The Evaluation of Anthropomorphic Test Device Response under Vertical Loading

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ABSTRACT

During the winter of 2018, a series of vertical tests was conducted on three sizes of Anthropomorphic Test Devices (ATDs) for the evaluation of their vertical loading response. The three sizes of ATDs represented a 5th percentile female, a 50th percentile male, and a 95th percentile male. There were two variations of the 50th percentile male as defined in 49 CFR Part 572: a Hybrid II and an FAA Hybrid III.

Tests were conducted on a drop tower located at NASA Langley Research Center's (LaRC) Landing and Impact Research (LandIR) Facility. The ATDs were seated on 14 CFR § 25.562 certified seats, in either a triple (window, middle and aisle) or a double (window and aisle) seat configuration, with seat leg spacing replicating a Fokker F28 MK-1000 aircraft. The seat and ATDs were attached to a drop plate on the tower, which was lifted to a height of 14 ft. The system was dropped onto different sections of crushable foam wedges to achieve multiple input deceleration environments. The purpose of the tests was to evaluate the differences in lumbar response, to examine scaling characteristics from sizing factors in the ATDs, and also to compare the results to computer simulation efforts. Results will be presented and comparisons will be discussed.

Introduction

Through a collaborative agreement between the Federal Aviation Administration (FAA) and NASA Langley Research Center (LaRC), a research effort is underway to obtain airframe and Anthropomorphic Test Device (ATD, a.k.a. crash test dummy) data through a series of tests that will support the development of airframe level crash requirements for transport category airplanes [1]. The initial focus of the research involved conducting two Fokker F28 MK-4000 fuselage section drop tests during in the spring and summer of 2017 [2-4]. The results from the tests showed differences in airframe response based on the section tested, along with differences in the ATD responses based on seating location and ATD size.

It was determined that component level ATD testing would be helpful to supplement the occupant data collected in the section tests. The objectives of the component level tests included:

- Compare and contrast different input loading environments and their effects on the ATD response
- Compare and contrast the different sized ATDs
- Compare and contrast different builds of ATDs (i.e. Hybrid II to FAA Hybrid III)
- Compare results to a full-scale drop test

In addition, data from these component tests were used to further understand the capabilities and limitations for ATD computational models. Comparisons of test and analysis will be briefly discussed.

Three distinct pulse shapes, along with three different sizes and two different types of ATDs were used in the component level test series. A summary of results of these items will be reported in this report. In the future, these results will be compared to horizontal acceleration sled test results.

Test Setup

Unlike the full-scale tests where the seats and ATDs were a part of the entire aircraft system, the component level drop tests only included the seats with ATDs mounted to a

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rigid triangular drop plate, which was a part of a 50-ft. vertical tower at the Landing and Impact Research Facility (LandIR) at NASA LaRC. The tower is capable of lifting the drop plate, seat and ATD system via three straps to a designated height. Upon release, the system free falls along a series of guide rails onto a crushable impact surface at the base of the tower. The crushable structure is typically composed of crushable foam, paper honeycomb, or metallic honeycomb. The size, type, and shape of the crushable structure determined the input acceleration pulse into the plate/seat/ATD system.

Three unique input acceleration pulse shapes were used for the tests. The first pulse was intended to replicate the acceleration environment experienced at the floor level in the Forward Section full-scale drop test [2]. In this test, the generalized pulse shape was trapezoidal in nature, achieving an average sustained acceleration of approximately 8 g as measured on the floor for a duration of 0.140 s. The second pulse shape was intended to replicate the seat certification test for a transport category aircraft in 14 CFR § 25.562 [5]. This pulse shape was triangular in nature, achieving a peak acceleration of 14 g at a rise time of 0.080 s. The third was intended to replicate the pulse shape from the seat certification test from a transport category rotorcraft in 14 CFR § 29.562 [6]. This pulse shape was triangular in nature, achieving a peak acceleration of 35 g at a rise time of 0.035 s. The three pulse shapes were generated by stacking layers of paper or aluminum honeycomb. The three pulse shapes are shown in Figure 1, with the actual input measured pulse shown in red and the desired comparative curve shown in black. The pulse generators are also shown in Figure 1 for clarity.

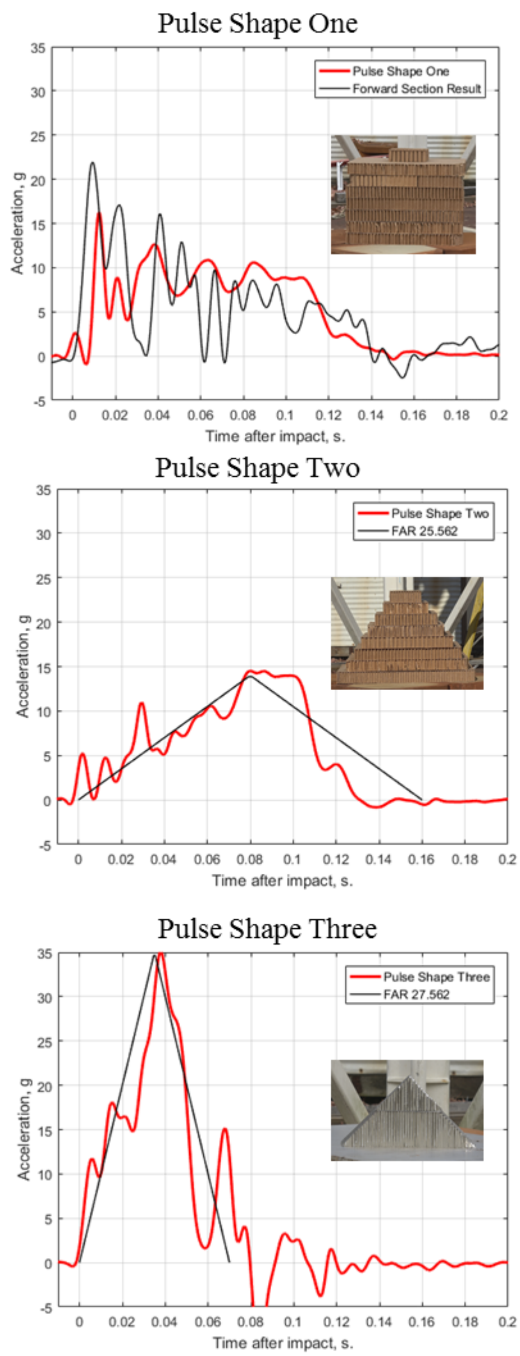

Figure 1 - Input pulse shapes

Accelerometers were mounted on both of the seat leg bases and the middle of the drop plate to capture the input acceleration into the seat and ATDs. Five different types of ATDs were used in testing. Either two or three ATDs were used per test, depending on the seat configuration, and these were chosen from the following types and sizes: a Hybrid III 5th percentile (H3 5), Hybrid III 95th percentile (H3 95), Hybrid II 50th percentile (H2 50) and a FAA

Hybrid III 50th percentile (FAA H3 50) [7]. The test series intentionally varied the configuration of the ATDs, seat and pulse in order to study sizing variability, pulse variability, and seat location variability. All ATDs were instrumented with accelerometers in the head, chest and pelvis measuring the vertical and fore/aft directions. Additionally, all ATDs contained a lumbar load cell capable of measuring lumbar loads in the vertical and fore/aft directions, along with the bending moment at the base of the spine. The Hybrid III ATDs also were capable of measuring neck forces and moments at the top and bottom of the neck. All data were collected via an offboard data acquisition system (DAS), sampling at 10 kHz. All data were low-pass filtered in accordance to SAE J211 specifications [8], with the exception of the FAA Hybrid III ATD's pelvic vertical accelerometer. This sensor had significant signal noise for a subset of tests, so it was low-pass filtered at a much lower Channel Frequency Class (CFC) 180 filter.

The seats used were all certified to 14 CFR § 25.562, and were removed from an in-service Boeing 737-800 aircraft in the fall of 2016. The seat legs were reconfigured to match the seat track spacing on an F28 aircraft by moving the seat legs outboard from their original positions. Additionally, to create a double seat, a triple seat was modified by removing the original window seat and then repositioning the seat leg rails outboard. For the triple seat, the final configuration featured a large unsupported overhang of the aisle seat at almost 25 in. when measured between the aisle armrest and the inboard seat leg. For the double seat, the seat legs were generally centered but biased slightly inboard below the two individual seats. The seats were attached to seat tracks that were fastened to an aluminum plate, which was rigidly attached to the drop plate. The seats and ATDs were positioned to ensure the composite center of gravity (CG) of the entire drop plate/seat/ATD system was centered between the three guide rails. The original lap-belt restraints were used to secure each ATD for each test and each seat was only used once. Figure 2 shows a picture of the triple and double seat installed onto the drop plate.

