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Optimal Restraint System Routing Procedures for Restraint System Development

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ABSTRACT

A process for donning restraints did not exist as related to Soldier gear encumbrance. For laboratory testing restraint donning was left to the discretion of the technician or test engineer setting up the Anthropomorphic Test Dummy (ATD) and resulted in increased occupant excursion. Therefore the Ground System Survivability (GSS) Blast Mitigation Team (BMT), United States Army Tank Automotive Research, Development and Engineering Center (TARDEC), Warren, MI. conducted studies which were accomplished through restraint system testing. This testing consisted of both Blast and Crash test modes. It was discovered that the ideal testing method couples the occupant to the seat and reduces the amount of restraint to gear interaction. When properly donned the occupant experiences reduced amounts of excursion vs. the improperly restrained occupant. This resulted in a procedure for which restraint systems are to be donned for test events. The routing procedure is included in this publication.

INTRODUCTION

The United States Army employs various types of vehicles to perform tactical, logistical and peace keeping related operations. Vehicle sizes and weights range accordingly as required by the mission. Each of these vehicles are susceptible to Blast, Crash, Rollover and other injury causing events. As such the mission of the Ground System Survivability Blast Mitigation Team is to counteract these events and help protect the Soldiers as they perform their required mission.

The performance of the stated Military vehicles when subjected to Blast, Crash, Rollover and other injury causing events will vary depending on vehicle size, weight, crush/energy absorbing structures and devices in addition to the under body shape and/or kit installed on the vehicle. In conjunction with these systems, a restraint system acts as a coupling mechanism to the energy absorbing seat. Ideally the amount of relative motion the occupant has to the seat is limited to prevent contact to surrounding surfaces.

As Soldiers perform their missions they find themselves in vehicles that are not comfortable and do not allow much space for movement. Surfaces in these vehicles are hard and rarely (if ever) contain energy absorbing surfaces that would allow for the energy to be absorbed in case of an event. It is therefore critical for the Soldiers to don their restraint System properly at all times, regardless of comfort and/or annoyance.

When the design for a restraint system for Military applications is approached, Soldier Gear (Encumbrance), Vehicle Interior Dimensional Limitations (Either Legacy or New Platform) and Future Retrofits/Upgrades (Equipment and/or Entire Platform) must be considered. Failing to take these considerations into account will result in the restraint system not being utilized or completely removed or cut out of the vehicle.

The United States Army Tank Automotive Research, Development and Engineering Center (TARDEC), Ground System Survivability (GSS) team, Warren, MI had designed an optimized restraint system for the Soldier, however during blast and sled testing improper donning was found to increase occupant excursion raising the potential of contacting interior surfaces. When evaluated, excessive excursion caused gear damage and increased restraint loading. Therefore a proper routing procedure was created and evaluated.

METHODOLOGY

The restraint system was evaluated in various testing scenarios namely Crash[1], Drop Tower and Blast testing. Initially no particular methodology was employed for donning the restraints other than ensuring that the restraints were over the gear and "tight" as per the test technicians and test engineers judgment. Any manually adjusted segments of the restraints were cinched as tight as possible, the technicians used both hands and pulled until the restraints were as taut as possible. This type of donning would not represent what is seen in the field, the likeliness of having a Soldier don restraints for another Soldier is low (but possible in certain situations). For an occupant to don a restraint they will have limited ability to pull the restraints tight on themselves while seated vs. standing in front of an occupant utilizing their entire body mass to tighten a restraint.

Sled Testing

During the development cycle of the restraint system for Occupant Centric Platform Technology Enabled Capability Demonstration (OCP TECD), sled testing was conducted as the first step[1]. The frontal crash sled test series used for this effort utilized a rigid seat mounted on a servo-hydraulic sled. The sled was propelled by an open-loop pneumatic actuator and the acceleration profile was controlled by a closed-loop 10 kHz hydraulic servo-brake A fix rigid steel seat intended for ECE R16 certification testing was modified to accept a 5th point, to replicate the intended seat design angle and to replicate the mounting of the remainder of the restraints in the intended design locations[1]. The test matrix for the series is represented in Table 1. Runs 003 and 007 are compared in this analysis

Table 1: Sled Series Test Matrix

Run Number	RUN 003	RUN 004	RUN 005	RUN 006	RUN 007
Torso Restraint	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	FMVSS 209 ELR (2)	FMVSS 209 ELR (2)	FMVSS 209 ADDITIONAL WEB LENGTH ELR (2)
Pelvis Restraint	FIXED (2)	FIXED (2)	MANUAL ADJUST (2)	MANUAL ADJUST (2)	IMMI MACR REDUCED WEB LENGTH ALR (2)
Crotch	Fixed	Fixed	Fixed	Fixed	Fixed
Foot Rest	High 8"	High 8"	High 8"	Low 3"	Low 3"

The pulse utilized for this series was derived from internal U.S. Army modeling and simulation studies, historical crash data conducted prior to the inception of this project and the comparison of FMVSS and other readily available crash pulses. Due to the rigidity of Military vehicles and lack of frontal deformation, higher G forces are created and were taken into account with the development of this pulse. The final developed pulse for the OCP TECD program is captured in Figure 1.

