**SHORT COMMUNICATION**
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# Warrior Injury Assessment Manikin Oblique Vertical Testing

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**ABSTRACT** – The Warrior Injury Assessment Manikin (WIAMan) was developed to assess injury in Live Fire Test and Evaluation (LFTE) and laboratory development tests of vehicles and vehicle technologies subjected to underbody blast (UBB) loading. While UBB events impart primarily vertical loading, the occupant location in the vehicle relative to the blast can result in some inherent non-vertical, or off-axis loading. In this study, the WIAMan Technology Demonstrator (TD) was subjected to 18 tests with a 350g, 5-ms time duration drop tower pulse using an original equipment manufacturer (OEM) energy attenuating seat in four conditions: purely vertical, 15° forward tilt, 15° rearward tilt, and 15° lateral tilt to simulate the partly off-axis loading of an UBB event. The WIAMan TD showed no signs of damage upon inspection. Time history data indicates the magnitude, curve shape, and timing of the response data were sensitive to the off-axis loading in the lower extremity, pelvis, and spine.

## INTRODUCTION

The US Military has encountered buried improvised explosive devices (IEDs) in vehicle attacks in the Iraq and Afghanistan combat operations (Alvarez, 2011). These underbody blast (UBB) events are characterized by high rate vertical acceleration into the underbody of the vehicle, resulting in severe loading to the occupants via the floor and seat. In 2011, Alvarez reported mounted Warfighter casualties suffered injuries to the foot/leg (26% wounded in action – 64% killed in action), pelvis (5-46%), and spine (45-65%), related to UBB loading. The Warrior Injury Assessment Manikin (WIAMan) was developed to more accurately assess mounted soldier injuries in UBB events and drive improved vehicle technologies.

UBB events can result in off-axis loading to the occupants due to varied locations of IED explosions beneath the vehicle, the shape and design of the underbody, and varied seating arrangements. To be considered a robust tool for use in UBB test and evaluation, the WIAMan anthropomorphic test device (ATD) must be durable and sensitive to off-axis loading. This study evaluated the response of the WIAMan Technology Demonstrator (TD) to 15° off-axis loads, simulating a vehicle occupant located away from the center of blast in various seat orientations. The TD is an early prototype of the WIAMan that, unlike the Generation 1 (Gen-1) version, does not utilize an in-dummy data acquisition system (DAS). Instead, all sensors are wired, which leads to a large bundle of cables exiting the ATD that must be properly restrained. The two versions are comparable in design and function.

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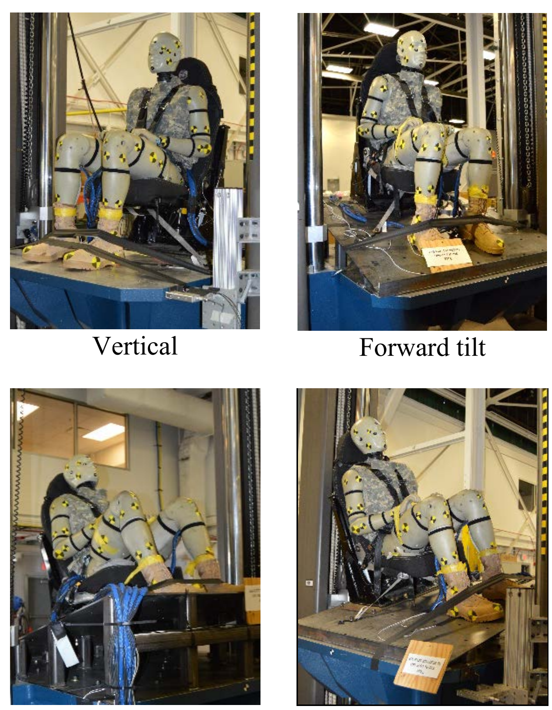
## METHODS

The WIAMan TD was tested using a drop tower with an original equipment manufacturer (OEM) active energy attenuating seat. Baseline tests were conducted in a purely vertical position. An angled platform, 15° from horizontal, was used to test forward, rearward, and lateral tilt positions, as shown in Figure 1. The seat is reusable and was inspected between tests for any signs of damage. A previous TARDEC test series demonstrated the ability to safely reuse the OEM seat at 15° angle drops.



