Summary of the FAA's Commuter Airplane Crashworthiness Program

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ABSTRACT

The Federal Aviation Administration (FAA) is evaluating the adequacy of current certification standards for seat and restraint systems for small commuter category airplanes (Title 14 Code of Federal Regulations (CFR) Part 23 and small Part 25). To provide data for those size airplanes, the FAA conducted four full-scale vertical impact tests of commuter category airplanes to characterize their impact response. 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.

The results showed that the fuselage acceleration and dynamic crush was consistent with the results of an idealized triangular impact. The results also showed that flat-belly fuselages developed higher accelerations with shorter pulse durations than curved-belly fuselages and that within each airplane design, as expected, the apparent stiffer structure resulted in higher accelerations and shorter pulse durations. The data indicated that two groups of fuselage responses have emerged: those with higher accelerations and shorter pulse durations and those with lower acceleration and longer pulse duration. Group one has an average dynamic crush depth of 10 inches and group two of 16 inches. Only the ATR 42 of group 2 was able to effectively use its underfloor crush depth to reduce fuselage acceleration. The ATR 42 wing and the Shorts 3-30 overhead fuel tanks intruded into the cabin after their support structures failed. The results indicate that 14 CFR Part 23 and small Part 25 commuter airplanes have similar fuselage response characteristics.

INTRODUCTION

The Federal Aviation Administration (FAA) is evaluating the adequacy of current certification standards for seat and restraint systems for small commuter category airplanes (14 CFR Part 23 and small Part 25). These standards were established empirically using the results of prior airplane crash impact test programs. In the development of those standards, it was noted that the full-scale airplane impact test database did not include airplanes representative in size of commuter category airplanes. To provide data for those size airplanes, the FAA conducted four full-scale vertical impact tests of commuter category airplanes to characterize their impact response.

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 (ATDs) were 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.

The geometry of the four airplanes was unique. All the 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 (ATDs) was measured for each test.

TEST ARTICLES

Various modifications were made to the airplane and the weights and center of gravity (CG) of each airplane was compensated for.

A brief description of each test is given below.

a. A vertical impact test of a Fairchild Metro III airplane was conducted in 1992 [1]. 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 (figure 1) was dropped onto a wooden platform from a vertical height of 11.2 feet, resulting in an impact velocity of approximately 26.8 ft/sec.

FIGURE 1. FUSELAGE TEST SECTION METRO IIII

b. A vertical impact test of a Beechcraft 1900C (B 1900C) airplane was conducted in 1995 [2]. The B 1900C is a metal, low-wing, flat-belly, 19-passenger commuter airplane with a14 CFR Part 23 SFAR 41 type certificate. The fuselage (figure 2) was dropped onto a wooden platform from a vertical height of 11.2 feet, resulting in an impact velocity of approximately 26.8 ft/sec.

FIGURE 2. FUSELAGE TEST SECTION BEECH 1900C

c. A vertical impact test of a Short Brothers PLC, Model SD 3-30 (Shorts 3-30) airplane was conducted in 1998 [3]. The Shorts 3-30 is a metal, high-wing, flat-belly, 30-passenger regional transport airplane. It is certified to 14 CFR Part 25 and has been primarily operated as a regional transport in a commuter role. The fuselage (figure 3) was dropped onto a wooden platform from a vertical height of 14 feet, resulting in an impact velocity of 30.0 ft/sec. The fuel tanks were located over the cabin and before and aft of the wing.

FIGURE 3. FUSELAGE TEST SECTION SHORTS 3-30

d. A vertical impact test of an ATR 42-300 (ATR 42) airplane was conducted in 2003 [4]. The ATR 42 is a metal, low-wing, curved-belly, 42-passenger regional transport airplane. It is certified to 14 CFR Part 25 and has been primarily operated in a commuter role. The fuselage (figure 4) was dropped onto a concrete surface from a vertical height of 14 feet, resulting in an impact velocity of 30.0 ft/sec.

FIGURE 4. FUSELAGE TEST SECTION ATR 42

INSTRUMENTATION

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.

VISUAL IMAGING

High-speed (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.

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.

DATA REDUCTION

An SAE J211 class 600 (1000 Hz) digital filter [5] was used to filter the ATD load cell data. An SAE J211 class 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. 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 20-Hz digital filter was designed using SAE J211 guidelines to remove unwanted signals and provide the needed pulse definition. CFC 20 data is reported for the ATR 42.

