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Warrior Injury Assessment Manikin (WIAMan) Generation 1 Anthropomorphic Test Device (ATD) Positioning in Highly Reclined and Other Alternative Postures

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14. ABSTRACT
The initial Warrior Injury Assessment Manikin (WIAMan) project primarily focused on developing biofidelity response corridors and injury assessment risk curves associated with a reference seating environment that consisted of a vertical seat back, horizontal seat pan, and horizontal floor. Occupant posture consisted of an upright torso, level thighs, and 90° hip, knee, and ankle angles. This "90-90-90" posture and the associated seating condition were identified as the baseline seating environment for the Warfighter around which the WIAMan Generation 1 (Gen1) anthropomorphic test device (ATD) was designed. To determine if the initial design posture could be expanded, a series of tests was conducted positioning the WIAMan Gen1 in a reconfigurable seating environment capable of highly reclined seat-back angles. The goal of this test series was to determine at what angles, if any, nonbiofidelic behaviors emerge in the ATD across a range of reclined postures. Reclining the torso past the design posture was found to force the pelvis flesh to tilt up, making it difficult to match the targeted pelvis location point. Additionally, the ATD was unable to achieve the target Frankfurt plane angle tests with a 45° seat-back angle in the postures proposed. However, the WIAMan Gen1 was able to reproduce the mean posture within 1 standard deviation of the proposed targets for postmortem human surrogate (PMHS) testing for the majority of targets. This suggests that differences in ATD and PMHS posture are unlikely to impede a comparison of WIAMan Gen1 responses and PMHS injuries in matched pair analysis.

15. SUBJECT TERMS
Warrior Injury Assessment Manikin, WIAMan, Anthropomorphic Test Device, ATD, Under-Body Blast, Live Fire, Biomechanics

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1. Introduction

The initial Warrior Injury Assessment Manikin (WIAMan) project primarily focused on developing biofidelity response corridors (BRCs) and injury assessment risk curves (IARCs) associated with a reference seating environment that consisted of a vertical seat back, horizontal seat pan, and horizontal floor (Pietsch et al., 2016). Occupant posture consisted of an upright torso, level thighs, and 90° hip, knee, and ankle angles. This "90-90-90" posture and the associated seating condition were identified as the baseline warfighter seating environment for which the WIAMan Generation (Gen) 1 anthropomorphic test device (ATD) was designed. Although some variations in this condition were explored in tests aimed at BRC and IARC development (Zaseck et al., 2019), the biofidelity and injury assessment capability of the WIAMan Gen1 has not yet been assessed over the wide range of seating environments and associated warfighter postures that might exist in future fielded vehicles. For this reason, a series of ATD and postmortem human surrogate (PMHS) tests is being performed aimed at exploring the biofidelity and ability of the Gen1 WIAMan to assess injury in a wider range of warfighter seating environments.

Five representative seating conditions that use reclined seat-back angles and varied foot positions are under consideration for PMHS tests to be conducted at The Johns Hopkins University Applied Physics Laboratory (JHU/APL), University of Michigan Transportation Research Institute (UMTRI), and Wayne State University (WSU). However, the WIAMan Gen1 had not been positioned in the warfighter postures associated with these seating conditions, and initial simulations highlighted potential difficulties in simultaneously achieving the target torso, pelvis, and thigh angles for the most highly reclined of these postures. The series of tests described in this report, which involves positioning the WIAMan Gen1 in a reconfigurable seating environment capable of highly reclined seat-back angles, was performed to examine ATD positioning in the physical environment, given the caveats of using explicit finite-element modeling for a static loading event. Specific goals of this work were the following:

1. Define the range of reclined postures that the WIAMan Gen1 ATD can achieve, and identify any angles at which non-humanlike behaviors begin to occur (e.g., thighs lifting off the seat pan).
2. Determine if the WIAMan Gen1 can be positioned in the seating conditions proposed for PMHS testing and achieve body segment positions and orientations that are consistent with the distributions of body-segment positions and orientations associated with active warfighters in similar seated conditions.

2. Methods

Table 1 describes the four series of static positioning tests. All tests were conducted using a generic seat with planar representations of the seat pan and seat back, which could be reclined for rapid transition between seat-back angles. For postures with extended knees and alternative foot positions, a wedge was clamped in front of the foot to replicate the salient aspects of the geometry of the stirrup surrogate proposed for use in JHU/APL and WSU tests.

To identify the range of reclined postures that the WIAMan Gen1 ATD can achieve, a series of tests was performed in which the seat back was progressively reclined to increasing seat-back angles while the feet were positioned in a reference posture (90° knee angle, 90° ankle angle with the foot flat on the floor). This 90-90 reference posture is the baseline lower extremity posture used in previous PMHS tests (Reed and Rupp, 2015). The remaining three test conditions were intended to reproduce seating conditions and target postures intended to be used in PMHS tests conducted by UMTRI, JHU/APL, and WSU.

Table 1. Seat Conditions Investigated

Condition	Condition Description	Test Purpose
Progressive Recline	Progressive recline with simplified positioning	Assess range of motion
UMTRI Postures	45° and 22.5° seat back with lower extremities in 90-90 reference posture	Assess ability of WIAMan Gen1 to achieve target postures
JHU/APL Posture	0° seat back with pelvis, torso, and head in the WIAman design posture 15° femur angle, extended knees, and alterative foot posture	Assess ability of WIAMan Gen1 to achieve target posture
WSU Postures	45° and 22.5° seat back, 15° seat pan with extended knees and alterative foot posture	Assess ability of WIAMan Gen1 to achieve target postures

During these positioning experiments, the position of the WIAMan Gen1 was defined using the angles of the Frankfurt plane, pelvis, femur, knee, and foot, as well as the distance of the neck bracket rearward of the hip joint center. These measurements were selected because they can be related to measurements of seated warfighter postures in the previous UMTRI studies and the corresponding posture targets for PMHS tests (Reed and Ebert, 2020; Reed & Ebert, 2013). The Frankfurt plane angle, which was defined based on the orientation of the landmarks on the Gen1 headform relative to horizontal, is shown in Figure 1. The distance between the hip joint center and a posterior landmark on the neck block used to define torso posture is shown in Figure 2. The pelvis angle was measured using landmarks on the Gen1 lateral pelvis flesh and reported relative to horizontal, as shown in Figure 3. The femur angle was the elevation angle of the line connecting the hip joint and knee joint centers relative to horizonal, as shown in Figure 4. Finally, the knee angle was defined as the included angle between hip center, knee bolt, and lateral malleolus, as shown in Figure 5. For these tests, a coordinate measurement machine (CMM) (FARO, Lake Mary, Florida) was used to record the locations of ATD landmarks that define position and body segment angles. Additionally, sensor data were recorded during the progressive recline tests. However, sensor responses are being further analyzed and are not reported here.