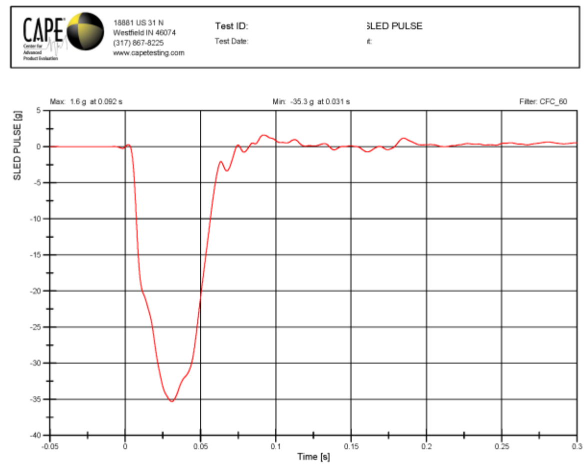

FIGURE 1: TARDEC DEVELOPED OCP TECD PULSE

Initial Restraint Routing

As shown by Figure 2 and Figure 3 the lap restraints were routed over the packs and the restraint load cells were placed in a manner where the gear was in contact with them prior to test. Figure 4 illustrates the shoulder webbing passing over gear, in this particular gear set configuration the restraints were uniformly placed on the occupant.

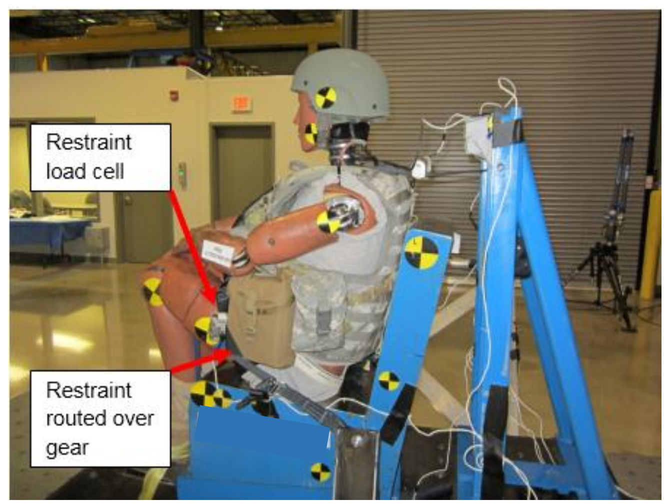

Figure 2: Left View of ATD On Sled Pre-Test.

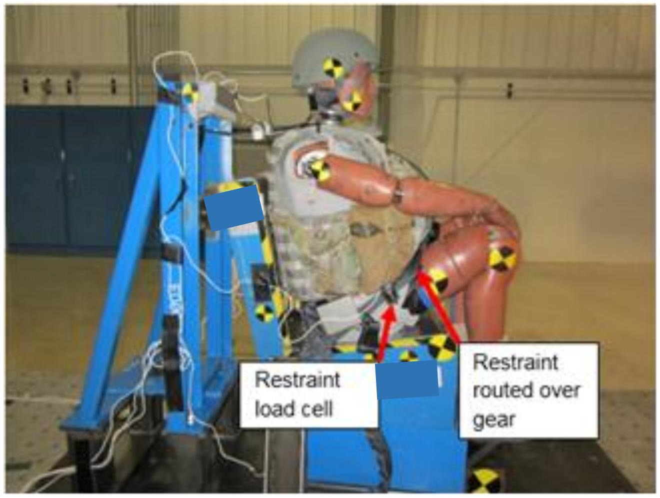

Figure 3: Right View of ATD on Sled Pre-Test.

Figure 4: Frontal View of ATD on Sled Pre-Test.

Crew Seating Blast Effects Simulator (CSBES)

During blast confirmation testing for the OCP TECD program an anomaly was discovered. The ATD had travelled upwards towards where the vehicle ceiling location would be located. The particular test asset did not contain a roof, but if it did the potential of contact with the head would be very likely. This prompted testing to be conducted on the Crew Seating Blast Effects Simulator (CSBES) at the Army Research Laboratory (ARL) in Adelphi, Maryland. The purpose of the testing was to identify the excursion the occupant encountered in the blast seat when subjected to the blast pulse in an ideal restraint routing condition and in a condition mimicking the blast test restraint routing. The test matrix for the series is represented in Table 2. Runs 001 and 003 are compared in this analysis

Table 2: Sled Series Test Matrix

Run Number	RUN 001	RUN 002	RUN 003	RUN 004	RUN 005
Torso Restraint	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	Fixed
Pelvis Restraint	MACR ALR (2)	MACR ALR (2)	MACR ALR (2)	MACR ALR (2)	Fixed
Crotch	Fixed	Fixed	Fixed	Fixed	Fixed

The accelerative pulse utilized for this series closely mimicked the actual blast test. Due to the sensitivity of this data a graph depicting this pulse has been omitted

Blast Test Restraint Placement

As shown by Figures 5 through Figure 8 the restraints were purposefully routed incorrectly to mimic the test setup during the blast test. The lap restraints were routed over the packs where the gear was in contact with them prior to test and the left hip retractor was rotated forward to best replicate the blast test setup condition. In addition a test was run with proper placement of restraints to compare the effect that it had on the restraint load cell results.

