Report on OPL CCUBS Tests with PRIMUS Dummy

In Accordance with Terms of CRADA Number 21-11

between DEVCOM GVSC and Kistler Instrument Corporation.

SUMMARY

A series of laboratory scale tests using the Crew Compartment Underbody Blast Simulator (CCUBS) were conducted at the Occupant Protection Laboratory (OPL) at Selfridge ANGB, MI. The tests were designed to compare the responses of a PRIMUS dummy to a Hybrid III (HIII) 50th percentile male Anthropomorphic Test Device (ATD). Additionally, the test data will be used to derive correlation between testing on the CCUBS and in a live-fire surrogate, such as the OPL's Generic Hull (GH).

The tests reported in this study were designed to simulate the position of the dummies in a live-fire GH test conducted in December 2021. In that test the PRIMUS and HIII were positioned side-by-side, like driver and passenger in a vehicle, and seated facing forward. Each dummy was positioned in a Commercial-off-the-shelf (COTS) blast mitigating seat with a stroking mechanism. The seats used in the CCUBS tests were the same seats used in the December GH test.

The seated dummies were accelerated vertically at three different peak acceleration levels, 150g, 250g, and 350g. Five (5) tests were conducted at each level. Data captured comprised of Head accelerations, Chest accelerations, Pelvis accelerations, HIII Lumbar loads, lap seatbelt loads, seat pan displacement, seat stroking portion vertical accelerations, seat rigid mount accelerations, platform (input) accelerations, and high-speed video for kinematic analysis. All data was recorded on Diversified Technical Systems (DTS) Slicepro data acquisition systems (DAS) and the internal Kistler DAS of the PRIMUS dummy. All data was recorded at 20,000 samples per second (kHz). Endevco model 7270-2k accelerometers were used to capture seat and platform accelerations.

INTRODUCTION

Vehicle occupant injury assessment is a specialized field that requires unique tools to determine the effectiveness of safety technologies designed to reduce injury potential during vehicular events. These events can include frontal car crashes, rear-end impacts, vehicular rollovers, pedestrian impacts, and blast events, such as under-body blasts or even vehicle borne explosives.

To assess developed or developing occupant protection technologies, Anthropomorphic Test Devices are used as vehicle occupant surrogates. ATDs are specially developed surrogates that are designed to respond to impact events seen in vehicular mishaps. The responses of the ATDs are engineered to match those of humans and are based on cadaveric tests that provide data for the injury response mechanisms.

Typically, ATDs are engineered to be biofidelific for certain types of vehicular mishaps, i.e., frontal, side, rear, pedestrian, and vertical. ATDs are also developed to represent certain segments of the population based on size, i.e., 50th (average male), 95th (large male), 5th (small female), and numerous smaller sizes to represent children. The PRIMUS Dummy, and the HIII used in this study, represent an average male. While these ATDs are designed for their specific impact conditions, mainly for vehicle safety certifications, in research environments they are used in areas that tend to fall outside their intended impact conditions. The U.S. Army has used the HIII, a frontal-impact dummy, for many years now to validate vehicle safety systems for under-body blasts. The PRIMUS Dummy was originally designed to be used in pedestrian impacts but it's use in other environments has been growing over the years to include military applications.

The PRIMUS Dummy is manufactured by Crash Test Services GmbH (CTS) of Muenster, Germany, and marketed in North America by Kistler Instruments, Inc. CRADA number: 21-11 (PRIMUS Dummy Demonstration) was drawn up between DEVCOM GVSC and Kistler to allow examination of the PRIMUS Dummy in the OPL's environment.

The CRADA between DEVCOM GVSC and Kistler provides a unique opportunity for both parties to acquire assessment information for the PRIMUS Dummy in a military environment. In the terms of the CRADA the PRIMUS will be tested on a number of systems that the OPL utilizes; live-fire (Generic Hull), and CCUBS. This report details the findings from the second phase of the CRADA effort, testing conducted using the CCUBS. In all tests the responses of PRIMUS will be compared to the inputs delivered to it and to those of either a HIII or a WIAMan ATD depending which test system is utilized.

Compared to HIII or WIAMan, PRIMUS is a lower cost alternative that may prove to be useful in some of the unique environments confronted by the OPL, and to those developing injury mitigating technologies. The PRIMUS Dummy in this study had nine accelerometers arranged in tri-axial configurations in the pelvis, chest, and the head, it also had three angular rate sensors in the head to measure head rotations about the three principle axes. The HIII had similar instrumentation and also included the ability to measure forces and moments in the legs, lumbar, and neck. Similar measurements could also be incorporated into a PRIMUS Dummy if needed. For this study the accelerations in the head, chest, and pelvis of the PRIMUS Dummy will be compared to the seat acceleration inputs and to the corresponding measurements from a HIII.

METHOD

In April 2022 a series of CCUBS tests were conducted at the GVSC OPL at Selfridge Air National Guard Base, MI USA. The test series is part of the overall test plan in CRADA 21-11. The tests were designed to provide a seating environment similar to a live-fire GH test conducted in December 2021.

The Crew Compartment Underbody Blast Simulator (CCUBS) is a vertically accelerated platform capable of accommodating four (4) seated occupants. CCUBS is powered by four (4) high pressure nitrogen cylinders that accelerate a bullet mass into the underside of the CCUBS platform. Peak acceleration and duration are controlled by charge pressure and arrangement of elastomeric programmers mounted on the bullet mass. Figure 1 below shows a typical setup for this series of tests.

