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14. ABSTRACT

The overall objective of the project was to develop biofidelic response corridors, human injury curves for post-mortem human specimens (human cadavers) and anthropometric test devices (ATDs) under field relevant under body blast (UBB) loading conditions. These conditions involve very high onset rates, accelerative and vertically oriented loadings quite different from automotive accident conditions. A new manikin called WIAMan (War injury assessment manikin) need to be built based on the test results of these projects. A novel test device, AENID, Advanced ENergetic Innovative Device based on validated shock tube technology was conceived, designed, fabricated and tested as a part of this project. AENID when tested with a fully instrumented Hybrid III dummy was able to be loaded with very high onset rate as specified by the army. A number of tests under varying input conditions were tested and the resulting onset rate demonstrated that the system is capable of achieving a range needed for the generation of response to specify WIAMan.

In addition to demonstrating the capability of AENID, procedures and protocols to use full-body and body regions of PMHS were developed, discussed and were in the final stages of approval. When the PI left University of Nebraska to assume the position of the Director of Center for Injury Biomechanics at New Jersey Institute of Technology, the funding and the project were discontinued by the army.

15. SUBJECT TERMS
Underbody blast, Advanced blast test device, WIAMan, Injury-risk response

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1 Introduction

Underbody blast (UBB) is an explosive event causing significant number of death and serious disabilities to warfighters. In order to improve the design of the vehicles and personnel protective systems, test dummies capable of withstanding the extreme loading conditions and still simulate human behavior is needed. Thus the US Army outlined a plan to deliver fully-validated Warrior Injury Assessment Manikin (WIAMan) Anthropometric Test Devices (ATDs) for use in Under Body Blast (UBB) testing [1-6]. PI Namas Chandra and his team proposed a novel test device called AENID (Advanced ENergetic Impact Device) based on validated shock tube technology. AENID will be a game-changer in creating extremely high onset rate loading typically seen under UBB conditions. Further, the ability of shock tube technology in producing different shock strength will allow a range of injury causing conditions, needed in the development of injury response corridors (IRCs), injury probability curves, and matched-pair testing with cadavers and WIAMan.

AENID was designed, tested and capabilities demonstrated as a part of the proposed work. Protocols to test human cadavers (PMHS) for full-body and lower extremities were submitted and the visiting army team was in the final stages of approving the protocols. Unfortunately PI left University of Nebraska-Lincoln to become the Director of Center of Injury Biomechanics, materials and medicine at New Jersey Institute of Technology during summer of 2014. Army decided not to execute option years and thus discontinue a promising effort. This report summarizes the activities during July 2012 to summer 2013.

2 Background

The US Army has outlined a five-year plan to deliver three fully-validated Warrior Injury Assessment Manikin (WIAMan) Anthropometric Test Devices (ATDs) for use in Under Body Blast (UBB) testing [1-6]. Fulfillment of this ambitious objective will require concurrent development of post-mortem human subject (PMHS)–based injury response corridors (IRCs), injury probability curves, and design of a WIAMan dummy based on these medically-validated results. Matched-pair testing between a WIAMan dummy and appropriate cadaver parts or whole cadavers will be conducted to evaluate the biofidelity of the dummy and to develop injury assessment reference values (IARVs) for WIAMan.

The Army's plan for developing ATDs for UBB is responsive to the fact that between October 2001 and January 2005, a total of 1,566 combatants sustained 6,609 combat wounds. Explosions accounted for 78% of these injuries, which is the highest proportion seen in any large scale conflict [7]. Consequently, there has been a paradigm shift in the design of armored vehicles to help ensure soldier safety by creating necessary protective structures and features around vehicle occupants, achieving what is known as "Occupant Centric Integrated Design" [8]. Such a design approach is predicated upon balancing vehicle protection, performance, and payload through an integrated occupant-centered survivability strategy[9, 10].

As new threats arise around the globe, new transport, armor, anti-armor, supply, medical, and other field vehicles will operate in harsh and extremely unfriendly conditions will be built; as a result occupant needs and functions will change; new ***loading vectors, loading rates,*** and ***a combination of insults*** will arise; and all these will lead to new occupant safety requirements and new vehicle designs. Hence, the

PMHS tests conducted to inform the Army's WIAMan development efforts must accommodate both current and future complex biomechanical threats.

2.1 Need for Novel PMHS Testing Equipment and Protocols

Although a rapid acceleration pulse may be generated by direct impact of a pendulum or a pneumatically driven impactor on a test model, the loading profile depends on the interaction between the impactor and the test object [11]. This makes it very difficult to ***independently control the rise time, magnitude, and duration of loading***. Under the same test conditions different materials (or systems) will exhibit different acceleration histories. It is also possible that the impact configurations necessary to realize certain needed dynamic loading histories are actually not practical or feasible.

To address this issue, we have developed a new test methodology. Instead of generating dynamic loading via impactor-sample interaction, we drove a plate that simulates the vehicle floor, with shock-tube generated air shock waves tailored to mimic the temporal and spatial characteristics of UBB blast waves. In this way, the motion history of the driving plate can be designed and controlled independent of the test object response. Since the techniques for shaping the profile of shock-tube generated air shock waves have been developed in our blast test facility, we believe our proposed experimental technique can provide a better replication of the field conditions of an UBB event than any existing testing methods [12].

The AENID was specifically designed to develop bio-medically validated injury risk curves. The key features of AENID are:

- The system is agile, flexible, and inexpensive. The system can be reconfigured very quickly, reducing costs and set-up time between different types of tests. This functionality significantly reduces overall product development cycle time and cost and improves the quality of experimental data. Further, it can easily replicate different loading conditions (in terms of force, moment, or acceleration) on different parts of the body, as prescribed by the Army.
- It can be configured to test PMHS and ATD, for the same input pulse the forces will be identical on both the specimens reducing the variability in ***matched-pair testing.***
- The design was implemented and the capabilities demonstrated to the government both in review meetings as well as site visit by the army team.

3 Public Purpose

Successful completion of the proposed work will provide the DoD with the most comprehensive quantitative understanding of UBB ever developed, which will significantly advance the fundamental understanding of the UBB injury processes, and, in turn, enhance warfighter survivability. The research outcomes will provide an invaluable basis for developing the next generation of protective equipment against UBB and can potentially be integrated with other DoD and academic programs focused on biomechanical computational modeling of blast exposure. Finally, the analytical methodologies developed during this project will provide a comprehensive platform for blast impact studies that may reciprocally inform the development of MVA testing and preventative design, ultimately benefitting the civilian population much more broadly.

4 AENID development and Testing

4.1 Literature Review (Appendix A)

Before the design of the device was started, a comprehensive literature review was carried out and is attached as Appendix A in the report. In this report, we compare all existing devices that are relevant to represent the physics of under body blast experienced in theater. As it turns out, many of the devices used for this purpose including some by the current UBB research team members were adapted from the tests conducted for conventional automotive crashes at lower onset rates. The review also outlines the test methodology for different body regions and their injury criteria.

4.2 Design and testing of AENID (Appendix B)

AENID was designed to fully utilize the power of the shock wave generated in the shock tube. The problem was to come up with an engineering design of structure that can be withstand the enormous power (force within a short period of time). Most of the conventional systems failed-for example, most of the commercially available bearing systems failed within one or two applications. The total weight of the system including the Hybrid III dummy (or PMHS) weighed about 200 lbs with significant inertial loading.

Appendix B outlines the details of the test apparatus, seating procedure, data collection methods, data analysis alogrithms, and summary of tests conducted on AENID. In this appendix, we also show the test results obtained with AENID with that of live fire test results that were made available to us by the sponsors. We summarize all the tests done with 5, 10 and 15 membranes that showed forces on the tibia, femur and neck from probability of injury from very low to very high. Thus AENID was capable of producing the needed force and rate of loading applicable for the design of WIAMan. In almost all the case while 5 membranes produced no injury, 15 exceeded all the known limits.

4.3 Whole body PMHS tests (Appendices C and D)

In appendix C, we present the overall goals of whole-body testing. There were so many unanswered questions at that time which were not resolved. For example, it was not exactly clear what ranges of rise times we need to test the specimens; whether the PMHS can be used only once or more; the number of measurements to made and with what instruments; what type of data collection procedure and analysis techniques need to be used; the number of restraints in the seat system-4 or 5 points; and the measurements to be made of the position and orientation of the PMHS before the test can be done. First few tests were done with Hybrid III dummy that were on loan from army.

Upon the approval of the protocol, a team from army and Johns Hopkins research team visited the facility and witnessed the actual tests. Appendis D details the test readiness review procedure submitted by our team and discussed in detail. At that meeting, the actual test velocities and duration were finalized. Three test set ups M5, M10 and M15 were identified and the details are shown in this appendix. The report also shows the approval for PMHS testing provided by the US army.

4.4 Lower extremity PMHS tests (Appendix E)

In appendix E, we present the overall goals of lower extremity testing. Most of the injuries in UBB occur as a result of floor plate intrusion and hence foot and lower extremity. Hence this is a critical body region. The appendix outlines all the details of test and specimen preparation, data acquisition and analysis and imaging requirements.

5 Reportable outcomes

The contract had very strict guidelines on publications and none of the data was allowed to be published.

However, there was one graduate student Kurtis Palu who included some of the design aspects of the AENID as a design exercise.

There were a number of faculty, post-doctoral research associates, PhD and MS students and undergraduate students involved in the project. They were

Personnel Name	Responsibilities
Prof. Namas Chandra, PhD, PE	Principal Investigator
Prof. Ruqiang Feng	Co-PI
James Rinaldi, DC	Project Manager
Dr. Jayaraman Srinivasan, PhD	Laboratory Manager
Mr. Michael Bergen, MS BME	Biomedical Engineer
Mr. Nagarajan Rangarajan, PhD	Sub-contractor
Mr. Sailesh Ganpule, MSME	PhD Student Research assistant
Mr. Kurtis Palu, BSME	Test Engineer
Mr. Steve Gloor/Shawn Schumaker	Student Assistants

Most of the students were trained in both computational and experimental aspects of the project.

6 Key Research Accomplishments

- AENID based on shock tube technology was designed, built and tested to meet the requirements of WIAMan.

- Basic testing showed that both Hybrid III and human PMHS (both full body and body regions) can be used in AENID for developing bio-fidelity curves, injury-risk response and high rate material properties.
- Protocols for full body and lower extremity testing were developed and demonstrated to the sponsors.

