2021 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
SURVIVABILITY TECHNICAL SESSION
AUGUST 10-12, 2021 - NOVI, MICHIGAN

COMPARISONS OF SSDT AND CCUBS SEAT TESTS

Craig D Foster[1], Matthias Rudek[2]

[1]DEVCOM GVSC OPL, US Army, Warren, MI
[2]BAAINBw, Koblenz, DE

ABSTRACT

The successful fielding of occupant protection technologies require understanding their behavior and performance under field-like conditions. To achieve this, the Occupant Protection Laboratory (OPL) at Selfridge Air National Guard Base (SANGB) uses a drop tower, called the Sub-System Drop Tower (SSDT), and a vertical accelerator, called the Crew Compartment Under-Body Blast Simulator (CCUBS). These two systems have the capability to deliver specified acceleration profiles to items, such as blast-mitigating seats under test. To gain confidence that the two systems are producing similar testing conditions for a given system, a series of experiments was designed to determine the existence of a correlation between the two systems. A representative seat and an Anthropomorphic Test Device (ATD) were tested under similar acceleration profiles on both systems. Tests were initially conducted without a payload to determine the testing parameters for each system and to determine the effect of adding a payload. Spectral analysis techniques were employed to determine signal processing metrics and descriptive statistics were calculated to evaluate each systems' repeatability. The correlation between the two systems was examined to determine how well the systems produced similar responses for a given test condition. This study found that each system was highly repeatable and that the correlation between the two systems was good, but differences did exist.

1. INTRODUCTION

Improvised Explosive Devices (IED) and similar threats deliver energy to the underbody of a vehicle with the intent to disable the vehicle and its occupants. Engineers and Scientists from the Government, Industry, and Academia work in collaboration to develop IED countermeasures to ensure Warfighters succeed in their mission and return home with minimal injuries.

To ensure development of technology and to improve the efficiency of information exchange between collaborators, U.S. Army DEVCOM GVSC use the SSDT and the CCUBS to examine and demonstrate the correlation of these two systems for testing and evaluating vehicle seats using an ATD. Both of these systems are housed in the OPL at SANGB and are regularly used to evaluate manufacturers' seats and other occupant

DISTRIBUTION A. Approved for public release; distribution unlimited. OPSEC5333.

protection technologies. Demonstrating correlation between these two systems gives confidence that the data produced on either system is representative of results that could be achieved on the other system. Data analysis in this study represents a series of experiments conducted during the winter of 2021. The motivation for this study resulted from analysis of previous test data that raised questions regarding the similarity of assumed matching test conditions.

Initial analysis of previous seat test series by product development engineers revealed that high levels of variation existed for a given impact condition and that for an assumed similar condition was not reproducible when moving from one system to the other. This led to a bottom-up look at the analysis methods employed and then to a carefully designed series of experiments to reveal the intricacies of utilizing these systems for evaluation of seats.

Given that in the live-fire or field exposure environment, a range of accelerations can be experienced by a seated occupant. These accelerations can be the result of the initial blast phase, the global motion of the vehicle, or the subsequent return to Earth. Therefore, it was decided that the experiments for this study should examine the performance of the systems over a range of acceleration impulses.

The Sub-System Drop Tower (SSDT) is a gravity driven test device. It consists of a rail-guided table, where an article under test is mounted for evaluation. There is also a reaction mass that is mounted to shock absorbers and a gas damping system that are affixed the floor. On the top surface of the reaction mass, are urethane programmers and layers of industrial felt, these together, along with the drop height of the table, and the payload mass determine the resulting impact acceleration profile. For a test, the table is raised to a specified height, released, falls under the force of gravity, impacts the reaction mass programmers, rebounds, and then is stopped by a braking mechanism. The impact and resulting rebound produces the desired impact acceleration profile. The impact acceleration profile is adjustable by manipulating the drop height, the mass of the table, the programmers on the reaction mass, and adjustment of the gas dampening system.

The Crew Compartment Under-Body Blast Simulator (CCUBS) is a pneumatically driven impact system, consisting of a table guided by four rails, and a bullet mass powered by four high-pressure nitrogen cylinders. CCUBS is capable of testing a maximum of four seats and ATDs. The impact event is generated when the bullet mass is accelerated upwards and allowed to strike the underside of the table. Acceleration profiles are dependent on the charge pressure delivered to the nitrogen cylinders, impact interface programmers on the bullet mass, and adjustment of the table braking system.

2. METHOD

This study set out to determine the repeatability of the SSDT and the CCUBS systems and to determine if there was a correlation between the two test fixtures.

To achieve the goals, a series of impact tests were conducted. The tests were designed to capture the relevant data at a series of different impact acceleration levels. The levels were chosen based on the lowest possible level that the CCUBS could effectively accelerate the table; the standard 350g 5ms seat impact test; and the number of seats available to tests. Based on those parameters, four different impact conditions were targeted; 150g; 200g; 250g; and 350g. The impact test matrix is given in Table 1 below. All impact tests were conducted with an acceleration duration of 5ms. For the purposes of this report, the impact acceleration levels are labeled as LO, ML, MH, and HI.