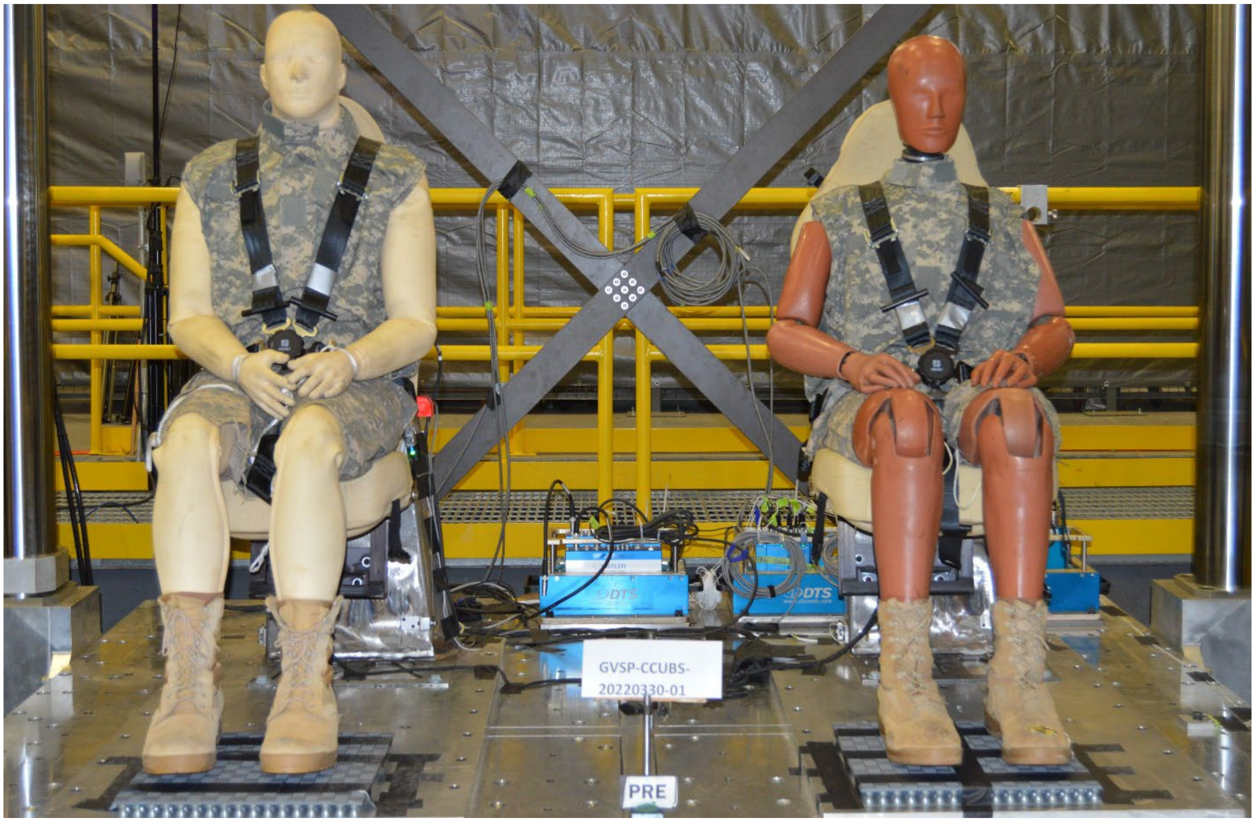

Figure 1 CCUBS test setup. HIII on the right (Position 1), PRIMUS on the left (Position 2).

For this test series, the targeted peak platform accelerations were 150g, 250g, and 350g. Five (5) tests were conducted at each peak acceleration level.

The setup consisted of two (2) dummies seated in COTS blast mitigating seats with stroking mechanism. On board data acquisition was accomplished with a DTS Slicepro DAS sampling at 20 kHz. Platform accelerations were measured using a pair of Endevco model 7270-2k accelerometers. Seatbelt loads were measured using Humanetics model IF-966 seatbelt loadcells. Seat stroke was measured through TE Connectivity model MT2A string pots attached to the stroking portion of the seat and terminated at the CCUBS platform. Seat stroke accelerations were measured using Endevco model 7270-2k accelerometers. Input accelerations for the seat mount were measured using a tri-axial arrangement of Endevco model 7270-2k accelerometers. Dummy kinematic responses were measured and recorded utilizing the on-board instrumentation and DAS for each of the respective dummies. Three (3) high-speed video cameras recorded each event at 2000 frames per second.

Table 1 below catalogs the test identification numbers and the associated impact level for those tests. Table 2 below lists the dummy instrumentation used in this report. Dummy instrumentation, common between both dummies was, Tri-axial accelerations in the head, chest and pelvis. In addition, PRIMUS had a Tri-axial array of angular rate sensors in the head, while HIII was fitted with a 6-axis lumbar load cell, and upper and lower tibia load cells. Table 3 below catalogs the data channels for the input accelerations (Platform, and Seat Mount), seatbelt load cells, and seat stroke string pots.

Table 1 Test Matrix

150g	250g	350g
GVSP-CCUBS-20220330-01	GVSP-CCUBS-20220330-06	GVSP-CCUBS-20220404-01
GVSP-CCUBS-20220330-02	GVSP-CCUBS-20220331-01	GVSP-CCUBS-20220404-02
GVSP-CCUBS-20220330-03	GVSP-CCUBS-20220331-02	GVSP-CCUBS-20220404-03
GVSP-CCUBS-20220330-04	GVSP-CCUBS-20220331-03	GVSP-CCUBS-20220405-01
GVSP-CCUBS-20220330-05	GVSP-CCUBS-20220331-04	GVSP-CCUBS-20220405-02

Table 2 Dummy Instrumentation

	HIII	PRIMUS
Head CG X	D1HEAD0000H3ACX0	01HEAD0000BFACXP
Head CG Y	D1HEAD0000H3ACY0	01HEAD0000BFACYP
Head CG Z	D1HEAD0000H3ACZ0	01HEAD0000BFACZP
Chest X	D1CHST0000H3ACX0	01CHST0000BFACXP
Chest Y	D1CHST0000H3ACY0	01CHST0000BFACYP
Chest Z	D1CHST0000H3ACZ0	01CHST0000BFACZP
Pelvic X	D1PELV0000H3ACX0	01PELV0000BFACXP
Pelvic Y	D1PELV0000H3ACY0	01PELV0000BFACYP
Pelvic Z	D1PELV0000H3ACZ0	01PELV0000BFACZP
Lumbar Spine Load Z	D1LUSP0000H3FOZ0	NA

Table 3 Input Accelerometers and Belt Load Cells

	HIII	PRIMUS
Platform Accel 1	T0PLAT70A010ACZ0	
Platform Accel 2	T0PLAT70A020ACZ0	
HIII Right Lapbelt	D1LAPBRGHTH3FOXD	
HIII Left Lapbelt	D1LAPBLEFTH3FOXD	
PRIMUS Right Lapbelt		D2LAPBRGHTBFFOXD
PRIMUS Left Lapbelt		D2LAPBLEFTBFFOXD
HIII Seat Mount X Accel	D1SEATRIGID0ACXC	
HIII Seat Mount Y Accel	D1SEATRIGID0ACXC	
HIII Seat Mount Z Accel	D1SEATRIGID0ACZC	
HIII Seat Stroke Z Accel	D1SEATSTROKEACZC	
PRIMUS Seat Mount X Accel		D2SEATRIGID0ACXC
PRIMUS Seat Mount Y Accel		D2SEATRIGID0ACXC
PRIMUS Seat Mount Z Accel		D2SEATRIGID0ACZC
PRIMUS Seat Stroke Z Accel		D2SEATSTROKEACZC
HIII Seat Stroke Z Disp	T0SEATDISP0100Z0	
PRIMUS Seat Stroke Z Disp		T0SEATDISP0200Z0

RESULTS

Fifteen (15) tests were conducted using the CCUBS, the tests were conducted at three (3) distinct peak acceleration levels. Two (2) dummies, one (1) HIII ATD, and one (1) PRIMUS dummy, were positioned in COTS blast mitigating seats with stroking mechanism. The dummies and seats were each tested five (5) times at each peak acceleration level.

