

**DOT/FAA/AR-08/20**

Air Traffic Organization  
Operations Planning  
Office of Aviation Research  
and Development  
Washington, DC 20591

# **Vertical Impact Response Characteristics of Four Commuter/Regional Airplanes**

Allan Abramowitz  
Dr. Tong Vu

Federal Aviation Administration  
William J. Hughes Technical Center  
Airport and Aircraft Safety Research and  
Development Division  
Atlantic City International Airport, NJ 08405

September 2008

Final Report

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1. Report No. DOT/FAA/AR-08/20		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle VERTICAL IMPACT RESPONSE CHARACTERISTICS OF FOUR COMMUTER/REGIONAL AIRPLANES				5. Report Date September 2008	
				6. Performing Organization Code	
7. Author(s) Allan Abramowitz and Dr. Tong Vu				8. Performing Organization Report No.	
9. Performing Organization Name and Address Federal Aviation Administration William J. Hughes Technical Center Airport and Aircraft Safety Research and Development Division Materials and Structures Branch Atlantic City International Airport, NJ 08405				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Air Traffic Organization Operations Planning Office of Aviation Research and Development Washington, DC 20591				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code ANM-100	
15. Supplementary Notes Crashworthiness Program Manager: Curt Davies Crashworthiness Project Manager: Allan Abramowitz					
16. Abstract <p>The Federal Aviation Administration (FAA) proposed seat dynamic performance standards for Title 14 of the Code of Federal Regulations (CFR) Part 23 commuter category airplanes. Current 14 CFR Parts 23 and 25 seat dynamic performance standards were established empirically using the results of prior airplane crash impact test programs. In the development of these standards, it was noted that the full-scale airplane impact test database did not include airplanes representative in size of commuter/regional airplanes. To provide data for these size airplanes, the FAA conducted four full-scale vertical impact tests of commuter/regional airplanes.</p> <p>The tests were conducted at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The structural response of the airframes, seats, and anthropomorphic test dummies was measured for each test. The airplanes tested were a 19-passenger Fairchild Metro III, a 19-passenger Beechcraft 1900C, a 30-passenger Short Brothers 3-30, and a 42-passenger ATR 42-300.</p> <p>The results showed that flat-belly fuselages developed higher accelerations with shorter pulse durations than curved-belly fuselages, and the dynamic crush during the test was consistent with the results of an idealized triangular impact. The ATR 42 wing and the Shorts 3-30 overhead fuel tanks penetrated the occupied volume of the cabin after their support structures failed. The overall data showed two groups of fuselage responses: Group 1 with higher accelerations and shorter pulse durations and Group 2 with lower acceleration and longer pulse duration. Group 1 had an average crush depth of 10 inches and Group 2, 18 inches. Only one of the four fuselages was able to effectively use its underfloor crush depth to reduce fuselage acceleration.</p>					
17. Key Words Crash testing, Vertical impact, Drop test, Dynamic testing, Acceleration, Airplane, Metro III, Beechcraft 1900C, ATR 42, Shorts 3-30			18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 49	22. Price

## ACKNOWLEDGMENTS

The authors would like to thank Mr. Gary Frings, Crashworthiness Program Manager (retired), and Mr. Stephen Soltis, Chief Scientific and Technical Advisor for Crash Dynamics (retired), of the Federal Aviation Administration for their technical direction during this program.

They would also like to thank Mr. Anthony Dang, airframe and powerplant technician, for his invaluable assistance.

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## LIST OF ACRONYMS

ATD	Anthropomorphic test dummy
c.g.	Center of gravity
CFC	Channel frequency class
CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
FS	Fuselage station
HS	High-speed
MGTOW	Maximum gross takeoff weight
SFAR	Special Federal Aviation Regulation

## EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) proposed seat dynamic performance standards for Title 14 Code Federal Regulations (CFR) Part 23 commuter regional airplanes. Current 14 CFR Parts 23 and 25 seat dynamic performance standards were established empirically using the results of prior airplane crash impact test programs. In the development of these standards, it was noted that the full-scale airplane impact test database did not include airplanes representative in size of commuter/regional airplanes. To provide data for these (30 and 42 passenger) size airplanes, the FAA conducted four full-scale vertical impact tests of small regional airplanes. The tests were structured to assess the impact response characteristics of airframe structures and seats and the potential for occupant impact injury. This report presents the impact response characteristics of the four metal airframes that were tested by the FAA. This information will provide a basis to assess the adequacy of current regulatory standards for small commuter airplanes.

The tests were conducted at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The geometry of each of the four airplanes was unique. All tests were designed to simulate maximum takeoff configuration, including seats, simulated occupants, and cargo. The structural response of the airframes, seats, and anthropomorphic test dummies was measured for each test. A brief description of each test is given below.

- A vertical impact test of a metal, low-wing, curved-belly, 19-passenger Fairchild Metro III commuter airplane, with a 14 CFR Part 23, SFAR 41 type certificate, impacting at 26.8 ft/sec
- A vertical impact test of a metal, low-wing, flat-belly, 19-passenger Beechcraft 1900C commuter airplane, with a 14 CFR Part 23, SFAR 41 type certificate, impacting at 26.8 ft/sec
- A vertical impact test of a metal, high-wing, flat-belly, 30-passenger Short Brothers PLC, Model SD 3-30 small regional airplane certified to 14 CFR Part 25, impacting at 30 ft/sec
- A vertical impact test of a metal, low-wing, curved-belly, 42-passenger ATR 42-300 small regional airplane certified to 14 CFR Part 25, impacting at 30 ft/sec

The results showed

- acquired and idealized triangular impact pulse shapes that might be used for the definition of seat dynamic performance standards for 14 CFR Part 23 commuter category and 14 CFR Part 25 small regional airplanes were defined for the range of planes tested.
- the overall data indicated that both fuselage shape and underfloor structural depth are governing factors that determine the impact response characteristics of an airframe structure.

- flat-belly fuselages developed higher accelerations with shorter pulse durations than curved-belly fuselages.
- dynamic crush during the tests was consistent with the results of an idealized triangular impact.
- the ATR 42 wing and the Shorts 3-30 overhead fuel tanks penetrated the occupied volume of the cabin after their support structures failed.
- high-wing and overcabin fuel tanks had little effect on fuselage acceleration near the floor areas.
- there were two groups of fuselage responses: Group 1 with higher accelerations and shorter pulse durations ( $G_{\max}$  101 g and 20 msec) consisting of the B 1900C, Shorts 3-30, and Metro III, and Group 2 with lower acceleration and a longer pulse duration ( $G_{\max}$  20 g and 84 msec) consisting of the ATR 42.
- group 1 had an average available crush depth of 10 inches and Group 2 had 18 inches.
- only one of the four fuselages was able to effectively use its underfloor crush depth to reduce fuselage acceleration.

## 1. INTRODUCTION.

The Federal Aviation Administration (FAA) is evaluating the adequacy of current certification standards for seat and restraint systems for small commuter regional airplanes (Title 14 Code of Federal Regulations (CFR) Part 23 and small Part 25). Current 14 CFR Parts 23 and 25 seat dynamic performance standards were established empirically using the results of prior airplane crash impact test programs. In the development of these standards, it was noted that the full-scale airplane impact test database did not include airplanes representative in size of commuter/regional airplanes. To provide data for these size airplanes, the FAA conducted full-scale vertical impact tests of four metal, small regional (30 and 42 passenger) airplanes. The tests were structured to assess the impact response characteristics of airframe structures and seats and the potential for occupant impact injury. This report presents impact response characteristics of the airframes that were tested by the FAA. This information will provide a basis to assess the adequacy of current regulatory standards for small commuter airplanes.

### 1.1 BACKGROUND.

To support the FAA Aircraft Safety Research Plan [1], four severe, but survivable, full-scale vertical impact tests of commuter/regional airplanes were conducted at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The geometry of each airplane was unique. All tests were designed to simulate maximum takeoff configuration, including seats, simulated occupants, and cargo. The structural response of the airframes, seats, and anthropomorphic test dummies (ATD) was measured for each test. A brief description of each test is given below:

- A vertical impact test of a Fairchild Metro III airplane was conducted in 1992 [2]. The Metro III is a metal, low-wing, curved-belly, 19-passenger commuter airplane with a 14 CFR Part 23 SFAR 41 type certificate. The fuselage was dropped onto a robust wooden platform from a vertical height of 11.2 feet, resulting in an impact velocity of approximately 26.8 ft/sec.
- A vertical impact test of a Beechcraft 1900C (B 1900C) airplane was conducted in 1995 [3]. The B 1900C is a metal, low-wing, flat-belly, 19-passenger commuter airplane with a 14 CFR Part 23 SFAR 41 type certificate. The fuselage was dropped onto a robust wooden platform from a vertical height of 11.2 feet, resulting in an impact velocity of approximately 26.8 ft/sec.
- A vertical impact test of a Short Brothers PLC, Model SD 3-30 (Shorts 3-30) airplane was conducted in 1998 [4]. The Shorts 3-30 is a metal, high-wing, flat-belly, 30-passenger, small regional airplane. It is certified to 14 CFR Part 25 and was primarily operated as a regional transport in a commuter role. The fuselage was dropped onto a robust wooden platform from a vertical height of 14 feet, resulting in an impact velocity of 30 ft/sec.
- A vertical impact test of an ATR 42-300 (ATR 42) airplane was conducted in 2003 [5]. The ATR 42 is a metal, low-wing, curved-belly, 42-passenger airplane. It is certified to

14 CFR Part 25 and has been primarily operated as a regional transport in a commuter role. The fuselage was dropped onto a concrete surface from a vertical height of 14 feet, resulting in an impact velocity of 30 ft/sec.

## 2. DESCRIPTION OF TESTS.

### 2.1 DROP TEST FACILITY.

The drop test facility is comprised of two 57-foot vertical steel towers connected at the top by a horizontal platform (figures 1-3). The Metro III, B 1900C, and Shorts 3-30 airplanes were dropped onto a 15-ft by 36-ft robust wooden platform, which rests on steel I-beams and is supported by 12 load cells (figure 1). The ATR 42 was dropped onto a 10-ft-wide by 64-ft-long by 8-in.-thick temporary concrete pad (figure 2).

