Summary of the FAA's Overhead Stowage Bin Crashworthiness Program

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ABSTRACT

From 1991 to 2000, the Federal Aviation Administration (FAA) conducted vertical and longitudinal and static and dynamic tests of various narrow-body transport airplane fuselage sections, which included different types of in-service overhead stowage bins. Vertical drop impact tests were conducted at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. Longitudinal, simulated impact sled tests were conducted at the Transportation Research Center (TRC), East Liberty, Ohio. This paper summarizes the results of those tests and includes results from the analytical modeling performed in conjunction with the last vertical drop impact test. This information will provide a basis to assess the adequacy of the design standards and regulatory requirements for overhead stowage bins.

INTRODUCTION

Prior cabin safety research efforts have led to the definition of the survivable crash environment, the development of crash dynamic analytical modeling methodologies, and improved design standards and regulatory requirements for aircraft seats and aircraft interiors [1]. Additional information was needed to determine the impact response characteristics of overhead stowage bins installed onboard transport category airplanes.

To obtain the necessary information, the FAA conducted a series of narrow-body transport airplane fuselage section tests from 1991 to 2000. The tests consisted of two longitudinal simulated impact tests [2-4] and two vertical drop impact tests [5, 6], which resulted in severe deformation of the test section. A summary report of the tests can be found in reference 7.

TEST FACILITY

The longitudinal sled tests were conducted at the TRC Laboratory Impact Simulator Facility in East Liberty, Ohio (figure 1). This facility uses a 24-in.-diameter HYGE™ crash simulation system to replicate the deceleration conditions of an impact in a nondestructive manor. The test article was attached to a steel frame that was mounted on a test sled and accelerated down a test rail. The steel fixture was fabricated to minimize any effect on load paths between the fuselage and the overhead stowage bins, the auxiliary fuel tank (when installed), and the fuselage floor.

Figure 1. Longitudinal Impact Simulator Facility

The vertical drop impact tests were conducted at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The drop test facility was comprised of two 57-foot vertical steel towers connected at the top by a horizontal platform (figure 2). A 15- by 36.5-foot wooden platform impact surface, which rests upon steel I-beams and is supported by 12 load cells, was located between the tower legs.

Figure 2. Dynamic Drop Test Facility

TEST ARTICLES

The test article used in the first longitudinal and vertical bin test was a 10-foot section cut from a Boeing 707 transport airplane (figure 3). The test article used in the second longitudinal and vertical test was a 10-foot section cut from a Boeing 737 transport airplane (figure 4). After the longitudinal test, the Boeing 737 test section was used in a drop test regarding auxiliary fuel tanks. Therefore, an identical fuselage section from a different Boeing 737 airplane was used in the vertical bin test.

