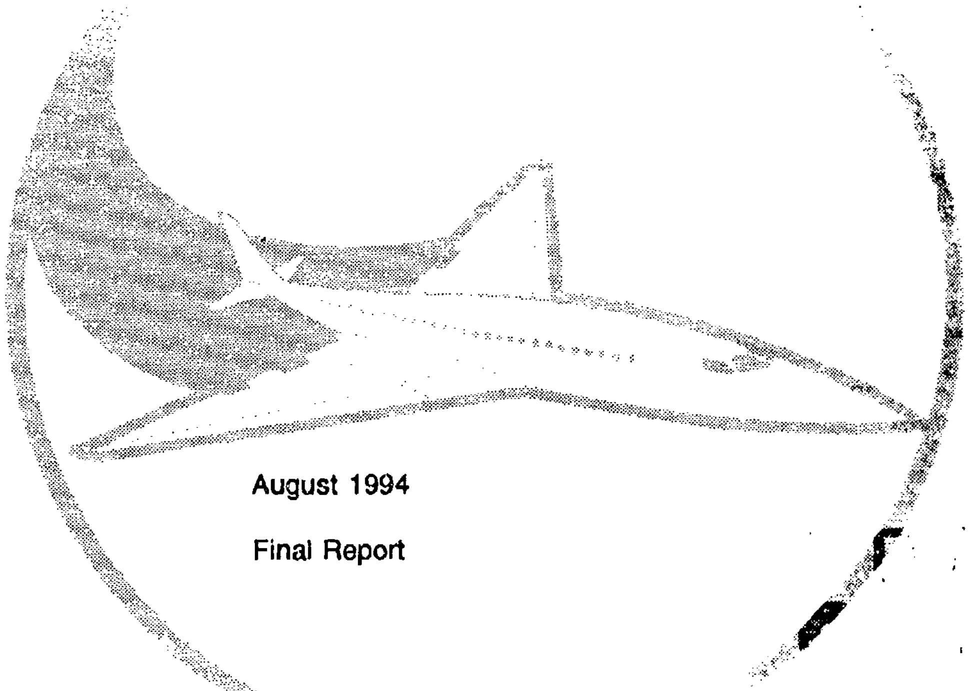
DOT/FAA/CT-94/75

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Commuter Airplane Accident Data Analysis



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16. Abstract

This report presents the results of a review of data from 120 commuter and air taxi airplane accidents that occurred from 1978 through 1986. The main objectives of this study are (a) to present the severe, but survivable impact condition data from the accident database and (b) to formulate appropriate crash design impact parameters.

In 1980 the Federal Aviation Administration Technical Center (FAATC) initiated the Aircraft Crashworthiness Program, which resulted in a compilation of commuter airplane accident data. The program's objectives were (a) to define potentially survivable commuter airplane crash scenarios and (b) to provide impact parameters associated with the appropriate crash scenarios.

Based on the data that was received, a crash survivable design envelope was defined for commuter airplanes.

17. Key Words

Commuter Airplane
Mild-Survivable
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Accident Database
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LIST OF ABBREVIATIONS AND SYMBOLS

CFR	Code of Federal Regulations
FAATC	Federal Aviation Administration Technical Center
ft/sec	feet per second
GTOW	Gross Takeoff Weight
NTSB	National Transportation Safety Board

EXECUTIVE SUMMARY

This report presents the results of a review of data from 120 commuter and air taxi airplane accidents that occurred from 1978 through 1986. The main objectives of this study were (a) to present the severe, but survivable impact condition data from the accident database as it relates to severe, but survivable impact conditions, and (b) to formulate appropriate crash design impact parameters.

All the accidents in the database were determined to be impact-survivable. The accidents in the database occurred mostly during a takeoff or landing phase. Over one-third of the accidents occurred while the airplane was on the ground and at the airport. The majority of the aircraft included in the accident database exhibited substantial damage or were destroyed. More than two-thirds of the accidents occurred without serious injuries or fatalities. More than half the occupants involved in the commuter airplane accident database were not injured.

Several conclusions were made based on the data compiled from 80 air-ground impacts, of which 39 had either a serious injury or fatality. A crash survivable design envelope was defined. The impact parameters that define this envelope were based on a 77th to 85th percentile range, or on a similar frequency of occurrence range. This envelope is defined by both impact attitude and velocities. The following parameters define the impact attitude based on percent of occurrence: 0 to 12 degrees flight path angle, -15 to +15 degrees pitch, -15 to +15 degrees roll, and 0 degrees yaw. The impact velocities, based on percentiles (except for flight path velocity) are 30 to 36 ft/sec sink speed, flight path velocity greater than stall speed, and a lateral velocity less than or equal to 10 ft/sec. This range of occurrence is less severe than military 95th percentiles and is considered appropriate for civil aircraft.

Velocity change profiles for the vertical and lateral directions were also determined and were based on 77th to 80th percentile values. The vertical velocity change was less than or equal to 36 ft/sec and the lateral velocity change was less than or equal to 10 ft/sec. The longitudinal velocity change could not be determined from the data.

1. INTRODUCTION.

1.1 BACKGROUND.

In 1980 the Federal Aviation Administration Technical Center (FAATC) initiated the Aircraft Crashworthiness Program, (reference 1) which resulted in a compilation of commuter airplane accident data. (reference 2) This report supersedes reference 2. The program's objectives were (a) to define potentially survivable commuter airplane crash scenarios and (b) to provide impact parameters associated with the appropriate crash scenarios.

This database consists of commuter and air taxi accident statistics for 1978--1986. The following analysis describes the commuter airplane database acquisition and selection.

1.1.1 Accident Data Acquisition.

The accident database was compiled from accident dockets using National Transportation Safety Board (NTSB) Forms 6120.1, 6120.2, 6120.3, and 6120.4. In 1983 the NTSB introduced the expanded accident and incident report form (NTSB Form 6120.4). This provides a systematic investigative technique for reporting accident data emphasizing crashworthiness. NTSB Form 6120.4 reports on the nature of impact conditions of the aircraft, amounts of structural damage, injuries, and injury sources.

The previous forms used to gather accident data did not consistently report preimpact kinematic data. This coupled with the inadequacy and inconsistency of injury source reporting, did not allow for a detailed study of crashworthiness specifics.

Dockets for accidents involving airplanes operating in accordance with 14 Code of Federal Regulations (CFR) Part 121 and 14 CFR Part 135 were obtained from the NTSB for 1978 through 1986. Table 1 illustrates the total sample and available database concerning the number of accidents, the accidents with fatalities, and the number of fatalities. (reference 3) Contact with airplane manufacturers indicated that the accident data available from the manufacturers would be the same as that found in the NTSB dockets.

TABLE 1. COMMUTER AND AIR TAXI ACCIDENT STATISTICS, 1978–1986

	Total Sample*	Database for Study
Number of Accidents	453	120
Number of Accidents with Fatalities	95	11
Number of Fatalities	1264	25

*Data taken from reference 3

1.1.2 Accident Case Selection Procedure.

Of the 453 accidents identified, two hundred and twenty-seven accident dockets were acquired from the NTSB for the compilation of the database. All of the obtained dockets involved aircraft with a maximum passenger seating capacity of 20 seats, or with a Gross Takeoff Weight (GTOW) of 19,500 pounds. Of the 227 accident dockets obtained, 120 were chosen as the database for the study of survivable, non-trivial commuter airplane accidents.

The database criterion was based on the premise that the accidents were non-catastrophic (occupants have a chance for survival). Trivial cases, such as incidents in which no system failures occur or which involve injury to ground personnel only, were eliminated.

1.1.3 Method of Accident Data Analysis.

The analysis procedure of the final database consisted of:

a. Formulation of definitions.
b. Compilation of data summary sheets for pertinent data.
c. Analysis of crash environment (e.g., airplane velocity, pitch, roll, yaw, sink rate, and ground terrain).
d. Identification of specific types of accidents.
e. Definition of several crash scenarios.
f. Identification of airplane system failures.
g. Identification of injury types and causes.

1.1.4 Nature of Commuter and Air Taxi Accidents.

All the accidents in the database were determined to be impact-survivable; that is the occupants were deemed to have a chance of survival. The accidents in the database occur mostly during a takeoff or landing phase. Over one-third of the accidents occur while the airplane is on the ground and at the airport. The majority of the aircraft included in this accident database exhibited substantial damage or were destroyed. More than two-thirds of the accidents occurred without serious injuries or fatalities. More than half the occupants involved in the commuter airplane accident database were not injured.