Table 1: The test matrix (number of tests).

	SSDT		CCUBS	
	W/O Payload	W Payload	W/O Payload	W Payload
LO	7	3	2	3
ML	4	3	2	3
MH	5	5[1]	2	3
HI	2	1[2]	1	1[2]

[1] Seat failed, seat replaced, testing continued. [2] Seat failed, testing halted.

Tests at each level were conducted with and without a payload, this would allow examination of the effect of a payload on impact acceleration. For each impact level, three tests were performed. For the tests with a payload, the same seat was used for three tests at each level; a new seat was used when the next impact level was advanced. When moving between impact levels, repeat tests without a payload, were conducted to ensure that the impact conditions had not changed.

Impact acceleration and ATD response data were collected with a DTS SlicePro data acquisition system set with a sampling rate of 20,000 samples per second. Impact acceleration data was measured using three different accelerometers to assess the performance of those accelerometers on these systems. All three accelerometers were manufactured by Endevco using model numbers: 7264C-2K; 7270-2K; and a 7280-20K. The same three accelerometers were used on both systems to avoid confounding factors. A Hybrid III 50th percentile male ATD was used as the occupant surrogate in the payload tests. The ATD was unencumbered by PPE to reduce variability. A typical non-stroking carbon fiber composite seat was used. This was done to reduce variability due to the energy mitigating system. A string potentiometer was used to measure ATD motion relative to the table of the test system. Post-processing of the data was accomplished using custom scripts written in MATLAB (2015b).

2.1. Impact Testing

The impact testing was developed under a number of constraints: the availability of seats, which limited the total number of payload tests; and the lower limitations of the CCUBS to accelerate the table, which set the lower level for the test matrix. Nine seats were tested with an ATD at four different levels on both the CCUBS and the SSDT.

The test pulses were carefully developed to allow examination of ATD responses on similar acceleration profiles. Testing without a payload allowed examination of the effect of payload on impact acceleration. For the SSDT, the programmers mounted on the reaction mass determined the pulse duration, while drop height determined the peak acceleration. For CCUBS, programmers on the bullet mass controlled duration while charge pressure determined peak acceleration. All test parameters were developed using CFC 180 filtered acceleration data.

Between each payload test, seats were carefully examined for any signs of damage. During the payload testing at the MH condition on the SSDT, damage was discovered on a seat, after the second test. The seat was replaced and the payload series was repeated. On both the CCUBS and the SSDT, seats failed catastrophically on the first test at the HI condition tests; therefore, they are not a part of this analysis.

A total of forty-five tests were conducted; twenty-two of those were payload tests. Of the twenty-two payload tests, seven are not a part of this analysis: two MH payload tests from the SSDT and all the HI condition tests from both systems.

To determine repeatability, test conditions were held constant throughout each of the four impact levels. For the SSDT, drop heights were pre-determined for each impact level. Then for each test, the table was raised to the respective height as controlled by the system, the height was then double checked by manually measuring the height with a laser. For the CCUBS, pressure settings for each impact level were pre-determined. For each

Commented [JMG1]: Presumably this is samples per second. It is more common (and compact) to use hertz (Hz) to specify frequency.

Commented [JMG2]: Plumb bob?

Commented [JMG3]: The version should be referenced.

test, the system was charged to the corresponding pressure and recorded in a test log.

3. RESULTS

Eighteen tests are analyzed for the comparison of responses between the CCUBS and the SSDT. This report will concentrate on the payload tests, which was comprised of an unencumbered Hybrid III 50th percentile male ATD seated in a non-stroking carbon fiber composite seat. The payload tests presented here are from the LO, ML, and MH test conditions. Not included are the two MH payload tests on the SSDT where damage was discovered on the second test of the series.

Data presented consists of impact acceleration measurements, ATD lumbar vertical compression loads, and ATD displacements relative to the table. Three different accelerometer models were used to measure table impact acceleration. For the purposes of this report only the acceleration measurements from the Endevco 7270-2k accelerometers are presented.

The measured data are presented as line plots with a time scale in seconds (s) on the abscissa and magnitude of physical phenomena, in the corresponding unit, on the ordinate. CCUBS data is represented by black colored lines and SSDT data by gray colored lines.

For each measurement presented, three plots are provided; one each for the LO, ML, and MH condition. The measurements at each condition, from payload tests that are part of this analysis, are plotted together on a single plot to allow comparison of the two systems and to illuminate repeatability of each system.

3.1. Impact Accelerations

show the CFC 180 filtered table impact acceleration profiles, measured from an Endevco 7270-2k accelerometer for the seat and ATD payload tests.

