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PRELIMINARY IMPACT SPEED AND ANGLE CRITERIA FOR DESIGN OF A NUCLEAR AIRPLANE FISSION PRODUCT CONTAINMENT VESSEL

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16. Abstract

Reports and photographs of 96 major accidents occurring before 1965 and involving multiengine jet aircraft were studied. Impact speed and angle are presented for landing and takeoff accidents, cruise accidents without in-flight structural failure, and in-flight structural failure accidents. The landing and takeoff accidents had an average impact velocity of 200 ft/sec (61 m/sec) from any direction and a maximum impact velocity of 300 ft/sec (91.5 m/sec) with a 10^{o} solid angle about the roll axis. The cruise accident without structural failure had an average impact velocity of 400 ft/sec (122 m/sec) and a maximum possibly as high as 1000 ft/sec (305 m/sec), both within a 10^{o} solid angle about the roll axis. The in-flight structural failure accident had an average impact velocity of 400 ft/sec (122 m/sec) from any direction and a maximum possibly as high as 1000 ft/sec (305 m/sec) within a 10^{o} solid angle about the roll axis. The in-flight structural failure accident determines the most severe impact speed for all impact angles.

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SUMMARY

Studies show that if the gross weight of a nuclear aircraft is greater than a million pounds, the payload should be greater than 15 percent. However, these studies make only marginal provisions for systems to contain fission products in an accident.

One method of containing fission products is to put the reactor in a containment vessel and then protect the vessel from rupture during an accident. One source of rupture is ground impact. To design a system to prevent rupture during impact, the impact speed and angles must be known. This report estimates the probable impact speed and angles based on a survey of accident data compiled at Norton Air Force Base.

Reports and photographs of 96 major accidents occurring before 1965 and involving multiengine jet aircraft were studied. Impact speeds were estimated by examining damage to aircraft and components, depth of impact craters, and depth of penetration in the earth of heavy objects like engine shafts. Impact angles were determined by estimating the order in which parts of the aircraft contacted the ground. The order was determined by scrape marks on the ground, damage to the airframe, and distribution of parts torn from the aircraft.

Impact speed and angle are presented for landing and takeoff accidents, cruise accidents without in-flight structural failure, and in-flight structural failure accidents. The landing and takeoff accidents had an average impact velocity of 200 feet per second (61 m/sec) from any direction and a maximum impact velocity of 300 feet per second (91.5 m/sec) within a 10° solid angle about the roll axis. The cruise accident without structural failure had an average impact velocity of 400 feet per second (122 m/sec) and a maximum possibly as high as 1000 feet per second (305 m/sec), both within a 10° solid angle about the roll axis. The in-flight structural failure accident had an average impact velocity of 400 feet per second (122 m/sec) from any direction and a maximum possibly as high as 1000 feet per second (305 m/sec) within a 10° solid angle about the roll axis. Reactor containment vessel impact speed and angle design criteria are established by the in-flight structural failure accident. Impact speed and angles for other accidents fall within the speed-and-angle envelope for the in-flight structural failure accident.

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INTRODUCTION

Nuclear airplane studies have shown that nuclear power is not feasible for airplanes with gross weights under 500 000 pounds (227 000 kg) (ref. 1). If a 500 000-pound (227 000-kg) aircraft were designed with radiation levels sufficiently low so that it could be flown and serviced with procedures like a chemical airplane, the payload would be essentially zero. If a 500 000 pound (227 000-kg) aircraft were designed for reasonable payloads, the radiation levels in the cargo compartment and near the reactor shield package would be high and special expensive flight and ground operating and maintenance procedures would be required. Studies also showed that the nuclear powerplant weight does not increase proportionally with aircraft gross weight but more like the square root of the gross weight. Thus, if the gross weight were increased by 100 percent from 500 000 to 1 million pounds (227 000 to 454 000 kg), the powerplant weight would increase by only about 40 percent and the difference could be used for payload. The potential large increase in payload with an increase in gross weight is one of the major reasons for another look at nuclear power for aircraft.

Today there are airplanes flying with gross weights greater than 700 000 pounds (318 000 kg) (C5A and 747) and airplanes on the drawing boards with gross weights greater than 1 million pounds (454 000 kg). Studies show that the payload fraction for a nuclear-powered 1- to 1.5-million-pound (454 000- to 680 000-kg) gross weight aircraft is 15 to 25 percent. However, these studies do not include weight penalties for systems to contain fission products in an aircraft accident. Feasibility of a nuclear airplane now may depend not on shield weight but on the weight of the fission product containment systems.

One method of containing fission products is to put the reactor in a containment vessel (CV) and then protect the vessel from rupture during a crash. Major sources of rupture are midair collisions, ground impact, postcrash fire, and postcrash fission product decay heat. This report is concerned with only one source of CV rupture, ground impact.

The purpose of the report is to establish preliminary impact velocity criteria for the design of a fission product containment vessel which could sustain a ground impact during an aircraft accident without rupturing. The critieria will be in the form of impact angle and impact speed that a nuclear-powered airplane containment vessel may be expected to experience. The speed and angles will be determined from a study of the records of accidents involving large aircraft.

The source of data was the Air Force accident records at Norton Air Force Base. Reports and photographs of 96 major accidents occurring before 1965 and involving multi-engine jet aircraft were studied. The accidents were analyzed by Dr. James W. Turnbow of AvSER Division of Dynamics Sciences Corporation under contract to NASA.

NASA personnel and H. Firstenberg of NUS Corporation helped Dr. Turnbow search the records and collect the data for analysis.

Dr. Turnbow estimated the impact speeds and angles by studying the accident records and photographs and comparing the aircraft and ground damage with that resulting from aircraft crash experiments conducted by AvSER for the Air Force. Impact speeds were estimated by examining damage to aircraft and components, depth of impact crater, and depth of penetration in the earth of heavy objects like engine shafts. Impact angles were determined by estimating the order in which different parts of the airplane contacted the ground. The order was determined by examining scrape marks on the ground, damage to the airplane, and distribution of parts torn from the airplane.

The data obtained from the survey of the accident records are presented in the appendix. The reactor and containment vessel that must survive an accident are briefly described. The type of accidents studied and the method used to analyze the accidents are described and the probable impact speeds in the primary directions about the containment vessel are presented.

DESCRIPTION OF REACTOR AND CONTAINMENT VESSEL

Two reactor locations in the airplane are being considered. In one, the reactor shield - containment vessel system (RSCV) is in the cargo bay (fig. 1(a)); and in the other, it is mounted above the cargo bay (fig. 1(b)). The latter design separates the RSCV from the airframe and cargo with the advantage that it follows its own independent crash trajectory and is not impacted by the cargo. These sketches do not show any of the provisions that may be required to protect the CV from rupture during impact.

The RSCV is shown schematically in figure 2. During a crash the reactor and shield may be damaged severely but this may not be important to safety as long as the CV does not rupture. The CV has penetrations for coolant and electrical leads. Valves will be provided for the coolant penetrations, and electric leads will be sealed in the vessel wall. Systems will be provided to assure the valves are closed before the CV contacts the ground.

TYPE OF ACCIDENTS SURVEYED

During the search of the aircraft accident records, information was collected on nine categories of major accidents: takeoff, landing, cruise over land, in-flight structural failure, in-flight refueling, cruise over water, midair collision, taxi accidents, and fire during repair. All the accidents studied resulted in major damage, essentially complete destruction of the airplane. The data for the 96 accidents reviewed are presented in the appendix. However, this report is concerned with the ground impact problem only and, therefore, cruise-over-water, taxi, and fire accidents are not considered. In-flight refueling and midair collisions are considered because their ground impact characteristics are similar to those resulting from in-flight structural failure.

The ground impact period of the aircraft accident is assumed to start the moment the first part of the aircraft contacts the ground and to end when the aircraft comes to rest. The kinetic energy of the aircraft is absorbed by sliding friction between the aircraft and the ground, by deformation of aircraft parts, and by displacement of earth (or cratering).

An artist's idea of the crash history for two major types of impact is shown in figures 3 and 4. Figure 3 shows a low-velocity, low-impact-angle accident; and figure 4 shows a high-velocity, high-impact-angle accident. These figures describe the major classes of crash history for an aircraft with a heavy package, similar to the RSCV of a nuclear airplane, loosely secured to the airframe. These types of impact are discussed in the following section and the probable impact angles and speeds are estimated.

METHOD USED TO ANALYZE THE ACCIDENTS

The analysis of aircraft accidents relies heavily on the experience and judgment of the investigator since little quantative data is available. Each of the accidents presented in this report had been studied by an Air Force investigation team at the time the accident took place. This investigation team tried to estimate the impact speed and the orientation of the aircraft at the time of impact, which is the information needed for this report. They also took photographs of aircraft damage, cratering, and scrape marks on the ground. They measured lengths of scrape marks, depth and volume of craters, and depth of penetration of heavy objects. And they tried to estimate the order in which parts of the airplane struck the ground. Some of the data presented in the appendix were taken directly from the accident record. The remaining data in the appendix were estimated by Dr. Turnbow based on his examination of the photographs and records and on a comparison with the results of controlled crash experiments conducted by AvSER for the Air Force. The speed-against-angle data presented in table I were prepared by NASA from data in the appendix.