7 Glossary of Acronyms

Abbreviate Injury Scale (AIS)

Advanced Energetic Impact Device (AENID)

Anthropometric Test Devices (ATDs)

Anterior-posterior (A-P)

Biofidelic side impact dummy (BioSD)

Bone Mineral Density (BMD)

Computed Tomography (CT)

Crash injury research and engineering network (CIREN)

Dynamic Response Index (DRI)

Euroside 2 rib extension (ES2RE)

Facial Ocular Countermeasure for Safety (FOCUS)

Hybrid III (H3)

Injury Assessment Risk Values (IARVs)

Injury Response Corridors (IRCs)

Joint theater trauma registry (JTTR)

Medical College of Wisconsin, Milwaukee [36]

Moments of Inertia (MoI)

Motor Vehicle Accidents (MVAs)

Orthopedic Trauma Association (OTA)

Personal Protective Equipment (PPE)

Post-Mortem Human Subject (PMHS)

Side NCAP [NCAp = new car assessment programme](SINCAP)

Test data analysis system – (TDAS)

Under Body Blast (UBB)

University of Nebraska-Lincoln (UNL)

Warrior Injury Assessment Manikin (WIAMan)

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Appendix A

Literature Review

2012

Underbody Blasts: Mechanics, Simulation and Injury – A Review

University of Nebraska - Lincoln

Contents

1 Introduction

The Defense Casualty Analysis System reported more than 55,000 hostility related casualties among American warfighters during the Global War on Terror (GWOT) since 2001[1]. Current US military conflicts differ significantly from previous efforts in that the enemy employs unconventional methods of warfare, including improvised explosive devices (IEDs) and suicide bombings. IEDs pose a greater threat to warfighters than any other means and have accounted for up to 62% of fatalities in Operation Iraqi Freedom (OIF) [2]. A query of the Joint Theater Trauma Registry over 2001-2005 demonstrated that IEDs were the mechanism of injury in 38% of combatants wounded in action (WIA) [3]. However, an analysis of mechanized battalion injury data collected over a 6 month period in 2004 during OIF demonstrated that 97% of 125 casualties were injured secondary to IED or mine explosion. All casualties were mounted at the time of attack [4]. While the likelihood of exposure to IED threats depends on a warfighters role, the incidence of IED produced casualties has increased as these campaigns have continued. An analysis of brigade combat team casualties sustained in the "The Surge" effort of OIF during 2006-7 revealed that IEDs were causative in 77% of WIA and 81% of KIA trauma [5]. An analysis of 555 mounted individuals (116 KIA and 439 WIA) injured in 296 underbody blast events, typically produced by IED or mine detonation, demonstrated that while KIAs sustained more head and torso trauma, WIAs sustained more lumbar spine and distal lower extremity injuries [6].

2 Mechanics of Under Body Blast (UBB)

The under body blast can occur due to anti vehicle mine explosion or due to explosion of improvised explosive devices (IEDs). Without the loss of generality, we will use the term Under Body Blast (UBB) for such threats.

2.1 The physics of Under Body Blast (UBB) explosion in theater

In an UBB explosion, when a vehicle triggers a mine or IED, it causes the explosive to detonate. Detonation is a process whereby a shock-wave propagates through a chemical compound and initiates a rapid, exothermic and explosive chemical reaction in its wake. The chemical reaction releases the potential energy of the explosive via a phase transformation process. The detonation wave leaves a mass of superheated, high-pressure gas, called the detonation products, in its wake. In the wake region, Local pressures are typically of the order of 1.4 – 3 million psi whilst temperatures are of the order of 2000°C to 6000°C. Once the detonation wave has completely consumed the explosive, the detonation products are not in thermal and mechanical equilibrium with their surroundings. Several physical processes then take place that determine the amount of energy transmitted to a target. For the UBB these processes can be characterized by three distinct phases: (i) explosive interaction with the soil, (ii) gas expansion to the surface and (iii) soil ejecta interaction with the vehicle [7].

2.2 Explosive Interaction with Soil

This phase spans the time period from the point at which the explosive has been totally consumed by the detonation wave, to the time at which the resulting detonation products vent through the soil surface. This phase involves heat transfer to the soil and transmission of the detonation wave from the detonation products to their immediate surroundings. The transmitted shockwave compresses the soil material in its wake followed by wave reflection at the soil-air interface. As the reflected wave propagates downwards, the soil cap is fractured above the detonation products. This, in turn, creates failure planes through which the gas preferentially expands. In addition, a small fraction of the incident shockwave is transmitted into the air and a thin layer of soil is ejected upwards. After this phase, some of the high-pressure gas is propelled (jets) through the voids (created due to fracture) within the soil. The gas pressure reduces as it flows through these voids within the soil, and its velocity increases. Hence, gas gains kinetic energy to a point at which it reaches a state of 'chocked flow' (equivalent to the local speed of sound) where the mass flow rate increases no more, and consequentially, the driving pressure does not reduce either. This high pressure collapses the soil matrix in its immediate vicinity. In the extreme, if the explosion takes place deep underground, the soil collapse process absorbs all the energy from the detonation. Dependent upon the mine position, the high-velocity gas acts to eject the soil cap. The soil particles are ejected at supersonic speed, between 800 – 2000 mph, depending on soil characteristics and explosive mass.

2.2.1 Gas Expansion

Detonation of the explosive results in the formation of large quantities of gas, determined by the amount of a specific explosive. As the detonation products expand, they eject the soil plug at supersonic speed. The high pressure of the ejecting gases can cause localized deformation of the floor of the vehicle depending on the gas expansion and soil properties (e.g. soil density, moisture content).

2.2.2 Soil Ejecta

The soil ejecta phase occurs towards the end of the gas expansion phase. It is set in motion by the force of the original explosion. It can interact with the target either in the form of radial compression wave or hollow cone of soil ejecta is being formed. Soil ejecta phase can act on a target for at least 20 to 100 ms longer than the gas expansion phase. The flow of ejecta is more vertical when the mine is buried deeper, or if the soil is more dense, or has higher moisture content. The physical momentum transfer from the soil ejecta to the vehicle can cause vertical displacement of the vehicle, resulting in significant injury to the occupants.

2.3 Interaction of explosive products with vehicles

As described previously, the two dominant load transfer mechanisms to the target vehicle is the expansion of the detonation products and the physical momentum transfer from soil ejecta. For a typical anti-vehicular mine which is 5-8 kg [7] of high explosive, the gas expansion occurs during the first 5-10 ms after detonation [7]. The soil ejecta phase takes place shortly thereafter and lasts between 50- 100 ms [7]. The gas expansion phase provides the first phase of impulse. During this phase, any portion of the vehicle located in the expansion zone of the detonation products is exposed to a high pressure, transient, supersonic flow field. The transfer of momentum from the detonation products to the vehicle is governed by gas dynamics characteristics of the detonation products. This, in turn, is a direct function of local and global target geometry. If a body is sufficiently slender, the flow adapts to the boundary through a system of oblique shock waves that effectively “bend” the path of the flow that follows a path of least resistance. If the angle imposed by the vehicle floor is greater than the limiting turn angle, the flow experiences a rapid slow down and pressure concentration; flat vehicle floors trap the detonation product and allow time for considerable energy transfer to occur. This often causes rupture of the floor pan and endangers the occupants who are then exposed to lethal secondary fragments and hot gases. Even in cases where floor does not rupture, rapid deformation of floor plates in localized regions present a great danger to occupants. The pressure concentration acts on the vehicle and results in vertical acceleration of the vehicle. The magnitude of the vertical displacement is dependent upon the total mass and, for asymmetric loading, on the moments of inertia around the center of mass, which is a function of the load distribution of the combined vehicle and occupants. After reaching the peak of its force dependent displacement, the vehicle will accelerate to the ground under the effects of gravity, potentially resulting in significant injury, especially if the occupants are not appropriately restrained. All these effects can be categorized into following broad categories [8]:

2.3.1 Local Effects

The local effects are preliminary caused due to propagating shock wave within first few milliseconds of UBB event. This shock wave hits the bottom plate of the vehicle within approximately 0.5 ms and is subsequently reflected causing an extremely large peak pressure resulting in a local acceleration of the bottom plate. Within approximately 5 ms after the detonation the bottom plate can deform elastically and plastically depending on the shape, thickness, material and additional stiffeners. Sometimes the bottom plate sometimes the bottom plate ruptures and causes possible overpressure, fragmentation, heat and toxic effects inside the vehicle. The shock wave also causes a mechanical shock in the material of the vehicle structure, which travels with speeds up to 5000 m/s [8] through the whole structure and causes strong vibrations in all vehicle parts. Depending on the boundary conditions, the bending bottom plate may cause deformations in the side walls of the vehicle. All parts mounted on or just above the bottom plate, like torsion bars, can be hit and accelerated in an upward direction.

2.3.2 Global Effects

The effects due to gross motion of the vehicle are considered as global effects. The gross motion is caused due to a pressure force acting on a bottom section of a vehicle resulting from reflecting blast waves. The gross motion of the vehicle in turn causes vertical jump of the vehicle. The jump height depends on the total impulse load of this pressure force, total mass and, for asymmetric loading, on the moments of inertia around the center of gravity. For typical UBB explosion, it takes about 10 to 20 ms after detonation before the complete vehicle starts moving and 100 to 300 ms before it reaches its maximum jump height.

2.3.3 Drop Down Effects

Drop down effect occur as vehicle can fall due to gravity after reaching its maximum jump height. Drop down effect can be significant or insignificant depending on the maximum height reached by the vehicle that in turn depends upon intensity of explosion.

2.3.4 Subsequent Effects

Other effects like crash, roll over or penetration can also occur. In addition, resulting fragments, toxic fumes and gases, blast overpressure and heat are serious threats for the human body as well.

2.4 Loading experienced by the base of the vehicle

WIAMan Baseline Environment (WBE) provides loading envelope for UBB loading [9]. The WBE is based on the Live Fire Test and Evaluation (LFTE) measurements carried out to define the range of loading conditions for the UBB environment. Figure 1 shows the correlation between calculated peak floor velocity and time to peak from LFTE measurements. The velocities are calculated from floor accelerations. The probability of injury (Figure 1) is derived from logistic regression analysis on these two variables. Similar data is derived for seat velocities. Based on these data, the loading scenarios are suggested to simulate UBB loading. These loading scenarios are shown in Figure 2. The laboratory equipment studying UBB should be able to replicate these loading conditions.

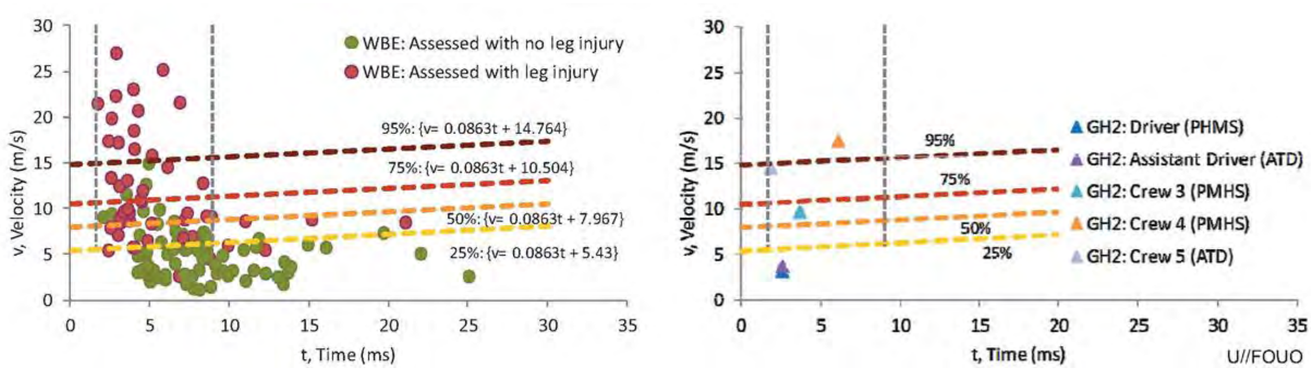
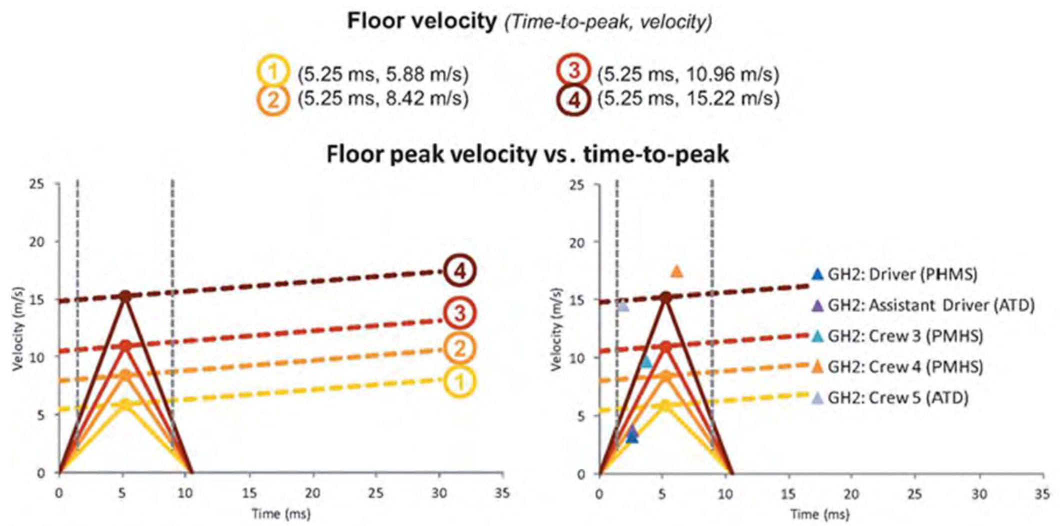
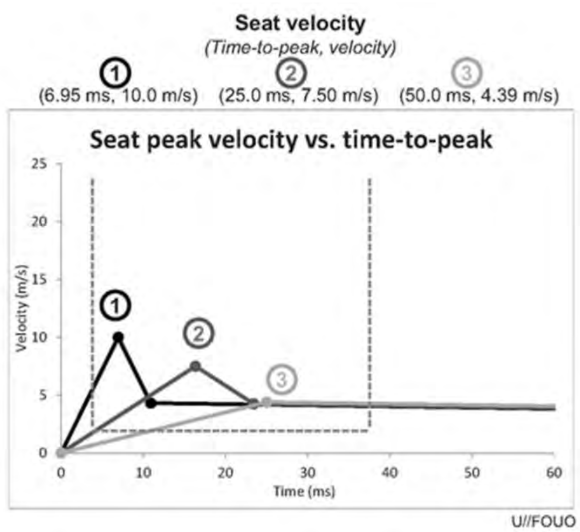