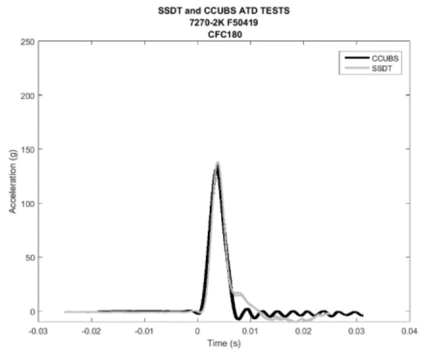

Figure 1: CCUBS and SSDT LO impact accelerations

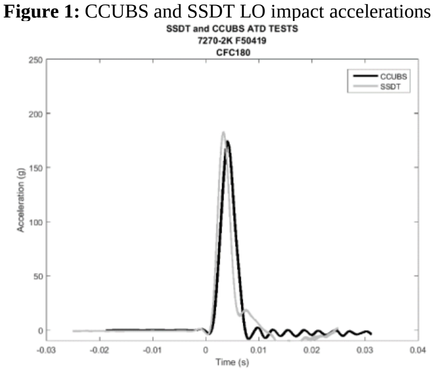

Figure 2: CCUBS and SSDT ML impact accelerations

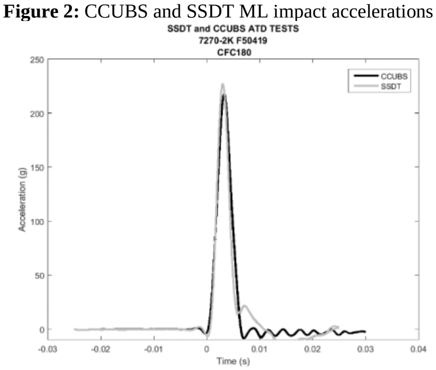

Figure 3: CCUBS and SSDT MH impact accelerations

The data shows the generally half-sine characteristic acceleration produced by both the CCUBS and the SSDT. Differences in the SSDT profile are noted. The SSDT profile contains a trailing characteristic that is present in both the payload and non-payload tests. The trailing characteristic is more pronounced in payload tests due to ATD interactions with the seat and the relatively low mass of the SSDT table. The same phenomena are not apparent in the data from the CCUBS.

Both systems appear to be highly repeatable as each plot contains data from six tests. For both systems, the peak values and durations are relatively close. However, it does appear that the SSDT produced a slightly higher peak impact table acceleration.

3.2. ATD Responses

The ATD used in these tests was the Hybrid III 50th percentile male. No PPE was used to reduce the possibility of influences on ATD responses. The ATD was dressed in a standard combat uniform consisting of a tunic, trousers, and standard issue boots.

A string pot was mounted to the table directly below the ATD H-point and the string was attached to an adaptor insert in the lateral aspect of the ATD pelvis, to allow monitoring of the ATD position from initiation of the test until the end of the data collection cycle.

For this study, ATD lumbar compressive loads, which will be used to assess correlation between the two systems, are presented in Figures 4-6 below. The figures show the unfiltered ATD Lumbar F_z loads collected, and each contains data from six tests.

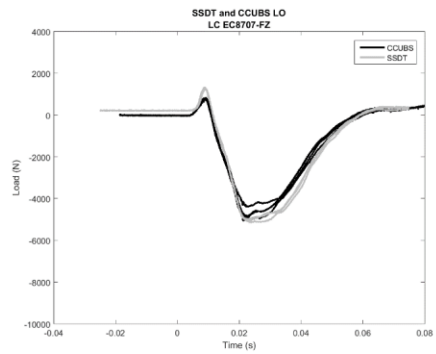

Figure 4: ATD Lumbar F_z loads LO condition

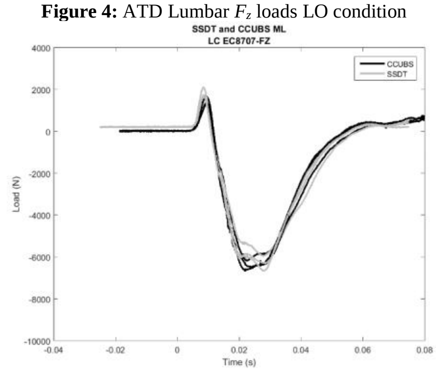

Figure 5: ATD Lumbar F_z loads ML condition

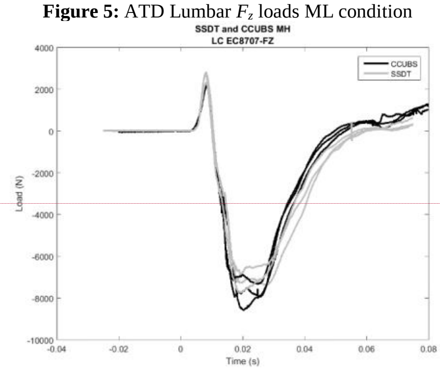

Figure 6: ATD Lumbar F_z loads MH condition

Commented [JMG4]: This variable is described below even though it is referenced here first. The authors should explain new variables the first time they appear, or they should mention that the variable will be explained/introduced below.

The ATD lumbar compressive loads (F_z), which is the large negative portion of the data, for both systems follow the same general path. The magnitudes, within each impact level, are all very close to each other and show that as impact severity is increased lumbar load increases; however, as impact severity increases, the SSDT produces lower loads than the CCUBS. Rate and duration of loading on each system is essentially identical, while peak load tends to vary slightly from test to test. It is noted within the SSDT tests that a pre-load is exhibited prior to onset of compressive loading, which appears to be less pronounced as impact severity increases. This is due to the ATD "floating" above the seat, starting shortly after the SSDT table starts to fall. This phenomenon can be seen by observing the output of the string pot that tracks the ATD displacement relative to the table.