The following characteristics are used to define ground impact: impact speed, terrain impact angle, yaw angle, roll angle, and pitch angle (see fig. 5). Impact speed is defined as the speed relative to the ground. Terrain impact angle is the angle between the roll axis and its projection on the impact surface. The roll angle is the angle between the weight vector and the yaw axis. The yaw angle is the angle between the roll axis and the velocity vector perpendicular to the yaw axis. And the pitch angle is the angle between the roll axis and the velocity vector perpendicular to the pitch axis. The

TABLE I. - SURVEY OF IMPACT VELOCITY AND ANGLE (AIR FORCE MULTIENGINE JET ACCIDENT STATISTICS COMPILED FROM REVIEW OF AIR FORCE AIRCRAFT ACCIDENTS, 96 ACCIDENTS OCCURRING FROM 1960 TO 1965)

Type of accident	Number of aircraft involved	In-flight structural failure	Percentage distribution of velocity at impact					Percentage distribution of terrain impact angle				Percentage distribution of roll angle				Percentage distribution of yaw angle				
			Velocity, V, ft/sec (m/sec)																	
			<100 (31)	<200 (61)	<300 (91.5)	<400 (122)	>400 (122)	$<10^{\circ}$	$<30^{\circ}$	$<60^{\circ}$	$<90^{\circ}$	$>10^{\circ}$	$<30^{\circ}$	$<90^{\circ}$	$<180^{\circ}$	$<10^{\circ}$	$<30^{\circ}$	$<60^{\circ}$	$<90^{\circ}$	$<180^{\circ}$
Takeoff:	20	0	25	60	10	5	---	85	10	---	5	75	10	15	---	95	---	---	---	5
On airport	5	0	40	60				100				80		20	---	80	---	---	---	20
Off airport	15	0	20	60	13.3	6.7	---	80	13	---	7	74	13	13	---	100		---	---	---
Landing:	30	2	47	47	3	----	3	87	3	10	---	97	---	---	3		---	---	---	---
On airport	17	1	65	35		----		94		6	---	100	---	---	---		---	---	---	---
Off airport	13	1	23	61	8	----	8	77	8	15	---	93	---	---	7		---	---	---	---
Cruise over land	15	9	7	7	20	13	53	33	33	7	27	60	7	20	13	86	---	7	---	7
Refueling	7	4	---	43	----	----	57	43		14	43	57	---	---	43	57	---	---	---	43
Cruise over water	4	1	---	---	----	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Midair collision	6	4	---	---	----	----	100	33	---	---	67	33	---	---	67	33	---	---	---	67
Taxi	13	---	100	---	----	----	---	100	---	---	---	100	---	---	---	100	---	---	---	---
Fire during repair	1	---	100	---	----	----	---	100	---	---	---	100	---	---	---	100	---	---	---	---
Total	96	20	---	---	----	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---
In-flight structural failure	96	20	8	23	8	----	61	36	28	18	18	41	17	17	25	71	---	---	---	29

pitch angle is more difficult to estimate than the other angles and is not tabulated in table I. Consequently, two assumptions about the pitch angle are made. When the velocity is high (i.e., above stall speed), the pitch angle is assumed to be small ($\pm10^{\circ}$). When the velocity is low (i.e., below the stall speed), the pitch angle is assumed to be any angle from 0° to 90°.

IMPACT SPEED AND DIRECTION FOR THE BASIC TYPES OF ACCIDENTS

Impact speed and direction are estimated for the three basic types of flight accidents: landing and takeoff accidents, cruise accidents without structural failure, and cruise accidents with structural failure. The major types of impact are described in figures 3 and 4. The impact speed and angle data from the 96 accidents are summarized in table I for the three types of accidents. Figures 6 to 8 present the data for each type of accident graphically superimposed on the RSCV.

Landing and Takeoff Accidents

On the average, landing accidents are the least severe type of accident. This is because during landing the aircraft velocity is relatively low and the angle between the ground and the aircraft is small. Most of the kinetic energy is absorbed by sliding friction between the fuselage and the ground. Generally, the wings will tear off and the fuselage will break into several pieces; but in most landing accidents, the fuselage will not be crushed significantly. The landing accident is similar to the accident described in figure 3 except that the impact angle can vary over a broad range, as discussed below.

The impact speed and terrain and the roll and yaw angles at impact are presented in table I. The impact speed for the average landing accident is 200 feet per second (61 m/sec) and the impact can come from any direction. The impact speed for the maximum landing accident is about 300 feet per second (91.5 m/sec). In the maximum accident, the pitch angle will be small ($\pm10^{\circ}$). The terrain angle may vary from 0° to 60°. The roll angle may vary from 0° to 180°. The yaw angle will be small ($\pm10^{\circ}$). The probable solid angle within which the 200- and 300-feet-per-second (61- and 91.5-m/sec) velocity will occur is shown in figures 6(a) and (b). Figure 6(c) shows the combined average and maximum velocity profile for landing accidents.

The severity of the maximum takeoff accident is about the same as that of a landing accident. The severity of the average takeoff accident is slightly higher than that of the average landing accident. As shown in table I, the percentage of accidents below 200 feet per second (61 m/sec) is 85 percent for takeoff accidents and 93 percent for landing accidents. Since the severity of the landing and takeoff accidents is about the same, the landing accident impact speed and angle distribution, as shown in figure 6(c), is also applicable to takeoff accidents.

Cruise Accident Without Structural Failure

The nonstructural failure accident is characterized by high speeds parallel to the roll axis and small pitch and yaw angles. The aircraft cannot maintain high speeds parallel to the yaw and pitch axis. High speeds in these directions cause large aerodynamic forces which would tear the aircraft apart. If the speed in the yaw or pitch directions increase, the aircraft turns into the wind, decreasing the speed in these directions; or the wing and/or tail stalls (or breaks off) and the aircraft becomes unstable, the drag rises, and either the aircraft speed decreases or the aircraft breaks up. The cruise accident without structural failure is described schematically in figure 4. Six of the 15 cruise overland accidents did not have structural failure; and of these, about one-half had impact velocities below 400 feet per second (122 m/sec). It is very difficult to determine the impact velocities above 400 feet per second (122 m/sec) because the destruction for higher velocities is very similar to the destruction at 400 feet per second (122 m/sec). However, if no drag devices were used to slow the aircraft down, the impact velocities could be as high as 1000 feet per second (305 m/sec). The yaw angle and pitch angles are small (i.e., $\pm 10^{\circ}$). The terrain angle can range from 0° to 90°. The maximum and average accidents have the same angle distribution. The probable solid angle within which the 400- to 1000-feet-per-second (122- to 305-m/sec) speed will occur is shown in figure 7.

In-Flight Structural Failure Accident

The in-flight-structural-failure accident category includes structural failure during landing, takeoff, cruise overland, in-flight refueling, and midair collision accidents. The refueling and midair collision accidents are included in the structural failure category because the ground impact in these accidents is similar to the ground impact due to structural failure during landing, takeoff, or cruise.

If the fuselage, wing, or control surface fails, the accident is characterized by tumbling of the aircraft; relatively low impact velocities (terminal velocity of broken fuselage); and 0° to 360° terrain roll, yaw, and pitch angles. If the major parts of the aircraft stay intact, the accident characteristics are similar to in-flight accidents without structural failure.

Twenty of the 96 accidents had in-flight structural failure. About 60 percent of these accidents had an impact speed of 400 feet per second (122 m/sec) or greater, possibly approaching 1000 feet per second (305 m/sec). The aircraft that broke up in flight had impact velocities less than 400 feet per second (122 m/sec). The terrain impact angle ranged from a few degrees to 90°. The roll angle ranged from a few degrees to 180° or an inverted impact. When the aircraft stayed intact, the yaw angles were small. When the aircraft broke up in flight, the yaw angles ranged from 0° to 180°. The impact velocity profiles for the average and most severe accidents are shown in figures 8(a) and (b). The combined velocity profile is shown in figure 8(c).

CONTAINMENT VESSEL IMPACT SPEED AND ANGLE DESIGN CRITERIA

The CV impact speed and angle design criteria are a combination of the impact speeds and angles for takeoff and landing accidents and for cruise accidents with and without structural failure. The individual impact speed and angle diagrams are shown in figures 6 to 8. The impact speed and angle diagram for the design criteria accident is shown in figure 9. It is determined by the structural failure accident. Impact speed and angles for other accidents fall within this envelope. The speed in the 10° solid angle about roll axis can range from 400 to 1000 feet per second (122 to 305 m/sec). The velocity in all other directions will be 400 feet per second (122 m/sec) or less.

CONCLUDING REMARKS

The landing and takeoff accidents had an average impact velocity of 200 feet per second (61 m/sec) from any direction and a maximum impact velocity of 300 feet per second (91.5 m/sec) within a 10° solid angle about the roll axis. The cruise accident without structural failure had an average impact velocity of 400 feet per second (122 m/sec) and a maximum possibly as high as 1000 feet per second (305 m/sec), both within a 10° solid angle about the roll axis. The in-flight structural failure accident had an average impact velocity of 400 feet per second (122 m/sec) from any direction and a maximum possibly as high as 1000 feet per second (305 m/sec) within a 10° solid angle about the roll axis. From this data a "design basis velocity profile" was established. This velocity profile is 1000 feet per second (305 m/sec) at a 10° solid angle in the frontal direction and 400 feet per second (122 m/sec) in all other directions.

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126-15.