Figure 1: Calculated floor velocities vs. time to peak from Live Fire Test and Evaluation (LFTE) measurements [9]



(a)



(b)

Figure 2: Desired loading conditions for simulated UBB loading scenarios: (a) desired floor velocities and time to peak (b) desired seat velocities and time to peak

2.5 Occupant loading

The analysis of under body blast events is necessary in understanding the effects of blast detonations under vehicles on the human body. The response of the occupant inside the vehicle is influenced by both the local effect (shock and deformation) and the global effect (vehicle motion) of the vehicle mine detonation process (see Section 2). The human body or parts of the body can be loaded directly by the shock (primary effect) or by the local vehicle deformation (secondary effect) or indirectly by impacts against vehicle structure (tertiary effect). The severity of the threat, and therefore, the severity of the loads on the occupant, depends on the distance between the vehicle occupant and the detonation point as well as on the vehicle structure, the interior structure, like seat and seat mountings, and the floor plate configurations. When a seat or a footrest is mounted on or close to the deforming bottom plate large loads are most likely transferred to respectively the feet, the ankles, the legs and the lumbar spine. Additionally, the chance of injury depends on initial body posture, use of personal protection equipment and restraint systems. Also age, gender, health, training, etc., may influence the injury probability.

In general, the leg and foot/ankle complex are usually in the position closest to the detonation point and the deforming structure, so they are loaded first. When the feet are placed on the floor plate, they are loaded severely and accelerated rapidly. The loads can reach levels high enough to damage feet, ankles, legs and knees. Due to the acceleration induced by the floor, the legs move upwards with the risk of hitting other vehicle parts. The leg motion may also have its influence on the lumbar spine and other body parts. The pelvis can be loaded through either the lower extremities or the seat of the vehicle. The vertical acceleration and motion of the pelvis can cause a compression force in the lumbar spine, which can result in injury. For local effects, the maximum spine force is reached at about 20 ms [8] after detonation, for global effects the maximum will be at about 40 ms [8]. The pelvis acceleration and motion will also load the upper body parts, including the neck and the head. The whole body will be launched (mostly) vertically due to the seat impact. When no or inappropriate restraint systems are used, the head can hit the roof of the vehicle. Tests have proven that head contact with a stiff roof structure may cause high acceleration peaks in the head and extremely high loads in the neck. Such high neck loads are life-threatening and must be prevented. The detailed account of occupant loading for each body region is presented in the section 3.

2.6 Current experimental designs to simulate UBB loading

2.6.1 Test Rig for Occupant Safety Systems (TROSS)

The Test Rig for Occupant Safety Systems (TROSS™) (Figure 3) was developed by IABG (Lichtenau, Germany) to load a human surrogate with a force comparable to an AV blast mine detonated under a light military vehicle. This test apparatus consists of a membrane bottom plate. The footplate is loaded by scaled explosive charges under the bottom plate. Thus it can simulate actual explosion. The disadvantage of this design is that it is too stiff and does not represent the vehicle bottom. [10]

Figure 3: TROSS developed by IABG (Lichtenau, Germany)

2.6.2 The Defence R&D Canada air canon

This device was developed by Canadian Defence R&D. It consists of an air cannon that drives a piston and sled along a rail towards the target. Prior to impact, the piston is arrested and the sled, to which the impact face is mounted, is allowed to continue unassisted to impact the target (Figure 4). The impactor can allow for either a part of or the whole ATD to be used during testing. The loading curves (e.g. acceleration, velocity time histories) obtained with this device are not available in the literature hence it is difficult to access the capabilities of this device and its relevance to UBB loading. [11]

Figure 4: The Defense R&D Canada air canon setup

2.6.3 Wayne State University horizontal sled system

The Wayne State University horizontal sled system (Figure 5) uses an impactor that is tuned using an absorption material to obtain a loading profile. The impactor is driven by gas gun. The test method requires a completed ATD to be positioned horizontally on its back. The center of the heel of the foot of the impacted leg is aligned with the center of the plate. This meant that the impact occurred straight through the shaft of the lower leg, which insured acceleration and force curves with a single peak. They can achieve seat acceleration of 400G and floor acceleration of 1000G. The only concern is the rise time to achieve these peaks (they are in the range of 4-6 msecs). [12]

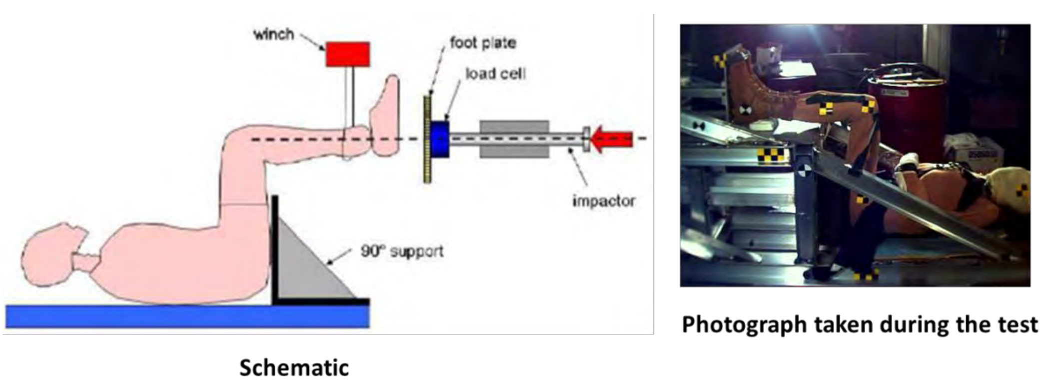
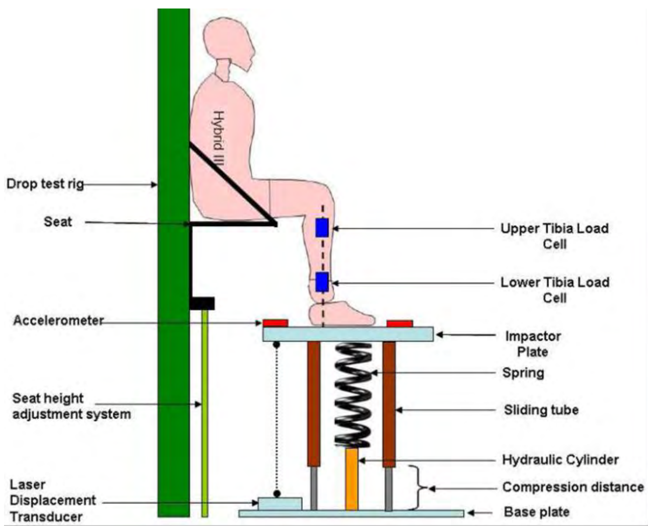


Figure 5: Wayne State University horizontal sled system

2.6.4 LLI developed by CSIR, South Africa

Lower leg impactor (LLI) was developed by the Council for Scientific and Industrial Research (CSIR), South Africa. It consists of a steel plate that is driven by a compressed spring. The whole

or part of the ATD can be mounted in a vertical position over the impactor (Figure 6). The LLI can provide a maximum peak velocity of 7.2 m/s [13, 14]. Other details like time to achieve peak velocity and peak acceleration are not known from the available literature regarding this device.



Schematic

Photograph taken during the test

Figure 6: Experimental testing setup for testing with the LLI developed by CSIR, South Africa

2.6.5 Army Research Laboratory's (ARL's) mechanical shock facility

ARL's mechanical shock facility employs several shock machines with the capability of testing seated crew members to range of levels and durations. Vertical and horizontal shock machines can be used to simulate various UBB scenarios. Vertical shock machine (Figure 7) is a drop tower and produce velocities of 3-9 m/s with the drop heights of 20-70 inches. To simulate lateral impacts horizontal shock machine is used. The horizontal shock machine can produce velocities between 5 m/s to 9 m/s. Besides ARL, other institutions such as University of

Michigan Transportation Research institute [UMTRI] use vertical drop towers to simulate UBB loading. [15]

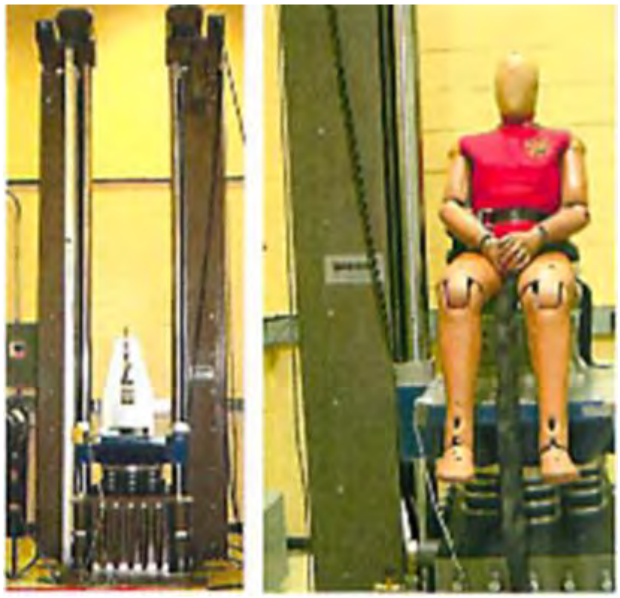


Figure 7: Lansmont vertical shock machine (left) and mounted ATD (right) at ARL's mechanical shock facility

2.6.6 UVA Under-Body Blast Simulator - ODYSSEY

The device consists of air cannon that drive a piston along a rail towards the target. The accelerations of 500-1800 G can be achieved in 1.5 msec.