Figure 7 through Figure 9 show the output for the ATD displacement from the string pot. It can be observed that for each of the impact levels the ATD, in the SSDT tests, is above the position it had at the start of the test. This is why there is a positive output from the string pot prior to the start of impact. It will be demonstrated that the ATD does not return to its original starting position until after the impact acceleration of the SSDT is mostly completed. For tests on both systems, at the same impact acceleration level, the ATD displacement into the seat has a similar magnitude, rate of displacement, and duration of displacement.

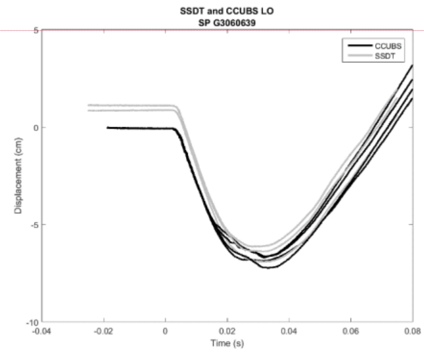

Figure 7: ATD displacements LO condition

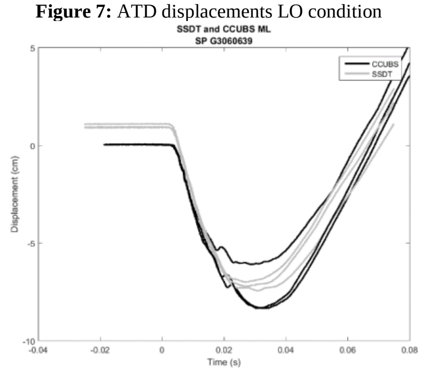

Figure 8: ATD displacements ML condition

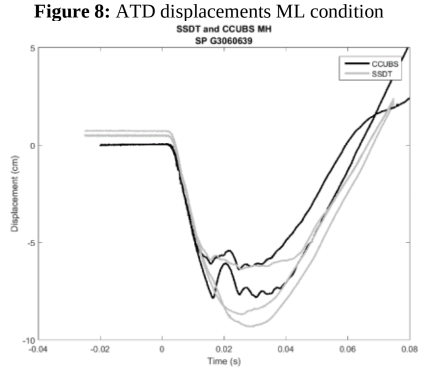

Figure 9: ATD displacements MH condition

Commented [JMG5]: The load, F_z, should be italicized, and the z should be a subscript to designate the direction. This is because it should be italicized in an equation (if one were to be used). Please do this for all for all instances.

4. DISCUSSION

Forty-five tests were conducted on the CCUBS and the SSDT with and without a payload for the purposes of comparing the two test systems. A goal of this study was to determine if the two systems provided an equivalent test for a seat with an ATD. Other questions that were to be answered by this study: how repeatable are the two test systems; what is the most appropriate filter for post-processing of the impact acceleration data; what affect does a payload have on either system; and what are the differences between testing on the SSDT and the CCUBS.

Of the forty-five tests conducted, thirty-eight were found to be useful for determining repeatability and for determining if there was a correlation between the two test systems. This report examines eighteen of those thirty-eight tests in which a seat and a Hybrid III ATD were used as payload.

4.1. Statistical Analysis of Data

To quantify the outcome of the test series, some basic statistical data has been calculated. When analyzing those values, it has to be considered that the amount of tests for each test condition was limited and is fairly low (mostly just two or three tests) for statistical purposes. However, the generated data gives a good impression of the behavior, the repeatability, and the predictability of both test systems. To add to the understanding of the performance of the two systems, the discussion of the statistical performance includes the non-payload tests, which were not a focus of this report.

Table 2 and Table 3 below detail the repeatability of the peak impact table accelerations for the SSDT and the CCUBS, respectively. Table 4 and Table 5 detail the responses of the ATD and the displacement of the ATD relative to the impact table.

As can be seen in Table 2, there is more variation in the peak acceleration for similar test conditions (i.e. drop height) on the SSDT depending on whether there is a payload on the table or not. This is due to the relatively low mass of the table on the SSDT. Therefore, it is necessary to keep the influence of the payload in mind when preparing for a test series to get the desired peak accelerations in the actual test.

Table 2: The SSDT Average Peak Accelerations

	W/O Payload		W Payload	
	Ø g	σ	Ø g	σ
LO	150.55	3.02	134.29	1.53
ML	194.30	5.38	176.10	3.02
MH	242.29	6.15	219.58	2.98

Ø Average σ Standard Deviation

For the CCUBS, there appears to less variation in impact table accelerations, as shown in Table 3, when comparing non-payload data to payload data. This indicates that the relatively high table mass is immune to the payload used in these tests. This makes it easier to operate since a possible error when estimating the weight of the payload is very low.