The input accelerations and dummy responses are presented as time-based series plots below. Time duration for the plots depend on the parameter of interest and where in the timeline the region of interest exists.

Input Accelerations

Figure 2 below presents the unfiltered platform (input) accelerations. In Figure 2 the top row of plots are from platform accelerometer 1, while the second row is from platform accelerometer 2. The first column of plots is for the 150g tests, the middle column 250g tests, and the third column for the 350g tests. It can be seen in Figure 2 that CCUBS delivers a highly repeatable input for each test condition.

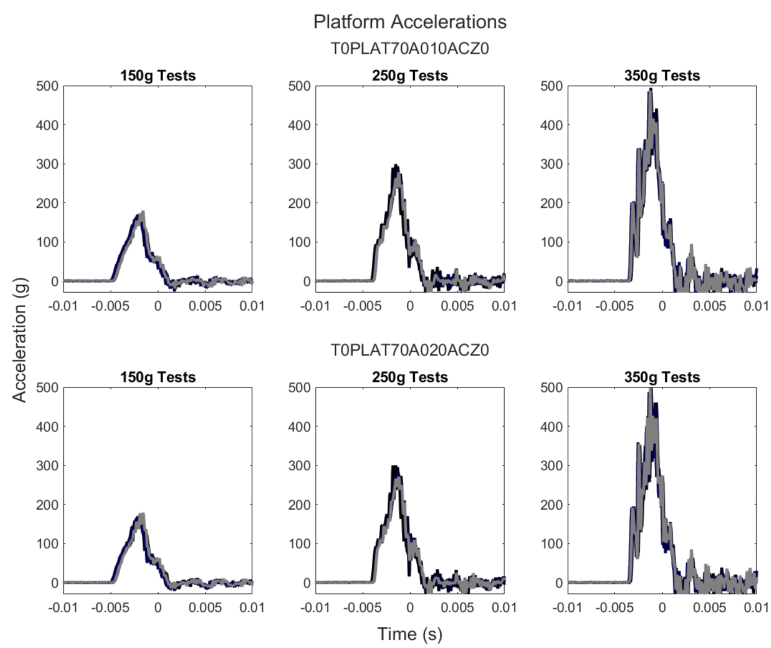

Figure 2 Unfiltered Input (Platform) Accelerations

Figure 3 below is the SAE Channel Class CFC180 filtered accelerations presented in Figure 2 above.

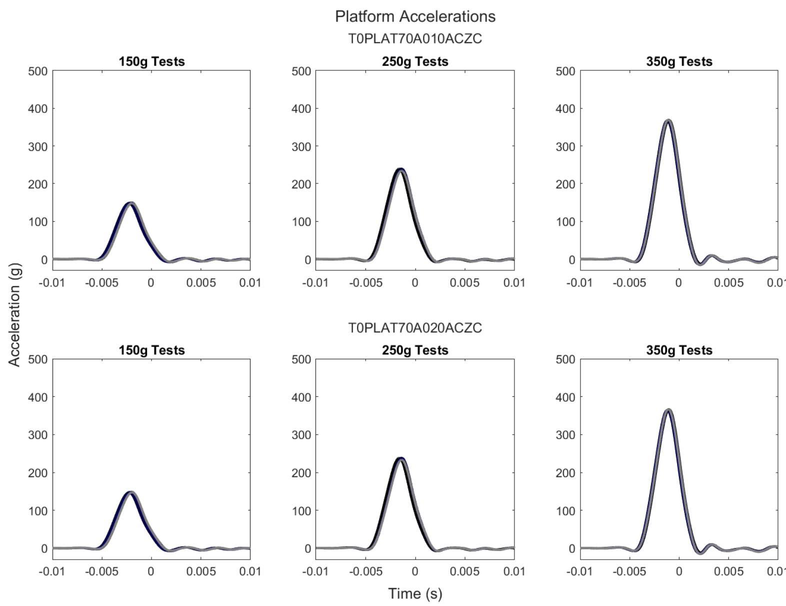

Figure 3 SAE Channel Class CFC180 Input (Platform) Accelerations

Seat Responses

Figure 4 below presents, for the 150g tests, the SAE Channel Class CFC180 filtered seat rigid mount vertical accelerations, seat stroking portion accelerations, and the seat pan displacement measured by the string pot. Figure 5 and Figure 6, present the SAE Channel Class CFC180 filtered seat rigid mount vertical accelerations, seat stroking portion accelerations, and the seat pan displacement for the 250g and 350g tests, respectively.

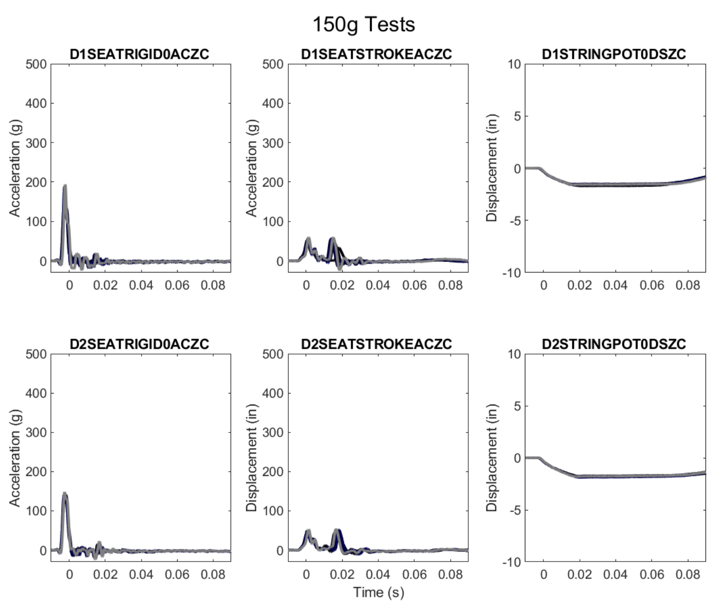

Figure 4 SAE Channel Class CFC180 Seat Accelerations and Vertical Displacement (150g)