1.2 APPROACH.

There are three parts to the approach used to assess the commuter accident data: (a) review of the data, (b) determine and use the statistical data that is relevant to potential crash design criteria, and (c) present the relevant data.

2. ACCIDENT DATA ANALYSIS.

2.1 INJURIES AND AIRCRAFT DAMAGE.

The 120 accidents presented in the database comprise mild-survivable (81) or severe-survivable (39) accident subsets. Tables 2 and 3 show the distribution of injury severity and aircraft damage for the mild- and severe-survivable subsets. By definition mild-survivable accidents do not have any fatalities or serious injuries associated with them. Yet mild-survivable accidents have a large occurrence of substantial or destructive structural damage. This study defines substantial damage as "Damage or failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which normally would require major repair or replacement of an affected component." Considering this definition, it is not surprising that 84 percent of mild-survivable accidents sustain substantial damage.

The severe-survivable statistics, while representative of a smaller number of accidents than the mild-survivable accidents (39 vs. 81), are more realistic concerning crash scenarios or impact conditions. These accidents have either or both serious injuries/fatalities, along with significant structural damage. Implied in these subsets is that the injury and fatality criteria are more significant than the damage assessment. The database was analyzed with an emphasis on establishing impact scenarios for commuter aircraft based on severe-survivable accidents.

TABLE 2. DISTRIBUTION OF INJURY SEVERITY FOR THE DATABASE SAMPLE AND EACH SUBSET

Injury Type	Total Database		Mild-Survivable		Severe-Survivable	
	Number of Occupants	Percent of Total	Number of Occupants	Percent of Total	Number of Occupants	Percent of Total
Fatal	25	4.0	0	0.0	25	8.9
Serious	121	19.2	0	0.0	121	42.9
Minor	121	19.2	30	8.6	91	32.3
None	364	57.7	319	91.4	45	16.0
Total	631	100.0	349	100.0	282	100.0

TABLE 3. DISTRIBUTION OF AIRCRAFT DAMAGE FOR THE DATABASE SAMPLE AND EACH SUBSET

Damage	Total Database		Mild-Survivable		Severe-Survivable	
	Number of Accidents	Percent of Total	Number of Accidents	Percent of Total	Number of Accidents	Percent of Total
Destroyed	32	26.7	8	9.9	24	61.5
Substantial	83	69.2	68	84.0	15	38.5
Minor	5	4.2	5	6.2	0	0.0
None	0	0.0	0	0.0	0	0.0
Total	120	100.0	81	100.0	39	100.0

2.2 CRASH SITE CONDITIONS.

Tables 4 through 8 provide data for severe-survivable accidents with regard to:

a. Phase of operation.
b. Distance from airport.
c. Impact terrain.
d. Obstacles hit.
e. Fire occurrence.

Severe-survivable accident data indicate that:

a. The predominant phase of operation is a forced landing, the distribution among forced landing, takeoff, approach, and normal landing is close, ranging from 20.5 to 30.8 percent.

b. Over half the accidents occur within 5 miles of the airport. Almost all the fatalities and many serious injuries are associated with off-airport accidents.

c. These types of accidents occur on both hard, flat terrain (asphalt and concrete) and soft, flat terrain (soft soil and grassy areas). Soft, flat terrain is impacted more often than hard, flat terrain. Water and snow covered terrain are impacted frequently and are present in 50 percent of the fatalities.

d. The presence of trees, poles, and fences is noted in approximately two-thirds of the severe-survivable accident fatalities. More than half the serious injuries are sustained when no obstacles are present.

e. Nearly two-thirds of the fatalities occur when fires are present. However, approximately three-fourths of the serious injuries occur when there is no occurrence of fire.

TABLE 4. DISTRIBUTION OF PHASE OF OPERATION FOR THE SEVERE-SURVIVABLE ACCIDENTS

			Injuries*				Damage**	
Phase of Operation	Number of Accidents	Percent of Total	Fat.	Ser.	Min.	None	Des.	Sub.
Forced Landing	12	30.8	4	38	32	18	6	6
Approach	8	20.5	4	35	11	5	7	1
Takeoff	10	25.6	12	27	23	18	5	5
Landing	8	20.5	4	19	24	4	6	2
Cruise	1	2.6	1	2	1	0	0	1
Total	39	100.0	25	121	91	45	24	15

TABLE 5. DISTRIBUTION OF DISTANCE FROM AIRPORT FOR THE SEVERE-SURVIVABLE ACCIDENTS

			Injuries*				Damage**	
Distance from Airport (miles)	Number of Accidents	Percent of Total	Fat.	Ser.	Min.	None	Des.	Sub.
On airport	13	33.3	1	42	24	26	7	6
$0 < x \leq 5$	21	53.8	20	51	59	19	14	7
$x > 5$	5	12.8	4	28	8	0	3	2
Total	39	100.0	25	121	91	45	24	15

* Fatal = Fat.
Serious = Ser.
Minor = Min.

** Destroyed = Des.
Substantial = Sub.

TABLE 6. DISTRIBUTION OF IMPACT TERRAIN FOR THE SEVERE-SURVIVABLE ACCIDENTS

			Injuries*				Damage**	
Impact Terrain	Number of Accidents	Percent of Total	Fat.	Ser.	Min.	None	Des.	Sub.
Hard, Flat	9	23.1	2	34	34	9	6	3
Soft, Flat	10	25.6	1	12	17	17	5	5
Rough, Rocky	3	7.7	0	15	1	3	1	2
Water	4	10.3	3	11	24	2	3	1
Snow Covered	7	17.9	10	23	5	14	5	2
Ice	2	5.1	1	14	1	0	1	1
Other	4	10.3	8	12	9	0	3	1
Total	39	100.0	25	121	91	45	24	15

TABLE 7. DISTRIBUTION OF OBSTACLES HIT FOR THE SEVERE-SURVIVABLE ACCIDENTS

			Injuries*				Damage**	
Obstacles Hit	Number of Accidents	Percent of Total	Fat.	Ser.	Min.	None	Des.	Sub.
Tree, Pole	11	28.2	13	26	13	2	10	1
Building	1	2.6	0	4	3	0	1	0
Fence	3	7.7	4	7	3	0	2	1
Ditch	2	5.1	0	10	16	0	2	0
Embankment	2	5.1	0	9	2	0	1	1
None	19	48.7	8	64	54	35	8	11
Other	1	2.6	0	1	0	5	0	1
Total	39	100.0	25	121	91	42	24	15

* Fatal = Fat.
Serious = Ser.
Minor = Min.

** Destroyed = Des.
Substantial = Sub.

TABLE 8. DISTRIBUTION OF FIRE OCCURRENCE FOR THE SEVERE-SURVIVABLE ACCIDENTS

			Injuries*				Damage**	
Fire Occurrence	Number of Accidents	Percent of Total	Fat.	Ser.	Min.	None	Des.	Sub.
None	29	74.4	7	92	70	45	15	14
In-Flight	1	2.6	1	10	1	0	1	0
On Ground	7	17.9	8	17	17	0	6	1
Both	2	5.1	9	2	3	0	2	0
Total	39	100.0	25	121	91	45	24	15

* Fatal = Fat.
Serious = Ser.
Minor = Min.

** Destroyed = Des.
Substantial = Sub.

2.3 AIRCRAFT CHARACTERISTICS DATA.

As expected, the commuter aircraft configuration most often involved in the accident database is the multiple-engine, low-wing type (76.7 percent). The distribution of airplane types listed in the accident database are:

a. Single-engine high-wing (14) < 10,000 pounds GTOW
b. Single-engine low-wing (6) < 10,000 pounds GTOW
c. Multiple-engine low-wing (58) < 10,000 pounds GTOW
d. Multiple-engine low-wing (34) > 10,000 pounds GTOW
e. Multiple-engine high-wing (1) < 10,000 pounds GTOW
f. Multiple-engine high-wing (7) > 10,000 pounds GTOW

Many of these commuter aircraft, particularly the low-wing type, utilize fuel tanks that are either pressure-fed wet wing, bladder, or tip-tank types; and the landing gears are retractable.

2.4 PREIMPACT PARAMETERS AND IMPACT KINEMATICS.

The severe-survivable accident preimpact database consists of:

a. flight path velocity,
b. flight path angle,
c. sink rate,
d. impact attitude (pitch, roll, yaw), and
e. angle of attack.