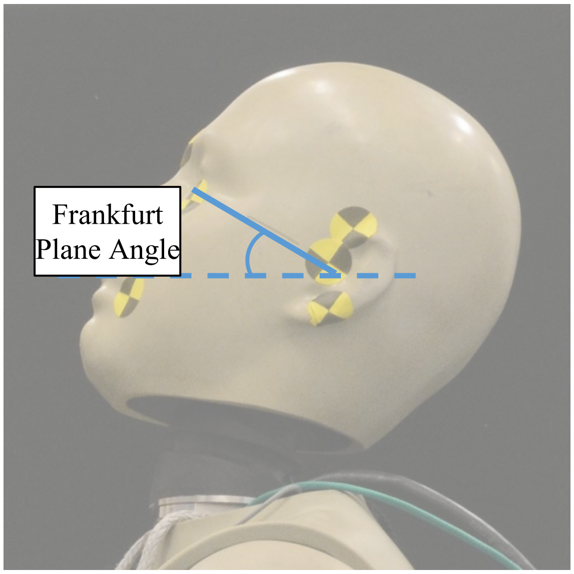

Figure 1. Frankfurt plane measurement

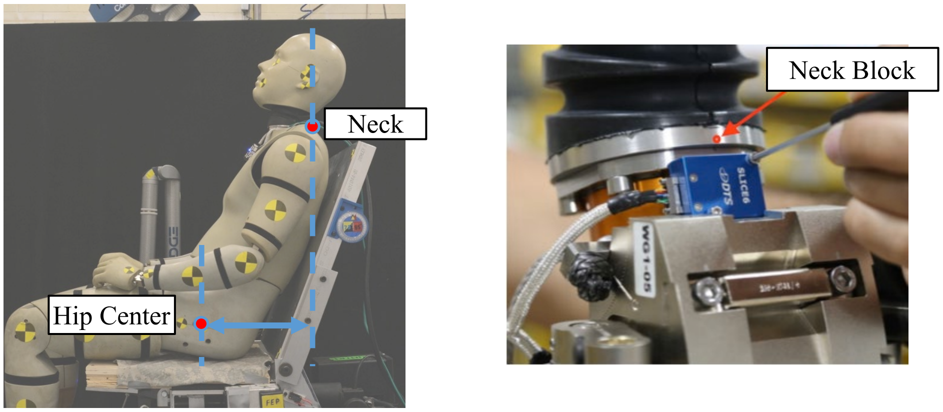

Figure 2. Torso posture definition (distance of neck bracket rearward of hip center)

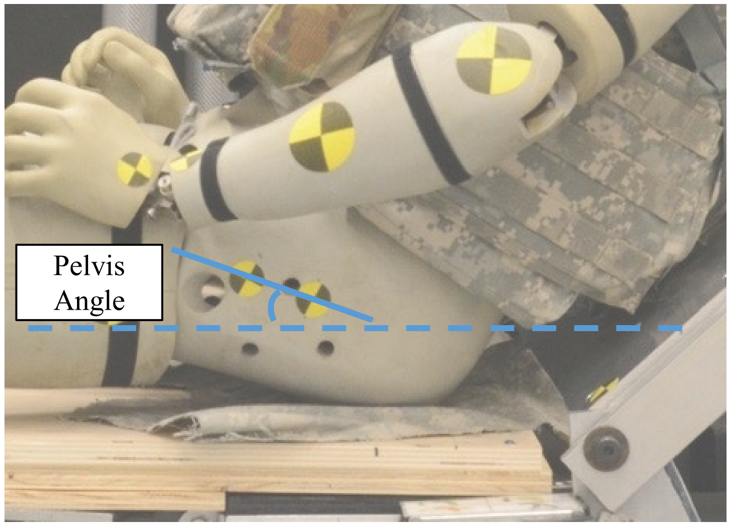

Figure 3. Pelvis angle measurement

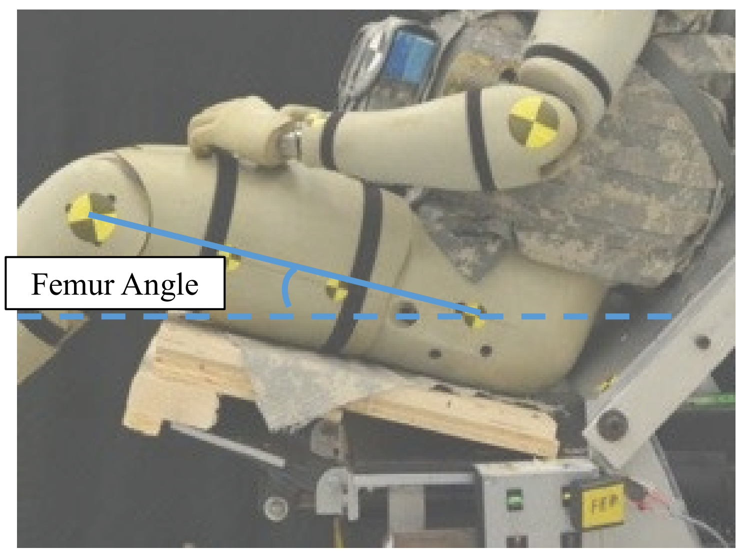

Figure 4. Femur angle measurement

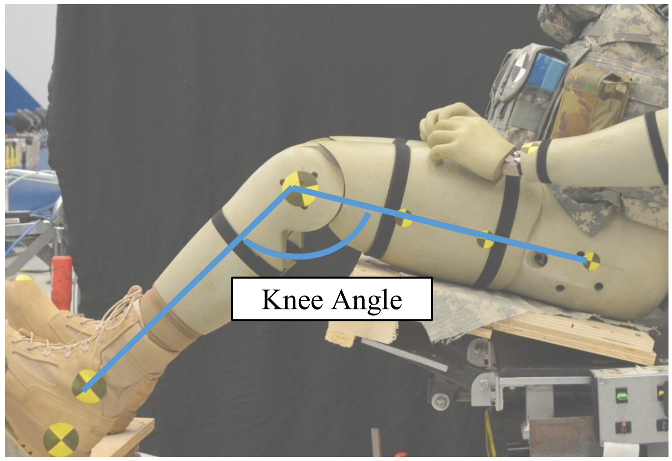

Figure 5. Knee angle measurement

Tests aimed at exploring the range of recline postures that the WIAMan Gen1 can achieve were initially performed with torso cables that serve to limit thorax extension installed. These tests were subsequently repeated without the torso cables, and a comparison of ATD postures with and without the torso cables at seat-back angles varying from 0° to 50° is provided. Figure 6 illustrates these cables.

