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Beechcraft 1900C Vertical Impact Test

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16. Abstract

In October 1995, a commuter category Beechcraft 1900C airliner was subjected to a vertical impact drop test at the William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The purpose of this test was to measure the impact response of the fuselage, cabin floor, cabin furnishings (including standard and modified seats), and anthropomorphic test dummies. The test was conducted to simulate the vertical velocity component of a severe but survivable crash impact. A low-wing, 19-passenger fuselage was dropped from a height of 11′2″ resulting in a vertical impact velocity of 26′8″ per second. The airframe was configured to simulate a typical flight condition, including seats (normal and experimental), simulated occupants, and cargo. For the test the wings and engines were removed; the vertical and horizontal stabilizers were removed; the landing gear was removed; and the pilot and copilot seats were not installed. The data collected in the test and future tests will supplement the existing basis for improved seat and restraint systems for commuter category Code of Federal Regulation, 14 CFR Part 23, airplanes.

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INTRODUCTION

This report presents the results of a dynamic airplane vertical impact test conducted at the William J. Hughes Technical Center, Atlantic City International Airport, New Jersey, in October 1995. The purpose of the test was to determine the impact response of the fuselage, cabin floor, cabin furnishings (including standard and modified seats), and anthropomorphic test dummies. The test simulated the vertical velocity component of a severe but survivable crash impact. A low-wing Beechcraft 1900C 19-passenger commuter airliner fuselage was dropped from a height of 11′2″ resulting in a vertical impact velocity of 26′8″ per second. The airframe was configured to simulate a typical flight condition, including seats, simulated occupants, and cargo. The data collected in the test and future tests will supplement the existing basis for improved seat and restraint systems for commuter category Code of Federal Regulation, 14 CFR Part 23, airplanes.

BACKGROUND

This vertical impact test is one of a series of fuselage section and full-scale airplane tests conducted in support of the Federal Aviation Administration's (FAA) ongoing Aircraft Safety Research Plan [1]. The FAA has proposed seat dynamic performance standards for 14 CFR Part 23 commuter category airplanes. Those standards were established empirically using the results of prior airplane crash impact test programs. In development of those standards, it was noted that the full-scale airplane impact test database did not include airplanes representative in size to commuter category airplanes. To provide data for those size airplanes, the FAA initiated a full-scale vertical impact test program of 14 CFR Part 23 commuter category airplanes. A previous test involving a Metro III aircraft was conducted in April 1992 [2]. The tests were structured to assess the impact response characteristics of airframe structures, seats, and the potential for occupant impact injury.

DESCRIPTION OF TEST FACILITY AND TEST ARTICLE

TEST FACILITY.

The William J. Hughes Technical Center drop test facility, shown in figure 1, is comprised of two 50-foot vertical steel towers connected at the top by a horizontal platform. An electrically powered winch, mounted on the platform, is used to raise or lower the test article and is controlled from the base of one of the tower legs. The current lifting capacity of the winch is 13,600 pounds. Attached to the winch is a reeved hoisting cable which is used to raise the test article. A sheave block assembly hanging from the free end of the reeved cable is engaged to a solenoid operated release hook. The release hook is connected to the airframe by a cable/turnbuckle assembly with hooks bolted to the fuselage section at four locations. Located below the winch cable assembly and between the tower legs is a 15- by 36-foot wooden platform which rests upon I-beams and is supported by 12 independent load cells.

FIGURE 1. DROP TEST FACILITY

TEST ARTICLE.