Figure 1 shows the relationship between the aircraft coordinate system and the crash attitudes.

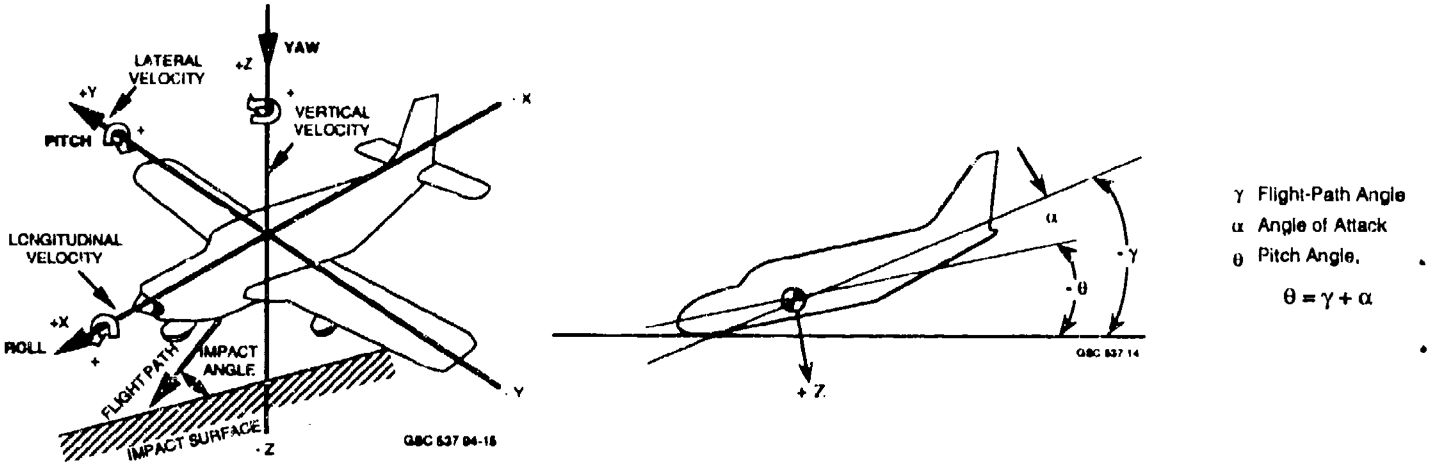

FIGURE 1. AIRPLANE COORDINATE SYSTEM

The severe-survivable preimpact data are presented in tables 9 through 15 and figures 2 through 4. The following are the approximate percentiles of occurrence or percent of data, ranging up to nearly the 90th percentile or percent of occurrence:

a.	flight path angle (+ nose-up)	< -6 deg. < -12 deg.	54th percentile 82th percentile
b.	sink rate	< 15 ft/sec < 30 ft/sec < 36 ft/sec	47th percentile 77th percentile 82th percentile
c.	pitch attitude (+ nose-up)	0 deg. 0 to+15 deg. -15 to+15 deg.	33.3 percent 56.6 percent 89.7 percent
d.	roll attitude	0 deg. -15 to+15 deg.	64.1 percent 84.6 percent
e.	yaw angle	0 deg.	82.1 percent
f.	flight path velocity	< 175 ft/sec > *	74th percentile min. stall speed

*GTOW configuration dependent; Stall velocities for 7500 pounds GTOW to 10,000 pounds GTOW aircraft range from approximately 90 ft/sec to 130 ft/sec. While the airplanes with > 10,000 pounds GTOW have stall speeds over 130 ft/sec.

TABLE 9. DISTRIBUTION OF FLIGHT PATH VELOCITY FOR THE SEVERE-SURVIVABLE ACCIDENTS

Velocity (ft/sec)	Number of Aircraft	Percent of Total	Cumulative Percent
$50 \le x < 75$	1	2.6	2.6
$75 \le x < 100$	5	12.8	15.4
$100 \le x < 125$	6	15.4	30.8
$125 \le x < 150$	7	17.9	48.7
$150 \le x < 175$	10	25.6	74.3
$175 \le x < 200$	6	15.4	89.7
$200 \le x < 225$	3	7.7	97.4
$225 \le x < 250$	1	2.6	100.0
Total	39	100.0	

Figure 2 shows the frequency of occurrence of flight path velocity for severe-survivable cases.

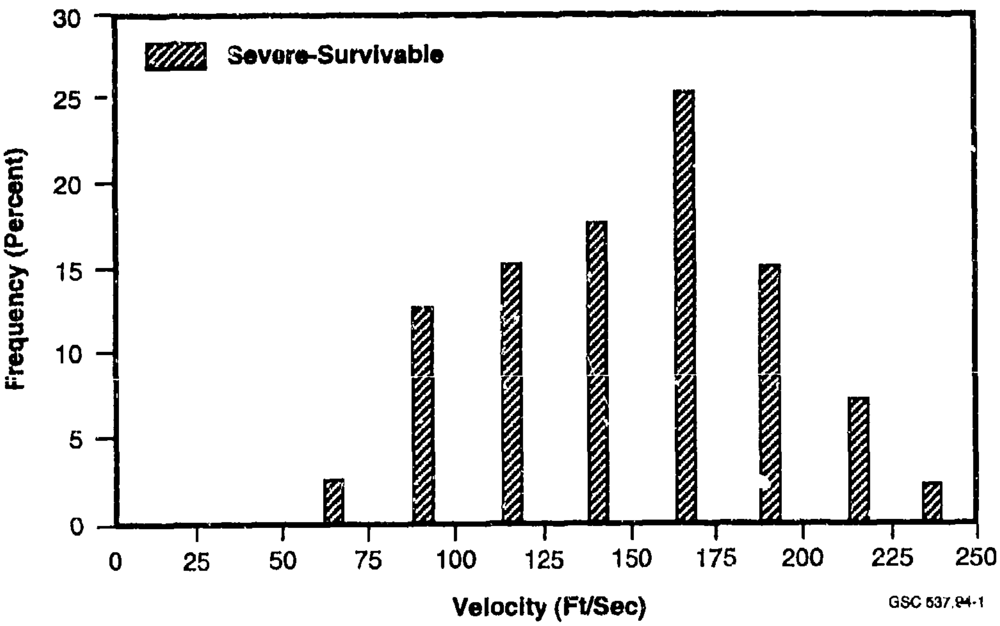

FIGURE 2. FREQUENCY OF OCCURRENCE OF FLIGHT PATH VELOCITY FOR SEVERE-SURVIVABLE CASES

TABLE 10. DISTRIBUTION OF FLIGHT PATH ANGLE FOR THE SEVERE-SURVIVABLE ACCIDENTS

Angle (deg) Down	Number of Aircraft	Percent of Total	Cumulative Percent
0	4	10.3	10.3
0 < x ≤ 3	9	23.1	33.4
3 < x ≤ 6	8	20.5	53.9
6 < x ≤ 9	4	10.3	64.2
9 < x ≤ 12	7	17.9	82.1
12 < x ≤ 15	1	2.6	84.7
15 < x ≤ 18	3	7.7	92.4
18 < x ≤ 21	1	2.6	95.0
21 < x ≤ 24	1	2.6	97.6
24 < x ≤ 27	0	0.0	97.6
27 < x ≤ 30	1	2.6	100.0
Total	39	100.0	

Figure 3 shows the frequency of occurrence of flight path angle for severe-survivable cases.