APPENDIX - A BRIEF SURVEY OF THE CRASH SURVIVABILITY POTENTIAL OF A LARGE PACKAGE MOUNTED AT THE CENTER OF GRAVITY OF A LARGE FIXED-WING AIRCRAFT

As a means of estimating the probability of crash survival of large loads mounted near the center of gravity of typical fixed-wing multiengine jet or propeller-driven aircraft, a survey was made of approximately 96 accidents of large aircraft occurring during the period 1960 to 1965. The accumulated data are presented in table II. The table provides an estimate of the following factors:

(1) Type of accident
(2) Approximate impact conditions
(3) Accident location (on or off airport)
(4) Severity of accident
(5) Ground area involved
(6) Cause of accident
(7) Percent of aircraft destroyed
(8) Survival rate for a package mounted near the center of gravity

It should be pointed out that, in many instances, the data presented in table II are not exact. Many factors such as area of destruction, impact acceleration, percent of fuselage destroyed prior to postcrash fire, etc., have been estimated from photographs and other evidence available. For example, visual comparison of the damaged aircraft with similar damage obtained in engineering tests is often the only means of estimating impact acceleration. In table II the notation 100 to 200+ g's simply implies total destruction of the aircraft and that the true decelerations are actually unknown. Estimates in the 0- to 30-g range are probably reasonably correct.

The accidents reported in table II are believed to be quite appropriate to the study under consideration. The best interpretation of the data is made by considering in-flight, takeoff, and landing accidents separately. Taxi accidents and accidents to parked aircraft, while reported in table II, have not been further examined in this report.

TABLE II. - ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WIND MULTIENGINE AIRCRAFT

	Takeoff accidents				
	1	2	3	4	5
Type of aircraft	KC-135A	KC-135	C-133	B-47	B-47
Velocity at impact	270 ft/sec (82 m/sec)	250 to 340 ft/sec (76 to 104 m/sec)	Takeoff speed	270 ft/sec (82 m/sec)	275 ft/sec (84 m/sec)
Impact angle with terrain	---	30°	Assumed shallow	Shallow	60° to 70°
Roll angle	20° left	Extreme 70° right bank	---	45° right	---
Yaw angle	---	---	---	---	---
Terrain	Flat; trees, wall, building	Flat; small trees	Water	Flat	Flat
Distance from runway	4900 ft (1490 m) from liftoff	12 600 ft (3840 m)	3/4 mile (1210 m)	1/2 mile (810 m)	23 000 ft (7000 m) from start of takeoff
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	Postcrash fire	Postcrash fire	Fire and explosion	Postcrash fire	In-flight postcrash fire
Percent of fuselage intact before fire	Unknown	0	0	30	0
Percent of fuselage intact after fire	0	0	0	0	0
Fuselage breakage	Crashed in fog after takeoff, completely destroyed	Total destruction	Fragmented	Unknown	Total destruction
Wings separated?		Yes	Yes	---	Yes
Impact severity rating		---	10	6	10
Ground marks:					
Length of gouge marks	---	500 ft (152.1 m)	---	2000 ft (610 m)	Crater
Depth of gouge marks	---	4 ft (max) (1.2 m)	---	1 ft (0.3 m)	6 to 8 ft (1.8 to 2.4 m) or more
Area of destruction	200 ft by 1800 ft (61 m by 550 m)	300 ft by 800 ft (92 m by 204 m)	---	---	150 ft by 200 ft (46 m by 61 m)
Estimated g-level	---	---	---	10 to 15	100 to 200+
Cause of accident	---	Mechanical failure, lost two engines	Lost propeller in flight	Lost thrust on takeoff roll	In-flight fire and loss of control
Number of casualties:					
Crew	9 fatal	4 fatal	6 fatal	4 fatal	4 fatal
Ground	0	0	0	0	2
Percent of aircraft loss	100	100	100	100	100
Estimated chance of survival of package at center of gravity	Unknown but possibly poor	0 percent	Poor	50 percent, except for fire	0 percent

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Takeoff accidents				
	6	7	8	9	10
Type of aircraft	C-130	C-124A	B-47	B-47E	B-47E
Velocity at impact	132 ft/sec (40 m/sec)	220 ft/sec (67 m/sec)	575 ft/sec (175 m/sec)	290 ft/sec (89 m/sec)	169 ft/sec (est.) (52 m/sec)
Impact angle with terrain	Forced landing following takeoff	Shallow	8^{o}	10^{o} (est.)	Nose high altitude
Roll angle		Left roll	Right wing touched, then left wing low at impact	---	---
Yaw angle		---		---	---
Terrain		Flat wooded; large trees	Flat	Flat	Flat
Distance from runway	1/2 mile (810 m)	2 miles (3200 m)	$4\frac{1}{2}$ miles (7250 m)	Several miles	240 ft (73 m)
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	No fire	Explosion and fire	Postcrash fire	Postcrash	Postcrash fire
Percent of fuselage intact before fire	100	50	0	0 (est.)	---
Percent of fuselage intact after fire	---	0	0	0	0
Fuselage breakage	None	1 (tail section)	Many	Probably many	---
Wings separated?	No	Yes	Yes	Yes	---
Impact severity	1	8	10	10	7
Ground marks:					
Length of gouge marks	---	1300 ft (400 m)	1900 ft (580 m)	900 ft (270 m)	1200 ft (370 m)
Depth of gouge marks	---	---	Few inches	1 to 2 ft (0.31 to 0.62 m)	1 to 2 ft (0.31 to 0.62 m)
Area of destruction	---	100 ft by 1000 ft (31 m by 310 m)	---	150 ft by 900 ft (46 m by 270 m)	200 ft by 1200 ft (62 by 360 m)
Estimated g-level	1	20+	15 to 25+	15 to 25	18 (est.)
Cause of accident	---	Pilot error	Fire in tail section from ATO bottle	Pilot error, insufficient deicing	Pilot error
Number of casualties:					
Crew	0	18 fatal; 4 major	1 fatal	1 fatal; 2 minor	4 fatal
Ground	0	0	0	0	0
Percent of aircraft loss	Landing gear	100	100	100	100
Estimated chance of survival of package at center of gravity, percent	100	25	0	0	50

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Takeoff accidents				
	11	12	13	14	15
Type of aircraft	C-130A	KC-135	C-123B	C-131	B-52
Velocity at impact	Slow	Takeoff speed	169 ft/sec (52 m/sec)	209 ft/sec (64 m/sec)	---
Impact angle with terrain	---	---	Shallow	Struck on 15° slope	---
Roll angle	---	20° roll	0°	---	Left roll
Yaw angle	---	10° yaw	0°	---	---
Terrain	Flat	Flat; trees	Runway	Rising; wooded	Wooded hills
Distance from runway	5000 ft (1500 m)	3000 ft (910 m)	On runway	---	4.75 miles (7600 m)
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	Postcrash fire	Postcrash fire	Small fire	No fire	Fire and explosion
Percent of fuselage intact before fire	Perhaps 30	Estimated to be small	100	80	0
Percent of fuselage intact after fire	20	0	50	---	0
Fuselage breakage	Many breaks	Fragmented	None	2 major	Many
Wings separated?	Yes	Yes	No	Yes	Yes
Impact severity rating	10	10	1	6	10
Ground marks:					
Length of gouge marks	---	1000 ft (305 m)	157 ft (48 m)	306 ft (94 m)	Crater
Depth of gouge marks	---	1 to 2 ft (0.3 to 0.6 m)	---	---	---
Area of destruction	400 ft by 400 ft (122 m by 122 m)	200 ft by 1000 ft (61 m by 305 m)	---	---	250 ft by 60 ft (76 m by 18 m)
Estimated g-level	---	---	1 to 2	10+	100 to 500+
Cause of accident	Engine failure	Engine failure, pilot error	Stall	Pilot error	Pilot disorientation
Number of casualties:					
Crew	5 fatal	6 fatal	5 fatal; 10 fatal	1 fatal, 10 major, 10 minor	9 fatal
Ground	0	0	0	0	0
Percent of aircraft loss	100	100	100	100	100
Estimated change of survival of package at center of gravity, percent	10	0	Good, except for fire	100	0

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Takeoff accidents				
	16	17	18	19	20
Type of aircraft	B-47E	RB-47E	C-130	WB-47	C-123
Velocity at impact	Stall speed	169 ft/sec or greater (52 m/sec)	50 to 68 ft/sec (15 to 21 m/sec)	270 ft/sec (83 m/sec)	186 ft/sec (51 m/sec)
Impact angle with terrain	Low (also tail low)	Low	Estimated at impact with 7-ft (2. 1-m) dike	Nose high; shallow flightpath	---
Roll angle	0°	35° right	---	Wallowing; right tire hit first	---
Yaw angle	0°	---	Right	Yawed 180° in final 500 ft	---
Terrain	Flat	Flat	7-ft (2. 1-m) dike	Flat	---
Distance from runway	3000 ft (920 m) beyond	Just off runway	Crashed into embankment 4000 ft (1120 m) from runway end	On runway	On runway
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					Aircraft settled back on runway after take-off and overran runway. No major damage to fuselage; no fire.
Fire?	Postcrash fire	Postcrash fire	No fire	Postcrash fire	
Percent of fuselage intact before fire	60	80	80	60	
Percent of fuselage intact after fire	0	0	80	0	
Fuselage breakage	1 break aft of wing trailing edge	---	1 break just aft of cockpit	3 major pieces	
Wings separated?	No	Yes	No	No	
Impact severity rating	3	4	4	5	
Ground marks:					
Length of gouge marks	1400 ft (430 m)	900 ft (270 m)	---	1900 ft (580 m)	---
Depth of gouge marks	Nil	1 ft (31 m)	---	Nil	---
Area of destruction	150 ft by 1400 ft (46 m by 430 m)	---	---	100 ft by 1900 ft (31 m by 58 m)	---
Estimated g-level	5+	10	10 (short duration)	---	---
Cause of accident	---	Hump in runway; pilot disorientation	Engine failure on takeoff	Hump in runway; pilot disorientation	Pilot error; weather
Number of casualties:					
Crew	4 fatal	3 fatal (from fire; 2 major)	1 major	3 fatal (from fire; 2 major)	0
Ground	0	0	0	0	0
Percent of aircraft loss	100	100	70	100	---
Estimated chance of survival of package at center of gravity	Good, except for fire	Good, except for fire	100 percent	Good, except for fire	100 percent