DISCUSSION

TIME TO IMPACT

The Metro III and the B 1900C are 14 CFR Part 23 certified commuter category 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 paper reflect corrected velocity measurements correlated with visually recorded data. Impact velocity corresponds to the velocity component of the combined vertical/longitudinal dynamic down test requirement for airplane seat certification for 14 CFR Part 23 airplanes, §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. Impact velocity corresponds to the velocity component of the combined vertical/longitudinal dynamic down test requirement for airplane seat certification for 14 CFR Part 25 airplanes, §25.562(b)(1).

FUSELAGE ACCELERATION

Airframe acceleration data is given in terms of three parameters: peak measured acceleration (G_{peak}), pulse duration (Δt), and maximum acceleration (G_{max}). G_{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_{max} values were computed based on an idealized triangular pulse:

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

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.

Airframe acceleration data are presented in two groups for each airplane: (a) fuselage sidewall accelerations and (b) floor seat track accelerations.

SIDEWALL ACCELERATIONS

In general, the Metro III experienced G_{max} sidewall accelerations of 50–65 g with a 26- to 36-msec pulse duration (table 1). G_{max} sidewall accelerations at the cockpit area where the under floor structure is very stiff, were slightly higher.

TABLE 1. METRO III SIDEWALL ACCELERATIONS

Fuselage Station	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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_{max} sidewall accelerations of 130-160 g with a 9- to 10-msec pulse duration (table 2). Table 2 shows that the highest G_{peak} and G_{max} occurred at the wing box section, where the structure was very stiff.

TABLE 2. B 1900C SIDEWALL ACCELERATIONS

Fuselage Station	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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 fuselage station (FS) 340 and FS 89 of the Shorts 3-30 during the impact as seen 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 fuselage stations indicate that the Shorts 3-30 experienced G_{max} sidewall accelerations of approximately 100 g with a 5-msec pulse duration.

TABLE 3. SHORT 3-30 SIDEWALL ACCELERATIONS

Fuselage Station	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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 frame 18 through frame 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

Frame Number	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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 5 shows a typical plot of the sidewall accelerations for the four tests.

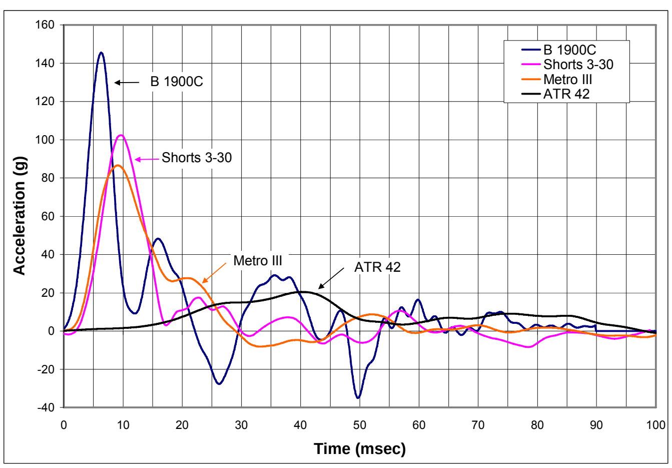

FIGURE 5. TYPICAL SIDEWALL ACCELERATIONS

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_{peak} and short pulse duration. Overall, the Metro III floor tracks experienced a G_{max} of 50-65 g with a 26- to 36-msec pulse duration (tables 5 and 6).

TABLE 5. METRO III INBOARD FLOOR TRACK ACCELERATIONS

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

TABLE 6. METRO III OUTBOARD FLOOR TRACK ACCELERATIONS

Fuselage Station	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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 B 1900C impact test slightly exceeded the expected full-scale value (200 g), which had been programmed into the data acquisition system. The original clipped data are given in [2]. The G_{peak} and G_{max} values in table 7 are based on the clipped data. The actual impact G_{peak} and G_{max} values was estimated to be slightly, but not significantly, 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. This paper does not include sidewall seat track data for this airplane.

TABLE 7. B 1900C FLOOR TRACK ACCELERATIONS

Fuselage Station	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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 close to the Shorts 3-30 sidewall and sidewall seat track acceleration and are listed in table 8. The Shorts experienced a G_{max} of approximately 90 g with a pulse duration of 15- to 18-msec.

TABLE 8. SHORTS 3-30 FLOOR TRACK ACCELERATIONS

Fuselage Station	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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 [4]. 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 accelerations are listed in tables 9 and 10.

TABLE 9. ATR 42 INBOARD FLOOR TRACK ACCELERATIONS

Frame Number	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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 10. ATR 42 OUTBOARD FLOOR TRACK ACCELERATIONS

Fuselage Station	Left Side			Right Side		
	G_{peak} (g)	G_{max} (g)	Duration (msec)	G_{peak} (g)	G_{max} (g)	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
18	---	---	---	24	28	66

Figure 6 shows a typical plot of the sidewall accelerations for the four tests.