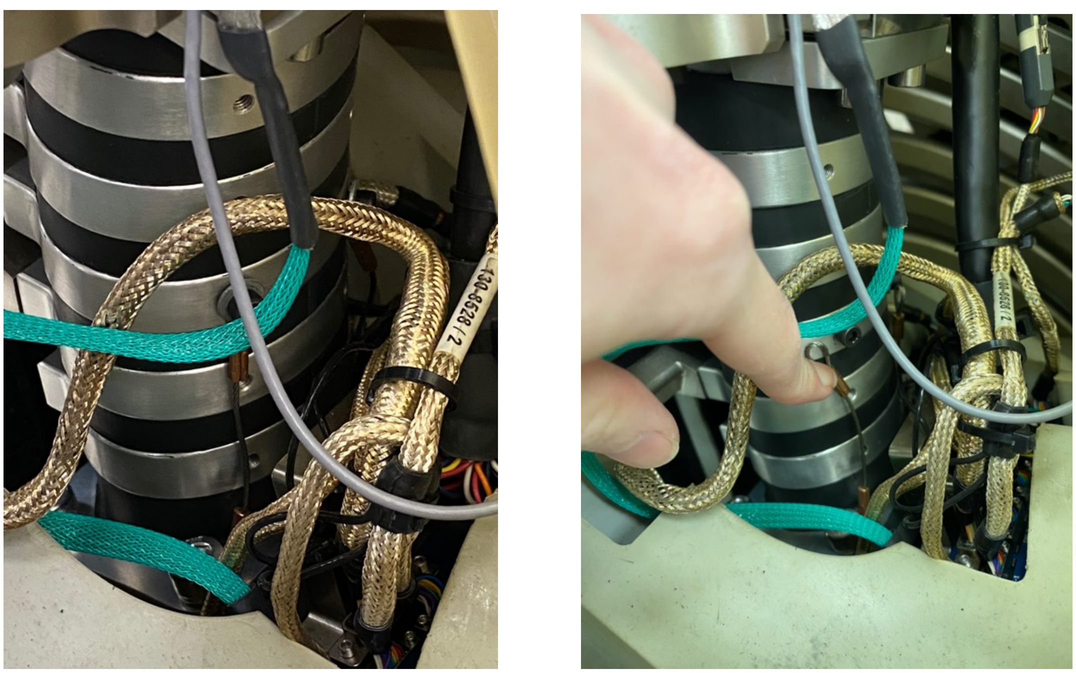

Figure 6. Torso cable as installed (left) and detached (right)

3. Progressive Recline Tests

To explore its range of motion, the WIAMan Gen1 was progressively reclined to increasing torso angles using the following procedure:

1. Position the WIAMan Gen1 in the design torso posture 90-90 lower extremity posture using a 0° (vertical) seat back. Collect 3-D locations of the heel, ankle, knee bolt, hip center, neck block, Frankfurt plane, and head center of gravity (CG) using a CMM.
2. Recline the seat back to 10°, and hold legs down while pushing torso back into the seat. Once the ATD is in contact with the seat back, release the torso. Collect 3-D CMM data.
3. Repeat Step 2 for 20°, 30°, 40°, and 50° seat back.

These tests were conducted with and without personal protective equipment (PPE), and with and without the torso cables attached, for a total of four trials.

4. UMTRI Posture Tests

For tests in the UMTRI posture (22.5° or 45° seat back, and lower extremities in the 90-90 reference posture; Figure 7), positioning targets for the hip location, pelvis angle, distance of the neck bracket rearward of hip joint center, and Frankfurt plane angle were derived based on data collected from Soldiers seated in reclined seating postures (Reed & Ebert, 2020). Targets were determined based on these data and are listed with their residual standard deviations in Table 2. The seat height was adjusted as needed to achieve a horizontal femur angle. These tests were conducted with PPE installed and the torso cables disconnected from the WIAMan Gen1 thoracic spine. Additionally, a seat index point (SIP) measurement tool was used to define the SIP, which was used as a reference for the WIAMan Gen1 target hip location. The target fore–aft ATD hip location was defined as 14.5 mm forward of the SIP, while the vertical position was defined as hip center at 5 mm below the SIP. The pelvis angle for a human is measured from the pubic symphysis to the mid-anterior superior iliac spine (ASIS) (i.e., the midpoint between the left and right ASIS) relative to vertical, while the WIAMan Gen1 pelvis angle is measured from an impression on the flesh relative to horizontal. To develop a relationship between WIAMan Gen1 and PMHS pelvis angles, an assumption was made that the ATD pelvis angle in the design posture (Reed, 2013) is equivalent to the human pelvis angle in the same posture.

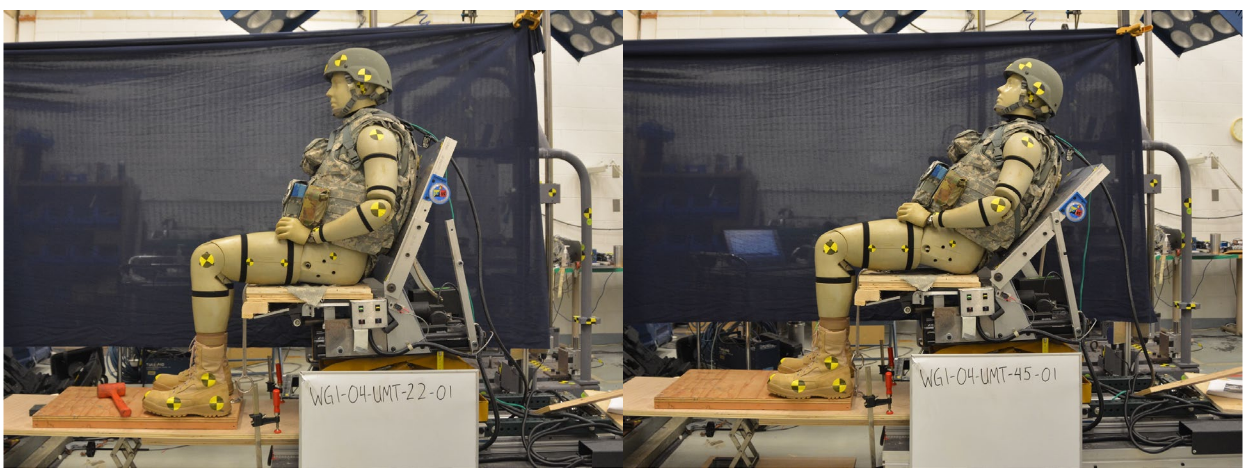

Figure 7. Test setups from 22.5° seat back (left) and 45° seat back (right) conditions with neutral lower extremity

Table 2. Target Positioning Values for UMTRI Posture Tests

Measurement	Target	
	22.5˚ Seat-Back Angle	**45˚ Seat-Back Angle**
Hip Forward of SIP	14.5 mm	14.5 mm
Pelvis Angle	4.4 ± 5°	14.7 ± 5°
Neck Aft of Hip	175.5 ± 10 mm	333 ± 10 mm
Femur Angle	0°	0°
Knee Angle	90°	90°
Frankfurt Angle	0 ± 6.1°	11 ± 6.1°
Patella distance	295 mm	295 mm

5. JHU/APL Posture Tests

Table 3 provides the positioning targets for JHU/APL tests, which use a 0° seat-back angle with the head, torso, and pelvis in the design posture, a 15° femur angle, extended knees, and alternative foot position. Torso position/posture targets for tests in the JHU/APL posture are based on the WIAMan Gen1 design posture (Reed et al., 2013). The lower extremity posture for these tests was defined using prescribed knee, femur, and ankle angles, with the lateral spacing between knees and feet from the PMHS posture knee spacing (Reed and Rupp, 2015). Tests were performed with PPE installed prior to ATD positioning and torso cables removed.

