DOT/FAA/CT-84/3

AD-A142 092

Study on Transport Airplane Unplanned Water Contact

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February 1984
Final Report

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US Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-84/3	2. Government Accession No. AD-A142092	3. Recipient's Catalog No.
4. Title and Subtitle STUDY ON TRANSPORT AIRPLANE UNPLANNED WATER CONTACT		5. Report Date January 1984
		6. Performing Organization Code ACT-330
7. Author(s) Dick Johnson		8. Performing Organization Report No. DOT/FAA/CT-84/3
9. Performing Organization Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. T1704A
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		13. Type of Report and Period Covered Final 1981 - 1982
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This study provides for an identification of accident scenario(s) and associated occupant risks and survival equipment needs, relating to the inadvertent or unplanned water contact of transport category airplanes. This identification was obtained, in part, from the results of contractual studies of transport accident data. The subject study concludes that while the unplanned water contact of a transport airplane occurs less frequent than corresponding ground contact, the impact loads are often higher, leading to greater fuselage damage. Also, the unplanned water contact occurs more frequent than a planned water landing (ditching) and usually involves adverse flooding conditions. These conditions, in turn, affect the ability of occupants to retrieve, deploy and/or don on-board floatation equipment.

17. Key Words	18. Distribution Statement
Unplanned Water Contact	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	36	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

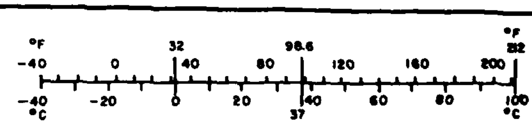
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This study identifies the accident scenario(s) and associated occupant risks and survival equipment needs, relating to the inadvertent or unplanned water contact of transport category airplanes. This study focuses on the results contained under a recent industry evaluation of survivable transport aircraft accidents. These results are summarized with emphasis placed upon the definition of the unplanned water crash environment. From this and other available information, the behavior of typical transport airplanes in unplanned water contact type accidents is identified to include the general condition of the cabin, structural damage, floatation time, attitude, availability of emergency exits, emergency evacuation equipment, and other factors found relevant to occupant survival.

INTRODUCTION

PURPOSE.

The purpose of this study was to identify the accident scenario(s) and associated occupant risks and survival equipment needs, relating to the inadvertent or unplanned water contact of transport category airplanes.

BACKGROUND.

During the 1970's the Federal Aviation Administration (FAA) and aviation community directed a significant amount of research towards the development of improved aircraft water evacuation and survival equipment. With emphasis placed upon occupant survivability during the controlled or normally configured emergency landing of an aircraft on the water, this effort was focused primarily on improving the access and use of onboard floatation equipment. The availability of new low weight materials made possible the development of lighter, more accessible liferaft designs including door mounted slide/raft devices that could be launched automatically from the aircraft exit. Such materials also provided for new lifevest designs characterized by higher buoyancy performance. These equipment improvements were reflected under the establishment of new design and installation requirements and associated crew training and operational procedures. To date, requirements, applicable to new slide/raft, liferaft and lifevest designs, have been adopted under recent airworthiness and operational rule changes and/or are currently being promulgated under new proposed minimum performance standards (references 1 to 8).

In 1981, the FAA initiated further research to improve occupant survivability in aircraft accidents resulting from inadvertent or unplanned water contact. Areas addressed under this research effort were: aircraft certification and operational provisions for unplanned water landings near airport terminals; aircraft floatation equipment needs which take into account occupant hypothermic effects and equipment accessibility and use; and airport water/sea rescue procedures. The subject study represents a supporting part of this research effort. Specifically, it is aimed at the identification of the unplanned water contact scenario(s) and includes occupant risks and survival equipment needs. The study focuses on the results contained under a recent industry evaluation of survivable accidents (references 9, 10, and 11). These results will be summarized with emphasis placed upon the identification of the unplanned water-crash environment. Also, from available information, the study will characterize the behavior of typical transport airplanes in unplanned water contact type accidents to include the general condition of the cabin, structural damage, floatation time and attitude, availability of exits and emergency equipment, and other factors found relevant to occupant survival.

ACCIDENT SUMMARY

DATA BASE.

In January 1980, an accident study was contracted with three major aircraft manufacturers (references 9, 10, and 11) for the primary purpose of defining a range of crash situations that would form the basis for improved crashworthiness design technology and the identification of structural components and aircraft systems that influence the crash behavior of an aircraft. The data base for this effort began with a review of some 933 transport ground/water accidents which had occurred between the years of 1959-1979. The accident data were obtained from various sources including FAA/Civil Aeronautics Board (CAB) and National Transportation Safety Board (NTSB) reports, and information released by foreign government organizations, airlines, and aircraft manufacturers. The accidents selected for evaluation were survivable accidents in which the governing criteria were established around (a) a survivable airframe volume (prior to fire), (b) the capability of at least one occupant able to withstand the accident environment, (c) the potential for occupant egress, and/or (d) a demonstration of structural system performance.

For the purpose of this report the accident data base selected under reference 9 was used because of the emphasis placed upon the water contact occurrence. This data base is presented in table 1 and contains a total of 153 worldwide transport aircraft accidents in which water involvement was identified in 16 of the cases. As noted, the summary provided in table 2 covers 11 of these accident cases, since water was only incidental to 5 of the 16 accidents and not directly associated with resulting fatalities/injuries. The cases that have been excluded are the B707 Oso accident; L1011 Everglades accident; B727 Maderia accident; B727 Mexico City accident; and the B707 Rio de Janiero accident. The 11 water impact accidents are characterized by the presence of 218 fatalities and 80 serious injuries. A brief assessment of both the 153 land and water accidents, as they relate to severity of occurrence, occupant survivability, aircraft size and configuration, operational phases, structural damage, and system participation is provided in the following sections of this report.

SEVERITY/SURVIVABILITY.

The 153 accidents in the data base were assessed on the amount of damage to the aircraft and the effect of this damage on survivability. The extent of damage is categorized in table 3 with the effect on occupant survivability summarized in table 4. First, as regards to the selected data base and overall survivability, fire presented the greatest hazard. Known fire fatalities outnumbered known trauma fatalities by 2.84:1. Fire hazard was most severe for accidents having major fuel spills due to rupturing of fuel tank (categories 4, 5, and 6). Trauma fatalities occurred mostly in categories 5 and 6, which involved severe fuselage breaks. The single instance in category 2 resulted from a local loss of survivable volume; and 5 instances in category 4 resulted from severe lower fuselage crush. While deep water impact accidents represented less than 10 percent of the study data base, little structural or detailed information is available on such accidents in which a large percentage of the occupant fuselage perished. Water impact usually results in severe damage to the lower fuselage, often accompanied by class 2 breaks in the fuselage and separation of wings, engines, and landing gear. In some cases involving low impact conditions, many occupants drowned after evacuating the aircraft. In such cases, the high fatality rate was due to inappropriate action of the cabin crews after the aircraft came to rest. As noted, drownings accounted for 218 fatalities, at least 15 of which occurred after evacuation. In most accidents involving drowning, few details are available, except for the DC9 St. Croix accident. In this case, the drownings were found to have occurred after evacuation with fatalities due to trauma occurring as a result of floor distortion and seat separation, and to occupants who did not use their seatbelts. In general, the overall survivability of either the ground or water impact accident decreases as the major structural damage to the aircraft increases.

TABLE 1. STUDY DATA BASE

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING
101959	707	OSO, WASHINGTON	X	8	4	0	APP	FIRE	PAR	WAT
082759	CMT	ASCUNCION	X	50	2	?	APP		UDF	
022060	CMT	BUENOS AIRES	X	6	0	0	LDG	FIRE	YES	
071161	DC8	DENVER	X	122	17	0	LDG	FIRE	YES	
011961	DC8	JFK	X	106	4	?	TO	FIRE	PAR	
061561	707	LISBON		103	0	2	LDG	FIRE	YES	
122161	CMT	ANKARA	X	34	27	6	CLI	FIRE	UDF	
092461	720	BOSTON		71	0	2	LDG		YES	WAT
092761	CVL	BRASSILA	X	?	?	?	LDG	FIRE	UDF	
072761	707	HAMBURG	X	41	0	10	TO	FIRE	YES	
060362	707	PARIS, ORLY	X	132	130	2	TO	FIRE	UDF	
082062	DC8	RIO DE JANIERO	X	105	15	?	TO		YES	WAT
070363	CVL	CORDOBA, ARGENTINA	X	70	0	?	APP	FIRE	YES	
031864	BAC	WISLEY, ENG.		5	0	1	LDG		YES	
040764	707	JFK	X	145	0	7	LDG		YES	WAT
112364	707	ROME	X	73	48	20	TO	FIRE	YES	
032264	CMT	SINGAPORE	X	86	0	0	LDG	FIRE	YES	
050265	720	CAIRO	X	127	121	6	APP	FIRE	UDF	
070165	707	KANSAS CITY	X	66	0	2	LDG		YES	
110865	727	CINCINNATI	X	62	58	4	APP	FIRE	PAR	
111165	727	SALT LAKE CITY	X	91	43	35	LDG	FIRE	YES	
091365	880	KANSAS CITY	X	4	0	0	CLI	FIRE	YES	
022765	880	IKI IS., JAPAN	X	6	0	2	LDG	FIRE	YES	
070466	DC8	AUCKLAND	X	5	2	1	TO	FIRE	PAR	
082666	880	TOKYO	X	5	5	0	TO	FIRE	YES	
030466	DC8	TOKYO	X	71	64	8	APP	FIRE	UDF	
063066	TRI	KUWAIT	X	83	0	0	APP		YES	
122466	DC8	MEXICO CITY	X	110	0	6	APP	FIRE	YES	
021566	CVL	NEW DELHI	X	81	2	14	APP	FIRE	YES	
110667	707	CINCINNATI	X	36	1	2	TO	FIRE	PAR	
112067	880	CINCINNATI	X	82	70	12	APP	FIRE	PAR	
030567	DC8	MONROVIA	X	90	51	23	APP	FIRE	UDF	
063067	CVL	HONG KONG	X	80	17	5	APP		YES	WAT
092967	CMT	ROME	X	66	0	0	LDG		YES	
110567	880	HONG KONG	X	137	1	?	TO		YES	WAT
122768	DC9	SIOUX CITY	X	66	0	3	TO		YES	
032868	DC8	ATLANTIC CITY	X	4	0	2	LDG	FIRE	YES	
061368	707	CALCUTTA	X	63	6	2	APP	FIRE	YES	
060368	727	JFK		102	0	4	LDG		UDF	
032168	727	CHICAGO	X	3	0	1	TO	FIRE	YES	
020768	707	VANCOUVER, B.C.	X	61	1	0	LDG		PAR	
021668	727	TAIPEI	X	63	21	42	APP	FIRE	UDF	
040868	707	LONDON	X	127	5	?	CLI	FIRE	YES	
042068	707	WINDHOEK	X	128	123	5	CLI	FIRE	PAR	
080268	DC8	MILAN	X	95	12	?	APP	FIRE	YES	
011469	BAC	MILAN	X	33	0	0	TO		YES	
101669	DC8	STOCKTON, CA.	X	5	0	0	LDG	FIRE	YES	
010569	727	LONDON GATWICK	X	65	50	14	APP	FIRE	PAR	
011369	DC8	LOS ANGELES	X	45	15	17	APP		YES	WAT
092169	727	MEXICO CITY	X	118	28	78	APP		PAR	WAT
091269	BAC	MANILA	X	47	45	2	APP	FIRE	PAR	

