ANTHROPOMORPHIC TEST DUMMY LUMBAR LOAD VARIATION

Joseph A. Pellettiere,
David Moorcroft
Federal Aviation Administration
USA
Gerardo Olivares
National Institute for Aviation Research
USA
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ABSTRACT

The Federal Aviation Administration (FAA) has a number of standards and regulations that are designed to protect occupants in the event of a crash. Compliance with these regulations is described in the Code of Federal Regulations 14 CFR 25.562 for transport category aircraft, with similar regulations for other types of aircraft in parts 23, 27, and 29. One of these required tests is a seated dynamic impact with either a Hybrid II or FAA Hybrid III Anthropomorphic Test Device (ATD) with a pulse which has a primary vertical component. Vertical loading can be obtained in other environments such as under vehicle blast, ejection seat testing, or as part of a vehicle rollover. When the commonly used ATDs were developed, focus was placed on frontal impact performance with some consideration given to rear and lateral loading. It has recently been brought up that there could be significant variability in the compressive lumbar load measurement during vertical impacts. This variability could be between tests with the same ATD, between tests within the same ATD family, and between ATDs attempting to measure the same response. To quantify this issue, data from several test sources including from the Civil Aerospace Medical Institute, National Institute for Aviation Research and the Air Force Research Laboratory was collected. Cases were selected where the primary loading phase was in the vertical direction on a variety of ATDs including the Hybrid II, FAA Hybrid III, Hybrid III, and aerospace variants. These cases also included different configurations including restraint systems, cushions, and acceleration levels. This study was limited to only investigating the compressive variability and not the bending moment or in cases where significant multi axial loading could occur. Also, since these data were from different test laboratories, slight differences in test procedures could also have affected the results. Through this analysis it was shown that the Hybrid III had the most repeatable response whether it was the FAA Hybrid III or the aerospace Hybrid III. One issue noted was the lack of calibration methods for the lumbar spine to assess its current characteristics. Without this calibration method, there is no way other than visual inspection which would only show gross changes to determine when a lumbar spine segment has been degraded. Such a performance requirement should be developed for both ATDs currently in the field and those being newly developed and used such as the THOR.

BACKGROUND

The Federal Aviation Administration (FAA) has a number of standards and regulations that are designed to protect occupants in the event of a crash. As a part of these regulations dynamic testing and occupant injury assessment have been required for seats in newly certified aircraft since the adoption of Title 14 of the Code of Federal Regulations (CFR) Part 25, 25.562, and similar regulations in Parts 23, 27, and 29 [1]. There are two basic tests that must be conducted (Figure 1). For part 25 aircraft, Test 1 is a primarily vertical impact test with the characteristics of a minimum impact velocity of 35 fps with peak acceleration of 14 G's and an impact angle of 30 degrees off vertical. Test 2 is primarily a frontal test with a minimum impact velocity of 44 fps with peak acceleration of 16 G's and an impact angle of 10 degrees of yaw. Both tests also have limits on the rise time. Other aircraft categories have similar requirements. Both of these test conditions have associated injury metrics that must be met before a test is considered a pass and the seat is certified for use in aviation. These injury metrics include limits on lumbar and leg loads, limits on the Head Injury Criterion (HIC), limits on shoulder strap loads when used, and requirements that belts remain in place. For complete details, please see the applicable regulation. Of particular importance is the requirement that during Test 1, the peak compressive lumbar load in a Part 572 subpart B (Hybrid II) or equivalent must be below 1500 lb.