Table 3. Target Positioning Values for a 0° Seat Back with Extended Knees

Measurement	Target[a]
Hip X Forward of Seat Back	240 ± 10 mm
Neck Block Forward of Seat Back	176 ± 10 mm
Head CG Forward of Seat Back	232 ± 10 mm
Pelvis Angle	0 ± 5°
Femur Angle	15°
Knee Angle	120°
Frankfurt Angle	0 ± 6.1°
Patella Distance	295 ± 10 mm

[a] Tolerances based on allowable error in PMHS positioning.

The inclined position of the femurs in the JHU/APL tests produced interference between the thigh flesh and the Improved Outer Tactical Vest (IOTV) mass surrogates, as shown in Figure 8. This interference prevented the target femur angle from being achieved without sacrificing lateral spacing. Therefore, tests were performed using two lower extremity postures: 1) knees maintained at the designed lateral knee spacing and a reduced femur incline, and 2) with the femurs at the targeted 15° angle from horizontal, as shown in Figures 9 and 10.

Figure 8. Interference of thigh flesh with IOTV mass surrogates

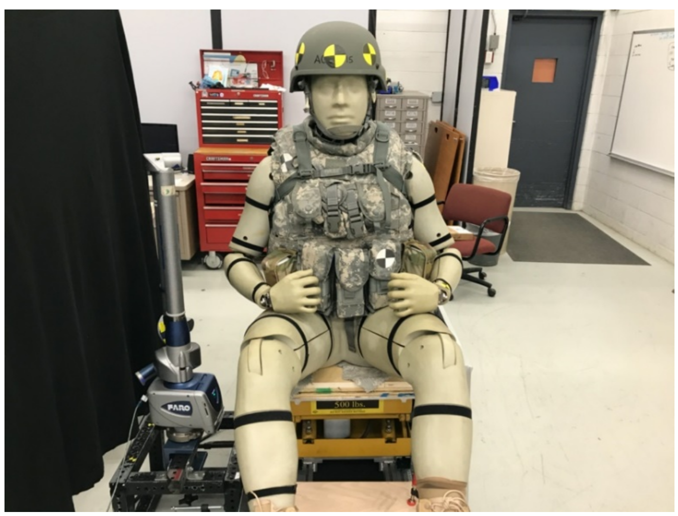

Figure 9. Front view of JHU/APL posture allowing for knee splay

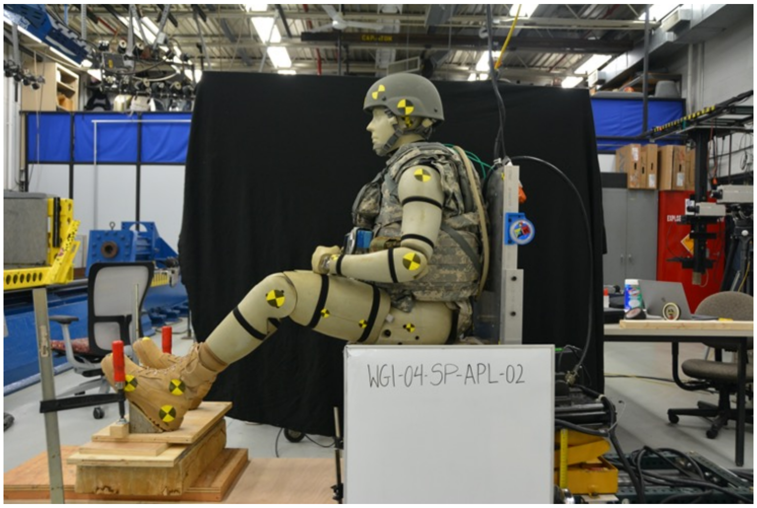

Figure 10. 0° seat back with extended knees (torso cables detached)

6. WSU Posture Tests

Table 4 provides target positioning values for the 45° seat-back angle and 15° seat-pan angle with extended knees condition (WSU posture). Hip and torso posture targets were similar to those used in tests in the UMTRI posture with the exception of the vertical target for the ATD hip location, which was not used due to the seat pan incline. Lower extremity posture targets were defined using the prescribed angles, and lateral spacing was maintained from the WIAMan Gen1 design posture. Tests were conducted with PPE installed prior to ATD positioning and the torso cables removed, as shown in Figure 11.

Table 4. Target Positioning Values for WSU Tests: 22.5° or 45° Seat Back with 15° Seat Pan with Extended Knees

Measurement	Target ± Standard Deviation	
	22.5° Seat-Back Angle	**45° Seat Back Angle**
Hip Forward of SIP	14.5 mm	14.5 mm
Pelvis Angle	4.4 ± 5°	14.7 ± 5°
Neck Aft of Hip	175.5 ± 10 mm	333 ± 10 mm
Femur Angle	15°	15°
Knee Angle	120°	120°
Frankfurt Angle	0° ± 6.1°	11 ± 6.1°
Patella Distance	295 ± 10 mm	295 ± 10 mm

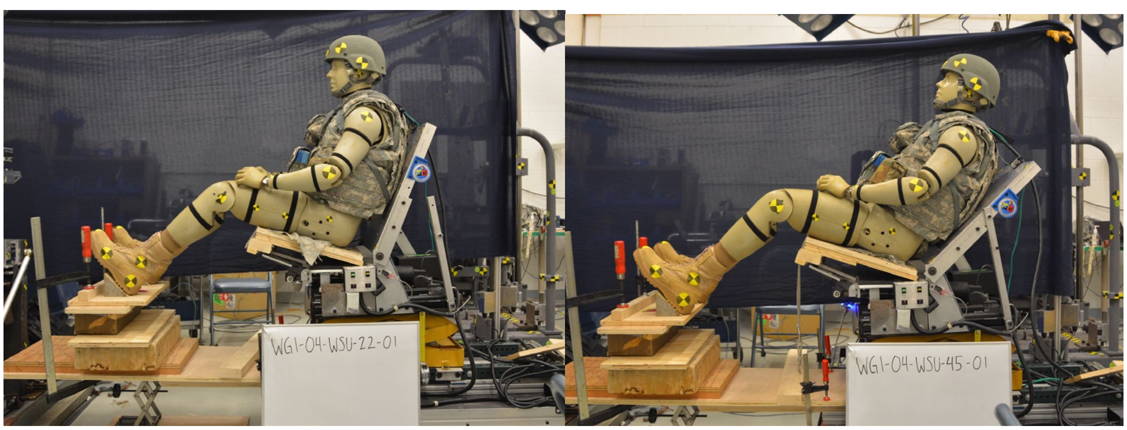

Figure 11. Test setups from 22.5° seat-back condition (left) and 45° seat-back (right) condition with extended knees

7. Results

7.1 Progressive Recline Tests

Body-segment angles measured in the progressive recline tests designed to assess WIAMan Gen1 range of motion are shown in Tables 5 and 6 for tests with the torso cables attached without and with PPE, respectively. Joint and body-surface-landmark locations for each of the test conditions with and without PPE are shown in Figure 12. Tables 7 and 8 and Figure 13 show similar measurements with the torso cables removed. For all tests, the neck bracket was in the full forward position prior to achieving the Frankfurt angle that matched the seated Soldier condition as close as possible.