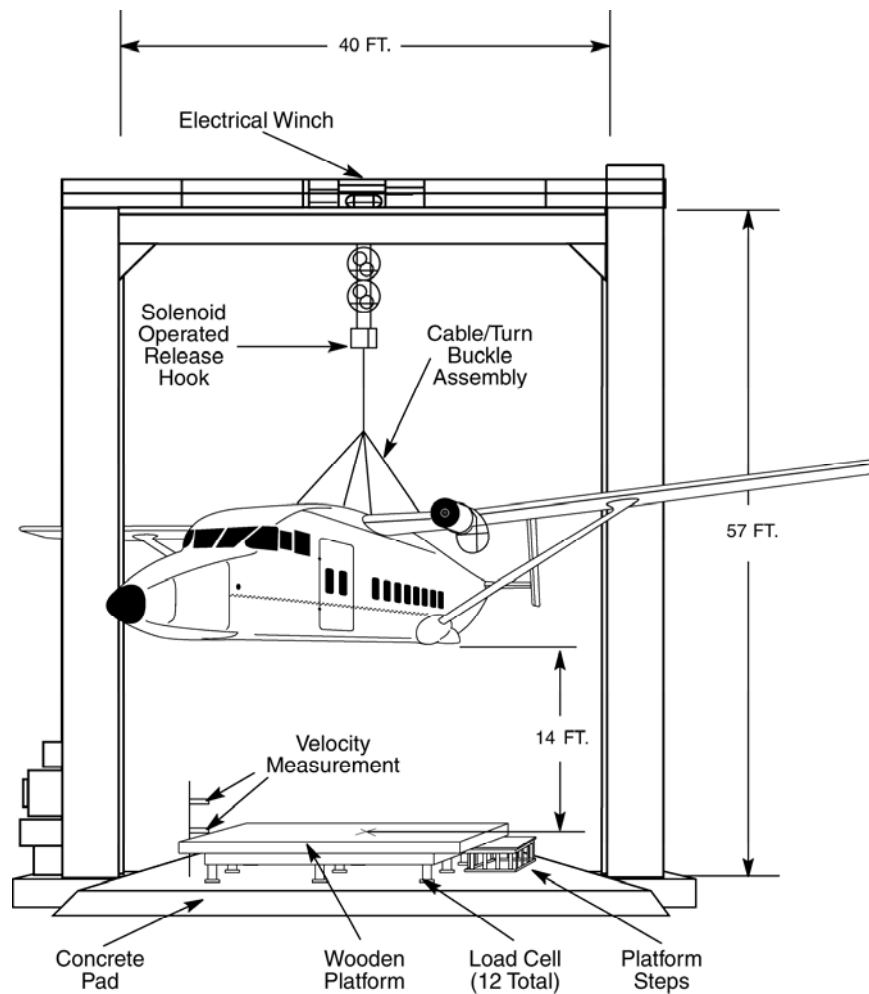


Figure 1. Schematic of Dynamic Drop Test Facility With Wooden Platform

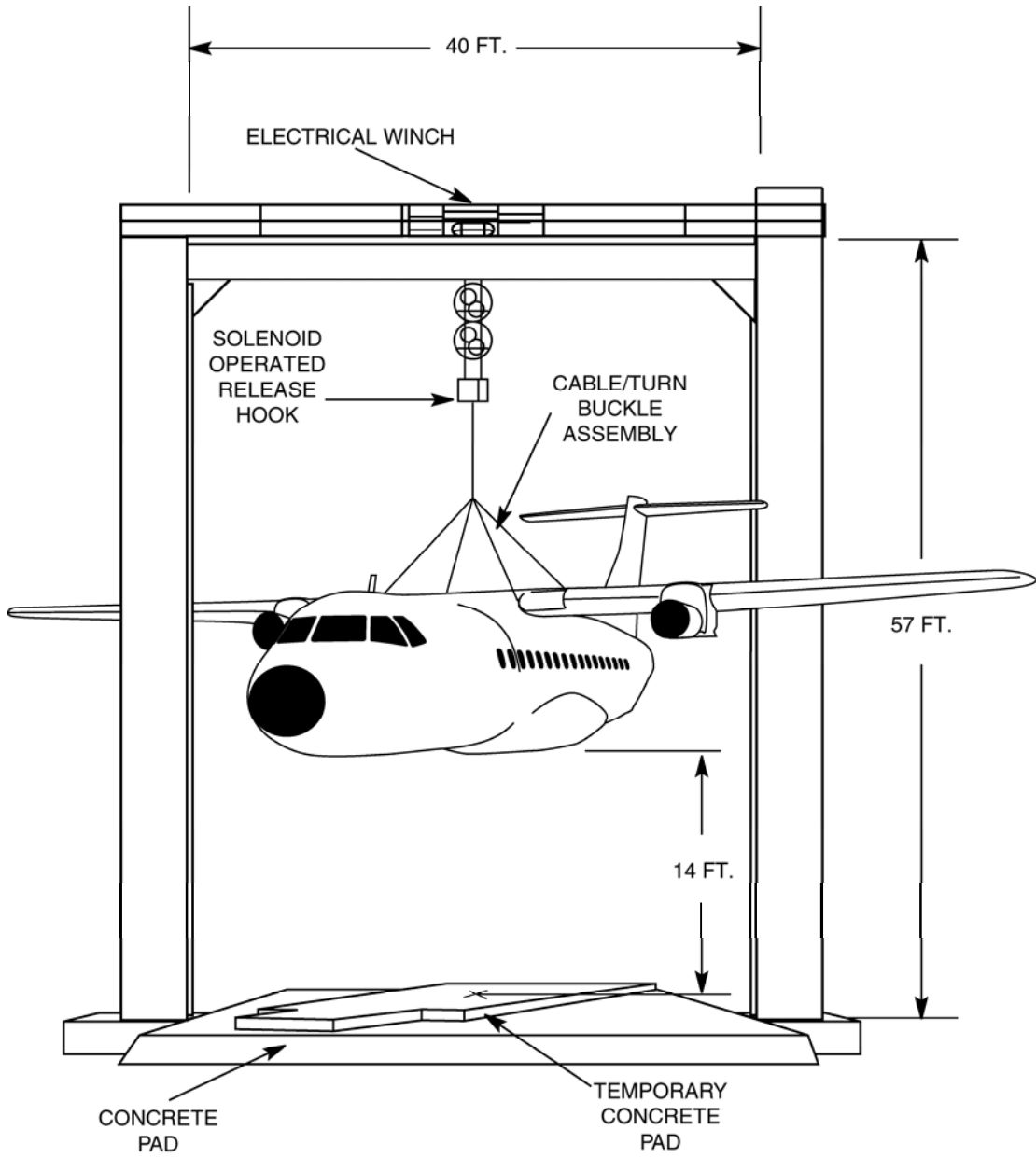


Figure 2. Schematic of Dynamic Drop Test Facility With Temporary Concrete Pad

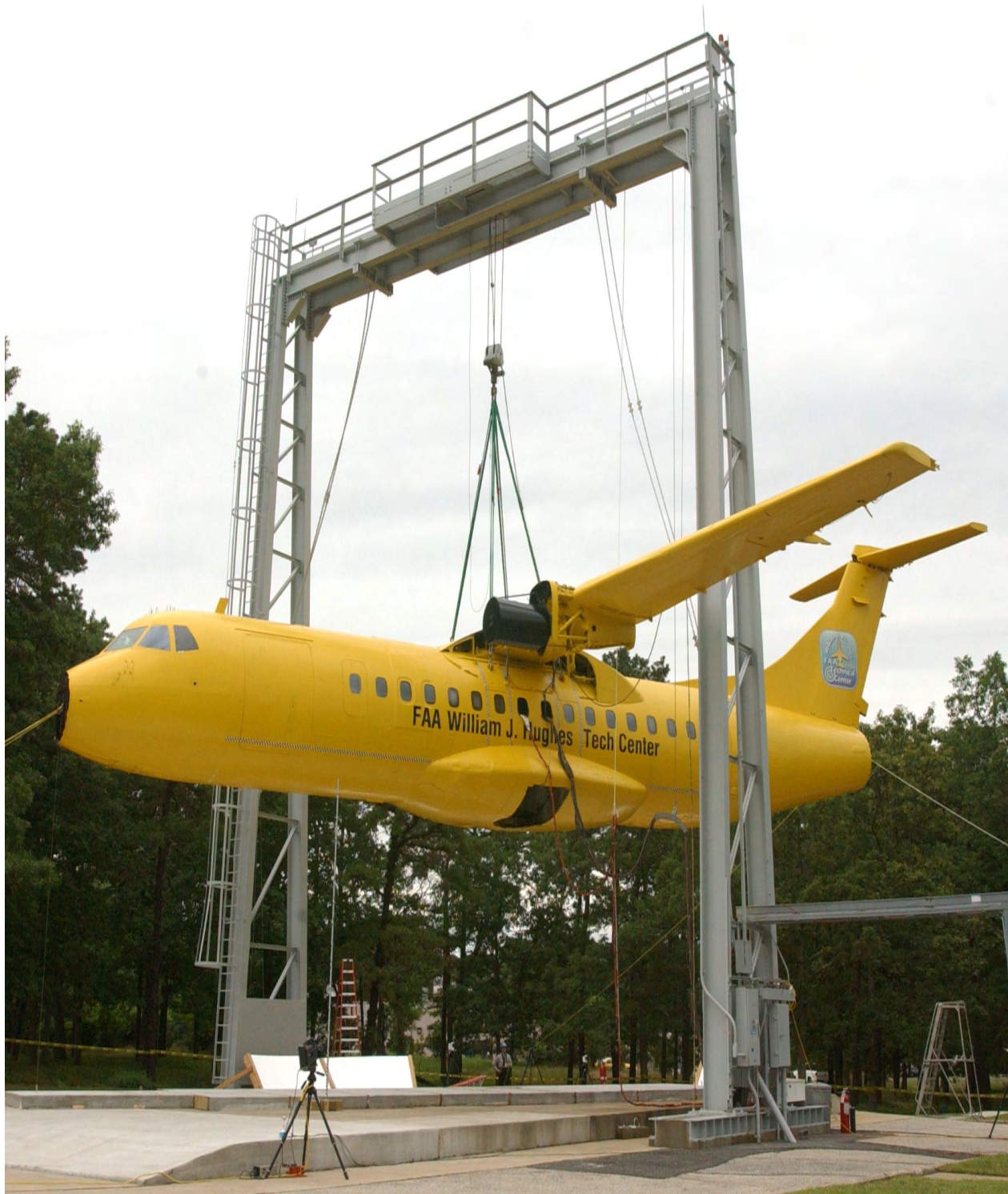


Figure 3. Dynamic Drop Test Facility With ATR 42 Airplane

## 2.2 TEST ARTICLES.

### 2.2.1 Fairchild Metro III.

The Metro III, shown in figure 4, is a low-wing, twin-turboprop, 19-passenger commuter airplane built by Fairchild Aircraft Company of San Antonio, Texas.

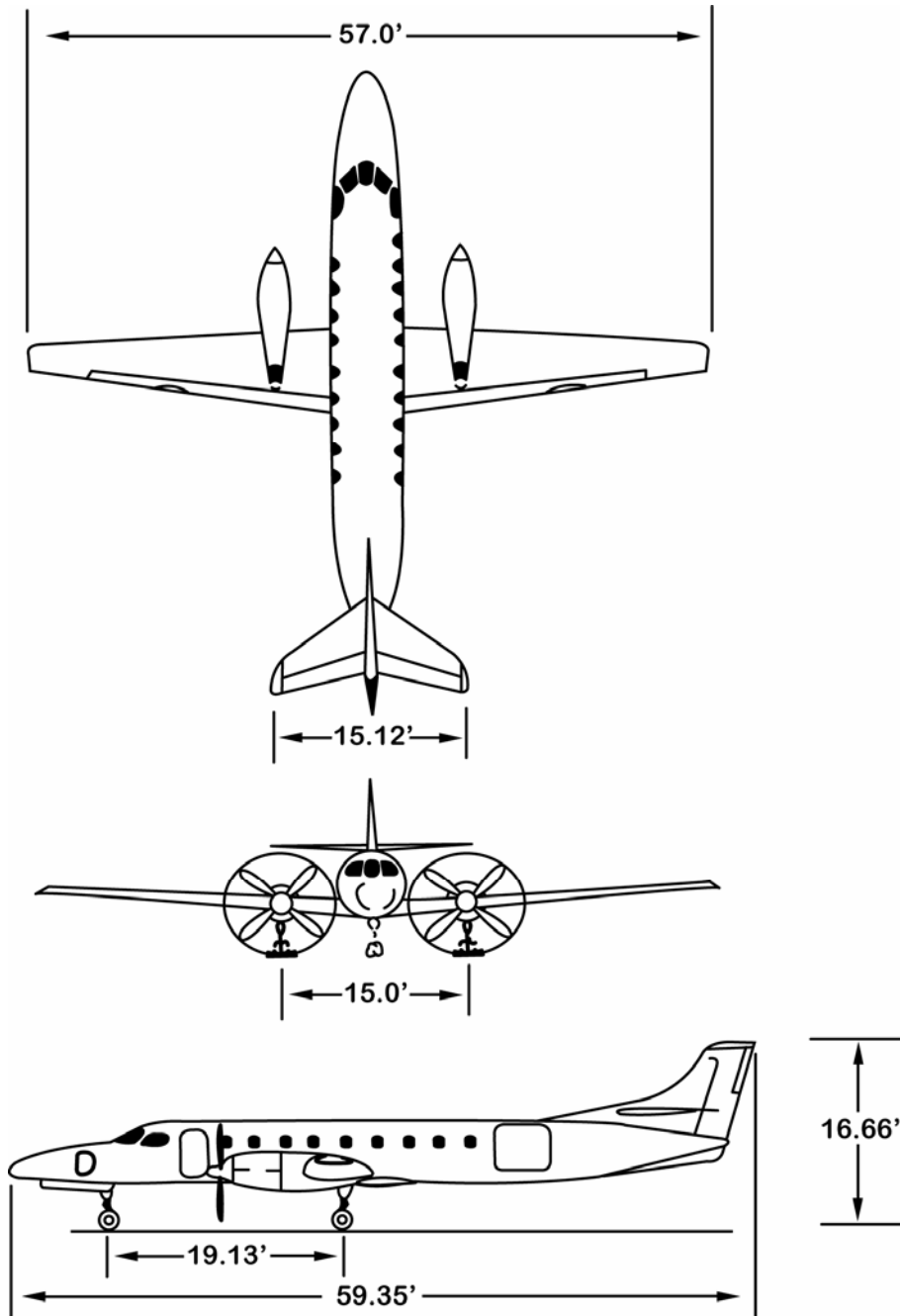


Figure 4. Metro III Dimensions



The following modifications were made to the Metro III prior to the test (figure 5):