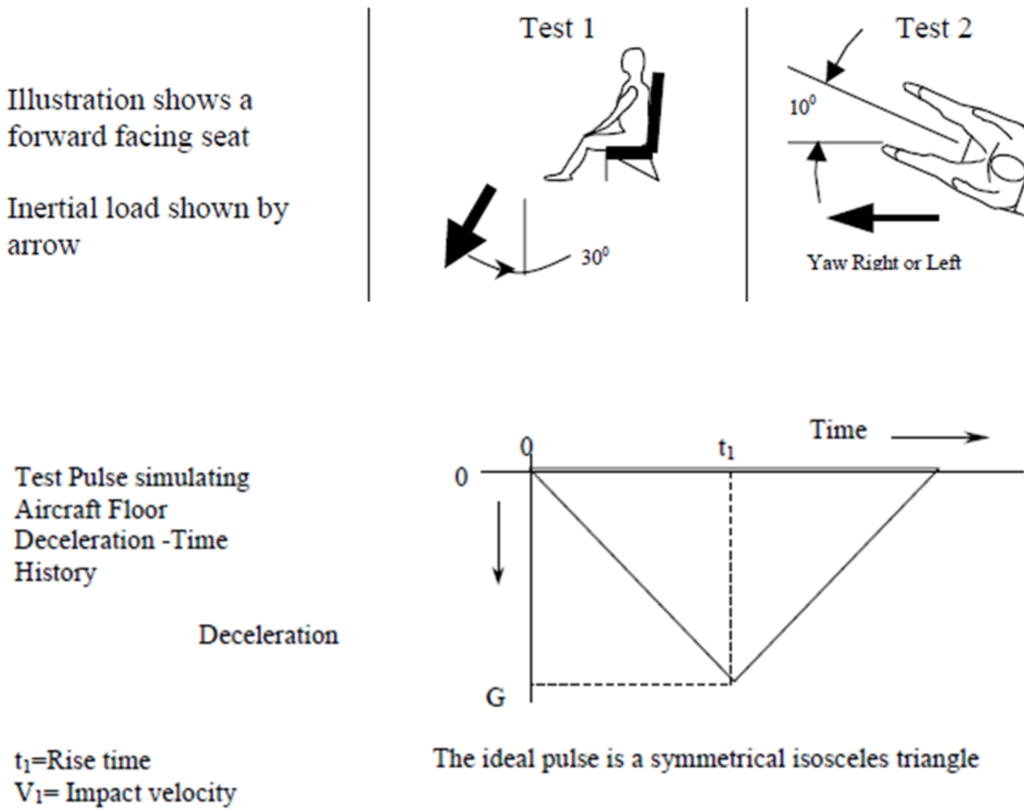

Figure 1. FAA Dynamic Seat Tests

LUMBAR INJURY

Over the years the criteria for assessing the safety of a system to vertical impacts has changed. Eiband [2] developed the earliest criterion in the 1950's. Using human volunteer and animal data, exposure limits for uninjured, moderately injured, and seriously injured occupants were developed. For vertical impacts, it was reported that human volunteers tolerated 10-G's for 0.1 seconds and 15-G's for 0.05 seconds (Figure 2).

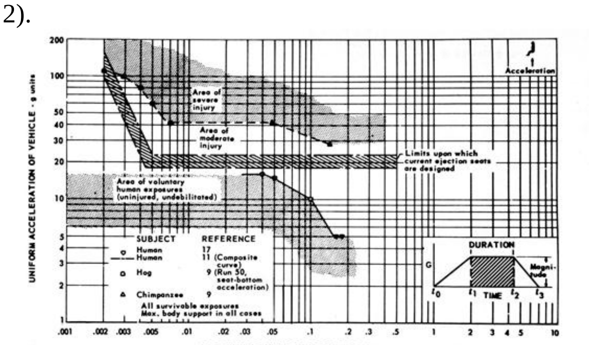

Figure 2: Human tolerance limits to vertical acceleration

Application of the Eiband curve had several limitations. It primarily characterized the response to whole body acceleration and did not break out injuries by body region. It also was not sensitive to changes in the pulse shape or mitigation methods that may have been developed. Initial ejection seat designs had acceleration limits in the 20-G range. This range falls at the boundary of moderate injury in the Eiband criteria. It was found that spinal fractures frequently occurred during ejection seat incidents and that improved seat designs were needed. As part of a revised ejection seat development program, a new criterion was also developed that is known as the Dynamic Response Index (DRI) [3]. The DRI model represents the spinal column of the human occupant as a lumped mass-spring-damper model. Input to the model consisted of seat pan accelerations and model output consisted of the acceleration time history of the DRI system. The maximum value of the DRI response was the parameter of interest. This value could then be correlated with operational injury data and an accepted value of 18 was selected (Figure 3).

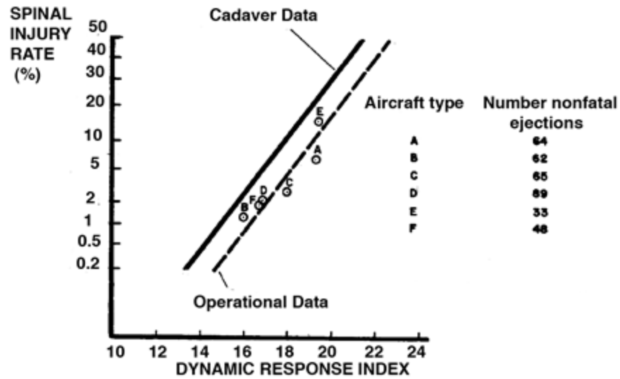

Figure 3: Spinal injury rate from ejection seats

The primary limitation of the DRI model is that it was developed for ejection seat pulses and is not sensitive to seat design changes such as different seat cushions, different restraint systems, or ATDs. While these changes may have only a minor effect on the overall seat acceleration, thereby changing the DRI only slightly, they can have a large effect on the risk of injury.. To address these issues, the FAA developed a lumbar load tolerance value. Since load in the lumbar region is the primary factor causing injuries, it was thought that a criterion based directly on measured lumbar load response was prudent. To determine the threshold, the FAA conducted a series of dynamic impact tests using aviation specific pulses. For each test, a lumbar load was measured and the DRI of the test condition was calculated. Based upon this correlation, a lumbar load of 1500-lb measured in the Hybrid II ATD was correlated to a DRI of 19 which was considered acceptable. One limitation is that these measurements were made using a Hybrid II ATD, but later tests included the FAA Hybrid III.