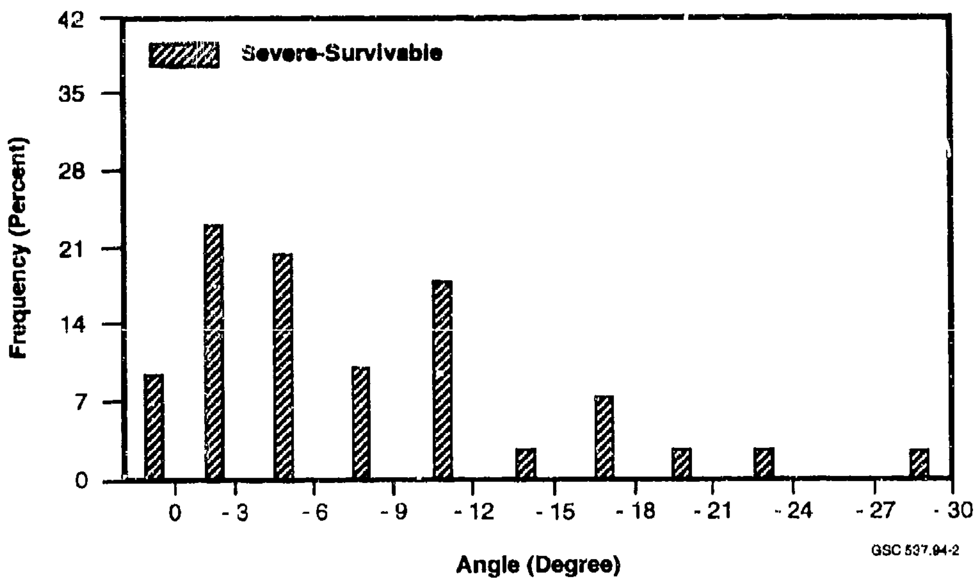

FIGURE 3. FREQUENCY OF OCCURRENCE OF FLIGHT PATH ANGLE FOR SEVERE-SURVIVABLE CASES

TABLE 11. DISTRIBUTION OF SINK RATE FOR THE SEVERE-SURVIVABLE ACCIDENTS

Sink Rate (ft/sec)	Number of Aircraft	Percent of Total	Cumulative Percent
0	4	10.3	10.3
0 < x ≤ 6	5	12.8	23.1
6 < x ≤ 12	5	12.8	35.9
12 < x ≤ 18	9	23.1	59.0
18 < x ≤ 24	5	12.8	71.8
24 < x ≤ 30	2	5.1	76.9
30 < x ≤ 36	2	5.1	82.0
36 < x ≤ 42	3	7.7	89.7
42 < x ≤ 48	1	2.6	92.3
48 < x ≤ 54	3	7.7	100.0
Total	39	100.0	

Figure 4 shows the frequency of occurrence of sink rate for severe-survivable cases.

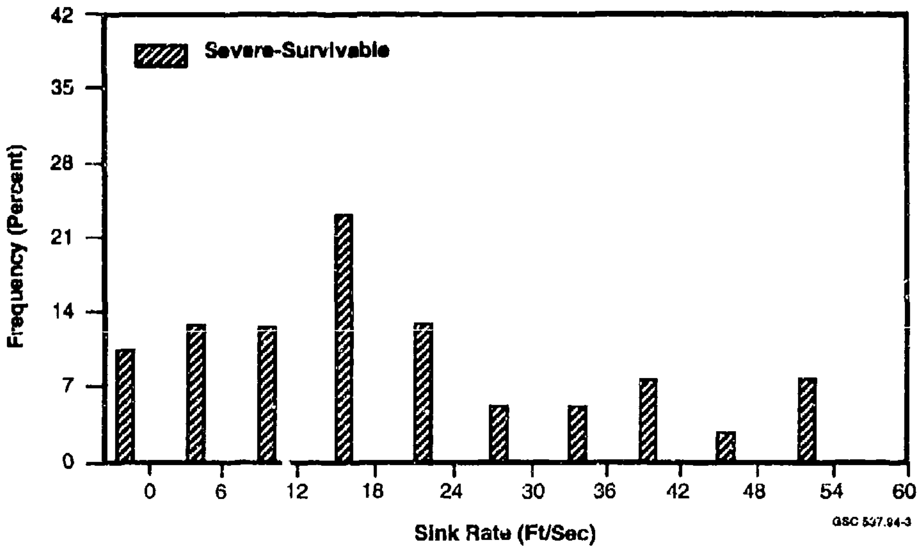

FIGURE 4. FREQUENCY OF OCCURRENCE OF SINK RATE FOR SEVERE-SURVIVABLE CASES

TABLE 12. DISTRIBUTION OF PITCH ANGLE AT IMPACT FOR THE SEVERE-SURVIVABLE ACCIDENTS

Pitch Angle (deg) Nose Up	Nose Down	Number of Aircraft	Percent of Total	Cumulative Percent
15 ≥ x > 0		13	33.3	33.3
	0	13	33.3	66.6
	0 < x ≤ 15	9	23.1	89.7
	15 < x ≤ 30	2	5.1	94.8
	30 < x ≤ 45	1	2.6	97.4
	45 < x ≤ 60	0	0.0	97.4
	60 < x ≤ 75	1	2.6	100.0
Total		39	100.0	

TABLE 13. DISTRIBUTION OF ROLL ANGLE AT IMPACT FOR THE SEVERE-SURVIVABLE ACCIDENTS

Roll Angle (deg) Right Wing Down	Left Wing Down	Number of Aircraft	Percent of Total	Cumulative Percent
30 ≥ x > 15		1	2.6	2.6
15 ≥ x > 0		2	5.1	7.7
	0	25	64.1	71.8
	0 < x ≤ 15	6	15.4	87.2
	15 < x ≤ 30	4	10.3	97.5
	30 < x ≤ 45	0	0.0	97.5
	45 < x ≤ 60	1	2.6	100.0
Total		39	100.0	

TABLE 14. DISTRIBUTION OF YAW ANGLE AT IMPACT FOR THE SEVERE-SURVIVABLE ACCIDENTS

Yaw Angle (deg) Nose Right	Nose Left	Number of Aircraft	Percent of Total	Cumulative Percent
15 ≥ x > 0		2	5.1	5.1
	0	32	82.1	87.2
	0 < x ≤ 15	3	7.7	94.9
	15 < x ≤ 30	1	2.6	97.5
	30 < x ≤ 45	0	0.0	97.5
	45 < x ≤ 60	0	0.0	97.5
	60 < x ≤ 75	1	2.6	100.0
Total		39	100.0	

TABLE 15. DISTRIBUTION OF ANGLE OF ATTACK AT IMPACT FOR THE SEVERE-SURVIVABLE ACCIDENTS

Angle of Attack (deg) Negative	Positive	Number of Aircraft	Percent of Total	Cumulative Percent
75 ≥ x > 60		1	2.6	2.6
60 ≥ x > 45		0	0.0	2.6
45 ≥ x > 30		1	2.6	5.2
30 ≥ x > 15		0	0.0	5.2
15 ≥ x > 0		3	7.7	12.9
	0	5	12.8	25.7
	0 < x ≤ 15	22	56.4	82.1
	15 < x ≤ 30	6	15.4	97.5
	30 < x ≤ 45	1	2.6	100.0
Total		39	100.0	

The kinematic data for severe-survivable accidents of aircraft initial velocities presented in the database are shown in tables 16 through 18 and figures 5 through 7 for the longitudinal, vertical, and lateral directions.

If the severe-survivable initial impact velocity data were viewed in the same perspective as the severe-survivable preimpact data with regard to percentiles it follows that:

a.	Initial longitudinal velocity	< 150 ft/sec	54th percentile
		< 175 ft/sec	77th percentile
b.	Initial vertical velocity	< 18 ft/sec	56th percentile**
		< 36 ft/sec	77th percentile**
c.	Initial lateral velocity	0 ft/sec	62th percentile
		< 10 ft/sec	80th percentile

** based on eliminating 4 accidents with velocities > 60 ft/sec.

The initial longitudinal velocity by and in itself is not a definitive parameter for defining crash pulses. The data presented do not allow for a longitudinal velocity change or pulse definition.

TABLE 16. DISTRIBUTION OF INITIAL LONGITUDINAL VELOCITY FOR THE SEVERE-SURVIVABLE ACCIDENTS

Velocity (ft/sec)	Number of Aircraft	Percent of Total	Cumulative Percent
0 ≤ x < 25	0	0.0	0.0
25 ≤ x < 50	1	2.6	2.6
50 ≤ x < 75	3	7.7	10.3
75 ≤ x < 100	4	10.3	20.5
100 ≤ x < 125	7	17.9	38.5
125 ≤ x < 150	6	15.4	53.9
150 ≤ x < 175	9	23.1	77.0
175 ≤ x < 200	7	17.9	94.9
200 ≤ x < 225	1	2.6	97.5
225 ≤ x < 250	1	2.6	100.0
Total	39	100.0	

Figure 5 shows the frequency of occurrence of initial longitudinal velocity for severe-survivable cases.