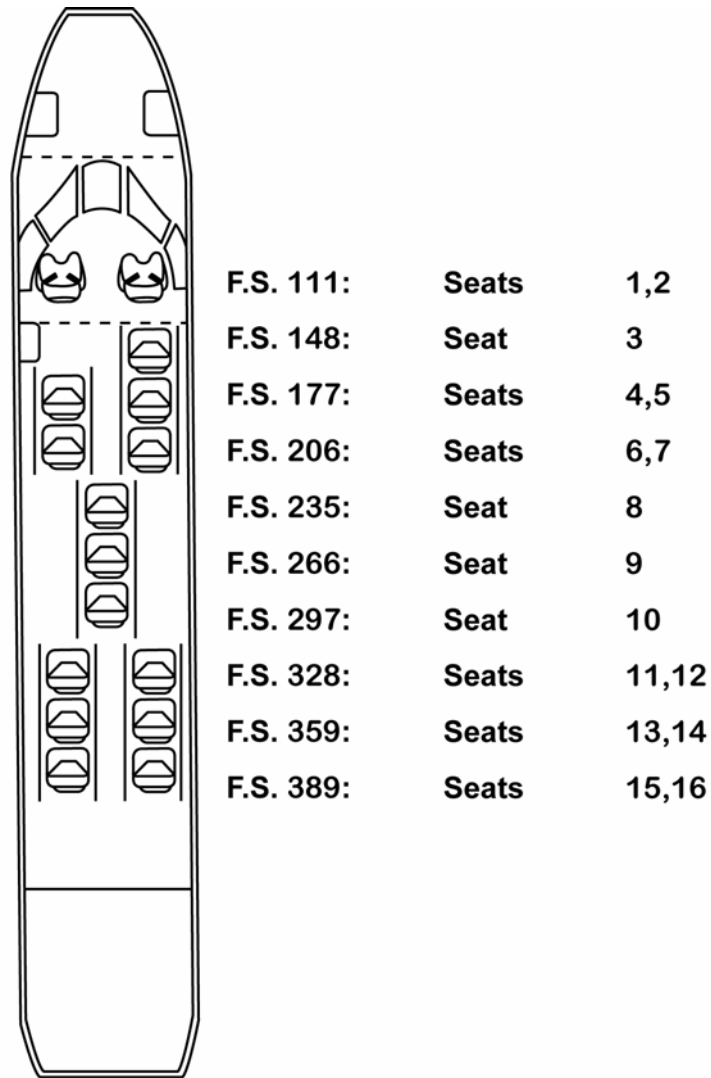
- The wings (including landing gear) and engines were removed, since they have little influence on the fuselage impact response.
- The cabin lining and insulation (both nonstructural) were removed to allow for the pre- and posttest documentation of the airframe structure.
- Ballast was added to the aft section to simulate baggage and empennage.
- Ballast was placed in the forward baggage compartment to simulate baggage.
- The empennage was removed.



Figure 5. Metro III Fuselage

The internal seating arrangement was modified for the test to accommodate a variety of seats (figure 6). Each seat was occupied by either a 50th percentile male Hybrid II Anthropomorphic

Test Dummy (ATD) or a mannequin, comparable in size and weight, to represent the weight of an occupant. Seat and dummy types are detailed in reference 2.



**HYBRID II ANTHROPOMORPHIC DUMMY (170lbs, Fiftieth Percentile)**  
 Seats 1,2,8,9,11,12

**ARMSTRONG MEDICAL "Rescue Randy" (165lbs)**  
 Seats 3,4,5,6,7,10,13,14,15,16

Figure 6. Metro III Seat Configuration

The Metro III fuselage airframe was circular (figure 7) with 11.1 inches of underfloor crush depth between the airplane floor and the belly skin (figure 8).



Figure 7. Front-to-Rear View of the Metro III Cabin

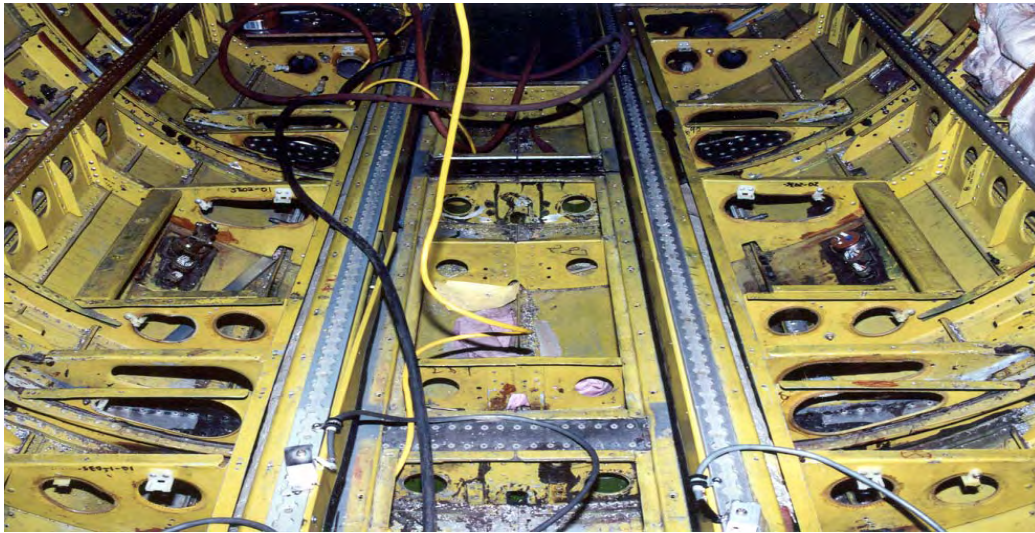


Figure 8. Crushable Area Between the Cabin Floor and the Belly of the Metro III

The test weight was 7347 pounds. This weight represents the maximum gross takeoff weight (MGTOW) of the airplane minus portions of the airplane that were removed. The airplane center of gravity (c.g.) was located at fuselage station (FS) 258 (258 inches aft of the nose).

### 2.2.2 Beechcraft 1900C.

The B 1900C is a 57' 10" long, low-wing, twin-turboprop, 19-passenger commuter airplane. The following modifications were made to the airplane prior to the test (figure 9):

- The wings (including landing gear) and engines were removed, since they have little influence on the fuselage impact response.
- The vertical and horizontal stabilizers were removed; ballast was added to the tail section to compensate for the weight.
- The cabin lining and insulation (both nonstructural) were removed to allow for the pre- and posttest documentation of the airframe structure.
- The pilot and copilot seats were not installed; ballast simulated the weight of the seats and occupants.



Figure 9. The B 1900C Fuselage

The internal seating arrangement was modified for the test to accommodate a variety of seats (figure 10). Each seat was occupied by an ATD or ballast to represent the weight of an occupant. Seats and simulated occupants are detailed in reference 3.

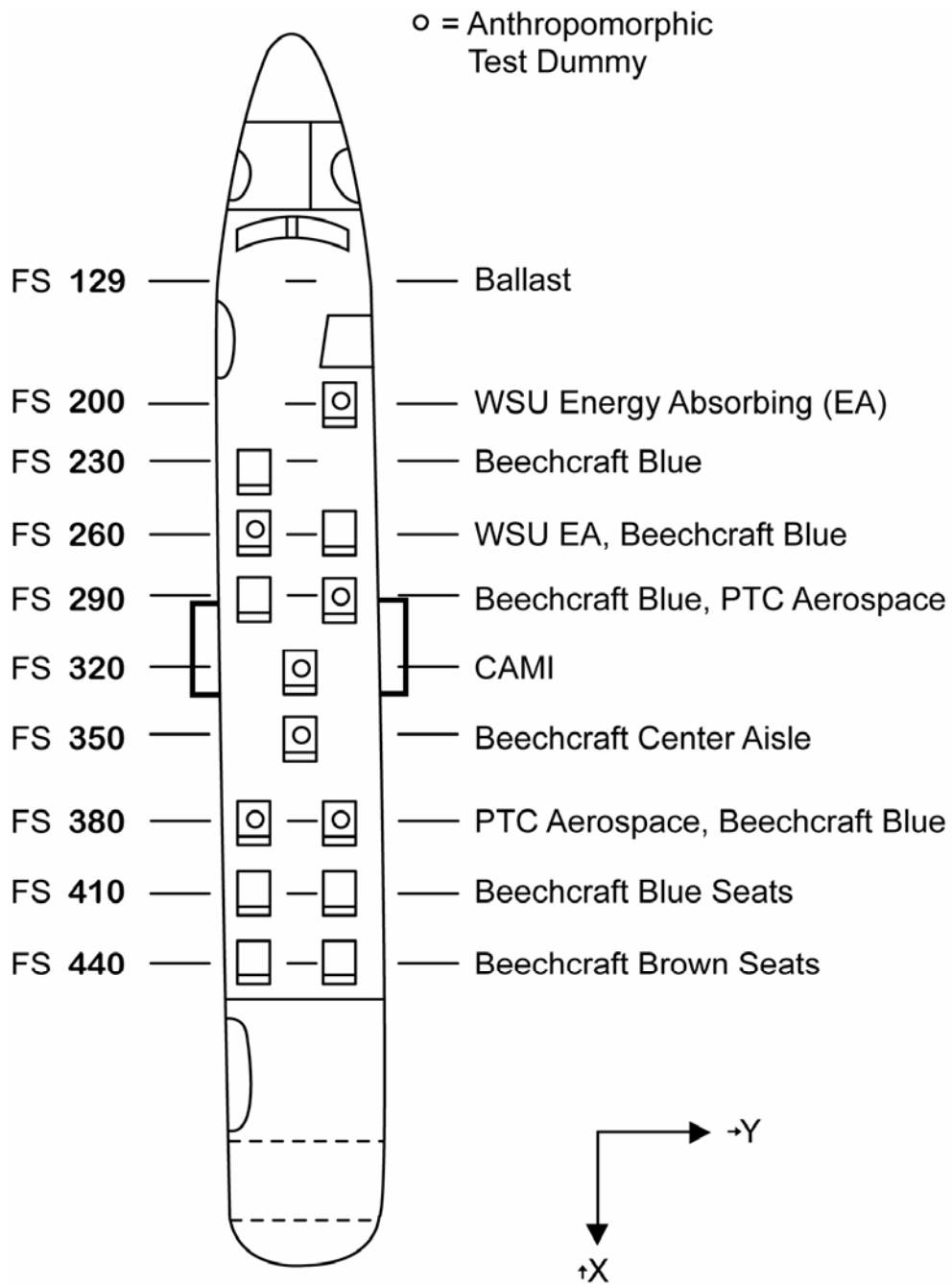


Figure 10. The B 1900C Seat Configuration

The B 1900C fuselage airframe is rectangular with round corners. Crushable depth between the airplane floor and the flat-belly skin is approximately 9.9 inches. The floor tracks are attached to the belly airframe by stiff short stanchions (figure 11).



Figure 11. Front-to-Rear View of the B 1900C Cabin

The total weight of the test article was 8475 pounds. This weight was chosen to represent the MGTOW of the airplane, taking into consideration the weight of the portions of the airplane that were removed. The airplane c.g. was located at FS 303.

### 2.2.3 Shorts 3-30.

The Shorts 3-30, shown in figure 12, is a high-wing, twin-turboprop, 30-passenger, small regional airplane.

