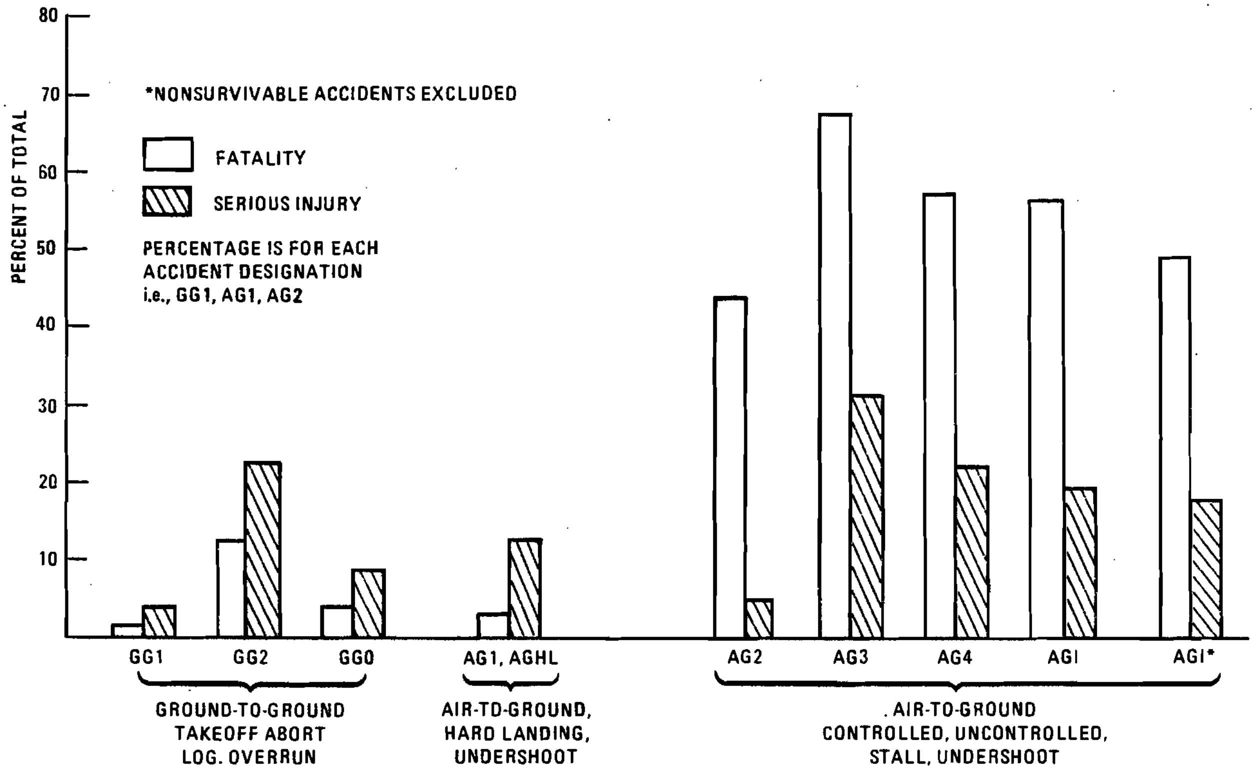


Figure 4-1. - Percentage of occupants sustaining fatal or serious injuries as related to candidate crash scenarios.

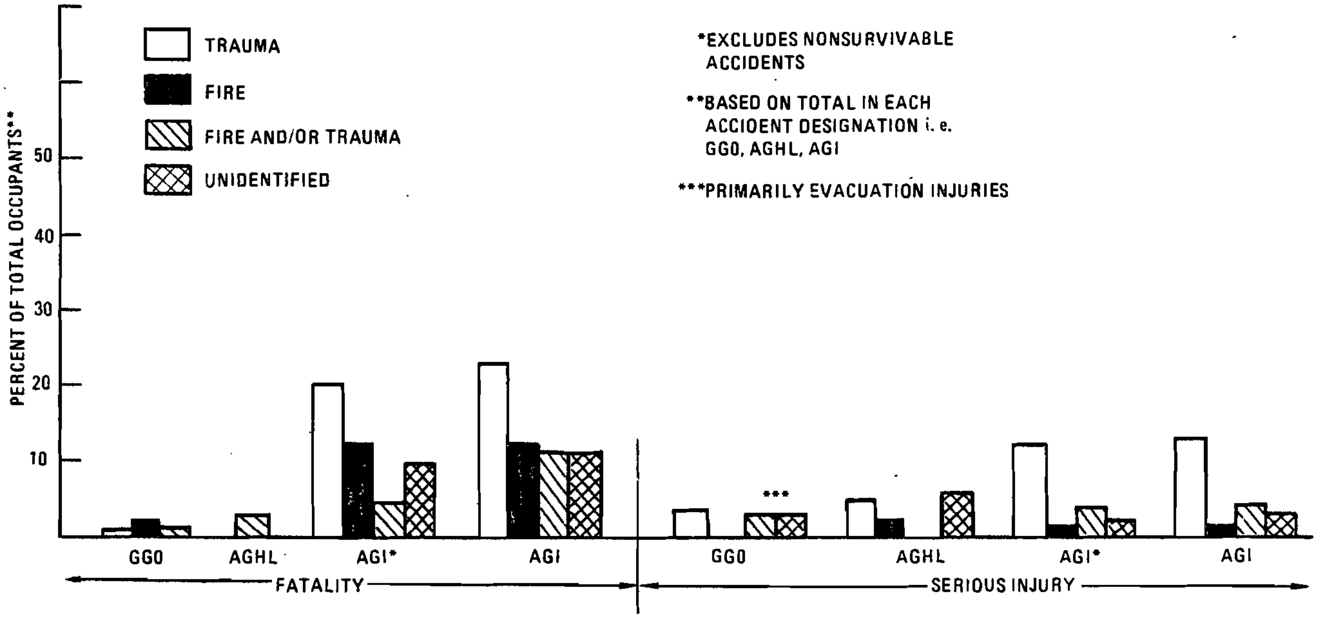


Figure 4-2. - Distribution of injury and fatality modes as related to candidate crash scenario.

burns or smoke inhalation (<1 percent). From figures 4-1 and 4-2 it can be seen that the totals shift somewhat with the exclusion of nonsurvivable accidents, but the same trend exists with regard to injury mode. Figures 4-3 through 4-6 give some indication of the contributing factors. Figure 4-6, in particular, indicates the severity of the accident both in regard to survivability and fuselage breakup which relates very strongly to a large number of fatalities and serious injuries. The involvement of the structure and systems such as airframe, landing gear, fuel containment, and seats and restraints is described later in this section.

4.2 Seat and Restraint Systems

A review of accidents with regard to seat and restraint system performance is described. Table 4-5 summarizes the total number of accidents, number of seat performance accidents, the total number of occupants injured and the number of occupants injured in which seat performance is cited. From table 4-5 it can be noted that the ratio of injuries in seat performance cited accidents to total number of injuries is higher for AG3 and AG4 accident types than for GG1, GG2, AG1 and AG2 accident types. The AG3 and AG4 accident types have a substantially higher incidence of fuselage separation, fuselage disintegration, cabin collapse and floor disruption than the other accident types. The major contributing injury factor in accidents in which seat performance is cited appears to be airframe and/or floor integrity and not seat integrity. The 35 accidents in which seat performance is cited are shown in table 4-6. The association with fuselage breakup and the types of hazards involved are evident in the tabulated data.

Figures 4-7 through 4-10 give some indication of contributing factors for crash scenarios GG1, GG2, AG1 and AG2. Since fuselage separation, disintegration and/or floor disruption occurs in nearly all crash scenario AG3 and AG4 accidents, no seat performance flow chart is presented for them. AG3 and AG4 type accidents include 8 propeller aircraft out of a total of 22 accidents and 5 NTSB designated nonsurvivable accidents.

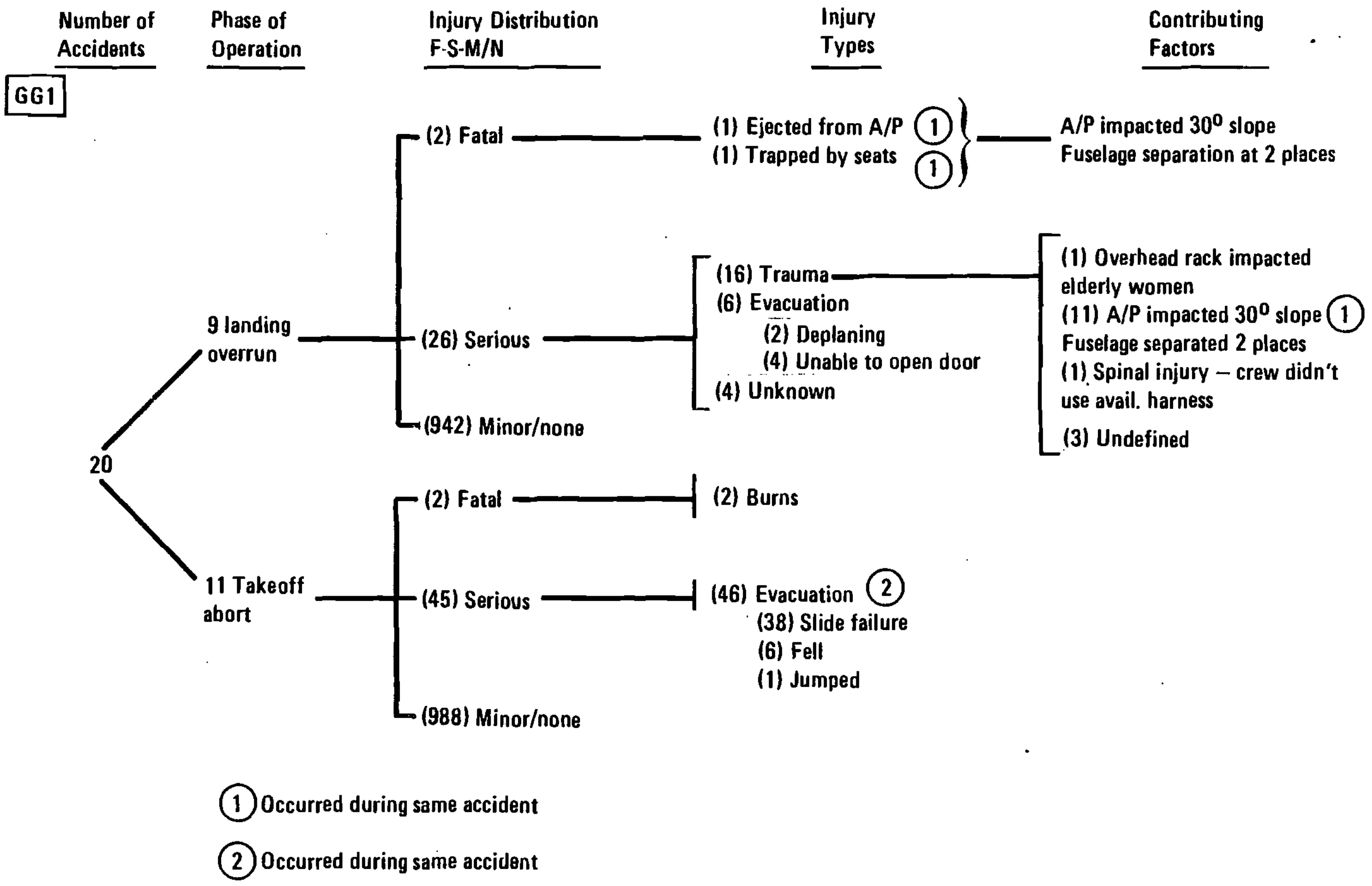


Figure 4-3. - Injury distribution, GG1 crash scenario.

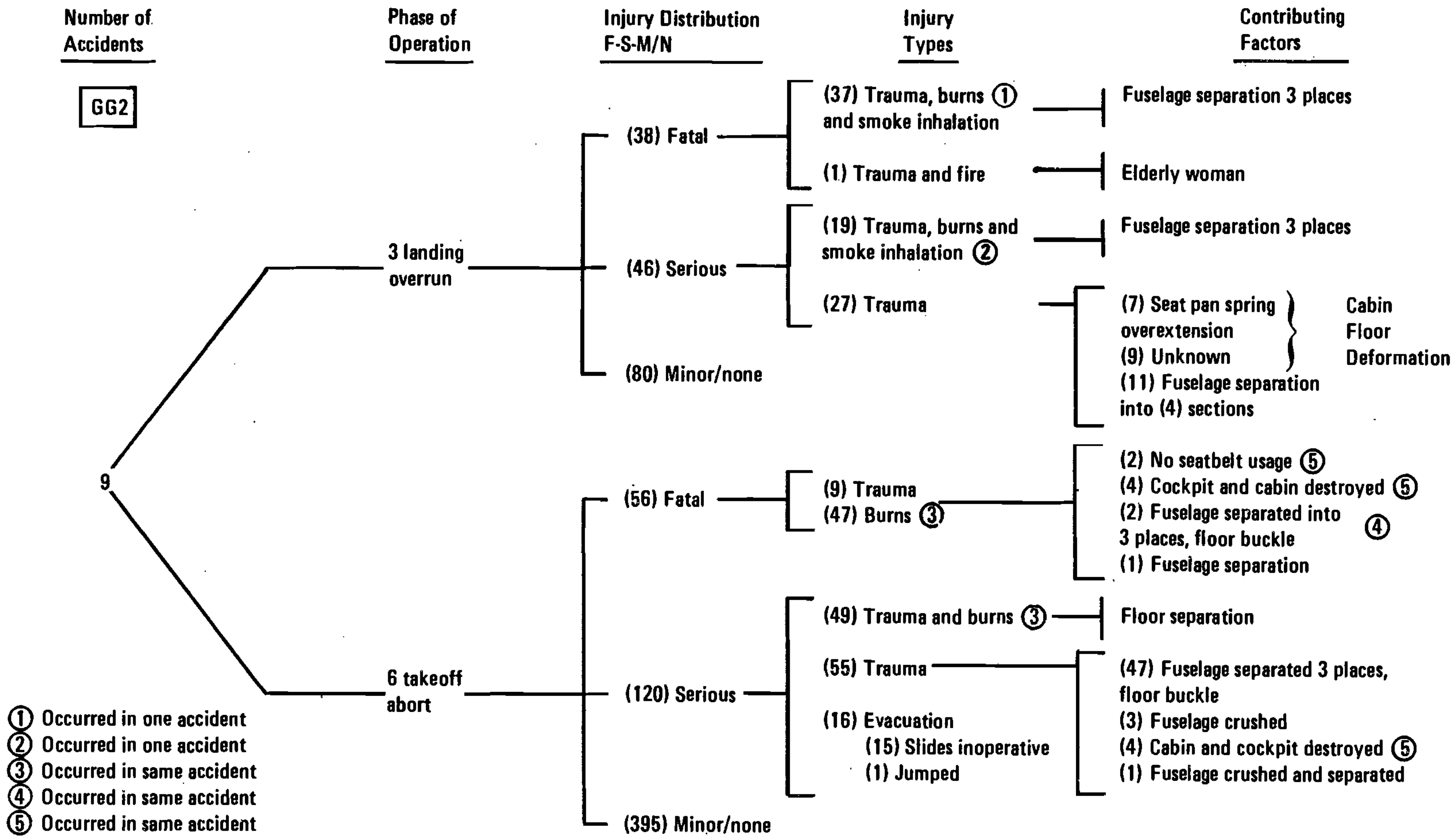


Figure 4-4. - Injury distribution, GG2 crash scenario.

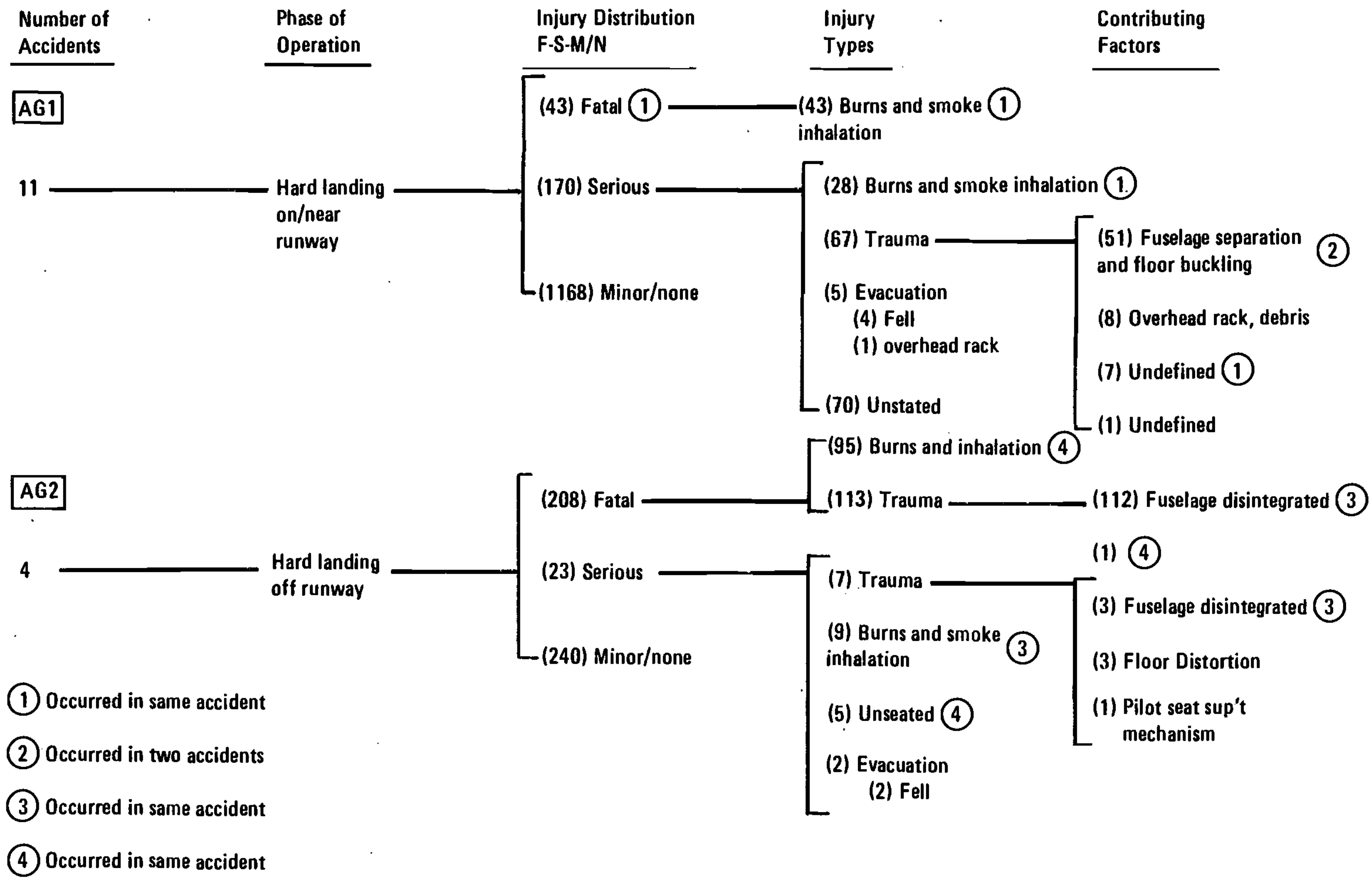


Figure 4-5. - Injury distribution, AG1 and AG2 crash scenarios.

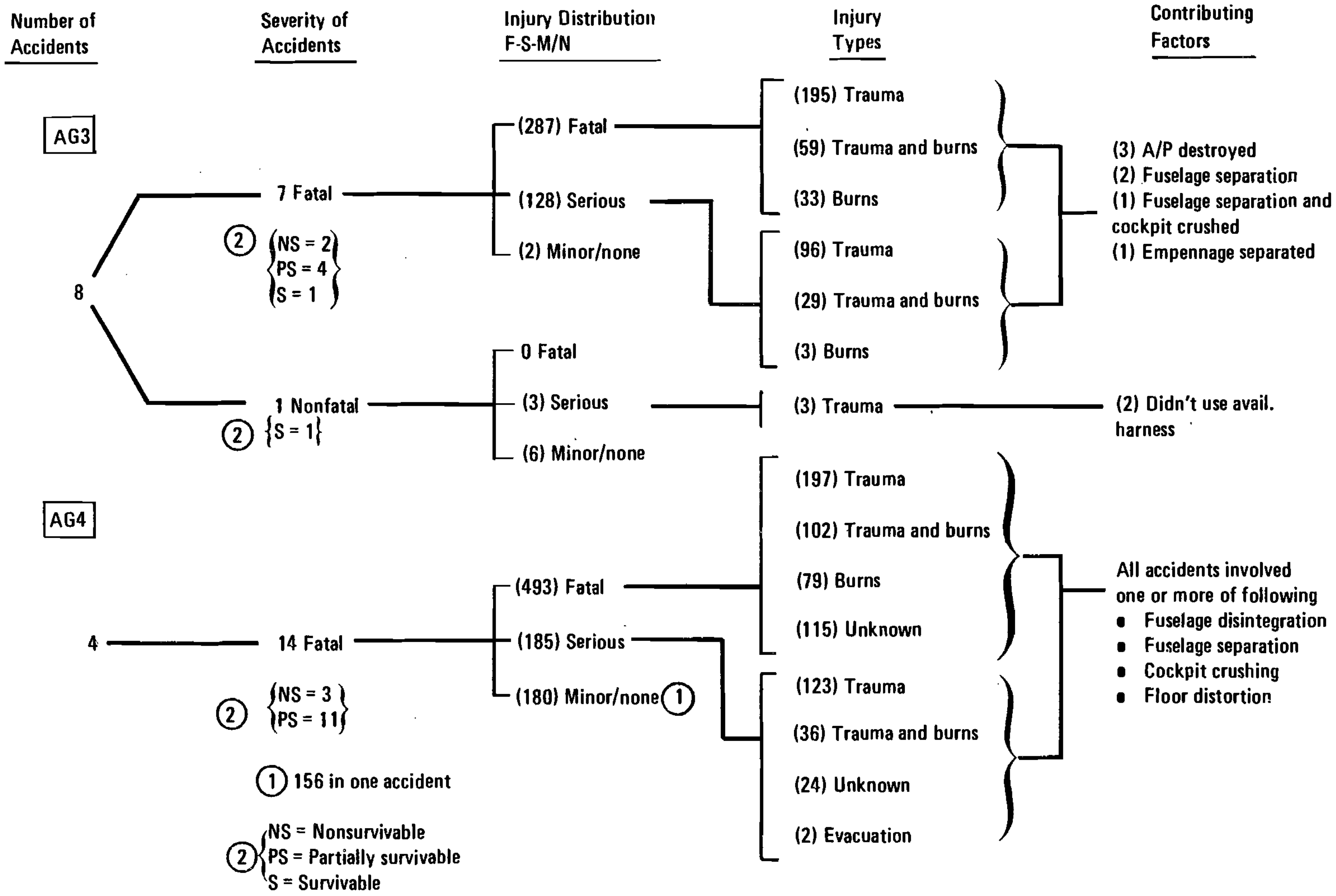


Figure 4-6. - Injury distribution, AG3 and AG4 crash scenarios.

TABLE 4-5. - SUMMARY OF SEAT PERFORMANCE ACCIDENTS

	Candidate Crash Scenarios*						
	GGO		AGHL	AGI			
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	20	9	11	4	8	14	66
Number of Accidents Involving Seat Performance	3	6	6	3	5	12	35
Serious (Trauma Only) Injuries in Seat Performance Accidents	15	78	63	6	95	125	382
Total Number of Serious Injuries in all Accidents	73	166	170	23	131	185	748
Serious (Trauma Only) Injuries in Accidents Involving Seat Performance as well as Fuselage Separation, Disintegration and/or Floor Disruption	15	78	52	6	92	125	368

① Incidence of fuselage separation, fuselage disintegration and/or floor disruption in these accidents is 100% in each category.

② 47 injuries occurred in one accident involving fuselage separation at 2 locations, (See Figure 4-9).

③ 36 injuries involved in one accident in which cabin floor buckled, lower frames crushed and fuselage tail section separated, (See Figure 4-10).

* GGO = Ground to Ground, overrun

AGHL = Air to Ground, Hard Landing

AGI = Air to Ground, Impact

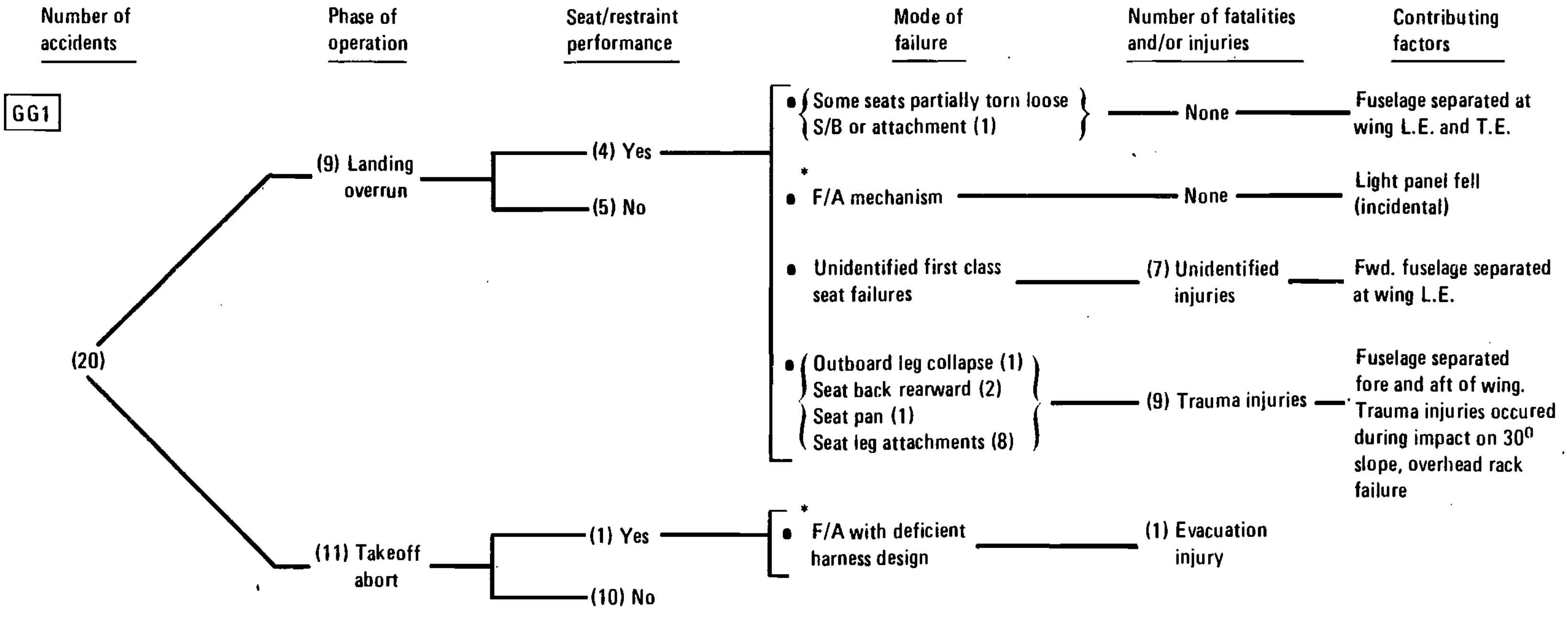
TABLE 4-6. - SEAT PERFORMANCE CITED ACCIDENTS

Accident ①	Fuselage Break/Damage ②										Floor Buckle/ Collapse	Lower Fuselage Crush	Cockpit Cabin Crush	Obstacles/ Hazard	Terrain	No. Trauma Only Injuries	Comments
	a	b	c	d	e	f	g	h	i								
GG1-1		X													Water	3	
-6					X									Road		1	
-11					X									30° Slope		11	
GG2-1				X							X			Embankment		16	
-2							X							Ravine		11	
-3							X							Embankment		–	
-6		X											X	Ditch, Canal		4	
-7					X						X			Ravine		47	
-9						X								Ditch	Rough	–	
AG1-2												X			Runway	8	
-4				X											Runway – Soft Dirt	1	
-5				X							X	X			Runway	36	
-6					X						X				Hard Grass	15	
-8			X								X				Grassy Dirt	0	
-9															Grass	0	
AG2-2								X			X			Approach Lights, Embankment	Rough	2	
-3											X	X		Approach Light, Dike		3	
-4			X								X			Approach Light, Pier, Embankment		1	
AG3-2	X	X												Hill		–	
-3				X										Hill		9	
-5								X						Everglades		63	
-6							X				X		X	Mountain		20	
-8									X					Tree Grove		3	
AG4-2				X							X			Hanger		16	Deep Roll, Inverted
-3								X						Houses, Trees		–	
-4		X			X									Houses, Trees		6	
-5								X						Wooded, Ravine		–	
-6							X						X	Bldg., Vehicles, Trees		–	
-7			X											Wooded		19	
-8								X						Trees		12	
-9			X											Trees		17	
-11						X							X	House		32	
-12				X									X	Seawall		–	
-13	X										X	X	X	Building		–	
-14	X										X	X		House, Trees		23	Tree Penetration Factor

① See Table 3-4 for accident identification.

② Location

(a) = Aft of Cockpit
(b) = Aft of Wing L.E.
(c) = Aft of Wing T.E.
(d) = Fwd. of Empennage
(e) = At (b) & (c)
(f) = At (a) & (d)
(g) (3) or (4) breaks
(h) A/P Destroyed
(i) = Airframe Wrinkled/Torn

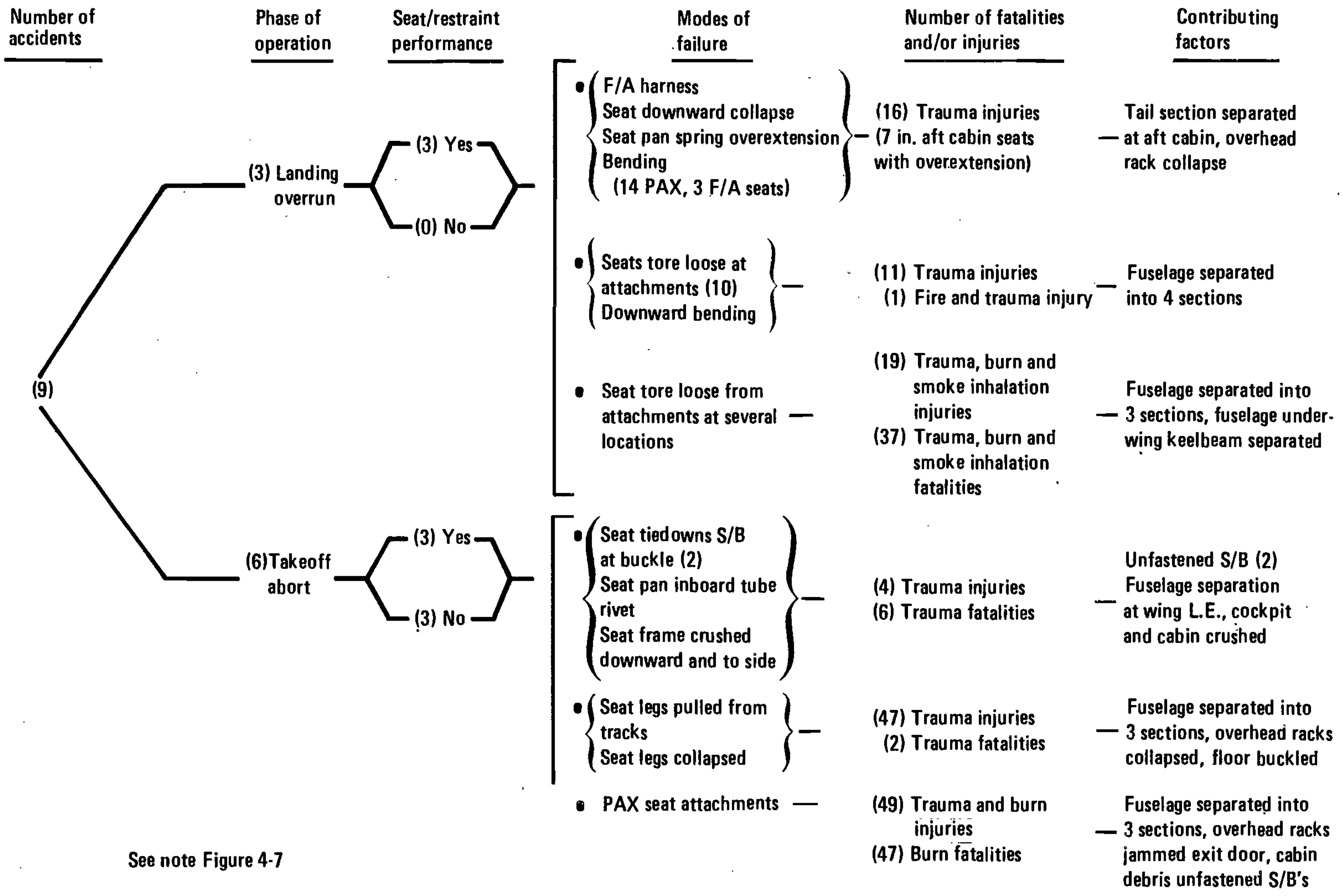


S/B = Seat belt
F/A = Flight attendant
L.E. = Leading edge
T.E. = Trailing edge
(X) = Number involved

PAX = Passenger

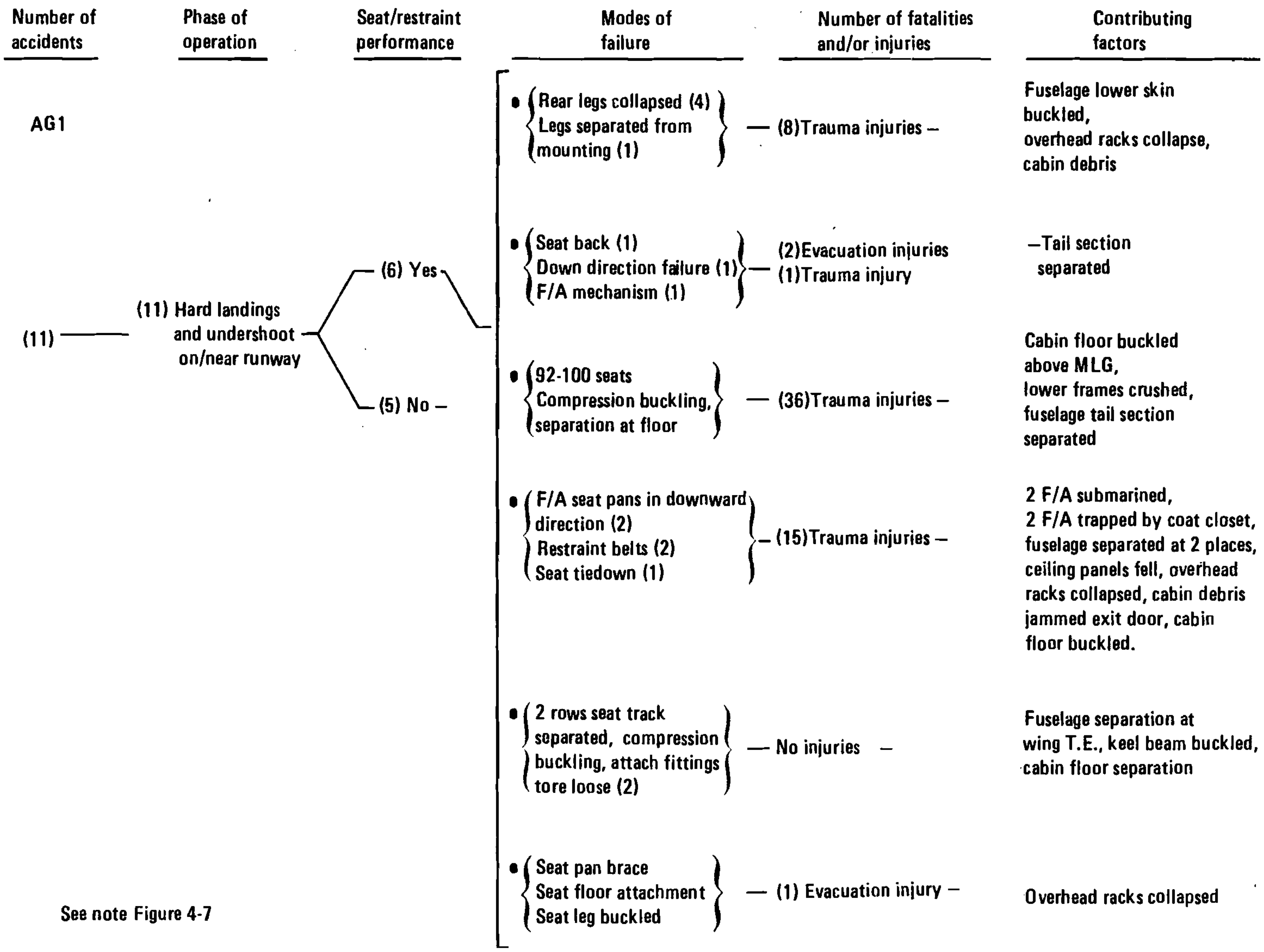
*Not included in Table 4-5 summary

Figure 4-7. - Seat performance GG1 crash scenario.



See note Figure 4-7

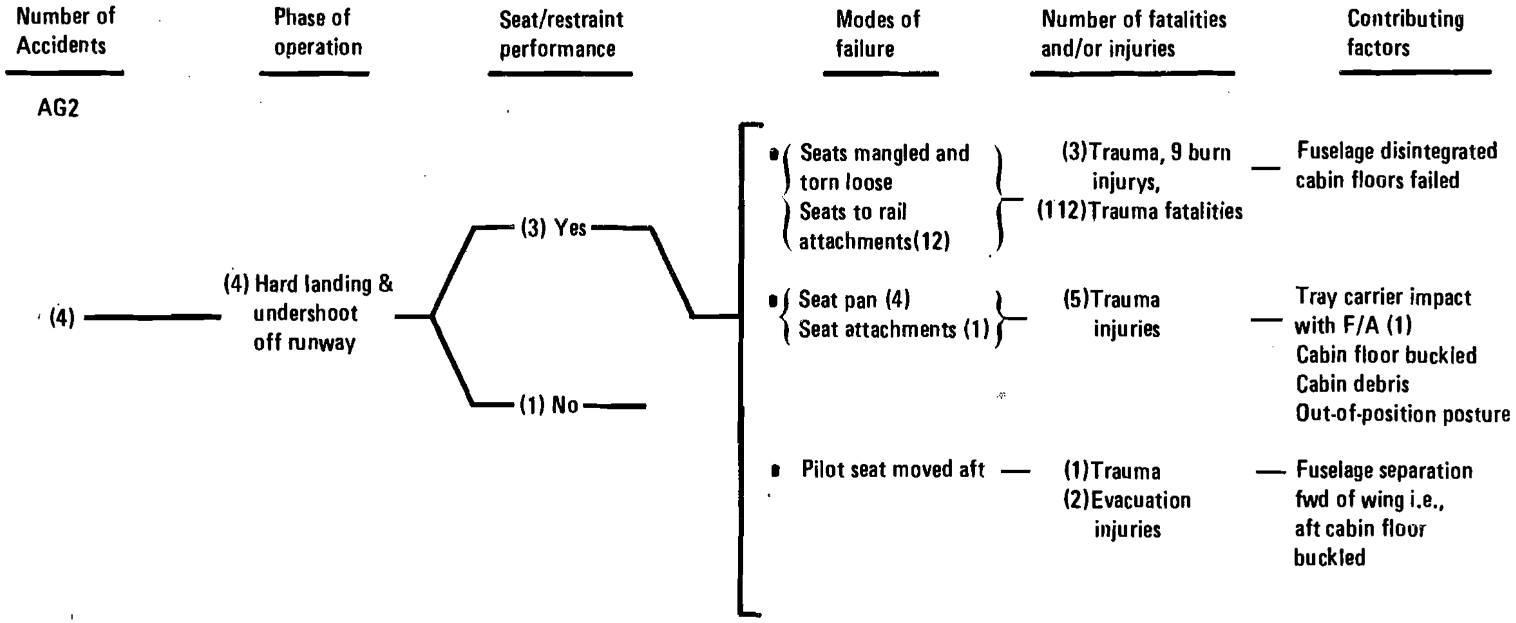
Figure 4-8. - Seat performance, GG2 crash scenario.



Number of accidents	Phase of operation	Seat/restraint performance	Modes of failure	Number of fatalities and/or injuries	Contributing factors
AG1 (11)	(11) Hard landings and undershoot on/near runway	(6) Yes (5) No	Rear legs collapsed (4) Legs separated from mounting (1)	(8)Trauma injuries	Fuselage lower skin buckled, overhead racks collapse, cabin debris
			Seat back (1) Down direction failure (1) F/A mechanism (1)	(2)Evacuation injuries (1)Trauma injury	–Tail section separated
			92-100 seats Compression buckling, separation at floor	(36)Trauma injuries	Cabin floor buckled above MLG, lower frames crushed, fuselage tail section separated
			F/A seat pans in downward direction (2) Restraint belts (2) Seat tiedown (1)	(15)Trauma injuries	2 F/A submarined, 2 F/A trapped by coat closet, fuselage separated at 2 places, ceiling panels fell, overhead racks collapsed, cabin debris jammed exit door, cabin floor buckled.
			2 rows seat track separated, compression buckling, attach fittings tore loose (2)	No injuries	Fuselage separation at wing T.E., keel beam buckled, cabin floor separation
			Seat pan brace Seat floor attachment Seat leg buckled	(1) Evacuation injury	Overhead racks collapsed

See note Figure 4-7

Figure 4-9. - Seat performance, AG1 crash scenario.



See note Figure 4-7

Figure 4-10. - Seat performance, AG2 crash scenario.

The review of seat performance in accidents also includes a flow diagram of each accident which describes load type and direction, seat location and failure, failure mode, post-crash motion, and seat-related injuries, insofar as the accident data allow such an assessment. A sample seat performance flow diagram is shown in figure 4-11.

The results of the review of the seat performance indicate that the seats and restraint systems designed to current FAA criteria are providing a system that protects the occupant. To help explain the reason the current 9G static strength seats perform adequately in a dynamic crash environment, the L1649 Constellation (reference 7) crash test data are presented in figures 4-12 and 4-13, to illustrate the dynamic relationship between floor acceleration, seat and occupant responses.

Figures 4-12a, b, and c show measured longitudinal acceleration response for forward cabin floor, seat and occupant pelvis. The seats in this location remained in place during the crash test. The seats experienced no lateral deterioration.

Vertical loading caused slight downward bending of both front and aft lateral seat frame tubes. The time histories of 4-12a, b and c are associated with three distinct events: a) impact with poles, b) impact onto a 6 degree slope, and c) impact onto a 20 degree slope, respectively.

It can be observed from figure 4-12a that at approximately 0.300 seconds, the floor exhibits a few short pulses in the range ±12 g* and a duration of less than 0.020 seconds. The seat and occupant do not respond to these pulses and show magnitudes less than 5 g. From figure 4-12b it can be observed that the floor exhibits a sharp 22 g forward acceleration with a pulse of less than 0.020 seconds at 0.90 seconds in time. Neither the seat or the occupant respond to this pulse at that time. As can be noted, the seat responds in the time period from 1.00 to 1.20 seconds with an overall response of approximately -5 g. Also, the data exhibit a higher frequency oscillation. The occupant pelvis exhibits responses between 1.10 to 1.30 seconds which approach -10 g for durations of up to 0.030 seconds.

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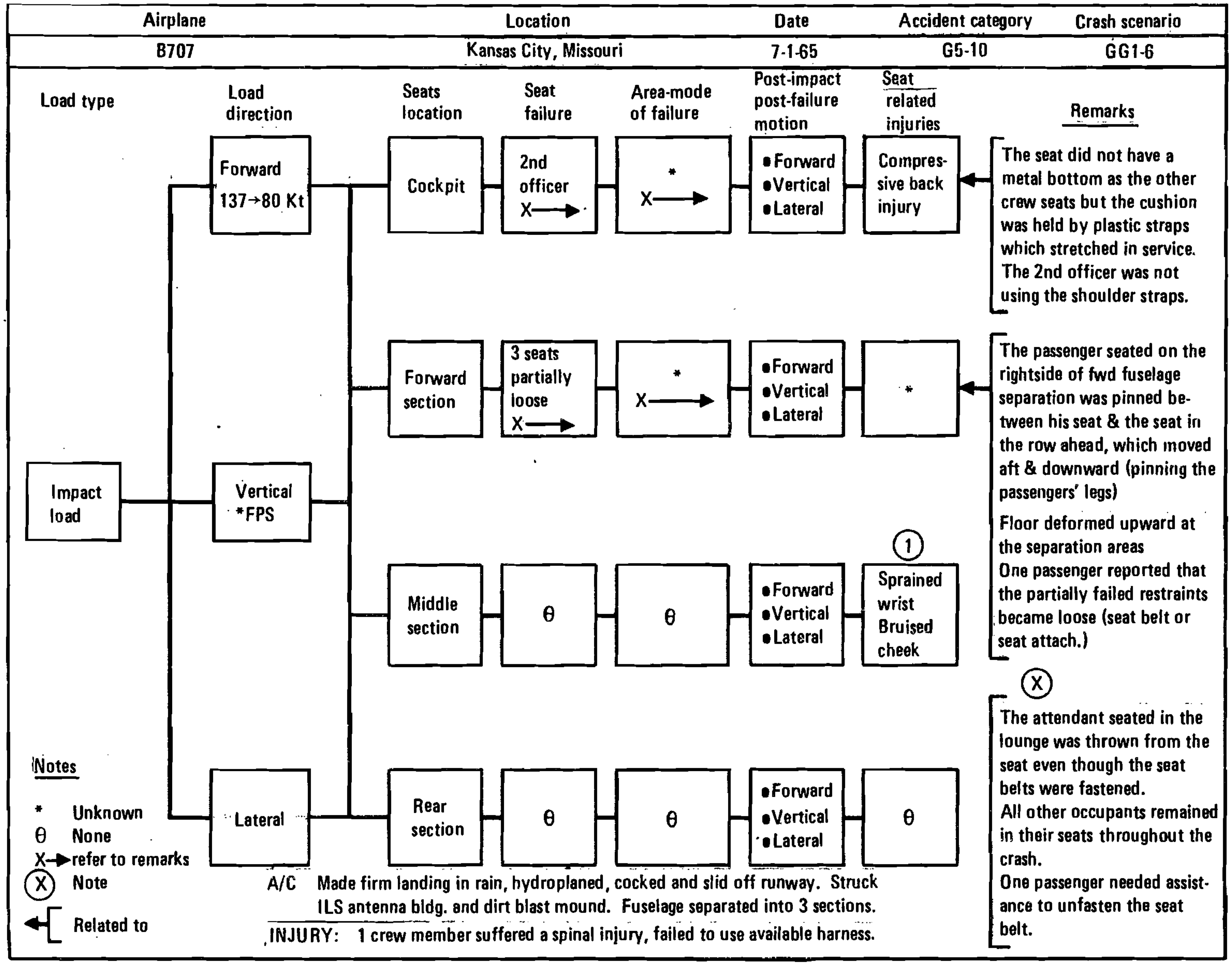
*(A + acceleration represents the occupant applying a forward or a down load to the seat)



Airplane	Location	Date	Accident category	Crash scenario
B707	Kansas City, Missouri	7-1-65	G5-10	GG1-6

The seat did not have a metal bottom as the other crew seats but the cushion was held by plastic straps which stretched in service. The 2nd officer was not using the shoulder straps.

The passenger seated on the rightside of fwd fuselage separation was pinned between his seat & the seat in the row ahead, which moved aft & downward (pinning the passengers' legs)

Floor deformed upward at the separation areas

One passenger reported that the partially failed restraints became loose (seat belt or seat attach.)

The attendant seated in the lounge was thrown from the seat even though the seat belts were fastened.

All other occupants remained in their seats throughout the crash.

One passenger needed assistance to unfasten the seat belt.

A/C Made firm landing in rain, hydroplaned, cocked and slid off runway. Struck ILS antenna bldg. and dirt blast mound. Fuselage separated into 3 sections.

INJURY: 1 crew member suffered a spinal injury, failed to use available harness.

Figure 4-11. - Accident seat performance flow diagram.

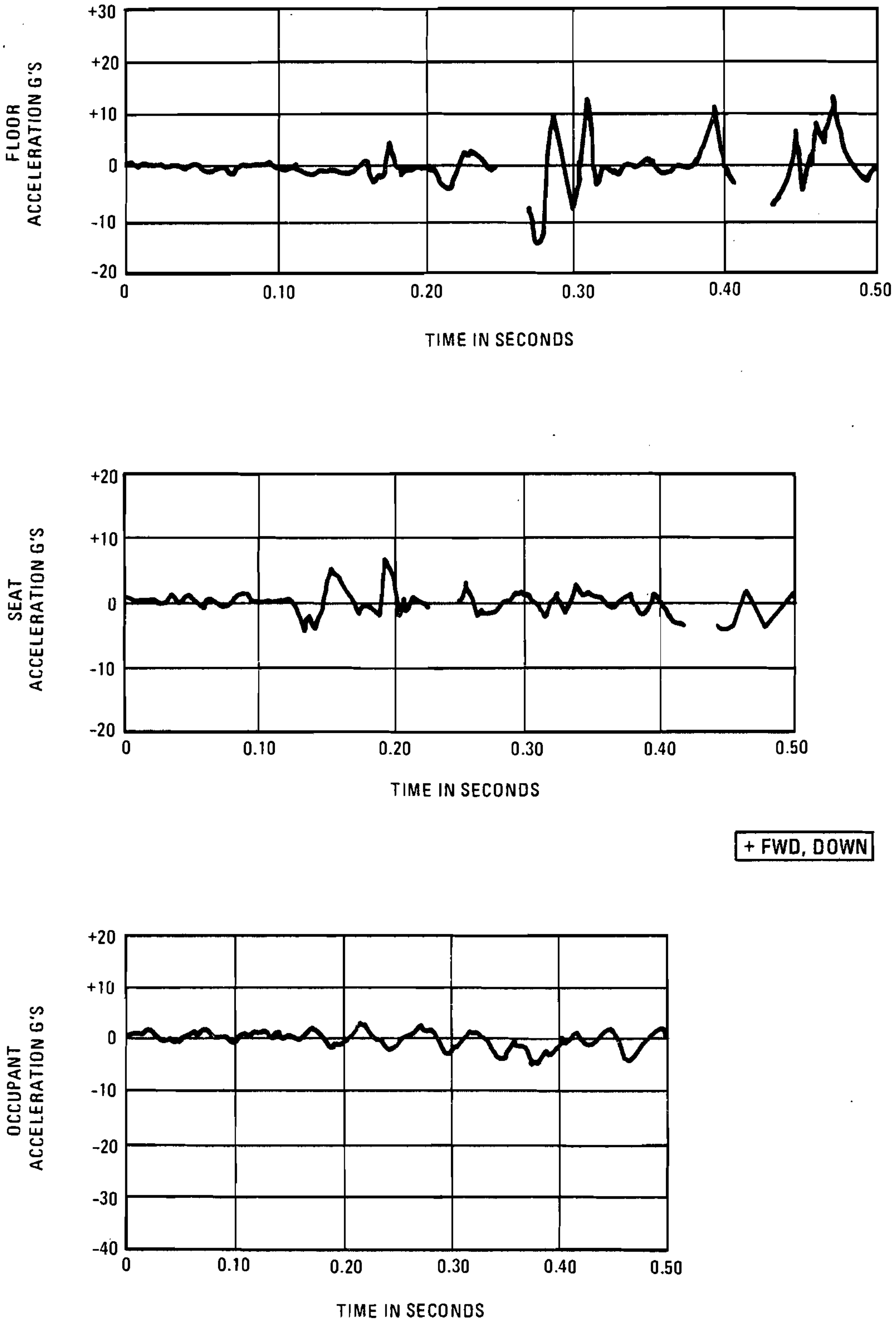


Figure 4-12(a). - L1649 crash test forward cabin longitudinal acceleration - pole impact.

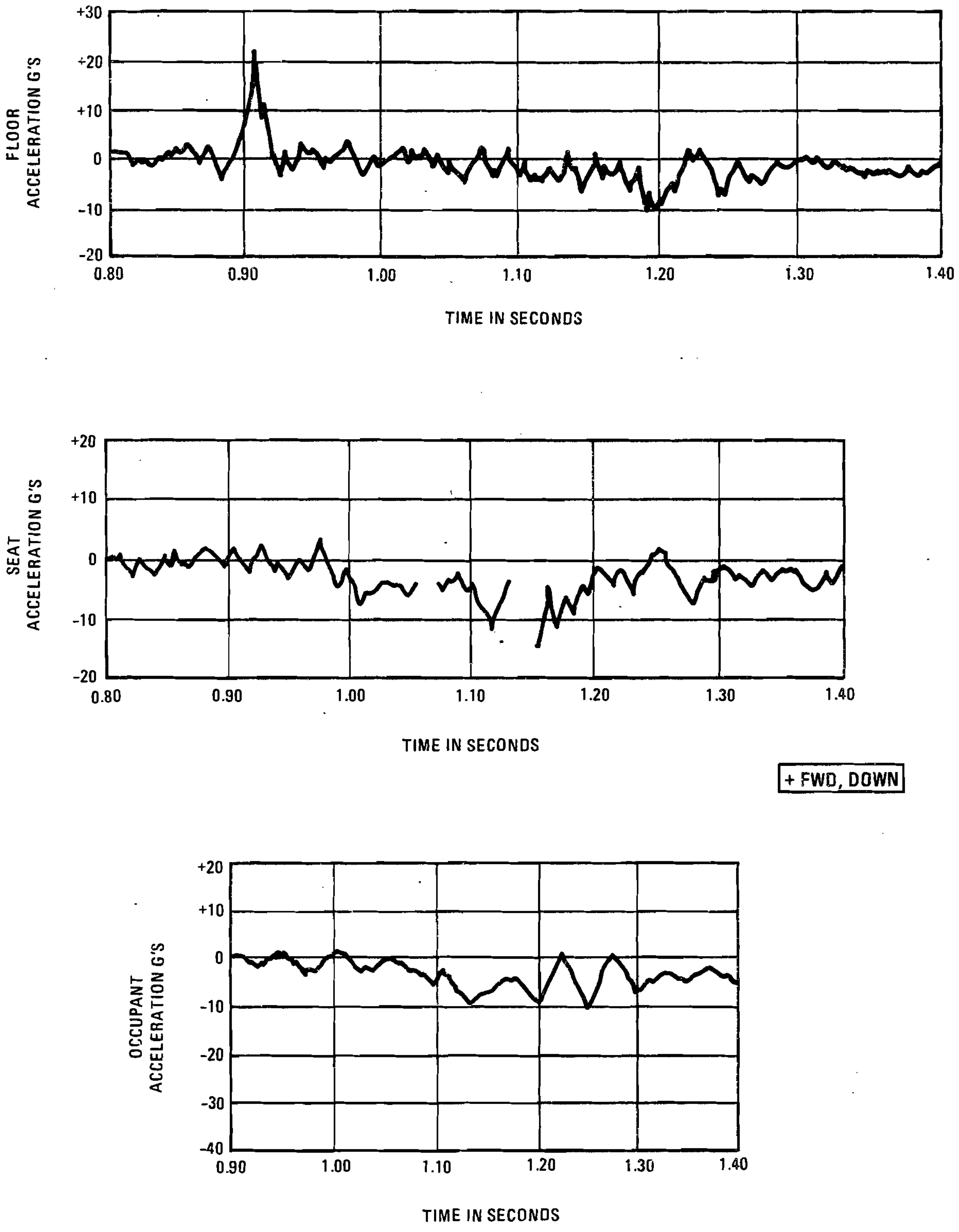


Figure 4-12(b). - L1649 crash test forward cabin longitudinal acceleration - 6° slope impact.

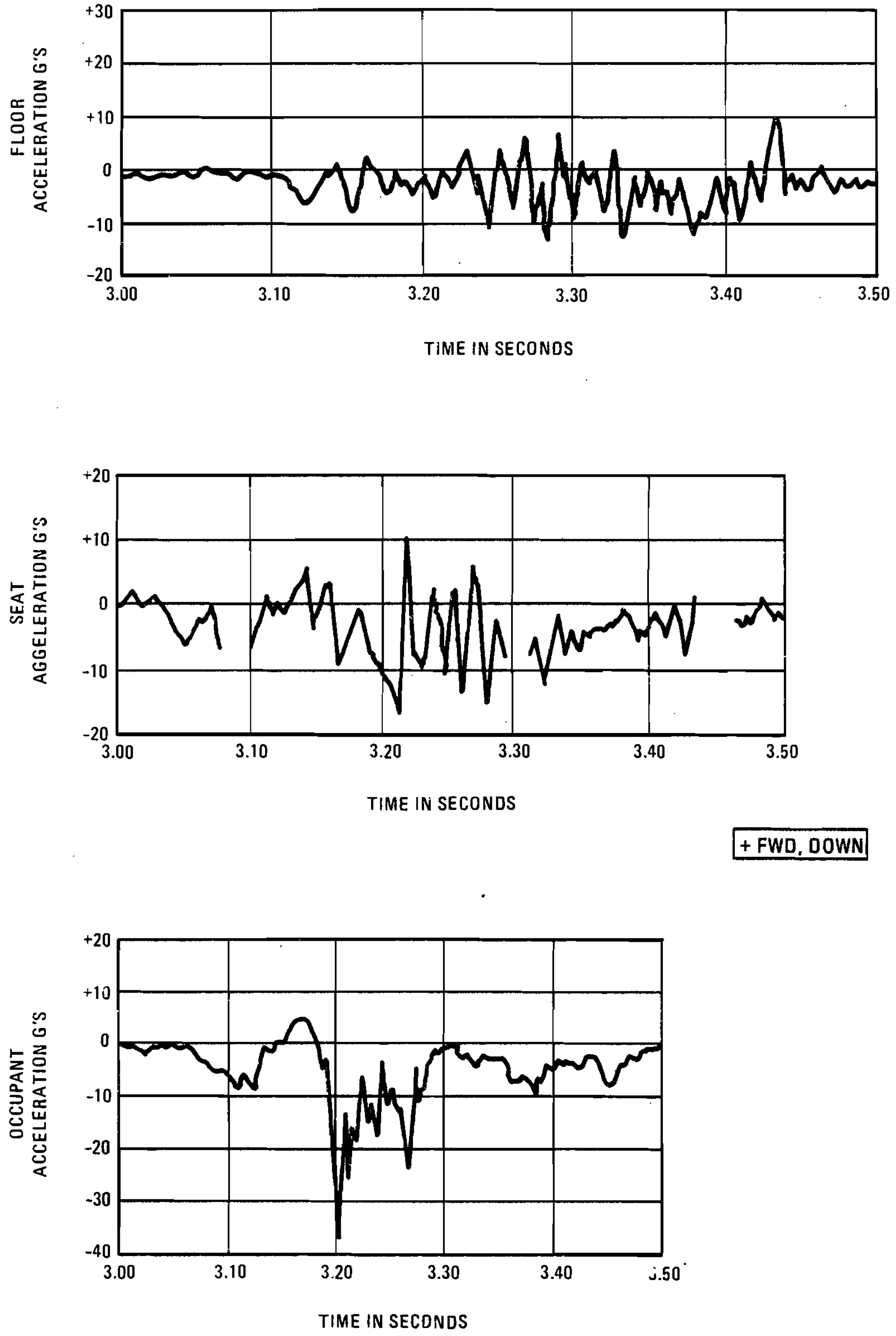


Figure 4-12(c). - L1649 crash test forward cabin longitudinal acceleration - 20° slope impact.

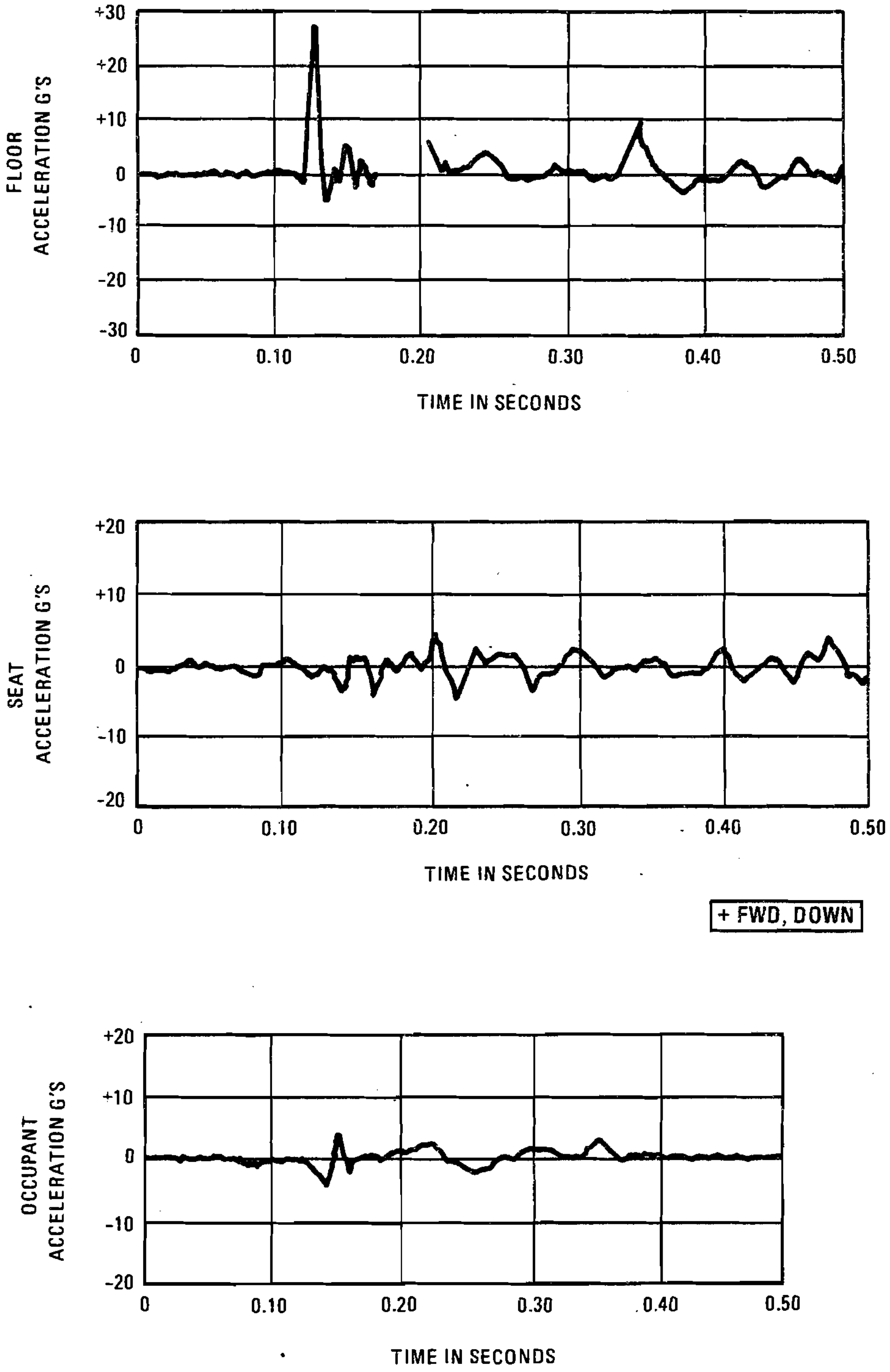


Figure 4-13(a). - L1649 crash test mid cabin longitudinal acceleration - pole impact.

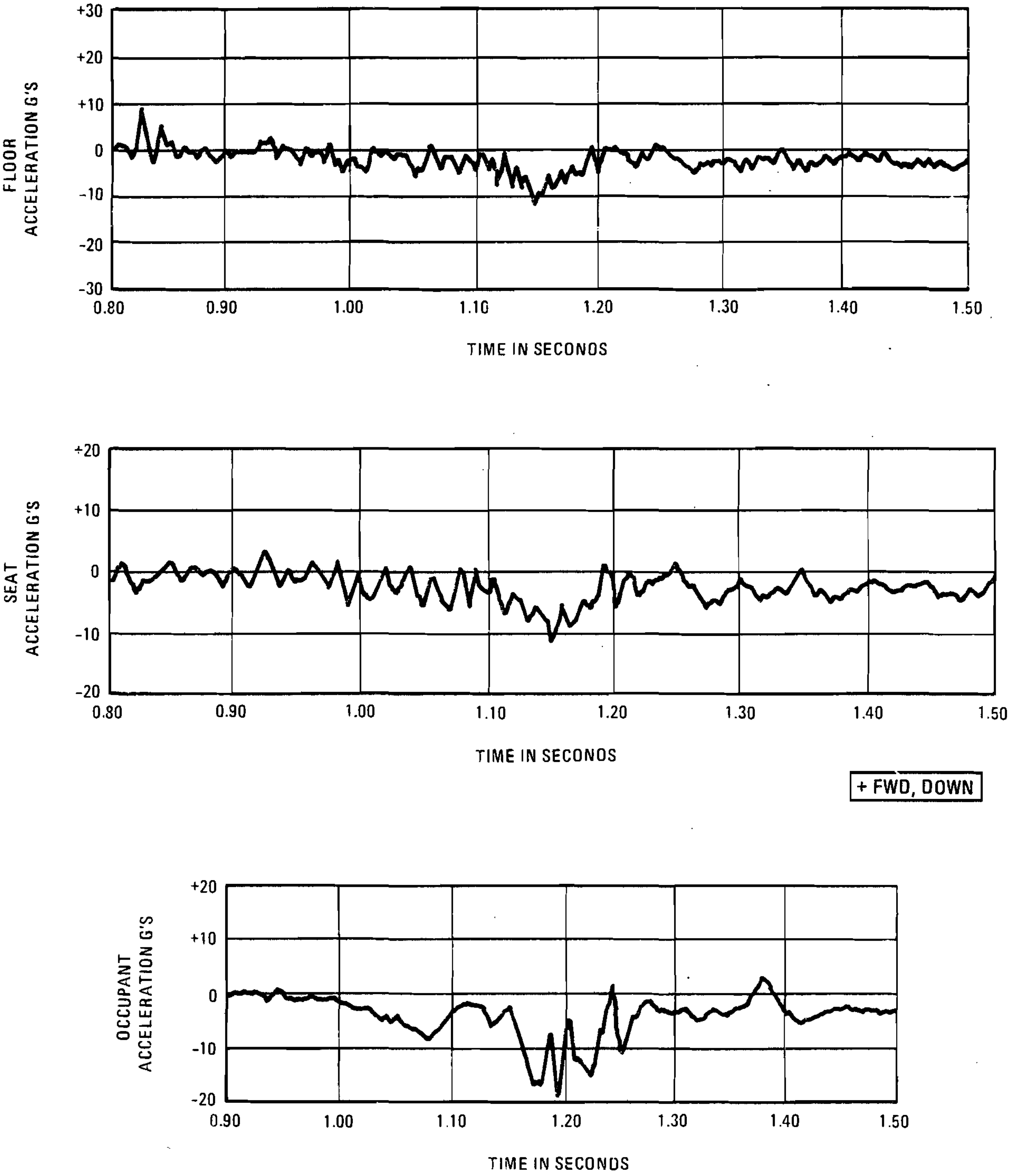


Figure 4-13(b). - L1649 crash test mid cabin longitudinal acceleration - 6° slope impact.

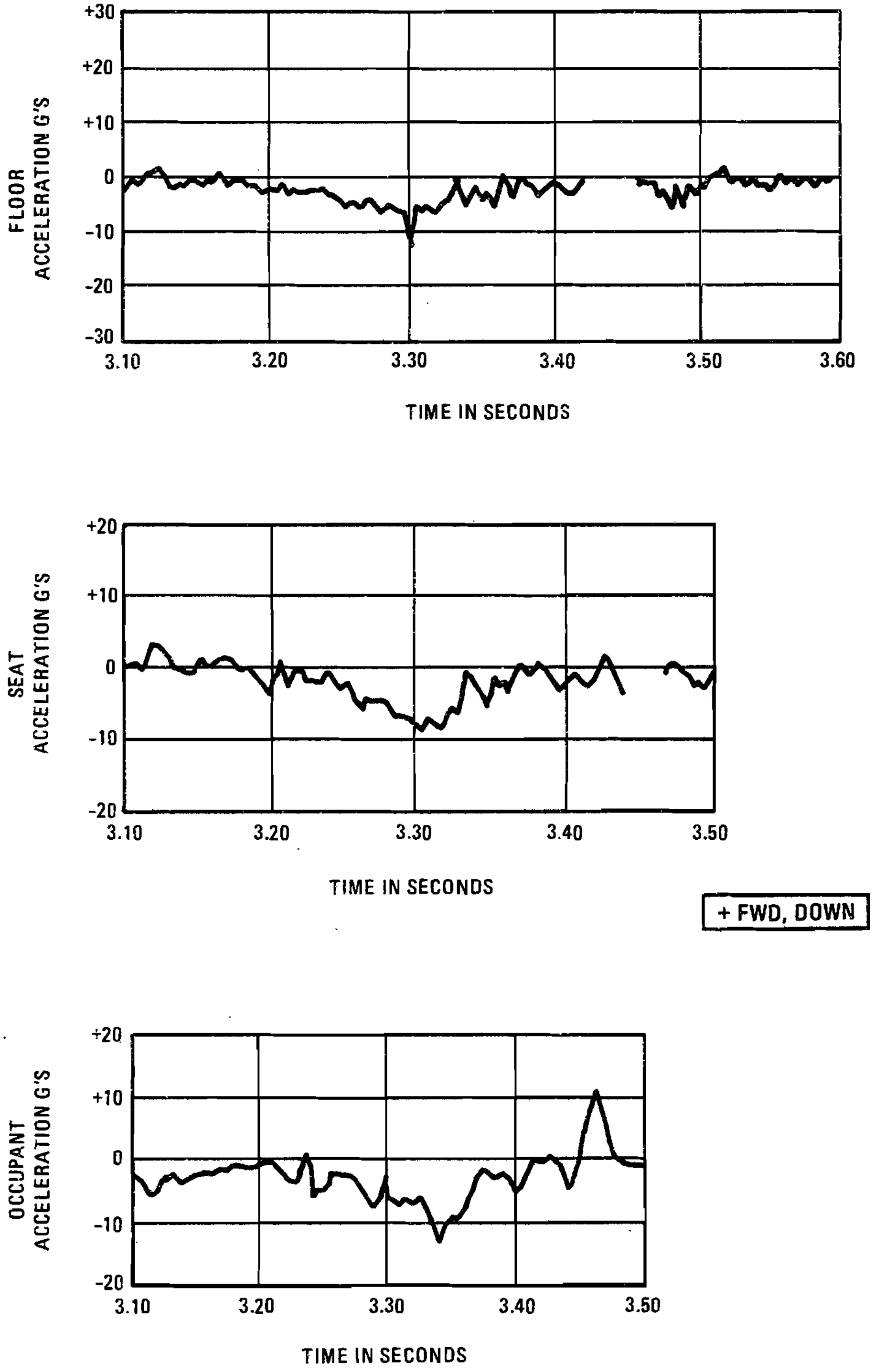


Figure 4-13(c). - L1649 crash test mid cabin longitudinal acceleration - 20° slope impact.

During the third impact event, the floor responds with high frequency ringing of ±10 g magnitude in the time frame from 3.2 to 3.4 seconds. During this same time frame, the seat response exhibits high frequency (0.010 second pulse) with peaks of +10 and -15 g. The occupant pelvis accelerations show some sharp responses, -37 g and -22 g, for a few thousandths of a second. The overall occupant response is an average of approximately -12 g for 0.080 seconds.

Figures 4-13a, b, c, show the measured longitudinal acceleration response for mid-cabin floor, seat and occupant pelvis. The seats in this location did not fail and the dummies remained in the seats. Figure 4-13a shows similar results to 4-12a in that a sharp +25 g short duration (.012 second duration) pulse on the floor is not experienced by the seat and occupant which show no response above 5 g during this time period.

Figure 4-13b shows some correlation of the floor, seat and occupant in the time period of 1.10 to 1.20 seconds. The floor exhibits less than -10 g (probably closer to -5 g overall). The seat exhibits a similar response in this instance.

The occupant shows several sharper responses up to -20 g. However, eliminating these sharp pulses attributed to occupant fore-aft movement, the response for .100 second interval is closer to 10 g. The higher occupant accelerations in Figure 4-13(b) are attributable to dynamic amplification occurring being occupant, seat and floor.

During the 20° slope impact there appear to be peak negative responses at about 3.3 seconds at all three locations approaching 10 to 15 g. Eliminating some of the oscillations the responses would be closer to -5 g over a .100 second response period.

Table 4-7 summarizes the peak g and times of duration for the time history plots shown in figures 4-12 and 4-13. It can be observed that when the wing impacts the pole the fuselage experiences peak g of ±12 to +26 for short (.010 to .020 seconds) duration. While these g levels are in excess of the 9 g requirement, the fuselage doesn't break at this time because the response is too short a duration to transmit detrimental loads. The

TABLE 4-7. - SUMMARY OF FLOOR LONGITUDINAL PEAK ACCELERATIONS L-1649 CRASH TEST DATA

	Impact Condition	Peak	Duration Seconds	Approximate Type
Fwd Cabin	Pole	±12G	≤0.020	Triangular
	6° Slope	+22G	≤0.020	Triangular
		9G	0.015-0.020	Trapezoidal
	20° Slope	±10G	≤0.010	Triagnular
Mid Cabin	Pole	+25G	≤0.012	Triangular
	6° Slope	-10G	≤0.010	Triangular
		- 5G	0.100	Half sine pulse
	20° Slope	-12G	≤0.005	Triangular
		- 5G	0.100	Half sine pulse

loads that cause fuselage separation occur later on during the 6 degree and 20 degree slope impacts. They are of the order of 5 g for 0.100 seconds duration and -12 g for 0.005 to 0.010 seconds.

Several points are illustrated by these figures:

1. The floor pulse may not necessarily be experienced by the seat and occupant. The extent that these upper masses experience floor pulses greatly depends upon system frequency responses and phasing of motions.

2. In a dynamic response the floor, seat and occupant can all experience short duration load pulses in excess of 9 g without experiencing failure. Seats, while designed to a 9 g static loads, can and do perform to higher "g" dynamic pulses.

3. Airframe capability, judged to be in excess of 9 g static on the basis of measured sharp short duration pulses, is misleading on two accounts:

   a) There is little energy associated with such short duration pulses and the airframe as a whole does not respond to such a pulse.

   b) These pulses generally represent localized structure response and exhibit "ringing" which does not transmit large forces through to the supported masses unless tuned.

What is apparent in the seat performance in the L1649 crash test, in the accidents described earlier and in the dynamic seat tests, is that seats designed to a 9 g static strength criterion can survive higher g short duration pulses.

To help understand this dynamic performance, the transmissibility curve for a simple highly damped one degree-of-freedom system* excited with a triangular pulse is used. In this model the mass can be considered to represent the occupant, and the spring represents the seat and restraint system. The triangular pulse corresponds to the floor acceleration. For this system the curve in figure 4-14 represents those combinations of pulse magnitude and duration that would produce a maximum acceleration of 9 g for the mass (occupant). For example, the short duration (.010 seconds) 50 g peak pulse and the long duration (.100 seconds) 9 g peak pulse result in the same level of system response. For different shaped pulses the curve will shift slightly, but the general shape of the curve will prevail.

From figure 4-14 several important dynamic considerations for seats are illustrated:

1. The 9 g associated with seats is only a static value.
2. The 9 g static seats have a varying dynamic capability which is dependent on the pulse period and seat response characteristics.
3. The dynamic capability of 9 g static seats results in a certain level of isolation against damage from sharp pulses in a crash depending on the seats dynamic response characteristics.
4. If a seat is made stronger (20 g), presumably it will also be stiffer. The consequence of stiffening the seat will be to tune the seat response closer to the floor pulse which will, in effect, reduce the dynamic capability by virtue of shifting the solid line in figure 4-14 to the left.
5. The dynamic characteristics curve provided in figure 4-14 is also applicable to understanding the relationship between occupant response (highly damped, low frequency system) and short duration high amplitude excitation functions.

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*The simple highly damped on degree-of-freedom system used to demonstrate the floor to occupant transmissability idealizes the responses of the seat-occupant which is in reality at least a two degree-of-freedom system. A multidegree of freedom system would show additional response modes associated with the phasing of the seat and occupant masses.

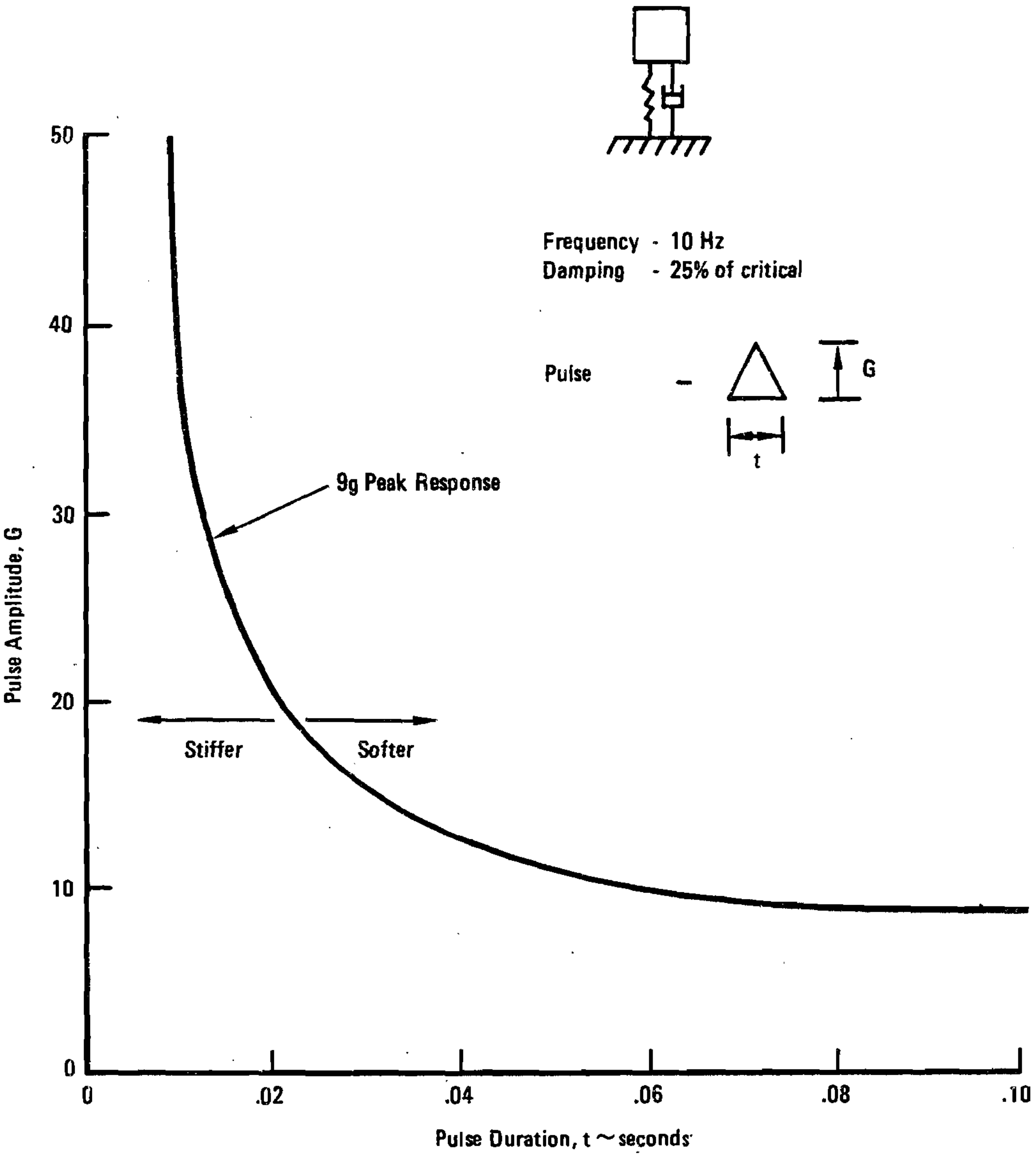


Figure 4-14. - Input pulse amplitude and duration to produce a 9 g peak response for a single degree of freedom system.

The terminology "9 g seat" can be misleading. Seats have demonstrated capability to perform satisfactorily under 20 and 30 g pulses with durations in the order of up to .080 seconds. The current static criteria serves only to insure a level of seat strength and has demonstrated occupant survivability in actual crashes.

4.3 Engine Arrangement

The accident data are compiled for three types of airplane engine arrangements, wing/pylon mounted engines, aft fuselage mounted engines and combined aft fuselage - wing/pylon mounted engines. The distribution of accidents as they relate to the different airplane configurations is shown in table 4-8. Tables 4-9 through 4-15 show the frequency of occurrence of fuel spillage in relation to the occurrence of fuselage separation for the different engine configured airplanes. Tables 4-16 through 4-19 show the relative fire hazard potential for all the airplanes as well as the different engine configurations. Tables 4-20 through 4-23 show the structural systems damage involvement for all the airplanes, as well as for the different engine configurations. The available accident data is mostly associated with wing/pylon or aft fuselage mounted engine configurations. Sixty-one of the 66 accidents in the Lockheed files are for these 2 configurations.

Of a total of 36 accidents involving airplanes with wing/pylon mounted engines, 27 accidents show fire occurrences or the potential of a fire hazard (table 4-17). Of these 27 fire hazards, 11 involve fuselage break or separation (tables 4-9 through 4-15). The data in table 4-17 shows that wing fuel tank rupture occurred in 10 of the 27 fire hazard accidents, followed by 8 occurrences of wing fuel line severence. Miscellaneous or unstated causes account for 9 fire hazard accidents.

TABLE 4-8. - DISTRIBUTION OF ACCIDENT DATA AS RELATED TO AIRPLANE ENGINE ARRANGEMENT

	Candidate Crash Scenario*							
	GGO			AGHL	AGI			
	GG1							
Engine Arrangement	Landing	Takeoff	GG2	AG1	AG2	AG3	AG4	Totals
Aft Fuselage	4	2	4	7	2	3	3	25
Wing/Pylon	6	6	5	3	1	4	11	36
One Aft Fuselage – Two Wing/Pylon	–	2	–	1	1	1	–	5
Totals	10	10	9	11	4	8	14	66

*Defined Tables 3-1, 3-2, and 3-3.

Of a total of 25 accidents involving aft fuselage mounted engine airplanes, 16 accidents show fire occurrence or fire potential (table 4-18). Of the 16 fire hazard accidents aft-fuselage breaks occurred 12 times (tables 4-9 through 4-15); however, in only 3 of these 12 instances is it surmized that fuselage separation/break may have contributed to the fire hazard. From table 4-18 it can be observed that wing fuel tank rupture is a prevalent occurrence (6) followed by fuselage fuel line severence (5), and wing fuel line severence, particularly at the wing root (4).

Table 4-24 summarizes the data provided in tables 4-8 through 4-23. Fuselage break, engine separation and wing failure occurrences in terms of relative frequency are similar for wing/pylon or aft fuselage engine mounted configurations. While some percentages differ for the two different configurations they are, generally, within ±10 percent of the total of all 66 accidents.

The location of the engines on the wing or at the aft fuselage does not significantly alter the accident statistics with regard to overall structure participation.

TABLE 4-9. - FUSELAGE BREAK AND FUEL SPILL OCCURRENCE (GG1 CRASH SCENARIO, LANDING OPERATIONS)

Engine Arrangement	Number of Accidents	Occurrence of Fuselage Break/Separation, Aft of Wing Trailing Edge ①		No Occurrence of Fuselage Break/Separation Aft of Wing Trailing Edge ②	
		Fuel Spillage	No Fuel Spillage	Fuel Spillage	No Fuel Spillage
Aft Fuselage	4	1③			3
Wing/Pylon	6		1	1④ 1⑤	3⑥
One Aft Fuselage/ Two Wing Pylon					

① Can include more than one break/separation

② Can include break/separation forward of wing leading edge

③ At wing root

④ MG collapse – wing fuel tank rupture

⑤ Wing fuel tank rupture

⑥ Includes one accident involving forward fuselage separation/break only

TABLE 4-10. - FUSELAGE BREAK AND FUEL SPILL OCCURRENCE (GG1 CRASH SCENARIO, TAKEOFF OPERATIONS)

Engine Arrangement	Number of Accidents	Occurrence of Fuselage Break/Separation, Aft of Wing Trailing Edge ①		No Occurrence of Fuselage Break/Separation Aft of Wing Trailing Edge ②	
		Fuel Spillage	No Fuel Spillage	Fuel Spillage	No Fuel Spillage
Aft Fuselage	2	1④	1	1③	
Wing/Pylon	6			1⑤	4⑥
One Aft Fuselage/ Two Wing Pylon	2			1③ 1⑤	

① Can include more than one break/separation

② Can include break/separation forward of wing leading edge

③ MG collapse – wing fuel tank rupture

④ Wing fuel tank rupture

⑤ Wing engine separation

⑥ Includes one accident involving forward fuselage separation/break

TABLE 4-11. - FUSELAGE BREAK AND FUEL SPILL OCCURRENCE (GG2 CRASH SCENARIO, LANDING AND TAKEOFF OPERATIONS)

Engine Arrangement	Number of Accidents	Occurrence of Fuselage Break/Separation, Aft of Wing Trailing Edge ①		No Occurrence of Fuselage Break/Separation Aft of Wing Trailing Edge ②	
		Fuel Spillage	No Fuel Spillage	Fuel Spillage	No Fuel Spillage
Aft Fuselage	4	*1 1③1④	1		
Wing/Pylon	5	1⑤	1	1③	2⑥
One Aft Fuselage/ Two Wing Pylon					

① Can include more than one break/separation

② Can include break/separation forward of wing leading edge

③ Near tail and at wing-fuselage separation

④ Wing fuel tank rupture

⑤ At wing root

⑥ Includes 2 accidents involving forward fuselage/separation break only

* Fuselage separation contribution to fuel spill

TABLE 4-12. - FUSELAGE BREAK AND FUEL SPILL OCCURRENCE (AG1 CRASH SCENARIO)

Engine Arrangement	Number of Accidents	Occurrence of Fuselage Break/Separation, Aft of Wing Trailing Edge ①		No Occurrence of Fuselage Break/Separation Aft of Wing Trailing Edge ②	
		Fuel Spillage	No Fuel Spillage	Fuel Spillage	No Fuel Spillage
Aft Fuselage	7	1④	3	1⑤	2
Wing/Pylon	3		1	1③	1
One Aft Fuselage/ Two Wing Pylon	1			1③	

① Can include more than one break/separation

② Can include break/separation forward of wing leading edge

③ Wing engine separation

④ At wing root

⑤ MG collapse – wing fuel tank rupture

TABLE 4-13. - FUSELAGE BREAK AND FUEL SPILL OCCURRENCE
(AG2 CRASH SCENARIO)

Engine Arrangement	Number of Accidents	Occurrence of Fuselage Break/Separation, Aft of Wing Trailing Edge ①		No Occurrence of Fuselage Break/Separation Aft of Wing Trailing Edge ②	
		Fuel Spillage	No Fuel Spillage	Fuel Spillage	No Fuel Spillage
Aft Fuselage	2	1④		*1⑤	
Wing/Pylon	1			1③	
One Aft Fuselage/ Two Wing Pylon	1	1③			

① Can include more than one break/separation

② Can include break/separation forward of wing leading edge

③ Wing fuel tank rupture

④ Fuselage disintegrated, wing failure caused fuel spill

⑤ Wing and/or engine separation

TABLE 4-14. - FUSELAGE BREAK AND FUEL SPILL OCCURRENCE
(AG3 CRASH SCENARIO)

Engine Arrangement	Number of Accidents	Occurrence of Fuselage Break/Separation, Aft of Wing Trailing Edge ①		No Occurrence of Fuselage Break/Separation Aft of Wing Trailing Edge ②	
		Fuel Spillage	No Fuel Spillage	Fuel Spillage	No Fuel Spillage
Aft Fuselage	3	*1③ 1④		1⑦	
Wing/Pylon	4	1⑥ 2④		1⑤	
One Aft Fuselage/ Two Wing Pylon	1	1④			

① Can include more than one break/separation

② Can include break/separation forward of wing leading edge

③ Fuselage or engine separation

④ Airplane destroyed, unstated details

⑤ Wing separation, fuel tank rupture

⑥ Wing or engine separation

⑦ Wing fuel tank rupture

* Fuselage separation contribution to fuel spill

TABLE 4-15. - FUSELAGE BREAK AND FUEL SPILL OCCURRENCE (AG4 CRASH SCENARIO)

Engine Arrangement	Number of Accidents	Occurrence of Fuselage Break/Separation, Aft of Wing Trailing Edge ①		No Occurrence of Fuselage Break/Separation Aft of Wing Trailing Edge ②	
		Fuel Spillage	No Fuel Spillage	Fuel Spillage	No Fuel Spillage
Aft Fuselage	3	1⑤ 2⑥			
Wing/Pylon	11 ⑪	4⑦ 1⑧ 1 ⑩		2⑥ 1③ 1④ 1⑨	
One Aft Fuselage/ Two Wing Pylon					

① Cen include more than one break/separation

② Can include break/separation forward of wing leading edge

③ Forward/mid fuselage disintegration, left wing fuel spill

④ Fuselage separation aft of cockpit, fuel spill outboard of nacelle

⑤ Wing separation, fuel line rupture, airplane broke up in woods

⑥ Wing spillage, fuel line or fuel tank

⑦ Wing tank rupture, includes 2 accidents involving fuselage disintegration

⑧ Wing fuel line severence

⑨ Fuselage break occurred forward of wing leading edge, fuel tank rupture

⑩ Unstated

⑪ Includes 8 propeller airplanes

TABLE 4-16. - FIRE HAZARD SUMMARY, ALL AIRPLANE CONFIGURATIONS

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	20	9	11	4	8	14	66
FIRE HAZARD							
Total Number Fires Occurred	8	6	5	4	7	11	41
Fuel Containment, Struc. Related (Fuel Spill)	6	5	3	4	5	8	31
Friction, Ground, Hydraulic Line Related	2		1⑧				3
Unstated		1	1⑩		2⑥	3⑥	7
Fuel Spill, No Fire	2	1			1	3	7
Total Number of Fires and Potential Fires	10	7	5	4	8	14	48
ESTIMATED CONTRIBUTIONS TO FIRE HAZARDS⑦							
• Wing Fuel Line Severed							
a. Engine/Pylon Separation	2		2				4
b. Wing Root/Inboard Failure		3④		1④⑨		4⑨	8
c. Wing Outboard Failure						1⑨	1
d. L.G. Penetration							0
e. Wing L.E.							0
f. Miscellaneous						1⑨	1
• Fuselage Fuel Line Severed							
a. Fuselage Separation					1④		1
b. Engine Separation		1④		1④	2④		4
c. Landing Gear Penetration			1⑤				1
• Wing Fuel Tank Rupture							
a. L.G. Collapse/Penetration	3						3
b. Columnar Impact ①		1		3	1	2	7
c. Contour Impact ②	2				3		5
d. Frontal Obstruction ③		1				2	3
e. L.G. Collapse and Fus. Impact							0
f. L.G. Trunnion Attach Fitting	1						1
g. Miscellaneous		1				1	2

* Defined in Tables 3-1 through 3-3

① Pole, Tree, Pier, Light

② Ditch, Ravine, Hill, Embankment

③ Fence, Building, Wall

④ Includes possibility of either or both occurrences on same accident

⑤ Fuselage line/routing redesigned as a result of accident in 1965

⑥ Obstacles involved, wing separation occurred

⑦ Fuel containment related fires and spills

⑧ Nose gear collapse, severed hydraulic line

⑨ Possible fuel tank rupture

⑩ Wing root area

TABLE 4-17. - FIRE HAZARD SUMMARY, WING/PYLON MOUNTED ENGINES

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	12	5	3	1	4	11	36
<u>FIRE HAZARD</u>							
Total Number Fires Occurred	3	4	2	1	4	8	22
Fuel Containment, Struc. Related (Fuel Spill)	1	3	1	1	2	5	13
Friction, Ground, Hydraulic Line Related	2		1⑤				3
Unstated		1			2	3	6
Fuel Spill, No Fire	2					3	5
Total Number of Fires and Potential Fires	5	4	2	1	4	11	27
<u>ESTIMATED CONTRIBUTIONS TO FIRE HAZARDS</u> ④							
• Wing Fuel Line Severed							
a. Engine/Pylon Separation	1		1				2
b. Wing Root/Inboard Failure		2				2	4
c. Wing Outboard Failure						1	1
d. L.G. Penetration							0
e. Wing L.E.							0
f. Miscellaneous						1	1
• Fuselage Fuel Line Severed							
a. Fuselage Separation							0
b. Engine Separation							0
c. Landing Gear Penetration							0
• Wing Fuel Tank Rupture							
a. L.G. Collapse/Penetration	1						1
b. Columnar Impact ①				1	1	2	4
c. Contour Impact ②					1		1
d. Frontal Obstruction ③		1				2	3
e. L.G. Collapse and Fus. Impact							0
f. L.G. Trunnion Attach Fitting	1						1
g. Miscellaneous							0

* Defined in Tables 3-1 through 3-3

① Pole, Tree, Pier, Light

② Ditch, Ravine, Hill, Embankment

③ Fence, Building, Wall

④ Fuel Containment Related Fires and Spills

⑤ NG Collapse, Severed Hydraulic Line

TABLE 4-18. - FIRE HAZARD SUMMARY, AFT FUSELAGE MOUNTED ENGINES

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	6	4	7	2	3	3	25
FIRE HAZARD							
Total Number Fires Occurred	3	2	2	2	2	3	14
Fuel Containment, Struc. Related (Fuel Spill)	3	2	1	2	2	3	13
Friction, Ground, Hydraulic Line Related							0
Unstated			1				1
Fuel Spill, No Fire		1			1		2
Total Number of Fires and Potential Fires	3	3	2	2	3	3	16
ESTIMATED CONTRIBUTIONS TO FIRE HAZARDS ⑥							
• Wing Fuel Line Severed							
a. Engine/Pylon Separation							0
b. Wing Root/Inboard Failure		1④		1④		2	4
c. Wing Outboard Failure							0
d. L.G. Penetration							0
e. Wing L.E.							0
f. Miscellaneous							0
• Fuselage Fuel Line Severed							
a. Fuselage Separation					1④		1
b. Engine Separation		2④		1④	1⑤④		4
c. Landing Gear Penetration			1				1
• Wing Fuel Tank Rupture							
a. L.G. Collapse/Penetration	1						1
b. Columnar Impact ①							0
c. Contour Impact ②	2	1			1		4
d. Frontal Obstruction ③					1		1
e. L.G. Collapse and Fus. Impact							0
f. L.G. Trunnion Attach Fitting							0
g. Miscellaneous				1		1	2

* Defined in Tables 3-1 through 3-3

① Pole, Tree, Pier, Light

② Ditch, Ravine, Hill, Embankment

③ Fence, Building, Wall

④ Either could have occurred on same accident

⑤ Fuselage separation could have contributed

⑥ Fuel containment related fires and spills

TABLE 4-19. - FIRE HAZARD SUMMARY, AFT FUSELAGE-WING/PYLON MOUNTED ENGINES

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	2	0	1	1	1	0	5
<u>FIRE HAZARD</u>							
Total Number Fires Occurred	2	0	1	1	1	0	5
Fuel Containment, Struc. Related (Fuel Spill)	2	0	1	1	1	0	5
Friction, Ground, Hydraulic Line Related							0
Unstated							0
Fuel Spill, No Fire							0
Total Number of Fires and Potential Fires	2	0	1	1	1	0	5
<u>ESTIMATED CONTRIBUTIONS TO FIRE HAZARDS</u> ④							
• NG Collapse, Severed Hyd. Line							
• Wing Fuel Line Severed							
a. Engine/Pylon Separation	1		1				2
b. Wing Root/Inboard Failure							0
c. Wing Outboard Failure							0
d. L.G. Penetration							0
e. Wing L.E.							0
f. Miscellaneous							0
• Fuselage Fuel Line Severed							
a. Fuselage Separation							0
b. Engine Separation							0
c. Landing Gear Penetration							0
• Wing Fuel Tank Rupture							
a. L.G. Collapse/Penetration	1						1
b. Columnar Impact ①				1			1
c. Contour Impact ②					1		1
d. Frontal Obstruction ③							0
e. L.G. Collapse and Fus. Impact							0
f. L.G. Trunnion Attach Fitting							0
g. Miscellaneous							0

* Defined in Tables 3-1 through 3-3

① Pole, Tree, Pier, Light

② Ditch, Ravine, Hill, Embankment

3 Fence, Building, Wall

4 Fuel Containment Related Fires and Spills

TABLE 4-20. - STRUCTURAL DAMAGE SUMMARY, ALL AIRPLANE CONFIGURATIONS

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	20	9	11	4	8	14	66
<u>Fuselage Break/Separation</u>							
a. Aft of Cockpit Fwd. Fuselage						3	3
b. Wing, Leading Edge (L.E.)	2	1				1	4
c. Wing, Trailing Edge (T.E.)			2	1	1		4
d. Forward of Empennage	1	1	2		1	3	8
e. Wing, L.E. and T.E.	2	3	1				6
f. Aft of Cockpit and Fwd. of Empennage						2	2
g. Three or Four Breaks		2			2	1	5
h. Fuselage Destroyed				1	2	4	7
<u>Engine Separation</u>							
Fuselage Mounted Configuration	2	2	3	2	1	2	12
Wing Mounted Configuration	6	1	2	1	4	6	20
Fuselage and Wing Mounted	2		1	1	1		5
<u>Wing Failures</u>							
Root-Inboard	2	3		2	3	11	21
Outboard-Tip	2	3		2	1	1	9
Miscellaneous/Unknown	2	1			1	2	6
<u>Landing Gear Collapse</u>							
MLG Collapse Only	4	2	6			3	15
NLG Collapse Only	5	1	1				7
MLG and NLG Collapse	7	3	1	3	3	3	20
<u>OCCURRENCES OF</u>:							
Floor Buckling	1	3	4	3	1	3	15
Cockpit Crushing	1	1			1	5	8
Lower Fuselage Crushing/Abrasion	5	3	4	2		2	16
Overhead Racks/Panel Failures	3	4	3			1	11
Jammed and/or Deformed Doors	5	3	1	1		3	13
Slide Related Failure	3	1				2	6
Galley Equipment Failures		1					1
Tire/Wheel Damage	5	1					6

* Defined in Tables 3-1 through 3-3

** Numbers in table indicate number of accidents in which stated events occurred

TABLE 4-21. - STRUCTURAL DAMAGE SUMMARY, WING/PYLON MOUNTED ENGINE

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	12	5	3	1	4	11	36
Fuselage Break/Separation							
a. Aft of Cockpit Fwd. Fuselage						3	3
b. Wing, Leading Edge (L.E.)	1	2				1	4
c. Wing, Trailing Edge (T.E.)			1		1		2
d. Forward of Empennage					1	2	3
e. Wing, L.E. and T.E.	1	1					2
f. Aft of Cockpit and Fwd. of Empennage						2	2
g. Three or Four Breaks					1		1
h. Fuselage Destroyed						3	3
Engine Separation							
Wing Mounted Configuration	6	1	2	1	4	6	20
Wing Failures							
Root-Inboard		2			3	8	13
Outboard-Tip	1	2		1		1	5
Miscellaneous/Unknown						2	2
Landing Gear Collapse							
MLG Collapse Only		2	1			3	6
NLG Collapse Only	4	1	1				6
MLG and NLG Collapse	4	1	1	1	2	1	10

* Defined in Tables 3-1 through 3-3

** Numbers indicate number of accidents in which stated events occurred

TABLE 4-22. - STRUCTURAL DAMAGE SUMMARY, AFT FUSELAGE MOUNTED ENGINE

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	6	4	7	2	3	3	25
Fuselage Break/Separation							
a. Aft of Cockpit Fwd. Fuselage							
b. Wing, Leading Edge (L.E.)							
c. Wing, Trailing Edge (T.E.)			1				1
d. Forward of Empennage	1	1	2				4
e. Wing, L.E. and T.E.	1	2	1				4
f. Aft of Cockpit and Fwd. of Empennage						1	1
g. Three of Four Breaks		1			1	1	3
h. Fuselage Destroyed				1	1	1	3
Engine Separation							
Fuselage Mounted Configuration	2	2	3	2	1	2	12
Wing Failures							
Root-Inboard		1		1		3	5
Outboard-Tip	1	1		1	1		4
Miscellaneous/Unknown	2						2
Landing Gear Collapse							
MLG Collapse Only	2		4				6
NLG Collapse Only	1						1
MLG and NLG Collapse	3	2		1		2	8

* Defined in Tables 3-1 through 3-3

** Numbers indicate number of accidents in which stated events occurred.

TABLE 4-23. - STRUCTURAL DAMAGE SUMMARY, AFT FUSELAGE-WING/PYLON MOUNTED ENGINE

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	2		1	1	1		5
Fuselage Break/Separation							
a. Aft of Cockpit Fwd. Fuselage							0
b. Wing, Leading Edge (L.E.)							0
c. Wing, Trailing Edge (T.E.)				1			1
d. Forward of Empennage							0
e. Wing, L.E. and T.E.							0
f. Aft of Cockpit and Fwd. of Empennage							0
g. Three or Four Breaks							0
h. Fuselage Destroyed					1		1
Engine Separation							
Fuselage and Wing Mounted Configuration	2		1	1	1		5
Wing Failures							
Root-Inboard	1			1			2
Outboard-Tip							0
Miscellaneous/Unknown					1		1
Landing Gear Collapse							
MLG Collapse Only	2		1				3
NLG Collapse Only							0
MLG and NLG Collapse				1	1		2

* Defined in Tables 3-1 through 3-3

** Numbers indicate number of accidents in which stated events occurred

TABLE 4-24. - SUMMARY OF FUEL CONTAINMENT HAZARDS AND STRUCTURAL DAMAGE AS A FUNCTION OF ENGINE ARRANGEMENT CONFIGURATION

	Engine Arrangement		
	Wing/Pylon	Aft Fuselage	All
Number of Accidents	36	25	66
Fire Potential Fuel Containment Related	18 (50)	15 (60)	38 (57.6)
Wing Fuel Line Severence	8 (22.2)	3 (12)	14 (21.2)
Fuselage Fuel Line Severence	–	4 (16)	5 (7.6)
Wing Fuel Tank Rupture	10 (27.8)	8 (32)	19 (28.8)
Structural System Damage*			
Fuselage Break/Separation	20 (55.6)	16 (64)	38 (57.6)
Engine Separation	20 (55.6)	12 (48)	37 (56.0)
Wing Failures			
Root-Inboard	13 (36.1)	5 (20)	21 (31.8)
Outboard Tip	5 (13.9)	4 (16)	9 (13.6)
Miscellaneous	2 (5.6)	2 (8)	6 (9.1)

( ) Denotes Fuel Containment and Structural Damage Data in percentages; based on total number of accidents for the particular engine arrangement configurations noted at the top of the respective columns.