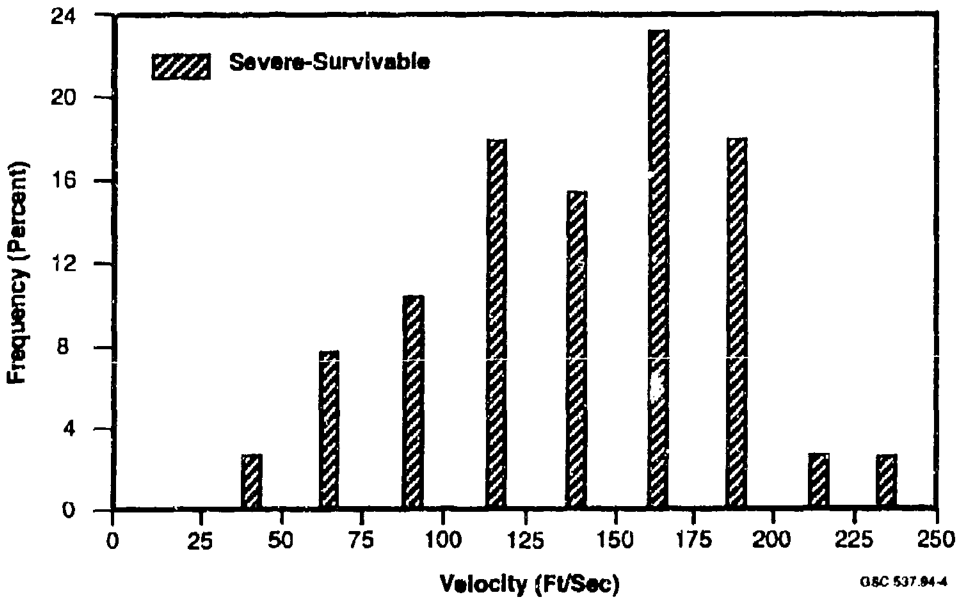

FIGURE 5. FREQUENCY OF OCCURRENCE OF INITIAL LONGITUDINAL VELOCITY FOR SEVERE-SURVIVABLE CASES

TABLE 17. DISTRIBUTION OF INITIAL VERTICAL VELOCITY FOR THE SEVERE-SURVIVABLE ACCIDENTS

Velocity (ft/sec)	Number of Aircraft	Percent of Total	Cumulative Percent
0	4	10.3	10.3
0 > x ≥ -12	12	30.8	41.1
-12 > x ≥ -24	7	17.9	59.0
-24 > x ≥ -36	4	10.3	69.3
-36 > x ≥ -48	3	7.7	77.0
-48 > x ≥ -60	5	12.8	89.8
-60 > x ≥ -72	2	5.1	94.9
-72 > x ≥ -84	0	0.0	94.9
-84 > x ≥ -96	0	0.0	94.9
-96 > x ≥ -108	1	2.6	97.5
-108 > x ≥ -120	1	2.6	100.0
Total	39	100.0	

Figure 6 shows the frequency of occurrence of initial vertical velocity for severe-survivable cases.

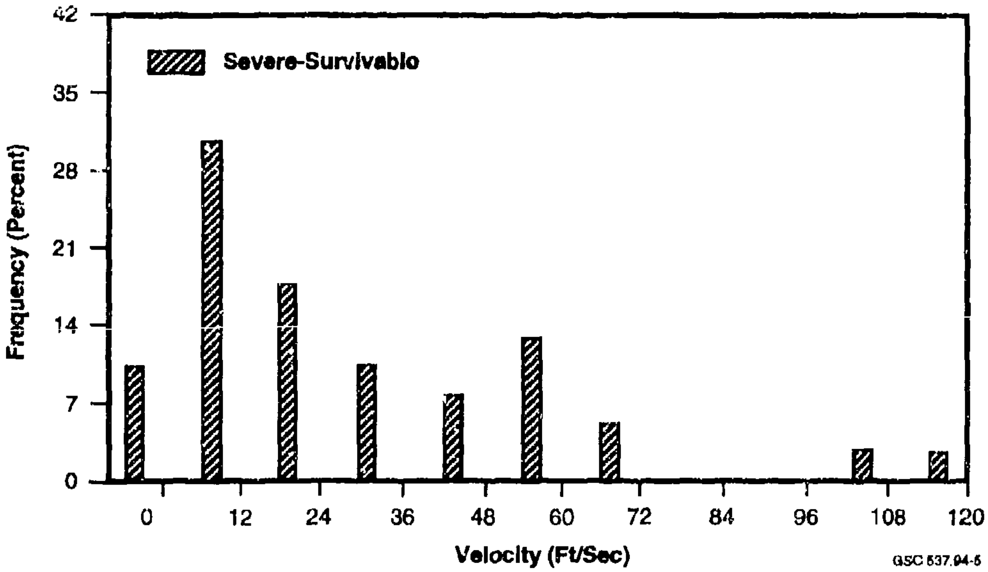

FIGURE 6. FREQUENCY OF OCCURRENCE OF INITIAL VERTICAL VELOCITY FOR SEVERE-SURVIVABLE CASES

TABLE 18. DISTRIBUTION OF INITIAL LATERAL VELOCITY FOR THE SEVERE-SURVIVABLE ACCIDENTS

Velocity (ft/sec)	Number of Aircraft	Percent of Total	Cumulative Percent
0	24	61.5	61.5
$0 < x \leq 10$	7	17.9	79.4
$10 < x \leq 20$	4	10.3	89.7
$20 < x \leq 30$	2	5.1	94.8
$30 < x \leq 40$	0	0.0	94.8
$40 < x \leq 50$	0	0.0	94.8
$50 < x \leq 60$	0	0.0	94.8
$60 < x \leq 70$	2	5.1	100.0
Total	39	100.0	

Figure 7 shows the frequency of occurrence of initial lateral velocity for severe-survivable cases (absolute value).

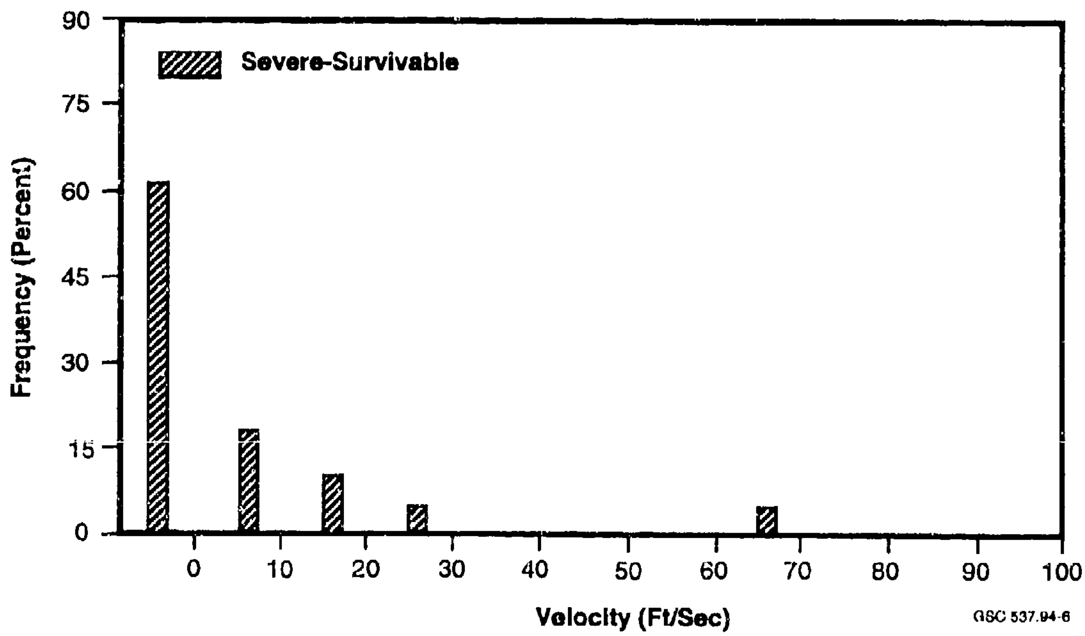

FIGURE 7. FREQUENCY OF OCCURRENCE OF INITIAL LATERAL VELOCITY FOR SEVERE-SURVIVABLE CASES (ABSOLUTE VALUE)

It is important to reconcile the vertical velocity profile relative to the sink speed profile. For example, the data presented for these two parameters are shown in tables 11 and 17, and figures 4 and 6, for sink rate and initial vertical velocity, respectively. Based on the overall data the 77th percentiles are 30 ft/sec and 48 ft/sec for sink rate and vertical velocity, respectively. However, it can be observed that no sink rate above 54 ft/sec is recorded, while the initial vertical velocity database contains two data points between 60 and 72 ft/sec and two others over 96 ft/sec. It is expected that with a low pitch attitude (< 15 degrees), the difference between the sink rate and initial velocity change would be small. The elimination of a few extreme cases in which the flight parameters such as pitch angle, flight path angle, and angle of attack are not known, shows that the initial vertical velocity is 36 ft/sec at the 77th percentile. This value is about 20 percent higher that the 77th percentile sink rate (table 11) for severe-survivable accidents.