2.6.7 Acceleration sleds

The device consists of acceleration sled driven by pneumatic accelerator or by pendulum. In the pneumatic accelerator designs pneumatic accelerator uses pressurized air to propel the sled to desired velocities. The pendulum type of designs consists of mini sled pendulum device and transfer pendulum apparatus. The velocities in the range of 3.6 m/s to 15.8 m/s can be obtained with this device. The rates at which these velocities can be obtained are not reported in the literature. [16, 17]

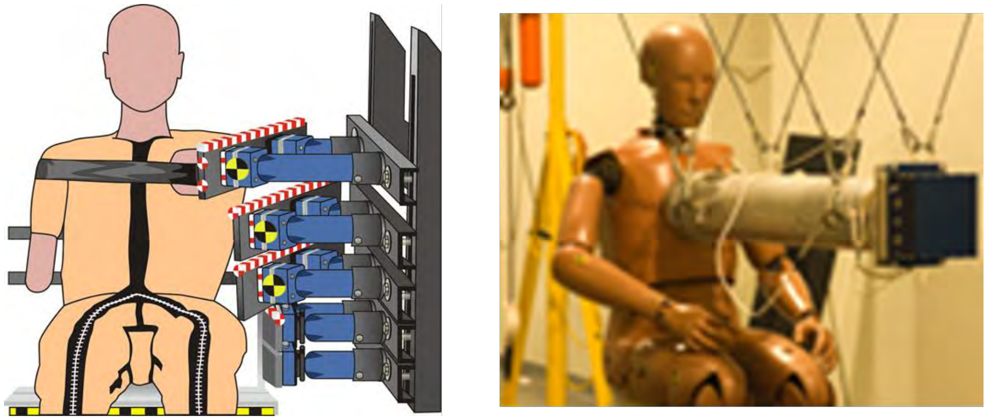


Figure 8: Sled and pendulum devices at Medical College of Wisconsin

2.6.8 Charge Simulators

Charge simulators can also be used to simulate UBB loading (e.g. Anderson2011). The limitation of charge simulators is that only small loads can be simulated due to restrictions on the mass of charge that can be used in the laboratory setting. [18]

2.6.9 University of Nebraska's AENID device

The UNL AENID (Figure 9) has been specifically designed to simulate UBB loading. AENID is loaded by air shock using 28"x28" shock tube. AENID can simulate range of velocities (i.e. 3-15 m/sec) with rise time in the range of 0.1-5 msec.

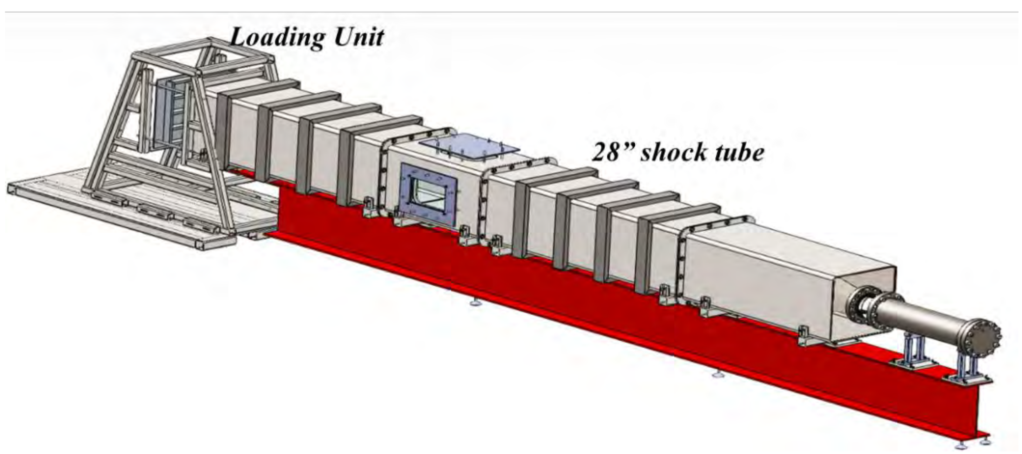


Figure 9: UNL AENID device

3 Current ATD Used for Underbody blast

The use of IED and mines has resulted in the exposure among US combat vehicles to underbody blasts (UBBs). When exposed to these blasts, an occupant inside the vehicle will experience a wide range of physical injuries. Increased knowledge of specific injury mechanisms and associated injury tolerances permits engineers to develop effective injury countermeasures. Four surrogates, each with a distinct set of inherent advantages and disadvantages, are commonly employed to simulate humans: cadavers, Anthropomorphic Test Devices (ATDs), animal models, and computational models [19].

ATD also known as test dummy is a sophisticated mechanical representation of a real human body in anthropometry, structural response, and joint kinematics. According to Crandall and his associates, a dummy should not only possess internal biofidelity (accurate kinematic and mechanical representation of humans) but also external biofidelity (interaction with the surrounding environment such as vehicle roof) to replicate human behavior under loading [19]. In order to achieve such a biofidelity, modern dummy is not a simple anthropometric manikins but rather a complex device made from metal, polymer composites, and foams. These dummies are instrumented throughout the body which gives kinetic and kinematic measures during experimentation [8]. Given the degree of complexity, the costs of instrumented dummies can be hundreds of thousands of dollars; however, they are reusable.

3.1 Comparative Studies: Biofidelity of Various ATDs

Hybrid III ATD is the state of the art frontal crash test dummy used for automotive crash safety testing. Although not designed to assess injuries from underbody blast, they are used either in experimentation or in simulation (computer models) by various research groups and defense organizations for injury predictions for occupants of vehicles from landmines and IEDs [9, 10, 12, 13, 20, 21]. THOR-Lx and Denton leg of Hybrid III are two commonly available surrogate legs used in the testing of vehicle occupant injury in a mine blast. Bir et. al assessed the ability of surrogate lower limb to predict injury due to foot/floor plate impact in military vehicles during UBB. They evaluated the lower legs of the two biomechanical surrogates: 50th percentile

Hybrid III and Test Device for Human Occupant Restraint (THOR). They applied two loading condition: (a) a 24 Kg mass impacting at 4.7m/s and (b) a 37 Kg mass impacting at 8.3 m/s and recorded the tibial response. Figure 10 shows the tibial force recorded on the Hybrid III for the loading condition (a) is over 10 kN whereas in the case of THOR leg it was 3.84 kN, which lies within the bounds of the PMHS results [12].

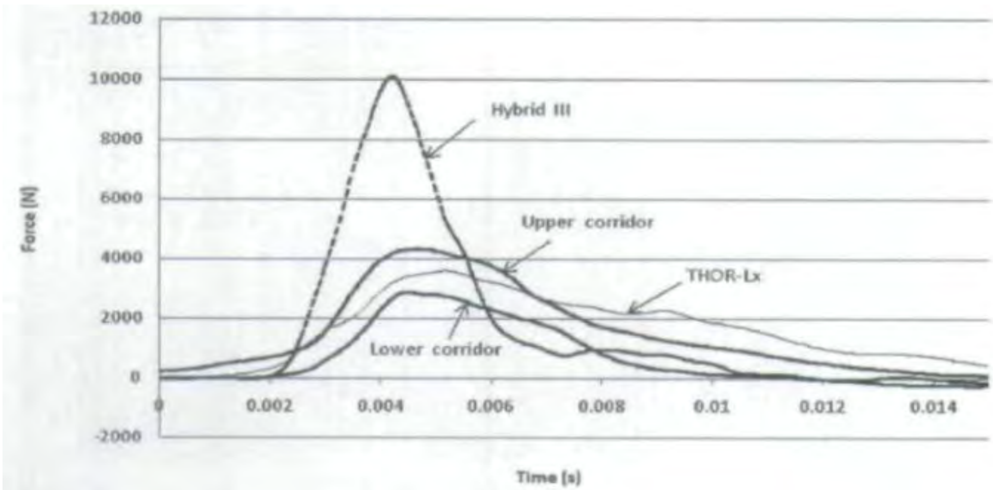


Figure 10: Comparison tibial force recorded in Hybrid III for a load of 24 kg mass impacting at 4.7 m/s, THOR-Lx and PMHS (reprint [12]).

Van der Horst and his co-workers did a similar study to evaluate the biofidelity of THOR-Lx and Hybrid III lower leg using TROSS to apply the loading. The ratio between the tibia axial force measured on the Hybrid III and the THOR ranged from 1.4 to 2.1 [10]. Pandelani used LLI (lower leg impactor) to compare the biofidelity of Mil-Lx and THOR-Lx. Peak velocity of the plate was varied between 2.6 m/s to 7.2 m/s. The MiL-Lx peak tibia compressive load, loading rate, and duration compare favorably to the PMHS non-injury corridor. The THOR-Lx average upper tibia load was calculated to be 6.4 kN, which falls just outside the upper bounds of the PMHS corridor. They concluded that Mil-Lx improves the accuracy and sensitivity needed to evaluate blast mitigation technologies designed to reduce injury to occupants of vehicles encountering AV landmines [21]. From these studies, it can be seen that THOR-Lx and Mil-Lx has a better overall biofidelity compared to Hybrid III; however, latter is most frequently used in for UBB testing in both experiments and computational models.

3.2 ATDs in Computer Models

ATDs are not only used in physical experiments but also in computer models. They serve the same purpose as the physical model, that is, to measure the kinetic and kinematic response of the body parts. In most cases, these models were used to evaluate the design changes to vehicle hull, seat energy management. Arepally and his colleagues used validated MADYMO Hybrid III 50th percentile male ATD model, which is capable of calculating accelerations, forces, and moments experienced by the major body regions: head, neck, thorax, lumbar, pelvis, femur, and lower extremities. With these results, they were able to evaluate the seat energy management and concluded that except lower tibia value, loading in all other body parts were lowered with the implementation of their seat energy management [22]. Henisey used Hybrid III dummy to study the extent of lower extremity injury for four different hull geometries. Author concluded that there exists a positive correlation between floor plate displacement and loading on the ATDs legs [23]. Hoffenson et al used a two-stage simulation to examine the impact of vehicle weight and seating design variables on occupant injury. They used a 50th percentile male Hybrid III finite element model to conduct optimization studies and concluded that the optimization of the seating system and increasing the weight of the vehicle should lower the leg injuries [24].

Van der Horst and his associates used 50th-percentile male Hybrid III dummy to do a parametric study of the initial lower leg position and its influence on the loads experienced by the lower leg. They concluded that positioning on lower leg loading during a mine strike has a considerable influence of occupant lower leg injury [10]. Kendale and his colleagues conducted a simulation study to understand the effects of seat attachment (floor vs. sidewall) inside the vehicle and seatbelt on lower extremity injuries. A 50th-percentile Hybrid III model in a MADYMO/LS-DYNA coupled environment was used with LS-DYNA modeling the explosion and MADYMO modeling the occupant kinematics. They concluded from the simulation that use of seat belt may not reduce lower extremity injuries significantly but it will position the occupant favorably in case of rollover events. Seat attachment location on the floor instead of on the sidewall reduced tibia injuries marginally [25].

4 Thoraco-lumbar Spine

4.1 Injuries in Theater

Spinal injuries sustained in underbody blast exposures are classified as tertiary blast injuries and result from transfer of primarily vertical vehicle accelerations to the occupant via the seat. Additionally, an unrestrained occupant may contact other structures within the vehicle, e.g. roof, complicating the injury mechanism[26]. Spinal injury may also result from vehicle slam-down. Spinal injuries, both stable and unstable, are more frequent secondary to IED etiology than any other mechanism [27]. Lower lumbar spine burst fracture and lumbosacral dissociation are rarely encountered in the civilian population, but increases in the incidence of these injuries have been documented in GWOT. Exposure to high energy IED blast is usually causative [28].