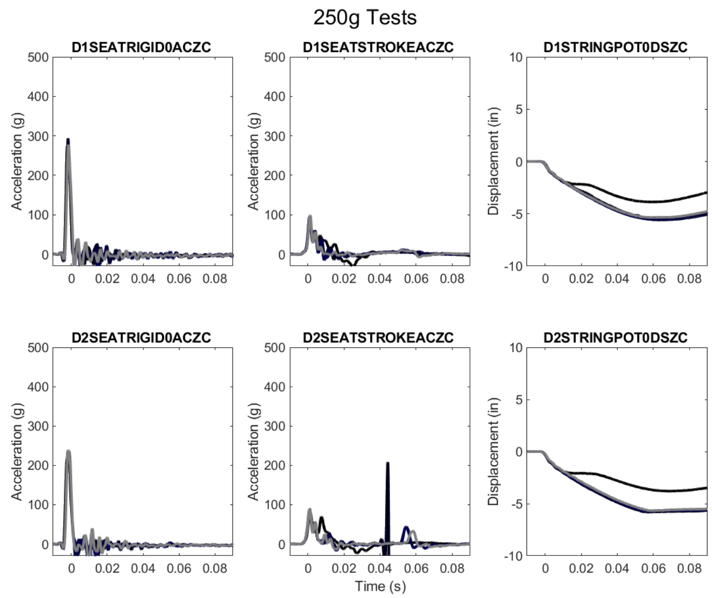

Figure 5 SAE Channel Class CFC180 Seat Accelerations and Vertical Displacement (250g)

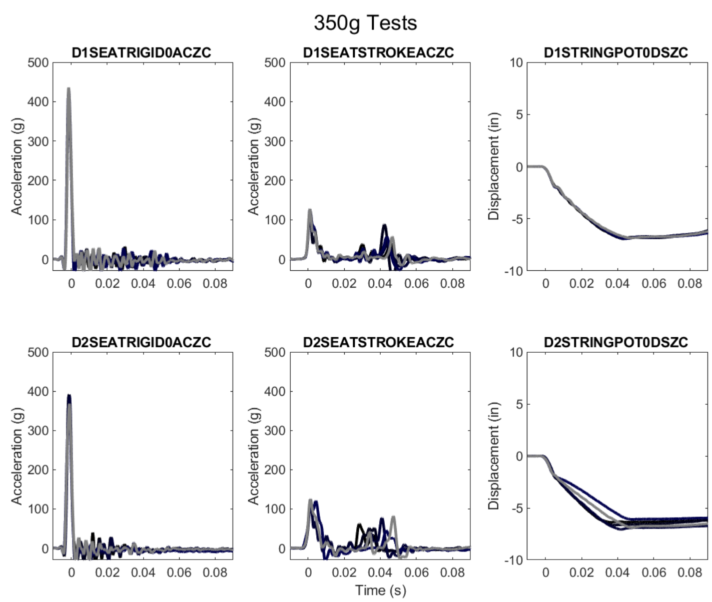

Figure 6 SAE Channel Class CFC180 Seat Accelerations and Vertical Displacement (350g)

Figure 7, Figure 8, and Figure 9 present the SAE Channel Class CFC60 filtered lapbelt loads for both dummies, and the SAE Channel Class CFC600 filtered HIII vertical lumbar loads for the 150g, 250g, and 350g tests, respectively.

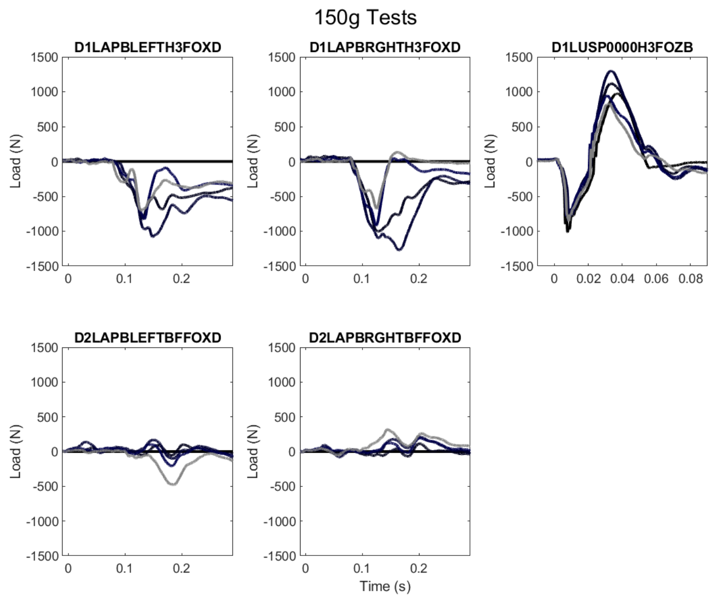

Figure 7 SAE Channel Class CFC60 Lapbelt Loads and CFC600 HIII Lumbar Vertical Load (150g)

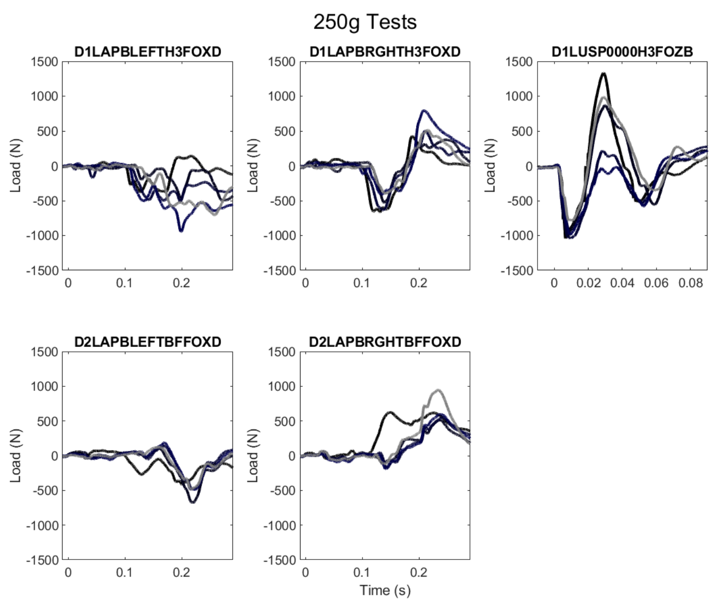

Figure 8 SAE Channel Class CFC60 Lapbelt Loads and CFC600 HIII Lumbar Vertical Load (250g)