In examining the kinematics and taking into account the pitch, flight path, and attack angles, the following can be observed: In only 5 of the 39 severe-survivable accidents is the angle of attack negative (table 15). In two of the five accidents the angle of attack was > -30 degrees. In 70 percent of the severe-survivable accident data, the angle of attack is between zero and +15 degrees. In approximately 80 percent of the severe-survivable accidents the flight path angle is between zero and -12 degrees. Ignoring wing incidence angles, these data imply that the pitch attitude is generally shallow. Without individual accident cases to examine it is difficult to know the combination of pitch, flight path, and attack angles that are appropriate. However, the flight path and angle of attack data previously noted, along with the fact that in 85 percent of the severe-survivable accident data, the pitch attitude is within ±15 degrees illustrates a degree of consistency. This supports the expectation that the pitch angle is small enough so that a comparable sink rate and vertical velocity relationship exists in the accident database. The vertical velocity change is near the sink rate (30 ft/sec) and the initial vertical velocity (36 ft/sec) is at the severe-survivable 77th percentile, when eliminating accidents that skew the statistics. Therefore, the expectation of comparable sink speeds and vertical velocities is confirmed when the data are examined to exclude extremes.

The initial lateral velocity shows 10 ft/sec at the 80th percentile level for severe accidents. This value as a velocity change appears realistic considering the yaw angle is 0 degrees in 82 percent of the severe-survivable accidents and that a 0-degree roll angle exists for 64 percent of the data and the roll angle is equal or less than 15 degrees in nearly 85 percent of the data.

If the two severe-survivable accidents (table 18) in which an initial lateral velocity is recorded as greater than 60 ft/sec are eliminated from the database, then the statistical database of < 10 ft/sec for lateral velocities would increase from the 80th to the 84th percentile. In several instances, some of which were noted previously, there are extreme accidents which skew the data to the high side.

2.5 CRASH SCENARIO DEVELOPMENT DATA.

The database refers to five crash scenarios to represent the accident data; two ground-to-ground scenarios and three air-to-ground scenarios. Both ground-to-ground scenarios are associated with mild-survivable accidents, while the air-to-ground accidents (scenarios 3, 4, and 5) are related to the severe-survivable accidents. However, not all air-to-ground accidents in the database are severe-survivable.

Since the emphasis on developing commuter airplane crash design criteria is based on severe-survivable accidents, the air-to-ground scenarios have more meaning. The air-to-ground crash scenarios can represent varying degrees of severity; the least occurring with 50th percentile sink rates of 10 ft/sec (scenario 3) to 15 ft/sec (scenario 4) and on rigid airport terrain, or near the airport (< 5 miles), and with pilot control available. Forced landings (under pilot control) accidents have a landing speed between stall speed and design landing speed. In an extreme air-to-ground scenario (5) there can be increased sink rates (50th percentile 15-20 ft/sec), more hazards (trees and poles) and potential loss of aircraft control. This scenario contains the largest number of fatalities although the number of occupants is the least of all five scenarios. The impact velocities and attitudes are more severe with lack of control or awareness by the crew. The air-to-ground scenarios become more complicated (and severe) by the increased impact with obstacles and non-rigid terrain, such as soft soil. Approximately one-third of the severe-survivable accidents occur in soft, flat terrain as compared to about 20 percent on hard, flat terrain.

A major difficulty in reviewing the crash scenario data is in determining the relationship between the crash scenarios to impact parameters with the present database format. Using the paired drawings (see figures 8 through 13), it is possible to extract a relationship between flight path angle and sink speed (figure 14). If the sink speed is comparable to the initial vertical velocity and low pitch angles associated with the accident data, then the least mean square fit of the data shows a flight path angle of less than 15 degrees at a sink rate or vertical impact velocity of 30 to 36 ft/sec. These data are consistent with respective parameter values for the percentiles and percentage of occurrence. However, they provide some insight into the relationship between impact attitude and velocity for most of the 39 severe-survivable accidents, which is not obvious in the statistical database.