Figure 2 - Triple (top) and double (bottom) seats attached to drop plate in LandIR 50-ft drop tower

Table 1 shows the configuration, weight and impact velocities of all tests conducted. The tests shown in the table are a subset of the full test suite, with some tests not reported for brevity. Impact velocity was nominally 30 ft./s. for all tests. The actual impact velocity, measured through photogrammetry on the drop plate, is also included in Table 1, and is slightly lower than expected due to the drop plate/rail interactions. Also note the triple seat configuration is labeled with the window designated first, while the double seat configuration is labeled with the aisle seat designated first. This layout mimics the left to right designations when viewing the seats from a forward direction. This designation will also match how the images are presented in this report.

Table 1 - Test Matrix

Test #	Pulse Shape #	Window	Middle	Aisle	Impact Velocity (ft./s.)
		Triple seat configuration			
1	1	FAA H3 50	H2 50	H2 50*	29.1
2	1	H3 5	H3 95	FAA H3 50	28.9
3	1	H2 50	FAA H3 50	H3 5	28.9
4	1	H2 50	H2 50*	FAA H3 50	28.8
6	2	H3 5	H3 95	FAA H3 50	28.9
8	2	FAA H3 50	H2 50	H2 50*	28.9
9	2	FAA H3 50	H2 50	H2 50*	28.9
10	3	FAA H3 50	H2 50	H2 50*	28.8
11	3	H3 5	H3 95	FAA H3 50	28.7
		Double seat configuration			
		Aisle		**Window**	
12	1	H2 50		FAA H3 50	29.0
14	1	H3 95		H3 5	28.7
16	2	H2 50		FAA H3 50	28.6
17	2	H3 95		H3 5	28.6
20	3	H2 50		FAA H3 50	28.6
21	3	H3 95		H3 5	28.8
*uninstrumented					

Figure 3 shows an example test of the fully instrumented ATDs seated in a triple seat in the drop tower with the crushable material underneath. In addition to the sensors present on the ATDs, seats and drop plate, there were a series of high speed and ultra-high definition cameras filming the impact location. These cameras were present to capture honeycomb crush, seat deformation and ATD motion throughout the impact event.

Figure 3 - Test setup. ATDs at drop height

A series of results will be presented in the next section. The results will include summarized comparisons between loading environments using the different pulse shapes, between the H2 50 and FAA H3 50 ATDs using similar input pulses, and between the actual Forward Section full-scale drop test results and the simulated drop test input pulse. The test results will additionally be compared to a simulated test using developed computer models for both triple and double seat configurations.

Results

Comparison of Loading Environments

The differences in the loading environments due to the three different input pulse shapes were first examined. Pulses one, two and three all differ in magnitude, rise time, and duration. Pulse shapes one and two were similar in magnitude and duration, however the rise time for pulse shape one was shorter than pulse shape two. Additionally, pulse shape two exhibited a higher peak value of approximately 14 g, which was almost 2 times greater than the 8 g plateau generated from pulse shape one. Pulse shape three, in contrast, exhibited a peak magnitude of approximately 2 times over pulse shape two and 3 times over pulse shape one, with a duration of approximately half the time for both.

Results in all three sizes of ATDs will be presented with the data for the FAA H3 50 presented first. Figure 4 shows the lumbar load, pelvic vertical acceleration and head acceleration for pulse shape one (blue), pulse shape two (red) and pulse shape 3 (green) taken from Tests 1, 9 and 10. The FAA H3 50 was seated in the window seat of a triple seat configuration for all three tests. The maximum values for the lumbar load for pulse shapes one and two were 1,257 lb. and 1,044 lb. respectively, a difference of 18.4%. The peak lumbar load occurred 0.05 s. after impact for pulse shape one and 0.061 s. after impact for pulse shape two. These results were contrasted by the 2,784 lb. lumbar load measured from pulse shape three, which occurred 0.04 s. after impact. Similar trends were observed for the pelvic and head accelerations. Pulse shapes one and two displayed generally similar results in both magnitude and duration. For the pelvic accelerations, the ATD measured peak values of 25.8 g and 24.2 g for pulse shapes one and two, respectively, while the ATD measured a peak value of 65.5 g for pulse shape three. In the head, the ATD measured peak values of 24.6 g, 22.6 g for pulse shapes one and two, respectively, while measuring 53.5 g for pulse shape three. The timing characteristics mimicked those of the lumbar load values, which showed the pulse shape three peak values occurring at 0.033 s. and 0.039 s. for the pelvis and head, respectively. Pulse shape one showed a slight delay in achieving the peak loading values for the pelvis and head at 0.043 s. and 0.048 s, respectively. Finally, pulse shape two exhibited the slowest onset rate to reach peak values in the pelvis and head, which were 0.052 s. and 0.064 s, respectively.

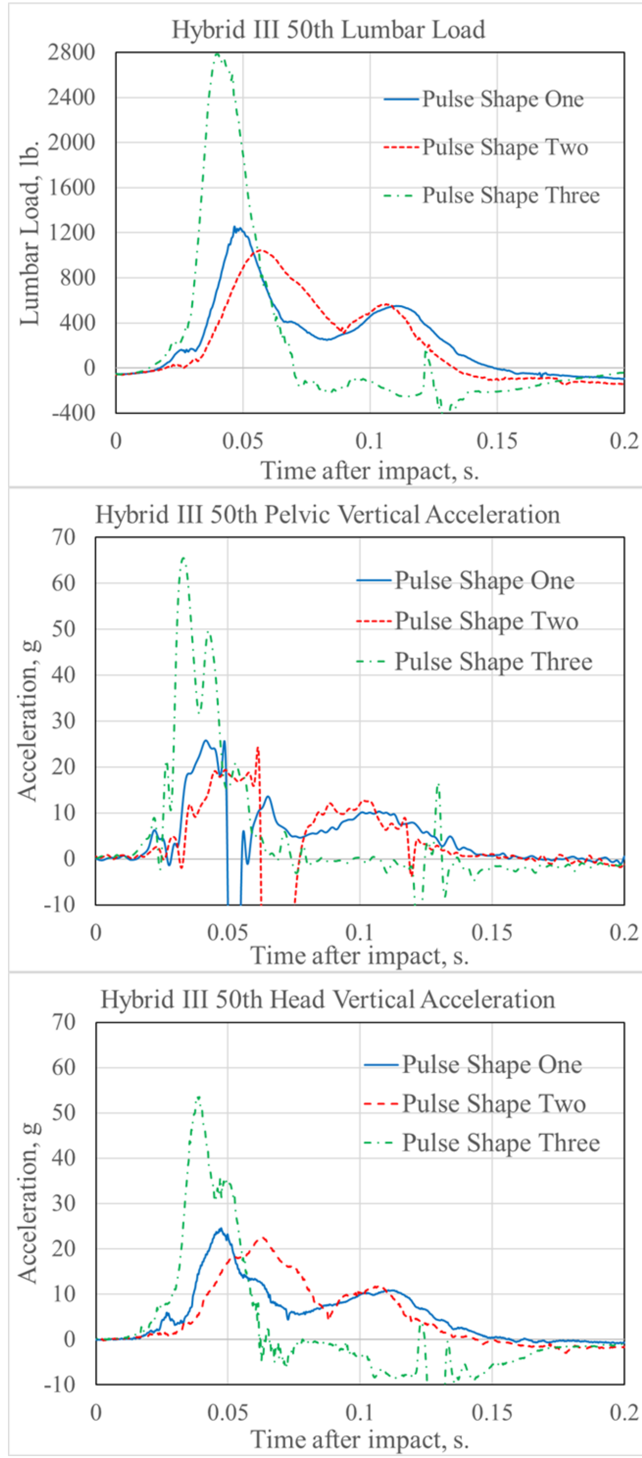

Figure 4 - Pulse shape comparisons for the FAA Hybrid III 50th

The H3 5 ATD was next examined. The data for the H3 5 are next plotted in Figure 5 for tests 2, 6 and 11, representing pulse shapes one, two and three. As with the FAA H3 50 configuration, the ATD was seated in the window seat of a triple configuration. The general trends measured in the FAA H3 50 were also observed in the H3 5 ATD response. The lumbar loads for pulse shapes one and two were 594 lb. and 652 lb., a difference of approximately 10.7%. The differences in the pelvic and head accelerations were of similar magnitude of 12.3% and 8.0%, respectively. There results were contrasted by pulse shape three, which showed a significantly higher response from the ATD. The lumbar load maximum value was 2,145 lb., and the maximum accelerations were 98.3 g and 92.0 g, measured in the pelvis and head, respectively. The ATD also showed a noticeable difference in response shapes for pulse shape three. The ATD responses were very similar for both pulse shapes one and two which were generally a single peak value occurring at around the 0.050 s. mark after impact, with a gradual decay for a total response duration of approximately 0.150 s. for all three measurements. In contrast, the response from pulse shape three clearly showed a double peak response for all measurements, with the double peak response being most defined in the head measurements.