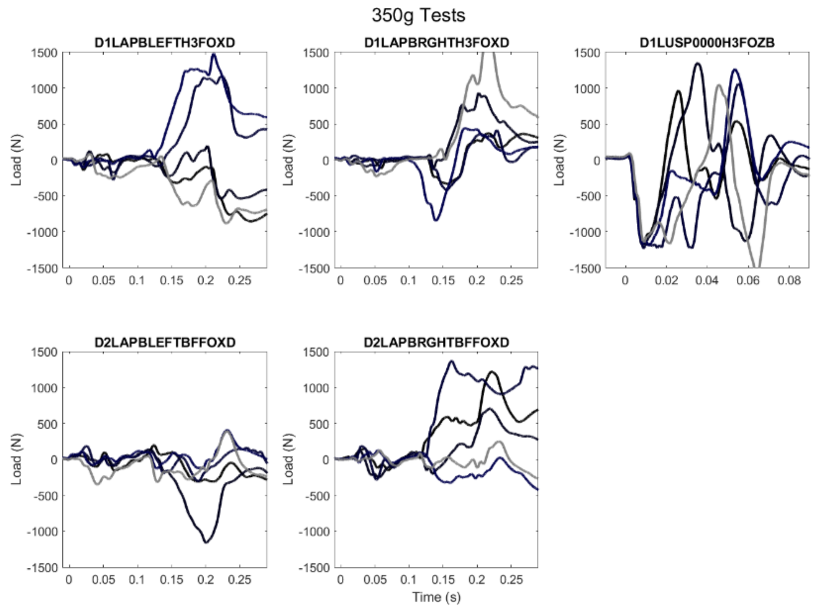

Figure 9 SAE Channel Class CFC60 Lapbelt Loads and CFC600 HIII Lumbar Vertical Load (350g)

Dummy Responses

Figure 10 – 15 below present the dummy responses. Figure 10 and Figure 11 are for the HIII and PRIMUS 150g tests, Figure 12 and Figure 14 are for the 250g tests, and Figure 14 and Figure 15 are for the 350g tests. For Figures 10 through Figure 15 the vertical axes are fixed, peak values beyond the maximum scales are mechanical noise and therefore not significant for comparative purposes.

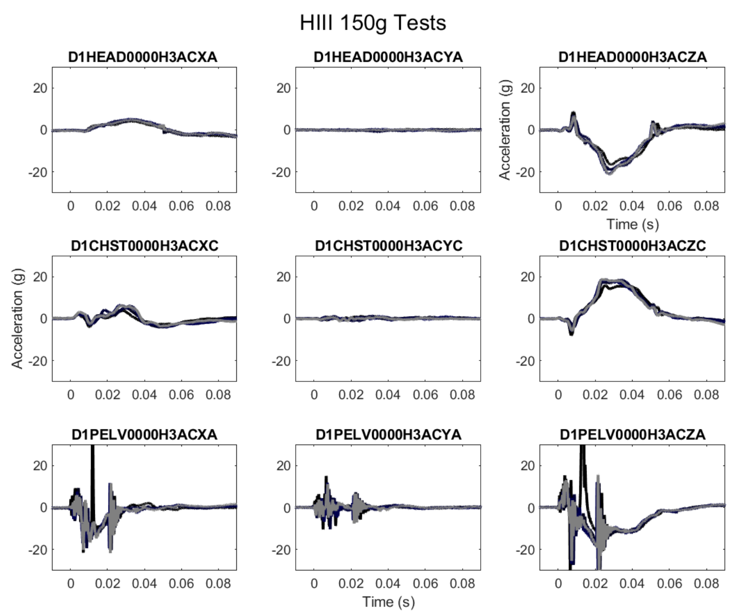

Figure 10 HIII SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (150g)

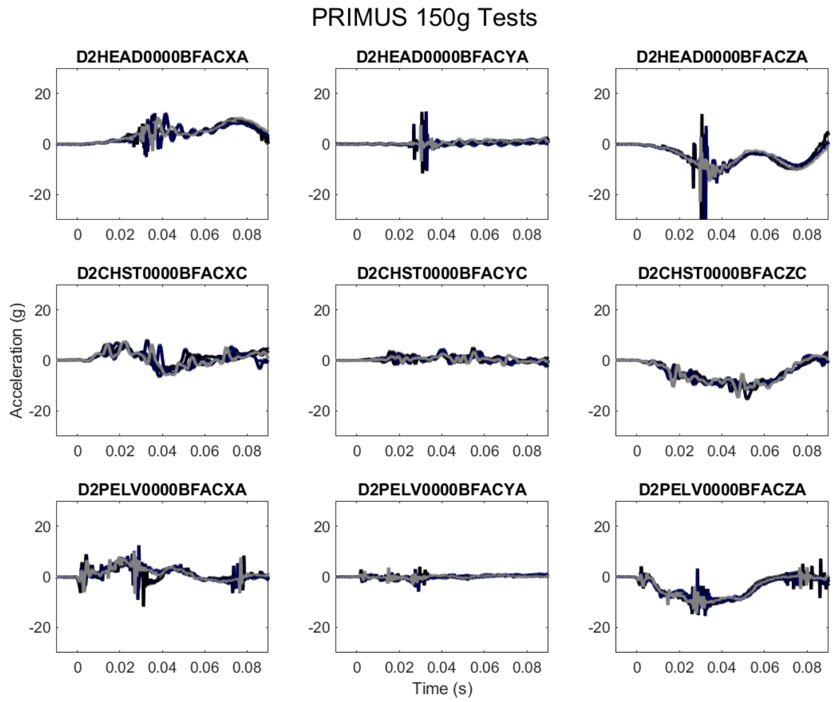

Figure 11 PRIMUS SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (150g)