Figure 5: Rear Right Oblique View of ATD with Misplaced Restraints

Figure 6: Front Right Oblique View of ATD with Misplaced Restraints

Figure 7: Front Left Oblique View of ATD with Misplaced Restraints

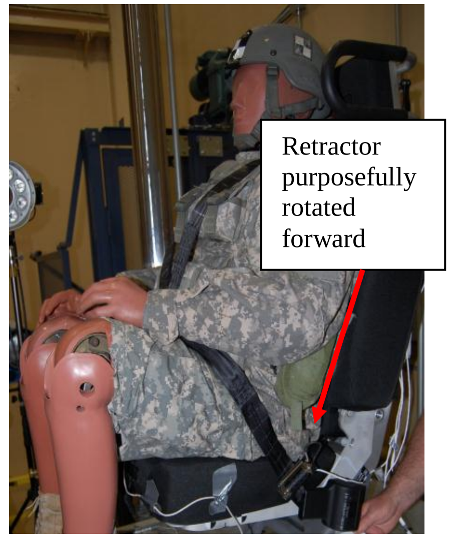

Figure 8: Left View of ATD with Misplaced Restraints

TESTING RESULTS

Sled Testing

Results indicate that the improperly routed restraints contributed to increased excursions as is depicted in Figure 9. Measurements were taken at the knee during the maximum excursion via video analysis. The improperly routed restraints contributed to increased maximum pelvic excursion. The maximum pelvic excursion of the dummy with the improperly routed restraint was 80mm greater than the properly routed restraints as seen in Figure 9.

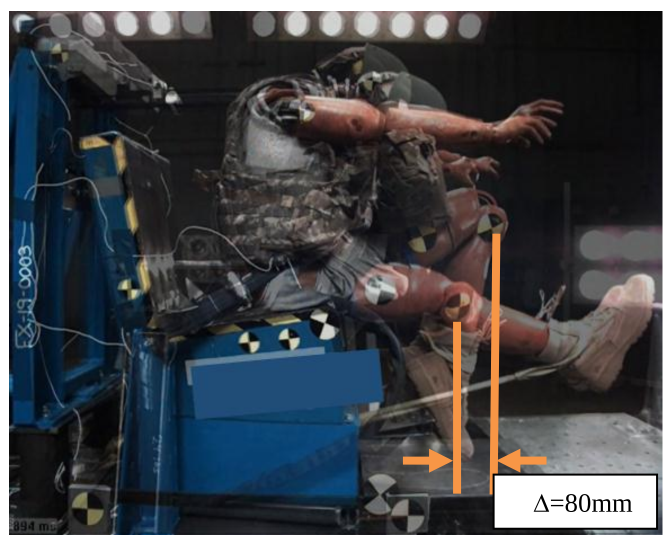

Figure 9: Maximum ATD Pelvic Excursion Properly vs. Improperly Routed Restraints

The lap restraints slipped under the packs causing a drop in load on the lap restraints. Figure 11 and Figure 12 highlight the drop in load (loss of restraint). The rise in the data occurs once the restraints have worked their way under the gear set and begin loading the ATD once again.

