Report on OPL Test with PRIMUS Dummy

In Accordance with Terms of CRADA 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 Warrior Injury Assessment Manikin (WIAMan) Anthropomorphic Test Device (ATD).

The tests reported in this study were designed to simulate the position of dummies in a live-fire Generic Hull (GH) test conducted in December 2021. In that test the PRIMUS dummy and a Hybrid III ATD 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 reported here were the same model as used in the December 2021 GH test.

The seated dummies were accelerated vertically at three different targeted peak acceleration levels, 150g, 250g, and 350g. Five (5) tests were planned to be conducted at each level. Data captured comprised of Head accelerations, Chest accelerations, Pelvis accelerations, WIAMan 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.

Fifteen (15) tests were planned in the test matrix. However, the seats used in this study did not continue to function repeatably, therefore the test matrix was modified twice, and a total of twelve (12) tests were performed. During the 150g tests the seat occupied by the PRIMUS Dummy began failing and performed differently than the comparative seat that WIAMan occupied. As a result, the PRIMUS dummy was removed from the tests after the 250g test series. During the 350g tests, the seat occupied by the WIAMan ATD failed and the testing was halted. This report will focus on the tests where both PRIMUS and WIAMan were present. The responses of the dummies will be examined using body segment speeds. This will allow for discussion of the differences in the dummy responses relative to seat stroking speed.

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 biofidelic 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 WIAMan 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 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 systems that the OPL utilizes; live-fire (Generic Hull), and CCUBS. This report details the findings from the third 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 principal axes. The WIAMan 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 WIAMan.

METHOD

In January 2023 a series of CCUBS tests were concluded 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 replicate a seating environment in 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. PRIMUS on the left (Position 2), WIAMAN on the right (Position 1).

For this test series, the targeted peak platform accelerations were 150g, 250g, and 350g. Five (5) tests were planned 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. Five (5) 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 lists the dummy channels and ISO channel codes 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 WIAMan was fitted with a six-axis lumbar load cell, and upper and lower tibia load cells.

Table 1 Test Matrix

150g	250g	350g
GVSP-CCUBS-2022121301	GVSP-CCUBS-2023010401	GVSP-CCUBS-2023011001
GVSP-CCUBS-2022121401	GVSP-CCUBS-2023010501	GVSP-CCUBS-2023011002
GVSP-CCUBS-2022121402	GVSP-CCUBS-2023010502	
GVSP-CCUBS-2022121501	GVSP-CCUBS-2023010503	
GVSP-CCUBS-2022121502	GVSP-CCUBS-2023010901	

Table 2 Dummy Instrumentation

	PRIMUS	WIAMan
Head CG X	01HEAD0000BFACXP	D1HEAD0000WAACXP
Head CG Y	01HEAD0000BFACYP	D1HEAD0000WAACYP
Head CG Z	01HEAD0000BFACZP	D1HEAD0000WAACZP
Chest X	01CHST0000BFACXP	D1THSP0100WAACXP
Chest Y	01CHST0000BFACYP	D1THSP0100WAACYP
Chest Z	01CHST0000BFACZP	D1THSP0100WAACZP
Pelvic X	01PELV0000BFACXP	D1PELVFRBOWAACXP
Pelvic Y	01PELV0000BFACYP	D1PELVFRBOWAACYP
Pelvic Z	01PELV0000BFACZP	D1PELVFRBOWAACZP
Lumbar Spine Load Z	NA	D1LUSP0500WAFOZP

Table 3 below catalogs the data channels and ISO channel codes for the input accelerations (Platform, and Seat Mount), seatbelt load cells, and seat stroke string pots.

Table 3 Input Accelerometers and Belt Load Cells

	PRIMUS	WIAMan
Platform Accel 1	T0PLAT70A010ACZ0	
Platform Accel 2	T0PLAT70A020ACZ0	
PRIMUS Right Lapbelt	D2LAPBRGHTBFFOXD	
PRIMUS Left Lapbelt	D2LAPBLEFTBFFOXD	
WIAMan Right Lapbelt		D1LAPBRGHTH3FOXD
WIAMan Left Lapbelt		D1LAPBLEFTH3FOXD
PRIMUS Seat Mount X Accel	D2SEATRIGID0ACXC	
PRIMUS Seat Mount Y Accel	D2SEATRIGID0ACYC	
PRIMUS Seat Mount Z Accel	D2SEATRIGID0ACZC	
PRIMUS Seat Stroke Z Accel	D2SEATSTROKEACZC	
WIAMan Seat Mount X Accel		D1SEATRIGID0ACXC
WIAMan Seat Mount Y Accel		D1SEATRIGID0ACYC
WIAMan Seat Mount Z Accel		D1SEATRIGID0ACZC
WIAMan Seat Stroke Z Accel		D1SEATSTROKEACZC
PRIMUS Seat Stroke Z Disp	T0SEATDISP0200Z0	
WIAMan Seat Stroke Z Disp		T0SEATDISP0100Z0

RESULTS

Twelve (12) tests were conducted using the CCUBS, the tests were conducted at three (3) distinct peak acceleration levels. Two (2) dummies, one (1) PRIMUS dummy, and one (1) WIAMan ATD, were positioned in COTS blast mitigating seats with stroking mechanism. Both dummies and seats were each tested five (5) times at the 150g level, and five (5) times at the 250g level, and WIAMan only for two (2) at the 350g level.

The input speeds 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 SAE Channel Class CFC180 filtered platform (input) accelerations. In Figure 2 the first column of plots is from platform accelerometer 1, while the second column is from platform accelerometer 2. The first row of the plots is for the 150g tests, the middle row the 250g tests, and the third row for the 350g tests. It can be seen in Figure 2 that CCUBS delivers a highly repeatable input for each test condition.