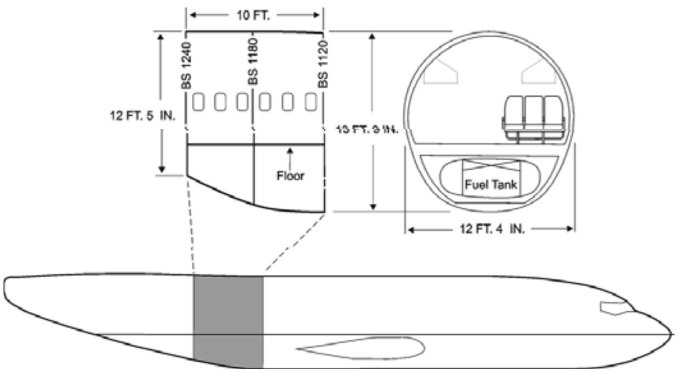


Figure 3. Boeing 707 Airplane

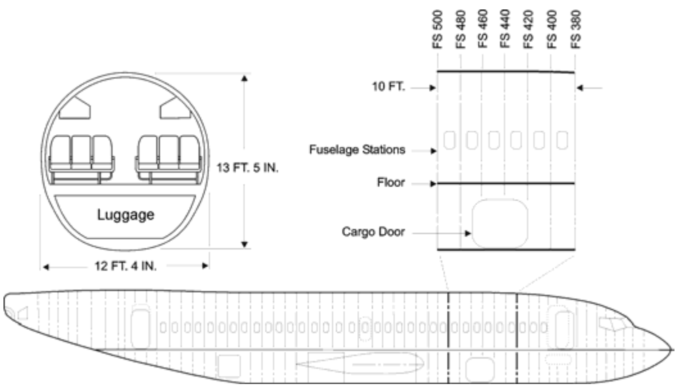
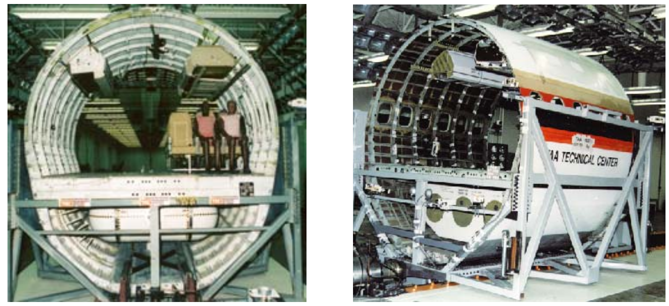


Figure 4. Boeing 737 Airplane

LONGITUDINAL TESTS

The Boeing 707 and 737 fuselage sections are shown in figure 5. Tests were conducted at nominal 6-, 9-, and 16-g acceleration levels for each fuselage section. A typical triangular input pulse is shown in figure 6. The sled, fuselage, and two overhead stowage bins were instrumented with accelerometers and the bin support members were instrumented with calibrated strain gage bridges. A static longitudinal calibration test was conducted prior to each of the dynamic test series to determine the relative loading (static influence coefficient) of the longitudinal support brackets. The auxiliary fuel tanks shown in figure 5 were suspended from the cabin floor beams in the cargo area and were part of another test series.



(a) (b)

Figure 5. Boeing 707 (a) and 737 (b) Longitudinal Test Configuration

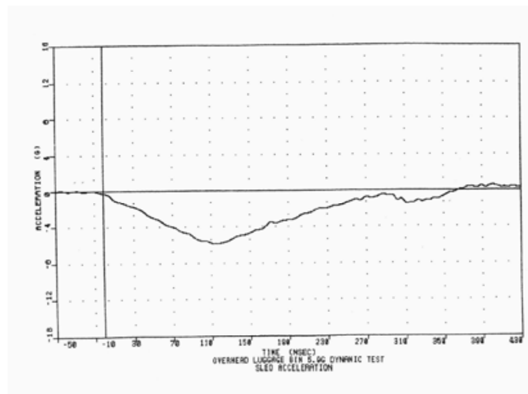


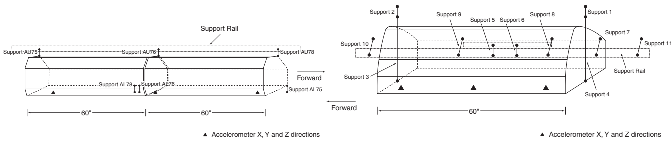
Figure 6. Typical Acceleration Pulse

The Boeing 707 cabin area was configured with two overhead stowage bins (figure 7). A 60-in. Hitco overhead storage bin was mounted on the right side between fuselage station (FS) 1137 and FS 1197. The bin was loaded with luggage to the specified placard weight. A 20-in. Boeing overhead stowage bin was mounted in front of the 60-in. bin, and another 20-in. bin was mounted behind the 60-in. bin to account for the potential interaction between adjacent bins and support structure. The bins were mounted on the left side between FS 1137 and FS 1237. Two passenger service units (PSU) were attached to the Boeing bin. The bins were loaded with plywood ballast to achieve the placarded weight and maintain the bin's center of gravity (cg).

(a) Boeing Bin (b) Hitco Bin

Figure 7. Boeing 707 Overhead Stowage Bins

The Boeing 737 cabin area was configured with two overhead stowage bins (figure 8). A 120-in.-long C&D stowage bin was mounted on the left (pilot) side of the cabin between FS 400 and FS 500A. A 60-in.-long Hexcel stowage bin was mounted on the right (copilot) side of the cabin between FS 420 and FS 480. The bins were loaded with plywood ballast to achieve the placarded weight and maintain the bin's center of gravity.



(a) C&D bin (b) Hexcel Bin

Figure 8. Boeing 737 Overhead Stowage Bins

Results

Longitudinal data was filtered using an SAE channel frequency class (CFC) 60 (100 Hz) filter [8]. Results from the longitudinal tests are listed in tables 1 to 3. In Table 1, the overhead stowage bins show some dynamic amplification compared to the fuselage section.