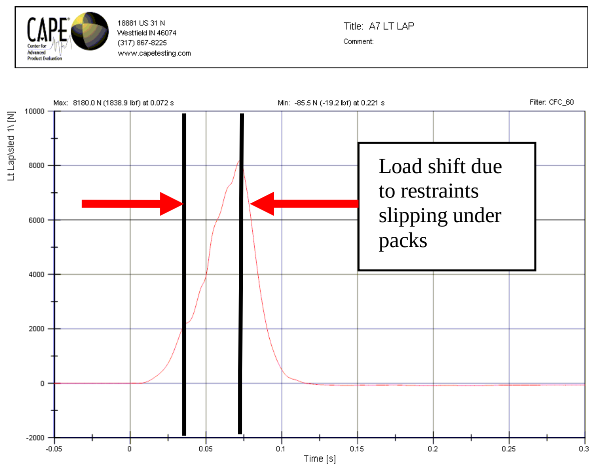

Figure 11: Left Lap Load Cell Data

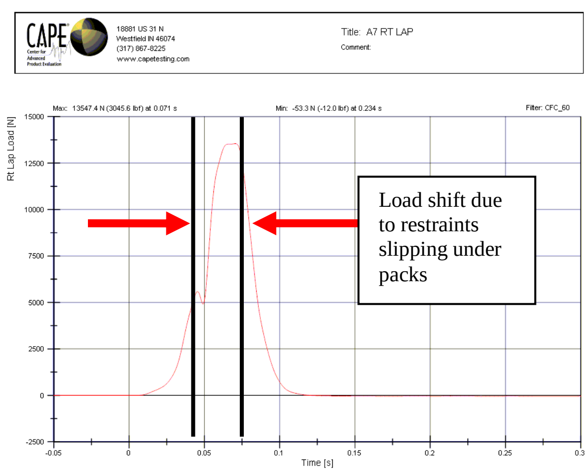

Figure 12: Right Lap Load Cell Data

Crew Seating Blast Effects Simulator (CSBES)

Results indicate that the improperly routed restraints contributed to increased excursions as is depicted in Figure 13. Measurements were taken at the cheek during the maximum excursion via video analysis. The improperly routed restraints contributed to increased head excursion. The maximum head excursion of the dummy with the improperly routed restraint was 113mm greater than the properly routed restraints as seen in Figure 13.

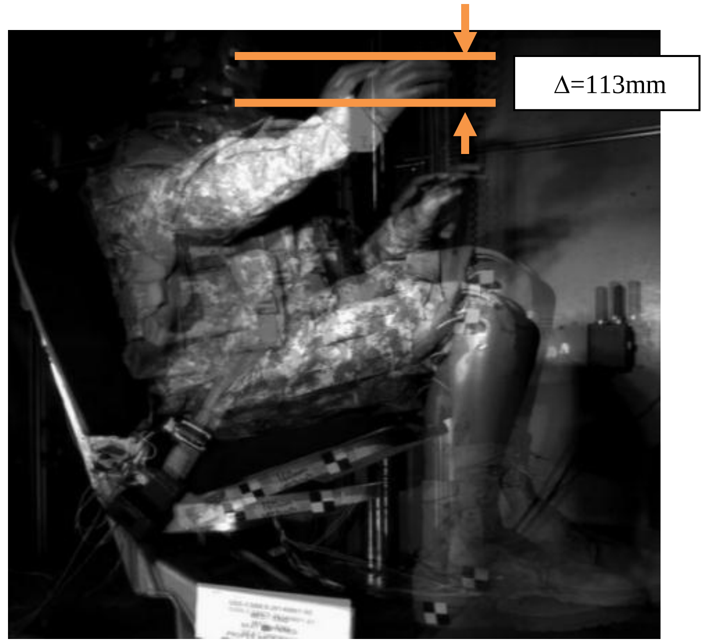

Figure 13: Maximum ATD Pelvic Excursion Properly vs. Improperly Routed Restraints

The load on the lap caused a drop in load in the restraints as illustrated in Figures 14 and Figure 15.

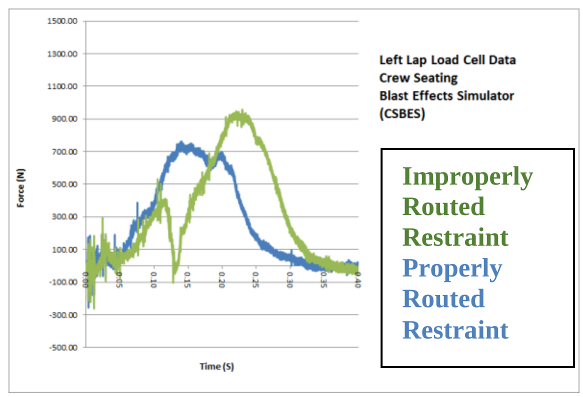

Figure 14: Left Lap Loads During Blast Simulation Test

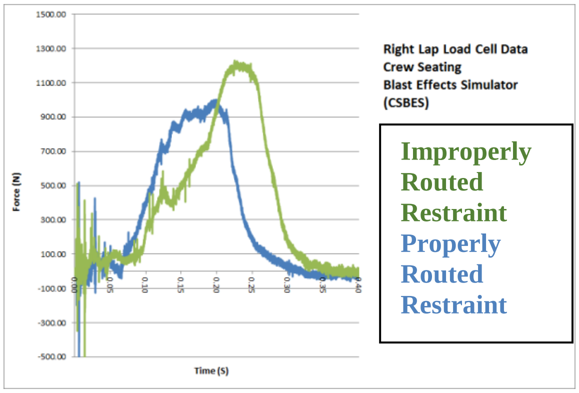

Figure 15: Right Lap Loads During Blast Simulation Test

DISCUSSION

Sled Testing

When the restraint is routed over the encumbrance it will continue to load and provide restraint. It is when the webbing finds the path of least resistance it then slips under the pouches. During this time the load drops until it is able to load up against the abdomen again. Once the abdomen is being loaded again the load begins to rise. This loading can result in higher occupant injury values and further excursion.