Figure 14 illustrates that torso cables did not meaningfully affect the relationship between pelvis and torso orientation. Coupled with the similarity in measurements between Tables 5 and 7 and Tables 6 and 8, this indicates that the torso cables had minimal effect on the postures achieved by the ATD when positioned in a similar seating configuration across a range of seat-back angles.

Table 5. Posture Measurements in Progressive Recline Tests without PPE and with Torso Cables Attached

No PPE, Torso Cables Attached						
Seat-Back Angle (deg)	0	10	20	30	40	50
Neck Bracket Aft of Hip (mm)	66	166	263	350	428	492
Pelvis Angle (deg wrt nominal)	0.8	7.7	12.6	16.6	18.8	21.0
Femur Angle (deg wrt horiz)	0.2	1.1	2.0	2.7	3.1	3.3
Frankfurt Angle (deg)	1.2	12.4	26.1	39.0	54.5	66.9

Note: wrt = with regard to

Table 6. Posture Measurements in Progressive Recline Tests with PPE and with Torso Cables Attached

With PPE, Torso Cables Attached						
Seat-Back Angle (deg)	0	10	20	30	40	50
Neck Bracket Aft of Hip (mm)	81	157	240	314	384	424
Pelvis Angle (deg wrt nominal)	0.35	6.1	12.0	15.5	17.8	19.3
Femur Angle (deg wrt horiz)	0.1	1.1	1.7	2.4	2.7	2.8
Frankfurt Angle (deg)	4.8	15.1	25.5	36.6	51.2	61.0

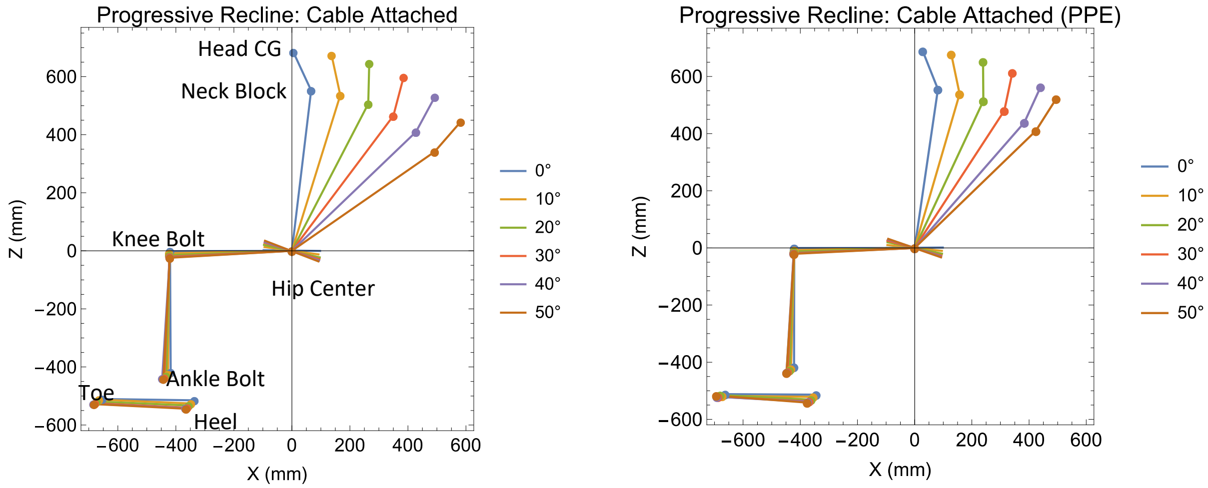

Figure 12. Body segment orientations in progressive recline tests with the torso cable attached without PPE (left) and with PPE (right)

Table 7. Posture Measurements in Progressive Recline Tests without PPE and with Torso Cables Detached

No PPE, Torso Cables Detached						
Seat-Back Angle (deg)	0	10	20	30	40	50
Neck Bracket Aft of Hip (mm)	66	166	263	350	428	492
Pelvis Angle (deg wrt nominal)	0.8	7.7	12.6	16.6	18.8	21.0
Femur Angle (deg wrt horiz)	0.2	1.1	2.0	2.7	3.1	3.3
Frankfurt Angle (deg)	1.2	12.4	26.1	39.0	54.5	66.9

Table 8. Posture Measurements in Progressive Recline Tests with PPE and with Torso Cables Detached

PPE, Torso Cables						
Seat-Back Angle (deg)	0	10	20	30	40	50
Neck Bracket of Hip (mm)	81	157	240	314	384	424
Pelvis Angle (deg wrt nominal)	0.4	6.1	12.0	15.5	17.8	19.3
Femur Angle (deg wrt horiz)	0.1	1.1	1.7	2.4	2.7	2.8
Frankfurt Angle (deg)	4.8	15.1	25.5	36.6	51.2	61.0

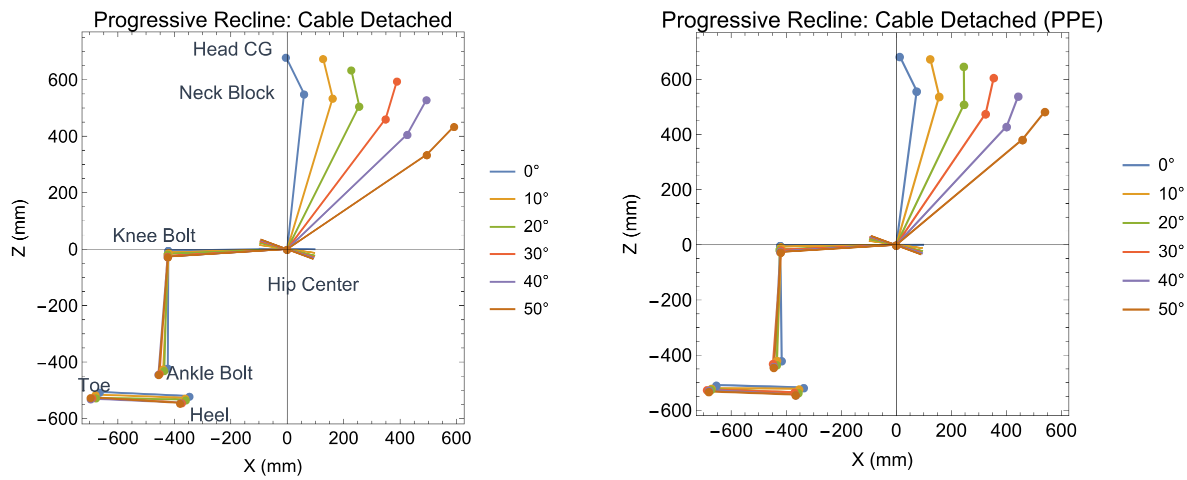

Figure 13. Body-segment orientations in progressive recline tests with the torso cable detached without PPE (left) and with PPE (right)