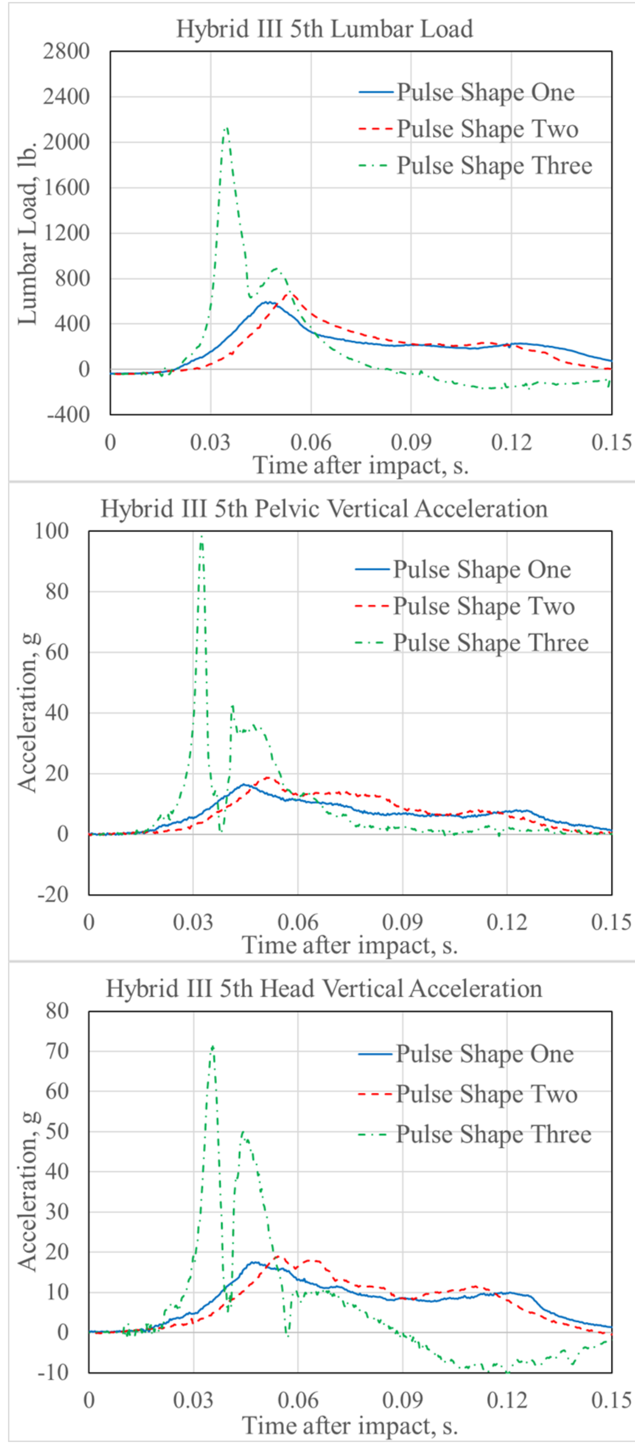

Figure 5 - Pulse shape comparisons for the Hybrid III 5th

The data for the H3 95 are next plotted in Figure 6 for tests 2, 6 and 11, representing pulse shapes one, two and three. The ATD was seated in the middle seat of a triple configuration. The general trends measured in both the FAA H3 50 and the H3 5 responses were also observed in the H3 95 ATD response. The lumbar loads for pulse shapes one and two were 1,750 lb. and 1,903 lb., representing a difference of approximately 8.3%. The differences in the pelvic and head accelerations were of similar magnitude, and showed differences of 3.5% and 7.8%, respectively. Pulse shape two led to higher values measured in the lumbar load and head acceleration; however, pulse shape one led to higher measured pelvic acceleration. These results were contrasted by pulse shape three. The lumbar load maximum value was 4,162 lb., which was also the maximum measured load for all tests conducted. The maximum accelerations were 99.6 g and 64.3 g, when measured in the pelvis and head, respectively. As with the H3 5 ATD, the H3 95 ATD demonstrated noticeable differences in response shapes for pulse shape three. For the lumbar load, the ATD measured a single peak, which occurred at 0.043 s. after impact. However, the accelerations measured in the pelvis and head exhibited a distinct double peak characteristic.

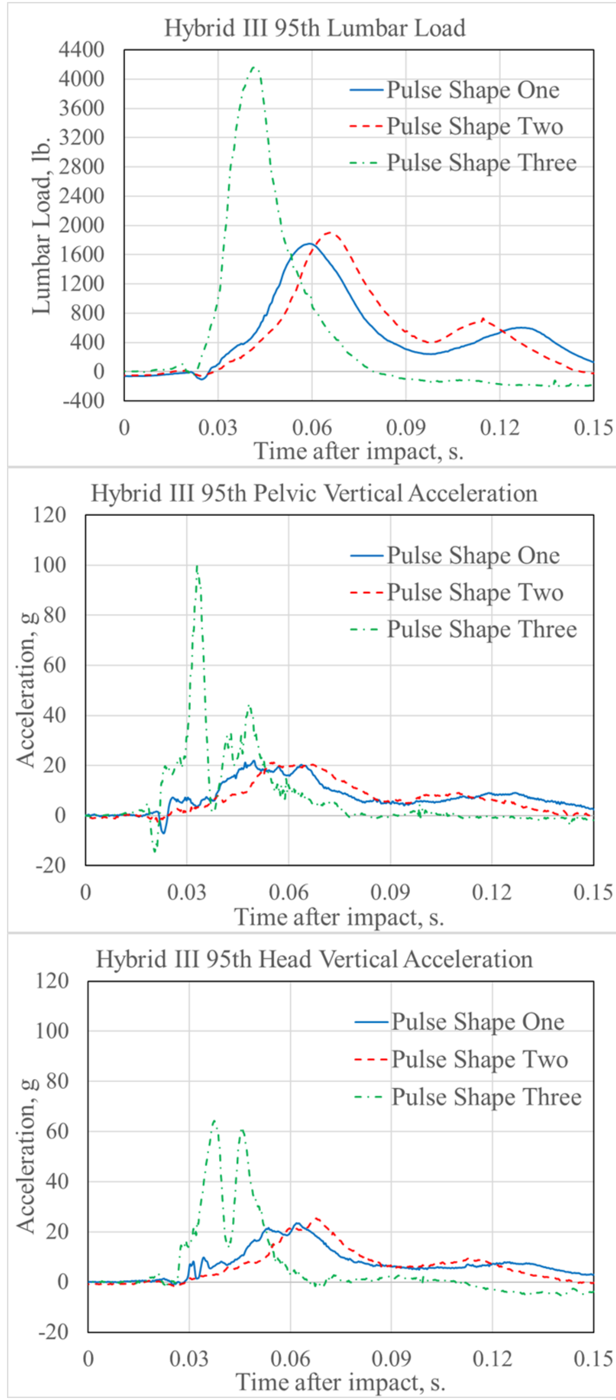

Figure 6 - Pulse shape comparisons for the Hybrid III 95th

The observed general trends in the pulse shapes were reflected in the ATD responses for each of the tests. For example, the trends in the overall vertical accelerations and loads were significantly higher for pulse shape three over pulse shapes one and two. For the FAA H3 50, differences of 74% to 92% were observed between pulse shape three and pulse shapes one and two. For the H3 5, differences of 105% to 142% were observed when examining between pulse shape three and pulse shapes one and two, and for the H3 95, differences of 74% to 129% were observed when examining between pulse shape three and pulse shapes one and two. The ATDs reached their peak values at a shorter rise time in pulse shape three over pulse shapes one and two, and all experienced shorter durations. The ATD responses from pulse shapes one and two were generally closer together in both magnitude and shape. Finally, the majority of the responses showed a shorter rise time in pulse shape one than in pulse shape two. Many further comparisons can be made; however, the comparisons in this report are limited to examinations of the vertical measurements acquired in the pelvis, lumbar, and head. Future publications will examine the other acquired measurements.