TABLE 1. STUDY DATA BASE (Continued)

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING
062469	880	MOSES LAKE	X	5	3	?	CLI	FIRE	YES	
021170	707	STOCKTON, CA		6	0	1	LDG		YES	
071970	737	PHILADELPHIA	X	62	0	1	TO		YES	
090870	DC9	LOUISVILLE		94	0	0	LDG	FIRE	YES	
122870	727	ST. THOMAS	X	55	2	11	LDG	FIRE	YES	
080870	990	ACAPULCO	X	8	0	8	LDG	FIRE	YES	
112770	DC8	ANCHORAGE	X	229	47	47	TO	FIRE	YES	
072770	DC8	NAHA, OKINAWA	X	4	4	0	APP		PAR	WAT
020970	CMT	MUNICH	X	23	0	0	TO	FIRE	YES	
033170	CVL	CASABLANCA	X	82	61	21	APP	FIRE	UDF	
050270	DC9	ST. CROIX, V.I.	X	63	25	25	LDG		PAR	WAT
070570	DC8	TORONTO	X	108	108	0	LDG	FIRE	YES	
091570	DC8	JFK	X	156	0	11	LDG	FIRE	YES	
010570	990	STOCKHOLM	X	10	5	4	CLI		PAR	
071970	BAC	GERONA, SPAIN	X	85	0	3	TO		YES	
120770	BAC	CONSTANA	X	27	18	?	APP		UDF	
113070	707	TEL AVIV	X	3	0	0	TO	FIRE	YES	
012371	707	BOMBAY	X	5	0	0	TO	FIRE	YES	
090671	BAC	HAMBURG	X	121	22	?	CLI	FIRE	UDF	
121571	707	URUNCHI, CHINA	X	3	0	0	LDG		YES	
051872	DC9	FT. LAUDERDALE	X	10	0	3	LDG	FIRE	YES	
092472	DC8	BOMBAY	X	120	0	0	LDG	FIRE	YES	
120872	737	CHICAGO MIDWAY	X	61	43	12	APP	FIRE	PAR	
121572	747	MIAMI	X	160	0	0	LDG		YES	
122072	DC9	CHICAGO O'HARE	X	45	10	9	TO	FIRE	YES	
122972	L10	MIAMI	X	176	99	60	APP	FIRE	NO	WAT
012172	DC9	ADANA	X	5	1	?	APP	FIRE	UDF	
041772	VC1	ADDIS ABABA	X	107	43	?	TO	FIRE	UDF	
081372	707	JFK		186	0	0	TO	FIRE	YES	
112872	DC8	MOSCOW, USSR	X	76	61	15	CLI	FIRE	UDF	
122372	F28	OSLO	X	45	40	?	APP	FIRE	UDF	
122872	F28	BOLBAO, SPAIN	X	4	0	4	LDG		YES	
030573	707	DENVER		3	0	0	TO	FIRE	YES	
073173	DC9	BOSTON, MASS.	X	89	89	0	APP	FIRE	PAR	
112773	DC9	CHATTANOOGA	X	77	0	5	APP	FIRE	YES	
112773	DC9	AKRON, OHIO	X	26	0	16	LDG		YES	
012273	707	KHANO, NIGERIA	X	202	172	?	LDG	FIRE	YES	
053173	737	NEW DELHI	X	65	52	?	APP	FIRE	YES	
060973	707	RIO DE JANEIRO	X	4	2	0	APP		PAR	WAT
102873	737	GREENSBORO		96	0	0	LDG	FIRE	YES	
061673	707	BUENOS AIRES		86	0	0	LDG	FIRE	YES	
062373	DC8	JFK		128	0	8	LDG	FIRE	YES	
121773	DC9	GREENSBORO		91	0	0	TO	FIRE	YES	
121773	DC1	BOSTON	X	151	0	3	LDG	FIRE	YES	
121973	707	NEW DELHI	X	109	0	3	LDG	FIRE	YES	
122373	CVL	MANAUS, BRAZIL	X	57	0	1	LDG		YES	
011674	707	LOS ANGELES	X	63	0	3	LDG	FIRE	YES	
011374	707	PAGO PAGO, AM. SAMOA	X	101	97	5	APP	FIRE	YES	
091174	DC9	CHARLOTTE, N.C.	X	82	71	10	APP	FIRE	PAR	
091174	727	PORTO ALEGRE, BRAZIL		74	0	0	LDG		YES	
010174	F28	TURIN, ITALY	X	42	38	4	APP	FIRE	UDF	

TABLE 1. STUDY DATA BASE (Continued)

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING
010274	F28	IZMIR, TURKEY	X	72	65	7	CLI	FIRE	UDF	
031574	CVL	TEHRAN, IRAN	X	96	15	?	TAX	FIRE	YES	
112074	747	NAIROBI, KENYA	X	157	59	44	CLI	FIRE	PAR	
020975	BAC	LAKE TAHOE	X	44	0	0	TO		YES	
033175	737	CASPER, WYO.	X	99	0	1	LDG		YES	
062475	727	JFK	X	124	112	12	APP	FIRE	PAR	
080775	727	DENVER	X	134	0	15	CLI		YES	
092475	F28	PALEMBANG	X	62	25	?	LDG	FIRE	UDF	
111275	727	RALEIGH, N.C.		139	0	1	APP		YES	
111275	DC1	JFK	X	139	0	2	TO	FIRE	YES	
111575	F28	NR. BUENOS AIRES	X	66	0	0	APP		YES	
121675	747	ANCHORAGE		121	0	2	TAX		YES	
010276	DC1	ISTANBUL	X	373	0	1	LDG	FIRE	YES	
040576	727	KETCHIKAN	X	57	1	32	LDG	FIRE	YES	
042276	720	BARRANQUILLA, COL.	X	4	0	1	APP	FIRE	YES	
042776	727	ST. THOMAS, V.I.	X	88	37	19	LDG	FIRE	PAR	
062376	DC9	PHILADELPHIA	X	105	0	36	LDG		YES	
121676	880	MIAMI	X	3	0	1	TO		YES	
111676	DC9	DENVER	X	85	0	2	TO	FIRE	YES	
030477	DC8	NIAMEY, NIGER	X	4	2	2	APP	FIRE	YES	
031777	707	PRESTWICK	X	4	0	0	TO	FIRE	YES	
032777	747	TENERIFE	X	396	334	62	TAX	FIRE	PAR	
032777	747	TENERIFE	X	246	246	0	TO	FIRE	YES	
040477	DC9	NEW HOPE, GA.	X	85	62	22	APP	FIRE	PAR	
092777	DC8	KUALA LUMPUR	X	79	34	?	APP	FIRE	UDF	
100277	DC8	SHANNON	X	259	0	1	TO	FIRE	YES	
111977	727	MADEIRA	X	164	128	36	LDG	FIRE	PAR	WAT
112177	BAC	BARILOCHE, ARG.	X	79	45	34	APP		UDF	
121877	CVL	MADEIRA	X	57	36	13	LDG		YES	WAT
041877	DC8	TOKYO	X	140	0	0	TO		YES	
111777	747	JFK		3	0	0	LDG		YES	
021178	737	CRANBROOK, B.C.	X	49	42	5	LDG	FIRE	PAR	
030178	DC1	LOS ANGELES	X	197	2	31	TO	FIRE	YES	
030378	DC8	SANTIAGO DE COMPO.	X	222	0	52	LDG		YES	
040278	737	SAO PAULO	X	42	0	0	LDG	FIRE	YES	
040478	737	CHARLROI, BELGIUM	X	3	0	0	LDG	FIRE	YES	
050878	727	PENSACOLA	X	58	3	11	APP		YES	WAT
052578	880	MIAMI	X	6	0	0	TO		YES	
062678	DC9	TORONTO	X	107	2	?	TO		PAR	
070978	BAC	ROCHESTER		77	0	1	LDG		YES	
103179	DC1	MEXICO CITY	X	87	70	17	LDG	FIRE	UDF	
111578	DC8	COLUMBO, SRI LANKA	X	259	195	?	APP	FIRE	UDF	
121778	737	HYDERABAD, INDIA	X	126	1	4	TO	FIRE	YES	
122378	DC9	PALERMO, ITALY	X	129	108	?	LDG		UDF	WAT
122978	DC8	PORTLAND, OREGON	X	186	10	23	APP		PAR	
032578	720	LONDON		82	0	?	LDG		YES	
020979	DC9	MIAMI	X	5	0	1	CLI		YES	
021979	707	ST. LUCIA		170	0	0	APP		YES	
031479	727	DOHA, QATAR	X	64	45	15	APP	FIRE	PAR	
042679	737	MADRAS	X	67	0	8	LDG	FIRE	YES	
100779	DC8	ATHENS	X	154	14	0	LDG	FIRE	YES	

TABLE 2. ACCIDENT DATA BASE SUMMARY (1959-1979)

	LAND	WATER	TOTAL
Accidents	142	11	153*
Fatalities	3573	218	3791
Serious Injuries	1046	80	1126

*Foreign 91
U.S. and Possessions 62

AIRCRAFT SIZE/CONFIGURATION.

Figure 1 identifies the size of aircraft represented in the data base, and figure 2 provides for the percentage of accidents as a function of aircraft size and configuration. Small commuter type short haul aircraft, constitute approximately 40 percent of the accident cases; larger short haul group, approximately 20 percent of the cases; narrow-body long haul group, approximately 35 percent; and wide-body long haul aircraft, approximately 5 percent. Of particular interest is the effect of size on aircraft crash performance and survivability. Considering the effects of scale, as in dynamic modeling, it might be expected that larger aircraft would fare better than smaller aircraft if the crash environment is not scaled up. Further, the individual occupant does not scale up but becomes relatively smaller in the larger aircraft with a corresponding improvement in his survival prospects. For instance, fuselage structural elements such as frames and stringers are stronger in an absolute sense and offer greater energy absorbing capability for larger commercial jet aircraft than for smaller propeller driven aircraft. This feature provides an inherent crashworthiness performance of the jet as compared to the propeller aircraft. An assessment of the accident data seems to indicate that relative size within the jet group has only minor effects on the crash performance. In general, it takes a larger tree, a larger house, and a deeper or wider ditch to do equivalent damage to a large aircraft. There are exceptions however, when considering accidents between smaller commuter aircraft with pressurized and non-pressurized fuselage of unequal strength but equivalent size. Notwithstanding that no two accidents are identical, an accurate comparison of damage between a large and small aircraft with or without pressurized fuselages can be made.

With respect to the effects of aircraft configuration on the total number of accidents, figure 2 also provides for the difference between aircraft types and service classes. It can be seen that approximately 20 percent involved non-passenger service as further broken down into cargo, training, and positioning flights. As regards to cargo service, a review of the accident data showed some cases where cargo shift during the accident increased the hazard to the flight crew. (A notable instance was the 880 Miami accident in 1976 where cattle pens broke loose during an overrun and blocked the cockpit door.) Training accidents most frequently involve engine-out takeoff attempts. These accidents involved extreme yaw and roll angles with ground strikes of wings, engines, or aft fuselage.