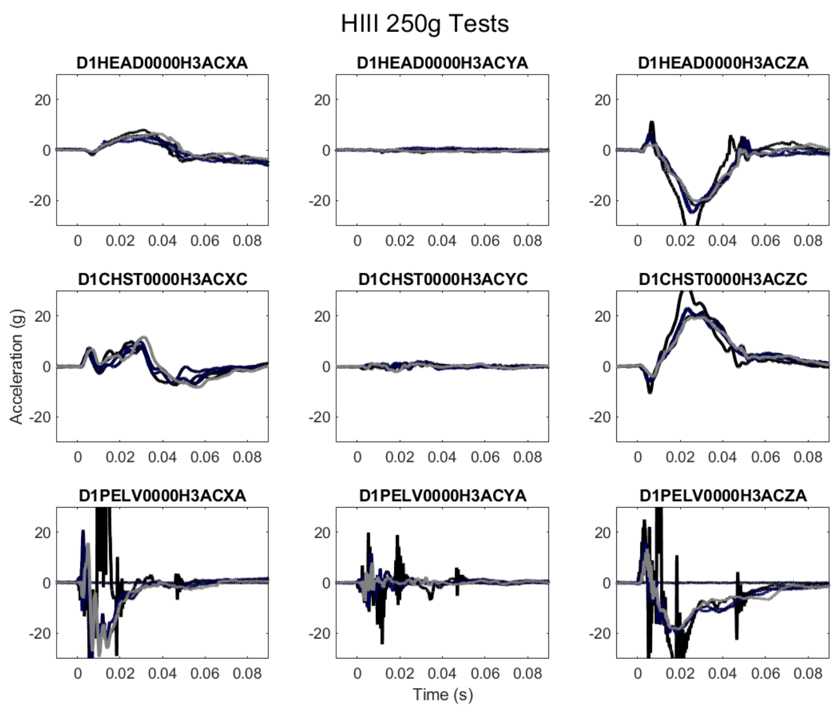

Figure 12 HIII SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (250g)

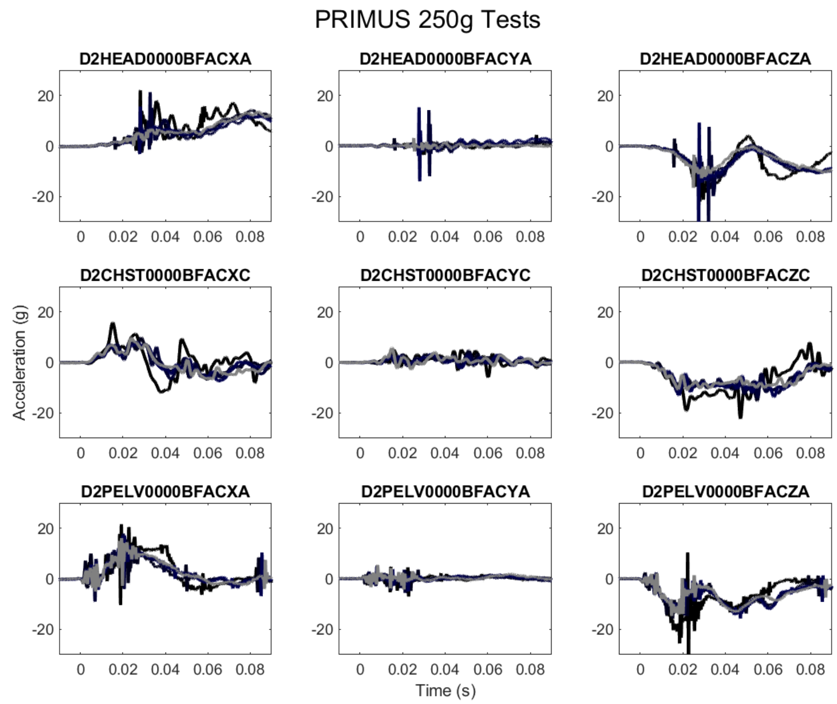

Figure 13 PRIMUS SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (250g)

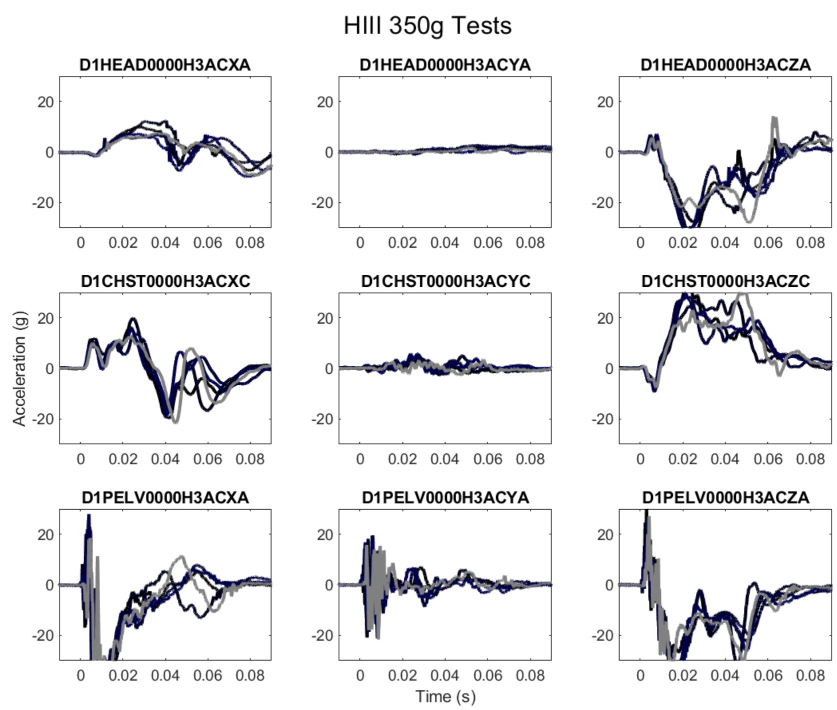

Figure 14 HIII SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (350g)