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Landing accidents				
	1	2	3	4	5
Type of aircraft	KB-50J	C-97	C-124A	C-131E	RC-121D
Velocity at impact	160 to 180 ft/sec (49 to 55 m/sec)	169 ft/sec (52 m/sec)	---	135 ft/sec (41 m/sec)	135 ft/sec (41 m/sec)
Impact angle with terrain	25°	1° to 2°	50°	5° (est.)	0°
Roll angle	Left	0°	Left wing down	0°	0°
Yaw angle	---	0°	---	---	0°
Terrain	Flat	Flat	Flat	Flat	Flat
Distance from runway	1500 ft (460 m) left, 10 000 ft (3050 m) from end (down)	28 feet short (8.5 m)	1.3 miles (2100 m)	650 ft short (200 m)	Ran off side of runway
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	Postcrash fire	Small fire	No fire	No fire	Fire
Percent of fuselage intact before fire	20 (est.)	100	0	95	100
Percent of fuselage intact after fire	0	100	0	95	100
Fuselage breakage	Tail, many others (fire)	0	Completely destroyed	1 break, at leading edge of wing	0
Wings separated?	Yes	No	Yes	No	No
Impact severity rating	9	1	10	3	1
Ground marks:					
Length of gouge marks	100 ft (est.) (31 m)	---	Crater	---	---
Depth of gouge marks	Unknown	---	Unknown	---	---
Area of destruction	150 ft by 300 ft (46 m by 92 m)	---	200-ft (61-m) diameter	---	---
Estimated g-level	30+	1 to 3	500	3 to 5	3
Cause of accident	Stall after bounced landing	Gear-up landing short of runway	Rudder and elevator control malfunction	Fuel system and/or engine failure	Collapse of left main gear
Number of casualties:					
Crew	5 fatal; 1 major	0	7 fatal	3 major; 1 minor	0
Ground	7 various	0	0	0	0
Percent of aircraft loss	100	30	100	---	100
Estimated chance of survival package at center of gravity, percent	0	100	0	100	100

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Landing accidents				
	6	7	8	9	10
Type of aircraft	C-133B	KB-50J	KC-97G	B-47E	KC-97G
Velocity at impact	160 ft/sec (49 m/sec)	---	140 ft/sec (43 m/sec)	220 ft/sec (67 m/sec)	169 ft/sec (52 m/sec)
Impact angle with terrain	Level attitude; high descent rate	Aircraft left runway on landing; nose gear collapsed	5^{o}	Shallow ($<2^{o}$)	Shallow
Roll angle	---		0^{o}	Right wing hit first	Right wing hit ground
Yaw angle	---		0^{o}	0^{o}	---
Terrain	Flat	---	Over water on approach	Flat	Flat
Distance from runway	5000 ft (1500 m)	On runway	3000 ft short (910 m)	525 ft short (160 m)	On runway
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	Postcrash fire	No fire	Postcrash fire; aircraft sank	Minor postcrash fire	Postcrash fire controlled
Percent of fuselage intact before fire	Probably 15 to 20	100	60	100	95
Percent of fuselage intact after fire	5	---	60	100	95
Fuselage breakage	Probably many	None	2 breaks; tail intact	None	1 break, aft of wing trailing edge
Wings separated?	Yes	No	Right wing separated	No	No
Impact severity rating	9	---	6	1-	1
Ground marks:					
Length of gouge marks	100 ft to 200 ft (est.) (31 m to 61 m)	---	---	2000 ft (610 m)	None
Depth of gouge marks	---	---	---	---	None
Area of destruction	200 ft by 400 ft (61 m by 122 m)	---	---	---	None
Estimated g-level	30 (vertical)	---	5 to 10	1	3
Cause of accident	Unknown	Pilot error	Low approach	Stall	Stall; hit fuel trucks on roll-out
Number of casualties:					
Crew	9 fatal	0	5 fatal	4 fatal	1 major
Ground	0	0	0	0	0
Percent of aircraft loss	100	20	100	50	Not repaired
Estimated chance of survival package at center of gravity	Very poor	100 percent	Fair to good	Excellent	Excellent

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Landing accidents				
	11	12	13	14	15
Type of aircraft	B-47E	KC-135A	B-47	KB-50J	B-52
Velocity at impact	---	270 ft/sec (82 m/sec)	- -	169 ft/sec (52 m/sec)	34 ft/sec (10 m/sec)
Impact angle with terrain	Went off runway after touchdown	Nearly flat	Ground looped; slid backward; struck building	0°	---
Roll angle	---	Left	---	0°	---
Yaw angle	---	0°	Yawed to right	0°	---
Terrain	Flat	Trees	Flat	Runway	Runway
Distance from runway	Just off runway	$1\frac{1}{4}$ miles (2000 m)	1000 ft to right (305 m)	On runway	On runway
In-flight structural failure	No	No	No	No	Yes
Condition of aircraft:					
Fire?	Postcrash fire	Postcrash fire	Postcrash fire	Postcrash fire	Postcrash fire
Percent of fuselage intact before fire	100	40 (tail)	90	100	100
Percent of fuselage intact after fire	0	0	20	0	0
Fuselage breakage	None	Many breaks	None	None	None
Wings separated?	No	Yes	Right wing	No	Yes, on landing
Impact severity rating	2	9	3	2	3
Ground marks:					
Length of gouge marks	6000 ft (1830 m)	<300 ft (92 m)	---	2100 ft (640 m)	---
Depth of gouge marks	---	---	---	---	---
Area of destruction	---	150 ft by 300 ft (46 m by 92 m)	---	---	---
Estimated g-level	3 to 5	15+	3 to 5	1 to 3	0
Cause of accident	Pilot error	---	Bounced landing; veered off runway; ground looped	Emergency, wheels up on landing	In-flight refueling accident, wings collapsed on rollout
Number of casualties:					
Crew	0	1 fatal; 1 major; 1 minor	1 fatal; 2 major	0	3 major; 2 minor
Ground	0	0	0	0	0
Percent of aircraft loss	100	100	100	100	100
Estimated chance of survival package at center of gravity	100 percent	0 percent	80 percent, except for fire	Excellent, except for fire	Excellent, except for fire

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Landing accidents				
	16	17	18	19	20
Type of aircraft	B-47	C-124C	C-97	B-47	B-47
Velocity at impact	---	200 ft/sec (61 m/sec)	140 to 150 ft/sec (43 to 46 m/sec)	Landing speed	317 ft/sec (98 m/sec)
Impact angle with terrain	8°	6°	---	45°	---
Roll angle	Right wing hit ground, then left wing	---	---	Right	---
Yaw angle	---	---	---	---	---
Terrain	---	Flat; wooded	Flat	Flat	Flat
Distance from runway	4757 ft (1450 m)	Some distance from airport	On runway	500 ft (152 m) right of runway	900 ft (270 m) beyond end of runway
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	Small fire	Postcrash fire	No fire	Small fire	Postcrash fire
Percent of fuselage intact before fire	100	85	99	100	100
Percent of fuselage intact after fire	100	0	---	90	10
Fuselage breakage	None	1 break (tail)	None	None	---
Wings separated?	No	Yes (1)	No	No	Yes
Impact severity rating	1	5	1	3	10
Ground marks:					
Length of gouge marks	---	675 ft (206 m)	---	1000 ft (305 m)	750 ft (230 m)
Depth of gouge marks	---	---	---	---	---
Area of destruction	---	---	---	---	---
Estimated g-level	3	10+	---	5 to 8	5
Cause of accident	Pilot error	Pilot error, clipped tree	Landing gear collapse	Pilot error during landing	Material failure and pilot error
Number of casualties:					
Crew	1 fatal	3 major	0	1 major	1 fatal; 3 major
Ground	0	0	0	0	0
Percent of aircraft loss	10	100	5	10	100
Estimated chance of survival package at center of gravity	100 percent	80 percent, except for fire	100 percent	100 percent	Excellent, except for fire

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Landing accidents				
	21	22	23	24	25
Type of aircraft	C-140A	C-123B	C-123B	C-123B	B-52
Velocity at impact	Landing speed	---	186 ft/sec (57 m/sec)	186 ft/sec (57 m/sec)	---
Impact angle with terrain	Shallow	Ran off runway after landing; slight damage to belly	Pancake landing	0^{o}	50^{o} inverted
Roll angle	Slight right		---	---	---
Yaw angle	---		---	---	---
Terrain	Flat	Flat	Flat	Fall	Hilly; wooded
Distance from runway	1900 ft short (580 m)	Just off runway	On runway	450 ft (137 m)	---
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	Postcrash fire	No fire	No fire	No fire	Explosion
Percent of fuselage intact before fire	90	99	75	100	0
Percent of fuselage intact after fire	10	---	---	---	0
Fuselage breakage	None	None	1 break near tail	None	Many
Wings separated?	No	No	No	No	Yes
Impact severity rating	3	0+	3	0+	10
Ground marks:					
Length of gouge marks	1000 ft (305 m)	---	---	---	200 ft (61 m)
Depth of gouge marks	---	---	---	---	---
Area of destruction	200 ft by 1000 ft (61 m by 305 m)	---	---	---	---
Estimated g-level	10+	1 to 2	3 to 5	---	100+
Cause of accident	Stuck elevator	---	Pilot error	Failure of thrust reversal	Fin failure
Number of casualties:					
Crew	5 major	0	1 major; 3 minor	0	2 fatal; 3 major; 1 minor
Ground	0	0	0	0	0
Percent of aircraft loss	100	15	50	5	100
Estimated chance of survival package at center of gravity, percent	Excellent, except for fire	100	100	100	0