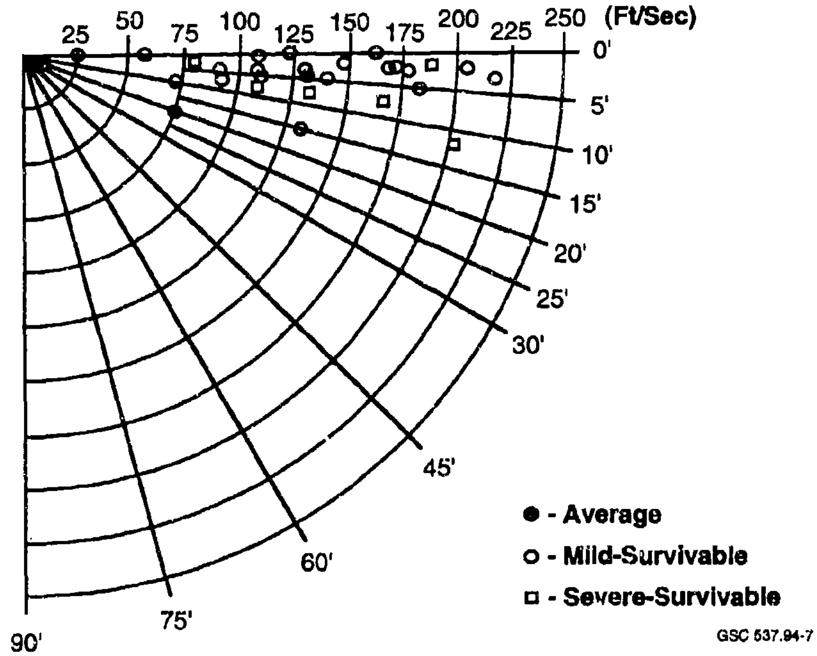

FIGURE 8. FLIGHT PATH VELOCITY VS. FLIGHT PATH ANGLE FOR SCENARIO 3

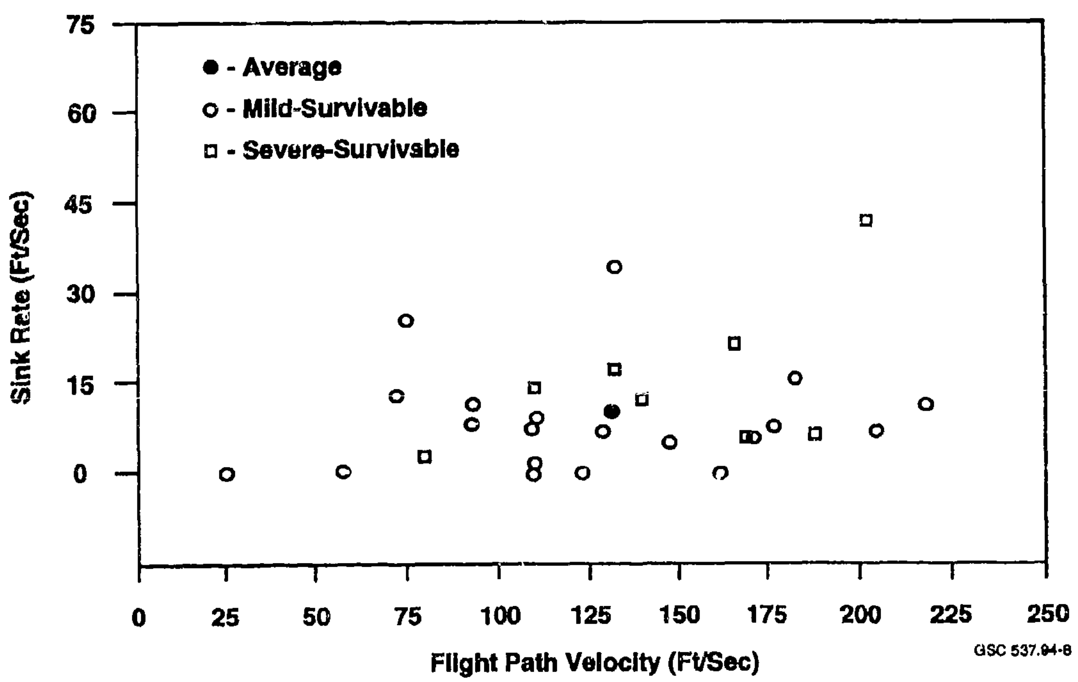

FIGURE 9. FLIGHT PATH VELOCITY VS. SINK RATE FOR SCENARIO 3

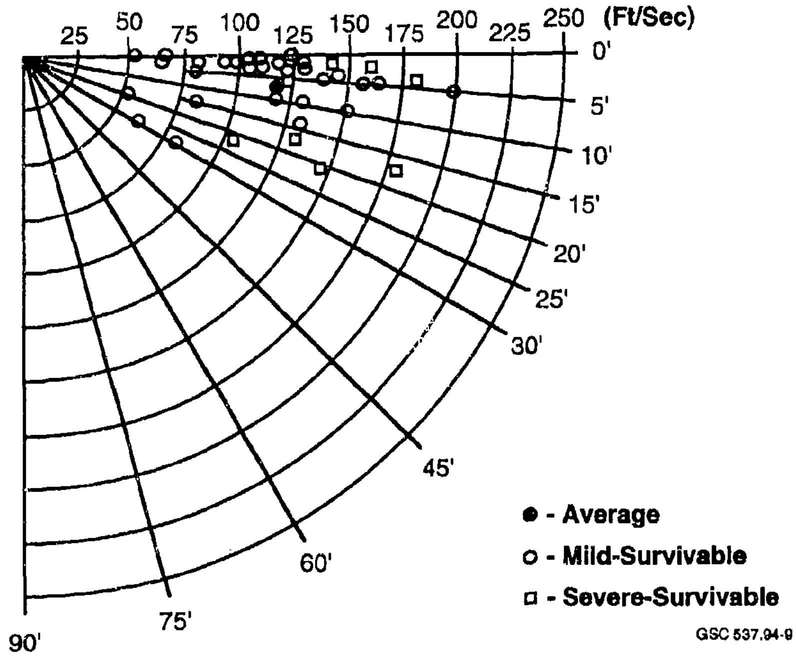

FIGURE 10. FLIGHT PATH VELOCITY VS. FLIGHT PATH ANGLE FOR SCENARIO 4

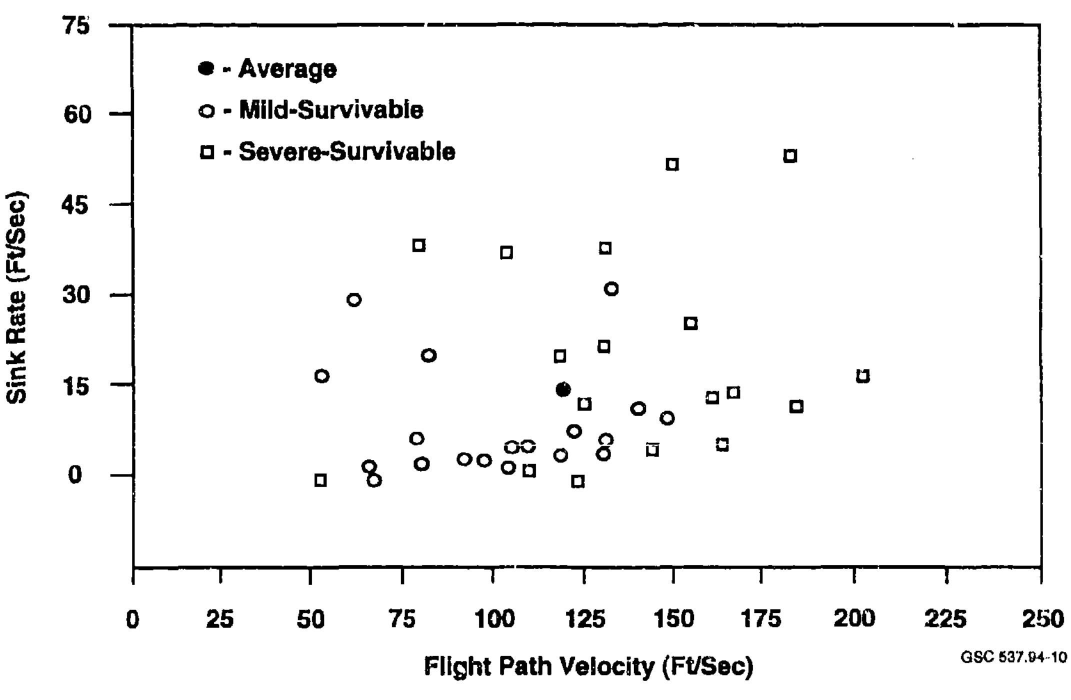

FIGURE 11. FLIGHT PATH VELOCITY VS. SINK RATE FOR SCENARIO 4

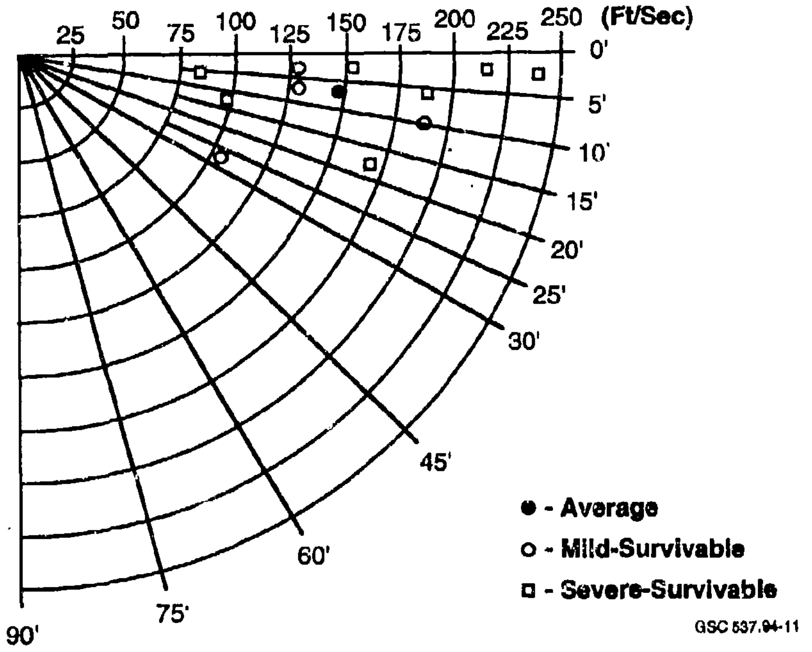

FIGURE 12. FLIGHT PATH VELOCITY VS. FLIGHT PATH ANGLE FOR SCENARIO 5

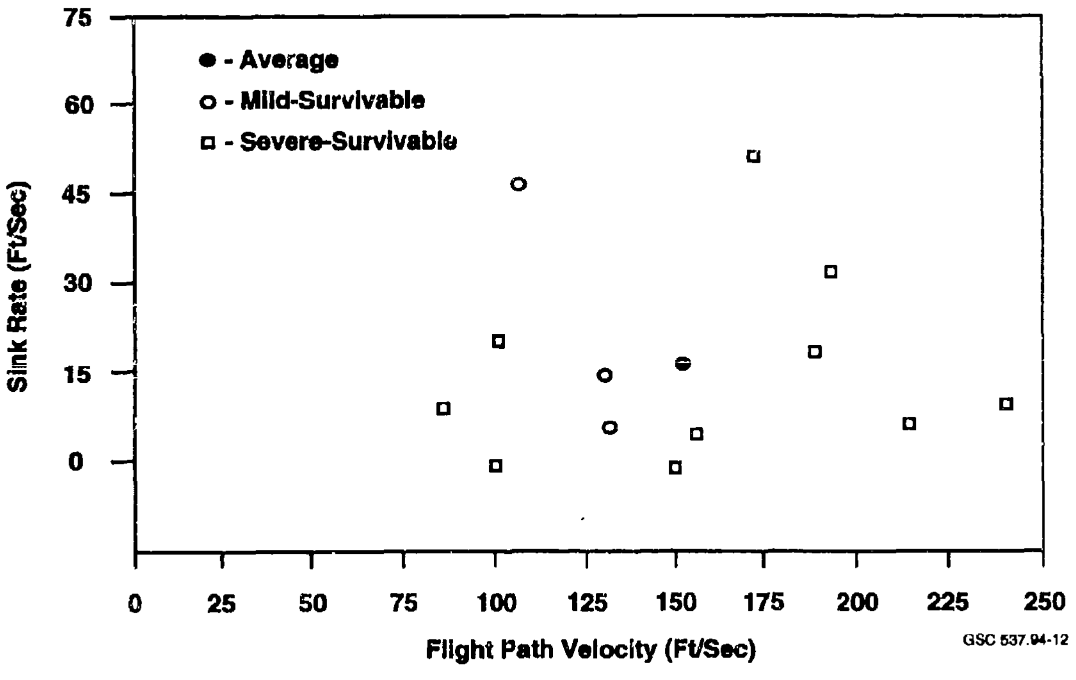

FIGURE 13. FLIGHT PATH VELOCITY VS. SINK RATE FOR SCENARIO 5

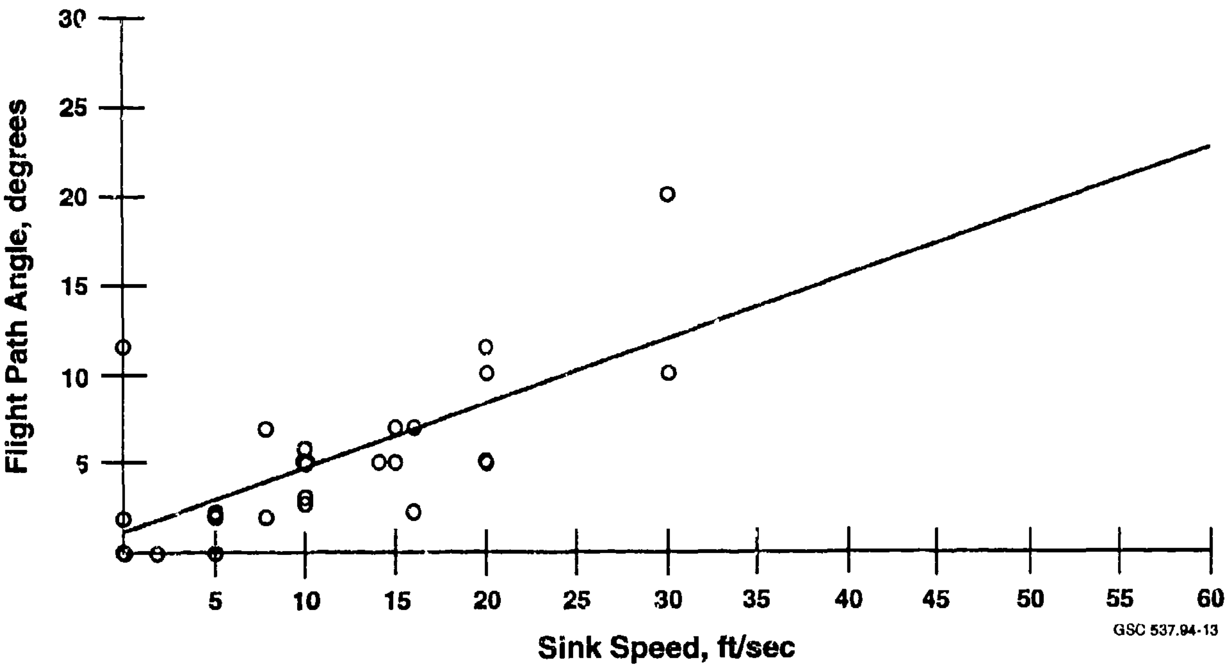

FIGURE 14. FLIGHT PATH ANGLE VS. SINK SPEED FOR SEVERE-SURVIVABLE ACCIDENTS

The crash environment, as well as the initial impact conditions, has to be considered when discussing crash scenarios. Data taken from the database for the three air-to-ground impact scenarios for the 39 severe-survivable accidents for phase of operation, impact terrain, and obstacles involved are shown in tables 4, 6, and 7, respectively. The statistical data for all 80 air-to-ground crash scenario types, whether they are mild or severe survivable are shown in tables 19, 20, and 21, for phase of operation, impact terrain, and obstacles, respectively.

TABLE 19. DISTRIBUTION BY PHASE OF OPERATION FOR AIR-TO-GROUND SCENARIOS

Phase of Operation	Total	Scenario 3	Scenario 4	Scenario 5
Forced Landing	32	2	25	5
Approach	8	3	3	2
Go-Around	2	1	1	0
Takeoff	19	12	4	3
Landing	18	11	4	3
Cruise	1	0	1	0
Number of Accidents	80	29	38	13

TABLE 20. DISTRIBUTION OF IMPACT TERRAIN FOR AIR-TO-GROUND SCENARIOS

Impact Terrain	Total	Scenario Three	Scenario Four	Scenario Five
Hard, Flat	27	17	7	3
Soft, Flat	21	4	12	5
Rough, Rocky	5	1	3	1
Water	8	1	7	0
Snow Covered	10	5	3	2
Ice	3	0	3	0
Other	6	1	3	2
Number of Accidents	80	29	38	13

TABLE 21. DISTRIBUTION OF OBSTACLES HIT FOR AIR-TO-GROUND SCENARIOS

Obstacles Hit	Total	Scenario Three	Scenario Four	Scenario Five
Tree, Pole	21	1	13	7
Building	1	0	1	0
Fence	3	1	0	2
Powerline	2	1	1	0
Ditch	1	1	0	0
Embankment	5	5	0	0
None	45	18	23	4
Other	2	2	0	0
Number of Accidents	80	29	38	13

Tables 22, 23, and 24 show the comparison of these data.

TABLE 22. COMPARISON OF PHASE OF OPERATION FOR AIR-TO-GROUND ACCIDENTS

	Severe-Survivable (percent)	Scenarios 3, 4, and 5 (percent)
Forced landing or landing	51.3	51.2
Takeoff	25.6	23.8