The test article was a Beechcraft 1900C which is a low-wing, twin-turboprop, 19-passenger commuter airliner 57′10″ in length. The following modifications were made to the airplane prior to the test:

- The wings and engines were removed from the fuselage wing box structure
- The vertical and horizontal stabilizers were removed from the empennage; however, ballast was added to the tail section of the airplane to compensate for the missing stabilizers
- The landing gear was removed
- The pilot and copilot seats were not installed; ballast was added to simulate the weight of the seats and occupants

The internal seating arrangement was modified for the test to accommodate a variety of seats. Seats included in this test were PTC Aerospace seats, Wichita State University (WSU) experimental energy-absorbing seats, the FAA Civil Aeromedical Institute's (CAMI) experimental energy-absorbing seat, a center aisle Beechcraft seat, and standard Beechcraft seats both blue and brown in color. The blue and brown Beechcraft seats are structurally identical except the brown seats have a lower seat back. The following is a listing of the type of seats located at the fuselage stations (FS) along the length of the airplane. Seat configuration and locations are shown in figure 2:

FS 129 - Flight deck seats were not installed, ballast was used
FS 200 - Wichita State University experimental energy-absorbing seat
FS 230 - Standard Beechcraft seat (blue)
FS 260 - WSU experimental seat and Standard Beechcraft seat (blue)
FS 290 - Standard Beechcraft seat (blue) and PTC Aerospace seat
FS 320 - FAA Civil Aeromedical Institute's energy-absorbing seat
FS 350 - Center aisle Beechcraft seat
FS 380 - PTC Aerospace seat and standard Beechcraft seat (blue)
FS 410 - Two standard Beechcraft seats (blue)
FS 440 - Two standard Beechcraft seats (brown)

Each of the seats was occupied by a test dummy or ballast to represent the weight of a 170 pound occupant. Seven of the seats were occupied by instrumented Hybrid II anthropomorphic test dummies (ATD), six others were occupied by dummies without instrumentation capability, and one seat was loaded with a wooden body block. Figure 2 shows the locations of the ATDs. All the dummies and ballast were strapped firmly into the seats with lap belt restraint systems.

The total weight of the test article was 8475 pounds. This weight represents the maximum gross takeoff weight of the airplane, taking into consideration the weight of the portions of the airplane that were removed.

The test article also had seven onboard cameras which will be discussed in the instrumentation section of this report.

TEST INITIATION

Prior to the test, the airframe test section was leveled by adjusting the supporting turnbuckles. The test article was then raised to the desired height of 11′2″. Four guide ropes, manned by members of the drop test team, steadied the test article while it hung above the platform. Once the test article was steady and level, the timing sequence began, the high-speed film cameras began running, the airplane was released and began accelerating toward the platform. At the point of impact with the platform the fuselage section had reached a velocity of 26.8 ft/sec. Wind speed during the test was less than 5 mph.