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Landing accidents				
	26	27	28	29	30
Type of aircraft	C-130	C-135A	B-47	C-121G	B-58
Velocity at impact	---	Landing speed	Landing speed	---	257 ft/sec (73 m/sec)
Impact angle with terrain	---	Nose low; steep angle of descent	---	---	Hard landing
Roll angle	---	---	---	---	0
Yaw angle	---	---	---	---	0
Terrain	Flat	Flat	Flat	---	Flat
Distance from runway	28 ft (8.5 m) short	0.8 mile (1290 m) short	100 ft (31 m) short	---	5000 ft (1520 m) from approach end of runway
In-flight structural failure	No	No	No	No	No
Condition of aircraft:					
Fire?	Postcrash fire	Postcrash fire	Postcrash fire	Postcrash fire	Postcrash fire
Percent of fuselage intact before fire	---	100	100	0	100
Percent of fuselage intact after fire	---	0	10	0	20
Fuselage breakage	None	None	---	Fragmented	None
Wings separated?	No	No	No	Yes	No
Impact severity rating	1	---	9	10	3
Ground marks:					
Length of gouge marks	---	700 ft (210 m)	3500 ft (1060 m)	---	5000 ft (1520 m)
Depth of gouge marks	---	---	---	---	---
Area of destruction	---	200 ft by 700 ft (61 m by 210 m)	---	---	---
Estimated g-level	---	10+	---	100+	3
Cause of accident	Pilot error	---	Pilot error	To low on let down	Pilot error
Number of casualties:					
Crew	0	3 fatal	0	3 fatal; 5 major	2 fatal; 1 major
Ground	0	0	0	0	0
Percent of aircraft loss	Small	100	100	100	100
Estimated chance of survival package at center of gravity, percent	100	---	50	0	Good, except for fire

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	In-flight accidents over land				
	1	2	3	4	5
Type of aircraft	B-52D	B-52B	B-47	C-117A	C-117A
Velocity at impact	High	710 ft/sec (216 m/sec)	---	---	---
Impact angle with terrain	57°	5° to 15°	---	---	---
Roll angle	155° left	30° left	---	65°	---
Yaw angle	---	---	---	---	---
Terrain	Hills	Flat	---	Flat	---
Distance from runway	---	---	---	---	---
In-flight structural failure	Yes	Yes	Yes	Yes	Yes
Condition of aircraft:					
Fire?	Postcrash fire	Postcrash fire	Postcrash fire	Postcrash fire	Postcrash fire
Percent of fuselage intact before fire	0	0	50	0	0
Percent of fuselage intact after fire	0	0	0	0	0
Fuselage breakage	Total destruction	Many	Many	Fragmented	Many
Wings separated?	Yes	Yes	Yes	Yes (1)	Yes
Impact severity rating	10	10	10	10	10
Ground marks:					
Length of gouge marks	500 ft (150 m)	3100 ft (950 m)	---	---	---
Depth of gouge marks	---	2 ft or less	---	---	---
Area of destruction	---	1000 ft by 3100 ft (305 m by 950 m)	---	150 ft by 300 ft (46 m by 92 m)	---
Estimated g-level	100 to 200+	---	---	---	200+
Cause of accident	Clear-air turbulence; structural failure	In-flight fire; bailout at 20 000 ft (6100 m)	Material failure	Lost wing due to metal fatigue	Material failure
Number of casualties:					
Crew	1	0	2 fatal	9 fatal	9 fatal
Ground	0	0	0	0	0
Percent of aircraft loss	100	100	100	100	100
Estimated chance of survival package at center of gravity, percent	0	0	0	0	0

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	In-flight accidents over land				
	6	7	8	9	10
Type of aircraft	B-47	B-52	C-130A	C-130	KB-50J
Velocity at impact	---	---	Cruise speed	---	Wreckage scattered over 400-yd (365-m) radius after explosion and fuselage breakup at 800 ft (240 m)
Impact angle with terrain	Crashed on mountain, 80° slope	Started to disintegrate in air	Flew into mountain, 30° slope; total destruction	---	
Roll angle				---	
Yaw angle				---	
Terrain	---	---	Wooded hills	---	Water
Distance from runway	---	---	18 miles (29 km)	---	---
In-flight structural failure	No	Yes	No	Yes	Yes
Condition of aircraft: Fire? Percent of fuselage intact before fire Percent of fuselage intact after fire Fuselage breakage Wings separated? Impact severity rating	 Fire and explosion 10 0 Many Yes 10	 Fire and explosion 20 0 Many Yes 10	 Postcrash fire Perhaps 10 0 Many Yes 10	 No fire --- --- Landed safely following loss of propeller and engine	 Postcrash fire --- 0 Exploded in flight at 800 ft (242 m) --- 10
Ground marks: Length of gouge marks Depth of gouge marks Area of destruction	 --- --- 2800-ft (850 m) long	 --- --- 5 miles by $1\frac{1}{2}$ miles (8000 m by 2400 m)	 --- --- ---	 --- --- ---	 --- --- 1200-ft (367-m) radius
Estimated g-level	Perhaps 100	200+	Perhaps 100+	---	---
Cause of accident	Pilot error	Material failure	Pilot error (too low)	---	Disintegration of turbine wheel
Number of casualties: Crew Ground	 4 fatal 0	 3 fatal; 1 major 0	 13 fatal 0	 0 0	 2 fatal; 1 major 0
Percent of aircraft loss	100	100	100	---	100
Estimated chance of survival package at center of gravity, percent	0	0	0	100	0

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	In-flight accidents over land				
	11	12	13	14	15
Type of aircraft	RB-66B	B-47E	C-124	C-124C	B-47E
Velocity at impact	270 ft sec (82 m sec)	500 ft sec (152 m sec)	---	340 ft sec (107 m sec)	680 ft sec (210 m/sec)
Impact angle with terrain	20°	20°	90°	60° to 90° (struck mountain)	80°
Roll angle	Right	90° right	Broke up in air	---	---
Yaw angle	---	Some yaw		---	---
Terrain	Flat	Flat: trees and marsh	Flat and marshy	Mountain	Hilly
Distance from runway	6.9 miles from approach end	---	---	---	---
In-flight structural failure	---	---	---	---	---
Condition of aircraft:					
Fire?	Postcrash fire	No fire	Postcrash fire	---	Postcrash fire and explosion
Percent of fuselage intact before fire	20	0	0	0	0
Percent of fuselage intact after fire	0	0	0	0	0
Fuselage breakage	Tail and many others (fire)	Gross fragmentation	Many	Total destruction	Fragmentation
Wings separated?	Yes	Yes	Yes	Yes	Yes
Impact severity rating	10	10	10	10	10
Ground marks:					
Length of gouge marks	600 ft (183 m)	300 ft (91 m)	200-ft (61-m) diameter	---	Craters
Depth of gouge marks	2 ft for 20 ft (0.6 m for 6 m)	2 to 3 ft (0.6 to 0.9 m)	---	None (rock)	4 ft (1.2 m)
Area of destruction	150 ft by 600 ft (46 m by 183 m)	---	Area 200 ft (61 m) in diameter	300 ft by 1000 ft (91 m by 305 m)	300 ft by 200 ft (91 m by 61 m)
Estimated g-level	20 to 30	100 to 200	---	100 to 200+	100 to 500+
Cause of accident	Flameout (crew ejected)	Mechanical failure in flight	Disintegrated at 9000 ft due to cyclone	Pilot error	Asymmetrical loading of fuel tanks (probable cause)
Number of casualties:					
Crew	0	4 fatal	6 fatal	10 fatal	1 fatal; 1 minor
Ground	0	0	0	0	0
Percent of aircraft loss	100	100	100	100	100
Estimated chance of survival package at center of gravity, percent	0	0	0	0	0

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Midair collisions				
	1	2	3	4	5 and 6
Type of aircraft	HC-97	HC-54	B-47	B-47	2 KC-135A's
Velocity at impact	Midair collision resulted in (1) separation of tail from fuselage at midsection (station 790) due to internal explosion, and (2) fire in fuselage and number 3 engine	Midair collision resulted in (1) wing failure due to explosion between inboard and outboard engines (wing separated from aircraft), and (2) fuselage broke in two at main cabin entrance door	Impacted in level attitude; slight left turn, low longitudinal velocity	Nose-down attitude; low horizontal velocity	Midair collision over water, no witnesses and no survivors
Impact angle with terrain					
Roll angle					
Yaw angle					
Terrain					Water
Distance from runway					---
In-flight structural failure	Yes	Yes	Yes	Yes	---
Condition of aircraft:					
Fire?	---	---	Postcrash fire	Postcrash fire	---
Percent of fuselage intact before fire	---	---	---	---	---
Percent of fuselage intact after fire	---	---	0	0	---
Fuselage breakage	---	---	Many	Many	---
Wings separated?	---	---	Yes	Yes	---
Impact severity rating	---	---	10	10	---
Ground marks:					
Length of gouge marks	---	---	50 ft (15 m)	50 ft (15 m)	---
Depth of gouge marks	---	---	3 ft (0.9 m)	3 ft (0.9 m)	---
Area of destruction	---	---	---	---	---
Estimated g-level	---	---	High vertical g	100+	---
Cause of accident	---	---	Midair collision; pilot error		---
Number of casualties:					
Crew	---	---	3 fatal; 1 major; 1 minor		11 fatal
Ground	---	---	0		0
Percent of aircraft loss	---	---	100		---
Estimated chance of survival package at center of gravity, percent	---	---	0		---