Crew Seating Blast Effects Simulator (CSBES)

During the test the lap restraints slipped under the packs in addition to the left hip retractor rotating upwards, causing excessive excursion. As with the sled testing the webbing finds the path of least resistance. During this time the load drops until it is able to load up against the thighs. In the case of this test series the left lap load has a sharper drop in load as the retractor rotates upwards. The properly routed restraints did not produce a drop in load instead the load was distributed over a longer time period. This allowed for a sustained loading profile.

CONCLUSION

When the restraint system was evaluated in Crash and Blast testing the restraints were initially placed as they have been in previous test series. No particular methodology was employed other than ensuring that the restraints were over the gear and "tight" as per the test technicians and test engineers judgment.

It has been proven through this testing series that it is critical to place the restraint system in a manner which is described in the Appendix A of this document. The procedure covers both manual adjust restraint systems and restraint systems which contain retractors.

REFERENCES

[1] S.Karwaczynski, R.Hoover, C.Jessup and K.Paulson, "The Effects of Soldier Gear Encumbrance on Restraints in a Frontal Crash Environment", Proceedings of the ASME 2015 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2015

ACKNOWLEDGEMENTS

To my friend Craig Foster, your guidance is always greatly appreciated. Your ability to work under pressure in a short amount of time in a test environment is amazing. It was an absolute pleasure working with you on this project and I look forward to working with you in the future.

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INSTRUCTIONS FOR SEATS CONTAINING SEAT BELT RETRACTORS

1. Before beginning, ensure that all the restraints are in their proper design location and are not rotated forward or rearward of intended location.

2. Locate the 5th point belt and buckle assembly and lengthen the belt to provide working room. Attach both lap belts and both shoulder belts to the fifth point belt buckle assembly. (Figure 1)

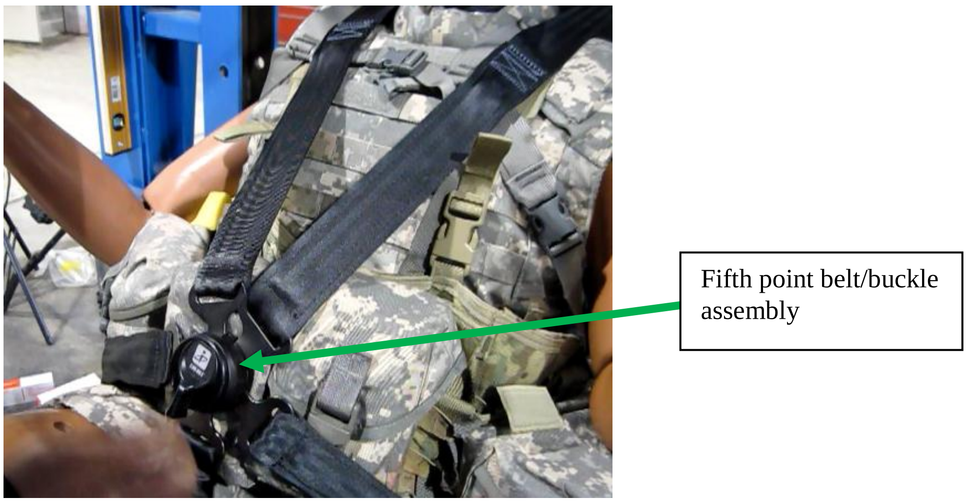

Figure 1

3. Position the buckle assembly at the pants waist. (Where pants and shirt meet, centerline of ATD.) Tighten the 5th point belt to keep buckle in position. (Figure 2)

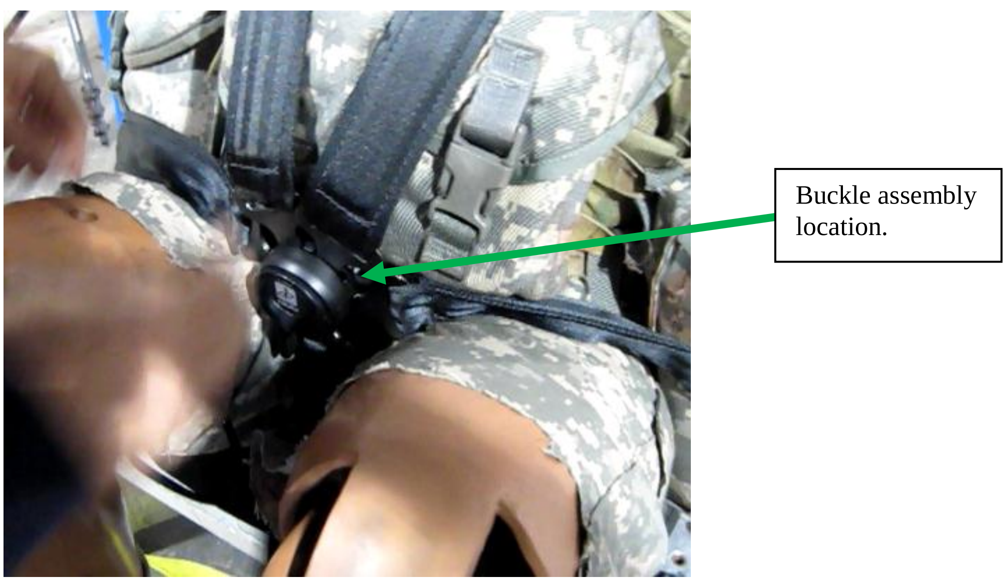

Figure 2

4. Route the left and right lap belts under any pouches and insert the tongues into the buckle. The belts can be over the IOTV. (Fig 3)