Comparison of ATD Type

The type of ATD was investigated because both the Hybrid II and FAA Hybrid III ATDs are used in FAA seat certification testing – often interchangeably – for the examination of occupant loads and injury. For the component drop tests, the tests were conducted using the double seat since seat supports and positions of the seat legs were generally the same for both the window and aisle seats in the double seat configuration. Tests 12, 16 and 20, were used for the comparisons. Each of those tests represented one of the three pulse shapes. The setup for these tests is depicted in Figure 7, and shows the H2 50 was seated in the aisle seat (left in Figure 7) and the FAA H3 50 seated in the window seat (right in Figure 7).

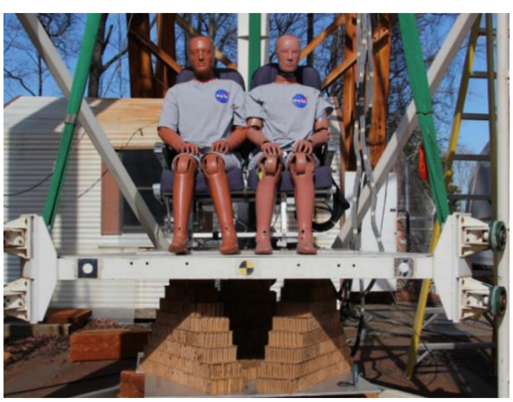

Figure 7 - ATD comparison setup (Test 16 shown)

The lumbar loading and head vertical acceleration results are shown in Figure 8. The plots show six curves each. The red curves represent the results from pulse shape one (Test 12), the blue curves represent the results from pulse shape two (Test 16), and the black curves represent the results for pulse shape three (Test 20). The H2 50 is plotted as a dotted line, while the FAA H3 50 is plotted as a solid line.

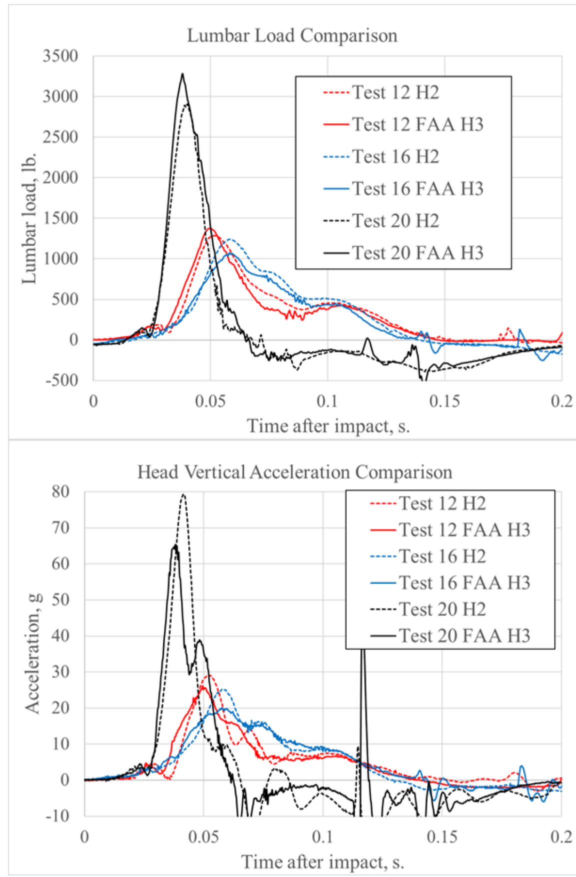

Figure 8 - ATD comparison results. Lumbar vertical load (top), and head vertical acceleration (bottom)

For the lumbar loads, the ATD responses generally matched well for all three pulse shapes. The H2 50 ATD peak load value was higher than the FAA H3 50 for pulse shape two but lower for pulse shapes one and three, though the actual values are not significantly different. For pulse shape two, if this test had been an actual certification test, both ATDs would be below the 1,500 lb. limit, as specified in 14 CFR § 25.562 (c)(2). The head acceleration results showed higher magnitudes for the H2 ATD for all three pulse shapes. The durations and shapes were similar between ATDs for each of the pulse shapes, with the exception of a small but noticeable second peak, which occurred in the FAA H3 for test 20, at 0.049 s. after impact. The ATDs also both showed a second spike in acceleration at 0.117 s. after impact. The second spike was a result of the heads contacting each during the ATD rebound, post-impact. Table 2 summarizes the peak values for each of the measured responses for the vertical direction in both ATDs for each pulse shape. The table also includes the pelvic acceleration responses, which, for brevity, were not included in Figure 8.

Table 2 - Peak value analysis between Hybrid II and FAA Hybrid III

Test 12 (Pulse one)	**Hybrid II 50 Value**	**FAA Hybrid III 50 Value**	**Percent difference**
Lumbar Load (lb.)	1,286	1,375	6.7
Pelvic Acceleration (g)	27.5	28.1	2.2
Head Acceleration (g)	29.1	26.2	10.7
Test 16 (Pulse two)			
Lumbar Load (lb.)	1,242	1,074	14.4
Pelvic Acceleration (g)	25.3	21.5	16.2
Head Acceleration (g)	25.3	20.0	23.2
Test 20 (Pulse three)			
Lumbar Load (lb.)	2,907	3,285	12.1
Pelvic Acceleration (g)	72.8	76.3	4.7
Head Acceleration (g)	79.4	65.4	19.3

The largest difference was in the head accelerations for pulse shape two at 23.2 percent. However, all head differences were above 10% for all three pulses, whereas difference in the pelvic acceleration and lumbar loads varied between a value as low as 2.2% to a value as high as 16.2%. Some of the differences can be attributed to minor positioning differences and some due to test variability; however, the consistently large difference in the head response is most affected by the presence of the articulating neck on the FAA H3 50 and also the slightly different weights of the heads. The weight of the H2 50 is 11.2 lb., while the weight for the FAA H3 50 is 10.0 lb.

Comparison of ATD Size

ATD size for a given pulse shape and seat location was evaluated. For brevity, only a subset of the total amount of available comparisons are presented in this section. Two example tests are shown in an attempt to provide bounds on the entire results suite. The two example cases shown are for the triple seat pulse shape three results and double seat pulse shape one results. In addition, for these conditions, only lumbar loads and head vertical accelerations are presented.

Figure 9 first shows the comparisons for the triple seat with pulse shape three. The lumbar load responses from the three ATDs trended from the lowest to the highest when comparing the H3 5 up to the H3 95. The H3 5 lumbar load peak value was 2,145, the FAA H3 50 was 2,785 lb. and the H3 95 was 4,163 lb. This trend was expected due to increasing torso mass compressing the ATD’s “spine” as the ATD increased in size. The duration for the H3 5 and H3 95 was approximately 0.080 s, while the duration for the FAA H3 50 was approximately 0.070 s. The head vertical accelerations, however, did not follow the same trend as the lumbar load. The maximum acceleration was 71.9 g, and occurred in the H3 5 response. The minimum acceleration was 53.3 g, and occurred in the FAA H3 50 response. The vertical accelerations were also root-sum-squared with the measured horizontal acceleration in order to determine if the differences were due to the influence of the horizontal acceleration. Though not displayed in this report, the trends did not change when horizontal acceleration was also considered. The 18.3 g difference in response was due to either the ATD itself, seat position, or other potential variable, and simply noted as the scatter in the data. However, the shapes and durations of the curves were similar, and each curve contained a double peak response, though the magnitude of the second peak magnitude was mixed.