Vertical | Forward tilt
Rearward tilt | Lateral tilt

Figure 1. Vertical and off-axis loading positions

Repeatable ATD position was achieved using a coordinate measuring machine (CMM) to set the hip-point, legs, and feet. Landmarks throughout the body were also recorded. Tape was used to hold the feet and hands in place during the drop and broke away upon impact. The ATD was subjected to a generic 350g, 5-ms time duration pulse developed to represent the initial blast phase of an UBB event (Arepally, et al., 2008). An example pulse is shown in Figure 2.

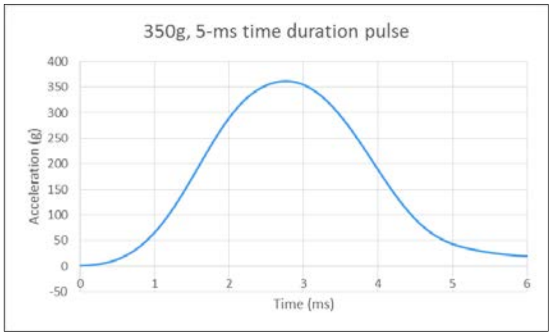



Figure 2. Drop tower pulse, vertical input condition

The series consisted of tests in each of the four positions, as shown in the test matrix in Table 1. The seat was mounted on the following floor conditions: purely vertical, forward tilt, rearward tilt, and lateral tilt (with the ATD's right side positioned lower). Two vertical tests were conducted to start the series and then five of each tilt. A final vertical test was conducted to conclude the series, however, loss of power to the seat damaged the energy attenuation mechanism. The intent of this test was to ensure the ATD and seat responded in the same manner as the original tests as a check for damage.

Table 1. Drop tower series test matrix

| Floor Position | Floor Angle | Number of tests |
|---|---|---|
| Flat | 0° | 2 |
| Forward tilt | 15° | 5 |
| Lateral tilt | 15° | 5 |
| Rearward tilt | 15° | 5 |
| Flat | 0° | 1* |

*seat damaged during test

## RESULTS

Seventeen successful tests were conducted. In test eighteen, the final test, the seat was damaged, preventing repeat tests in the flat condition. The damaged seat imparted a greater load onto the ATD and is worth noting with respect to WIAMan durability. A detailed inspection of the ATD revealed no damage after eighteen tests.

Response differences related to the seat positions were evident in both magnitude and timing of the spine, pelvis, and lower extremities. Representative plots from each seat position are shown in all axes for the lumbar spine in Figure 3-5. Figure 6 shows the Z-direction loading for the left tibia, and Figure 7 for the left heel.