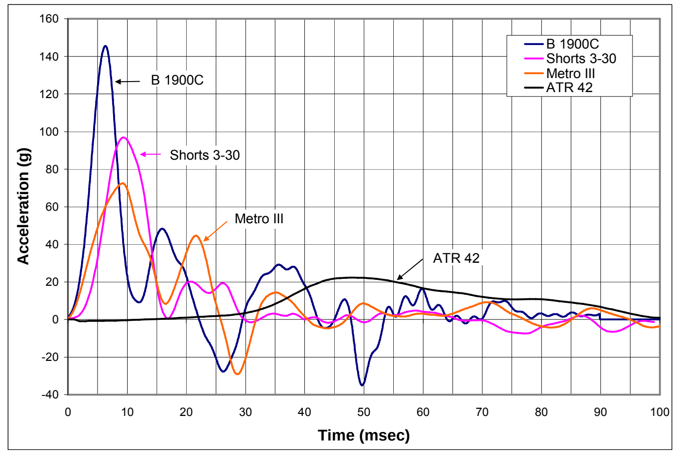

FIGURE 6. TYPICAL FLOOR TRACK ACCELERATIONS

EFFECTS OF OVERHEAD ITEMS OF MASS

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 affect on fuselage acceleration near the cabin floor areas.

COMPOSITE ACCELERATIONS

A single composite acceleration profile of each airplane was made by averaging the data from representative channels from each test. The results from the primary pulse are listed in table 11, and the composite acceleration plots are shown in figure 7. Using the composite data, four idealized triangular pulses were created using G_{max} acceleration values and are shown in figure 8.

TABLE 11. 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
ΔV (ft/sec)	23/27	25/30	27/27	26/30

*ΔV corresponds with the primary pulse duration; the second value is the impact velocity.

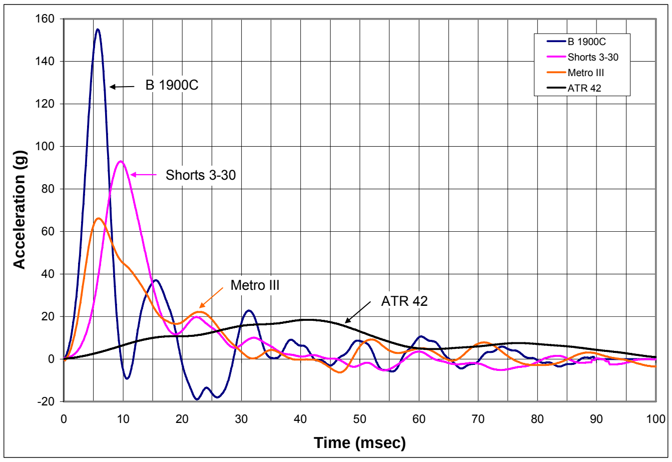

FIGURE 7. COMPOSITE FUSELAGE RESPONSE

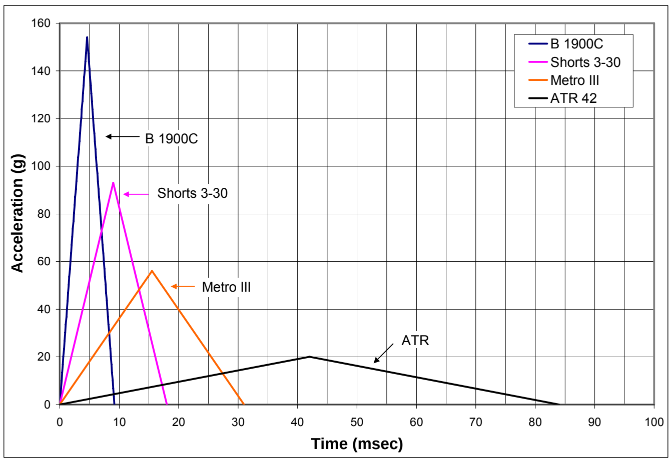

FIGURE 8. IDEALIZED TRIANGULAR FUSELAGE ACCELERATIONS

The data indicates that 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. The data also shows that within the flat- and circular-belly fuselage design, the apparent stiffer structures have higher fuselage acceleration and shorter pulse duration (B 1900C vs. Shorts 3-30 and Metro III vs. ATR 42).