TABLE 3. STRUCTURAL DAMAGE SEVERITY

DAMAGE CATEGORY	
1	MINOR IMPACT DAMAGE - INCLUDES ENGINE/PYLON DAMAGE OR SEPARATION, MINOR LOWER FUSELAGE DAMAGE, AND MINOR FUEL SPILLAGE.
2	MODERATE IMPACT DAMAGE - INCLUDE HIGHER DEGREES OF DAMAGE OF TYPE 1 AND INCLUDES GEAR SEPARATION OR COLLAPSE.
3	SEVERE IMPACT DAMAGE - INCLUDES SEVERE LOWER FUSELAGE CRUSH AND/OR CLASS 1 OR CLASS 2 FUSELAGE BREAKS, MAY HAVE GEAR COLLAPSE, BUT NO TANK RUPTURE.
4	SEVERE IMPACT DAMAGE BUT NO FUSELAGE BREAK - INCLUDES MAJOR FUEL SPILLAGE DUE TO WING LOWER SURFACE TEAR AND WING BOX DAMAGE.
5	EXTREME IMPACT DAMAGE - INCLUDES CLASS 1 OR CLASS 2 FUSELAGE BREAKS WITH WING SEPARATION OR BREAKS, MAY HAVE GEAR AND/OR ENGINE SEPARATION.
6	AIRCRAFT DESTRUCTION - INCLUDES CLASS 3 FUSELAGE BREAKS OR DESTRUCTION WITH TANK RUPTURE, GEAR AND/OR ENGINE SEPARATION.

FUSELAGE BREAKS:

CLASS 1 - SECTIONS BREAK REMAIN TOGETHER

CLASS 2 - SECTIONS BREAK AND OPEN

CLASS 3 - SECTIONS BREAK AND MOVE OFF

TABLE 4. SUMMARY OF FATALITIES AS A FUNCTION OF DAMAGE SEVERITY

Cat	Accidents	Hull Loss	Fire	Occupants	Total Fat. #	Total Fat. %	Fire #	Fire %	Trauma #	Trauma %	Drowning #	Drowning %	Unk. #	Unk. %
1	5	3	4	616	53	8.6	53	8.6	0	0	0	0	0	0
2	24	12	6	1684	1	.06	0	0	1	06	0	0	0	0
3	22	20	9	2024	225	11.11	55	2.72	5	0.25	165	8.15	0	0
4	40	36	35	3425	875	25.54	722	21.08	5	.15	16	.53	130	3.80
5	35	35	28	2618	934	35.68	335	12.80	210	8.02	32	1.22	357	15.93
6	20	20	18	1990	1547	77.74	169	9.50	190	9.54	3	0.15	1165	58.54
UNK*	7	7	3	311	156	50.16	2	.64	65	20.90	0	0	89	28.62
	153	133	103	12668	3791	29.93	1356	10.70	476	3.76	218	1.72	1741	13.74

* Insufficient information for category assignment

Some accidents involve touch-and-go landing practice. The principal variation in structural configuration is in placement of engines. Approximately 60 percent of the accidents involved aircraft with wing-mounted and aft body-mounted engines. The aft-mounted engines only separated from the aircraft due to high acceleration loading, while the wing/pylon-mounted engines separated both from high accelerations and from contact with external objects.

STRUCTURAL DAMAGE.

Of the 153 accidents studied, 94 involved aircraft with engines on the wing pods and 59 involved aircraft with engine pods on the aft fuselage. In figure 3, it may be seen that engine separation occurred in 55 percent, landing gear collapse or separation occurred in 75 percent, wing box breaks occurred in 45 percent, fuselage breaks occurred in 48 percent, and water ditching impact breakup occurred in 3 percent of the accidents. The separation of an engine and the breaking of a wing-box imply fuel spills. In some instances, a fuselage break in an aircraft with aft-mounted engines also caused a fuel spill. The wide-body long haul aircraft have main body landing gear which transfers high impact loads to the fuselage structure. Water ditching impact breakup is considered separately from fuselage breaks because, in general, the hydrodynamic forces involved are different.

Considering fuselage breaks (excluding fuselage lower surface rupture) of the 153 impact survivable accidents, 64 are known to have experienced one or more breaks. Forty-six of the 64 were fatal accidents. Available data indicates that 39.5 percent of the persons onboard in the 64 accidents were fatalities. The other 82 accidents in this study did not experience fuselage breaks, and 27 of these were fatal accidents of which 20.6 percent of the persons onboard were fatalities. These data are plotted under figure 4. Of the 64 accidents experiencing fuselage breaks, 6 involved the aircraft touching down (impacting) on ground or in swampy areas with shallow water. Data on these accidents are plotted in figure 5. The six water entry accidents, in which the fuselage broke into several pieces and had a 36.8 percent fatality rate (36.8 percent of occupants onboard), are further discussed under the "Unplanned Water Contact" section of this study. The 58 ground slide accidents experienced fuselage breaks due to main landing gear separation/collapse, excessively hard touchdown on hard flat/impact after takeoff, touchdown in areas of trees/building/objects or on rocky/rough terrain, or combinations of these conditions.

With respect to fuselage lower surface rupture of the 153 impact survivable accidents, 57 aircraft are known to have experienced considerable damage to the lower fuselage and little or no damage to the upper fuselage (above the floor line). Seventeen of these 57 were fatal accidents, with 17.5 percent of the persons onboard being fatalities. In addition to the accidents with lower surface damage, three of these were fatal accidents with 45.8 percent of the persons onboard being fatalities. Lower fuselage tear or rupture generally occur when landing gear fails to support the aircraft. Thus, scrubbing on rough surfaces (sometimes even on the runway) rips open the thin skins and body frames. At the same time, wing-box fuel tanks are also subject to rupture and fuel spillage. In 37 of 53 ground slide accidents (4 of the 57 accidents were water entry accidents), the wing-box was probably ruptured and of these, 32 to 35 involved minor to severe fires. Lower surface damage accidents are divided into three groups for study purposes: extensive rupture, minor or moderate damage, and those involving water entry. The four accidents involving water entry are discussed under the "Unplanned Water Contact" section of this study.

SUBSYSTEM PARTICIPATION.

The crash dynamic response and interaction of the various components and their structural systems are shown in table 5. The frequency of occurrence or participation of each of these structural system failures in the data base of accidents considered is shown in table 6. The diagonal shows the total participation of any one component while the off-diagonal values show co-participation of other components. The data presented on cabin interior, seats, doors, and floors are as cited in the accident data reports. The failures associated with these subsystem areas have such a significant effect on occupant survivability during an emergency evacuation on either land or water. Those failures affecting occupant survivability during water impact occurrence will be further discussed in the "Unplanned Water Contact" section of this report. In this regard, it should be noted that in field investigations of accidents, interior structural component failures are not consistently documented and omission of mention of a particular component does not necessarily indicate no failure has occurred. The participation of structural factors in fatalities is shown in figure 6 (the percentage fatality participation coming from table 4). The major factor in fatalities is fire/smoke. The unknown represents a combination of trauma and fire. The role of trauma injuries in fire fatalities is undefined.

Available factual data relating to the 47 accidents citing door/exit problems are tabulated in figure 7. These data also indicate that most occurrences (47 percent) involved doors at the front of the fuselage and only 16 percent at mid-body and 27 percent at the aft fuselage. This ratio is expected, since during ground-slide accidents the forward fuselage is the first to impact objects such as buildings, trees, poles, etc. These data also indicate that forward fuselage doors involved jamming in 64 percent of the cases and blockage in 35 percent of the cases. Doors in the aft fuselage had approximately the same ratio. Mid-body exits, however, had this ratio reversed with blockage being 64 percent of the cases and jamming only 36 percent of the cases. It is probable that wing-box structure provides protection from jamming of the mid-body over-wing exits.

Of the 153 accidents, 36 are known or reported to have experienced passenger or crew area floor displacement or rupture. Such failures were reported as "probable" in 4 other accidents. Statistical data on these occurrences are tabulated in figure 8. For study purposes, these 36 accidents are divided into three groups: 15 that did not involve a fuselage break, 17 that did involve a fuselage break, and 4 that involved the aircraft touching or overrunning into water.

OPERATIONAL PHASE.

The percentage of accidents by operational phase and by operational time is shown in figure 9. Considering those operational phases taking place near or on the ground (load, taxi, takeoff, initial climb, initial approach, final approach, landing), 79.3 percent of the accidents occur in 18 percent of the operational time. Further, those accidents that occur during climb, cruise, and descent are generally non-survivable and were considered outside the range of study and selected data base. The average distance from the airport that the various accident types occur is shown in table 7. Figure 10 compares a fatality rating to the distance from 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

TABLE 5. STRUCTURAL SYSTEMS

SYSTEM	CRASH FUNCTION	CRASH DYNAMICS	INTERACTION	DIRECT RESULT
Fuselage	React Obstructions	Lower Fuselage Crush	Floor Displacement Cargo Displacement Upper Fuselage Distortion Body Fuel/Elec. Line Rupture	Energy Absorption by Deformation Energy Absorption by Grd. Friction Fuel/Fire/Smoke/ Water/Mud Entry Floatation Loss Fuselage Damage
	Energy Absorption	Upper Fuselage Distortion	Seats Door/Hatches Cabin Interior Floor Structure	Survivable Vol. Loss Egress Blockage Seat Lateral Displace
	Floatation Egress	Fuselage Break	Seats/Track/Floor Beam Cabin Interior Items Doors/Hatches Body Fuel Lines	Energy Absorption by Deformation Survivable Vol. Loss Occupant Ejection/ Egress Route Loose Cabin Interior Items Floor/Seat Track Rupture High Floor Accel.
	Support Floor Beams Support Cabin Interior Items	Fuselage Disintegration	Floor Struc. Displace. Seats Cabin Interior Items	Fuel/Fire Entry Seat Separation/ Ejection Cabin Debris Floatation Loss Energy Absorption Fueselage Damage
	Constrain/Baggage-Cargo			
Fuel Task Storage System	Retain Structural Integrity Limit Fuel Spillage	Engine Line Rupture Body Line Rupture	Pylon/Engine Fuselage	Fuel Spill
Floor Structure	Restrain Seats/Tracks Energy Absorption Provide Egress	Deformation	Seat Track/Seats Cabin Interior Items Doors/Hatches	Energy Absorption Egress Blockage
	Cabin Interior Items Retain Structural Integrity	Rupture	Seat Tracks/Seats Cabin Interior Items	
Seats/ Restraints Systems	Occupant Containment/ Protection	Seat Track Deform./ Rupture	Floor Beams	Seat Elevation/ Separation
	Energy Absorption	Seat Deformation	Seat Tracks	Energy Absorption Load Limiting
Remain Attaches	Remain Attached to Floor Release as Required (Belts/Harness)	Seat Rupture Belt/Harness Rupture	Seat Structure Bulkhead Structure	Occupant Relaease/Injury Occupant Ejection/Injury Energy Absorption
Cabin Interior System	Contents Containment Remain Attached to Structure	Overhead Compartment Spillage	Upper Fuselage	Cabin Debris
		Overhead Compartment Separation	Floor Beams	Egress Blockage
		Ceiling Panel/Sidewall Separation	C·i	
		Galley/Closet/Divider Separation Galley/Closet Spillage		
Entry and Escape Doors	Operate as Required	Blockage by Debris Jammed by Floor Jammed by Fuselage Distort. Inadvertent Opening	Cabin Interior Sys. Floor Structure Upper Fuselage	Egress Blockage Fuel/Fire/Smoke Entry

TABLE 5. STRUCTURAL SYSTEMS (Continued)