To expand the lumbar criteria to different anthropometries, tests and simulations were conducted using seating systems with different sized ATDs. The results of this effort formed the basis for the lumbar criteria used in the Joint Services Specification Guide (JSSG) [4]. The JSSG specified maximum lumbar loads for various sized occupants, some of which there was no equivalent ATD in existence. In a later analysis, it was shown that the JSSG limits were too high [5], based primarily on the analysis program that tended to calculate higher loads than what were measured during testing. Revised limits were proposed based on this re-analysis. The U.S. Air Force had been using the 1500-lb compressive limit for its mid-sized ATD's and used a linear mass scaling based upon the total ATD weight to generate limits for the other dummy sizes. These dummies were typically from the Aerospace Hybrid III family and had similar body weight distributions. These limits were applied to seat cushion development programs to select replacement cushions.

Recently, the modified limits (Table 4) proposed by Desjardins [5] were also proposed for a revised lumbar injury criterion to be applied to rotorcraft [6]. The limits provide a different tolerance value based upon dummy type. It should be noted that the Mid-size Male Hybrid II type includes the FAA Hybrid III because of its similarity in response [7]. Since each size of ATD and even the different types were demonstrated to have slightly different responses, it is important that the response of any particular ATD be characterized before it can be used for injury determination.

Table 1. Maximum Values for Lumbar Injury for Specific Occupant Sizes

	Small Female Hybrid III Type ATD (103 to 118 lb)	Mid-Size Male Hybrid II Type ATD (170 lb)	Mid-Size Male Hybrid III Type ATD (170 lb)	Large Male Hybrid III Type ATD (200 to 245 lb)
Compression (lb)	933	1500	1395	1757

DUMMY DEVELOPMENT

In the FAA airworthiness standards 14 CFR Parts 23, 25, 27, and 29 Section 562 (Emergency Landing Dynamic Conditions) there is the requirement that "The tests must be conducted with an occupant simulated by a 170-pound anthropomorphic test dummy, as defined by 49 CFR Part 572, Subpart B, or its equivalent, sitting in the normal upright position." This dummy is more commonly referred to as the Hybrid II 50th percentile male ATD.

The Hybrid II can be characterized as having a solid, straight neck, an erect spine seated posture, a straight lumbar spine aligned with the thorax, 164 +- 3 lb weight with a 35.7 in sitting height. The Hybrid II was the original ATD specified in US automobile regulations (49 CFR 571.208) and was used for the development of aircraft dynamic seat standards. The lumbar load criterion in section 562 is based on the Hybrid II. However, the regulations do allow for an equivalent ATD. In order to address issues with the aging of the Hybrid II since its first development and to certify an additional ATD that would be equivalent, the FAA Hybrid III was [7] developed. The standard Hybrid III (49 CFR Part 572 Subpart E) had several key differences to the Hybrid II, including a slouched spine sitting posture, a curved lumbar spine, a weight of 172 +- 2.4 lb with a 34.6 in sitting height. The FAA Hybrid III combined parts from the standard Hybrid II and Hybrid III to create a Hybrid III that mimicked the key features of the Hybrid II for the aviation environment. In order to maintain an upright sitting posture, the Hybrid II lumbar spine, load cell and pelvic adapter block are used. This required the creation of a unique upper lumbar-thorax adapter, which is described in the original paper [7]. To recreate the Hybrid II loading pattern into a seat, specifically for a vertical test, the Hybrid III abdominal insert, chest jacket, and lower leg assembly where replaced with Hybrid II parts (Figure 4).