* More than one system can be damaged in an accident, therefore, percentages can total more than 100%.

4.4 Fire Hazard Potential

The fire hazard data is tabulated in tables 4-16 through 4-19. Since rupture of the wing fuel line or fuel tank is difficult to assess from the accident data, table 4-16 was modified to show the effect of shifting the estimated contribution from fuel line rupture occurrences to fuel tank rupture. This data is shown in table 4-25. In modern day jets, wing fuel line break most likely occurs after the wing tank has been damaged. Since most of these failures occur as a result of columnar, contour or frontal impacts, there is a reasonable chance that wing tank ruptures occur before wing fuel lines sever. Table 4-26 shows the involvement of hazards and terrain in the candidate scenarios. Table 4-27 shows the involvement of columnar, contour and frontal obstructions with regard to fuselage breakup, engine separation and wing failure. Figure 4-15 graphically illustrates frequency of occurrence of fuel tank or fuel line ruptures and the manner in which they might occur. Landing gear collapse and contour impact, mostly ditches, mounds and embankments cause fuel tank rupture in ground-to-ground type accidents. Fuel tank or fuel line ruptures rarely occur in air-to-ground hard landings on runways or near airports. For severe air-to-ground impact, columnar and frontal obstructions are a major contributor to structural related fuel containment. Figure 4-16 shows that the wing location at which failures most frequently occur is at the root-inboard section. This is particularly true for air-to-ground impacts. Hard landings on the runway or near the runway do not show wing failure to be a cause of concern.

4.5 Structure and System Involvement

Depending on the crash impact conditions, terrain, hazards and obstructions involved, the performance of the structures and systems for different crash scenarios may vary. Figures 4-17 and 4-18 show the cumulative distribution of structure and system involvement as a function of the crash scenario candidates. From the graphic illustrations in figures 4-17 and 4-18, some general observations can be made. For example, for a ground-to-ground accident

TABLE 4-25. - FIRE HAZARD SUMMARY, ALL AIRPLANE CONFIGURATIONS

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	20	9	11	4	8	14	66
FIRE HAZARD							
Total Number Fires Occurred	8	6	5	4	7	11	41
Fuel Containment, Struc. Related (Fuel Spill)	6	5	3	4	5	8	31
Friction, Ground, Hydraulic Line Related	2		1				3
Unstated		1⑥	1		2⑥	3⑥	7
Fuel Spill, No Fire	2	1			1	3	7
Total Number of Fires and Potential Fires	10	7	5	4	8	14	48
ESTIMATED CONTRIBUTIONS TO FIRE HAZARDS							
• NG Collapse, Severed Hyd. Line			1				1
• Wing Fuel Line Severed							
a. Engine/Pylon Separation	2		2				4
b. Miscellaneous						1	1
• Fuselage Fuel Line Severed							
a. Fuselage Separation							0
b. Engine Separation		1④		1④	2		4
c. Landing Gear Penetration			1⑤				1
• Wing Fuel Tank Rupture							
a. L.G. Collapse/Penetration	3						3
b. Columnar Impact ①		1		3	1	3	8
c. Contour Impact ②	2	3④			3		8
d. Frontal Obstruction ③		1		1④		6	8
e. L.G. Trunnion Attach Fitting	1						1
f. Miscellaneous		1				1	2

① Pole, Tree, Pier, Light

② Ditch, Ravine, Hill, Embankment

③ Fence, Building, Wall

④ Includes possibility of either or both occurrences on same accident

⑤ Fuselage line/routing redesigned as a result of accident in 1965

⑥ Obstacles involved, wing separation occurred

* Defined in Tables 3-1 through 3-3

TABLE 4-26. - HAZARD AND TERRAIN INVOLVEMENT

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	20	9	11	4	8	14	66
<u>HAZARD OCCURRENCES</u>							
<u>Columnar Impact</u>							
• Tree		1		1	3	8	13
• Light Poles	2	3		2		2	9
<u>Contour Impact</u>							
• Ditch/Drain	6	2					8
• Service Road/Mound/ Sidewalk/Slab	7						7
• Ravine/Embankment		5		2		1	8
• Hill/Slope	1	1			4		6
• Rocky Terrain		1		1	1		3
<u>Frontal Impact</u>							
• Fence	2	2		1			5
• Building	1	1				8	10
• Vehicle		2				1	3
• Dike/Seawall				1		1	2
<u>TERRAIN INVOLVEMENT</u>							
Runway/Taxiway	4		4				8
Hard Dirt	4						4
Grassy Dirt	1	1	2				4
Mud/Soft Dirt	1	1	1				3
Water, Sand and Water, Marshland	2	1			1		4
Rough, Rocky		1		1	1		3
Mountainous/Hilly/Ravine		5			4		9
Unstated	8		4	3	1	14①	30

* Defined in Tables 3-1 through 3-3

① Generally occurred at distance from airport.

TABLE 4-27. - INVOLVEMENT OF COLUMNAR, CONTOUR, AND FRONTAL OBSTRUCTIONS IN STRUCTURAL FAILURES

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
Number of Accidents	20	9	11	4	8	14	66
<u>INVOLVEMENT IN FUSELAGE BREAKUP</u>							
<u>Columnar Impacts</u>							
• Trees						8	8
• Lights/Poles/Piers				2		2	4
<u>Contour Impacts</u>							
• Ditch/Drain	1	2					3
• Service Road/Mound/ Sidewalk/Slab	1						1
• Ravine/Embankment		4		2		1	7
• Hill/Slope	1	1			3		5
• Rough, Rocky				1	1		2
Frontal Impact							
• Fence							0
• Building/Residence						10	10
• Vehicle						1	1
• Dike/Seawall						1	1
<u>INVOLVEMENT IN ENGINE SEPARATION</u>							
<u>Columnar Impacts</u>							
• Trees					1	3	4
• Lights/Poles/Piers				{1① 1②}			2
<u>Contour Impacts</u>							
• Ditch/Drain	3						3
• Service Road/Mound/ Sidewalk/Slab	1						1
• Ravine/Embankment		3		{1② 1①}			5
• Hill/Slope	1	1			3		5
• Rough, Rocky							0

* Defined in Tables 3-1 through 3-3

① Occurred in same accident.

② Occurred in same accident.

TABLE 4-27. - INVOLVEMENT OF COLUMNAR, CONTOUR, AND FRONTAL OBSTRUCTIONS IN STRUCTURAL FAILURES (Continued)

	Candidate Crash Scenarios*						
	GG1	GG2	AG1	AG2	AG3	AG4	Total
INVOLVEMENT IN ENGINE SEPARATION							
Frontal Impact							
• Fence							0
• Building/Residence						4	4
• Vehicles							0
• Dike/Seawall						1	1
INVOLVEMENT WITH WING FAILURE							
Columnar Impacts							
• Trees				1	1	10	12
• Lights/Poles/Piers/ILS		2		3		1	6
Contour Impacts							
• Ditch/Drain	1						1
• Service Road/Mound/ Sidewalk/Slab							0
• Ravine/Embankment		2		2		1	5
• Hill/Slope		1			3		4
• Rough/Rocky		1		1			2
Frontal Impact							
• Fence		1		1			2
• Building/Residence					7		7
• Vehicles							0
• Dike/Seawall				1		1	2

* Defined in Tables 3-1 through 3-3

① Occurred in same accident.

② Occurred in same accident.

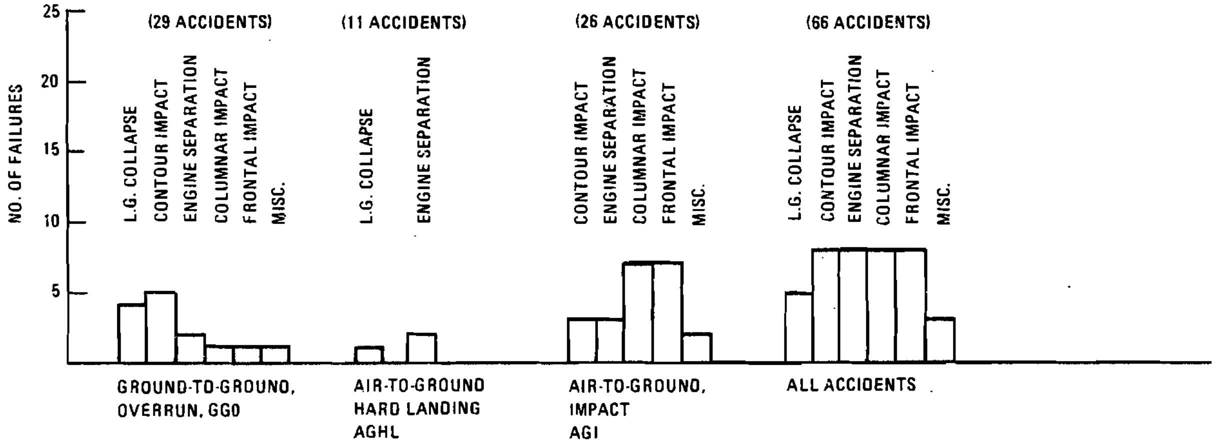


Figure 4-15. - Fuel tank or line rupture occurrences.

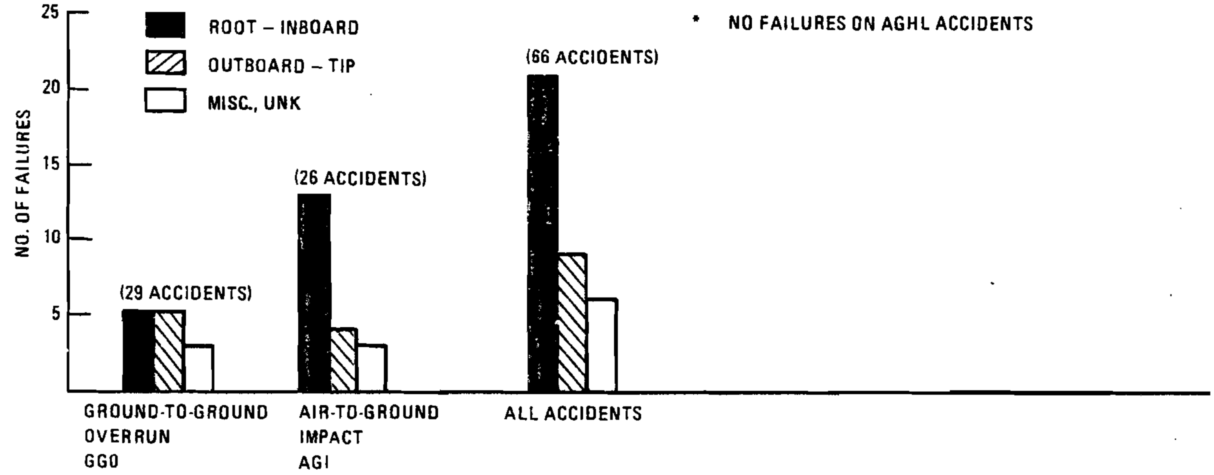


Figure 4-16. - Wing failure location.

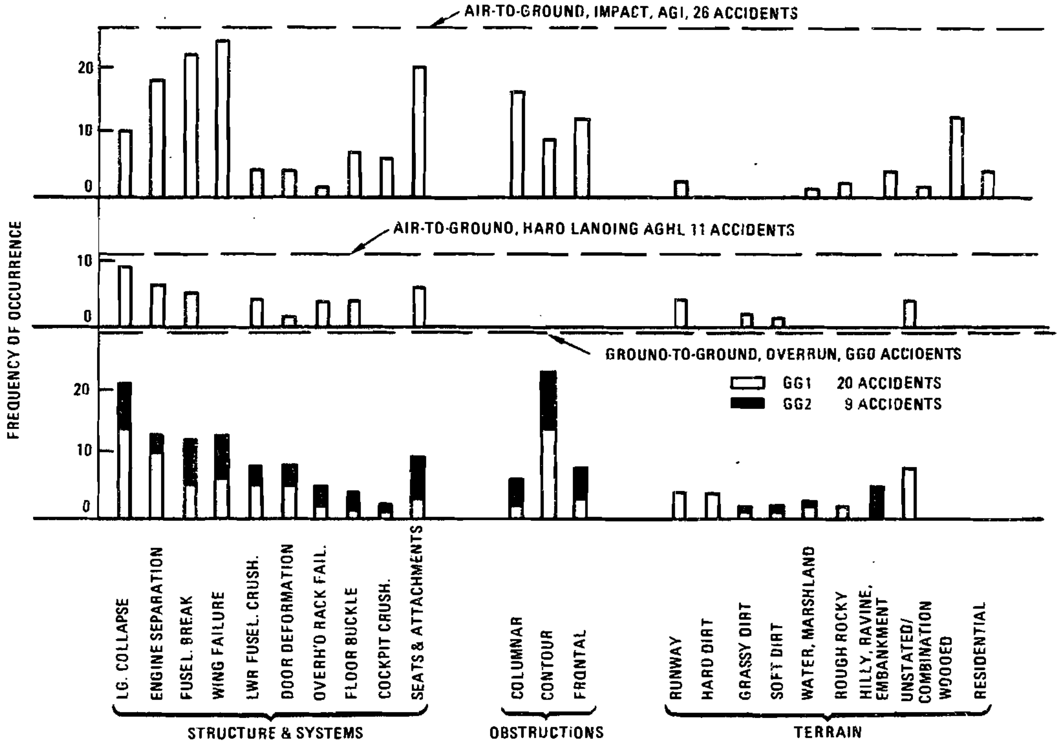


Figure 4-17. - Involvement of structure, systems, obstructions and terrain in candidate crash scenario accidents.

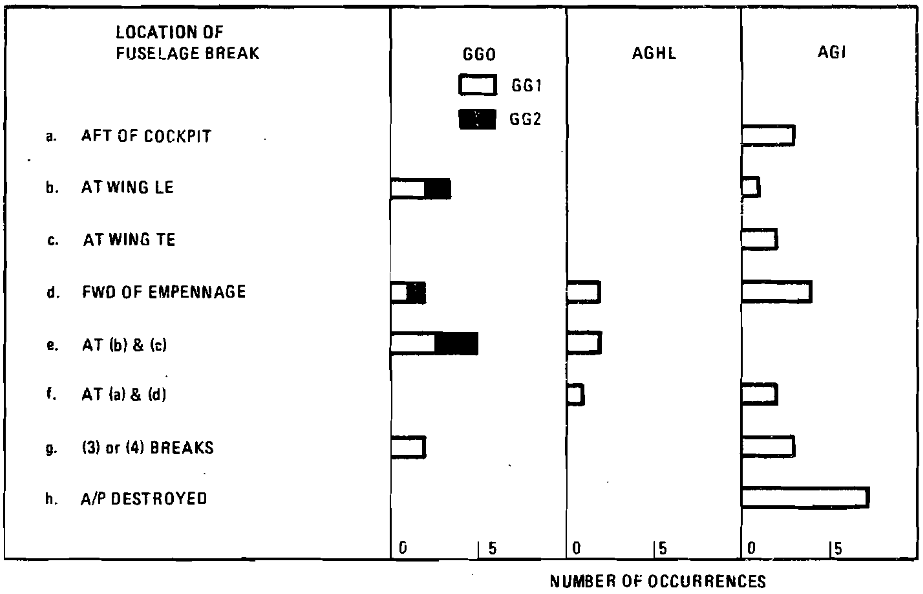


Figure 4-18. - Number of occurrences and location of fuselage break.

scenario, landing gear collapse is the most frequent structural failure occurrence. Accidents in the GG2 designation show a higher percentage of structural and system failures, particularly as related to the wing, fuselage, floor and seat. The predominant terrain associated with this category of accident is characterized as a ravine or embankment, hilly and rough. This helps explain why this category of accident shows higher fatality and injury ratios (figure 4-1) than the GG1 designation, which also represents ground-to-ground accidents. The terrain associated with GG1 accidents is primarily runway/taxiway and hard ground. There are several accidents in which the terrain is not stated. The distance beyond the runway for these accidents varies from 90 to 350 meters which is comparable to the 27 to 335 meters associated with the accidents where this data is available. Thus, one can expect a similar distribution for the terrain.

Hard landing accidents on and around the runway generally wind up on or just off the runway and, therefore, do not involve obstructions. These accidents experience landing gear collapse, engine separation and fuselage separation, but not wing failures.

Air-to-ground impacts, which are associated with obstructions and unsymmetrical impact conditions show a high rate of structural damage for the wing, engine, fuselage and seats. From figure 4-18 it can be seen that extensive airplane fuselage break-up occurs in 13 of the 26 accidents shown, which accounts for the high percentage of seat performance notations. Due to the destructive nature of these accidents, the statistics regarding lower fuselage crushing, door deformation, equipment failures and floor deformation are probably on the low side. Columnar obstructions in ground-to-ground accidents are more likely to be light stanchions. For the air-to-ground impacts the columnar obstructions are generally trees. The contour obstructions are hills and slopes and the frontal obstructions are buildings and vehicles. The locations of the AGI accidents are generally far from an airport and usually involve wooded and residential areas.

4.6 Priority Rating

The overall involvement of structure, systems, obstructions and terrain is of interest but does not give a clear picture of what may occur during an accident. Since the performance of a structural feature is often dependent on the performance of other structure and systems, flow diagrams of each accident comprising the candidate scenarios were established. Sample flow diagrams for GG1, GG2 and AGI accidents are shown in figures 4-19, 4-20 and 4-21, respectively. Utilizing the flow diagrams, a table is established for each scenario candidate in which the relative contributions of structural damage, system involvement and airport surroundings are identified. Tables 4-28 through 4-33 illustrate this relationship. The following terminology is associated with the data provided in tables 4-28 through 4-33.

ACCIDENT INVESTIGATION

Engine Arrangement:
W = Wing Mounted
F = Fuselage Mounted
B = Wing and Aft Fuselage Mounted

Operational Mode:
L = Landing
T = Takeoff
F = Inflight or Enroute

Injuries/Fatalities:
F = Fire
T = Trauma
F/T = Fire and/or Trauma
E = Evacuation
U = Unknown

Gear Position:
E = Extended
R = Retracted

STRUCTURAL DAMAGE

Fuselage Break/Location
a = aft of cockpit
b = at wing leading edge (LE)
c = at wing trailing edge (TE)
d = forward of empennage
e = at (b) and (c)
f = at (a) and (d)
g = three or four breaks
h = airplane destroyed
i = miscellaneous, i.e. wrinkled, distorted

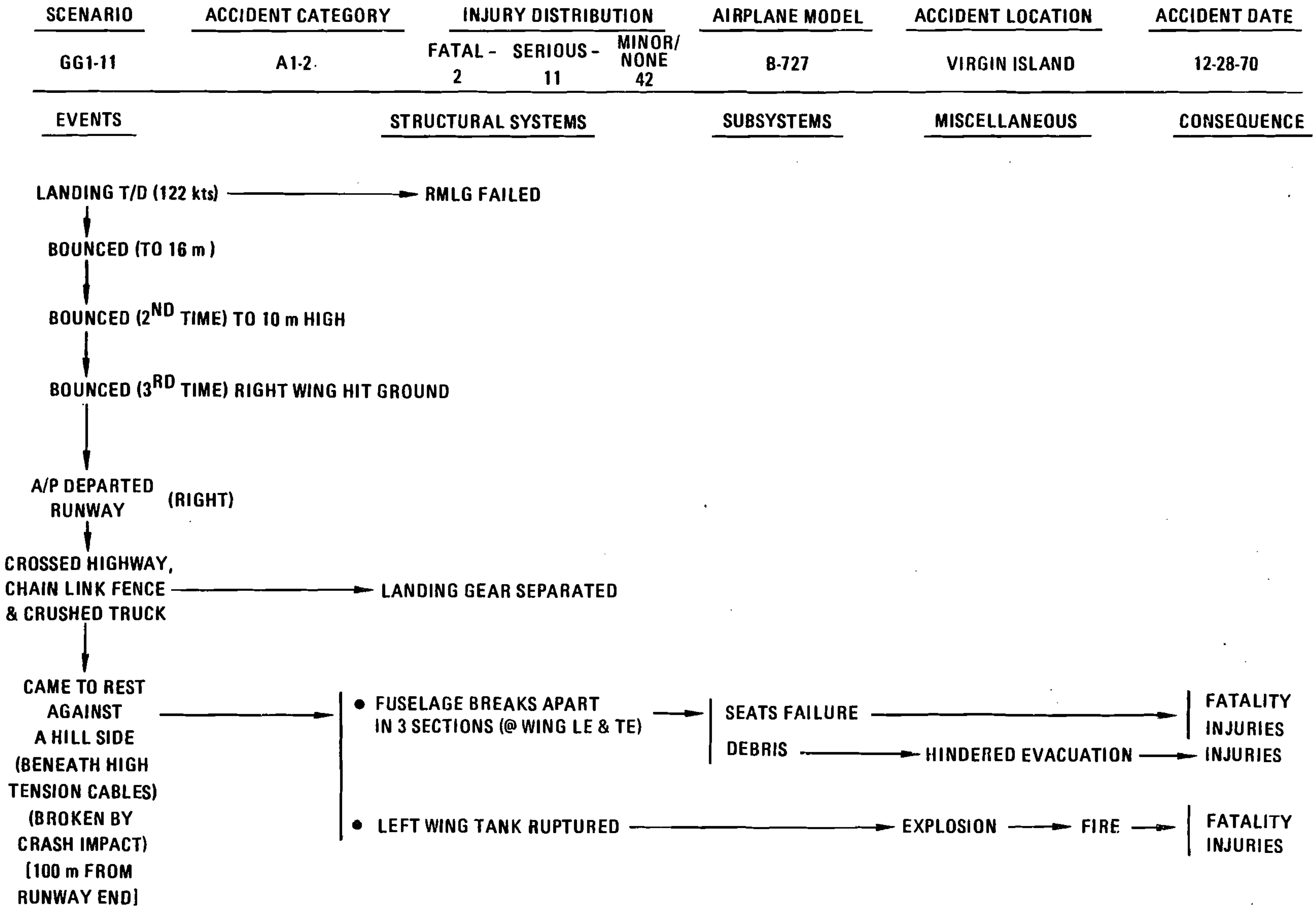


Figure 4-19. - Flow diagram GG1 accident type.

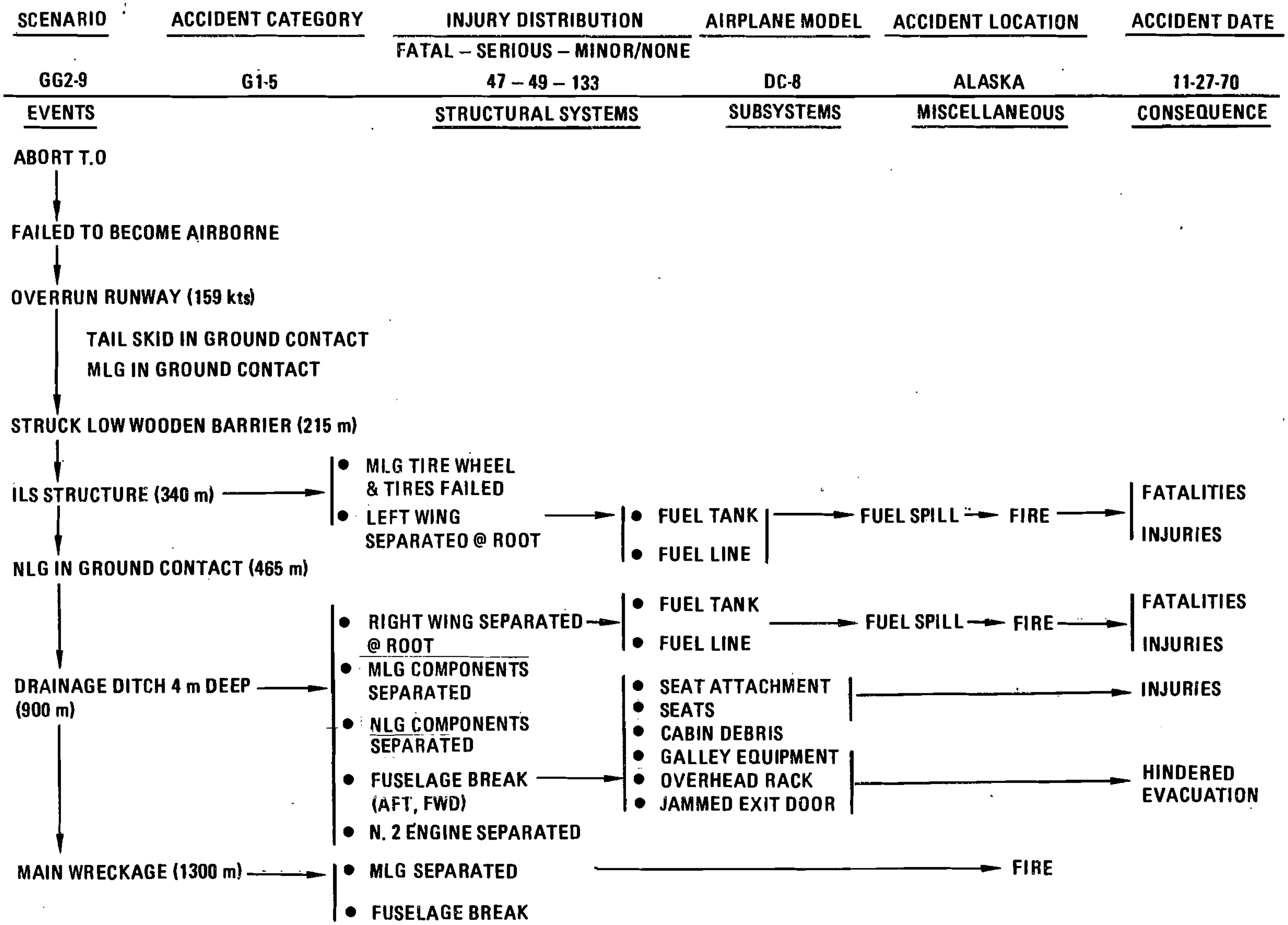


Figure 4-20. - Flow diagram GG2 accident type.

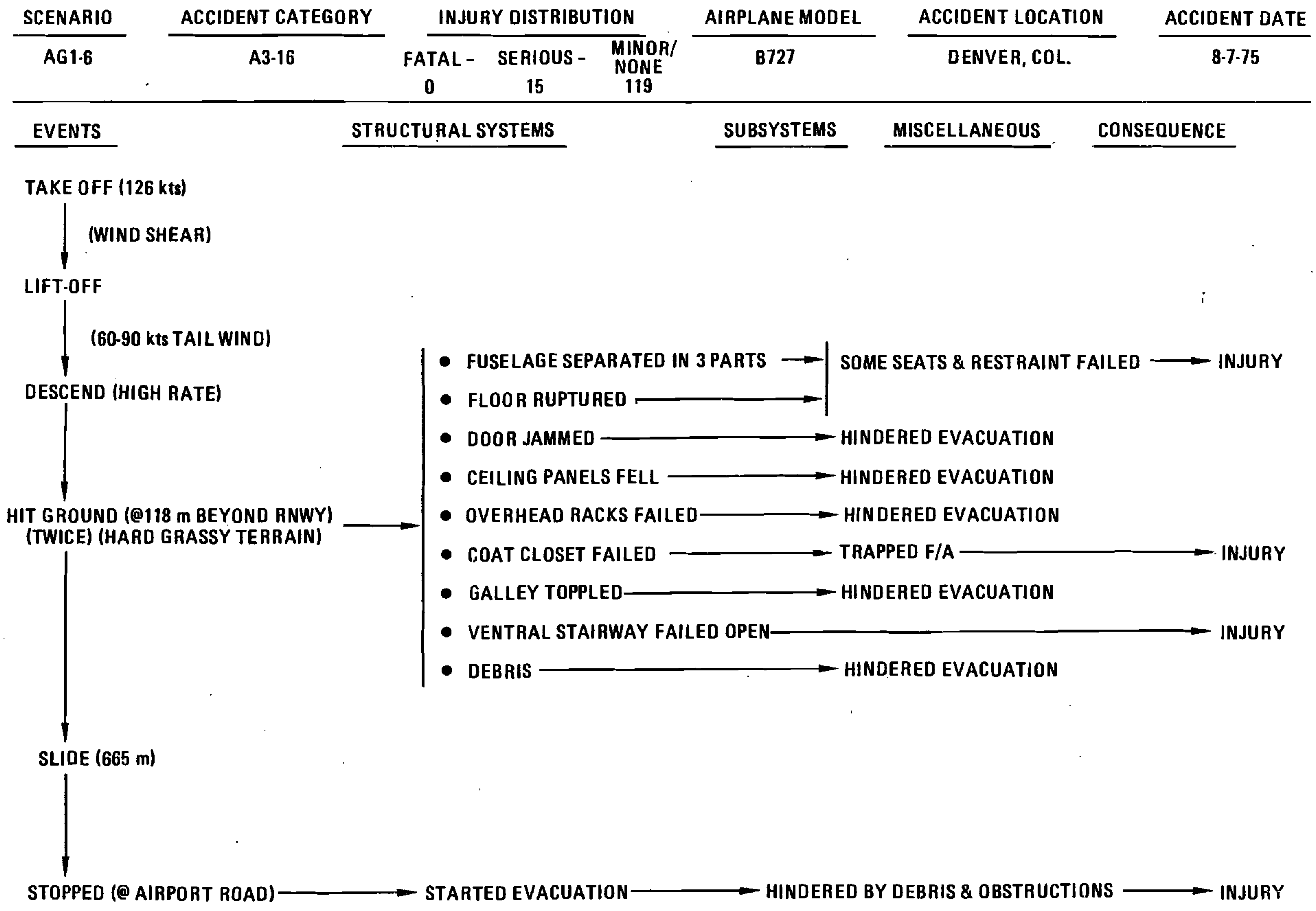


Figure 4-21. - Flow diagram AG1 accident type.

The following symbols are used:

○ Occurrence noted, but not considered a significant factor in the accident

◓ May have hindered survival efforts

◑ Contributed to subsequent failure or indirectly to cause of injury/fatality

● Direct contribution to injury/fatality or a contribution to a subsequent failure and an indirect cause of injury/fatality

The symbols used to define relative influence in an accident are at best a means of distinguishing between levels of involvement. Unfortunately the accident data even in flow diagram form requires some subjectivity. From Table 4-28 it can be seen that in 20 accidents, there are some failures that occur often, but do not generally result in injury/fatality. Landing gear collapse, tire damage, engine separation, and wing damage fall into this category. On the other hand, post-crash fire and fuselage break show a relatively high influence on survivability for the number of times they occur. For this type of scenario, slide system and evacuation procedures appear to influence injury frequency in all the accidents in which they are noted. Fuel rupture is also severe in this respect as can be seen from its influence in the five accidents it was noted. Contour obstructions, particularly ditches, mounds, roadways and walls are contributors to structural failures moreso than columnar obstructions such as approach lights. GG2 accidents (Table 4-29), of which there are 9 in the file, show a higher degree of severity associated with contours such as ravines and embankments, resulting in fuselage breakup which influence the structural integrity of the floor and subsequently the seat and its attachments. Fuel tank rupture and overhead rack failure are also relatively severe in relation to other occurrences. These accidents occur mostly in an area which extends up to 350 meters past the runway, which is not too different than for the GG1 accidents.

The AG1 accidents, tabulated in Table 4-30, show that fuselage breaks occur often and influence occupant injury. Many of the systems such as seats and attachments, floor, door deformation and mass items are also affected and their failures have a bearing on the resultant injuries. The one fatal accident is related to a MLG collapse, causing a wing fuel tank rupture and subsequent fire. Evacuation in this case was hindered because the airplane position after slideout kept the aft stairway from being used. The tabulated data clearly shows that these accidents generally occur on or near the runway with no significant influence from obstructions or hazards.

Table 4-31 includes only four accidents, all of which involved the airplane landing short of the runway and the severity of damage being related to the airport surroundings. These surroundings included contour obstructions such as embankments and ravines, and columnar obstructions such as trees and poles. In all four accidents, post crash fire occurred and the fire is considered a contributor to or a direct cause of fatality.

Tables 4-32 and 4-33 show the relative involvement for 7 AG3 and 14 AG4 type accidents, respectively. These accidents are extremely severe and show substantial structural damage and heavy involvement of columnar, contour and frontal obstructions. With the exception of two accidents on the runway and two accidents within 350 meters of the runway, all the other accidents occurred at a distance greater than 1000 meters and usually several thousand meters away from the runway. The complete breakup of the aircraft in many of the accidents prevents an accurate assessment of subsequent system failures. Many of the failure modes noted in GG1, GG2 and AG1 accidents such as door deformation, overhead rack failures and loose galley equipment are not noted since the major structure damage probably far overshadows the individual system failures. Post crash fire is a major contributor to injuries/fatalities for these types of accidents. The relationship between fire and severity of structural damage as a function of candidate crash scenarios is illustrated in figure 4-22.

Based on the matrix of data provided in tables 4-28 through 4-33, a relative priority for future research effort is established. This priority is listed as follows:

- Post Crash Fire Reduction

  There is a significant involvement of fuel tank and/or fuel lines in accidents resulting in injuries and/or fatalities. There is also a

TABLE 4-28. RELATIVE CONTRIBUTION TO INJURY/FATALITY, GG1 TYPE ACCIDENT

ACCIDENT IDENTIFICATION										STRUCTURAL DAMAGE												SYSTEM INVOLVEMENT																AIRPORT SURROUNDINGS								
SCENARIO	ENGINE ARRANGEMENT	OPERATION MODE	ACCIDENT CATEGORY	FATAL INJURIES	SERIOUS INJURIES	MINOR/NO INJURIES	GEAR POSITION		POST-CRASH FIRE	ENGINE SEPARATION	WING SEPARATION	WING DAMAGE	FUSELAGE BREAK/LOCATION	MLG COLLAPSE/SEP	NLG COLLAPSE/SEP	CLG COLLAPSE/SEP	COCKPIT CRUSHING	FUSELAGE KEEL BEAM	TIRE AND/OR WHEEL		WING FUEL LINE RUPTURE	FUSELAGE FUEL LINE RUPTURE	FUEL TANK RUPTURE	LOWER FUSELAGE CRUSH/PENETRATION	OVERHEAD RACK	CEILING PANELS	SEATS	SEAT ATTACHMENTS	RESTRAINT SYSTEM	FLOOR BUCKLE	DOOR DEFORMATION	GALLEY EQUIPMENT	SLIDE SYSTEM/EVACUATION PROCEDURE	DEBRIS	NONUSE OF RESTRAINT SYSTEM		COLUMNAR OBSTRUCTION	CONTOUR OBSTRUCTION	FRONTAL OBSTRUCTION	TERRAIN	RUNWAY, ON/OR SHORT OF	< 150 M PAST RUNWAY	150 M – 350 M PAST RUNWAY	350 M – 1000 M PAST RUNWAY	> 1000 M	TYPE OF OBSTRUCTION/TERRAIN
-1	W	L	G5-1	0	3T 4U	138	E			○			● b														●	●										○		◑		○				SERVICE ROAD SAND/WATER
-2	W	L	G5-3	0	0	96	E		①	○		◑		○	◑								◑	○														◑				○				SERVICE ROAD
-3	W	L	G5-8	0	0	160	E								◑									○						○								◑					○			CONCRETE SLAB
•-4	F	L	G5-11	0	4E	88	E							○																			●									○				
•-5	F	L	G5-7	0	1T	176	E							◑	◑									○	●						○							◑					○			DITCH
•-6	W	L	G5-10	0	1T	165	E			○			○ •	○	○									○				○	○		○				●		○	◑					○			EARTHEN HOUND ILS ANTENNA
-7	F	L	G5-2	0	0	119	E					○			◑									○														◑				○				SIDEWALK
-8	W	L	G5-4	0	1E	98	E			○				○	○																◓			◓			○	◑					○			DITCH APPROACH LIGHTS
-9	F	T	G1-2	0	1E	2	E		◑	○		◑	○ d	○	○								◑															◑					○			DITCH SOFT MUD
-10	W	T	G1-3	0	0	5	E		○	◑				○	○							○																◑					○			DITCH, ROAD
-11	F	T	A1-2	2F	11T	42	E		●				● •	○	○								●				○	○						◓				◑				○				30^0 SLOPE HARD GROUND
-12	W	T	G1-7	0	0	3	E			○		○	○ b		○																									◑			○			WATER
-13	W	T	G1-8	0	3E	258	E		○										○														◑								○					
-14	B	T	G1-10	0	2E	137	E		◑	○				○		○			◑		◑		◑		○								◓								○					
-15	F	T	G1-11	0	0	84	E		○			○		◑	◑								○	○								○					○	◑					○			LIGHT STANCHION DITCH
•-16	B	T	G1-12	2F	31E	167	E		●	○		○		●					○				●										●										○			
-17	W	T	G1-14	0	1E	230	E		○										○																						○					
18	W	T	G1-16	0	0	6	E								○				○																							○				
-19	W	T	G1-17	0	7E	94	R																										●								○					
-20	W	T	G1-4	0	1E	60	E		②					○	○									○													○	◑	○				○			LIGHT, MOUND, FENCE

•AIRPLANE YAWED

① FUEL DRAINED AWAY

② FUEL SPILL

TABLE 4-29. RELATIVE CONTRIBUTION TO INJURY/FATALITY, GG2 TYPE ACCIDENT

ACCIDENT IDENTIFICATION										STRUCTURAL DAMAGE											SYSTEM INVOLVEMENT																AIRPORT SURROUNDINGS									
SCENARIO	ENGINE ARRANGEMENT 1	OPERATION MODE 2	ACCIDENT CATEGORY	FATAL INJURIES	SERIOUS INJURIES	MINOR/NO INJURIES	GEAR POSITION		POST-CRASH FIRE	ENGINE SEPARATION	WING SEPARATION	WING DAMAGE	FUSELAGE BREAK/LOCATION	MLG COLLAPSE/SEP	NLG COLLAPSE/SEP	CLG COLLAPSE/SEP	COCKPIT CRUSHING	FUSELAGE KEEL BEAM	TIRE AND/OR WHEEL		WING FUEL LINE RUPTURE	FUSELAGE FUEL LINE RUPTURE	FUEL TANK RUPTURE	LOWER FUSELAGE CRUSH/PENETRATION	OVERHEAD RACK	CEILING PANELS	SEATS	SEAT ATTACHMENTS	RESTRAINT SYSTEM	FLOOR BUCKLE	DOOR DEFORMATION	GALLEY EQUIPMENT	SLIDE SYSTEM/EVACUATION PROCEDURE	DEBRIS	NONUSE OF RESTRAINT SYSTEM		COLUMNAR OBSTRUCTION	CONTOUR OBSTRUCTION	FRONTAL OBSTRUCTION	TERRAIN	RUNWAY, ON/OR SHORT OF	< 150 M PAST RUNWAY	150 M – 350 M PAST RUNWAY	350 M – 1000 M PAST RUNWAY	> 1000 M PAST RUNWAY	TYPE OF OBSTRUCTION/TERRAIN
-1	F	L	G5-9	0	16T	10	E						●[d]												●		●	●		●								◑				○				EMBANKMENT
-2	F	L	G5-6	1F/T	11T	38	E		●	◑	◑		●[g]	◑	○							◑	◑				●	●									○	◑		○			○			RAVINE TREE STUMPS ROUGH TERRAIN
-3	F	L	G5-6	37 F/T	19 F/T	32	E		●	○	●		●[e]	○				○					●				●	●		●								◑	◑				○			EMBANKMENT VEHICLE, BLDG.
-4	W	T	G1-1	1T	1T	34	E		○	◑	○		◑[b]	○	◑						○			◑						◑	◓							◑				○				HILL, EMBANKMENT
-5	W	T	G1-6	0	16E	70	E		○		◑												◓		◓								◑	◓					◑	○		○				BLAST FENCE, STAND
-6	W	T	G1-9	6T	4T	0	E		○				◑[b]				●										●	●	◑						●		○	◑	○				○			DITCH CANAL, LIGHT, VEHICLE
-7	F	T	G1-13	2T	47T	58	E		①				●[e]	○	○				○				◓				●	●		○	○			◓				◑					○			RAVINE
-8	W	T	G1-15	0	3T	0	E					○			○		●							●													○	◑					○			ILS ANTENNA DRAINAGE DITCH
-9	W	T	G1-5	47F	49 F/T	133	E		●	○	●		●[e]		○	○			○		●		●		◓		●	●			◓	◓		○			◑	◑							○	ILS STRUCTURE DITCH

① FUEL SPILL

TABLE 4-30. RELATIVE CONTRIBUTION TO INJURY/FATALITY, AG1 TYPE ACCIDENT

ACCIDENT IDENTIFICATION										STRUCTURAL DAMAGE											SYSTEM INVOLVEMENT																AIRPORT SURROUNDINGS									
SCENARIO	ENGINE ARRANGEMENT 1	OPERATION MODE 2	ACCIDENT CATEGORY	FATAL INJURIES	SERIOUS INJURIES	MINOR/NO INJURIES	GEAR POSITION		POST-CRASH FIRE	ENGINE SEPARATION	WING SEPARATION	WING DAMAGE	FUSELAGE BREAK/LOCATION	MLG COLLAPSE/SEP	NLG COLLAPSE/SEP	CLG COLLAPSE/SEP	COCKPIT CRUSHING	FUSELAGE KEEL BEAM	TIRE AND/OR WHEEL		WING FUEL LINE RUPTURE	FUSELAGE FUEL LINE RUPTURE	FUEL TANK RUPTURE	LOWER FUSELAGE CRUSH/PENETRATION	OVERHEAD RACK	CEILING PANELS	SEATS	SEAT ATTACHMENTS	RESTRAINT SYSTEM	FLOOR BUCKLE	DOOR DEFORMATION	GALLEY EQUIPMENT	SLIDE SYSTEM/EVACUATION PROCEDURE	DEBRIS	NONUSE OF RESTRAINT SYSTEM		COLUMNAR OBSTRUCTION	CONTOUR OBSTRUCTION	FRONTAL OBSTRUCTION	TERRAIN	RUNWAY, ON/OR SHORT OF	< 150 M PAST RUNWAY	150 M – 350 M PAST RUNWAY	350 M – 1000 M PAST RUNWAY	> 1000 M PAST RUNWAY	TYPE OF OBSTRUCTION/TERRAIN
-1	W	L	A1-1	0	UN	87	E			○			◑(c)	○	○															◑	◓										○					
-2	W	L	A1-3	0	BT	120	E		◑	◑			○(l)								◑			○	●		●	●		◑				◓							○					
-3	W	L	A1-4	0	2E	63	E		◓						◑				○					○						◓	◓										○					
4	F	L	A1-5	0	1T 2E	7	E		○				◑(l)	○					○		○					○	●														○					SOFT DIRT
-5	F	L	A3-17	0	16T	70	R			○			◑(l)											◑			●	◓	●	◑	◓		◓	◓							○					
-6	F	T	A3-11	0	147	119	R						◑(a,c)												◓	◓	●	●		●	◓	◓		◓								○		○		
-7	F	L	A4-1	43F	7T 28F	13	E		●	●				●							●				○								◓				○				○	○				APPROACH LIGHT
-8	F	L	A4-3	0	0	94	E						○(c,l)					○										○		○											○	○				
-9	F	L	A4-6	0	1E	138	E			○				○	○										◓			○	○												○					LANDED 94M SHORT OF RUNWAY, GRASS
-10	S	L	A4-8	0	1U	378	E		◓	○				○					○		○																				○					LANDED 94 M SHORT OF RUNWAY,SOFT DIRT
-11	F	L	A4-9	0	0	83	E							○																											○					LANDED 65 M SHORT OF RUNWAY

TABLE 4-31. - RELATIVE CONTRIBUTION TO INJURY/FATALITY, AG2 TYPE ACCIDENT

TABLE 4-31. RELATIVE CONTRIBUTION TO INJURY/FATALITY, AG2 TYPE ACCIDENT

ACCIDENT IDENTIFICATION										STRUCTURAL DAMAGE											SYSTEM INVOLVEMENT																AIRPORT SURROUNDINGS										
SCENARIO	ENGINE ARRANGEMENT 1	OPERATION MODE 2	ACCIDENT CATEGORY	FATAL INJURIES	SERIOUS INJURIES	MINOR/NO INJURIES	GEAR POSITION		POST-CRASH FIRE	ENGINE SEPARATION	WING SEPARATION	WING DAMAGE	FUSELAGE BREAK/LOCATION	MLG COLLAPSE/SEP	NLG COLLAPSE/SEP	CLG COLLAPSE/SEP	COCKPIT CRUSHING	FUSELAGE KEEL BEAM	TIRE AND/OR WHEEL		WING FUEL LINE RUPTURE	FUSELAGE FUEL LINE RUPTURE	FUEL TANK RUPTURE	LOWER FUSELAGE CRUSH/PENETRATION	OVERHEAD RACK	CEILING PANELS	SEATS	SEAT ATTACHMENTS	RESTRAINT SYSTEM	FLOOR BUCKLE	DOOR DEFORMATION	GALLEY EQUIPMENT	SLIDE SYSTEM/EVACUATION PROCEDURE	DEBRIS	NONUSE OF RESTRAINT SYSTEM		COLUMNAR OBSTRUCTION	CONTOUR OBSTRUCTION	FRONTAL OBSTRUCTION	TERRAIN	RUNWAY, ON/OR SHORT OF	< 150M PAST RUNWAY	150M - 350M PAST RUNWAY	350M - 1000M PAST RUNWAY	> 1000M PAST RUNWAY	TYPE OF OBSERVATIONS/TERRAIN	COMMENTS
-1	L	W	A4-4	① 96	U 5	0	E		●	○		○		○	○			●			◑		◑	●													●			●					○	LANDED SHORT THRU TREES	
-2	L	F	A4-5	② 112	12	0	E		◑	◑		○	● (a)								◑		◑	◑			●	●		●				◓					●	●				○		CRASHED SHORT OF RNWY	
-3	L	F	A7-9	0	T 3	76	E		◑	◑	◑			○	○						◑			◑				◑		◑	◓			◓			●		●		○		○			STRUCK APPROACH LIGHTS	
-4	L	B	A4-7	0	③ 3	164	E		◓	◑				○	○	○					◑		◑					◑		◑	◓			◓			●	●			○	○				LANDED 150 M. SHORT OF RNWY	

① 1T, 95F

② 2T, 33 F/T, 77U

③ 1T, 2E

TABLE 4-32. - RELATIVE CONTRIBUTION TO INJURY/FATALITY, AG3 TYPE ACCIDENT

TABLE 4-32. RELATIVE CONTRIBUTION TO INJURY/FATALITY, AG3 TYPE ACCIDENT

ACCIDENT IDENTIFICATION										STRUCTURAL DAMAGE											SYSTEM INVOLVEMENT															AIRPORT SURROUNDINGS									
SCENARIO	ENGINE ARRANGEMENT 1	OPERATION MODE 2	ACCIDENT CATEGORY	FATAL INJURIES	SERIOUS INJURIES	MINOR/NO INJURIES	GEAR POSITION		POST-CRASH FIRE	ENGINE SEPARATION	WING SEPARATION	WING DAMAGE	FUSELAGE BREAK/LOCATION	MLG COLLAPSE/SEP	NLG COLLAPSE/SEP	CLG COLLAPSE/SEP	COCKPIT CRUSHING	FUSELAGE KEEL BEAM	TIRE AND/OR WHEEL		WING FUEL LINE RUPTURE	FUSELAGE FUEL LINE RUPTURE	FUEL TANK RUPTURE	LOWER FUSELAGE CRUSH/PENETRATION	OVERHEAD RACK	CEILING PANELS	SEATS	SEAT ATTACHMENTS	RESTRAINT SYSTEM	FLOOR BUCKLE	DOOR DEFORMATION	GALLEY EQUIPMENT	SLIDE SYSTEM/EVACUATION PROCEDURE	DEBRIS	NONUSE OF RESTRAINT SYSTEM		COLUMNAR OBSTRUCTION	CONTOUR OBSTRUCTION	FRONTAL OBSTRUCTION	TERRAIN	RUNWAY, ON/OR SHORT OF	< 150M PAST RUNWAY	150M - 350M PAST RUNWAY	350M - 1000M PAST RUNWAY	> 1000M PAST RUNWAY	TYPE OF OBSERVATIONS/TERRAIN	COMMENTS
-1	F	L	A2-5	F/T 58	T 4	O	R		●	◐		○	● (g)	○		○					◐			◐													●	●		●					○	HIT TREES & SLOPE	
-2	W	L	A3-4	T 83	F/T 15	O	E		◐	○	◐	○	◐ (a)	○			◐				◐		●				◐	◐										●		●					○	HIT HILL CREST	
-3	W	F	A2-9	F/T 30	① 10	O	R		●	◐	◐		○ (d)										◐					◐										●		●					○	HIT MOUNTAIN	
-4	F	L	A3-12	② 4	0	O	E		●				● (h)								◐		◐																		●					WAKE TURBULANCE	⑥
-5	B	F	A3-13	T 99	③ 77	O	E		●	○		◐	● (h)	○	○						○		○							◐				◓						●					○	EVERGLADES	
-6	W	L	A3-19	T 10	T 20	2	E		○	◐	○		● (g)	○	○		●				◐			◐			◐	◐		◐								●							○	STRUCK SIDE OF MOUNTAIN	
-7	W	T	A2-25	④ 3	F 2	O	E		●	◐	◐		◐ (c)			○					◐																			●	●						
-8	F	T	A5-1	0	3T	6	R		⑤			◐	○ (i)										◐					◐							●									○		TREE GROVE	

① 9T, 1F
② 3T, 1F
③ 63T, 14F
④ 2F, 1 F/T
⑤ FREEZING TEMPERATURE
⑥ AIRPLANE DESTROYED

TABLE 4-33. - RELATIVE CONTRIBUTION TO INJURY/FATALITY, AG4 TYPE ACCIDENT

TABLE 4-33. RELATIVE CONTRIBUTION TO INJURY/FATALITY, AG4 TYPE ACCIDENT

ACCIDENT IDENTIFICATION										STRUCTURAL DAMAGE											SYSTEM INVOLVEMENT																AIRPORT SURROUNDINGS										
SCENARIO	ENGINE ARRANGEMENT 1	OPERATION MODE 2	ACCIDENT CATEGORY	FATAL INJURIES	SERIOUS INJURIES	MINOR/NO INJURIES	GEAR POSITION		POST-CRASH FIRE	ENGINE SEPARATION	WING SEPARATION	WING DAMAGE	FUSELAGE BREAK/LOCATION	MLG COLLAPSE/SEP	NLG COLLAPSE/SEP	CLG COLLAPSE/SEP	COCKPIT CRUSHING	FUSELAGE KEEL BEAM	TIRE AND/OR WHEEL		WING FUEL LINE RUPTURE	FUSELAGE FUEL LINE RUPTURE	FUEL TANK RUPTURE	LOWER FUSELAGE CRUSH/PENETRATION	OVERHEAD RACK	CEILING PANELS	SEATS	SEAT ATTACHMENTS	RESTRAINT SYSTEM	FLOOR BUCKLE	DOOR DEFORMATION	GALLEY EQUIPMENT	SLIDE SYSTEM/EVACUATION PROCEDURE	DEBRIS	NONUSE OF RESTRAINT SYSTEM		COLUMNAR OBSTRUCTION	CONTOUR OBSTRUCTION	FRONTAL OBSTRUCTION	TERRAIN	RUNWAY, ON/OR-SHORT OF	< 150M PAST RUNWAY	150M - 350M PAST RUNWAY	350M - 1000M PAST RUNWAY	> 1000M PAST RUNWAY	TYPE OF OBSERVATIONS/TERRAIN	COMMENTS
-1	W	L	A2-7	U 70	T 12	0			◓				● (h)																								●			●					○	STRUCK TREES	⑥
-2	W	L	A5-2	T 27	T 16	2	E		◓	○	○		◑ (d)								○		○				◑	◑		○									●				○			STRUCK HANGAR	
-3	W	L	A5-4	U 45	U 12	8	R		◑	○	◑		○ (a)(b)		○		◑				◓		◓					◑						◓			●		●						○	STALLED	
-4	W	L	A2-13	T 38	T 6	0	E		◓	○	◑		◑ (a)	○	○						○	○	○				●										●			●					○	STRUCK BY LIGHTNING	
	F	L	A2-17	① 71	F/T 10	1			●		◑	○	● (h)	○	○						○							●	●	○				◓			●	●		●					○	STRUCK TREES	
-6	F	F	A2-20	② 62	F/T 22	J	E		●		◑		● (h)	○	○						◑		◑				◑	◑			◓			◓			●			●					○	HAIL INGESTION STOP ENGINES	
-7	W	L	A2-2	T 6	T 19	1			⑤			○	◑ (b)				●				○		○	◑			◑	◑									●			●					○	STRUCK HANGAR	
-8	W	L	A7-1	T 20	T 12	15	E		○	○		○	● (h)								○		◓					◑			◓						●			●					○	HIT TREES & CRASHED INVERTED	
-9	W	L	A7-2	T 11	T 17	0	E		○	○	○	○	◑ (b)								○		○					◑									●			●					○	STRUCK TREES	
-10	W	L	A7-5	③ 28	F/T 3	0	E		●	○		○	◑ (a)(d)				●				◑		◑																●	●					○	HIT GROUND STRUCTURES	
-11	W	L	A7-7	T 16	T 32	0	R		⑤	○		○	◑ (a)(d)				●										◑	◑	◑	○	◓								●						○	STRUCK HOUSE	
-12	W	L	A7-8	④ 88	T 1	0	E		◑	○	○		◑ (d)	○	○		●				◑		◑				◑												●					○		STRUCK A SEAWALL	
	W	L	A7-11	T 3	0	3	E		◑	◑			◑ (a)	○	○		●				◑	◑	◑				◑	◑		○							◑		●						○	LOST POWER AT BEGINNING OF FLIGHT	
		L	A7-13	T 10	T 23	156	E		⑤		◑		● (a)				●							●			◑	◑		◑				◑			●		●						○	RUN OUT FUEL LANDED EMERG	

① 32T, 33F, 6 F&T
② 31T, 20F, 9 F&T, 2U
③ 26F, 2 F/T
④ 3T, 85 F/T

⑤ LOW ON-FUEL
⑥ AIRPLANE DESTROYED

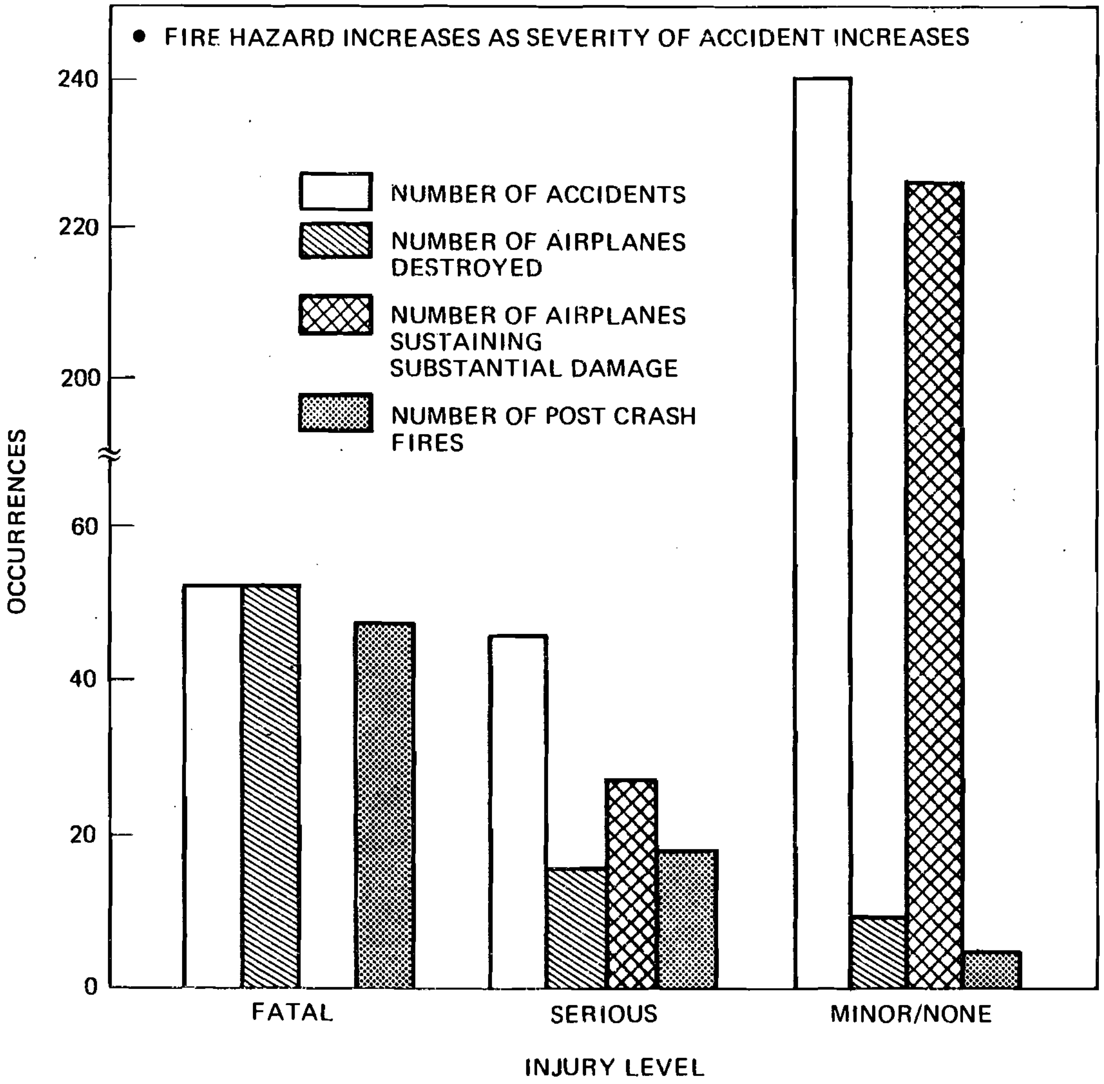


Figure 4-22. - The occurrence of post crash fire as a function of airplane damage.

strong correlation between the frequency of occurrence of post-crash fire with the more extensive structural damage that the aircraft sustains in an accident. The more severe accidents generally occur at distances of more than a kilometer or more from the airport. A vulnerable structural area is wing-root separation. Penetration of the wing fuel tank region by trees also is a major contributor to a structural failure that results in fuel spill and the potential for fire. Landing gear collapse during an overrun, or a hard landing can lead to fuel tank rupture either by direct penetration or subsequent wing impact with terrain.

- Seat Restraint System-Occupant Dynamics

  The performance of seats with regard to protecting occupants during an accident is generally good provided the structural integrity of the fuselage shell and supporting floor structure is maintained. The most vulnerable area for seat failure appears to be at the attachment to the floor. While seats exhibit desirable deformation characteristics in the process of failing there is little quantitative data available with regard to load vs. stroke characteristics. Static tests are performed to determine strength. The current static requirements appear to account for dynamic effects, possibly because:

  1) seats may have higher strength than is required and,

  2) metal support structure has inherent crush capability which provides energy absorption in an overload condition.

The interaction between airframe, seat, cushion and occupant depends on the relative masses and stiffnesses of each of the parts of the system. The transport seat-occupant dynamics is more complicated than corresponding military helicopter and general aviation seat systems because of the multiple seating arrangements, range of occupant sizes and weights and difficulties associated with appropriate restraint attachment locations. The dynamics of transport seat-occupant dynamics has to be fully evaluated analytically and validated with tests. A major thrust of future R&D effort should be directed toward establishing dynamic requirements and establishing compliance procedures, whether they be dynamic test, static equivalent tests, analysis or some combination of procedures.

- Lower Fuselage Crushing

  The lower fuselage design in current modern day large jet transport airplanes provides a substantial crushable region. This is particularly important for failure modes of landing gears which can penetrate fuselage structure. During overruns, the aircraft has a tendency to slide along rough terrain for a substantial distance. The structural integrity of the airframe is maintained in that the fuselage "holds together." However, the potential future increased usage of advanced materials could jeopardize this situation. There is little available data for crushing, abrasion or tearing characteristics of composites under crash loading conditions. To ensure that the structural integrity of an airframe is maintained during overrun accidents, empirical data and analytical procedures are needed.

- Fuselage Breakup Characteristics

  The modern day jet transport fuselage does not sustain large acceleration loads before collapse, separation or breakup occurs. However, the strength of the fuselage is consistent with the capability of the other structure and systems such as floor, seat, and mass items. The type of fuselage failure varies depending on the crash impact conditions and sequence. During an overrun (GGO) the fuselage separation is mild and the aircraft hangs together. During a hard landing (AGHL) the fuselage separation is noticeable and occurs at one or two distinct locations. The fuselage break, however, is not generally large enough to allow exiting by passengers. During a severe ground impact as characterized by AGI accidents, the breakup of the airplane often occurs at several locations and is complete in the sense that whole sections separate. The determination of floor pulses to which seats are subjected is related to the severity of the accident, the location of the seat relative to impact and the compliance of the structure between the impact location, through the fuselage, and to the seat attachments. Combined loading can influence the failure modes of the airframe. Research in this area would help assess how design concepts can provide practical improvements in transport crash dynamics over a wide range of impact parameters.

- Landing Gear Failure Modes

  Landing gear failures influence the dynamic response in several ways such as:

  1) provide potential to penetrate fuselage, wing structure, or fuel tank,

  2) subsequently provide a mechanism by which wing or airframe impact the ground.

Unlike helicopters, transport airplane landing gears are not designed to absorb a high percentage of the available kinetic energy in failing. The attitude of the airplane at impact and the location and attachment to wing structure will have a bearing on the failure load. Understanding the mechanisms of failure of landing gears, and consequently possible design improvement are desirable in order to reduce potential failures and alleviate the consequence of landing gear failure.

The SAFER advisory committee reported in 1979 (reference 98) on post-crash fire hazard reduction. Included in the SAFER committee recommendations are:

- Continue and expedite research to establish a realistic crash scenario
- From the crash scenario, develop design criteria which transport category aircraft must meet
- Expand the investigation of **Anti-Misting** Kerosene (AMK) and its properties with respect to all operational aspects of commercial transport aircraft

As part of the SAFER committee a study of various fuel crash resistant and containment concepts (reference 99) were evaluated in a matrix which takes into consideration weight, volume, range, cost, maintainability, reliability hazards, retrofit effectiveness, equivalent protection and general commentary. Table 4-34 obtained from reference 99 presents this data. This matrix illustrates that it is difficult to assess all the ramifications of incorporating a concept. Furthermore it is, with few exceptions, impractical to quantify the penalties.

TABLE 4-34. - MATRIX OF CONCEPT VERSUS PENALTY CONSIDERATIONS (Reference 99)

CONCEPT	WEIGHT (lbs) (1)	VOLUME/ RANGE	COST $	MAINT-ABILITY	RELIA-BILITY	ADDITIONAL HAZARD?	RETROFIT	EFFECTIVENESS	EQUIVALENT PROTECTION	COMMENTS
Crash-Resistant Tanks in Fuselage. (MIL T 27422B Type)	At least .34 lbs/gal (450 gallon tank design and 65 ft drop test on small tanks results): DC-8 centerwing tank + 3860 lbs.	Loss of 5430 lbs. fuel from DC-8 centerwing			O.K. as passive, Life and wear of material affect on burst resistance?	No worse than conventional bladder (leakage potential -must design to contain)	Possible	Not proven in sizes greater than 400 gallons. Not effective against all penetration possibites.	Yes: Impact resisted by present bladder, and safe location and fuselage bulk main reaction to penetration and crushing loads - meets FAR 25,963 Keel under center wing tanks.	Increased safety minimal as no previous record of fuselage tank involvement in crashes Will need representative full scale and comparison tests.
Crash-Resistant Tanks in Wing	+5,000 lbs DC-8 +4,568 lbs B-52 (3) DC-7	20%+, for DC-8 30%+, for B-52 (3) DC-7	490,000 dollars estimated for DC-8 in 1965 optimistic estimate ref. (4)	Liner, ref (3) prevents inspection of main structure. How would numerous valves be checked? (3)	as above	Hazard in flight due to numerous leakage sources. Increase in take-off and landing,	Access panels required for every bay. Larger panels to insert liners etc., or remove entire surface.	Effective against inertia loads and some pentrations. Ineffective against concentrated impact, (5)	Integral effective against inertia loads up to as acceptable limits as c.r. bladder.	Not considered cost effective for conventional wing structure.
Leading edge reinforcement (to resist other aircraft parts and the ground)	1,670 for CV880 to cut down up to 17" Dia. trees. (6)		(6) 36,312 (1970 dollars)	NONE	Passive	NONE	Redesign of wing	Reduced flexibility worse for wing tip impact mode. Some increase in impact load resistance but only at inner wing and is it enough to be beneficial?	Some present airliners inherently more impact resistant than old tested non-representative wing tanks.	Would not have been cost effective if installed on jet fleet between 1958 and 1968. (7)
Ductile lower wing wing skins								Will more ductile skins give significantly more resistance to skidding and rocks.		Is it possible to make aluminum skins significantly more ductile?
Retain tank integrity with breakaway fitting, fuel lines, landing gear.	Some additional weight	No loss	Moderate increase	How would valves be checked?	Must prove operationally reliable.	Increased possibility of functional failure.	Support structure redesign	Not proven completely, must prove each installation individually	Already using a form of breakaway valve for present supplementary tanks.	Also should consider quantity probes, ailerons, flap breakaway etc.
Better tank location -away from gear -damage, wing tip -by locating high wing -by keeping behind front spar.										Other design requirement conflicts -balance, c.g. travel, fuel for range requirements.

TABLE 4-34. - MATRIX OF CONCEPT VERSUS PENALTY CONSIDERATIONS (Reference 99) (Continued)

CONCEPT	WEIGHT (lbs) (1)	VOLUME/ RANGE	COST $	MAINTAINABILITY	RELIABILITY	ADDITIONAL HAZARD?	RETROFIT	EFFECTIVENESS	EQUIVALENT PROTECTION	COMMENTS
Increased compartmentation of integral wing tanks	Extra bulkheads pumps, valves.	More unusable fuel.	Some increase	More access doors needed for gages etc.		Putting potential break points at most critical structure location in airplane not good design	Excessive rework	Less fuel spilled initially, but hazard not eliminated.		
Isolating tanks from expected separation points (e. g. wing roof) by double walls (breakaway fuel cells)	Increased due to double wall at each separation plane.		Increase		Requires tests to determine.		Not feasible	If lose wings and fuel this reduces chance of fuselage fire and reduce kinetic energy of crashing body. Will wing loss make fuselage more vulnerable to contact.		Great chordwise strength inherent in wing roots - also some aircraft have continuous fuel. Therefore, build for resistance here and for breakaway at (say) engine plane?
Intumescent paint or external low density foams as cavity liners								Limited		
Integral Wing tanks designed for 35g.	10,000 lbs for DC-8 retrofit	Reduce volume by 340 gallons for DC-8 retrofit.					DC-8 changes include 3 spar to 4 spar wing, 4 ribs to full bulkheads plus flapper valves, Increase stringer gage and strengthen front spar.	Resist fuel inertia only and not necessarily direct structural damage.		Ref. Douglas report L.B 31820 Ref. also old FAA N.P.R.M. and resulting comments - no resulting regulation.
Internal liners (e.g. foam and bonded extendible film)	3,310 lbs for foam lined CV 880 (6)	Some reduction approx. 3%	68,485 (1970 dollars)	How inspect major structure?	Must ensure retention.	Static electricity effect? Must ensure retained not to impede transfer	Need frangible bond development, must be compatible with fuel.	Penetration by an object large enough to destroy a bulkhead or rib outside capability of concept.		See comments on leading edge reinforcement (above 3rd from top)
Membranes or Curtains								DC-7 droptests showed little improvement obtainable; structure damage overwhelmed concepts		Goodyear tests of elastometric liners, curtains, boot type liner etc. (8)
Crash energy absorbing devices (on leading edge etc.)	Heavy							Nebulous improvement, still allows fuel leakage.		
Flow restrictors in fuel (multicellular polyhedron)	Heavy							Limited (leakage)		

( ) denotes Reference Number.

5. EVALUATION OF U.S. ARMY AIRCRAFT CRASH SURVIVAL DESIGN GUIDE

5.1 General

The revised U.S. Army Aircraft Crash Survival Design Guide (reference (4)), is reviewed with regard to possible application to transport aircraft. The five volumes contained in the revised edition are titled:

Volume I - Design Criteria and Checklists

Volume II - Aircraft Crash Environment and Human Tolerance

Volume III - Aircraft Structural Crashworthiness

Volume IV - Aircraft Seats, Restraints, Litter and Padding

Volume V - Aircraft Post Crash Survival

The U.S. Army Aircraft Crash Survival Design Guide is undertandably oriented toward helicopter design. The crash environment, aircraft utilization, occupant types, restraint systems and design principles for helicopters are substantially different than that of transport airplanes. Consequently, one can expect that much of the design information would not be directly applicable to large transports without some clarification or elaboration. The Design Guide presents a conglomoration of information and data which cover the spectrum of background information, design requirements, design principles, criteria, analysis, test, and reference material, some of which can be expected to be useful in assessing transport crash dynamics. To facilitate the evaluation of the Design Guide and its applicability to transport airplanes, the following several levels of applicability were established and used:

NA - Not applicable or very limited

A_1 - Directly applicable

A_2 - Represents the type of information that should be made (or is) available

A_3 - Represents general information that may be useful to document

A_4 - Represents the type of information whose availability should be noted.

A summary of Volumes I through V is presented with an overview of the material available in reference 4.

Volume I contains a summary of information provided in Volume II-V. Thus the review and evaluation will be directed toward Volumes II-V.

Volume II contains information on the aircraft crash environment and the response of the human body to such an environment. Following a general discussion of aircraft crashworthiness in Chapter 1, a number of words commonly referred to in discussing the crash environment are defined in Chapter 2. Chapter 3 describes the crash environment itself, in terms of impact conditions, terrain, and the nature and frequency of different types of injuries. Chapter 4 discusses the tolerance of the human body and various body parts to impact loading. Chapter 5 presents data on occupant motion during a crash. Chapter 6 provides data on human anthropometry that may be useful in preparing input for computer simulation models such as those discussed in Volume IV. Chapter 7 describes the crash test dummies used in evaluating protective systems such as seats and restraints.

Volume III contains information on aircraft structural crashworthiness. Following a general discussion of aircraft crashworthiness in Chapter 1, a number of terms commonly used in discussing the crash environment and aircraft structures are defined in Chapter 2. Chapter 3 presents a general discussion of aircraft types, principles for the design of crashworthy vehicles, and testing for evaluation of crashworthiness. Although Volume II discusses the crash environment in detail, a summary of information pertinent to aircraft structural design is presented in Chapter 4. Structural design and testing requirements for improved crashworthiness are described in Chapter 5. Principles and concepts for improving crashworthiness in aircraft structures are described in Chapter 6. Chapter 7 discusses analytical techniques for evaluating structural crashworthiness.

Volume IV contains information on aircraft seats, litters, personnel restraint systems, and hazards in the occupant's immediate environment. Following a general discussion of aircraft crashworthiness in Chapter 1, a number of terms commonly used in discussing the crash environment, seats, and occupant protection are defined in Chapter 2. Chapter 3 presents design considerations for aircraft seats, and Chapter 4, principles for crashworthy seat design. Energy absorption is discussed in Chapter 5. Principles for cushion and restraint system design are presented in Chapters 6 and 7, and strength and deformation requirements for seats and litters are stated in Chapters 8 and 9, respectively. Cockpit delethalization, including protective padding, is discussed in Chapter 10.

Volume V contains information on the aircraft postcrash environment and design techniques that can be used to reduce postcrash hazards. It contains a great deal of background information, including data from such sources as full-scale aircraft burn tests, laboratory materials testing, and research and development programs in aircraft fuel systems. Chapter 1 presents a general discussion of designing for crashworthiness. Chapter 2 contains definitions of terms pertinent to the volume. Chapter 3 describes the postcrash fire environment and relates this environment to human tolerance data in the areas of heat, smoke, and toxic gases. Chapter 4 discusses methods of preventing postcrash fires by containing flammable fluids in crashworthy fuel, oil, and hydraulic systems, modifying fuel properties to reduce crash-induced fuel misting, and controlling potential ignition sources. Chapter 5 discusses the fire behavior of interior materials and presents data on material flammability tests and selected material properties. Chapter 6 describes the ditching environment and provisions that can be incorporated into the aircraft design to increase ditching survival. Chapter 7 presents design requirements for emergency escape exits and lighting, and Chapter 8 discusses crash locater beacons.

Table 5-1 provides a summary of the reference (4) evaluation, utilizing the applicability ratings described earlier. For each volume the section titles are listed and levels of applicability are noted. Omitted from the summary

TABLE 5-1. - SUMMARY EVALUATION OF REVISED U.S. ARMY AIRCRAFT CRASH SURVIVAL DESIGN GUIDE

Section	Subject	Evaluation Rating				
		NA	A_1	A_2	A_3	A_4
	Volume II Aircraft Crash Environment and Human Tolerance					
II	Definitions		X	X		
III	Aircraft Crash Environment			X		
IV	Human Tolerance to Impact					X
V	Occupant Motion Envelopes					X
VI	Human Body Dimensions and Mass Distribution		X			
VII	Crash Test Dummies					X
	Volume III Aircraft Structural Crashworthiness					
II	Definitions		X	X		
III	General Design Considerations	X				
IV	Crash Environment			X		
V	Design Requirements				X	
VI	Airframe Principles and Concepts				X	X
VII	Analytical Methods		X			X
	Volume IV Aircraft Seats, Restraints, Litter and Padding					
II	Definitions		X	X		
III	Primary Design Considerations			X	X	
IV	Design Principle for Seats and Litters	X				X
V	Energy Absorbing Devices					X
VI	Seat Cushions				X	X
VII	Design Principles for Personnel Restraint Systems				X	X
VIII	Seat Strength and Deformation Requirements			X		X
IX	Litter Strength and Deformation Requirements	X				
X	Delethalization of Cockpit and Cabin Interiors	X				X
	Volume V Aircraft Post Crash Survival					
II	Definitions		X	X		
III	Postcrash Fires					X
IV	Postcrash Fire Protection			X	X	X
V	Interior Materials				X	X
VI	Ditching Provisions			X		
VII	Emergency Escape Provisions			X		
VIII	Crash Locater Beacons				X	

table for each volume is Section 1 (Background Discussion) and References. Section 1 data generally explain the data contained in the volume under review and how the revised Design Guide differs from the earlier versions. This information is not applicable to transport crashworthiness except for some isolated general comments. The reference data, while not evaluated in the summary, would of course provide some valuable reference material.

The following is a summary discussion for some of the major subject areas described in reference 4, Volumes I-V. Included are:

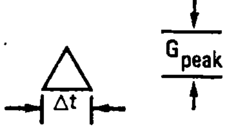
- Aircraft Crash Environment
- Occupant Environment
- Human Tolerance to Impact
- Seats and Restraint Systems
- Crash Design Requirements and Procedures
- Energy Absorbing Seat Designs
- Analysis Methods
- Post Crash Fire
- Crash Test Dummies

5.2 Aircraft Crash Environment

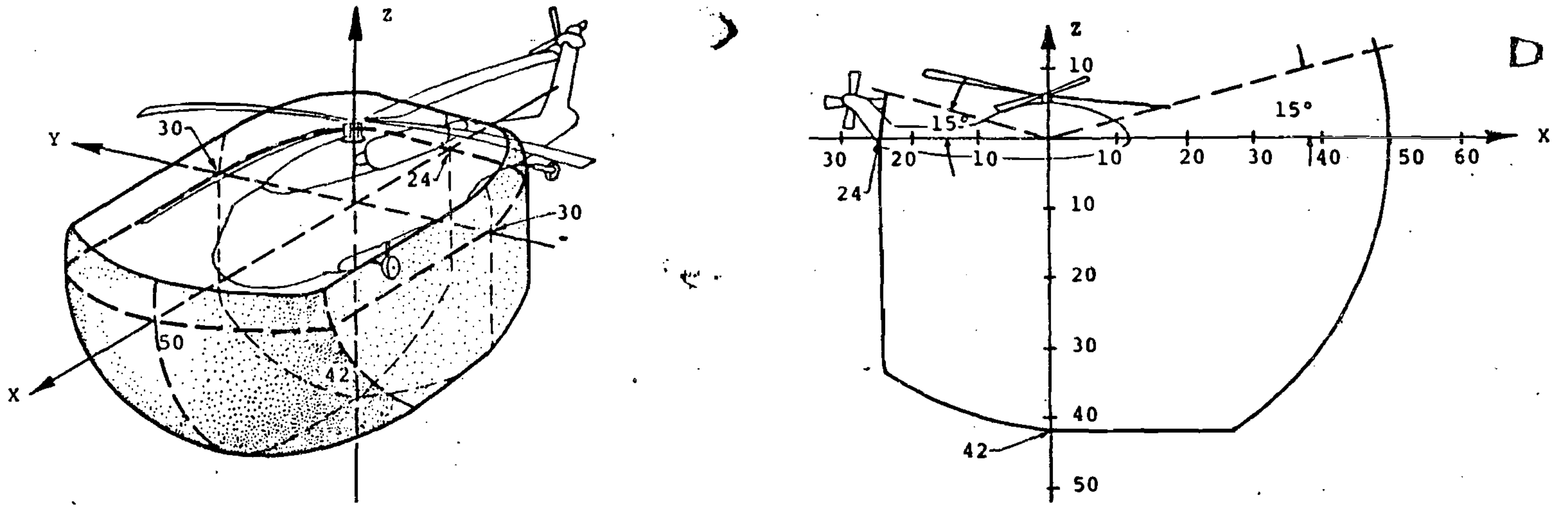
The crash environment for military helicopters as defined by ninety-fifth (95th) percentile survivable crash pulses, in different directions, was established for U.S. Army helicopters on the basis of 373 accidents that occurred between July 1960 and June 1965 (reference 3). The U.S. Army defines a survivable accident (reference 4) as "an accident in which the force transmitted to the occupant through his seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations and in which the structure in the occupant's immediate environment remains substantially intact to the extent that a livable volume is provided for the occupants throughout the crash sequence." The U.S. Army further defines a survivable envelope (reference 4) as: "the range of impact conditions - including magnitude and direction of pulses and the duration of forces occurring in an aircraft accident—wherein the occupiable area of the aircraft remains substantially intact, both during and following the impact, and the forces transmitted to the occupants do not exceed the limits of human tolerance when current state-of-the-art restraint systems are used." The crash impact conditions for helicopters and light fixed-wing aircraft design obtained from reference 4, Volume III, are shown in table 5-2. The three-dimensional display of resultant velocity changes is illustrated in figure 5-1 (Volume III, reference 4).

A comparison of the survivable crash environment and the responses of the structures indicate significant differences between small and large airplanes. The survivable large transport accident usually occurs around airports at flight path velocities under 150 knots and vertical descent rates at impact of less than 20 feet per second. These conditions are normally associated with landing and take-off operations such as landing short, overruns, and skidding off the runway. Smaller aircraft, such as helicopters and general

TABLE 5-2. - SUMMARY OF CRASH IMPACT CONDITIONS FOR HELICOPTERS AND LIGHT FIXED-WING AIRCRAFT DESIGN

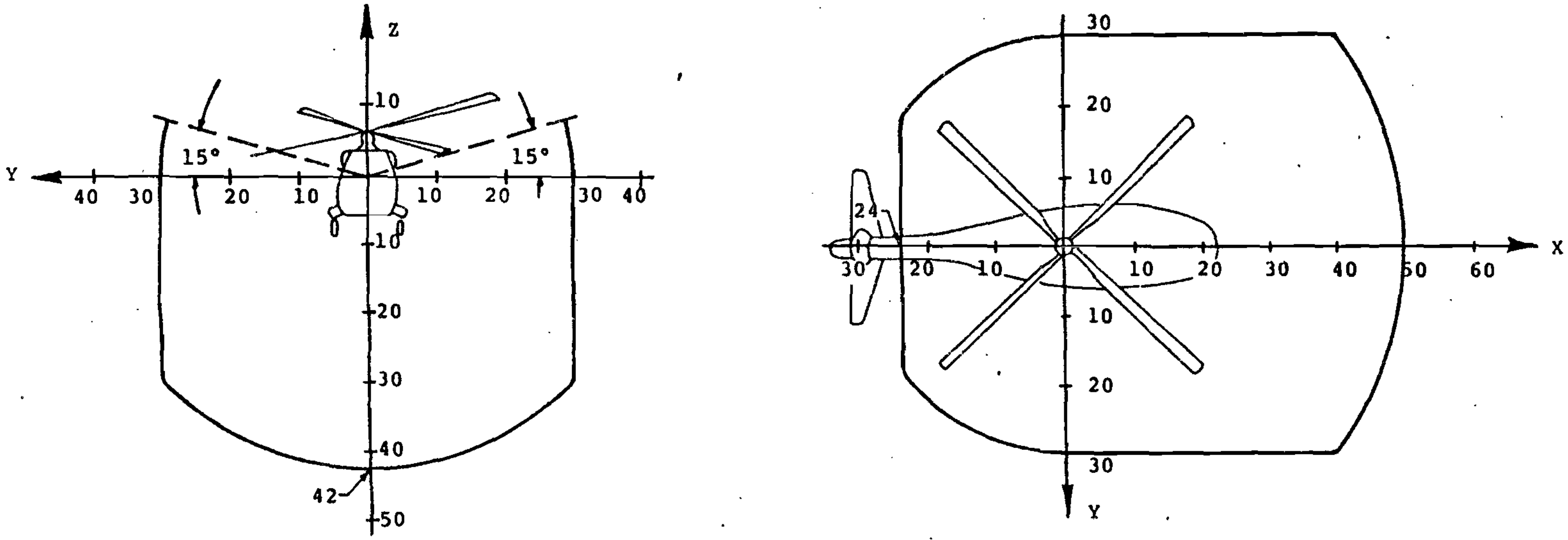
Impact Direction (Aircraft Axes)	Velcoity Change, Δv (Ft/Sec)	Peak Acceleration (G)	Pulse Duration, Δt Sec)	Comments
Longitudinal (Cockpit)	50	30	0.104	Triangular deceleration pulse: 
Longitudinal (Cabin)	50	24	0.130	
Vertical	42	48	0.054	
Lateral	25^a	16	0.097	Δt calculated from known or assumed values for G_{peak} and Δv: $\Delta t = \frac{2 (\Delta v)}{g \ G_{peak}}$
	30^b	18	0.104	

a) Light fixed-wind aircraft, attack and cargo helicopters.
b) Other helicopters.



(a) Design velocity changes
(three-dimensional display)

(b) Longitudinal-vertical



(c) Lateral-vertical

(d) Longitudinal-lateral

Figure 5-1. - Design velocity change - off-axis requirements.

aviation airplanes, have lower longitudinal velocities but higher vertical rates of descent which can be associated with accidents such as stall/spin and emergency landings on unprepared terrain. The percentage of occupiable space in large transports is much greater than in smaller aircraft. Furthermore, the occupants of small aircraft are much closer to the airframe/terrain impact point due to obvious airframe construction differences.

The accident data review has shown that the development of a survivable crash envelope for transport airplanes is difficult because of the range of effects that varied accident conditions can have on occupant safety. For example, table 2-2 and figure 2-1, presented earlier show that the accident severity is related to the distance from the airport at which the accident occurs. Accidents around airports are less likely to result in fatalities or injuries than accidents away from the airport. Obviously no two accidents are exactly alike. However, since there are broad similarities associated with accidents, they can be classified into several categories as has been proposed. The crash scenarios which embrace these broad similarities should provide a description of the accident conditions, namely:

- Flight path velocity at impact
- Sink speed at impact
- Impact attitude
- Terrain contour, flexibility
- Impact obstacles
- Airplane configurations (i.e., weight, cg position, gear positions)

Unlike the helicopter accidents, a large percentage of transport accidents involve ground-to-ground operations. Operations on the ground can often occur at low forward velocities and virtually no significant sink speed.

The accident parameters for each scenario need not be exact values but could include a range. In this sense a crash envelope might be considered for each scenario. However, the impact parameters associated with transport airplane accidents are substantially different than those for helicopters. Thus, the format for presenting the crash environment might be different.

5.3 Occupant Environment

The occupants in a survivable military helicopter accident are not to be exposed to forces exceeding human tolerance limits. In addition the structure is to provide the occupants with a liveable volume throughout the crash sequence. The occupant environment is not explicitly stated in the U.S. Army Survival Design Guide. Instead, an aircraft crash environment is specified as well as design impact conditions. For example, in Volume II, 95th percentile velocity changes are given in the vertical (42 fps) longitudinal (50 fps) and lateral (25 fps) (for light fixed-wing aircraft; 30 fps for cargo and attack helicopters) directions. Based on the kinematic relationship:

$$G_{avg} = \frac{V^2}{2gs}$$

average impact accelerations were estimated. These accelerations are 25 G 15 G, and 16 G in the vertical, longitudinal and lateral directions, respectively. Table 5-2 summarizes crash impact conditions for helicopter and light-fixed-wing aircraft design. Figure 5-1 illustrates the three dimensional display of resultant velocity changes.

Human survival is determined by acceleration magnitudes, durations and rates of acceleration actually experienced by the body, rather than by the aircraft velocity change. Thus, the velocity change can only act as a guide. The deceleration loads are a function of the strength and failure characteristics of the structure, thus systems analysis should be performed to establish energy absorption properties and distribution.

The transport airplane occupant crash environment is currently defined (reference 5, P25.561) as the condition for which the structure must be designed to give occupants every reasonable chance of escaping injury when experiencing loads (relative to the surrounding structure) up to those shown in table 5-3. Any item of mass that could injure an occupant if it came loose in a minor crash landing must also be designed to the loads shown in table 5-3.

TABLE 5-3. - FAR 25.561 INERTIA LOADS

Direction	Ultimate Inertia Forces
Upward	2.0 g
Forward	9.0 G
Sideward	1.5 g
Downward	4.5 g

[1] Or any lesser force that will not be exceeded when the airplane absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. at design landing weight.

5.4 Human Tolerance to Impact

The U.S. Army Survival Design Guide discusses human tolerance in Volume II. Included are discussions of:

- whole body acceleration tolerance
- head impact tolerance
- neck impact tolerance
- chest impact tolerance
- abdominal impact tolerance
- spinal injury tolerance
- leg injury tolerance

The tolerance data presented in reference 4 provides an excellent summary of available types of data. This information combined with the data contained in reference 16 covers much of the pertinent material. A great deal of research has been conducted in the field of biodynamics. While general guidelines have been established, there still remain many areas of uncertainty and disagreement. The following quotes from reference 16 provide some insight into the level of confidence associated with human tolerance as an absolute measure of occupant survivability.

"Human tolerances have been variously defined and different researchers have established different end points as criteria." For deceleration tests; "Stapp uses criteria resulting from the limit beyond which either the subject or the experimenter fears to go lest there be serious injury. For the determination of survivability end points using anesthesized animals, the criteria of 50 percent fatalities is sometimes used."

"Determination of human tolerance to impact is complicated by many physical factors including: restraint support, tightness and configuration; body orientation, and the magnitude, direction, distribution, and duration of the force. In addition, biological factors including sex, age, physical and mental condition have been identified as influencing survival. Individual variability must be considered, for tolerance under identical test conditions will vary in the same individual as well as from person to person."

"Almost all available data from human impact tests have resulted from studies utilizing military volunteer subjects. These subjects may be characterized as young, male, in good health, and as such, represent a rather small segment of the total population, and may be at considerable variance with the tolerance of females, children, the elderly, the infirm, the obese, or even the middle-aged U.S. male. Furthermore, such tests are conducted under optimal conditions, with a strenuous physical examination prior to tests and continuous pre- and post-medical monitoring. Restraint is optimal, tightened beyond the characteristics of automotive occupants, and with a secondary back-up system. Volunteers wear mouthpieces or other protection and, for the higher impact levels which have been reported to date, restraint usually consists of that typical only of Apollo space vehicles or supersonic military aircraft.

Measurement data from sled subjects should also be used with caution. In a single impact test, the accelerometer readings from the sled, head, and chest mounts may vary considerably. Because external chest accelerometers are not attached to the body in a manner to entirely prevent movement between the accelerometer and the body, the resulting 'slap' may result in distorted measures, usually on the high side."

"To date we know very little about impact tolerances of the major part of the U.S. general population."

The last statement touches on a very significant difference between the occupants associated with the military population versus the civilian traveling public for transport airplanes. The U.S. Army Survival Design Guide provides data regarding occupant motion, human body dimension and mass distribution. This information as well as much of the tolerance data is based on U.S. Army personnel who vary in weight from 133 lb (5th percentile) to 212 lb (95th percentile) and are considered good physical specimens.

The transport industry is faced with a traveling public of a much wider range in weight, as well as physical stature. Thus, an area of information that can be improved to be of benefit to the transport airplane designers would be providing a definition of the body dimensions and mass distribution for the commercial traveling public and relating the human tolerance data to such specimens.

It would be beneficial if the occupant tolerance data were summarized in a matrix format to show the advantages and limitations of each technique along with suggested conditions for which application of the technique is used. Another consideration would be the relative reliability of each method in the event there are conflicting conclusions drawn from usage of these methods.

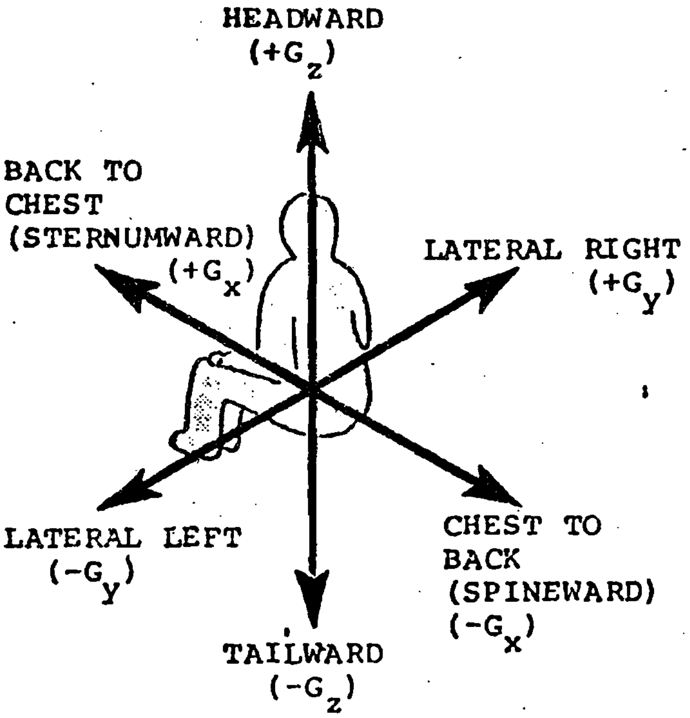
The development of criteria to establish the acceptable limits of human tolerance levels requires the capability to analyze and measure the dynamic relationship between the structural system (airframe and restraint system), the human system, and surrounding objects. The evaluation of degree of injury is complicated by the many types of injuries that can occur and the fact that the tolerance of individual humans to injury will vary. Furthermore, data obtained from animal studies cannot be correlated accurately to human tolerance nor can data at the subinjury level be extrapolated accurately to the threshold of injury.

There are many factors affecting human impact tolerance including location, direction, area, and time duration of impact, maximum force, pressure or acceleration; dynamic response of the human body; and crushing characteristics of impacted objects.

There are several means available by which occupant response can be assessed. Most notable of these are the:

- Dynamic Response Index (DRI)
- Weighted Impulse Criterion (Gadd Severity Index)
- NASA Tolerance (Eiband) Curves
- Extremity Strike Envelope
- Threshold Loads

The terminology associated with directions of force applied to the body, described in the U.S. Army Crash Survival Design Guide (reference 4), is compatible with NATO terms. This terminology is illustrated in figure 5-2.



DIRECTION OF DECELERATIVE FORCE

VERTICAL

Headward - Eyeballs down
Tailward - Eyeballs up

TRANSVERSE

Lateral Right - Eyeballs left
Lateral Left - Eyeballs right
Back to Chest - Eyeballs in
Chest to Back - Eyeballs out

Note: The decelerative forces applied to the body act in the same direction as the arrows, the resulting inertia forces act opposite.

Figure 5-2. - Decelerative forces on the body (reference 4).

In a mechanical sense, the human body is a complex, nonlinear, damped, distributed mass system. As such, it is subjected to dynamic response in any of its many modes of vibration. This means that the response or actual acceleration time history experienced by the body, or a portion thereof may differ markedly from the acceleration time input to the body applied at the point of impact. The problem has been to define some form of parameter which is indicative of the degree of severity of a particular excitation. Various indicators, referred to as SEVERITY INDICES have been developed. Two of the more common indices are:

- Dynamic Response Index (DRI)
- Gadd Severity Index (weighted impulse criterion)

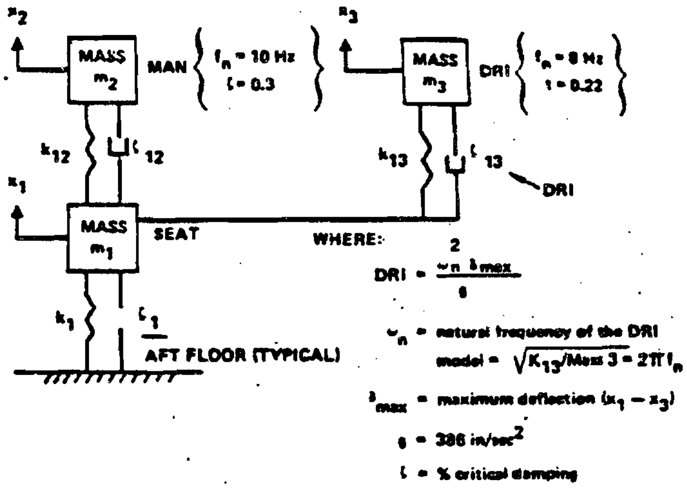
A brief description of the Severity indices (DRI, Gadd) as well as the Eiband curves, extremity strike envelope and threshold loads follows.

5.4.1 Dynamic Response Index

The human response to short duration accelerations applied in the upward vertical direction parallel to the spine (+ Gz) has been modeled by a single lumped-mass damped spring system as shown in figure 5-3a. In this model it has been assumed that the total body mass that acts upon the vertebrae causing deformation is represented by the single mass. In use, the relationship:

$$\frac{d^2\delta}{dt^2} + \zeta\omega_n \frac{d\delta}{dt} + \omega_n^2\delta = Z$$

is solved by using a computer. The third term is representative of the deformation of the spine and when divided by g is referred to as the Dynamic Response Index (DRI). The model is used to predict the maximum deformation of the spine and associated force within the vertebral column for various short-duration acceleration inputs. The properties used in the model were derived from human samples or tests. The spring stiffness was determined from tests of cadaver vertebral segments; damping ratios were determined from measurements of mechanical impedance of human subjects during vibration and impact.