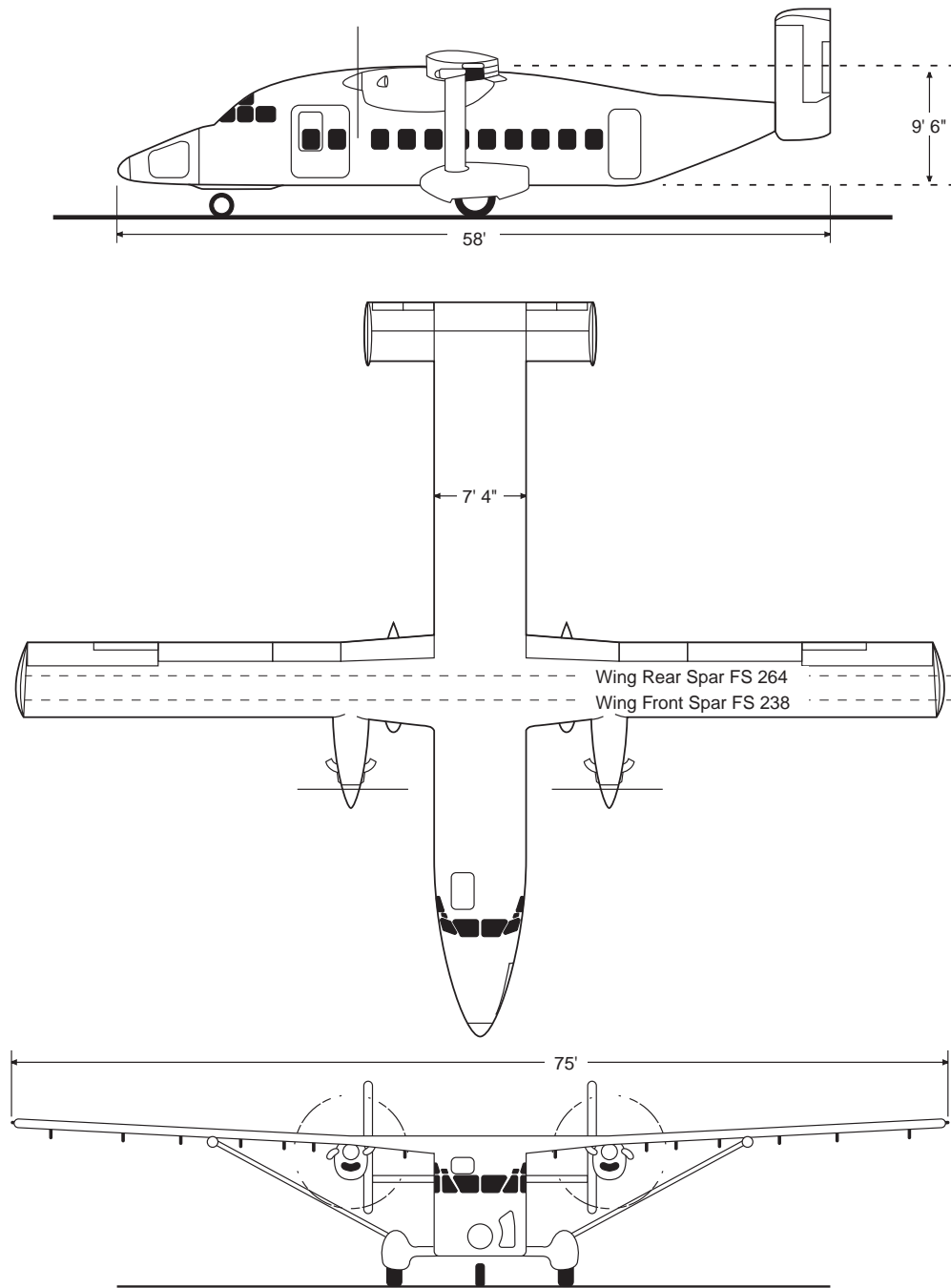


Figure 12. Shorts 3-30 Dimensions

Prior to the test, the following modifications were made to Shorts 3-30 (figure 13):

- The weight and c.g. of the engines were simulated using partially filled concrete barrels.
- The landing gear was removed, since it would have little influence on the fuselage impact response.

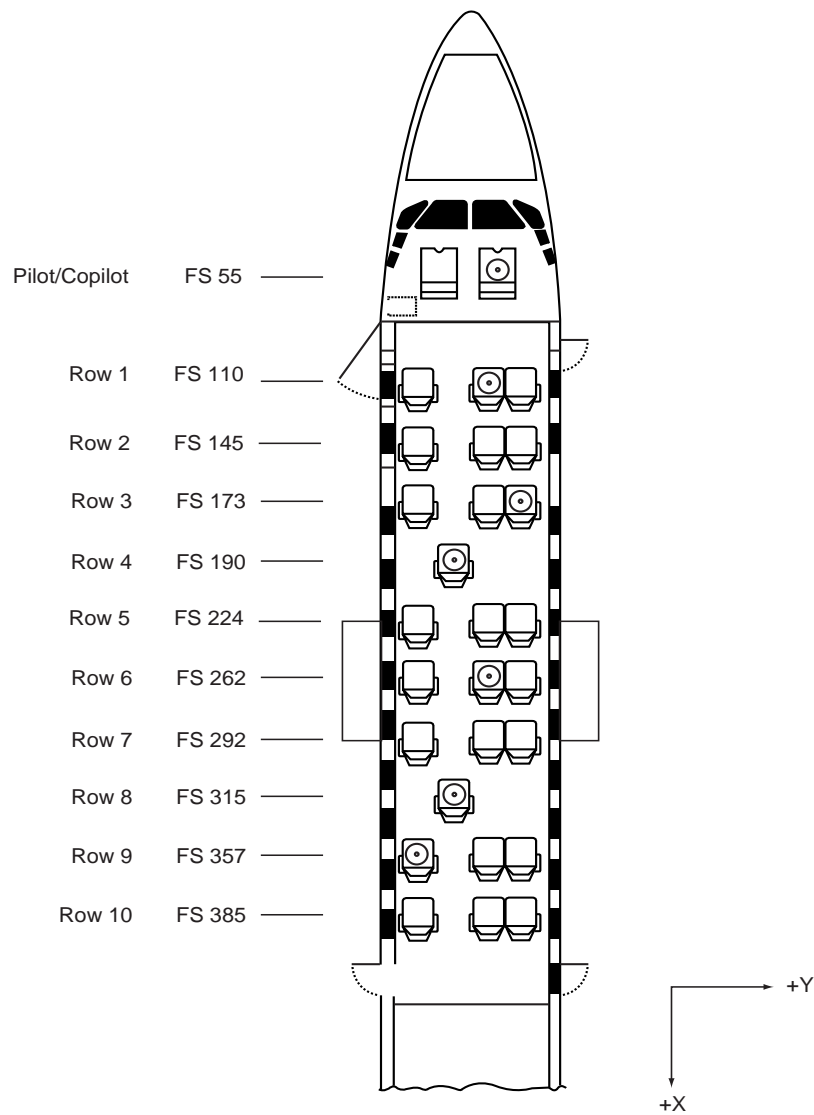
- The lower portion of the landing gear fairing on the stub wing was removed, since it would have little influence on the fuselage impact response.
- All fuel ports on the tanks were capped before the test, with the exception of the cell 3-4 interconnect pipe.
- The cabin lining and insulation (both nonstructural) were removed to allow for the pre- and posttest documentation of the airframe structure.
- Water was used to simulate fuel.



Figure 13. Shorts 3-30 Fuselage

The internal seating arrangement was modified for the test to accommodate two nonstandard seats (figure 14). Each seat was occupied by an ATD or a mannequin to represent the weight of an occupant. Seats and simulated occupants are detailed in reference 4.





Notes:  
 ⊗ = Anthropomorphic test dummies (ATD)  
 All remaining seats were occupied by mannequins.

Figure 14. Shorts 3-30 Seat Configurations

The Shorts 3-30 fuel system configuration is unique because two fuel tanks are located on top of the fuselage (figure 15). Even though cells 1, 2, and 3 are physically housed together and cell 4 is separate, cells 1 and 2 comprised tank 1, and cells 3 and 4 comprised tank 2. Each tank holds 288 gallons of fuel. For this test, the tanks were filled to approximately 3/4 capacity with water to represent a full load of fuel (fuel is approximately 3/4 the weight of water).

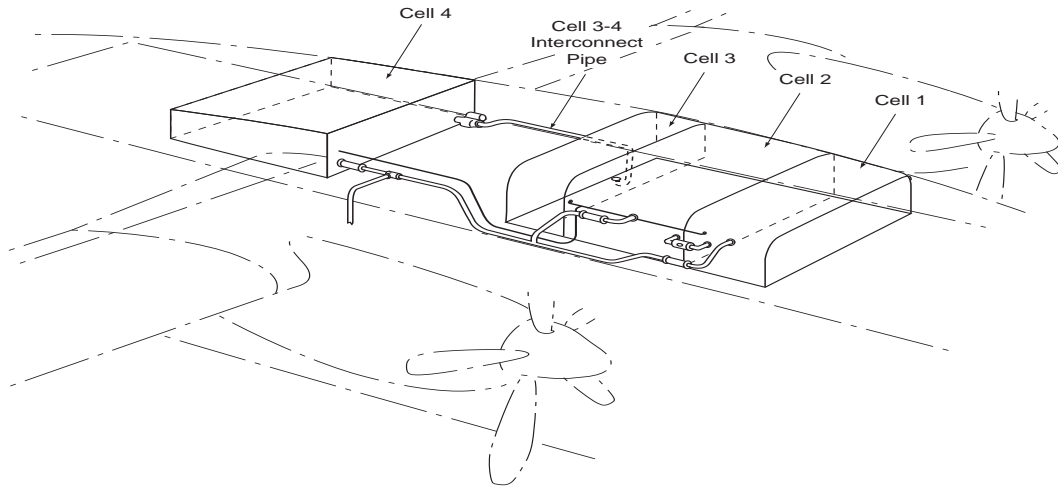


Figure 15. Shorts 3-30 Fuel System

The Shorts 3-30 fuselage airframe is square (figure 16). The seat tracks are connected directly to the belly skin by solid I-beams, which are also attached to the airframe. The distance between the floor and the belly skin is approximately 8.2 inches.



Figure 16. Rear-to-Front View of the Shorts 3-30 Cabin

The total test weight of the airplane was 21,210 pounds. This weight represents the MGTOW (22,352 pounds) minus portions that were removed and/or modified (1,142 pounds). The c.g. was calculated to be at FS 240.

#### 2.2.4 ATR 42-300.

The ATR 42, as shown in figure 17, is a high-wing, twin-turboprop, 42-passenger, small regional airplane. The airplane was manufactured by a joint effort between Aerospatiale (France) and Aeritalia (Italy).

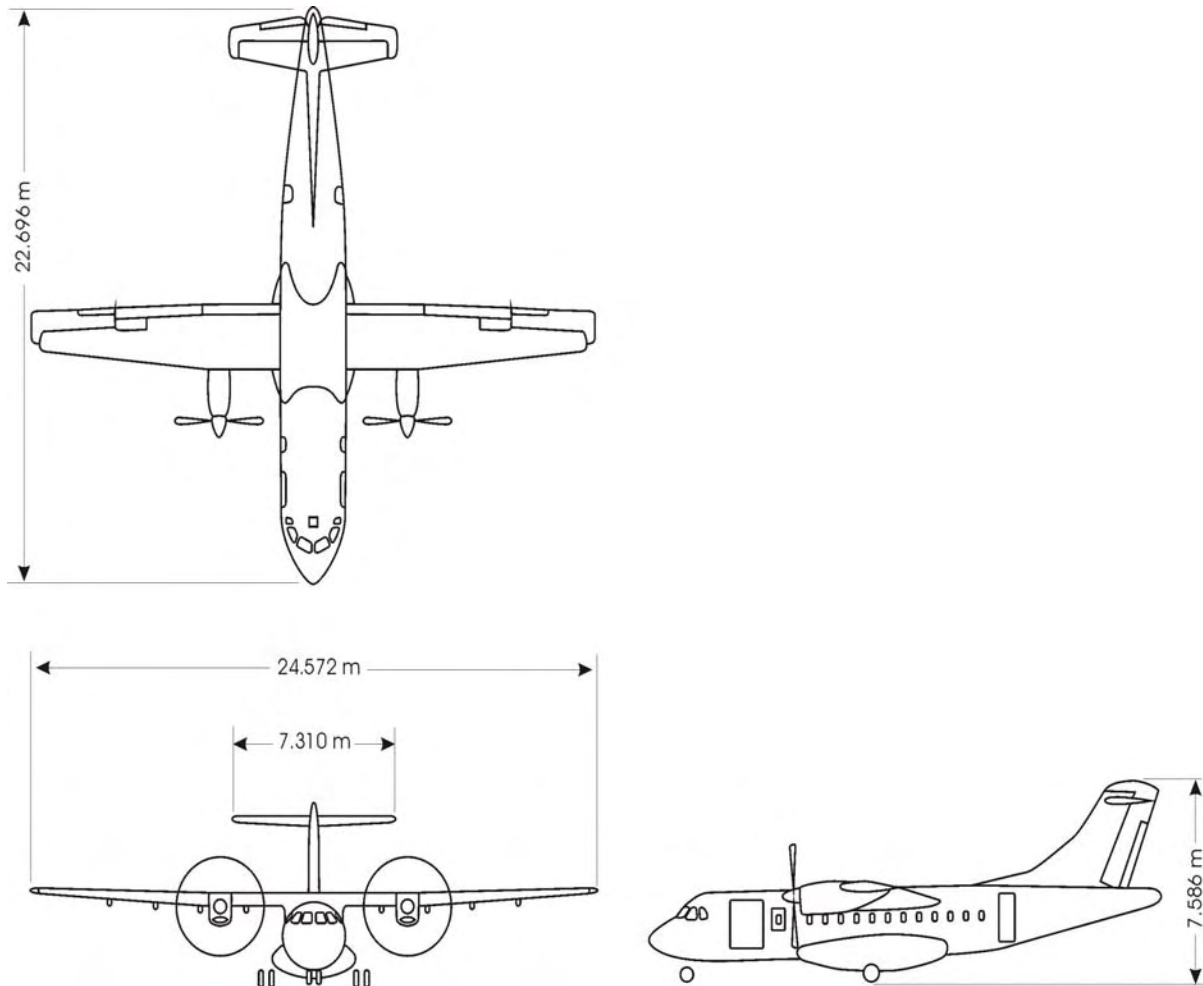


Figure 17. ATR 42 Dimensions

The ATR 42 was modified as follows for the test (figure 18):

- Engines and nacelles were simulated using partially filled concrete barrels designed and constructed to replicate the weight and the c.g. of the engines and nacelles.
- Water was used to simulate fuel.
- The control surfaces (ailerons, flaps, and rudder), wing fairings, tail cone, and radar dome were missing. Their weights and c.g. was compensated with ballast.