Table 3: The CCUBS Average Peak Accelerations

	W/O Payload		W Payload	
	Ø g	σ	Ø g	σ
LO	133.01	0.47	131.46	1.99
ML	170.07	1.13	167.32	0.16
MH	200.29	4.39	199.77	7.20

Ø Average σ Standard Deviation

The statistical analysis of the data for the payload tests with an ATD and a seat is shown in Table 4 and Table 5. Looking at the statistical values for the displacement (*DP*) and especially the lumbar load (F_z), it might be concluded that the variation gets higher with increasing peak accelerations, i.e. that the repeatability for both test fixtures isn't very high. However, to understand these values, it has to be taken into account that peak accelerations on the SSDT and the CCUBS were not exactly the same. Therefore, it is more informative to assess the similarity of the two systems using a normalized relationship of lumbar load (F_z) and peak impact

Commented [JMG6]: This should be italicized due to reasons mentioned above.

table acceleration (g), producing the numerical value (Fz/g).

Table 4: The SSDT Average ATD Responses

	Ø DP (cm)	σ	Ø Fz (N)	σ	Ø Fz/g	σ
LO	-6.49	0.40	-5056.12	108.86	35.94	0.57
ML	-7.33	0.23	-6297.97	338.46	33.94	2.04
MH	-8.26	1.57	-7317.18	423.99	31.60	1.94

Ø Average σ Standard Deviation

Table 5: The CCUBS Average ATD Responses

	Ø DP (cm)	σ	Ø Fz (N)	σ	Ø Fz/g	σ
LO	-6.87	0.26	-4850.36	310.17	35.27	2.05
ML	-7.71	1.31	-6437.55	244.45	36.28	1.44
MH	-7.23	1.06	-7951.97	623.32	36.90	1.83

Ø Average σ Standard Deviation

The average Fz/g value (together with its standard deviation) gives a pretty good idea of the repeatability of the tests. Comparing both test fixtures, the Fz/g relationship is very similar at the LO test condition for both the SSDT and the CCUBS. For CCUBS, this relationship remains relatively constant as impact acceleration is increased; however, on the SSDT, the relationship appears to decrease as impact acceleration increases. This confirms the impression of the lumbar load being lower on SSDT compared to CCUBS at higher peak acceleration. This discrepancy also seems to increase the higher the peak acceleration gets.

In an attempt to compare both test systems regarding correlation and predictability, a linear regression analysis was calculated with the lumbar load (Fz) and the peak acceleration (g), as shown in Figure 10.

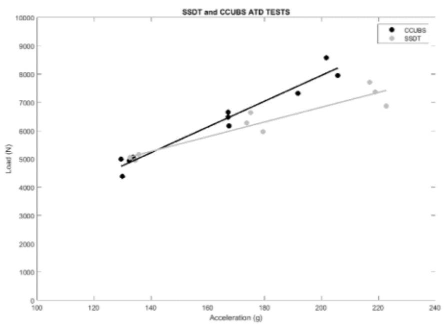

Figure 10: Regression of Load versus Acceleration

The regression shows that both test systems seem to have a linear behavior, at least in the range of accelerations in this study. To quantify this observation, the coefficients of determination (R^2) for the linear regression plots have been calculated with a resulting R^2 for SSDT of 0.895, and a R^2 for CCUBS of 0.956. These values verify a very high linear dependence between the lumbar load and the peak acceleration, especially on CCUBS.

This leads mainly to two observations. First, the predictability of test results for both test systems seems to be very high, at least within the chosen test configuration. Second, both test systems seem to behave very similar at the LO test conditions, but SSDT generates lower lumbar loads compared to CCUBS with increasing peak accelerations and this effect gets more distinct with increasing peak impact acceleration.

4.2. Impact Table Acceleration Filtering

Part of the motivation for this study resulted from an internal report of high variability of measured impact acceleration in previous seat testing efforts. That report noted that for a given impact acceleration level, the peak acceleration tended to vary significantly. Additionally, when making small adjustments to impact severity, the peak acceleration did not necessarily correlate to the change in impact condition. That report prompted a review of the post-processing techniques utilized at the time. In particular, the low-pass filter used to process the impact acceleration data was examined. For the previous work performed, an SAE Channel Class CFC 1000 filter, which is a Butterworth low-pass filter with a -3dB point at 1650 Hz and a roll-off of -24 dB/Octave, had been used as part of the analysis. The table acceleration data, when filtered using CFC 1000, exhibits an extreme amount of variability in the peak value, and the profile is characterized by many short duration changes in the direction of acceleration. Since both the CCUBS and the SSDT are designed to deliver relatively half-sine acceleration profiles, the measured acceleration should closely exhibit similar characteristics. This leads to the assumption that those short duration changes in acceleration riding on the table acceleration pulses represent local vibrations of the table.

To verify the appropriate filter for the impact acceleration measurement, a number of methods were employed. First knowing that the systems are designed to deliver half-sine impacts, the acceleration measurements were filtered at CFC 1000, CFC 600, and CFC 180. The filtered profiles were examined, and it was found that CFC 180 produced the desired half-sine profile. Next, velocity was calculated using the three sets of filtered data, and it was noted that there was no significant difference in velocity at CFC 1000 versus CFC 180. Then spectral analysis techniques were employed to determine the frequency content of interest in the impact acceleration measurements.