WHERE:

$$DRI = \frac{\omega_n^2 \delta_{max}}{g}$$

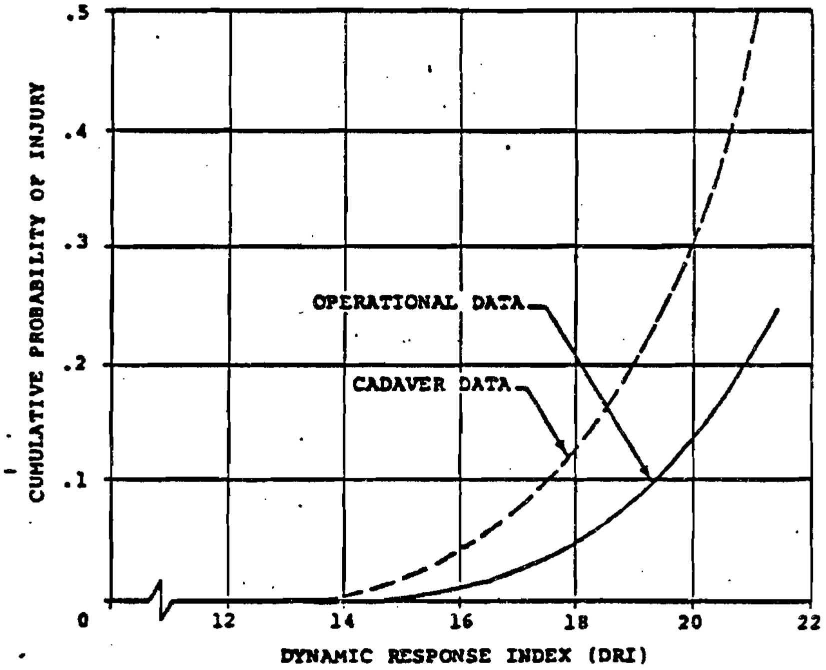
ω_n = natural frequency of the DRI model = $\sqrt{K_{13}/\text{Mass } 3} = 2\pi f_n$

δ_{max} = maximum deflection $(x_1 - x_3)$

g = 386 in/sec^2

ζ = % critical damping

(a) DRI model.



(b) Probability of spinal injury predicated from cadaver data compared to operational experience (reference 4)

Figure 5-3. - DRI model and probability of injury.

A correlation of the cumulative probability of spinal injury versus DRI is shown in figure 5-3b. In this figure, the cumulative probability of injury is plotted against DRI for both cadaver data and operational data. It is seen that the injury probability does vary with the DRI but that the cadaver data show a higher probability of injury than do the operational data. It would be expected that the intact, living vertebral column imbedded in the torso would be stronger than cadaver segments; consequently, this result might be predicted.

The DRI has been shown to be effective in predicting spinal injury potential for $+G_z$ acceleration environments. Although work is being done to apply the DRI to the other directions, confidence in predictions is hampered by difficulty in establishing injury threshold because of the many possible modes of injury and variations in tolerance to these modes.

The application of a severity index to assess occupant injury should be weighed with regard to the type of accident that is involved. For example, in an impact involving large longitudinal forces and small vertical forces, the DRI is of little value since it is applicable only to vertebrae compression type injuries.

5.4.2 GADD Severity Index

Human tolerance data has shown that high forces or accelerations can be tolerated for only short periods of time while lower values can be tolerated for longer periods of time. Figure 5-4 illustrates the relationship in brain injury for forehead impacts. The SAE (reference 17) has accepted the weighted impulse criterion for evaluating the injury potential of an impact as noted in the following expression:

$$SI = \int_{t_o}^{t_s} a^n dt$$

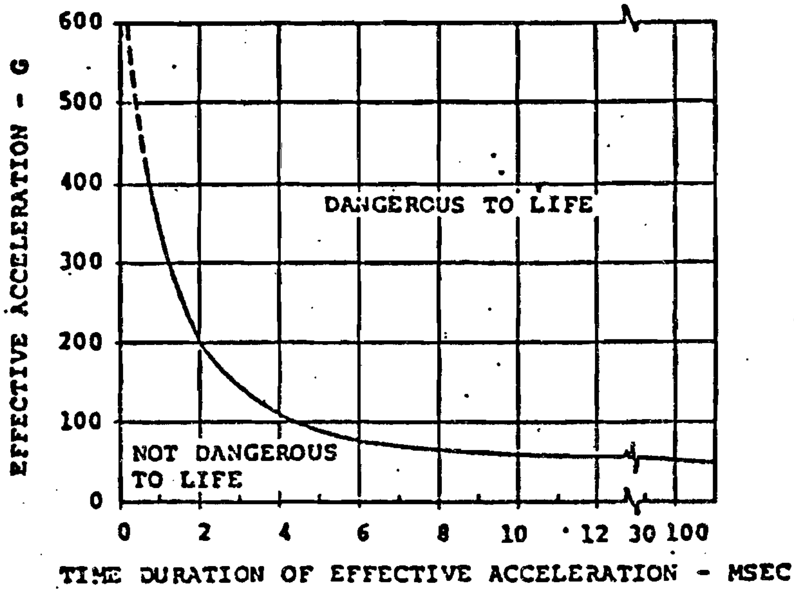


Figure 5-4. - Impact tolerance for the human brain in forehead impacts against plane, unyielding surfaces (reference 17).

where

SI = Severity Index

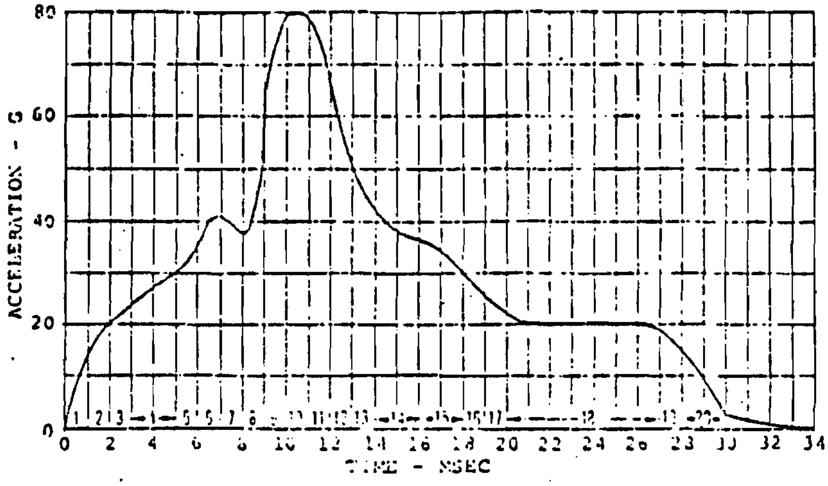
a = acceleration as a function of time

n = weighting factor >1 (2.5 for head and face impacts)

t = time

A severity index sample calculation is shown in figure 5-5.

Table 5-4 provides samples of experimentally obtained injury data relating to different body areas and shows the corresponding severity index limit.



Calculations

Increment No.	Time of Increment (sec)	Midpoint G Value	$G^{2.5}$	Incremental SI Index (Time x $G^{2.5}$)
1	0.001	7	130	0.13
2	0.001	18	1,400	1.40
3	0.001	23	2,500	2.50
4	0.002	27	3,800	7.60
5	0.001	33	6,300	6.30
6	0.001	40	10,000	10.00
7	0.001	38	8,800	8.80
8	0.001	47	15,000	15.00
9	0.001	75	46,000	48.00
10	0.001	80	57,000	57.00
11	0.001	73	46,000	46.00
12	0.001	56	23,000	23.00
13	0.001	43	12,000	12.00
14	0.002	37	8,300	16.60
15	0.002	33	6,200	12.40
16	0.001	27	3,800	3.80
17	0.001	24	2,800	2.80
18	0.007	20	1,300	12.60
19	0.001	17	1,200	1.20
20	0.002	10	330	0.66
			Severity Index	237.79

Figure 5-5. - Sample calculation of a severity index (reference 17).

TABLE 5-4. - EXPERIMENTALLY DETERMINED LEVELS OF IMPACT, PRODUCING MINOR TO MODERATE INJURY (RESPONSE FUNCTION) (REFERENCE 17)

Body Area Impacted	Minimum Contact Area, Sq. In.	Effective Weight, lb	Peak Force, lb	Peak g	Severity Index Limit	Conditions Used to Obtain Tolerance Data
Face[a] (localized loading)	4	15	600	40	400	Smooth, collapsible, padded surface, with accelerometers mounted on bone opposite impact
Face[a] (distributed loading)	15	15	1200	80	1000	
Throat	2		150[b]			Force distributed with deforming pad
Brain (skull)	3	15	1500	100	1000	Various surfaces with accelerometers mounted as with "face".
Chest	30	75	1500			Load cell mounted to conformable chest contact surface
Side above pelvis, below ribs	10	75	Maximum dynamic penetration into subject area of 1.25 in.			
Knee-thigh-hip complex (load applied through knees)	3	40	1400	35		Load cell mounted to conformable knee contact surface

[a] Below eyebrows.

[b] This is considered to be a reasonable value in the opinion of biomechanics investigators, based on the strength of similar human structure throughout the body. The number may be modified as better data is gathered.

5.4.3 Eiband Curves

Eiband curves are a set of data obtained from measurement of live subjects to determine tolerance thresholds for humans. Factors that affect human tolerance are included in the presentation of the Eiband curve data and include:

- Applied force magnitude, duration, rate of onset and direction
- Body restraint

Figures 5-6 and 5-7, obtained from reference 18, illustrate the type of data that are available. A summary of reference tolerance acceleration levels is presented in table 5-5.

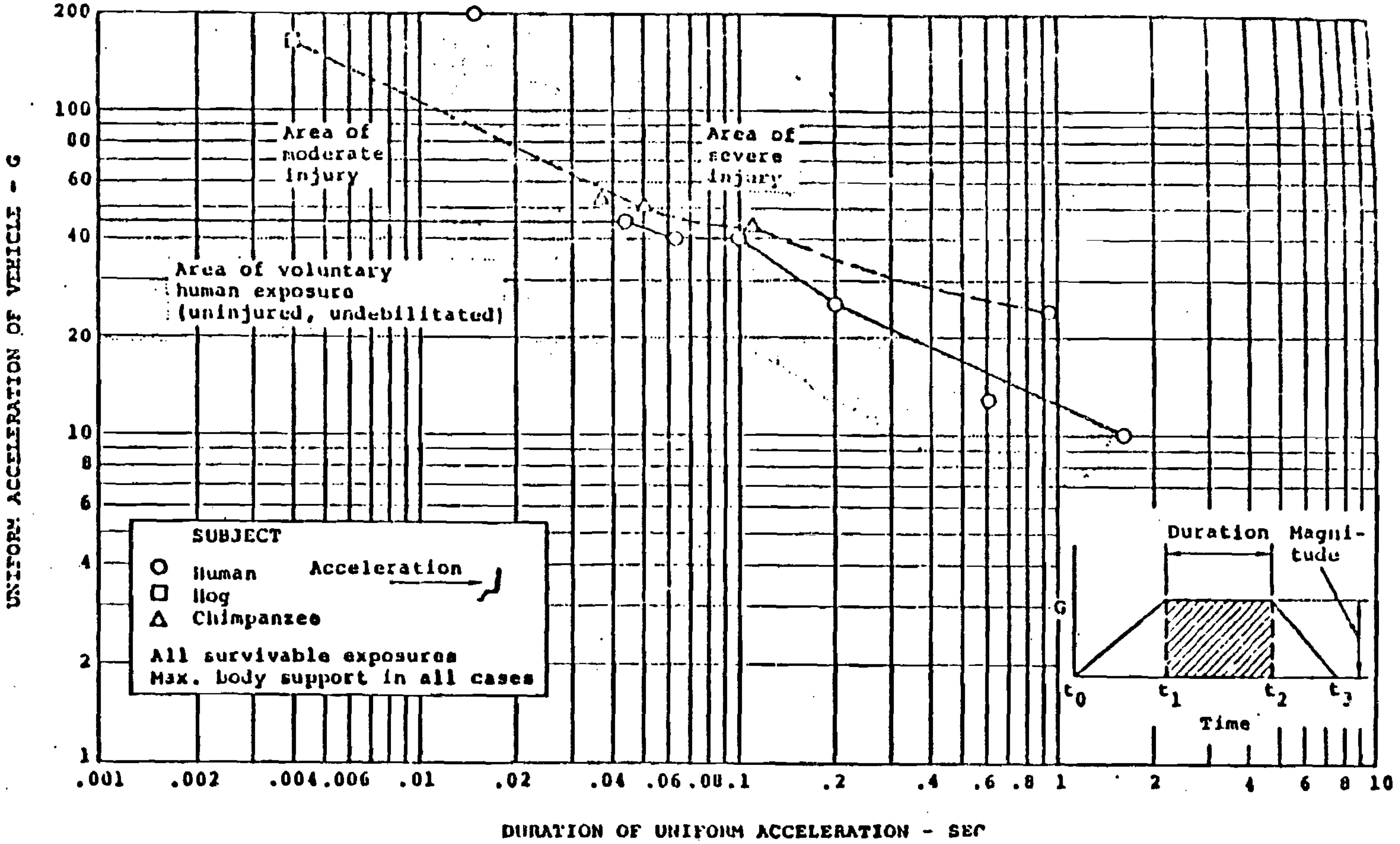


Figure 5-6. - Duration and magnitude of spineward (chest-to-back) acceleration endured by various subjects (taken from reference 18).

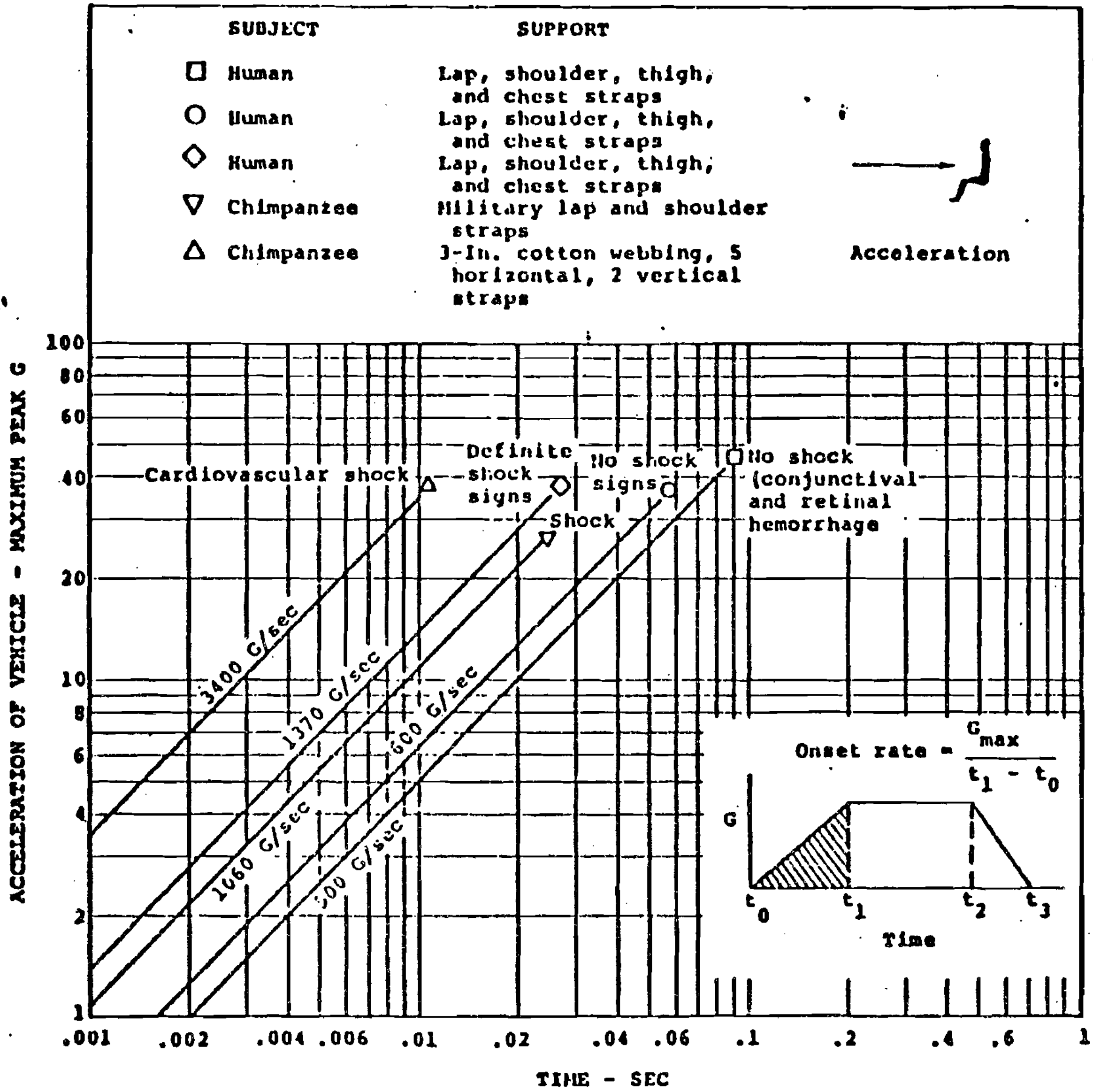


Figure 5-7. - Initial rate of change of spineward (chest-to-back) acceleration endured by various subjects (taken from reference 18).

TABLE 5-5. - TOLERANCE ACCELERATION LEVELS FOR OCCUPANTS (REFERENCE 18)

	Voluntary Exposure		Severe Injury		
Direction	Peak g	τ	Peak g	Duration sec	Peak g @ τ = .004 sec
Forward	35	.1	55/40	.02/.1	90
Aft	45	.04	75/44	.02/.1	160
Up	16	.04	42	.007 – .050	60
Down	10	.01	50	.02 – .160	70

τ = Duration in seconds

5.4.4 Extremity Strike Envelope

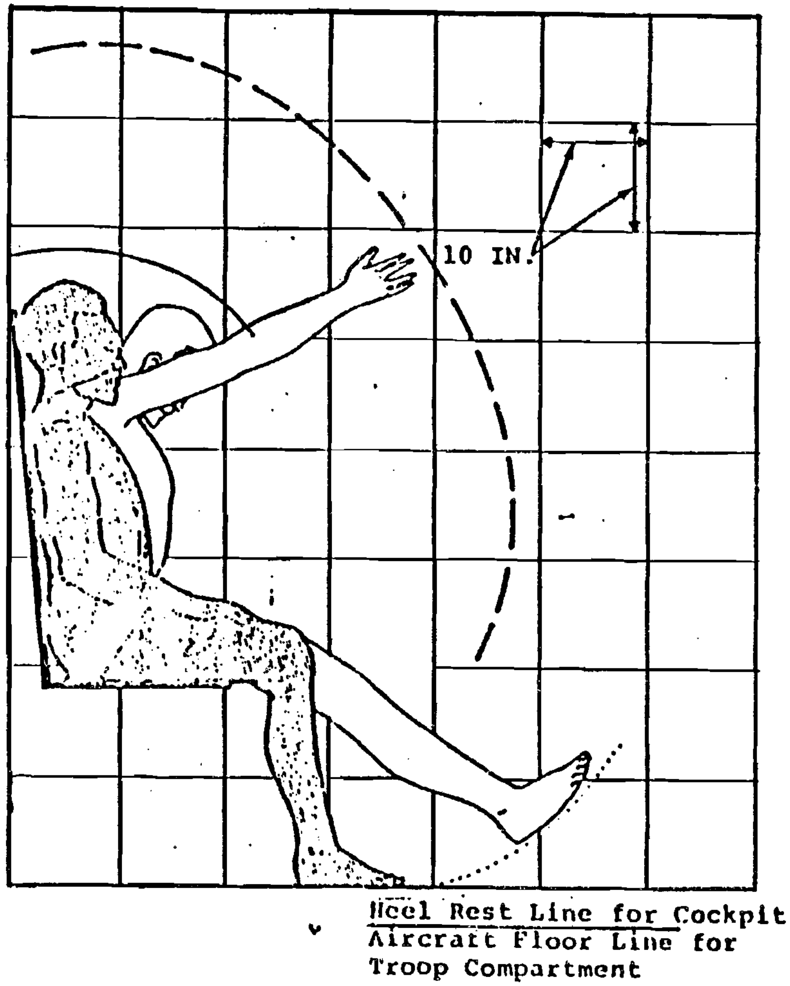
The U.S. Army (reference 4) provides body extremity strike envelopes for two conditions:

1. The occupant restrained with a lap belt only
2. The fully restrained occupant

The strike envelopes are based on the following parameters:

- 95th percentile U.S. Army personnel
- 4G acceleration with human subjects
- 4 inches of lower torso movement away from the seat back, both laterally and forward.
- 4 inches of upper torso movement

Figures 5-8 and 5-9 illustrate typical extremity strike side-view envelopes for fully restrained and lap-belt-only occupants, respectively.



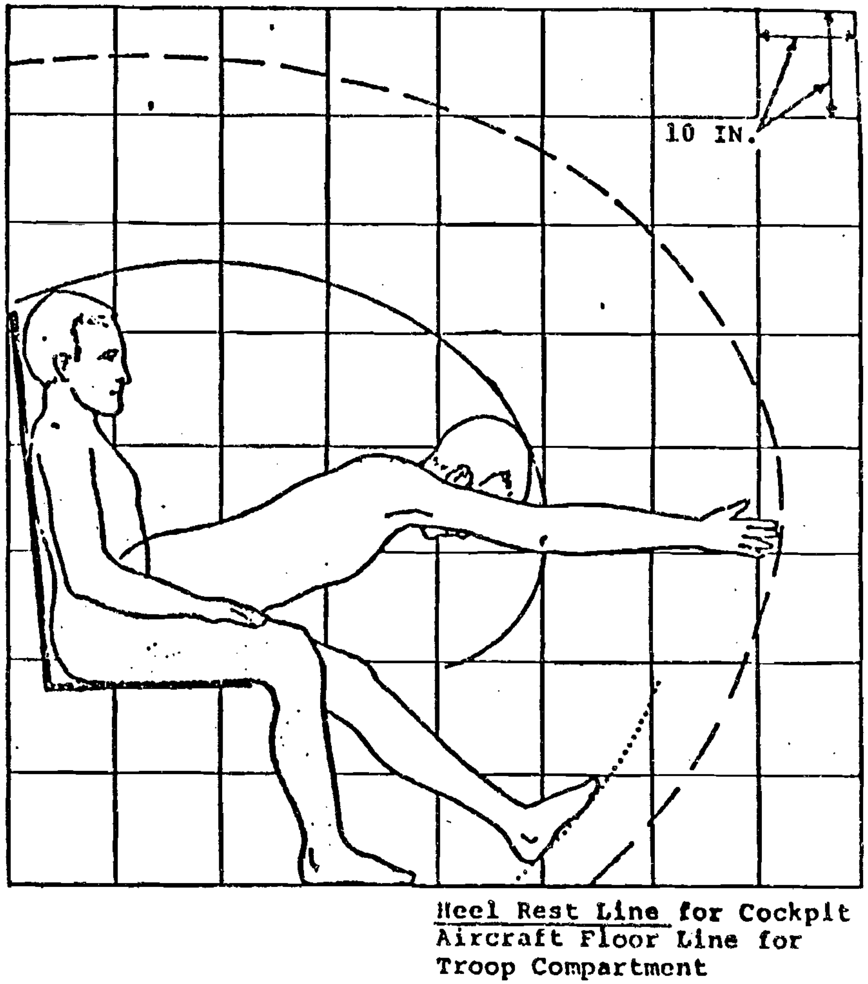


Figure 5-8. - Full-restraint extremity strike envelope - side view. (reference 4)

Figure 5-9. - Lap-belt-only extremity strike envelope - side view. (reference 4)

5.4.5 Threshold Loads

Some areas of the body such as the knee-thigh-hip complex, permit the use of peak force or deceleration as the injury criterion; therefore, for these areas the tolerance limit in peak force or deceleration is useful. Table 5-3, obtained from reference 16, gives some tolerance limits. These values should ignore all "spikes" of acceleration or force above the general envelope of the curve, that are 1 ms. or less in time duration. The data in table 5-4 provide samples of experimentally obtained impact injury data relating to different body areas. These data indicate moderate injury levels as a combination of magnitude and duration of impact. The levels given are discrete data points only and cannot be used to extrapolate tolerance levels for other magnitudes of acceleration. To specify adequately the overall picture for the entire human anatomy, it will be necessary to obtain experimentally determined curves similar to figure 5-4 pertaining to various body areas of interest. Also it is necessary that such curves be qualified by a specification of the impact characteristics employed, i.e., direction of blow and areas of contact. Considerable effort is being devoted to this end. Reference 16 provides a substantial amount of data regarding force limits as well as 446 reference reports from which the data are obtained.

5.4.6 Seats and Restraint Systems

Seats and restraint systems are discussed in reference 4, Volume IV. Static and dynamic tests of seats are recommended. The purpose of the static tests is to demonstrate that the seat has the strength and other properties required to provide the desired performance in all the principal loading directions. The reference 4 static requirements are shown in table 5-6. Dynamic Test Requirements are shown in figures 5-10 and 5-11. The data in figures 5-10 and 5-11 is for seats with 12 inches or more of vertical stroke. For seats with less vertical stroke the Army (reference 4) describes a procedure for establishing the test. However, no specific quantitative limits are presented since it is recognized that the pulse is a function of the dynamic crush behavior of the various portions of the structural systems.

TABLE 5-6. - SEAT DESIGN AND STATIC TEST REQUIREMENTS (REFERENCE 4)

Test ref. no.	Loading direction with respect to fuselage floor	Load required	Percentile occupant used in load determination	Load/deformation requirements[a,i]
1	Upward	8-G minimum	95	No requirement
2	Downward[b,d]	11.5 $^{+1.0}_{-0}$ G	50	See Section 8.3.4
3	Aftward	12-G minimum	95	No requirement
4	Forward	See Figure 59	95	See Figure 59
5	Combined			
	Forward [e,f]	See Figure 59	95	See Figure 59
	Downward[c]	11.5 $^{+2.0}_{-1.0}$ G	50	Same as Test 2[h]
	Lateral[f]	9-G minimum	95	No requirements
6	Lateral[g]	See Figure 60	95	See Figure 60

(a) The aircraft floor or bulkhead should be deformed as detailed in in Figures 61 and 62, simultaneously with, or prior to the conduct of all static tests and kept deformed throughout load application.

(b) If more than one load-limiter setting is provided, a representative sample of settings spanning the range of loads should be tested.

(c) If more than one load-limiter setting is provided, the highest load should be used.

(d) Subsequent to the stroking of the vertical energy-absorbing device, cockpit seats should carry a static load of 25 G, based on the effective weight of the 95th-percentile clothed and equipped occupant per Section 8.2 plus seat without loss of attachment to the basic structure except when the seat pan has stroked to and is supported by the floor.

(e) In the event that no load-limiting device is used in the forward direction, a 20-G load for cabin seats and a 25-G load for cockpit seats may be used for this combined loading.

(f) For seats employing vertical guides which could distort under combined loading and cause binding, the maximum forward and lateral loads should be reached prior to initiation of stroking. This sequence demonstrates whether the seat will stroke downward after transverse loads are applied.

(g) The lateral loads should be applied in the most critical direction. In the case of symmetrical seats, the loading direction is optional.

(h) Failure to meet the 11.5-G +2.0/-1.0-G static vertical load limit should not be cause for seat rejection if the seat vertical energy-absorbing system meets dynamic load requirements.

(i) Plastic deformation is permissible; however, structural integrity must be maintained.

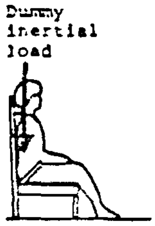
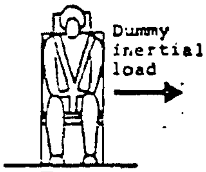
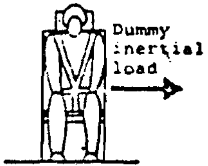
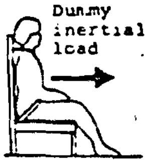
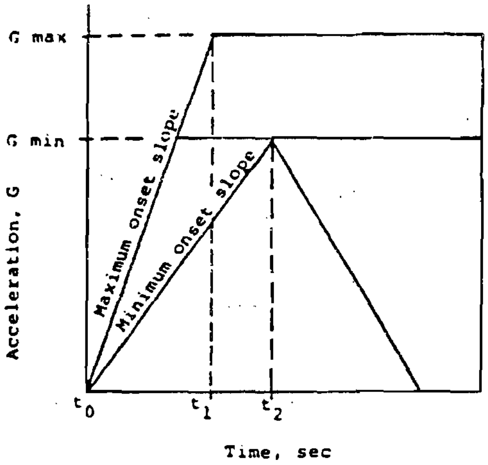
			Cockpit seats		Cabin seats	
Test	Configuration	Parameter	Qualification	R&D	Qualification	R&D
1		t_1 sec	0.036	0.020	.050	.028
		t_2 sec	0.051	0.051	.074	.074
		G min	46	46	32	32
		G max	51	51	37	37
		Δv min, ft/sec	42	42	42	42
2a	Utility and observation helicopters 	t_1 sec	0.062	0.036	.062	.036
		t_2 sec	0.104	0.104	.104	.104
		G min	16	16	16	16
		G max	21	21	21	21
		Δv min, ft/sec	30	30	30	30
2b	Light fixed-wing, cargo and attack helicopters 	t_1 sec	0.057	0.033	.057	.033
		t_2 sec	0.100	0.100	.100	.100
		G min	14	14	14	14
		G max	19	19	19	19
		Δv min, ft/sec	25	25	25	25
3		t_1 sec	0.066	0.038	.081	.046
		t_2 sec	0.100	0.100	.127	.127
		G min	28	28	22	22
		G max	33	33	27	27
		Δv min, ft/sec	50	50	50	50

Figure 5-10. - Requirements of dynamic tests if substituted for static tests. (Reference 4)



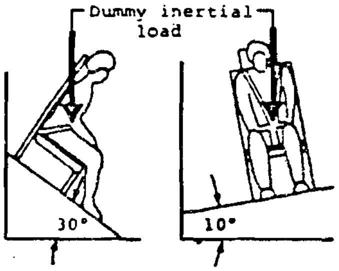
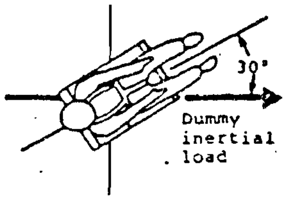
Test	Configuration	Parameter	Cockpit seats		Cabin seats	
			Qualification	R&D	Qualification	R&D
1		t_1 sec	0.043	0.024	0.059	0.034
		t_2 sec	0.061	0.061	0.087	0.087
		G min	46	46	32	32
		G max	51	51	37	37
		Δv min, ft/sec	50	50	50	50
2		t_1 sec	0.066	0.038	0.081	0.046
		t_2 sec	0.100	0.100	0.127	0.127
		G min	28	28	22	22
		G max	33	33	27	27
		Δv min, ft/sec	50	50	50	50

Figure 5-11. - Dynamic test requirements for qualification and for research/development testing. (Reference 4)

The transport airplane requirements state that the seat must be good for the inertia loads stated in FAR 25.561 with a 1.3 factor for the attach fittings. The seat requirements in FAR 25.561 are based on static equivalent to dynamic capability. A simple representation of a seat response to pulse excitation, described earlier, shows there is validity to this approach. Since the structure and load paths are different for transports than helicopters, the dynamic pulses for seat tests shown in reference 4 are most likely not directly applicable to transports. However, the application of analytical techniques based on potential crash scenarios could yield a better definition of floor dynamic pulses. With the availability of quantitative data, dynamic tests or revised static equivalents, if necessary, could be established.

The design of transport seats under dynamic loading conditions is more involved than in helicopters. As mentioned earlier there is a wider range of occupant weight associated with transport travel. In addition, there are more seat configurations and loading combinations that could occur. Simple analysis of seat performance shows that increasing seat strength by 100 percent increases the Dynamic Response Index (DRI) by 22 percent for a 100 pound occupant, by 51 percent for a 170 pound occupant, and by 62 percent for a 200 pound occupant. This is for a single seat. For a triple seat the results would vary greatly depending on the number, location and weight of occupants involved.

5.5 Crash Design Requirements and Procedures

The Crash Survival Design Guide presents crash dynamics design data for potentially survivable aircraft crashes. The Design Guide treats rotary-wing, light fixed-wing and transport aircraft. This document contains information related to:

- Aircraft crash kinematics and human tolerance
- Structural design principles concerned with strength, deformation and living volume within collapsible structure
- Techniques for minimizing rapid deceleration due to earth gouging and structural rigidity

- Crash design criteria for seats and restraint systems
- Techniques for "delethalization" of an occupied area
- Strike hazards and envelopes
- Post crash fire hazards and recommended techniques to minimize fuel spillage from line and tank ruptures

5.5.1 Military Specifications

Military specifications include:

MIL-STD-1290	Light Fixed and Rotary Wing Aircraft Crashworthiness (reference 19)
ADS-11	Aeronautical Design Standard Survivability/ Vulnerability (reference 20)
MIL-T-27422B	Aircraft Crash-Resistant Fuel Tank (reference 21), Applicable to all Department of Defense departments and agencies
MIL-S-58095	Seat System: Crashworthy Non-Ejection, Aircrew General Specification (Reference 22)
MIL-A-8865A	Airplane Strength and Rigidity Miscellaneous Loads (reference 23)
AR-56	Structural Design Requirement (Reference 24)

MIL-STD-S-58095 specifies test methods and static and dynamic test requirements. The test levels and directions are specified in tables III and IV of the reference document. The acceleration level is to be such that the 5th through 95th percentile occupants will not experience vertical accelerations in excess of human tolerance during crash pulses up to and including the 95th percentile potentially survivable accident impulse. A 95th percentile clothed anthropomorphic dummy occupant shall be used to simulate the seat system occupant for the tests.

MIL-T-27422B specifies the crash impact test requirements for rotary wing and fixed wing aircraft for all departments and agencies of the Department of Defense.

MIL-STD-1290 is essentially a condensed version of the Crash Survival Design Guide in military standard format. The crashworthy design techniques and analytical approaches discussed in the Design Guide were omitted and only the required results were retained.

The crashworthiness portion of ADS-11 is similar in scope to MIL-STD-1290 but is not so detailed or definitive. This document is devoted primarily to a procedure for evaluating the crashworthiness provisions.

MIL-A-8865A is a U.S. Air Force document which provides a crash loads section (paragraph 3.3, reference 23) in which load factors are specified for the longitudinal, vertical and lateral directions. The requirements are applicable to installation of the following:

- crew, passenger and troop seats
- capsules
- internal fuel tanks
- mechanisms for holding canopies, door and other exits open for egress
- equipment items
- cargo
- engines
- aerial delivery equipment
- litters

AR-56 is a U.S. Navy document which specifies crash loads and loading conditions (paragraph 3.4.8, reference 24) which are applicable to the design of crew seats, passenger seats, troop seats, litters, capsules, mechanisms for holding canopies and doors in their open positions, attachments of equipment items, cargo, engines, fuel tanks, turrets and aerial delivery equipment and their carry-through structures. The specification provides for ultimate inertia-load factors and maximum impulse requirements.

Government regulations have been established for crash design requirements of passenger cars, trucks and buses, as well as commercial and military aircraft. The Department of Transportation (National Highway Traffic Safety

Administration, Federal Aviation Administration and federal Railroad Administration), the Department of Defense and the Society of Automotive Engineers have issued regulations, standards and guides for crash design provisions. A review of the various agencies' and organizations' crash design requirements are summarized below:

5.5.2 Department of Transportation National Highway Traffic Safety Administration

The following crashworthiness standards are currently effective and are being incorporated in the manufacture of highway vehicles (reference 25):

Standard No. 201 - Occupant Protection in Interior Impact -
Specifies requirements for padded instrument panels, seat backs, sun visors and armrests

Standard No. 202 - Head Restraints -
Specifies requirements for a head rest to reduce frequency and severity of "whiplash" type neck injuries from rear-end collisions

Standard No. 203 - Impact Protection for the Driver from the Steering Control System -
Specifies requirements for minimizing chest, neck and facial injuries by providing a steering system that yields forward, absorbing much of the driver's impact energy in forward collisions

Standard No. 204 - Steering Control Rearward Displacements -
Specifies requirements for limiting penetration of the control column into passenger compartment from forward collisions

Standard No. 205 - Glazing Materials - Passenger Cars, Trucks, Buses -
Specifies requirements for glazing materials to reduce the likelihood of lacerations to face, scalp and neck, and minimize penetration into the windshield during collision

Standard No. 206 - Door Locks and Door Retention Components -
Specifies load requirements for door latches for forces encountered during vehicle impact

Standard No. 207 - Seating Systems -
Establishes load requirements for seats, attachment assemblies, and installations for forces experienced during vehicle impact

Standard No. 208 - Occupant Crash Protection -
Specifies requirements for active or passive crash protection systems for occupant restraint

Standard No. 209 - Seat Belt Assemblies -
Specifies requirements for straps or webbing and hardware fitting materials

Standard No. 210 - Seat Belt Assembly Anchorages -
Specifies the requirements for seat belt and shoulder strap anchorage strength

Standard No. 211 - Wheel Nuts, Wheel Disks and Hub Caps -
Specifies requirements for delethalization of wheel protrusions for the protection of pedestrians and cyclists

Standard No. 212 - Windshield Mounting -
Specifies windshield load retention requirements for impact by two 95th percentile male occupants during a crash

Standard No. 213 - Child Seating Systems -
Specifies requirements for protection and restraint of child occupants in a crash

Standard No. 214 - Side Door Strength -
Specifies side door strength requirements to minimize intrusion into the passenger compartment in a side impact collision

Standard No. 215 - Exterior Protection -
Specifies strength and deformation requirements and damage limitations for crash impact into a barrier

Standard No. 216 - Roof Crush Resistance -
Specifies minimum strength requirements for roofs in rollover accidents

Standard No. 217 - Bus Window Retention and Release -
Establishes requirements for window retention and release to minimize passenger ejection in accidents and to facilitate passenger exit in emergencies

Standard No. 218 - Motorcycle Helmets -
Establishes requirement for impact attenuation, retention and penetration minimization

Standard No. 301 - Fuel System Integrity -
Specifies fuel retention requirements for 20 mph impacts and rollover

Standard No. 302 - Flammability of Interior Materials -
Specifies burn resistance requirements for materials used in the occupant compartment

5.5.3 Department of Transportation, Federal Railroad Administration

Federal regulations (reference 26) for rail vehicle collision or accident safety provisions are minimal. A summary of the Department of Transportation, Federal Railroad Administration document of regulations (reference 27) shows requirements are established for shatterproof glass in the locomotive cab, non-skid floor surfaces and proper protection to avoid contact with fan blades. Guards and protective devices are specified for hand-operated electrical controls and switches to avoid hazards to the operator. Exposed moving parts of mechanisms and pipes carrying hot gases are required to be isolated or guarded against personnel contact. Safety regulations for passenger cars and cabooses pertain only to handrails, steps and ladders.

The specification for AMTRAK locomotive propelled passenger cars specifies a few collision safety requirements. These include requirements for safety glass, fire-retardant materials, emergency escape sash units, seat attachments capable of 6000-pound force on each fitting and car collision load test requirements.

5.5.4 Society of Automotive Engineers

The SAE Handbook, Standards, Recommended Practices and Information Reports (reference 28) is updated regularly. This document provides Testing Procedures for Passenger car components and systems in the form of SAE JXXX procedures. The Department of Transportation National Highway Safety Regulations closely parallel many of the SAE Standards.

5.5.5 Department of Transportation, Federal Aviation Administration

Federal Aviation Regulations have been established for various aircraft types. The most applicable regulations are:

FAR 23	Airworthiness Standards: normal, utility and acrobatic category airplanes (reference 29)
FAR 25	Airworthiness Standards: transport category airplanes (reference 5)
FAR 27	Airworthiness Standards; normal category rotorcraft (reference 30)

FAR 29 Airworthiness Standards; transport category rotorcraft (reference 31)

By contrast to Military Helicopter Requirements, the current emergency landing requirements for civil helicopters are described in FAR 27.561 (reference 30) and FAR 29.561 (reference 31) for normal category and transport category rotorcraft, respectively. The ultimate inertia forces relative to the surrounding structure that the occupant can experience are shown in table 5-7. The supporting structure must also be designed to restrain, under any load up to those shown in table 5-7, any item of mass that could injure an occupant if it came loose in a minor crash landing.

Light fixed-wing (general aviation) aircraft weighing ≤ 12,500 pounds operate at speeds up to 280 knots, carry 1 to 17 people, are single-engine or twin-engine, low-wing or high-wing configured (reference 12). Aircraft of this type may be involved in stalls, ground collisions and collisions with obstacles. Accidents occur on terrains which are flat (~40 percent) rolling (~22 percent) or mountainous (~11 percent), hilly (~8 percent), dense with

TABLE 5-7. - SUMMARY OF FAA EMERGENCY LANDING REQUIREMENTS

	Ultimate Inertia Forces				
	FAR 23-561 (Ref. 4)		FAR 25-561 (Ref. 5)	FAR 27-561 (Ref. 6)	FAR 29-561 (Ref. 7)
	Small Airplanes				
Direction	Normal Utility Category	Aerobatic Category	Transport Category Airplanes	Normal Category Rotorcraft	Transport Category Rotorcraft
Upward	3.0g	4.5g	2.0g	1.5g	1.5g
Forward	9.0g	9.0g	9.0g	4.0g	4.0g
Sideward	1.5g	1.5g	1.5g	2.0g	2.0g
Downward	---	---	4.5g (1)	4.0g (2)	4.0g (2)

(1) "Or any lessor force that will not be exceeded when the airplane absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. at design landing weight."

(2) "Or any lower force that will not be exceeded when the rotorcraft absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. at design maximum weight."

trees (~9 percent), or on airports (~2 percent). Figure 5-12, obtained from reference 32, shows the operational velocity-weight envelope for current general aviation airplanes. The categories noted in figure 5-12 are described in reference 12.

The current emergency landing conditions for Normal, Utility and Acrobatic Category Airplanes are described in FAR 23.561 (reference 29). The ultimate inertia forces relative to the surrounding structure that the occupant can experience are shown in table 5-7. Except as provided in P.23.787* (reference 29), the supporting structure must be designed to restrain, under loads up to those shown in table 5-7 of this section, each item of mass that could injure an occupant if it came loose in a minor crash landing.

The current emergency landing conditions for Transport Category Airplanes are described in FAR 25.561 (reference 5). The ultimate inertia forces relative to the surrounding structure that the occupant can experience are shown in table 5-7. The supporting structure must be designed to restrain under all loads up to those shown in table 5-7, each item of mass that could injure an occupant if it came loose in a minor crash landing.

A comparison of information contained in FAR 25 and the revised U.S. Army Crash Survival Design Guide is shown in table 5-8, with regard to occupant, environment, strength deformation, energy absorption, ditching, analytical methods, composites, systems and compliance.

5.6 Energy Absorbing Seat Designs

The reference 4 deals with energy absorbing seat designs in Volume IV under a section entitled, "Energy Absorbing Devices." This section is a

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*P.23.787(c) states "There must be a means to protect the occupants from injury by the contents of any cargo compartment when the ultimate forward inertia forces is 4.5g.

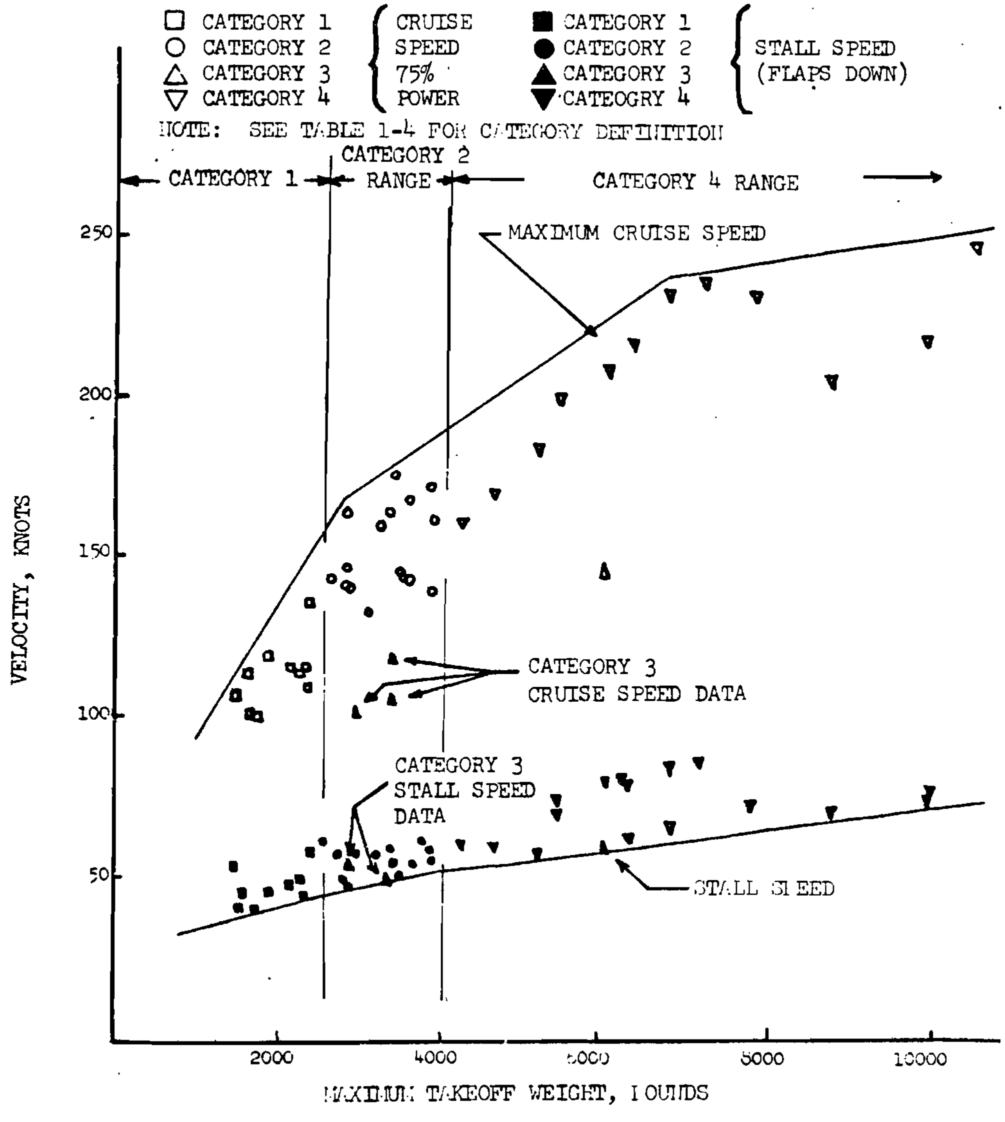


Figure 5-12. - Operational velocity weight envelope for current general aviation airplanes (reference 32).

TABLE 5-8. - IDENTIFICATION OF FAR 25 AND USAAMRDL-TR-79-22 CRASH REQUIREMENTS

Requirement	FAR 25 Applicable Section	USAAMRDL-TR-79-22 Applicable	
		Volume	Section
Occupant			
Loads	25.561b(3)	II	4
Lethal blows	25.561c	II, IV	4, 10
Collapsible structure	25.561	III	6
Extremity strike envelope and environmental hazards	25.785	IV	10
Delethalization	None	IV	10
Crash Environment			
Design conditions/requirements	25.561a, b	III	4 (table 2, figure 10)
Crash fire	25.721	V	4
Occupant	25.561b	III, IV	4, 4
Strength	25.561	III	6
Deformation	25.783c	IV	8
Energy Absorption	None	IV, III	4 & 5, 6
Structure			
Airframe/fuselage	25.801	III	6
Wing	None		None
Empennage	None		None
Powerplant	None		None
Landing gear	25.721	III	4, 6
Floor	None	III	4
Supported mass items	25.561c, 25.789	III	6
Fuel tanks	25.963	V	4
Emergency exits	25.783	V	7
Ditching	25.801	V	6
Analytical Methods	None	III, IV	7, 4
Composites	None	III	6

TABLE 5-8. - IDENTIFICATION OF FAR 25 AND USAAMRDL-TR-79-22
CRASH REQUIREMENTS (Continued)

Requirement	FAR 25 Applicable Section	USAAMRDL-TR-79-22 Applicable	
		Volume	Section
Systems			
Restraints	25.785	IV	7
Seats and attachments	25.785, 25.625	IV	4
Egress/evacuation	25.803 - 25.813	IV	7
Doors/exits	25.807 - 25.809	V	7
Aisles	25.807	V	7
Lighting	25.812	V	7
Identification	25.811	V	7
Access	25.813	V	7
Stowage equipment, mass items	25.787 - 25.791	V	6
Fuel/fuel containment	25.963	V	4
Tanks/cells	25.963	V	4
Installation	25.967	V	4
Fittings/attachments/liners	25.993	V	4
Vents	25.975	V	4
Leakage	25.721	V	4
Materials	25.967	V	5
Fire and smoke	25.1359	V	3
Fire protection	25.851, 25.1191	V	4, 5
Materials	25.853 - 25.857	V	5
Flammable fluids	25.863 - 25.867	V	5
Compliance			
Landing gear	25.721 - 25.727	None	None
Seats/restraint system	25.785	IV, IV	7, 8 (table 11) (figure 64, 65)
Cargo restraint	None	III	6, (table 8)
Evacuation	25.803		None
Fuel tank	25.965	V	4
Airframe	None	None	None
Wing	None	None	None
Propulsion system	None	None	None
Fuel spillage/crash fire hazard	25.721C	V	4.0

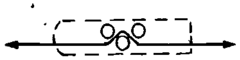
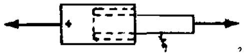
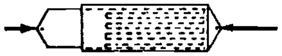
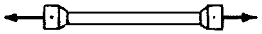
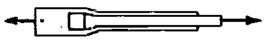
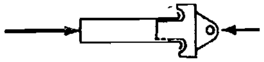
general description of energy absorbing techniques which, while applicable to seat design is not strictly for seats. Included in the devices are:

- wire or strap bending
- inversion tube
- rolling forms
- crushing honeycomb
- extension of basic metal tube or flat strap
- elongation of basic stranded cable
- rod pull-through tube
- tube flaring

Table 5-9 summarizes the energy-absorption data contained in reference 4, Volume IV. The data is only suggested as guidelines with the recognition that each specific application be reviewed.

As discussed earlier current transport aircraft seat design exhibit energy absorption characteristics via deformation of the support structure which appears consistent with the strength of the airframe for practical design conditions. This, of course, does not mean additional absorption would not be beneficial. However, once again the utilization of a technique or device has to be carefully weighed with regard to the accident condition and airframe design. For example, the wire or strap bending device shown in reference 2 for a crashworthy seat involves tiering into the aircraft ceiling. For a helicopter this may be practical. However, for a transport airplane, particularly the wide-body type, this presents a major problem. Most of the applications of energy absorption for seats in helicopters are for absorption of energy due primarily to vertical impacts. Transport airplane accidents involve relatively high longitudinal velocities and this is a major consideration in utilizing energy absorption techniques. Optimizing an energy absorber for a triple seat and many combinations of occupancy provides a unique problem for transport airplane seat design with which helicopter seat design need not be concerned. The data contained in reference 4 should serve as a good reference point which can be enhanced by the addition of future research for transport

TABLE 5-9. - COMPARISON OF LOAD-LIMITING DEVICES FOR 1000-TO-4000-LB LOADS

Device description	Energy-absorption process	Operation sketch	Tension or compression	SEA[a] (ft-lb/lb)	Stroke-to-length ratio[b]	Long-term reliability	Ability to sustain rebound loads	Constant load level	Potential application
Strap/wire over die or roller	Metal bending and friction		T and C[c]	1200[d]	Good - T Poor - C	Good to excellent	Zero to excellent[c]	Excellent	Seat strut or support
Inversion tube	Hoop tension/ compression and bending		T and C	1800	Excel - T Poor - C	Excellent	Excellent	Excellent	Seat support
Rolling torus	Cyclic compression and bending		T and C	1500	Good - T Avg - C	Fair to good	Excellent	Good	Seat strut or support
Honeycomb compression	Buckling of membrane "columns"		C	2500-3500	Average	Good	Poor[e]	Fair	Seat strut or support
Basic metal tube or plate	Elongation of metal		T	3400-4500	Poor	Good to excellent	Poor[e]	Fair	Seat support
Basic stranded cable	Elongation of stainless steel		T	3000-4500	Poor	Excellent	Zero	Fair	Seat support or brace
Rod pull-through tube	Hoop tension and friction		T and C	600[f]	Good - T Poor - C	Good	Poor	Good	Seat support
Tube flaring	Hoop tension, friction, and bending		C	700	Good to excellent	Good	Poor[e]	Fair	Seat strut
Tension pulley	Shear and bending of sheave housing		T	Unknown	Good	Good	Zero	Good	Seat support

(a) SEA is very dependent on materials and design. To be directly comparable the devices would need to be designed for the same application. The SEA values for the first three devices listed, those now being used in operational energy-absorbing seats, are reasonably comparable.
(b) In some cases, final length is significant; in other cases, initial length is significant.
(c) Simplest devices operate in tension (T) only; a recently developed troop seat strut is capable of tension (T) or compression (C) (Section 5.2).
(d) Specific energy measured for device that operates in tension or compression.
(e) This device could be rated higher if an integral rebound device were incorporated into the design.
(f) This value is based on the compressed tube device tested. This value could be doubled in a more efficient design.

airplane seat applications. This is particularly important if future seat designs incorporate advanced material for strength to weight characteristics without regard to energy absorption. Since current requirements do not address seat deformation quantitatively, future research should.

5.7 Analysis Methods

Analytical methods are discussed in two volumes in reference 4. Volume III describe Structural Crashworthiness Simulation Computer Programs including KRASH, DYCAST and WRECKER. Volume IV, describes occupant simulation computer programs, including SOM-LA, Calspans Crash Victim Simulator (CVS), PROMETHEUS, Air Force Head Spine Model and One-Dimensional Seat Occupant Models. The information contained in these two volumes is brief and serves as a good reference starting point for those interested or involved in simulation techniques. None of the Structural Crashworthiness Simulation Computer Programs have been used to analyze transport airplane crash dynamics, with the exception of the KRASH application described in this program. The application of simulation computer programs to transport airplanes conceptually is the same as its application to general aviation airplanes or helicopters. However, the size of the modern day jets indicates that the same degree of modeling detail would be far costlier for transports than helicopters. However, selective modeling detail in critical regions for different crash scenarios could be an effective approach. Techniques of modeling small aircraft may have to be modified for the transport airplane simulations. It is also significant to note that throughout the last 20 years there have been numerous helicopter crash tests, and general aviation airplane tests, and very few full scale transports. The last two full-scale transport tests were with DC-7 and L1649 airplanes which are not the same size nor design of current jets. Thus, we have substantial gap of available crash test dynamic behavior developed data for modern day transports as compared to smaller aircraft.

5.8 Post Crash Fire

Reference 4 provides a complete volume (V) to postcrash survival. The data presented in Volume V is very extensive covering such areas as the post crash fire environment, human survival and escape, postcrash fire protection, interior materials, ditching, emergency escape, and crash locator beacons.

The success the Army has had with crashworthy fuel cells (CWFS) in reducing and virtually eliminating helicopter fire fatalities is very impressive. The highly visible success of CWFS makes direct application of this technology to jet transport aircraft tempting. The obvious differences in aircraft characteristics, crash scenarios and accident experience may, however, dictate another course of action. To date the major factor hampering the application of helicopter technology in this area, to transport airplanes, is the lack of a thorough dynamic description of the survivable transport crash. Furthermore the Army considers an accident impact survivable based on assessment of the inertia forces transmitted to the occupant through his seat and restraint system, and on whether or not the cabin structure collapsed within the occupant's envelope. The FAA considers a crash survivable if one occupant survives the impact event.

It is anticipated that some occupants can survive high crash impact velocities because of the size of transport aircraft and the correspondingly high energy absorbing potential. Conversely, because of the relatively small size of helicopters all occupants and systems are exposed to approximately the same crash environment.

Transport fuel tanks are either integral wing or fuselage. The helicopter CWFS may be suitable and beneficial for transport fuselage tanks. In which case some of the discussion in reference 4 will be directly applicable. However, it appears that the application of crashworthy bladder tanks to integral wing tanks could not be accomplished without a complete redesign of the wing itself.

The discussion on fuel containment in reference 4, Volume II provides good general design principles and philosophies which should be applicable to transport airplanes.

5.9 Crash Test Dummies

The U.S. Survival Design Guide discusses crash test dummies in Volume II. The chapter on crash test dummies briefly outlines the evolution of current dummy technology, indicates the design features that are desireable for aircraft system testing and summarizes research and comparative performance of dummies and human. To be consistent with occupant tolerance and response data, dummy designs should represent the transport airplane travelling public. However, it would appear that data obtained from dummies used in helicopter and automobile testing, if representative of humans would provide valuable information for transport airplane studies. Since this chapter is brief and general in nature it would best serve transport airplane technology in a reference capacity.

6. ASSESSMENT OF ADVANCED MATERIAL USAGE

6.1 Literature Search

A literature search was performed in reference 34 in which the major topics were:

- Composites
- Crashworthiness
- Energy Absorption
- Impact
- Compression
- Stability

The method used to reduce the number of topics in the reference 34 search is shown in figure 6-1. The literature search performed in this current study expands and updates that of the reference 34 study. The following data files are searched:

- DOD
- NASA
- Transportation Research Information Services (TRIS) - DOT
- Sci Search
- Smithsonian Science Information Exchange (SSIE), Current Research
- Frost & Sullivan Defense Market
- Compendex (Engineering Index, N.Y.)
- National Technical Information Services

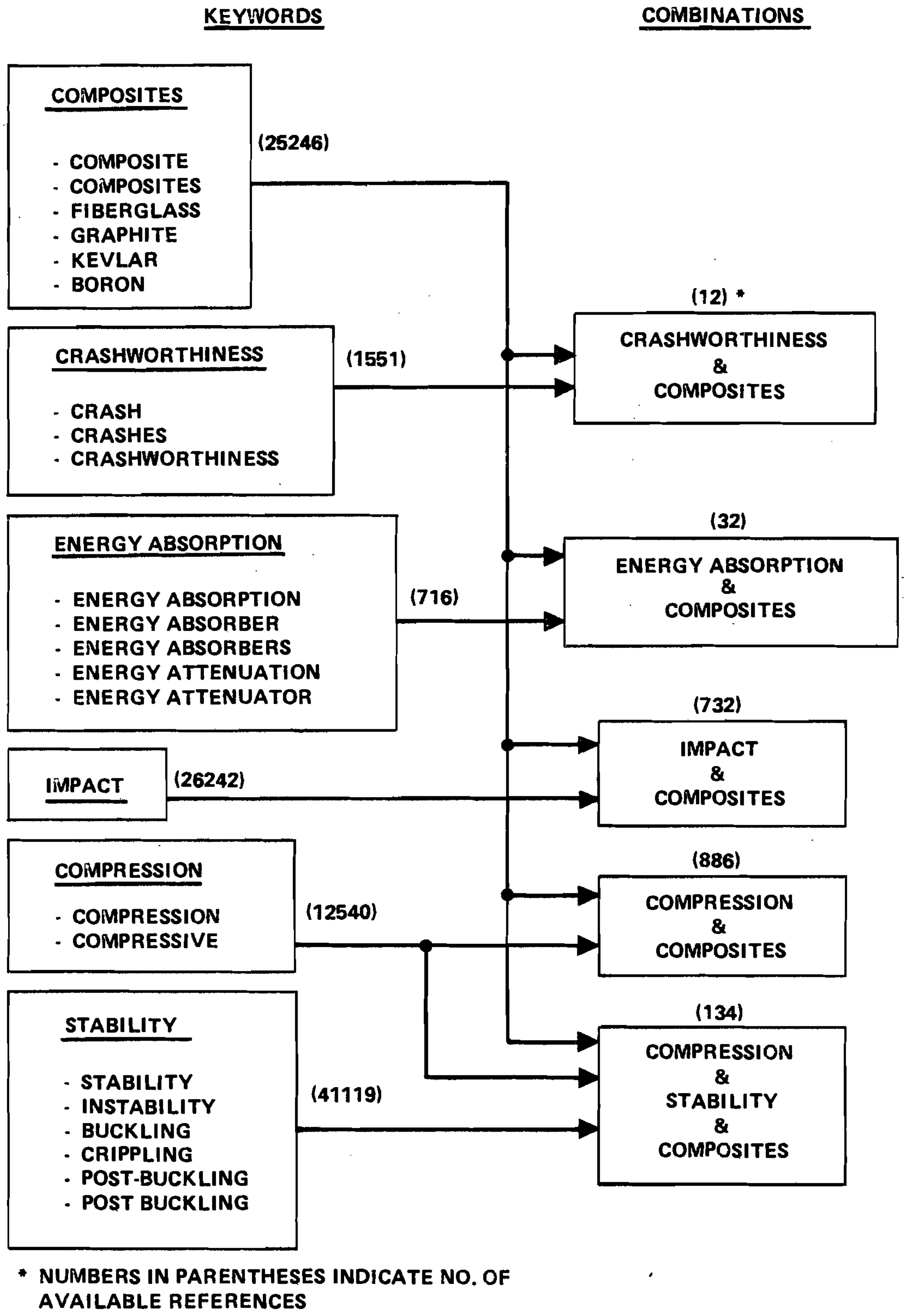


Figure 6-1. - Literature survey topic reduction from combination of key words (reference 33).

The topics scanned, to date, are as follows:

- COMPOSITES (Set 29)
  1. Composites
  2. Fiberglass
  3. Fibreglass
  4. Graphite
  5. Kevlar
  6. Boron
  7. Advanced Material(s)
  8. Honeycomb
- CRASHWORTHINESS (Set 30)
  9. Crash
  10. Large Deformation
  11. Post-failure
  12. Inelastic behavior
  13. Energy Absorption
  14. Energy Absorber
  15. Energy Attenuator
  16. Energy Attenuation
  17. Energy Dissipation
- CONFIGURATION (Set 31)
  18. Helicopter
  19. Aircraft
  20. Fuselage
  21. Fixed Wing

22. Airframe
23. Airplane
24. Automotive
25. Automobile
26. Transport Airplane
27. Transport Aircraft
28. Rotary Wing

The general procedure followed in the current search is depicted below. The sets, which consist of various topics as noted earlier, are grouped in combinations. For example, the combined subjects of crashworthiness and composites (set 32) is obtained from sets 29 and 30 where references contain both subjects (match). The individual topics in set 31 (items 18 thru 28) are then matched with set 32 to form sets 55 through 65.

Table 6-1 summarizes the number of applicable reports contained in the different search files. The same report can be available in more than one file, thus the number of reports available is not the sum total of all files for each subject. The following is a brief description of the available information.

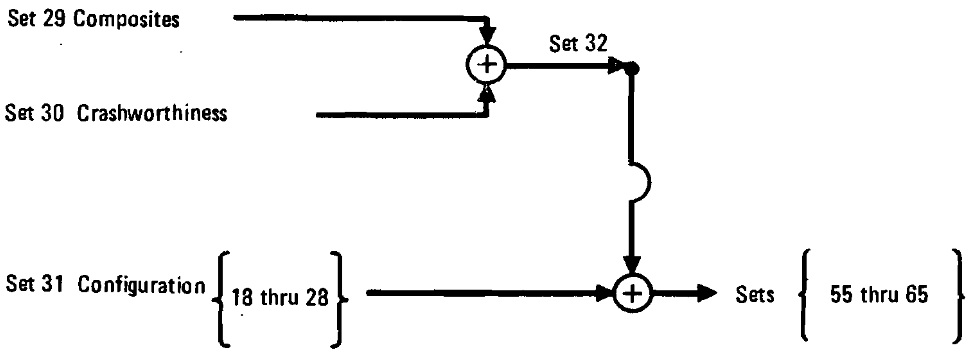


TABLE 6-1. - SUMMARY OF LITERATURE SEARCH

Set	Subject	Search File and No.					
		COMPENDEX 8	TRIS 63	SSIE 65	NTIS 6	Sci Search 34	Conference Papers 77
29	Composites	21771	1977	2629	14979	5252	5629
30	Crashworthiness	2366	5022	258	2366	218	308
31	Configuration	30015	19277	5410	39207	1311	4716
32	Composites & Crashworthiness	97	80	20	57	4	1
	Composites, Crashworthiness and						
55	18. Helicopter	2	1	4	4	1	
56	19. Aircraft	6	5	12	5		
57	20. Fuselage	3		2		1	
58	21. Fixed Wing						
59	22. Airframe			4	1		
60	23. Airplane						
61	24. Automotive	4	16		2		
62	25. Automobile	18	32		2		
63	26. Transport Airplane						
64	27. Transport Aircraft						
65	28. Rotary Wing			4			

A total of 15 research studies are presented. The latter 3, while not directly applicable to crashworthiness, are of interest since they discuss other aspects of composite design and/or fire hazard.

1. CRASHWORTHINESS DESIGN PARAMETER SENSITIVITY ANALYSIS.
   Investigators: Lowry, D; Carnell, B
   Performing Org: United Technologies Corp., Sikorsky Division, N. Main St., Stratford, Connecticut, 06602, United States of America
   Sponsoring Org: U.S. Dept. of Defense, Army Aviation Research & Development Command, Applied Technology Lab., Fort Eustis, Newport News, Virginia, 23604, United States of America
   Contract/Grant No.: DAOGO420; DAAK51-79-C-0043
   8/79 to N/A FY: 81 Funds: $15,900
   Minimize the adverse impact of crashworthiness design criteria on the cost, weight and performance of future Army helicopter designs and identify R&D efforts required to reduce the cost and weight associated with crashworthiness requirements.

The work to be performed under this procurement shall investigate the effect of MIL-STD-1290 crashworthiness requirements on future light helicopters. Both metal and composite airframe structures shall be investigated. Trend data shall be developed for crashworthiness cost and weight as a function of helicopter weight and as a function of the level of crashworthiness specified. Crashworthiness cost drivers are to be identified to assist in determining future R&D efforts necessary to reduce the cost of incorporating crashworthiness into future helicopter designs without reducing the level of crash impact protection from that specified in MIL-STD-1290.
Descriptors:
Aeronautical Engineering, 2. Aircraft Components, 3. Airframes; 2. Aircraft Types, 3. Military Aircraft, 4. Military Aircraft - other; 3. Vertical/Short Takeoff Craft, 4. Rotary Wing Aircraft, 5. Helicopters
Engineering Methodology, 2. Design, 3. Design Data; 2. Engineering Assessment, 3. Economic Factors; 2. Industrial Methods, 3. Standardization, 4. Standards; 2. Performance, 3. Crashworthiness, 3. Performance - other
Composite Materials, 2. Composite Materials - other
Applications of Materials, 2. Aerospace Applications
Metals and Alloys, 2. Metals and Alloys - other
Info. Sys. & Operations Res., 2. Control Theory, 3. Sensitivity Techniques
Mechanics & Mech. Properties, 2. Weight Properties, 3. Weight Reduction
Mechanics of Structures, 2. Structures, 3. Aero Structures

2. INVESTIGATION OF THE CRASH IMPACT CHARACTERISTICS OF HELICOPTER COMPOSITE STRUCTURES
Investigators: Cronkhite, J
Performing Org: Bell Helicopter Textron, Hwy 183, P.O. Box 482, Fort Worth, Texas, 76101, United States of America
Sponsoring Org: U.S. Dept. of Defense, Army Aviation Research & Development Command, Applied Technology Lab, Fort Eustis, Newport News, Virginia, 23604, United States of America
Contract/Grant No.: DAOG041B; DAAK51-79-C-0037
8/79 to 11/81 FY: 81 Funds: $71,000
A. To investigate the crashworthiness of composite helicopter airframe structures in comparison to similar metal structures. B. To develop design, test, and analytical procedures for crashworthiness composite helicopter airframe structures.
During task I, a review of work-in-progress, preliminary designs of crashworthy composite fuselage structures, and design support testing will be performed. During task II, the contractor will perform the analytical, crash impact testing data analysis, and correlation effort required by the task II test plan.

Descriptors:
Aeronautical Engineering, 2. Aircraft Components, 3. Airframes, 4. Fuselages; 2. Aircraft Types, 3. Vertical/Short Takeoff Craft, 4. Rotary Wing Aircraft, 5. Helicopters
Engineering Methodology, 2. Design, 3. Structural Design, 3. Design - other; 2. Performance, 3. Crashworthiness; 2. Testing, 3. Testing - other
Metals and Alloys, 2. Metals and Alloys - other
Data Analysis by Computers, 2. Data Proc., Reduction, & Anal., 3. Data Analysis
Mechanics & Mech. Properties, 2. Forces and Loadings, 3. Dynamic, 4. Impact, 5. Impact - other
Mechanics of Structures, 2. Composite Structures, 2. Structures, 3. Aero-Structures

3. RESEARCH IN STRUCTURES
Investigators: Shipley, JL
Performing Org: U.S. Dept. of Defense, Army Aviation Research & Development Command, Research & Technology Lab., Hampton, Virginia, 23665, United States of America
Sponsoring Org: U.S. Dept. of Defense, Army, Aviation Research & Development Command, Research & Technology Lab., Hampton, Virginia, 23665, United States of America
Contract/Grant No.: DAOE3550; N/A
10/77 to Cont FY: 81 Funds: NA
To conduct basic research for fundamental structures and materials application technology necessary for a viable structures program. Efforts include analytical techniques for complex structures, development of fatigue and fracture mechanisms in composite materials, the demonstration of advanced materials on helicopters, and the improvement of prediction techniques for structural dynamics.
In conjunction with NASA-LRC, analytical techniques for complex structures will include the application of minicomputers in finite element analysis and participation in the IPAD program. In the analysis and prediction of fatigue and fracture composites, experimental data will then be incorporated into a statistical model for fatigue behavior of graphite epoxy. Environmental effects on fatigue will be continued. The evaluation of environment effects and durability of composite components in a service environment and comparison to specimens under the same environment will be initiated. The composite fuselage investigation will continue, a program to develop an efficient technique for attachment of hardpoints to an all-composite panel. The crash impact energy absorption capability of composites will be compared to conventional sheet metal construction designed to the same static strength requirements. Fuselage structural dynamics will explore other finite element techniques to helicopter dynamic response.

Descriptors:
Nonresearch & Selected Topics, 2. Demonstration Projects
Aeronautical Engineering, 2. Aircraft Components, 3. Airframes,
4. Fuselages; 2. Aircraft Types, 3. Vertical/Short Takeoff Craft,
4. Rotary Wing Aircraft, 5. Helicopters
Engineering Methodology, 2. Design, 3. Structural Design;
2. Engineering Environments, 2. Performance, 3. Durability
Polymer Chemistry, 2. Organic Polymers, 3. Epoxies
Composite Materials, 2. Reinforced Systems, 3. Plastic Matrix,
4. Plastic Matrix - other; 2. Composite Materials - other
Form and State, Materials, 2. Sheet
Materials Resources Management
Applications of Materials, 2. Energy Absorbing, Damping Mtl. Mechanics
& Mech. Properties, 2. Fatigue Properties, 3. Fatigue Properties -
other; 2. Fracture Mechanics, 2. Mechanical Vibrations, 3. Response;
2. Strength Properties
Mechanics of Structures, 2. Panels, 2. Structures, 3. Aero
Structures
Mechanical Power, 2. Mechanical Devices, 3. Rotors-propellers
Elements & Inorganic Compounds, 2. Metalloids, 3. Carbon,
4. Graphite

4. INVESTIGATION OF THE CRASH-IMPACT CHARACTERISTICS OF ADVANCED AIRFRAME STRUCTURES
Bell Helicopter Textron Fort Worth TX, Army Research and Technology
Labs., Fort Eustis, VA (054200)
Final rept.
Author: Cronkhite, James D.; Haas, Thomas J.; Berry, Victor L.;
Winter, Robert
G0141H4 Fld: 1C, 11D, 9B, 51C, 71F GRA18003 Sep 79 222p
Contract: DAAJ02-77-C-0062
Project: 1L262209AH76
Task: 00
Monitor: USARTL-TR-79-11
Prepared in cooperation with Grumman Aerospace Corp., Bethpage, N.Y.
Abstract: The purpose of this program was to investigate the crash-impact characteristics of advanced troop transport helicopter airframe structures constructed of composite materials. Currently available information was surveyed on the crash-impact behavior of composite materials, analytical tools for design of crashworthy airframe structures, and airframe structure crashworthiness design criteria. Information on the crash-impact behavior of composite materials was found to be limited. Automotive studies showed that by innovative design, composite materials could function efficiently as energy absorbers to reduce crash-impact loads. Other pertinent studies were found that are currently in progress at Bell Helicopter Textron, the NASA Langley Research Center and the U.S. Army's Research and Technology Laboratories and are summarized. Finally,

effects of composite materials on the compliance of airframe structures with current Army crashworthiness requirements are discussed.
Descriptors: Airframes, Helicopters, Crash Resistance, Composite Materials, Impact Shock, Impact Strength, Airworthiness, Fiber Reinforced Composites, Mathematical Models, Finite Element Analysis, Computerized Simulation, Computer Aided Design, Computer Programs
Identifiers: Crashworthiness, Krash Computer Program, Dycast Computer Program, NTISDODXA.

5. ENERGY-ABSORBING MATERIALS FOR IMPROVING HELICOPTER CRASHWORTHINESS
Kimball, CE; DeHart, RC
Southwest Research Inst San Antonio Tex; Office of Naval Research Arlington, VA.
Mar 1976 27 p
Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161
AD-A023006/OST
Contract No.: N00014-70-C-0265; Contract
Subfile: NTIS
The purpose of the program was to identify materials which were not only suitable for structural components but were capable of absorbing energy at acceptable deceleration levels in a crash environment. After review of available materials for their energy absorption capability, five candidate materials were selected and a test program initiated to demonstrate their attenuation properties. Those selected were three types of honeycomb, a rigid foam, and a flexible foam.
Descriptors:
Aluminum Alloys
Aviation Safety
Crash Resistance
Crash Worthiness
Energy Absorbers
Expanded Plastics
Fiber Reinforced Composites
Fiberglass Reinforced Plastics
Helicopters
Honeycomb Structures
Impact Tests
Materials
Phenolic Plastics
Polyethylene Plastics
Polystyrene

6. ENERGY ABSORBER
Phillips, NS; Walcott, WB
Department of the Navy Washington DC
19 p
Available from: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161
Report No.: PAT-APPL-899 956; AD-D005226/6ST
Subfile: NTIS
This patent application is on a notched-energy absorber for attenuating high level accelerations such as would occur during aircraft crashes, thereby avoiding injury to a user. The energy absorber force-displacement curve has a large initial spike, followed by a valley or 'notch' and then by a constant force level intermediate the spike and valley levels. In one embodiment, a conventional square-response type shock absorber is connected between a vehicle seat and the vehicle body by a shearable diaphragm fixed to vehicle structure. The diaphragm fixed to vehicle structure. The diaphragm shears at a notch when it experiences an initial high force, after which the conventional absorber moves freely without deforming until it encounters a stop. The conventional absorber then elongates or compresses in a conventional manner. In an alternative embodiment, a spring is connected between the seat and the vehicle body. Initially, the spring is compressed by experienced forces until at a predetermined force level it forces out a retaining clip or ring. The spring thereupon crushes a honeycomb, forming the valley or 'notch'. After the honeycomb is crushed, a conventional shock absorber attached thereto is compressed in a conventional manner. (Author) Availability: This Government-owned inventional available for U.S. licensing and possible for foreign licensing. Copy of application available NTIS.
Descriptors:
  Aviation Safety
  Crashes
  Energy Absorbers
  Impact
  Patent Applications
  Protective Equipment
  Safety Equipment
  Shock Absorbers
  Survival Personnel

7. CRASH SIMULATION OF COMPOSITE AND ALUMINUM HELICOPTER FUSELAGES USING A FINITE-ELEMENT PROGRAM.
Winter, R.; Cronkhite, J. D.; Pifko, A. B.
Grumman Aerosp Corp, Bethpage, NY
Collect Tech Pap AIAA ASME Struct Struct Dyn Mater Conf 20th, St. Louis, Mo. Apr 4-6 1979. Publ by AIAA, New York, NY, 1979 Pap on on Dyn and Loads, Pap 79-0781 p 233-240 CODEN: CIPCD3
This paper describes a mathematical investigation of the crash-impact responses of an all-composite helicopter cockpit section incorporating an energy absorbing concept and one of conventional aluminum construction, using the Grumman DYCAST finite-element nonlinear structural

dynamics computer program. The overall objective of this initial investigation was to explore the application of DYCAST to the design of future helicopter structures. The specific purposes are to assess the value of the finite-element code as a crashworthiness design analysis tool, and to compare the responses of the two fuselage sections. 5 refs.
Descriptors: (Helicopters, Fuselage), (Structural Design, Impact Resistance). (Mathematical Techniques, Finite Element Method).

8. COMPOSITE APPLICATIONS AT BELL HELICOPTER
McCaskill, O. K. Jr.
Bell Helicopter Textron
SAE paper 790578 for Meet Apr 3-6 1979 11 p
Bell Helicopter Textron has used fiber reinforced plastic materials in many applications since the earliest appearance of these materials. An overview of past, present and future usage is presented. The discussion includes examples of fuselage, control system, main rotor, energy attenuator and engine cowling/firewall applications.
Descriptors: Helicopters, (Aircraft Materials, Composite Materials), (Plastics, Reinforced, Applications).

9. COLLECTION OF TECHNICAL PAPERS AIAA/ASME STRUCTURES, STRUCTURAL DYNAMICS AND MATERIALS CONFERENCE, 19th, 1978.
Anon
AIAA, New York, NY
Collect Tech Pap AIAA ASME Struct Struct Dyn Mater Conf 19th, Bethesda, Md Apr 3-5 1978. Publ by AIAA, New York, NY, 1978 430 p
The volume contains 48 papers presented at the conference, 43 of which are indexed separately. Among the subjects covered are design of composite wings, composite structural panels, minimum weight design of structures, the effect of strain rate on automobile crash dynamic response, design of a crashworthy locomotive cab, crashworthiness of aircraft fuselage structures, low pressure diffusion bonding of titanium, service life prediction for solid propellant motors, dynamics of spinning spacecraft during flexible boom deployment, environmental effects on composites, visualization of quasi-periodic unsteady flows, composite wing failure investigation, buckling of imperfect anisotropic cylindrical shells, estimation of payload loads, and others.
Descriptors: Structural analysis, Materials Science, Spacecraft, Automobiles, Railroad Rolling Stock, Aircraft.
Identifiers: Minimum Weight Design, Aeroelasticity, Crashworthiness, Thermal Protection Systems, Structural Materials.

10. AIAA/ASME/SAE STRUCTURES, STRUCTURAL DYNAMICS, AND MATERIALS CONFERENCE, 16TH, TECHNICAL PAPERS, 1975.
AIAA, New York, NY
AIAA/ASME/SAE Struct, Struct Dyn, and Mater Conf, Proc, Tech Pap, Denver, Colo, May 27-29 1975 Sponsored by AIAA, New York, NY, 1975, 2 vol

Proceedings includes 67 papers on design and analysis of structural materials (panels, plates, shells, trusses, etc.), in particular composite materials for aerospace applications, structural dynamics. In particular vibrations and impact resistance of structural materials, problems of fatigue and fracture mechanics, aerodynamical problems. In particular flutter, involved in the design and fabrication of wings and airfoils, thermal protection systems for supersonic and hypersonic environment, vehicle crash simulation, etc. Selected papers are indexed separately.
Descriptors: Structural Design, Structural Analysis, Aerodynamics, Structural Panels, Composite Materials, Aircraft Materials.

11. ADVANCED TECHNOLOGY HELICOPTER LANDING GEAR
Hughes Helicopters, Culver City, Calif (409164)
Final rept. Apr 75-Apr 77
Author: Goodall, Ralph E.
E0655D4 Fld: 1C, 11D, 51C, 71F GRAI7808
Oct 77 151p
Rept No: HH-77-41
Contract: DAAJ02-75-C-0028
Project: 1F262209AH76
Task: 00
Monitor: USAAMRDL-TR-77-27
Abstract: This report covers the work performed on the advanced helicopter landing gear program by Hughes Helicopters. The objectives of the program were to design, fabricate, and test a wheel-type advanced main landing gear concept possessing high-energy-absorbing characteristics for helicopters in the 15,000-pound class. These objectives were achieved by formulating design criteria through a data search, choosing the most cost-effective composite material, and through a design analysis, selecting the most promising landing gear concept. This concept used graphite epoxy as a structural material to fabricate the trailing arm of the main landing gear of the Hughes YAH-64 helicopter by wet-filament winding (WFW). The graphite arm was successfully tested; demonstrating the practicality of employing composite structures in the construction of high-energy-attenuating landing gear components. The program showed that the graphite trailing arm was 11 percent lighter than the baseline steel arm. The weight of the baseline landing gear could be reduced by maximizing the use of composites: 7 percent by using existing WFW equipment, and 26 percent by developing and using a toroid winding machine. (Author)
Descriptors: Landing Gear, Helicopters, Filament Wound Construction, Graphite, Epoxy Resins, Energy Absorbers, Shock Absorbers, Composite Materials, Aviation Accidents
Identifiers: YAH-64 aircraft, H-64 aircraft, NTISDODXA

12. ARMOR PROTECTION FOR PILOT/COPILOT SEAR WITH CRASH SAFETY FEATURES FOR CH-47A HELICOPTER
Vertol Div Boeing C Morton P (000000)
Technical rept.

Author: Thompson, David F.; Harper, Philip
1391G1 USGRDR6506
Dec 64 2 p
Rept No.: vac-R-361
Contract: DA44 177AMC94T
Project: 1A121401A150
Monitor: TRECOM-TR64 73
Abstract: Pilot/copilot protected crash-safety seat was designed and manufactured. Optimum seat and torso protection was attempted. Detail load and stress analysis for accelerations of 20 g vertically and 45 g longitudinally and laterally was made. By using crushable honeycomb type material, an improved torso restraint system and a variable attenuation mechanism were adopted. The feasibility of using protection media as a load bearing structure was demonstrated. (Author)
Descriptors: (Helicopters, Aircraft Seats), (Aircraft Seats, Safety Devices), (Aviation Safety, Aircraft Seats), Aviation Accidents, Impact Shock, Aviation Personnel, Pilots, Honeycomb Cores, Sandwich Construction, Feasibility Studies, Loading (Mechanics), Stresses, Design, Acceleration, Aviation Injuries
Identifiers: H-47 Aircraft

13. ADVANCED AIRCRAFT STRUCTURES
Investigators: Unknown
Performing Org: U.S. National Aeronautics & Space Admin., Langley Research Center, Hampton, Virginia, 23665, United States of America
Sponsoring Org: U.S. National Aeronautics & Space Admin., Office of Aeronautics & Space Technology, Washington, District of Columbia, 20543, United States of America
Monitor: Mathauser EE
Contract/Grant No.: 505-33-43
10/77 to N/A FY: 80 Funds: NA
The objective is to develop the technology required for obtaining improved efficiency and reduced costs in aircraft structures by the application of advanced composit materials and composite design concepts to commercial aircraft. Research and development are being carried out to establish a technology base of advanced analytical methods for predicting the service life, strength, stiffness, and stability of composite laminates, stiffened cover panels and shear webs. Included are studies to develop fundamental understanding of procedures for quality control of graphite/epoxy composites, environmental effects, accelerated test and analysis methods for prediction long term performance, effects of flaws and damage, and to identify failure modes and failure strain levels. An adequate test data base is being established for substantiation. Confidence is being built in the use of composite aircraft components through longtime flight service programs on both commercial and military transport aircraft. Outdoor environmental degradation of both materials coupons and structural components subjected to static and fatigue loads is being studied over ten-year exposure periods.

Descriptors:
Aeronautical Engineering, 2. Aircraft Components, 2. Aircraft Types, 3. Commercial Aircraft, 3. Military Aircraft, 4. Military Aircraft - other; 3. Transport Aircraft, 4. Transport Aircraft - other.
Engineering Methodology, 2. Design, 3. Design - other; 2. Engineering Assessment, 3. Economic Factors; 2. Engineering Environments, 2. Performance, 3. Damage Survey, 3. Durability; 2. Testing, 3. Accelerated Testing, 3. Quality Control, 4. Quality Control, 4. Quality Control - other.
Polymer Chemistry, 2. Organic Polymers, 3. Epoxies
Composite Materials, 2. Laminates, 2. Reinforced Systems, 3. Plastic Matrix, 4. Plastic Matrix - other; 2. Composite Materials - other.
Defects in Materials, 2. Defects - other.
Corrosion, Deterioration, 2. Corrosion Effects, 3. Thermal Degradation.
Mechanics & Mech. Properties, 2. Failure, 2. Fatigue Properties, 3. Fatigue Properties - other; 2. Forces and Loadings, 3. Static; 2. Mechanical Vibrations, 3. Stiffness and Flex; 2. Stability, 2. Strength Properties, 2. Stresses.

14. COMPOSITE COMPONENTS TECHNOLOGY
Investigators: Unknown
Performing Org: U.S. National Aeronautics & Space Admin., Langley Research Center, Hampton, Virginia, 23665, United States of America
Sponsoring Org: U.S. National Aeronautics & Space Admn., Office of Aeronautics & Space Technology, Washington, District of Columbia, 20543, United States of America
Monitor: Vosteen LF
Contract/Grant No.: 534-03-13
10/77 to N/A FY: 80 Funds: NA
The objective of the composite components program is to accelerate the introduction of composite structures in commercial transport aircraft. This will be accomplished through the progressive introduction of selected components in current aircraft production. Design technology for typical secondary structure components and medium sized primary structures will be developed. Manufacturing processes suitable for production will be developed and verified through comprehensive ground testing.
Descriptors:
Aeronautical Engineering, 2. Aircraft Types, 3. Commercial Aircraft, 3. Transport Aircraft; 2. Flight Testing
Engineering Methodology, 2. Design, 3. Structural Design; 2. Industrial Methods, 3. Manufacturing; 2. Performance
Composite Materials, 2. Composite Materials - other
Applications of Materials, 2. Aerospace Applications
Mechanics of Structures, 2. Composite Structures, 2. Structures, 3. Aero Structures

15. INVESTIGATION OF THE STRUCTURAL DEGRADATION AND PERSONNEL HAZARDS FROM HELICOPTER COMPOSITE STRUCTURE EXPOSED TO FIRE AND/OR EXPLOSIONS
Investigators: Schlitz, R : Haas, T
Performing Org: Bell Helicopter Textron, Hwy. 183 P.O. Box 482, Fort Worth, Texas, 76101, United States of America
Sponsoring Org: U.S. Dept. of Defense, Army, Aviation Research & Development Command, Applied Technology Lab., Fort Eustis, Newport News, Virginia, 23604, United States of America
Contract/Grant No.: DAOE3859: DAAK51 79 C 0009
3/79 to 12/80 FY: 81 Funds: $56,858
To investigate the effects of fire/explosion on the structural integrity of composite materials and the personnel hazards (toxicity, smoke, etc.) resulting from same.
Following a literature and organizational survey to establish design guidelines and requirements, composite specimens will be fabricated and laboratory tested to ascertain the structural degradation and resulting hazards (smoke, toxicity, etc.) to personnel when burning/explosion occurs. Based on the test findings, design guidelines will be developed to minimize the structural and personnel harmful effects due to composites exposed to post-crash in-flight or explosive induced fire. A computer program simulating the result of a helicopter composite structures fire will be demonstrated at Atl. Ft Eustis, VA. upon completion of the technical effort.
Descriptors:
Pharmacology, 2. Toxicology
Aeronautical Engineering, 2. Aircraft Types, 3. Vertical/Short Takeoff Craft, 4. Rotary Wing Aircraft, 5. Helicopters.
2. Aviation Safety, 3. Aircraft Fires, 3. Hazardous Conditions
Engineering Methodology, 2. Simulators, 2. Testing, 3. Testing - other
Chemical Energy Conversion, 2. Explosions, 3. Explosive Types, 4. Explosives - other; 3. Explosions - other; 2. Flame Research, 3. Combustion, 4. Burning
Chemical Reactions, 2. Decomposition, 3. Degradation
Composite Materials, 2. Composite Materials - other
Corrosion, Deterioration, 2. Corrosion Effects, 3. Thermal Degradation
Mechanics of Structures, 2. Composite Structures, 2. Structures, 3. Aero Structures

6.2 Crash Dynamics

The reference 33 study showed that there is an abundance of research in the area of impact strength of composite materials, but that this research has been mainly directed toward local impacts produced by tool drops, foreign objects, missiles and particles. While the damage due to local impact can compromise the compressive failure mode of a structure, reference 33 states that the techniques used are not applicable to gross structural deformations.

The reference 33 study also showed that the work done in the area of "Compression failure mode" has been primarily on metal structures to predict and improve the post-buckling characteristics of the airframe structure.

Figure 6-2 is an example of load-deflection characteristics of various aluminum plate-stringer panel configurations. The integrally stiffened panel experiences an explosive fracture failure mode and, consequently, exhibits poorer energy absorption characteristics than that of the rolled zee and hat stringers. The higher failure load also translates to potentially higher inertial forces transmitted to the occupants and large mass items during a crash.

Compression failure mode research on composites has been directed mostly toward predicting static allowable loads of structural elements and not load-deflection or energy absorbing characteristics of structures.

For the combined topic of Energy Absorption/Composite Materials, the reference 33 survey states that:

> "With the exception of the automobile tests, the use of composite materials as energy absorbers or attenuators has been limited to low velocity impact applications such as bumpers. There has been work on improving the energy absorption characteristics of composite materials at the micro or local structural level, but no correlation has been drawn between this research and its application in a crash environment."

The current literature search evaluation is consistent with the results of the reference 33 study.

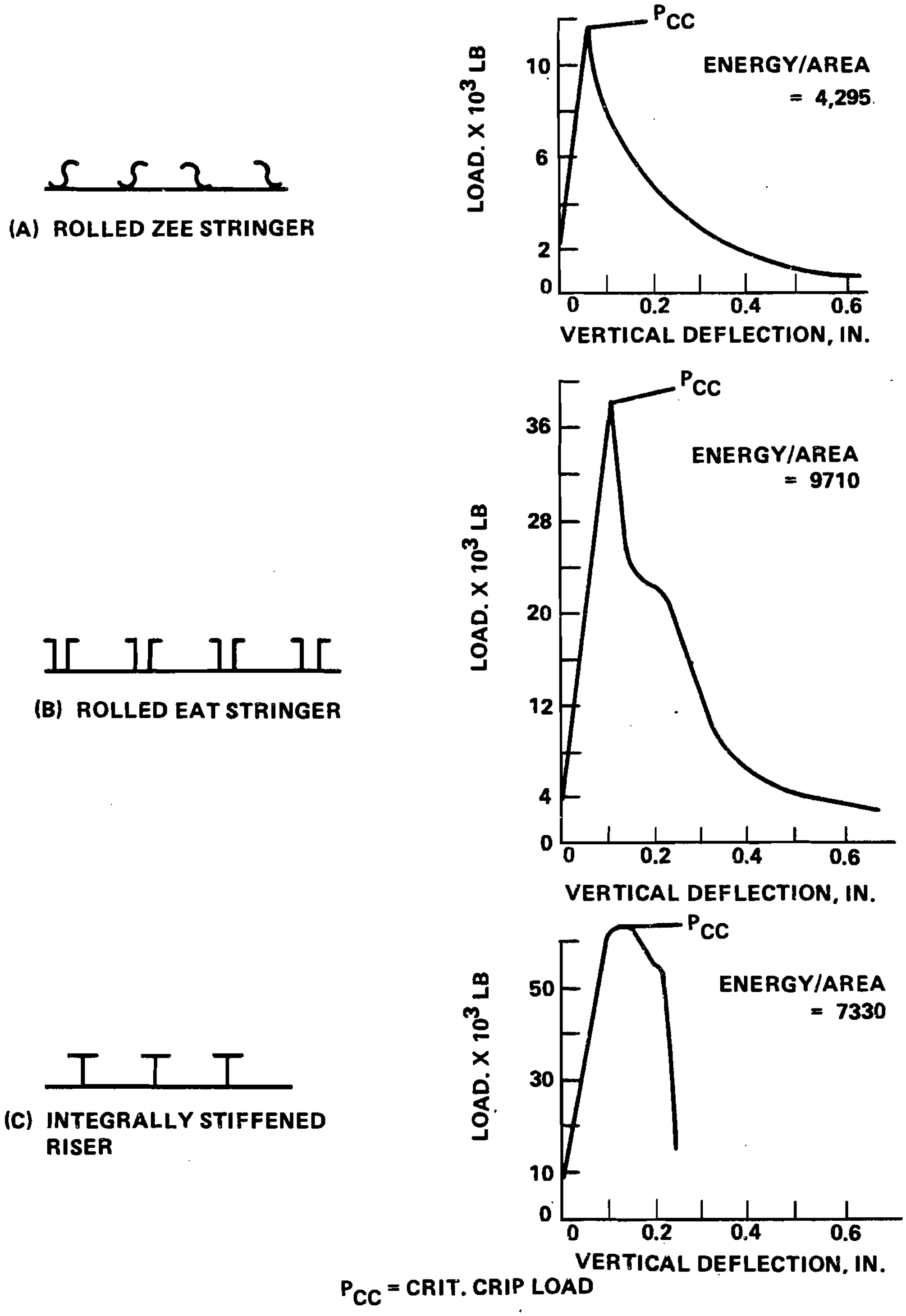


Figure 6-2.- Load-deflection curves for various aluminum sheet/stringer panel.

7. REVIEW AND EVALUATION OF ANALYTICAL TECHNIQUES AND REQUIREMENTS

7.1 Requirements for Analysis of Candidate Crash Scenarios

The structural systems and the degree to which they are involved in each of the crash scenarios are discussed in Section 4. From the flow diagrams developed for each of the accidents (Appendix C) and the summary of interaction (tables 4-28 to 4-30), the characteristic events associated with each of the candidate crash scenarios are developed. Figures 7-1, 7-2 and 7-3 depict the structure related events, including initial failures, subsequent failures, the consequence of such failures and the injurious hazards with regard to each candidate crash scenario. The analysis of transport accidents requires candidate computer programs to have the capability to describe terrain and hazard conditions, airplane operating parameters, structure failure modes and system failure modes. Since the characteristics of the analysis can differ depending on the nature of the crash condition and the ultimate objective of the analysis, different analytical techniques can be applicable. In addition to meeting the requirements to describe the airplane, impact conditions, terrain conditions and failures, the analytical computer program candidates are to be evaluated, where information allows, with regard to:

- source and type of input data requirements
- cost associated with establishing the model and performing computation
- ease of usage of program and level of background required or analyst to perform modeling and analysis
- documentation of computer program input/output, theory and application
- verification of the program with experimental data; extent and range
- availability for general usage

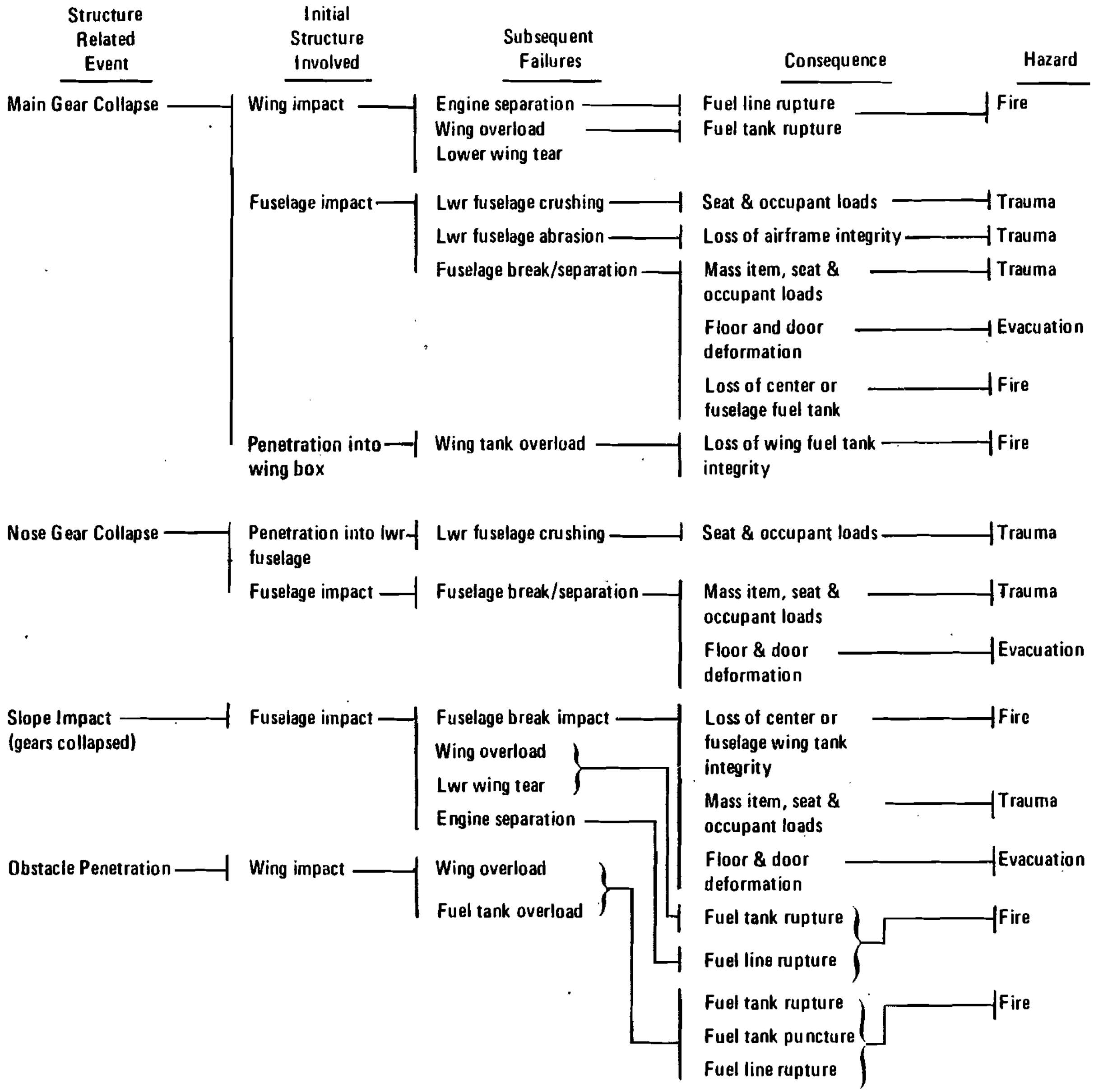


Figure 7-1. - Ground-to-ground, overrun crash scenario sequence.