- Landing gears and associated equipment were removed.
- Only two overhead stowage bins were mounted in the aircraft, and they were of secondary interest.
- The cabin lining and insulation (both nonstructural) were removed to allow for the pre- and posttest documentation of the airframe structure.



Figure 18. Aerial View of the ATR 42

The internal seating was rearranged to accommodate other test equipment. Arrangement of seats, ATDs, mannequins, and lead shot ballast bags are shown in figure 19. Details of the seats are described in reference 5.

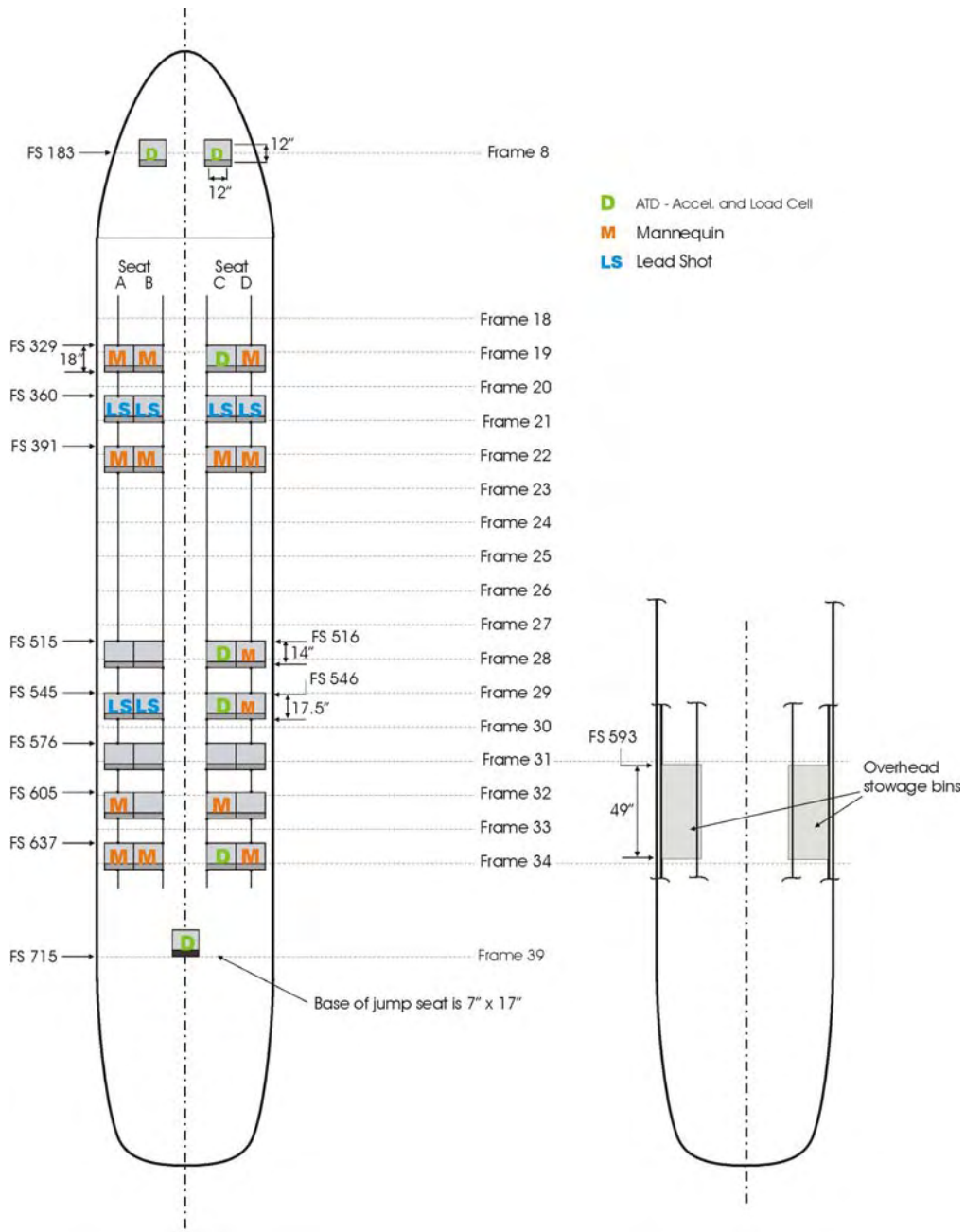


Figure 19. ATR 42 Seat Configuration

The ATR 42 airframe is circular in shape (figure 20). The ATR 42 seat tracks rest on the floor beams, which are connected to the belly skin by vertical stanchions. Maximum crushable distance from the floor beams to the belly skin is approximately 18 inches (figure 20).



Figure 20. Front-to-Rear View of the ATR 42 Cabin

The ATR 42 fuel system consisted of two wing tanks, one in each side of the fuselage. Each tank was filled to approximately 3/4 capacity with water for a weight of 4350 lb. Each tank was capable of holding 4960 lb of useable fuel.

The total test weight of the airplane was 33,200 lb. This weight represents the MGTOW of the airplane minus the removed items and a fuel load 1220 lb less than maximum. The airplane was loaded with 23 simulated occupants, luggage, fuel, miscellaneous related test equipment and bags of lead shot. Lead shot was used in the cockpit, tail section, and on several seats to compensate for missing items, weight and c.g. requirements. The c.g. was located at FS 469.

### 2.3 TEST INITIATION.

Prior to each test, the four supporting cable and turnbuckle assemblies were adjusted to level the fuselage forward/aft and left/right. The test article was raised to the desired height. Four guide ropes steadied the airplane while it hung above the platform. When the test article was steady and level, a Bowen 10-channel, automatic timing sequencer was started. High-speed (HS) film cameras, video cameras, and data acquisition systems were started; then the test article was released.

## 2.4 INSTRUMENTATION.

Fuselage reference locations are measured in three directions, longitudinal (x), lateral (y), and vertical (z). Generally, the origin for location reference is in the nose of the airplane, laterally centered at the floor seat track level; except for the ATR 42 airplane where the original reference location is in the longitudinal axis at 93 inches forward of the nose section. All measurements are taken from the origin. Positive measurements are from the origin aft (x), toward the copilot side (y), and toward the ceiling (z).

### 2.4.1 Fuselage and Cabin.

All the fuselages were instrumented with an array of accelerometers and had seats occupied by 50th percentile male ATDs. All ATDs were instrumented with load cells to measure spinal column axial loading in the lumbar area and accelerometers to measure g forces in the pelvic area. Additional test instrumentation included strain gages, displacement transducers, load cells, and velocity-measuring equipment. Details of sensors' properties, locations, and configurations for the tests are described in references 2-5. Airframe and seat track accelerations were of primary interest.

### 2.4.2 Visual Imaging.

HS 500 ft/sec film and video cameras, as well as standard-speed film and video cameras, were used to record the tests. Still photography was used to document the test articles pre- and posttest.

### 2.4.3 Data Acquisition.

Each data channel was simultaneously sampled at 5000 samples per second for the Metro III fuselage and at 10000 samples per second for the other fuselages. The data was prefiltered with a 2-kHz, anti-aliasing filter.

### 2.4.4 Data Reduction.

An SAE J211 Channel Frequency Class (CFC) 600 (1000 Hz) digital filter [6] was used to filter the ATD load cell data. An SAE J211 CFC 60 (100 Hz) digital filter was used to filter all the other sensor data. The Metro III was originally filtered using a 60-Hz filter; therefore, the raw data was refiltered using an SAE J211 CFC 60 digital filter. However, the use of this filter did not provide adequate filtering to determine the fundamental accelerometer pulse shape for the ATR 42 test. Posttest analysis of the fuselage and bin acceleration data indicated that the data exhibited large swings in value. These swings greatly influenced the pulse shape and amplitude, yet had a minimum affect on the fuselage and bin structural response. A 33-Hz digital filter was designed using SAE J211 guidelines to remove unwanted signals and provide the needed pulse definition. CFC 20 (33 Hz) data are reported for the ATR 42.

### 3. RESULTS AND DISCUSSION.

#### 3.1 IMPACT VELOCITY.

The Metro III and the B 1900C are 14 CFR Part 23-certified commuter/regional airplanes. They were dropped from a vertical height of 11.2 feet, resulting in an impact velocity of approximately 26.8 ft/sec. Velocities cited in this report reflect corrected velocity measurements correlated with visually recorded data. The impact velocity selected for each test corresponds to the velocity component of the combined vertical/longitudinal dynamic test requirement for airplane seat certification for 14 CFR Part 23.562(b)(1).

The Shorts 3-30 and the ATR 42 are 14 CFR Part 25-certified airplanes. They were dropped from a vertical height of 14 feet, resulting in an impact velocity of approximately 30.0 ft/sec. Velocities reflect corrected velocity measurements correlated with visually recorded data. The impact velocity selected for each test corresponds to the velocity component of the combined vertical/longitudinal dynamic test requirement for airplane seat certification for 14 CFR Part 25.562(b)(1).

#### 3.2 AIRFRAME ACCELERATIONS.

Airframe acceleration data are given in terms of three parameters: peak measured acceleration ( $G_{\text{peak}}$ ), pulse duration ( $\Delta t$ ), and maximum acceleration ( $G_{\text{max}}$ ).  $G_{\text{max}}$  acceleration values are used because they are better at determining the overall pulse amplitude than peak values, which show greater sensitivity to localized events. The  $G_{\text{max}}$  values were computed based on an idealized triangular pulse:

$$G_{\text{max}} = 2 \frac{\Delta V}{\Delta t} \quad (1)$$

where  $\Delta t$  is the difference between the start and stop times of the integration interval, and  $\Delta V$  is the velocity change determined by integrating the acceleration data during  $\Delta t$ .

Airframe acceleration data are presented as (1) fuselage sidewall accelerations, (2) sidewall seat track accelerations (if applicable), (3) floor track accelerations, and (4) composite accelerations (average data from representative channels from each test).

##### 3.2.1 Sidewall Accelerations.

In general, the Metro III experienced  $G_{\text{max}}$  sidewall accelerations of 50 to 65 g with a 27- to 36-msec pulse duration (table 1).  $G_{\text{max}}$  sidewall accelerations at the cockpit area (FS 121), where the underfloor structure is very stiff, were slightly higher.



Table 1. Metro III Sidewall Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)
121	86	79	26	72	67	29
174	58	65	27	—	—	—
317	49	50	36	89	43	36
422	48	52	33	—	—	—

In general, the B 1900C experienced G<sub>max</sub> sidewall accelerations of 130 to 161 g with a 9- to 10-msec pulse duration (table 2). Table 2 shows that highest G<sub>peak</sub> and G<sub>max</sub> occurred at the wing box section, where the structure was very stiff.

Table 2. The B 1900C Sidewall Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)
129	144	135	9.2	111	111	9.4
200	139	130	12.6	127	126	10.1
260	172	161	10.5	157	140	10.3
320	154	146	10.2	148	129	10.1
410	151	149	8.6	137	132	8.8

Multiple events occurred at FS 340 and FS 89 of the Shorts 3-30 during the impact as shown by the double pulses that were observed on both sides of FS 340 and on the right side of FS 89. Only the first pulses are presented in table 3. The data at the other FSs indicate that the Shorts 3-30 experienced G<sub>max</sub> sidewall accelerations of approximately 100 g with a 15-msec pulse duration.