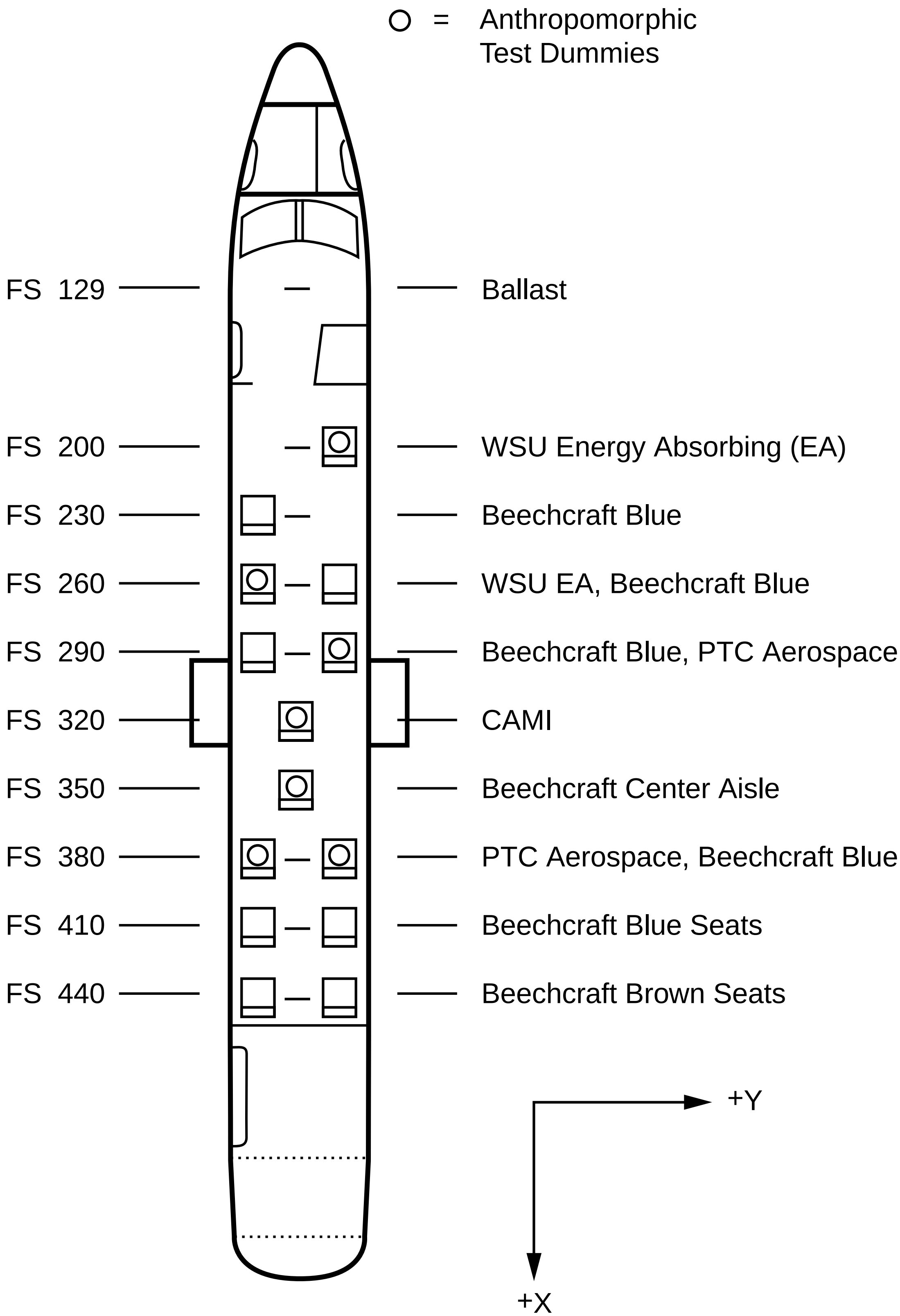

FIGURE 2. BEECHCRAFT 1900C AIRLINER

INSTRUMENTATION

FUSELAGE.

The fuselage instrumentation for this test included 39 accelerometers located at various stations along the length of the airplane. Thirty-four of the accelerometers were rated for 750 g's, four were rated for 100 g's, and one was rated for 200 g's. The accelerometers were located on the floor, the side wall seat track, and along the side wall to determine the fuselage response throughout its entire length.

SEATS.

The two WSU energy-absorbing (EA) seats were instrumented with accelerometers to determine their impact response directly. The WSU seats were located at FS 200 and FS 260, and each had one accelerometer attached to its seat pan.

TEST DUMMIES.

Seven of the test dummies were 50th percentile Hybrid II anthropomorphic dummies. All of the anthropomorphic test dummies were instrumented with load cells and accelerometers. The instumented test dummies were located at fuselage stations 200, 260, 290, 320, 350, and 380 (see figure 2).

PLATFORM LOAD CELLS.

The impact platform rests on 12 load cells, each with a load capacity of 50,000 pounds. A hydraulic jack is located under each load cell, and each jack was activated simultaneously with a central pump. After the platform was raised off the ground its tare weight was zeroed by the computer system. The platform load cells measured the reactive forces generated during the drop of the test article and were used to verify the impact loads and determine their distribution.

CAMERAS.

Five high-speed film cameras were used to record the exterior of the airplane during the test. One forward view, two quarter views, and one side view of the test article were filmed. The fifth camera, intended to provide a rear view of the test article, malfunctioned during the test.