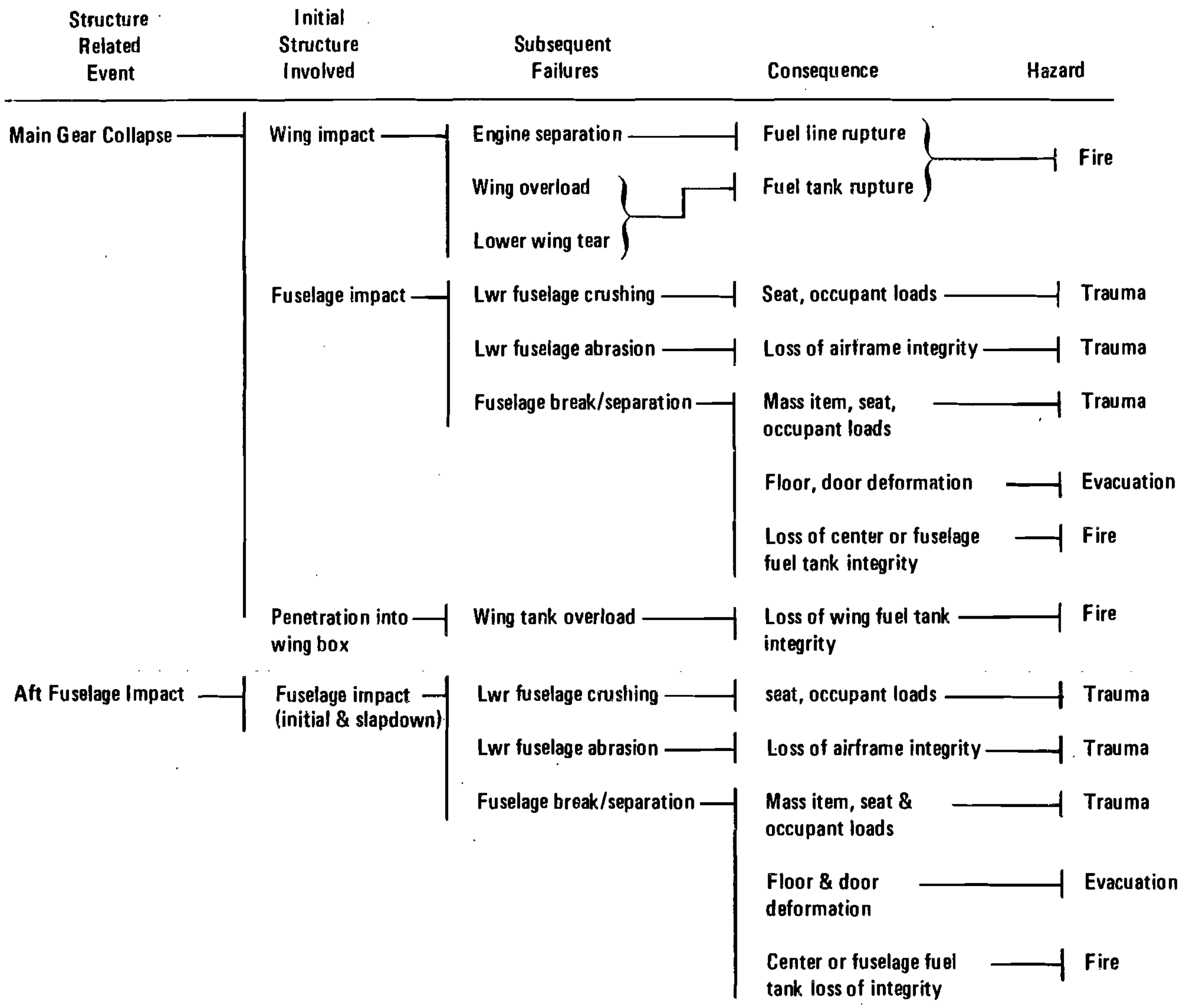


Figure 7-2. - Air-to-ground, hard landing crash scenario sequence.

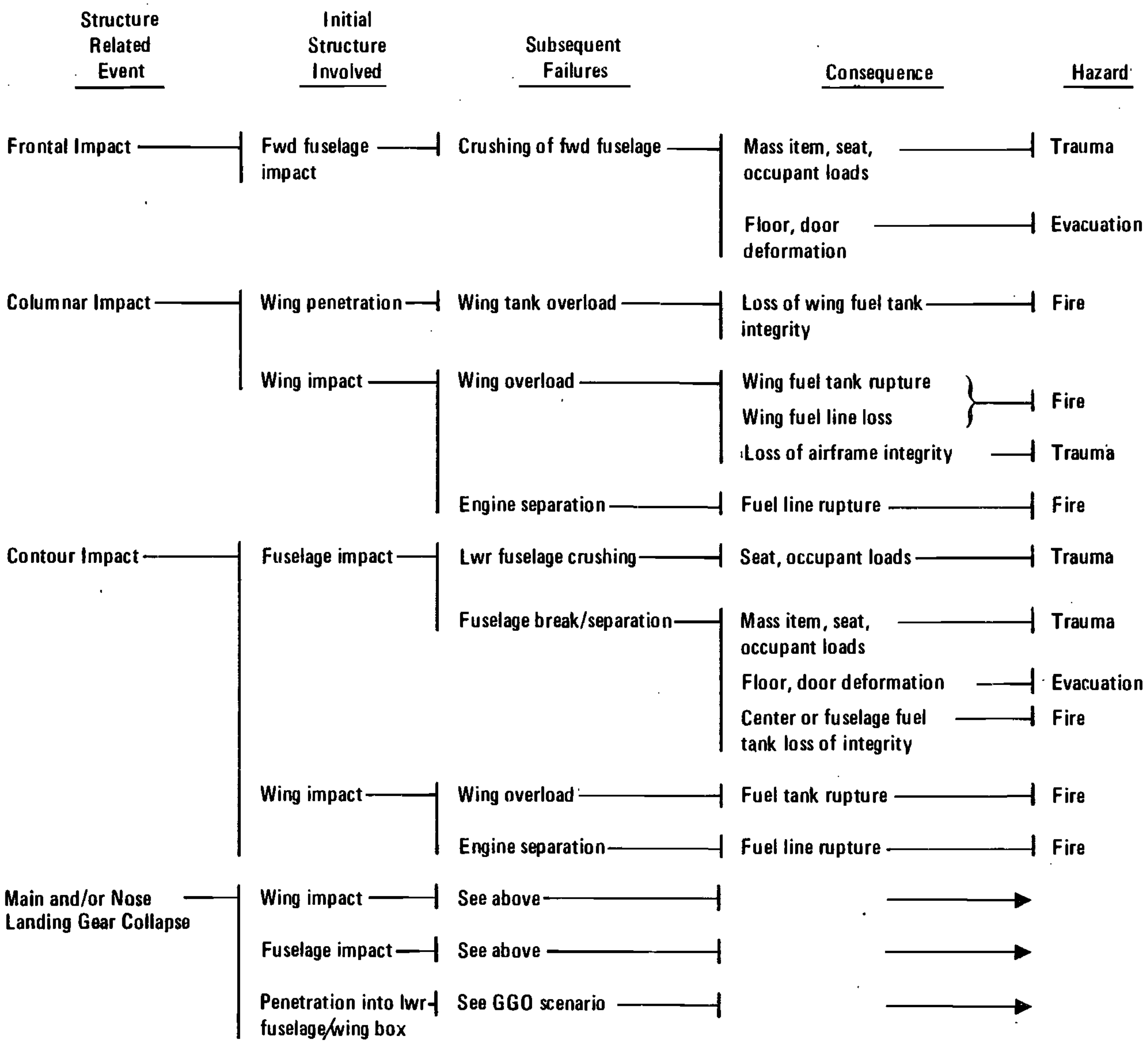


Figure 7-3. - Air-to-ground, impact crash scenario sequence.

Table 7-1 shows some basic requirements for analytical programs which are to be used in Transport Airplane Crash dynamics studies. The requirements are related to the crash scenario candidates and reflect the evaluation of accident data presented in Sections 2, 3 and 4.

The types of programs to be evaluated include those applicable to structural analysis, as well as those oriented toward occupant/restraint system analysis. A major consideration in the evaluation is the documentation available from which an assessment of capability can be made. No attempt is made to check out or validate candidate programs unless a current version is operational at Lockheed.

7.2 Structural Programs

There are many computer programs which have been developed for nonlinear and/or crash analysis of vehicle structure. These programs represent different levels of capability and applicability. Some of these programs are mentioned in references 33 and 34. For example, some simple programs (<10 masses, 50 D.O.F., one-two dimensional) are described in references 35 through 40. These programs, because of limited capability and/or their orientation toward automobile collision analysis, do not appear to be appropriate for transport airplane crash analysis in light of the requirements set forth in table 7-1. These requirements represent primary considerations based on accident data review. In reality almost every parameter, mode or terrain can be involved in each category. However, some are more prominent or influential for a particular scenario. Other programs referred to as "intermediate" are described in references 41 through 44. These programs generally treat structure as a two-dimensional array of beams with yielding at their ends (reference 41), or a three-dimensional model of a framework of rods and beams (reference 42 to 44). The efforts of these programs appear to have been toward automobile crash simulation and no known correlation with aircraft structure is presented for these methods. They are referred to as "intermediate" based on anticipated usage in the range of up to 100 masses and 500 D.O.F.

TABLE 7-1. - REQUIREMENTS FOR ANALYSIS OF CRASH SCENARIOS

Analytical Requirements	Candidate Crash Scenario		
	GGO	AG HL	AGI
Terrain Hazard Description			
Rigid Flat Surface		0	
Sloped	0		0
Flexible	0		0
Contoured (ditch, ravine)	0		
Columnar Obstruction			0
Frontal Barrier			0
Multiple Impacts			0
Airplane Operating Parameters			
Aerodynamics	0	0	0
Pilot Control Post Landing (i.e., Thrust, Spoiler)	0		
Attitude			
Pitch	0	0	0
Roll	0		0
Yaw	0		0
Gear Position - Extended	0	0	0
- Retracted	0		0
Balanced Ground Loads	0		
Structure Failure Modes			
Main Landing Gear Collapse	0	0	0
Nose Landing Gear Collapse	0	0	0
Penetration of NLG into Fuselage	0		
Penetration of MLG into Wing	0		
Wing Separation			0
Fuselage Break(s)	0	0	
Fuselage Separation(s)			0
Fuselage Impact with Ground	0	0	0
Wing Impact with Ground	0		0
Lower Fuselage Crushing	0	0	
Engine Separation	0	0	0
System Failure Modes			
Floor Beam Rupture	0	0	0
Seat Attachment	0	0	0
Seat/Occupant Loads	0	0	0
Restraint System	0	0	0
Fuel Tank Rupture	0	0	0
Mass Items Failure	0	0	
Door Deformation	0	0	
Slideout and Evacuation	0	0	

Another program which fits in this category in terms of intended size is program "KRASH". Program KRASH is often referred to as "hybrid" in nature because it utilizes test data to satisfy some of the input requirements. However, program KRASH is not totally dependent on test data but rather allows the user to make the maximum use of available information: test, analysis, heuristic, intuitive or otherwise. The concept of utilizing test data to simplify the representation of complex structure or the so-called "hybrid" approach is now being adopted by some of the more complex finite-element programs. Program KRASH is the most widely used program for aircraft crash analysis. Past and current users of KRASH include:

- Lockheed-California Company
- Boeing Vertol
- Bell Helicopter
- Hughes Helicopter
- Sikorsky Helicopter
- Cessna Aircraft Co.
- Beech Airplane Co.
- Aerospatiale Helicopter Division

Others that are currently investigating its potential application are Boeing Airplane Company and Westland Helicopters.

Program KRASH documentation and application is extensive; references 1, 32 and 45 through 54 contain pertinent information.

Three-dimensional finite-element programs are WHAM (reference 55), WRECKER (reference 56) ACTION (reference 57) and DYCAST (references 58 through 61). These programs are acknowledged to be costly to run and as of this date have not been used to model and correlate with full scale aircraft crash tests. Because of its development in conjunction with the NASA Langley Crash Test Program, DYCAST has an advantage over the others. It has been used (along with ACTION) to model and compare with aircraft section drop test data.

Another type of approach to be considered for transport aircraft crash analysis is the modal technique. Analyses of aircraft dynamic response for 5 ft/sec emergency landing and overrun conditions were performed (references 62, 63) using the modal technique at Lockheed. This program is referred to as the General Airplane/Ground-Interaction Program (AGIP) and is described in reference 64. There are some features of this type of approach that are worthy of consideration in the formulation of an analytical approach for transport airframe crash analysis.

The following is a description of some candidate structural programs based on available published information.

7.2.1 KRASH

The computer program KRASH was originally developed under U.S. Army auspices to analyze the dynamic response of helicopters subjected to a multidirectional crash environment. Subsequent development of KRASH was sponsored by the Federal Aviation Administration. The FAA's goal was to acquire an analytical tool with minimal additional development that could assist in the performance of structural crash dynamic analyses of general aviation fixed-wing airplanes. The general aviation version of KRASH has been exercised on 4 full-scale single-engine, high-wing, aircraft crash tests performed at NASA Langley's Impact Dynamics Research Facility (reference 65). KRASH analytical models have been verified with 9 instrumented crash tests. A summary of KRASH experimental verification is shown in table 7-2.

Program KRASH is a digital computer program that solves the coupled Euler equations of motion for N interconnected lumped masses, each with a maximum of six degrees of freedom defined by inertial coordinates x_i, y_i, z_i and Eulerian angles ϕ_i, θ_i, ψ_i, i = 1, 2, . . ., N. The interaction between the concentrated rigid body masses is through interconnecting structural elements which are attached at their ends with the appropriate fixity (pinned, clamped). These interconnecting elements represent the stiffness characteristics of the structure between the masses and are specified by the

TABLE 7-2. - 'KRASH' EXPERIMENTAL VERIFICATION

Aircraft	Gross Weight Kg (Lbs)	Impact Velocities (m/sec (ft/sec)		
		Vertical	Longitudinal	Lateral
1. Rotary Wing,*** Utility Type	3805 (8600)	7.0 (23)	–	5.6 (18.5)
2. Single-Engine,*** High-Wing	1087 (2400)	12.8 (42)	21.2 (69.5)	–
3. Single-Engine,*** High-Wing	1087 (2400)	6.6 (21.7)	21.7 (71.3)	–
4. Single-Engine,*** High-Wing	1087 (2400)	14.8 (48.7)	21 (69.8)	–
5.* Single-Engine High-Wing	1087 (2400)	14.3 (46.8)	21.6 (71)	–
6. Twin-Engine, Low-Wing Substructure	247 (545)	8.4 (27.5)	–	–
7. Rotary Wing Cargo Type	11007 (24300)	12.8 (42)	8.3 (27.1)	–
8. Rotary Wing**	1745 (3840)	6 (19.7)	6 (19.7)	–
9. Rotary Wing**	1657 (3650)	10 (32.8)	–	–

*Test performed on soil; all other tests on rigid surface. *** Involved unsymmetrical impact attitude.

**Reported by Aerospatiale Helicopters.

user through input of linear beam properties and selection of nonlinear stiffness versus deflection curves. The equations of motion are explicitly integrated (predictor-corrector scheme) to obtain the velocities, displacements, and rotations of the lumped masses under the influence of the external forces (gravity, aerodynamic, impact), as well as the internal element forces. The incremental deflections during each time step result in a set of incremental forces calculated using a linear stiffness matrix and user input stiffness reduction factors.

KRASH has the capability to:

- Determine response (accelerations, velocities, and displacements) for each mass and internal member loads (stresses) and deformations at each time interval.

- Represent general nonlinear stiffness properties in the plastic regime, including different types of load-limiting devices, and determine the amount of permanent deformation.

- Define rupture of an element and redistribution of the internal loading.

- Define occupiable volume and mass intrusion during the analysis.

- Track changes of the occupiable volume due to structural deformations.

- Simulate ground contact (sliding friction and nonrigid surface) by external structure.

- Treat symmetric and unsymmetric impact conditions.

- Output a measure of occupant injury potential (Dynamic Response Index).

- Calculate various energy distributions among the masses, elements, and external springs.

- Permit initial conditions of linear and angular velocity about three axes and impact into a horizontal ground and/or an inclined slope.

- Calculate the airplane c.g. velocity; and

- Permit analysis of a mathematical model consisting of up to 80 masses and 150 internal beam elements.

KRASH analysis results are printed histories of:

- Mass and node point displacements, velocities and accelerations in six directions for all NM lumped masses and NNP node points, in mass axes and ground axes

- Internal beam strain forces, total forces (strain + damping) and displacements in six directions for all NB internal beams

- External spring compressions, ground deflections, axial loads, and ground contact loads (3 directions) in ground axes and mass axes for all NSP external springs

- DRI number for all DRI beam elements

- Overall vehicle c.g. translational velocity (3 directions)
- Volume change data, including current volume, current volume/initial volume, and the changes in length of the 3 lengths of the volume (optional)
- Energy distribution by type
- Energy distribution by mass (kinetic and potential), beam (strain, damping) and spring (crushing, friction)
- Stress output for internal beam elements, including ratios of current stress/failure stress for 2 failure theories
- Mass location plots

and summaries of:

- Energy Summary
- Yield and Rupture Summary
- Energy Error Messages
- Time History Plots

KRASH has been comprehensively documented in reports and presentations. Tables 7-3 and 7-4 list these reference documents.

7.2.2 DYCAST

The computer program DYCAST (DYnamic Crash Analysis of STructures) is one module of the PLANS (Plastic and Large deflection ANalysis of Structures) system of nonlinear finite element structural analysis computer codes. These programs have been developed by Gruman Aerospace Corporation under contract to NASA Langley Research Center as part of the joint NASA/FAA program in general aviation crashworthiness. The modules for static analysis of structures are described in reference 61.

As usual in finite element modeling the structure is idealized into natural structural components: stringers, frames, beams, skin sheets, and bulkhead sheets, using the element library of DYCAST. Some portions could

TABLE 7-3. - 'KRASH' REPORTS

Agency	Report No.	Content
U.S. Army (USAAMRDL)	TR-72-72	KRASH Development and UH-IH Correlation
	TR-74-12	Substructure Test and Analysis
Federal Aviation Administration (FAA)	RD-76-123	General Aviation Task I
	RD-77-188	General Aviation Task II
	RD-77-189 I, II, III	KRASH User's Manual (Revised)
	RD-78-119	General Aviation Task III
	RD-78-120	KRASH Programmer's Manual (Revised)
	RD-79-13	Low-Wing, Twin-Engine Substructure Correlation
U.S. Army (USARTL)	TR-78-24	Simulation, Correlation and Analysis of the Structural Response of a CH-47A to Crash Impact

be modeled crudely if in the judgement of the analyst detailed modeling was not necessary. The element library consists of:

- Stringers - Two types of axial force members are available, constant or linearly varying between nodes.

- Beams - Ten different cross sections are currently available for the 12 degree of freedom beam element. Axial force, shear forces, and torque are uniform along the length, with a linear variation of bending moments.

- Membranes - Triangular membrane elements are available with either constant strain or linear strain. Hybrid elements permit mixed strain condition, i.e., constant strain along an edge with linear strain along the other two sides.

- Springs - An axial force stringer with the spring constants specified in tabular form has recently been added to the element library. It can be used to simulate structural sections with

TABLE 7-4. - 'KRASH' PUBLICATIONS AND PRESENTATIONS

Presentation	Date	Location	Title
AHS Paper No. 781	May 1973	Washington, D.C.	A Consistent Crashworthiness Design Approach For Rotary-Wing Aircraft
AIAA. Paper No. 75-273	Feb. 1975	Washington, D.C.	Experimentally Verified Analytical Technique for Predicting Vehicle Crash Response
Aircraft Crashworthiness Symposium	Nov. 1975	Cincinnati, Ohio	Analytical Techniques for Predicting Vehicle Crash Response
Aircraft Crashworthiness Symposium	Nov. 1975	Cincinnati, Ohio	Application of KRASH to the SOAC Accident
ASME-Structures and Biodynamics	Dec. 1976	New York, New York	A Method of Analysis for General Aviation Airplane Structural Crashworthiness
SAE Paper No. 790588	April 1979	Wichita, Kansas	Nonlinear Structural Crash Dynamics Analyses
SAE Paper No. 790589	April 1979	Wichita, Kansas	Experimental Verification of Program KRASH - A Mathematical Model for General Aviation Structural Crash Dynamics
DTFA03-80-C-00043	Oct. 1980	Atlantic City, New Jersey	Computer Program 'KRASH' Workshop and Seminar

known axial load versus deflection behavior; to represent an energy absorbing device; or, as a gap element with zero stiffness over a certain range of deflection and nonzero thereafter.

DYCAST accounts for two types of nonlinearities which occur in dynamically loaded structures: material and geometric. The nonlinear material behavior, exhibited by metals yielding plastically, enters the simulation process through the stress-strain curves input by the analyst. Three types of stress-strain curves are permitted: elastic-perfectly plastic, elastic-linearly hardening, and elastic-nonlinearly hardening. The current element stiffnesses during a multi-step analysis are determined using the tangent moduli corresponding to the current stress and strain, generalized for multiaxial states at various points in the element.

Geometric nonlinearities due to large deformations of the structure change the effective stiffness of the structure and are treated in DYCAST by an incremental convected coordinate approach. After each time increment the structure is reformed with straight elements between the displaced nodes and the previous values of accumulated strain, stress, and internal loads are carried forward as initial states in the reformed elements.

The incremental equations of motion for the system written in matrix form for an increment of time are:

$$[M]\{\Delta\ddot{u}\} + [K]\{\Delta u\} = \{\Delta P\} + \{R\}$$

where $[M]$ is the consistent mass matrix, $[K]$ the stiffness matrix, (Δu) and $(\Delta\ddot{u})$ the displacement and acceleration increments, (ΔP) the incremental external load vector, and (R) the vector of equilibrium corrections. Both material and geometric nonlinear effects enter the system of incremental equations through the stiffness matrix $[K]$. This system of equations is integrated numerically to obtain the response of the structural model.

Currently, both "explicit" and "implicit" algorithms are implemented in DYCAST. Central differences and Modified Adams predictor-corrector methods are the "explicit" algorithms; and, Newmark $-\beta$ and Wilson $-\theta$ methods are the "implicit" algorithms. All methods but central differences permit a variable time step throughout the analysis.

DYCAST analysis results are printed histories of:

- Nodal displacements, velocities, and accelerations
- Nodal forces and moments
- Element strains and stresses through the cross sections.

Post-processing of saved data permits plotting of:

- Time histories of displacements, velocities, and accelerations
- Views of the deformed structure at any time and from any viewing angle.

7.2.3 ACTION

The ACTION computer program was developed by faculty and graduate students at Virginia Polytechnic Institute and State University with grant supported by NASA Langley Research Center. Dr. Manohar P. Kamat has been the principal developer during the past several years.

The capabilities of the ACTION finite element computer program (reference 5) are similar to those of DYCAST, described in the previous section. Both material and geometric nonlinearities are handled by ACTION in a manner similar to DYCAST. The element library is also comparable to that of DYCAST. The difference between ACTION and DYCAST lies in the formulation and solution of the equations. DYCAST formulates a system of equations, reduces them to an algebraic set by application of an integration algorithm, and solves the set simultaneously for the increment of response at the end of an increment in time. This is the more common step-by-step procedure used by analysts. In this procedure the effective stiffness of the structure is linearized over the timestep and/or updated or corrected at the end. ACTION does not develop a set of equations describing the structure, but represents the structural characteristics by a scalar function. The equilibrium configuration of the structure is established based upon derivatives of this scalar function. The ACTION formulation consists of step-by-step numerical integration in time coupled with a function minimization procedure. Discrete time steps are taken at which mathematical function minimization produces the solution.

The approach consists of the following briefly described steps:

1. Discretize the structure producing a set of unknown generalized joint displacements.
2. Incorporate the prescribed boundary conditions.
3. Develop expressions for elemental strains as functions of the global generalized displacements.
4. Determine the corresponding elemental stresses and strain energy densities of the assemblage using respective material models.

5. Integrate the strain energy density over the elemental volumes to yield strain energy as a function of the global generalized displacements.
6. Specify the displacement - time relationship through selection of a finite-difference integration algorithm and form the scalar functional.
7. Minimize the functional to determine the equilibrium configuration at the end of the time increment.

Two points should be made about this approach: it can be shown that the usual second-order equilibrium equations are the stationary conditions of the scalar functional; and, the minimization approach, unlike the incremental stiffness approach, solves the actual nonlinear equations within a given time step without linearization.

7.2.4 Airplane/Ground Interaction Program (AGIP)

AGIP is a proprietary Lockheed program which has been used to show compliance of the L-1011 with the 5-FPS emergency landing conditions defined in FAR 25. The program computes the time history response of an airplane to the loads imposed by aerodynamic forces, thrust forces, gravity, landing gear forces and "crash" forces resulting from direct interaction between the airplane structure and the ground. The airplane has all 6 rigid body degrees of freedom, and a flexible structure represented by a maximum of 24 normal modes of vibration. The airplane has 2 vertical strut 6 wheel "bogie" type main gears and one vertical strut steerable nose gear with 2 trailing wheels. Four and 2 wheel main gears can also be analyzed. The flexibility of each landing gear is represented by a maximum of 4 normal modes.

The aerodynamic forces and moments are steady state, acting at the center of gravity of the airplane. They do not excite the airplane flexible modes. The aerodynamic parameters are specified by means of conventional stability derivatives. Provision is made to input time histories of elevator angle, aileron angle and rudder angle. In addition, spoiler aerodynamic coefficients are input in time history tables to allow various combinations of spoiler deployment.

The thrust forces are represented by inputting individual time histories of thrust for each engine (up to 4 engines are allowed). The thrust forces can excite the airplane flexible modes. Reverse thrust and unsymmetric thrust can be applied. The engines can be located and oriented arbitrarily.

The gear forces and moments excite the airplane flexible modes. Each gear has a single oleo consisting of a piston moving inside a cylinder which is attached to the airframe. The oleo representation includes an air curve, hydraulic damping including metering pin, rebound snubber damping, Coulomb friction and friction proportional to the normal bearing loads. The nose gear can be steered by inputting a time history of steering angle. Coulomb torsional friction is included in the nose gear.

All airplane tires develop vertical, lateral and fore-aft forces at the ground plane, as well as torsion about a vertical axis. Tire vertical stiffness, vertical damping, cornering power and yawed rolling coefficient of friction are all input as functions of the vertical deflection. Fore-aft tire forces are computed using a tire-ground coefficient of friction input as a function of tire-ground skidding velocity. Runway roughness profiles can be input separately for each gear.

Up to 8 "crash points" can be input, located arbitrarily on the airplane. Crash loads are computed whenever these points touch the ground. Each crash point has a separate vertical load-stroke curve allowing elastic and partially restoring plastic deformation. Vertical, fore-aft and side crash loads are computed at each crash point, and these forces drive the airplane rigid body and flexible modes. The program allows the specification of which of the 3 landing gears are deployed, so that all possible combinations of missing gear crashes may be analyzed. If all 3 gears are deployed, no crash loads will be computed, unless a crash point is specified at an unusual location, allowing ground contact with all three landing gears deployed.

The AGIP has been used to analyze transport aircraft for emergency landing conditions (references 62, 63). The type of emergency landings dealt with are those in which the pilot has flight control of the airplane but is deprived of normal means of mobility in the ground environment due to a malfunction of the landing gear system. Airplane configurations and conditions that are investigated include:

- one or more landing gears deranged
- an overrun condition

The latter condition is required for an airplane configuration with passengers or crew on the lower deck. The fundamental assumptions upon which the AGIP analysis is based are:

- the overall vehicle remains intact and, to a first approximation, behaves linearly
- nonlinear behavior is restricted to localized areas on the lower extremities of the airplane in direct contact with the ground
- since the local crushing and nonlinear behavior is not sufficiently widespread throughout the airplane to alter the basic linear behavior of the overall structure, normal modes of vibration are used to predict the dynamic response of the overall airplane structure
- these normal modes are driven by crash forces applied at selected discrete locations which represent the local crushing behavior

The crash point locations may contact the ground singly or in combination depending on the landing gear arrangement under investigation. For compliance with governing criteria the impact loads acting at the fuselage, landing gear and wing engine control points must be within the structural strength of these components or subsequent analyses are required. The post-impact loads are of significance, particularly wherein engine contact with the ground occurs. Consequently low speed slideout loads are calculated to determine not only the possibility of an engine-wing attachment failure occurring but also the manner in which such a failure might occur.

The airplane loads for the emergency landing conditions are expressed in panel loads format. Each individual load condition, thus defined, represents a set of forces in the entire airplane, in equilibrium, occurring at a given instant in time. These sets of external panel loads provide appropriate inputs to the finite-element structural model used to determine internal loads or stresses throughout the structure. The internal loads, thus obtained, are used to determine distortions of the door surround structure to ensure that the door is operable. This method is employed for all calculations in which the local areas (doors and floors) are under internal loads which are in the linear region of the load/deformation relationship. Those local areas of interest that are subjected to internal loads in the nonlinear region are treated individually, using techniques similar to those used in the crushing analysis.

The features of a modal approach are:

- readily available structural data
- relatively economical to run
- details of gear/tire behavior accurately modeled
- comprehensive aerodynamic representation

The major limitations of the current modal approach is that it does not:

- treat nonlinear behavior of the overall airframe
- represent loss of ruptured members and the consequences of such losses

7.3 Occupant Simulation Models

There are a number of finite segment computer models of the human body that have been developed for the purpose of performing crash-victim analysis. Several of these programs are described in the following sections:

7.3.1 SOMLA

The following description has been taken from references 66-68:

The aircraft occupant is modeled by twelve rigid mass segments, illustrated in figure 7-4, with rotational springs and dampers at the joints.

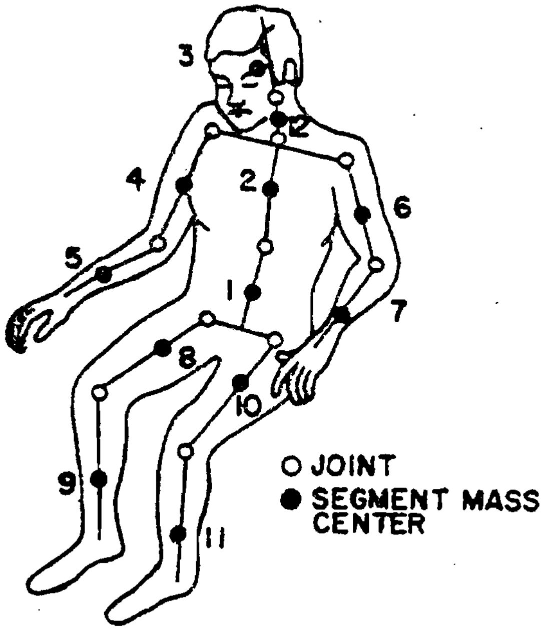


Figure 7-4. - Twelve-mass occupant model.

Twelve segments are thought to represent the minimum number that will permit meaningful, accurate predictions. The 4 arm and leg segments are necessary for prediction of contact between these extremities and the aircraft interior. Whereas automobile seating positions are usually configured such that proper restraint may prevent contact between the occupant and the vehicle interior except in side impact or very severe frontal impact, higher density seating arrangements are common in aircraft. Because contact is likely to occur, the ability to accurately determine the point of impact would facilitate design of a safer interior. Although leg and arm injuries, in themselves, may not be as serious as head or chest injuries, they may prevent escape from a stricken aircraft and the potential hazard of postcrash fire.

Each of the torso joints possesses 3 rotational degrees of freedom. Because of the hinge-type motion at elbow and knee joints, the position of a forearm or lower leg relative to an upper arm or thigh, respectively, is described by one additional angular coordinate. In total, the occupant model possesses 29 degrees of freedom.

The response of the occupant is described by Lagrange's equations of motion, which are written as functions of 29 independent generalized coordinates that define the position of the system. The equations are written in the form

$$\frac{d}{dt}\left[\frac{\partial T}{\partial \dot{q}_j}\right] - \frac{\partial T}{\partial q_j} + \frac{\partial V}{\partial q_j} = Q_j ; \quad j = 1,2,\ldots,29 \tag{1}$$

where T and V are the system kinetic and potential energies, Q_j are the generalized forces that are not necessarily derivable from a potential function, and q_j are the generalized coordinates.

Joint resistance. - Rotation of the body joints is resisted by nonlinear torsional springs and viscous dampers.

External forces. - The external forces that act on the twelve body segments can be characterized as either contact forces or restraint forces.

The method used in calculating the forces exerted on the body by the restraint system differs somewhat from that used for the contact forces. The principal difference is that the restraint forces do not act at any fixed point on the body, but, rather, the points of application depend on current belt geometry. The four available restraint system configurations consist of a lap belt alone or combined with a single diagonal belt, over either shoulder, or a double shoulder belt. The restraint loads are transmitted to the occupant through ellipsoidal surfaces fixed to the upper and lower torso segments, shown in Figure 7-5. The locations of the anchor points A_1, A_2, and A_3 on either the seat or the airframe structure and of the buckle connector B are determined by user input along with webbing properties.

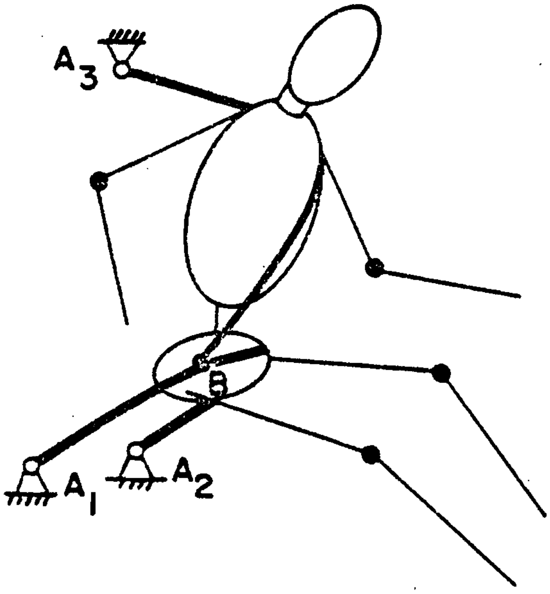


Figure 7-5. - Restraint system configuration (lap belt with diagonal shoulder belt).

The capability of the belts to move relative to the torso surfaces allows simulation of "submarining" under the lap belt, an important consideration in design of a restraint system.

Occupant physical properties. - Because it has been assumed that the principal user of this program is interested chiefly in the seat or restraint system, a minimum of information is required to describe the occupant. Input data include the selection of human or dummy, the main difference being the joint model, as discussed earlier. The dimensions and inertial properties for "standard" occupants, a 50th percentile civilian male and a 50th percentile anthropomorphic dummy, are included in the program. The segment lengths, masses, center-of-mass locations, and moments of inertia for the human occupant model are based on cadaver data reported in Reference 72, averaged and adjusted to approximate 50th percentile values. Corresponding properties for the dummy model are based on the specifications of Federal Motor Vehicle Safety Standard 208, Part 572. Should a user wish to simulate a larger or smaller occupant, provision is made to input non-standard properties.

For calculation of external forces exerted on the occupant by the seat cushions and restraint system and for prediction of impact between the occupant and the aircraft interior, 23 surfaces are defined on the body. These surfaces are ellipsoids, spheres, and cylinders, as shown in Figure 7-6. The dimensions of these surfaces were obtained from an anthropometric study of the U. S. civilian population.

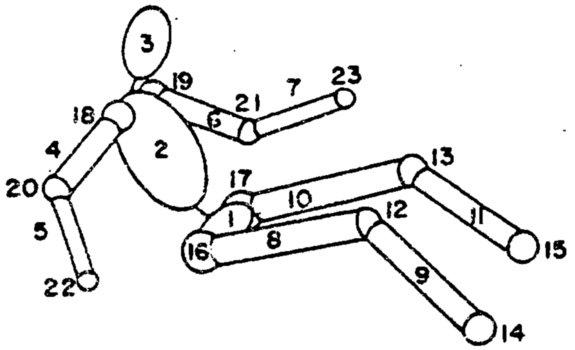


Figure 7-6. - Occupant model contact surfaces.

Seat model. - The seat model employs conventional finite element analysis techniques. In order to make maximum use of commonality and to minimize input complexity, the seat model is divided into two major components. The first, which includes seat pan and back, retains the same configuration regardless of the particular type of seat being analyzed. The supporting structure, on the other hand, can vary widely in its overall geometry and number of elements. The characteristics of each of the components of the seat model are discussed below with attention being focused first on the common part of the structure, which is actually made up of three types of elements, as shown in Figure 7.7.

The seat pan is composed of membrane elements. The seat cushion load is distributed parabolically over 9 nodes, which are selected according to the current position of the occupant on the seat. A seat pan frame formed of 16 beam elements transmits the seat pan loads to the supporting structure. Also applied to this frame are loads from the seat back, the occupant's legs,

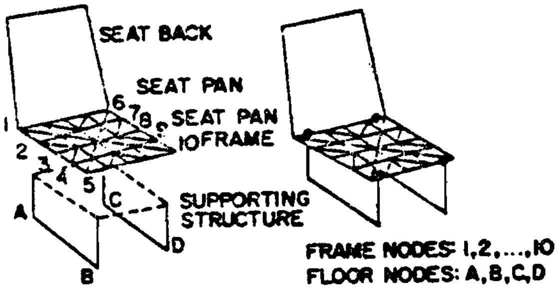


Figure 7-7. - Seat model components (Type 1 shown).

and the lap belt, should the user wish it attached to the seat. The seat back is made up of 2 simple beams connected at their upper ends by a rigid crossmember. The back cushion loads are distributed along the sides of the seat back and are thus transmitted to the seat pan frame. If the shoulder harness is attached to the seat, its load is applied to the crossmember.

The configuration of the supporting structure can be varied to represent a particular seat by selecting any of 6 seat structure models. Five of these models are rather restrictive in form but permit simulation of a large number of seats that are currently used in light aircraft. Because their geometries are stored in the program, the only input data required are seat dimensions and material properties. The 6th seat type is a general structural model, which requires additional input data but is expected to be the most useful model in the long run.

Program input and initialization.- Input data are read by the program in the following 7 categories:

1. Simulation control information
2. Cockpit description
3. Restraint system description
4. Cushion properties
5. Crash conditions
6. Seat design data
7. Occupant description

Program output. - Output data consist of 10 blocks of information that are selected for printing by user input. The data include time histories of the following variables, which are stored during solution at predetermined print intervals for output in both digital and plot form:

1. Occupant segment positions (X, Y, Z, pitch, and roll)
2. Occupant segment velocities (X, Y, and Z)

3. Occupant segment accelerations (x, y, z, and resultants)

4. Restraint system loads (tensile loads in webbing and resultant normal loads on pelvis and chest)

5. Cushion loads

6. Aircraft displacement, velocity, and acceleration

7. Seat deflections at critical points

8. Floor reactions (forces and moments)

and the following information:

9. Details of contact between the occupant and the aircraft interior

10. Injury criteria.

The injury criteria used in the program are all computed from segment accelerations. The dynamic response index (DRI) provides an indication of the probability of spinal injury due to a vertical acceleration parallel to the spine.[12] The Severity Index[13] is calculated for the chest and head, and the Head Injury Criterion (HIC) of Federal Motor Vehicle Safety Standard 208 is also computed.

Computer resource requirements. - Execution time for the program varies somewhat from one case to another because of the variable step size integration method, but typical times can be cited for a sample case. Simulation of a 13.4 m/sec longitudinal impact using a rigid seat model and carrying the solution to 0.150 sec requires about 60 sec of central processor time on the CDC 6600 and 90 sec on the IBM 370 Model 168. The use of a nonrigid seat model increases the time for execution by five to ten times, depending on the desired level of accuracy in the seat analysis. The program requires approximately 260,000 bytes of memory on the 370/168 system. For operation on a smaller system an overlay structure could probably be utilized quite effectively because the occupant and seat segments of the program are about the same size and operate essentially independent of each other.

Results. - The response of the occupant model was optimized by adjustment of the joint damping coefficients, which are the only model parameters that cannot be directly measured, in order to achieve the best overall agreement with dynamic test data. The principal source of data for validation was a series of ten identical acceleration sled tests conducted at the FAA Civil Aeromedical Institute (CAMI) during an evaluation of several new generation anthropomorphic dummies, references 69-70. The tests utilized a 50th percentile dummy in a lightly-padded rigid seat, which was equipped with a lap belt and diagonal shoulder belt. The tests were conducted at an impact speed of 13.4 m/sec; the longitudinal deceleration pulse was approximately a half-sine wave of amplitude 21 G and duration 0.1 sec. Belt loads were recorded as were the head and chest accelerations, which were subsequently used in calculation of severity indices. Reference 70 contains plotted data from individual tests along with means and standard deviations for the ten tests.

7.3.2 Calspan Crash Victim Simulation Program (CVSP)

The following description is obtained from reference 71:

The model was developed to complement experimental research in automobile crash environments and to provide a functional instrument for parametric investigations. The equations of motion and constraints are formulated from Euler's rigid body equations in a manner that allows variation of the number of segments and joints in the formulation. In this respect, the present model differs from existing three-dimensional occupant models, most of which were formulated with Lagrange's equations of motion. These include models developed by the Texas Transportation Institute [12 segments, 31 degrees of freedom (reference 72)] and the Highway Safety Research Institute [3 segments 12 degrees of freedom (reference 73], and work reported by the Society of Automotive Engineers of Japan [3 segments, 12 degrees of freedom(8)].

Evolution of the Calspan Three-Dimensional Crash Victim Simulation Program (hereafter called CAL 3D) is documented in Phases I and II (references 75, 76), in which versions I and II of the program were developed under the joint sponsorship of the Department of Transportation and the Motor Vehicle Manufacturers Association.

The Phase I effort consisted primarily of the formulation and implementation in the computer program of a 15-segment body dynamics model with forty degrees of freedom, a contact model to generate external forces acting on the simulated crash victim, and a graphics display model to simplify diagnosis and interpretation of results. In addition, an injury criteria model, to provide a means of readily assessing the degree of injury sustained by the simulated crash victim, was developed and partially implemented in the computer program.

The Phase II effort consisted of a continuing research effort, generalization of the computer program, and experimental validation of the model. Program generalizations consisted primarily of the addition of an airbag model, a program for a passenger compartment with 6 degrees of freedom to simulate crashes in which the motor vehicle undergoes general three-dimentional motions, treatment of multiple impacts between the crash victim and vehicle, initialization of the crash victim, and improvements in input/output format. In addition, other generalizations, such as incorporation of a variable-step exponential integrator to reduce computation costs, were included.

The current version (Version III) is a generalization of the CAL 3D Model (Version II) which was completed in December 1972. Version III was sponsored by the Department of Transportation. An important generalization is that the program is now available to accommodate any desired number of segments up to the storage limits specified for the program. The vehicle and the ground are now considered segments and are designated as segment N+1 and N+2, respectively, for a system in which N occupant segments are used. Disjoint sets of segments may be defined, enabling the user to model multiple occupants and the interactions that may occur. This capability is realized by utilizing a "tree structure" for defining the connection between segments and allowing specification of a "null joint" indicating no connection between the segments involved. The basic reference system for describing the segments is located at the center of mass (cm) of the segment and is aligned with the principal moment of inertia axes (i.e. the inertia tensor is diagonal).

Version III is also available with 3 additional features that were made to study the pilot ejection problem. These additions were sponsored by the Mathematics and Analysis Branch of the Aerospace Medical Research Laboratory. These are: the addition of prescribed time-dependent forces (such as aerodynamic forces) which may act on the segments; allowing for asymmetric joint torques which are functions of both flexure angle and azimuth angle; a harness routine that allows the definition of systems of interactive restraint belts that act on several segments.

The program is written in Fortran. It has eighty subroutines and consists of ten thousand cards. The system equations were derived by considering each segment as a free body subject to the forces and the torques of constraint and of external contacts. A typical 15-segment body dynamics model is illustrated in figure 7-8.

Two distinct advantages of using the free body techniques are:

1. Complete flexibility in describing the model.
2. Ease of adding additional constraints and contact force routines.

The principal disadvantages are:

1. Since constraints are imposed as forces and torques, computational errors may be accentuated by integration and cause violation of the constraints.
2. The flexibility of the model was achieved at some expense in storage and computing time.

Outline of Input to the Program

CARDS A Date and run description, units of input and output, control of restraint integrator, and optional output

CARDS B Physical characteristics of the segments and joints

CARDS C Description of the vehicle motion

CARDS D	Contact planes, belts, air bags, contact ellipsoids, constraints, and symmetry options
CARDS E	Functions defining force deflections, inertial spike, energy absorption factor, and friction coefficients
CARDS F	Allowed contacts among segments, planes, belts, air bags and contact ellipsoids
CARDS G	Initial orientations and velocities of the segments
CARDS H	Control of output of time history of selected segment motions and joint parameters

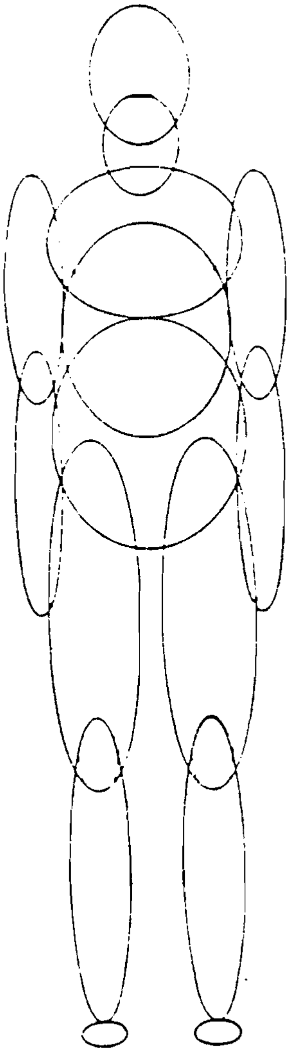


Figure 7-8. Fifteen-segment model.

7.3.3 UCIN

The following description is obtained from reference 77.

The model consists of 12 rigid bodies representing the human limbs together with a vehicle cockpit. The rigid bodies are frustrums of elliptical cones, elliptical cylinders and a spherical. The 12 bodies of the model

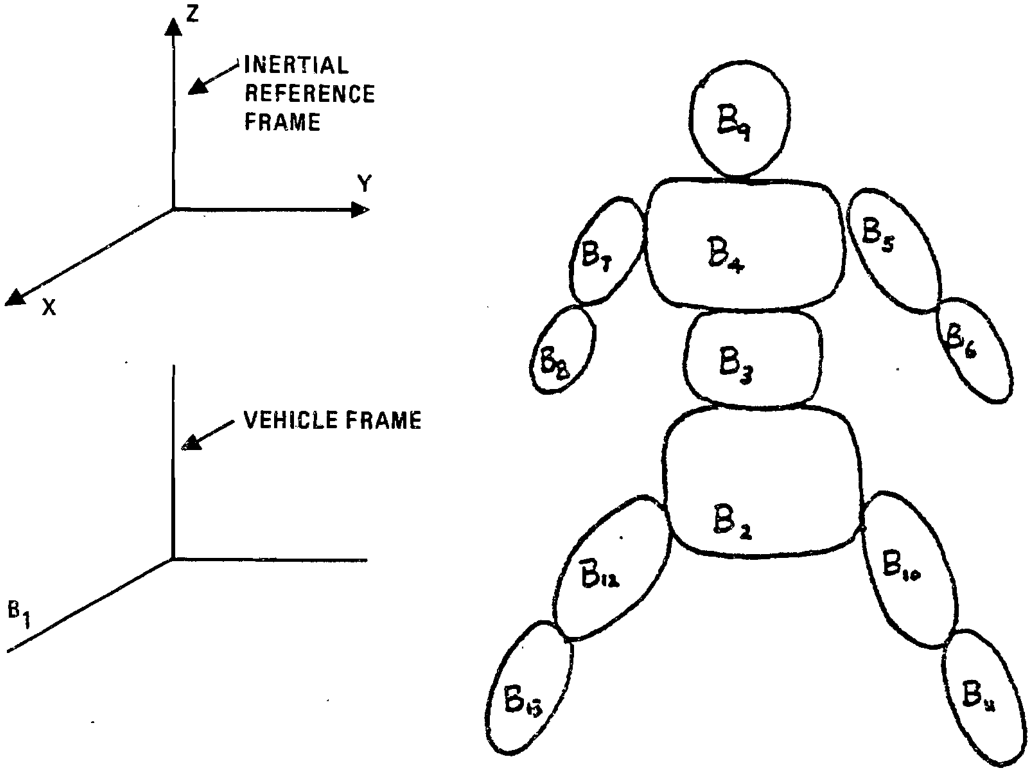


Figure 7-9. - The model and cockpit.

are connected together with ball-and-socket joints as shown in Figures 7-9 and 7-10.

Forty-eight variables are required to describe the position and orientation of the model. These are:

x_1, x_2, x_3	position of the vehicle relative to an inertial frame
x_4, x_5, x_6	orientation of the vehicle relative to an inertial frame
x_7, x_8, x_9	position of a reference point in B_2, the lower torso relative to the origin of the vehicle frame
x_{10}, x_{11}, x_{12}	orientation of B_2, the lower torso, relative to the vehicle frame

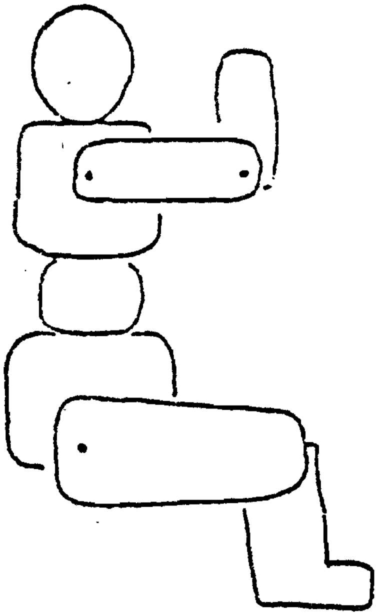


Figure 7-10. - Side view of the model in sitting configuration.

x_{13}, x_{14}, x_{15}	orientation of B_3, the middle torso, relative to B_2, the lower torso
x_{16}, x_{17}, x_{18}	orientation of B_4, the upper torso, relative to B_3, the middle torso
x_{19}, x_{20}, x_{21}	orientation of B_5, the upper left arm, relative to B_5, the upper left arm
x_{22}, x_{23}, x_{24}	orientation of B_6, the lower left arm relative to B_5, the upper left arm
x_{25}, x_{26}, x_{27}	orientation of B_7, the upper right arm, relative to B_4, the upper torso
x_{28}, x_{29}, x_{30}	orientation of B_8, the lower right arm, relative to B_7, the upper right arm
x_{31}, x_{32}, x_{33}	orientation of B_9, the head, relative to B_4, the upper torso
x_{34}, x_{35}, x_{36}	orientation of B_{10}, the upper left leg, relative to B_2, the lower torso
x_{37}, x_{38}, x_{39}	orientation of B_{11}, the lower left leg, relative to B_{10}, the upper left leg
x_{40}, x_{41}, x_{42}	orientation of B_{12}, the upper right leg, relative to B_2, the lower torso
x_{43}, x_{44}, x_{45}	orientation of B_{13}, the lower right leg, relative to B_{12}, the upper right leg
x_{46}, x_{47}, x_{48}	position of a reference point in B_9, the head, relative to an attach point in B_4, the upper torso

The model allows for the arbitrary specification of external forces and moments on each of its bodies. These forces and moments are represented on each body as a single force passing through its mass center, together with a couple. These forces and the moments of the couples are part of the input data.

The model's initial position is generally in an erect sitting position as shown in figures 7-10 and 7-11. In this position, all the body coordinate axes and the vehicle frame are aligned and thus all the orientation angles are zero. The model has a seat which in turn is modelled by springs as shown in figure 7-11. Essentially, there are 7 springs which may exert forces on the model with the points of contact being the mass centers of bodies 2, 3, 4, 9, 10 and 12. Viscous damper stops are used to provide limited seat deflection. The amount of seat deflection and spring constants are input data.

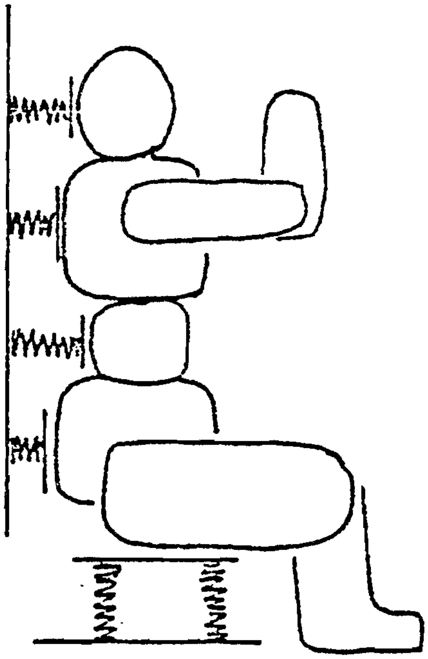


Figure 7-11. - The model and seat in initial configuration.

The computer model provides for the use of up to 10 restraining belts attached at arbitrary points between the cockpit and the bodies of the model. These belts are modeled as springs with the spring constants and attach points as part of the input data.

The ball-and-socket connection joints of the model are provided with angle-stops, modeled by one-way dampers, to simulate motion constraints of human limbs. The angle limits and the damping coefficients are part of the input data.

The model also has the provision of a "stretching" or extending neck. Neck stretch is modeled by a spring and a damper between attach points in bodies 4 and 9. The spring constant and the damping coefficient are input data.

Finally, the computer model provides for the use of 12 intrusion surfaces to simulate the cockpit or vehicle interior. These intrusion surfaces are planes and the output of the code records when a body or limb of the model collides with or passes through an intrusion surface. The intrusion surfaces are listed as follows:

1) Left windshield
2) Front windshield
3) Right windshield
4) Upper left door
5) Lower left door
6) Upper right door
7) Lower right door
8) Roof
9) Firewall
10) Top dash
11) Front dash
12) Bottom dash

The locations and inclination of these intrusion surfaces are also part of the input data.

Computer Code: Input/output. - The following brief paragraphs provide a general description of the input data required and the output provided by the computer code.

Input

- Physical parameters. - These are the masses, inertia dyadics, mass center positions, connection point positions, and orientation angle limits, for each of the 12 bodies of the human model.

- Cockpit geometry. - This consists of a normal vector and a location point for each of the 12 intrusion surface planes. Also the floor position and supporting spring force constant are part of the cockpit specifications.

- Cockpit motion. - The cockpit displacement and rotation relative to an inertia frame are required as input $(x_1, \ldots, x_6)$. Typically, it is desired to express this in the form of linear and angular acceleration of the cockpit. The computer program is written so that the cockpit acceleration components may be "read in" by simply specifying the acceleration at selected time intervals of the acceleration profile. (This is, in effect, a straight line approximation to an acceleration curve.) Six (3 translation and 3 rotation) such acceleration profiles or curves may be employed.

- Spring and damping constants. - This includes the seat, restraining belt, orientation angle constants, and neck parameters. Also, the attach points of the restraining belts are included.

- Initial conditions. - This includes the initial values of the unknown variables and their derivatives. Also the external forces and moments (if any) which are applied to the bodies of the models must be specified.

Output

- Output Data. - The output data is labeled on the computer print-out and thus is primarily self-explanatory. It consists of 2 parts: The first part is simply an "echo" or copy of the input data. (In the input motion section, the velocity and position at the beginning of each acceleration interval is computed and also listed.) The second part contains at each output time (depending upon the printing priority):

i) All variables and the first derivative of the variables (angles are in radians)

ii) Joint positions (in both inertia space and relative to the vehicle)

iii) Mass center positions (in both inertia space and relative to the vehicle)

iv) Mass center velocities and accelerations

v) All variables and the first and second derivatives of the variables (angles are in degrees)

vi) Moments and forces associated with variables which are specified

vii) Seat belt forces

7.3.4 PROMETHEUS III

Several two and three dimensional automobile occupant crash simulation programs sponsored by public and private establishments were reviewed for adaptation to low-speed helicopter and fixed wing aircraft crashes. Comparative testing was performed for the five programs shown in table 7-5 (reference 78). From this comparative study SIMULA was used as the framework from which the original PROMETHEUS Model was developed. PROMETHEUS is described in reference 79.

The main program was restructured into four modular sections: an integration section, a section to calculate occupant accelerations, an input and initialization section, and an output section.

PROMETHEUS I, developed under Office of Naval Research (ONR) sponsorship, was at its initial stage of development an interactive program for simulating a side-facing victim with one arm and one leg, subjected to a translational deceleration pulse. The program was then reworked to provide capability to model a forward facing model with 2 arms, 2 legs and finite torso and pelvic widths and designated PROMETHEUS II. Figure 7-12 (a) & (b) shows the I & II model versions. PROMETHEUS II was developed for the U.S. Department of Transportation.

PROMETHEUS III is a Boeing proprietory program which provides features which are different than its predecessors. In the earlier versions the articulation of the spine was limited, belt and harness were "pinned" to the joints, and anchors could not be moved to any possible position of choice. The latest version includes submarining, and added spinal joints and compression features more closely approximate the real spine. Figure 7-13 notes some of the added features of PROMETHEUS III versus the earlier version.

Prometheus III refinements (reference 80) include:

Body Dimensions

Mass Distribution

Neck/Waist Stiffness

Muscle Tension

Joint Friction

Pelvis - Design Interactions

    Angle
    Length
    Center of Mass
    Stiffness
    Friction

Back-Stiffness

    Erectness
    Compression

Belts - Anchor Points/Angles

    Location/Position on Body
    Mass Properties
    Damping
    Tension
    Stretch
    Slack
    Length
    Friction

TABLE 7-5. - CANDIDATE OCCUPANT SIMULATION PROGRAMS (Reference 78)

SIMULA	Dynamic Science's two-dimensional aircraft occupant simulation
ROS	Cornell Aeronautical Laboratory's two-dimensional automobile occupant simulation, Revised Occupant Simulation
TTI	Texas Transportation Institute's three-dimensional automobile occupant simulation
UCIN	University of Cincinnati's three-dimensional restrained human body dynamics model
CAL3D	Cornell Aeronautical Laboratory's Three-Dimensional automobile occupant simulation

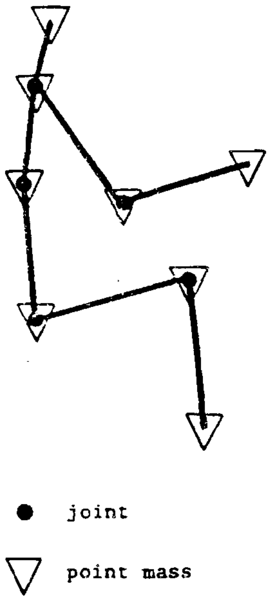


Figure 7-12a. - Side-facing model.

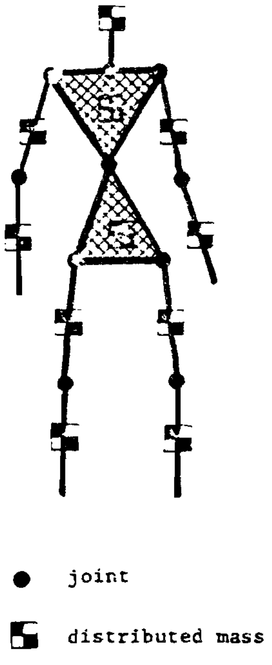


Figure 7-12b. - Forward-facing model.

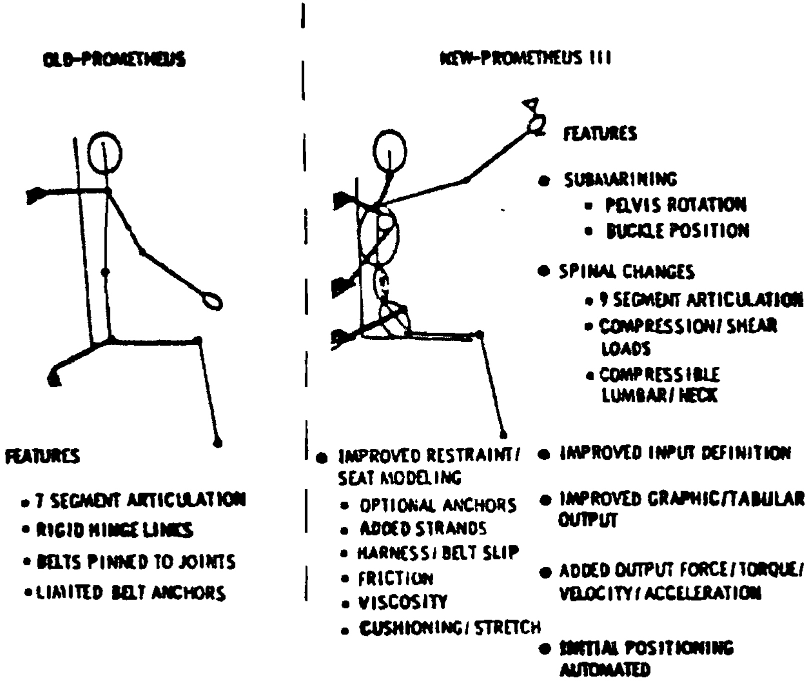


Figure 7-13. - Added features of Prometheus III.

Seat Pan-Angle

  Friction
  Cushioning
  Viscosity

Seat Back - Angle

  Cushioning
  Viscosity

7.4 Assessment of Analytical Methods

7.4.1 Structural Programs

There have been several general assessments made of the various structural programs. For example, Reference 33 compares hybrid and finite elements with regard to their treatment of

plastic collapse and crush

material failure

skin and bulkhead representation

anisotropic laminates

cored sandwiches

crippling

joint deformation and failure

strain rate stiffening

As can be expected no method is complete in the sense that it has total capability. However, the assessment does show that except for combined loading effects hybrid simulation techniques encompass most of the desired features. The development of crash test input data for combined loading will not only further enhance hybrid application, but it will also be beneficial to improving confidence in finite element techniques.

Several computer programs are reviewed in reference 34. This review also points out the attractiveness of the hybrid approach as a source of great potential for accurate prediction of crash response in light of the fact that such phenomena as local effects, joint eccentricities, stress concentrations and joint compliances are extremely difficult to model accurately with existing techniques. Excellent correlation exhibited by KRASH supports this viewpoint. The finite element simulations have not had a similar level of substantiation via correlation studies at this stage in their development and application. Reference 34 notes that most of the finite element simulations, contrary to all claims, do not qualify for the analysis of problems involving large strains, but can only analyze problems with small strains with at most arbitrarily large rotations. Further, these programs do not account for strain rate effects and they currently lack the capability to provide useful information on the probability of failures or probable estimates of important trauma parameters under random crash conditions.

Reference 60 describes the modeling of a fuselage section of a twin-engine, low-wing airplane approximately 1.5 meters (56 inches) long and weighing 247 Kg (545 lbs), including the weight of two 74.8 Kg (165 lb.) dummies using KRASH, ACTION and DYCAST. This represents the only direct comparison between three methods using the same test data, structural data and computer facility. The comparison of model sizes is shown in table 7-6. The results showed that KRASH overall gave significantly better results with regard to the floor inboard accelerations as well as better results for the occupant pelvic vertical accelerations. DYCAST results were comparable with KRASH results for the primary outboard floor acceleration and motions associated with occupant, roof and window ledge. ACTION results were less favorable, in general. Cost comparisons are shown in table 7-7. Several observations can be made from the comparison of KRASH, ACTION and DYCAST.

- If a choice of finite element programs were to be made. DYCAST would be favorable over ACTION because it showed overall better agreement with test data and is less costly to run, although not necessarily quicker.

- Analysis of transport airplane accidents can require substantial computer time. A minimum of .150 seconds would mean each of the analysis costs could increase 15 fold. KRASH would cost ≈ $150 while finite element methods could cost in the $12000-15000 range for the same size models used in the substructure correlation study. For larger models the costs would increase still further.

TABLE 7-6. - COMPARATIVE MODEL SIZES FOR KRASH, ACTION, DYCAST

KRASH Substructure Model		ACTION Substructure Model		DYCAST Substructure Model	
Degrees of Freedom (DOF)	177	Maximum degrees of freedom	336	Degrees of freedom	493
Total number of masses	32	Number of nodes	105	Maximum semi-bandwidth	98
Total number of beam elements	57	Total number of elements	209	Number of nodes	200
Number of nonlinear degrees of freedom associated with beam elements	44	Number of rods	36	Number of elements	432
Number of unsymmetrical beams (tension - or compression - only)	6	Number of frame elements	77	Number of stringers	36
Number of external springs representing subfloor crushing	10	Number of membranes	96	Number of beams	130
Occupant mass	2	Occupant mass	1	Number of membranes	263
Dynamic Response Indicator (DRI)	1			Number of springs	4
				Lumped masses	1

TABLE 7-7. - COST COMPARISON OF KRASH, ACTION, DYCAST

Program	(a) CPU Time Per .01 Sec. Response	(b) $ Cost Per .01 Sec. Response
KRASH	76.34	$ 9.44
ACTION	874.46	963.00*
DYCAST	1851.06	790.00*

*Cost in relation to CPU time may reflect different utilization of peripheral equipment

- KRASH, because of its premises, philosophy and approach, could be expanded to much larger structure representations with a relatively small increase in masses and D.O.F.'s. For example, the utility helicopter and fixed wing aircraft noted in table 7-2 required between 30 and 60 masses for the range of test conditions shown.

- The finite element approach, in order to model large structure in a reasonable economic framework, would be required to compromise modeling fidelity and, thus, utilize some KRASH concepts. On the other hand, KRASH, to provide details normally associated with finite elements, would compromise its flexibility and cost advantage.

Based on previous analysis of transport emergency landing conditions it is surmised that:

- The Modal Approach as exhibited in the Ground Interaction Program offers some advantages for performing analysis of selected accident conditions, particularly those involving local crushing and nonlinear behavior such that the basic linear behavior of the overall structure is not altered, and thus normal modes of vibration can be used to predict the dynamic response of the overall airplane structure.

- Structural breakup and post-breakup consequences require analytical capability to define the large deformation behavior.

7.4.2 Occupant Models

All the occupant model codes described are three-dimensional with the exception of PROMETHEUS, which is a two-dimensional model. While each of the models has been verified with experimental data, the prevailing comment in the available reviews is that additional verification is needed. SOMLA has the most elaborate seat and restraint modeling since its purpose is as an aid in seat and restraint design. However, verification of the program to date has only been with rigid seats. Also the seat configurations included in the program are for light general aviation type aircraft. PROMETHEUS III has been used in conjunction with studies associated with transport seats, although the seat is not modeled in a PROMETHEUS analysis. The programs reviewed provide features for occupant response which are elaborate and utilize state-of-art occupant characteristic data. However, research with regard to occupant joint movement and characteristics continues. The choice of occupant model depends on the user's objective and accident condition being investigated. PROMETHEUS and SOMLA appear most applicable to transport crashworthiness because of their inclusion of severity indices and ability to model submarining and evaluate restraint design. SOMLA, being three-dimensional and readily available in the public domain, may thus have an edge on PROMETHEUS. Both programs will need verification with transport airplane seat tests involving a range of design configurations and occupant weight/loading conditions. The current lack of substantiation of the capability to model flexible seats with finite element segments may not be a major hindrance. Beam element modeling of the seat as in KRASH can be used to assess seat failure and loads transmitted. Secondly, floor pulses could be established on the basis of allowable occupant loads via the use of transmissibility curves. Thirdly, simpler representations, such as spine models and severity indices could be used for selected accident conditions.

8. ANALYSES OF SELECTED ACCIDENT CONDITIONS

8.1 Analyses With Airplane/Ground Interaction Program

The Airplane Ground Interaction Program (AGIP) is a computer program that calculates the time history response of an airplane to loads resulting from contact with the ground via the landing gears or direct structural contact. The program is used for analyses of landing impact, ground maneuvering (including turning and braking) and emergency landing conditions with various combinations of deranged landing gears. The airplane structure is modeled by means of normal modes of vibration, so the analysis covers only the linear region of structural behavior. However, the analytical model includes provisions for direct structural contact with the ground, resulting in localized nonlinear structural deformations. The premise of this analysis is that the localized nonlinear deflections at selected contact points do not alter the basic linear behavior of the overall airplane structure, which can still be modeled using normal vibration modes. The formulation of the model thus precludes crash impact analyses involving large-scale structural break-up. The direct structures/ground contact feature was developed to analyze 5 fps emergency landing conditions with various combinations of deranged gears, as specified in FAR25. For these conditions only minor lower fuselage crushing takes place. The majority of the program coding involves a very detailed model of the landing gears and tires, capable of analyzing ground contact conditions involving all 6 rigid body degrees-of-freedom of the airplane. In addition, the program has extensive aerodynamic control modeling capabilities. For a more detailed description of the features of the Ground Interaction Program, see Section 7.2.4.

8.1.1 Analytical Results - Overrun Condition

The overrun condition is analyzed for a design taxi weight condition for a widebody jet. The specific weight case is 195,950 Kg (432,000 lb.) at 21 percent MAC. Mode shapes were generated for that weight case for use in AGIP.

The input data included 5 crash points: three along the fuselage and one on each wing engine. A load-deflection curve is described for each crash point to account for the failure of the structure as the airframe hits the ground following the failure of one or more of the landing gears. The conditions were analyzed with all landing gears down and functioning normally.

The cases specify a slope beyond the end of the runway. The slopes that are used in the initial cases are for a vertical velocity of .61, 1.22, 1.83 and 2.43 m/sec and a constant forward velocity of 80 knots. The terrain surface is rigid.

The results of the first 4 cases analyzed indicate that the ultimate design nose gear loading was achieved with a slope yielding an effective normal velocity of around 1.83 m/sec (6 ft/sec). The results of this case were post-processed to calculate the range of accelerations experienced along the length of the fuselage. These fuselage acceleration results were then used as input to a seat/occupant model using program KRASH. This model, shown in figure 8-1, was run to determine occupant response at various fuselage locations. Table 8-1 shows the peak fuselage accelerations obtained from the Airplane/Ground Interaction Program, and the corresponding peak Dynamic Response Indices (DRI) for a 77 Kg (170 pound) occupant at each location, obtained from the KRASH seat/occupant model.

From table 8-1 it can be seen that the moderate normal velocity (1.83 m/sec) resulting in nose gear failure does not result in substantial excitation of the fuselage, and the corresponding peak occupant responses are mild.

The AGIP analysis of this condition ascertains the initial gear failure and the approximate impact at which the failure occurs. Subsequent analysis

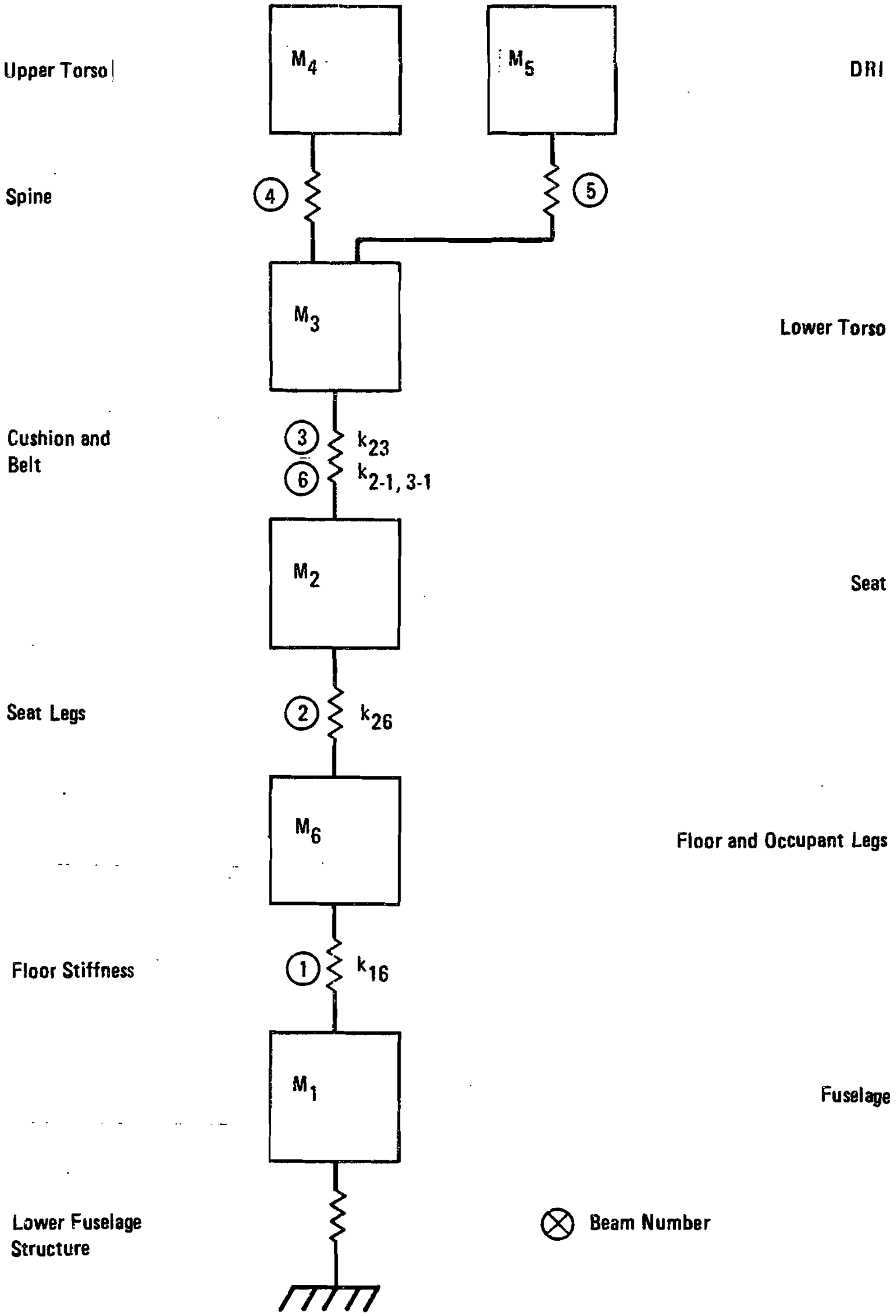


Figure 8-1. - KRASH 6-mass fuselage-floor-seat-occupant model.

TABLE 8-1. - FLOOR AND OCCUPANT PEAK RESPONSES, 1.83m/sec OVERRUN CONDITION

Location	Peak Floor Vertical Accelerations, g's	Peak Occupant DRI
FS 177	1.9	3.3
330	1.6	3.0
867	1.3	2.9
1247	1.7	2.9
1720	1.7	2.9

to determine the consequence of this failure is required. A KRASH analysis with gears collapsed is discussed in Section 8.2.2.

8.1.2 Analytical Results - Hard Landings

The hard landing conditions are analyzed at the design landing weight of 162390 kg (358,000 lb.) for a representative wide-body jet. The weight case is 162390 kg at 28.7 percent MAC. This particular condition is representative of an AGHL type crash scenario candidate.

It is necessary to run AGIP for a number of sink speeds between 3.05 m/sec (10 ft/sec) and 6.1 m/sec (20 ft/sec) in order to determine the particular condition for which the ultimate gear load is obtained. The initial AGIP runs compute the appropriate trim conditions for each sink speed. These trim conditions are then input to each run in order to position the aircraft appropriately.

The results of the survey of sink speeds indicate that the ultimate main gear loading is obtained at a sink speed of approximately 5.33 m/sec (17.5 ft/sec). A second run was then made for the 5.33 m/sec sink speed with the program modified to remove the main gears from the model when the ultimate gear load was exceeded. The modification was too simplistic in that the gears disappeared completely when, in reality, the failure mode would include a great deal of gear/airframe interaction. The AGIP lacks the capability to model that type of failure so the simpler scheme was used.

The results of the 5.33 m/sec landing run were input to a post-processor run which computed time histories of fuselage acceleration at 5 locations along the fuselage. These acceleration time histories were then input to a Program KRASH 6-mass fuselage-floor-seat-occupant model (figure 8-1), in order to determine the response of the seat support systems to the crash excitations. Table 8-2 shows the peak floor vertical accelerations and occupant DRI responses along the fuselage as a result of the impact.

In this case the floor and occupant responses are significantly greater than for the overrun condition, but the peak DRI's are all still below the threshold for zero probability of spinal injury (DRI = 15).

Hard landing analyses were also conducted at airplane roll angles of 15 and 30 degrees. Figure 8-2 shows an envelope of sink speed versus roll angle that could result in failure of the main landing gear. At roll angles of zero and 15 degrees, the loading is predominantly vertical and failure would occur at the wing box rear beam as opposed to a landing gear failure. At a roll angle of 30 degrees, the side loading can be sufficient to buckle the gear side brace. In the latter case, the landing gear would still be attached to the wing but is free to fold inward toward the fuselage.

TABLE 8-2. - FLOOR AND OCCUPANT PEAK RESPONSES, 5.33 m/sec HARD LANDING

Location	Peak Floor Vertical Acceleration, g	Peak Occupant DRI
FS 177	4.1	11.9
330	3.3	6.4
867	2.4	4.7
1247	2.9	4.6
1720	2.9	4.9

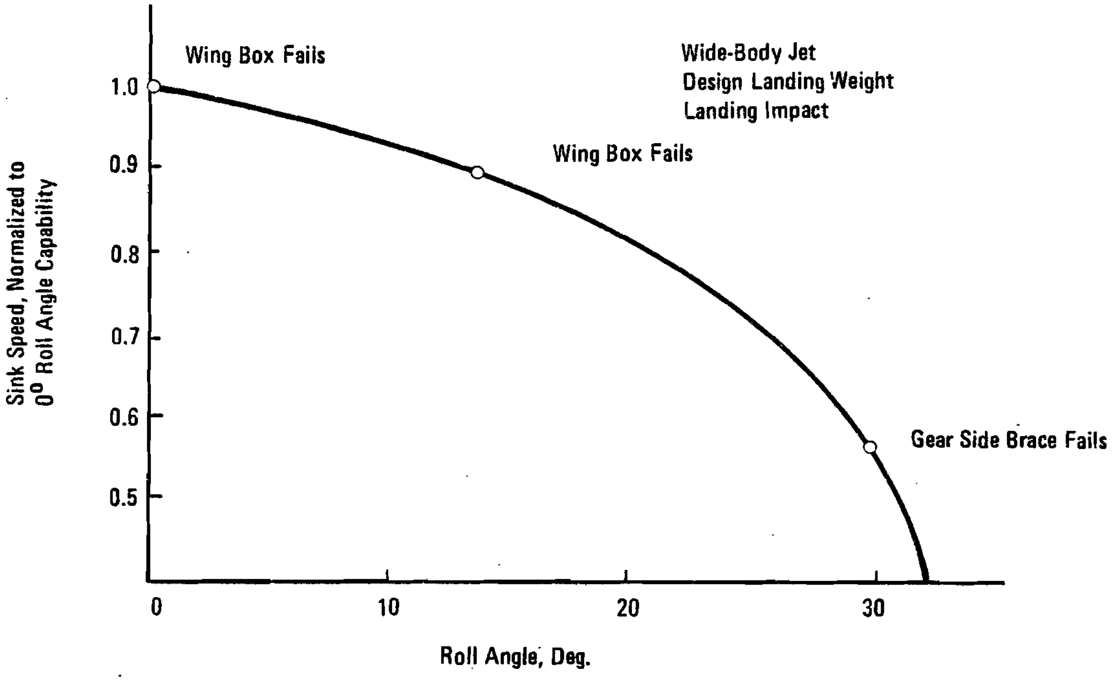


Figure 8-2. - Envelope of sink speed versus roll angle.

Parameter variations on initial pitch attitude were run for pitch angles of 8.5 degrees nose-up and a level landing. (The nominal condition is 3.2 degrees nose-up). For these conditions, the aerodynamic lift varies significantly from 1g which was used for the other runs. For the nose-up condition, the aerodynamic lift is 1.6 g and the sink speed required to fail the main gear is approximately 33 percent higher than for the nominal condition. For the level landing condition, the aerodynamic lift is only 0.6 and the sink speed required to fail the nose gear is reduced to approximately 75 percent of the nominal condition. The nose gear is more critical in this case. From these results it can be ascertained that variations in pitch attitude cause substantial deviations from 1g lift, and the landing gear sink speed capability is very sensitive to the degree of lift on the airplane.

Figure 8-2 illustrates that the failure mode of the landing gear and, thus, its capability is dependent on the impact condition, including the aerodynamics. The amount of roll angle is a significant factor in defining capability.

Since the AGIP is not set up to evaluate post-failure sequences, only the initial mode of failure and the effect of variation in roll angle and aerodynamics was investigated. The next step in an analysis procedure is to examine the aircraft behavior and the consequence to the occupant as a result of the landing gear or wing box failure. The vertical accelerations and occupant DRI's during this phase of the analysis are not sufficient to be of any concern with regard to trauma injuries. However, subsequent impacts as a result of gear/attachment failure could be.

8.2 Analyses with Program KRASH

KRASH analyses are performed for the purpose of evaluating the capability of current analytical procedures to simulate candidate crash scenarios and to determine the type and extent of modifications that may be necessary. A current widebody jet airplane is modeled in each instance for the following reasons:

- structural data is readily available
- airplane represents current jet transport capability

Program KRASH, which allows the user to maximize the use of available data, is described in Section 7.2.1.

8.2.1 Analysis Results - Air-to-Ground Impact

The first analysis involved a severe-air-to-ground impact which was denoted nonsurvivable by the NTSB. The accident identification is AG3-5 (File No. A3-13). The purpose of this analysis is to determine if structural break-up could be predicted within the sequence as defined in the accident report. Since the accident occurred in the Everglades near Miami the sensitivity of the structure's dynamic response to the flexibility of the impact surface is also to be addressed in the analysis.

The impact conditions for this accident are well defined due to the extensive output available from the Digital Flight Data Recorder (DFDR). The initial airplane attitude at impact is primarily left wing down roll (28°), with a slight nose up pitch attitude (0.8°) and no yaw. The impact velocity is about 107.6 m/sec (353 feet/sec) forward and 11.3 m/sec (37 feet/sec) down. The airplane, at impact, is in a pull-up maneuver with a lift of approximately 1.6g. The roll, pitch and yaw rates are 0, 0.4 deg/sec (nose up) and 2.6 deg/sec (nose left), respectively. The high vertical descent rate in this accident qualifies it as a severe air to ground accident, category AG3. The actual impact terrain is described in the accident report as 15.2 to 30.4 cm (6 to 12 inches) of water above a 1.7 meter soft mud base, with 1 to 3 meter high saw grass. Despite the severity of the accident, 77 of the 176 occupants survived.

The estimated airplane trajectory and wreckage distribution are illustrated in figure 8-3. The airplane contacts initially on the left wing tip, progressively shearing off the left wing, number 1 engine and left main landing gear. This impact causes a slight nose left yawing of the airplane. The forward fuselage contacts at around 150 meters from the initial contact point, initiating the fuselage break-up. The right wing tip contacts at around 270 meters, yawing the fuselage structure back to the right along the approximate path shown in figure 8-3.

The fuselage wreckage distribution is in five major sections:

1. Radome
2. Cockpit area (FS 123 to FS 449)
3. 11.3 m. (37 foot) section including galley and electrical bay (FS 538 to FS 982)
4. Center wing section and portion of right wing (FS 982 - FS 1350)
5. Empennage aft of FS 1480 including center engine and tail structure

The final locations of these sections are shown in figure 8-3. Figure 8-4 shows a typical seating arrangement with the major sections identified. Although the fuselage wreckage can be segregated into the 5 sections shown, it should be noted that the destruction was so substantial that no complete circumferential cross-section of the passenger compartment remained intact.

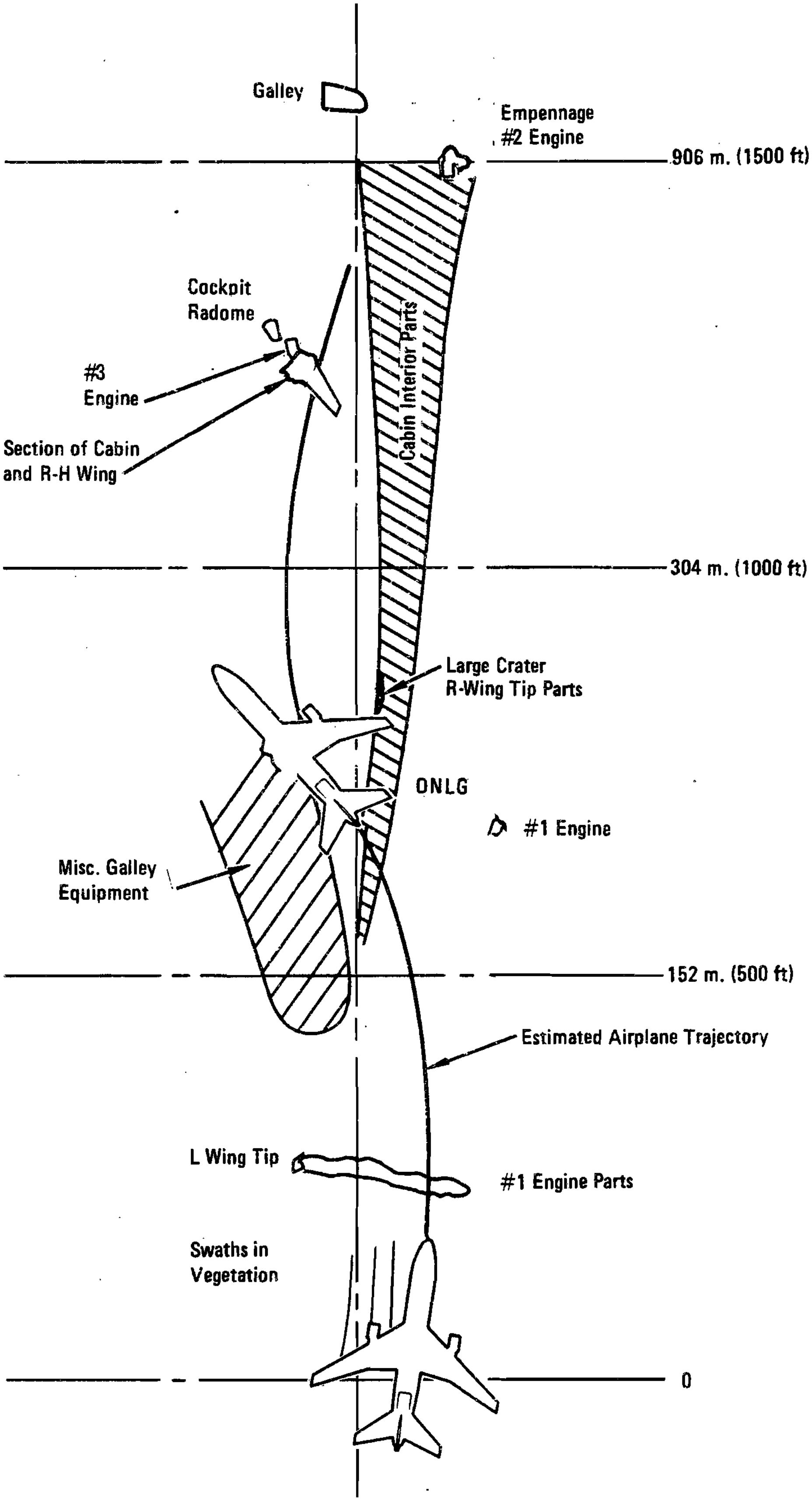


Figure 8-3. - Estimated airplane trajectory and wreckage distribution.

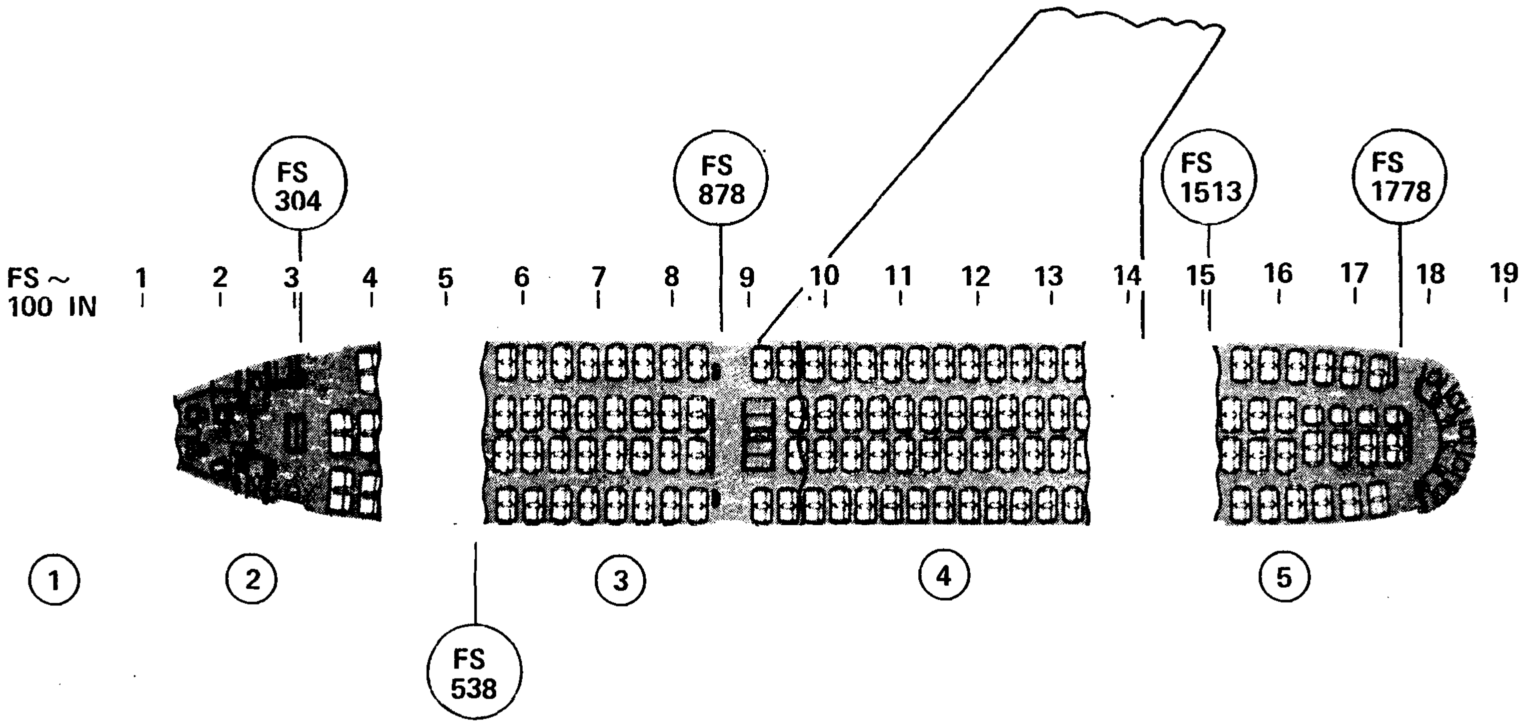


Figure 8-4. - Fuselage breakup locations.

The accident described is simulated analytically with program KRASH. The analytical model of the airplane is shown in figure 8-5, and the mass point locations are defined in table 8-3. The vertical tail is not represented explicitly in the analytical model, although its inertia properties are included in the data for mass 8. The model is not a flat planar model as it may appear in figure 8-5. Table 8-3 shows that the Water Lines vary to model the wing and horizontal stabilizer dihedral. Data for only the first 18 masses are input into KRASH; the program calculates the remaining model data to develop the complete symmetrical model shown in figure 8-3. Since the impact condition is unsymmetrical, the complete airplane model is analyzed.

The analysis utilizes weight/inertia data representing the condition of the airplane at the time of impact in the Everglades (W = 148780 kg (328000 pounds), CG = 23.0 percent MAC). The stiffness of the structural elements is represented by inputting overall EI and GJ properties for the appropriate wing, fuselage and tail sections. The model also includes main and nose landing gears (in the down position) with nonlinear load/deflection curves, hydraulic damping and tire springs. External springs are utilized at masses along the fuselage and wing (including the wing engine) and at the horizontal stabilizer tip. Failure loads are input for all beam elements based on ultimate design load envelopes for the widebody jet.

The analysis of an actual accident condition is obviously more difficult than the analysis of a controlled crash test condition, because there exists no post-impact-measured airplane response data. The degree of correlation between the analysis and the actual accident must, by necessity, be rather subjective, based solely on the wreckage distribution and passenger survival data. For the widebody jet accident analyzed herein, the areas of correlation that are desirable include:

- Overall airplane longitudinal stopping distance
- Sequence of structural failures
- Passenger compartment acceleration levels commensurate with the observed survival rate

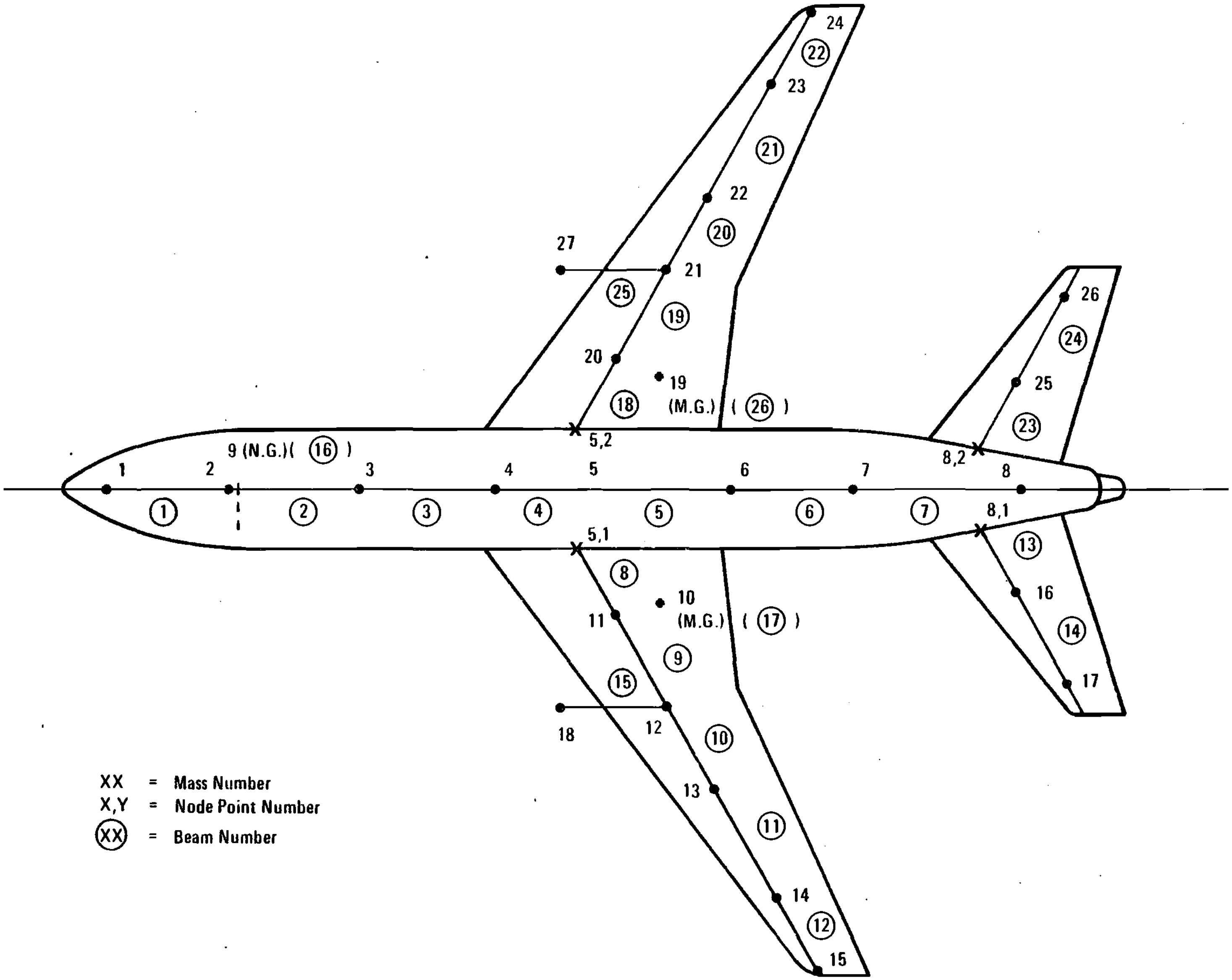


Figure 8-5. - Program KRASH transport category analytical model.

TABLE 8-3. - KRASH MODEL MASS LOCATIONS

Mass No.	Description	FS	BL	WL
1	Fuselage	177.5	0	200
2	Fuselage	426	0	200
3	Fuselage	677	0	200
4	Fuselage	955	0	200
5	Fuselage	1117	0	200
6	Fuselage	1424	0	200
7	Fuselage	1663	0	200
8	Fuselage	1992	0	200
9	Nose Gear Unspr. Mass	440	0	17.4
10	Main Gear Unspr. Mass	1280	216	13.9
11	Wing	1194.2	242.6	169.6
12	Wing	1296.3	418.0	186.0
13	Wing	1383.2	567.3	200.0
14	Wing	1512.2	788.7	220.0
15	Wing	1589.5	921.6	233.0
16	Horizontal Stabilizer	1997.2	202.0	228.9
17	Horizontal Stabilizer	2100.4	370.0	237.1
18	Wing Engine	1089.6	423.0	114.4

Based upon the observed wreckage distribution, the significant events in the failure sequence are the following:

(a) Failure of left wing, starting at tip and progressing inboard, including left wing engine and left main landing gear.

(b) Slight nose left yaw of airplane in response to (a).

(c) Nose gear touchdown and failure within 213 m. (700 feet) of initial contact point.

(d) Forward fuselage failure (beam (2) in figure 8-5) within 137 m. (450 feet) of initial contact point.

(e) Right wing tip contact at 253 m. (830 feet) from initial contact point. Failure of right outer wing outboard of engine pylon; loss of right engine.

(f) Aft fuselage failure beyond 244 m. (800 feet) from initial contact point (beam (6) in figure 8-5).

The wreckage distribution pattern is spread over 488 m. (1600 feet) longitudinally, and the initial contact velocity is 107.6 m/sec (353 feet/second). If the total airplane came to rest at the 488m. (1600 foot) point, the average deceleration rate would be 1.21g, and the time required would be 9.1 seconds. Since some portions come to rest earlier, they are exposed to higher average decelerations.

The initial series of computer runs consisted of variations of ground friction coefficient (μ) to determine the relationship between overall airplane longitudinal deceleration and μ. These runs used a maximum run time of 1 second, and the ground was modeled as rigid. The relationship between average longitudinal deceleration and μ is shown in figure 8-6; from this figure the desired average acceleration of 1.21g corresponds to a μ of 0.6. The average deceleration is greater than the ground friction coefficient because the average vertical load factor is greater than 1g (about 1.7g for these runs). (The average decelerations are calculated from the overall airplane average velocity, which is calculated in program KRASH based on the total linear momentum of the system of lumped masses that constitute the vehicle model).