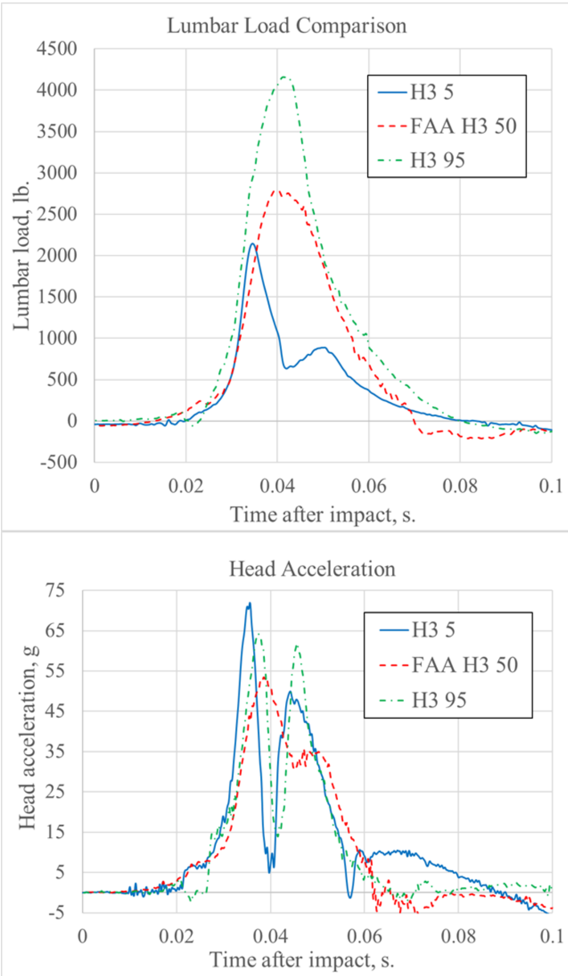

Figure 9 - Triple seat pulse shape three

Pulse shape one is shown in Figure 10. Pulse shape one responses were unlike the pulse shape three responses. The FAA H3 50 lumbar load value was measured at 1,375 lb., while the H3 95^{th} measured a slightly lower 1,287 lb. The H3 measured only 719 lb., which was significantly lower. This trend is unlike pulse shape three because the peak lumbar load value did not scale directly with ATD size. For the head vertical accelerations, the FAA H3 50 again measured a maximum value of 26.2 g, while the H3 5 measured slightly lower accelerations of 22.8 g. The H3 95 measured the lowest head acceleration at 18.8 g. As with pulse shape three, the accelerations were root-sum-squared to determine the influence (if any) of horizontal acceleration in the overall response. The root-sum-square results did not change the order of the magnitudes of the responses, and a difference of 7.3 g existed between the highest measured FAA H3 50 ATD and the lowest measured H3 95 ATD.

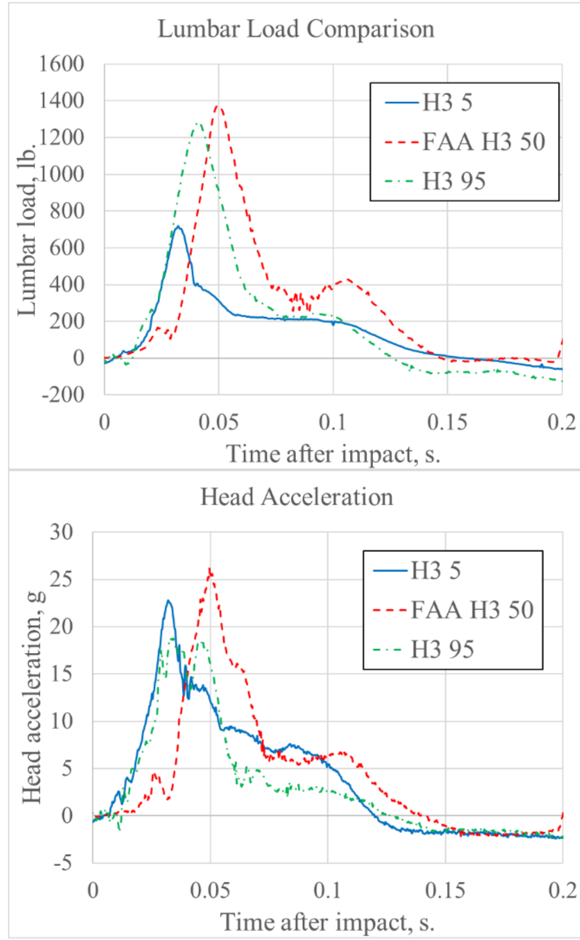

Figure 10 - Double seat pulse shape one

Comparison to Forward Section Drop Test

Finally, the data were compared to the data obtained from the Forward Section drop test [2]. In the Forward Section drop test, the test article was configured to mimic a fully loaded F28 condition undergoing a vertical impact at 30 ft./s. It contained two rows of triple seats on the starboard side two rows of double seats on the port side. It was filled with underfloor luggage and overhead ballast mass. During the test, the bottom of the fuselage crushed and multiple floor failures occurred. The seats and floor came to rest bearing up against the underfloor luggage. As previously described, the acceleration as measured on the floor approximated a rectangular pulse lasting approximately 0.140 s., with a magnitude of approximately 8 g. Tests 4 and 1 replicated the forward and rear rows of the Forward Section drop test on the port side triple configuration, while Test 12 replicated the starboard double side configuration, both for the forward and rear rows, which were identical. Figure 11 shows the comparison setups between the Forward Section test and the equivalent drop tests. Note the clothing worn in the Forward Section test was for tracking purposes only, and although the starboard side ATDs appear in different outfits, the ATD make and positions are the same. For brevity, only the forward row comparisons will be shown in this report. A full examination of the data will be presented in a future publication.

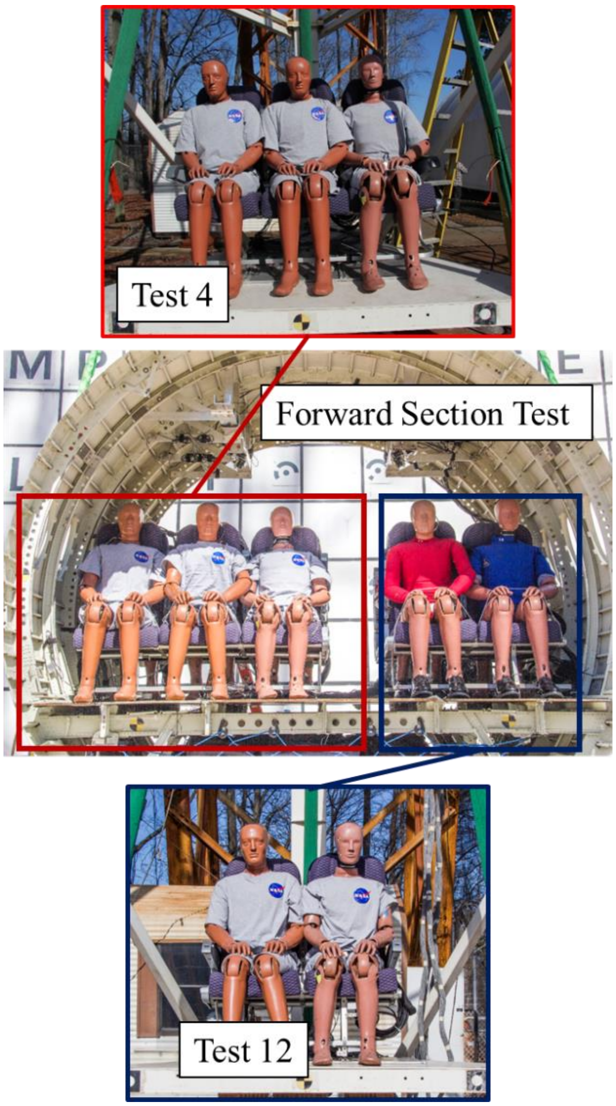

Figure 11 - Forward Section test comparisons (front row)

Lumbar load, along with pelvic and head vertical accelerations were compared between the component level tests and the full-scale drop test. The port side double seat comparisons are first shown in Figure 12. In the plots, the Forward Section results are shown in solid lines, while the component level drop tests are shown in dashed lines. The black lines represent the H2 50 seated in the aisle seat, while the red lines represent the FAA H3 50 seated in the window seat.

Results from the Forward Section full-scale drop test showed higher values than the component level Test 12 for the lumbar loads. Both lumbar loads and pelvic accelerations were slightly lower in the component tests, and the results were much closer for the head accelerations. The shape of the response curves matched well for the accelerations, but the lumbar load trends show an initial peak at approximately 0.050 s. after impact with an additional peak occurring much later at 0.105 s. This double peak response measured in the lumbar load did not match the Forward Section lumbar results, which measured a very distinct single peak loading response.