To determine frequency content of interest, the methods reported by Alem [1] were employed to calculate the Power Spectral Density (PSD) of the unfiltered table impact acceleration measurements. The PSD was then normalized and integrated, landmarks on the cumulative PSD curve were identified. These landmarks represent the power of frequencies on the curve, and are 50%, 75%, 90%, 95%, and 99% of Normalized Power versus Frequency. Analysis of the data collected in this study, using Alem's methodology, showed that frequency content dropped off significantly after 300 Hz. Figure 11 below shows an example of the results from applying the Alem method to an acceleration signal collected from the SSDT in this study. An additional feature of Alem's method is that characteristics of a low-pass filter are identified in terms of a cut-off frequency and the slope of the roll-off.

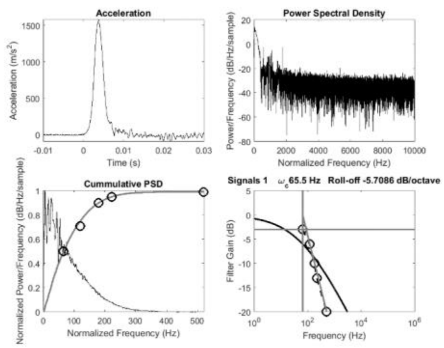

Figure 11: Sample analysis of acceleration data showing frequency content dropping off before 300 Hz.

Finally, a method reported by DiMasi [2] was used to estimate displacements of the impact table surface by way of a Displacement Spectral Density. The analysis utilizing that method showed that the displacements associated with frequencies above 300 Hz were incredibly small. Figure 12 below shows an example of the results from utilization of the DiMasi method.

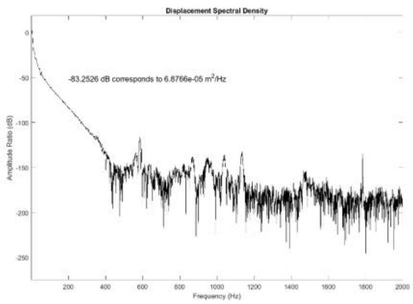

Figure 12: Sample displacement spectral density showing very small displacements at frequencies above 300 Hz.

Combining the knowledge from the three different analysis methods, it was decided that the SAE Channel Class CFC 180 filter was the most appropriate filter to use for the impact table accelerations. The CFC 180 filter is a Butterworth profile with a -3dB point at 299 Hz and a roll-off of -24 dB/Octave.

4.3. ATD Response Considerations

One of the goals of this study was to determine if there was a correlation between data collected from testing on the CCUBS and the SSDT. Since lumbar load is a key injury metric in assessing the protective ability of seats, it was decided to use that measurement as a correlating factor.

While this study made efforts to produce impacts that were comparable in terms of impact acceleration, differences in ATD response were observed. In general, the SSDT produce slightly higher peak impact accelerations, but the corresponding lumbar loads tended to have lower peak values as impact severity increased.

In the MH condition, average peak ATD lumbar compressive loads are 8% lower on the SSDT versus the CCUBS. This is likely due to the “float” condition of the ATD. It can be observed that, in general, the peak tensile loads in the ATD on the SSDT are higher and occur just before the compressive phase associated with seat pan loading of the pelvis. Bosch [3] noted this condition and surmised that this tensile load was due to the upward acceleration of the lower legs. The upward acceleration occurs on both the SSDT and the CCUBS. However, on the SSDT, the acceleration of the legs is enhanced due to two factors; 1) the feet of the ATD are typically two to four centimeters above the table of the SSDT at time of impact and 2) by the time the legs contact the table, the table has started rebounding causing the legs to reverse direction at a rate that is higher than if they were in contact at impact. This reaction at the legs likely has a negating effect on the ATD loading into the seat pan, thereby reducing the compressive lumbar loads. Table 2 below shows the peak compressive loads for the SSDT and the CCUBS test in the MH condition, along with the calculated percent difference of the average peak compressive loads between the two systems.

Table 6: MH Condition Peak Lumbar Fz

	Peak Compressive Load (N)			AVG
	Test 1	Test 2	Test 3	
CCUBS	-8,5754	-7,9518	-7,3287	-7,9520
SSDT	-7,3668	-6,8706	-7,7142	-7,3172
	Average Percent Difference (%)			8.3148

4.4. Drop Tower Testing Considerations

Analyzing seat test data from drop tower tests, such as the ones conducted on the SSDT, require awareness of special conditions that result from the falling phase of the impact table. Namely, there is a separation between the ATD and the seat that starts shortly after the table is released at the initiation of the test. The FAA [4] noted difficulties associated with assessing seat performance using drop towers especially in determining the effects of the separation on ATD kinematics. Cheng [5] detailed boundary condition adjustments necessary for modeling drop tower seat tests and noted that those conditions can be highly variable between different seats.

The separation between ATD and the seat pan cushion results in a change of the initial position of the ATD and appears to influence the kinematic response of the ATD. This is demonstrated in the reduced lumbar compressive loads given an equivalent impact acceleration. This separation is very noticeable in high-speed video where the legs can be seen to be hovering above the surface of the impact table just prior to impact. However, it usually cannot be discerned, from high-speed video, the amount of separation between the pelvis of the ATD and the seat pan cushion. To overcome that limitation, this study incorporated a string pot to measure the ATDs position relative to the impact table surface from initiation of test until after completion of the rebound phase.