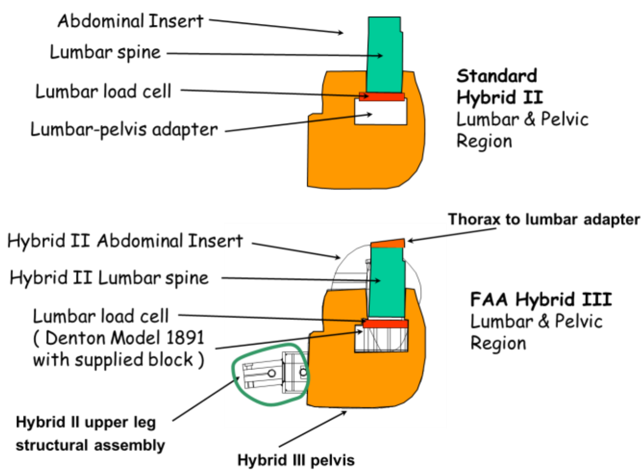

Figure 4. Hybrid II and FAA Hybrid III Pelvis

The United States Air Force also had a need for a dummy to respond to vertical accelerations. The USAF was actively involved in ejection seat testing and required a durable dummy which could be placed into a variety of seating positions and collect data onboard. The result of this effort was the development of the Hybrid III Aerospace line [8]. These dummies range in size from small (approximately 5th percentile female), mid-size (50th percentile male) and large (95th percentile male). The aerospace Hybrid IIIs have a straight spine, but unlike the FAA Hybrid III, the aerospace Hybrid III uses the spine from the pedestrian dummies. Because of this, the spine is made from natural rubber instead of the butyl rubber in the Hybrid II and it has a slightly different geometry. The material for the construction of the hard elements was also modified to withstand the extremes of ejection seat testing. However, the construction is mainly of a Hybrid III design, instead of borrowing Hybrid II components as was done for the FAA Hybrid III.

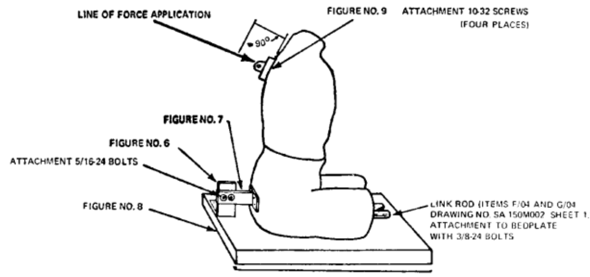

Figure 5. Lumbar flexion test

Since the various ATDs used in testing are commonly used for certification testing, there is a whole series of calibration tests that must be routinely conducted for each ATD. These tests include but are not limited to: chest compression, knee compression, neck flexion, and a quasi-static spinal flexion (Figure 5). The spinal flexion test is conducted to verify that the lumbar spine, abdominal insert and pelvis are properly functioning. This test is described in 49 CFR 572.9. The test consists of continuously applying a force to the thorax of the dummy and recording the flexion angle and force and allowing the ATD to return to its initial position afterwards. The response must fall within a prescribed corridor (Table 2). In addition, when the load is removed, the ATD must return to its initial position within 12 degrees.

Table 2. Lumbar spine calibration corridor

Flexion (degrees)	Force (+- 6 lb)
0	0
20	28
30	40
40	52

Besides this test, there is also a test to measure the compressibility of the abdominal insert separately (Figure 6). It should be noted that this test procedure is really measuring how the dummy will perform during a frontal flexion type of test. It is doing nothing to verify the compressibility of the lumbar spine itself. There is no test procedure to verify the condition of the ATD to vertical loading. The ATD is routinely inspected to determine if there is any damage to the lumbar spine or the dummy flesh itself

Figure 6. Abdominal insert compression test

DATA SOURCES

As part of a cushion replacement and modeling and simulation program, the USAF has conducted a number of vertical impact tests with various ATDs over the years. This data is available on a publicly accessible website, https://www.biodyn.wpafb.af.mil [9]. One study of importance for the discussion here is the Seat Cushion Lumbar Support (SCLS) study from 2003 [10]. This study was a series of vertical impacts with a mostly rigid seat. Tests consisted of conditions with and without seat cushions. The no cushion tests were investigated here as they will provide the most insight into the ATD response. The ATD used for these tests was the 50th percentile Hybrid III Aerospace dummy.

Table 3. Hybrid III 50th Aerospace Lumbar Loads

Test Number	Peak Acceleration (G's)	Peak Lumbar (lb)	Normalized Lumbar (lb)	AVG
V4583	8.04	706	703	710
V4584	8.03	735	733	STD
V4585	8.1	704	695	19.62
V4586	10.19	983	965	AVG
V4587	10.13	960	948	989
V4588	10.1	1071	1060	STD
V4589	10.14	995	981	49.70
V4590	11.21	1177	1260	AVG
V4891	11.59	1251	1296	1288
V4892	12.05	1286	1281	STD
V4893	11.97	1343	1346	36.08
V4894	12.08	1266	1258	

Twelve tests were conducted without seat cushions ranging from 8 to 12 G's (Table 3). The measured lumbar load was normalized to the target acceleration level as described in paragraph 5.3.9.5 of SAE AS8049B [11]. In addition, the Standard Deviation, based on the normalized load, was calculated for each acceleration range and ranged from 19 to 50 lb, or from 2.8 % to 5% of lumbar range. These results are consistent with other test series from this data source using the Hybrid III 50th percentile Aerospace dummy.