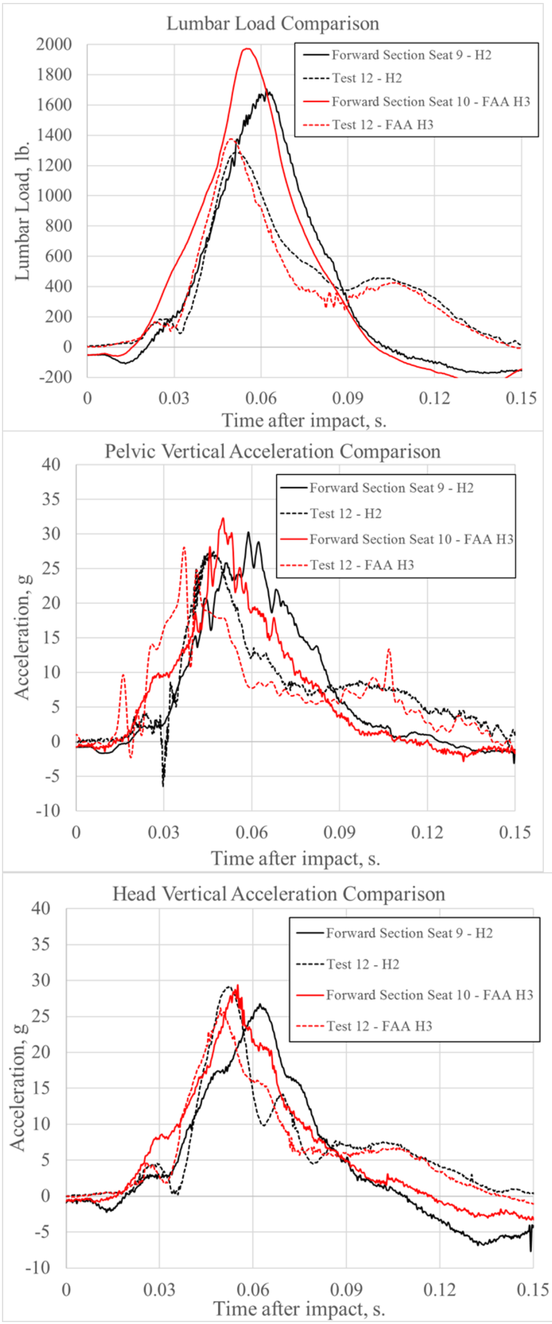

Figure 12 - Port side front row double seat comparisons

When examining the lumbar load in detail, there is one important item to note. If the 1,500 lb. limit from 14 CFR § 25.562 (c)(2) is used to evaluate injury, both the H2 50 and FAA H3 50 ATDs in the component level test would pass with values of 1,286 lb. and 1.376 lb., respectively, while both ATDs in the Forward Section full-scale test would be over the limit. However, acceleration levels in the pelvis were all very close in magnitude with the minimum pelvic acceleration peak value occurring on the component level H2 50 at 27.4 g and the maximum occurring on the FAA H3 in the Forward Section test with a value of 32.3 g. Similarly, the head accelerations were all very close in magnitude and duration. The minimum head acceleration differences were 11.6%, which occurred in the FAA H3 50 ATD. On average, the differences were much smaller for the accelerations than for the lumbar loads. These values are summarized in Table 3.

Table 3 - Peak value analysis between component level Test 12 and Forward Section Test

Hybrid 2 50	**Forward Section Test**	**Component Test 12**	**Percent difference**
Lumbar Load (lb.)	1,706	1,286	28.1
Pelvic Acceleration (g)	30.3	27.4	9.7
Head Acceleration (g)	26.8	29.1	8.5
FAA Hybrid 3 50			
Lumbar Load (lb.)	1,972	1,376	35.7
Pelvic Acceleration (g)	32.3	28.1	14.0
Head Acceleration (g)	29.4	26.1	11.6

Test 4 was used to compare the component level to Forward Section results for the triple seat configuration. Since in Test 4, the middle seat H2 50 ATD was un-instrumented, comparisons were only made for the window H2 50 (labeled seat 6 for the Forward Section data) and the aisle FAA H3 50 (labeled seat 8 in the Forward Section data).

There was a significant difference between the lumbar load value in FAA H3 50 ATD seated in the overhung aisle seat between the component level and the Forward Section test. For the component level test, the lumbar load in the FAA H3 50 measured a peak value of 1,168 lb., while the FAA H3 measured a peak lumbar load value of 739 lb. This difference of 45% is significant, and much greater than the differences in the pelvic and head accelerations, which showed maximum percent differences of 23.7%. The overhung position in the F28 triple seat was unique from the rest of the seat places examined, and could be the major contributor to the large differences measured in the lumbar loads between the component level and full scale tests. Figure 13 shows the Forward Section triple seat configuration in which the overhung aisle seat was not supported by a seat leg with the closest seat leg positioned under the middle seat place. As discussed in the *Test Setup* portion of this report, this configuration allowed for an overhang of 25 in. when measured between the inboard leg and the aisle armrest.

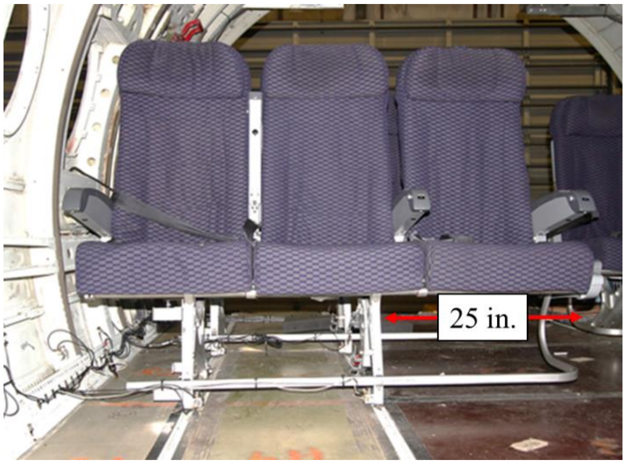

Figure 13 - Triple seat configuration in F28 Forward Barrel test

Due to this configuration, the deformation of the seat during the tests proved to be the defining factor for differences measured in the lumbar loads. The post-test seat deformations for both the component Test 14 and Forward Section test are shown in Figure 14. The deformation results were measured by examining the vertical change in distance at the aisle armrest location of the horizontal support tube. The Test 4 deformation was 1.95 in. while the Forward Section test was approximately 4.5 in. The added deformation of the seat in the Forward Section test caused the lumbar loads in the H3 50 ATD to be significantly lower than in the component Test 4. Furthermore, the significant inward lean from the Forward Section test is not replicated in the component Test 4, suggesting differences in response for the acceleration levels as well.

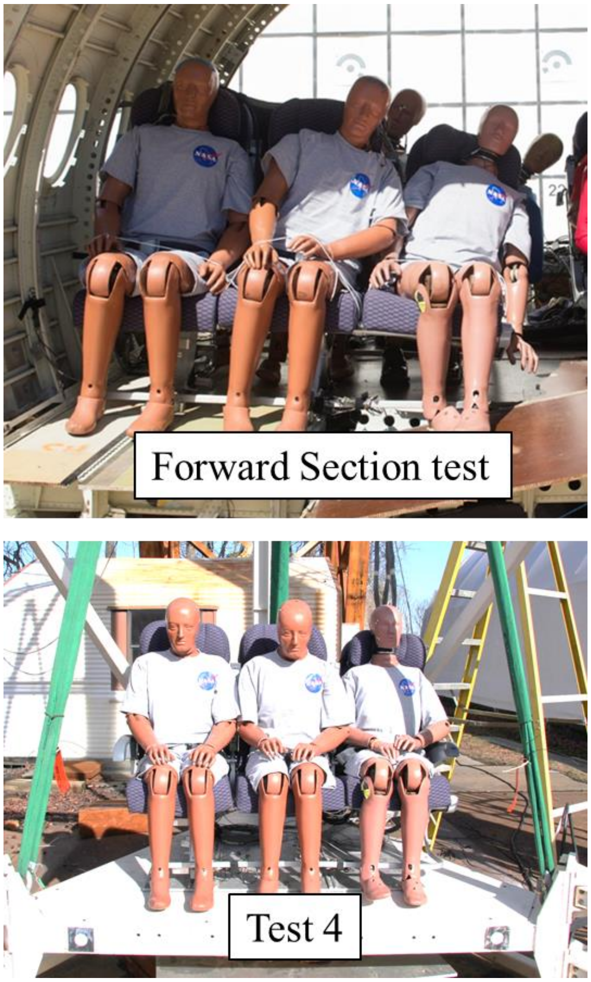

Figure 14 - Post-test triple seat configurations

For the H2 50 comparisons in the window seat, the opposite results were true. The lumbar load differences were small at 7.3% relative to the acceleration difference, which reached a maximum of 31.5%. Figure 15 shows the comparisons between the component level Test 4 and the Forward Section test. As in the double seat results, in the plots, the H2 50 results are shown in black, and the FAA H3 50 results are shown in read. Table 4 summarizes these results in tabular form.