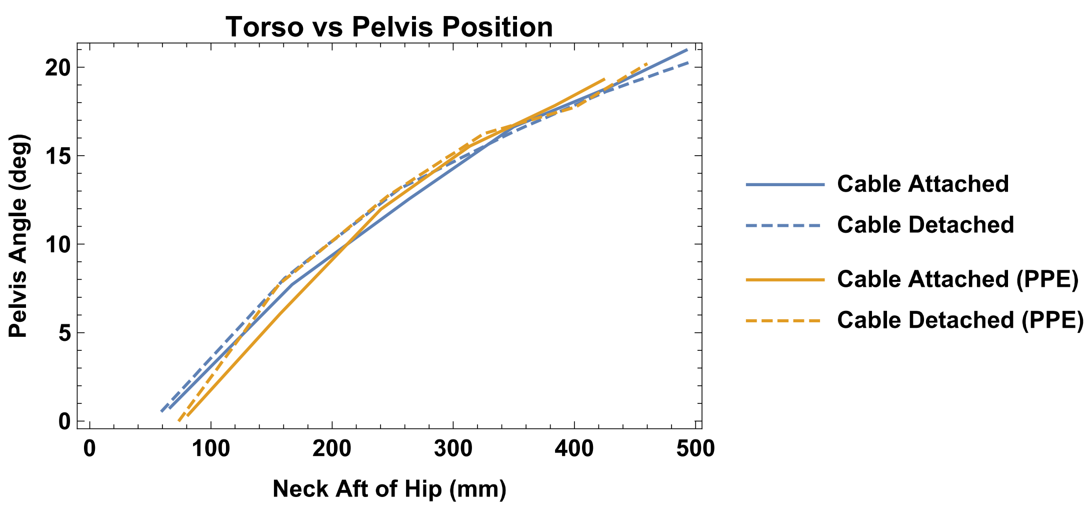

Figure 14. Effect of torso cable on posture with and without PPE

7.2 UMTRI Posture Tests

The results from positioning the WIAMan Gen1 in the UMTRI test condition with a 22.5° seat-back angle are compared with reclined human targets in Table 9 and Figure 15. Table 10 and Figure 16 provide similar information and comparisons for the postures with a 45° seat-back angle. All of the measurements were within the target plus-or-minus standard-deviation range, with the exception of the Frankfurt plane angle for the 45° back angle, which was inclined approximately 15° above the target and approximately 9° above the upper bound on the target.

Table 9. Measurements from UMTRI Posture Tests with 22.5° Seat Back (Torso Cables Detached)

Measurement	UMTRI 22.5°	Target
Hip Forward of SIP	46.7 mm	14.5 mm
Pelvis Angle	5.3°	4.4 ± 5°
Neck Aft of Hip	175.5 mm	175.5 ± 10 mm
Femur Angle	0.7°	0°
Knee Angle	88.7°	90°
Frankfurt Angle	0.2°	0° ± 6.1°
Patella Distance	294.7 mm	295 ± 10 mm

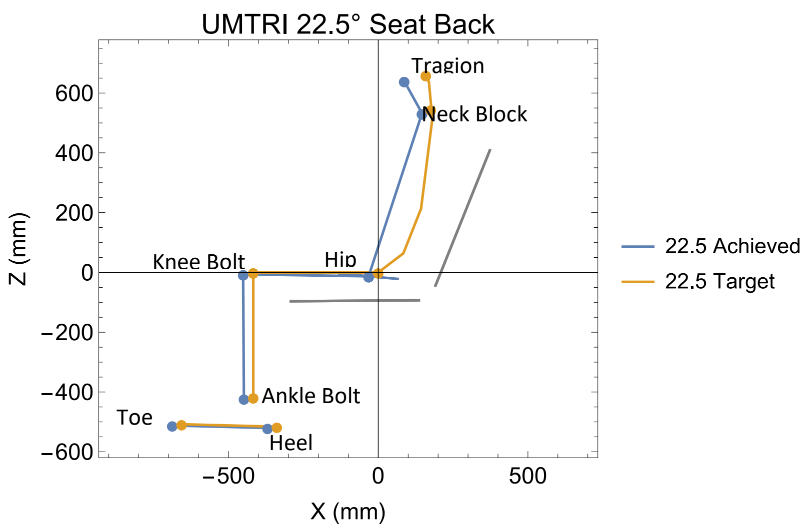

Figure 15. Target (human) vs. ATD position and posture in 22.5° back angle (torso cables detached)

Table 10. Measurements from UMTRI Posture Tests with 45° Seat Back Angle (Torso Cables Detached)

Measurement	UMTRI 45˚	Target
Hip Forward of SIP	23.0 mm	14.5 mm
Pelvis Angle	15.9°	14.7 ± 5°
Neck Aft of Hip	335.8 mm	333 ± 10 mm
Femur Angle	0.4°	0°
Knee Angle	89.4°	90°
Frankfurt Angle	25.9°	11 ± 6.1°
Patella Distance	286.9 mm	295 ± 10 mm

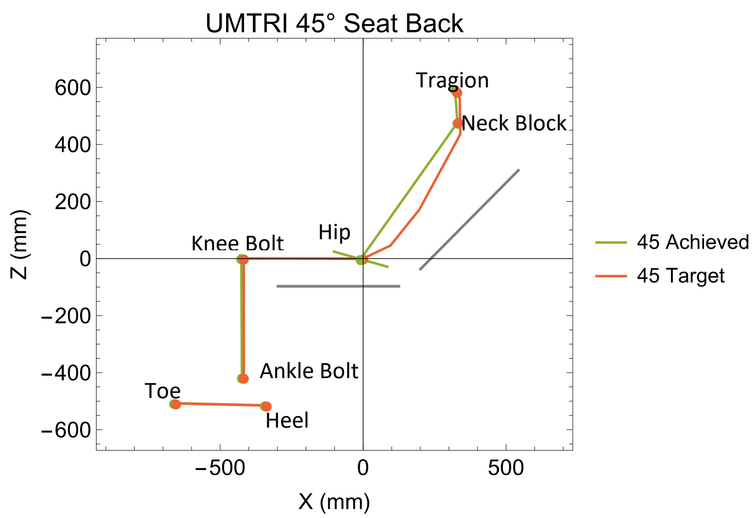

Figure 16. Target (human) vs. ATD position and posture in 45° back angle (torso cables detached)

7.3 JHU/APL Posture Tests

The results from tests conducted in the JHU/APL posture (0° seat back with 15° target femur angle and extended knees) are shown in Table 11. Contact between the seat back and IOTV prevented the target fore–aft ATD hip location from being achieved.