A comparison between measured loads and inertial loads was made by converting the measured load values from the instrumented strain gages to their equivalent g- loads. The results listed in table 1 show they are comparable to the inertial loads measured by the accelerometers.

During the 6-g Boeing 707 test, the Boeing bin sustained damage at the bracket/bin attachment location. The bin was modified, the brackets were reattached and the bins were tested at the 9-g condition. Both bins sustained dynamic loads greater than 9-g. During the Boeing 707 test, the Boeing bin sustained a slight bump in its readings 20 msec prior to the maximum sled acceleration. The bins were then tested at the 16-g condition. Both bins remained attached to the fuselage section; however, the Boeing bin sustained substantial structural damage.

Table 1. Maximum Longitudinal Bin Accelerations

Test section	Peak Acceleration (g) Sled	Floor	Sidewall	Crown	Boeing Bin Left-Side Peak Acceleration (g)	Hitco Bin Right-Side Peak Acceleration (g)
Boeing 707	5.9	6.0	6.3	6.7	*	6.7
	8.8	9.1	9.6	10.3	**12.7	10.7
	13.2	14.5	14.9	15.1	*	17.4
Test section	Peak Acceleration (g) Sled	Floor	Sidewall	Crown	***C&D Bin Left-Side Peak Acceleration (g)	***Hexcel Bin Right-Side Peak Acceleration (g)
Boeing 737	6.1	7.0	NA	NA	7.1 (6.9)	7.7 (7.0)
	8.2	8.6	NA	NA	10.1 (10.1)	9.0 (9.1)
	14.2	16.5	NA	NA	****14.7 (14.7)	16.7 (16.8)

100-Hz data. *Bin failed – still suspended. **Occurred approximately 20 msec prior to peak sled pulse. ***Second reading () indicates measured load equivalent g-level. ****Bin detached after this reading.

Table 2 lists the maximum acceleration values in the x, y, and z direction for the four bins. Only when the bins failed did the accelerations in the y and z direction exceed Title 14 Code of Federal Regulations (CFR) Part 25.561 requirements (y-dir ±3, z-dir -6/+3 g).

Table 2. Maximum Bin Accelerations

Bin	Maximum Inertial Load (g)			Maximum Inertial Load (g)			Maximum Inertial Load (g)		
	X-dir	Y-dir	Z-dir	X-dir	Y-dir	Z-dir	X-dir	Y-dir	Z-dir
	Test 707-6			Test 707-9			Test 707-14		
Hitco bin	6.7	±2	±2	**10.7**	±2	±2	****17.4**	+2/-4	+13/-10
Boeing bin	**	**	**	**12.7**	±2	±1	*	*	*
	Test 737-6			Test 737-9			Test 737-14		
C&D bin	6.9	±1	±2	**10.1**	±1	±1	*****14.7**	±2	±2
Hexcel bin	7.7	±2	±3	9.0	±1	±1	**16.7**	±1	±3

100-Hz data. * Bin detached at 14.7g. ** Bin failure - still suspended. *** Bin failure - still suspended - PSU hanging. Current certification bin requirements are X-dir +9/-1.5, y-dir ±3, z-dir -6/+3.

Table 3 shows the influence coefficients of the support brackets that react longitudinal loads. There was little difference between the static influence coefficients obtained during the static calibration tests and the dynamic influence coefficients obtained during the dynamic simulated impact tests. Since the Boeing bin and the Hitco bin only have one bracket designed to react longitudinal loads, their values were not listed.

Table 3. Static and Dynamic Influence Coefficients

Support Member Time of Measurement	Longitudinal Component Influence Coefficient *Measured Static	Test 737-6 Dynamic	Test 737-9 Dynamic	Test 737-14 Dynamic
Hexcel 5	0.532	0.540	0.539	0.530
Hexcel 6	0.468	0.460	0.461	0.470
C&D AU75	0.247	0.221	0.198	0.192
C&D AU76	0.335	0.335	0.306	0.278
C&D AU78	0.025	0.033	0.066	0.103
C&D AL78	0.073	0.067	0.064	0.060
C&D AL76	0.186	0.208	0.205	0.206
C&D AL75	0.129	0.136	0.161	0.160

100-Hz data. *Longitudinal loads are reacted by bin support members 5 and 6.