While this analysis, with $\mu = 0.6$, yielded the desired overall average deceleration rate, the use of a rigid ground led to substantial fuselage failures. In fact, every beam representing fuselage structure reached a load that would fail the structure within the one second run time. Since the longitudinal travel of the airplane was only 101.8 m. (334 feet) after one second, total fuselage failure was premature.

This led to a reevaluation of the initial impact data to determine the total lift at impact. The previous runs had used 1g lift, while a closer examination of the available flight recorder data indicated the airplane was in a pull-up maneuver at impact with a lift of around 1.6g. Using this increased lift, a series of runs were made introducing ground flexibility in an attempt to more realistically model the actual terrain. The flexible ground model in program KRASH merely provides a linear spring, representing the ground in series with each external spring representing airplane structure; the ground spring is not allowed to rebound.

Both the softer terrain and the increased lift alter the relationship between longitudinal deceleration and ground friction coefficient. Figure 8-6 shows the comparison between rigid ground with 1g lift and a ground flexibility of 30.5 cm. (12 inches) with 1.6g lift. The flexibility is the ground deflection at a load equal to the total airplane weight. (The actual input flexibilities are in/lb at each contact point.) However, since the airplane model contacts the ground at many points (there is an external spring at virtually every mass point in figure 8-5), if the airplane were just resting statically on the flexible ground, the load at each mass point would be well below the total airplane weight, so the overall airplane "sinkage" into the ground would be much less than the 30 cm. for ground flexibility.

The introduction of a flexible ground and increased lift substantially lowers the average longitudinal deceleration for a given ground friction coefficient, as can be seen in figure 8-6. This is due to the lower average vertical loading at each spring. However, even the reduced loading resulting from the inclusion of ground flexibility and increased lift is still sufficient to fail the fuselage prematurely.

Figure 8-7 shows the variation of peak forward fuselage vertical shear (beam 2 in figure 8-5), normalized to the maximum ultimate design load, with ground friction and flexibility. As expected, increased flexibility reduces the peak fuselage shear load, as does reduced ground friction. However, the peak load is below ultimate only for combinations of high ground flexibility and low friction coefficient. For these combinations, the longitudinal deceleration is lower than the desired overall average value. Furthermore, the load plotted in figure 8-7 is not the most critical fuselage load. In general, lateral shear and bending, as well as torsion, all reach ultimate load levels more readily than the vertical shear shown in figure 8-7.

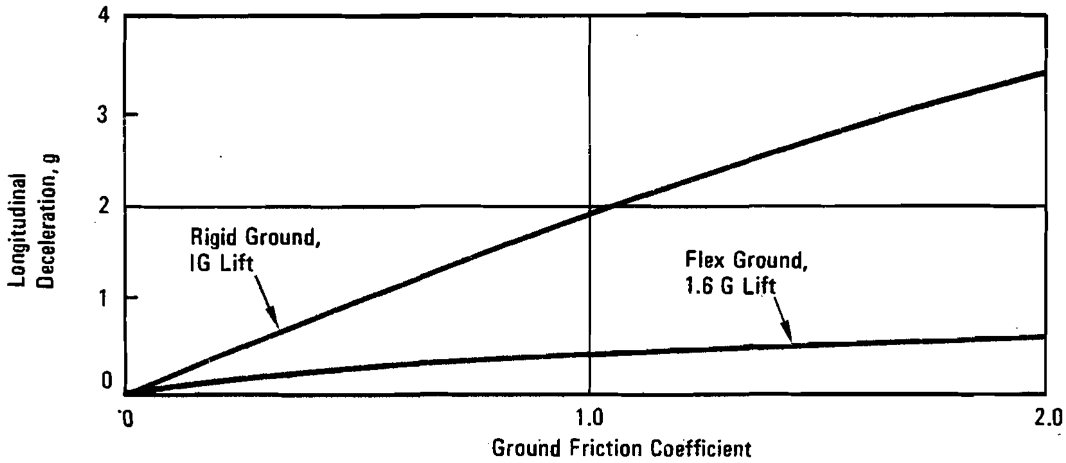


Figure 8-6. - Variation of longitudinal deceleration with ground friction.

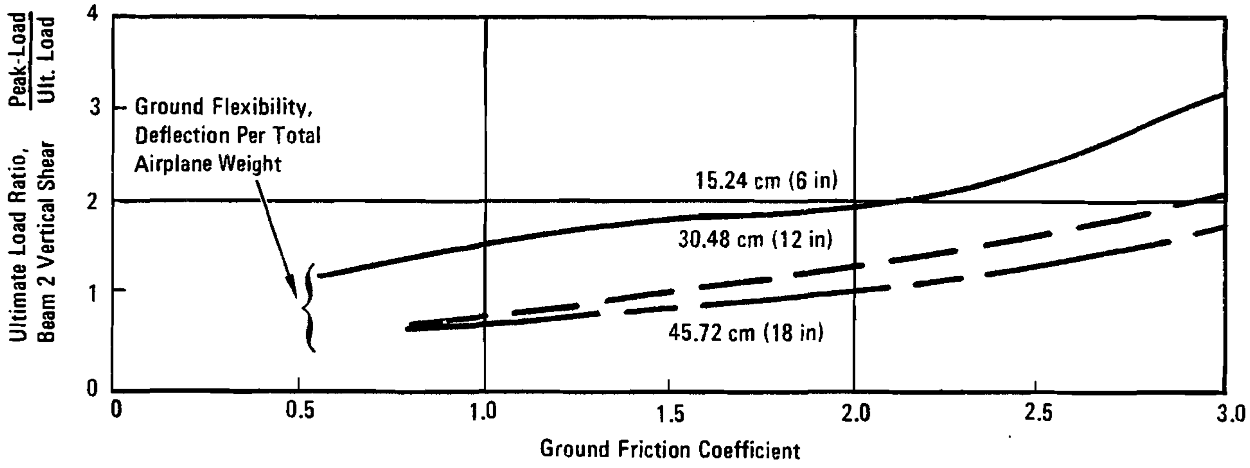


Figure 8-7. - Variation of fuselage vertical shear with ground friction, flexible ground.

The previous results lead to the conclusion that in the actual accident the initial longitudinal deceleration was probably much less than the overall average of 1.2g. The complex interaction of the airplane with the swamp terrain may result in rather low initial deceleration rates as the airplane cuts through saw grass and skims over the water, followed by high rates of deceleration as the airplane plows into the water/mud. Based on this line of reasoning, runs were made at lower values of ground friction and higher ground flexibility. For these runs, the fuselage beam elements are allowed to yield nonlinearly at deflections corresponding to ultimate design load levels.

Representative of these analyses is a condition in which the ground friction coefficient is 0.5 and the ground flexibility is 152.4 cm (60 inches) (input ground flexibility = 8.77E-4 cm/kg (1.83E-4 in/lb). The 152.4 cm flexibility, although large relative to the previous analyses of 15.24 - 45.72 cm, still represents moderate airplane sinkage, for example, only 24.5 cm if supported at 6 external springs. Table 8-4 outlines the sequence of events for this run. The mass and beam numbers in table 8-4 are identified in figure 8-5. The initial contact of the left outer wing and subsequent wing tip failures (beams 12 and 11) are as desired. In addition, the contact of the left wing engine, left main gear and failure of the left pylon are appropriate for this accident. The sequence of failures of the left inboard wing elements (beams 8, 9 and 10) may or may not be correct, but the time span for these three events is very short (.023 seconds). The left main gear (beam 17) does not fail, reaching peak loads of only 40 to 50 percent of ultimate. This is consistent with the observed wreckage in which the left main gear is intact and attached to the torque box, a 1.83 meter length of rear spar and about (254 cm by 127 cm) of the upper wing surface. The nose gear (beam 16) does fail at time = .81 seconds due to lateral loads, which is also consistent with the actual wreckage, in which the inner cylinder was fractured approximately flush with the end of the strut, and the wheels were separated. The right main gear and wing engine contact during this run, and neither fails in the 1.5 second time span of the run. In the accident, the right main gear remains attached to the right wing, which itself is intact out to about 1 meter beyond the engine pylon. The right wing engine does separate in the accident,

TABLE 8-4. - SEQUENCE OF EVENTS

Time Seconds	Distance Travelled, Ft.	External Spring Contact, Mass Number*	Internal Beam Yielding, Beam Number*	Internal Beam Rupture, Beam Number*	Comments
0	0	15			Initial L. Wing Contact
.047	17			12	L. Wing Tip Failure
.131	46	14			Outer L. Wing Contact
.214	75			11	Outer L. Wing Failure
.215	76	18			L. Engine Contact
.265	93		7 lateral		Aft Fuselage Yielding
.304	107	10			L. Main Gear Contact
.337	119	13			L. Wing Center Contact
.378	133			15	L. Engine Pylon Failure
.477	168		7 vertical		Aft Fuselage Yielding
.598	210	9			Nose Gear Contact
.667	234		3 lateral		Fwd. Fuselage Yielding
.704	247			8	L. Wing Inboard Failure
.722	253			9	L. Wing Inboard Failure
.727	255			10	L. Wing Center Failure
.735	258		3 torsion		Fwd. Fuselage Yielding
.751	264		2 torsion		Fwd. Fuselage Yielding
.810	284			16	Nose Gear Failure
.932	327	19			R. Main Gear Contact
1.012	355	2			Fwd. Fuselage Contact
1.125	394	1			Fwd. Fuselage Contact
1.139	399	3			Fwd. Fuselage Contact
1.220	427	27			R. Engine Contact
1.500	524				End of Analysis

*See figure 8-5 for mass and beam numbers but ends up near the right wing and well down the wreckage trail approximately 396 m. (1300 feet), (figure 8-3), indicating that right engine separation probably occurred late in the actual sequence of events. Therefore, the analytical non-failure of the right wing engine at initial contact (at 130 m. (427 feet) from initial left wing tip contact) appears reasonable.

The internal beam yielding shown in table 8-4 may be premature, particularly for beam 7 representing the aft fuselage, which yields both laterally and vertically before the airplane has travelled 51.8 m. (170 feet). The analytical model used does not include failure (rupture) of the fuselage beam elements, only nonlinear yielding. Therefore, the fuselage "holds together" analytically even though beams 7, 3 and 2 all yield. The peak fuselage beam deflections and rotations are all very small (less than 0.25 cm and 0.3 degree), so that even though ultimate design level loads are analytically attained, it is unlikely that major structural breakup would occur at such small deflections.

Analysis of the accident condition beyond the 1.5 seconds run requires a better knowledge of the fuselage strength capabilities and post-yielding behavior. After fuselage breakup, the validity of the calculated responses of the individual separated fuselage masses would be questionable. The degree of occupant survivability is related to the acceleration levels experienced by the occupants, as well as overall fuselage breakup hazards and fire potential. The analytical model shown in figure 8-5 does not include any direct representation of the occupants. The only measure of survivability in the analysis is the acceleration levels achieved at the various mass locations along the fuselage.

Figure 8-8 shows the peak fuselage accelerations attained analytically. These accelerations are all relatively moderate and should be within the strength capability of the passenger seats. However, as discussed previously, the analysis deliberately utilizes a low friction coefficient (0.5) and high ground flexibility (152.4 cm) to reduce fuselage loading during the first 1.5 seconds. Later in the accident sequence the effective ground friction must increase substantially to stop all the separate structure within 488 m (1600 feet). The average deceleration for the first 1.5 seconds, analytically,

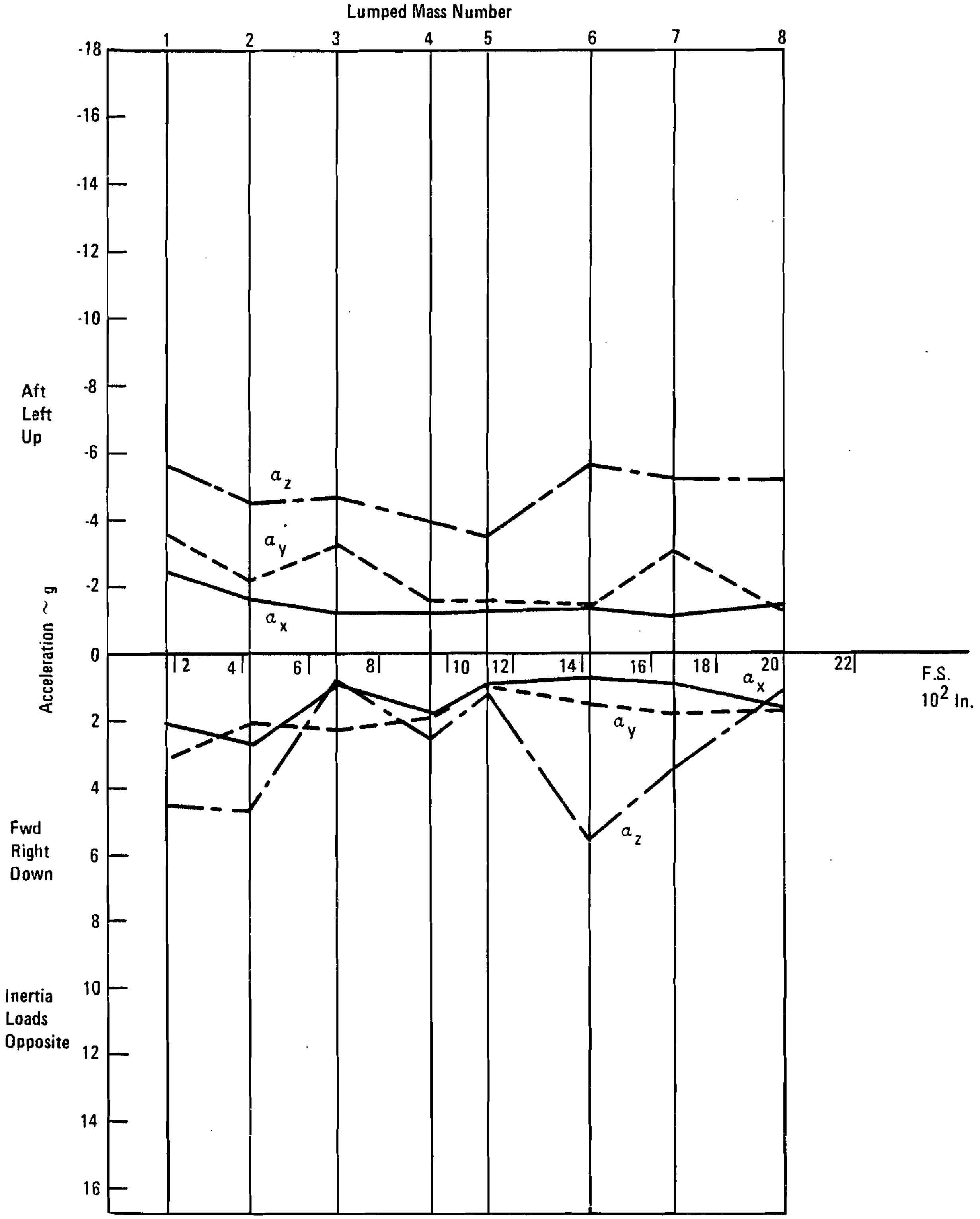


Figure 8-8. - Peak fuselage accelerations, AGI analysis.

is only 0.15g, compared to the overall average from the accident of 1.2g. Therefore, the fuselage accelerations can be expected to increase significantly once the fuselage starts to break up. Analyses with a ground friction coefficient of 1.0 and flexibility of 45.7 cm (18 inches) show peak fuselage accelerations as follows:

a_x = 5.5 fwd., 7.15 aft (2.5, 2.7)
a_y = 4.7 right, 7.7 left (3.6, 3.2)
a_z = 4.3 down, 13.9 up (5.7, 5.5)

{ Figure 8-8 results are shown in parentheses }

Even higher accelerations could be expected following fuselage breakup, and consequently, loss of airframe integrity. When the fuselage loads are within the airplane capability seat strength is adequate. However, once the fuselage separates and the floor buckles or distorts, seat performance is no longer a major concern.

In summary, the analysis using program KRASH does a reasonable job of predicting the initial sequence of failures of the left wing, the landing gears and engines. The proper timing of fuselage breakup is much more difficult to predict, and would require additional model "tuning". Fuselage acceleration levels are dependent on the assumed parameters defining the airplane/terrain interaction.

8.2.2 Analysis Results - Slope Impact

The second phase of the analytical capability evaluation involved modeling an impact into a dirt slope. The impact conditions were obtained from a report (reference 7) of test results for a Lockheed Constellation L1649 which was crashed under controlled conditions in 1965.

The Constellation crash test involved the following sequence of events (see figure 8-9):

- Airplane is accelerated up to a velocity approximating minimum climbout speeds (112 knots) using engine power, remote control and a guide rail. Airplane is at maximum takeoff gross weight of 72580 kg (160,000 pounds).

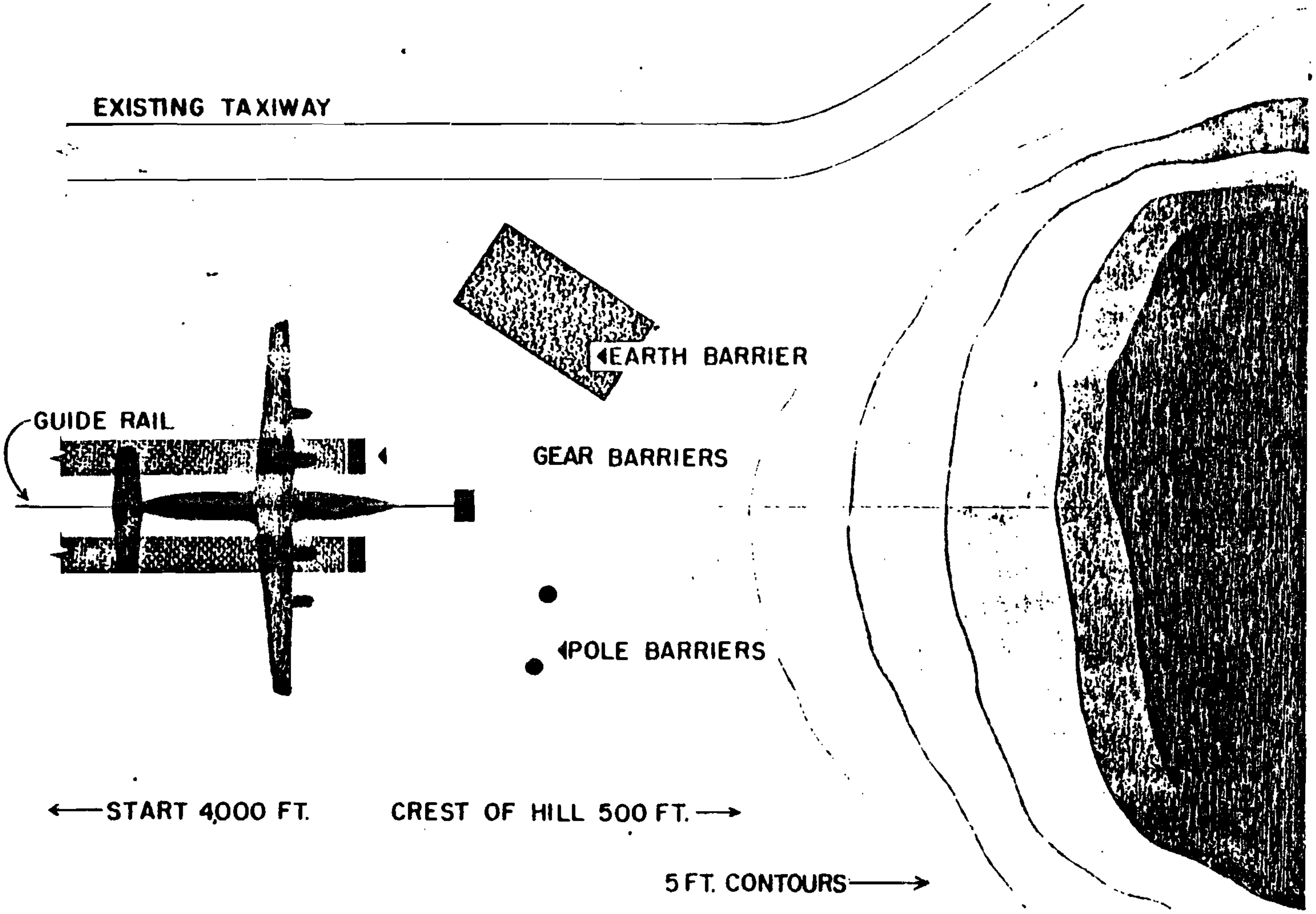


Figure 8-9. - Plan view of test site, Constellation crash test.

- Landing gear barriers simultaneously knock off all three landing gears.
- Pole barriers sever the right wing at two places, while the left wing contacts an earthen mound 6.1 m. (20 feet) high with a 30 degree slope.
- Airplane contacts a 6 degree slope extending about 53.3 m. (175 feet) along the path of the airplane.
- A secondary slope of 20 degrees is contacted about 22.9 m. (75 feet) after the end of the first slope.

This rather complicated crash sequence was used to incorporate into one test the features of a number of real crash conditions, specifically the following:

- A hard landing causing failure of landing gear and damage to surrounding structure.
- A wing-low impact with the ground.
- An impact into large trees in an off-airport forced landing.

Program KRASH cannot at present be used to analyze this complex scenario in a direct fashion. First of all, it is difficult to balance the airplane initially on the ground rather than in the air. The only way to do this is to run the program to simulate a gentle landing and let the program run long enough to achieve a stable taxiing condition. The stable condition is then saved on tape, and the restart capability of KRASH is used to initiate subsequent analyses from the stable "initial" conditions saved on tape. The improvement of Program KRASH's initial condition routine to provide more comprehensive balance equations would rectify this problem.

The separate impacts with poles and gear barriers cannot easily be modeled with KRASH, since the analytical model is based upon impacting a single smooth flat surface, inclined at a specified angle. The important current limitation is that a single surface is used for impacting all portions of the airplane, whereas the Constellation crash test involved multiple separate impact surfaces, as well as two separate earthen slopes. The multiple surface and different sloped impacts can be performed by KRASH in its present form only by creating special coding to treat individual situations. For example, the analytical model could be set up with extremely large fictitious masses which serve as finite barriers. These masses, unlike the other masses, would be coded to have a zero initial velocity and be spring connected to actual system masses where induced rupture forces are desired (i.e., landing gear failure). One could also utilize a specified force time history acting on selected masses in a desired direction to create false barriers (i.e., tree impact with wing). Another scheme would involve specifying surfaces for each spring (i.e., 6°, 20° and 30° slopes). All of these schemes are possible, involve additional coding, but represent a temporary approach with limitations in application to a host of general problems. The development of a general purpose representation of finite, multiple and different sloped surfaces is more desirable and, in the long run, more practical.

With this current limitation in mind, the KRASH analysis focuses on the slope impact portion of the test, because determining the response of the fuselage, floor, seat and occupant was the primary objective of this analysis. Neither the right wing pole impact nor the left wing slope impact is modeled. The purpose of these impacts was to damage the wing in such a manner as to allow fuel spillage and cause a fire hazard. The landing gears are assumed to be removed at the start of the analysis, which commences with the impact of the 6° slope. Since it would be too time-consuming to develop a KRASH model of the Constellation, and the availability of structural data in the desired KRASH format for this airplane is limited, the analysis is done for the same airplane for which a KRASH model had already been established. The model used is the same as that employed for the previous accident analysis described, except that the total weight is 195950 kg (432,000 pounds maximum takeoff gross weight) versus 148780 kg (328,000 pounds) for the AG3 analysis. This model is shown in figure 8-10. Another difference between the two models is that the Constellation test simulation is a symmetric condition, whereas the previous air-to-ground analysis was an unsymmetrical condition. Therefore, the symmetric condition is analyzed with a half-airplane model.

The airplane model used for the Constallation test analysis also includes two seat/occupant models, located above masses 3 and 6 in figure 8-10. Each of these includes a representation of the floor, seat, occupant lower and upper torso as well as a Dynamic Response Index (DRI) model, as shown in figure 8-11.

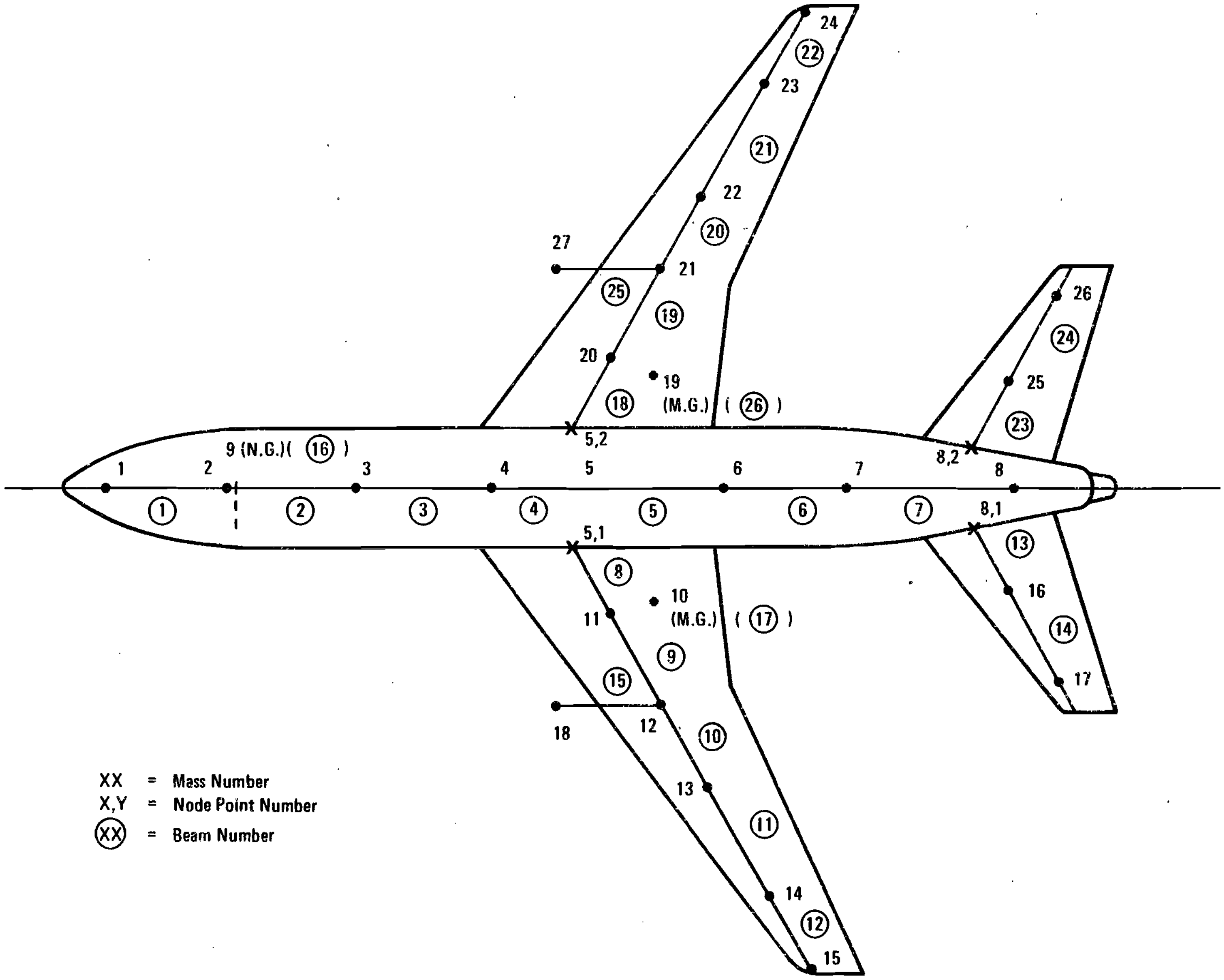


Figure 8-10. - Program KRASH analytical model.

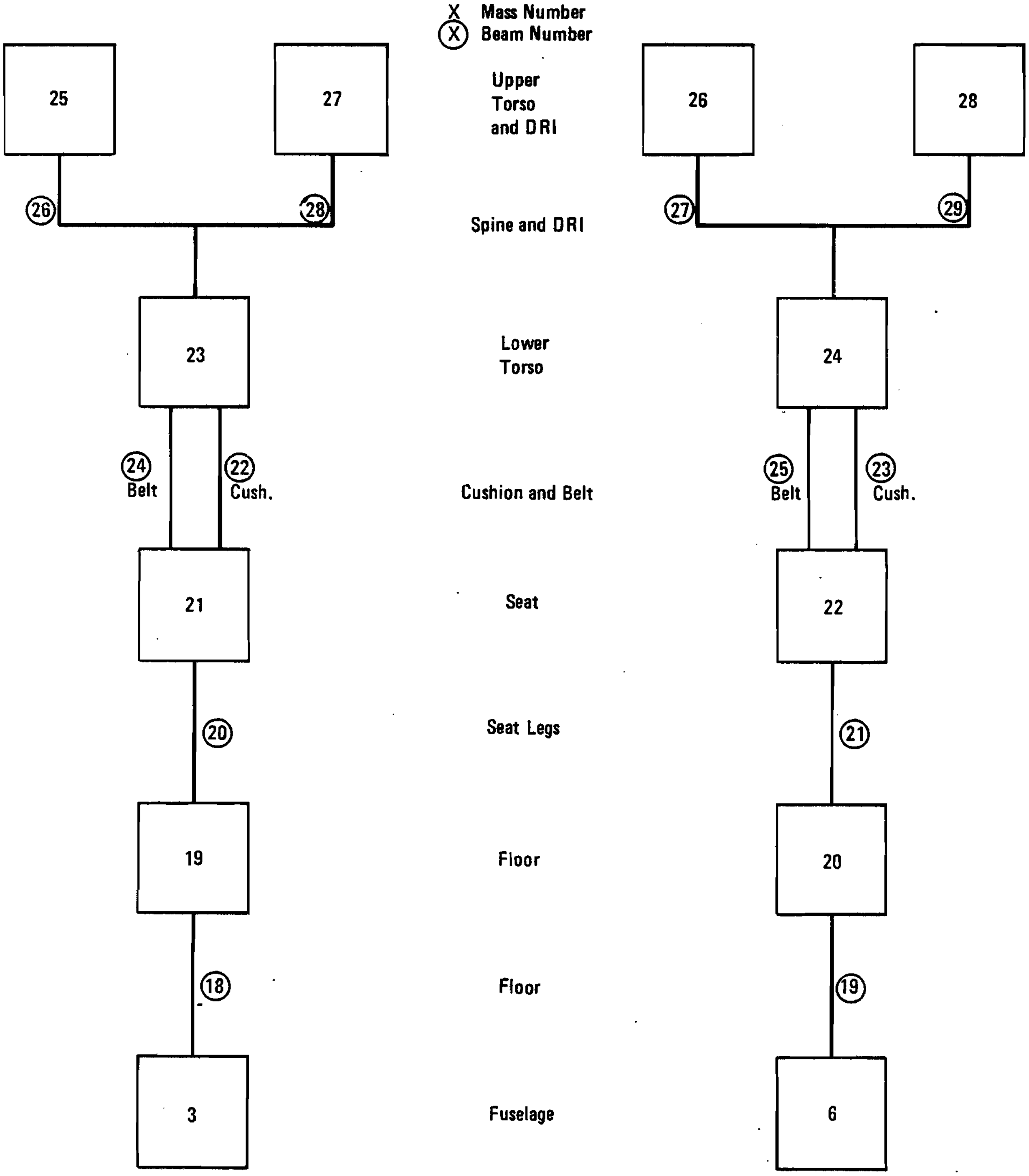


Figure 8-11. - Seat/occupant model.

The analysis of the airplane impacting a 6° earthen slope is conducted with the same initial velocity as was used for the Constellation tests, 112 knots. The airplane is initially balanced with 1g lift, but this is ramped out to zero after 1 second. This very roughly accounts for the fact that the Constellation would have had a significant amount of lift at 112 knots and also that there is an upload on the left wing due to hitting the 30° slope local to the left wing. The lift is not maintained because the Constellation test involved deliberately severing the right wing, and the left wing failed at the root sometime during the test.

Figure 8-12 shows the peak fuselage vertical shear and bending moments, normalized to the ultimate strength at each fuselage station, for three different runs. The nominal condition has the time varying lift described above and a ground flexibility of 45.72 cm. per total airplane weight, or 23.3 E-5 cm/kg (4.16 E-5 inches/pound) at each external spring. Also shown are the results for a ground flexibility of 152.4 cm (77.8 cm/kg) with the nominal ramped lift, and zero lift with nominal (45.7 cm) ground flexibility. From figure 8-12 it can be seen that the nominal condition yields fuselage shears or moments that exceed the theoretical ultimate design load of the fuselage at all locations except between FS1000 and FS1600. The zero lift condition is worse with only a small region around FS1100 having both shear and bending below ultimate. The results for 152.4 cm ground flexibility all lie below the ultimate design load except for vertical bending forward of FS600. All analyses model the fuselage as linear, with no yielding or failure allowed, regardless of the loads achieved.

There is no direct correlation possible between these analytical results and the Constellation test results, since the two structures are different and the analysis does not simulate the total test sequence. About the only observation that can be made is that the photographs of the Constellation test seem to indicate no significant fuselage breakup resulting from impact with the 6 degree slope. (The fuselage did break up later on the 20° slope). The current analytical results for a 152.4 cm ground flexibility indicate that if this ground model were correct the airplane would probably show no fuselage breakup on the 6 degree slope. The slight exceedance of ultimate design

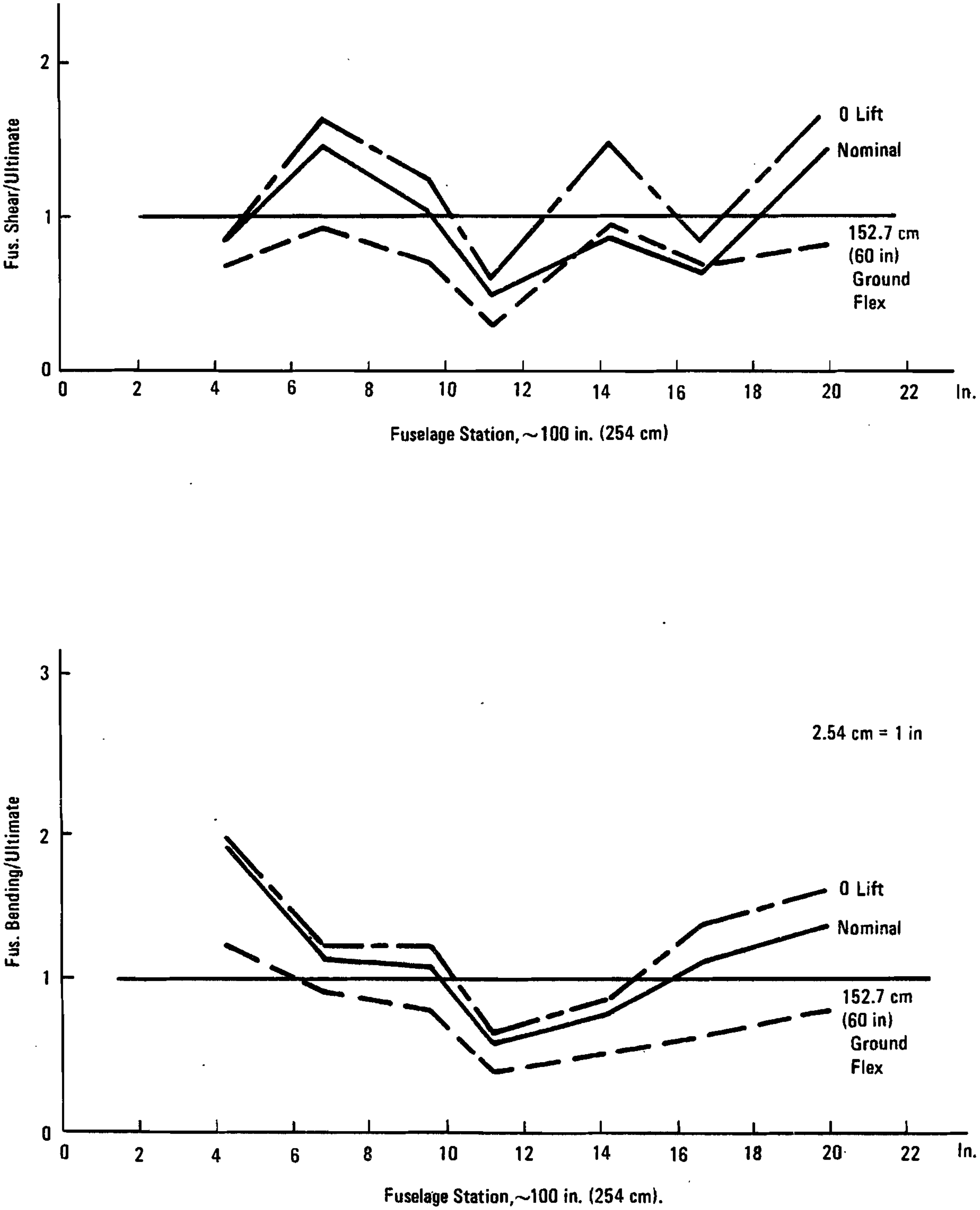


Figure 8-12. - Fuselage shear and bending loads, 6 degree slope impact.

bending at the forward fuselage stations can be interpreted in part as due to extremely small ultimate bending design loads forward of FS600. The actual fuselage strength at these locations would probably be sufficient to preclude breakup.

Figure 8-13 shows the responses of the forward fuselage (mass 3 in figures 8-10 and 8-11), floor, lower torso and dynamic response index (DRI), for the nominal condition (refer to figure 8-11 for the seat/occupant model). The seat response is virtually identical to the floor response, and is not shown. The DRI is a non-dimensional measure of spinal deflection (between masses 23 and 27) which can be related to the probability of spinal compression injury. In figure 8-13 it can be seen that the fuselage acceleration, representing a large section of fuselage structure, is of low frequency and magnitude. In comparison, the floor acceleration has a higher frequency content (33 Hz) with oscillatory peaks above and below the fuselage acceleration. In this analysis, even the floor (mass 19) represents a large section of the airplane, but its mass is much less than that of the total fuselage in the region represented by mass 3. (Mass 3 = 8260.5 kg (18,235 pounds), mass 19 = 650 kg (1434 pounds). An accelerometer placed on the floor in this region would probably measure localized accelerations of much higher frequency and amplitude than those shown for mass 19 in figure 8-13. Furthermore, the model assumes that a large section of floor behaves as one mass, with all portions moving in phase. Local structural details would result in higher frequency modes being excited, with different portions of the floor moving out of phase. In addition the seat, lower torso and upper torso/DRI masses all represent totals for the mass 3 region of the fuselage (around 32 seats and passengers), and these too are assumed to all move in phase (all occupants weigh 77 kg (170 pounds)). Therefore, the results in figure 8-13 represent a sort of sectional average response, whereas individual seat/occupant responses could be both higher and lower.

In this particular condition, the fuselage response frequency is very close to the natural frequency of the DRI element (8 Hz), so that a significant amplification of the average floor acceleration occurs. In the other region containing a seat/occupant model, mass 6, the peak fuselage acceleration is

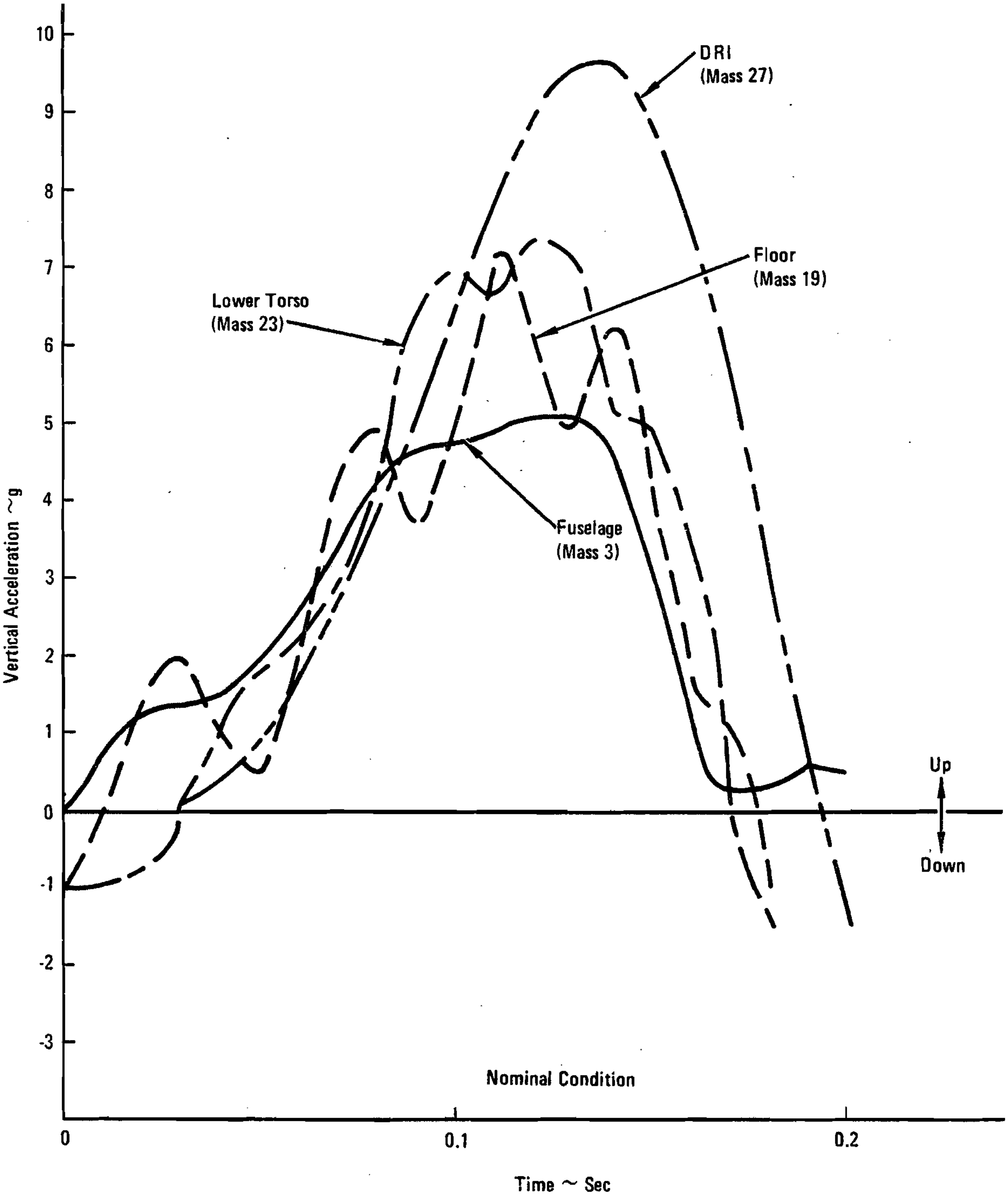


Figure 8-13. - Fuselage/seat/occupant responses.

only around 2.0g (in the same time frame as the peak DRI response), while the floor responses about this are more substantial, with a peak of 11.6g. However, this is not a sustained peak and the DRI responds only moderately, reaching a peak of 7.4. Therefore, depending on the nature of the floor response time history, the peak DRI may be either greater or less than the peak floor acceleration. It should be noted that for both masses 3 and 6, the peak fuselage acceleration does not occur in the same time frame as the peak DRI; in each location the peak fuselage acceleration is greater than the figures quoted in the preceding discussion of occupant responses. Table 8-5 shows the peak fuselage, floor, seat and DRI responses over the duration of the analysis (1 second), for the three conditions analyzed.

It can be seen from table 8-5 that, relative to the nominal condition (Run 3013), increased ground flexibility reduces all peak responses significantly, whereas zero aerodynamic lift increases all responses except the aft DRI. Also, the peak DRI is less than the peak floor acceleration for all conditions except the forward fuselage region, nominal condition. Therefore, the relationship between floor acceleration and DRI shown in figure 8-13 should be viewed as the exception rather than the rule. On the other hand, the peak DRI is always (with one minor exception) greater than the peak fuselage acceleration. With the exception of the zero lift condition, all the floor/seat responses are within the strength capability of the airplane seat, and in all cases the DRI's are below the threshold for nonzero probability of spinal injury (DRI $\approx$ 15).

The peak vertical and horizontal accelerations along the fuselage are shown in figures 8-14 and 8-15. Once again the general trend is for the zero lift condition to be the most severe, and the 152.4 cm. ground flexibility condition to be the least severe. The peak accelerations at the extreme forward and aft ends of the airplane are around twice as large as in the center of the fuselage. The results in table 8-5 indicate that peak floor vertical accelerations are generally on the order of 2 times the overall fuselage section accelerations. From figure 8-14 one could conclude that the peak upward floor accelerations would vary from around 20 g at the forward and aft extremities to 9 g at the center, for the nominal condition. Test data from

TABLE 8-5. - PEAK FUSELAGE, FLOOR, SEAT AND DRI VERTICAL RESPONSES

Run	Ground Flexibility cm (in)	Aerodynamic Lift	Peak Vertical Responses, g (Fwd/Aft)*			
			Fuselage	Floor	Seat	DRI
3013	45.72 (18)	lg ramped to 0	5.10/4.81	8.09/12.2	9.14/10.8	9.60/7.41
3014	152.4 (60)	lg ramped to 0	3.04/2.57	6.15/6.09	6.33/8.97	4.59/3.38
3016	45.72 (18)	0	5.50/6.87	12.7/29.5	12.6/37.9	10.44/6.84

*Fwd = Mass 3 region, Figure 8-10

Aft = Mass 6 region, Figure 8-10

reference 7 for the Constellation impacting the 6° slope show peak upward fuselage acceleration varying from 30 g's at the forward end to 10 g at the aft end, with around 20 g in the mid-fuselage region. The test floor accelerations, in general, have a frequency content of 60 to 80 Hz, compared to 30 to 35 Hz for the airplane analyzed.

Analyses were performed with a model of the airplane expanded to 15 fuselage masses rather than the 8 masses shown in figure 8-10. This model was developed from that in figure 8-10 by redistributing the fuselage mass to include points midway between those in figure 8-10. The original external spring characteristics were maintained at the original mass locations (1 through 8). The floor/seat/occupant response models shown in figure 8-11 were resized to represent half as many seats (16 instead of 32). The impact condition analyzed was the nominal condition with 45.72 cm ground flexibility and ramped aerodynamic lift.

Figures 8-16 through 8-18 show comparisons between the coarse and fine fuselage models for fuselage, floor and DRI response at the forward location during the primary response which occurs within 200 milliseconds after impact. This is no discernable difference in the acceleration levels obtained from the 8 mass and 15 mass fuselage models. However, the finer fuselage model can introduce additional modes of response which could, during the course of 1 second of simulation, result in some deviation in peak response values.

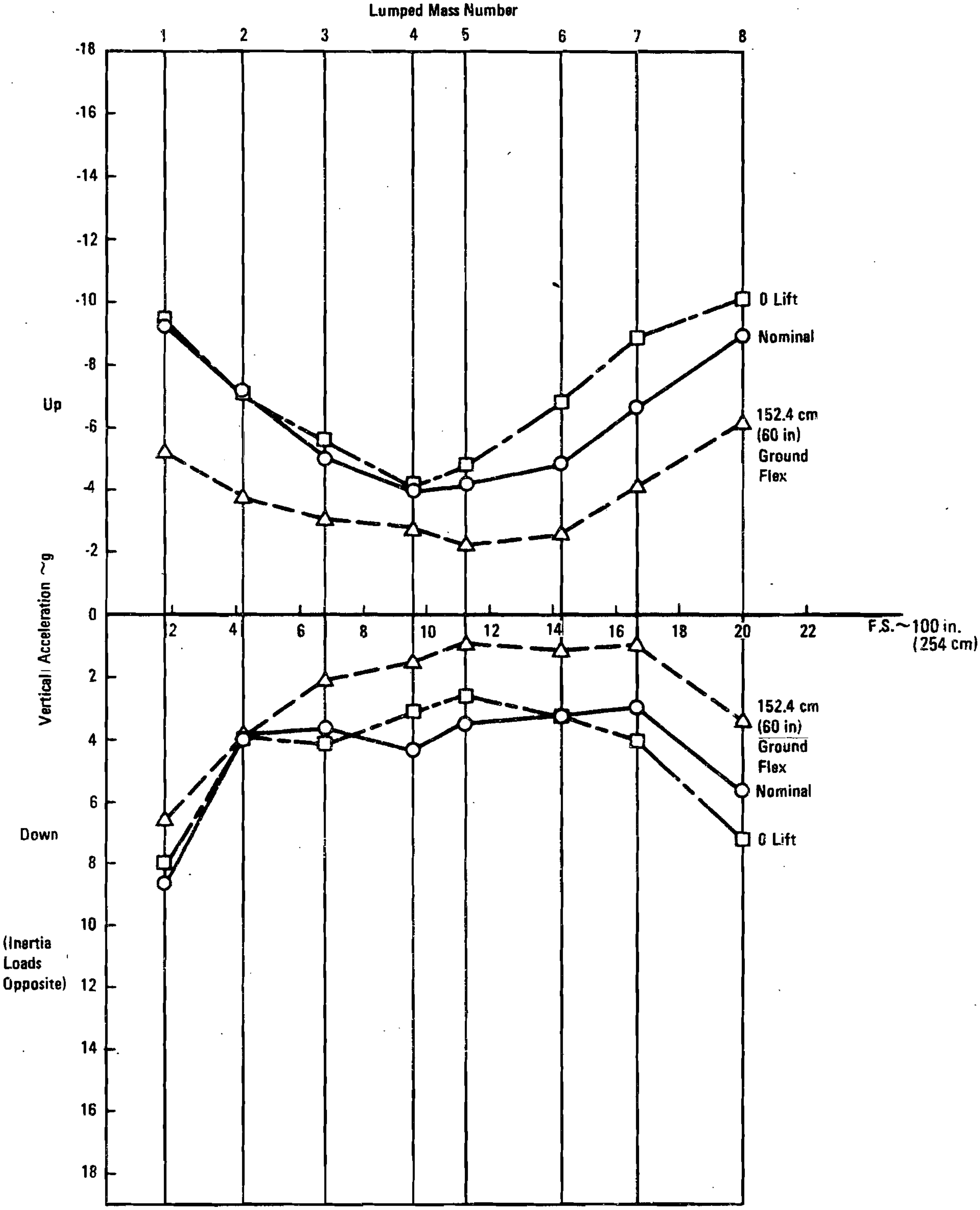


Figure 8-14. - Fuselage peak vertical accelerations.

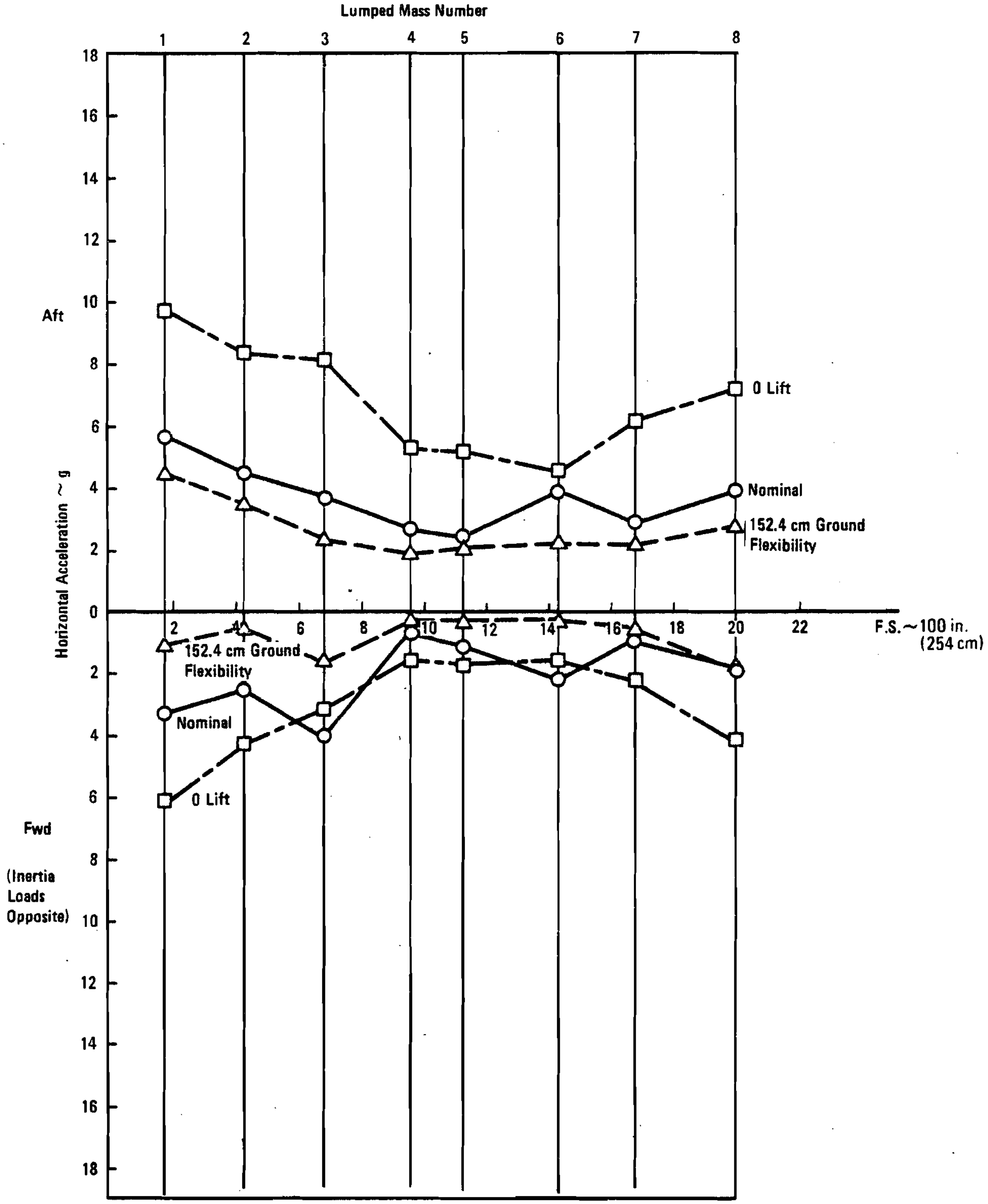


Figure 8-15. - Fuselage peak horizontal accelerations.

Table 8-6 summarizes the peak fuselage, floor and occupant responses throughout the entire 1 second analytical simulation.

Figure 8-19 shows a comparison of the peak fuselage loads, normalized to the maximum load at each location, for the two levels of fuselage modeling detail. The finer 15 mass fuselage exhibits approximately the same peak shear and bending loads as the coarser 8 mass fuselage except at the extreme ends (FS 390 and FS 1800). The finer fuselage model shows approximately the same peak bending moments as the coarse model. The 15 mass model shows a finer distribution of loads as might be expected with more masses. However, the trends and magnitudes associated with both models are reasonably close.

Figures 8-20 and 8-21 show comparisons of peak fuselage vertical and horizontal accelerations, respectively. The finer fuselage model shows a moderate variation in peak accelerations throughout the length of the fuselage. However, the shape of the curve depicting acceleration versus fuselage station is similar in both the vertical and longitudinal directions. The data plotted in figures 8-20 and 8-21 includes all peak responses within a 1 second simulation and not just the initial peak responses.

An assessment of the results of the 8 and 15 mass fuselage models indicates that additional investigation should be performed to understand differences in results. For example, subsequent modeling of the fuselage with

TABLE 8-6. - PEAK FUSELAGE, FLOOR, SEAT AND DRI VERTICAL RESPONSES FOR TWO LEVELS OF MODELING DETAIL

Run	No. of Fuselage Masses	Peak Vertical Responses, g (Fwd/Aft)				
		Fuselage	Floor①	Seat	DRI	Floor②
3013	8	5.10/4.81	8.09/12.2	9.14/10.8	9.60/7.41	7.2/11.6
3025	15	5.93/5.114	10.26/15.1	11.64/13.9	9.59/9.47	5.33/6.84

① Peak during entire 1 second run

② Peak corresponding to peak DRI response

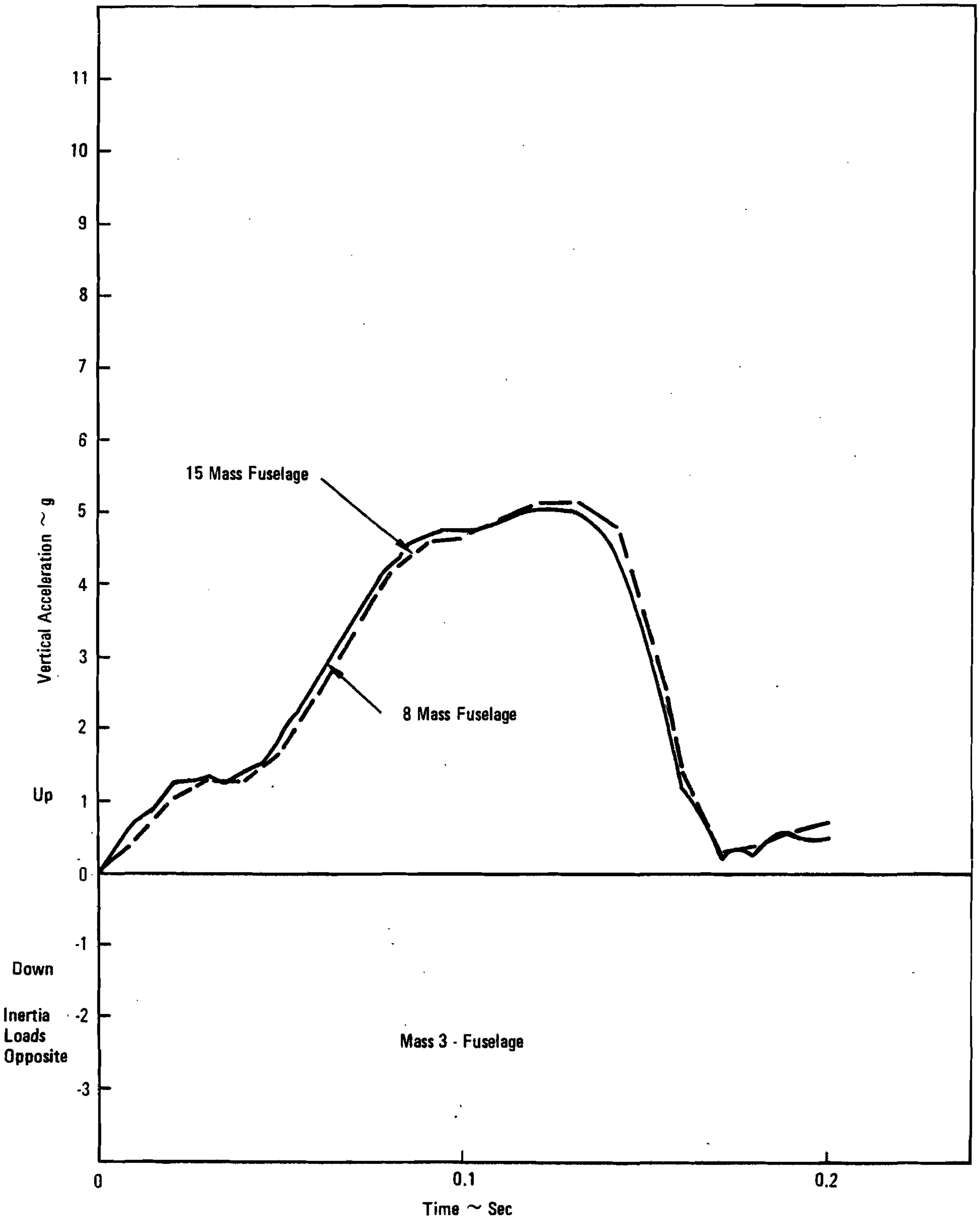


Figure 8-16. - Forward fuselage response for two levels of modeling detail.

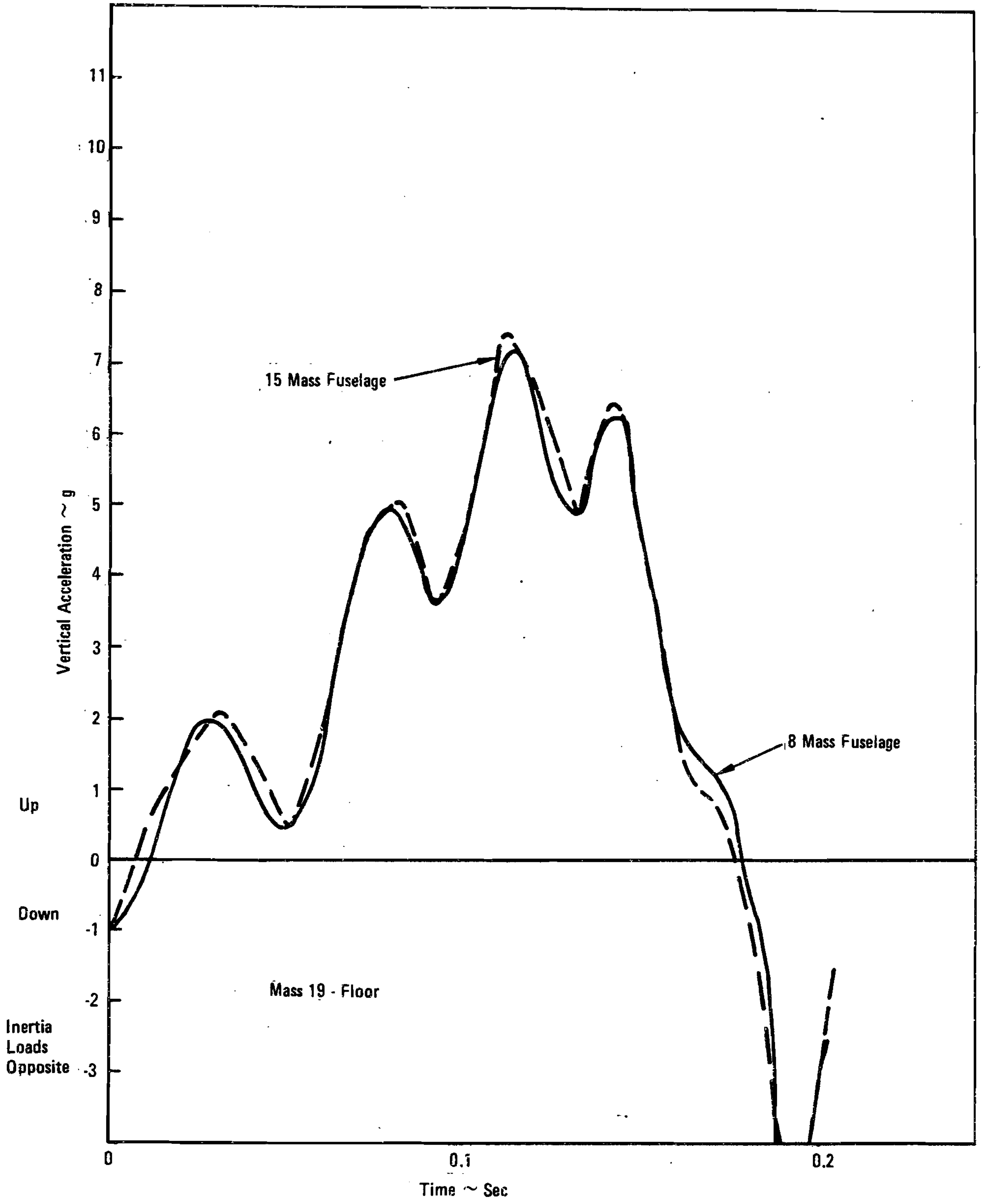


Figure 8-17. - Forward floor response for two levels of modeling detail.

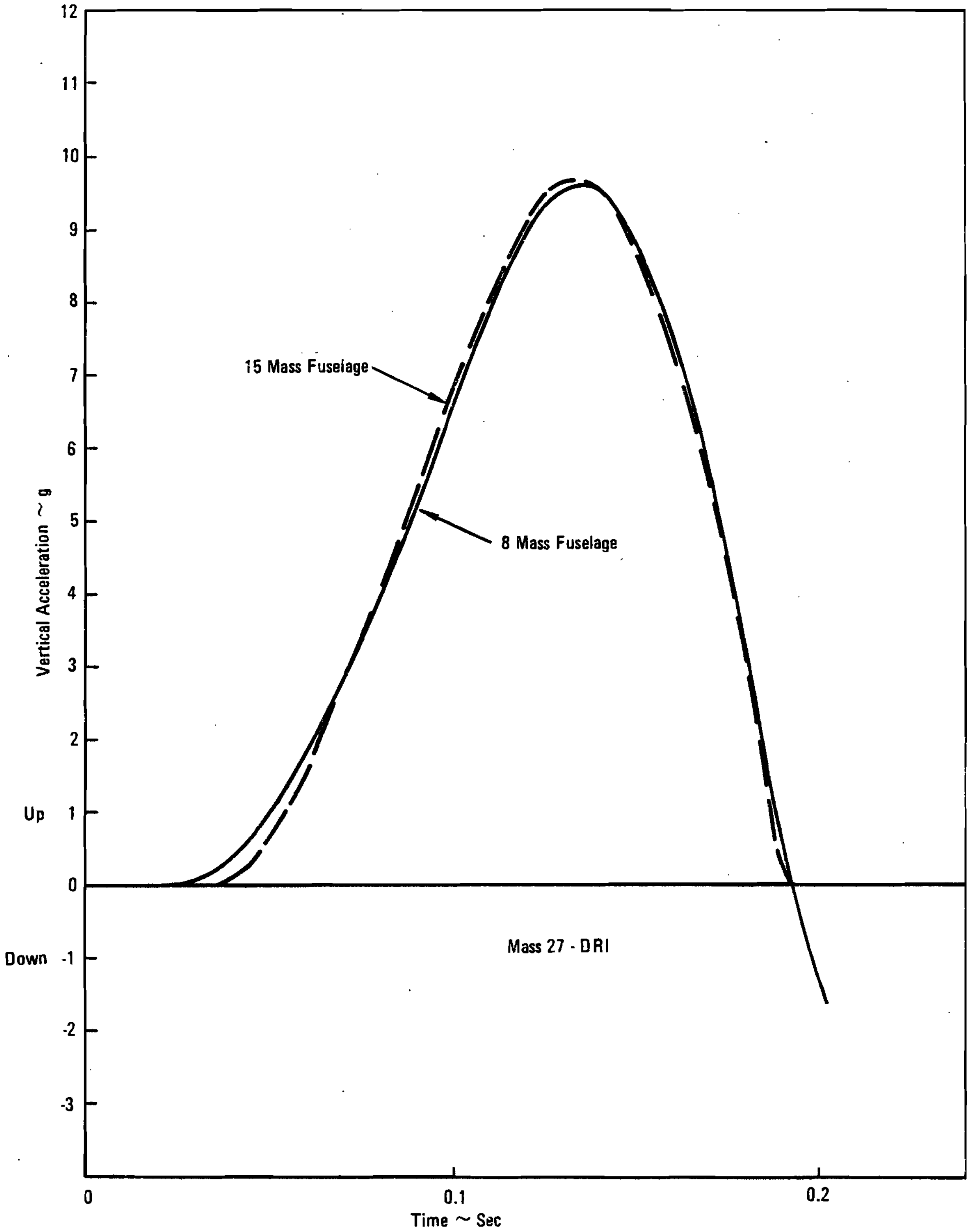
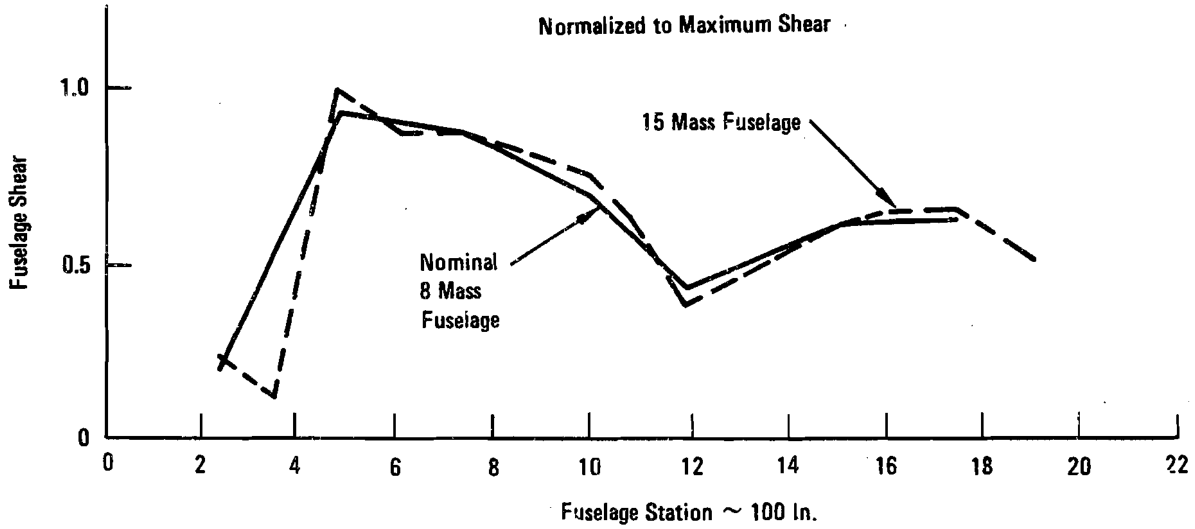


Figure 8-18. - Forward DRI response for two levels of modeling detail.



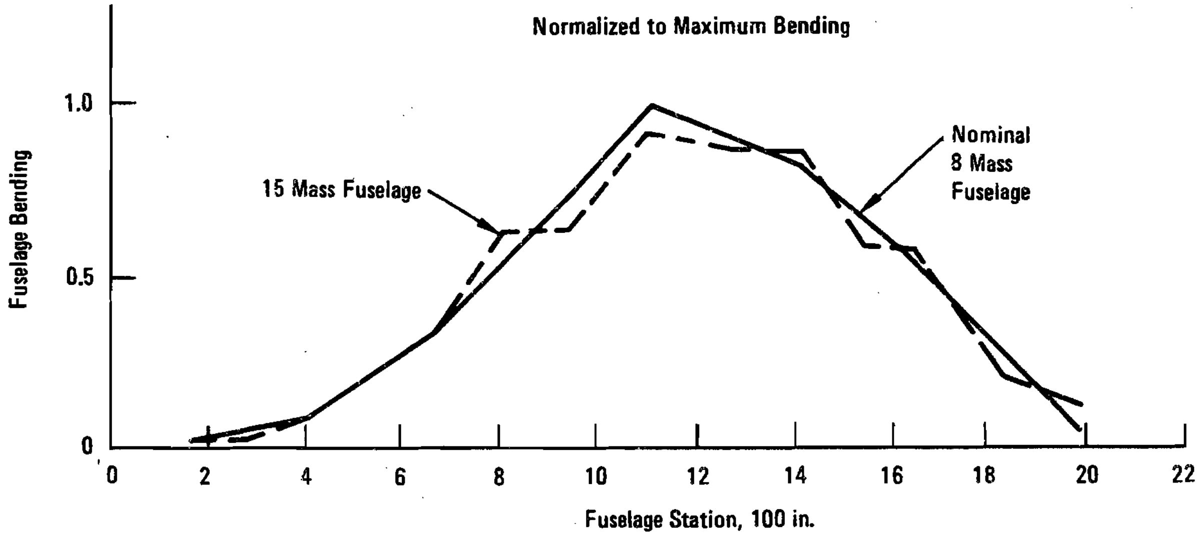


Figure 8-19. - Fuselage bending and shear loads vs. modeling detail.

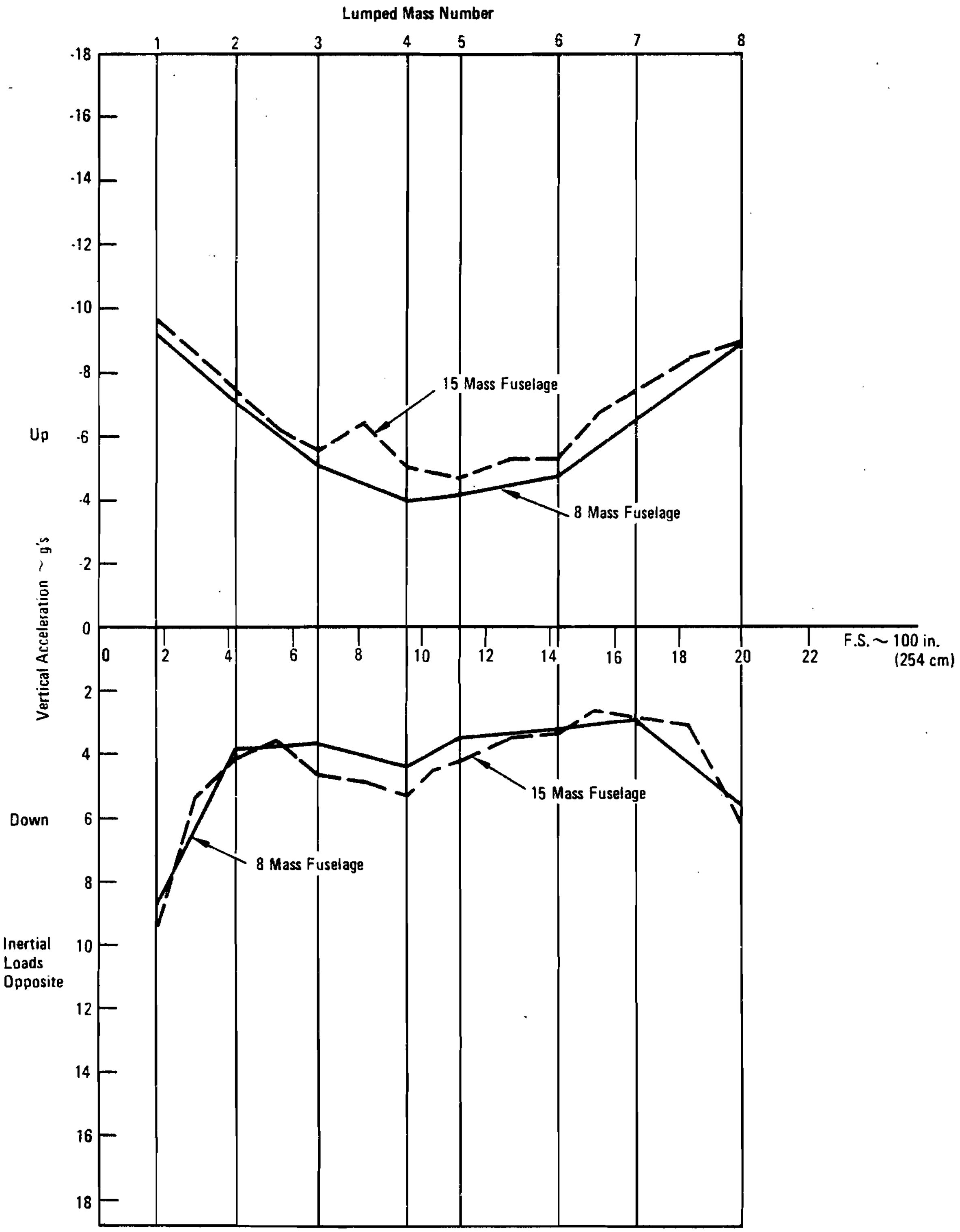


Figure 8-20. - Fuselage peak vertical accelerations for two levels of modeling detail.

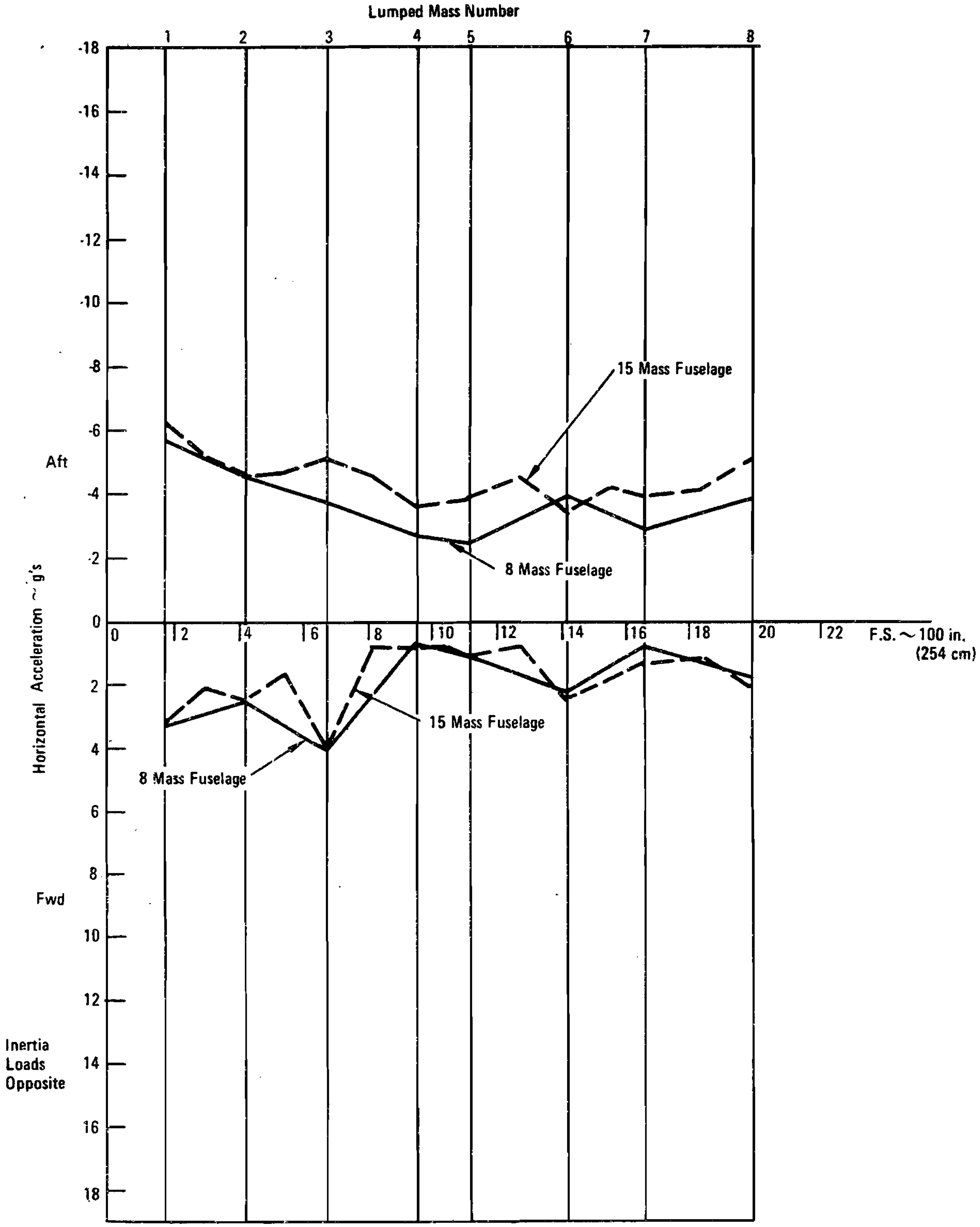


Figure 8-21. - Fuselage peak horizontal accelerations for two levels of modeling detail.

15 masses but with external springs at the same original 8 mass locations of the coarser fuselage has shown many simularities in accelerations and loads between the two models. However, a finer representation of the crushable structure via additional springs could lead to additional response modes and deviations in response. Ideally the analyst would want to achieve accurate results with the minimum size model possible. For large transports model size requirements are significant. Also consideration should be given to modeling airframe, floor, seat/occupant in one combined model or as individual models in which the output of one model is utilized as an input to the other model.

As noted earlier, the analyses discussed herein assume a linear fuselage that does not fail in any way. From figure 8-12 it would appear that bending moments on the order of 2 times ultimate design would clearly fail the fuselage, provided the ultimate levels were accurate. However, one cannot establish accurate failure levels without actual strength envelopes at different fuselage stations. Development of these envelopes requires a substantial stress analysis effort that is beyond the scope of the current study. For this reason, the Constellation test simulation analysis using a wide body airplane configuration did not include fuselage nonlinearities and failure modes.

The results of this analysis are intended to illustrate the degree of sensitivity of the analytical results to certain parameters. From these results one can conclude that significant parameters include ground flexibility, aerodynamic loading of the airplane and refinement level of the fuselage model.

8.3 Results Of The Analyses

Section 7 contains a discussion of analytical requirements, structural failure modes and a review and evaluation of analytical techniques. Two programs which have been utilized at Lockheed in crash dynamics analysis were exercised to investigate:

- candidate crash scenarios
- an NTSB accident
- a previously performed controlled crash test

The two techniques, Airplane/Ground Interaction Program (AGIP) and KRASH, represent two entirely different philosophies and serve different purposes. The Airplane/Ground Interaction Program is a modal technique which more accurately represents the linear range of structural behavior, and thus, is limited to defining initial failure regimes and types. KRASH, which approximates nonlinear behavior in a simplistic but effective manner as witnessed by substantial correlation with test data, provides a means by which large deformation, post-failure behavior can be evaluated. Furthermore, because of its flexibility KRASH can be used to model subsystems such as the 6-mass fuselage-floor-seat-occupant model to assess primary occupant responses.

A third approach, the finite element technique, as characterized by DYCAST was not utilized since a version of that program was not available at Lockheed at the time the analyses were being performed.

The analyses described earlier in this section illustrate some salient points.

1. The analyses of transport accidents may best be served with the utilization of complementary analytical tools. For example, a modal technique such as AGIP may economically provide a first indication of failure mode to be encountered. The failure data obtained from an initial analysis could be utilized in the hybrid model which provides tremendous user flexibility and represents an effective means by which structural break-up and its consequences could be evaluated. The hybrid model could also benefit from load deflection characteristic data generated by a detailed model such as a finite element technique. The finite element approach is at a decided disadvantage in modeling large transport structures since its strength is detail representation and large transports would require an inordinate number of finite elements.

2. The application of the current available techniques to transport airplane crash analyses would be enhanced with several modifications and verification with experimental data. The capabilities of an appropriate mathematical model should include:

   - initialization of balanced loads
   - combined loading criteria
   - impact environment to include multiple and varied obstacles or surfaces

3. The sensitivity of the landing gear failure mode to the airplane impact attitude as illustrated in figure 8-2 highlights the need to provide a planned program of test and analysis to ensure that critical failure modes are understood and analytical capability to represent them are available.

8.4. Future Analytical Improvements

The analyses of accident conditions using program KRASH and AGIP indicate a number of improvements that can enhance current programs for analyzing this type of condition. The improvements, while discussed directly for KRASH, are applicable to any program envisioned for transport airplane crash analysis.

A. Initial Conditions - The current program is coded such that the internal beam loads are all zero at the start of the analysis. This would be true only for a free-falling airplane with zero aerodynamic lift. While this approximation is not too unreasonable for some helicopter and small airplane accident conditions, the large transport accidents being studied occur under conditions resulting in substantial lift. The program currently allows the direct input of either a lift/weight ratio for each mass (constant with time), or a time-varying external force on each mass. The latter option was used to simulate the 1.6g lift for the typical AG3 accident discussed above. However, the internal beam loads still start at zero. In order to minimize the abrupt beam load discontinuities that could occur, the lift on each mass is input in proportion to the mass's weight, so that every mass has the same acceleration at time zero. The resulting lift distribution is not an accurate representation of the true distribution; the lift will be exaggerated on the fuselage and too low on the wing (and possibly in the wrong direction on the horizontal stabilizer).

While the lift distribution approximation was satisfactory for the KRASH analysis described earlier, the program needs a more general initial condition balance algorithm that allows for any applied or aerodynamic load distribution and calculates the resulting non-zero internal beam loads. Also of value would be the capability to balance the airplane on the ground as well as in the air. A more realistic aerodynamic load model would also be desirable.

B. Generalized Multiple Surface and Impact Capability Program KRASH was not able to model the complex scenario described in reference 14 in a direct fashion. Impacts with poles and barriers can be performed in the current version of KRASH in several ways, as described in section 8.2.2. However, the inclusion of a general purpose representation of finite, multiple and different sloped surfaces is more desirable, and, in the long run a practical approach. Along with multiple surface representation, rigid body equations to represent periods of time during which little structural activity is occurring may be a viable means of reducing computer costs for some specialized accident conditions.

C. Terrain Model - Program KRASH has provisions for a flexible ground characterized by a linear spring rate and zero rebound. Horizontal forces are generated as a constant friction coefficient times the vertical load. This model is really only adequate for the analysis of impacts with a virtually rigid surface, such as the runway. Impacts with dirt surfaces, or with water/dirt combinations such as the swamp encountered in the AG3 category accident discussed above, result in a complex relationship between the ground interaction forces and the local structural geometry, penetration and velocity. If accidents involving penetrable terrain are to be analyzed, then a more involved model of the airplane/ground interface including plowing effects must be developed.

The airplane/ground interface relationships are complex and will require extensive analysis and experimental verification. The reports researched in reference 33 and categorized into applicable areas of content, form an initial basis for determining directions to be taken. The evaluation of terrain behavior could ultimately lead to modular representations of different impact terrains including a water surface.

D. Fuselage Shell Modeling - The analysis of the wide-body transport AG3 category accident clearly indicates some difficulties associated with modeling large transport aircraft fuselage shell structure as a straight line stick model of lumped masses with interconnecting beams (figure 8-5). While this may yield acceptable results prior to fuselage breakup, the actual separation of fuselage structure and consequent loss of structural integrity can involve complex failure modes for which accurate modeling representations are dependent on the detail design of the shell structure. The resulting structural behavior may not be readily predictable with the current capabilities of program KRASH. Even a more detailed model using additional lumped masses to define the fuselage may not yield significantly improved analysis, and the larger model size would significantly increase the cost of the analysis. Thus, a question that remains to be resolved is "How much beyond structural breakup should analysis be performed?"

Another difficulty with modeling the fuselage is the utilization of the available design load data. The only readily available information on the strength of the fuselage shell is the published design loads. These are in the form of design load envelopes, typically showing combinations of shear and bending. Considerable stress analysis is required to bridge the gap between design load envelopes and actual structural strength, and even then some test data is desirable to define actual failure modes and load levels. Although the beam model used in program KRASH accounts for the coupling between shear and bending in the load calculations, the final rupture of the element is based on exceeding an input load or deflection in any one of the loading directions, independent of what the loading is in the other directions. Therefore, an envelope of combined shear and bending cannot be used directly in KRASH to define beam rupture.

The most reasonable approach to fuselage shell modeling with KRASH probably involves utilizing stick model elements with overall average EI and GJ properties, but with expanded capability to monitor the combined loading interaction. Element nonlinearities should be initiated by combinations of loads, or even reference stresses, calculated for each beam, rather than by beam deflections as currently done. This would require stress analysis external to KRASH to define critical structure locations and post-yielding behavior. Reference 63, Appendix C, describes a piecewise-linear computer analysis of lower fuselage structure that is typical of the type of back-up effort required to develop input data for KRASH.

The sample analysis described in reference 63 involved the impact of a nose landing gear on fuselage frames designed to support such loads and the extension of conventional elastic frame analysis to account for inelastic behavior as local areas of the structure are stressed above the material proportional limit stress. The procedure used involves the following steps:

1. Erect a two-dimensional detailed structural model of the frame with shell support (see figure 8-22).

2. Apply loads at the support points as shown.

3. From examination of the stresses in the frame elements, determine the maximum load for which all element stresses are elastic.

4. Increase load by a small increment.

5. Using a Ramberg-Osgood representation of the stress-strain relationship for the materials, adjust the effective modulus of elasticity for each element to correspond to the secant modulus at its stress level.

6. Increase load by another small increment. This, in effect, is an incremental elastic analysis with flexibilities determined by the stresses at the previous load level.

7. Repeat steps 5 and 6 until the maximum permissible elongation is reached in any element.

This technique produces a non-linear load-deflection curve for the frame using conventional well established linear and elastic analysis methods. Small increments of load may be used because of the rapidity of solution for each iteration, and errors are a function of the increment size and are not accumulative. A typical load-deflection curve is shown in figure 8-23. When the load-deflection characteristics for each frame are determined, the frames are represented as a non-linear external spring in program KRASH.

Similarly, other analytical techniques such as DYCAST could be used to develop substructure load-deflection curves for input to KRASH. The advantage of combining these techniques would be to utilize the strengths of each program and minimize their deficiencies. Program KRASH is relatively efficient cost-wise but obtains gross behavior by representing complex structure in a simple manner. DYCAST, as most finite element techniques, is oriented toward detail design considerations, which usually require extensive modeling and computing time for large structures.

It is also necessary, through either additional tests or analyses, to establish the relationship between local floor responses that drive the passenger seats and the overall average fuselage section accelerations obtained from KRASH. Proper fuselage shell modeling may require some form of auxiliary floor response calculations, based on the mass point accelerations representative of overall fuselage behavior.

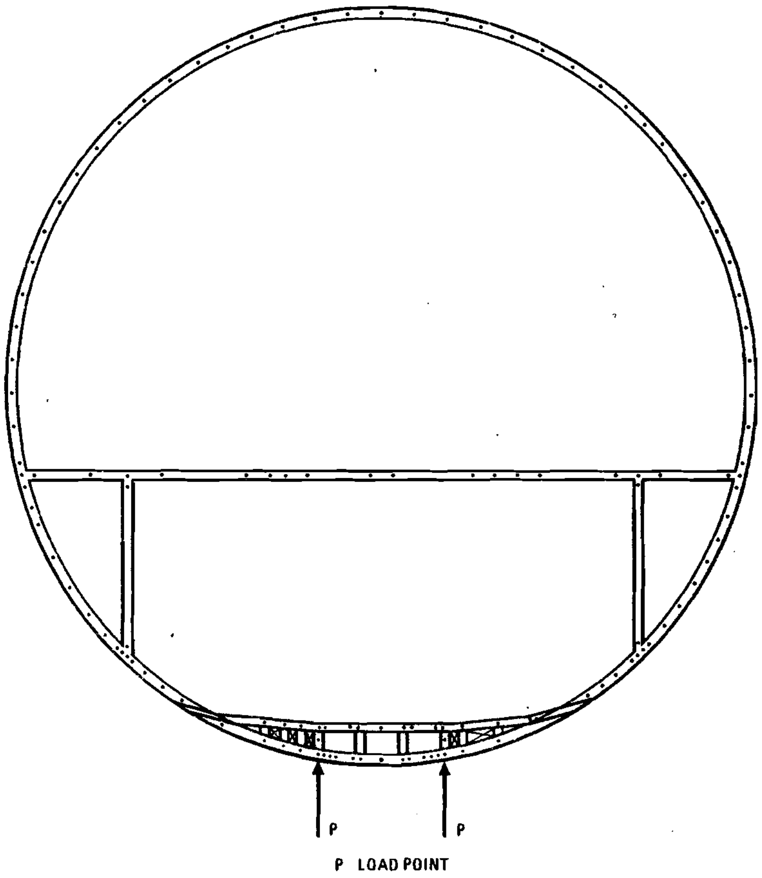


Figure 8-22. - Two-dimensional model of typical forebody frame.

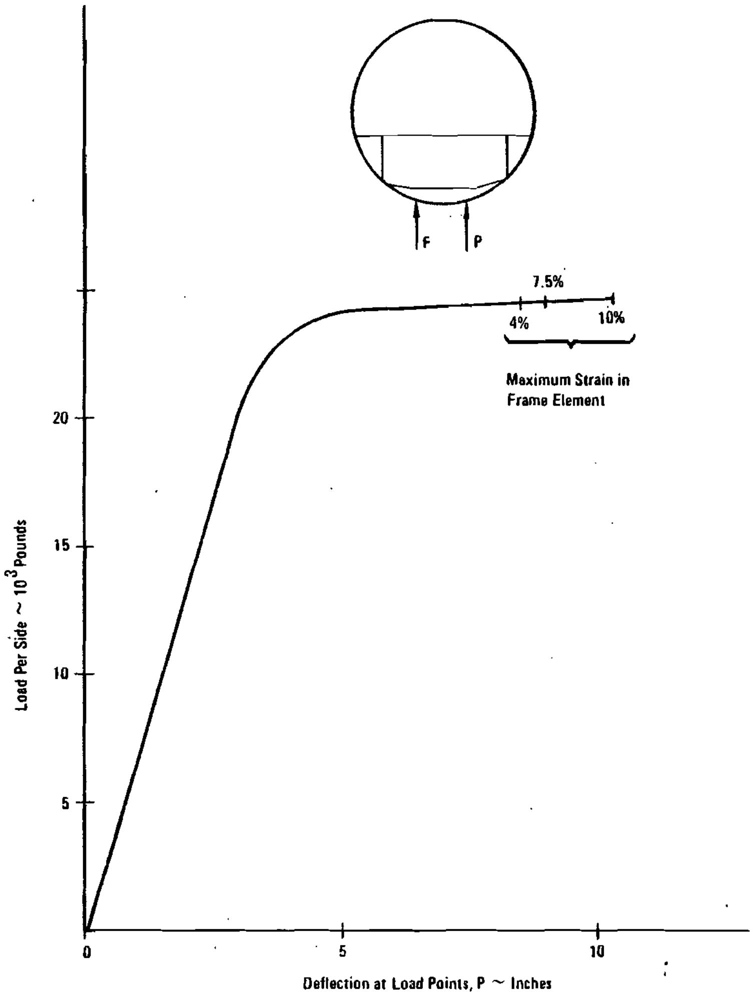


Figure 8-23. - Load/deflection characteristics of typical forebody frame.

9. REVIEW AND EVALUATION OF TEST DATA AND TECHNIQUES

9.1 Review of Light Fixed-Wing Aircraft Crash Tests

The most comprehensive crash test program that has been performed in the last decade involves the light fixed-wing aircraft tests conducted at the NASA LaRC Impact Dynamics Research Facility. Crash tests at NASA have included single-engine high-wing and low-wing airplanes as well as unpressurized and pressurized twin-engine low-wing airplanes. The weight range of the airplanes is from approximately 1040 Kg (2300 lbs) to 3080 Kg (6800 lbs). The maximum flight path speed achieved with the aid of booster rockets is 145 km/hr (90 mph). The test facility structure is shown in figure 9-1. The method for crash testing the aircraft is shown pictorially in figure 9-2. The aircraft is swung pendulum style into the impact surface. The flight path angle can vary from 0^o to 60^o. A description of the test facility is presented in Reference 65. To date a total of 24 light-fixed-wing airplane crash tests have been performed at the NASA Facility. References 81 through 84 describe some of the NASA tests. Tests of the single-engine low-wing airplanes were performed under FAA sponsorship and are described in Reference 47. The data from this series of crash tests were used to correlate with program KRASH.

The test method used at NASA Langley involved recording up to 60 AC and DC channels of accelerometers through an umbilical cable from the vehicle to the recording center. The frequency response of the data recording system is flat to approximately 1000 Hz. For analysis purposes subsequent low pass filtering is performed as a post-process step. Up to 20 cameras record an individual test, covering a number of views and camera speeds. On board lighting is provided. Pyrotechnics are used to achieve cable separation.

Crash tests involving light-fixed-wing airplanes are described in references 85, 86, 87 and 88. The tests described in reference 85 simulated

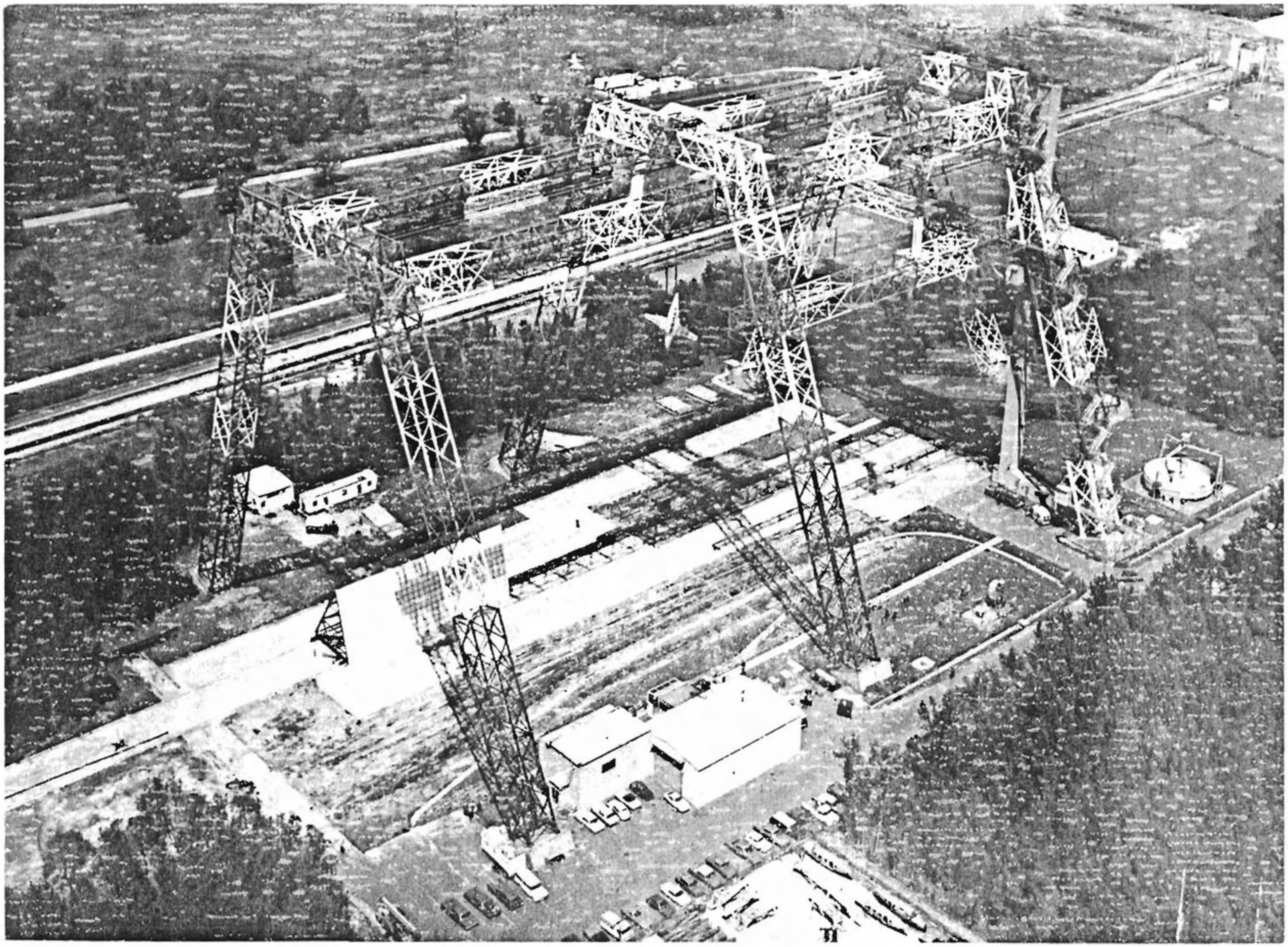


Figure 9-1. - Basic facility structure.