SYSTEM	CRASH FUNCTION	CRASH DYNAMICS	INTERACTION	DIRECT RESULT
Landing Gear	Energy Absorption Maintain Grd. Clearance Separate with no Damage to Airframe	Stroke/Gear Deformation	Load Airframe	Energy Absorption by Gear
Nose		Collapse Aft/Side and/or Separation	Forward Fueselage Grd. Contact	Energy Absorption by Grd. Friction Energy Absorption by Lwr. Fuse. Def.
			Penetrate Lower Fuselage	Gear Damage Floor Deformation Fire Entry to Cabin Fuselage Break
Main/Body		Collapse or Separation Aft/Side	Center Fuselage	Water/Fuel/Fire Entry to Lwr. Fuse.
			Lwr. Fuse. Penetration	Energy absorption by Pylon Def.
			Wing Pod Grd. Contact	Grd. impact loads to Wing
			Wing Grd. Impact	
			Wing Box Tear	Fuel Spill/Fire
			Slewing of A/C	Fuselage Break
			Lwr. Fuse. Penetration	Body Fuel Line Break/Fire
			Aft Structure Contact	Empennage Damage
Wing Pylon/Engine	React Obstructions	Deformation	Load Wing Structure	Pylon/Engine Damage Energy Absorption Load Wing Structure Grd. Friction
	Energy Absorption Separate with no Damage to Airframe	Collapse/Separation	Fuel/Electric/Hydraulic Line Rupture	Pylon/Engine Damage Fluid Spill/Arcing fire
			Wing Box Web Tear	Wing Box Break
			Wing Lower Surface Penetration	Energy Absorption
			Wing Ground Contact	
	Provide Gr. Reaction			
Aft Pylon/Engine	Separate with no Damage to Airframe	Deformation/Separation	Fuel/Electric Line Rupture	Pylon/Engine Damage Fuel Spill/Arcing/fire Fuselage fire damage
Wing Structure	Support Main Gear Support Engine/Pylon	Deformation	Load Fuse. Structure	Energy Absorption Fuel Leak Wing Damage
	Contain Fuel Reacts Obstructions	Separation	A/C Dynamics/Floatation Loss Hinder Egress	Fuel Spill/Fire Wing Damage
	Prevent A/C Roll Energy Absorption	Wing Box Break	A/C Dynamics/Floatation Loss	Fuel Spill/Fire Wing Damage
	Egress Route Provide Floatation	Lower Surface Tear	Fuel Spill/Fire Wing Damage	

TABLE 6. STRUCTURAL COMPONENT PARTICIPATION

Numbers of Accidents - 153 Total

	Hull Loss	Fire	Gear Sep.	Engine Sep.	Fuselage Crush & Break	Tank Rupture	Cabin Interior	Seats	Doors	Floors	Body Fuel Lines	Water
Hull	133	95	80	70	90	100	37	36	40	32	7	15
Fire	95	103	64	59	70	85	25	27	28	21	5	4
Gear	80	64	95	57	62	71	33	26	38	33	5	8
Engine	70	59	57	80	61	61	30	28	28	26	4	10
Fuselage	90	70	62	61	100	73	34	38	41	38	5	14
Tank	100	85	71	61	73	107	33	32	31	25	6	10
Cabin	37	25	33	30	34	33	45	26	24	22	2	7
Seats	36	27	26	28	38	32	26	41	23	24	3	5
Doors	40	28	38	23	41	31	24	23	47	30	3	5
Floors	32	21	33	26	38	25	22	24	30	42	3	7
Lines	7	5	5	4	5	6	2	3	3	3	7	2
Water	15	4	8	10	14	10	7	5	5	7	2	16

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 of about 1.2 miles from the airport are severe accidents. The airplane's uncontrolled attitude at impact during a stall contributes to this severity. Collision 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 at an average distant of 2.3 miles from the airport and has a fatality ratio equal to 1.86. Uncontrolled ground/water collisions occur at an average distant of 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 from the airport (excludes one accident approximately 80 miles from the airport) and has a normalized fatality ratio of 3.59, which is the highest of all the categories.

TABLE 7. AVERAGE DISTANCE FROM AIRPORT ASSOCIATED WITH ACCIDENT CATEGORIES

Description	Average Distance from Airport (Miles)
Hard landing	0.00
Controlled collision	7.80
Uncontrolled collision	2.70
Undershoot	.16
Stall	1.20
Collision with obstacle (all)	(1.50)
(a) off airport	2.30
(b) at airport	0.00
Aborted takeoff	.13
Overshoot	.11

SCENARIO(s)

From the study of both ground and water accidents in reference 9, three representative crash scenarios were identified with their selection based upon accident conditions involving consequences such as the aforementioned structural failures and occupant injury levels. As identified, these scenarios are described in the following paragraphs.

AIR-TO-SURFACE, HARD LANDINGS.

This scenario considers those types of accidents in which the aircraft impacts a level surface from the air, is characterized by a high sink rate with wheels up or down, with the airplane in a symmetric noseup or nosedown attitude typical of a hard landing or approach accident. Crashes on a final approach usually occur because the aircraft is not where the pilot thinks it is. The forward speed of the aircraft is between the speed for flap deployment (160 to 175 knots) and stall (120 to 126 knots). The rate of descent is between 3 and 12 meters per second (m/s) (600 and 2400 feet per minute (ft/min). The angle of the aircraft relative to the ground (pitch) is dependent on the slope of the ground and the attitude of the aircraft. The airplane altitude is assumed symmetrical with +15° pitch, with impact on the runway or within 200 meters of the runway. The aircraft gross weight is weight at takeoff less weight of fuel burned. For landing accidents, forward speed may be between the prescribed landing speed and stall speed. Some instances of higher speeds were noted, but these cases resulted in overruns. The pitch of the aircraft is between 3° to 4° nosed down/up to the noseup stall angle. Rate of descent is between 3 and 12 m/s (600 and 2400 ft/min).

AIR-TO-SURFACE, FLIGHT INTO OBSTRUCTION.

This scenario considers those accidents in which an airplane encounters a hostile environment at impact such as during an undershoot. In this scenario the hazard and terrain conditions have a significant influence on the severity of damage the airplane sustains. The hazards include ravines, embankments, lights, poles, trees, dikes, buildings, and vehicles. These accidents can be generally described as controlled or *uncontrolled collisions with obstacles, hostile terrain* or *water* (undershoot) occurring near the airport (from 150 to 1200 meters off the runway) or in some cases several miles from an airport. If the accident occurs during the landing or approach phase, the airplane is in a level attitude with 0° to +15° pitch, and approximately zero roll and yaw. If the accident occurs during takeoff, the pitch can range from 0° to +45°, roll from +5° to +45°, and the yaw from 0° to +10°. The ranges of forward speed and sink speed are from 120 to 200 knots and from 3 to 12 m/s (600 to 2400 ft/min), respectively. The hazards and terrain conditions have a significant effect on the structural damage and airplane post-impact behavior.

The Air-To-Surface Hard Landing and Flight Into Obsruction scenarios or crash environments are most representative of seven unplanned water impact cases identified in table 1. As applicable to a high sink rate approach or landing undershoot on the water, the scenarios describe an impact condition in which fuselage rupture and loss of lives is most likely, due to a combination of high impact loads, obstructed escape routes, and/or instantaneous cabin flooding. In addition, the scenarios define the situation in which onboard survival equipment items, normally intended for use during a planned ditching occurrence, would probably not be readily available, due to non-accessible stowage (doors, overhead, etc.) and insufficient retrieval and deployment time. For example, the use of multiple occupant liferaft and slide-raft devices is dependent upon an intact fuselage with operational exits and/or accessibility to equipment stowage areas not affected by severe cabin flooding conditions.

SURFACE-TO-SURFACE.

This scenario considers those accidents in which the aircraft is on the ground and encounters obstructions. The accident is characterized by horizontal motion of the airplane into a hazard such as during takeoff-abort or landing overrun. The sink speeds, including ground-slope effects, range from 70 knots to rotation speed with the airplane in a level attitude of the hazard encountered and range from paved surface, and hard ground (sliding contact) to ditches, humps, vehicles, light poles, buildings, soft earth, and/or water.

The surface-to-surface crash scenario characterizes the three identified cases of an aircraft overrun or slide/roll into the water (table 1). It describes relatively minor impact conditions in which the cabin remains generally intact and allows time for occupants to evacuate with full use of all onboard emergency equipment. This scenario describes an impact occurrence with a high probability of survival.

RISKS/EQUIPMENT NEEDS

Prior to identifying the occupant risks and equipment needs associated with an unplanned water contact occurrence, it is necessary to review the boundary conditions which have already been identified for both the uncontrolled ground and water impact crashes as presented under the scenario section of this report. It is also necessary to review those conditions which have resulted from a controlled or planned emergency water landing. This review will allow for an understanding of differences that exist between ground versus water crash occurrences which involve a "controlled" or "uncontrolled" aircraft. Notwithstanding the limited number of water impact occurrences and associated information available, the review will provide a better insight into those aspects affecting occupant survivability during the inadvertent impact of aircraft on the water.

From the aforementioned study results, it is obvious that the operating conditions and circumstances leading to either a ground- or water-impact occurrence are generally equivalent. However, during the actual impact event, it should be noted that the impact loads are transmitted into the aircraft fuselage/floor structure in a different manner as a result of surface variations (ground versus water), plowing, hydraulic effects, etc. Accordingly, the damage to an aircraft structure under equivalent crash conditions will vary between a ground and water impact. There are other variances as exhibited by the fact that the ground impact may involve a fire threat while the water impact concerns the potential of a sinking fuselage.

Considering strictly the unplanned water contact occurrence, and the small number of survivable cases reported during the last 20 years, it must be recognized that a larger accident base with more detailed information is needed to determine and develop any substantial improvements. For example, in the review of the 11 water impact cases in this study, very little postcrash information was available because the fuselages needed for subsequent evaluations were most often nonexistent (due to sinking). Also, unlike the controlled water impact or ditching occurrence, no analysis or tests have ever been conducted which describe quantitatively the behavior of an aircraft during an unplanned water contact. However, sufficient information is available which depicts a controlled emergency landing on the water, as well as an uncontrolled impact on the ground. While the controlled water and uncontrolled ground impact accelerations are usually less severe than the same characteristic pulses experienced during an uncontrolled water crash (due to plowing), it is believed that accident data obtained from the larger number of unplanned ground impact occurrences can be correlated to some degree with data already obtained from known controlled water impact (ditching) occurrences, analysis, and model tests. From this information it should be possible to form a rational basis which provides for the identification of occupant risks and survivable equipment needs appropriate to the unplanned water contact occurrence. A more indepth review of the planned and unplanned water contact occurrence is provided under this section. With respect to this review, it should be noted that many of the reported ground impact accidents could have equally involved water crashes, had the impact zones of the surrounding airport areas been water rather than land. Notwithstanding the higher number of ground impact occurrences, the number of water crash events could have been potentially higher.

PLANNED WATER CONTACT.