Figure 8 shows that the forward Boeing bin PSU swung open during the 14-g test and that the PSU was still attached at the hinged side. The aft PSU was not secured at the front aisle corner.

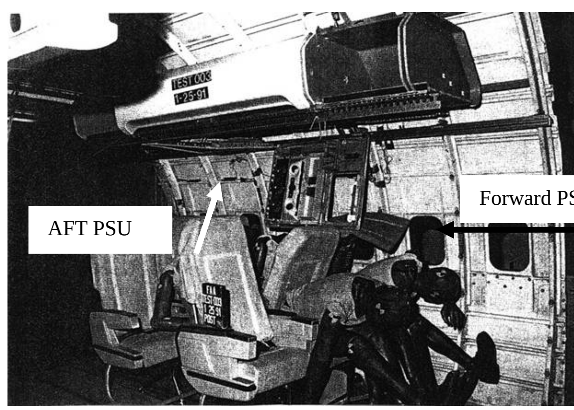


Figure 8. Boeing Bin Post 14-g Test

VERTICAL TESTS

The Boeing 707 and 737 fuselage sections are shown in figure 9. The outer floor beams at each end of the section were reinforced to minimize open-end effects. The fuselage sections were dropped from a height of 14 feet, thereby generating a final velocity at impact of 30 fps. The cabin areas were equipped with two overhead stowage bins and 3 rows of 9-g triple-passenger seats with anthropomorphic test dummies (ATD) and mannequins placed in the seats. The fuselage and bins were instrumented with accelerometers, and the bin support members were instrumented with calibrated strain gage bridges. The bin doors were latched and strapped shut to ensure the bin contents remained inside the bins during the impact to subject the bins to the most adverse load condition. The bins were loaded with plywood ballast to achieve their placarded maximum weight and design cg's. A static vertical calibration test was conducted prior to each dynamic test to determine the static influence coefficients of the support brackets.


(a) Boeing 707

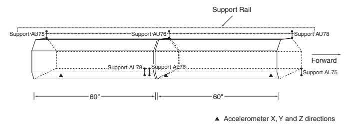

(b) Boeing 737

Figure 9. Vertical Test Configurations

The Boeing 707 cabin area was configured with two overhead stowage bins (figure 10). A 60-in. Boeing overhead stowage bin was mounted on the left side of the fuselage. A 20-in. Boeing overhead stowage bin was mounted in front of the 60-in. bin, and another 20-in. bin was mounted behind the 60-in. bin to account for the potential interaction between adjacent bins and support structure. Two PSUs were attached under the 60-in. Boeing bin. The strap used to secure the bin door closed was located between the two PSUs. A 113-in. C&D stowage bin was mounted on the right side of the fuselage. The straps used to secure the bins closed also supported the PSUs.

A double-wall cylindrical auxiliary fuel tank was suspended from the passenger cabin floor in the cargo area. The total weight of the test section was 8097 lb.

The Boeing 737 cabin area was configured with two overhead stowage bins (figure 11). A 60-in. Hitco bin was mounted on the left side between FS 409 and FS 469 (schematic - figure 7) and a 60-in. Heath Tecna bin was mounted on the right side between FS 415 and FS 475. Two PSUs were attached under each bin. The cargo area was filled with luggage and the total weight of the test section was 8900 lb. The strap used to secure the Hitco bin closed also supported the aft PSU near its forward area. The strap used to secure the Heath Tecna bin closed was located between its two PSUs.



(a) C&D Bin

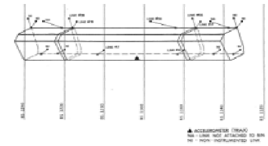
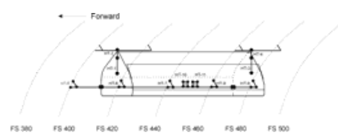

(b) Boeing Bin

Figure 10. Boeing 707 Overhead Stowage Bins



(a) Heath Tecna Bin


(b) Hitco Bin – With Wood Ballast

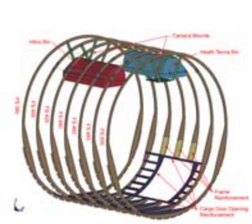

(c) Heath Tecna Bin


(d) Hitco Bin

Figure 11. Boeing 737 Overhead Stowage Bins

SIMULATION

Two modeling efforts were undertaken to model the vertical drop test of the Boeing 737 fuselage section [9, 10]. Representative data for the two efforts are included in the results. Figure 12 shows one fuselage model layout.