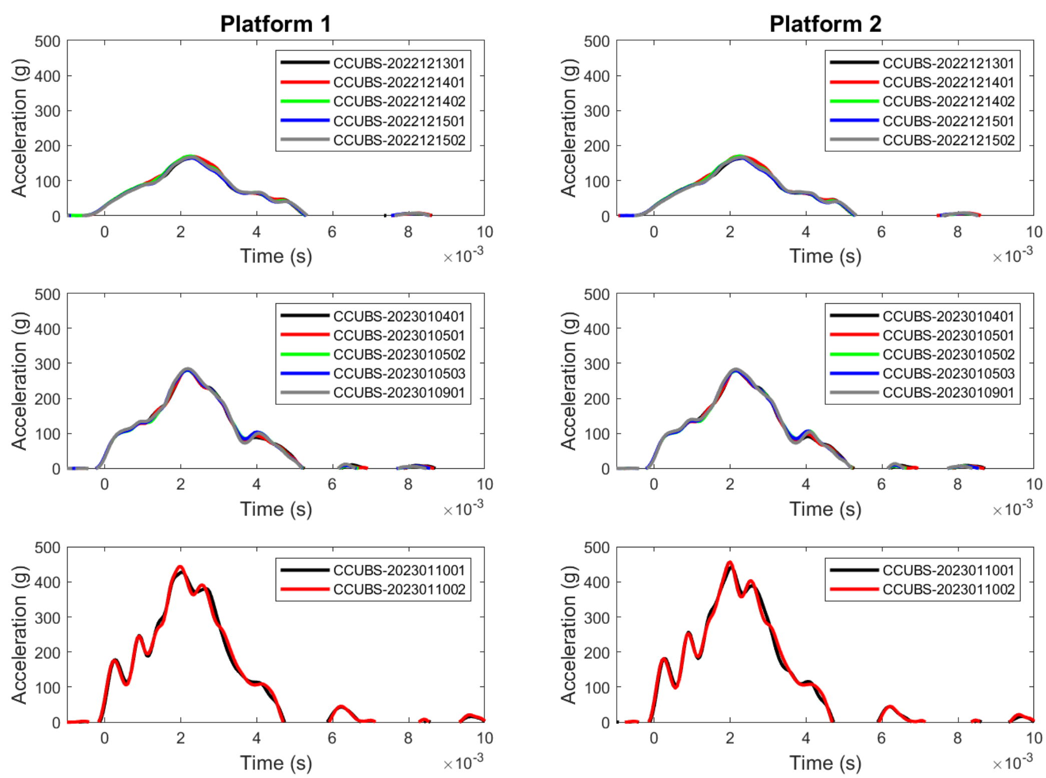

Figure 2 SAE Channel Class CFC180 Input (Platform) Accelerations

Seat Responses

Figure 3 below presents, for the 150g tests, the SAE Channel Class CFC180 filtered seat rigid mount vertical accelerations (first column), seat stroking portion accelerations (second column), and the seat pan displacement (third column) measured by the string pot. Figure 4 and Figure 5, 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. The stroke accelerations and displacements for the seat that PRIMUS was in and shown in Figure 3 and Figure 4 demonstrate the less than consistent seat behavior that started with the second 150g targeted test.

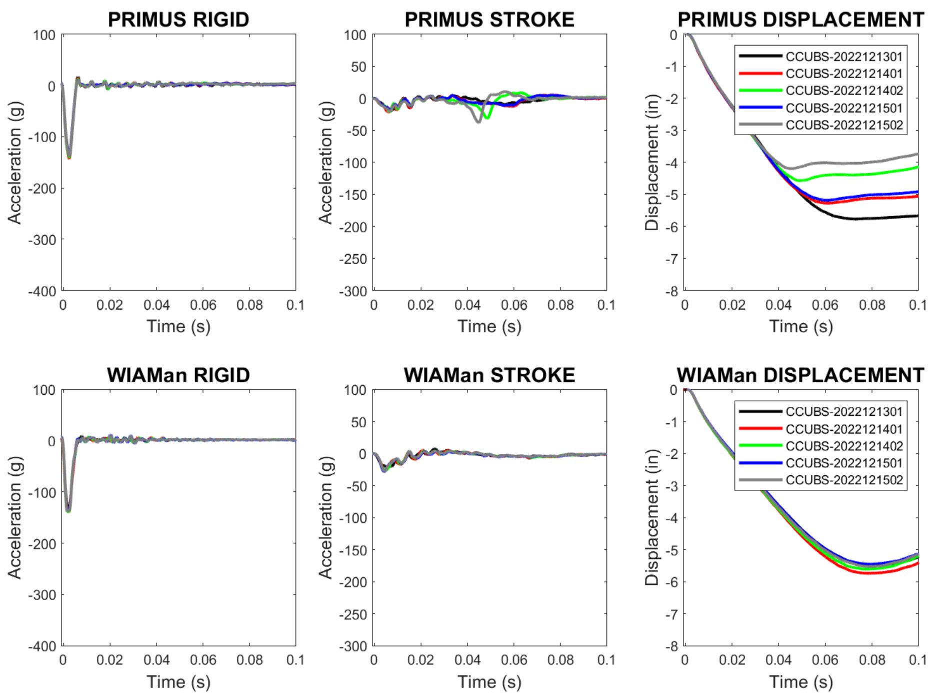

Figure 3 SAE Channel Class CFC180 Seat Accelerations and Vertical Displacement (150g)

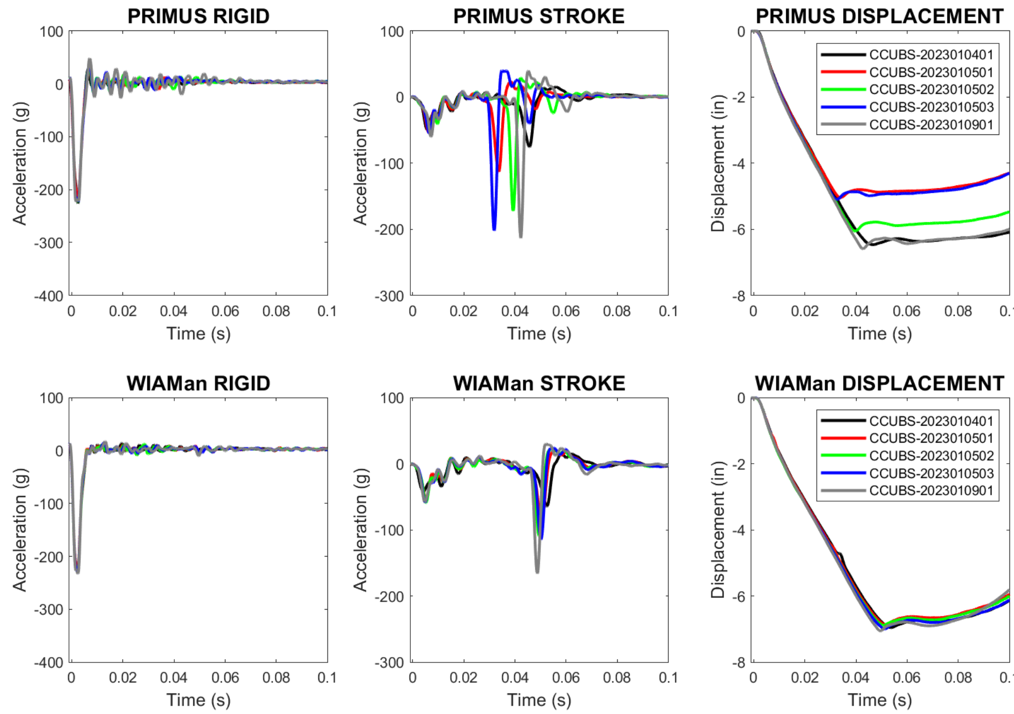

Figure 4 SAE Channel Class CFC180 Seat Accelerations and Vertical Displacement (250g)