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	In-flight accidents over water			
	1	2	3	4
Type of aircraft	C-133A	B-52G	C-124C	C-133A
Velocity at impact	---	---	---	---
Impact angle with terrain	---	---	---	Possible breakup in flight
Roll angle	---	---	---	---
Yaw angle	---	---	---	---
Terrain	Water	Water	Water	Water
Distance from runway	---	---	---	25 miles (40 km) out at sea
In-flight structural failure	No	No	No	Yes
Condition of aircraft:				
Fire?	Lost at sea; complete destruction on impact	Lost at sea; no witnesses	Disappeared on overwater flight	---
Percent of fuselage intact before fire				---
Percent of fuselage intact after fire				---
Fuselage breakage				---
Wings separated?				---
Impact severity rating				---
Ground marks:				
Length of gouge marks	---	---	---	---
Depth of gouge marks	---	---	---	---
Area of destruction	---	---	---	---
Estimated g-level	---	---	---	---
Cause of accident	---	Low approach; pilot error		
Number of casualties:				
Crew	6 fatal	8 missing	9 missing (assumed fatal)	10 missing
Ground	0	0	0	0
Percent of aircraft loss	100	100	100	100
Estimated chance of survival package at center of gravity, percent	0	---	---	---

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Refueling accidents (in flight)					
	1	2	3	4	5	6
Type of aircraft	B-52	C-135	B-47E	B-52G	B-47E; KC-135A	B-47B
Velocity at impact	---	---	---	1000 ft/sec (305 m/sec)	---	---
Impact angle with terrain	---	---	Aircraft broke up in air due to dynamic overload	60°	---	Refueling accident at 15 000 ft
Roll angle	---	---		Left wing low	---	---
Yaw angle	---	---		---	---	---
Terrain	---	---	Flat	Small trees; hills	---	---
Distance from runway	Normal landing on runway	Normal landing on runway	---	---	---	Normal landing on runway
In-flight structural failure	Yes	Yes	Yes	No	---	Yes
Condition of aircraft:						
Fire?	No	No	Fire on impact	Fire and explosion	---	---
Percent of fuselage intact before fire	---	---	Fragmented	0	---	---
Percent of fuselage intact after fire	---	---	0	0	---	---
Fuselage breakage	Fin and rudder lost	Engine lost	2 breaks (in flight)	Fragmented	---	Left wing beyond outboard engine missing
Wings separated?	No	No	In flight	Yes	---	---
Impact severity rating	1	1	10	10	---	---
Ground marks:						
Length of gouge marks	---	---	Crater	Crater	---	---
Depth of gouge marks	---	---	6 ft (1.8 m)	8 ft (2.5 m)	---	---
Area of destruction	---	---	Crater 50 ft (15 m) in diameter	400 ft by 1000 ft (122 m by 305 m)	---	---
Estimated g-level	---	---	100 to 500	---	---	---
Cause of accident	Collision during refueling		Spin after stall in refueling operation	Pilot error, stall during refueling	---	---
Number of casualties:						
Crew	0	0	4 fatal; 1 major	6 fatal; 2 major	3 fatal; 1 major	0
Ground	0	0	0	0	0	0
Percent of aircraft loss	10	10	100	100	---	Left wing
Estimated chance of survival package at center of gravity, percent	100	100	0	0	---	100

TABLE II. - Continued. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Taxi accidents				
	1	2	3	4 to 10	11
Type of aircraft	C-130E	C-130E	C-121G	(a)	C-130
Velocity at impact	---	8 ft/sec (2.5 m/sec)	---	---	---
Impact angle with terrain	---	---	---	---	---
Roll angle	---	---	---	---	---
Yaw angle	---	---	---	---	---
Terrain	---	Flat	---	---	---
Distance from runway	---	---	---	---	---
In-flight structural failure	---	---	---	---	---
Condition of aircraft:					
Fire?	---	No fire	Postcrash fire	Postcrash fire	---
Percent of fuselage intact before fire	---	100	100	100	---
Percent of fuselage intact after fire	---	---	20	90 to 100	---
Fuselage breakage	---	None	---	None	---
Wings separated?	---	---	---	No	---
Impact severity rating	---	2	---	1	---
Ground marks:					
Length of gouge marks	---	---	---	---	---
Depth of gouge marks	---	---	---	---	---
Area of destruction	---	Small	---	---	---
Estimated g-level	---	1	---	---	---
Cause of accident	---	Pilot error	Pilot error	Faulty materials	Pilot error
Number of casualties:					
Crew	0	0	0	0	0
Ground	0	0	0	0	0
Percent of aircraft loss	15	20	100	0 to 30	5
Estimated chance of survival package at center of gravity, percent	100	100	0	100	100

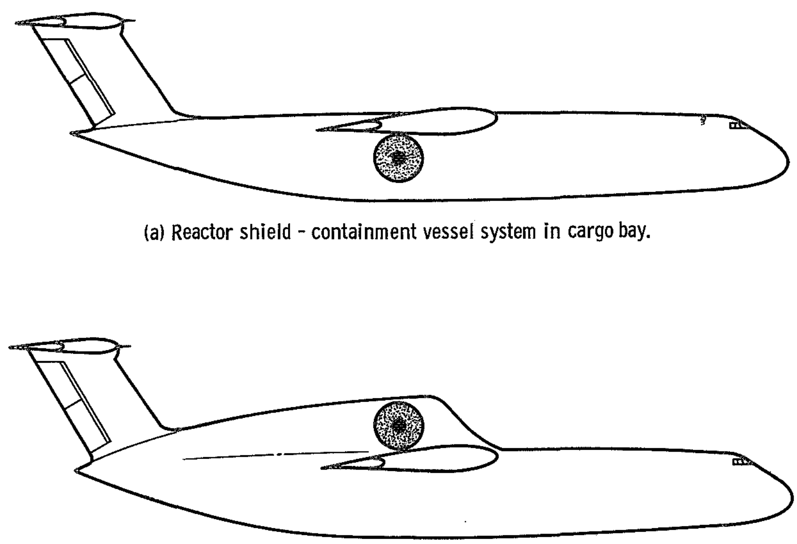
[a]Seven separate accidents to parked aircraft: B-52, C-118, C-121, two C-124's, and two C-130's.

TABLE II. - Concluded. ACCUMULATED DATA FOR 96 AIRPLANE ACCIDENTS TO FIXED-WING MULTIENGINE AIRCRAFT

	Taxi accidents		Fire during repair
	12	13	1
Type of aircraft	C-130B	B-58A	C-133A
Velocity at impact	Taxi speed	Slow taxi	---
Impact angle with terrain	---	Gear collapsed and fire started after aircraft slid off runway	---
Roll angle	---		---
Yaw angle	---		---
Terrain	---	Flat	---
Distance from runway	On runway	On runway	---
In-flight structural failure	No	No	---
Condition of aircraft:			
Fire?	No	Postcrash fire	Fire
Percent of fuselage intact before fire	---	100	100
Percent of fuselage intact after fire	---	20	100
Fuselage breakage	---	None	None
Wings separated?	---	No	Left wing
Impact severity rating	2	1	---
Ground marks:			
Length of gouge marks	---	---	---
Depth of gouge marks	---	---	---
Area of destruction	---	---	---
Estimated g-level	1	1 to 2	---
Cause of accident	Inexperienced personnel at controls	Pilot error	Fire during repair
Number of casualties:			
Crew	0	1 fatal; 2 major	---
Ground	0	0	1 major
Percent of aircraft loss	100	100	15
Estimated chance of survival package at center of gravity, percent	Good, except for fire	Good except for fire	100

REFERENCE

1. Wild, J. M.: Nuclear Propulsion for Aircraft. Paper 67-508, AIAA, July 1967.



(a) Reactor shield - containment vessel system in cargo bay.

(b) Reactor shield - containment vessel system above cargo bay.

Figure 1. - Reactor locations in aircraft.

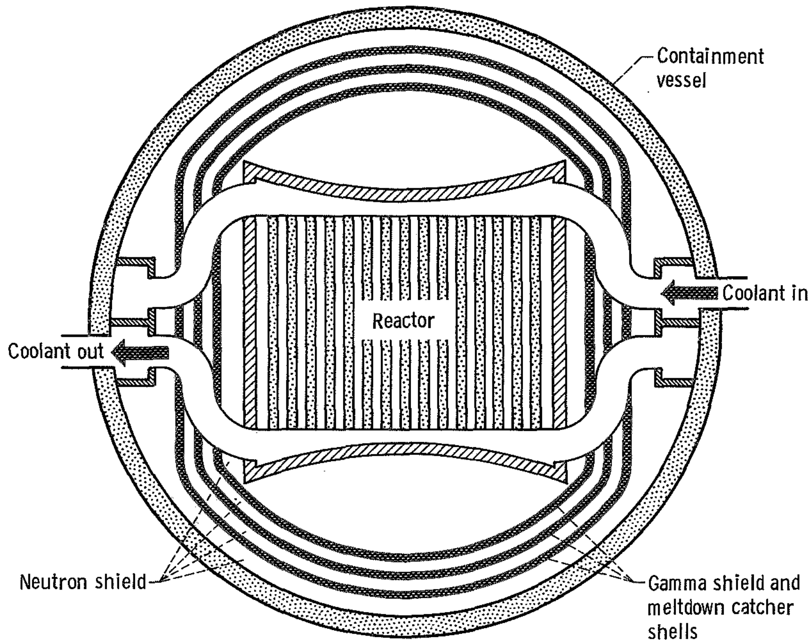


Figure 2. - Schematic of reactor shield - containment vessel system.