The composite data indicates that two groups of fuselage responses have emerged: those with higher accelerations and shorter pulse durations (B 1900C, Shorts 3-30, and Metro III) and those (ATR 42) with lower acceleration and longer pulse duration. The first group has an average available underfloor crush depth of 10 inches and pulse durations in the range of approximately 9 to 31 msec. The pulse durations were below the range (50 to 150 msec) used in developing current 14 CFR Part 23 certification standards for general aviation airplane metal fuselage structures. The second group had 18 inches of available crush depth and a pulse duration of 84 msec. This was within the range and close to the average of the reference group. The data indicates that 14 CFR Part 23 and some small Part 25 commuter airplanes have similar fuselage response characteristics.

STATIC (POSTTEST AT REST) AND DYNAMIC CRUSH (MAXIMUM AT IMPACT)

The composite acceleration data was integrated twice to calculate the dynamic crush. The results are listed in table 12, and the static and dynamic crush data are plotted in figure 9. Figure 9 includes plots of acceleration vs displacement for the response of impact with a resulting idealized triangular pulse at 26.8 ft/sec and 30 ft/sec. The Metro III, B 1900C and Shorts 3-30 experienced approximately 1 in. of static crush and 2-4 inches of dynamic crush. The percentage of dynamic crush per available crush depth varied between 20% and 52%. The ATR 42 experienced approximately 12 in. of static crush and 16 inches of dynamic crush. The percentage of dynamic crush per available crush depth was 92%. The data shows 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 in the report Seat Dynamic Performance Standards for a Range of Sizes [6]. The data shows that the ATR 42 was the most effective of the airplanes at using its available crush depth to reduce the acceleration level of the fuselage.

TABLE 12. STATIC AND DYNAMIC CRUSH

Test Article	B 1900C	Shorts 3-30	Metro III	ATR 42
App. Static Crush (in)	1	1	1	12
App. Dynamic Crush (in)	2.0	4.3	3.9	16.4
Available Crush Depth	9.9	8.2	11.1	18
% Available Crush Depth	20	52	35	92

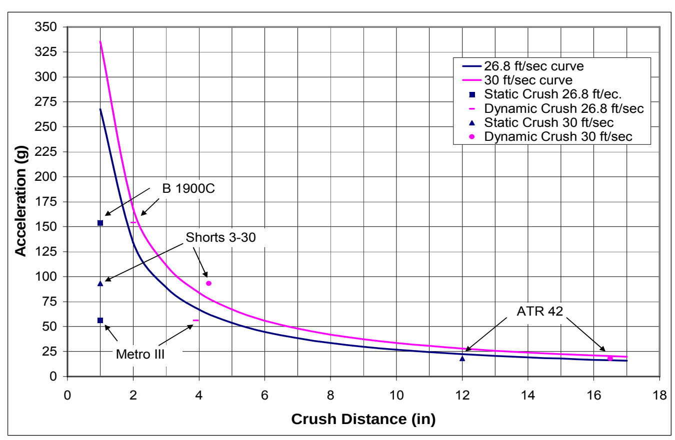

FIGURE 9. ACCELERATION VS DISPLACEMENT

FUSELAGE PENETRATION

The wing of the ATR 42 and the overhead fuel tanks of the Shorts 3-30 fractured their support structures and penetrated into the survivable volume of cabin space (figures 10 and 11).

FIGURE 10. ATR 42 POSTIMPACT

FIGURE 11. SHORTS 3-30

RESULTS AND CONCLUSIONS

14 CFR Part 23 and small Part 25 commuter airplanes with comparable crushable underfloor depth have similar fuselage response characteristics.

The B 1900C, Shorts 3-30, and the Metro III had pulse durations in the range of approximately 9 to 32 msec and are near the extreme range (50-150 msec) of data currently used to develop 14 CFR Part 23 standards.

The ATR 42's pulse duration was approximately 84 msec and was consistent with the pulse durations found within the range (50-150 msec) and near the average of 100 msec used to develop 14 CFR Part 23 airplane seat certification standards.

The overall fuselage accelerations were consistent with the theoretical accelerations of an idealized triangular pulse.

The dynamic crush depth of the four fuselages was consistent with the theoretical crush depth 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 intruded into 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 affect on fuselage acceleration near the cabin floor areas.

The overall data indicates that two groups of fuselage responses have emerged: Group 1 - those with higher accelerations and shorter pulse durations of (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 available potential crush depth of 8.2 to 11.1 inches and group 2 had 18 inches.

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

The flat-belly B 1900 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.

Within the flat- and curved-belly fuselage design the apparent stiffer structures have higher fuselage acceleration and shorter pulse duration (B 1900C vs. Shorts 3-30 and Metro III vs. ATR 42).

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 52% of the available crush depth and 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.

REFERENCES

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