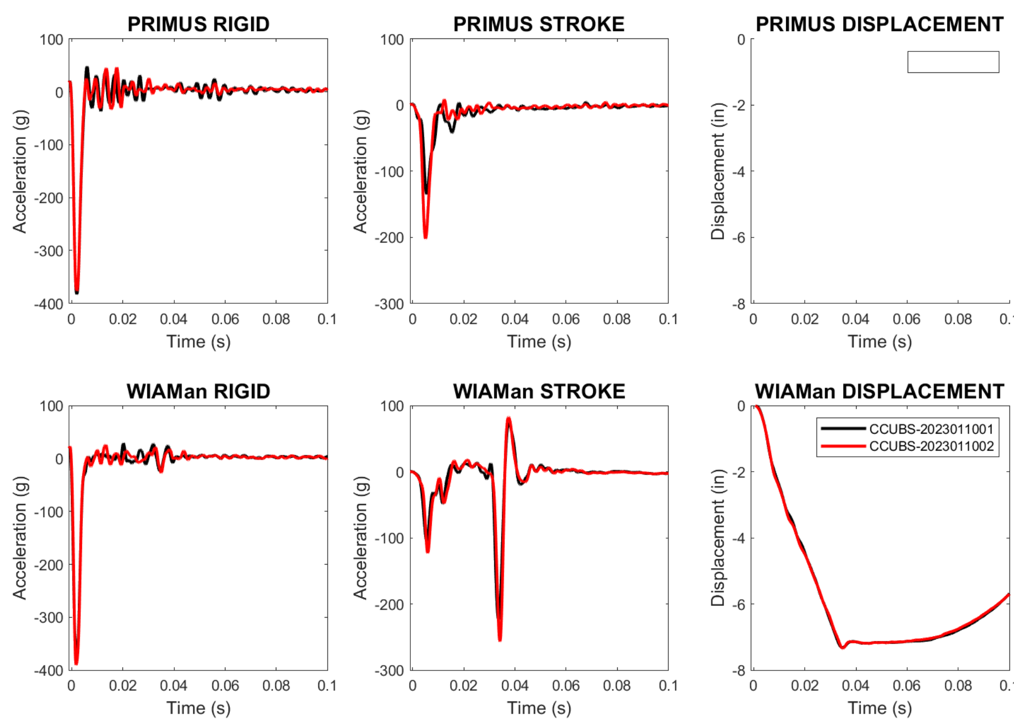

Figure 5 SAE Channel Class CFC180 Seat Accelerations and Vertical Displacement (350g)

Figure 6, Figure 7, and Figure 8 present the SAE Channel Class CFC60 filtered lapbelt loads for both dummies, and the SAE Channel Class CFC600 filtered WIAMan vertical lumbar loads for the 150g, 250g, and 350g tests, respectively. The first three test of this series were run with the lapbelts misconfigured (Figure 6), starting with test CCUBS-2022121501 and on, the lapbelt loads are correct. In Figure 7 below, for the 250g targeted tests, WIAMan produced significantly higher lapbelt loads than PRIMUS.

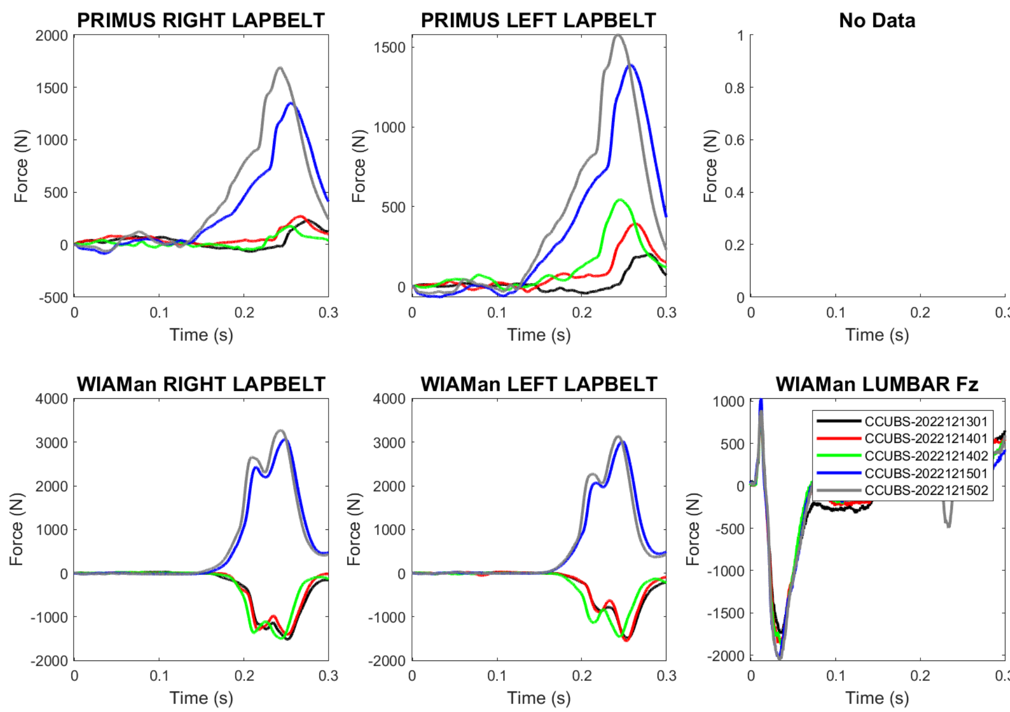

Figure 6 SAE Channel Class CFC60 Lapbelt Loads and CFC600 HIII Lumbar Vertical Load (150g)

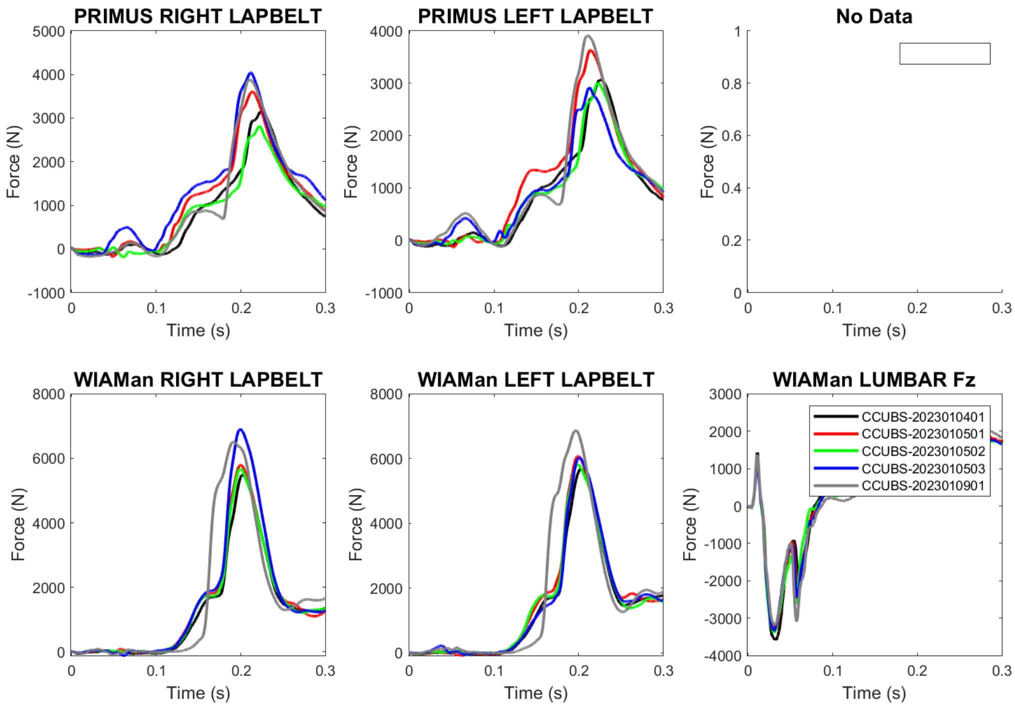

Figure 7 SAE Channel Class CFC60 Lapbelt Loads and CFC600 HIII Lumbar Vertical Load (250g)