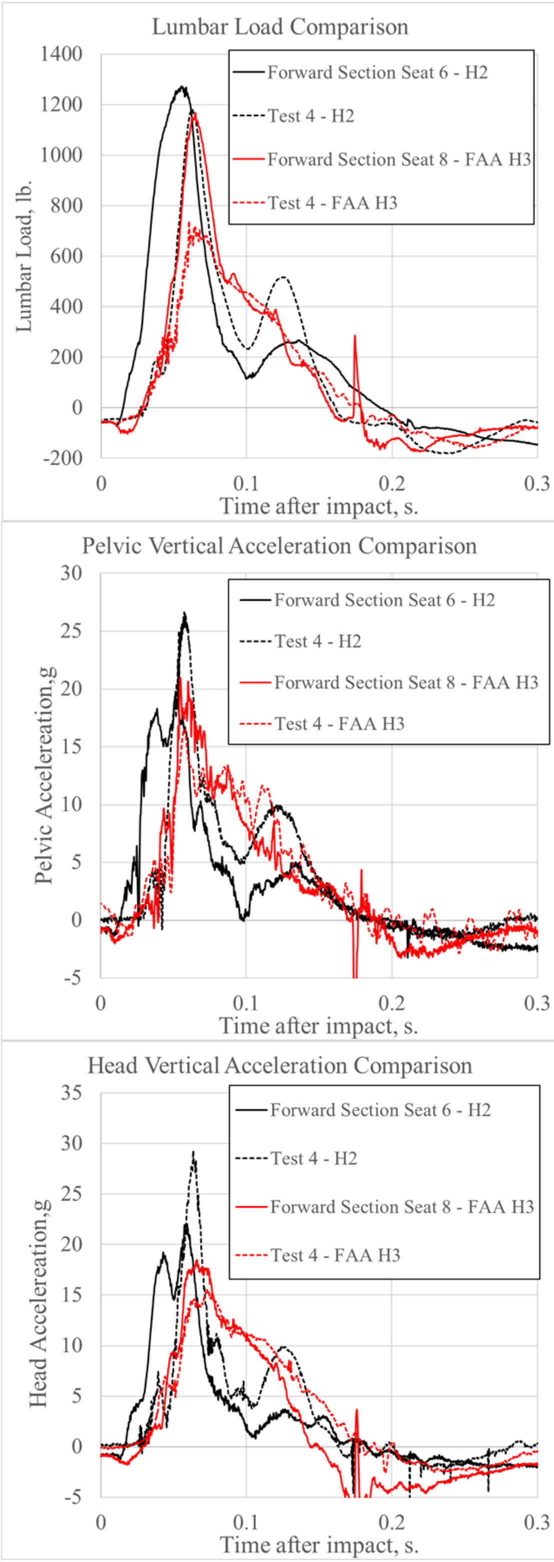

Figure 15 - Starboard side front row triple seat comparisons

Table 4 - Peak value analysis between component level Test 4 and Forward Section Test

Hybrid 2 50	**Forward Section Test**	**Component Test 4**	**Percent difference**
Lumbar Load (lb.)	1,273	1,183	7.3
Pelvic Acceleration (g)	19.4	26.6	31.5
Head Acceleration (g)	22.0	29.3	28.3
FAA Hybrid 3 50			
Lumbar Load (lb.)	1,168	739	45.0
Pelvic Acceleration (g)	21.0	16.5	23.7
Head Acceleration (g)	18.4	15.6	17.0

Comparison to Computer Simulations

The test data were also used to compare with computer modelling efforts. The double and triple seat models were previously developed for the full-scale drop test efforts and available for use in the component level analyses. A complete description of the efforts to develop the seat models is described in reference [9]. The ATD model used for the simulations was an automotive Hybrid III model known as the "LSTC Detailed Finite Element Model (FEM)" [10], developed by Livermore Software Technology Corp. (LSTC), and is mainly used in automotive applications. A major difference between the ATD model and the ATDs used in the tests was in the lumbar spine region. The automotive ATD used a curve spine, whereas the ATDs used in the tests were dictated by 14 CFR § 25.562, and configured with a straight spine. These differences in lumbar region both caused minor positioning differences between the simulation model and actual ATD, and differences in the measured lumbar load cell's location and orientation. It is because of this difference that they lumbar loads were unable to be compared directly. Instead, the vertical acceleration in the pelvis was used as the metric for comparison since it was the best way to measure (beside the lumbar load) the pulse transmission from the seat/impact plate into the ATD. Two component level tests were used in the comparison efforts. The first was Test 4, which replicated the forward row triple seat in the full-scale drop tests. For this test, there were H2 50 ATDs seated in the window and middle seats, while the FAA H3 50 was seated in the overhung aisle seat. Due to computing constraints, only the aisle FAA H3 50 ATD FEM was included in the simulation. The H2 50

ATDs were included by using a 170 lb. rigid torso and pelvis mass surrogate. These two ATDs were not evaluated in the test to simulation comparisons. Figure 16 shows the test-to-simulation comparison images, taken at a time of the maximum FAA H3 50th sink into the seat.

Figure 16 - Test 4 (top) to simulation (bottom) comparison at maximum ATD sink

The general motion for the ATD between the test and analysis showed good agreement. The ATD sank into the seat and tilted slightly to its right. The agreement for the seat was not as good. The previously measured maximum vertical deformation measured at the aisle-side armrest in the seat pan support tube was 1.95 in. for the test and 2.3 in. for the analysis. Additionally, the seat model did not include a headrest component, which would account for differences in mass properties of the seat back. Further investigations into the performance of the seat were not preformed.

Figure 17 shows the data plotted for the pelvic acceleration on the FAA H3 50 between the test and simulation. The seat deformation differences were reflected in the ATD pelvic response. The peak acceleration experienced in the test was 21.0 g, which occurred at 0.055 s. after impact, while the maximum acceleration experienced in the simulation was 17.7 g, which occurred at 0.093 s. after impact. The response shapes generally agreed for times outside of these two peak occurrences, specifically before the first 0.050 s. and after 0.100 s. For the first 0.050 s, the test and simulation results agree both in trends and in magnitude. They begin to deviate afterward, and then trend back toward each other after the 0.100 s. mark. For both the test and simulation curves, all significant acceleration occurred before the first 0.200 s. of the impact.

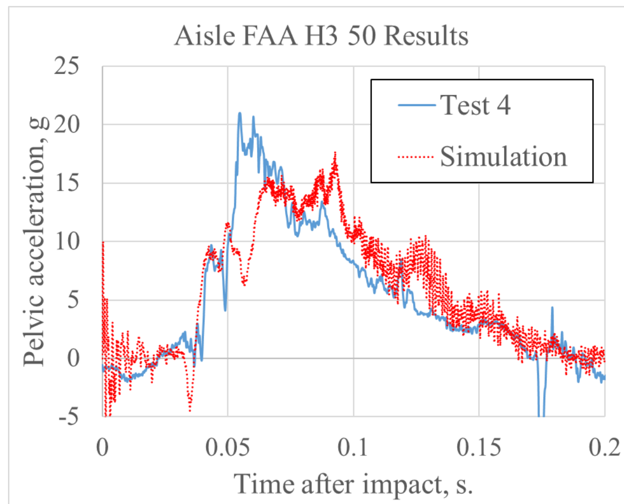

Figure 17 - Test to simulation results for pelvic acceleration for FAA H3 50 ATD

The second test used in the comparison efforts was Test 20, which consisted of the ATD configuration from the Forward Section test, but instead using pulse shape three as the input. As with Test 4, the FAA H3 50 ATD seated in the window seat was the only ATD in the simulation and the H2 50 was simulated using the torso/pelvis rigid configuration. Figure 18 shows the test to simulation comparison images, taken at a time of the maximum FAA H3 50th sink into the seat.

In both the test and analysis, the seat deformation was negligible during the impact. Figure 18 show similar qualitative results with the test image showing the ATD exhibiting a slight right lean at the point of maximum ATD sink into the seat.