In addition to the high-speed film cameras, two high-speed video cameras were placed outside the fuselage to record front- and rear-quarter views.

Seven high-speed film cameras were located in the test article. These cameras focused on various seats in addition to providing an overall view of the activity inside the fuselage during the test.

DATA ACQUISITION SYSTEM

The NEFF 490 data acquisition system is a high-speed data acquisition system which has the capability to sample and record data at sampling rates up to 1 MHz. The system consists of 92 channels. Each channel includes a 12 bit analog-to-digital converter with an accuracy of 0.1% of programmable full scale, a 6-pole Bessel low-pass filter with four programmable cutoff frequencies which cover a range from 100 Hz to 200 kHz, and a differential input amplifier with 12 programmable gain steps. Input signals range from ±5 mV dc to ±10.24 V dc full scale.

For the test, the system was set to sample and record 79 channels of data simultaneously at 10,000 samples per second per channel. All data channels were prefiltered at a cutoff frequency of 1 kHz and temporarily stored in the NEFF 256K word DRAM memory during the test. Test data were then transferred to an IBM compatible computer by an IEEE-488 interface for further analysis.

The system was externally triggered by the sequencer unit which controlled all the test processes. Block recording mode was selected for the NEFF 490 system to prevent any time shifts that might have occurred due to the use of two control computers.

DATA ANALYSIS

DATA REDUCTION.

As stated, the sensor data was first filtered with a 1-kHz analog filter and then recorded at a sampling rate of 10,000 samples/second. The data were then filtered with a SAE J211 class 600 digital filter for the anthropomorphic dummy load cell data channels and class 60 digital filter for the acceleration and platform load cell data channels.

The data were recorded for 22 seconds starting 3 seconds prior to hook release. However, only 100 milliseconds of data, starting 10 milliseconds before the impact, are presented in this report. The peak acceleration (G_{peak}) values were read directly from the filtered data. The maximum acceleration (G_{max}) values were computed using equation 1 which assumes an idealized triangular pulse

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

where Δt is the difference between the start and stop times of the integration interval, and ΔV is the velocity change determined by integrating the acceleration data during Δt.

TEST VELOCITY.

The impact velocity was verified by comparing the analytical velocity to the measured velocity and the observed velocity. Using the energy conservation principle, the analytical impact velocity (v_f) can be determined by equation 2

$$v_f = \sqrt{2gh} \tag{2}$$

where h is the drop test distance (11.2 ft), and g is the acceleration due to gravity (32.2 ft/sec^2). Impact velocity in this method was calculated to be 26.8 ft/sec. This velocity was cross-checked with the velocity determined from a velocity trap (26.2 feet/sec) and the high-speed film analysis (26.7 feet/sec), and no noticeable discrepancies were found.

FUSELAGE STRUCTURE.

PERMANENT DEFORMATION. Due to the structure of the fuselage and the uneven platform surface, the posttest fuselage deformations varied from station to station. At the bottom of the test article, there was little or no crush at the wing box section and the pilot/copilot section. However, deformation of the fuselage from FS 188 through FS 243 and from FS 333 through FS 423 was noted. The measurements of the bottom deformation at FS 200, FS 260, FS 320, and FS 410 were 1.2, 0.3, 0.5, and 1.6 inches, respectively.

AIRFRAME ACCELERATION. Most of the airframe acceleration raw data exceeded the full-scale limit of the data acquisition system which was set at ±200 g's. However, if the data remained within the linear range of the accelerometer, which was the case for all 750-g accelerometers, the data were used in the analysis. If the data experienced minor clipping or no clipping, it was deemed reliable for determining the impact pulse and the results are reported. Any data that significantly exceeded the ±200-g range was not considered valid for analysis. To compensate for the platform response (which was superimposed on the airframe response) the data were corrected by subtracting the platform acceleration data from the airframe acceleration data. Typical floor seat track and wall seat track acceleration plots are shown in figures 3 and 4, respectively.