IED attacks against mounted soldiers can produce thoracolumbar fractures through multiple mechanisms. A retrospective review of 12 male patients sustaining 16 thoracolumbar fractures identified flexion-distraction, compression and burst type injuries [29]. A radiology-based retrospective analysis of United Kingdom service members also demonstrated flexion-distraction, compression and burst type thoracolumbar injuries secondary to explosive exposure [30]. Vertebral body fractures, including compression and burst, were the most common injury with blunt etiology in a comparison of blunt and penetrating combat spinal injuries. Injuries to the thoracolumbar spine accounted for nearly 70% of these injuries. Blast exposure was the mechanism of injury in 85% of spine trauma soldiers[31]. In a retrospective review of 32 patients sustaining combat related thoracolumbar burst fractures nearly 60% had isolated low lumbar (L3-5) injuries. The most common etiology was IED blast with a motor vehicle component. The authors theorize that the rigidity of body armor influences the mechanics of the thoracolumbar spine such that the typical transition zone at the thoracolumbar junction is transferred caudally into the lower lumbar spine, thereby shifting the incidence of burst fracture to the lower lumbar spine [32].

Injury analysis of 555 mounted casualties in 296 UBB events was conducted for the WIAMan project. Twenty percent of WIA cases sustained lumbar spine fractures. Thirty percent of KIA cases sustained lumbar spine fractures. There were 215 fractures in the WIA group with 41% involving the vertebral body. Forty-six percent of fractures were relatively minor transverse process injuries. This percentage may be inflated by the common appearance of multiple transverse process fractures in lumbar spine trauma patients. Only 8% of fractures involved the posterior elements including the pedicles, facets, laminae, and spinous processes. In contrast, there were 109 fractures in the KIA group with 21% involving the vertebral body. Seventy percent of fractures were identified in the transverse processes. The remaining posterior elements constituted only 4% of diagnosed fractures (Figure 11) [6].

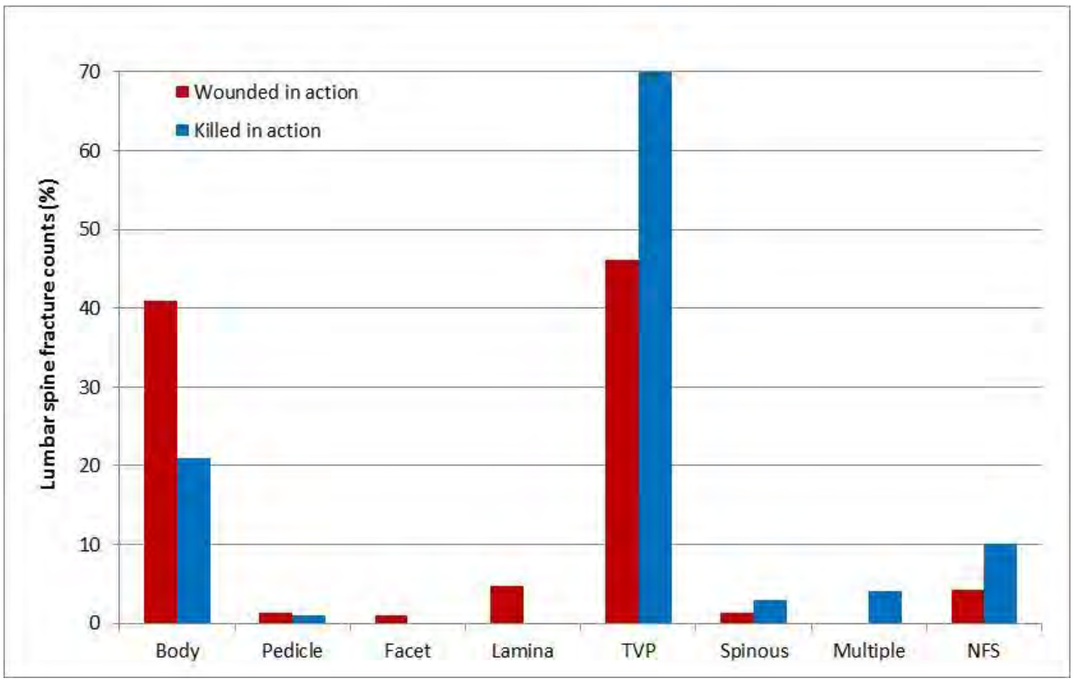


Figure 11: Distribution of lumbar spine fractures by type

Although lumbar transverse process fractures have been associated with serious abdominal injury after high energy trauma [33], it has been demonstrated that such fractures at lumbar levels 1-4 are easily produced experimentally by applying tensile loading through the lumbar fascia [34]. However, transverse process fracture at the L5 level with iliolumbar ligament injury can be associated with lumbosacral dissociation [35]. Although more numerous, isolated lumbar transverse process fractures represent a lower severity, threat to life, and potential for neurologic insult than vertebral body injuries. Additionally, transverse process fractures may be produced by secondary loading vectors that differ significantly from the load path inducing more serious vertebral body fractures.

When transverse process fractures are excluded, vertebral body injuries comprised the majority of fractures in both groups (Figure 12) with injury distribution favoring upper/middle lumbar levels over lower levels[6].

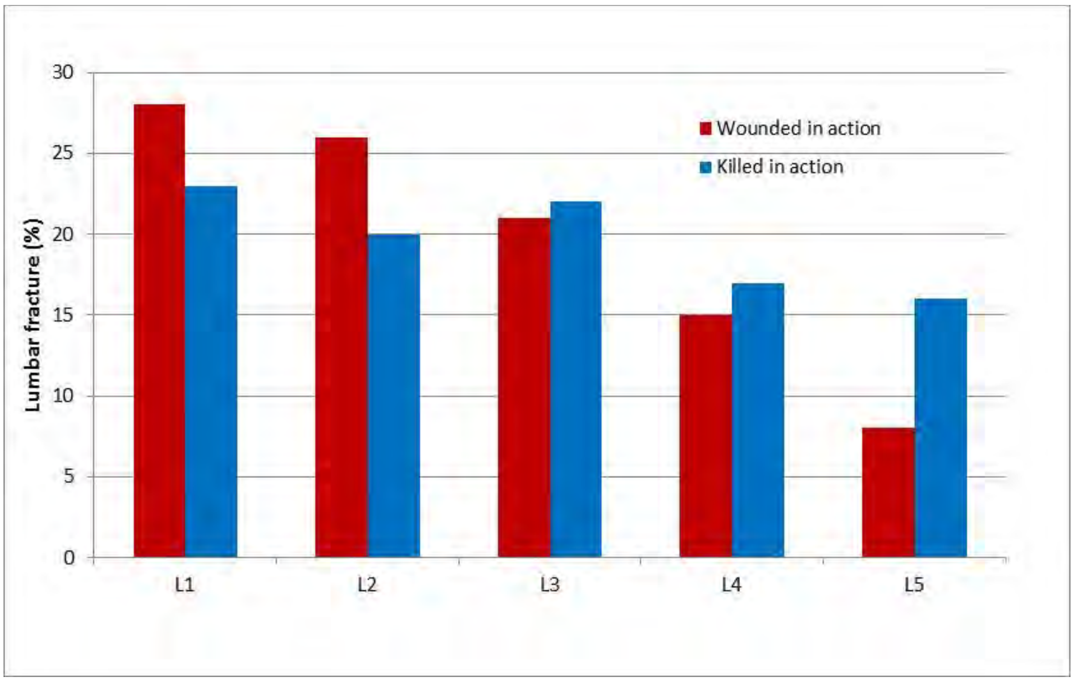


Figure 12: Distribution of lumbar vertebral body fractures by level

4.2 Thoraco-lumbar Spine Injury Assessment using ATDs

The spinal column is one of the vulnerable parts of crewmembers in vehicular mine incidents due to different loading mechanisms in the cranial (axial) direction. However, there is not a lot of injury risk study that has been done on the lumbar spine using ATDs. Table 1 shows the injury assessment reference values (IARVs) for lumbar spine recommended by the army for determining vehicle occupant injury [36]. In both axial and lateral directions, the minimum force beyond which the spine experiences permanent damage is 3.8 kN load for 30 to 45 ms duration.

With a reduction in the time duration, the critical force for injury increases. Similarly, the minimum bending moment along x, y and z direction are 0.675, 1.235 and 0.370 kN-m respectively.

Kendall and associates used an instrumented 50th percentile male Hybrid III dummy with the dummy being positioned on the seat and strapped with a lap belt. They determined the lumbar spine experienced approximately 7 kN load axially [25]. Alem used Hybrid III dummy to study the loading on the lumbar spine and he determined the peak lumbar forces were 9.60 kN [37]. Bird used Hybrid III dummy to UBB and determined the gross vertical motion will cause severe spinal injuries if the occupant is not restrained [9].

Loads with shorter duration (less than 10 ms) presume injury risk models, which consider the dynamic behavior of the thoraco-lumbar spine [8]. Hence, a dynamic model has to be employed to assess the injury of thoraco-lumbar spine. The Dynamic response index (DRI) is representative of the maximum dynamic compression of the spinal column and is calculated by describing the human body in terms of a lumped mass parameter model consisting of a mass, spring and damper [36]. Table 2 shows the army recommended IARVs for the seat DRI, which is 46G, 22G and 23G along forward, lateral and vertical directions respectively. These values are used as an input for determining the dynamic compression of the spinal column. However, the problem with using DRI for predicting thoraco-lumbar spine injury is the spine injury mechanism is force driven. Hence, using a model, which is based on another physical parameter than force, e.g. the pelvis acceleration or seat acceleration, may introduce uncertainties [8].

5 Pelvis

5.1 Injuries in Theater

Pelvic fractures sustained in combat often display high energy fracture patterns and typically have multiple associated injuries. It is not uncommon for service members to sustain multiple pelvic fractures secondary to underbody blast exposure, e.g., sacral and pubic rami fractures with dissociations of the sacro-iliac and/or pubic symphysis articulations. Fracture of the acetabulum has also been reported [38]. A study of combat-related pelvic fractures in service members that were KIA or died of wounds (DOW) during 2008 in OIF and OEF found that 30% of fatal casualties had sustained pelvic fracture. Sixty-five percent of nonsurvivors with pelvic fracture were mounted at the time of hostility related injury [39].

Table 1: Army recommended injury criteria of the lumbar spine for vehicle occupants in land mine explosion (reprint[36])

Hybrid III Simulant Response Parameter	Symbol (units)[a]	SAE Filter	Assessment Reference Values[b]
Lumbar spine lateral moment Lumbar spine flexion moment Lumbar spine extension moment	Mx (N-m) + My (N-m) - My (N-m)	CFC 1000 (1650 HZ)	675 N-m 1235 N-m 370 N-m
Lumbar spine shear force	Fx or Fy (N)	CFC 1000 (1650 HZ)	[c] 3800 N (45 ms), 5200 N (25-35 ms), 10700 N (0 ms)
Lumbar spine axial compression force	- Fz (N)		3800 N (30 ms), 6673 N (0 ms)
Lumbar spine axial tension force	+ Fz (N)		[c] 3800 N (45 ms), 10200 N(35 ms), 12700 N (0 ms)

[a] x = Longitudinal, y = Lateral, z = Vertical
[b] Exceeding values indicates a moderate to high risk of major injury
[c] Approximately 3.4 times neck force values
* Recommended deviations to referenced values.
DRI = Dynamic Response Index; CFC = Channel Frequency Class

A related study found that the mortality rate for service members sustaining combat related pelvic fracture with tertiary blast etiology was 93% over that same period [40]. Lumbosacral dissociation (LSD) injury has been associated with UBB exposure [41]. In LSD the blast-generated axial force is directed through the sacrum and pelvis producing characteristic sacral fracture with disruption of the iliolumbar and sacroiliac ligaments that contribute to lumbopelvic stability[35].