As part of the development of the FAA Hybrid III, a series of vertical impact tests were run at the Civil Aerospace Medical Institute (CAMI) with both the Hybrid II and the newly developed FAA Hybrid III [7]. The tests included a rigid seat with a thin cushion in a manner consistent with the 562 type tests. The peak acceleration was approximately 15G for the combined vertical test as opposed to 14G for a part 25 aircraft. While the tests were targeted for 15G, they were normalized here to 14G for comparison with other tests series (Table 4). For both dummies the average lumbar load was 1178 Lbs with a Standard Deviation of 20.5 or 1.7% of the average lumbar load for the Hybrid II and 26 or 2.2% of the average lumbar load for the FAA Hybrid III.

Table 4. FAA Hybrid III Development Tests

ATD	Test Number	Peak Acceleration (G's)	Peak Lumbar (lb)	Normalized Lumbar (lb)
H2	96041	15.96	1362	1195
H2	96042	16.0	1355	1186
H2	96043	15.6	1288	1155
FH3	98032	15.0	1236	1154
FH3	98033	15.2	1275	1174
FH3	99010	14.8	1275	1206
*H2= Hybrid II and FH3= FAA Hybrid III				

In 1999 the FAA completed a test program in coordination with industry to compare the results from testing at different facilities with the same test article [12]. Tests were conducted with a typical aircraft seat using the Hybrid II ATD in both the longitudinal and the vertical orientations. The facilities included two deceleration sleds, an acceleration sled, and a drop tower and included repeated testing. While these tests did have cushions and were not with rigid seats, because they were the same seat and cushion type tested at each facility and with similar pulses that were designed to meet the 562 type of testing, the results should be similar (Table 5).

Table 5. Hybrid II Facility Comparison Tests

Test Number	Peak Acceleration (G's)	Peak Lumbar (lb)	Normalized Lumbar (lb)
CAMI 92104	16.2	1547.39	1337.25
CAMI 94019	13.8	1149.2	1165.86
MGA1	14.1	1607.03	1595.63
MGA2	14.1	1408.06	1398.07
Sim1	15.5	-	
Sim2	15.5	1195.76	1080.04
WSU1	14.1	1202.16	1193.63
WSU2	14.3	1163.46	1139.05
AVG			1272.79
STD			181.11

While these tests would be expected to have a little more variability in them due to the fact that the test article (deformable seat and cushion at different facilities) should provide additional variation, the lumbar load from all the tests had a Standard Deviation of 181 lb or over 14% of the average measured lumbar load. Another way to consider this variability is to calculate the range from the lowest to the highest normalized lumbar load. In this test series the measured lumbar load varied over 500 lb or 40% of the average lumbar load.

The National Institute for Aviation Research (NIAR) at Wichita State University recently began investigating issues of lumbar load variability while trying to develop response corridors that could be used to validate computational models [13]. Two types of anthropomorphic test dummies per 49 CFR Part 572 Subpart B requirements were evaluated; the Hybrid II 50th percentile adult male ATD and the FAA Hybrid III 50th percentile adult male ATD. Two test series were conducted:

- Test series 06165: These tests were conducted on a rigid seat without a seat cushion. For this test series 14G Part 25 pulses were applied.
- Test series 07324: These tests were conducted on a rigid seat without a seat cushion (Figure 7). It should be noted that for this test series two Teflon sheets were used, one attached to the seat-pan aluminum surface and one additional sheet between the seat pan and the ATD pelvis. For this test series 19G Part 23 pulses were applied.

For 14G dynamic loads, the FAA Hybrid III measured higher average lumbar loads (10% higher) than the Hybrid II ATD (Figure 8). The test to test variability for this test series is very similar for both the Hybrid II and the FAA Hybrid III (standard deviations 38 and 63 lb respectively). For the 19G part 23 pulses the FAA Hybrid III consistently exceeds the 1500 Lbs limit, the average lumbar load value for this test configuration was 1737 lb. On the other hand, the Hybrid II did not show consistent results, the lumbar loads ranged from 1146 to 1698 lb with a standard deviation of 281 lb.

Table 6. NIAR Lumbar Comparison Tests

ATD	Teflon (# of sheets)	Test Number	Peak Acceleration (G's)	Peak Lumbar (lb)	Normalized Lumbar (lb)	
H2	2	07324-10	19.05	1410	1406	AVG
H2	2	07324-11	19.66	1757	1698	1399
H2	2	07324-12	19.43	1693	1655	STD
H2	1	07324-30	19.56	1120	1088	281
H2	2	07324-31	19.25	1161	1146	
H2	0	06165-5	14.7	858	817	AVG
H2	0	06165-6	14.6	960	921	862
H2	0	06165-25	14.65	837	800	STD
H2	0	06165-26	14.35	935	912.	63
FAA H3	2	07324-13	19.08	1713	1705	AVG
FAA H3	2	07324-14	19.14	1736	1723	1737
FAA H3	2	07324-15	19.18	1798	1781	STD 44
FAA H3	0	06165-7	14.6	1013	971	AVG
FAA H3	0	06165-8	14.8	1028	972	950
FAA H3	0	06165-28	14.28	924	906	STD 38