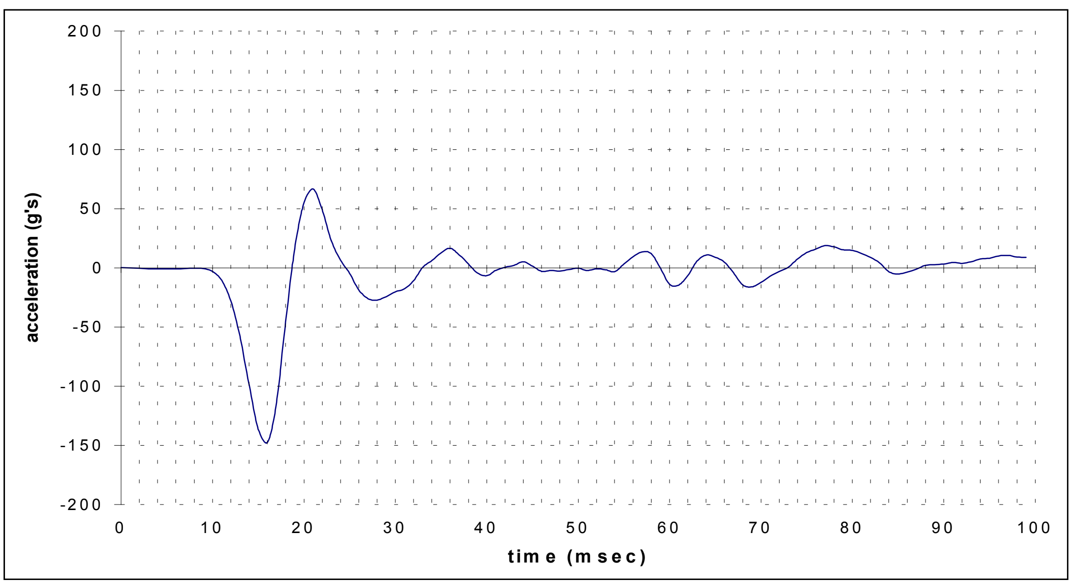

FIGURE 3. FS 260 FLOOR, LEFT SEAT TRACK VERTICAL ACCELERATION

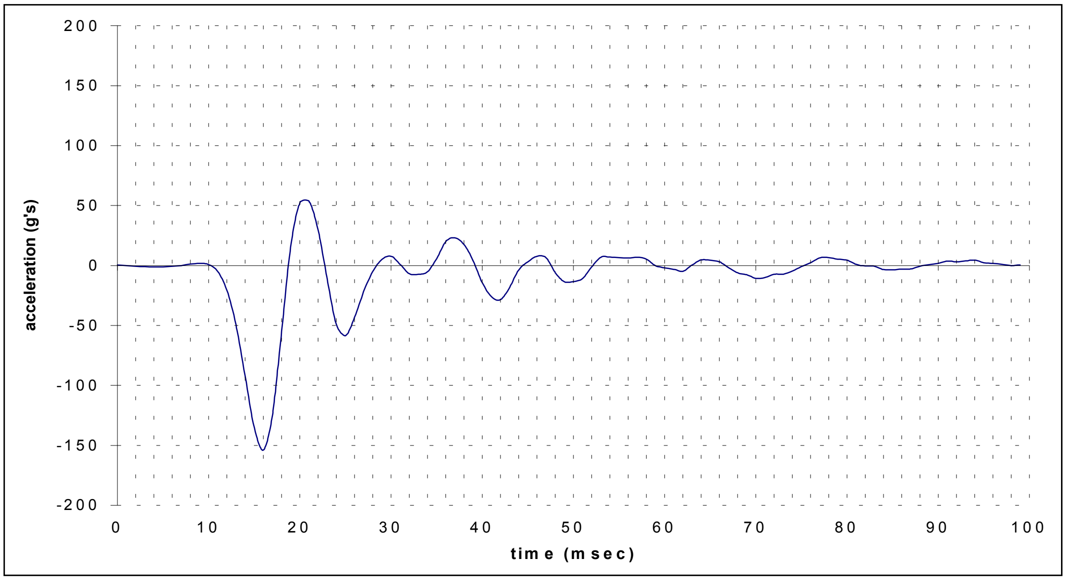

FIGURE 4. FS 290 RIGHT WALL, SEAT TRACK VERTICAL ACCELERATION

The floor seat track G_{peak} and G_{max} values in table 1 are based on the clipped data. The actual impact G_{peak} and G_{max} values should be slightly higher. Based on the G_{max} values of the side wall seat track and the side wall, the fuselage acceleration during the impact was in the range of 140-160 g's. From tables 1, 2, and 3, the impact pulse duration was in the range of 9-10 milliseconds. This is considered to be a severe but survivable impact [3].

TABLE 1. FLOOR SEAT TRACK ACCELERATIONS

Fuselage Station	G_{peak} (g)	G_{max} (g)	Pulse Duration (msec)
FS 129 P	135	131	8.9
FS 129 C	129	131	7.8
FS 200 P	Invalid	Invalid	Invalid
FS 200 C	Invalid	Invalid	Invalid
FS 260 P	148	140	9.1
FS 260 C	162	150	9.4
FS 290 P	143	135	9.0
FS 290 C	151	140	9.1
FS 320 P	153	144	9.1
FS 320 C	168	159	9.8
FS 350 P	168	165	8.4
FS 350 C	162	155	8.8
FS 410 P	170	173	9.2
FS 410 C	191	198	8.9

Note: P = Pilot/left side, C = Copilot/right side
Invalid = Invalid data at FS 200 due to effect of WSU seat collapse

TABLE 2. SIDE WALL SEAT TRACK ACCELERATIONS

Fuselage Station	G_{peak} (g)	G_{max} (g)	Pulse Duration (msec)
FS 200 P	153	151	10.9
FS 200 C	145	145	9.9
FS 260 P	170	163	9.9
FS 260 C	161	147	9.9
FS 290 P	166	160	8.7