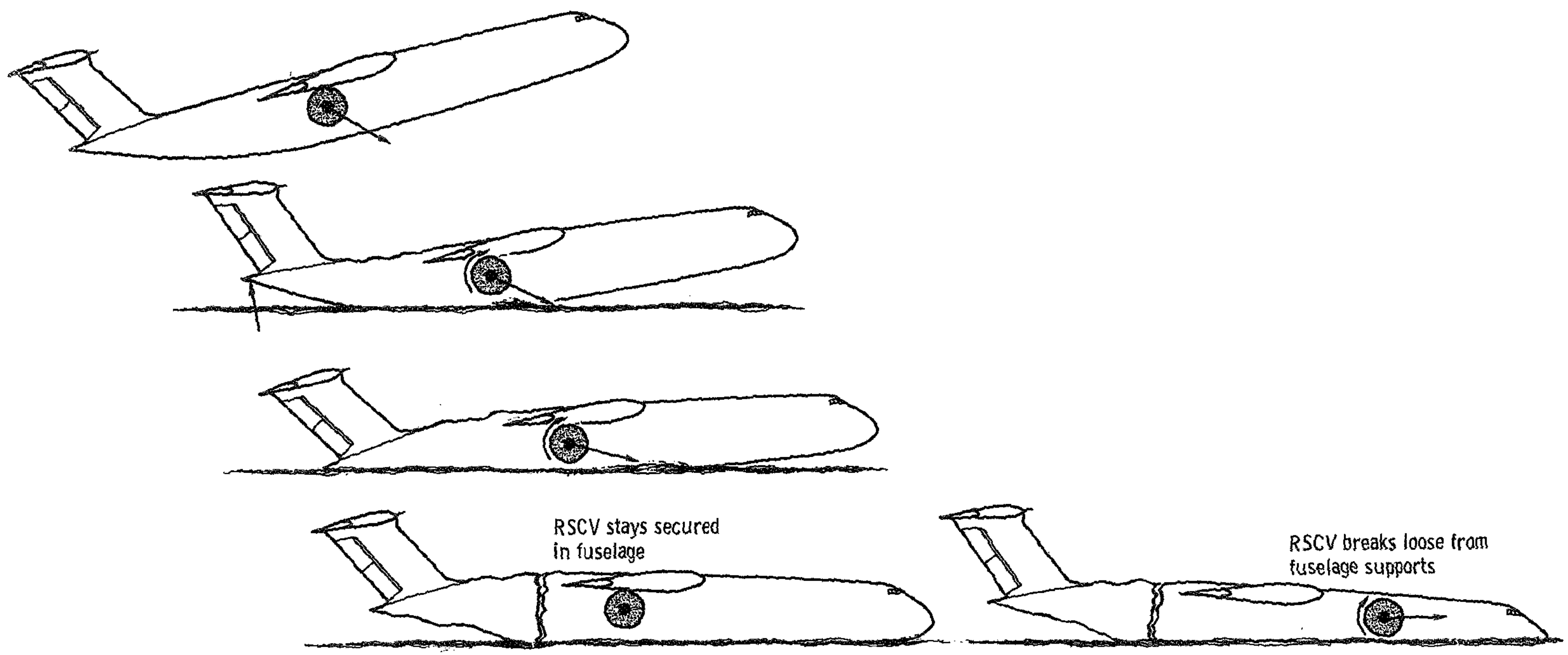


Figure 3. - Schematic of low-velocity, low-impact-angle aircraft crash with reactor shield - containment vessel system (RSCV) aboard aircraft.

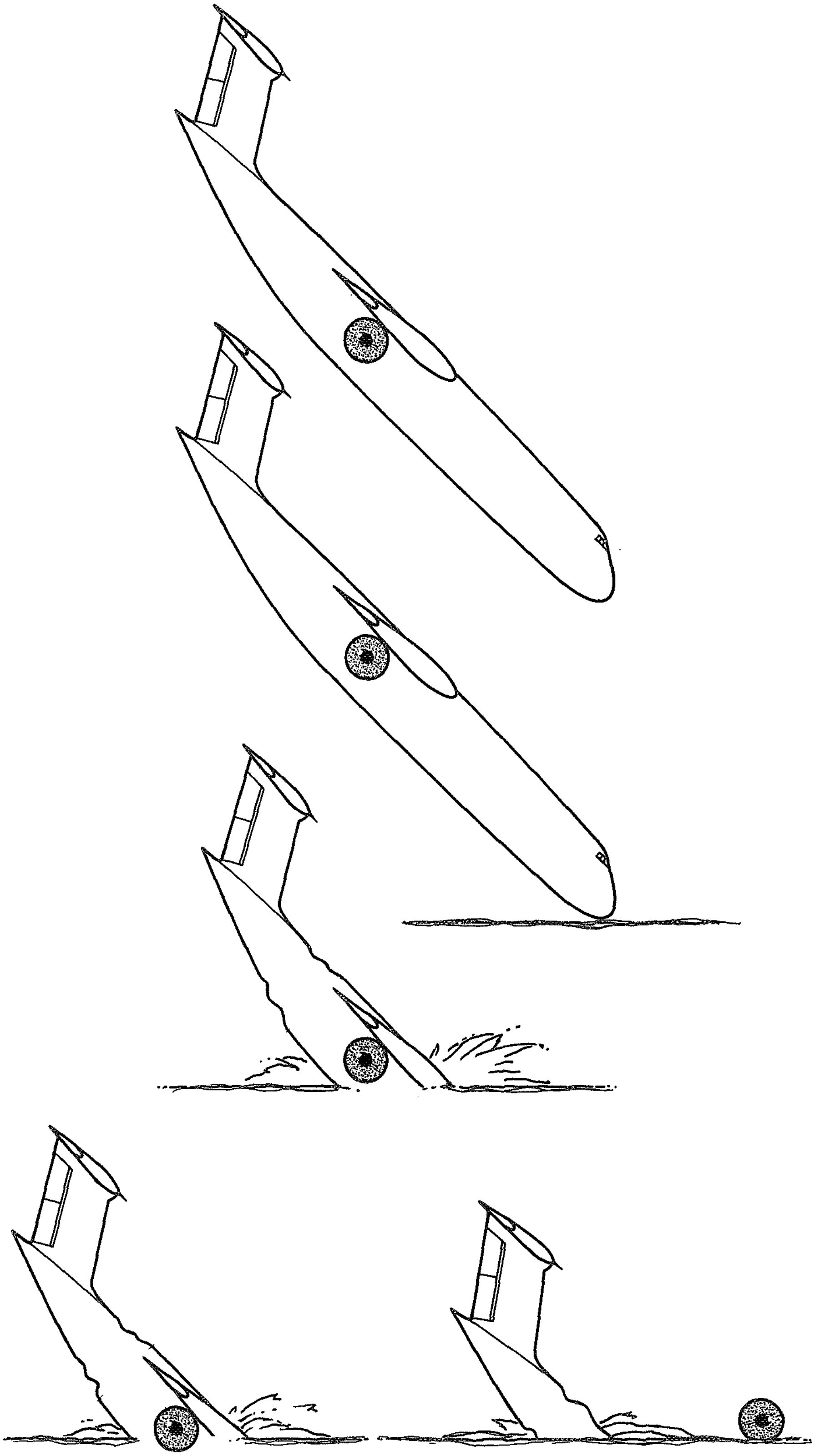


Figure 4. - Schematic of high-velocity, high-impact-angle aircraft crash with reactor shield - containment vessel system (RSCV) aboard aircraft.