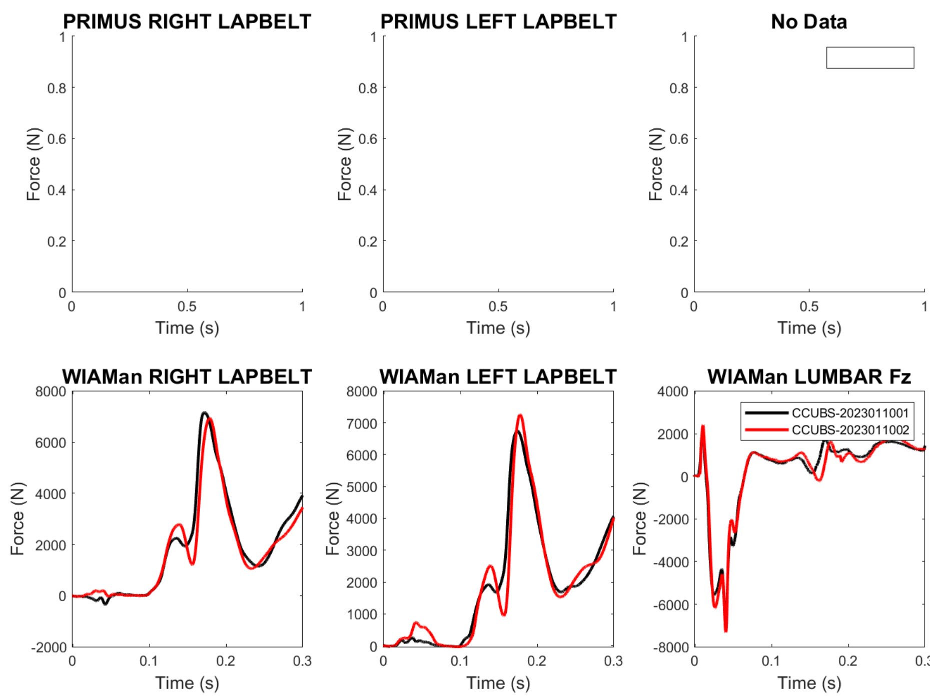

Figure 8 SAE Channel Class CFC60 Lapbelt Loads and CFC600 HIII Lumbar Vertical Load (350g)

Dummy Responses

Figure 9 – 11 below present the dummy vertical responses. Figure 9 is for the 150g tests, Figure 10 for the 250g tests, and Figure 11 for the 350g tests. For Figures 9 through Figure 11 the vertical axes are fixed, peak values beyond the maximum scales are mechanical noise and therefore not significant for comparative purposes. The PRIMUS Dummy was removed from the test matrix after the 250g series due to seat malfunction, therefore no responses from PRIMUS are presented in Figure 11 (350g tests).

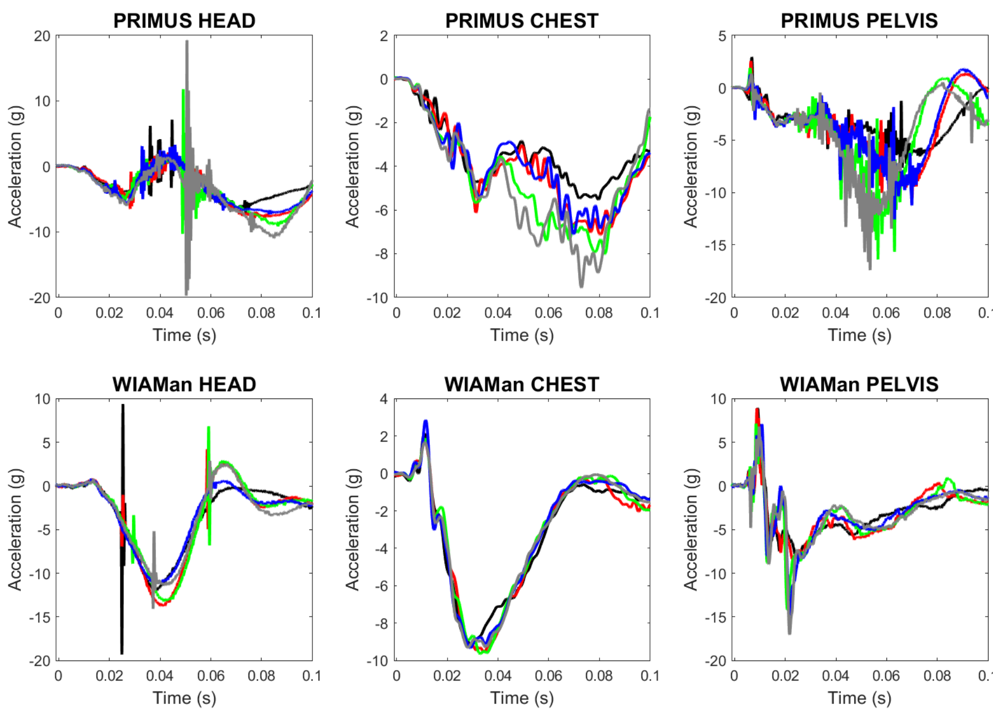

Figure 9 SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (150g)

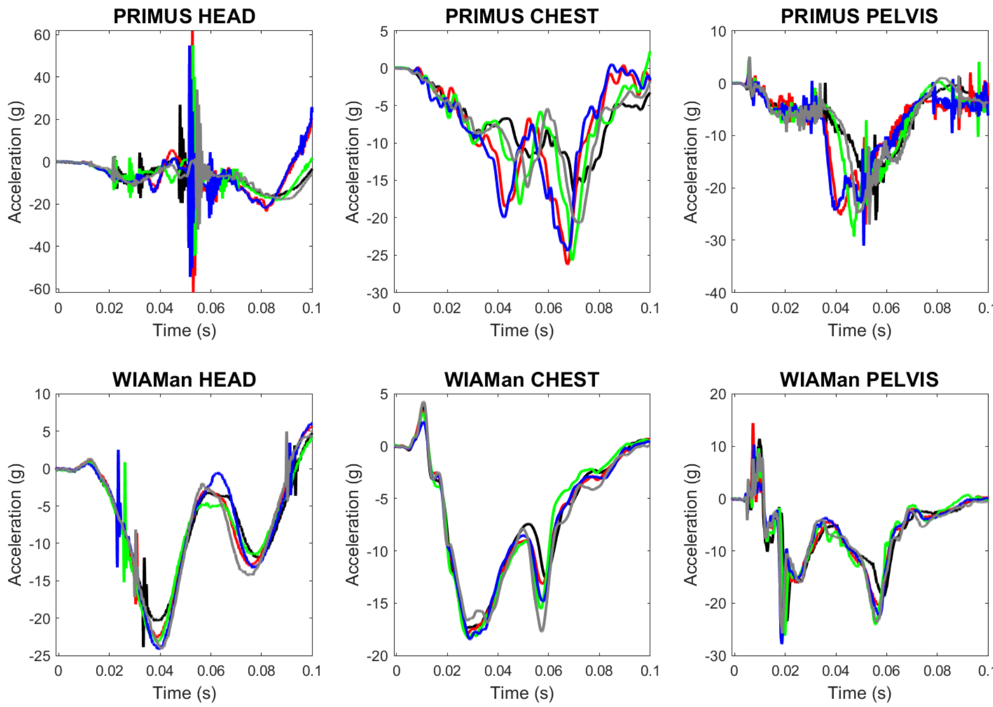

Figure 10 SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (150g)