The planned water contact occurrence can be described as a controlled and normally configured emergency landing of an aircraft on the water. This emergency water landing or "ditching" occurrence is further defined by the NTSB as a "forced landing of aircraft in water" (reference 13) of which such conditions exclude instances where an aircraft collided with land or water in uncontrolled flight. The basis for an established scenario covering an emergency water landing is prescribed under the various sections of the FAR's which relate to requirements on aircraft water impact behavior, floatation characteristics, emergency exits, equipment, and demonstrated occupant evacuation capability. Under the identified aircraft general ditching provisions of Part 25 (reference 1), it is required that all practical design measures, compatible with the general characteristics of the airplane, must be taken to minimize the probability that in an emergency landing on the water, the behavior of the airplane would cause immediate injury to the occupants or would make it impossible for them to escape. For example, there should not be any exclusively high vertical, lateral, or longitudinal accelerations developed, any dangerous tendency for the aircraft to dive under the water, or any excessive structural damage which would cause rapid sinking or collapse of the structure about the occupants. From the structural aspects, these provisions provide that external doors and windows have strength to withstand probable maximum water local pressures which are likely during a water landing, or if not so substantiated, the effects of their collapse must be considered in evaluating the aircraft water impact behavior and floatation characteristics. In addition, the provisions provide for a determination of fuselage buoyancy and substantiation that the floatation time and aircraft trim (considering exit sill heights, structural damage, and leakage) will allow the occupants a sufficient period to safely evacuate the aircraft. For the aircraft manufacturer's demonstrated compliance to these provisions, the fuselage bottom strength is verified to assure against ditching impact damage which might lead to excessive water influx to the cabin or lead to adverse ditching behavior. In addition, an analysis is provided to substantiate aircraft trim buoyancy and floatation periods with and without understructure rupture and impact damage. The methods of analysis vary between demonstrated scale strength model landing tests with and without simulated wave patterns to comparisons with other airplanes of similar configurations whose ditching performance is known.

From a review of these jet transport ditching substantiations, and taking into account various configured aircraft and their landing weights, approach attitudes, speeds, descent rates, floatation characteristics, sea states, etc., several observations were made. First, demonstrated emergency water landing approaches are made in a controlled manner with gear-up (if retractable), full flaps, and at a normal landing speed with an impact descent rate of less than 5 ft/sec. Several aircraft are limited to a maximum vertical descent of 3 ft/sec to preclude fuselage damage and, in such cases experience longitudinal and vertical accelerations (considering perpendicular beam sea approaches) in the 2 to 4g range, respectively. Floatation time, assuming no extensive fuselage damage but allowing the loss of buoyancy at appropriate non-pressurized areas, such as gear wells, fairings, empennage, and wing center sections, has been shown to extend up to a 10- to 45-minute period, depending on aircraft size and configuration. In such cases, the aircraft buoyancy and leakage effects are analyzed to assure sill heights remain above the water and emergency exits are useable during this period. It is further shown, within these floatation periods, that occupants have sufficient time to evacuate the aircraft, taking into account, the operation of emergency exits and the retrieval and deployment of stored survival equipment, i.e., lifevest, liferafts, sliderafts, etc. A nominal 3-minute evacuation period has been considered satisfactory under such emergency conditions. High-wing commuter aircraft usually display a water rollover attitude in which exits on one side, such as main entry doors, may or may not be useable. These aircraft, as well as any aircraft whose exits due to adverse fuselage floatation attitude may not be available, are designed with additional ditching exits to accommodate evacuation of the total onboard occupancy. Considering expected sea conditions, recent ditching substantiations have been predicted upon aircraft impacting water with 6- to 7-foot waves running parallel to the aircraft line of approach. Indicated are the conditions that if an aircraft is landing head-on into the face of a wave, excessive fuselage damage could occur.

To date, the planned emergency landing of a jet transport aircraft in water is rare, with only one intentional case involving an Overseas National Airways DC9, May 17, 1970. As identified in table 1, the aircraft ran out of fuel and was unexpectly ditched Northwest of St. Croix, Virgin Islands. While 40 occupants survived (35 passengers and 5 crew members), there were 25 occupant fatalities (including a stewardess and two infants). This ditching resulted in an NTSB special study (reference 4) which included the aircraft impact dynamics, equipment failure and post-ditching emergency egress problems. The magnitude of the deceleration was estimated to be 8-23g's (longitudinal) applied over 0.5 to 1.0 seconds, with the aircraft stopping in 15.2 to 24.4 meters. In this instance, the preditching briefing was incomplete, and the stewardess and at least five passengers were unrestrained at impact. At least seven restrained passengers were thrown from their seats, and their double-seats failed, which contributed to the fatalities. It was estimated that the aircraft floated for 5 to 6 minutes and most passengers were evacuated within 2 to 3 minutes. This floatation period was approximately one third the time identified under the DC9 ditching substantiation, which leads one to believe that significant lower fuselage damage may have been present. Also, while the estimated impact conditions were within survivable limits for a restrained occupant, such conditions (considering minimum floatation time) appear to represent the upper limit for either a planned or unplanned crash of an aircraft in which occupants without sufficient prior briefings have time to retrieve and deploy existing emergency equipment (lifevests, liferafts, etc.) and evacuate into the open water.

While not included under the aforementioned data base, an unexpected, but controlled ditching of a smaller Lear Model 23 aircraft occurred on Lake Michigan in March 1966 during an approach landing to Meigs Field (Chicago). The 12-passenger aircraft with only the pilot aboard had an engine flame-out on approach and the pilot landed the aircraft on the water (4-foot waves) at approximately 90 knots within 900 yards from the end of runway. An escape hatch was used by the pilot to evacuate the aircraft, since the water was over the lower main door sill. A liferaft was dropped by helicopter for the rescue of the pilot within 5 minutes after touchdown. The aircraft subsequently was towed to shore and prior to retrieval remained afloat approximately 24 hours. The damage extended to missing flaps, torn fairings and fuel/hydraulic lines, lost left wing tip tank gear door, and wrinkled fuselage skin. This case points out that for either a planned or unplanned water contact occurrence, if the impact forces are sufficiently low and the aircraft fuselage remains intact without significant rupture and leakage, the chances of occupant survivability, resulting from extended buoyancy and floatation of the fuselage, is substantially increased.

UNPLANNED WATER CONTACT.

The unplanned water contact occurrence defines an uncontrolled and/or improperly configured impact on the water. Accidents in which aircraft impact water unexpectedly involve special hazards. In air-to-surface accidents, which included the previously discussed DC9 St. Croix accident, 46.3 percent of the occupants drowned. Of the 16 water accidents identified in table 1, water was an important factor in 10 of the unplanned impact cases and in the aforementioned DC9 occurrence. These cases are reviewed under this section. Note, that under the DC9 occurrence, the pilot initiated a controlled descent into the water at approximately 90 knots (5° to 6° noseup). However, the passengers and crew had not been completely advised and the ditching occurrence was not truly a planned one. The number of fatalities (23) may have been reduced, if it was properly planned.

Unplanned water entry accidents, considering these 11 cases, appear to have some common factors. First, they usually occur at night. Second, there is usually a relatively rapid loss of floatation resulting in a portion or all of the aircraft sinking. Third, while there has been confusion, some occupants have been able to evacuate the aircraft. Finally, many of the drowning fatalities occur after the occupants have left the aircraft. Assessment of the water entry accidents is shown in figure 11. The accidents are divided into two groups: high energy impact and slide/roll into the water. There are eight high energy accidents. There are three cases where the aircraft rolled or slid into the water. For all these accidents the fuselage experienced either lower surface crush or had one or more breaks.

Six water entry accidents in which the fuselage broke into several pieces (fuselage break) had fatalities (36.8 percent of those persons onboard were fatalities). In five of these accidents, one section of the fuselage sank rapidly — some of the passengers and crew probably were ejected or fell into the sea without benefit of survival gear and others were trapped inside. The other sections floated briefly, allowing evacuations into rafts or floating slides. In other accidents, the fuselage sections floated briefly; however, 84 percent of those onboard drowned. Survivor reports indicated that in at least two accidents, interior and carry-on debris blocked evacuation routes and in two other accidents some exit doors were jammed. In another, the passenger compartment floor was displaced upward restricting evacuation.

Four accidents involved water entry; that is, touchdown in deep water or rolling into deep water at high speed, such that the lower surface of the fuselage was torn or ruptured but the fuselage did not break (lower fuselage crush). Three of these four accidents resulted in extensive lower surface damage and the aircraft sank rapidly. All three were fatal accidents with 18.1 percent of persons onboard being fatalities. One accident resulted in moderate damage to the lower surface as the aircraft rolled into water and came to rest on its gear with the water at or slightly above the cabin floor. There were no fatalities. However, in these accidents, the aircraft floated at least 5 minutes and in most cases 10 to 20 minutes, thus allowing adequate time to escape. In three of the four accidents it was established that the onboard rafts and float slides were not used.

The floor system was known to be disrupted in six of the eight high energy water entry accidents. Disruption was due, in part, to the hydrodynamic forces of water entering the fuselage through the underside through breaks in the fuselage. A part of this disruption resulted in displacement and elevation of floor beams with subsequent separation of seats, which contributed to problems in the evacuation of the aircraft. In addition, doors were jammed and debris from cabin interior systems were present.

Accidents, where aircraft skidded or rolled into water, experienced similar damage as the high energy impact, but to a lesser degree. However, close proximity of land, substantially reduced drowning. The 15 drownings in the DC8 Rio de Janeiro accident were attributed to disorientation of the occupants after they evacuated the aircraft, and to improper use of floatation devices.

With respect to the DC9 St. Croix accident, even though it was known that ditching was inevitable, there were problems associated with the deployment of stowed liferafts and lifevests. Other problems with this equipment were encountered in the DC8 Los Angeles accident. It is felt that incidence of drowning could be substantially reduced by better instructions and location of such equipment to improve accessibility.

It can therefore be concluded that in deep water entry accidents in which the fuselage does not break, the survivor rate should be very high with proper crew response/actions using available equipment such as liferafts and lifevests. However, when fuselage ruptures and immediate flooding occurs, it is evident that such equipment may not be readily available for use, in which case, seat cushions and/or more accessible floatation devices may represent the only means of survivabililty. This is characterized by the three of four deep water entry accidents in which, as stated above, onboard rafts and slides were not used.

CONCLUSIONS

In view of the findings contained in this study, and as they relate to the unplanned water contact occurrences, it is obvious that regardless of how well certain equipment is designed, such equipment may not be appropriate for use under severe environmental impact conditions. For example, the use of multiple occupant liferafts and slideraft designs has been demonstrated to provide a safe means of water evacuation and survival on aircraft involved in minor water impact conditions. On the other hand, and under more severe impact conditions involving a ruptured and rapidly sinking fuselage, such equipment by its very nature cannot be expected to be totally useable for egress. At this point, the occupant must rely on other existing personal equipment which is more readily available such as lifevest and/or individual floatation devices. Again, however, the successful use of personal floatation equipment under conditions of a sinking fuselage, is dependent upon the occupant's momentary knowledge of the equipment stowage location and manner of use, as described by passenger information cards and previous flight attendant briefings. It is also dependent upon the ability of the occupant to retrieve and don (in the case of the underseat packaged lifevests) this equipment under adverse flooding conditions (possibly under water).