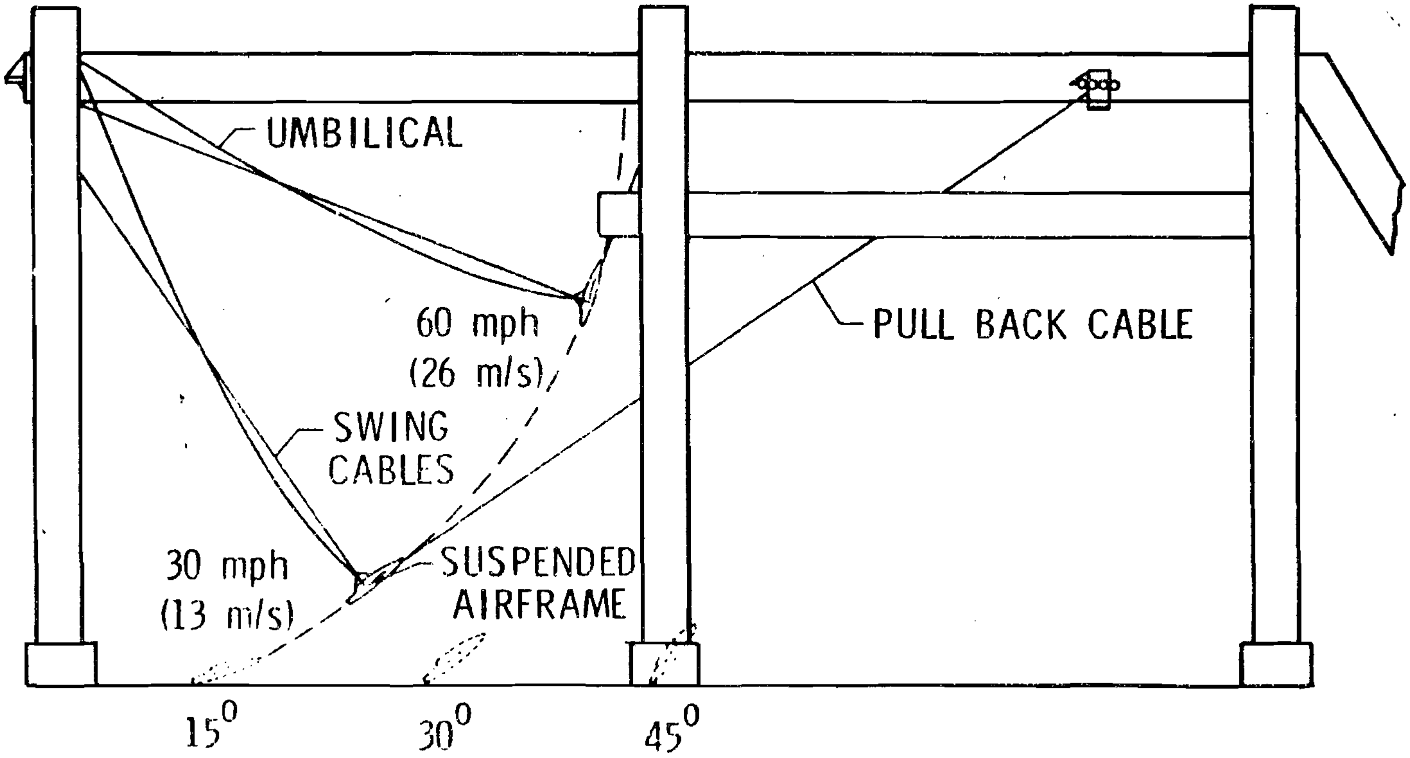


Figure 9-2. - Aircraft crash test method.

unflared landings at different impact angles, a ground cartwheel and a ground loop using single-place low-wing twin-engine jet fighters. Initially the airplane was propelled to 180 km/hr (112 mph) by its own power to the crash area, whereafter it was guided by a slipper, substituted for the nose wheel, and slaved to a guide rail. Crash barriers were arranged for each crash to produce the desired sequence of events. Barriers were used to tear off landing gears and earthen slopes were used to achieve impact angles. Onboard and surrounding cameras were used. The data was telemetered from accelerometers to a radio transmitter. The signals were sent on radio waves to the receiving station where the signals were converted back to electrical pulses which were recorded on photographic paper. The frequency response was essentially flat to 200 Hz.

The tests described in reference 86 simulated stall-spin accidents with impact speeds up to 97 km/hr (60 miles/hr). The airplanes were steel-tube, fabric covered, tandem two seat type ($\sim$ 544 kg). The airplanes struck an earthern barrier such that the left wing tip, left landing gear wheel and engine struck simultaneously. The test technique was the same as described in reference 85.

9.2 Review of Helicopter Crash Tests

There have been a substantial number of helicopter crash tests performed in the last 2 decades. Several of these tests are described in references 41, 45, 51, 89 and 90. In the last decade several tests have been performed with combined vertical-lateral or vertical-longitudinal velocities. These latter tests have been used to correlate with existing computer programs. A number of tests are planned by the U.S. Army in the 1980's. Tests of helicopters are generally free-fall impacts onto a flat rigid surface. When only a vertical velocity impact is desired, the vehicle is lifted by a crane and released. The combined velocity impacts involve a pendulum type arrangement. The current helicopter tests are being performed at the NASA dynamic impact/test facility. The impact conditions associated with the tests described in references 40, 45, 51, 89 and 90, respectively, are:

- 13.7 m/sec (45 ft/sec) vertical velocity combined with 13.4 m/sec (44 ft/sec) longitudinal velocity (crane-moving)
- 12.8 m/sec (42 ft/sec) vertical velocity (crane-stationary)
- 7 m/sec (23 ft/sec) vertical velocity combined with 5.6 m/sec (18.5 ft/sec) lateral velocity (pendulum)
- 12.2 m/sec (40 ft/sec) vertical velocity combined with 14.6 m/sec (48 ft/sec) longitudinal velocity (radio controlled)
- 12.8 m/sec (42 ft/sec) vertical velocity combined with 8.3 m/sec (27.1 ft/sec) forward velocity (pendulum)

The test article for the latter test was 11020 Kg (24300 lbs), while the other test specimens ranged in weights up to 3900 Kg (8600 lbs). Details of the instrumentation and data reduction techniques are described in the respective references.

9.3 Review of Transport Airplane Crash Tests

References 6, 7, 87, and 93 present results of test programs which were conducted with transport type aircraft. The transport aircraft ranged in weight from 9070 Kg (20,000 lbs) to 72120 Kg (159,000 lbs). A summary of several crash test results including a C-82 high-wing cargo airplane, a low-wing R-5-0 Lodestar transport airplane and a low-wing C-46 transport airplane, is provided in reference 87. The airplanes described in Reference 87 have design takeoff weights of approximately 9070 Kg (20,000 lbs) thru 18140 Kg (40,000 lbs), respectively. The actual test weights are not specified in the reference reports. Reference 93 describes a study which includes an analysis of the results of previous crash tests on both full-scale aircraft and aircraft components. The data is analyzed by relating the characteristics of the measured acceleration time histories to the characteristics of human tolerance to acceleration. The results of the analysis show that the severity of a crash for a given set of crash parameters is highly dependent upon the configuration, structural design and weight of the aircraft. Data from the L1649, C-46 and Lodestar crash tests are utilized in the study described in reference 93. References 6 and 7 describe two similar crash tests of 1950-1960 vintage transport airplanes, the DC-7 and L1649 respectively. These tests were part of a test program devised by the Federal Aviation Agency in conjunction with other participating organizations to explore the manner in which large aircraft are damaged in survivable accidents and to accurately measure the crash loads.

The following discussion has been obtained from reference 7 for the L1649 tests. The DC-7 tests were similar, but with some variations.

"Crash testing of complete transport aircraft has been conducted in the past by the National Aeronautics and Space Administration with C-46 and C-82 type aircraft, but data on larger aircraft, such as those in use at the time, has not been gathered. This test program does not include aircraft of the 'jet size', but it was hoped that analytical techniques being developed would be proven so that extrapolation of the results of this program would provide satisfactory definition of the crash environment in the newer, larger aircraft.

Three types of accidents are representative of many real crashes which are survivable or potentially survivable. These are:

1. A hard landing, with a high rate of sink, causing failure of landing gear and damage to its supporting and surrounding structure. A transport accident at Montego Bay in January 1960 was of this type.

2. A wing low impact with the ground such as occurred to a transport at the John F. Kennedy Airport in New York in November 1962.

3. An impact into large trees in an off-airport forced landing. The accident of a chartered transport near Richmond, Virginia, in November 1961 included this type of damage.

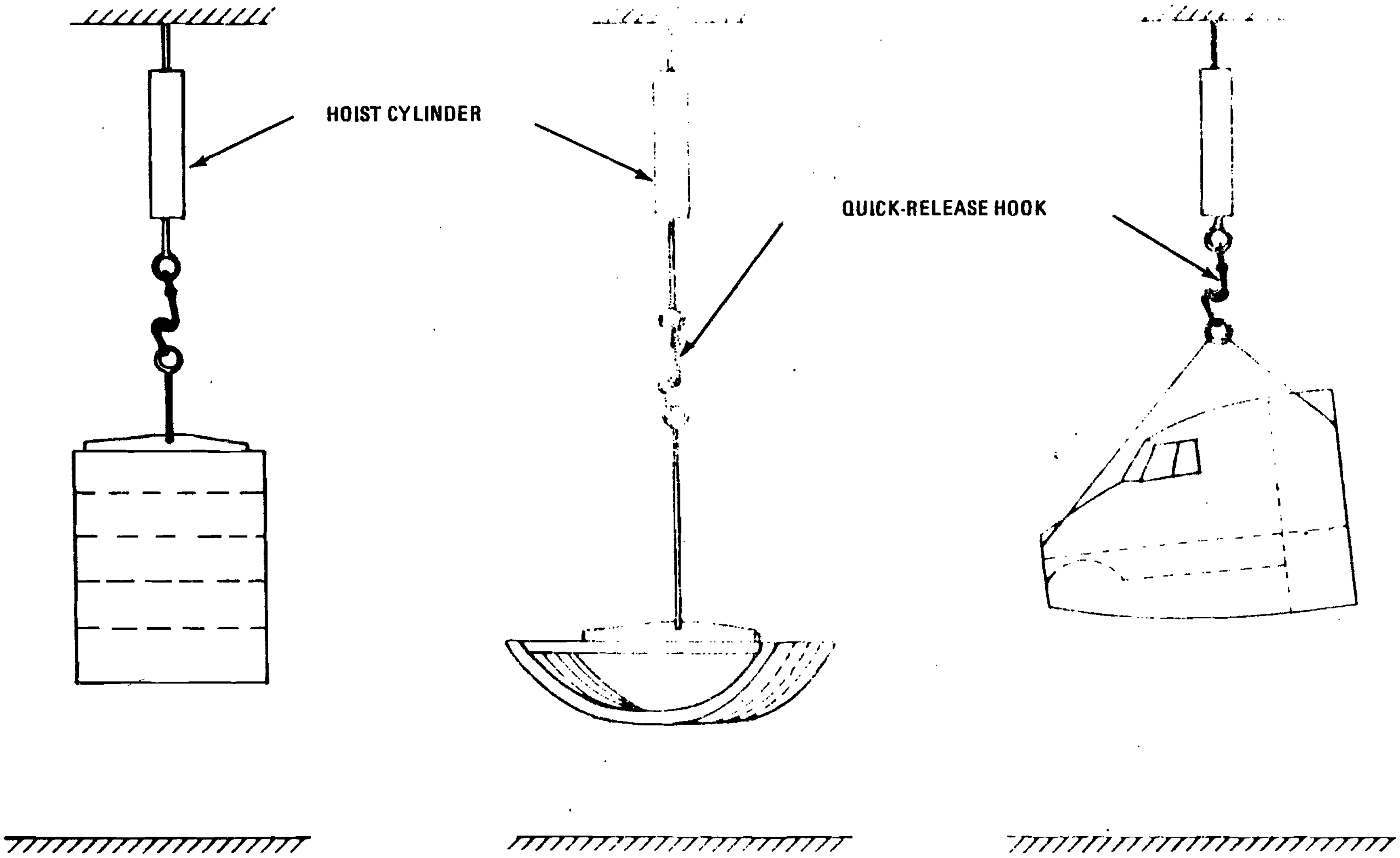
This test program was planned to produce crash conditions simulating these three circumstances followed by multiple fuselage impacts of successively increasing severity.

The test program required the design and construction of a special test site. The desired impact conditions called for accelerating the test vehicle to a velocity approximating minimum climbout speeds and final approach speeds for propeller driven transport aircraft of the types involved, and guiding of the aircraft to a closely controlled initial impact point. In addition, earthen barriers for wing and fuselage impacts had to be located and built to provide the desired sequence of impact events. The construction details of these barriers controlled the type and severity of the impacts which occurred."

Reference 94 describes a test program which included compression tests of plate-stringer panels and drop tests of representative fuselage structure consisting of 254 cm (100-inch) diameter axial cylinders, segments of a 254 cm (100-inch) diameter cylinder dropped laterally, and a structurally complete nose section of a jet transport dropped in a 10-degree nose-down attitude. The drop test set-ups for the axial cylinder, lateral segment and fuselage nose section are shown in figure 9-3. Three differently constructed axial cylinders were dropped several times from drop heights varying from .61m to 3.66m, resulting in impact velocities ranging from 3.5 m/s to 8.5 m/s. The weight of the cylindrical specimens varied from 1590 Kg (3500 lbs) to 4350 Kg (9600 lbs). Four differently constructed cylinder segments were drop tested from height variations of .61m (3.46 m/sec) to 1.22m (4.88 m/sec). The weight of each segment was 907 Kg (2000 lbs). The fuselage nose section weighed 4850 Kg (10700 lbs) and was dropped from heights of 1.83m (6.0 m/sec) and 2.44m (6.9 m/sec). The reference report provides interesting comparisons of load-deflection behavior. However, it must be noted that the lack of end closures for the lateral segment drop tests distorts the results. It is important in future test considerations to represent the load restraints and paths in a manner approximating the actual design situation.

9.4 Evaluation of Test Data

The data obtained from the FAA twin engine, low-wing and the single-engine high-wing crash tests is interesting in light of the U.S. Army dynamic test requirements for seats. Typically the acceleration response trace of a location on the floor during a crash test exhibits more than one peak depending on the events. Figure 9-4 shows a sample trace from reference 82. Note in figure 9-4 several contacts (forward cabin, main spar, wing and rear cabin) and the variation in response shape as a function of time and location. The primary triangular pulses for the -30 degrees flight path angle impact from reference 82 are plotted in figures 9-5 and 9-6 in terms of peak response

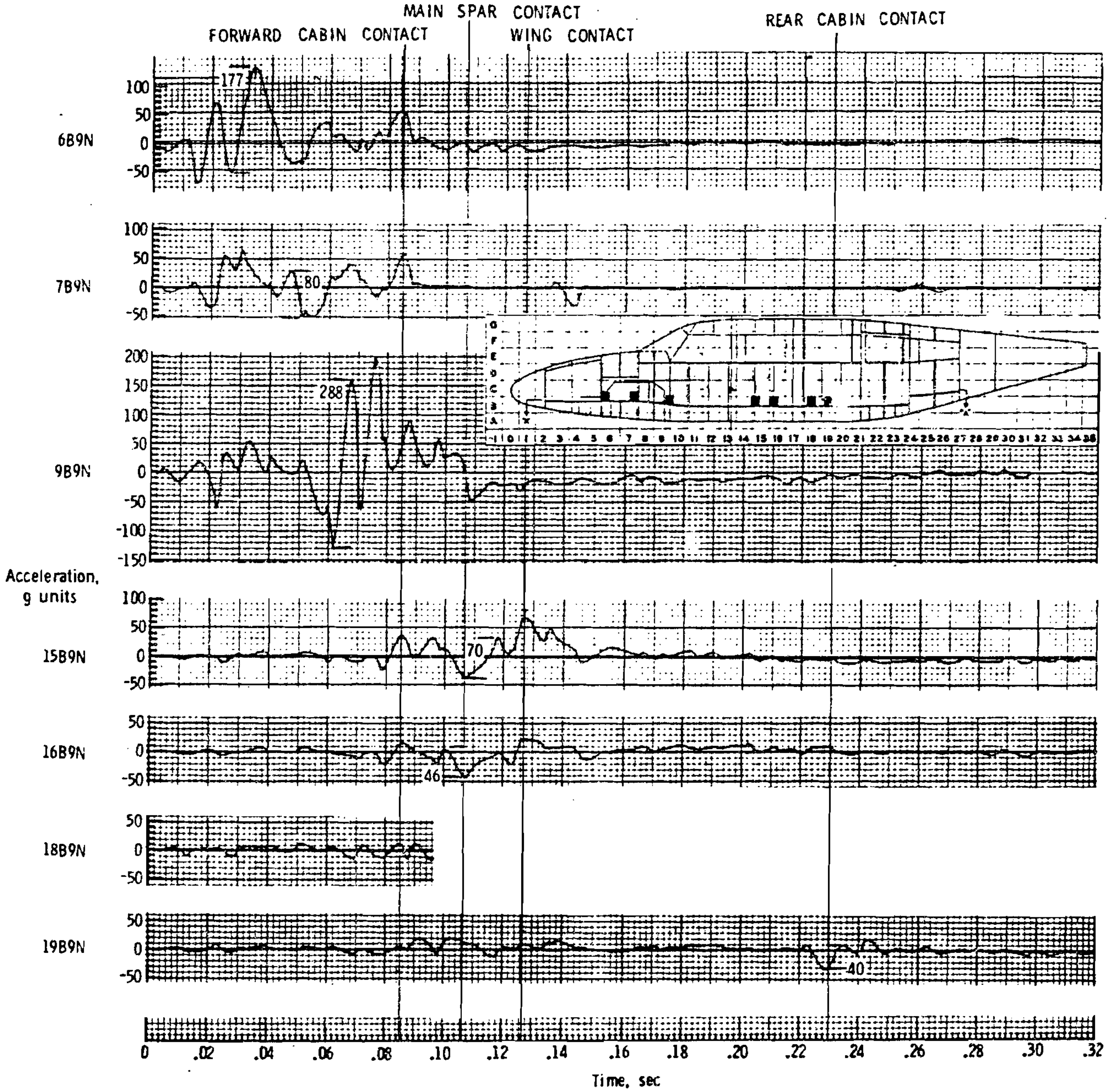


a. AXIAL CYLINDER

b. LATERAL SEGMENT

c. FUSELAGE NOSE SECTION

Figure 9-3. - Drop test setup.



(b) -30° test specimen.

Figure 9-4. - Histories of floor-beam vertical accelerations.

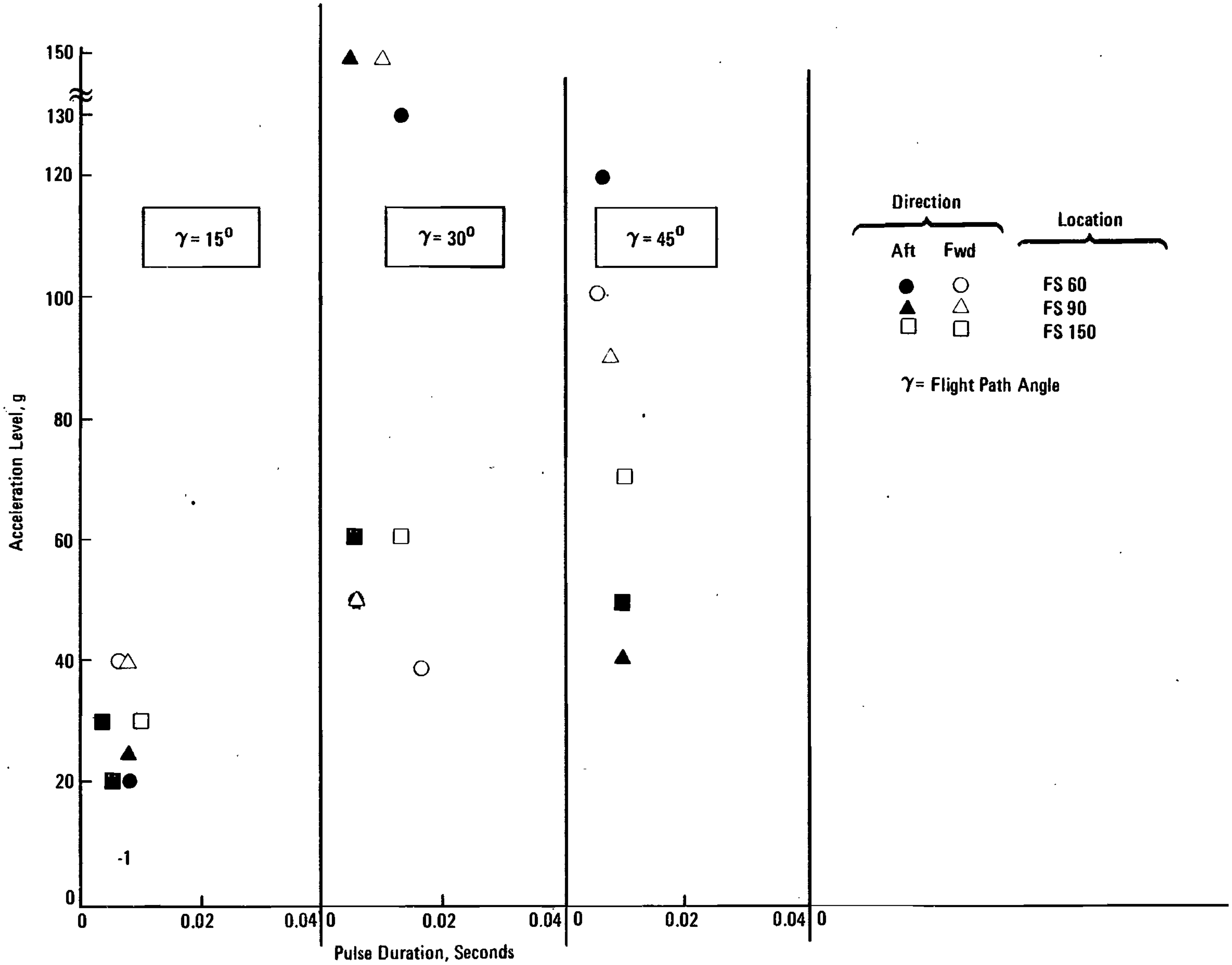


Figure 9-5. - Floor longitudinal accelerations for twin-engine, low-wing airplane as function of flight path angle.

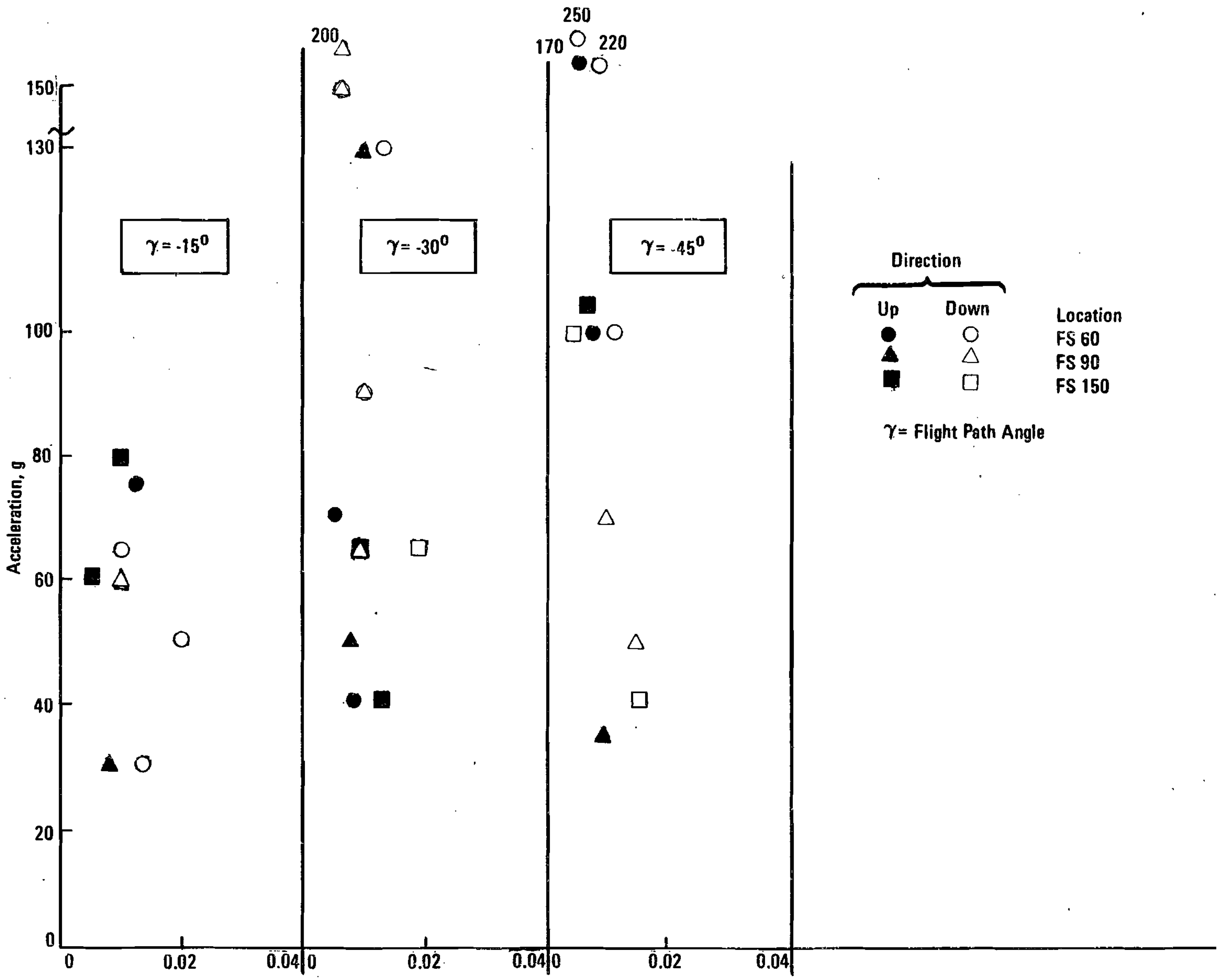


Figure 9-6. - Floor vertical accelerometers for twin-engine, low-wing airplanes as function of flight path angle.

versus duration. Data for the single-engine high-wing impact for a similar flight path impact condition is provided in figure 9-7. The impact velocities for these tests are:

	Longitudinal Velocity, m/sec	(Ft/Sec)	Vertical Velocity, m/sec	(Ft/Sec)
Twin-engine airplane	22.9	(75)	13.1	(43)
Single-engine airplane	14.3	(47)	8.5	(28)

The range of single-engine and twin-engine airplane impact velocities compare favorably with the U.S. Army 95th percentile accident design pulse velocities. Thus, it would seem reasonable that reduction of the NASA light aircraft crash test data could be performed for comparative purposes with U.S. Army crash design requirements. This could be done in one of several ways including:

- low pass filtering of the data and determining a "g" vs "ΔV" plot, which implies associated duration times
- a shock spectrum analysis of the data as described in reference 91 which includes occupant tolerance
- the utilization of single degree of freedom analysis of the response to ascertain dynamic amplification or attenuation factors

Longitudinal deceleration data obtained from other light fixed-wing aircraft tests (references 86 and 85) are shown in figures 9-8 and 9-9, respectively. The pulse shapes shown in figures 9-8 and 9-9 differ substantially from the recent NASA crash test data, in peak response, continuity of shape and duration.

There are several factors which contribute to the differences in response shapes, including:

- Tests for cub and fighter type aircraft were performed using sloped earthen mounds to impact upon while NASA tests impacted on a flat rigid surface. The earlier tests, particularly the light cub, resulted in extensive forward fuselage crushing, while in the latter tests the airplane slides along the ground.

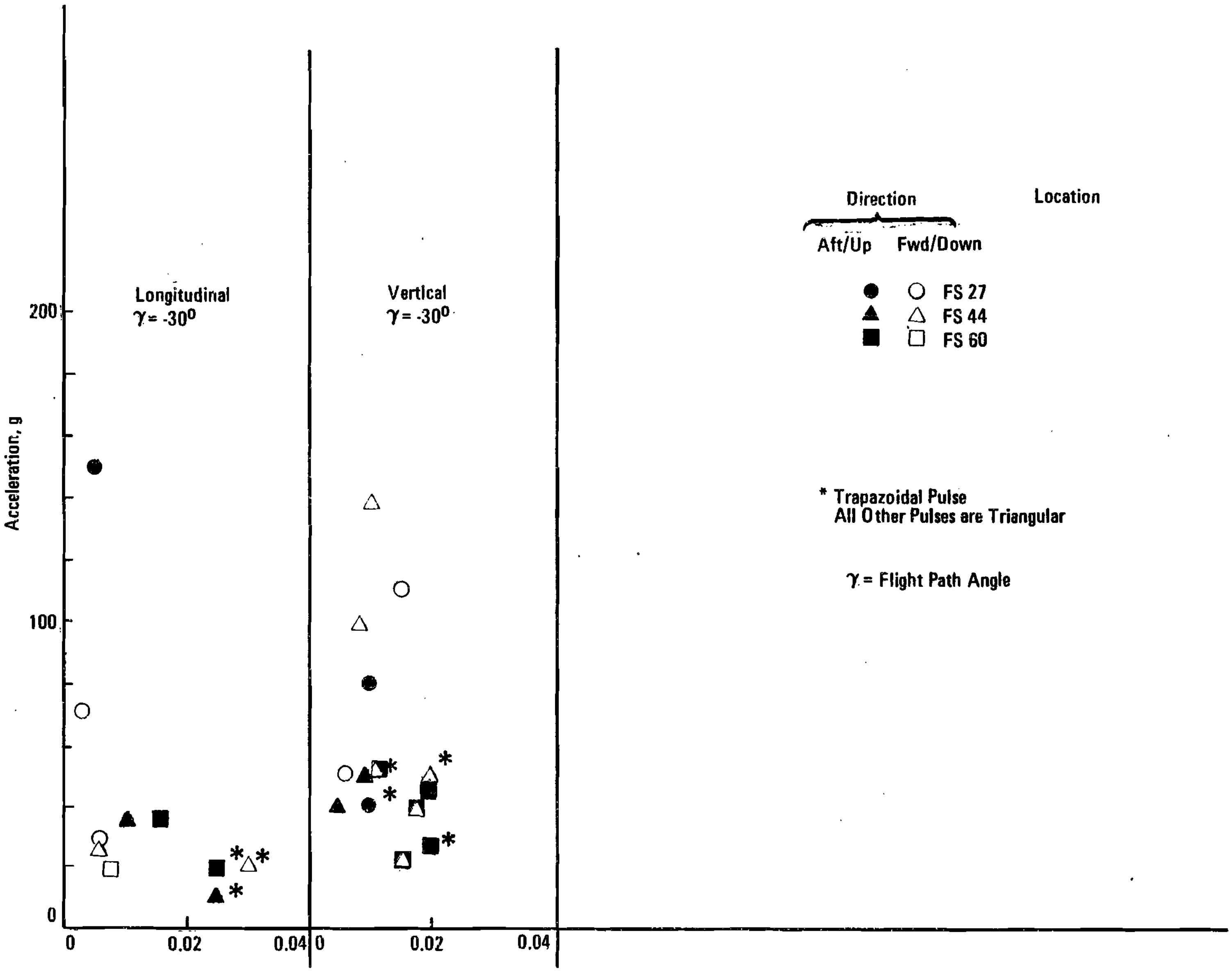


Figure 9-7. - Floor vertical and longitudinal accelerations for single-engine, high-wing airplane.

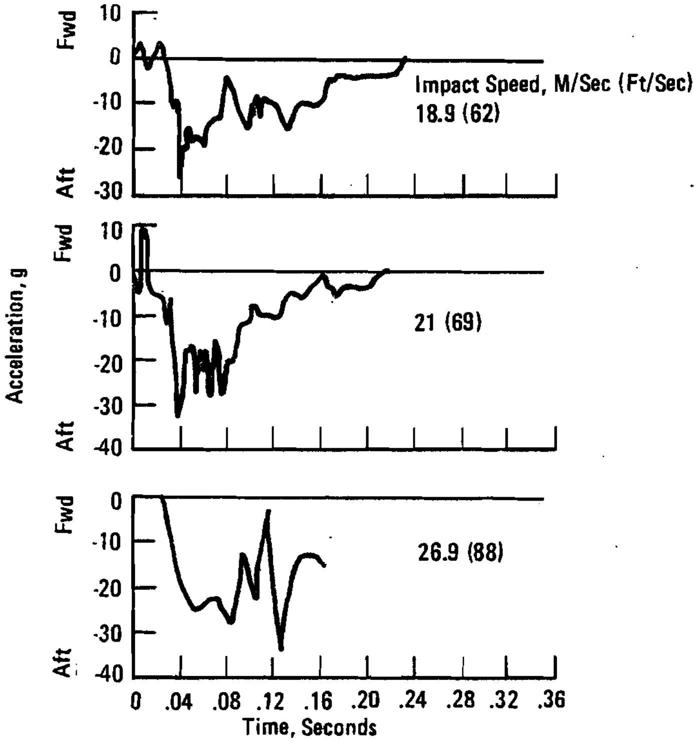
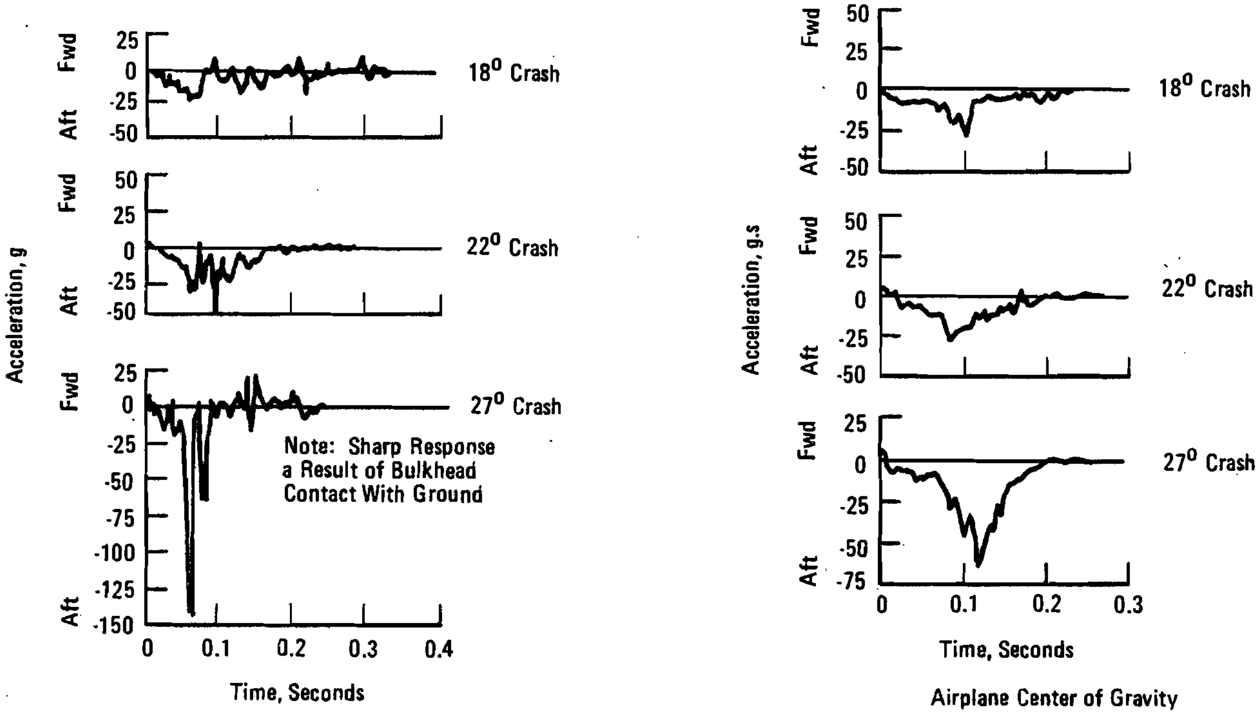


Figure 9-8. - Longitudinal deceleration of fuselage floor in crashes of cub-type light airplanes.



Cockpit Floor

Airplane Center of Gravity

Figure 9-9. - Longitudinal deceleration of FH-1 fighter airplane.

- The longer duration pulses are associated with progressive collapse of structure. The shorter duration pulses are related to intermittent impacts, some of which result from sudden failure of structure.

Figures 9-10, 9-11 and 9-12 show the longitudinal deceleration pulses for the C-82 (High Wing), R-5-0 Lodestar (Low Wing Pressurized) and C-46 (Low Wing Pressurized) airplanes, respectively. It is interesting to note that the trend is not only for reduced peak responses but also increased duration of pulse from light aircraft and fighter type aircraft to transport airplane structure.

The cargo airplane has a high wing with a fuselage pod suspended below the wing. Much of the mass of the airplane is concentrated in the wing - the wing structure, the fuel, and the engines. Consequently, this mass provides a large crushing force on the fuselage in a crash. The airplane speed at impact was 40.7 m/sec (91 miles per hour). The angle of impact of the airplane with the ground was 16°. Extensive crumpling of the fuselage forestructure occurred. As in the most severe fighter crash, the fuselage structure collapsed until the wing hit the ground. Deceleration data measured on the fuselage floor at a midship location builds up to several peaks of about 15 g as the fuselage crumples. One peak of 25 g results when the keel in the fuselage floor hits the ground. These peak decelerations endure for about 0.02 seconds each. The deceleration then essentially falls to zero, indicating that the structure is providing little resistance between 0.17 and 0.26 seconds. At 0.26 seconds the engines hit the ground and pitch the airplane up. The deceleration on the floor rises to about 7 g when the engines hit and plow the ground. From crash photos and the data in reference 86 it appears that the fuselage resisted a force corresponding to a deceleration of less than 15 g. The forward part of the fuselage is the part of the fuselage that collapsed during this crash. Structure of this type is essentially an aluminum bag suspended from the wings. This structure is soft and will transmit only small loads before it collapses. This situation is aggravated by the fact that, in this high-wing airplane, the fuselage structure must decelerate the wing and its associated high mass as well as the remainder of the fuselage. The transport airplanes described in reference 87 are low-winged and the wings

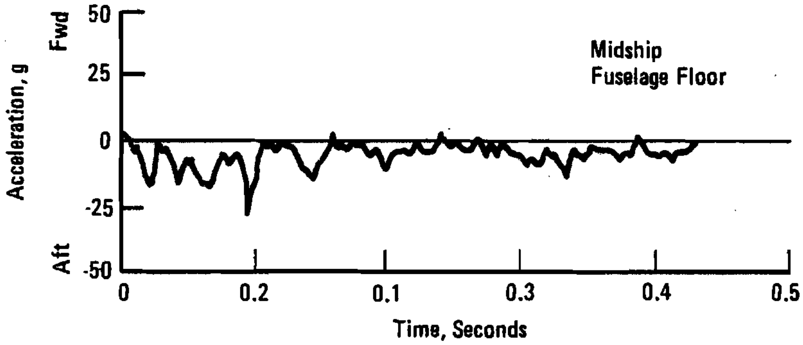
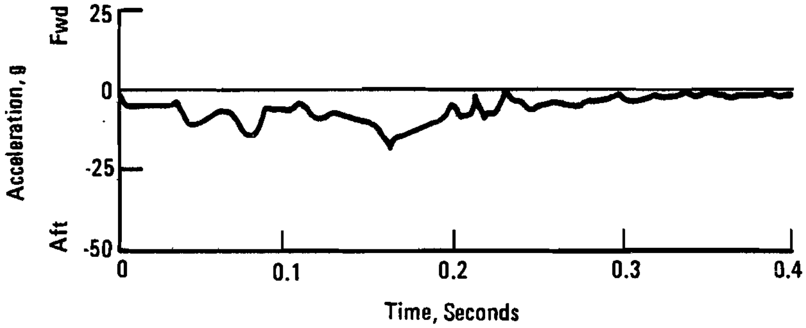


Figure 9-10. - Longitudinal deceleration resulting from first impact in 16° crash of C-82 cargo airplane.



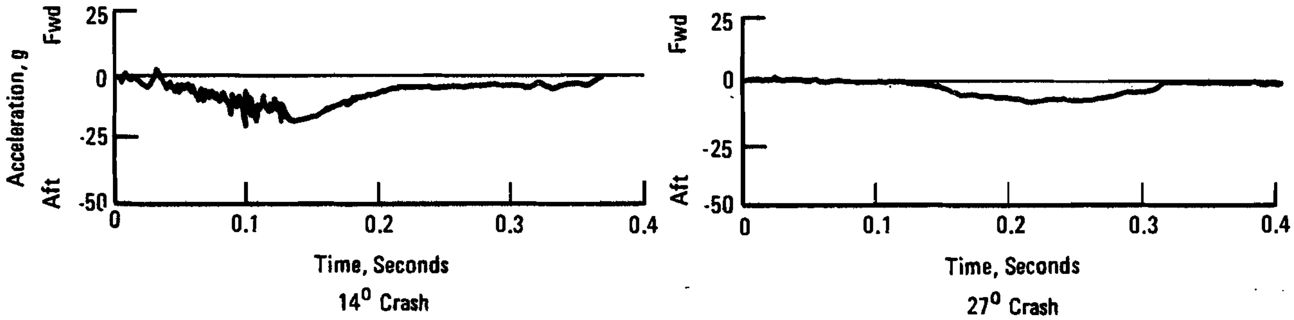


Figure 9-12. - Longitudinal deceleration of fuselage floor of C-46 transport airplane.

with their large mass hit the ground almost immediately. Consequently, the crushing force on the fuselage is considerably reduced. This effect was seen in the crash of an unpressurized transport, Lodestar airplane. The airplane speed just before impact was 48.8 m/sec (109 miles per hour). The angle of impact with the ground was 16°. The engines and wings took nearly all the crash blow. The fuselage did not crush to any significant extent. The deceleration measured on the fuselage floor at about the center-of-gravity of the airplane rises to a peak of about 8 g at 0.06 and 0.08 seconds when the engines and nacelles hit the ground. The deceleration rises again to a peak of 16 g at about 0.17 seconds when the fuselage hits the ground and the engines plow deeper.

Because of the little damage to the fuselage that resulted from this crash, it appeared that this airplane provides a greater crash tolerance than the high-wing cargo airplane. From the test results it was presumed that this airplane could withstand a more severe crash than the 16° crash to which it was subjected in this investigation. The wing, which took nearly all the crash blow, showed very little damage. It is reasonable to expect, therefore, that this airplane will provide a high crash tolerance in spite of the fact that the fuselage is not as strong as those of modern pressurized transports.

The fuselage on some low-wing transport airplanes, such as the C-46, protrudes far enough ahead of the wing to receive a considerable proportion of the main blow in a crash like this. When the C-46 transport was subjected to the same crash, little fuselage deformation occurred. The forestructure took a great deal of the crash blow. Despite this, the stiff forestructure did not crush. This provided a smooth surface for the airplane to slide on. In contrast to the Lodestar crash where the engines dug into the ground, the C-46 did not plow the ground heavily. The deceleration of the fuselage floor measured in the forward part of the cabin rose gradually to a peak of 9 g. The duration of the deceleration was long, lasting about 0.20 seconds. This represents a velocity change of about 12.2 m/sec (40 ft/sec), which appears low in light of the impact velocity of approximately 42.4 m/sec (139 ft/sec) associated with this test. Presumably the remaining velocity is reduced in sliding at a low deceleration level for the data to be correct.

A summary of the light fixed wing and transport aircraft test conditions is shown in table 9-1. All the tests were conducted utilizing an airplane guided along a track and impacting into a sloped dirt mound. Table 9-2 compares the peak acceleration of four of these aircraft.

The decelerations for the fighter airplane were high because the crashed structure in the forepart of the airplane exposed sharp edges of strong structure that dug deeply into the ground. This plowing produced a greater retarding force on the airplane and, consequently, greater decelerations.

The cargo airplane decelerations were lower than those of the fighter airplanes despite the extensive plowing of the fuselage, because the fuselage

TABLE 9-1. - SUMMARY OF FIXED-WING CRASH TEST CONDITIONS

Airplane	Approximate Weight, Kg (lbs)	Velocity m/sec (ft/sec)	Slope (Degrees)
Piper	543 (1,200)	18.8 (61.7)	55
		21.1 (69.1)	55
		20.8 (68.2)	55
FH-1	4530 (10,000)*	50.2 (164.6)	18
		50.2 (164.6)	22
		50.2 (164.6)	27
C-82	19026 (42,000)*	40.8 (133.8)	16
Lodestar	9739 (21,500)*	39 (127.9)	12
		48.8 (160.2)	16
C-46	18120 (40,000)	41.7 (136.7)	14
		43.5 (142.6)	27
L1649	72027 (159,000)	52.4 (172.0)	6
		39.0 (103.0)	20
DC-7	55266 (122,000)*	67.2 (220.5)	8
		49.3 (161.7)	20

*Max. Takeoff Weights, Test Weight Not Stated

TABLE 9-2. - COMPARISON OF PEAK DECELERATIONS AND DURATIONS
(Reference 87)

Airplane	Longitudinal Deceleration g	Approximate Duration Sec.
Fighter, FH-1	40	≤.02
Packet-Type Cargo, C-82	15	.02
Unpressurized Transport, Lodestar	16	.05 - .08
Pressurized Transport, C-46	9	.200

is made up almost entirely of soft structure which crumpled progressively. A 25-g peak occurred when the relatively strong floor keel dug into the ground. The crushing structure, however, voided a great deal of living space in the fuselage.

The low wing and stiff nose of the transport airplanes provided a smooth planing surface for the airplanes to slide on, and consequently, the longitudinal decelerations are low.

The floor measured longitudinal and vertical acceleration time histories for the L-1649 tests are shown in figures 9-13 and 9-14 for the 6 degree slope impact. The peak triangular pulse responses are summarized in table 9-3.

TABLE 9-3. - L1649 6 DEGREE SLOPE IMPACT FLOOR PULSES

	Longitudinal Direction		Vertical Direction	
Fuselage Station	Peak, G (Aft)	Duration, sec.	Peak, G (Up)	Duration, sec.
195	20	.020	24 20	.050 .100
460	10	.020	NA	NA
685	10	.080	10 20	.030 .010
925	10	.080	15	0.10
1165	8	.080	10	.020

NA Not Available

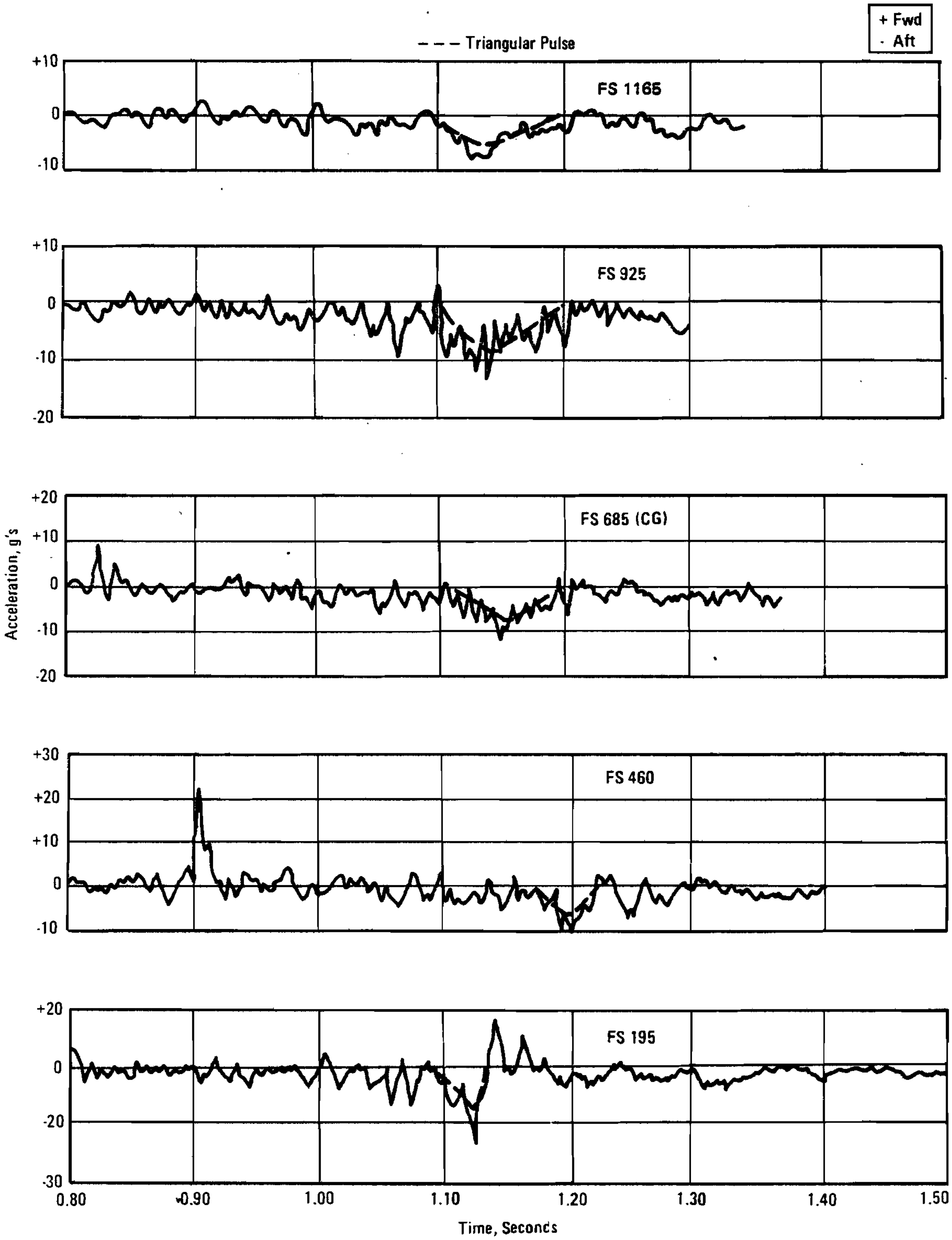


Figure 9-13. - Floor longitudinal accelerations, L1649 test, 6° slope impact.

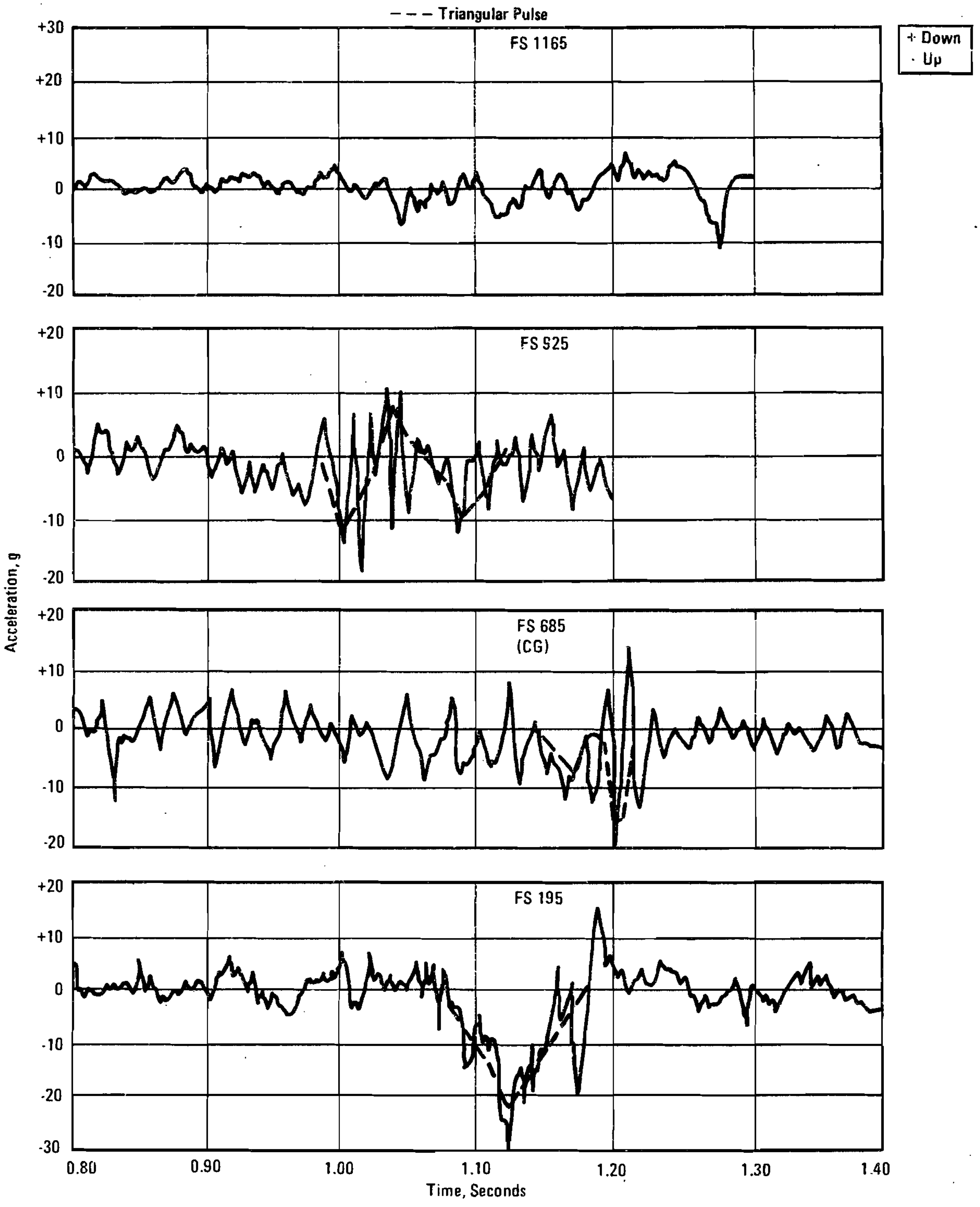


Figure 9-14. - Floor vertical accelerations, L1649 tests, 6° slope impact.

Figures 9-15 through 9-18 show typical vertical floor pulses for the Lodestar and C46 transport airplane tests, for which longitudinal responses were previously presented (figures 9-11 and 9-12).

Figure 9-19 shows the peak responses from figures 9-14 through 9-18 cross-plotted as a function of effective normal velocity (ENV), and duration. As can be anticipated, the overall trend is for increased peak acceleration as the ENV increases. The acceleration pulse durations, as shown in figure 9-19, show a range of scatter from .01 to .10 seconds.

In reference 92, a summary of transport airplane crash data is presented. This data is for the C-46, Lodestar and C-82 airplanes. The duration of pulses tabulated in reference 92 ranges from .10 to .35 seconds which appears high compared to the applicable time histories previously presented. The determination of a pulse duration can be very subjective as is illustrated in figure 9-20 which shows sample time-histories obtained from reference 91. This figure illustrates the manner in which the time-history response data is faired. To compare L1649 crash test results in the same basis as the previous transport crash test the L-1649 data was faired in a similar manner, as shown in figures 9-21 and 9-22. The L-1649 is then normalized to a 42.6 m/sec (95 mph) impact velocity and presented in figures 9-23 and 9-24. Figure 9-24 shows the L-1649 longitudinal acceleration slightly above the other low-wing transport data and below the high-wing data. Figure 9-24 shows that the L-1649 normal acceleration data for the 6° slope is between the 5° and 12° slope data and exhibits a similar trend as a function of distance from impact. Some salient observations regarding the available transport airplane crash pulse data are:

- The available test pulse data for transport airplanes is for one particular accident situation, e.g., airplane impact onto a sloped dirt terrain,

- The pulse definition, provided in the evaluation of the test data, is very dependent on the manner in which the data is reduced.

Figure 9-15. - Vertical decelerations resulting from first impact in 12° crash of R-5-0 Lodestar transport airplane.

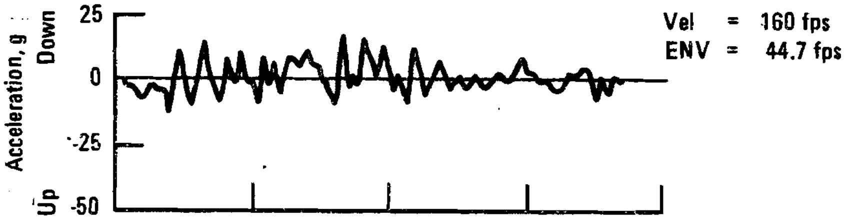


Figure 9-16. - Vertical decelerations resulting from first impact in 16° crash of R-5-0 Lodestar transport airplane.

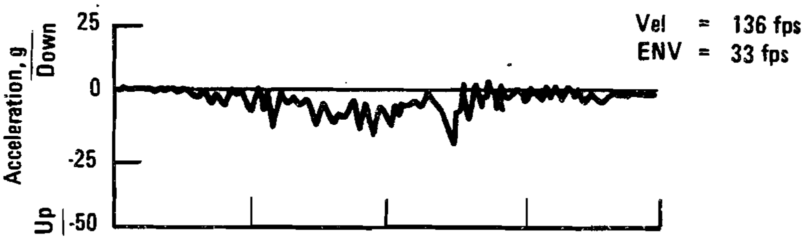


Figure 9-17. - Vertical decelerations resulting from first impact in 14° crash of C-46 transport airplane.

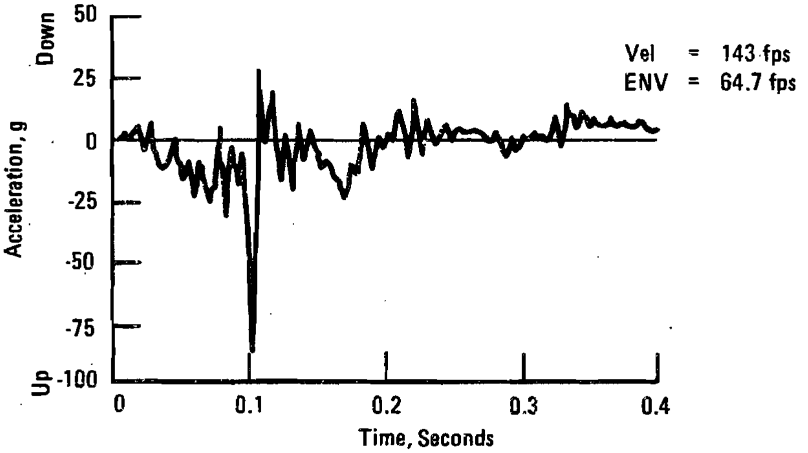


Figure 9-18. - Vertical decelerations in 27° crash of C-46 transport airplane.

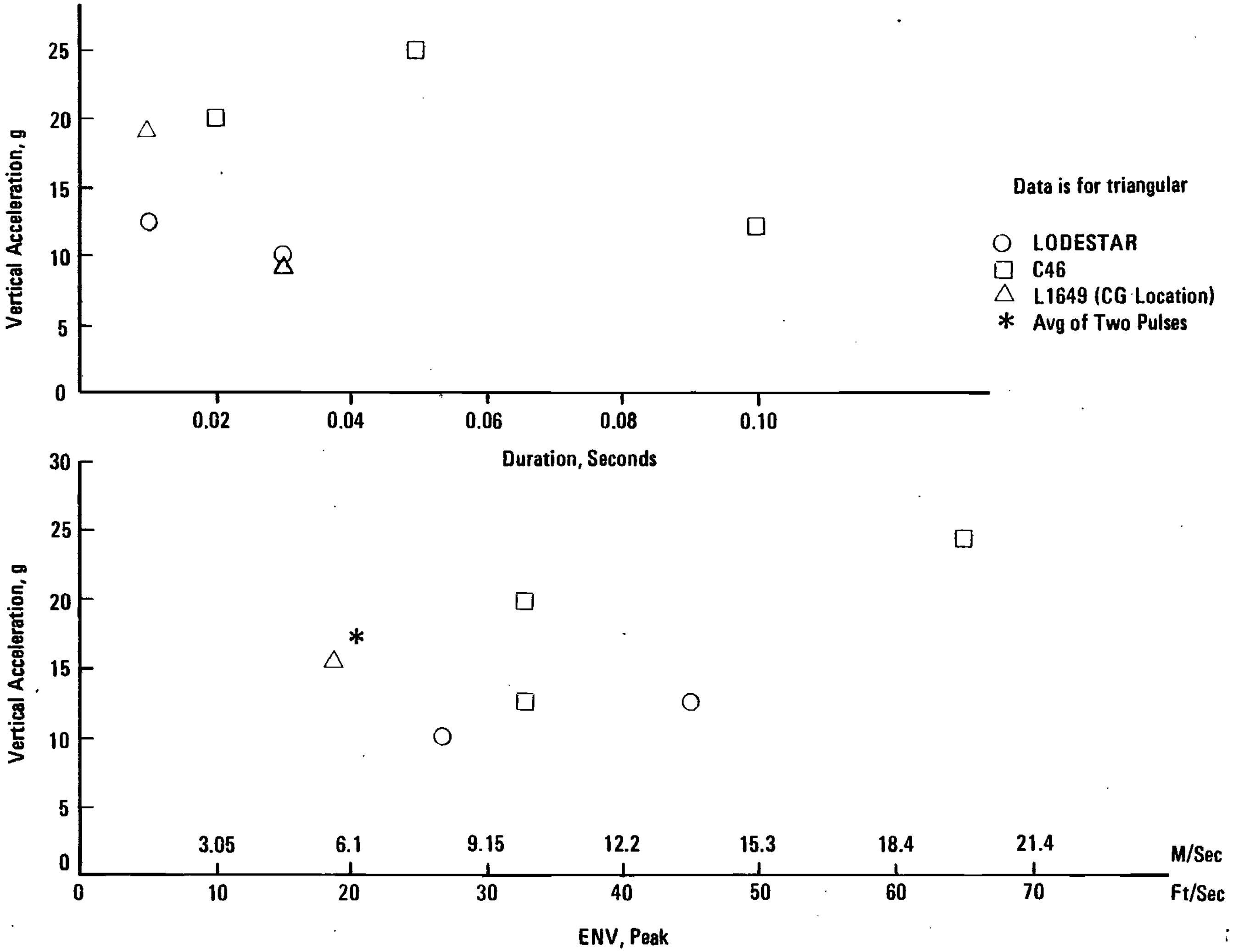


Figure 9-19. - Peak vertical acceleration as a function of ENV and duration.

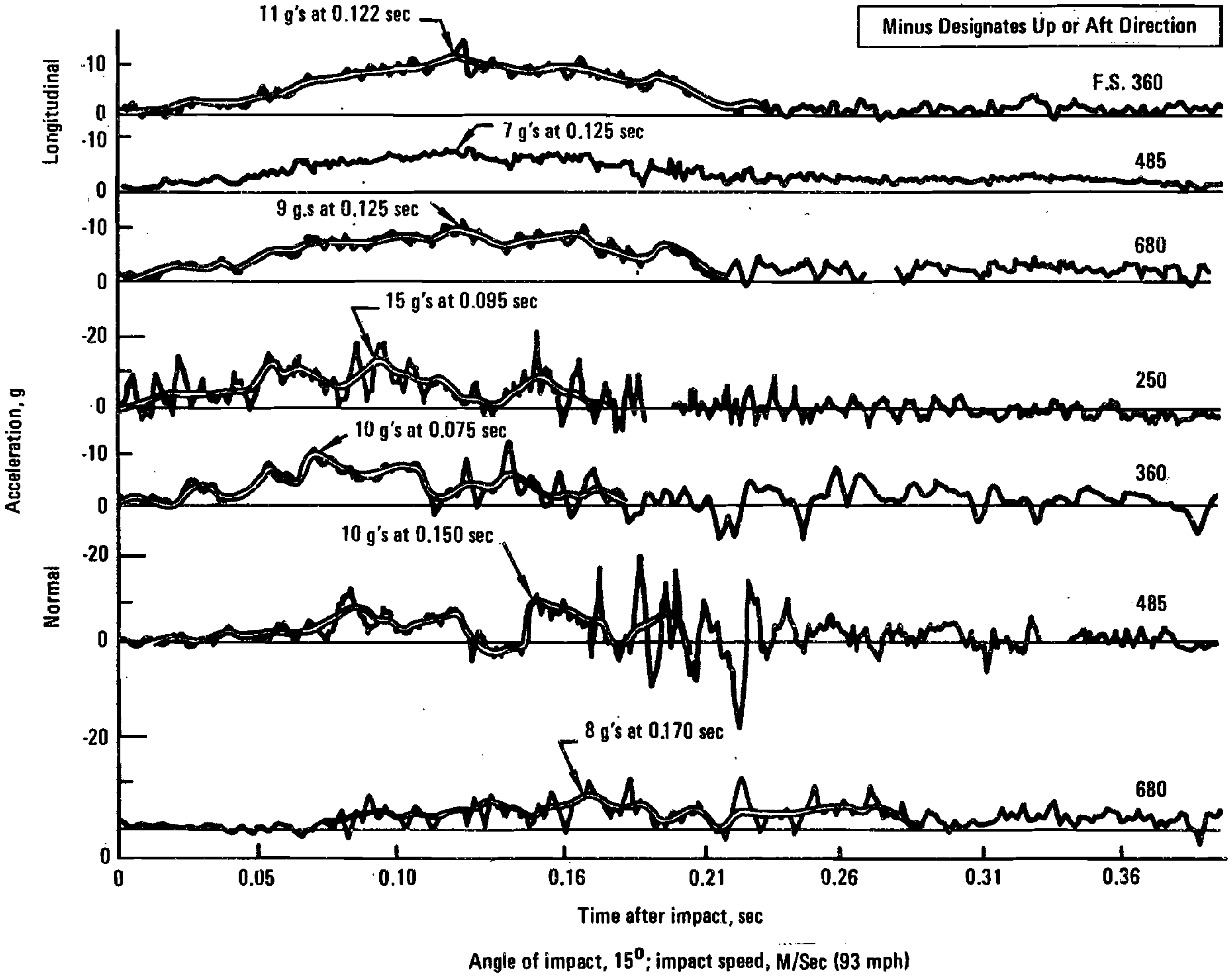


Figure 9-20. - Accelerations of crashes of pressurized transports. (Zero time is fuselage nose impact with ground.)

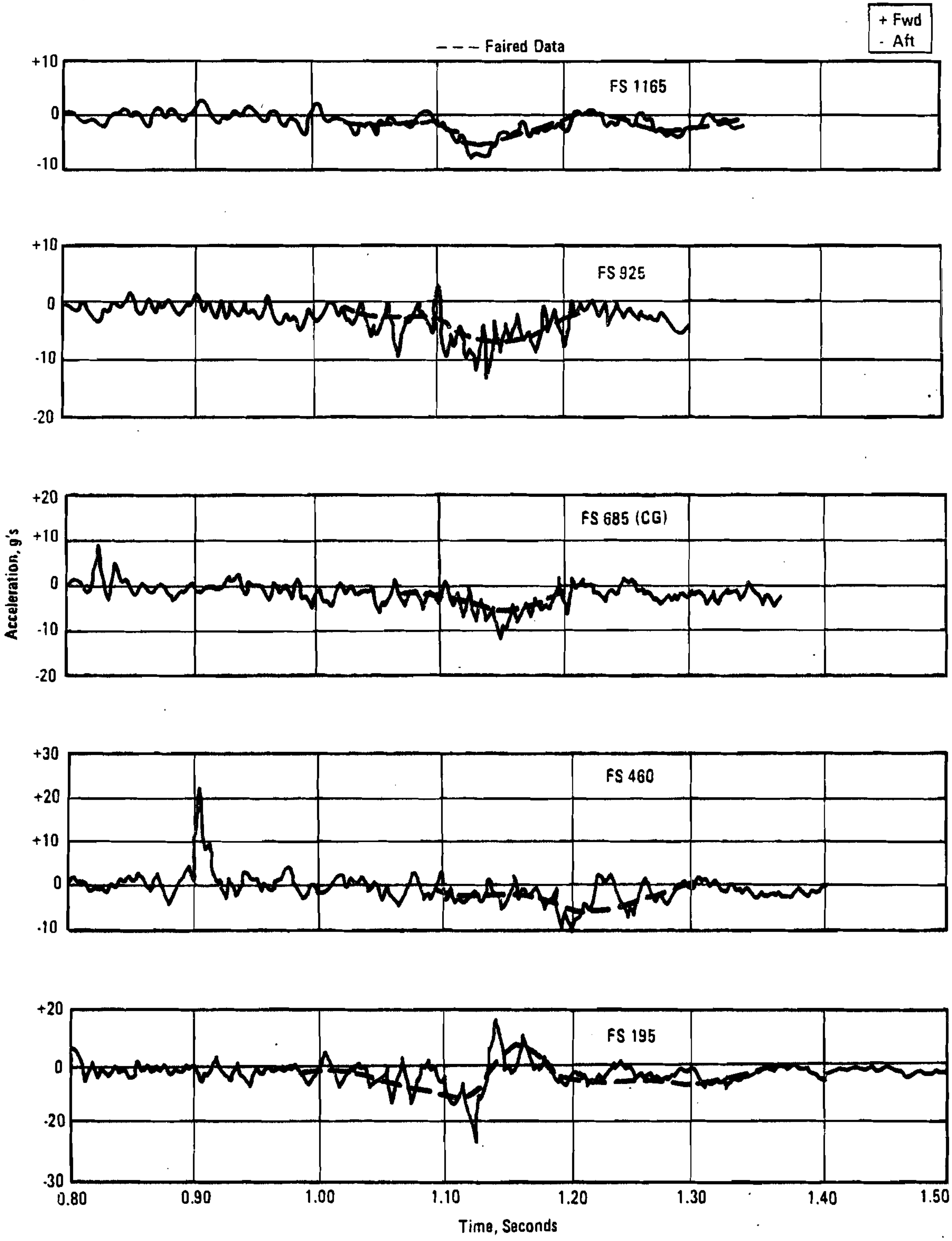


Figure 9-21. - Floor longitudinal accelerations, L1649 test, 6° slope impact.

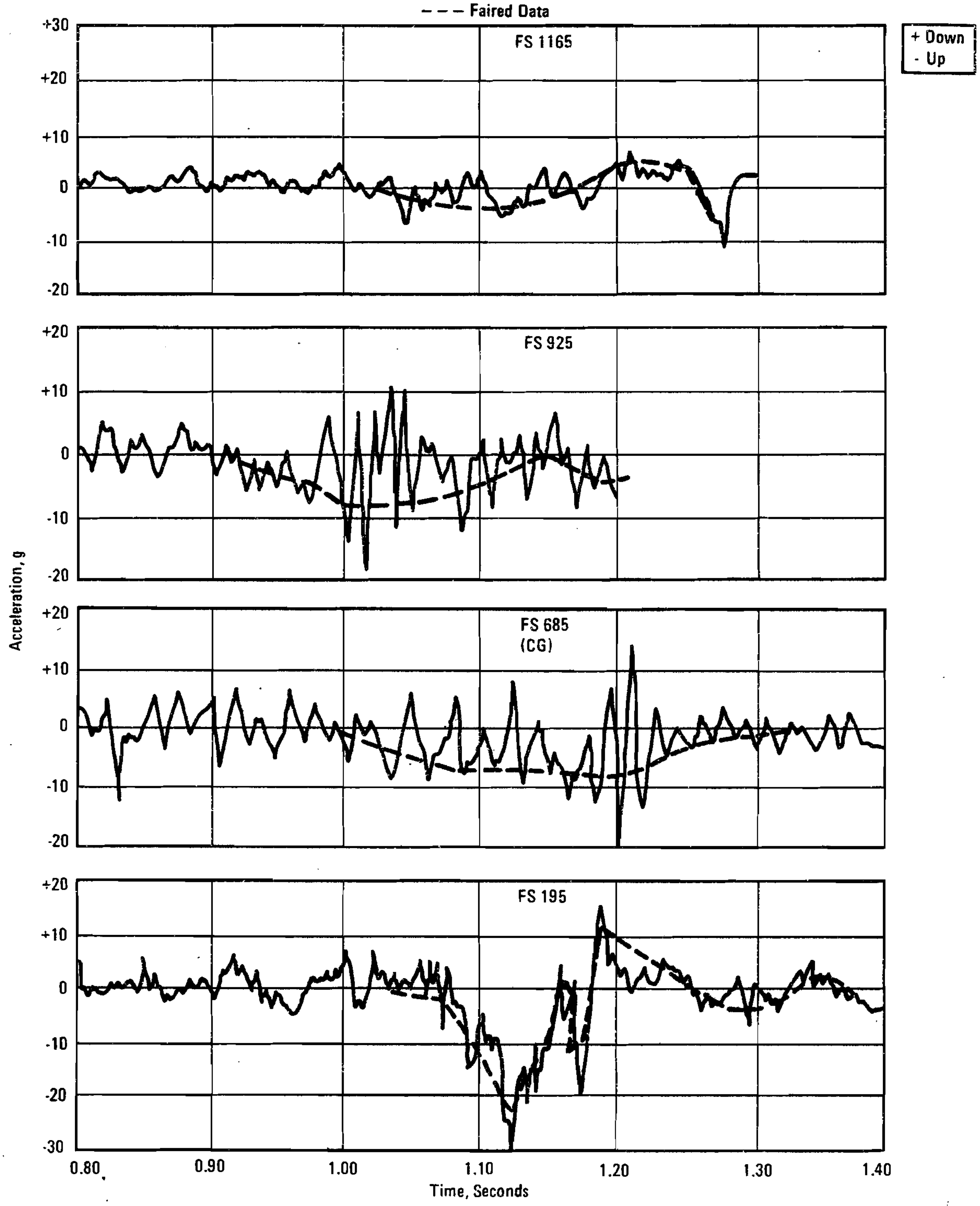


Figure 9-22. - Floor vertical accelerations, L1649 tests. 6° slope impact.

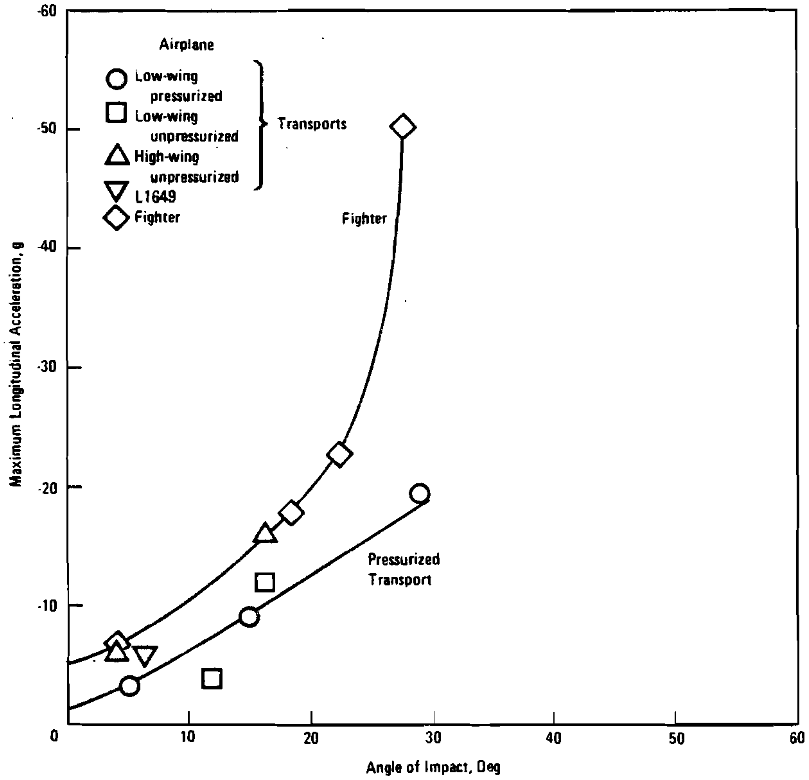


Figure 9-23. - Effect of airplane configuration on variation of maximum longitudinal acceleration with impact angle (all impact speeds corrected to 95 MPH).

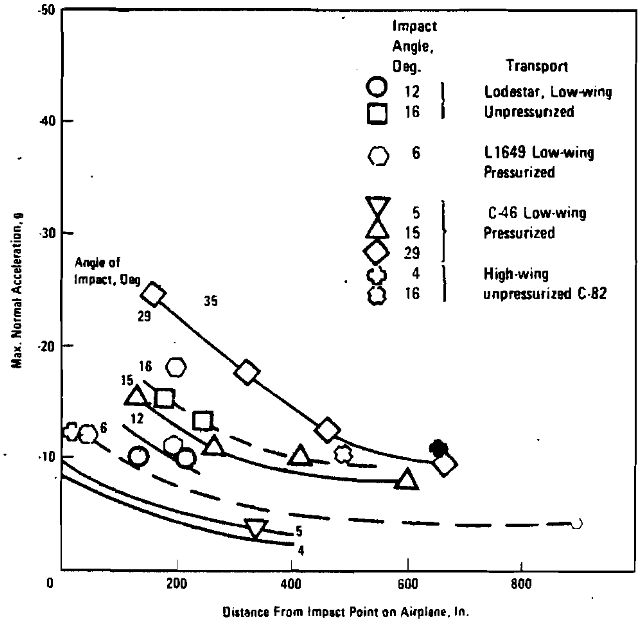


Figure 9-24. - Effect of position in airplane and airplane configuration on maximum normal accelerations during unflared landing crashes (impact velocity corrected to 95 MPH).

- The acceleration level and pulse shape is dependent upon such variables as airplane attitude, airplane structure, airplane velocity, type of surface and/or obstacles the airplane hits. Different accident conditions, i.e., hard landing on the runway versus an overrun off the runway, will produce different pulses. The pulse varies as a function of location along the fuselage and the relative distance from the impact point.

- The trend with larger jet transports indicates an anticipation of acceleration levels of lesser magnitude and longer duration than the earlier vintage transports and lighter aircraft despite the increase in weight and operating speed. The reasons for this are (1) the wider body jets have stronger airframes which could reduce plowing and (2) there is more crushable structure between the impact point and the floor location of the occupants.

10. PROPOSED ANALYSES AND TESTS

10.1 Proposed Analyses Program

The flow diagrams provided in figures 7-1, 7-2 and 7-3 illustrate that there are many potential failure modes associated with the candidate crash scenarios. While it may be desirable to perform a complete analysis using only one computer technique this may not be the most practical approach. For example, while the AGIP was used to determine if fuselage, wing or engine design loads were exceeded during 5 fps emergency landing conditions (reference 62), subsequent Conversational Program System (CPS) analysis, which is more economical than AGIP, was used to examine slide-out loads and static engine mount loads. The determination of these loads was important in order to assess doorsill heights relative to the ground for slide evacuation procedures. The use of one or more techniques and several stages of analysis are proposed. Figure 10-1 shows a flow diagram in which the different analytical techniques can be utilized for various stages and purposes of analysis. Table 10-1 describes briefly the applicable event, analysis and program/procedure purpose as well as advantages and/or disadvantages associated with the choice of analytical method. From table 10-1 and figure 10-1 it can be seen that several stages of analyses are considered. For each scenario there is an established set of impact parameters such as forward velocity, sink speed, airplane attitude, airplane configuration, terrain and hazards.

Stage 1 analyses consist of performing an analysis of a system or a section in detail, with the rest of the structure modeled either rigidly or crudely. The purpose of this analysis is to utilize the capability of a detailed analysis to define failure modes but to avoid the unnecessary cost associated with detailed modeling of regions which do not contribute significant responses or result in failures for the condition or time of

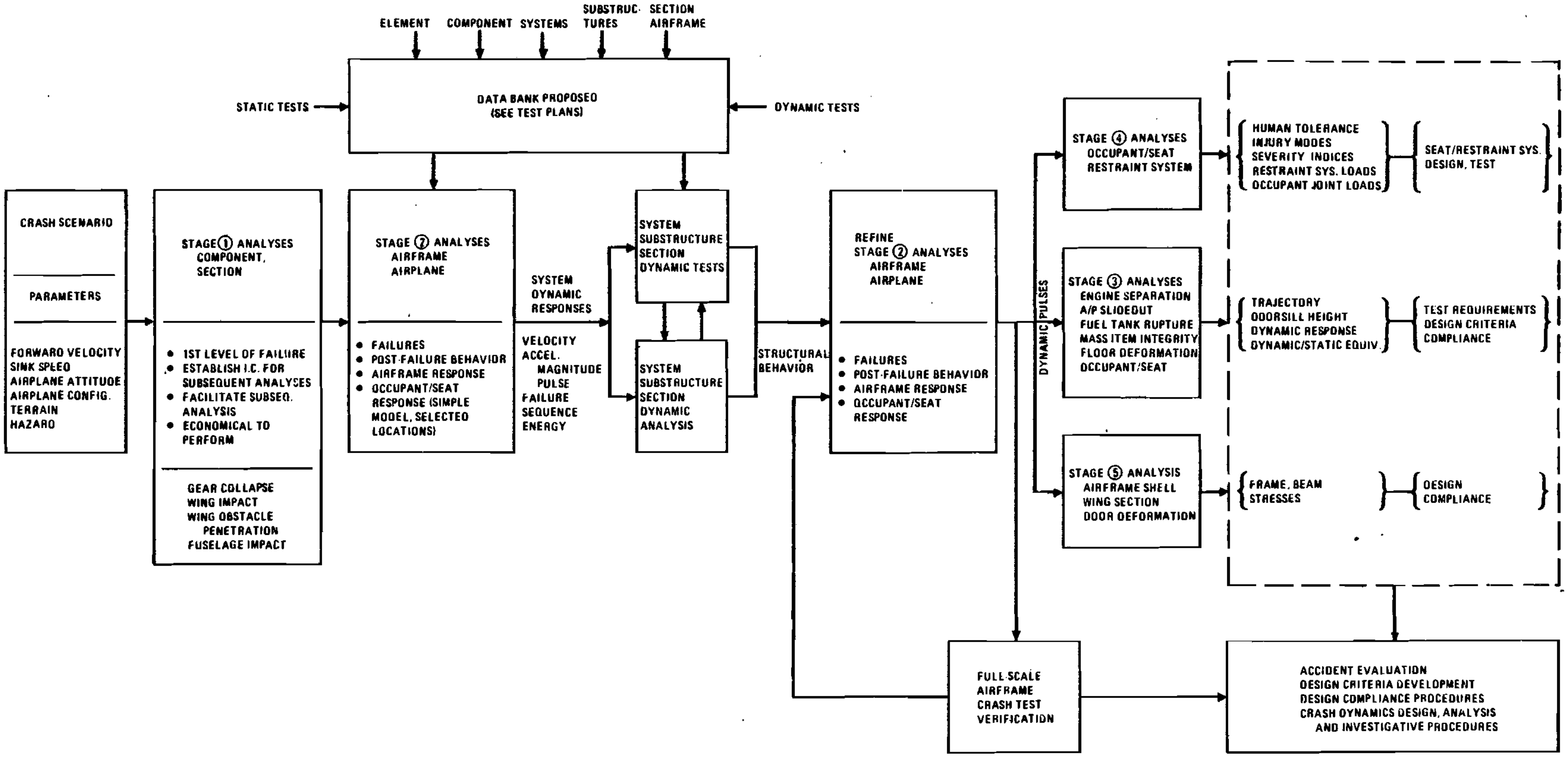


Figure 10-1. - Proposed analytical flow diagram.

TABLE 10-1. - PROPOSED ANALYTICAL PROCEDURES

APPLICABLE EVENT/RESPONSE	ANALYSIS	PROGRAM/PROCEDURE	PURPOSE	ADVANTAGE	DISADVANTAGE
• MAIN GEAR COLLAPSE • NOSE GEAR COLLAPSE • WING IMPACT (INITIAL)	STAGE (1) LANDING GEAR DETAIL, RIGID AIRPLANE, CONTOURED TERRAIN, I.E., SLOPE	• MODAL • HYBRID	• OBTAIN FAILURE MODE OF GEAR(S) • ESTABLISH IMPACT CONDITIONS FOR AIRFRAME AND/OR WING STRUCTURE	• ECONOMICAL TO RUN • MODEL DETAIL WHERE REQUIRED FOR INITIAL EVENT	• INCOMPLETE ANALYSIS INSOFAR AS POST-FAILURE BEHAVIOR AND OCCUPANT RESPONSES
• WING GROUND IMPACT • FUSELAGE GROUND IMPACT • OBSTACLE PENETRATION INTO WING • LANDING GEAR PENETRATION INTO WING BOX • NOSE GEAR PENETRATION INTO FUSELAGE	*/+ STAGE (2) AIRFRAME AND WING REPRESENTATION AND COMPLETE TIME HISTORY OF EVENTS SUBSEQUENT TO GEAR COLLAPSE	• HYBRID	OBTAIN • FAILURES • POST-FAILURE BEHAVIOR • AIRFRAME RESPONSES • OCCUPANT RESPONSES	• PERFORM CONTINUOUS ANALYSIS FOR AIRFRAME AND OCCUPANT BEHAVIOR	• COULD LACK DETAIL REPRESENTATION IN SOME AREAS • RELATIVELY COSTLY TO RUN FOR SLIDEOUT CONDITIONS
• ENGINE SEPARATION • SLIDEOUT • OCCUPANT/SEAT • OVERHEAD RACK • FUEL TANK	+ STAGE (3) SIMPLE ANALYSIS TO DETERMINE MASS RESPONSES, LOSS OF STRUCTURE AND POTENTIAL DOORSILL HEIGHTS AFTER SLIDEOUT	• DYNAMIC RESPONSE CURVE • HYBRID • EMPIRICAL RELATIONSHIP	DETERMINE • DYNAMIC RESPONSE OF MASS ITEMS • DYNAMIC STATIC RELATIONSHIPS • CONSEQUENCE OF LOSS OF STRUCTURE • DOORSILL HEIGHTS FOR EVACUATION	• SIMPLE TO APPLY • REPRESENTS THE BASIC PHENOMENA • CAN BE TRANSLATED INTO TEST REQUIREMENTS	• NOT DETAILED FOR STRESS PURPOSES
• SEAT/RESTRAINT/OCCUPANT	+ STAGE (4) OCCUPANT, SEAT, RESTRAINT MODEL	• OCCUPANT MODEL	• OBTAIN DETAILS FOR SEAT, RESTRAINT SYSTEM, AND DELETHALIZATION DESIGN	• UTILIZE PROGRAM SPECIALIZING IN RESTRAINT SYSTEM AND OCCUPANT BEHAVIOR	• NOT REQUIRED IF ONLY BASIC OCCUPANT RESPONSE IS TO BE EVALUATED
• AIRFRAME LOADS • DOOR DISTORTION • FLOOR DISTORTION	+ STAGE (5) AIRFRAME, FUSELAGE SHELL, DOOR DEFORMATION, WING SECTION DETAILS	• FINITE ELEMENT	• PERFORM DETAIL ANALYSIS OF A REGION, SECTION	• DETERMINE DETAIL BEHAVIOR WITH STRESS-STRAIN RELATIONSHIPS	• COST IS RELATED TO DEGREE OF DETAIL DESIRED

* PERFORM STAGE 1 AND STAGE 2 ANALYSIS OR START WITH STAGE 2

interest. The modeling of the system as opposed to the total airframe lends itself to utilizing relatively inexpensive tests with which to perform correlation with analyses. The modeling of a landing gear is a typical example of a stage 1 analysis.

Stage 2 analyses consist of a complete airframe or vehicle in which time histories of response for the structure are obtained. The analysis at this level is designed to determine failures, post-failure behavior and overall occupant responses. Using a program such as KRASH is desirable provided detail stresses are not required. Analysis at this level can be used to define dynamic inputs to element, component and systems in order to evaluate dynamic responses. Analyses for the response of the occupant, major mass items, structural system losses and fuel tanks can utilize stage 2 results.

Stage 3 analyses can be performed with cost-effective simple programs which utilize the data obtained from more complex analyses. Since these programs can account for the basic phenomena associated with the characteristics of a particular system they can be very effective. For example, a single degree-of-freedom response curve can be used to determine dynamic loads experienced by occupants for a number of floor pulses. A modified version of KRASH treating a flexible engine/pylon mount arrangement on a rigid wing and fuselage could be used for engine separation studies. Structure test data and human tolerance data could be utilized in a semi-empirical fashion to determine severity indices. An example of a severity index developed from the use of a shock spectra technique is presented in reference 91. This approach would allow for a trend evaluation as well as a first order approximation to determine if potentially severe occupant responses could be anticipated, but the approach would be limited if details for stress analyses purposes were desired.

Stage 4 analyses require the use of a specialized program such as SOMLA or PROMETHEUS. The intent of this analysis would be to analyze restraint system and occupant behavior, particularly submarining and flailing. While gross approximations of the occupants' behavior could be modeled with programs like KRASH, a designer would benefit most from a detailed assessment of the response loads. The input to this program would have to come from previous airframe analyses and/or established floor pulses.

Stage 5 analysis appears suited for large sections wherein detail behavior is desired. A program like DYCAST is designed to provide detail design data. A segment of the structure, while large, would not be prohibitively so for use with a finite-element model. The use of DYCAST for this type of analysis also indicates a potential usage of the finite-element approach in the analysis of test specimens and the development of analytical procedures for predicting component section and substructure behavior under crash dynamic loading conditions. This analysis, like the stage 4 analysis, represents a special level of analysis which could be considered optional.

10.2 Proposed Test Program

The proposed test plan involves testing of elements, systems, substructure, airframe segments and a complete test article. In particular, tests of the following structures and systems are provided for:

- wing section and fuel tank
- seat systems
- lower fuselage
- fuselage segment including floor section
- landing gears
- wing engine and pylon
- aircraft

The features of the proposed test include:

- static and dynamic tests

- measurements of load, acceleration, deflection, pressure
- data reduced to obtain load versus deflection, as well as acceleration, velocity, and displacement time histories
- failure modes such as shear, bending, compression, tension, crushing, abrasion and tear
- range of input loads or velocities

The purposes of performing the tests are severalfold and include:

1. Provide for a systematic approach in which various levels of tests are performed under conditions approximating actual loading associated with candidate crash scenarios.
2. Provide data with which to verify analytical procedures and help establish semi-empirical methods to eliminate the dependence on costly test programs.
3. Development of a data bank to benefit subsequent analyses.

The premises under which the following test plan is proposed are as follows:

- Analysis of the test specimens for the proposed conditions is required in order to maximize the use of the test data.
- The information presented is preliminary and is subject to change as analysis is performed and initial test results are obtained.
- The test plan is part of a total analysis/test program.

10.2.1 Wing Section and Fuel Tanks

Several test series are defined in table 10-2 for the purpose of investigating:

- overload during an overrun
- obstacle penetration
- landing gear penetration
- lower surface tear

TABLE 10-2. - PROPOSED WING SECTION AND FUEL TANK TESTS

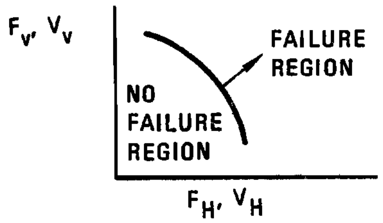
TEST ARTICLE: WING SECTION, FUEL TANK

CONFIGURATION	TEST		LOAD DIRECTION			APPROX. WEIGHT KG (LB)	APPROX. SIZE CM (IN.)	LOAD RANGE INPUT	NO. TESTS PER CONFIGURATION		MEASURED DATA					DATA REDUCTION						FAILURE MODES COMMENT							COMMENTS
	STATIC	DYNAMIC	VERTICAL	LONGIT.	LATERAL				DESIRED	MIN	LOAD	DEFLECT	ACCEL.	STRAIN	PRESSURE	LOAD VS. DEFLECT.	ACCEL. VS. TIME	VEL. VS. TIME	DEFLECT. VS. TIME	PRESSURE VS. TIME	ENERGY ABSORPT.	SHEAR	BENDING	COMPRESSION	TENSION	CRUSH	ABRASION	TEAR	
WING SECTION*	X		X						2	1	X	X				X					X	X	X	X	X	X			• OVERRUN OVERLOAD CONDITION 4 CONFIGURATIONS {FUEL TANK ¼, ½, ¾, FULL} • LANDING GEAR PENETRATION
	X			X					2	1	X	X				X					X	X	X	X	X	X			
	X		X	X					4	1	X	X				X					X	X	X	X	X	X			
		X	X						2	1		X	X				X	X	X		X	X	X	X	X	X			
		X		X				$V_H \leq 46$ M/SEC	2	1		X	X				X	X	X		X	X	X	X	X	X			
INCLUDES FUEL TANK		X	X	X				$V_V \leq 6$ M/SEC	4	2		X	X				X	X	X		X	X	X	X	X	X			
WING SECTION* INCLUDES FUEL TANK		X		X				$V_V \leq 6$ M/SEC $V_H \leq 6$ M/SEC	8	4	X	X				X	X	X	X		X	X	X	X	X				OBSTACLE PENETRATION FUEL TANKS {¼, ¾, FULL}
WING SECTION* INCLUDES FUEL TANK		X		X				$V_H \leq 46$ M/SEC	3	2	X	X	X		X	X	X	X									X	X	FUEL TANKS {¾, FULL} LOWER SURFACE ABRASION & TEAR
FUEL TANK		X	X					$V_V \leq 6$ M/SEC	2	1		X	X			X	X	X	X		X					X			(CENTER) FUEL TANK IMPACT {¼, ½, FULL}
		X		X				$V_H \leq 46$ M/SEC	2	1		X	X			X	X	X	X		X					X			
		X			X			$V_L \leq 6$ M/SEC	2	1		X	X			X	X	X	X		X					X			

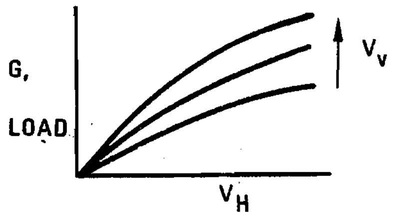
*CANDIDATES FOR SCALE TESTS

The test impact velocities can range up to 45.7 m/sec (150 ft/sec) in the longitudinal direction and 6 m/sec (20 ft/sec) in the vertical direction. The definition of the penetrating obstacle will have to be determined. The size, shape and location of impact of the obstacle have a bearing on the manner in which the wing section responds.

The data to be obtained from these tests would be in the form of:



or



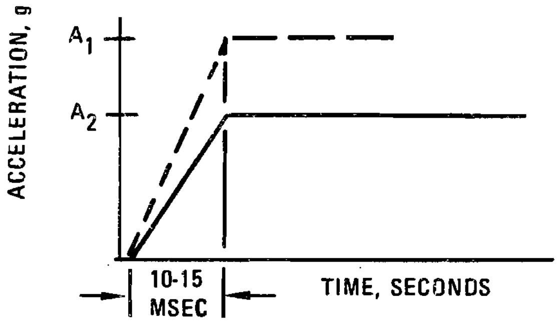
The accident data indicates that the concern for fuel tank and line integrity evolves about the structure's ability to withstand: (1) overload impact, (2) landing gear wheel penetration, (3) obstacle penetration, and (4) wing severance.

The wing section tests should be devised with a section of structure which houses the fuel tank. The tests can be performed with loading in the vertical, longitudinal and combined vertical and longitudinal directions. Four levels of fuel loading are suggested: 1/4, 1/2, 3/4, full.

10.2.2 Seats

The proposed seat test program takes into account the current on-going FAA-CAMI Oklahoma City test program (reference 96). At present the CAMI program consists of testing 10 seat types (double and triple seats), all with four legs for the following:

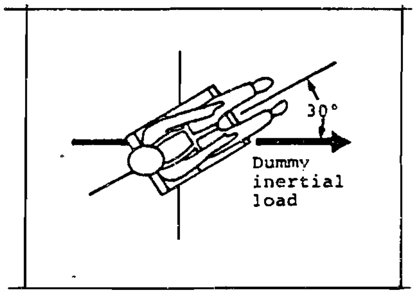
1. Static forward pull to failure.
2. Dynamic longitudinal trapazoidal acceleration pulse with different levels of acceleration starting at 6 g and a rate of onset between 10 and 15 msec. as shown below. These tests are run at equal velocities which means the areas under the acceleration-time curves are equal.



3. Repeat dynamic test but with floor deformation as defined in reference 4 and U.S. Army MIL-STD-1290. Figure 10-2 obtained from reference 4 shows a test set-up for this type of test.

4. Repeat sequence 2, but include a second row of seats and determine data on occupant impact with forward seat back.

5. Repeat sequence 2 but with introduction of 30° yaw as illustrated below:



6. Repeat sequence 5 but with deformed floor.

7. Perform dynamic tests so as to introduce a combination acceleration pulse which maintains a ratio of 9 g forward, 4.5 g down and 1.5 g side.

All the dynamic tests are performed with seats fully occupied with 50th percentile anthropomorphic male dummies.

Measurements include occupant pelvic, chest and head accelerations, seat belt loads, and floor loads and moments.

Tests are performed on a sled track with the pulses shaped on the basis of a selected number and location of 1/4 in. steel rods which pull through a metal bending braking system (rods pass over some rollers and are plastically deformed).

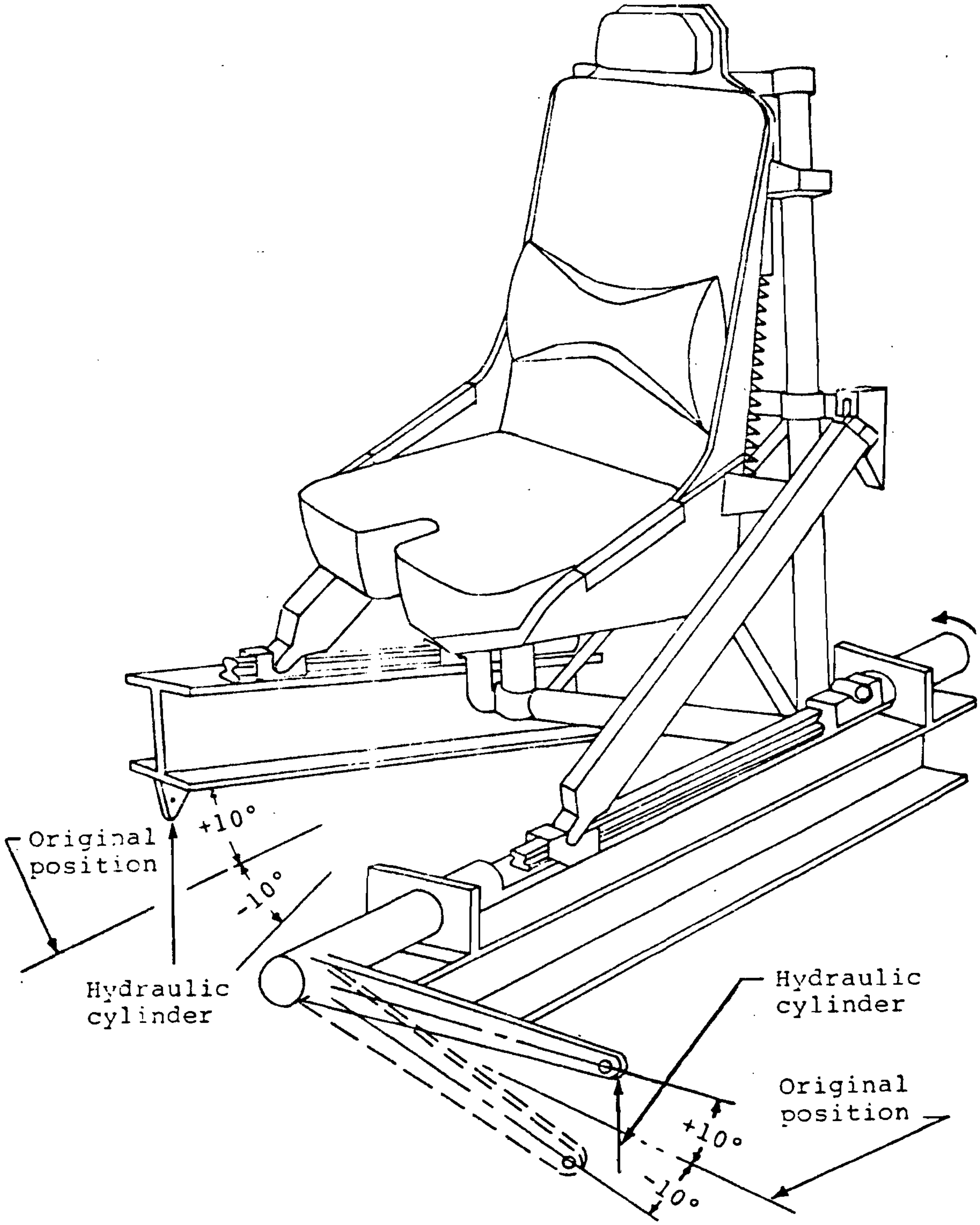


Figure 10-2. - A method of applying floor warping for testing of seats.