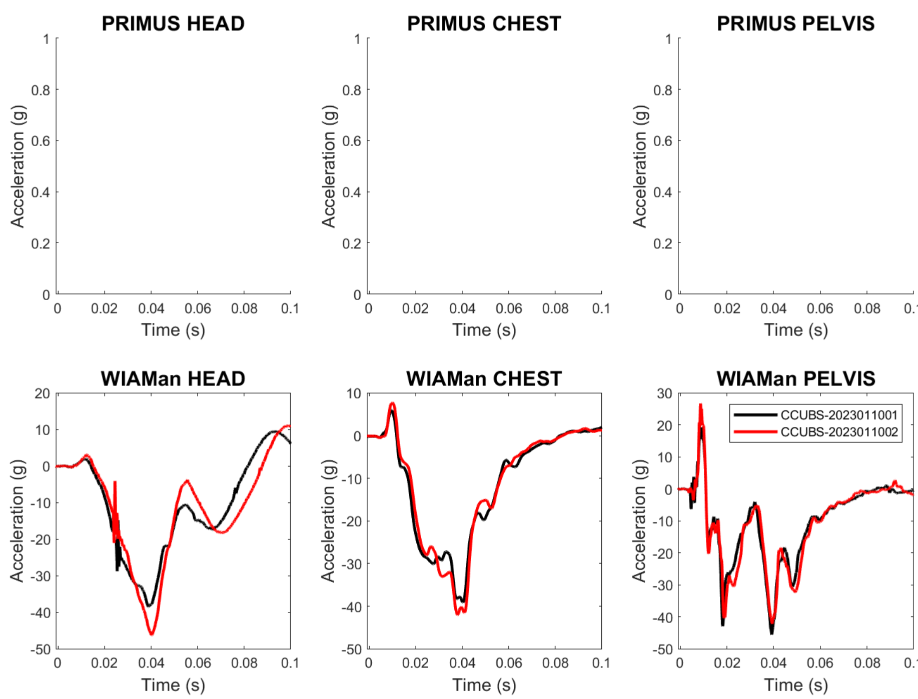

Figure 11 SAE Channel Class CFC1000 Head, Chest, and Pelvic Accelerations (250g)

DISCUSSION

Twelve (12) vertical seat loading tests, using a PRIMUS Dummy and a WIAMan 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 150g level, five (5) times at 250g, and WIAMan twice at the 350g level. The purpose of the tests was to compare the responses of the PRIMUS Dummy to that of the WIAMan ATD in an OPL environment.

Seat Responses

Acceleration measurements were collected from each seat. At the base of each seat mount was a tri-axial array of accelerometers. The stroking portion of the seat also had a single accelerometer measuring vertical seat accelerations.

A cumulative trapezoidal integration function in MATLAB R21 was used to calculate speed from the measured vertical accelerations of the rigid seat mount, the stroking seat accelerometer, and the accelerometers in the head, chest, and pelvis of both dummies.

Figure 12 and Figure 13 below show the speeds for the rigid and stroking portions of the seats. For both plots the first column is for the 150g tests, the second for the 250g tests, and the third for the 350g tests. The top row of the plots are from the PRIMUS seat, and the bottom row from the WIAMan seat. The speeds shown in Figure 13 demonstrate the consistent acceleration applied at each of the three different test levels.

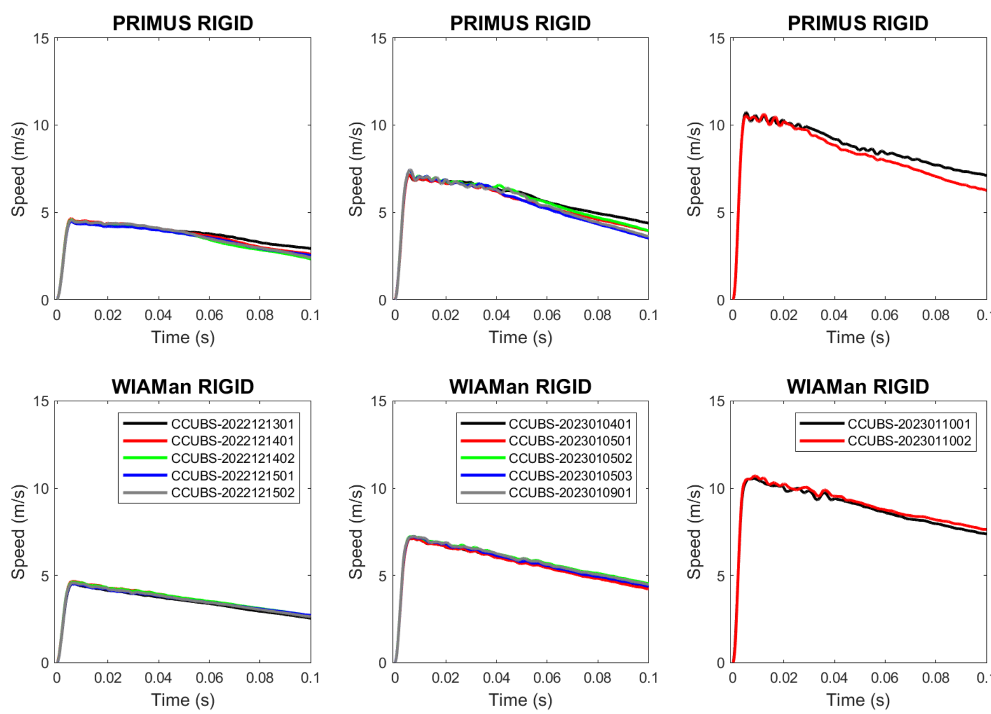

Figure 12 Rigid seat speeds

Figure 13 below shows the speeds derived from the accelerometer mounted to the stroking portion of the seats. In Figure 13 it can be observed that the PRIMUS stroking speed started varying around 3ms into the event. Essentially it appears from the data that the seat was not stroking the entire distance, stopping short of full displacement which had a significant effect on dummy responses. Testing was continued using this seat up through the 250g tests, after which, the PRIMUS dummy was removed from the remainder of the tests. However, the seat remained mounted to the CCUBS and the seat only responses were collected.