FS 290 C	154	148	8.6
FS 410 P	151	155	8.2
FS 410 C	146	149	8.2

Note: P = Pilot/left side, C = Copilot/right side

TABLE 3. SIDE WALL ACCELERATIONS

Fuselage Station	G_{peak} (g)	G_{max} (g)	Pulse Duration (msec)
FS 129 P	144	135	9.2
FS 129 C	111	111	9.4
FS 200 P	139	130	12.6
FS 200 C	127	126	10.1
FS 260 P	172	161	10.5
FS 260 C	157	140	10.3
FS 320 P	154	146	10.2
FS 320 C	148	129	10.1
FS 410 P	151	149	8.6
FS 410 C	137	132	8.8

Note: P = Pilot/left side, C = Copilot/right side

PLATFORM.

The platform accelerations were recorded by two accelerometers mounted underneath the center of the platform. The impact and rebound accelerations of the platform were about 50 g's and 52 g's, respectively. The impact load was measured by the 12 load cells that supported the platform. Posttest observation clearly showed that two rows of platform load cells had bottomed out. This might cause the total measured impact load to be less than the actual impact load. The total measured impact load was 230,000 pounds.

ANTHROPOMORPHIC DUMMIES.

Seven anthropomorphic dummies were used to measure loads and accelerations in their respective lumbar areas for various types of passenger seats during this test. Usable data were not recorded from the dummies in the two WSU energy-absorbing seats due to catastrophic failure of the seats and the mounting systems during the test. The data from the anthropomorphic test dummies are presented in table 4.