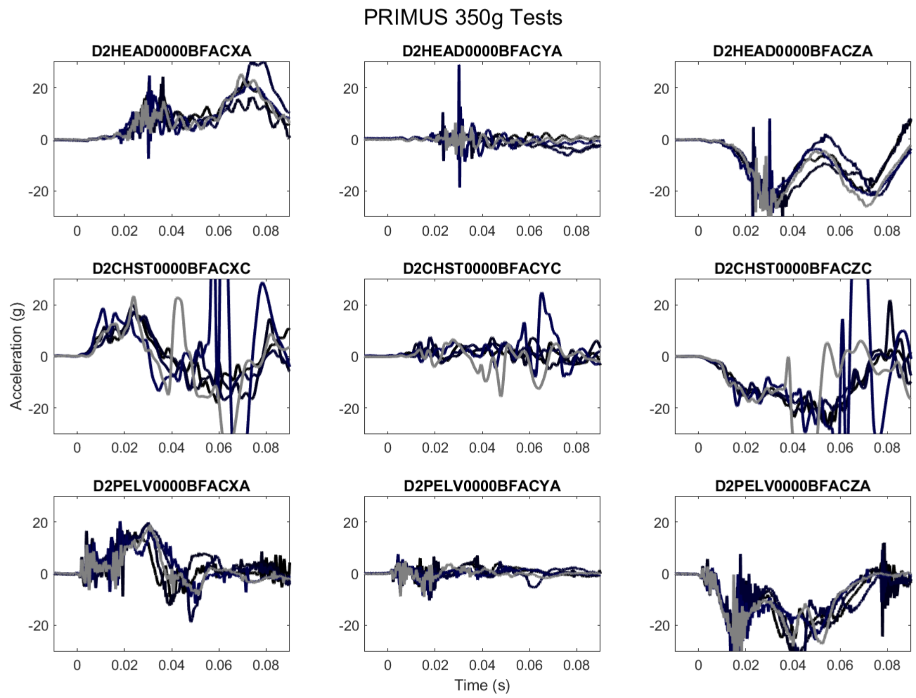

Figure 15 PRIMUS SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (350g)

DISCUSSION

Fifteen (15) vertical seat loading tests, using a PRIMUS Dummy and a Hybrid III 50th percentile male ATD, were conducted on the OPL CCUBS. The dummies were positioned in COTS blast mitigating seats with stroking mechanism. The seats and dummies were loaded five (5) times at three (3) distinct peak acceleration levels. The purpose of the tests was to compare the responses of the PRIMUS Dummy to that of the HIII in an OPL environment.

Input Accelerations

Figure 16 below shows the averaged platform accelerations (presented in Figure 2 and Figure 3) and the averaged rigid mount seat accelerations (presented in Figure 4 through Figure 6) for the three peak acceleration levels. For Figure 16 the top row of plots are the averaged accelerations applied to the HIII, and the bottom row are the PRIMUS applied average accelerations. It can be seen that the rigid seat mount accelerations had the same peak and duration as the platform accelerations, with the exception of the HIII 250g tests and the PRIMUS 350g tests. For both of those series of tests, the respective vertical rigid seat mount accelerations had a peak that was noticeably higher than the averaged platform accelerations. The averaged rigid seat mount accelerations will be used as inputs when examining dummy responses in this report.

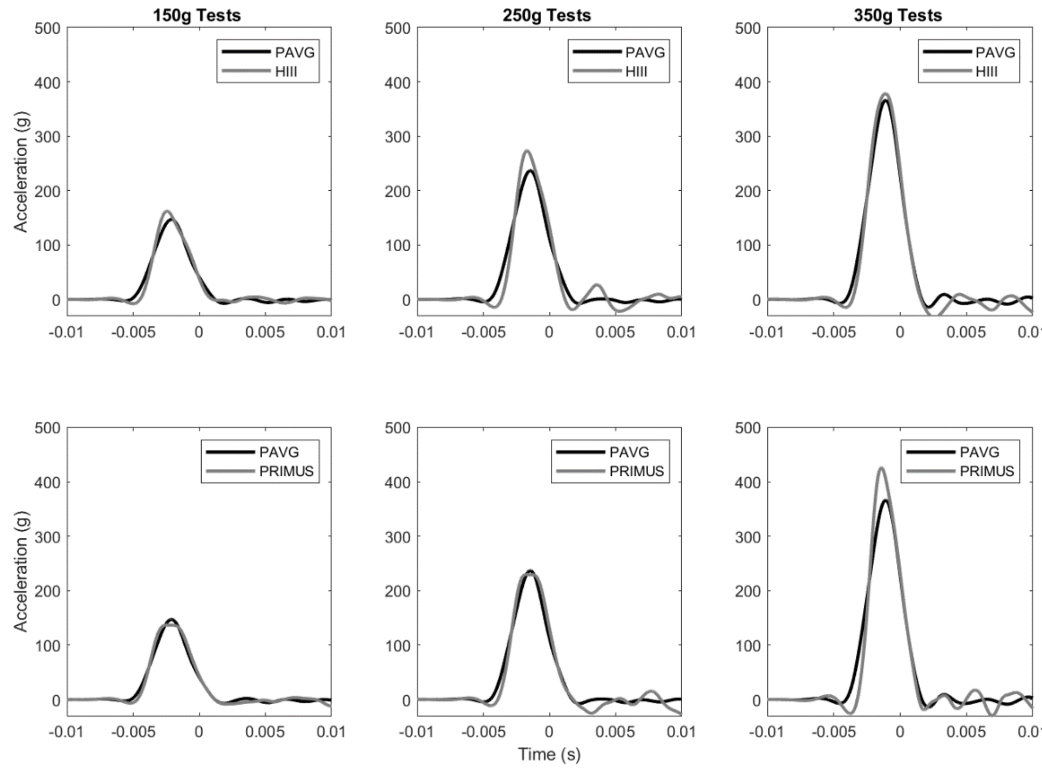

Figure 16 SAE Channel Class CFC180 Platform (AVG) and SAE Channel Class CFC180 Seat (AVG) Accelerations

Dummy Responses

Figure 17 shows the averaged seat rigid mount accelerations plotted against each dummy's vertical pelvic acceleration for each of the three distinct loading levels. The responses for HIII were noisy for the two lower-level test series, however the noise was less significant in the highest-level tests. Conversely, PRIMUS was quiet during the two lower-level series but started to get noisy during the mid-level tests and stayed noisy through the highest-level tests. The pelvic acceleration magnitudes reported for each dummy were close to each other with HIII reporting higher magnitudes than PRIMUS. Additionally, HIII exhibited initial positive accelerations, which also tend to influence lumbar load readings with initial tension loads. This phenomenon is thought to be a result of the loading of the legs. This initial positive acceleration was not present in the PRIMUS signals, which could be due to the difference in compliance between the two dummies. For Figure 17 the HIII responses are along the top row and PRIMUS responses on the bottom.