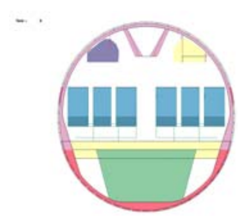


Figure 12. Boeing 737 Analytical Model

RESULTS

The drop tests resulted in substantial structural damage to the fuselage test section (figure 13). Both test sections were asymmetrical in construction, and thus resulted in asymmetrical crushing and loading.

The Boeing 707 section crushed relatively level; however, loads experienced at the forward section were greater than those in the aft section. Frame section damage was limited to the cargo area.

(a) Boeing 707 (b) Boeing 737

Figure 13. Posttest Fuselage Sections

The Boeing 737 section had a reinforced cargo door and door frame that limited the crushing on the right side of the fuselage. Both the test photomography and the simulation show deformation of the upper fuselage section. The Boeing 737 fuselage sustained fractures in the upper frame sections, which affected the response of the bins. The seats on the right side of the aircraft failed catastrophically while those on the left side were basically intact. The models assumed a rigid seat that did not fail. These, as well as other assumptions, may/would influence the results of the model.

Figure 14 shows a posttest comparison of the Boeing 737 drop test fuselage section and the simulation results; the results were comparable. The luggage was removed from the simulation model to show the cargo area and the exposed structural elements.

(a) Experiment (b) Simulation

Figure 14. Boeing 737 Fuselage Section Posttest

During the impact of the Boeing 707 fuselage, the C&D failed and the bin contents emptied onto the seats and aisles below the bin (figure 13). The forward PSU of the Boeing bin also detached.

During the impact of the Boeing 737 fuselage, the front aisle corner of the forward Hitco PSU swung down and then back up. The bin remained attached at the other three corners. As mentioned earlier, the aft bin was supported by the strap used to secure the bin closed. The aft PSU remained attached to the bin. The Heath Tecna bin PSUs remained attached to the bin.

Typically fuselage data is filtered using an SAE 100-Hz filter. However, due to large fluctuation in the data (figure 15), the data were filtered at 20 Hz. It was determined that, in this case, a CFC 20 filter was appropriate [9] to determine the fundamental and primary pulse, magnitude, and duration.

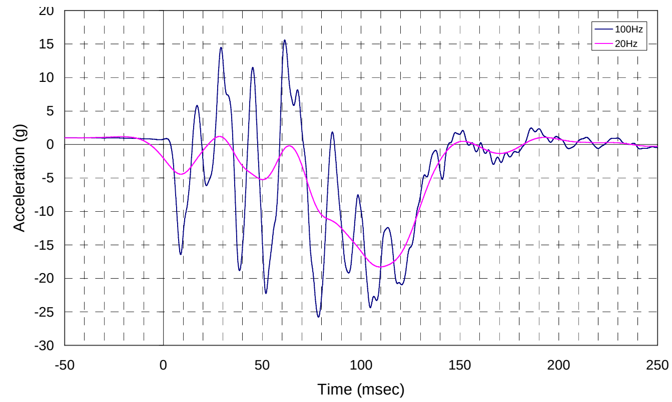


Figure 15. Boeing 737 Fuselage Acceleration

In the vertical drop tests, the inertial bin data were obtained using five accelerometers. An accelerometer measuring in the vertical (z) direction was placed at each end of the bin and one was located at the longitudinal/lateral c.g. location near the bottom of the bin. Accelerometers measuring in the x and y directions were also located at the c.g. location near the bottom of the bin. The vertical accelerations listed in this paper are the average values of the three vertically oriented accelerometers.

The vertical inertial acceleration data are listed in Table 4. The data show that the peak acceleration levels sustained by the bins were less than the fuselage section. Using the 20-Hz data as the reference data, the fuselage sustained 20-g loading and the bins 10 to 13 g. Converting the measured load data into its equivalent g-loading, the Hitco and Heath Tecna bins sustained 13 and 15 g (CFC 60 - 100-Hz filter), respectively. No additional filtering was necessary for the measured load data.