Table 3. Shorts 3-30 Sidewall Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)
89	103	107	15	60	69	16
161	101	104	14	95	106	13
264	95	98	15	107	110	14
340	69	79	13	77	79	13

Sidewall data of the ATR 42 test show consistent results from frames 18 through 28. In general, the ATR 42 experienced  $G_{max}$  sidewall accelerations of approximately 20 g with an 84-msec pulse duration (table 4).

Table 4. ATR 42 Sidewall Accelerations (CFC 20)

Frame Number	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)
18	22	20	72	21	—	—
20	21	21	81	—	—	—
22	21	19	85	23	19	84
24	21	18	87	24	18	84
25	20	22	85	24	19	85
27	18	19	82	—	—	—
28	15	19	82	22	15	81

Figure 21 compares typical sidewall accelerations at the forward location of each of the test articles.

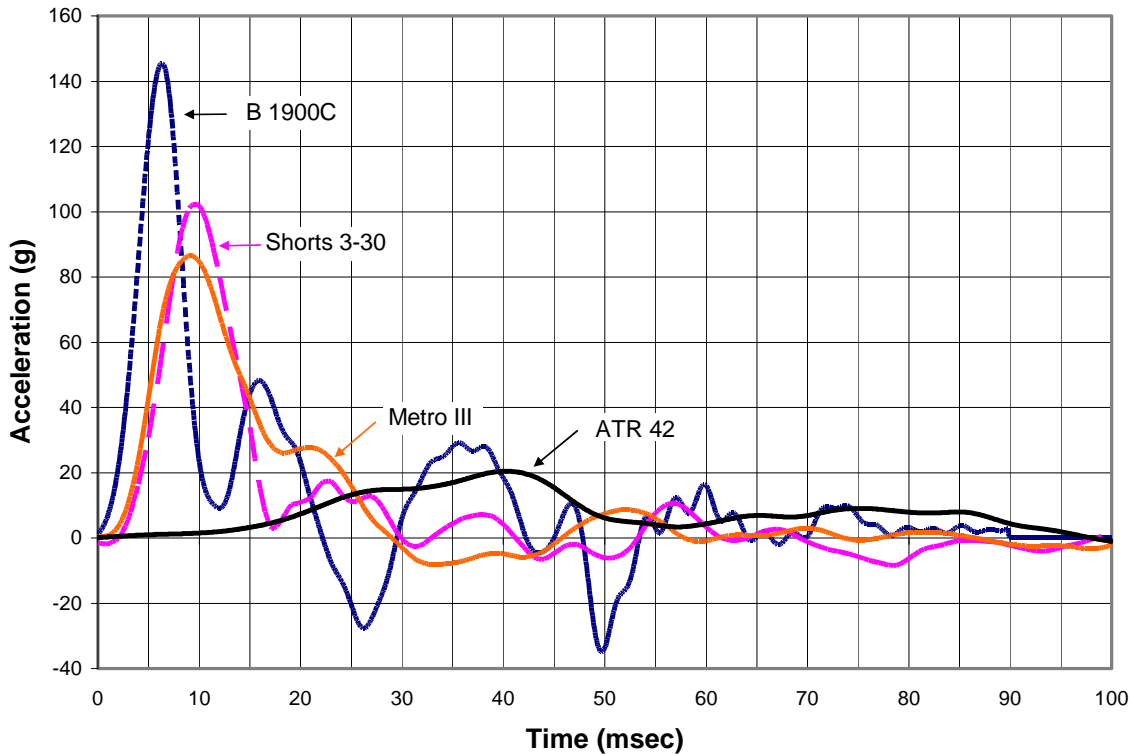


Figure 21. Typical Sidewall Accelerations at Forward Locations

### 3.2.2 Sidewall Seat Track Accelerations.

The ATR 42 airplane does not have sidewall seat tracks. Sidewall seat track data for the Metro III was not recorded during the test.

The B 1900C experienced a sidewall seat track  $G_{max}$  acceleration of 145-163 g with an 8- to 10-msec pulse duration (table 5). Similar to the B 1900C sidewall data, the highest  $G_{peak}$  also occurred at the wing box section.

Table 5. The B 1900C Sidewall Seat Track Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)
200	153	151	10.9	145	145	9.9
260	170	163	9.9	161	147	9.9
290	166	160	8.7	154	148	8.6
410	151	155	8.2	146	149	8.2

Similar to the sidewall data, Shorts 3-30 sidewall seat track data shows multiple events occurring at FS 340 and FS 89. The Shorts 3-30 data show that the  $G_{max}$  fuselage acceleration was 90 to 100 g with a 14- to 18-msec pulse duration (table 6).

Table 6. Shorts 3-30 Sidewall Seat Track Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)
89	90	89	17	64	75	15
161	96	100	17	92	97	14
187	93	95	18	94	89	17
238	92	98	15	105	102	15
264	89	92	15	102	101	15
340	74	79	14	75	81	13

Figure 22 compares the typical sidewall seat track accelerations at the center location of the two test articles.

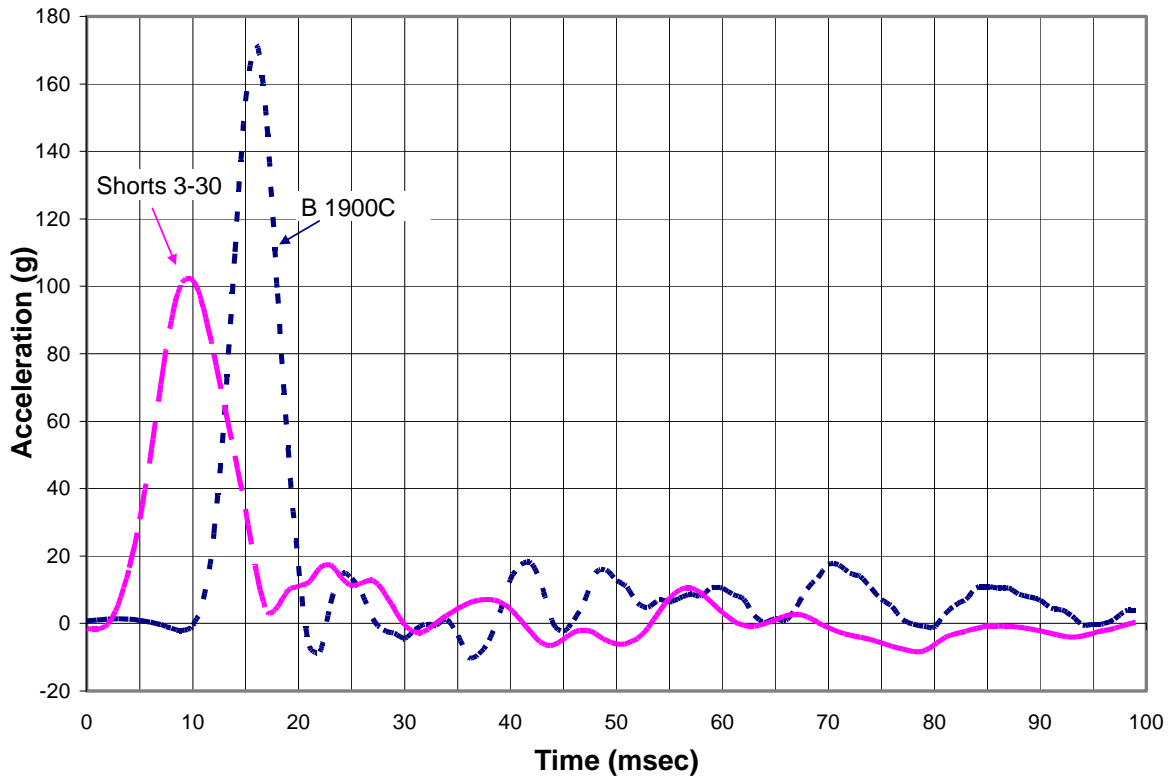


Figure 22. Typical Sidewall Seat Track Accelerations at Center Location

### 3.2.3 Floor Track Accelerations.

The Metro III wings tie into the stiffened fuselage wing box structure near FS 317. This area also protrudes slightly below the rest of the belly of the airplane. The floor track acceleration data in that area indicated multiple events, which resulted in a primary impact with a high  $G_{\text{peak}}$  and short pulse duration. Overall, the Metro III floor tracks experienced a  $G_{\text{max}}$  of 50 to 65 g with a 26- to 36-msec pulse duration (tables 7 and 8).

Table 7. Metro III Inboard Floor Track Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	$G_{\text{peak}}$ (g)	$G_{\text{max}}$ (g)	Pulse Duration (msec)	$G_{\text{peak}}$ (g)	$G_{\text{max}}$ (g)	Pulse Duration (msec)
174	72	71	26	62	65	32
317	84	48	36	101	32	36
422	47	48	28	59	60	31

Table 8. Metro III Outboard Floor Track Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)
174	65	67	28	51	52	30
317	78	51	35	119	48	36
422	58	64	28	59	56	31

The floor track acceleration in certain locations during the impact test of the B 1900C slightly exceeded the expected full-scale value (200 g), which was programmed into the data acquisition system. Original clipped data are given in reference 3. The  $G_{peak}$  and  $G_{max}$  values in table 9 are based on the clipped data. The actual impact  $G_{peak}$  and  $G_{max}$  values were estimated to be only slightly higher based on the pulse profile and consideration that the processed data was filtered with a CFC 60 filter and the raw data had a 2-kHz, anti-aliasing filter.

Table 9. The B 1900C Floor Track Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)
129	135	131	8.9	129	131	7.8
260	148	140	9.1	162	150	9.4
290	143	135	9	151	140	9.1
320	153	144	9.1	168	159	9.8
350	168	165	8.4	162	155	8.8
410	170	173	9.2	191	198	8.9

The Shorts 3-30 floor track accelerations were comparable to the Shorts 3-30 sidewall and sidewall seat track acceleration. The Shorts 3-30 experienced a  $G_{max}$  of approximately 90 g with a pulse duration of 15 to 18 msec (table 10).

Table 10. Shorts 3-30 Floor Track Accelerations (CFC 60)

Fuselage Station	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)
89	97	101	15	83	93	15
161	72	75	18	72	77	18
187	85	86	18	67	76	19
238	84	88	16	94	93	15
264	—	—	—	104	98	15
340	86	90	22	103	98	15

The ATR 42 floor track accelerations at frames 25 and 27 showed much higher accelerations and shorter pulse duration compared to the other frames due to the presence of the very stiff landing gear box located directly below these frames [5]. Major deformation of the lower lobe in this area resulted in the cabin floor heaving into the cabin; therefore, values listed for that area are for reference only. The inner-floor tracks experienced higher acceleration than the outer-floor tracks; this was attributed to their close proximity to the stanchions that supported the floor. The acceleration values are listed in tables 11 and 12.

Table 11. ATR 42 Inboard Floor Track Accelerations (CFC 20)

Frame Number	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)	G <sub>peak</sub> (g)	G <sub>max</sub> (g)	Pulse Duration (msec)
18	64	28	64	—	—	—
20	57	37	51	—	—	—
25	57	59	25	50	50	36
27	77	83	25	57	60	27
29	32	23	79	—	—	—
35	22	20	81	21	22	71

Table 12. ATR 42 Outboard Floor Track Accelerations (CFC 20)

Frame Number	Left/Pilot Side Acceleration			Right/Copilot Side Acceleration		
	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)	$G_{peak}$ (g)	$G_{max}$ (g)	Pulse Duration (msec)
18	—	—	—	24	28	66
20	29	30	52	25	32	72
25	27	—	—	22	28	39
29	23	21	82	—	—	—
35	—	—	—	17	17	64

Figure 23 compares the typical floor seat track accelerations at the forward locations of each of the test articles.