The proposed test plan shown in table 10-3 expands on this current set of tests. For double and triple passenger seats, tests to determine seat performance characteristics from vertical and lateral loading conditions are proposed. In addition, techniques for reducing potentially hazardous lethal blows from seat back impacts should be incorporated and investigated and the results compared to current seat back design results under similar conditions.

Flight attendant seat tests are proposed for loading in vertical, longitudinal and lateral conditions using 3/4 point and 5/6 point restraint systems. A lower priority exists for tests on crew seats.

The minimum objectives of the seat test program should be to determine:

- strength levels
- load-deflection characteristics
- energy absorption
- dynamic-static equivalence
- combined loading effects
- delethalization requirements

10.2.3 Lower Fuselage Structure

Table 10-4 describes the anticipated test conditions for lower fuselage structure and includes the potential for incorporating advanced materials. For each test arrangement the specimens consist of one baseline aluminum design, and at least one graphite/epoxy and one hybrid design. The literature search evaluation indicates that the crash dynamics characteristics of a "pure" composite may be lacking and that hybridization is probably necessary. Some of the tests wherein the specimens are faily simple call for 2 hybrid designs. Element/coupon tests to determine tearing and abrasion characteristics are intended to provide data necessary to judge the merits of advanced material skins during the airplane slideout phase of an overrun. The tests are for comparative purposes Crushing, compression and shear tests once again are for comparing characteristics of metallic, composite

TABLE 10-3. - PROPOSED SEAT TESTS

TEST ARTICLE: SEAT
TEST TYPE: SYSTEM

CONFIGURATION	TEST		LOAD DIRECTION			APPROX. WEIGHT KG (LB)	APPROX. SIZE CM (IN.)	LOAD RANGE INPUT	NO. TESTS PER CONFIGURATION		MEASURED DATA						DATA REDUCTION						FAILURE MODES COMMENT							COMMENTS
	STATIC	DYNAMIC	VERTICAL	LONGIT.	LATERAL				DESIRED	MIN	LOAD	DEFLECT.	ACCEL.	STRAIN	PRESSURE	VELOCITY	LOAD VS. DEFLECT.	ACCEL. VS. TIME	VEL. VS. TIME	DEFLECT. VS. TIME	PRESSURE VS. TIME	ENERGY ABSORPT.	SHEAR	BENDING	COMPRESSION	TENSION	CRUSH	ABRASION	TEAR	
PAX	X		X			100	PAX	$F_V \le 1500$ KG	3	2	X	X		X			X					X			X		X			**CONFIGURATIONS**
SEAT	X				X	TO	DOUBLE,	$F_H \le 2260$ KG	3	2	X	X		X			X					X	X	X						DOUBLE
	X					300	TRIPLE	$F_L \le 806$ KG	3	2	X	X		X			X					X	X	X						TRIPLE
		X	X				SEATS	{DYNAMIC PULSES	3	2		X	X				X	X	X	X		X			X		X			IMPROVED
		X			X			TO BE DETERMINED	3	2		X	X				X	X	X	X		X			X		X			DELETHALIZATION
																														CONCEPT
																														FUTURE DESIGN
FLIGHT	X		X					$F_V \le 376$ KG	3	2	X	X		X			X					X			X		X			
ATTENDANT	X			X		50	SINGLE	$F_H \le 750$ KG	3	2	X	X		X			X					X	X	X						
SEAT	X				X	TO	SEAT	$F_L \le 250$ KG	3	2	X	X		X			X					X	X	X						
		X	X			75			3	2	X	X	X				X	X	X	X					X		X			
		X		X				{DYNAMIC PULSES}	3	2	X	X	X				X	X	X	X		X	X	X						{3/4 PT RESTRAINT}
		X			X			TO BE DETERMINED	3	2	X	X	X				X	X	X	X		X	X	X						5/6 PT RESTRAINT
		X	X	X	X				3	2	X	X	X				X	X	X	X		X	X	X	X		X			
CREW	X		X					$F_V \le 500$ KG	3	1	X	X		X			X					X			X		X			
SEAT	X			X		60	SINGLE	$F_H \le 1000$ KG	3	1	X	X		X			X					X	X	X						
	X				X	TO	SEAT	$F_L \le 300$ KG	3	1	X	X		X			X					X	X	X						
		X	X			100			3	1	X	X	X				X	X	X	X		X			X		X			
		X		X					3	1	X	X	X				X	X	X	X		X	X	X						
		X			X				3	1	X	X	X				X	X	X	X		X	X	X						
		X	X	X	X				3	1	X	X	X				X	X	X	X		X	X	X			X			

TABLE 10-4.- PROPOSED LOWER FUSELAGE TESTS

TEST ARTICLE: LOWER FUSELAGE

TEST TYPE: COUPONS/ELEMENTS/SUBSTRUCTURE, SECTION

CONFIGURATION	TEST		LOAD DIRECTION			APPROX. WEIGHT KG	APPROX. SIZE CM	LOAD RANGE INPUT	NO. TESTS PER CONFIGURATION		MEASURED DATA						DATA REDUCTION						FAILURE MODES COMMENT							COMMENTS
	STATIC	DYNAMIC	VERTICAL	LONGIT.	LATERAL				DESIRED	MIN	LOAD	DEFLECT.	ACCEL.	STRAIN	PRESSURE	VELOCITY	LOAD VS. DEFLECT.	ACCEL. VS. TIME	VEL. VS. TIME	DEFLECT. VS. TIME	PRESSURE VS. TIME	ENERGY ABSORPT	SHEAR	BENDING	COMPRESSION	TENSION	CRUSH	ABRASION	TEAR	
1. SEE FIGURE 10-3 COUPON	X			X		.453	25 X 25 X .25-.5 THICK		6	6	X	X		X															X	4 CONFIGURATIONS 1 ALUMINUM 1 GRAPHITE/EPOXY 2 HYBRID IN-AND OUT-OF-PLANE TESTS
	X				X																									
2. SEE FIGURE 10-4 ELEMENT		X		X		(1.5)	30 X 10 X 6 DEEP .625 THICK	VEL = 22.5 TO 50 M/SEC PRESSURE = 50 TO 150 PSI	6	6	X			X	X	X	X		X		X							X		4 CONFIGURATIONS 1 ALUMINUM 1 GRAPHITE/EPOXY 2 HYBRID MEASURE TEMP. ALSO CONCRETE SURFACE
3. SEE FIGURE 10-5 ELEMENT	X		X			4.53	50 X 10 X 25 DEEP .625 THICK		2	1	X	X		X			X										X		X	5 CONFIGURATIONS 1 ALUMINUM 2 GRAPHITE/EPOXY 2 HYBRID CRUSH COMPRESSION SHEAR
	X			X					4	2	X	X		X			X						X		X				X	
		X	X						2	1	X	X	X				X	X	X	X					X				X	
4. SEE FIGURE 10-6 SUBSTRUCTURE	X		X			4.53	50 X 100 X 25 DEEP	$V_V \leq 6$ M/SEC $V_H \leq 36$ M/SEC	2	1	X	X		X			X					X		X	X		X			3 CONFIGURATIONS 1 ALUMINUM 1 GRAPHITE/EPOXY 1 HYBRID CONTOURED SURFACE OR IMPACT HEAD
	X		X	X					2	1	X	X		X			X					X	X	X	X		X			
		X	X						2	1		X	X				X	X	X	X		X		X	X		X			
		X	X	X					2	1		X	X				X	X	X	X		X	X	X	X		X			
5. SEE FIGURE 10-7 SECTION	X		X			13.5	150 X 300 X 20 DEEP	$V_V \leq 6$ M/SEC $V_H \leq 36$ M/SEC	2	1	X	X		X			X					X		X	X		X			2 CONFIGURATION ALUMINUM 1 HYBRID
	X		X	X					2	1	X	X		X			X					X	X	X	X		X			
		X	X						4	2		X	X				X	X	X	X		X		X	X		X			
		X	X	X					4	2		X	X				X	X	X	X		X	X	X	X		X			

*CANDIDATES FOR SCALE TESTS

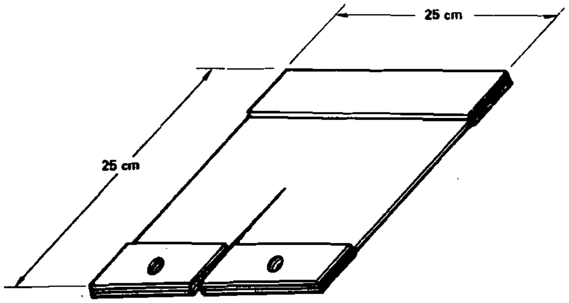


Figure 10-3. Coupon tear test specimen.

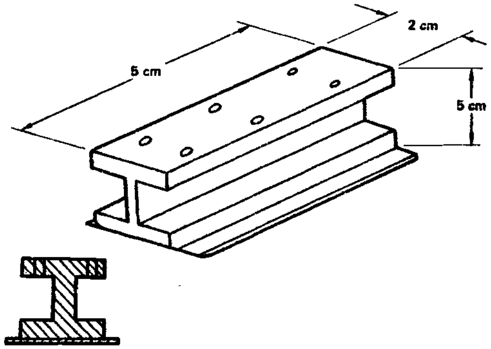


Figure 10-4. Element abrasion test specimen.

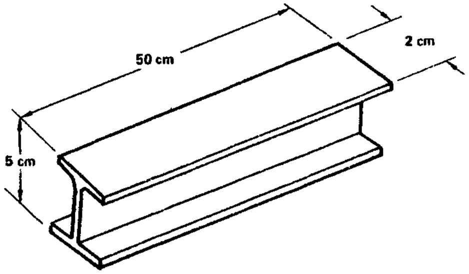


Figure 10-5. Element crush test specimen.

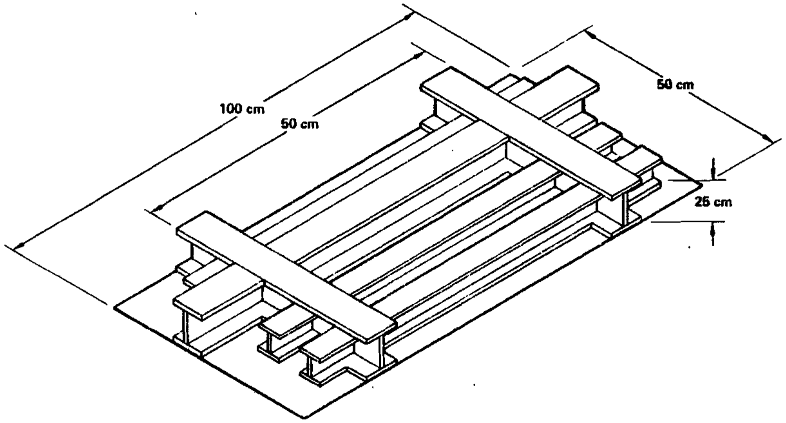


Figure 10-6. Substructure test specimen.

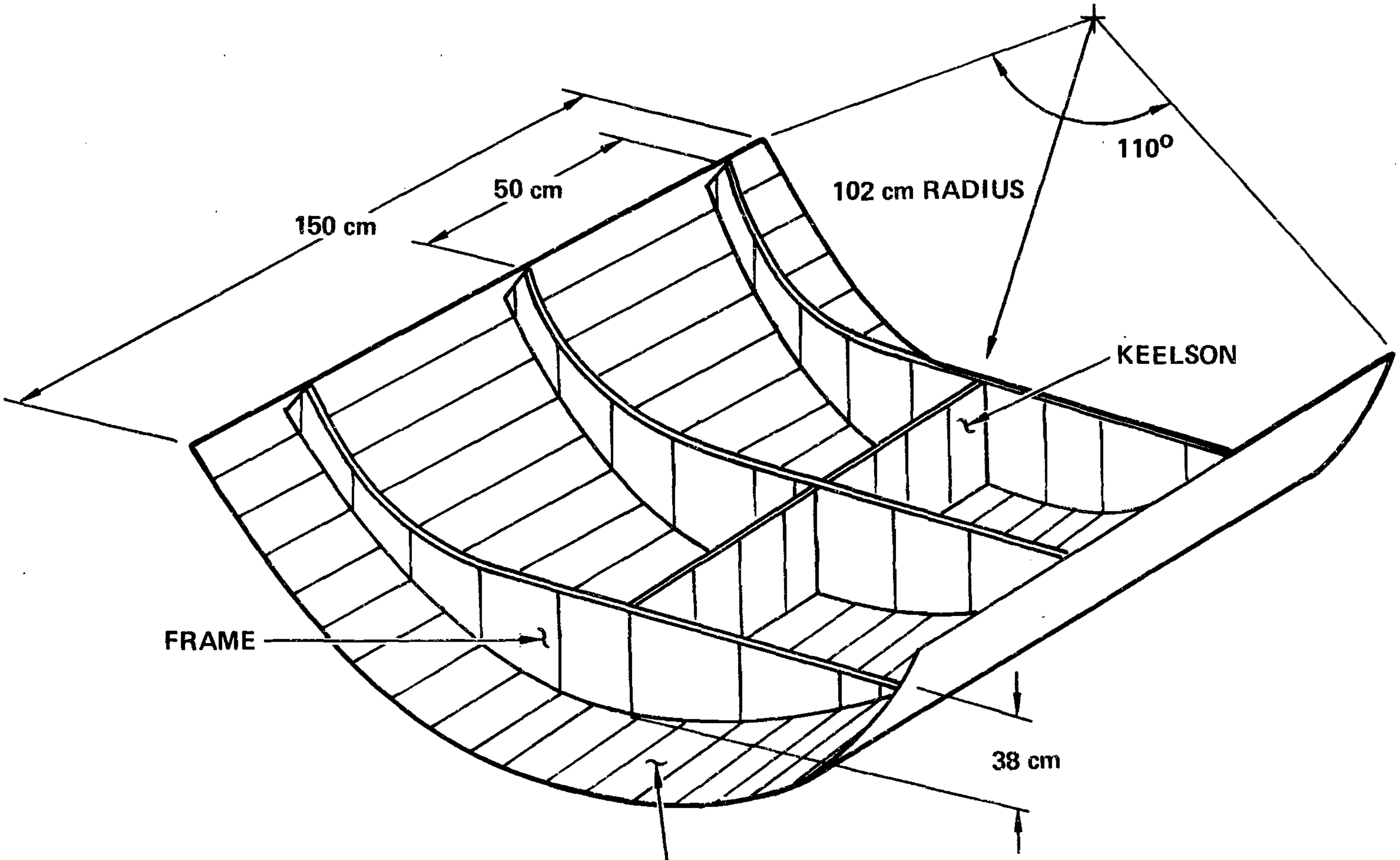
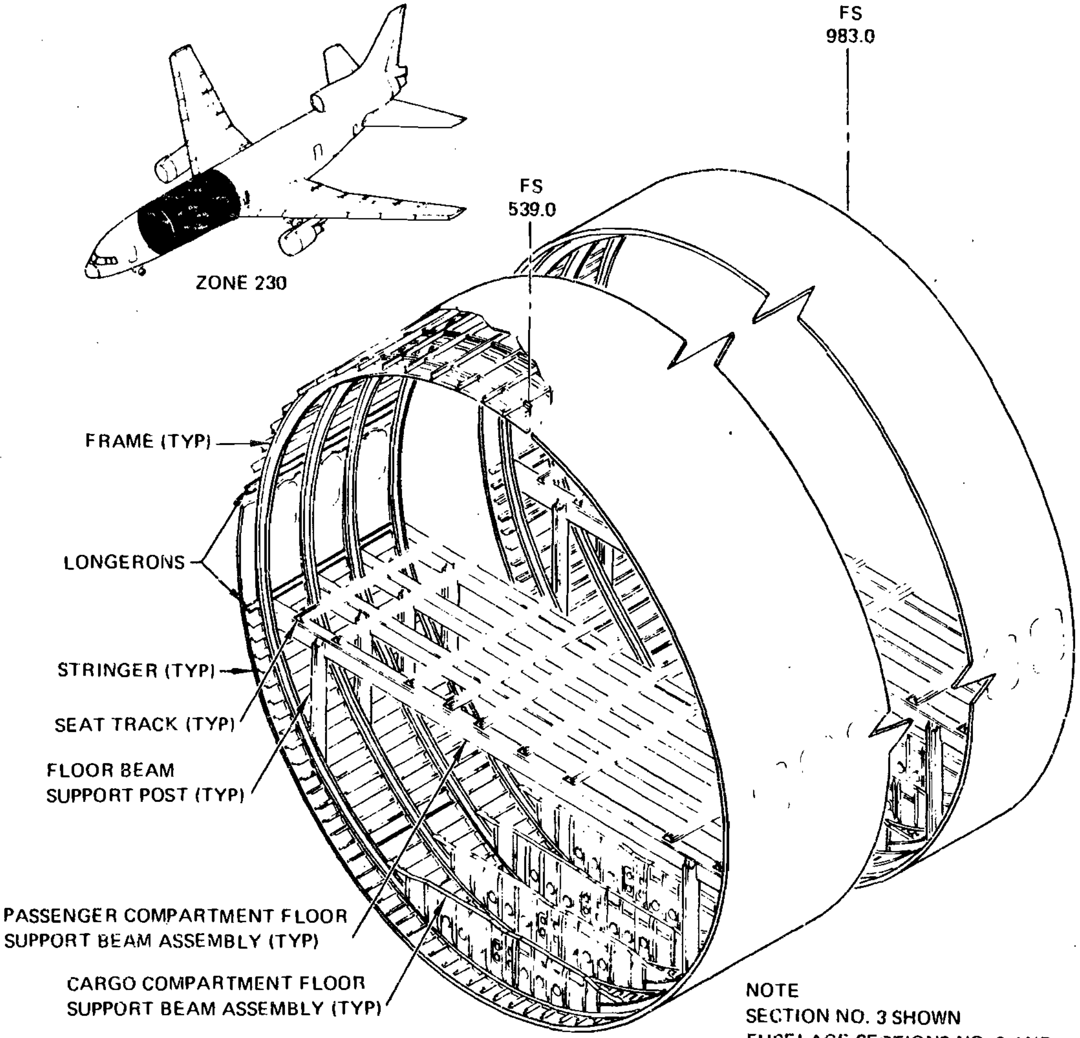


Figure 10-7. - Section test specimen.

and hybrid element designs. While the element and coupon tests do not ensure that the behavior of the elements will be the same as in a built-up structure, they should give an indication of the comparative responses for equal conditions. Substructure tests of lower fuselage structure carry the element and coupon tests one step further. Static and dynamic tests are called for as well as multi-directional loading conditions. The use of a contoured specimen or flat specimen with a contoured impact head for this type of testing will provide for a realistic loading condition. It is important that the specimen be restrained in its usual manner when an integral part of the aircraft structure. The sections for this phase of the test can be approximately 50 cm x 100 cm x 25 cm deep. Additional tests of lower fuselage structure are required utilizing larger sections approximating a section of the aircraft. Figure 10-8 illustrates the region and type of structure involved.

The lower fuselage tests serve several purposes including:

- Obtaining baseline data for current structure used in the lower fuselage region.
- Obtaining characteristic data for comparison with potential future designs and material usage.
- Establishing a "base" set of tests to which additional design configurations can be subjected so that a rapid assessment of the crash dynamics can be made.
- The tests involving the larger substructure can be used to evaluate instrumentation requirements for the proposed full scale crash tests. This is an important consideration because an increase in the number of required data channels would mean a smaller sampling rate for each channel, and consequently a lower frequency response for the recorded signal. In Reference 28 there is a discussion in which guidelines for frequency response and sampling rates are presented. The frequency response requirements could range from 60 Hz to 1000 Hz depending on the intended usage of the data and whether it pertains to structure or to the occupant. In fullscale aircraft tests in which data is to be telemetered, the tradeoff between the number of recorded data channels available and the desired frequency response should be considered in selection of instrumentation requirements.



NOTE
SECTION NO. 3 SHOWN
FUSELAGE SECTIONS NO. 2 AND
NO. 6 ARE BASICALLY SIMILAR
TO THIS FUSELAGE SECTION

Figure 10-8. - Substructure test specimen region.

10.2.4 Fuselage Segments

Several fuselage segment tests are proposed. These tests are along the lines of tests described in reference 93. Unfortunately, in those tests time history data was not presented. However, data obtained from structure representative of current jet aircraft, combined with the results described in reference 93 and analysis of structural response as a result of crash scenario impact conditions could prove useful in the formulation of a crash dynamics data base. The tests described in table 10-5 include axial compression, bending and crash impacts. Since segments for current generation widebody aircraft can be as large as 500 cm. in diameter, these types of specimens are candidates for scale model tests.

10.2.5 Landing Gears

The failure of landing gears has been shown to occur frequently during ground-to-ground overruns, hard landings and severe ground impacts. The possible consequences of a landing gear collapse or separation are: 1) subsequent impact of fuselage or wing with the ground, 2) penetration of the main landing gear into the wing box with the potential loss of fuel tank integrity, and 3) penetration of the nose gear wheel into the lower fuselage. The purposes of landing gear tests are to:

- ascertain critical failure modes
- develop load and impact velocity envelopes
- determine load-deflection characteristics
- facilitate post failure gear modeling

Table 10-6 shows a layout of proposed test conditions and parameters. From table 10-6 it can be seen that the approximate maximum loads and velocities associated with the landing tests in the different directions can be:

TABLE 10-5. - PROPOSED FUSELAGE SEGMENT TESTS

TEST ARTICLE: FUSELAGE/FLOOR SEGMENTS

TEST TYPE: SUBSTRUCTURE

CONFIGURATION	TEST		LOAD DIRECTION			APPROX. WEIGHT KG (LB)	APPROX. SIZE CM (IN.)	LOAD RANGE INPUT	NO. TESTS PER CONFIGURATION		MEASURED DATA						DATA REDUCTION						FAILURE MODES COMMENT							COMMENTS
	STATIC	DYNAMIC	VERTICAL	LONGIT.	LATERAL				DESIRED	MIN	LOAD	DEFLECT.	ACCEL.	STRAIN	PRESSURE	VELOCITY	LOAD VS. DEFLECT.	ACCEL. VS. TIME	VEL. VS. TIME	DEFLECT VS. TIME	PRESSURE VS. TIME	ENERGY ABSORPT.	SHEAR	BENDING	COMPRESSION	TENSION	CRUSH	ABRASION	TEAR	
1. •	X		X				500 CM.	$V_H \leq 36$ M/SEC	2	1	X	X		X			X					X	X	X						AIRFRAME BENDING,
	X				X		DIA.	V_H -46 M/SEC	2	1	X	X		X			X					X	X	X						COMPRESSION
SEE FIGURE 10-9a	X			X			X		2	1	X	X		X			X					X			X		X			CHARACTERISTICS
		X	X				1500 CM		2	1		X	X				X	X	X	X		X	X	X						
		X		X			LONG		2	1		X	X				X	X	X	X		X	X	X						
		X			X				2	1		X	X				X	X	X	X		X			X		X			
•		X	X				500 CM.	$V_V < 6$ M/SEC	2	1		X	X				X	X	X	X		X					X			FUSELAGE
		X	X	X			DIA.	$V_H < 46$ M/SEC	2	1		X	X				X	X	X	X		X					X			CRUSHING
SEE FIGURE 10-9b							X																							FLOOR RESPONSES
							1500 CM																							
							LONG																							
•		X	X				500 CM.	$V_V < 6$ M/SEC	2	1		X	X				X	X	X	X		X	X	X	X	X	X			AIRPLANE - GROUND
SEE FIGURE 10-9c		X	X	X			DIA.	$V_H \leq 46$ M/SEC	2	1		X	X				X	X	X	X		X	X	X	X	X	X			IMPACT ·
							X																							SEVERE CONDITION
							750 CM.																							

*CANDIDATE FOR SCALE TESTS

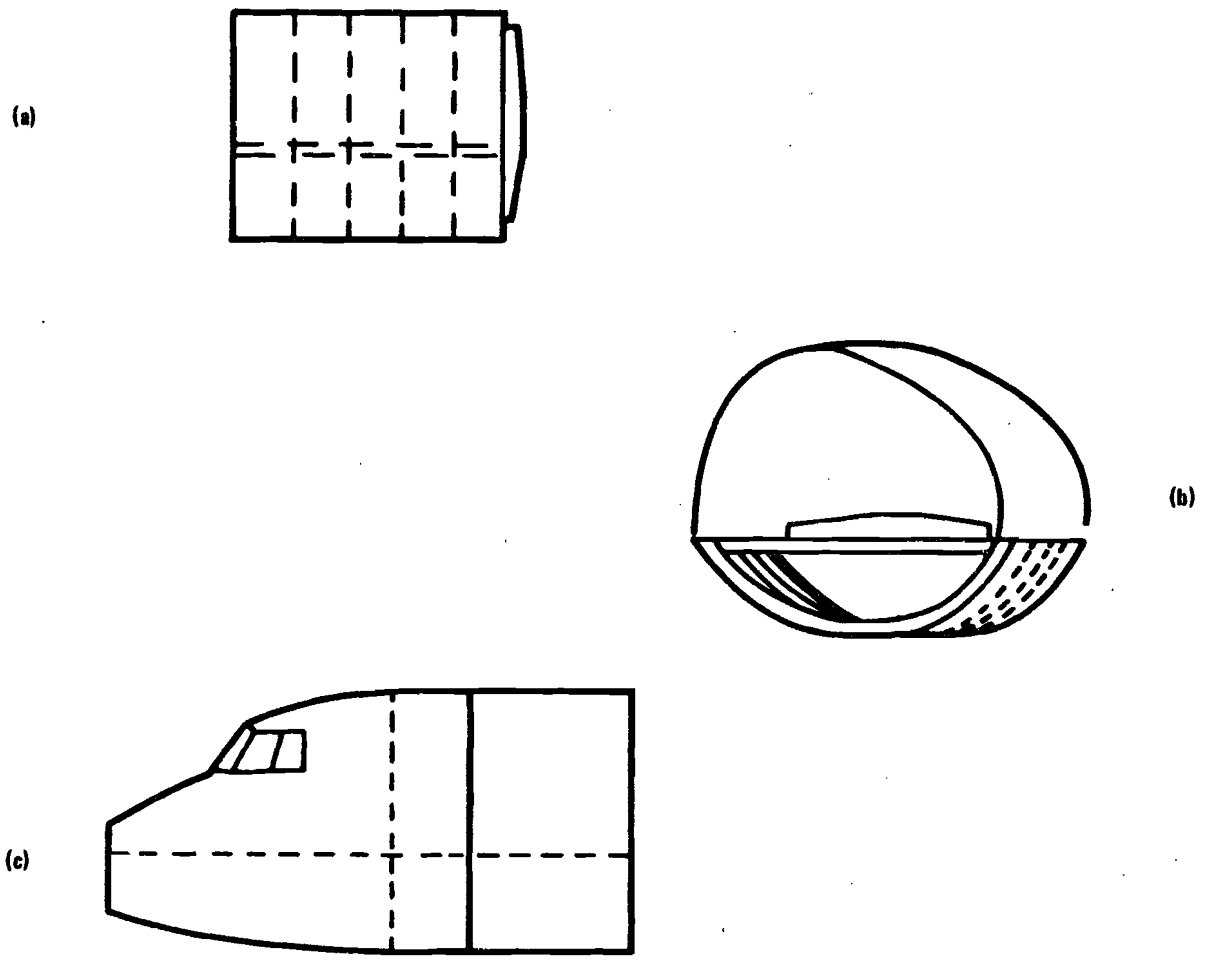


Figure 10-9. - Drop test setup.

TABLE 10-6. - PROPOSED MAIN AND NOSE GEAR TESTS

TEST ARTICLE: MAIN LANDING GEAR, NOSE LANDING GEAR
TEST TYPE: SYSTEMS

CONFIGURATION	TEST		LOAD DIRECTION			APPROX. WEIGHT KG (LB)	APPROX. SIZE CM (IN.)	LOAD RANGE INPUT	NO. TESTS PER CONFIGURATION		MEASURED DATA						DATA REDUCTION						FAILURE MODES COMMENT							COMMENTS
	STATIC	DYNAMIC	VERTICAL	LONGIT.	LATERAL				DESIRED	MIN	LOAD	DEFLECT.	ACCEL.	STRAIN	PRESSURE	VELOCITY	LOAD VS. DEFLECT.	ACCEL. VS. TIME	VEL. VS. TIME	DEFLECT. VS. TIME	PRESSURE VS. TIME	ENERGY ABSORPT.	SHEAR	BENDING	COMPRESSION	TENSION	CRUSH	ABRASION	TEAR	
MAIN GEAR	X		X					$F_V \le$ 272,000 KG	3	2	X	X		X	X		X					X		X	X					HARD LANDING & GROUND IMPACT CONDITIONS
	X			X				$F_H \le$ 204,000 KG	3	2	X	X		X	X		X					X	X	X						
	X				X			$F_L \le$ 136,000 KG	3	2	X	X		X	X		X					X	X	X						
	X		X	X					6	4	X	X		X	X		X					X	X	X	X					
		X	X					$V_V \le$ 6 M/SEC	3	2		X	X		X		X	X	X	X		X		X	X					
		X		X				$V_H \le$ 76 M/SEC	3	2		X	X		X		X	X	X	X		X	X	X						
		X			X			$V_L \le$ 15 M/SEC	3	2		X	X		X		X	X	X	X		X	X	X	X					
		X	X	X					6	4		X	X		X		X	X	X	X		X	X	X	X					
		X	X					$V_V \le$ 1.5 M/SEC	2	(1)		X	X		X		X	X	X	X		X			X					OVERRUN CONDITION
		X		X				$V_H \le$ 35 M/SEC	2	(1)		X	X		X		X	X	X	X		X	X	X						
		X			X			$V_L \le$ 10 M/SEC	2	(1)		X	X		X		X	X	X	X		X	X	X						
		X	X	X					4	(2)		X	X		X		X	X	X	X		X	X	X	X					
		X		X	X				4	(2)		X	X		X		X	X	X	X		X	X	X						
NOSE GEAR		X	X					$V_V \le$ 6 MSEC	2	*(1)		X	X		X		X	X	X	X		X			X					HARD LANDING
		X		X				$V_H \le$ 76 M/SEC	2	(1)		X	X		X		X	X	X	X		X	X	X						
		X	X	X				$V_L \le$ 10 M/SEC	4	(2)		X	X		X		X	X	X	X		X	X	X	X					
		X	X					$V_V <$ 1.5 M/SEC	3	(1)		X	X		X		X	X	X	X		X			X					OVERRUN CONOITION
		X		X				$V_H <$ 36 M/SEC	2	(1)		X	X		X		X	X	X	X		X	X	X						
		X	X	X				$V_L \le$ 10 M/SEC	4	(2)		X	X		X		X	X	X	X		X	X	X	X					

Direction	Approximate Load	Velocity
Vertical:	272,800 Kg (600,000 lb)	6.1 m/sec (20 ft/sec)
Longitudinal:	204,000 Kg (400,000 lb)	76.2 m/sec (250 ft/sec)
Lateral:	136,000 Kg (300,000 lb)	15.4 m/sec (50 ft/sec)

A total of 44 main gear and 16 nose gear tests are indicated. The test specimens are to be a typical current landing gear design configuration. Also indicated in table 10-6 is a reduced number of tests (23) based on priority. The use of alternate designs would require additional testing and could be performed to obtain comparative data.

11. SUMMARY OF RESULTS

The overall program is diagrammed in figure 11-1. The various tasks and the interaction of the tasks are shown to lead to:

1. Candidate Crash Scenarios
2. Proposed Analysis Requirements/Procedures
3. Proposed Test Requirements/Procedures
4. Conclusions
5. Recommendations

Conclusions and Recommendations are discussed in Sections 12 and 13, respectively.

The candidate crash scenarios for which analysis and/or test should be performed to ascertain transport airplane structural dynamic response and the consequence of such loads on occupant survivability are defined as:

- Ground-to-Ground overrun type accident, such as take-off abort or landing overrun, which occurs at a low forward speed (40-130 Kts), with the landing gears extended and the airplane in a level and symmetrical attitude. The accident occurs on paved runway or hard ground. Damage is sustained by the airplane as it traverses a ditch, road or mound. The effective normal velocity as a result of gear collapse or terrain impact, is ≤ 1.5 m/sec (5 ft/sec). The availability of pilot action to control impact severity is assumed to exist. Airplane weight can range between landing and maximum take-off.

  Failure modes associated with this type of accident, shown in figure 7-1, include:

  - nose and main gear collapse/separation
  - wing impact with ground (after gear collapse) and possible fracture

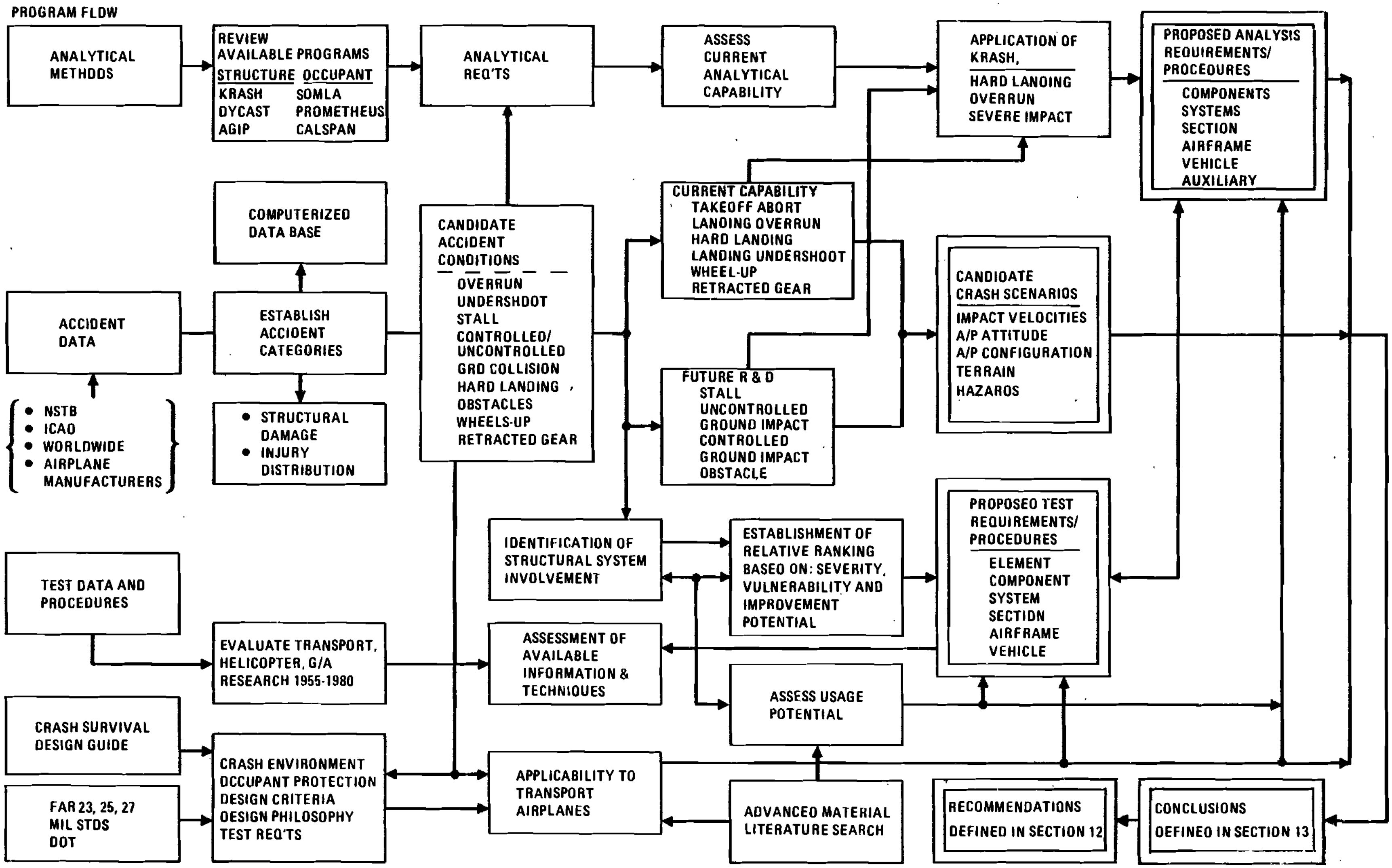


Figure 11-1. - Program flow diagram.

  - fuselage impact with ground (after gear collapse) and possible fracture
  - landing gear penetration into wing box
  - nose gear collapse into lower fuselage
  - fuselage break as a result of impact with sloping terrain
  - obstacle penetration into wing
  - engine separation as a result of wing impact
  - floor deformation
  - seat attachment failure
  - overhead mass item failure
  - wing fuel tank rupture
  - loss of seat integrity

- Air-to-ground hard landing accident such as touchdown just short of or on the runway. On the average the sink speed is in the vicinity of 5.2 m/sec (17 ft/sec). Forward velocity is in the range of 126 to 160 knots. The airplane lands with landing gear extended in a nose-up symmetrical attitude ranging from 0 to 14°. These accidents occur on a rigid flat surface with no obstacles or hazards. Analysis should be performed for maximum landing weight.

  Failure modes associated with this type of accident, shown in figure 7-2, include:

  - main gear collapse
  - wing impact (after gear collapse) and possible failure
  - engine separation upon wing impact
  - fuselage impact initially or as a result of gear collapse with subsequent fuselage failures
  - lower fuselage crushing and abrasion
  - landing gear penetration into wing box
  - wing fuel tank rupture
  - overhead mass item failure

- floor deformation
- seat attachment failure
- loss of seat integrity

- Air-to-Ground Impact accident type on hard ground on or off the runway. Sink speed can range up to 10 m/sec. Forward velocity is in the range of 126 to 160 knots. Airplane can land with gears retracted or extended in an unsymmetrical attitude. Range of unsymmetry is ± 10° for roll and yaw, with pitch attitude variations from 0° to +14°.

  Failure modes associated with this type of accident, shown in figure 7-3, include:

  - fuselage crush/collapse due to frontal impact
  - columnar obstacle penetration of wing
  - fuselage failure as a result of impact with sloping terrain
  - wing tank rupture
  - engine separation as a result of wing impact
  - landing gear collapse and subsequent wing, fuselage impact and/or penetration into lower fuselage and wing box
  - loss of floor and seat integrity

The individual candidate scenarios show that for each potential failure mode there are several sequences of events that occur. Currently the emergency landing conditions for transport airplanes (reference 5) have provisions which are designed to provide the occupants a reasonable chance of escaping a serious injury in a minor crash. Paragraph 25.561 of reference 5 specifies the emergency landing condition as retracted wheels and an ultimate descent velocity of 5 fps at design landing weight. Furthermore, Paragraph 25.721 states that the main landing gear must be designed so that if it fails due to an overload (dup to up and aft loads) during taxi and landing, the mode is not likely to cause spillage of enough fuel to constitute a fire hazard. During emergency landing conditions, seats (P25.785) and major mass items (P25.789) are to maintain integrity and not result in serious injury as a result of the inertia forces specified in P25.561, which are as follows:

upward	2g
forward	9g
sideward	1.5g
downward	4.5g

The results of the accident data review presented in Section 2 support the adequacy of the FAR25 requirements insofar as minor crashes are concerned. However, the crash scenarios, as defined earlier in this section, go beyond minor crashes and as such may require utilization of additional analytical tools not previously available. The review of analytical methods presented in Section 7 showed that there are several computer programs that can be applicable to crash scenarios. These include KRASH, AGIP and DYCAST, each of which has features which are desirable.

The candidate crash scenarios were formulated after a review of accident data and records for a period of approximately 15 years (1964-78). The accident records show that the trend with modern day large jet airplanes is for a reduction in the number of accidents, fatal accidents and accidents per year. The domestic airline travel safety record is particularly good in this respect, as illustrated in figures 2-3, 2-4 and 2-5. Further evidence of this safety record can be seen in the data presented in figures 11-2, 11-3 and table 11-1. Table 11-1, obtained from reference 97, shows that the percentage of fatalities for the period 1970-79 is 13.9 percent for smaller FAR25 aircraft compared to 5.5 percent for wide-body jets. The larger aircraft, while they account for less than 12 percent as many accidents as the smaller airplanes during this period, involve approximately twice as many passengers. Figure 11-2 illustrates this data graphically.

Figure 11-3 shows the trend of generally safer travel with the introduction of jets. The number of total accidents and fatal accidents shows a decreasing trend. Although the average number of fatalities per year is approximately the same, the latter years are weighted by the occurrence of a couple of catastrophic accidents. For example, the Tenneriffe accident in 1977 resulted in 580 fatalities. Without this accident, the average for 1974-1978 would be reduced to approximately 100 fatalities/year. On May 25,

TABLE 11-1. - LANDING AND TAKEOFF ACCIDENTS 1970-79 (Reference 97).

ICAO CATEGORY: III — NUMBER OF ACCIDENTS = 694

TYPE OF INJURY	NO. OF PASSENGERS	PERCENTAGE
FATAL	1,084	13.9
SERIOUS	458	5.9
MINOR	348	4.5
NONE	5,906	75.7
TOTAL	7,796	100.0

ICAO CATEGORY: IV — NUMBER OF ACCIENTS = 775

TYPE OF INJURY	NO. OF PASSENGERS	PERCENTAGE
FATAL	5,880	12.5
SERIOUS	1,164	2.5
MINOR	1,312	2.8
NONE	38,789	82.2
TOTAL	47,145	100.0

ICAO CATEGORY: V — NUMBER OF ACCIDENTS = 91

TYPE OF INJURY	NO. OF PASSENGERS	PERCENTAGE
FATAL	855	5.5
SERIOUS	152	1.0
MINOR	274	1.8
NONE	14,116	91.7
TOTAL	15,397	100.0

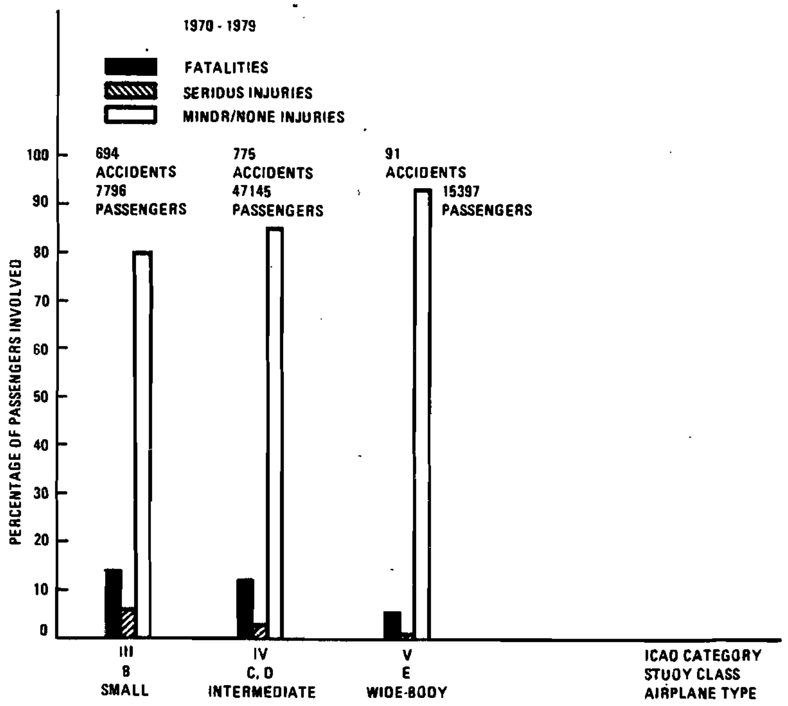


Figure 11-2. - Comparison of airplane accident performance by aircraft category/class/type.

1979, near Chicago, a tragic airplane loss of control involving a widebody jet resulted in the loss of all 273 people aboard. Without this accident the average for 1979 would be approximately 50 fatalities/year. In 1980 only 12 fatalities were sustained, none of which involved a passenger in a jet transport. While the Chicago and Tenneriffe accidents should not unduly influence future crash design requirements, they do serve to illustrate the potential danger associated with accidents involving large airplanes.

Worldwide accident figures for 1977-1978 show that while on a basis of passenger miles, revenue miles or flights jet transport is safe, the majority of airline persons killed are involved in jet travel.

Types	Fatal Accidents	Passenger and Crew Fatalities
Jets	20	1717
Turbo-Props	20	342
Piston Engines	14	249
Totals	54	2308

Thus, despite the very low accident rate, because they are large aircraft, and because they undertake the majority of the flying, improvements in jet crash design are desirable.

Another major consideration is the conditions under which airplane accidents occur. In particular, this relates to location relative to the runway, hazards and/or obstructions surrounding the airport, operating procedures on the airport, and warning systems on aircraft. Figure 11-4 shows that a higher percentage of occupants suffer fatal injuries when airport surroundings include hazards such as ravines, embankments, fences and vehicles. The percentage of fatalities and serious injuries for ground-ground overruns increases from 0.2 percent to 12.8 percent and from 3.6 percent to 22.6 percent, respectively, with the includsion of hazards. Similarly, hard landing just short of, or on the runway, shows a substantial increase in the ratio of fatalities to number of occupants involved.

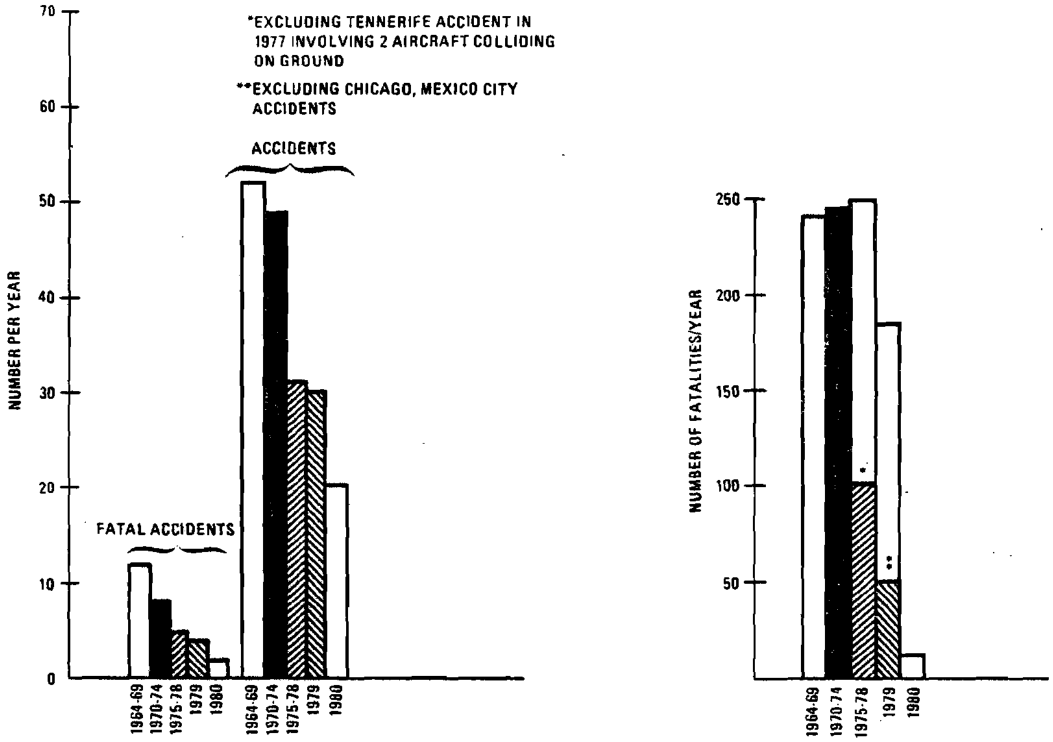


Figure 11-3. - Trend of number of accidents, fatal accidents and fatalities per year.

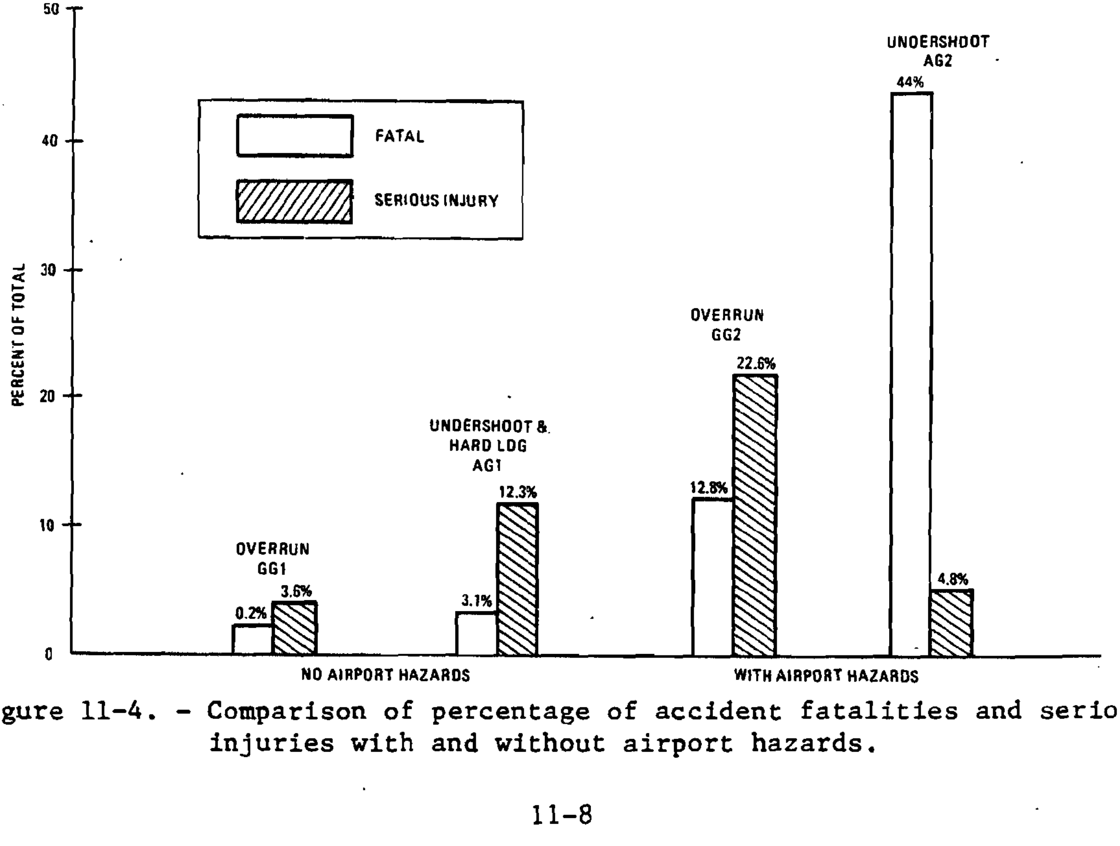


Figure 11-4. - Comparison of percentage of accident fatalities and serious injuries with and without airport hazards.

A close examination of the candidate crash scenarios indicates the following grouping is possible:

1. Airplane Design Related - accidents which occur around airports, i.e., on the runway or within 350 m. of the runway are moderately influenced by hazards and surrounding obstructions. The terrain is easy to define and the airplane configuration readily prescribed. The performance of the airplane for this type of crash scenario should be indicative of modern day jet transport crash design capability and an indication of the merits of current design requirements.

2. Airport Environs Related - accidents which occur in the vicinity of the airport, either on the runway or beyond the runway, and the resultant damage is significantly influenced by unpredictable hazards and terrain conditions. The performance of the airplane for these scenarios is to a large degree dependent on the airport surroundings and additional effort is needed to determine how improved design of airport environs and operating procedures can be incorporated to reduce accidents around the airport.

3. Warning System Related - accidents that occur away from the airport, result from loss of airplane control, are a result of pilot disorientation or are caused by unreliable warning systems generally involving impact at high speed, with a wide range of possible impact attitudes and amongst hazardous terrain. The performance of the airplane for these scenarios to a great extent is influenced by the severity of the impact conditions, which in turn, results from the pilot's inability to control the situation. Quite often this inability on the part of the pilot is directly related to his "unawareness of the situation" until it is too late to react in a manner to reduce the vulnerability of the aircraft to the impact conditions.

Figure 11-5 shows the accident data organized into three areas; airplane design-related such as aborts/overruns, airport off-runway hazards, and accident avoidance or warning system related.

Accident avoidance or "warning system related" improvements have resulted in a substantial reduction in the ratio of accidents to departures in the last 20 years. These include cockpit design and communication, improved simulators and trainers, improved system redundancy and improved air/ground traffic control systems. Further improvements in the use of ground proximity warning systems (GPWS) and early detection devices could have a significant effect on reducing the number of fatalities in the more severe impact accidents. Preventing airplanes from crashing into hillsides and mountains appears more

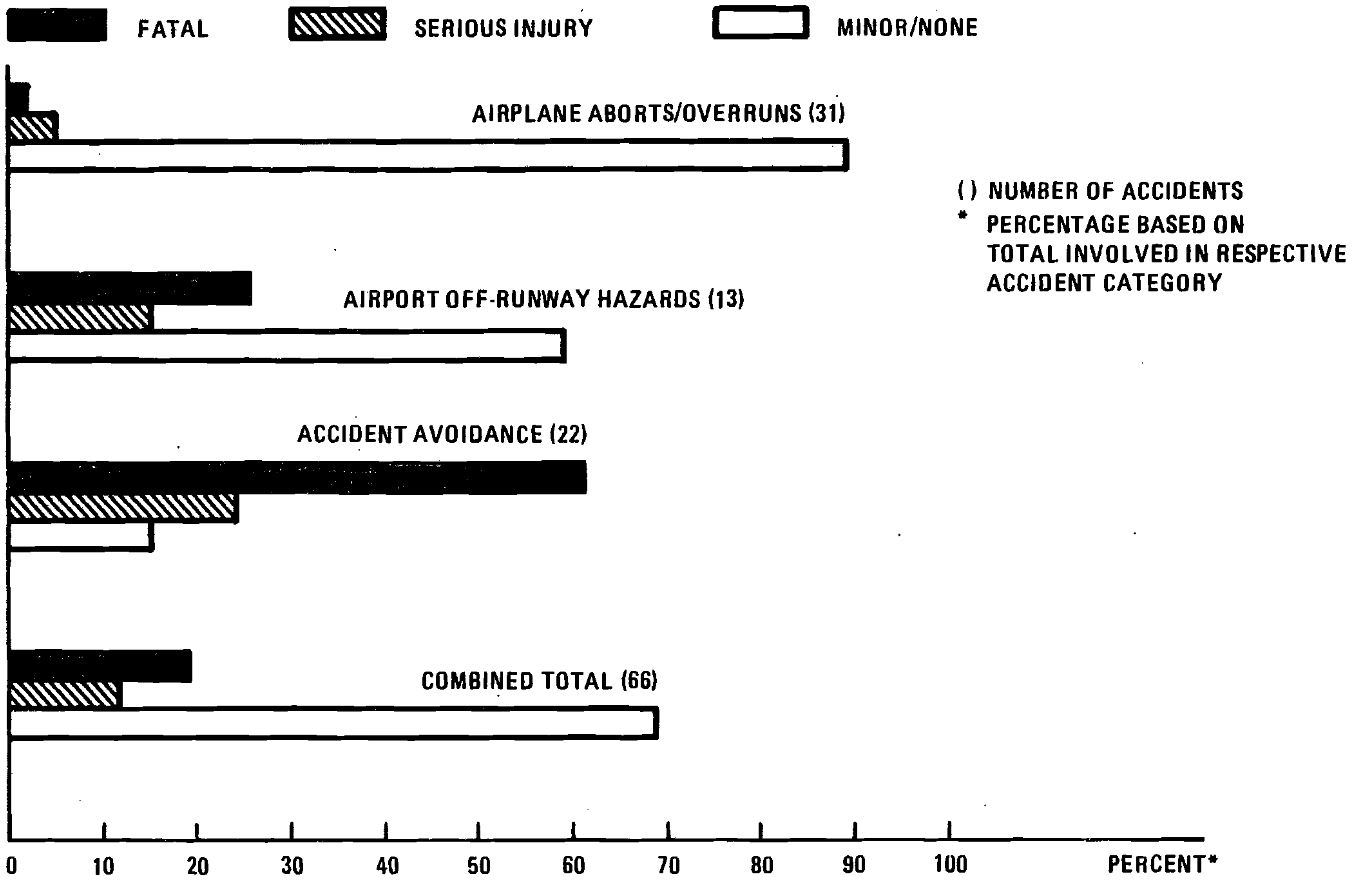


Figure 11-5. - Injury distribution as related to airplane design, airport off-runway hazards and design.

prudent than designing the airplane to resist the crash loads from each inadvertent and severe accident.

By the same token "airport environs related" improvements can be made to standardize airport surroundings, to minimize the prospect of airplanes in overrun and/or overshoot situations from impacting embankments, vehicles, steel fences and going over ravines. Reasonable clearances up to 1000 meters beyond the runway should be considered.

"Airplane design related" improvements involving the design and performance of the airplane structural systems under mild to moderately severe crash conditions are of paramount concern. Overrun and hard/landing crash scenarios have been presented in which impact and terrain conditions are specified which are considered "survivable" in light of current airplane capability. Extending the airplane capability beyond this current range of conditions to unsymmetrical attitude, higher risk speeds, and terrain requires additional analytical effort and empirical verification for what amounts to a new definition of a "survivable crash environment".

A summary of test measured floor acceleration data for various transport type aircraft is shown in figures 11-6 and 11-7 along with the longitudinal and vertical velocities for each data point. This data shows a range of peak accelerations stretching from 2.5 g to 20 g for durations from 20 to 300 milliseconds depending on aircraft type, location of measurement and severity of impact. For impact in which the sink speed is ≤6m/sec (20 ft/sec) and ignoring the more severe forward section responses, the pulses are shown to be within the envelopes shown in figures 11-6 and 11-7. From table 11-2 it can be seen that the available transport test data is limited when compared to the potential range of impact conditions associated with the candidate scenarios. In addition, the current jet aircraft (particularly classes D and E types) are heavier and larger than any aircraft tested in the 1955-65 time period. Consequently, to establish a dynamic pulse which is meaningful, the following must be accomplished:

- Analyze current candidate crash scenarios and formulate dynamic floor pulses

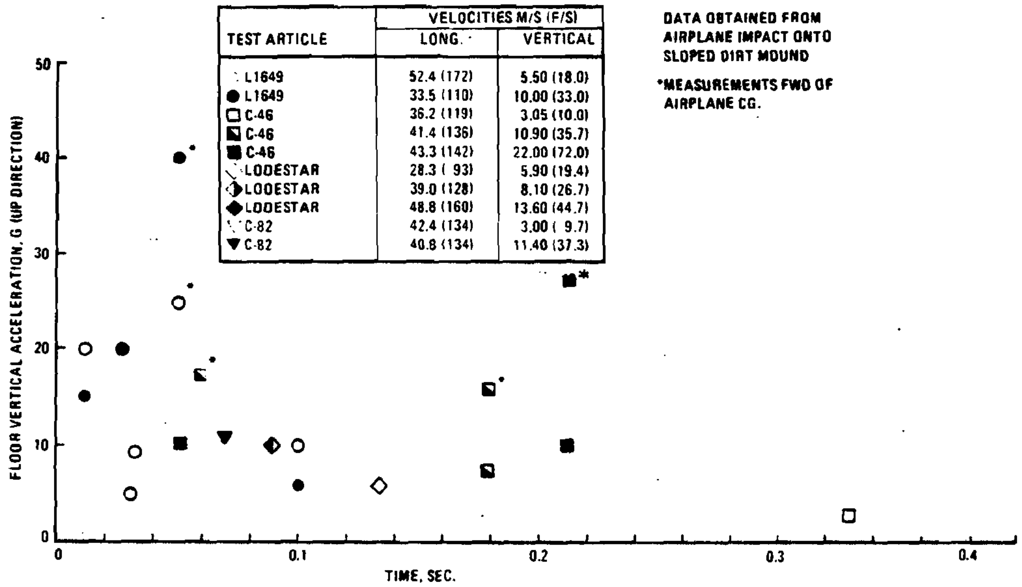


Figure 11-6. - Floor vertical pulses obtained from previous transport airplane test data.

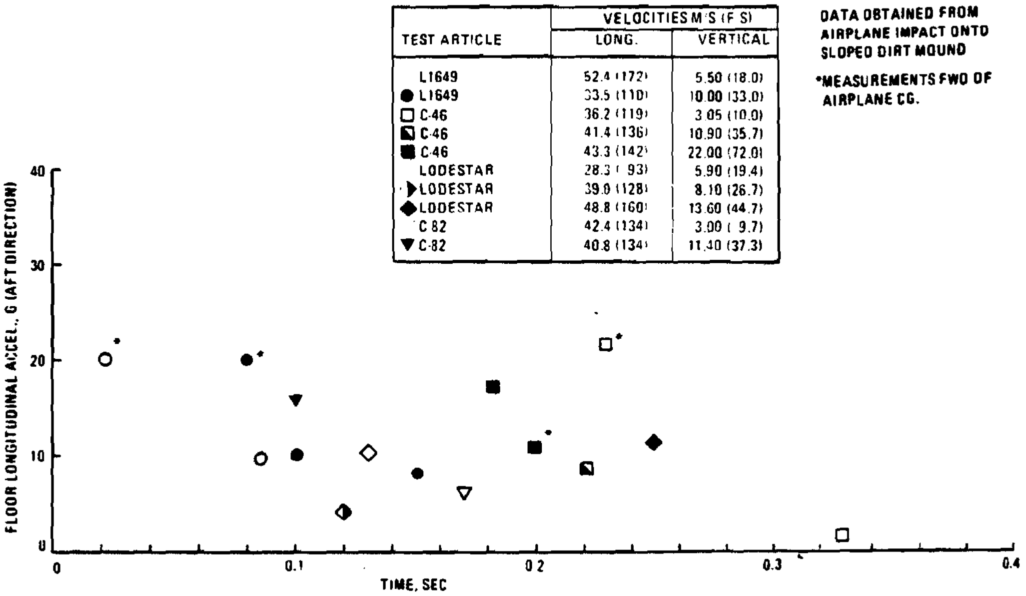


Figure 11-7. - Floor longitudinal pulses obtained from previous transport airplane test data.

TABLE 11-2. - COMPARISON OF AVAILABLE TRANSPORT TEST DATA WITH CRASH SCENARIO FAILURE MODE REQUIREMENTS

FAILURE MODES	CANDIDATE SCENARIO	TEST MAXIMUM IMPACT VELOCITY REQUIREMENTS M/SEC			C-46 (REF. 87)	C-82 (REF. 87)	LODESTAR (REF. 87)	L-1649 (REF. 6)	SUBSTRUCTURE (REF. 93)
		V_H	V_V	V_L					
• LANDING GEAR COLLAPSE	GGO AGHL AGI	36 76 76	1.5 6 6	3 3 3					
• MAIN GEAR WHEEL PENETRATION INTO WING BOX	GGO AGHL	36 76	3 3	– –					
• OBSTACLE (POLE) PENETION INTO WING	GGO AGHL	36 76	– –	– –				<u>2 IMPACTS</u> $V_H \sim 33.5$	
• FUSELAGE IMPACT WITH GROUND	GGO AGHL AGI	36 76 76	1.5 6 6	– – –	<u>3 IMPACTS</u> $V_H \sim 36.2, 41.4, 43.3$ $V_V \sim 3.05, 10.9, 22$	<u>2 IMPACTS</u> $V_H \sim 40.8, 42.4$ $V_V \sim 3., 11.4$	<u>3 IMPACTS</u> $V_H \sim 28.3, 39, 48.8$ $V_V \sim 5.9, 8.1, 13.6$	<u>2 IMPACTS</u> $V_H \sim 33.5, 52.4,$ $V_V \sim 10, 5.5$	• <u>NOSE SECTION</u> $V_V \cong 7$ • <u>LAT. SEGMENT</u> $V_V = 4.9$ • <u>AXIAL CYLINDER</u> $V_H = 9.5$
• WING IMPACT WITH GROUND	GGO AGHO AGI	36 76 76	6 6 6						
• NOSE GEAR WHEEL PENETRATION INTO FUSELAGE	GGO	36	3	3					
• LOWER FUSELAGE ABRASION	GGO	36	–	–					
• LOWER FUSELAGE TEAR	GGO	36	–	–					

① VELOCITIES IN M/SEC.

V_H = HORIZONTAL VELOCITY, V_V = VERTICAL VELOCITY, V_L = LATERAL VELOCITY

- Compare analytically derived floor pulses for current jet aircraft with previously acquired transport floor pulse data and postulate mass and speed effect factors

- Verify dynamic pulses with applicable tests from the proposed test program

- Establish dynamic-static equivalences and propose quantitative dynamic pulses, if applicable, and verify with experimental data

An important adjunct to determine dynamic pulse requirements is the need to establish human tolerance criteria for the transport traveling population. Data from reference 16 indicates a wide disparity in levels of human tolerance reported, partially because the conditions under which data is obtained are not presented.

The data that are available should be clarified with regard to:

- location of measurement, i.e., floor, seat, occupant

- level of injury, i.e., threshold of pain, serious injury

- restraint system used, i.e., lap belt, shoulder harness, chest straps

- percentile specimen involved, i.e., 50th male, 95th male

Proposed analysis and test plans are presented in sections 10.1 and 10.2, respectively. The premise for the proposed tests as stated earlier is that a coordinated test and analysis is required and that the combined results be utilized in a crash dynamics document so that future designs and designers would benefit from a "data bank" which could be expanded as needed. Figure 11-8 illustrates the integrated test/analysis program. The initial analytical effort should center on modifying and developing analytical techniques, and applying the techniques to: 1) the candidate crash scenarios, and 2) structures and systems to be analyzed. The analytical results can be used to establish test parameters for the substructure, systems and total

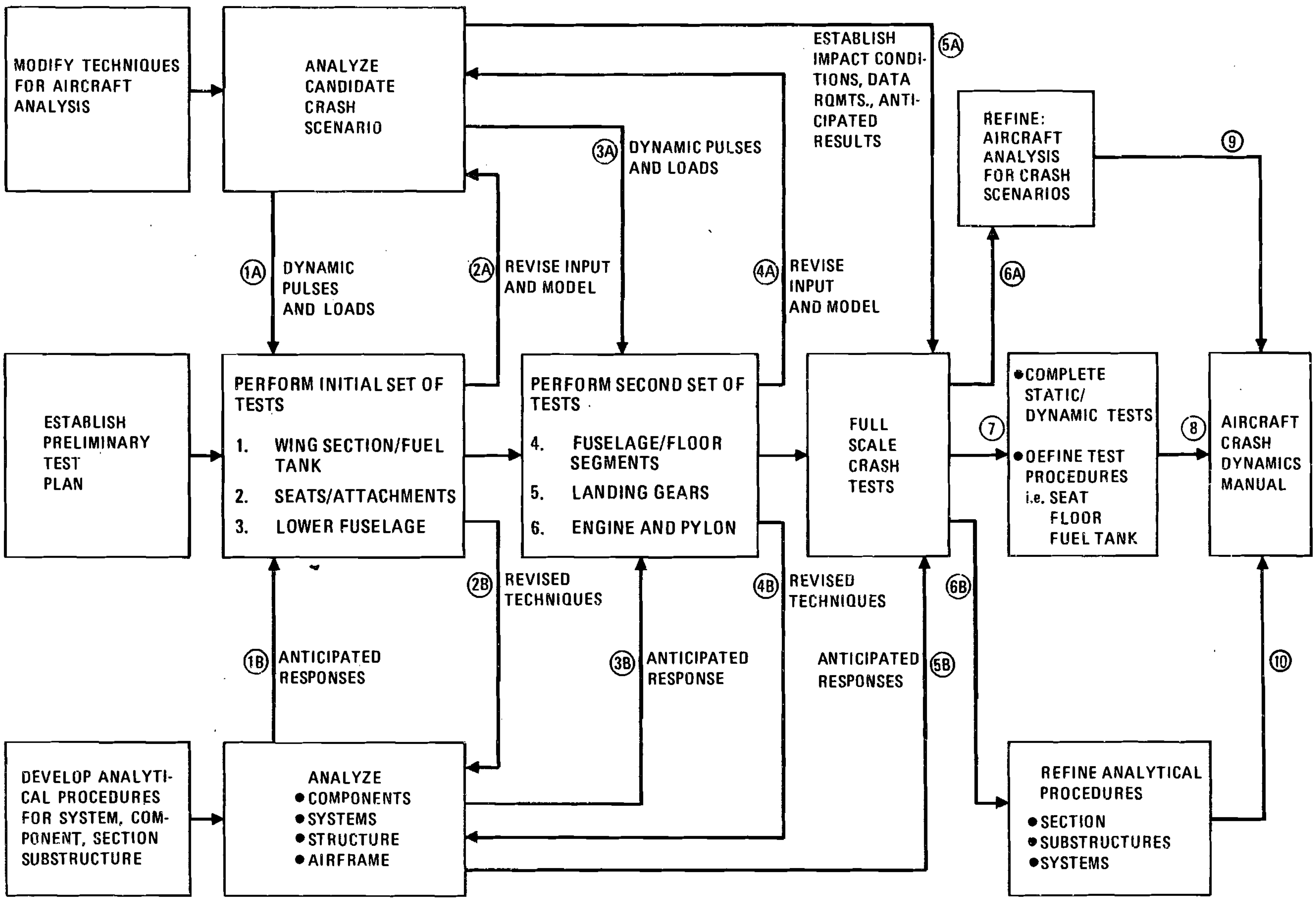


Figure 11-8. - Integrated analysis/test program.

aircraft as noted in path 1A, 1B, 3A, 3B, 5A and 5B. The results of the tests can be used to:

1. Refine aircraft analysis
2. Refine analytical procedures
3. Define test procedures

as noted by paths 2A, 2B, 4A, 4B, 6A, 6B and 7.

All of the data to be obtained from the analytical and test programs could then be incorporated in an Aircraft Crash Dynamics Document (paths 8, 9, 10). The Crash Dynamics Document would consist of the following information:

- Definitions and terminology commonly used in crash dynamics
- Crash design requirements
- Crash scenarios
- Crash dynamics accident data requirements and techniques for obtaining the data
- Crash dynamics data bank
- Analytical methods and techniques applicable for aircraft and substructure response
- Occupant tolerance measurement severity indices to be used.

A Crash Dynamics Document could be established which is applicable to transports, helicopters and General Aviation aircraft.

12. CONCLUSIONS

1. Transport airplane travel is a safe mode of transportation and the trend with modern day large jets is improving.

   - Air carrier travel results in less fatalities that other modes of travel such as automobiles and general aviation aircraft.
   - Accident data shows a decline in accident rates, and an improvement in occupant survivability with wide body jets.
   - Trend over the years is for less fatalities as measured in hours, departures or miles.
   - U. S. accident performance is better than worldwide performance.
   - Accident performance of jets is much better than nonjets and is improving.
   - U. S. air carriers and commuter trend is toward a decrease in number of accidents and fatal accidents.
   - Transport airplane emergency landing design requirements are adequate for minor accidents on or around airport runways.
   - Verified analytical procedures are needed to ensure that future aircraft designs maintain the current crash dynamics capability.

2. The transport aircraft environment can be rationally described by a set of crash scenarios for accidents that occur on or around airport runways.

   - Injury potential is related to accident condition:

     a. accidents that occur when the aircraft is on the ground or near the runway and no unpredictable hazards are involved are rarely fatal

     b. when the impact occurs at high speed and at a large impact angle, the accident has a high probability of fatality

c. in between the extremes much depends on the surrounding hazards and post-impact behavior.

- Accident data shows that severity is a function of accident type and location relative to the airport.

- No two accidents are alike, although there are broad similarities for groups of accidents.

3. To ensure a continuation of satisfactory seat performance in future transport aircraft a better understanding of seat-restraint system-occupant dynamics and test techniques are needed.

   - A static peak response for a single-degree-of-freedom system is equivalent to a dynamic pulse amplitude vs duration curve.

   - Available transport aircraft floor pulse data is limited and predominantly obtained for one particular type of accident, i.e., airplane impact onto a sloped dirt terrain.

   - The pulse definition provided in the evaluation of test data is very dependent on the subjective manner in which data is reduced.

   - Many factors influence seat performance including fuselage crush, fuselage separation and floor collapse. The involvement of obstacles, hazards and terrain conditions contributes to the potential loss of structural integrity and consequently seat and attachment failures.

   - The acceleration level and pulse shape is dependent upon such variables as airplane attitude, airplane structure, airplane velocity, type of surface and/or obstacles the airplane hits. Different accident conditions, e.g., hard landing on the runway versus an overrun off the runway, could produce different pulse amplitudes and durations. The pulse varies as a function of location along the fuselage and the relative distance from the impact point.

   - The trend with larger jet transports indicates an anticipation of acceleration levels of lesser magnitude and longer duration than the earlier vintage transports and lighter aircraft despite the increase in weight and operating speed. The reasons for this are: (1) the wider body jets have stronger airframes which could reduce plowing and, (2) there is more crushable structure between the impact point and floor location of the occupants.

- The tolerance data for occupants is based on military personnel in good physical condition. The transport traveling public consists of people with a wide range of weights, sizes and physical conditions.

4. The reduction of post-crash fires provides a high potential for increased occupant survivability.

   - Wing fuel tank/line rupture is related to crash scenarios.

   - Wing failure occurs most frequently at root-inboard and mostly during severe air-to-ground impacts.

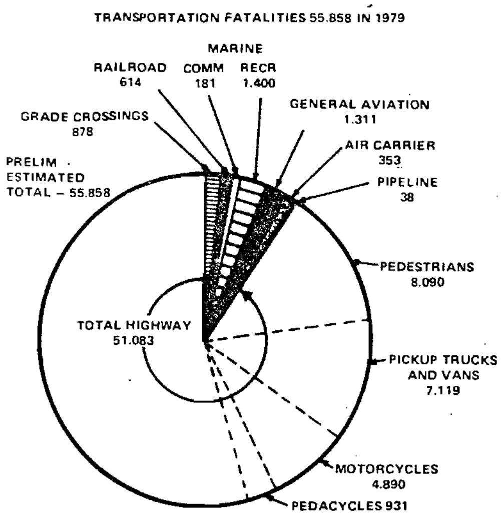
   - Fire hazard increases as the severity of the accident increases.

   - Fire and trauma related injuries occur during severe air-to-ground impacts.

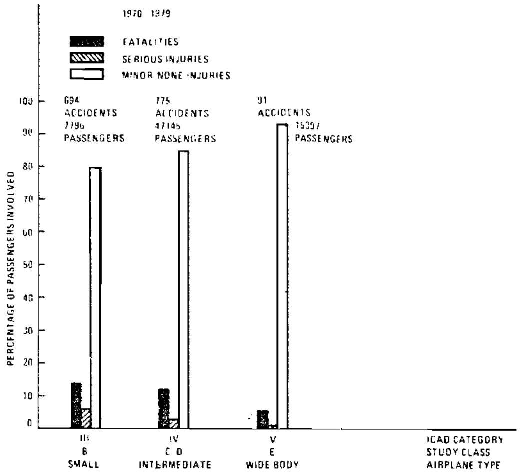
5. Improved design of airport environs, operating procedures and aircraft warning systems provide an opportunity for substantial reduction in occupant injuries and/or fatalities.

   - Higher percentage of accident fatalities occur as a result of hazards around the aircraft.

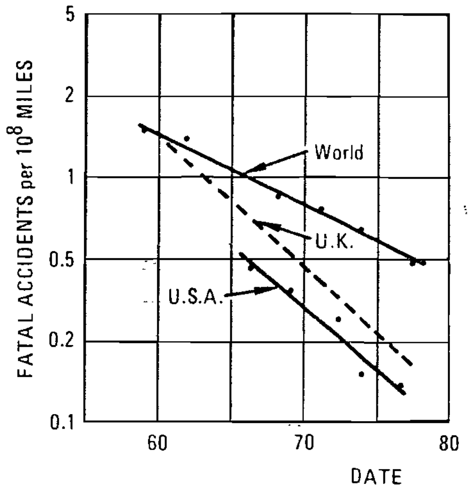
   - Potential payoff exists for reduced off-runway hazards and improved accident warning systems.



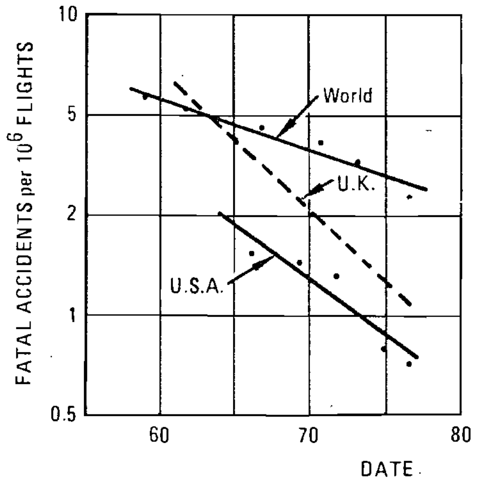
- AIR CARRIER TRAVEL RESULTS IN LESS FATALITIES THAN OTHER MODES OF TRAVEL SUCH AS AUTOMOBILES AND GENERAL AVIATION AIRCRAFT.



- ACCIDENT DATA SHOWS A DECLINE IN ACCIDENT RATES, AND AN IMPROVEMENT IN OCCUPANT SURVIVABILITY WITH WIDE BODY JETS.

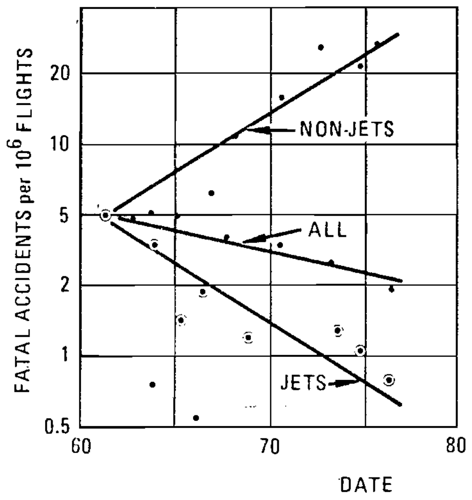


- TREND OVER THE YEARS IS FOR LESS FATALITIES AS MEASURED IN HOURS, DEPARTURES OR MILES.

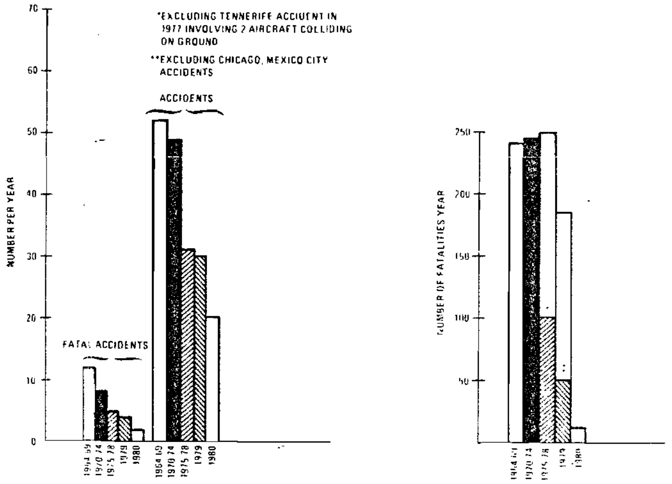


- U. S. ACCIDENT PERFORMANCE IS BETTER THAN WORLDWIDE PERFORMANCE.

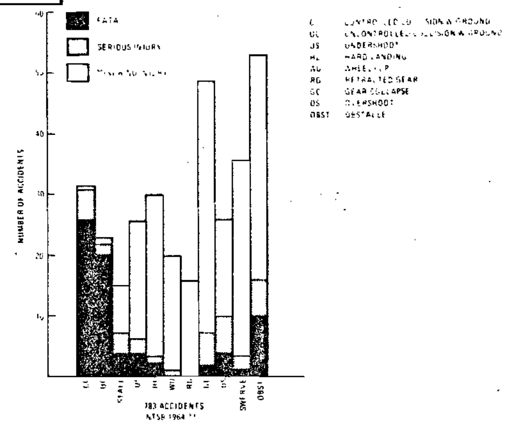
TRANSPORT AIRPLANE TRAVEL IS A SAFE MODE OF TRANSPORTATION AND THE TREND WITH MODERN DAY LARGE JETS IS IMPROVING.



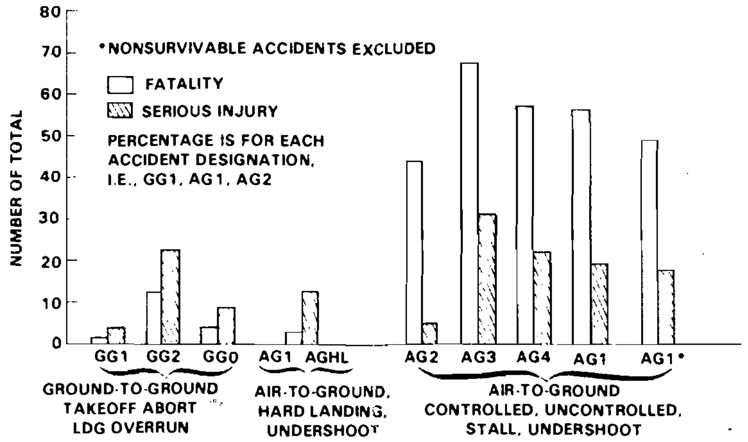
- ACCIDENT PERFORMANCE OF JETS IS MUCH BETTER THAN NONJETS AND IS IMPROVING.

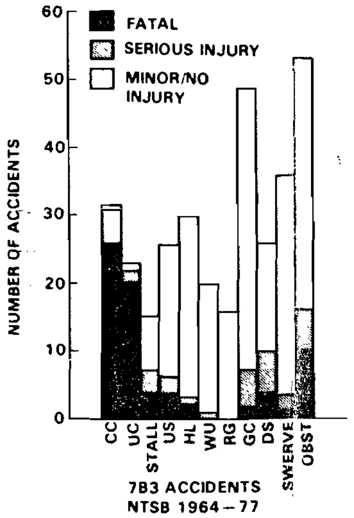


- U. S. AIR CARRIERS AND COMMUTER TREND IS TOWARD A DECREASE IN NUMBER OF ACCIDENTS AND FATAL ACCIDENTS.



- TRANSPORT AIRPLANE EMERGENCY LANDING DESIGN REQUIREMENTS ARE ADEQUATE FOR MINOR ACCIDENTS ON OR AROUND AIRPORT RUNWAYS.
- VERIFIED ANALYTICAL PROCEDURES ARE NEEDED TO ENSURE FUTURE AIRCRAFT DESIGNS MAINTAIN THE CURRENT CRASH DYNAMICS CAPABILITY.





CC – CONTROLLED COLLISION W/GROUND
UC – UNCONTROLLED COLLISON W/GROUND
US – UNDERSHOOT
HL – HARD LANDING
WU – WHEELS UP
RG – RETRACTED GEAR
GC – GEAR COLLAPSE
OS – OVERSHOOT
OBST – OBSTACLE

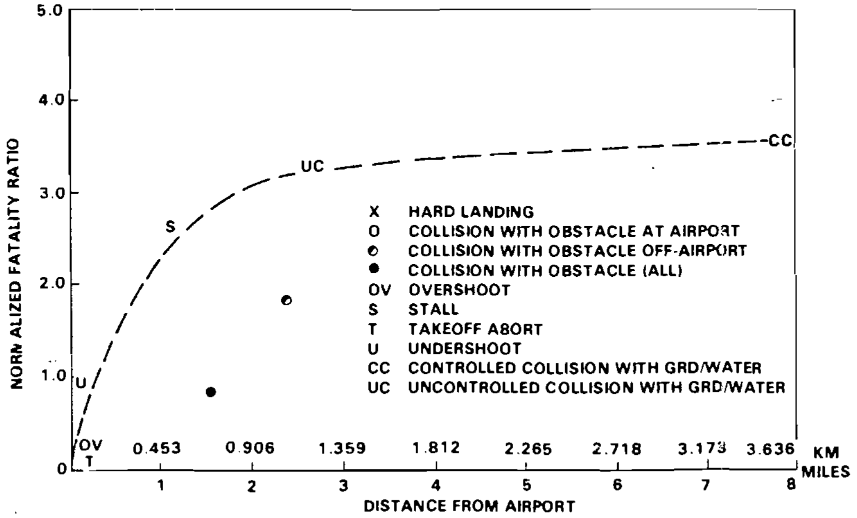
- INJURY POTENTIAL IS RELATED TO ACCIDENT CONDITION:

A. ACCIDENTS THAT OCCUR WHEN THE AIRCRAFT IS ON THE GROUND OR NEAR THE RUNWAY AND NO UNPREDICTABLE HAZARDS ARE INVOLVED ARE RARELY FATAL

B. WHEN THE IMPACT OCCURS AT HIGH SPEED AND AT A LARGE IMPACT ANGLE, THE ACCIDENT HAS A HIGH PROBABILITY OF FATALITY

C. IN BETWEEN THE EXTREMES MUCH DEPENDS ON THE SURROUNDING HAZARDS AND POST-IMPACT BEHAVIOR

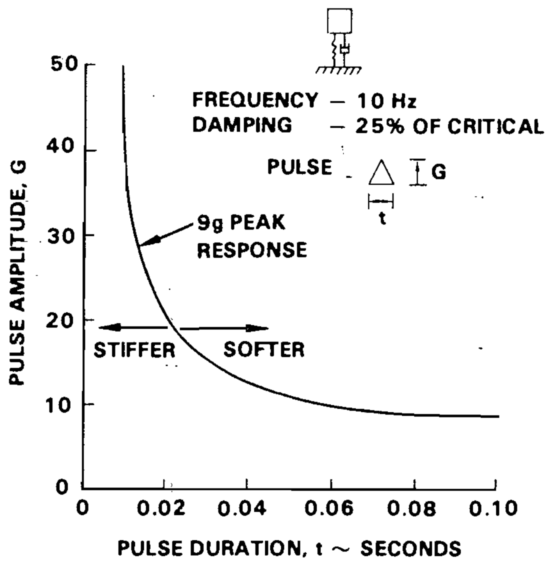
THE TRANSPORT AIRCRAFT ENVIRONMENT CAN BE RATIONALLY DESCRIBED BY A SET OF CRASH SCENARIOS FOR ACCIDENTS THAT OCCUR ON OR AROUND AIRPORT RUNWAYS.



- ACCIDENT DATA SHOWS THAT SEVERITY IS A FUNCTION OF ACCIDENT TYPES AND LOCATION RELATIVE TO THE AIRPORT

CANDIDATE CRASH SCENARIO	IMPACT CONDITIONS	ACCIDENT TYPE	TERRAIN	HAZARD
GROUND-TO-GROUND, OVERRUN	LOW SINK SPEED LOW FORWARD VELOCITY SYM. A/P ATTITUDE GEARS EXTENDED	TAKEOFF ABORT LANDING OVERRUN	RUNWAY HARD GROUND	DITCH MOUND SLOPE SLAB LIGHT STANCHION
AIR-TO-GROUND, HARD LANDING	HIGH SINK SPEED LANDING VELOCITY SYM. A/P ATTITUDE GEARS EXTENDED	HARD LANDING UNDERSHOOT	RUNWAY HARD GROUND	NONE
AIR-TO-GROUND, IMPACT	HIGH SINK SPEED LANDING VELOCITY UNSYM. A/P ATTITUDE GEARS EXTENDED/RET.	UNCONT/CONTROLLED GRD COLLISION STALL UNDERSHOOT	WOODED HILLY	TREES SLOPES BLDGS

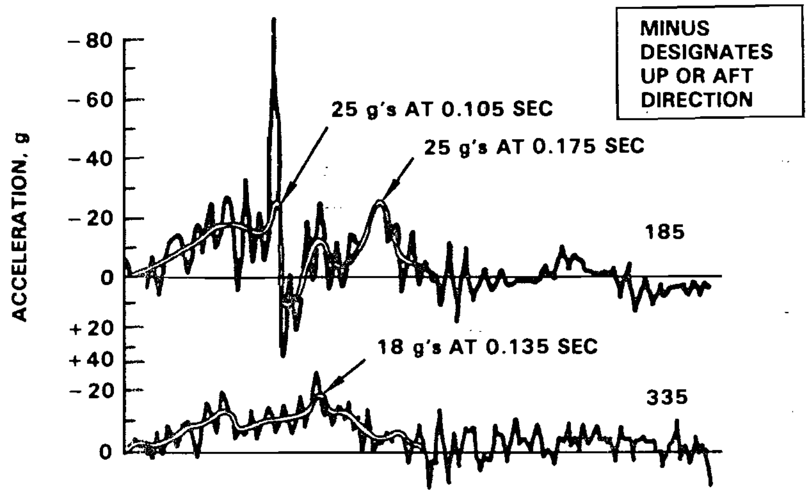
- NO TWO ACCIDENTS ARE ALIKE, ALTHOUGH THERE ARE BROAD SIMILARITIES FOR GROUPS OF ACCIDENTS



- A STATIC PEAK RESPONSE FOR A SINGLE-DEGREE-OF-FREEDOM SYSTEM IS EQUIVALENT TO A DYNAMIC PULSE AMPLITUDE VS DURATION CURVE.

- AVAILABLE TRANSPORT AIRCRAFT FLOOR PULSE DATA IS LIMITED AND PREDOMINANTLY OBTAINED FOR FOR PARTICULAR TYPE OF ACCIDENT, I.E., AIRPLANE IMPACT ONTO A SLOPED DIRT TERRAIN.

- THE TOLERANCE DATA FOR OCCUPANTS IS BASED ON MILITARY PERSONNEL IN GOOD PHYSICAL CONDITION. THE TRANSPORT TRAVELING PUBLIC CONSISTS OF PEOPLE WITH A WIDE RANGE OF WEIGHTS, SIZES AND PHYSICAL CONDITIONS.

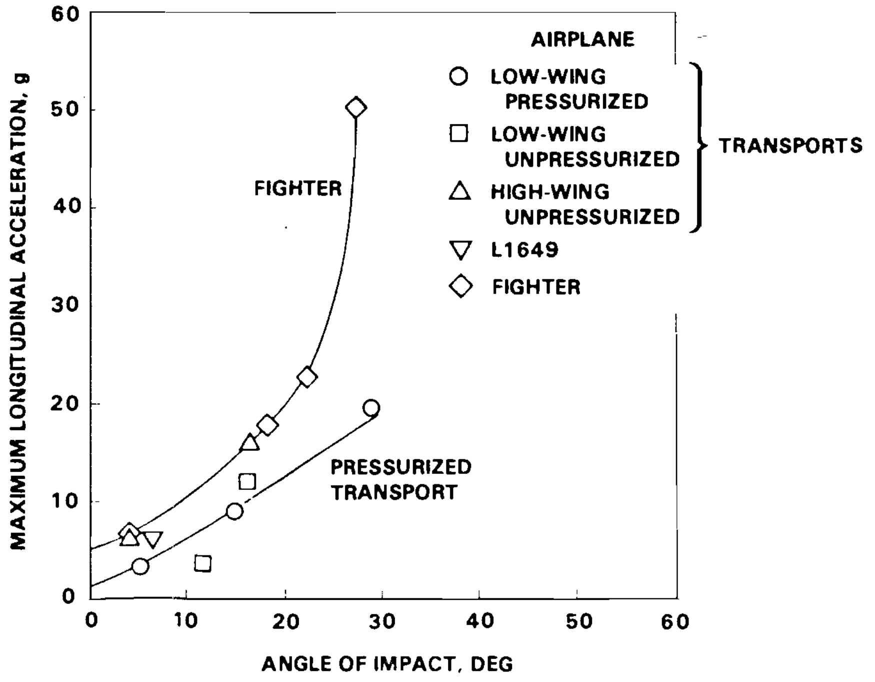


- THE PULSE DEFINITION PROVIDED IN THE EVALUATION OF TEST DATA IS VERY DEPENDENT ON THE SUBJECTIVE MANNER IN WHICH DATA IS REDUCED.

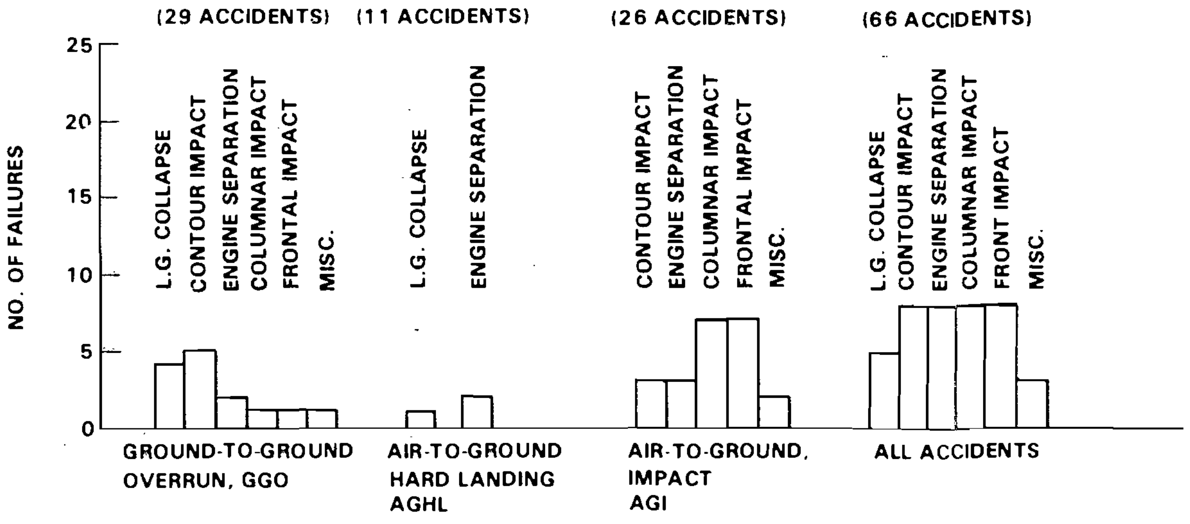
TO ENSURE A CONTINUATION OF SATISFACTORY SEAT PERFORMANCE IN FUTURE TRANSPORT AIRCRAFT A BETTER UNDERSTANDING OF SEAT-RESTRAINT SYSTEM-OCCUPANT DYNAMICS AND TEST TECHNIQUES ARE NEEDED

- MANY FACTORS INFLUENCE SEAT PERFORMANCE INCLUDING FUSELAGE CRUSH, FUSELAGE SEPARATION AND FLOOR COLLAPSE. THE INVOLVEMENT OF OBSTACLES, HAZARDS AND TERRAIN CONDITIONS CONTRIBUTE TO THE POTENTIAL LOSS OF STRUCTURAL INTEGRITY AND CONSEQUENTLY SEAT AND ATTACHMENT FAILURES.

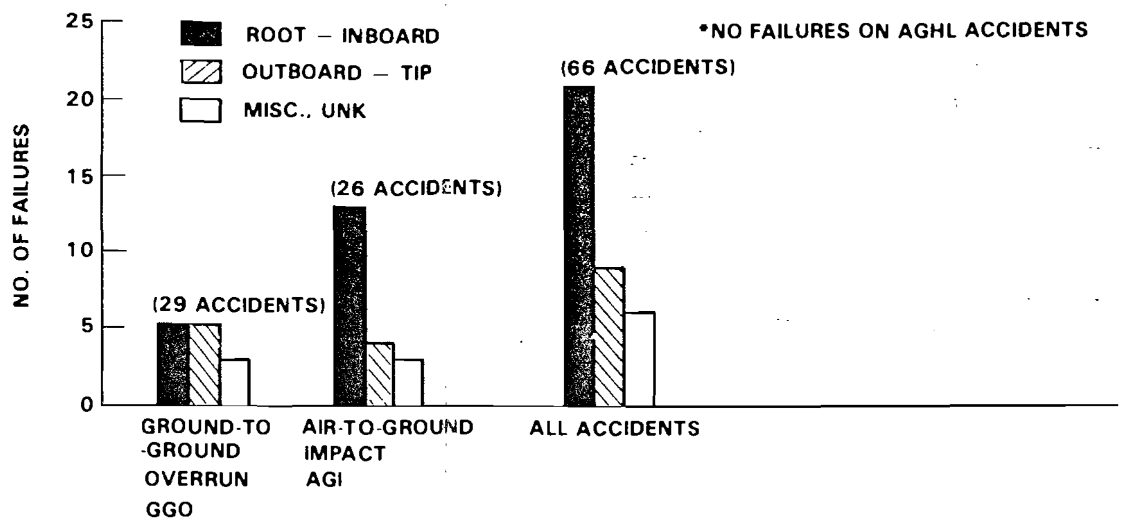
- THE ACCELERATION LEVEL AND PULSE SHAPE IS DEPENDENT UPON SUCH VARIABLES AS AIRPLANE ATTITUDE, AIRPLANE STRUCTURE, AIRPLANE VELOCITY, TYPE OF SURFACE AND/OR OBSTACLES THE AIRPLANE HITS. DIFFERENT ACCIDENT CONDITIONS, E.G., HARD LANDING ON THE RUNWAY VERSUS AN OVERRUN OFF THE RUNWAY, COULD PRODUCE DIFFERENT PULSE AMPLITUDES AND DURATIONS. THE PULSE VARIES AS A FUNCTION OF LOCATION ALONG THE FUSELAGE AND THE RELATIVE DISTANCE FROM THE IMPACT POINT.