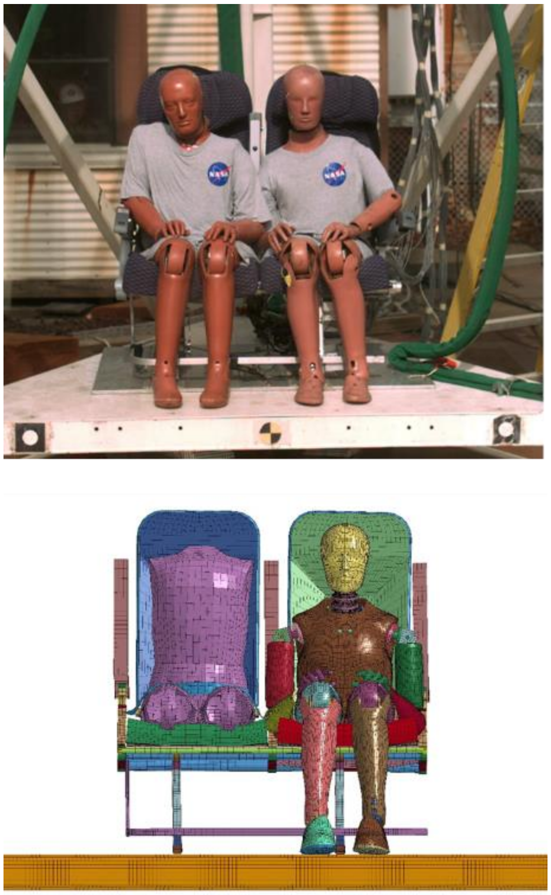

Figure 18 - Test 20 (top) to simulation (bottom) comparison at maximum ATD sink

As with the triple seat configuration, only the pelvic accelerations were compared between the test and simulation, and are shown in Figure 19. The test to simulation comparisons are in good agreement for the pelvic accelerations in the FAA H3 50 ATD. The peak acceleration value for the test was 76.4 g while the peak acceleration was 69.3 g, representing a 9.6% difference. The general shapes were similar, with both having responses consisting of a large initial peak and then a second smaller peak occurring almost immediately after. Both responses lasted less than 0.100 s., with the test response lasting 0.071 s. for the test and 0.081 s. for the model. The main difference was the timing at which the peak acceleration occurred. In the test, the peak acceleration occurred 0.033 s. after impact, while the simulation peak value occurred at 0.044 s. Differences in position, ATD preloading, or the previously stated seat properties could be the reasoning behind this lag.

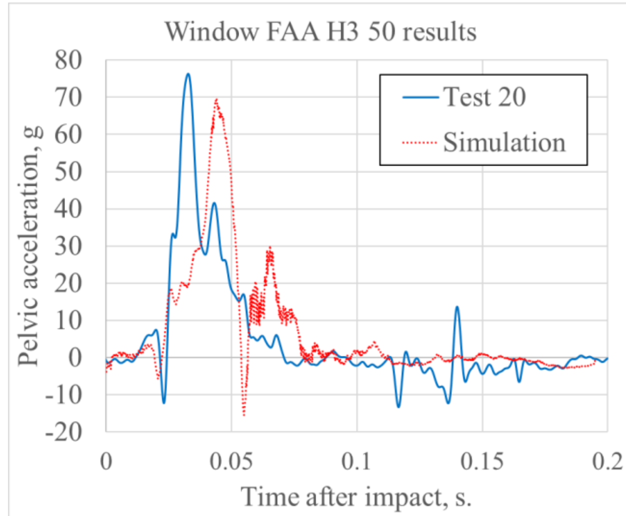

Figure 19 - Test to simulation results for pelvic acceleration for FAA H3 50 ATD

Discussion of Results

A series of 15 drop tests were conducted for a range of ATDs under various vertical loading environments to obtain data for a variety of objectives. While general data processing and analysis is still ongoing, a subset of the results have been presented and discussed.

When examining pulse shape variation, there were minimal differences in the responses between pulse shapes one and two. While pulse shape two exhibited a higher peak input load at 14 g, the shapes and peak magnitudes of the ATD measured responses are in general agreement. There are, however, variations that are sometimes unexplainable at present. Pulse shape three is unlike pulse shapes one and two because it provides a much higher loading magnitude with a much shorter duration. The responses of the ATDs reflect the different loading environment. In general, the response magnitudes for all of the ATDs are approximately 3-4 times their responses for pulse shapes one or two.

When comparing to the full-scale test results, the major difference seen between the Forward Section drop test and the component tests are in the levels of the lumbar loads. In one specific case presented, the lumbar loads would pass the 14 CFR § 25.562 (c)(2) requirement for the component level tests, but the equivalent loading environment in the Forward Section full-scale test would produce loading conditions that would exceed 14 CFR § 25.562 (c)(2). These results suggest complex interactions occur during full scale testing and that component level tests can be deficient in capturing all of the interactions that occur. Other differences were inconsistent, with component level tests producing loading environments that were generally lower than the full-scale for most of the measured values, but in at least one instance, the head acceleration in the H2 50 ATD was consistently higher.

This report also attempts to provide acquired data from tests arising from non-standard (from a certification standpoint) sized 5th and 95th percentile Hybrid III ATDs. While not used for certification testing, these ATDs are used for general research at LandIR (and other laboratories), and have been used to provide bounds when examining various loading environments [11]. The data presented shows that the lumbar load values generally scale up with increasing size of the ATD. The measured accelerations showed no correlation for ATD size – which was expected since acceleration response should be independent of the weight; however, the shapes and the magnitudes of the acceleration responses were not consistent between ATDs.

No individual seat suffered a catastrophic failure during the 15 tests conducted. Many seats, however, experienced permanent deformation to varying degrees, with the worst being consistently in the triple aisle overhung seat for pulse shape three. Accordingly, the tests using pulse shape three were conducted last in order due to the possibility of the seat (or other test hardware) failure resulting from the significantly higher impact levels occurring in both the seats and in the drop tower. In these tests, there were large amounts of plastic deformation both in the rear seat support tube and in the inboard (closest to the aisle) seat leg; however, a complete separation or fracture did not occur. This result is notable because pulse shape three was intentionally designed to be significantly higher than the seats original certification. The lack of failure in the seat hardware demonstrated robustness in the seat design during the pulse shape three tests. Additionally, because of the large amount of plastic deformation, the ATD seated in this seat typically showed significantly less lumbar load response, indicating that the location and support for the individual seat affects the occupant response. Figure 20 shows the deformation of the triple aisle seat from Test 11, in which a FAA Hybrid III 50th percentile ATD was seated.

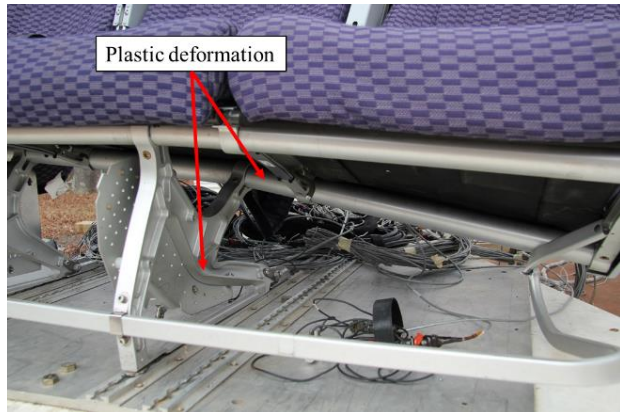

Figure 20 - Plastic deformation of the triple aisle seat for Test 11

The overhung triple seat was not tested with a Hybrid III 95th percentile ATD using pulse shape three. This configuration would have been the worst-case scenario having the most weight under the least amount of support. It is unknown whether the seat would fail under this configuration.

Due to differences in the lumbar loading measurement locations and configuration between the test and simulation ATDs, only pelvic responses were compared. For the triple seat configuration for Test 4, there were differences in the seat deformation between the test and simulation results with the model over predicting maximum seat deformation by 30%. Due to this difference, the peak value measured for the pelvic acceleration was 17% less than the test response. However, the general shape of the curves was in good agreement with both response durations occurring for approximately 0.200 s. In the double configuration Test 20, seat deformation differences were negligible, and the pelvic accelerations were more closely matched. The maximum pelvic difference was 9.6%, with the curves generally matching shapes. The only difference was the lag of approximately 0.011 s. in the simulation peak value response.

In general, the tests showed both expected results but also behaviors that were not expected. Some of the unexpected results could be potentially explained by conducting additional testing in order to isolate individual variables in seating, pulse or ATD configuration. However, due to the limited availability of seats, it was impossible to conduct all of the desired tests. Future work would involve filling in some of the missing gaps in the data by conducting additional tests to eliminate as many variables as possible.

Additionally, conducting tests on FAA sleds using the generated input pulse shapes, along with similar seats and ATDs would provide a valuable comparison with the drop test results presented. Follow on research should be conducted in this regard.

Acknowledgments

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