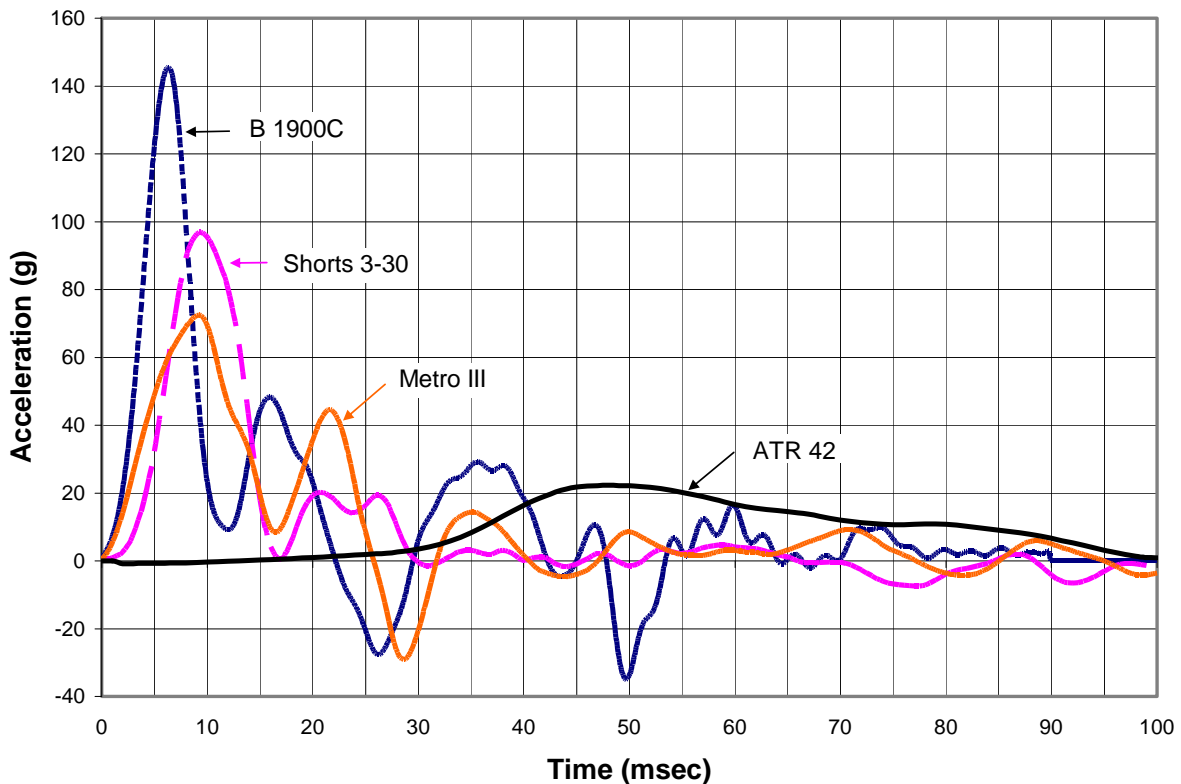


Figure 23. Typical Floor Track Accelerations at Forward Locations

The results show that the sidewall and sidewall seat track acceleration data of the Shorts 3-30 test were comparable throughout the structure. Sidewall acceleration data (no sidewall seat track) for the ATR 42 test were also comparable throughout the structure. This implies that the high-wing and overhead fuel tanks had little effect on fuselage acceleration near the cabin floor areas.

### 3.2.4 Composite Fuselage Accelerations.

A single composite acceleration profile of each airplane was made by averaging the data from representative channels from each test. The results are listed in table 13, and the composite acceleration plots are shown in figure 24. Using the composite data, four idealized triangular pulses were created using  $G_{max}$  acceleration values, which are shown in figure 25.

Table 13. Fuselage Response—Primary Pulse

Test Article	B 1900C Flat Belly	Shorts 3-30 Flat Belly	Metro III Curved Belly	ATR 42 Curved Belly
Acceleration (g)	154	94	65	20
Duration (msec)	9	17	31	84
$\Delta V$ (ft/sec)	23/27	25/30	27/27	26/30

\*  $\Delta V$  corresponds with the primary pulse duration; the second value is the impact velocity.

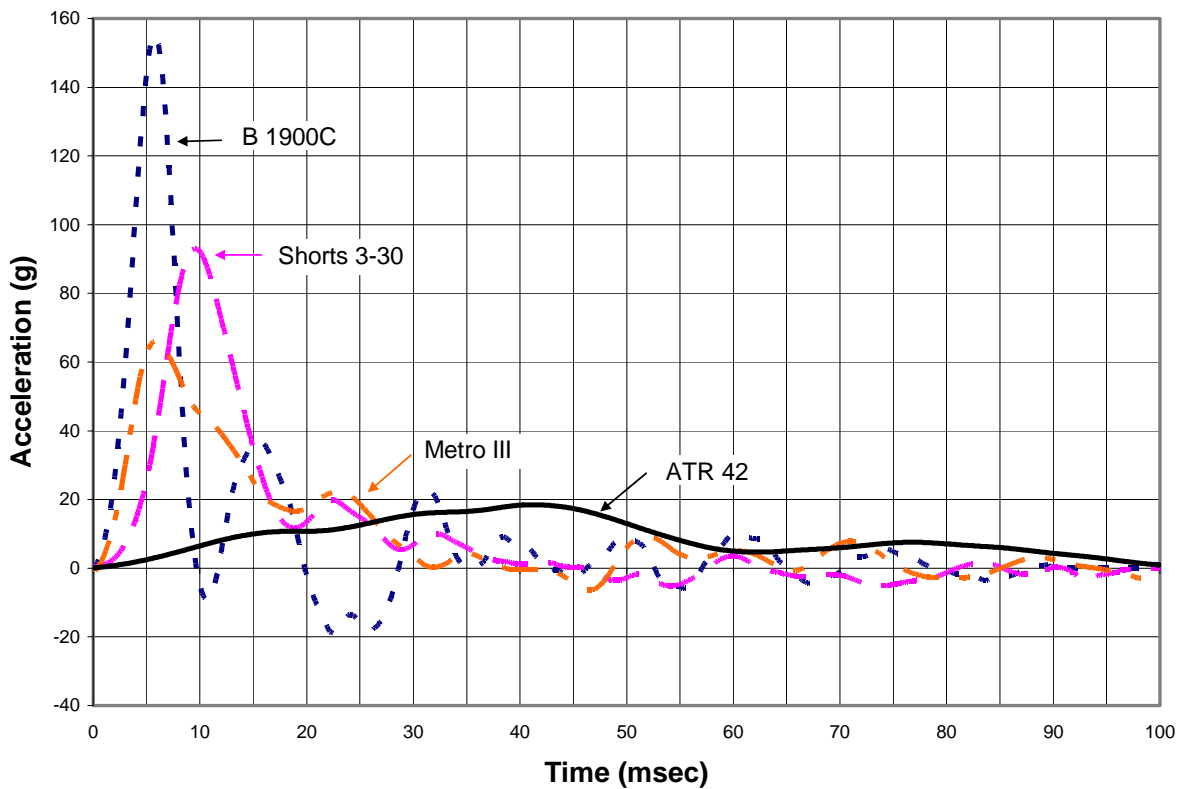


Figure 24. Composite Fuselage Accelerations



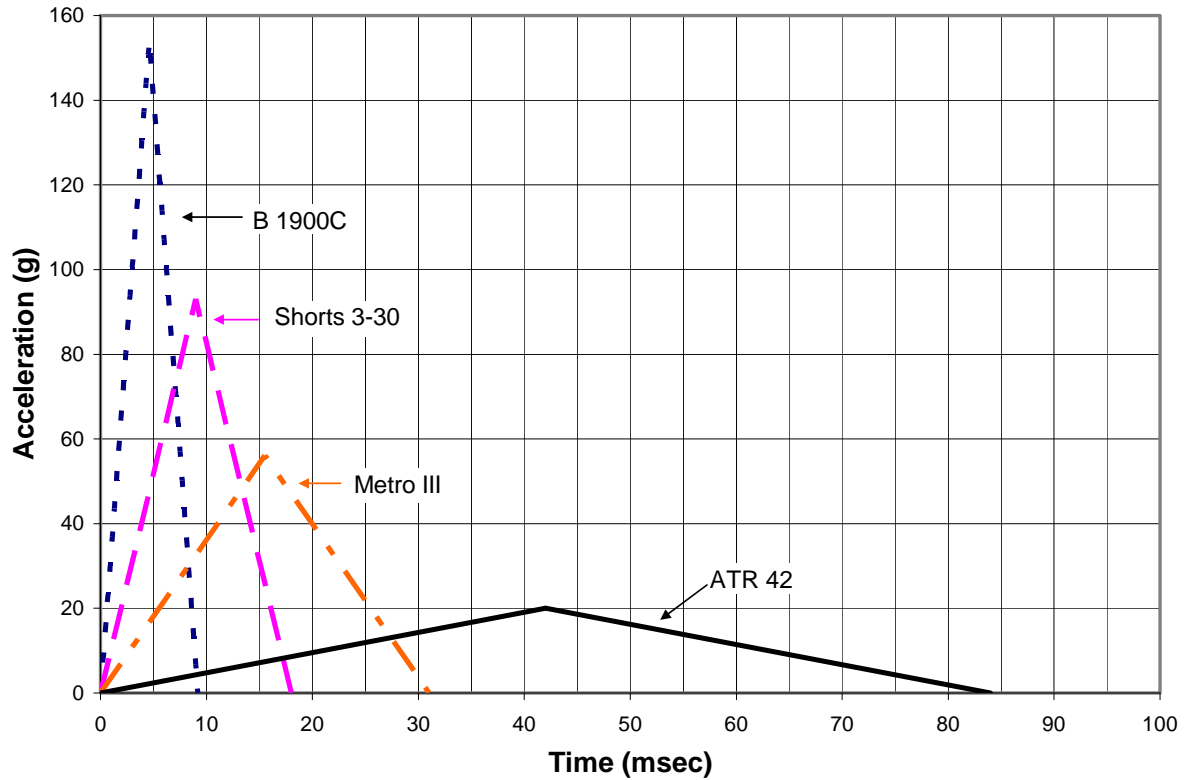


Figure 25. Idealized Triangular Fuselage Accelerations

The data indicate that

- both fuselage shape and underfloor structural depth are governing factors that determine the impact response characteristics of an airframe structure.
- the impact tests of the flat-belly B 1900C and Shorts 3-30 airplanes resulted in higher fuselage accelerations with shorter pulse durations than the impact tests of the curved-belly Metro III and ATR 42 airplanes.
- within the flat- and curved-belly fuselage designs, the apparent stiffer structures have higher fuselage acceleration and shorter pulse duration (B 1900C versus Shorts 3-30 and Metro III versus ATR 42).
- there were two groups of fuselage responses: Group 1 (B 1900C, Shorts 3-30, and the Metro III) with higher accelerations and shorter pulse durations and Group 2 (ATR 42) with lower acceleration and longer pulse duration.
- Group 1 had an average available underfloor crush depth of 10 inches and pulse durations in the range of 9 to 31 msec. The pulse durations were less than the 50- to 150-msec range used in developing current 14 CFR Part 23 certification standards for general aviation airplane metal fuselage structures [7].

- Group 2 had 18 inches of available crush depth and a pulse duration of 84 msec. This pulse duration was within the 50- to 150-msec range used in developing current 14 CFR Part 23 certification standards for general aviation airplane metal fuselage structures [7].
- 14 CFR Part 23 and some small Part 25 commuter airplanes have similar fuselage response characteristics.

### 3.3 STATIC AND DYNAMIC CRUSH.

#### 3.3.1 Static Crush.

Fuselage permanent-static crush (posttest at rest) was measured at several FSs (Metro III, B 1900C, and Shorts 3-30) or frame stations (ATR 42). The crush was calculated by measuring the distance from a set point or reference point on the airplane to the platform or the concrete pad, both prior to and after the tests.

The Metro III fuselage static crush was approximately 1 inch. The measurements are listed in table 14.

Table 14. Metro III Static Crush Measurements

Fuselage Station	Crush (inches)
95	0.9
189	1.1
254	1.2
347	1.4
438	0.7

The B 1900C test article exhibited little or no static crush at the wing box section and the pilot section. However, permanent deformation of the fuselage from FS 188 through FS 243 and from FS 333 through FS 423 was noted. Static crush measurements are listed in table 15.

Table 15. The B 1900C Static Crush Measurements

Fuselage Station	Crush (inches)
200	1.2
260	0.3
320	0.5
410	1.6

The Shorts 3-30 fuselage experienced a maximum static crush of approximately 1.3 inches at the forward section of the fuselage on the copilot's side. Permanent deformation was as little as 0.5 inch in the rear of the airplane. Table 16 shows overall static crush measurements at various fuselage stations, whereas the static crush of the rigid cabin underfloor structure is shown in table 17. The results in tables 16 and 17 show that the cabin underfloor structure acted as a rigid

platform and most of the fuselage static crush took place in the cabin floor/airframe interface structure.