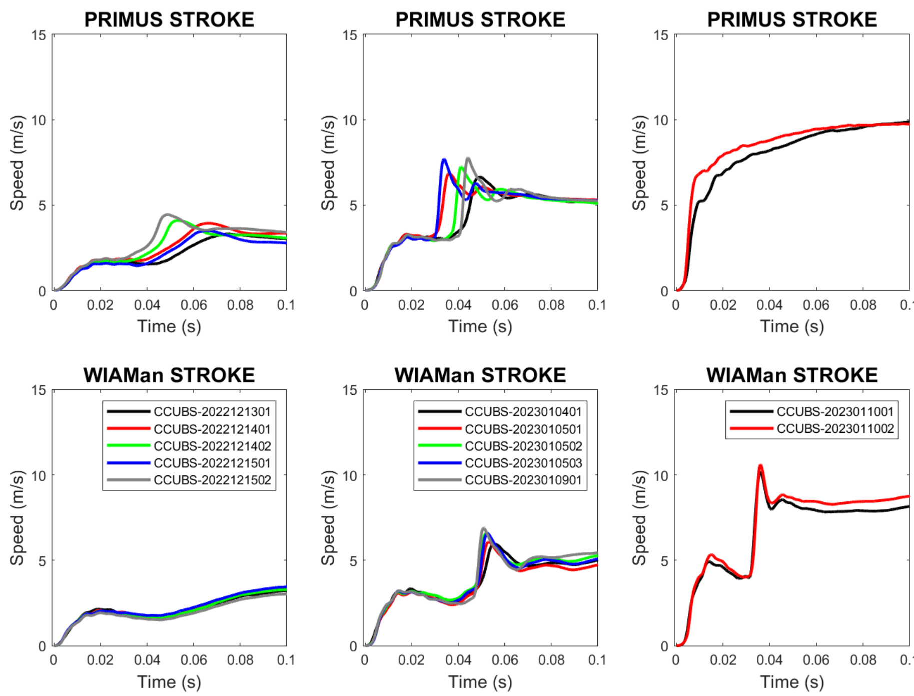

Figure 13 Stroking seat speeds

Dummy Responses

Figure 14 below presents the resultant Head, Chest, and Pelvis speeds for the 150g targeted tests for both dummies. The top row of plots are the PRIMUS speeds and the bottom row for WIAMan.

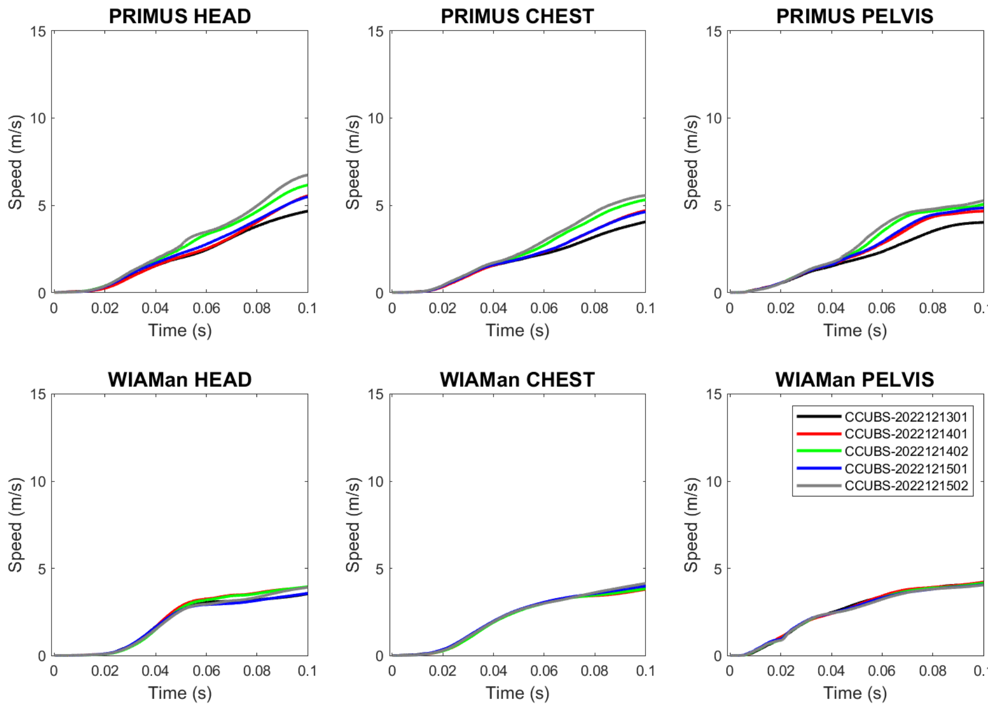

Figure 14 Dummy Body Segment Speeds speeds(150g)

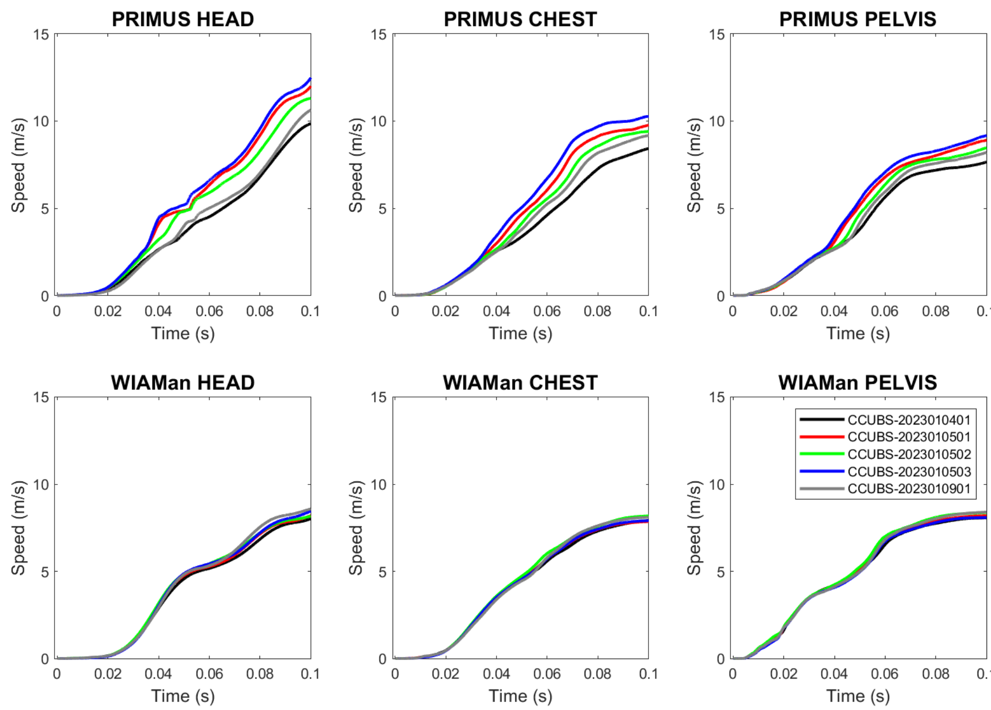

Figure 15 Dummy Body Segment Speeds speeds(250g)