Conclusions obtained under this study are as follows:

1. Occupant Risks

Unplanned Water Contact

- Involves different hazard than corresponding ground contact (sinking fuselage potential versus fire threat)

- Occurs less frequently than unplanned ground contact but more frequently than planned water landing (ditching)

- Leads to higher impact loads and greater fuselage damage than corresponding ground contact

- Usually involves flooding conditions which adversely affect the ability of occupants to retrieve, deploy and/or don on-board floatation equipment

- Most often occurs at night and in many cases drowning fatalities take place after occupants leave aircraft

2. Equipment Needs

Emergency Floatation Equipment

- That is intended for use during a planned ditching may not be useable during an unplanned water contact occurrence (multiple occupant type)

- That is readily accessible for use by each occupant may offer sole means of survival under severe unplanned water contact conditions (personal occupant type)

- That is available for use during an unplanned water contact occurrence may vary in type between extended overwater and non-overwater operations

- That provides for occupant out-of-water assistance offers additional protection against hyperthermia effects (multiple occupant type)

- That performs effectively is dependent upon effective cabin crew instructions and ease of equipment retrieval, deployment and use under adverse flooding conditions

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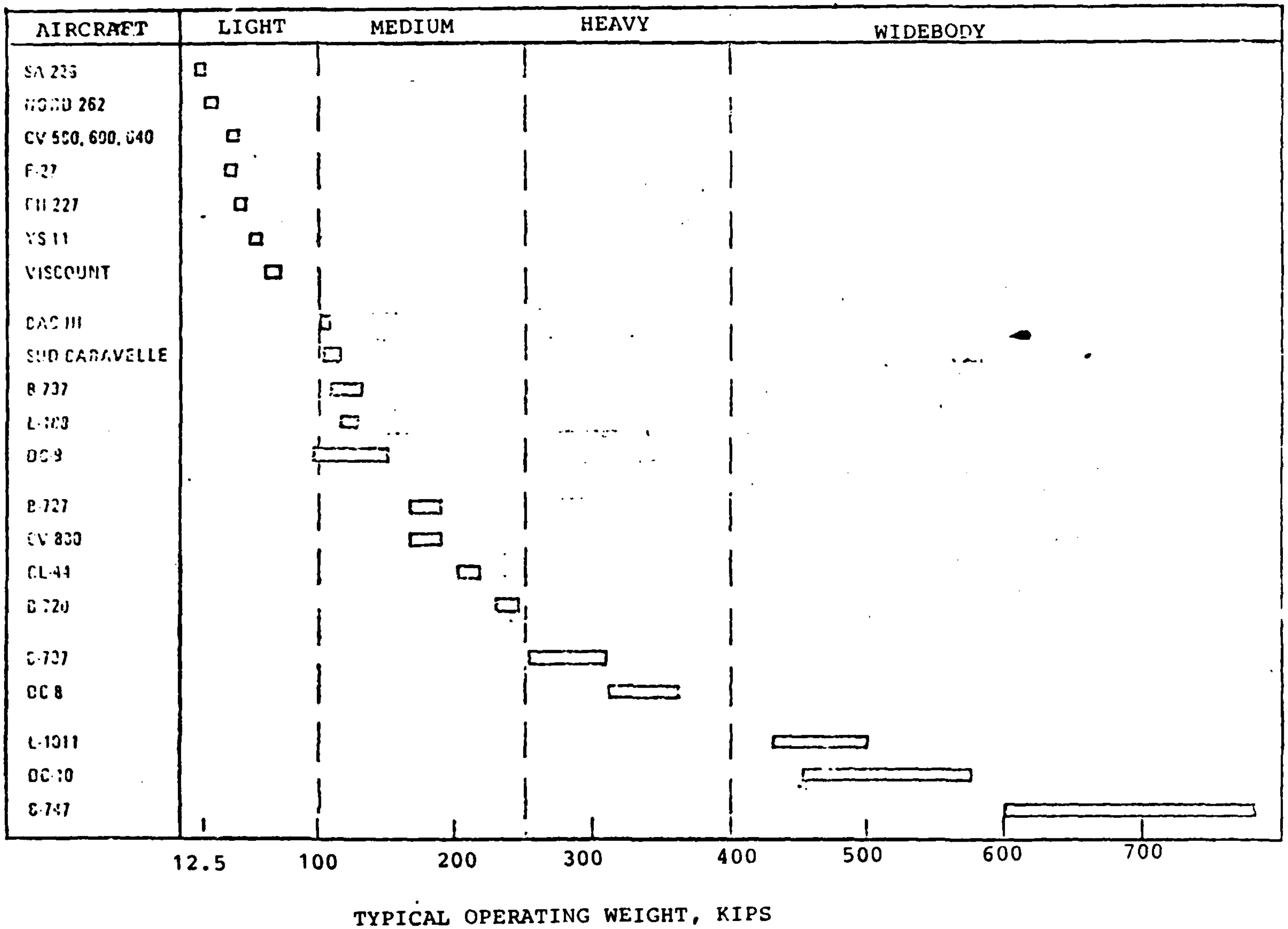