Injury analysis related to the WIAMan project demonstrated that 6% of WIA cases sustained pelvic fractures and these fractures comprised 3% of all injuries. On the other hand, 50% of KIA cases sustained a pelvic fracture, accounting for 7% of all injuries in this group. There were 47 fractures in the WIA group. The most commonly injured structures were the pubic rami and sacrum, which comprised 21% and 19% of fractures respectively. The most common injury in the KIA group involved the sacro-iliac joint, accounting for 20% of pelvic bony injury.

Fractures of the sacrum, pubic symphysis and pubic rami were diagnosed at a frequency of 14-16% each [6]. Pelvic fracture distribution is summarized in Figure 13.

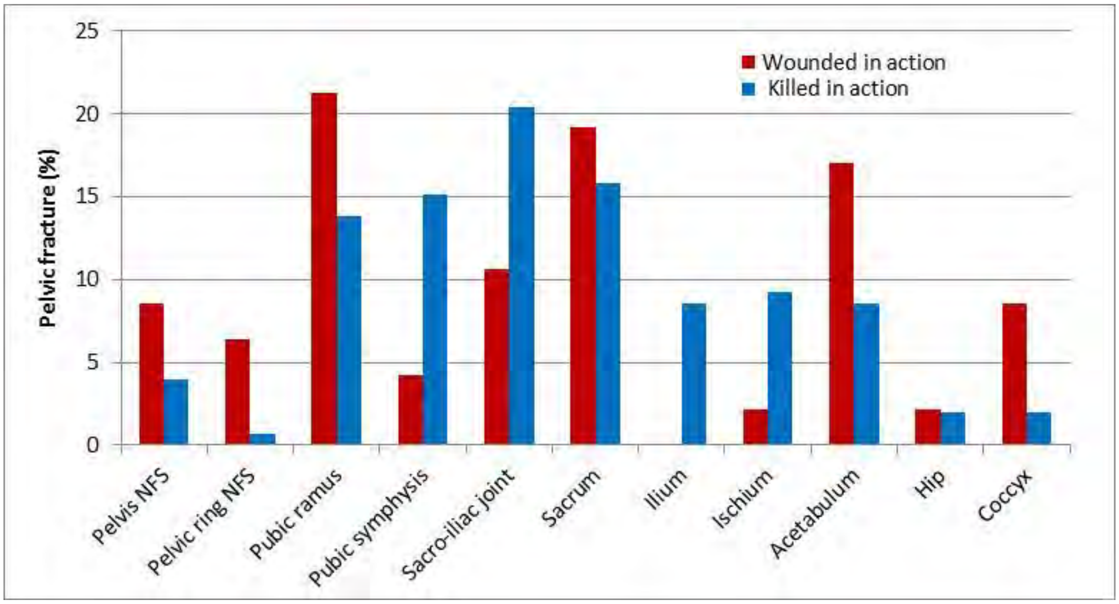


Figure 13: Distribution of injuries by pelvic component

5.2 Pelvis Injury Assessment using ATDs

The vertical acceleration and motion of the pelvis will cause a compression force in the lumbar spine, neck and head which can result in injury [8]. The pelvis can be loaded through either the floor (lower extremities) or the seat of the vehicle [42]. Table 2 shows the army recommended IARVs for the pelvis, which is 40G, 23G and 23G for 7 ms along forward, lateral and vertical directions respectively. Alem used Hybrid III dummy to study the pelvis acceleration along Z (vertical), Y (lateral) and X (forward). Accelerations at the pelvis were determined to be 85 Gx, 38 Gy, and 42 Gz, all of short durations (under 5 ms) occurring within the first 10 ms after the blast. Peaks of longer pulses (20-30 ms) occurred approximately 25 ms post impact and measured 43 Gx, 8.9 Gy, and 32 Gz [37]. Although, it is essential to understand the pelvic loading and acceleration, very little work has been carried out using ATDs.

Table 2: Army recommended injury criteria of pelvis for vehicle occupants in land mine explosion (reprint[36])

Hybrid III Simulant Response Parameter	Symbol (units)[a]	SAE Filter	Assessment Reference Values[b]
Pelvis forward acceleration	Ax (G)	CFC 180	40 G @ 7 ms
Pelvis lateral acceleration	Ay (G)	(300 HZ)	23 G @ 7 ms
Pelvis vertical acceleration	Az (G)		23 G @ 7 ms
Seat (Pelvis) forward DRI	DRI – x (G)	CFC 180	35, 40, 46 Gx (low, med, high risks)
Seat (Pelvis) lateral DRI	DRI – y (G)	(300 HZ)	14, 17, 22 Gy (low, med, high risks)
Seat (Pelvis) vertical DRI	DRI – z (G)		15, 18, 23 Gz (low, med, high risks)

[a] x = Longitudinal, y = Lateral, z = Vertical
[b] Exceeding values indicates a moderate to high risk of major injury
[c] Approximately 3.4 times neck force values
* Recommended deviations to referenced values.
DRI = Dynamic Response Index; CFC = Channel Frequency Class

6 Lower Extremity

6.1 Injuries in Theater

The foot/ankle/leg complex of the lower extremity is the body region most closely associated with the vehicle structure exposed to the brunt of the UBB loading. Therefore, it is the region exposed to highest rate of acceleration and compressive load [43].

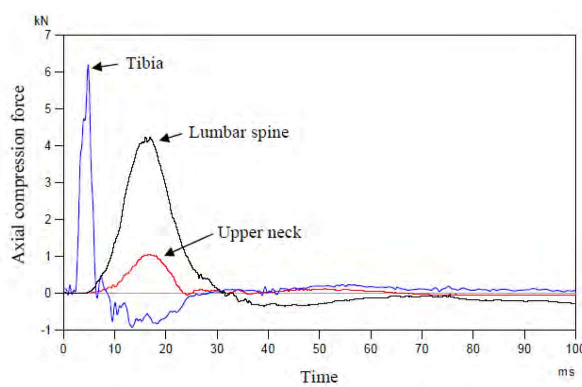


Figure 14: Magnitude and timing of compressive load profiles in UBB (reprint [44])

A retrospective analysis of extremity injuries in OIF and OEF found that 1281 service members sustained 454 lower extremity fractures involving the proximal femur to the foot. The tibia and fibula accounted for 48% of fractures and the most common mechanism was exposure to IED detonation [45].

Eighteen percent of WIA cases sustained lower leg fractures and these fractures comprised 8% of all injuries. On the other hand, 35% of KIA cases sustained lower leg fractures, accounting for 4% of all injuries in this group. The tibia and the fibula each accounted for 43% of lower leg fractures in the WIA group. The remainder, 14%, was attributed to the knee. The distribution was similar in the KIA group with the fibula, tibia and knee accounting for 47%, 42%, and 10% respectively (Figure 15) [6].

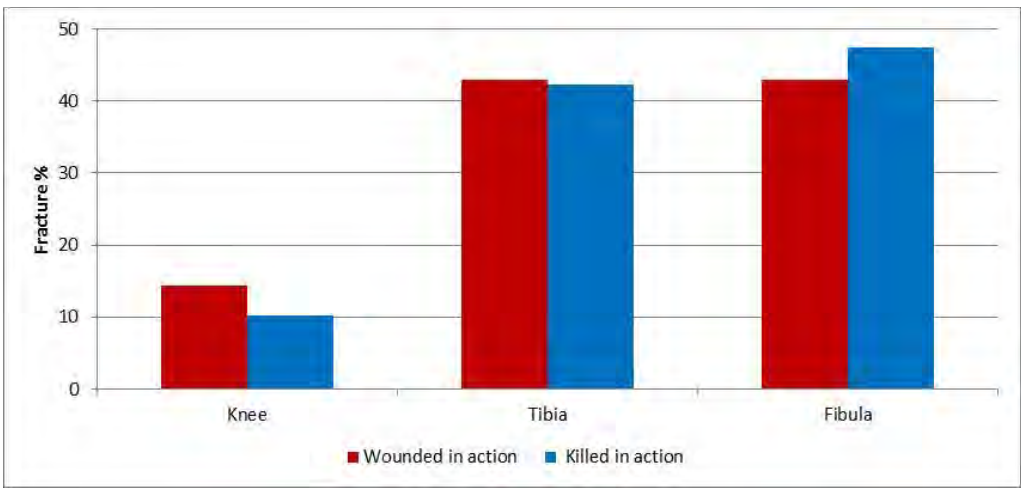


Figure 15: Distribution of lower leg fracture by anatomy involved

Calcaneal fractures can result from the acceleration and intrusion of the vehicle floor into the passenger compartment during UBB. A prospective study of UK service members sustaining calcaneal fracture secondary to UBB during a 2 year period identified 40 fractures in 30 patients. Eight-seven percent of these fractures were intra-articular, involving the subtalar joint, calcaneocuboid joint, or both. Eighty-five percent of calcaneal fractures were associated with injuries involving the ipsilateral foot and ankle leading to a 45% amputation rate [46].

Twenty-nine percent of WIA cases sustained foot-ankle fractures and these fractures comprised 21% of all injuries. On the other hand, 33% of KIA cases sustained pelvic fracture, accounting for 6% of all injuries in this group. There were 268 fractures in the WIA group. The most commonly injured structures were the calcaneus and talus, accounting for 30% and 16% of fractures respectively. Malleolar fractures comprised 14% of injuries. The most common injury in the KIA group involved the tibia, accounting for 27% of fractures while the calcaneus accounted for 23%. Fractures of the fibula and talus were sustained at a frequency of 14-15% each (Figure 16) [6].

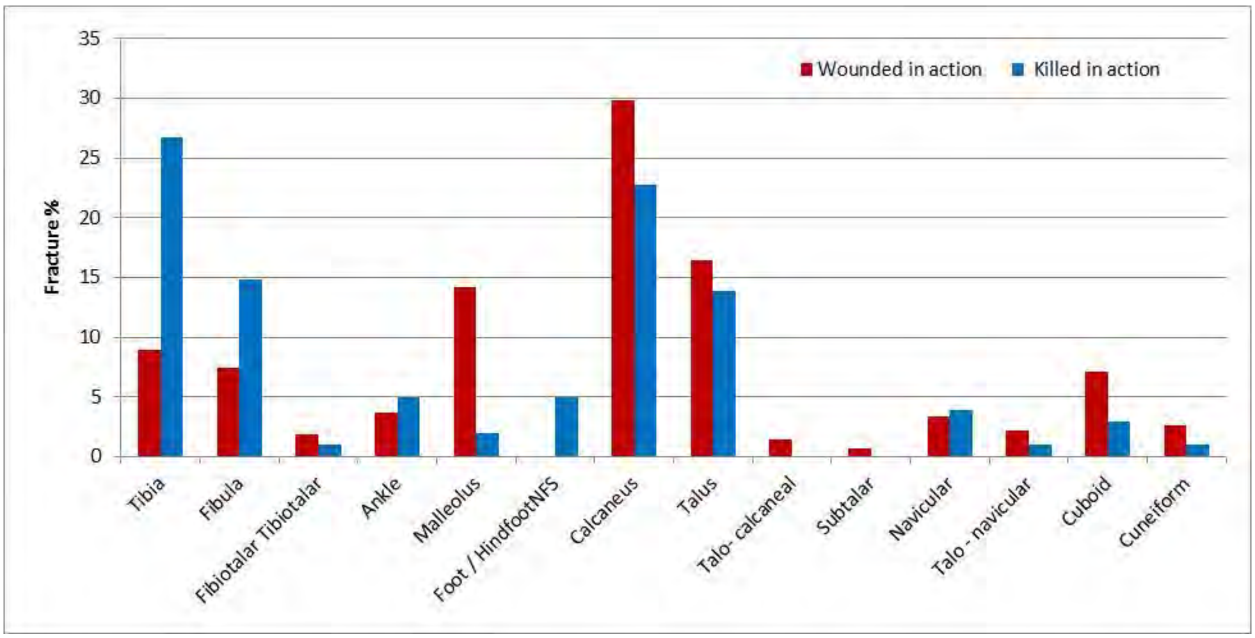


Figure 16: Distribution of foot/ankle fracture by anatomy involved

6.2 Lower Leg Injury Assessment using ATDs

The mechanism of loading on the lower leg during an anti-vehicular blast is comparable to those in the frontal car crash [8]. When a seat or a footrest is mounted on or close to the deforming bottom plate large loads are most likely transferred to feet, ankles and the legs [42]. Table 3 shows the IARVs for the tibia and femur, which is 7.5 kN at 10 ms and 9 kN at 0 ms.