Landing	20.5	22.5

TABLE 23. COMPARISON OF IMPACT TERRAIN FOR AIR-TO-GROUND ACCIDENTS

		Percentages of Total				
	Number of Accidents	Hard Flat	Soft Flat	Water	Snow Ice	Other
Severe-survivable	39	23.1	25.6	10.3	23.0	18.0
Scenarios 3, 4, and 5	80	33.8	26.3	10.0	16.3	13.6

TABLE 24. COMPARISON OF IMPACT OBSTACLES FOR AIR-TO-GROUND ACCIDENTS

	Severe-Survivable (percent)	Scenarios 3, 4, and 5 (percent)
Trees and poles	28.2	26.3
Embankments	5.1	6.2
NONE	48.7	56.0

These statistical data indicate that the development of a crash scenario for commuter airplane crash design criteria represents not only the severe-survivable accidents but a wider range of survivable impacts. The summary of the preimpact and kinematic data presented in percentiles is conservative (lower percentiles)—since it is for severe-survivable accidents, while this discussion indicates that in air-to-ground scenarios the environment is similar for both mild- and severe-survivable accidents. The effect of adding less severe air-to-ground accident data would lower the magnitude of the impact parameters associated with the same percentile level, or conversely increase the percentile associated with the same impact parameter magnitude.

3. CONCLUSIONS.

The data compiled from 80 air-ground impacts, of which 39 had either a serious injury or fatality, permits the following conclusions to be made.

a. The impact parameters that define this envelope are based on a 77th to 85th percentile range or on a similar frequency of occurrence range. This range of occurrence is less severe that military 95th percentiles and is considered appropriate for civil aircraft. The crash survivable design envelope is defined as follows:

Impact Attitude (based on percent of occurrence)
- Flight Path Angle; 0 to -12 degrees
- Pitch Angle; -15 to +15 degrees
- Roll Angle; -15 to +15 degrees
- Yaw Angle; 0 degrees

Impact Velocities (based on percentiles, except for flight path velocity)
- Sink Speed; 30 to 36 ft/sec
- Flight Path Velocity; > stall speed
- Lateral Velocity; ≤ 10 ft/sec

b. Velocity change profiles for the vertical and lateral directions were also determined and were based on 77th to 80th percentile values. These profiles are as follows:

Vertical Velocity Change; ≤ 36 ft/sec
Lateral Velocity Change; ≤ 10 ft/sec

The longitudinal velocity change could not be determined from the data.

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