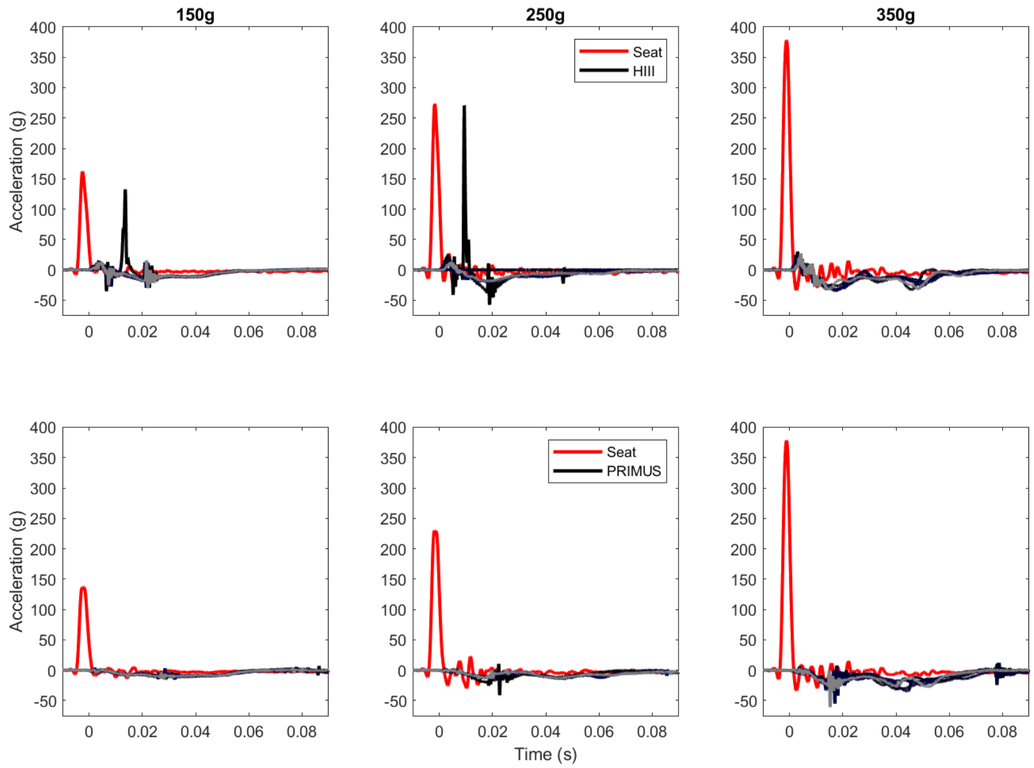

Figure 17 SAE Channel Class CFC180 Seat Rigid Mount (avg) and SAE Channel Class CFC1000 Pelvic Z Accelerations

Dummy Comparisons

To compare dummy responses piecewise continuous corridors were created from the HIII responses to allow for variation and to better illuminate the PRIMUS responses. The corridors were created by calculating the +/- 1 standard deviations of the average of the respective HIII responses. Figure 18 below shows, for the three different loading levels, the average of each PRIMUS body segment vertical acceleration plotted against the respective HIII corridors. For the most part PRIMUS responds within the same range as the HIII standard deviations. There were differences in the peak values of the responses, which are likely a result of the more compliant nature of PRIMUS, at the lower input levels. However, as impact acceleration increased PRIMUS became more compressed, and the peak values started approaching those of HIII.

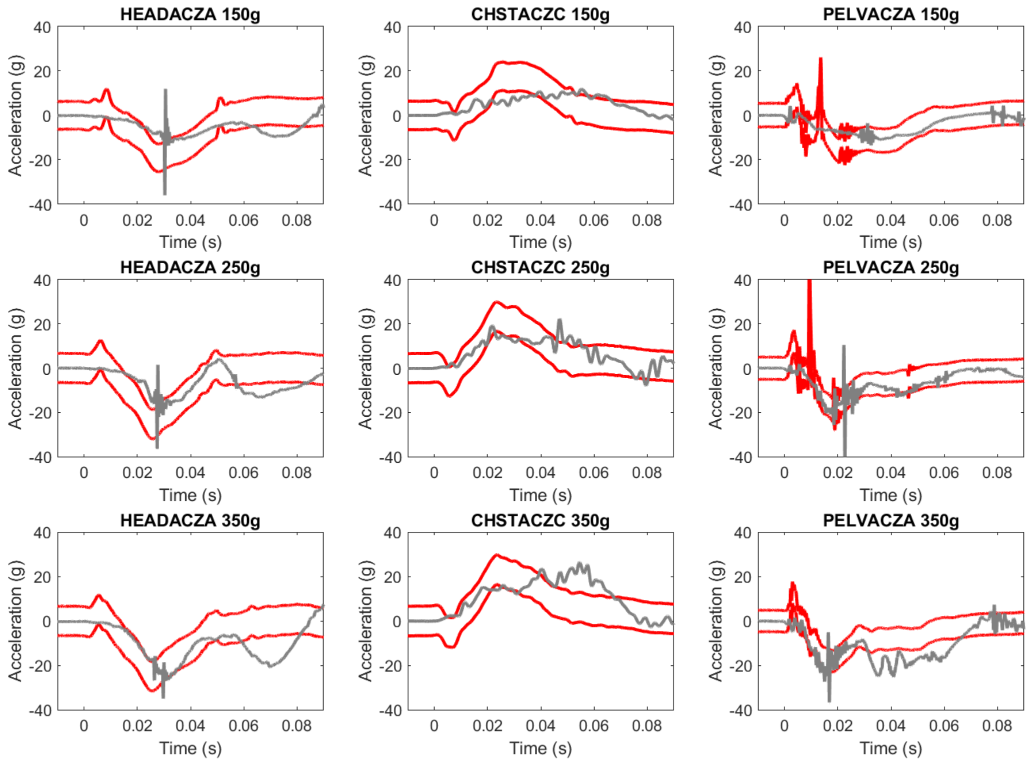

Figure 18 PRIMUS Responses(avg) compared to HIII Derived Corridors

CONCLUSION

Fifteen CCUBS tests were conducted in April 2022 to allow comparison of the PRIMUS Dummy to a Hybrid III 50th percentile male ATD in an OPL environment. As part of a CRADA between GVSP OPL and Kistler Instruments, Inc. the PRIMUS Dummy performance will be evaluated in several test systems in OPLs environment. PRIMUS performance will be compared to input accelerations applied as well as companion ATDs such as the Hybrid III 50th percentile male ATD and the WIAMan ATD. This test provided an opportunity to compare PRIMUS to a HIII on the CCUBS.

For this study:

- Seat and ATD acceleration data were filtered using SAE J211 suggestions and internal guidance
- ATD responses between the PRIMUS Dummy and the HIII were very similar
- PRIMUS compared well to corridors derived from HIII responses
- At lower impact levels PRIMUS peak responses were generally lower than HIII
- As impact acceleration increased, PRIMUS compressed, and peak responses approached HIII levels
- At this level and direction of loading the PRIMUS Dummy is a suitable surrogate