FIGURE 1. TRANSPORT AIRPLANE VERSUS TAKEOFF GROSS WEIGHT

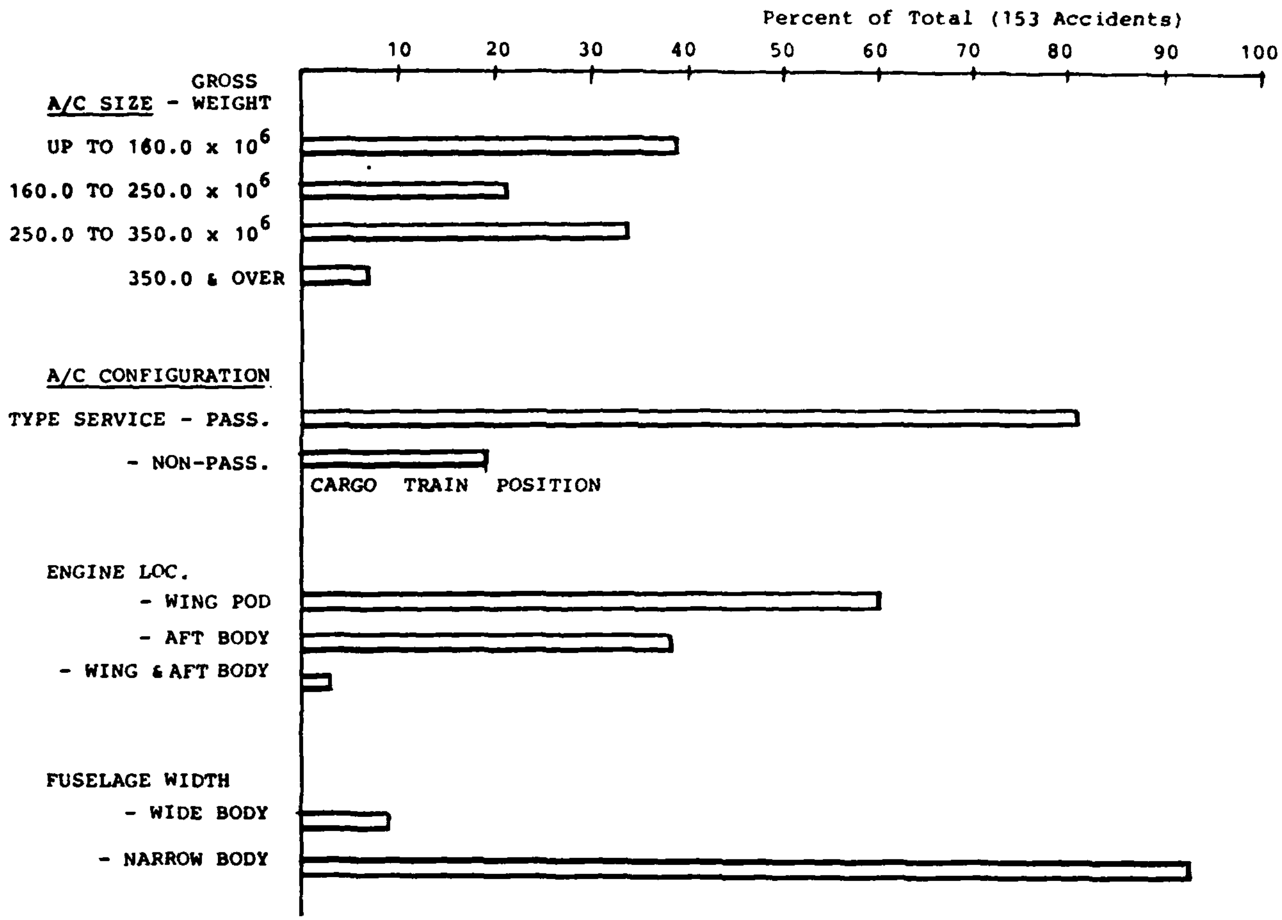

FIGURE 2. AIRCRAFT SIZE

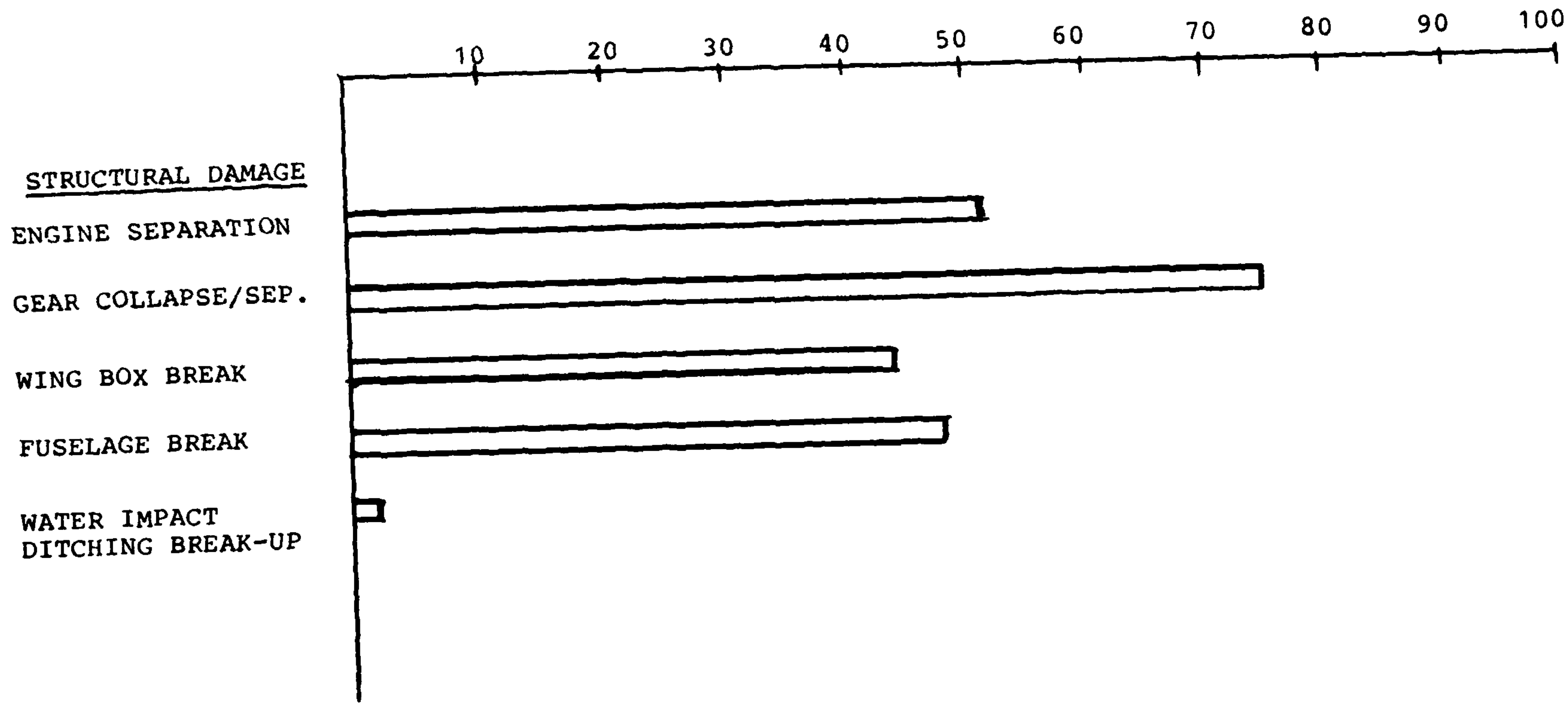

FIGURE 3. AIRCRAFT CONFIGURATION

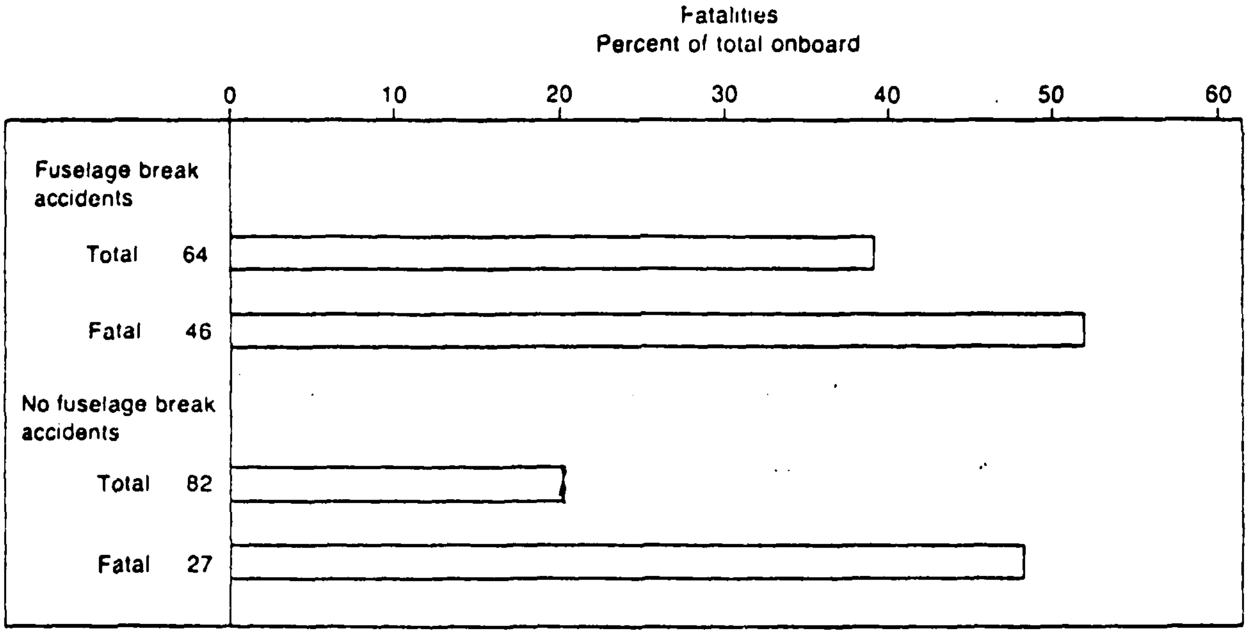

FIGURE 4. FATALITIES VERSUS FUSELAGE BREAK

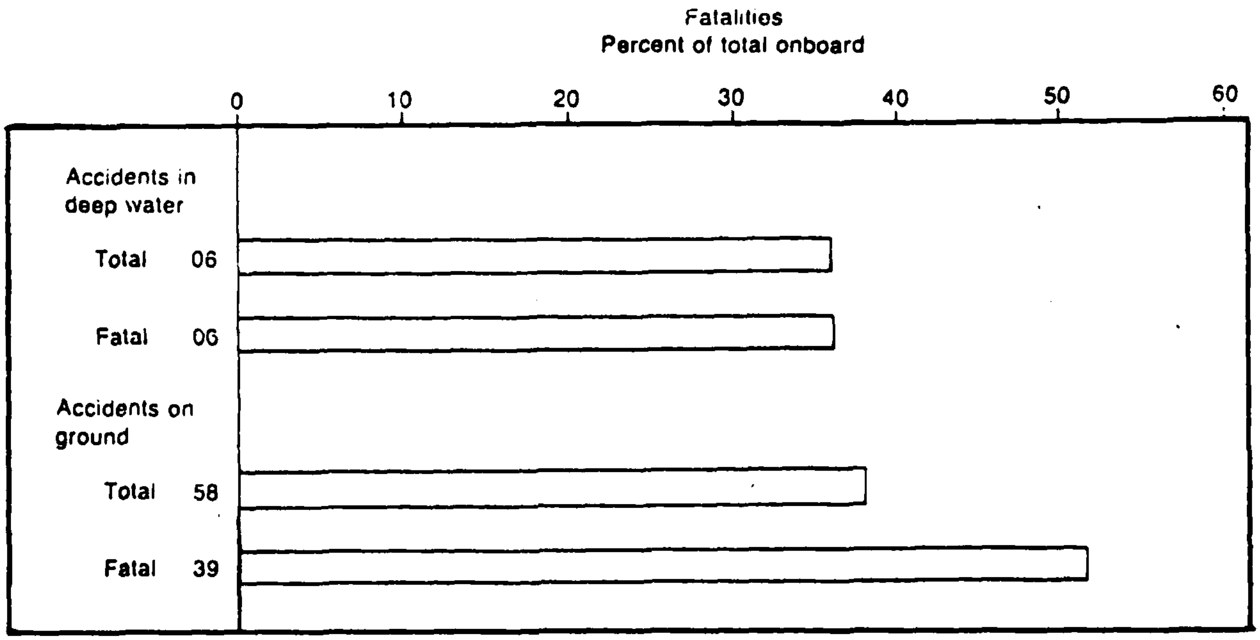

FIGURE 5. FATALITIES VERSUS ACCIDENT TYPE

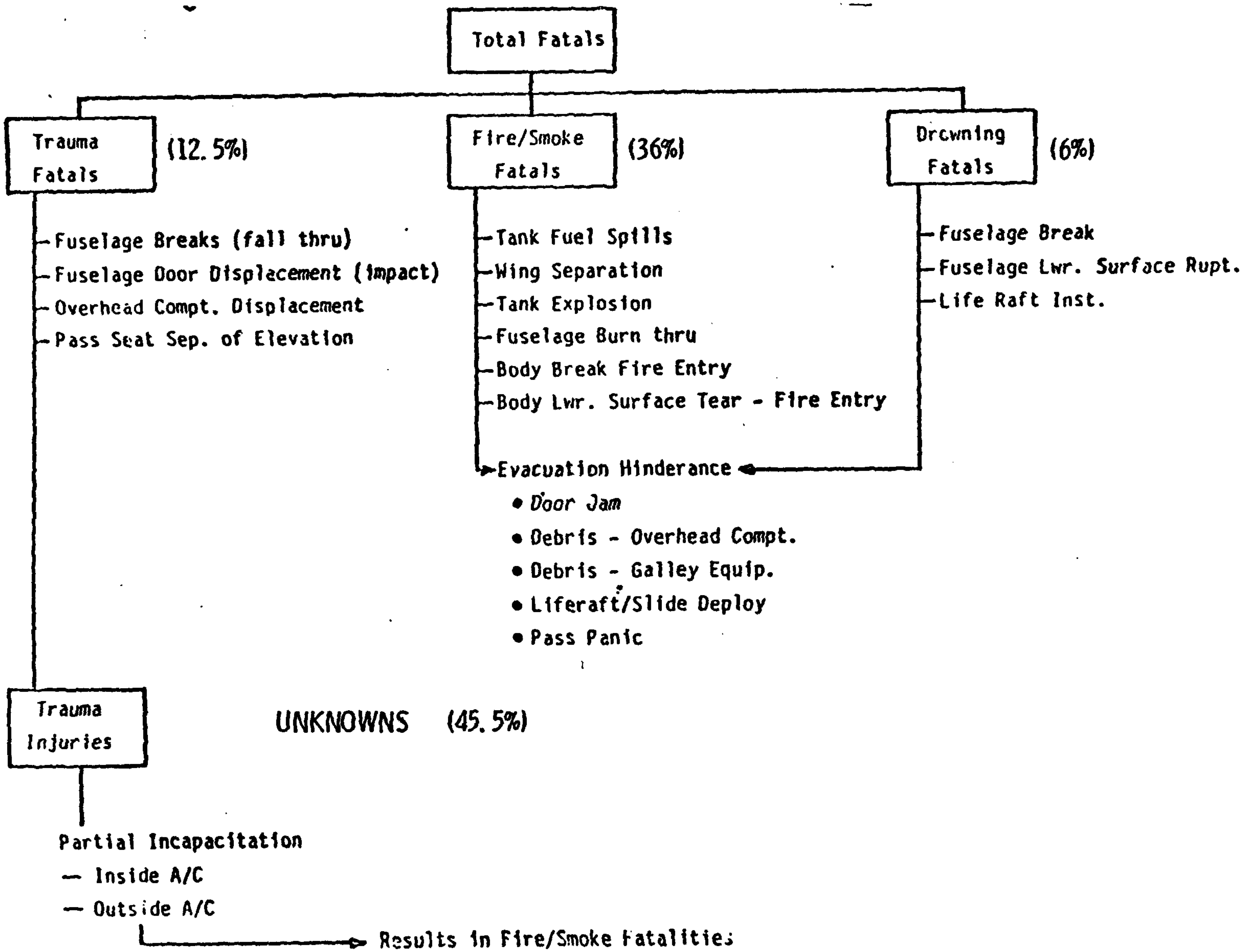

FIGURE 6. STRUCTURAL FACTORS IN FATALITIES

Occurrences cited in 47 accidents

Door - exit location	Door or exit position	Number of cited occurrences													
		Jamming cause				Blockage cause					Could not be opened			Delay in openning	
		Frame distortion	Floor lift	Latch mech.	Outside object	Galley debris	Interior & misc debris	Undefined	Evac. slide or life raft	People panic	No other exit avail. all fatals	Divert to other exits some fatals	Divert to other exits no fatals	Divert to other exits some fatals	Divert to other exits no fatals
Fwd (39) 47%	L. entry	10	4	1	2		2		2	1		5	7	6	4
	Galley	2	2	1		3	3		1	1		6	6		1
	Cockpit		3				1				1		3		
Mid body (11) 16%	Fwd wing Over wing Aft wing	3		1			6	1				4	3		4
Aft (18) 27%	L. entry	4	2				2					6	1		1
	Tail entry		2				1					1	1		1
	Galley		2	1		2	2					1	4	1	1
Total (68) 100%		19	15	4	2	5	17	1	3	2	1	23	25	7	12
		40 (59%)				28 (41%)					49 (72%)			19(28%)	

FIGURE 7. DOOR OR EXIT JAMMING AND/OR BLOCKAGE

	Total on board	Total fatal-ities	% fatal-ities	Number of accidents: Location of displacement											Fire	
				Fwd	Mid	Aft	Separ-ation	Seat eleva-tion	Exit door jam/blocked	Crew door jam/blocked	Egress inter-ference	Nose gear folded aft	MLG tumb. under body	Grd. slide	Sev-ere	Mod-erate
Floor displace. (Excluding fuselage break) Total – 15 (2 Fatal)	1126	18	1.6	12	1		3	7	5	4		8	1	8	4	4
Probable – 1 (1 Fatal)	63	6	9.5			1			1		1					
Floor displace. (Involving (fuselage break) Total – 17 (11 Fatal)	1477	368	24.9	10	7	9	13	9	5	2	4	1		14	7	3
Probable – 3	339	132	38.9	2	2	2	1	2	1						2	
Floor displace. Due to deep water entry Total – 4	254	35	13.8	3	1	1	2	3	2		1	1				