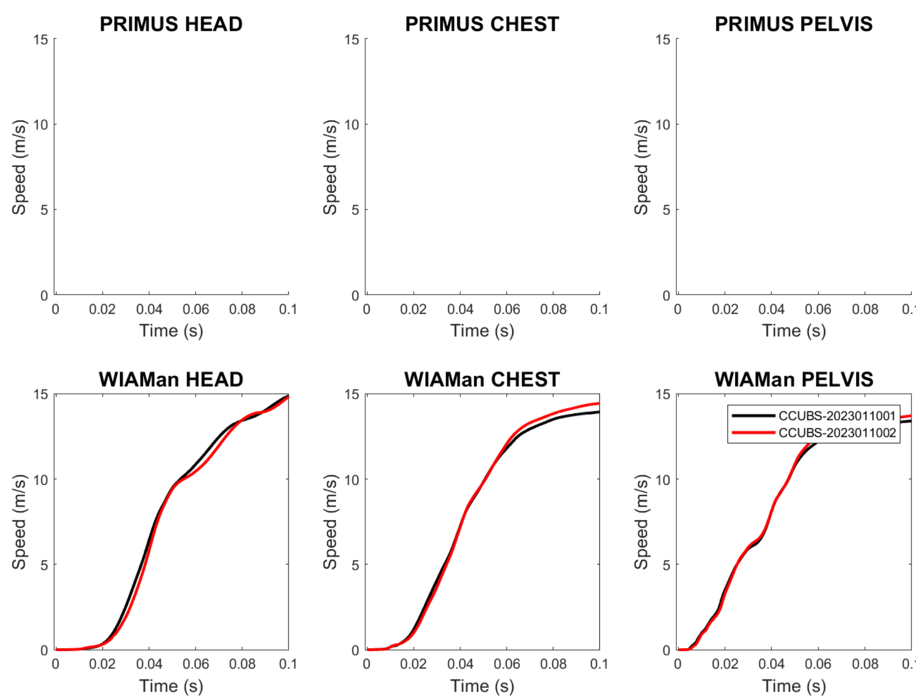

Figure 16 Dummy Body Segment Speeds speeds(350g)

Seat Stroke Considerations

For this series of tests, the seat occupied by PRIMUS appears to have been functioning inconsistently. This had a large effect on the dummy responses. Because of this, a strong comparison between PRIMUS and WIAMan is not possible, based on the data collected in this test series. As shown in Figure 17 below the PRIMUS seat exhibited very inconsistent behavior compared to the WIAMan seat and appears that the seat was only stroking about 75% the distance that the WIAMan seat was. This means that PRIMUS was being exposed to more of the input acceleration earlier than WIAMan, which resulted in higher peak pelvis speeds. This condition existed through the 250g tests when it was determined that the PRIMUS should be removed from the matrix to avoid potential damage to the dummy.

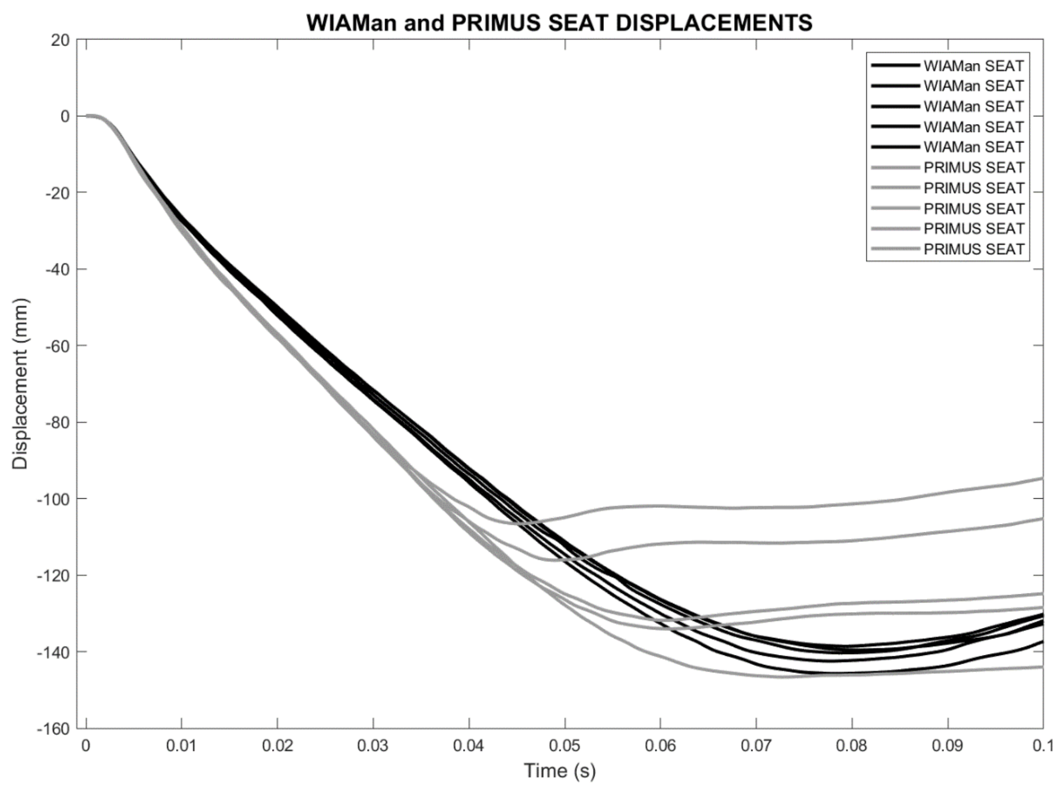

Figure 17 Comparisons of Seat Displacement (WIAMan/PRIMUS) from 150g tests

Figure 18 below shows a comparison for the 150g tests with the pelvis vertical speed (black) compared to the seat stroking speed (gray). In Figure 18 the PRIMUS data is on the left and WIAMan on the right. The dramatic difference in seat stroke and pelvis speeds for PRIMUS is obvious., the PRIMUS seat displaced faster and stopped stroking up to 1.5ms earlier than the WIAMan seat, this resulted in much higher PRIMUS peak vertical pelvis speeds as well as the remaining body segments of PRIMUS.