As shown in Figure 9 there are significant differences in the lumbar spine to upper torso interface geometry. The differences in the interface geometry and orientation with respect to the upper torso cg (Figure 9) are sufficient to change the slenderness ratio of the lumbar spine assembly; hence the differences in the dynamic behavior of the lumbar spines experienced during higher deceleration pulses. Preliminary data analysis indicates that the lumbar spine of the Hybrid II experiences limit point instability hence the scatter shown in the test data. NIAR is currently conducting a series of sled tests and simulations to identify the source of the test to test variability shown for higher deceleration loads. The parameters that will be analyzed in this study are geometric/inertia differences between ATDs, surface friction, seat pan stiffness (no seat cushion and various seat cushion material/thickness combinations), and ATD initial position.

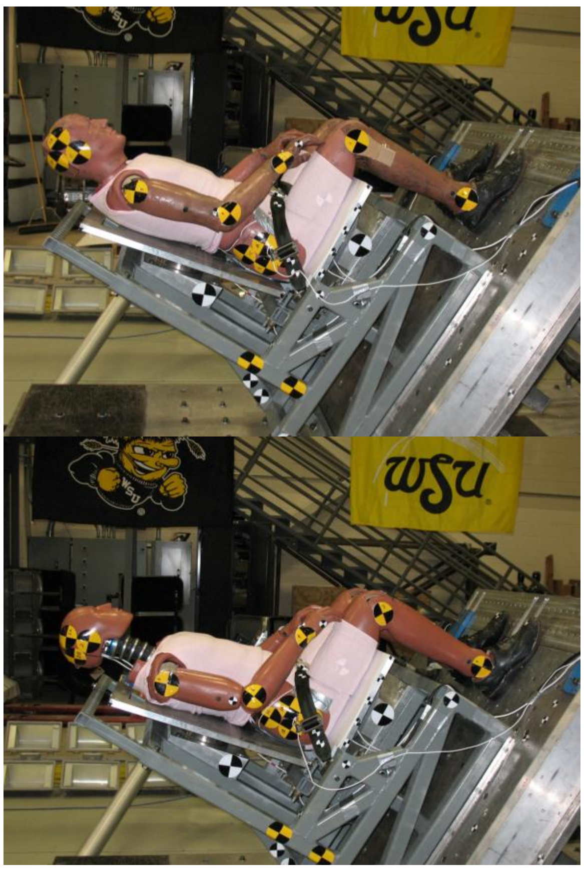

Figure 7. HII and FAA HIII NIAR test setup

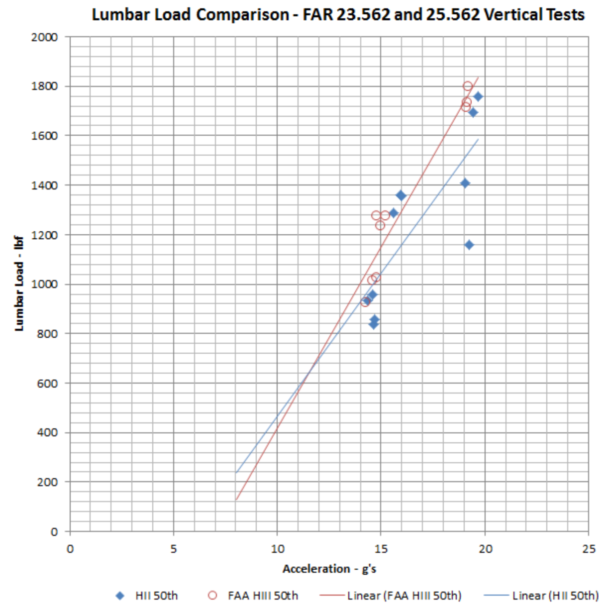

Figure 8. HII and FAA HII lumbar loads vs. sled acceleration

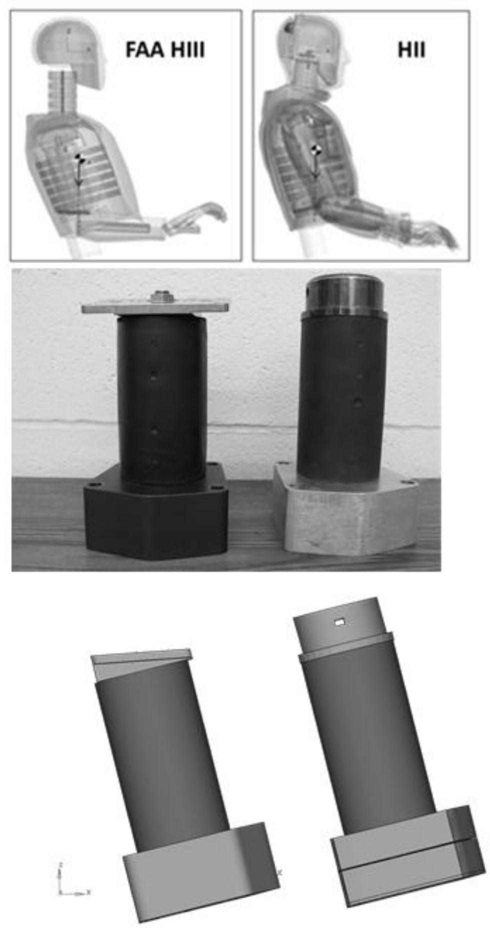

Figure 9. HII and FAA HII lumbar spines

DISCUSSION

At first glance it would appear that there is not much lumbar load variation, the USAF study had a Standard Deviation under 5%, the FAA Hybrid III development tests had less than 5% Standard Deviation, and even the 14G Part 25 tests at NIAR had Standard Deviations under 7%. Looking at each of these well controlled tests separately, does not tell the whole story. In the facility comparison study which all used the Hybrid II, the Standard Deviation increases to 14%. The highest variability observed corresponds to the NIAR test series with 19G Part 23 pulses with a standard deviation in excess of 20%. There are many factors which can affect the lumbar loads from these tests. They include different initial positions in setup, pulse variations between tests and between facilities, friction differences from the different setups, different ATDs used and condition of the ATDs used.

The first factor, different initial positions is something that can be controlled and documented with different test procedures. Research conducted at CAMI has shown that an ATD can be consistently placed in a seat and that by controlling the fore-aft and vertical position of the ATD, along with the pelvic orientation, good repeatability of lumbar load can be achieved. When seating the ATD per SAE AS 8049b procedures, apply a 20 lb force to the sternum while lowering the ATD into position. This procedure is similar to using a H-point machine, which is common in the automotive field. When using this procedure, researchers at CAMI found that the ATD's vertical position varied by no more than 0.05", the fore-aft position varied by less than 0.3" and the pelvic angle varied by less than 1.5° with a typical PAX seat cushion. During setup of a download test, an iterative process