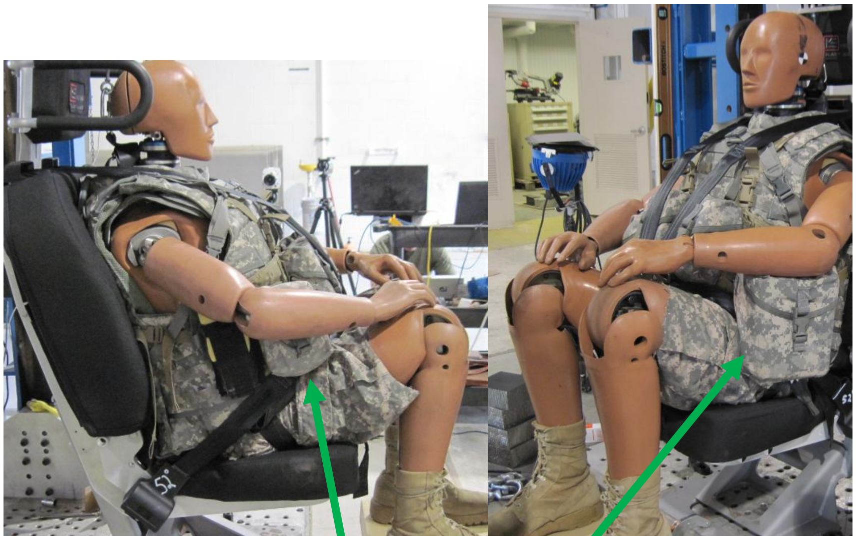

Figure 3

5. Route the left and right shoulder belts over any pouches on the chest and insert the tongues into the buckle. Make sure the belts stay closer to the center of the chest. (Figure 4)

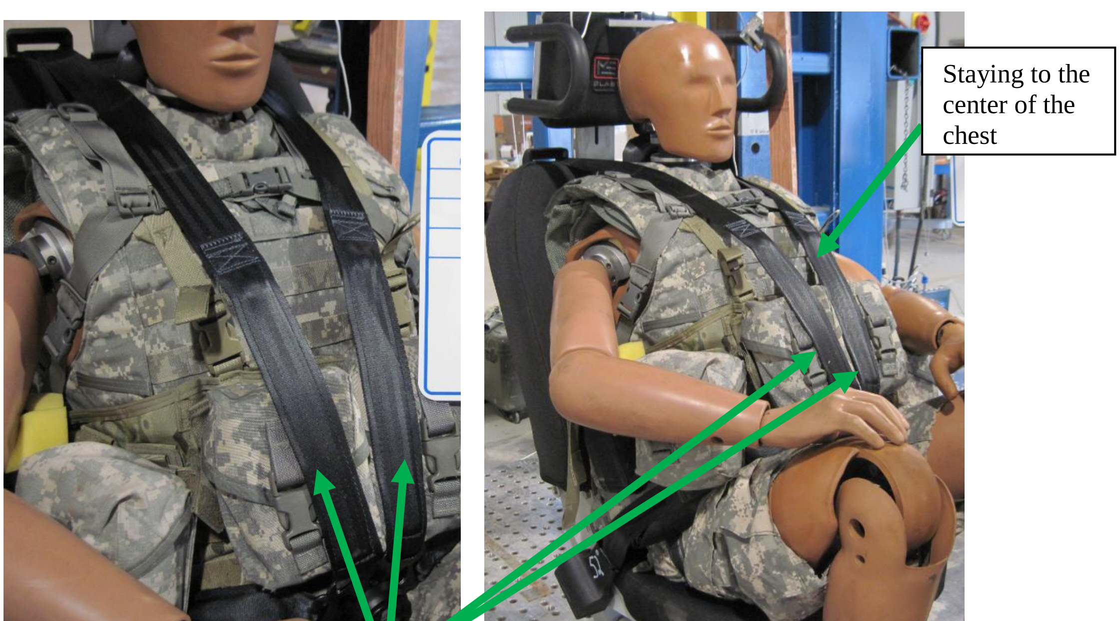

Figure 4

6. Pull the fifth point belt tight to position the buckle assembly at the waist.

7. Cycle the lap and shoulder lap belts to ensure that they are unlocked. (Fig, 6)

Figure 6

8. Confirm that the buckle assembly is still at the waist, the lap belts are under the pouches, the shoulder belts are routed over the pouches as applicable, the belts are not crossed, the belts are not twisted, and that the belts are lying as flat as possible.