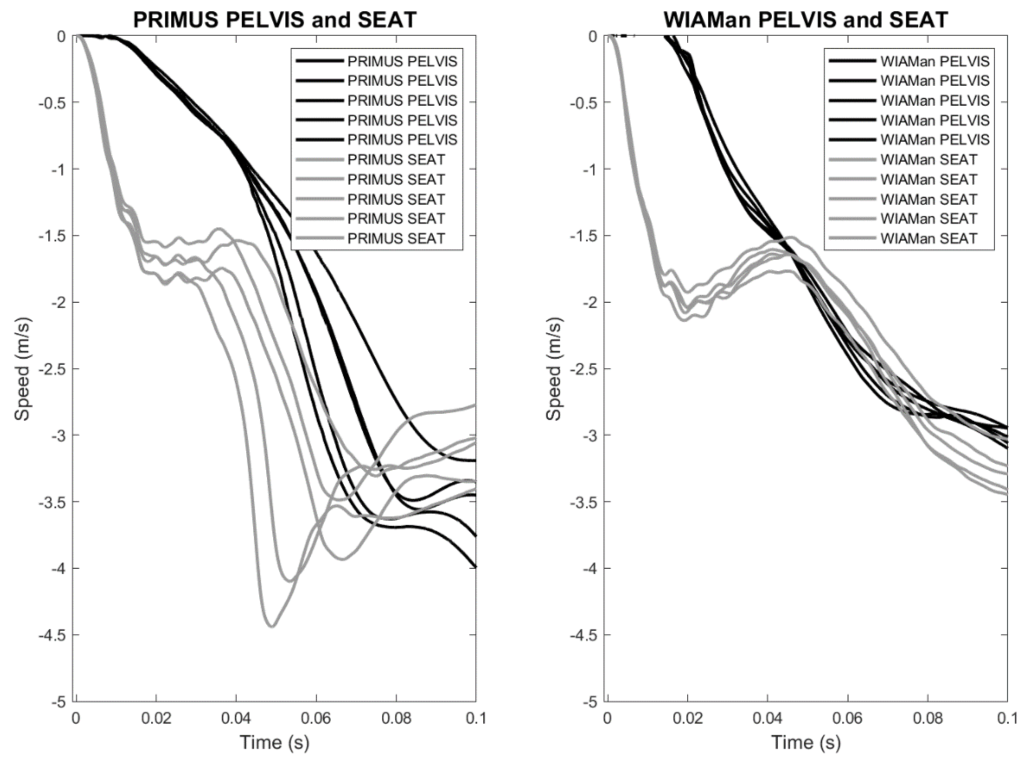

Figure 18 Comparisons Pelvis (black) and Seat (gray) Speeds (150g tests)

Comparison with Phase II Test Results

Since the seat for the PRIMUS dummy in these series of tests was performing in an erratic manner the data from PRIMUS could not be used to create a comparison. However, the PRIMUS data from the Phase II tests can be used, since both series were run under identical conditions, the PRIMUS data from that series is valid for comparison against the WIAMan responses.

To accomplish the comparison, continuous corridors were created from the average resultant body segment speeds of the WIAMan ATD head, chest, and pelvis. The corridors are the +/- standard deviation of the average response. For PRIMUS the average resultant body segment speed is plotted against the corresponding corridor.

Figure 19 below shows the results of the comparison. In general PRIMUS has very good agreement with WIAMan, with most responses staying within the corridors for 100ms. The PRIMUS response appears to be a little soft compared to WIAMan, and there are shape differences that are likely due to the difference in vertical stiffness between the two test dummies. The phase difference shown in Figure 19 is due to triggering mechanism differences.

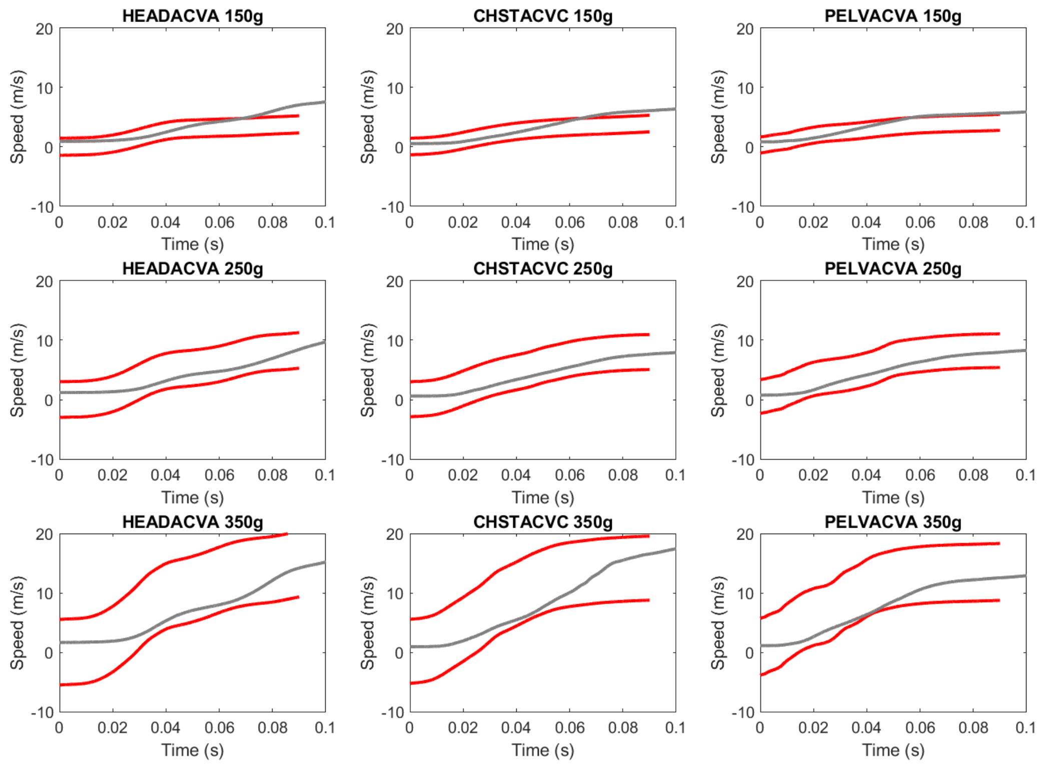

Figure 19 Average Body Segment Resultant Speed (PRIMUS) versus Speed Corridors (WIAMan)

CONCLUSION

A third phase of testing was conducted under CRADA 21-11 to examine the PRIMUS dummy response in an OPL environment. The Phase III testing goal was to compare the responses of PRIMUS with those of WIAMan under the same conditions as the Phase II tests with Hybrid III. However, the seat occupied by PRIMUS did not function consistently throughout this test series. This condition resulted in PRIMUS being removed from the test matrix after the 250g series tests had been ran. Additionally, the WIAMan seat changed behavior during the 350g series tests, resulting in that series being halted after two (2) of the five (5) scheduled tests were ran.

Despite seat problems the data collected in this series of tests was able to be used to compare PRIMUS responses in an OPL environment. PRIMUS responses were compared to WIAMan response corridors and showed that the average PRIMUS response lied within the +/- 1 standard deviation of the average WIAMan response. Phase and shape differences were minor and are the result of the different vertical stiffness of the two dummies, and triggering mechanism differences. Some of the phase differences in Figure 19 could be removed by adjusting the T=0 point in the data..

Based on the data collected during CRADA 21-11 PRIMUS faithfully produces kinematic data that is very close to Hybrid III and WIAMan. PRIMUS could be a lower cost alternative to either Hybrid III or, WIAMan for evaluative purposes. Currently there is no injury criteria available for PRIMUS, however those could be developed based on already collected data.

PRIMUS currently has no capability to measure loads to the skeletal structure, if that kind of capability were to become available that would increase the utility of PRIMUS. A load measuring capability could be reproduced in PRIMUS using the methods incorporated in the WIAMan development PMHS testing. In certain cadaver studies strain gage arrays were incorporated on the long bones of the legs of the PMHS in a manner that would allow calculation of loads at the gage locations.