Bird in his work used Hybrid III dummy to study right femur, left tibia and right tibia compression [9]. He determined that the floor acceleration and deformation from landmine detonations along with gross vehicle motion caused substantial lower leg injuries to occupant. Manseau and Keown used instrumented Hybrid III lower leg and subjected it to dynamic axial impacts at various severity levels mimicking anti-vehicular blast landmines. They used this data to develop a transfer function between Hybrid III tibia response and injury severity. Results show that peak axial force correlates well with injury severity [20].

Pandelani and his associates used LLI to determine the loading in Hybrid III dummy tibia with and without surrogate skin. They used two velocities to the impactor plates 2.6 and 3.4 m/s and determined the corresponding force to be 6.17, 11.12 kN and 5.10, 10.38 kN for with and without surrogate skin respectively [13].

Table 3: Army recommended injury criteria of the lower leg for vehicle occupants in land mine explosion (reprint[36])

Hybrid III Simulant Response Parameter	Symbol (units)[a]	SAE Filter	Assessment Reference Values[b]
Femur or Tibia axial compression force	Fz (N)	CFC 600 (1000 HZ)	7562 N (10 ms), 9074 N (0 ms)
Tibia axial compressive force combined with Tibia bending moment	F (N) M (N-m)	CFC 600 (1000 HZ)	F / Fc – M / Mc < 1 Where: Fc = 35,584 N and Mc = 225 N-m

[a] x = Longitudinal, y = Lateral, z = Vertical
[b] Exceeding values indicates a moderate to high risk of major injury
[c] Approximately 3.4 times neck force values
* Recommended deviations to referenced values.
DRI = Dynamic Response Index; CFC = Channel Frequency Class

Ahmed and colleagues used 50th percentile male Hybrid III dummy for the characterization of the LLI, an underbody blast loading simulator at various positions. They determined the lower leg forces to be between 5 to 10 kN at four different positions [47]. Kendale and associates used an instrumented 50th percentile male Hybrid III dummy with the dummy being positioned on the seat and strapped with a lap belt. The dummy measured extreme high loads in the lower legs due to the swinging floor plate. Axial compression forces in the lower and upper part of the tibia in both legs were loaded more than 15 kN [25].

7 Conclusion

The research area of underbody blast and vehicle mine protection is relatively new. Efforts to prevent and mitigate these injuries have been hampered by a lack of knowledge about injury mechanisms, the effects of UBB on the human body and an inability to adequately measure those effects in a live fire test and evaluation. It is known that UBB experienced on the battlefield exert forces on occupants of ground combat vehicles that are of higher magnitude, shorter duration and different directions than forces in civilian car accidents. However, when testing armoured vehicles for safety during UBB events, the researchers are still using anthropometric test devices (ATD) designed for civilian car accidents even though they were not designed or validated for UBB events [14]. Hence it is important to design and validate dummies, which has internal and external biofidelity to replicate human behavior under the UBB type of loading.

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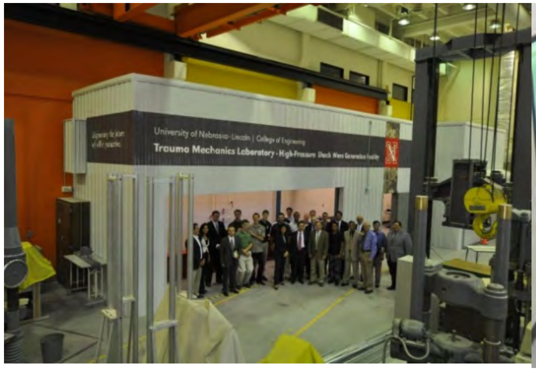
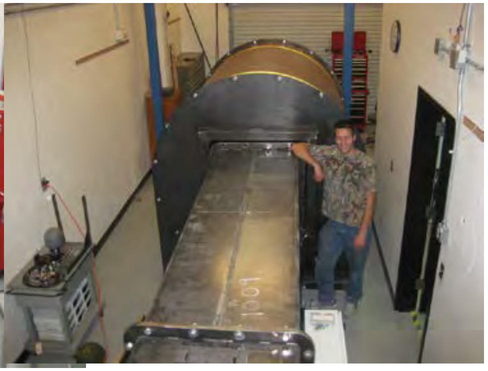
Appendix B

Design and Testing of AENID

Injury Probability Curves Using AENID (Advanced Energetic Impact Device)

Test Results with AENID
(as a part of Final Report-July 2014)
Namas Chandra-PI (presently at NJIT)





Presentation outline

- Objectives of tests
- Description of test apparatus
- Description of seating procedure
- Data collection methodology
- Data analysis algorithm
- Summary of tests
- Comparison of high energy input test loading pulse and dummy response with live fire test
- Summary of dummy responses
- Conclusion

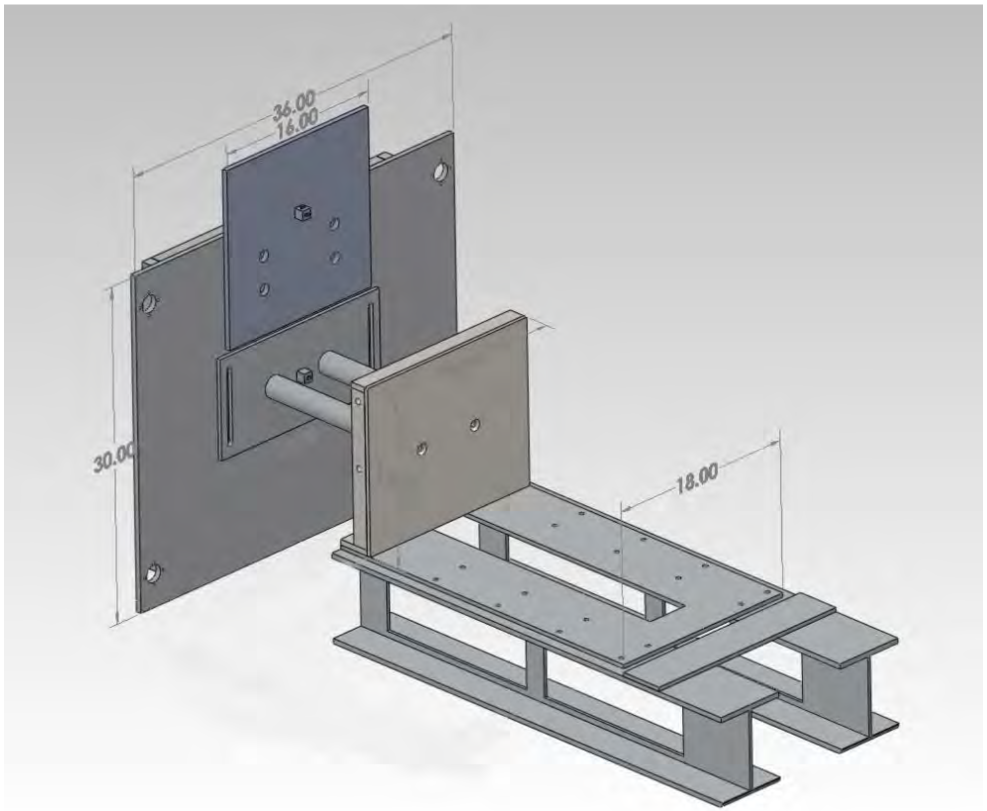
Objectives of tests

- Conduct whole body tests using an instrumented H3 dummy.
- Dummy has Mil-LX on left side and standard H3 legs on the right.
- Expose dummy to realistic UBB pulses using AENID.
- Compare responses of Mil-LX with standard H3 leg under realistic UBB conditions.
- Summarise responses of the dummy, develop response corridors.
- Develop parameters for component tests.

Description of test apparatus

- Seat and loading plate design
- Seat instrumentation
- Loading plate design

Seat and Loading Plate Design



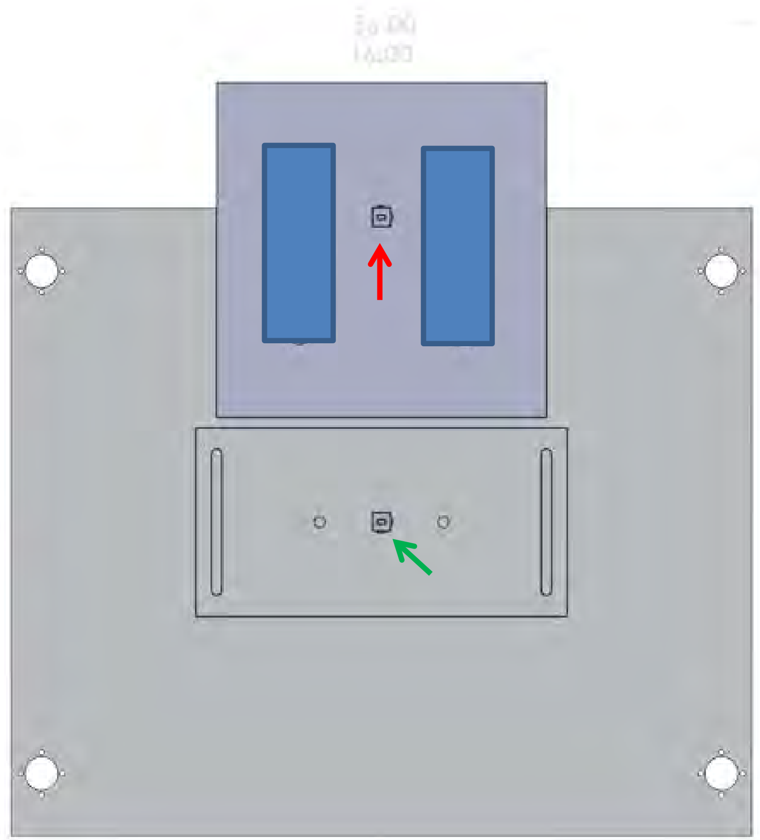
- Image at left shows the seat and loading plate. The loading plate is connected to the seat through 2 “stems.” This design allows the seat to push away from the loading plate
- Seat weighs approximately 42 kg
- Loading plate weighs approximately 45 kg

Seat Instrumentation

Sensor Type	Sensor Location	Axis
Accelerometer	Seat bottom - centered between seat stems (red arrow)	Az