Table 4. Drop Test Vertical Acceleration Data

Test	Average Sidewall Peak Acceleration (g)	Average Left-Side Peak Acceleration (g)		Average Right-Side Peak Acceleration (g)	
		*Boeing Bin		C&D Bin	
Boeing 707 100Hz	36	26		**12	
		Hitco Bin		Heath Tecna Bin	
Boeing 737 100Hz	32	15		18	
		Test	Model	Test	Model
Boeing 737 20Hz	20	10	11	11	13

*PSU separated from bin. **Last valid reading prior to bin failure.

Table 5 shows the maximum inertial loads in the x, y, and z directions of the four bins.

Table 5. Drop Test Acceleration Data

	Maximum Inertial Load		
	X-direction (g)	Y-direction (g)	Z-direction (g)
Boeing 707 Test			
Boeing Bin*	**+16/-20**	+2/**-20**	**+19/-26**
C&D Bin**	+7/**-8**	**+5/-6**	**-12**
Boeing 737 Test			
Hitco Bin***	+7/**-4**	**+11/-14**	**+6/-15**
Heath Tecna Bin	+7/**-6**	**+12/-7**	+2/**-18**

100 Hz data. * PSU came off. **Bin failed after this reading and detached. ***PSU detached at one corner. Bold indicates exceeded current static 14 CFR Part 25.561 certification requirements (x-dir +9/-1.5, y-dir ±3, z-dir -6/+3 g).

The static and dynamic support bracket influence coefficients of the Hitco bin are listed in Table 6. Support brackets H1 and H2 are the primary brackets that react vertical loads. The data show that there are differences between the static and dynamic vertical influence coefficients.

Table 6. Vertical Static and Dynamic influence Coefficients

Support Member	Static Equivalent Vertical (z) Load (lb) 6 g	Measured Dynamic Vertical (z) Load (lb) 6 g @ 16 msec	Static Equivalent Vertical (z) Load (lb) 15 g	Maximum Measured Dynamic Vertical (z) Load (lb) 15 g @ 113 msec	Vertical Component Influence Coefficient Static	Dynamic 6 g @16 msec	Dynamic 15 g @ 113 msec
H1	552	313	1291	892	0.358	0.203	0.247
H2	473	321	1107	1130	0.307	0.208	0.313
H3	91	110	213	172	0.059	0.071	0.048
H4	0	6	0	29	0.000	0.004	0.008
H5	163	257	382	464	0.106	0.167	0.129
H6	-3	-4	-7	-11	-0.002	-0.002	-0.003
H7	174	338	408	612	0.113	0.219	0.170
H8	2	-1	4	-12	0.001	0.000	-0.003
H9	99	174	231	293	0.064	0.113	0.081
H10	0	9	0	34	0.000	0.006	0.009
H11	-8	17	-18	3	-0.005	0.011	0.001
Total load	-------	1541	------	3607	-------	-------	-------

Figures 16 and 17 show the static influence coefficients and the experimental and analytically modeled dynamic influence coefficients. The figures show the values carried by the two principle vertical load supports of the Heath Tecna and Hitco bins. After free-fall and impact, the readings begin to settle around the static values. Note that the scales are different for the two bins.

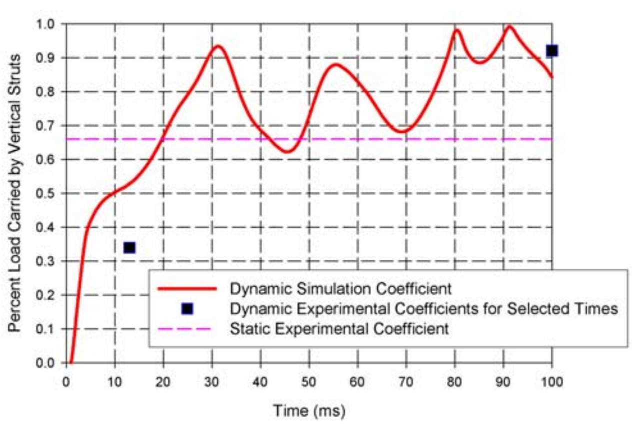


Figure 16. Static and Dynamic Influence Coefficients - Heath Tecna Bin Principle Vertical Supports