can be employed to position the ATD in the same pelvic location (X, Z, and angle) as during the 1-g measurement. It is recommended to control the Z position to within 0.15", the X position to 0.25", and the angle to 1.5°. When using the procedure across a range of cushions, the lumbar load typically varied by less than 10%. While these results are promising, the iterative nature of this procedure will increase the time required to setup a test. In most of the CAMI tests, the ATD was positioned and measured in 10-20 minutes. The researchers noted that there was a learning curve and that initially the procedure took longer to accomplish. It was also noted that the tolerance on the fore-aft position can depend on the particular seat being tested. On a rigid seat, this dimension is less critical than a flexible seat where the fore-aft location may be the difference between loading a tube and loading only a flexible (e.g. clothe) seat pan.

Each time a dynamic impact test is run, the resulting input from the test setup can vary slightly. For accelerator type systems, this pulse can be well controlled with only minimal differences. On decelerator sleds and drop towers, the pulse can vary slightly more, both between the tests and during a particular test the pulse may have some higher order frequency components that may be unintentional. The larger differences come in when trying to compare the results against different facilities. While the pulse obtained from a decelerator and an accelerator sled may meet the requirements of the FAR for 562 type testing, there are some differences in the rise time, peaks, and pulse widths which could contribute to variations in the resulting peak lumbar loads as was seen in the facility comparison tests. An interesting study would be to conduct a new facility comparison test program since many facilities have upgraded and replaced their impact systems.

Seat interface friction affected the lumbar response for both ATDs. For the case of the Hybrid II decreased friction increased the variation and for the FAA Hybrid III decreased friction decreased the variation. The change in friction may be a similar effect as slight changes in initial position. With the different amount of friction, the pelvis made slightly slide or rotate, changing the position and the response of the dummy. For practical applications, this generally would not be an issue as the ATD would be wearing standard garments and would typically be seated on a cushion, thereby setting what the frictional coefficients are for any particular test series. Since the variation increases dramatically for the Hybrid II when the friction is reduced, it is recommended to avoid testing in those configurations or to ensure that an adequate number of tests are conducted to avoid gathering data that might be at the boundary of acceptability. NIAR is currently conducting a series of sled tests and simulations to identify the source of the lumbar load variability due to surface friction.