TABLE 4. ANTHROPOMORPHIC DUMMY DATA

Fuselage Station and Seat	Lumbar Load (lb)	G_{peak} (g)	G_{max} (g)	Pulse Duration (msec)
WSU - FS 200 C	No Data	No Data	No Data	No Data
WSU - FS 260 P	No Data	No Data	No Data	No Data
PTC - FS 290 C	2302	57	43	44
CAMI - FS 320 CTR	2577	38	34	50
BEECH - FS 350 CTR	2345	66	45	44
PTC - FS 380 P	2304	69	37	50
BEECH - FS 380 C	1774	40	32	61

Note: P = Pilot/left side, C = Copilot/right side

Data verification tests conducted at the FAA's Civil Aeromedical Institute showed that the high measured lumbar load of the ATD in the CAMI seat was due to a mechanical malfunction that did not allow the seat to fully stroke as designed.

RESULTS AND DISCUSSION

FUSELAGE STRUCTURE.

EXTERNAL. The Beechcraft 1900C airliner fuselage experienced minimal external deformation during this dynamic drop test (see figure 5). The maximum external deformation was only 1.6 inches at FS 410. This was despite the fact that the fuselage experienced decelerations in the range of 140 to 160 g's with pulse durations in the range of 9 to 10 milliseconds. Only the empennage portion of the fuselage experienced any significant deformation due to the fact that the empennage protruded over the end of the drop test platform at impact. Film analysis showed that the fuselage deformation was minimal during the impact as well as after the test (i.e., the fuselage did not crush and then rebound after the impact). All normal exits and emergency exits were functioning properly after the impact.

INTERNAL. The structural deformation experienced on the inside of the test article was minimal. The seat tracks remained intact and in place. Minor buckling was seen along the fuselage underfloor and side walls (see figure 6).

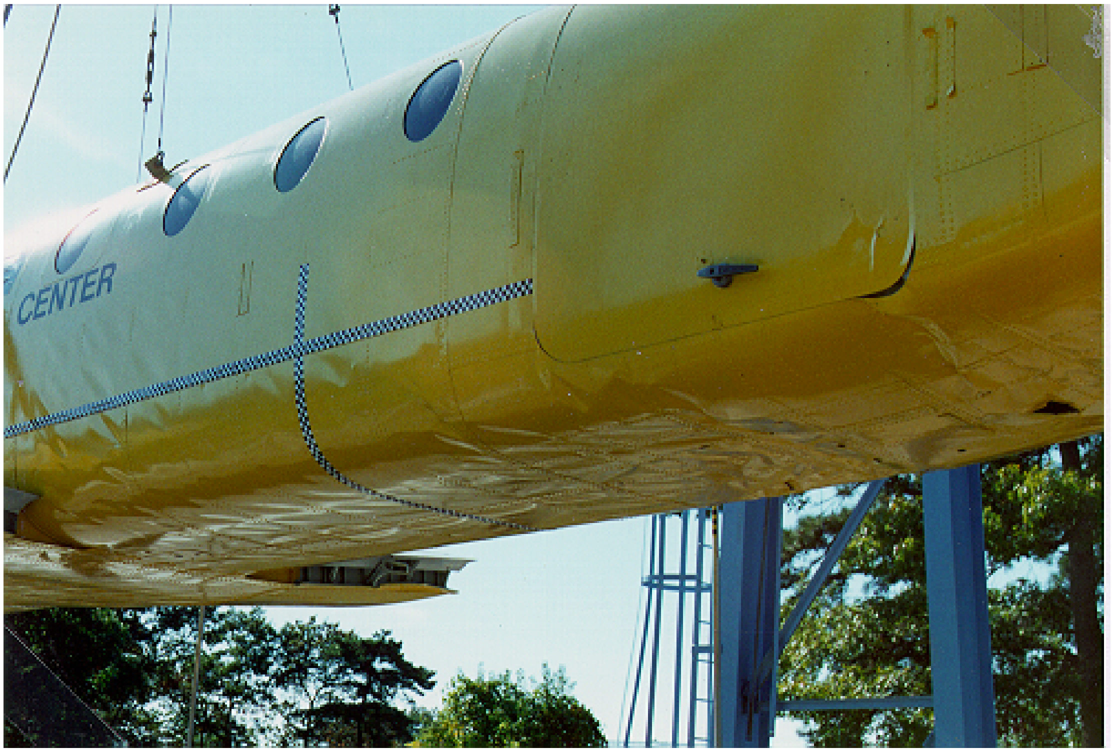

FIGURE 5. UNDERSIDE OF AFT SECTION OF FUSELAGE AFTER IMPACT

FIGURE 6. UNDERFLOOR BUCKLING RIGHT-HAND SIDE AFTER IMPACT

SEATS.