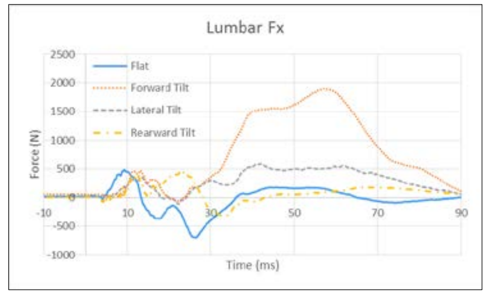



Figure 3. Representative plots of lumbar Fx

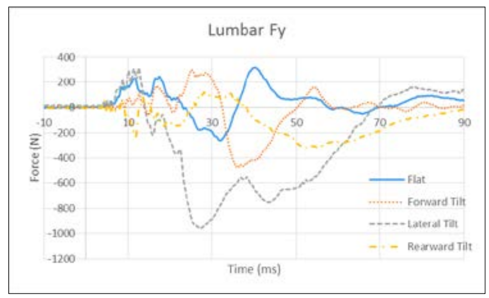



Figure 4. Representative plots of lumbar Fy

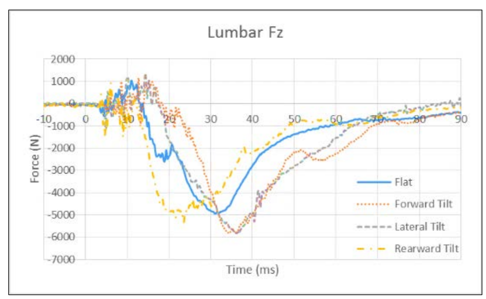



Figure 5. Representative plots of lumbar Fz

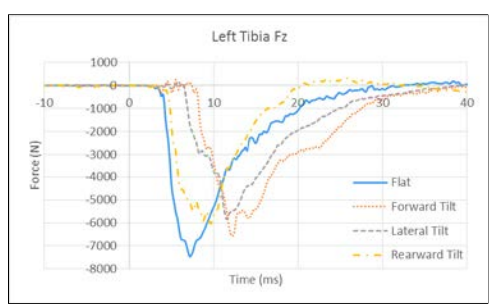



Figure 6. Representative plots of left tibia Fz

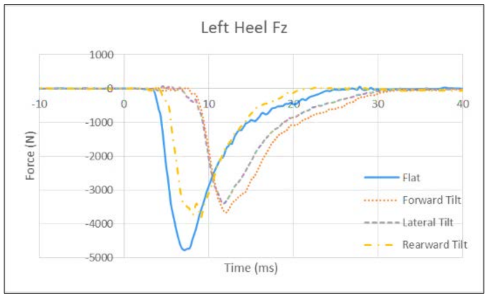



Figure 7. Representative plots of left heel Fz

## DISCUSSION

Despite the inability to repeat the purely vertical condition tests due to the damaged seat, the severity and quantity of tests show the WIAMan is durable in multiple UBB simulated drop tests. All 139 ATD channels were successfully collected throughout the test series with no evidence of damaged parts or unexpected part interferences. The data review did not reveal any anomalies such as flat lines, spikes, level shifts, or loading not matching the kinematics.

As the ATD was oriented at different angles, the forces and moment responses of the WIAMan TD changed in expected ways. Predictably, in the forward tilt there was a large increase in lumbar Fx (Figure 3) and in the lateral tilt there was a large increase in lumbar Fy (Figure 4). The lumbar Fz is greatest in the forward tilt, when the upper torso is the most vertically oriented (Figure 5). Because of the slightly reclined posture of the OEM seat, the flat and rear tilt are similar in magnitude, although shifted in time. In both the tibia and calcaneus forces, the vertical position has the greatest magnitude (Figure 6, Figure 7). The off-axis positions are all reduced by similar magnitudes. Given the same input, a 15° tilt of the load cell would be expected to reduce the Fz channel by multiplying by the cosine of 15°, with an equivalent increase to the Fx or Fy channel, depending on the position. The experimental measured forces changed in a similar fashion to this prediction.

While positioning was closely managed within each test condition, there were some variances. The feet exhibit a small amount of sliding forward or rearward on the angled platform in the video. This the likely cause for some of the variation in tibia and heel measured forces. Additionally, the lumbar forces in the forward tilt exhibit more variation than the other seat orientations. The forward tilt of the seat made it difficult to consistently position the torso and measure belt tension accurately.

This study is limited by the lack of an equivalent post mortem human surrogate (PMHS) test series to fully describe the levels of sensitivity an ATD would be expected to replicate with a 15° degree change in loading angle. Additionally, the WIAMan injury criteria have not yet been completed. These data should be reviewed once the injury criteria become available to determine the quantitative impact of off-axis loading on injury assessment measures. Since this study used the WIAMan TD, the ATD design was not the final version of the WIAMan and did not include in-dummy DAS. The functional design is similar enough to expect the off-axis sensitivity to be similar in the final WIAMan design, but this should be confirmed with the production ATD.

## CONCLUSION

This study was able to successfully evaluate the sensitivity of the WIAMan TD to small angle off-axis loading in a UBB simulated laboratory test. Because of varied inputs, seat locations, or underbody shape, off-axis loading is common in UBB events, therefore, this sensitivity to off-axis loading is desirable. Sensitivity to these varied conditions will support the WIAMan ATD's capability to properly assess injury responses in UBB events. Once injury criteria are fully available for production units of the WIAMan ATD, the quantitative impact of input angle on level of injury assessed can be studied. The absence of damage or data anomalies also provides confidence in the WIAMan response data to varied UBB inputs.

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