Table 16. Shorts 3-30 Fuselage Static Crush Measurements

Fuselage Station	Crush Left/Pilot Side (inch)	Crush Right/Copilot Side (inches)
89	0.9	1.3
161	1	1.3
340	1	0.5

Table 17. Shorts 3-30 Underfloor Static Crush Measurements

Fuselage Station	Crush Left/Pilot Side (inch)	Crush Right/Copilot Side (inch)
89	0.06	0.06
161	0.06	0.06
338	0.06	0.06
264	0.06	0.13
340	0.13	0.13
391	0.06	0.06

The landing gear box and lower fuselage frame sections 25-27 of the ATR 42 are integrated together to form a very strong and rigid structure. During the impact, the lower frame sections fractured and then penetrated upward into the cabin. Posttest static crush measurements in this area were difficult to determine. Due to the geometry of the fuselage, the crush measurements aft of frame 27 were most representative of the static crush. The crush measurements are found in table 18.

Table 18. ATR 42 Static Crush Measurements

Frame Station	Crush Left/Pilot Side (inches)	Crush Right/Copilot Side (inches)
14	4.2	5.4
16	4.9	6.9
18	6.2	6.9
20	7.8	8.3
21	8.0	8.9
32	11.6	11.4
33	12.6	11.9
34	12.9	11.8
35	12.0	10.9
36	11.3	9.8

### 3.3.2 Dynamic Crush.

The composite acceleration data was integrated twice to analytically derive the dynamic crush (maximum airframe structural deformation after impact and prior to rebound). The results are listed in table 19, and the static and dynamic crush data are shown in figure 26. Figure 26 shows

the acquired airframe acceleration versus derived structural deformation. The figure includes two analytically derived curves assuming an idealized triangular pulse and velocity changes of 26.8 ft/sec and 30 ft/sec. The Metro III, B 1900C, and Shorts 3-30 experienced approximately 1 inch of static crush and 2-4 inches of dynamic crush. The percentage of dynamic crush per available crush depth varied between 20% and 35%. The ATR 42 experienced approximately 12 inches of static crush and 16 inches of dynamic crush. The percentage of dynamic crush per available crush depth was 92%. The data show that the dynamic crush was consistent, as it should be, with the theoretical crush response. Similar crush and acceleration results were found for comparable airplanes [7]. The data show that the ATR 42 was the most effective of the airplanes at using its available underfloor crush depth to reduce the acceleration level of the fuselage.

Table 19. Static and Dynamic Crush

Test Article	B 1900C	Shorts 3-30	Metro III	ATR 42
Static Crush (in.)	1	1	1	12
Dynamic Crush (in.)	2.0	4.3	3.9	16.5
Underfloor Crush Depth Available (in.)	9.9	8.2	11.1	18
Underfloor Crush Depth Used (%)	20	*<1	35	92

\* Cabin floor/airframe interface structure failed.

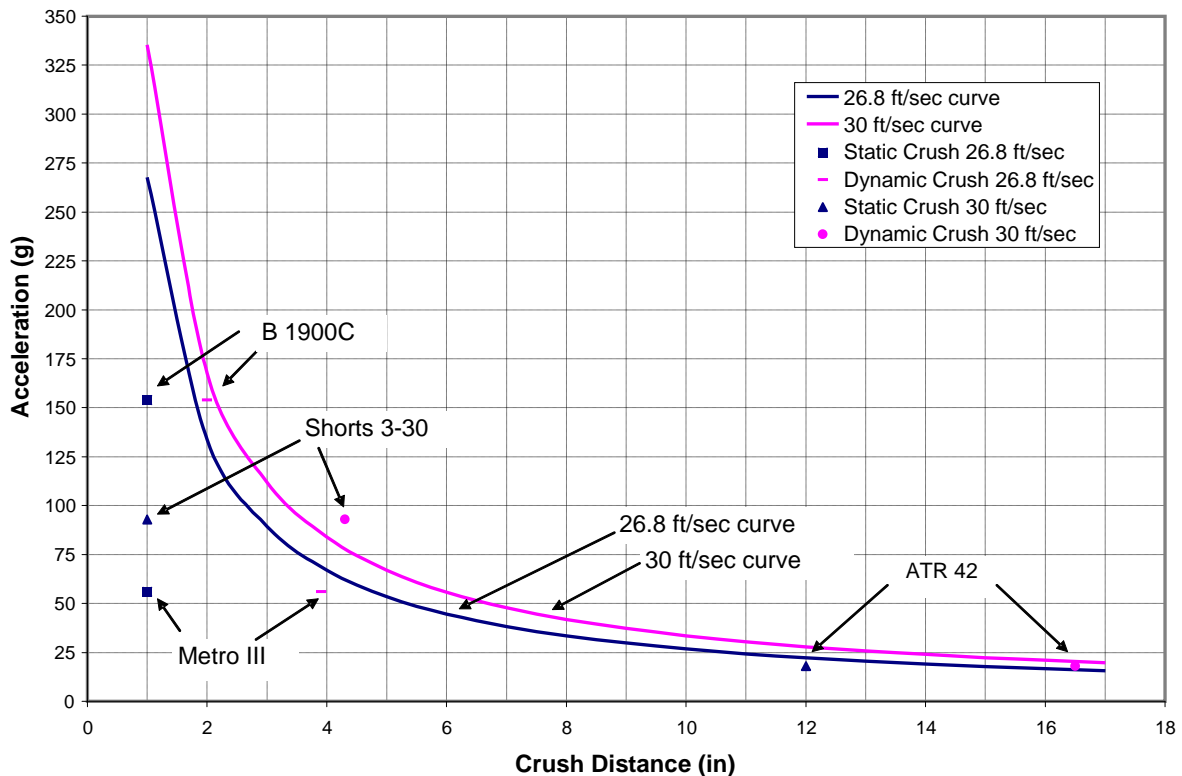


Figure 26. Airframe Acceleration vs Structural Deformation

### 3.4 FUSELAGE PENETRATION.

The supporting structures of the wing of the ATR 42 and the overhead fuel tanks of the Shorts 3-30 fractured and penetrated the survivable volume of cabin space. Figure 27(a) and (b) show these events.



(a)



(b)

Figure 27. ATR 42 (a) and Shorts 3-30 (b) Airplanes Postdrop

#### 4. SUMMARY.

Table 20 is a summary of all pertinent data.

Table 20. Summary Table

Test Article	B 1900C	SHORTS 3-30	Metro III	ATR 42
Part	23	25	23	25
Wing	Low	High	Low	High
Airframe	Rectangular	Square	Circular	Circular
Belly	Flat	Flat	Circular	Circular
Test Configurations				
Test Height (ft)	11.2	14	11.2	14
Impact Velocity (ft/sec)	27	30	27	30
Test Weight (lb)	8475	21210	7347	33200
Data Processing				
Sampling Rate (samples/sec)	10000	10000	5000	10000
SAE J211 Filter	CFC 60	CFC 60	CFC 60	CFC 20
Crush Results				
Static Crush (in.)	1	1	1	12
Dynamic Crush (in.)	2	4	4	16
Underfloor Crush Depth Available (in.)	9.9	8.2	11.1	18
Underfloor Crush Depth Used (%)	20	*<1	35	92
Acceleration (g), Duration (msec), $\Delta V$ (ft/sec)				
Sidewall Acceleration (g)	136	95	56	19
Sidewall Pulse Duration (msec)	10	14	36-56	83
Side Track Acceleration (g)	152	92	N/A	N/A
Side Track Pulse Duration (msec)	9	15	N/A	N/A
Floor Track Acceleration (g)	149	89	55	24
Floor Track Duration (msec)	9	16	38	72
Primary Pulse Acceleration (g)	154	94	56	20
Primary Pulse Duration (msec)	9	17	31	84
**Primary Pulse $\Delta V$ (ft/sec)	23/27	25/30	27/27	26/30

\* Cabin floor/airframe interface structure failed

\*\*  $\Delta V$  corresponds with the primary pulse duration; the second value is the impact velocity

## 5. RESULTS AND CONCLUSIONS.

This report presents impact response characteristics of the airframes that were tested by the Federal Aviation Administration. Acquired and idealized triangular impact pulse shapes that might be used for the definition of seat dynamic performance standards for Title 14 Code of Federal Regulations (CFR) Part 23 commuter category and 14 CFR Part 25 small (20 and 42 passenger) regional airplanes were defined for the range of airplanes tested. This information will provide a basis to assess the adequacy of current regulatory standards for small commuter airplanes. The following are specific results and conclusions.

### 5.1 OVERALL FUSELAGE RESPONSE.

The overall data indicate that both fuselage shape and underfloor structural depth are governing factors that determine the impact response characteristics of an airframe structure.

14 CFR Part 23 commuter/regional airplanes and small 14 CFR Part 25 small (30 and 42 passenger) regional airplanes with comparable crushable underfloor depth have similar fuselage impact response characteristics.

The two groups of fuselage responses are: Group 1 (B 1900C, Shorts 3-30, and Metro III) with higher accelerations and shorter pulse durations ( $G_{\max}$  101 g and 20 msec) and Group 2 (ATR 42) with lower acceleration and longer pulse duration ( $G_{\max}$  20 g and 84 msec).

The Beechcraft 1900C, Short Brothers 3-30, and the Fairchild Metro III had pulse durations in the range of 9 to 32 msec and are below the range (50 to 150 msec) of data used to develop 14 CFR Part 23.562 airplane seat certification standards.

The ATR 42's pulse duration was approximately 84 msec and was consistent with the pulse durations found within the range (50 to 150 msec) and near the average of 100 msec of data used to develop 14 CFR Part 23.562 airplane seat certification standards.

Overall the acquired fuselage accelerations were consistent with the theoretical accelerations of an idealized triangular pulse.

Heavy items of mass located above the cabin have the potential of penetrating the cabin. The ATR 42 wing and the Shorts 3-30 overhead fuel tanks penetrated the cabin after their support structures failed.

Sidewall and sidewall seat track acceleration data from the Shorts 3-30 test were comparable throughout the structure. Sidewall acceleration data (no sidewall seat track) for the ATR 42 test were also comparable throughout the structure. This indicated that the high-wing and overhead fuel tanks had little effect on fuselage acceleration near the cabin floor areas.

### 5.2 INDIVIDUAL FUSELAGE RESPONSE.

The B 1900C is a flat-belly airplane that sustained approximately 1 inch of static crush and 2 inches of dynamic crush after a 26.8-ft/sec vertical impact. The airplane used 20% of the

available crush depth and experienced a  $G_{\max}$  loading of approximately 154 g with a 9-msec pulse duration.

The Shorts 3-30 is a flat-belly airplane that sustained approximately 1 inch static crush and 4.3 inches of dynamic crush after a 30.0-ft/sec vertical impact. The airplane used less than 1% of the available crush depth due to the cabin floor/airframe interface failing. The airplane experienced a  $G_{\max}$  loading of approximately 94 g with a 17-msec pulse duration.

The Metro III is a curved-belly airplane that sustained approximately 1 inch of static crush and 3.9 inches of dynamic crush after a 26.8-ft/sec vertical impact. The airplane used 35% of the available crush depth and experienced a  $G_{\max}$  loading of approximately 56 g with a 31-msec pulse duration.

The ATR 42 sustained approximately 12 inches of static crush and 16 inches of dynamic crush after a 30.0-ft/sec vertical impact. The airplane used 92% of the available crush depth and experienced a  $G_{\max}$  loading of approximately 20 g with an 84-msec pulse duration.

### 5.3 FUSELAGE CRUSH.

The dynamic structural deformations acquired during the impact tests of the four fuselages were consistent with the theoretical underfloor structural deformations of an idealized triangular impact pulse.

Group 1, consisting of the B 1900C, Shorts 3-30, and Metro III, had an available underfloor structural crush depth of 8.2 to 11.1 inches and Group 2, ATR 42, had 18 inches.

The ATR 42 was the most effective airplane at using its available underfloor structural crush depth to reduce the acceleration level of the occupied area of the fuselage.

As expected, due to the differences in the locally loaded structural area during the impact event, the flat-belly B 1900C and Shorts 3-30 impact tests resulted in higher fuselage accelerations with shorter pulse durations than the curved-belly Metro III and ATR 42 impact tests.

As expected, stiffer underfloor structures have a higher fuselage acceleration and shorter pulse duration (B 1900C versus Shorts 3-30 and Metro III versus ATR 42).

## 6. REFERENCES.

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