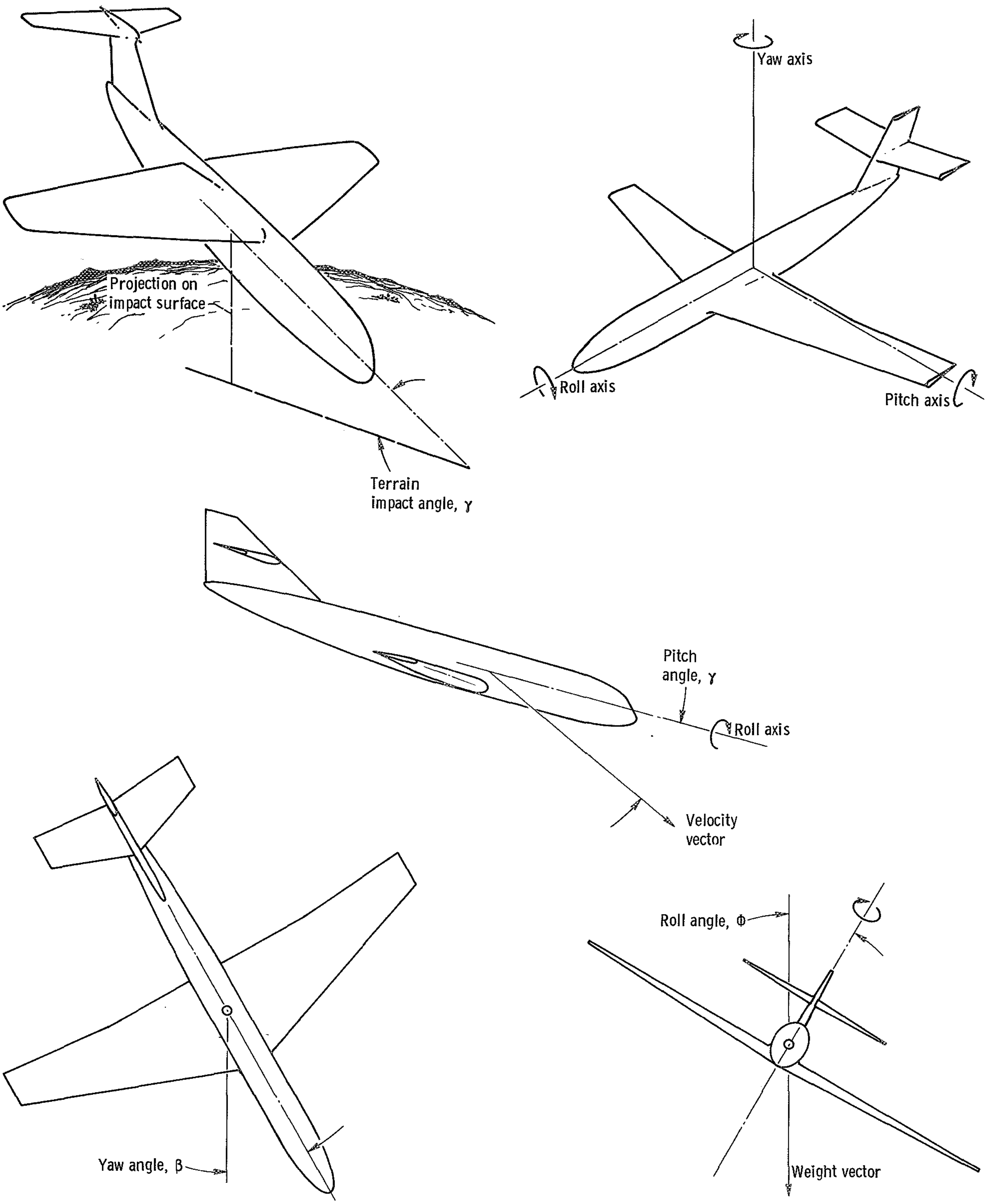
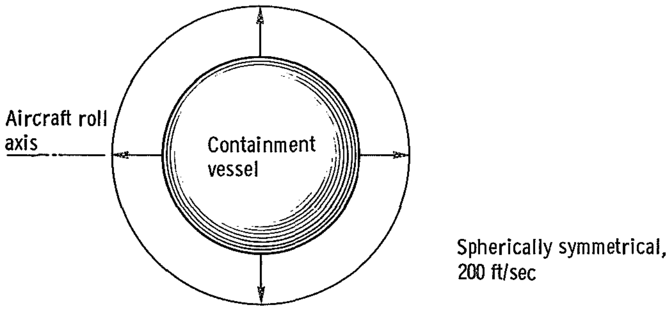
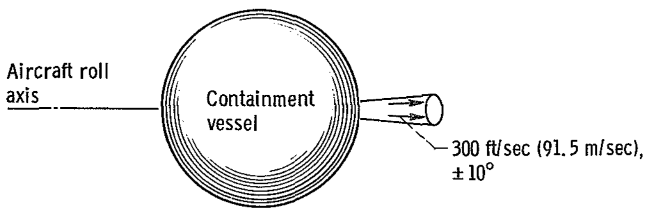


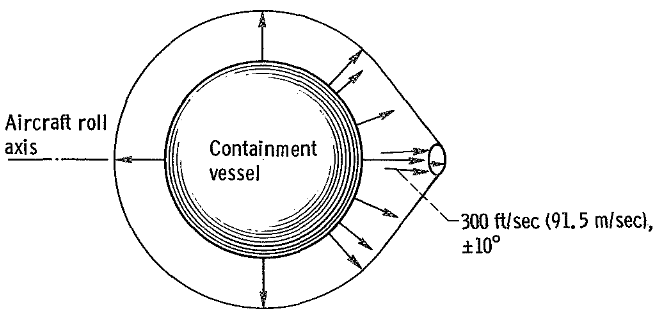
Figure 5. - Angular orientation of aircraft at impact.



(a) Average accident; terrain impact angle, 0° to 180°.

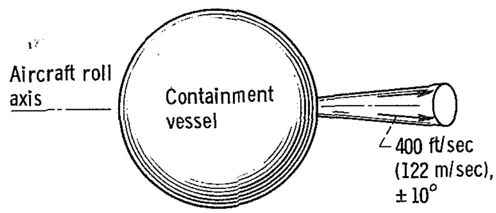


(b) Maximum accident; terrain impact angle, 0° to 90°.

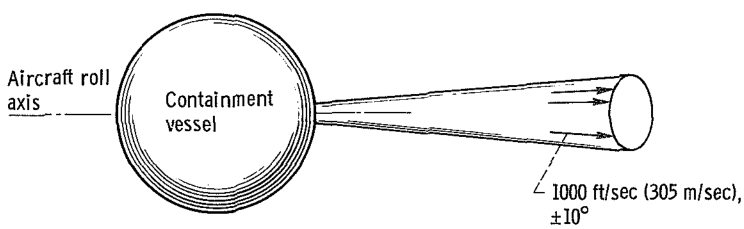


(c) Combined accident; terrain impact angle, 0° to 180°.

Figure 6. - Containment vessel impact velocity profile for landing and takeoff accidents.

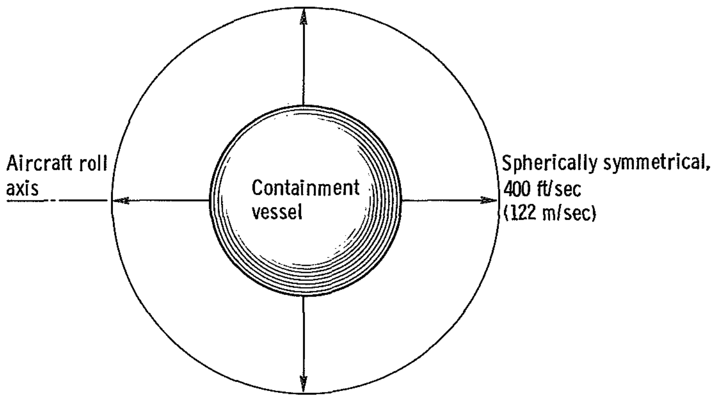


(a) Average accident; terrain impact angle, 0° to 180°.

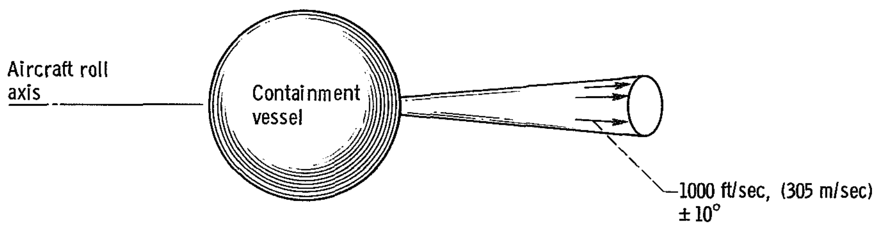


(b) Maximum accident (maximum accident includes average accident); terrain impact angle, 0° to 90°.

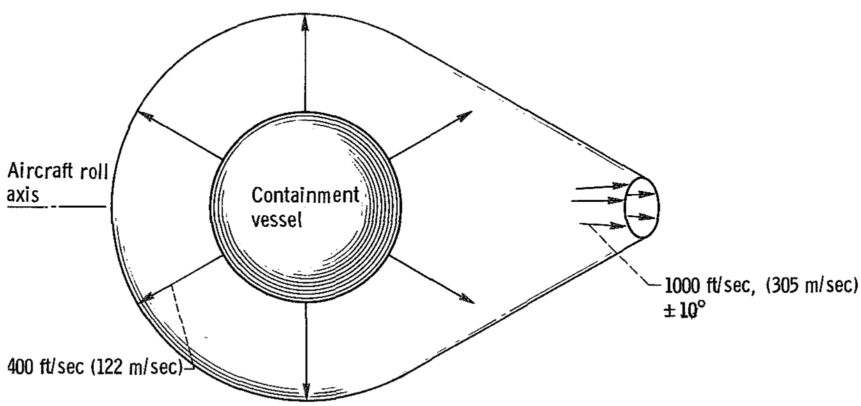
Figure 7. - Containment vessel impact velocity profile for cruise accident without structural failure.



(a) Average accident; terrain impact angle, 0° to 180°.



(b) Maximum accident; terrain impact angle, 0° to 90°.



(c) Combined accident; terrain impact angle, 0° to 180°.

Figure 8. - Containment vessel impact velocity for cruise accident with structural failure.

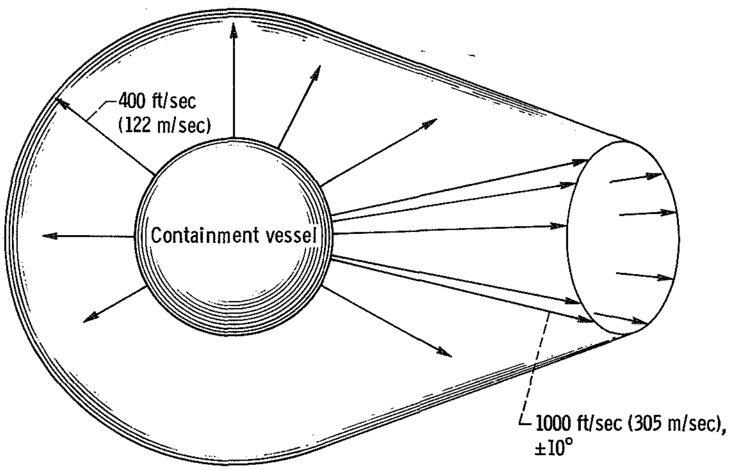


Figure 9. - Design criteria impact speed and angle for containment vessel.

NASA-Langley, 1971 —— 22 E-6025

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