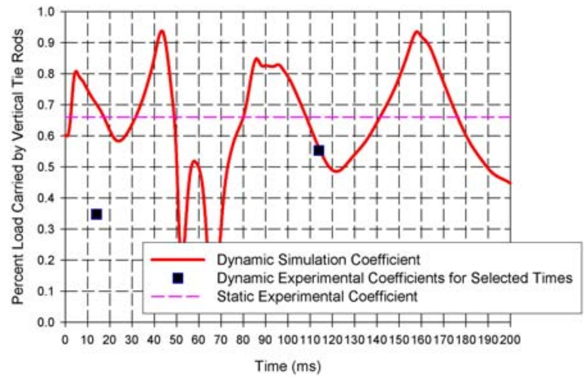
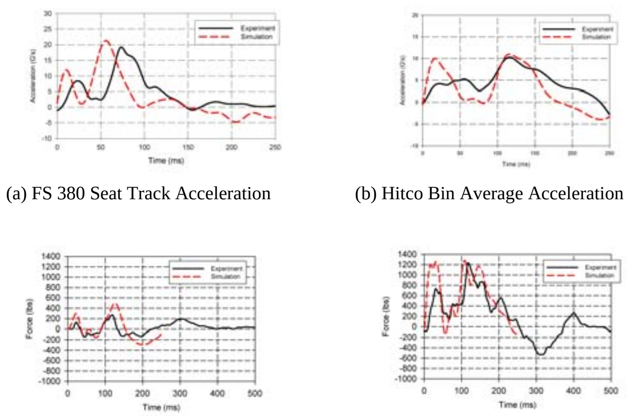


Figure 17. Static and Dynamic Influence Coefficients - Hitco Bin Principle Vertical Supports

Figure 18 shows various comparisons between the experimental data and the simulated data. The seat track data show some phase shift and a greater magnitude for first pulse. However, the overall results are reasonable and show good agreement between the two.



(a) FS 380 Seat Track Acceleration (b) Hitco Bin Average Acceleration

(c) Hitco Bin Horizontal Link (d) Hitco Bin Load Aft Tie Rod

Figure 18. Fuselage (a, b) and Bin Acceleration Responses (c, d)

CONCLUSIONS

A series of tests were conducted to evaluate the response of aircraft overhead stowage bins during static and dynamic load conditions. Two simulated impact sled tests and two vertical impact drop tests were conducted. A 10-foot fuselage section of a Boeing 707 and 737 served as the test articles. Both fuselage sections had two overhead stowage bins attached.

Overhead stowage bin doors have been documented to open during rough turbulence and crash impacts. Therefore, the bin doors were latched and strapped shut to ensure the bin contents remained inside the bins during the impact to subject the bins to the most adverse load condition.

The difference between static and dynamic loading of the bins was primarily a function of the deformation of the fuselage structure. Longitudinal simulated impact test resulted in small fuselage deformation and in small differences between static and dynamic loading. The lateral and vertical loads developed during the longitudinal simulated impact tests (6, 9, and 16 g) were below emergency landing loads specified in Title 14 Code of Federal Regulations (CFR) Part 25.561.

Three of the four bins were able to exceed 9 g simulated longitudinal impact dynamic loads without any modifications. The Boeing bin failed during the 6-g test due to tear out occurring at the mounting location of the longitudinal drag strut link. The damage was consistent with field reports. The bin was modified and subsequent tests revealed that the bin was able to withstand dynamic accelerations in excess of 9 g. An Airworthiness Directive was later issued to address this problem.

At the completion of the 16-g longitudinal test it was observed that the forward PSU in the Boeing bin had swung open and that the front aisle corner of the aft passenger service unit (PSU) was detached.

Vertical impact tests resulted in large fuselage deformation and in large differences between static and dynamic loading. The longitudinal and lateral loads developed during vertical impact tests exceeded emergency landing loads (14 CFR Part 25.561) and operational load requirements.

The failure of the C&D bin and mounting rail during the Boeing 707 drop test resulted in the contents falling out of the bin and onto the anthropomorphic test dummies occupying the seats below the bin. During this test, both PSUs of the Boeing bin detached.

During the impact of the Boeing 737 fuselage, the front aisle corner of the forward Hitco bin PSU swung down and then back up. The bin remained attached at the other three corners.

The modeling results showed reasonable agreement with the test results. Overall, maximum values of the fuselage and bins were comparable to the inertial data. The individual brackets also showed reasonable agreement. Greater details and additional information (i.e., geometry, material properties, luggage crush properties, etc.) in the model would help to improve the results.

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