INSTRUCTIONS FOR SEATS CONTAINING FIXED RESTRAINTS (ANCHORAGE POINTS)

1. Before beginning, ensure that all the restraints are in their proper design location and are not rotated forward or rearward of intended location.

2. Completely lengthen/loosen all belts.

3. Locate the 5th point belt and buckle assembly and attach both lap belts and both shoulder belts into the fifth point belt buckle assembly. (Figure 1)

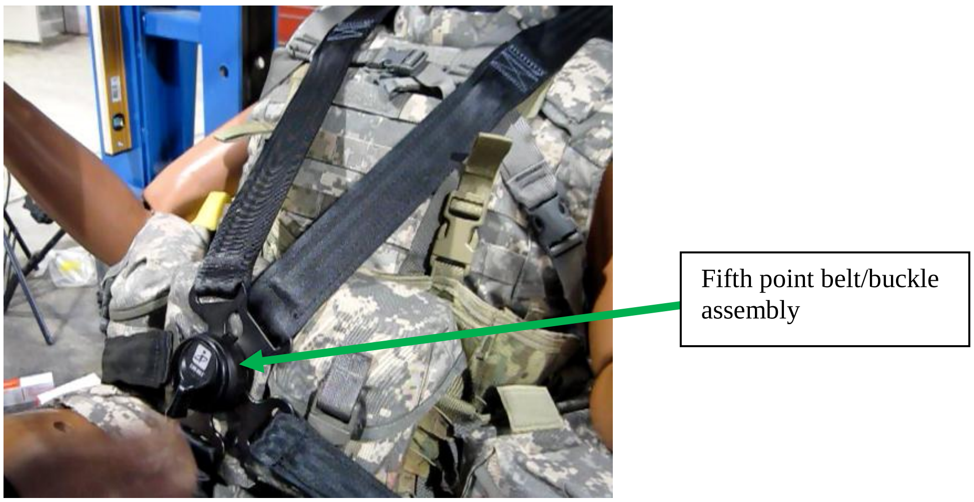

Figure 1

4. Position the buckle assembly at the waist. (Where pants and shirt meet, centerline of ATD.) (Figure 2)

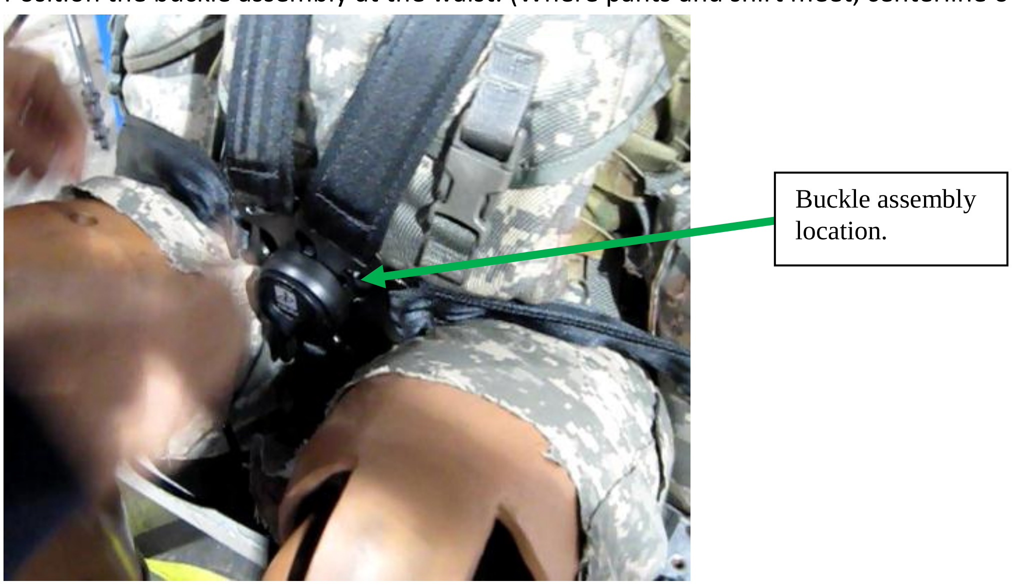

Figure 2

5. Remove the excessive belt slack, first by pulling on the fifth point, then the left and right lap belt, and finally on the left and right shoulder belts leaving approximately 1 inch of slack in each lap and shoulder belt so there is the ability to route the belts.

6. Route the left and right lap belts under any pouches and insert the tongues into the buckle. The belts can be over the IOTV. (Figure 3) Tighten the lap belts. When the belts are tight, two fingers positioned side by side, should be able to slide under the belts at a location on the side by the IOTV.