FIGURE 8. PASSENGER/CREW COMPARTMENT FLOOR DISPLACEMENT

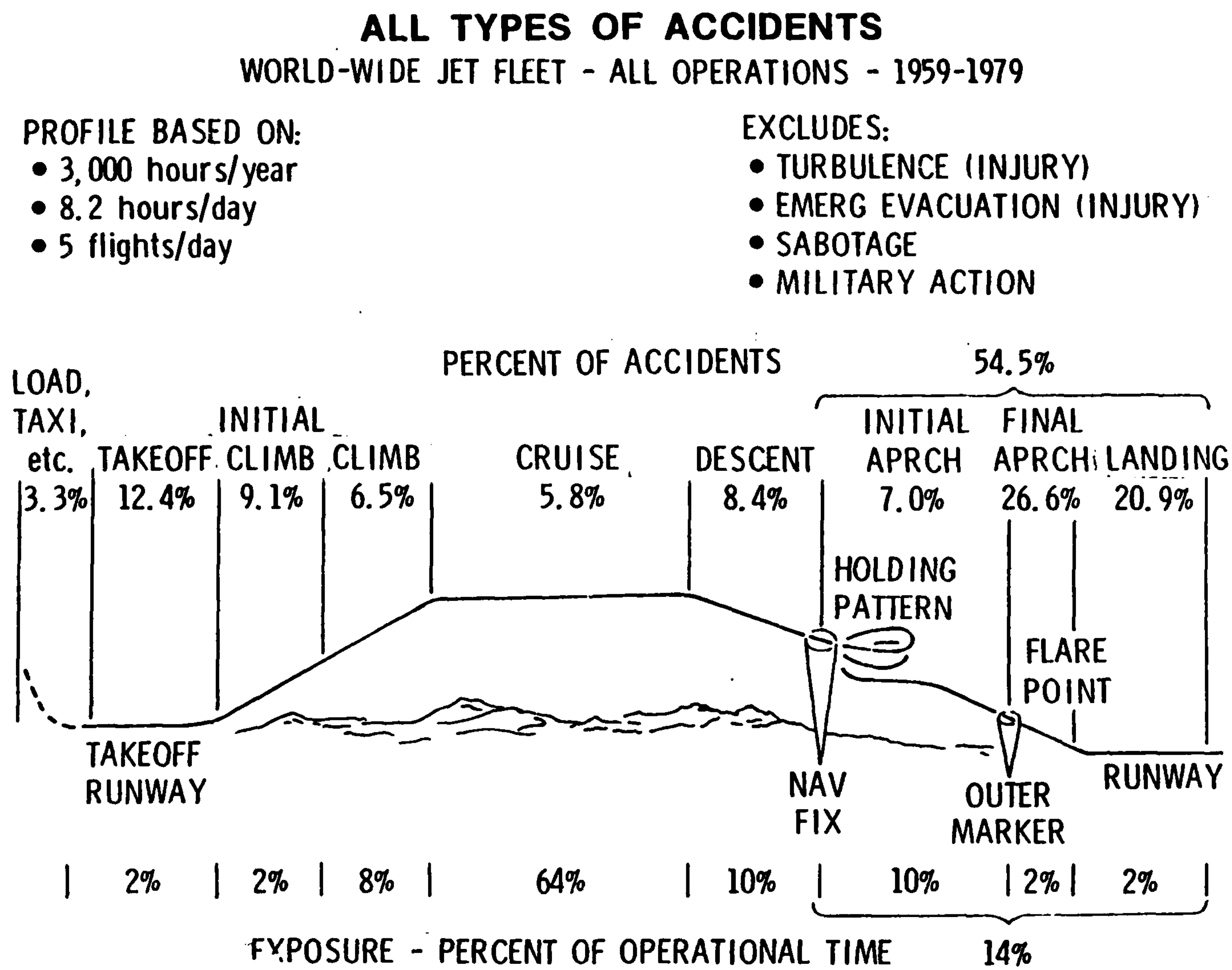

FIGURE 9. ACCIDENTS AS A FUNCTION OF OPERATIONAL TIME

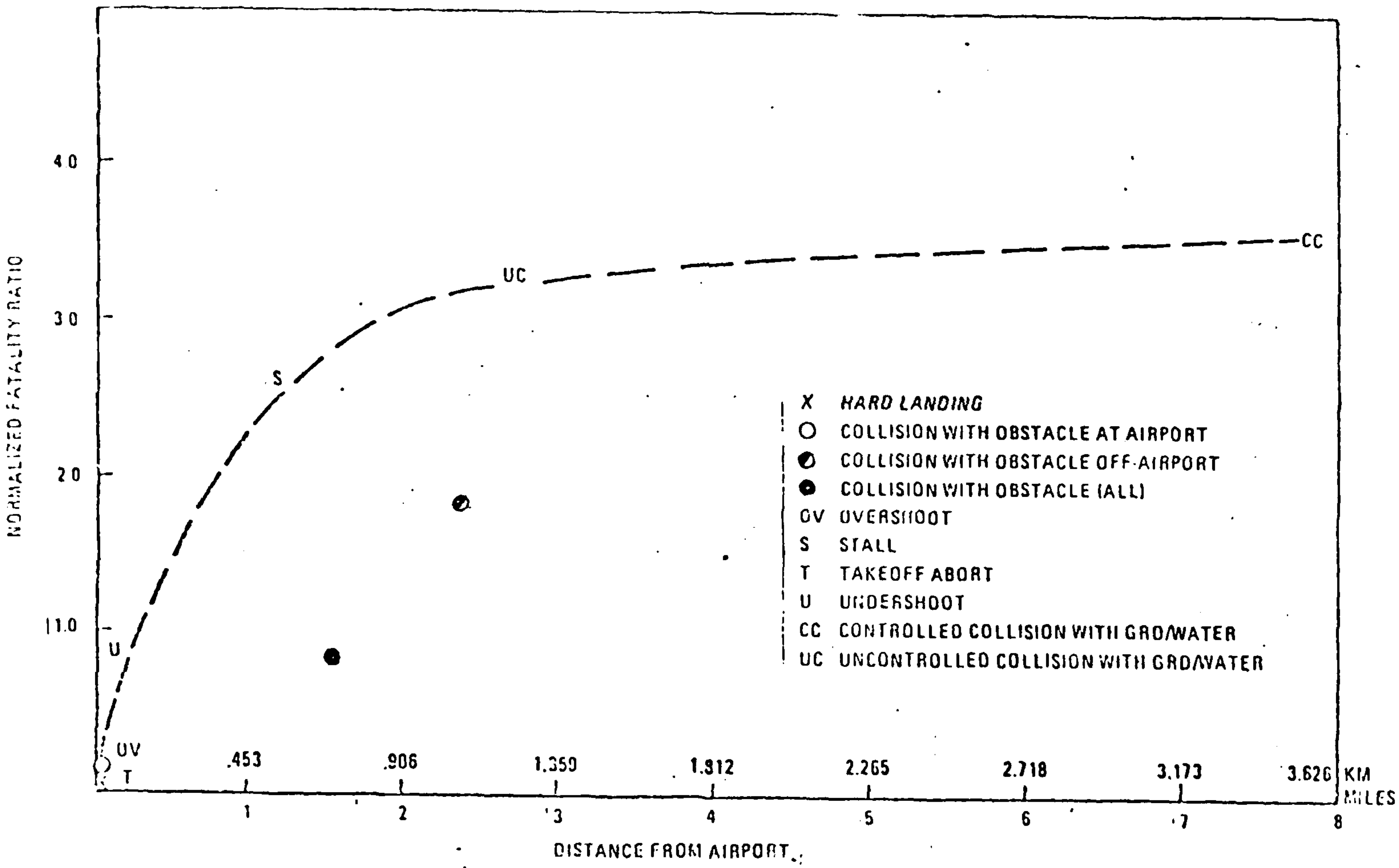

FIGURE 10. NORMALIZED FATALITY RATIO AS A FUNCTION OF DISTANCE FROM AIRPORT FOR CRASH SCENARIOS

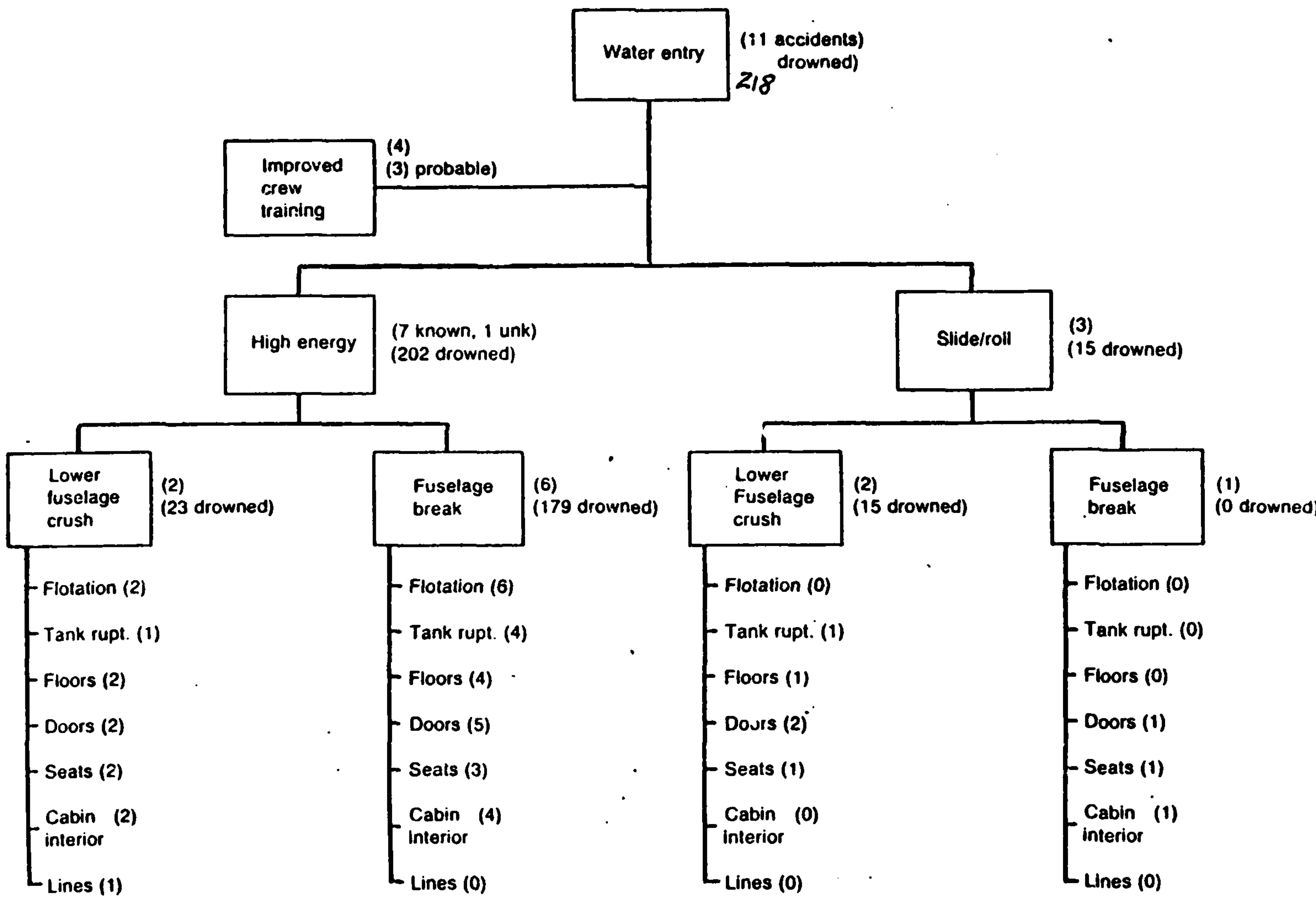

FIGURE 11. ASSESSMENT OF WATER ENTRY ACCIDENTS