Six distinctly different types of seats comprised the 14 seats which were onboard the test article. A number of the seats collapsed during the test (see figure 7). The majority of the seats (6) were standard, blue-colored Beechcraft seats which were distributed throughout the airplane (figure 2). Two structurally similar standard, brown-colored Beechcraft seats were onboard. Although the standard seats, both blue and brown, are offered by Beechcraft as standard equipment, most operators opt for PTC Aerospace seats; two PTC seats were onboard for the test. Two experimental Wichita State University energy absorbing seats, a CAMI energy absorbing seat, and a Beechcraft seat from a corporate airplane were also on the test article.

Airplane seats should provide enough protection so that the lumbar load on the occupant remains below 1500 pounds. As can be seen from the anthropomorphic test dummy data in table 4, none of the onboard seats provided sufficient protection to insure that the lumbar load remained below 1500 pounds. This was somewhat surprising since previous tests in other airplanes have shown that the CAMI seat was relatively effective in insuring that the lumbar loads remained below the desired level. It was found that the CAMI seat experienced a mechanical malfunction during the test which rendered its energy-absorbing feature inoperative. Likewise, the energy-absorbing feature of the experimental WSU seats was not properly tested because the attachment system failed. Both PTC Aerospace seats experienced approximately 40 g's and imparted 2303 pounds of lumbar load to the occupants. The corporate Beechcraft seat experienced 45 g's with 2345 pounds of lumbar load on the occupant.

FIGURE 7. FRONT INTERIOR OF TEST ARTICLE AFTER IMPACT

The standard blue Beechcraft seat experienced 32 g's with 1774 pounds of lumbar load on the occupant. Although this seat did not meet the requirement of a maximum of 1500 pounds of lumbar load, its load and g levels were significantly lower than the other seats. This could be attributed to the seat's construction which is of relatively flexible aluminum tubing and a webbed seat pan thereby providing a measure of energy absorption.

HIGH-SPEED FILM DOCUMENTATION.

Twelve high-speed film cameras were employed on this test to record the impact phenomenon. Five cameras were located outside the test article and seven were located inside the test article. Four of the five external cameras provided very good photographic coverage of the test. One external camera failed. Although all seven internal cameras functioned properly, no photographic coverage of the interior was obtained because the flash bulbs which were to illuminate the interior just prior to impact did not ignite until after impact. A failure of the sequencer mechanism was determined to be the cause.

PHOTOGRAPHIC DOCUMENTATION.

The still photographs in this report were taken with a 35-mm camera both prior to and following the drop test. Examples of these photographs are seen in figures 5 through 7.

CONCLUDING REMARKS

1. The Beechcraft 1900C test article was dropped from a height of 11′2″ with an impact velocity of 26′8″ per second.

2. The fuselage experienced an impact in the range of 140-160 g's, with an impact pulse duration of 9-10 ms.

3. The simulated occupants experienced g levels in the range of 32-45 g's with a pulse duration of 44-61 ms. This is considered to be a severe but definitely survivable impact.

4. The fuselage structure maintained a habitable environment during and after the impact.

5. The seat tracks (both the side wall and floor track on both sides of the airplane) remained attached to the floor along the entire length of the fuselage.

6. All standard seats (i.e., Beechcraft seats and PTC Aerospace seats) remained in the seat tracks in their preimpact locations.

7. The exit doors remained operable after the impact, and both emergency exits were functional.

8. None of the anthropomorphic test dummies recorded a lumbar load below the recommended maximum of 1500 pounds.

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