Table 11. Measurements from JHU/APL Posture Tests (Torso Cables Detached)

Measurement	APL-01 (295-mm lateral spacing)	APL-02 (knee splay)	Target
Hip X Forward of Seat Back	263.7 mm	262.6 mm	240 ± 10 mm
Neck Block Forward of Seat Back	222.9 mm	217.6 mm	176 ± 10 mm
Head CG Forward of Seat Back	283.2 mm	276.7 mm	232 ± 10 mm
Pelvis Angle	2.2°	1.4°	0 ± 5°
Femur Angle	8.1°	15.4°	15°
Knee Angle	123.6°	123.3°	120°
Frankfurt Angle	2.5°	2.1°	0 ± 6.1°
Patella Distance	305.9 mm	418.8 mm	295 ± 10 mm

7.4 WSU Posture Test

The results from the test in which the Gen1 was positioned in the postures proposed for WSU tests (22.5° and 45° seat-back angles, and 15° seat pan with extended knees and alternative foot position) are shown in Table 12 and Figure 17 for the 22.5° seat-back angle and Table 13 and Figure 18 for the 45°seat-back angle. Like static posture tests in the UMTRI condition with a 45° seat-back angle, the Frankfurt plane was approximately 15° more inclined than the midpoint of the target for WSU tests with a 45° seat-back angle. WSU static posture tests in both the 22.5° and 45° seat-back angle conditions had pelvis angles that were more reclined than the human target. This is likely because the buttock contour of the Gen1 is fairly flat and the pelvis and thigh flesh are stiffer quasi-statically than human flesh, causing the entire pelvis to tilt rearward more in the ATD than the human as the seatpan angle is increased.

Table 12. Measurements from WSU Posture Tests with 22.5° Seat Back (Torso Cables Detached)

Measurement	WSU 22.5	Target
Hip Forward of SIP	80.6 mm	14.5 mm
Pelvis Angle	14.2°	4.4 ± 5°
Neck Aft of Hip	182.1 mm	175.5 ± 10 mm
Femur Angle	15.2°	15°
Knee Angle	120.7°	120°
Frankfurt Angle	–1.0°	0 ± 6.1°
Patella Distance	300.9 mm	295 ± 10 mm

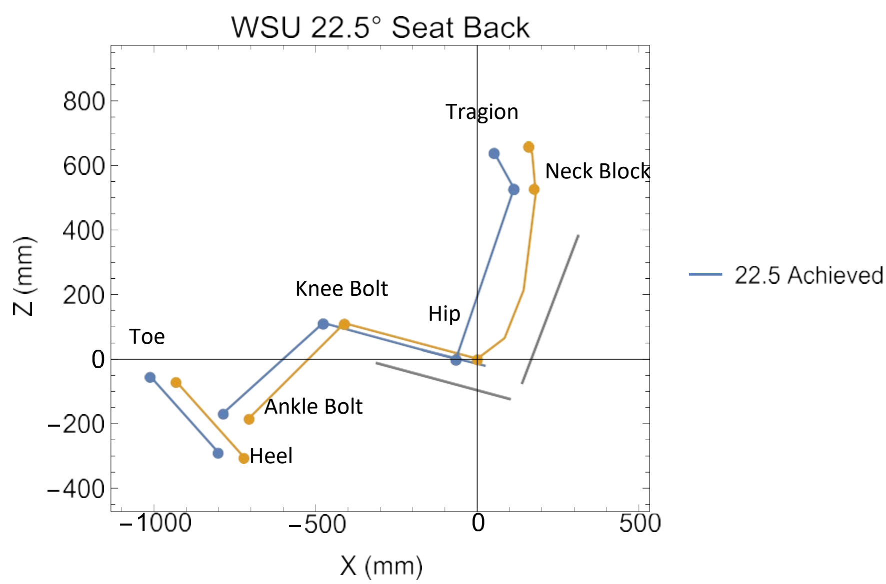

Figure 17. Target (human) vs. ATD position and posture in 22.5° seat-back angle

Table 13. Measurements from WSU Posture Tests with 45° Seat Back (Torso Cables Detached)

Measurement	WSU 45° Seat Back	Target
Hip Forward of SIP	67.6 mm	14.5 mm
Pelvis Angle	25.4°	14.7 ± 5°
Neck Aft of Hip	342.7 mm	333 ± 10 mm
Femur Angle	15.5°	15°
Knee Angle	120.8°	120°
Frankfurt Angle	25.9°	11 ± 6.1°
Patella Distance	298.7 mm	295 ± 10 mm

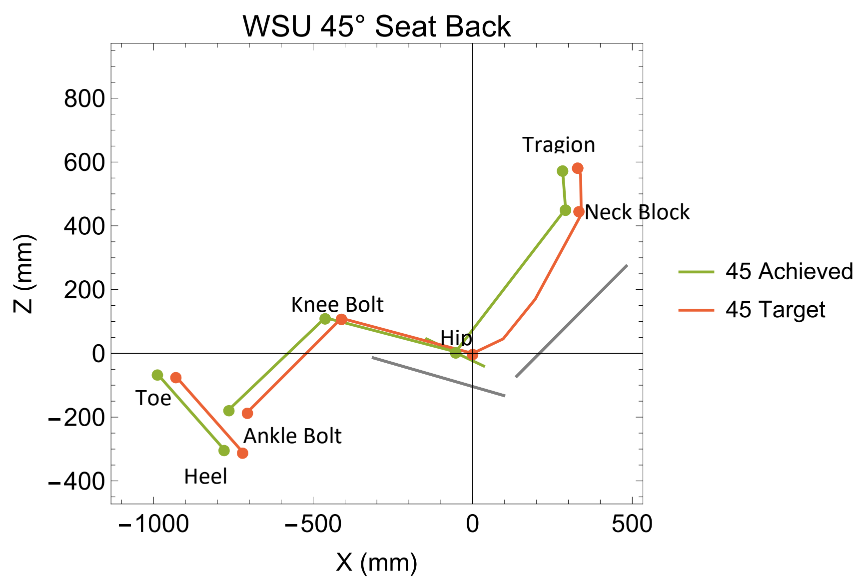

Figure 18. Target (human) vs. ATD position and posture in 45° back angle (torso cables detached)

8. Conclusion and Discussion

This study characterized the ability of the WIAMan Gen1 to be positioned in seats with highly reclined back angles and in humanlike postures in the seating environments proposed for an upcoming series of PMHS tests. Results of tests in which the torso angle of the WIAMan Gen1 was progressively reclined indicate the ATD is able to achieve a range of reclined torso angles up to 50° from vertical, both with and without PPE if given several minutes for the material of the spine to relax. However, the results of these same tests show that at some point between 20° and 30° of torso recline it is no longer possible for the Frankfurt plane to remain level, even when the full range of approximately 15° of adjustment provided by the neck bracket is employed. Results in tests where the Gen1 ATD was positioned in the UMTRI and WSU test conditions with a 45° seat-back angle confirm that for highly reclined postures it is not possible to achieve a humanlike orientation of the Frankfurt plane.