Measuring ATD pelvic position in this study served two purposes; 1) to verify that the pelvis was indeed separated from the seat pan cushion, and 2) to determine the timing relationship of the contact with the seat pan cushion relative to impact acceleration.

Figure 13 and Figure 14 below show an example of pelvis position (gray line) relative to impact acceleration (black line, inverted for comparative purposes) for the CCUBS and the SSDT for a MH condition test. The difference in timing is subtle, so it is not clear if the delay in pelvis contact on the SSDT plays a role in the reduction of lumbar loads. However, since the ATD is separated from the seat for a major portion of the impact event on the SSDT, this implies that the loads measured in the ATD are mostly a result of the ATD falling into the seat and not from the seat driving the ATD upwards. This raises questions as to what the response might look like if the ATD were to remain in contact with the seat during the impact phase.

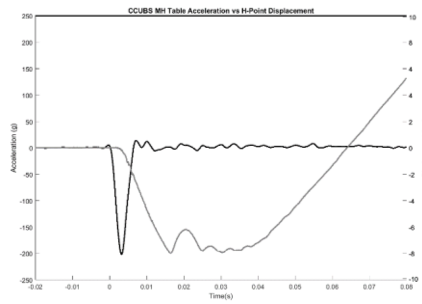

Figure 13: CCUBS Acceleration compared to displacement

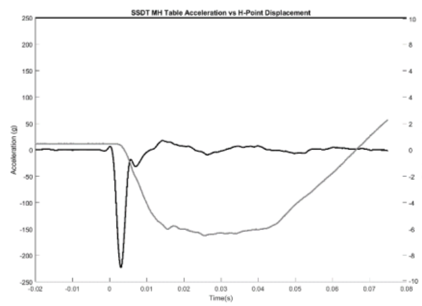

Figure 14: SSDT Acceleration compared to displacement

In Figure 14, several differences in the SSDT test responses compared to CCUBS in Figure 13 can be noted. Prior to onset of the impact acceleration, the separation of the pelvis from the seat pan cushion is observed. At the time where the pelvis returns to its initial position, the impact acceleration is almost completely over. This means that the upward speed of the impact table is quickly approaching zero. Therefore, there is very little input into the ATD from the seat. Also, it can be noted that the peak displacement into the seat is substantially less on the SSDT than it is on the CCUBS. This could be the result of not only the influence of the legs being driven upwards, but also the lack of input from the seat being driven upwards. Finally, the rebound of the ATD out of the seat is at a much lower rate on the SSDT than on the CCUBS. This is an additional indication that much less energy has been imparted to the ATD from the seat.

Figure 15 and Figure 16 show the comparison of ATD lumbar compressive loads to the displacement of the ATD relative to the impact table surface. For the SSDT tests, it can be seen that the ATD is separated from the seat pan cushion prior to impact. It can also be observed that the lumbar tensile loads on the ATD are much higher on the SSDT, indicating the influence of the legs being driven upwards at a higher rate. The peak ATD displacement into the seat and the resulting peak compressive lumbar loads are much lower on the SSDT even though the impact acceleration is higher. The duration of the plateau at peak loading on the SSDT is much longer than on CCUBS, showing that it takes more time for the ATD to change direction in the SSDT tests. Additionally, the rate of unloading on the lumbar, as the ATD rebounds off the seat, is lower on the SSDT, indicating the lower level of energy imparted to the ATD from the seat driving force.

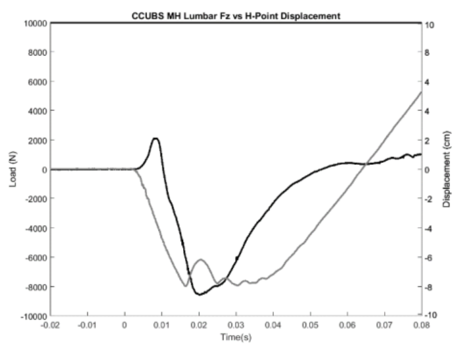

Figure 15: CCUBS Lumbar Fz vs ATD Displacement

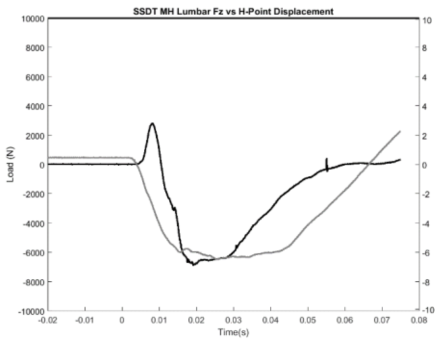

Figure 16: SSDT Lumbar Fz vs ATD Displacement

5. CONCLUSION

Forty-five tests were conducted on the CCUBS and the SSDT with and without a payload for the purposes of comparing the two test systems. Eighteen of those tests, with a payload, were presented here.