- THE TREND WITH LARGER JET TRANSPORTS INDICATES AN ANTICIPATION OF ACCELERATION LEVELS OF LESSER MAGNITUDE AND LONGER DURATION THAN THE EARLIER VINTAGE TRANSPORTS AND LIGHTER AIRCRAFT DESPITE THE INCREASE IN WEIGHT AND OPERATING SPEED. THE REASONS FOR THIS ARE: (1) THE WIDER BODY JETS HAVE STRONGER AIRFRAMES WHICH COULD REDUCE PLOWING AND, (2) THERE IS MORE CRUSHABLE STRUCTURE BETWEEN THE IMPACT POINT AND FLOOR LOCATION OF THE OCCUPANTS.



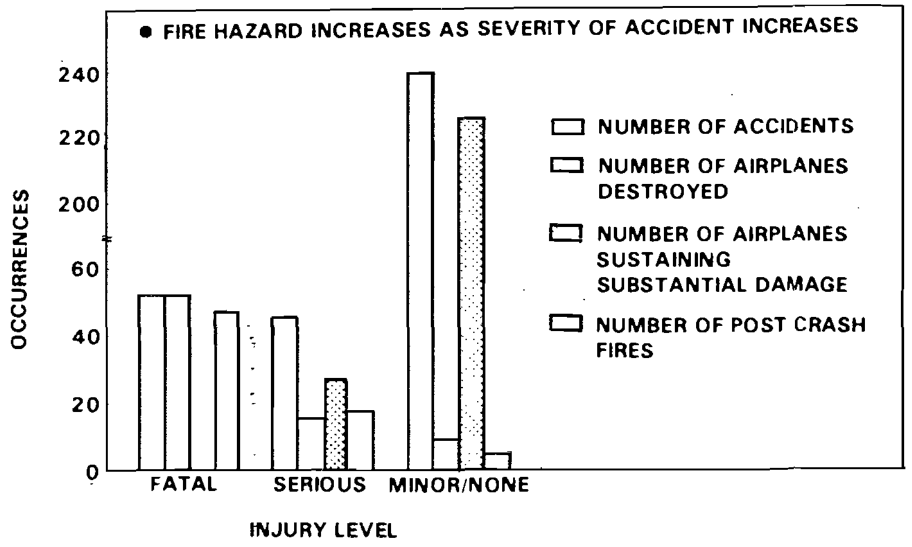
- WING FUEL TANK/LINE RUPTURE IS RELATED TO CRASH SCENARIOS.



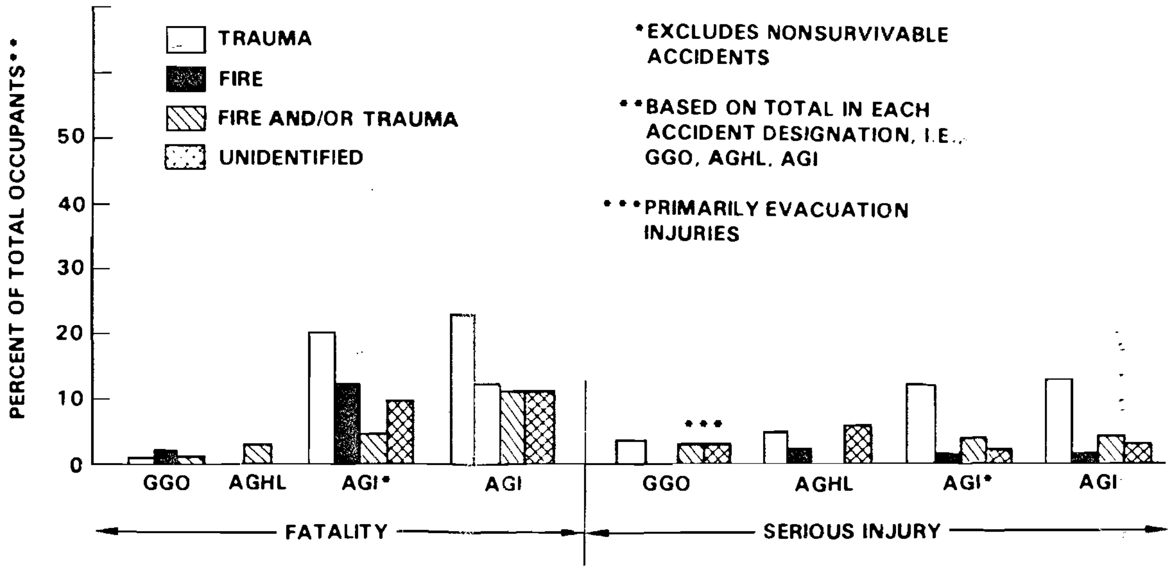
*NO FAILURES ON AGHL ACCIDENTS

- WING FAILURE OCCURS MOST FREQUENTLY AT ROOT-INBOARD AND MOSTLY DURING SEVERE AIR-TO-GROUND IMPACTS.

THE REDUCTION OF POST-CRASH FIRES PROVIDES A HIGH POTENTIAL FOR INCREASED OCCUPANT SURVIVABILITY.



- FIRE HAZARD INCREASES AS THE SEVERITY OF THE ACCIDENT INCREASES.

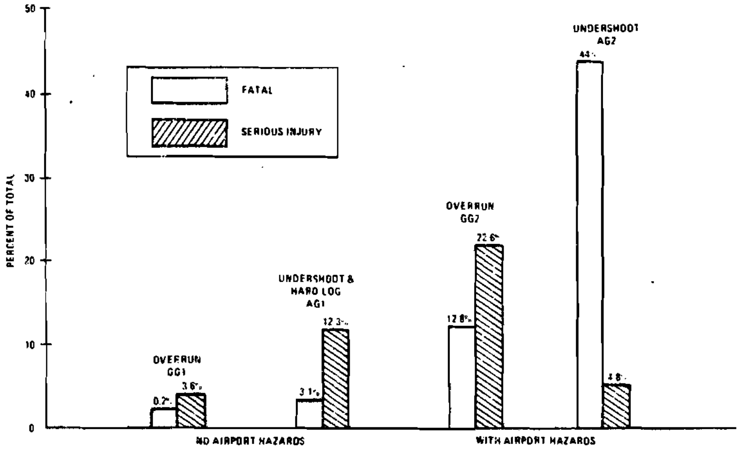


*EXCLUDES NONSURVIVABLE ACCIDENTS

**BASED ON TOTAL IN EACH ACCIDENT DESIGNATION, I.E., GGO, AGHL, AGI

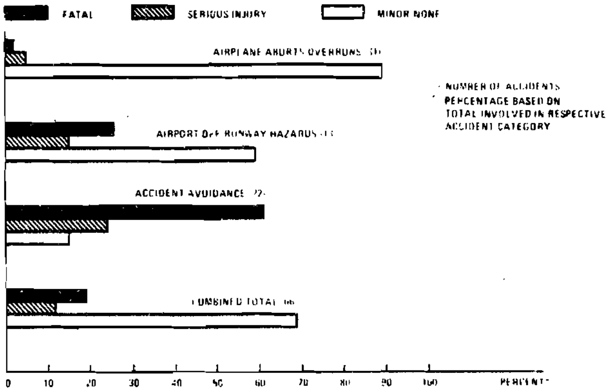
***PRIMARILY EVACUATION INJURIES

- FIRE AND TRAUMA RELATED INJURIES OCCUR DURING SEVERE AIR-TO-GROUND IMPACTS.



- HIGHER PERCENTAGE OF ACCIDENT FATALITIES OCCUR AS A RESULT OF HAZARDS AROUND THE AIRCRAFT.

IMPROVED DESIGN OF AIRPORT ENVIRONS, OPERATING PROCEDURES AND AIRCRAFT WARNING SYSTEMS PROVIDE AN OPPORTUNITY FOR SUBSTANTIAL REDUCTION IN OCCUPANT INJURIES AND/OR FATALITIES.



- POTENTIAL PAYOFF EXISTS FOR REDUCED OFF-RUNWAY HAZARDS AND IMPROVED ACCIDENT WARNING SYSTEMS.

13. RECOMMENDATIONS

1. Refine analytical capability and apply to candidate crash scenarios.

   Analysis methods need to be correlated with test data where possible and calibrated against existing structure with known service experience in order to validate the analytical techniques. Whenever refinements and improvements are made in the analytical techniques, this process of validation should be repeated to give confidence in the new techniques and analysis methods.

   - Definitize specific parameters associated with the candidate crash scenarios to develop an impact capability envelope for current transport aircraft. Thus, the satisfactory performance demonstrated by jet transports over the years can be maintained or improved upon when incorporating changes in materials and/or concepts in future aircraft.

   - Different analytical techniques are applicable depending on event and objective. Hybrid (KRASH), finite element (DYCAST), modal (AGIP), occupant (SOMLA), are applicable and their use depends on: 1) detail required, 2) availability of data, 3) anticipated failure modes, 4) cost, 5) analysis purpose, e.g., trend, design, tradeoff.

   - Candidate crash scenarios could require different analytical approaches:

     a. Ground-to-ground overrun type accident, such as take-off abort or landing overrun, which occurs at a low forward speed (40-130 Kts), with the landing gears extended and the airplane in a level and symmetrical attitude. The accident occurs on paved runway or hard ground. Damage is sustained by the airplane as it traverses a ditch, road or mound. The effective normal velocity as a result of gear collapse or terrain impact is $\leq$ 1.5 m/sec. The availability of pilot action to control impact severity is assumed to exist. Airplane weight can range between landing and maximum takeoff. Balanced group initial conditions are important. Fuselage breakup is not usually severe. Occupant accelerations should be relatively low since primary response longitudinally is associated with ground coefficient of friction.

b. Air-to-ground hard landing accident such as touchdown just short of or on the runway. On the average, the sink speed is in the vicinity of 5.2 m/sec: (17 ft/sec). Forward velocity is in the range of 126 to 160 knots. The airplane lands with landing gear extended in a noseup symmetrical attitude ranging from 0 to 14°. These accidents occur on a rigid flat surface with no obstacles or hazards. Analysis should be performed for maximum landing weight. Major concern for this type of accident is landing gear failure mode, fuselage breakup, fuel tank rupture and seat performance under potentially severe vertical loads.

c. Air-to-ground impact accident type on hard ground on or off the runway. Sink speed can range up to 10 m/sec. Forward velocity is in the range of 126 to 160 knots. Airplane can land with gears retracted or extended in an unsymmetrical attitude. Range of unsummetry is $0^\circ \leq$ roll $\leq 10^\circ$ with pitch attitude from 0° to +14°. The major concern in performing an analysis for this type of accident is determining limits of a survivable crash enviroment. Fuselage crush and/or breakup expected to be substantial and to influence floor and seat integrity. Wing fuel tank rupture potential is higher than for other candidate crash scenarios. Contour, columnar and frontal obstruction impacts should be evaluated over a wide range of possibilities.

- Analysis is the most practical approach to determining anticipated floor pulses for modern day jet transport aircraft because extensive crash testing of full scale test articles appears prohibitively costly. Analysis is necessary since floor pulses vary as a function of:

  a) impact conditions
  b) response location in proximity to impact point
  c) aircraft size, speed, design.

- Analysis parameter studies can be used to show sensitivity of results to variation in impact conditions in a more practical and cost effective manner than testing. Figure 8-2 illustrates the results of a parameter study performed analytically.

2. Quantify seat crash dynamic floor pulse and recommend appropriate compliance procedure for seat/occupant systems.

   - Dynamic pulse should be established: (1) utilizing existing test data, (2) application of analysis to candidate crash scenarios, (3) utilizing tests to verify influence of mass, size, speed, and design effects.

- Compliance with dynamic requirements should be shown feasible with one or more approaches:

  1) dynamic tests

  2) static tests based on dynamic equivalence

  3) analysis of occupant response utilizing a verified acceptable analytical procedure.

- Limited airframe and full scale crash test data could be used to confirm analytical predictions.

- Perform seat tests to evaluate test techniques and representative pulses both for unidirectional and combined loading.

3. Perform analysis and tests at the element, system, substructure, section, airframe and aircraft levels for the purpose of developing verified analytical procedures and creating a data base for future transport crash design considerations.

- There is a need for an integrated test/analysis program as outlined in figure 11-8. The tests should be performed:

  a) with representative structure

  b) for realistic crash impact conditions

  c) to identify critical failure modes

  d) determine dynamic response;

the analysis should be performed to

  a) predict responses

  b) utilize test data in establishing models. Both the analysis and test should be used to develop analytical and test procedures which can be used for showing compliance with design requirements.

- Little in the way of applicable data is available with regard to dynamic behavior of advanced materials in a crash environment.

- Abrasion, tearing and crushing characteristics of advanced materials under a crash loading situation are unknown. Metal structure is "forgiving" in the sense that while experiencing large deflections structural integrity is still maintained. To what extent composites will maintain structural integrity under similar loading conditions has to be ascertained. Coupon, element and section tests to establish comparative data relationships is a good starting point for developing a data base. While it is true that advanced materials are not currently being used in primary transport aircraft structure, now is the time to give consideration to the fact that it will take substantial time and effort to bring an understanding of composite behavior in a crash environment to a level comparable to the understanding of metals.

- The available transport aircraft crash test data is very limited when compared to the range of data that is desired. Table 11-2 shows a matrix comparing test data requirements with existing data.
- Scale model testing may be appropriate since transport aircraft sections are extremely large. However, if scale model tests are performed the primary emphasis should be on substantiating an analytical technique and not necessarily relating test data to design.

4. Develop a crash dynamics manual for aircraft in support of design, accident investigation and analysis. The manual to be applicable for a range of aircraft configurations including light fixed wing, helicopter and transport aircraft.

   - Crash dynamics document would consist of the following:

     a) definitions and terminology commonly used in structural crash dynamics

     b) crash design requirements

     c) crash scenarios

     d) crash dynamic accident data requirement and techniques for obtaining the data

     e) crash dynamics structures data bank

     f) analytical methods and techniques applicable for aircraft and substructure response

     g) occupant tolerance measurement severity indices to be used.

5. Review airport surrounding design requirements, airport runway operating procedures and airplane warning systems for the purpose of reducing frequency of accident occurrence.

   - A close examination of the candidate crash scenarios indicates the following grouping is possible:

a) Airplane design related - accidents which occur around airports, i.e., on the runway or within 350 m. of the runway are moderately influenced by hazards and surrounding obstructions. The terrain is easy to define and the airplane configuration readily prescribed. The performance of the airplane for this type of crash scenario should be indicative of modern day jet transport crash design capability and an indication of the merits of current design requirements.

b) Airport environs related - accidents which occur in the vicinity of the airport, either on the runway or beyond the runway and the resultant damage is significantly influenced by unpredictable hazards and terrain conditions. The performance of the airplane for these scenarios is to a large degree dependent on the airport surroundings and additional effort is needed to determine how improved design of airport environs and operating procedures can be incorporated to reduce accidents around the airport.

c) Warning system related - accidents that occur away from the airport, result from loss of airplane control, are a result of pilot disorientation or are caused by unreliable warning systems generally involving impact at high speed, with a wide range of possible impact attitudes and amongst hazardous terrain. The performance of the airplane for these scenarios to a great extent is influenced by the severity of the impact conditions, which in turn, results from the pilot's inability to control the situation. Quite often this inability on the part of the pilot is directly related to his unawareness of the situation, until it is too late to react in a manner to reduce the vulnerability of the aircraft to the impact conditions.

APPENDIX A

AIRPLANE ACCIDENT DATA

This section contains backup data for the discussion regarding Accident Data Review and Evaluation. Tables A-1 through A-8 list accidents which are eliminated from the NTSB data as potential candidates in the development of crash scenarios because they are not crash design related or are strictly evacuation related injuries in which no airplane structural damage was involved.

Tables A-9 and A-10 describe the accidents that comprise the initial categories presented in tables 2-12 and 2-13. The 14 accident types presented in table 2-12 and table 2-13 were pared down to eight accident types for consideration as crash scenarios. Table A-11 lists the accidents which comprise the eight accident types from which the candidate crash scenarios are formulated.

TABLE A-1. - LIST OF ACCIDENTS TO BE ELIMINATED IN THE DEVELOPMENT OF CRASH SCENARIOS (MISCELLANEOUS TYPE)

Airplane Weight Class: B, C, D, E
Injury Index: Fatal

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
Ⓑ 6-28-68	Flight	–		No	M	1	0	26	Inadvertent door opening, pax. fell out
Ⓒ 11-15-66	Landing, i.a.	Undetermined		Yes	D	3	0	0	E. Germany jurisdiction
Ⓓ 8-28-73	Flight	–		No	N	1	22	48	Seat belt sign off
9-23-64	Static	–		No	N	1	0	99	Hit ground crewman
Ⓔ 2-2-74	Flight	–		No	N	1	0	298	Unattended child asphyxiated by seatbelt

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach

l.o. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-2. - LIST OF ACCIDENTS TO BE ELIMINATED IN THE DEVELOPMENT OF CRASH SCENARIOS (MISCELLANEOUS LANDING, TAKEOFF, TAXI, STATIC TYPE)

Airplane Weight Class: B, C, D, E
Injury Index: Serious

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
Ⓑ 11-1-72	Landing, t.p.	–	–	No	N	0	1	15	Crankarm hit copilot
2-10-71	Landing, roll	–	–	No	S	0	2	0	Icy lake
12-21-76	Static	–	–	No	N	0	1	32	Pax. fell deplaning
Ⓒ 8-22-66	Unknown	–	–	No	N	0	1	68	Turbulence related
7-15-64	Takeoff, i.c.	–	–	No	N	0	1	19	Turbulence related
3-7-67	Taxi	–	–	No	N	0	1	3	Ground personnel
3-4-66	Static	–	–	No	N	0	1	66	Stain handrail failed
9-23-68	Static	–	–	No	N	0	5	80	Pax. jumped from wing
6-26-68	Static	–	–	No	N	0	2	30	Pax. jumped from wing
5-7-71	Static	–	–	No	N	0	1	69	Pax. jumped from wing
7-24-74	Static	–	–	No	N	0	1	70	Pax. fell deplaning
11-21-74	Static	–	–	No	N	0	1	49	Pax. fell deplaning
Ⓓ 5-18-72	Takeoff, run	–	–	No	N	0	1	81	Unfastened seatbelt
Ⓔ 9-19-76	Taxi	–	–	No	N	0	1	241	Unfastened seatbelt
4-16-74	Static	–	–	No	N	0	1	13	Ground crewman

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach
l.o. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-3. - LIST OF ACCIDENTS TO BE ELIMINATED IN THE DEVELOPMENT OF CRASH SCENARIOS (MISCELLANEOUS FLIGHT TYPE)

Airplane Weight Class: B, C, D, E
Injury Index: Serious

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
Ⓑ 1-18-65	Flight	–	–	No	N	0	1	12	Unfastened seat belt
2-22-65	Flight	–	–	No	N	0	1	46	Cabin attendant
5-19-67	Flight	–	–	No	N	0	1	2	Stewardess lost balance
Ⓒ 1-12-66	Flight	–	–	No	N	0	1	5	Trainee fell
8-10-68	Flight	–	–	No	N	0	1	47	Pax. fell
12-13-69	Flight	–	–	No	N	0	1	95	Pax. fell
8-16-73	Flight	–	–	No	N	0	1	55	Unfastened seat belt
8-22-73	Flight	–	–	No	N	0	1	45	Unfastened seat belt
6-8-75	Flight	–	–	No	N	0	1	7	Pax. lung collapse
Ⓓ 5-1-67	Flight	–	–	No	N	0	1	56	Stewardess lost balance
10-5-68	Flight	–	–	No	N	0	1	94	Pax. left seat
Ⓔ 12-27-70	Flight		–	No	N	0	1	75	Stewardess fell downstairs
8-10-73	Flight		–	No	N	0	1	212	Attendant injured by food cart
4-26-75	Flight		–	No	N	0	1	252	Attendant injured by food cart

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach
l.l. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-4. - LIST OF ACCIDENTS TO BE ELIMINATED IN THE DEVELOPMENT OF CRASH SCENARIOS (NON MISCELLANEOUS TYPE)

Airplane Weight Class: B
Injury Index: Fatal

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
Ⓑ 5-7-64	Flight	uc	–	Yes	D	44	0	0	Pilot and co-pilot shot
4-23-65	Flight	cc	–	No	D	5	0	0	A/c struck mountain
3-5-67	Flight	Prop. fail	Prop. fail.	No	D	38	0	0	Separation of engine
3-10-67	Flight	uc		Yes	D	4	0	0	Loss of control due to icing
3-10-64	Landing, i.a.	uc	–	Yes	D	3	0	0	Loss of horiz. stabilizer
2-2-69	Static	Prop. accident	–	No	N	1	0	29	Ground crewman
12-10-70	Static	Prop. accident	–	No	N	1	0	10	Ground crewman
3-5-72	Static	Prop. accident	–	No	N	1	0	29	Ground crewman

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach

l.l. == Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-5. - LIST OF ACCIDENTS TO BE ELIMINATED IN THE DEVELOPMENT OF CRASH SCENARIOS (NON MISCELLANEOUS TYPE)

Airplane Weight Class: C, D, E
Injury Index: Fatal

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damaga Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
Ⓒ 8-6-66	Flight	Airframe	–	No	D	42	0	0	Fin right tailplane & wing fail
5-3-68	Flight	Airframe	Fire	No	D	85	0	0	Wings separated in flight
5-23-74	Flight	Airframe	–	Yes	D	4	0	0	Wing spars failed
12-1-74	Flight	Stall	Airframe	No	D	3	0	0	Left H.S.. failed
6-23-67	Flight	Fire	u.c.	Yes	D	34	0	0	Elev. control system
4-22-66	Landing, t.p.	u.c.	–	Yes	D	83	15	0	Pilot suffered heart attack
3-31-71	Landing, m.a.	u.c.	–	Yes	D	5	0	0	Aircraft struck hill
11-19-68	Static	Prop. accident	–	No	D	1	0	66	Ground crewman
Ⓓ 2-25-64	Flight	u.c.	–	No	D	58	0	0	Lake
9-8-74	Flight	Fire	Fire	N.A.	D	88	0	0	At sea, sabotage
12-18-77	Flight	c.c.	–	Unknown	D	3	0	0	Hit mountain
7-26-69	Landing, m.a.	u.c.	–	Yes	D	5	0	0	Rudder control system
9-8-70	Takeoff, i.c.	Eng. failure	–	Yes	D	11	0	0	Loss of pitch control
Ⓔ 11-8-73	Flight		–	No	S	1	0	127	Rapid decompression Pax. pulled out of window

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach
l.o. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-6. - LIST OF ACCIDENTS TO BE ELIMINATED IN THE DEVELOPMENT OF CRASH SCENARIOS (NON MISCELLANEOUS TYPE)

Airplane Weight Class: B, C

Injury Index: Serious

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
Ⓑ 12-8-68	Taxi	Prop. accident	–	No	N	0	1	22	Ground crewman
12-6-65	Static	Prop. accident	–	No	N	0	1	2	Ground crewman
1-11-69	Static	Prop. accident	–	No	N	0	1	23	Ground crewman
9-19-65	Static	Prop. accident	–	No	N	0	1	7	Ground crewman
Ⓒ 3-3-68	Static	Prop. accident	–	No	N	0	1	83	Ground crewman
3-2-68	Static	Prop. accident	–	No	N	0	1	86	Boarding pax.

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach
l.o. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-7. - LIST OF ACCIDENTS INVOLVING EVACUATION INJURIES

Airplane Weight Class: D, E
Injury Index: Serious

1964-77 NTSB Data

Date of Accident	Operation Moda/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
Ⓓ 8-29-69	Static	Misc.	—	No	N	0	1	24	Hi-jack
3-3-72	Static	Fire	—	No	N	0	1	128	
11-1-72	Landing, roll	Eng. fail.	Fire	No	N	0	1	80	
3-27-74	Takeoff, run	Airframe	Misc.	Yes	N	0	1	232	
1-25-74	Takeoff, run	Eng. fail.	—	Yes	N	0	1	29	Jurisdiction of Lebanon
1-6-77	Takeoff, run	Eng. fail.	Misc.	No	N	0	7	94	
5-15-71	Static	Misc.	—	No	N	0	5	43	
Ⓔ 7-23-71	Taxi from ldg.	Eng. fail.	Fire	No	N	0	1	198	
6-29-71	Static	Misc.	—	No	N	0	1	183	
11-26-74	Static	Misc.	—	No	N	0	3	152	Jurisdiction of Italy
6-14-75	Static	Fire	—	No	N	0	1	242	
10-16-75	Taxi to takeoff	Fire	—	No	N	0	1	131	

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach
l.o. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around
ldg. = Landing

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-8. LIST OF ACCIDENTS INVOLVING EVACUATION INJURIES

Airplane Weight Class: C
Injury Index: Serious

1964-77 NTSB Data

Date of Accident	Operation Mode/Phase	Accident Type		Post Crash Fire	Airplane Damage Severity	Injury Distrib.			Comments
		Primary	Secondary			F	S	M/N	
3-14-65	Takeoff, run	Fire	c.c	No	N	0	1	23	
4-7-67	Landing, l.o.	Wheels up	–	No	N	0	1	102	
9-15-69	Taxi to takeoff	Misc.	–	No	N	0	2	74	
5-18-70	Taxi Fr. Ldg.	Fire	–	No	N	0	1	71	
4-1-71	Static	Misc.	–	No	N	0	4	56	
2-19-72	Static	Misc.	–	No	N	0	1	87	False fire warning
12-12-73	Static	Misc.	–	No	N	0	1	93	Bomb threat
1-4-74	Takeoff, run	Airframe	Eng. fail.	No	N	0	1	117	
7-10-74	Static	Misc.	–	No	N	0	2	51	False fire warning
1-17-76	Static	Misc.	–	No	N	0	2	54	
2-16-76	Takeoff, run	Eng. fail.	Fire	No	S	0	1	119	

Operation Mode/Phase

u.c. = Uncontrolled collision with ground/water
c.c. = Controlled collision with ground/water
i.a. = Initial approach
f.a. = Final approach
m.a. = Missed approach
l.o. = Level off
t.p. = In traffic pattern
i.c. = Initial climb
g.a. = Go-around

Injury Distrib.

F = Fatal
S = Serious
M/N = Minor/None

Airplane Damage

D = Destroyed
S = Substantial

Misc

N.A. = Not Avail.

TABLE A-9. - NTSB ACCIDENT REPORTS, AIR TO GROUND CRASH SCENARIOS

Date of Accident	NTSB Report/File No.	Airplane/Class
Crash Scenario: Hard Landing (A1)		
12-28-70	72-8	B727/C
1-16-74	74-10	B707/D
*9-15-70	71-9	DC-8/D
*6-23-73	73-20	DC-8/D
Crash Scenario: Controlled Collision (A2)		
11-15-64	1-0066	F-27/B
11-8-65	1-0031	B727/C
11-20-67	1-0033	CV880/C
7-27-70	72-10	DC-3/D
9-4-71	72-28	B727/C
5-18-72	72-31	DC-9/C
7-23-73	74-5	FH-227/B
9-8-73	74-6	DC-8/D
9-11-74	75-9	DC-9/C
12-1-74	75-16	B727/C
8-20-75	76-1	F27/B
*5-8-78	78-13	B727/C
11-14-70	72-11	DC-9/C
1-6-69	1-0001	CV440/B
12-24-64	1-0064	L-1049/C
*6-21-73	74-2	DC-7/B
*12-15-73	74-11	L-1049/C
8-16-65	1-0030	B727/C
Crash Scenario: Controlled Collision (A2) - (Cont'd)		
9-17-65	1-0082	B707/D
10-1-66	1-0015	DC-9/C
*10-2-70	71-4	M404/B
*3-13-74	75-1	CV340/B
4-4-77	78-3	DC-9/C
*10-20-77	78-6	CV240/B
12-18-77	78-8	DC-8/D
Crash Scenario: Uncontrolled Collision (A3)		
4-22-66	1-0001	L-188/C
3-30-67	1-0003	DC-8/D
5-30-72	73-3	DC-9/C
6-23-76	78-2	DC-9/C
12-26-68	1-0045	B707/D
8-7-75	76-14	B727/C
*12-13-77	78-10	DC-3/B
11-3-73	74-16	B707/D
2-25-64	1-0006	DC-8/D
7-9-64	1-0033	V745D/B
2-8-65	1-0001	DC-7/B
12-29-72	73-14	L-1011/E
9-8-74	75-7	B707/D
6-23-67	1-0004	BAC1-11/C
3-10-67	1-0007	F27/B
1-18-69	1-0004	B727/C
7-26-69	1-0017	B707/D
3-31-71	72-18	B720/C

---

*Not included in tables 2-7 through 2-10

TABLE A-9. - NTSB ACCIDENT REPORTS, AIR TO GROUND CRASH SCENARIOS (Continued)

Date of Accident	NTSB Report/File No.	Airplane/ Class
	Crash Scenario: Undershoot (A4)	
11-11-65	1-0032	B727/C
1-30-74	1-0001	B707/D
6-24-75	76-8	B727/C
9-8-70	71-15	DC-9/C
*1-13-69	70-14	DC-8/D
8-10-68	1-0014	FH-227/B
	Crash Scenario: Stall (A5)	
12-27-68	70-27	CV580/B
12-8-72	73-16	B737/C
9-8-70	71-12	DC-8/D
12-27-68	70-20	DC-9/C
12-1-74	75-13	B727/C
*1-13-77	78-7	DC-8/D

Date of Accident	NTSB Report/File No.	Airplane/ Class
	Crash Scenario: Obstacle (A7)	
7-31-73	74-3	B707/D
11-27-73	74-13	DC-9/C
3-3-72	73-8	FH227/B
2-17-71	71-14	DC-9/C
6-7-71	72-20	CV340/B
7-30-71	72-17	B747/E
9-20-75	76=11	DC-8/D
2-8-76	76-17	DC-6/B
6-3-77	78-9	B727/C
*7-25-78	79-4	CV580/B
9-13-72	73-4	B707/D
11-19-69	70-12	FH227/D
12-24-68	1-0033	CV580/B
12-28-78	79-7	DC-8/D

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*Not included in tables 2-7 through 2-10

TABLE A-10. - NTSB ACCIDENT REPORTS, GROUND TO GROUND CRASH SCENARIOS

Date of Accident	NTSB Report/File No.	Airplane/ Class
Crash Scenario: Aborted Takeoff (G1)		
3-21-68	1-0023	B727/C
11-6-67	1-0029	B707/D
11-27-70	72-12	DC-8/D
7-19-70	72-9	B737/C
11-16-76	77-10	DC-9/C
10-16-69	70-24	DC-8/D
*8-13-72	73-1	B707/D
3-1-78	79-1	DC-10/E
*6-21-78	79-3	DC-9/C
Crash Scenario: Taxi (G2)		
*12-16-75	76-12	B747/E
Crash Scenario: Takeoff Run (G3)		
6-20-73	74-1	DC-8/D
11-12-75	76-19	DC-10/E
9-13-72	73-14	B707/D
*6-24-69	70-11	CV880/C
Crash Scenario: Gear Retraction/Collapse (G4)		
12-15-72	73-13	B747/E
Crash Scenario: Overshoot (G5)		
4-5-76	76-20	B727/C
4-27-76	77-1	B727/C
4-7-64	1-0052	B707/D
8-12-69	70-23	DC-9/C
3-31-75	75-15	B737/C
10-28-73	74-7	B737/C
*9-27-75	76-9	CL-44/C
*7-9-78	79-2	BAC-1-11/B

*Not included in Tables 2-7 through 2-10.

TABLE A-11. - ACCIDENT DATA SUMMARY

Date of Accident	Location	NTSB Report/ File No.	Airplane/ Class
Crash Scenario: Hard Landing (A1)			
9-15-70	JFK, NY	71-9	DC-8/D
12-28-70	V.I.	72-8	B727/C
6-23-73	Jamaica, NY	73-20	DC-8/D
1-16-74	LA, CA	74-10	B707/D
5-18-72	Fla.	72-31	DC-9/C
Crash Scenario: Controlled Collision (A2)			
11-15-64	Las Vegas, Nev	1-0066	F27/B
12-24-64	S.F., CA	1-0064	L1049/C
8-16-65	Lake Mich., Ill.	1-0030	B727/C
9-17-65	B.W.I.	1-0082	B707/D
11-8-65	Const, Ky.	1-0031	B727/C
10-1-66	Wemme, Ore.	1-0015	DC-9/C
11-20-67	Const, Ky.	1-0033	CV880/C
7-27-70	Okinawa	72-10	DC-8/D
10-2-70	Silver Plume, Col.	71-4	M404/B
11-14-70	Huntington, W.Va.	72-11	DC-9/C
9-4-71	Alaska	72-28	B727/C
6-21-73	Miami Airport	74-2	DC-7/C
7-23-73	St. Louis, Mo.	74-5	FH227/B
9-8-73	Alaska	74-6	DC-8/D
12-15-73	Miami	74-11	L1049/C
3-13-74	Bishop, CA	75-1	CV340/B
9-11-74	Charlotte, NC	75-9	DC-9/C
12-1-74	Berryville, Va.	75-16	B727/C
8-30-75	Alaska	76-1	F27/B
4-4-77	Newhope, Ga.	78-3	DC-9/C
10-20-77	Mississippi	78-6	CV240/B
12-18-71	Kaysville, Utah	78-8	DC-8/D
Crash Scenario: Controlled Collision (A2) (Cont'd.)			
5-8-78	Pensacola, Fla.	78-13	B727/C
7-25-78	Kalamazoo, Mich.	79-4	CV580/B
6-24-69	Moses Lake, Wash.	70-11	CV880/C
1-13-69	LA, CA	70-14	DC-8/D
Crash Scenario: Uncontrolled Collision (A3)			
2-25-64	New Orleans, La.	1-0006	DC-8/D
7-9-64	Parrotsville, Tenn.	1-0033	V745D/C
2-8-65	L.I., NY	1-0001	DC-7/C
4-22-66	Ardmore, Okla.	1-0001	L-188/C
3-10-67	Klamath Falls	1-0007	F27/C
3-30-67	Kenner, La.	1-0003	DC-8/D
6-23-67	Blossburgh, Pa.	1-0004	BAC1-11/C
12-26-68	Alaska	1-0045	B707/D
1-18-69	LA, CA	1-0004	B727/C
7-26-69	Ponoma, NJ	1-0017	B707/D
3-31-71	Ontario, CA	72-18	B707/D
5-30-72	Ft. Worth, Tex.	73-3	DC-9/D
12-29-72	Miama, Fla.	73-14	L1011/E
11-3-73	Boston, Mass.	74-16	B707/D
9-8-74	Ionian Sea	75-7	B707/D
8-7-75	Denver, Col.	76-14	B727/C
6-23-76	Phila, Pa.	78-2	DC-9/C
Crash Scenario: Undershoot (A4)			
11-11-65	Salt Lake City, Utah	1-0032	B727/C
8-10-68	Charleston, W.Va.	1-0014	FH277/B
9-8-70	Louisville, Ky.	71-15	DC-9/C

TABLE A-11. - ACCIDENT DATA SUMMARY (Continued)

Date of Accident	Location	NTSB Report/ File No.	Airplane/ Class
Crash Scenario: Undershoot (A4) (Cont'd.)			
1-30-74	Pago Pago	1-0001	B707/D
6-24-75	Jamaica, NY	76-8	B727/C
11-12-75	Raleigh, NC	76-15	B727/C
12-17-73	Boston, Mass.	74-14	DC-10/E
Crash Scenario: Stall (A5)			
12-27-68	Sioux City, Iowa	70-20	DC-9/C
12-27-68	Chicago, Ill.	70-27	CV580/B
9-8-70	NY	71-12	DC-8/D
12-8-72	Chicago, Ill.	73-16	B737/C
12-1-74	Thiels, NY	75-13	B727/C
1-13-77	Alaska	78-7	DC-8/D
12-13-77	Gainsville, Ind.	78-10	DC-3/B
Crash Scenario: Collision With Obstacles (A7)			
12-24-68	Bradford, Pa.	70-4	CV580/B
1-6-69	Bradford, Pa.	1-0001	CV440/B
11-19-69	Glen Falls, NY	70-12	FH227/B
2-17-71	Gulfport, Miss.	71-14	DC-9/C
6-7-71	New Haven, Conn.	72-20	CV440/B
7-30-71	SF, CA	72-17	B747/E
3-3-72	Albany, NY	73-8	FH227/B
7-31-73	Boston, Mass.	74-3	B707/D
11-27-73	Chattanooga, Tenn.	74-13	DC-9/C
9-20-75	NY	76-11	DC-8/D
2-8-76	Van Nuys, CA	76-17	DC-6/B
6-3-77	Tucson, Arizona	78-9	B727/C
12-28-78	Portland, Ore.	79-7	DC-8/D
Crash Scenario: Takeoff Abort (G1)			
11-6-67	Canton, Ohio	1-0029	B707/D
3-21-68	Chicago, Ill.	1-0023	B727/C
10-16-69	Stockton, CA	70-24	DC-8/D
7-19-70	Philadelphia, Pa.	72-9	B737/C
11-27-70	Alaska	72-12	DC-8/D
8-13-72	JFK, NY	73-1	B707/D
9-13-72	San Francisco, CA	73-4	B707/D
6-20-73	Bangor, Me.	74-1	DC-8/D
9-27-75	Miami, Fla.	76-9	CL-44/C
11-12-75	JFK, NY	76-19	DC-10/E
11-16-76	Denver, Col.	77-10	DC-9/C
3-1-78	LA, CA	79-1	DC-10/E
1-26-78	Toronto	H80002*	DC-9/C
Crash Scenario: Overshoot (G5)			
4-7-64	JFK, NY	1-0052	B707/D
8-12-69	VI	70-23	DC-9/C
10-28-73	Greensboro, NC	74-7	B737/C
3-31-75	Casper, Wyo.	75-15	B737/C
4-5-76	Alaska	76-20	B727/C
4-27-76	VI	77-1	B727/C
7-9-78	Rochester, NY	79-2	BAC1-11/C
12-15-72	Miami, Fla.	73-13	B747/E

*Canadian Gov't Report

APPENDIX B
ACCIDENT DATA BASE COMPUTER PROGRAM

Introduction

The program described herein provides for the formation of a temporary data base of aircraft accident data. The data base contains 86 separate qualitative entries as well as 18 quantitative measurements for each accident. Any combination of entries may be interrogated to identify those accidents which meet a particular set of conditions.

The information stored in the data base is obtained from National Transportation Safety Board Accident Reports or similar sources. The program is configured to process only the data that are available - missing parameters can be left blank. Current accident reports are generally directed toward information that pertains directly to the type or cause of the particular accident being investigated. Consequently, many current reports do not contain data that are pertinent to crash dynamics considerations. However, this data base program has been established to provide the additional information.

INPUT DESCRIPTION

The input data for the data base are first transcribed from the NTSB Accident Report to the form shown in Table B-1. The numbers in parentheses represent the entry numbers in the data base into which the data will be stored. The contents of Table B-1 far exceed the contents of the data base. Thus, the forms can be used as reference documents once the data have been entered into the data base. The 104 separate quantities for which data are stored in the data base are listed, by entry number, in Table B-2.

The significant part of the required input data is the data base which contains the accident data entries. The accident data are entered on input cards 8-12. The data base can consist of a single file, that is, one card 8 defining the number of accidents in the data base followed by that many sets of cards 9-12; or the data base can be made up of a number of files, each with a card 8 and an appropriate number of cards 9-12. During the development the data on cards 9-12 are obtained from Table B-1 (Accident Investigation Data).

The volume of data associated with each accident creates the potential for data handling problems. For this reason, the capability was added to the program to permit the user to classify the accidents into various categories and to develop a separate file for each category. Note that the number of files to be input is the first entry on input card 1.

The categories associated with each of the input files for the program development testing are defined in List 5 of the input description. The user should recognize that these file definitions are somewhat arbitrary and that there are potentially many other methods of categorization.

The input formats are presented in Table B-3. The first data that are input are related to identification of the case that is being run. Card 1

TABLE B-1. - ACCIDENT IDENTIFICATION DATA

Accident File No. Card 1

Sources of Data Card 1

Date ①

A/C Model and Class ②

No. Engines

Engine Type

Engine Arrangement

Fuel Type

Gear Extended/Retracted ③

Denotes Input Cards 10, 11, 12 "Entries"

⑩

	Total	Fatal	Serious	Minor/None
Onboard				
Crew (+Non-Rev.)	⑪	⑫	⑬	⑭
Passengers	⑮	⑯	⑰	⑱

Air Carrier

Location Card 1

Time (Local)

Weather Temp.

Weather Cond.

Wind

Operational Mode: ④

Flight Phase:

Accident Type: ⑤

Accident Classification: ㊴

In-Flight Fire ⑦ Yes No

Post-Crash Fire Yes No

Structural Damage Severity ⑥

Destroyed Substantial Minor/None

Primary Secondary

Primary Secondary

Primary Secondary

Description of Accident

Probable Cause:

Avail. of Impact Conditions: Vel. Att. Rates Load Factors

Terrain: ⑧ Airport Water Trees Obstacle Type Other

Off Airport Proximity to Airport ⑨

Failure (Injury) Occurrence and Availability of Data for Analysis Purposes

	Failure Data		Failure Data
Wing	⑲	Restraint System	㉖
Fuselage	⑳	Seats	㉗
Empennage	㉑	Egress	㉘
Eng./Pylon	㉒	Evacuation	㉙
MLG	㉓	Fuel Tank	㉚
NLG	㉔	Fuel Line	㉛
Floor	㉕	Occupant Injury	㉜

Availability of: Sketch/Photo ㉟ Flight Recorder Data ㉞

Rating for Quality and Extent of Data (Poor/Fair/Good) NTSB Survival Aspect ㊳

Structure and damage ㊱ Survival Aspects ㊲ Overall

TABLE B-1. - CONTINUED

Accident File No.________________

Post-Crash Wing Damage

Separation ㊵ ________________
Abrasion ㊶ ________________
Fuel Spill ㊷ ________________
Tank Puncture ㊸ ________________
Tank Rupture ㊹ ________________
Line Rupture ㊺ ________________

Post-Crash Empennage Damage

	Horizontal Stabilizer ㊻	Vertical Tail ㊼
Separation		
Failure		

Post-Crash Fuselage Damage

Break/Separation ㊽ ________________
Abrasion ㊾ ________________
Crushing ㊿ (80) ________________
Other ________________

Post-Crash Interior Damage/Failures

Floor (56) ________________
Cabin Debris (57) ________________
Exit Doors (58) ________________
Interior Panels (59) ________________
Overhead Storage (60) ________________
Ventilation Problems (61) ________________
Evacuation Hindered ________________

Post-Crash Fire

Location: Engine (65) ______ Wing (63) ______ Fuselage (64) ______ Wing/Fuse. ______
Ignition Source ________________
Fuel or Nonfuel Fire: (62) ________________
Description ________________

TABLE B-1. - CONTINUED

Accident File No. ____

Post-Impact Propulsion System

Engines/Pylons

Location 1 ____ 2 ____ 3 ____ 4 ____

Separation 1 (66) 2 (67) 3 (68) 4 (69)

Damage 1 (66) 2 (67) 3 (68) 4 (69)

Trajectory: ____

Description: ____

Post-Impact Landing Gear Damage

Main Gears (1-4), Nose Gear (5)

Location 1 (70) 2 (71) 3 (72) 4 (73) 5 (74)

Separation 1 ____ 2 ____ 3 ____ 4 ____ 5 ____

Collapse 1 ____ 2 ____ 3 ____ 4 ____ 5 ____

Failure 1 ____ 2 ____ 3 ____ 4 ____

Brake/Steering Damage 1 ____ 2 ____ 3 ____ 4 ____ 5 ____

Description: ____

Restraint System(s)

Failures ____

Number, Location and Types ____

Crew ____ Pax ____

Harness ____ Belt ____ Attachment ____

Evacuation

VIA Doors ____ VIA Slides ____ VIA Fuselage ____

VIA Windows ____ VIA Overwing Exit ____ Other ____

Problem Area(s) ____

Elapsed Time ㉝

Seat Systems

Failures ____

Number, Location and Types ____

Pan ____ Leg ____ Floor Support/Attachment ____

Crew ____ Pax ____

TABLE B-1. - CONTINUED

Accident File No. ____________________

SUMMARY SHEET

HUMAN FACTORS CONTRIBUTING TO FATALITIES/INJURIES

		Fatal	Serious			Fatal	Serious
Trauma (Decel.)	(73)			Evacuation	(82)		
Lethal Blows	(76)			Egress Blockage	(83)		
Restraint Failure	(77)			Fire	(84)		
Seat Failure	(78)			Inhalation	(85)		
Floor Collapse	(79)			Drowning	(86)		
Thrown From A/C	(81)			Other			

Judgement Factors Summary

Contribution to Fatalities/Serious Injury

	Major	Minor	Unknown
Gear Separation/Collapse			
Engine/Pylon Separation			
Fuel Tank Rupture/Line Failure			
Post-Crash Fire			
Floor Structure Loads			
Trauma (Deceleration Forces)			
Lethal Blows			
Seat/Attachment Integrity			
Restraint System Integrity			
Evacuation/Procedures			
Egress Blockage			
Smoke/Inhalation			
Fuselage Separation/Collapse			
Other			

Crash Survivability

Survivable ____________________ Partially ____________________ Non-Survivable ____________________

Survivable with Regard to:

Deceleration Force ____________________
Fire ____________________
Intact Occupiable Area ____________________
Non-Lethal Blows ____________________
Restraint System ____________________
Other ____________________

TABLE B-1. - (CONTINUED)

Accident File No. ______________

Crash Impact Description

A/P Configuration

Weight ______________ Lbs

CG ______________ % MAC

Spoiler Deployment ______________

H.S. Setting ______________

Attitude (Deg) and Rates (Deg/Sec, Deg/Sec^2)

Roll ϕ	(90)	$\dot{\phi}$	(96)	$\ddot{\phi}$	(102)
Pitch θ	(91)	$\dot{\theta}$	(97)	$\ddot{\theta}$	(103)
Yaw ψ	(92)	$\dot{\psi}$	(98)	$\ddot{\psi}$	(104)

Velocities* and Angles (Deg)

Flight Path Vel.	(89)	Longitudinal Vel.	(93)
Rate of Desc. Vel.		Lateral Vel.	(94)
Flight Path Angle	(88)	Vertical Vel.	(95)
Angle of Attack	(87)		

*Ft/Sec = 1.688 Knots

Sign Conventions

$\phi, \dot{\phi}$: Positive Left Wing Up

$\theta, \dot{\theta}$: Positive Nose Up

$\psi, \dot{\psi}$: Positive Tail Left

γ = Negative in Dive

α = Positive Nose Up Relative to Flight Path

$\theta = \gamma + \alpha$

Flight Recorder Data

Outboard Model ______________

Data Presented ______________

Location ______________

Vert. Accel. "G" ______________

Impact Load Factors (G)

Longitudinal (99) Lateral (100) Vertical (101)

Terrain Description: ______________

Pilot Action: ______________

Structural Damage Summary

	Pre-Impact	Post Impact		
		Damage	Separation	Collapse
Wing				
Fuselage				
Eng/Pylon				
Empennage				
MLG				
NLG				
Floor				

TABLE B-1. - CONCLUDED

Accident File No. ____________________

Comments

Tests and Research

Recommendations

TABLE B-2. - DATA BASE ENTRY PARAMETERS

1	Year
2	Airplane class and type
3	Landing gear position
4	Operational mode
5	Accident type
6	Aircraft damage
7	Fire
8	Terrain description
9	Proximity to airport
10	Injury class
11	Total crew
12	Crew fatalities
13	Crew serious injuries
14	Crew minor/none
15	Total passengers
16	Passenger fatalities
17	Passenger serious injuries
18	Passenger minor/none
19	Wing failure data
20	Fuselage failure data
21	Empennage failure data
22	Engine/Pylon failure data
23	MLG failure data
24	NLG failure data
25	Floor failure data
26	Restraint system failure data
27	Seat system failure data
28	Egress failure data
29	Evacuation system failure data
30	Fuel tank failure data
31	Fuel line failure data
32	Occupant injury data
33	Evacuation time
34	Flight recorder data
35	Sketches
36	Structural rating
37	Survivability aspects
38	NTSB survivability rating
39	Accident classification
40	Wing separation
41	Wing abrasion
42	Wing fuel spill
43	Wing tank puncture
44	Wing tank rupture
45	Wing line rupture
46	Horizontal tail damage
47	Vertical tail damage
48	Fuselage separation/break
49	Fuselage abrasion
50	Fuselage crush
51	Fuselage fuel tank puncture
52	Fuselage fuel tank rupture
53	Fuselage fuel spill
54	Fuselage shear
55	Fuselage bending
56	Floor damage
57	Cabin debris
58	Exit doors
59	Interior panels damage
60	Overhead panels damage
61	Ventilation problems
62	Post-crash fire
63	Wing fire
64	Fuselage fire
65	Engine fire
66	Engine 1 damage
67	Engine 2 damage
68	Engine 3 damage
69	Engine 4 damage
70	MLG 1 damage
71	MLG 2 damage
72	MLG 3 damage
73	MLG 4 damage
74	NLG damage
75	Trauma
76	Lethal blows
77	Restraint system
78	Seats
79	Floor collapse
80	Fuselage crushing
81	Ejection
82	Evacuation
83	Egress
84	Fire
85	Inhalation
86	Drowning
87	Angle of attack
88	Flight path angle
89	Airspeed
90	Roll angle
91	Pitch angle
92	Yaw angle
93	X velocity
94	Y velocity
95	Z velocity
96	Roll rate
97	Pitch rate
98	Yaw rate
99	Nx
100	Ny
101	Nz
102	Roll acceleration
103	Pitch acceleration
104	Yaw acceleration

TABLE B-3. - INPUT FORMATS

GENERAL PURPOSE DATA SHEET

LOCKHEED-CALIFORNIA COMPANY
A DIVISION OF LOCKHEED CORPORATION

TITLE:						PAGE	OF
PREPARED BY	DATE	CHECKED BY	DATE	JOB NO.	GROUP		
				W.O.	EWA	ID	SEQ

```
1   5 7  10   15   20   25   30   35   40   45   50   55   60   65   70 73 7677 80
NF--------------------------TITLE---------------------------------------CARD   1
  NCS                                                                          2
  NCL  NVR----------COLID------------------------}REPEAT NCS TIMES             3
 NVAR (NVR VALUES)                               }                             4
  NCM                                                                          5
1   5 7  10   15   20   25   30   35   40   45   50   55   60   65   70 73 7677 80
  NCL  NVR----------COLID------------------------}REPEAT NCM TIMES             6
 NVAR (NVR VALUES)                               }                             7
  NAC                                                                          8
   [            ] }                                                            9
   [    SEE     ] }REPEAT NAC TIMES                                           10
1   5 7  10   15   20   25   30   35   40   45   50   55   60   65   70 73 7677 80
   [CARDS  9-12 ] }                                                           11
                                                                              12
1   5 7  10   15   20   25   30   35   40   45   50   55   60   65   70 73 7677 80
1   5 7  10   15   20   25   30   35   40   45   50   55   60   65   70 73 7677 80
```

FORM 8104-2

contains the number of input files of accident data in the first two columns followed by a case title containing up to 70 alphanumeric characters. The following cards identify the particular entries that are to be queried for the run as well as the values that are being sought for each entry.

The data base can be queried in two ways. The first method searches for those accidents which meet a combination of conditions (e.g., referring to the input descriptions, a user might look for all Class E aircraft (TOGW > 400k) which have had engine fires). Only those accidents meeting both conditions would be reported by the program. The other method for searching the data base finds those accidents which meet any one of the conditions.

The formats for the interrogation cards are the same for both methods. The first card (card 2) tells how many entries are to be queried using the first method. This identifies the number of pairs of cards 3 and 4 to follow. Card 3 identifies the data entry number, the number of values to be looked for, and (optionally) a brief description of the information sought. Card 4 contains those values being sought. Pairs of cards 3 and 4 are read for as many entries as are called out on the first card. Following these data, the input for the second interrogation method is identical to that required for the first. Cards 5, 6 and 7 are smiliar to cards 2, 3 and 4, respectively. Note that cards 2 and 5 must always be input, even if the input value is zero.

Following the interrogation data, the files of accident data are read. The number of files that are read is indicated on the first card. For each accident file, the first card (card 8) gives the number of accidents contained in that file. For each accident contained in the file, four cards must be input. Card 9 contains descriptive data. Cards 10 and 11 contain indices defining qualitative data. Card 12 contains quantitative data relating to attitude, speed and load factor. Cards 9-12 are repeated for each of the accidents in that file. The data in the next file begin with card 8. A complete description of the input formats for all 12 cards as well as the desired entries for cards 9-12 follows.

Table B-4 summarizes the data and purpose of the twelve input cards. Tables B-5 and B-6 summarize the available lists and tables.

TABLE B-4. - CARD DESCRIPTION

Cards	Type	Description	Note
1*	Case description*	• Number of input files • Case title	
2	Interrogation cards Method 1 to search data which meets a combination of conditions	• Number of entries that are to be queried for those accidents which meet a combination of conditions	
3		• Data entry number • Number of values to be looked for • Brief description of information sought (optional)	Pair
4*		• Value being sought in conjunction with card 3	
5*	Interrogation cards Method 2 to search data which meets any one condition	• Number of entries to scan	Pair
6		• Number of entries to be scanned • Number of variables requested • Description of data requested	
7		• First variable requested • Second variable requested • Nth variable requested	
8	Accident data to be read **	• Number of accidents contained in the file	Data set
9		• Accident identification data	
10		• Data availability	
11		• Types of damage • Injury factors	
12		• Quantitative data of interest	

*Always required **Data has to be accessed from files

TABLE B-5. - LIST DESCRIPTION

List No.	Description	Reference Card
1	Aircraft class and types	10
2	Operational modes	10
3	Accident types	10
4	Terrain types	10
5	Accident classification	10
6	MLG damage	11
7	NLG damage	11

TABLE B-6. - TABLE DESCRIPTION

Table No.	Description
B-1	Accident identification data
B-2	Data base entry parameters
B-3	Input forms
B-4	Input card description
B-5	List description

The input data formats are shown in Table B-1. A description of the contents of each card is presented below.

CARD 1

Column(s)	Variable	Description
1 - 2	NFILE	Number of input files
5 - 72	TITLE	Case title

CARD 2

This card defines the number of data base entries that will be scanned in order to find those accidents which meet the criteria for all the entries examined. The value of NCS defines the number of pairs of Card 3 and 4 which must be input.

Column(s)	Variable	Description
1 - 5	NCS	Number of entries to scan

CARD 3

The entry numbers defined on this card refer to the entries in Cards 10, 11 and 12 (also Table B-2)

Column(s)	Variable	Description
1 - 5	NCL	Number of entry to be scanned
6 - 10	NVR	Number of variables requested
11 - 50	COLID	Description of data requested

CARD 4

The variable numbers appropriate to each of the entry numbers are defined in the description of the input for Cards 10 and 11. Refer to the description of the requested entry to determine the appropriate variable number(s) to use.

Column(s)	Variable	Description
1 - 5	NVAR(1)	First variable requested
6 - 10	NVAR(2)	Second variable requested
:	:	:
4*NVR+1 - 5*NVR	NVAR(NVR)	NVRth variable requested

CARD 5

This card defines the number of data base entries that will be scanned in order to find those accidents which meet the criteria for any one of the entries examined. The value of NCM defines the number of pairs of Cards 6 and 7 which must be input.

Column(s)	Variable	Description
1 - 5	NCM	Number of entries to scan

CARD 6

The entry numbers defined on this card refer to the entries in Table B-2.

Column(s)	Variable	Description
1 - 5	NCL	Number of entry to be scanned
6 - 10	NVR	Number of variables requested
11 - 50	COLID	Description of data requested

CARD 7

The variable numbers appropriate to each of the entry numbers are defined in the description of the input for Cards 10 and 11. Refer to the description of the requested entry to determine the appropriate variable number(s) to use.

Column(s)	Variable	Description
1 - 5	NVAR(1)	First variable requested
6 - 10	NVAR(2)	Second variable requested
:	:	:
4*NVR+1 - 5*NVR	NVAR(NVR)	NVRth variable requested

CARD 8

This card defines the number of accidents for which data are stored in the current file. The value of NAC defines the number of complete sets of Cards 9-12 which must be input.

Column(s)	Variable	Description
1 - 5	NAC	Number of accidents in file

CARDS 9-12

A complete description of the variables and formats for Cards 9-12 is provided below. The number of complete sets of Cards 9-12 is equal to NAC, input on Card 8. All four cards are required for each.

OUTPUT DATA

The remaining cards contain the information that comprise the data base. For the data on cards 10-12, the entry number identifies the position in the data base, while the column number(s) identify the location of the data on the input card.

CARD 9

These data are only for accident identification purposes

Column(s)	Description
1 - 5	File number
7 - 10	NTSB report number
12 - 17	Accident location
19 - 24	Data of accident

CARD 10

Entry	Column(s)	Description
1	1 - 2	Year (last two digits)
2	3 - 4	A/c class and type (see list 1)
3	5	Landing gear position (1=extended, 2=retracted)
4	6 - 7	Operational mode (see list 2)
5	8 - 9	Accident type (see list 3)
6	10	A/c damage (1=destroyed, 2=substantial, 3=minor/none)
7	11	Fire (1=pre-crash, 2=post-crash, 3=pre– post-crash)
8	12 - 13	Terrain descriptions 1 and 2 (see list 4)
9	14	Proximity to airport (miles: 1=0-1, 2=1-2, 3=2-3, 4=3-5, 5=>5)
10	15	Injury class (1=fatal, 2=serious, 3-minor/none)
11	16 - 17	Total crew
12	18 - 19	Crew fatalities
13	20 - 21	Crew serious injuries
14	22 - 23	Crew minor/no injuries
15	24 - 26	Total passengers
16	27 - 29	Passenger fatalities
17	30 - 32	Passenger serious injuries
18	33 - 35	Passenger minor/no injuries

The following columns describe data availability. Entries 19-31 define the availability of structural/system failure data according to the following code:

0 = Unknown

1 = Failed, no data available

2 = Failed, data available

Entry	Column(s)	Description
19	36	Wing failure
20	37	Fuselage failure
21	38	Empennage failure
22	39	Engine/pylon failure
23	40	MLG failure
24	41	NLG failure
25	42	Floor failure
26	43	Restraint system failure
27	44	Seat system failure
28	45	Egress failure
29	46	Evacuation system failure
30	47	Fuel tank failure
31	48	Fuel line failure
32	49	Occupant injury (1=injury, no data; 2=injury, data)
33	50	Evacuation time (minutes: 1=0-1, 2=1-2, 3=2-3, 4=3-5, 5=>5)
34	51	Flight recorder data (1=data)
35	52	Sketches (1=yes)
36	53	Structural rating (1=good, 2=fair, 3=poor)
37	54	Survival aspects (1=good, 2=fair, 3=poor
38	55	MTSB survival aspects (1=survivable, 2=partially-, 3=non-)
39	56	Accident classification (see list 5)

CARD 11

The following entries describe types of damage.

Entry	Column(s)	Description
40	1	Wing separation (1=yes)
41	2	Wing abrasion (1=yes)
42	3	Wing fuel spill (1=yes)
43	4	Wing tank puncture (1=yes)
44	5	Wing tank rupture (1=yes)
45	6	Wing line rupture (1=yes)
46	7	Horizontal tail (1=yes)
47	8	Vertical tail (1=yes)
48	9	Fuselage separation/break (1=yes)
49	10	Fuselage abrasion (1=yes)
50	11	Fuselage crushing (1=yes)
51	12	Fuselage fuel tank puncture (1=yes)
52	13	Fuselage fuel tank rupture (1=yes)
53	14	Fuselage fuel spill (1=yes)
54	15	Fuselage shear (1=yes)
55	16	Fuselage bending (1=yes)
56	17	Floor (1=yes)
57	18	Cabin debris (1=yes)
58	19	Exit doors (1=yes)
59	20	Interior panels (1=yes)
60	21	Overhead storage (1=yes)
61	22	Ventilation problems (1=yes)
62	23	Post-crash fire (1=fuel; 2=non-fuel)

The following entries define post-crash fire locations.

Entry	Column(s)	Description
63	24	Wing (1=yes)
64	25	Fuselage (1=yes)
65	26	Engine (1=yes)

The following entries define engine and landing gear damage.

Entry	Column(s)	Description
66	27	Engine 1 (1=fail, 2=separate)
67	28	Engine 2 (1=fail, 2=separate)
68	29	Engine 3 (1=fail, 2=separate)
69	30	Engine 4 (1=fail, 2=separate)

The landing gear damage entries provide for two separate events for each accident. The first column identifies the initial cause (e.g., tire failure). The second column identifies the final failure (e.g., gear separation).

Entry	Column(s)	Description
70	31 - 32	MLG 1 damage (see list 6)
71	33 - 34	MLG 2 damage (see list 6)
72	35 - 36	MLG 3 damage (see list 6)
73	37 - 38	MLG 4 damage (see list 6)
74	39 - 40	NLG damage (see list 7)

The following columns designate contributing factors to injuries.

Entry	Column(s)	Description
75	41	Trauma (1=yes)
76	42	Lethal blows (1=yes)
77	43	Restraint system (1=yes)
78	44	Seats (1=yes)
79	45	Floor collapse (1=yes)
80	46	Fuselage crushing (1=yes)
81	47	Ejection (1=yes)
82	48	Evacuation (1=yes)
83	49	Egress (1=yes)
84	50	Fire (1=yes)
85	51	Inhalation (1=yes)
86	52	Drowning (1=yes)

CARD 12

The following entries contain quantitative data of interest.

Entry	Column(s)	Description
87	1 - 4	Angle of attack (deg)
88	5 - 8	Flight path angle (deg)
89	9 - 12	Airspeed (ft/sec)
90	13 - 16	Roll angle (deg)
91	17 - 20	Pitch angle (deg)
92	21 - 24	Yaw angle (deg)
93	25 - 28	X velocity (ft/sec)
94	29 - 32	Y velocity (ft/sec)
95	33 - 36	Z velocity (ft/sec)
96	37 - 40	Roll rate (deg/sec)
97	41 - 44	Pitch rate (deg/sec)
98	45 - 48	Yaw rate (deg/sec)
99	49 - 52	Nx (g's)
100	53 - 56	Ny (g's)
101	57 - 60	Nz (g's)
102	61 - 64	Roll acceleration (deg/sec^2)
103	65 - 68	Pitch acceleration (deg/sec^2)
104	69 - 72	Yaw acceleration (deg/sec^2)

LIST 1

A/C TYPE (COLUMNS 3 and 4)

Column 3 also identifies A/C class as follows:

COL. 3	CLASS	
0	A	(TOGW 12500 lb.)
1,2	B	(12500 lb. < TOGW < 100000 lb.)
3,4	C	(100000 lb. < TOGW < 250000 lb.)
5	D	(250000 lb. < TOGW < 400000 lb.)
6	E	(TOGW > 400000 lb.)

Data base entry	Type	Data base entry	Type
Class A 0	Gen. *	Class C 30	BAC1-11
.	Aviation *	31	B -720
.	Non *	32	B -727
.	Specific *	33	B -737
9	*	34	Caravelle
Class B 10	C -46 *	35	CL-44
11	CV-240 *	36	CV-880
12	CV-440 *	37	DC-9
13	CV-580 *	38	L -188
14	CV-600 *	39	L -1049
15	CV-640 *	40	Other
16	DC-3 *		
17	DC-4 *	Class D 50	B -707
18	DC-6 *	51	DC-8
19	DC-7 *	52	
20	F -27 *		
21	F -227 *	Class E 60	B -747
22	M -404 *	61	DC-10
23	N -262 *	62	L-1011
24	SA-226 *	63	
25	V -700 *		
26	V -745 *		
27	V -812 *		
28	YS-11 *		
29	Other *		

LIST 2

OPERATIONAL MODE (COLUMNS 6 and 7)

Data base entry	Mode	Abbrev.
1	Inflight climb	FLCL
2	Inflight cruise	FLCR
3	Inflight descent	FLDES
4	Inflight uncont. desc.	FLUND
5	Landing init. app.	LDGIA
6	Landing final app.	LDGFA
7	Landing go around	LDGGA
8	Landing holding	LDGHO
9	Landing level off	LDGLO
10	Landing miss. app.	LDGMA
11	Landing rollout	LDGRO
12	Landing traff. patt.	LDGTP
13	Landing other	LDGO
14	Static	STAT
15	Takeoff abort	ABTO
16	Takeoff init. climb	TOIC
17	Takeoff run	TO
18	Taxi to takeoff	TAXTO
19	Taxi from landing	TAXIN
20	Unknown	UNK

LIST 3

ACCIDENT TYPE (COLUMNS 8 and 9)

Data base entry	Type	Abbrev.
1	Airframe failure	AF
2	Collision, controlled	CC
3	CC with aircraft	CA
4	CC with ditch	CD
5	CC with fence	CF
6	CC with hillside	CH
7	CC with app. lts.	CL
8	CC with mountain	CM
9	CC with obstacle	CO
10	CC with person	CP
11	CC with seawall	CS
12	CC with tree	CT
13	CC with wire	CW
14	Evacuation	EV
15	Fire/explosion	FE
16	Gear collapse	GC
17	Gear retracted	GR
18	Hard landing	HL
19	Malfunction, engine	ME
20	Malfunction, prop	MP
21	Misc. flight	MF
22	Miscellaneous	MI
23	Overshoot	OV
24	Swerve	SW
25	Stall	ST
26	Turbulence	TU
27	Collision, uncontrolled	UC
28	UC with ditch	UD
29	UC with fence	UF
30	UC with hillside	UH
31	UC with app. lts.	UL
32	UC with mountain	UM
33	UC with obstacle	UO
34	UC with person	UP
35	UC with seawall	US
36	UC with tree	UT
37	UC with wire	UW
38	Undershoot	UN
39	Wheels up	WU

LIST 4

TERRAIN (COLUMNS 12 and 13)

The two columns are designed so that the entries listed below may be entered in combination; that is, one entry in column 13 and an associate entry in column 14.

Entry	Terrain	Abbrev.
1	Grassy	GRAS
2	Hill, mountain	HILL
3	Muddy	MUD
4	Runway	RWAY
5	Slope, ditch	SLOP
6	Soft	SOFT
7	Water	WATR
8	Wet, snow, ice	WET
9	Wooded	WOOD

LIST 5

ACCIDENT CLASSIFICATION (COLUMN 39)

Entry	Classification
1	AG1
2	AG2
3	AG3
4	AG4
5	AG5
6	GG1
7	GG2
8	GG3
9	GG4

LIST 6

MLG DAMAGE (COLUMNS 87-94)

The MLG data are presented in column pairs for up to 4 potential MLG's. The column pairs are 87-88, 89-90, 91-92, 93-94. For each pair, the first column designates the initial mode of failure (e.g., tire), while the second column indicates the resulting major failure (e.g., gear collapse). The possible entries are noted below.

Entry	Failure/damage	Abbrev.
1	Brake	BRAK
2	Tire	TIRE
3	Wheel	WHEL
4	Separate	SEP
5	Collapse fwd, no fuel	CFNF
6	Collapse fwd, fuel	CFFU
7	Collapse aft, no fuel	CANF
8	Collapse aft, fuel	CAFU
9	Collapse, miscellaneous	COLL

LIST 7

NLG DAMAGE (COLUMNS 95-96)

The NLG data are presented in a manner similar to that presented on the previous page for the MLG. As with the data in list 6, the first column designates the initial mode of failure (e.g., tire), while the second column indicates the resulting major failure (e.g., gear collapse). The possible entries are noted below.

Entry	Failure/damage	Abbrev.
1	Steer	STER
2	Tire	TIRE
3	Wheel	WHEL
4	Separate	CEP
5	Collapse fwd	CFWD
6	Collapse aft	CAFT
7	Collapse, miscellaneous	COLL

Output Data

For each case that is run, an output summary is provided. The first data in the summary are an echo of the input files, followed by the actual program output. The initial output lists the entries that were scanned and the values for which the program was searching. A description of the quantities that the program was looking for will be provided if the data were input.

Following the summary of the entries and values which were requested, a summary is provided of those accident table entries that met the specified criteria. Several sets of descriptive data as well as a number of qualitative indicators are shown for each accident which met the criteria. The data that are printed are as follows:

ACC:	The accident entry number
FILE:	The accident file number
NTSB:	NTSB report number
PLACE:	Location of accident
DATE:	Date of accident
A/C:	Aircraft designation
CLASS:	Aircraft class
ACC TYPE:	Accident type (See Input Table 4)
OPER MODE:	Operational mode (See Input Table 4)
INJURY:	Qualitative injury description (F = fatal, S = serious, N = none/minor)
DAMAGE:	Qualitative damage description (D = destroyed, S = substantial, N = none/minor)
FIRE:	Fire (Y = yes, N = no)
SURVIV:	Survivability assessment (S = survivable, P = partially-survivable, N = non-survivable)

STRDAM: Structural damage data availability (G = good, F = fair, P = poor)

HUMFAC: Human factors data availability (G = good, F = fair, P = poor)

SKETCH: Accident sketch availability (Y = yes, N = no)

FDRDAT: DFDR data availability (Y = yes, N = no)

The following descriptions represent qualitative designations of structural failures.

SEAT: Seat system (F = failed)

RSTRNT: Restraint system (F = failed)

FLOOR: Floor (F = failed)

FUSE: Fuselage (F = failed)

MLG: Main landing gear (F = failed)

NLG: Nose landing gear (F = failed)

WING: Wing (F = failed)

ENGINE: Engine (any) (F = failed)

TANK: Fuel tank (F = failed)

LINE: Fuel line (F = failed)

The following descriptions define structural failures of major components.

WING: Wing (S = separate, B = break)

FUSE: Fuselage (S = separate, B = break)

ENG: Engine (any) (S = separate, B = break)

MLG: Main landing gear (S = separate, B = break)

NLG: Nose landing gear (S = separate, B = break)

The last entry on this summary is evacuation time in minutes.

The final summaries contain quantitative descriptions of aircraft rates and altitudes. The summaries are duplicated to present the data in both metric and english units.

ACC:	The accident file number
ALPHA:	Angle of attack (Deg)
GAMMA:	Flight path angle (Deg)
VEL:	Aircraft forward velocity (m/sec or ft/sec)
PHI:	Aircraft roll attitude (Deg)
THETA:	Aircraft pitch attitude (Deg)
PSI:	Aircraft yaw attitude (Deg)
VX:	Aircraft x velocity (m/sec or ft/sec)
VY:	Aircraft y velocity (m/sec or ft/sec)
VZ:	Aircraft z velocity (m/sec or ft/sec)
PHDOT:	Aircraft roll rate (Deg/sec)
THDOT:	Aircraft pitch rate (Deg/sec)
PSDOT:	Aircraft yaw rate (Deg/sec)
NX:	Aircraft x load factor (q)
NY:	Aircraft y load factor (g)
NZ:	Aircraft z load factor (g)
PHDDT:	Aircraft roll acceleration (Deg/sec/sec)
THDDT:	Aircraft pitch acceleration (Deg/sec/sec)
PSDDT:	Aircraft yaw acceleration (Deg/sec/sec)

The following pages contain a complete output listing from a sample case. The output consists of an echo of the input, the identification of the input, and a listing of those accidents which met the requested criteria.

Sample Case Description

The following pages contain a sample case that was run to test the program. The data provided are an echo listing (Figure B-1) of the input data and a printout of the results (Figure B-2). The case finds those accidents which involved both Class D aircraft and post-crash fires. The following is a description of the input cards for the program based upon the input data for the sample case.

Case card 1 corresponds to input card 1 and contains the number of input files (6) and a case title. Case card 2 corresponds to input card 2 and defines the number of variables to be tested (2). The value on card 2 calls for that many sets of input cards 3 and 4. Case card 3 corresponds to the first input card 3. The first value shown (2) is the entry number for the parameter of interest. These values are defined in the description for input card 10. The second value on input card 3, (2), defines the number of values that are entered on input card 4. Following the instructions for input card 10/Entry 2, List 1 is inspected to identify quantities 50 and 51 as the Class D aircraft, the 707 and DC-8.

Case card 5 is the second input Card 3. The first value (7) is the entry number for fire conditions in the input card 10 description. The second value (2) calls for two values on input card 4. Case card 6 is the second input Card 4 and includes the values that describe a post-crash fire.

Case card 7 corresponds to input card 5. This card specifies the number of pairs of input cards 5 and 6 that will follow. For this case, no data were requested for this option. Case card 8 corresponds to input card 8. It gives the number of accidents for which data follow, that is, the number of sets of input cards 9-12 that follow. Each set of cards 9-12 contains all of the applicable data for a single accident.

There is a single input card 8 and appropriate number of cards 9-12 for each of the files (6 in this case) specified in input card 1.

A flow diagram (Figure B-3) is provided to assist the user in understanding input data sequence and requirements. In this particular sample case, accidents in the files which involve both class D aircraft and

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                              ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

                  1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

      1   6  SAMPLE CASE --- TO FIND CLASS D AIRCRAFT WITH POST-CRASH FIRES      00000010    CARD   1
      2      2                                                                   00000020           2
      3      2    2  CLASS D AIRCRAFT                                            00000030           3 }
      4     50   51                                                              00000040           4 }  ONCE FOR EACH ENTRY
      5      7    2  POST-CRASH FIRE                                             00000050           3 }
      6      2    3                                                              00000060           4 }
      7      0                                                                   00000070           5
      8     11                                                                   00000010           8
      9  A1-01 0003 NY      091570                                               00000020  }        9
     10  70511091810661210000505146000064082000000000000000010011                00000030  }       10
     11  0000000010100000000000000020222090900004000000000000                    00000040  }       11
     12          338.    2.3                                                     00000050  }       12
     13  A1-03 7320 JFK    062373                                                00000060
     14  73511061820441209000207119000006113010111001000010103311                00000070    10 MORE SETS OF CARDS 9-12
     15  0010010001000000000010100121100909000000100000000000                    00000080    (GROUPS OF 4 CARDS)
     16          217.                                                            00000090
     17  A1-04 7410 LA      011674                                               00000100
     18  74501091812441207000007058000002056000000000000000000011                00000110
     19  0000000000000100000000000100000000260000000000010010                    00000120
     20          253.                                            4.6             00000130
     21  A1-05 7231 FTLAUD 051872                                                00000140
     22  72371091812441204000202006000001005011010000001011013311                00000150
     23  0010111010000000000001110000000704000000100011001100                    00000160
     24      3.  228.    2.5                                                     00000170
     25  A3-16 7614 DENVER 080775                                                00000180
     26  75322162720611207000502127000010117010000100002004113211                00000190
     27  0000000010000000011001000000000000000000110000001000                    00000200
     28          213.    7.                                                      00000210
     29  A3-17 7802 PHILA  062376                                                00000220
     30  76372072710441204000400102000032070000000002000010112111                00000230
     31  1000001111100000100000000022000000000000100110011000                    00000240
     32          199.    13.                                                     00000250
     33  A4-06 7615 NC     111275                                                00000260
     34  75321063820841208000008131000001130100110000000022113311                00000270
     35  000000000000000000000000000020040400000000000001                        00000280
     36      -2.5248.                                                            00000290
     37  A4-09 0037 BOSTON 080768                                                00000300
     38  68321063800041306000006077000000077110010000000000000011                00000310
     39  0000000000000000000000000000000090900000                                00000320
     40          236.    9.                                                      00000330
     41  A4-08      TURKEY 010276                                                00000340
     42  76611063802061213000112364000000364100011000000004100011                00000350
     43  000000000100000001000000002100                                          00000360
     44          255.-2.19.1                                                     00000370
     45  A4-01 0032 UTAH   111165                                                00000380
     46  65321063812011106000600085043029013010111000000124000001                00000390
     47  000001000100000000000100021100400000000010000001011                     00000400
     48          203.                                                            00000410
     49  A4-03 7115 KY      090870                                               00000420
     50  70371093820051305000005089000000890100001000000000010001                00000430
```

Figure B-1. - Sample problem, echo of the input data in card image format.

```
                          ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

                . 1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     51  0000000010000001000000000                                               00000440
     52          211.                    18.5                                    00000450
     53      4                                                                   00000010    CARD  8
     54  A7-09 7413 TENN   112773                                                00000020           9
     55  73371063812011205000401074000038036110111100000123110002                00000030          10
     56  100000000000000000000000002000040400000411000000111                     00000040          11
     57          203.                                                            00000050          12
     58  A4-04 7707 SAMOA  013074                                                00000060
     59  74501063812011110100000091036005000111011000001020003202                00000070    3 MORE SETS OF
     60  000010000100000000000010102222040400000410000001011                     00000080    CARDS 9-12
     61          240.    -3.5                                                    00000090
     62  A4-07 7414 BOSTON 121773                                                00000100
     63  73611061822151214000113153000002151010111101001012000002                00000110
     64  0010100010000000100000110122000404090007000110001                       00000120
     65          258.    5.4                                                     00000130
     66  A4-05 7608 JFK    062475                                                00000140
     67  75321063812011108060200116106010000110100001001020013202                00000150
     68  00101000001000001100001100220000000000001001000001                      00000160
     69  -4.5    206.                                                            00000170
     70      9                                                                   00000010    CARD  8
     71  A2-05 0031 KY     110865                                                00000020           9
     72  65322060212922106050100056053003000110000000000020113323                00000030          10
     73  00000000100000000100000010202000000000000100000001                      00000040          11
     74          248.5.  5.                                                      00000050          12
     75  A3-04 0001 OKLA   040266                                                00000060
     76  66381122712212105050000093078015000110111001000020003223                00000070    8 MORE SETS OF
     77  100000001000000000000000010002099400000410010000001                     00000080    CARDS 9-12
     78       -7.253.10. 0.                                                      00000090
     79  A2-09 7104 COL    100270                                                00000100
     80  70222020212025103020100037028009000000000001000020013223                00000110
     81  10000000100000000000000000000000000000000101                            00000120
     82       -4. 231.31.                                                        00000130
     83  A3-12 7303 TEXAS  053072                                                00000140
     84  72371062612041104040000000000000000111111100001020003333                00000150
     85  10001011100000000000001100000000000000000000000001                      00000160
     86           506.                                          -4.              00000170
     87  A2-19 7601 ALASKA 083075                                                00000180
     88  75201100212252104030100028007019002110100102000020112223                00000190
     89  10000000100000001000001001020004040000000101110001                      00000200
     90           184.                                          1.5              00000210
     91  A2-25 7011 WASH   062469                                                00000220
     92  69361160112111105030200000000000000110111000000010103313                00000230
     93  00000000100000000010010000222204000000000000000001                      00000240
     94           196.40.    30.                                                 00000250
     95  A3-13 0016 MIAMI  122972                                                00000260
     96  72621022712831115051000161094067000000000000000000010003                00000270
     97  111110111110000011111010102020242000002411001001111                     00000280
     98           338.-28.                                                       00000290
     99  A5-01 7020 IOWA   122768                                                00000300
    100  683721625100912040003010640000000641100000000102000331                  00000310
    101  00101000000000011001000000000000000000000101                            00000320
```

Figure B-1 Continued

```
                         ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

                  1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

   102           87.745.                                                         00000330
   103   A2-09 7104 COL    100270                                                00000340
   104   70222020212025103020100037028009000000000000100002001322                00000350
   105   10000000100000000000000000000000000000000101                            00000360
   106       -4. 78.5                                                            00000370
   107      14                                                                   00000010
   108   A2-07 0033 KY     112067                                                00000020
   109   67361060212092107050200070065005000010000000000010103324                00000030
   110   0000000010000000000000000000000000000000                                00000040
   111           322.                                                            00000050
   112   A5-02 7027 OHARE  122768                                                00000060
   113   68131062512041104030001041024016001111100012001020103124                00000070
   114   0010101110000000000000100022220000000000001101                          00000080
   115           135.90.                                                         00000090
   116   A5-04 7316 CHIC   120872                                                00000100
   117   72332062512012106030102055040011004010111001000020003124                00000110
   118   00000000100000001100002000220000040000041001110001                      00000120
   119   -4.5    203.                                                            00000130
   120   A2-13 740; STLOU  072373                                                00000140
   121   73211060212213103010200041037004000111111001000020003224                00000150
   122   00000000000000000000000110000004040000001110010001                      00000160
   123   0000                                                                    00000170
   124   A2-17 7509 NC     091174                                                00000180
   125   74371060212294104020101078069009000111011010221020102124                00000190
   126   101101101000000011111111100000040400000411100101111                     00000200
   127       -4.5218.-5.53.                                                      00000210
   128   A2-20 7803 GA     040477                                                00000220
   129   77371021912880104020101081060021000111100022221120002124                00000230
   130   10111011111000111000000010220000000000001111100101                      00000240
   131   0000                                                                    00000250
   132   A2-21 7806 MISS   102077                                                00000260
   133   77112060210994102020000024004019001111100002000020012224                00000270
   134   100000001000000010000000002200000000000010011                           00000280
   135   -5.                                                                     00000290
   136   A7-08 7403 BOSTON 073173                                                00000300
   137   73371063812071106060000083082001000111100011110010113204                00000310
   138   10000011100000000000021102200000000000001000000001                      00000320
   139           219.                                                            00000330
   140   A7-13 7907 ORE    122878                                                00000340
   141   78511063610095108020204181008021152000000000000012003204                00000350
   142   1000000010000010111000000000000040400000100110001                       00000360
   143   0000                                                                    00000370
   144   A7-11 7617 CA     020876                                                00000380
   145   76181162012011106030003000000000000001001000100012001320                00000390
   146   00100100111000000100001010000004040000001001                            00000400
   147   0000                                                                    00000410
   148   A7-05 7220 CONN   060771                                                00000420
   149   71131060912011103020100028026002000010000000000000013204                00000430
   150   101010111000000000000010102200                                          00000440
   151           177.                                                            00000450
   152   A7-02 7010 PA     010669                                                00000460
```

CARD 8
9
10
11
12

13 MORE SETS OF CARDS 9-12

Figure B-1.Continued

```
                                  ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

                  1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

    153  69121061212094103020100025009016000222200010200020111104                00000470
    154  1000001110100000000000000002000000000000101100001                       00000480
    155      -4.5226.                                                            00000490
    156  A7-01 0033 PA     122468                                                00000500
    157  68131061212953103020001044018012014110100001001000102204                00000510
    158  0000100000000000001000110022001101                                      00000520
    159      -4. 219.                                                            00000530
    160  A7-07 7308 NY     030372                                                00000540
    161  72212062010014103020100045014031000000000011000010012104                00000550
    162  0010000001000000000100000000000000000000110110001                       00000560
    163      -5. 197.-1.55.                                                      00000570
    164     20                                                                   00000010
    165  G5-01 0052 NY     040764                                                00000020
    166  64501112320481209000108136000015121010100000000010003316                00000030
    167  0000000010000010010000000202200000000000000000000000                    00000040
    168          270.                                                            00000050
    169  G5-03 7407 NC     102873                                                00000060
    170  73331092322481304000004092000000092110111000001000103316                00000070
    171  0010100000000000000000100102002424000006000000000000                    00000080
    172          235.                                                            00000090
    173  G5-08 7313 MIAMI  121572                                                00000100
    174  72601161920161311000011149000000014900000000000001000016                00000110
    175  0000000000000000000000000000000000000006000000000000                    00000120
    176          236.                                            2.66            00000130
    177  G5-11 0025 SLC    060668                                                00000140
    178  68321112320441206000006086000004082000010000000002100016                00000150
    179  0000000001000000000000000029290000000000000000010000                    00000160
    180          213.                                                            00000170
    181  G5-07 7902 NY     070978                                                00000180
    182  78301092320441204000004073000001072010011000000022013316                00000190
    183  0000000000000110010100000000000404000006100000011                       00000200
    184          275.                                                            00000210
    185  G5-10 0019 KANCIT 070165                                                00000220
    186  65501112320481306000006060000000060110111000000000102316                00000230
    187  0000000101000000000000000022200000000000                                00000240
    188          228.                                                            00000250
    189  G5-02 7023 VRGNIS 081269                                                00000260
    190  69371112320481305000005114000000114010001000000000103316                00000270
    191  0000000010000000000000000000000020000026                                00000280
    192          226.                                                            00000290
    193  G5-04 7515 WYO    033175                                                00000300
    194  75331092320481206000006093000001092000111000000013003316                00000310
    195  100000000000000001010000000000904000000600000001                        00000320
    196          257.                                                            00000330
    197  G1-02 0023 OHARE  032168                                                00000340
    198  68321150412351203000102000000000000110011000001120003316                00000350
    199  01001000010000000000001100000000040400041                               00000360
    200  000                                                                     00000370
    201  G1-03 7024 CALIF  101669                                                00000380
    202  69511152312611305000005000000000000000111000000000002316                00000390
    203  0000000000000000000000100102000800000006                                00000400
```

CARD 8
9
10
11
12

19 MORE SETS OF CARDS 9-12

Figure B-1 Continued

```
                              ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

                  1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     204         219.                                                            00000410
     205 G1-07 7304 SANFRA 091372                                                00000420
     206 72501152320071303000003000000000000011010100000010103316                00000430
     207 1000000010000000000000000000000000000024                                00000440
     208         236.                                                            00000450
     209 G1-08 7401 MAINE  062073                                                00000460
     210 73511170130441210000010251000003248110010000010004003316                00000470
     211 000000000000000000000000002000000000210000000001                        00000480
     212         186.                                                            00000490
     213 G1-10 7619 JFK    111275                                                00000500
     214 75611170913441211000209128000000128000111000001000013316                00000510
     215 0010100000000000000000110100102400000904000000000110                    00000520
     216         283.                                                            00000530
     217 G1-11 7710 DENVER 111676                                                00000540
     218 76371152322451205000005081000002079110011000000002113216                00000550
     219 0010100000100001000000110000000407000006000000010000                    00000560
     220         265.                                            4.              00000570
     221 G1-12 7901 LA     030178                                                00000580
     222 78611151612411114000311186002028156000010000021014112216                00000590
     223 0000100000000000000000110000000700000000000000000000                    00000600
     224         268.                                                            00000610
     225 G1-14      ALASKA 032774                                                00000620
     226 74511152202441212000012219000001218000010000000100000016                00000630
     227 0000000000000000000000000000210200000000000000010000                    00000640
     228         219.                                                            00000650
     229 G1-16      MIAMI  052578                                                00000660
     230 78361152320411203000003003000000000300000100000000013316                00000670
     231 0000000000000001000000000001111202000006                                00000680
     232         270.                                                            00000690
     233 G1-04 7209 FHILA  071970                                                00000700
     234 70331161920411206000006055000001054110100000000011013316                00000710
     235 0010000000100000000000000001000004000006                                00000720
     236         169.                                            6.              00000730
     237 A1-02 7208 VRGNIS 122870                                                00000740
     238 70321091812151107000205048002009037010000000110010010016                00000750
     239 00000000100000000000002110020000000000000101000110000                   00000760
     240         197.    3.1                                                     00000770
     241 G1-17      BALT   011667                                                00000780
     242 77511150000001208000107093000006008700000000000000000006                00000790
     243 0000                                                                    00000800
     244 000                                                                     00000810
     245     9                                                                   00000010     CARD   8
     246 G5-09 7412 OHIO   112773                                                00000020            9
     247 73371132300051205000302021000013008010100101000010000007                00000030           10
     248 0000000010000000100010000022000000000000                                00000040           11
     249 0000                                                                    00000050           12
     250 G5-05 7620 ALASKA 040576                                                00000060
     251 76321092312841109000502041001006036110111002000020113207                00000070     8 MORE SETS OF
     252 10000000100000000010000000200024040000041101000011                      00000080
     253         228.                                                            00000090
     254 G5-06 7701 VIRGIS 042776                                                00000100
```

Figure B-1 Continued

ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

```
                  1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     255 76321092312011107020203081035017029110011001000120113327                00000110    CARDS 9-12
     256 0000010010000000000000111000000400000004                                00000120
     257         214.    11.                                                     00000130
     258 G1-01 0029 KY     110667                                                00000140
     259 67501151622051107000007029001001027110111100000110102307                00000150
     260 000001001000000010000110022210404000000700001                           00000160
     261         245.                                                            00000170
     262 G1-06 7307 JFK    081372                                                00000180
     263 72501150522001211000110175000015160000010000001010113307                00000190
     264 00101000000000000000001100                                              00000200
     265         260.                                                            00000210
     266 G1-09 7609 MIAMI  092775                                                00000220
     267 75351152312071106040200004002002000010010011000010011127                00000230
     268 0000000100000000000000000000000000000000101101                          00000240
     269         235.                                                            00000250
     270 G1-13 0002 CANADA 062678                                                00000260
     271 78371152310105000401100002043057010011101001005003100007                00000270
     272 00101000100000000100010000000000909000071101                            00000280
     273         251.    -16.                            16.     19.             00000290
     274 G1-05 7212 ALASKA 112770                                                00000300
     275 70511150412111010603219046043130010111000000000113230007                00000310
     276 00100000100000000111101100000024240000040000000011                      00000320
     277         268.    9.                                                      00000330
     278 G1-15 7707 MIAMI  121676                                                00000340
     279 76361152320071203000300000000000000000001000000001000 3307              00000350
     280 0000                                                                    00000360
     281         270.                                                            00000370
```

Figure B-1. Concluded

```
                     SAMPLE CASE --- TO FIND CLASS D AIRCRAFT WITH POST-CRASH FIRES

                          THE FOLLOWING ENTRIES IN THE DATA BASE WERE SCANNED FOR THE VALUES SHOWN

                          FOR THESE ENTRIES, ALL THE CRITERIA MUST BE MET BY EACH ACCIDENT

             COL     COLUMN DESCRIPTION                     VALUES REQUESTED

          1   2      CLASS D AIRCRAFT                         50   51

          2   7      POST-CRASH FIRE                            2    3


                THE FOLLOWING ACCIDENTS MET THE CRITERIA THAT WERE SPECIFIED FOR THE DATA BASE ENTRIES GIVEN ABOVE

   ACC   FILE# NTSB  PLACE  DATE   A/C    C  ACC  OPER  I  D  F  S  S  H  S  F  S  R  F  F  M  N  W  E  T  L SEPARATE/BREAK EVAC
                                          L  TYPE MODE  N  A  I  U  T  U  K  D  E  S  L  U  L  L  I  N  A  I                TIME
                                          A             J  M  R  R  R  M  E  R  A  T  O  S  G  G  N  G  N  N  W  F  E  M  N
                                          S             U  A  E  V  D  F  T  D  T  R  O  E        G  I  K  E  I  U  N  L  L
                                          S             R  G     I  A  A  C  A     N  R              N        N  S  G  G  G
                                                        Y  E     V  M  C  H  T     T                 E        G  E

1   3    A1-04 7410 LA     011674 B-707   D  GR   LDGLO  S  D  Y  P  G  G

2  13    A4-04 7707 SAMOA  013074 B-707   D  UN   LDGFA  F  D  Y  S     P                 F  F  F  F     F           S  S  S

3  48    G1-03 7024 CALIF  101669 DC-8    D  MI   ABTO   N  D  Y  P  P                       F  F     F              S

4  54    G1-14      ALASKA 032774 DC-8    D  MF   ABTO   S     Y  P  G  G                    F              F

5  62    G1-01 0029 KY     110667 B-707   D  FE   ABTO   F  S  Y  S  P        Y        F  F  F  F  F  F     F     S  S  S

6  63    G1-06 7307 JFK    081372 B-707   D  CF   ABTO   S  S  Y  S        Y  Y                       F  F

7  66    G1-05 7212 ALASKA 112770 DC-8    D  CD   ABTO      D  Y  S  G  G  Y  Y           F        F        F     S     S  S


               THE FOLLOWING PARAMETERS RELATE AIRCRAFT ATTITUDES, VELOCITIES, AND LOAD FACTORS IN METRIC UNITS

                 FLIGHT PATH       A/C ATTITUDE                VELOCITIES                        LOAD FACTORS
             -----------------   ----------------  ----------------------------------  ----------------------------------
      ACC     ALPHA GAMMA  VEL   PHI  THETA  PSI    VX    VY    VZ  PHDOT THDOT PSDOT   NX    NY    NX  PHDOT THDOT PSDOT

  1    3                    77                                                                     4.6

  2   13                    73        -3.5

  3   48                    66

  4   54                    66

  5   62                    74

  6   63                    79

  7   66                    81        9.
```

Figure B-2. - Sample case, to find class D aircraft with post-crash fires

```
                   SAMPLE CASE --- TO FIND CLASS D AIRCRAFT WITH POST-CRASH FIRES


              THE FOLLOWING PARAMETERS RELATE AIRCRAFT ATTITUDES, VELOCITIES, AND LOAD FACTORS IN ENGLISH UNITS

               FLIGHT PATH       A/C ATTITUDE                VELOCITIES                        LOAD FACTORS
           ------------------  ----------------- ----------------------------------- -----------------------------------
    ACC     ALPHA GAMMA  VEL   PHI  THETA  PSI    VX    VY    VZ  PHDOT THDOT PSDOT   NX    NY    NX  PHDOT THDOT PSDOT

1    3                  253.                                                                     4.6

2   13                  240.        -3.5

3   48                  219.

4   54                  219.

5   62                  245.

6   63                  260.

7   66                  268.        9.
```

Figure B-2 Concluded.

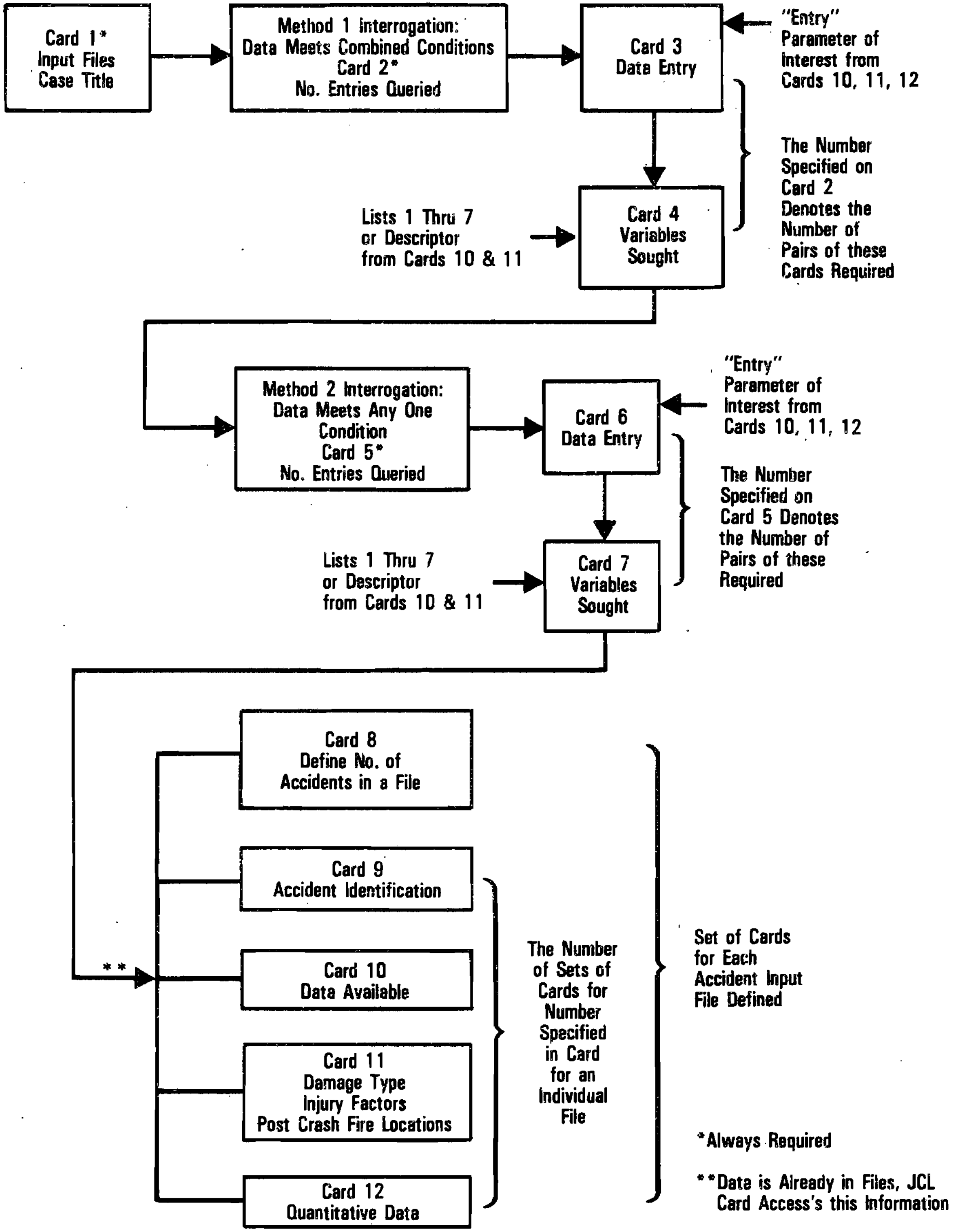

Figure B-3. - Flow diagram.

postcrash fires are being queried. The number of input files (input card 1) are stored on tape and are accessed via a job control language (JCL) card. In this case two pair of input cards 3 and 4 are needed, as defined by the requirements for 2 variables from input card 2. If input card 2 were a blank no input cards 3 and 4 would be necessary. Case card 3 corresponds to the first input card 3. The value shown in column 5 is 2 which denotes the "entry" of interest from input card 10. From input card 10 it can be observed that the description of aircraft class and type is available in List 1. From List 1 it can be noted that there are only two class D aircraft (B707 and DC-8). Thus on input card 3 a "2" is placed in column 10 since that is the number of variables that are required for card 4. Now input card 4 contains two inputs denoting B707 and DC-8 aircraft (see list 1). If all class E aircraft were desired instead of class D, input card 3 would have a 3 in column 10 and input card 4 would have the numbers 60, 61 and 62.

Case cards 5 and 6 respresent the second pair of input cards 3 and 4. The number 7 in column 5 of the second input card 3 is the "entry" number on input card 10 which denotes fire conditions. There are three possible descriptions for entry 7. Since we want post-crash fires, descriptors 2 and 3 are applicable. Thus two variables will be sought (column 10 of second input card 3). The second input card 4 shows the numbers 2 and 3 which are the applicable descriptors for entry 7 on input card 10. Case card 7 is input card 5. In this case it is a blank because we are searching for a combination of conditions to be met. It is a required input card just like input card 2. However, no input cards 6 and 7 are required for this problem. If required, the data for input cards 6 and 7 would be obtained in the same manner as input card 3 and 4 data.

Case card 8 corresponds to input card 8. It gives the number of accidents for which data follows, that is the number of sets of input cards 9-12 that follow. Each set of cards 9-12 contains all of the applicable data for a single accident.

There is a single input card 8 and appropriate set of input cards 9-12 for each of the files (6 in this case) specified in input card 1.

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