Reclining the torso past the design posture also causes the pelvis flesh to tilt up as shown in Figure 19. This tilt is presumed to increase sacrum loading and the proportion of seat load that goes into the pelvis, as direct loading of much of the pelvis flesh is reduced.

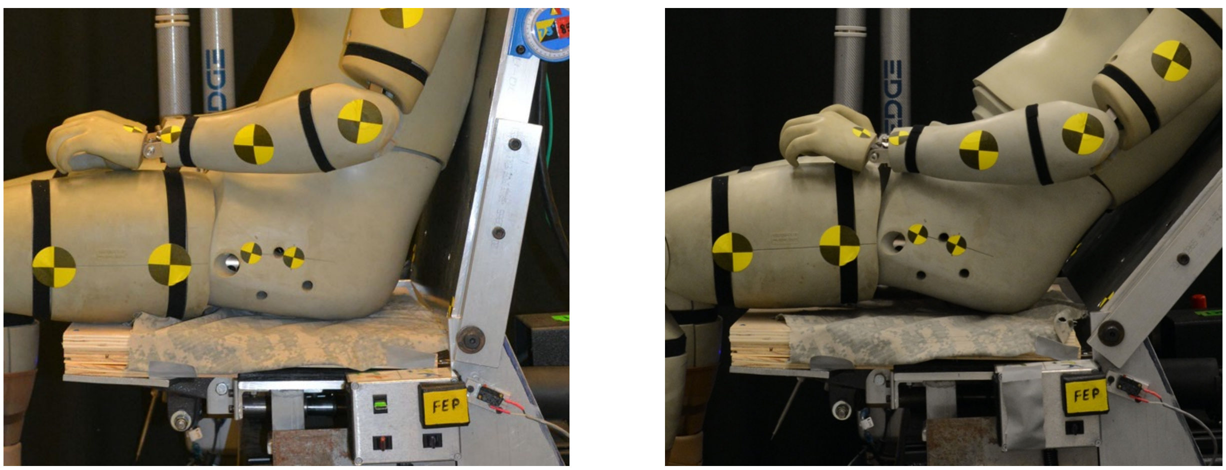

Figure 19. Pelvis flesh tilting up with torso recline at (left) 10° and (right) 40° seat-back recline

Results of tests where the WIAMan Gen1 was positioned in seating conditions proposed for an upcoming series of PMHS tests involving highly reclined torso angles and alternative foot postures indicate the WIAMan Gen1 was generally able to achieve body-segment orientations within 1 standard deviation of those expected for seated warfighters in similar seating environments. Exceptions to this include the following:

- The ATD was unable to achieve the target Frankfurt plane angle tests with a 45° seat-back angle in the postures proposed for UMTRI and WSU tests in this condition.
- There was interference between the thigh and IOTV in tests in the JHU/APL posture (0° seat back with a thigh elevation target of 15°).

- The pelvis angle in the WSU test conditions was more reclined than the corresponding human targets.

The difference between ATD and human Frankfurt plane angles in highly reclined tests suggests the human head's CG will be more forward relative to the base of the neck (C7/T1 joint center) than the ATD head's CG. This will change the forces and moments produced in the neck and may affect the validity of IARCs based on force and moment in the c-spine. Future modeling studies may be needed to explore and quantify this effect.

The inability of the WIAMan Gen1 with PPE to achieve a 15° femur angle while maintaining the target 295-mm lateral spacing of the lower extremities for tests in the JHU/APL condition suggests that leg splay may need to be added in these conditions. Alternatively, the addition of masking or other breakaway tape could be used to hold the knees in the target position prior to the initiation of loading. This is a technique commonly used for PMHS tests and could also be applied to assist with positioning of the ATD. Note that subsequent to the tests described in this report, JHU/APL was able to achieve a 15° femur angle in a matched pair test with a vertical seat-back angle by varying PPE fit.

The ATD pelvis angles in the WSU posture that were more reclined than targets are likely a result of the stiffer ATD flesh and the flat buttock contour, which allows the angled seatpan to have more influence on pelvis tilt than is expected for a seated Soldier. The effects of this more-reclined pelvis angle on predicted forces and load in the WSU test conditions should be explored in simulation.

In the 45° reclined postures, it was noted that the interaction of the pelvis flesh with the thigh flesh causes the thigh to lift up as the pelvis rotates rearward. In most cases, this can be mitigated by adjusting the height of the seat to bring the thigh back to horizontal. However, this causes the pelvis to rotate slightly farther forward.

Additionally, it was noted the position of the pelvis relative to the seat, as recorded in the SIP measurements, was consistently forward from the targets for all positions. This was determined to be a function of the molded shape of the pelvis, which was designed to the 90-90 seated posture and did not conform to the reclined angles tested. While the shape of the pelvis affected the position relative to the seat, and thus the location of the other target points, these locations achieved a better match to the target locations. Future work could look at additional modifications to the pelvic flesh to accommodate these reclined positions.

The ability of the WIAMan Gen1 to reproduce the mean within 1 standard deviation of postures proposed for PMHS testing suggests that differences in ATD and PMHS posture are unlikely to impede a comparison of WIAMan Gen1 responses and PMHS injuries in matched pair analysis. However, the methods that will need to be used to position PMHS in the highly reclined target postures (e.g., foam wedges, breakaway tape, and other temporary supports) may still affect the comparison between WIAMan Gen1 and PMHS responses. Future work (likely computational simulations) should be conducted to estimate the effects of positioning aids and other factors on the comparison between the WIAMan Gen1 and PMHS responses. Additionally, all positioning for these tests was conducted without seatbelts. While the lack of seatbelts is not expected to dramatically change the positioning of the WIAMan Gen1, belted positioning will need to be confirmed during initial tests.

9. REFERENCES

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Appendix A – List of Acronyms

3-D	three-dimensional
ASIS	anterior superior iliac spine
ATD	anthropomorphic test device
BRC	biofidelity response corridor
CG	center of gravity
CMM	coordinate measuring machine
Gen	Generation
IARC	injury assessment risk curve
IOTV	Improved Outer Tactical Vest
JHU/APL	Johns Hopkins University Applied Physics Laboratory
PMHS	postmortem human surrogate
PPE	personal protective equipment
SIP	seat index point
UMTRI	University of Michigan Transportation Research Institute
WIAMan	Warrior Injury Assessment Manikin
WSU	Wayne State University

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