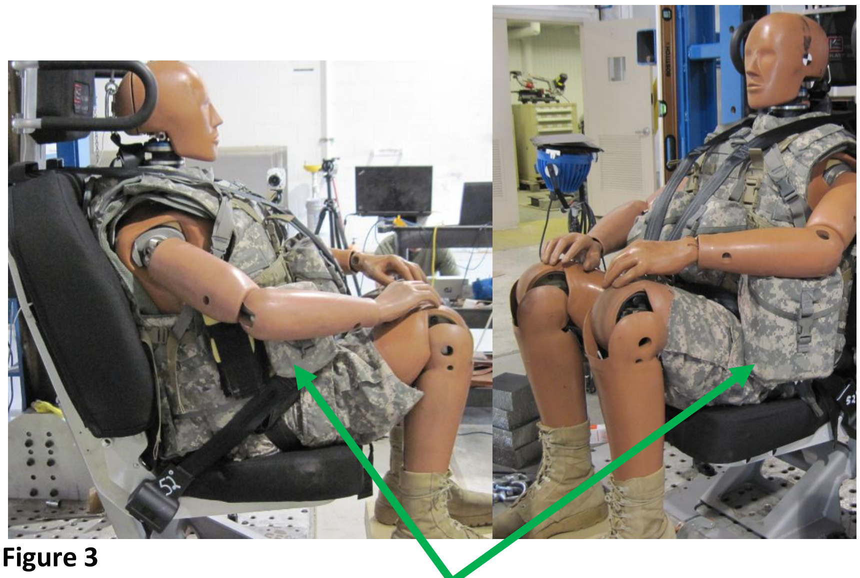

Figure 3

7. Route the left and right shoulder belts over any pouches on the chest and insert the tongues into the buckle. Make sure the belts stay closer to the center of the chest. Tighten the shoulder belts. When the belts are tight, two fingers positioned side by side, should be able to slide under the belt located on the shoulder of the ATD. (Figure 4)

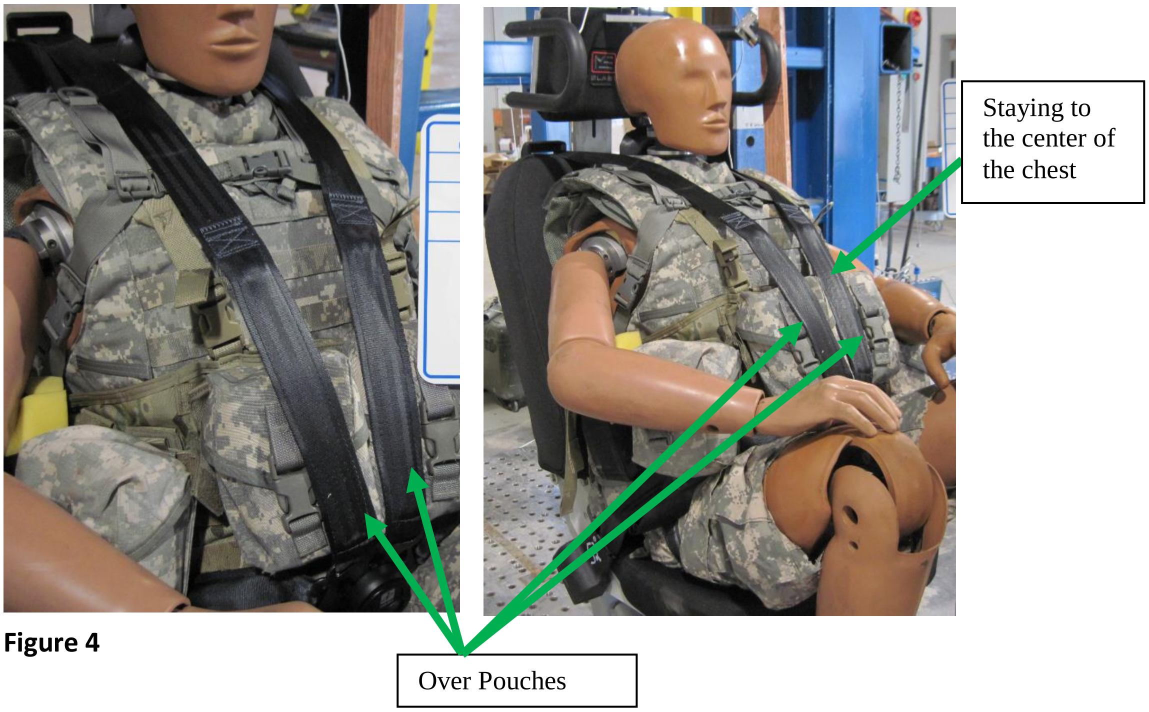

Figure 4

8. Confirm that the buckle assembly is still at the waist, the lap belts are under the pouches, the shoulder belts are routed over the pouches as applicable, the belts are not crossed, the belts are not twisted, and that the belts are lying as flat as possible.

9. Check belt tightness again by sliding two fingers under the lap belts and shoulder belts as described in steps 5 and 6.