Goals of this study included:

- What is the best filter to use to determine impact acceleration?
- Comparative analysis of impact accelerations for the CCUBS and the SSDT
- Do equivalent impact accelerations create equivalent ATD loading?
- Are each of the two systems repeatable?

Impact acceleration determination is a critical step in evaluating seat performance. Standards for seat performance specify a peak impact acceleration at which seats should be assessed. Therefore, proper filtering is essential to the amount of energy being delivered to a seat in an impact event. Since both the CCUBS and the SSDT are systems designed to deliver half-sine impact accelerations, an impact acceleration measurement should display those same qualities. Those measurements should be relatively smooth and not contain local changes in acceleration along the entire profile. Those changes are the result of vibrations of the impact table and are not considered to be a major factor of the global motion of the impact table. As such, they can be safely removed, by filtering, from the impact acceleration measurements. However, when observing the differences in peak acceleration measurements filtered at CFC 1000 versus CFC 180, CFC 180 produces a substantially reduced peak acceleration. Therefore, careful analysis was performed in this study to determine the power, and influence of data at frequencies above 300 hz. It was found that those frequencies do not contribute to ATD responses in a meaningful way and can therefore be ignored. Additionally, using filters higher than CFC 180 produces large variation in peak acceleration measurements. Given that gravity is fairly consistent, little variation in acceleration measurements on the SSDT should be expected; the same should be true for the CCUBS as well.

When comparing ATD responses between tests on the CCUBS and the SSDT, there are important considerations to keep in mind. On the SSDT, during the falling phase of test initiation, the ATD tends to change position relative to the impact table surface. This change in position was shown to have a noticeable effect on ATD kinematics compared to the CCUBS. In general, the responses between the two systems appears to be comparable; however, close examination shows that ATD loading on the SSDT is lower despite a higher peak acceleration input. It was also demonstrated that as impact severity increases then these differences become more pronounced. This is an important consideration when developing a seat using a drop tower, since the drop tower method may be under-predicting the resultant peak lumbar compressive loads for a given impact acceleration.

Impact acceleration in this study, on the SSDT, was shown to be affected by the ATD and seat combination. This was demonstrated by observing the trailing portion of (or end of) the impact acceleration profile. Those measurements revealed that impact acceleration would change direction when the ATD started fully loading the seat. This is due to the relatively lower mass of the impact table of the SSDT. This phenomenon was not present in the CCUBS tests which has a table mass that is 1000 kg versus 635 kg for the SSDT.

An additional consideration that likely influenced the results seen in this study is the repeatability of seat performance. The seats used in this study were a composite carbon-fiber structure. The performance of the seats would have a great influence on the measured responses of the ATD. If the construction of these seats were not consistent, variation in ATD responses could be expected. Since seat failure was present in the HI condition tests in this study, and one seat failure in the MH condition, this raises question on seat performance consistency and what influence that had on the measured ATD responses reported here.

While not necessarily the central focus of this study, it was shown that both the CCUBS and the SSDT are repeatable systems in terms of producing a peak acceleration. This gives confidence in the analysis of this data, and the observations reported are not random chance.

This study found that:

- The CFC 180 filter is the most appropriate for determining impact acceleration of the SSDT and the CCUBS.
- The CCUBS and the SSDT produce highly repeatable impact accelerations.
- The CCUBS and the SSDT produce similar ATD responses for a given impact condition, but that the SSDT generally produces lower ATD loads.
- As impact severity was increased, the differences between the CCUBS and the SSDT became more pronounced.

6. FUTURE WORK

Drop tower testing presents special unique challenges. It is likely that not all gravity powered drop towers would produce similar results to the

SSDT. In fact, contractors have demonstrated significant differences in drop tower test results between contractor test laboratories having identical impact acceleration pulses. In response to the realization that significant performance differences in contractor drop towers exist, a universal gage has been prototyped by the OPL at SANGB that will enable input-output data comparison of gravity-fed drop towers and other test systems. Gage data could provide contractors with an indication of alignment between their drop system performance and the SSDT performance prior to the contractor seeking test article certification at the SANGB OPL.

1. REFERENCES

[1] N. Alem, "Filter Characteristics for Processing Biomechanical Signals from Impact Tests", Filter Study Final Report, University of Michigan, Ann Arbor, 1986.

[2] F. DiMasi, Analysis of Automobile Crash Test Data and Recommendations for Acquiring and Filtering Accelerometer Data, U.S. Department of Transportation, National Highway Safety Administration, 1975

[3] K. Bosch, *et al.*, "Blast Mitigation Seat Analysis – Drop Tower Data Review", 2014 NDIA Ground Vehicle Systems Engineering and Technology Symposium, 2014.

[4] FAA, "Dynamic Evaluation of Seat Restraint Systems and Occupant Protection on Transport Airplanes", Advisory Circular, AC No: 25.562-1B, 2006.

[5] M. Cheng, *et al*., "On drop-tower test methodology for blast mitigation seat evaluation", International Journal of Impact Engineering, vol. 37, pages 1180-1187, 2010.

Commented [JMG7]: Since "*et al.*" comes from a foreign language, it should be italicized.