The final two factors, different ATDs and their condition, are two that a particular test lab does not have any control over, however, they should know about them and have a way to assess their affects. During the manufacturing process of the ATDs, there are many tolerances on the various components. Because of these tolerances, each ATD can be slightly different. Care is taken to minimize any of these differences, and these natural variations can be measured by such things as checking the weights and center of gravity of various parts, measuring the flesh thickness, checking the anthropometry of the as built dummy and conducting calibration tests. For the ATDs, there are several calibration tests that are performed to ensure that the ATDs are within accepted response corridors. These calibration tests serve two roles. The first is to certify that the as built dummy is suitable for testing and to quantify its natural variation from other dummies. The second is to ensure the continued suitability of the ATD for testing through the periodic calibration testing. This periodic testing will assess the ATDs current condition and determine if it can continue to be used. However, in the case of vertical compression of the lumbar spine, there currently is no calibration test to quantify the ATD variability or its changes over time. Because of this, there is no way to assess if a particular dummy is worn out and if any changes that are occurring are the result of the natural aging of the dummy materials.

The data does show small variability for repeated testing, but it should be noted that many of these tests were conducted in a short time from one another. For the USAF testing, each group of tests was run one right after another, as evidenced by the sequential test numbering. This is also true of the FAA Hybrid III development tests. In this case, the three Hybrid II tests were conducted sequentially and two of the three FAA Hybrid III tests were conducted sequentially. It can be noted here that the third test from this series which was run the following year also had the highest lumbar load and was the test that increased the test variability. This increased variability is also present in the facility comparison tests which spanned several years and the NIAR tests which also spanned some time. Apart from a visual inspection of the ATD, and calibration of the load cell and other instrumentation, no checks were done to assess the performance of the ATD to compressive lumbar loads.

To address this issue, a calibration test is needed to determine whether a particular ATD is suitable for vertical impact testing. The first requirement should be verification of the calibration of the lumbar load cell. This could be accomplished through a static 1 g measurement of the ATDs upper torso body weight with and without the abdominal insert. This measurement should then be compared with a separate standard scale measurement and the load cell measurement. In a previous Navy study [14] it was found that this measurement does not directly scale with body weight, so a standard tolerance band for both of these measurements would be needed for each ATD.

With the static torso weight verified, a test should be conducted to verify the dynamic behavior of the ATD. The dynamic test will be used to assess the condition of the pelvic flesh and lumbar spine. A couple of choices are possible and include a separate component test and a full scale dynamic sled test. A component test will have the advantage of the input being tightly controlled and repeatable. For example, if the test is conducted on a tensile test machine, the input parameters such as stroke and compressive force could be directly prescribed with tight conditions. Drawbacks would be that either a specialized test device or a specialized fixture would need to be developed. In addition, the component tests would have to be followed by full scale dynamic tests to verify the transfer function between the component and the full seat test. The second choice would be to just use a rigid seat fixture and use an input pulse similar to what the ATD would be expected to experience. This could be several dynamic impact tests conducted at different acceleration levels to ensure compliance with the different types of tests. Some drawbacks here are that an additional sled impact tests would have to be periodically run to ensure compliance of the ATD. Another drawback is this test itself may cause some degradation to the pelvis. To mitigate this issue, perhaps a well characterized cushion could be used. The advantage is that if the particular test lab is already involved in this type of testing, then they already have the facilities and expertise needed to run this test, this would only not be the case for those that support field type testing or testing with real world vehicles as opposed to within a test lab.

A new series of full scale dynamic tests can provide several benefits. The first would be to generate new data for facility comparisons as discussed previously. The second would be additional data collection on dummies for a detailed lumbar load comparison that can also now include several different test labs and different loading levels. The final benefit would be the development of the acceptable response corridors upon which to base the calibration acceptance criteria.

CONCLUSIONS

The aviation community has been using the lumbar load from the ATDs as both a regulatory requirement and as a research parameter for a number of years. Recently, lumbar loading has been proposed as an injury metric for other environments including under vehicle blast and possibly for vehicle rollover.

A limitation of the data presented here is that the tests were conducted with different purposes in mind, other than assessing lumbar load variation. While care was made in selecting tests that were similar, not all of the tests had the same configuration. For example, the facility comparison tests were conducted on a non-rigid seat. It is clear that the lumbar load in the current ATDs can vary, even in the environment for which it is widely used and may vary even more when it is used in different environments. Due to the high variability exhibited by the Hybrid II at higher deceleration pulses (19G Part 23); additional research will be conducted to identify the source of the problem. The first step that is necessary after appropriate injury criteria are adopted is to verify the performance of the ATD with a calibration test, similar to what is performed for the other body regions. This calibration test will allow test engineers to have confidence in the repeatability and usability of the generated test data.

While some options for this calibration test were discussed, the actual specifics were not presented. It is recommended that the proposed test methods be conducted on a variety of ATDs in several locations to develop the needed response corridors which can then become the calibration requirements. Dynamic and component tests should be conducted with the aim of determining if different calibration standards are required for part 23, 25, 27, and 29 requirements because of the differences in loading rates.

DISCLAIMER

The findings and conclusions in this paper are the opinions of the authors and should not be construed to represent any agency determination or policy.

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