Loading Plate Design

Sensor Type	Sensor Location	Axes
Accelerometer	Foot plate center at surrogate midfoot level (red arrow)	Ax, Ay, Az
Accelerometer	Loading plate center at seat stem level (green arrow)	Ax, Ay, Az
Contact switch	Foot plate corresponding to R & L feet (blue shading)	N/A



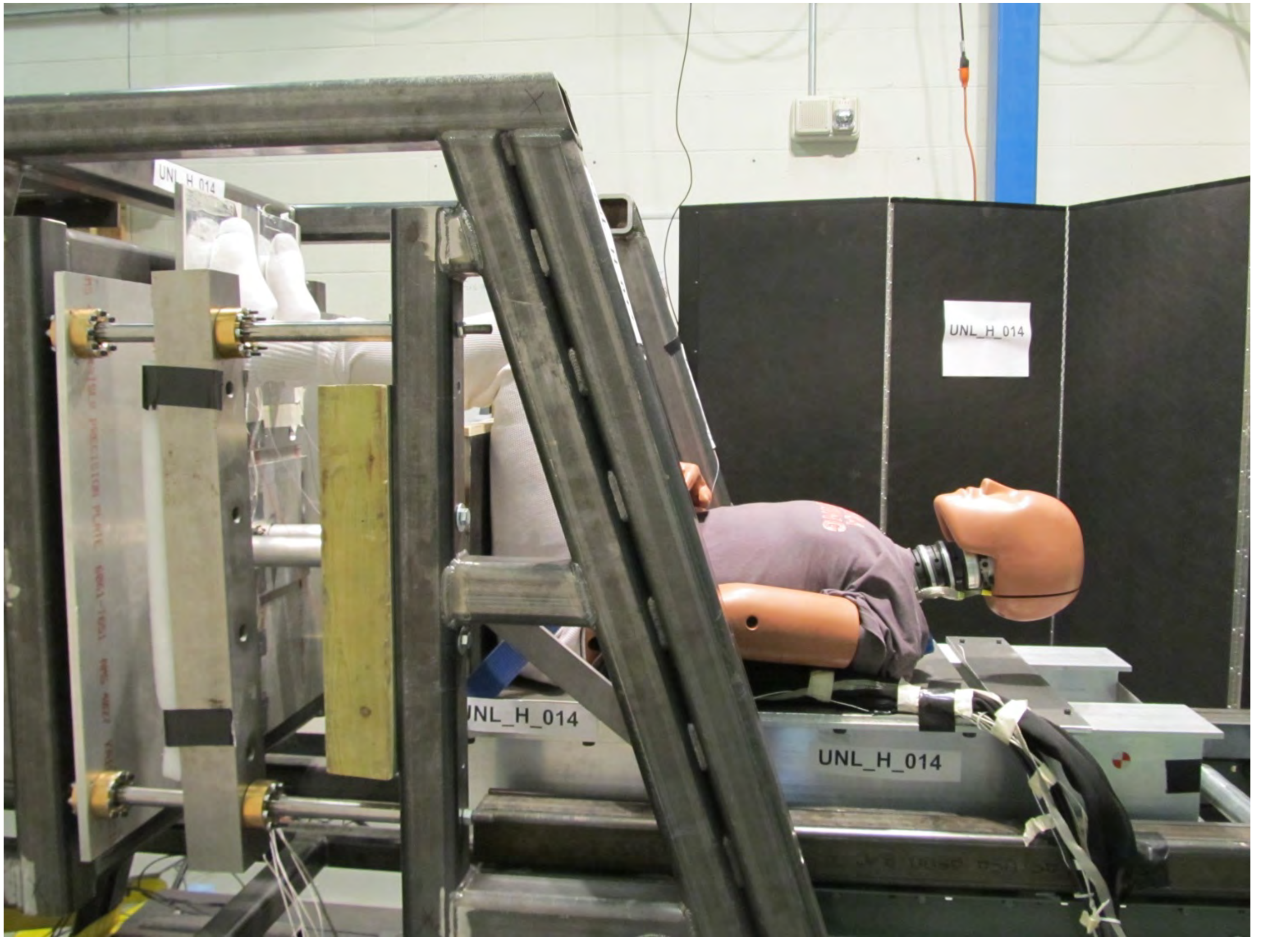
Description of seating procedure

- Seating procedure is described and pictures are provided to show seated dummy.
- Picture showing camera placement is provided

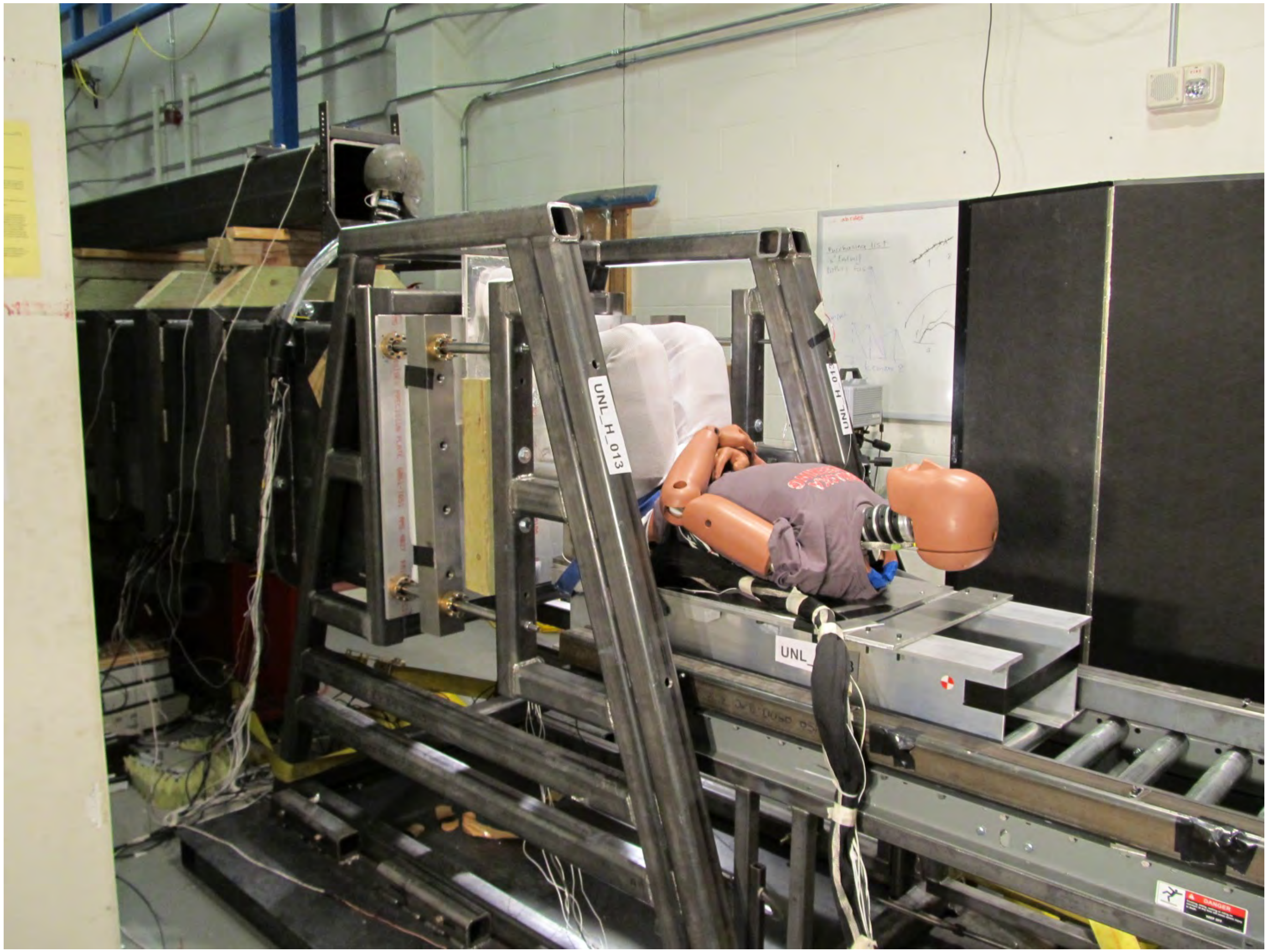
ATD Positioning Procedure

- Confirm load cell polarities through dummy manipulation
- Set friction in HIII joints to 1g
- Place ATD in seat
- Align ATD midsagittal plane with seat center longitudinal plane
- Position ATD without gaps between pelvis and seat bottom and back
- Restrain ATD with 2” lap belt
- Adjust pelvic angle to 50 ± 2.5°, measured with H-point tool
- Position ATD knees so outside flange distance = 270 mm
- Position lower extremity in 90°-90°-90° upright posture
- Four and five point belts will be accommodated in the seat design

ATD Initial Positioning



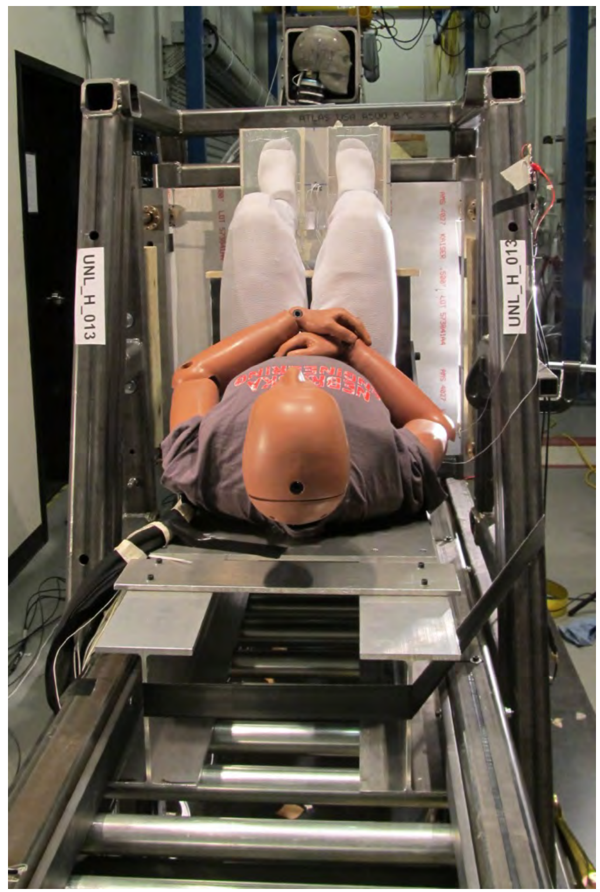
ATD and Seat on Rollers



High speed camera placement

Overhead view- Photron Fastcam SA3
640x1024, 1k fps

Side view- Photron
Fastcam SA1
1024x672, 1k fps



Loading plate - Photron
Fastcam SA3
640x880, 10k fps

Data collection methodology

- List of H3 sensors is provided
- Test procedure is summarised
- Data acquisition procedure is summarised

HIII Instrumentation

Channel count	Sensor Type	Sensor Location	Axis	Unit(s)
3	Accelerometer	HIII Head	Ax, Ay, Az	G
9	Load cell	HIII Upper Neck	Fx, Fy, Fz, Mx, My, Mz	N, Nm
12	Accelerometer	HIII Chest	Ax, Ay, Az	G
18	Load cell	HIII Lumbar	Fx, Fy, Fz, Mx, My, Mz	N, Nm
21	Accelerometer	HIII pelvis	Ax, Ay, Az	G
27	Load cell	HIII Femur - Right	Fx, Fy, Fz, Mx, My, Mz	N, Nm
32	Load cell	HIII Tibia - Upper Right	Fx, Fy, Fz, Mx, My	N, Nm
37	Load cell	HIII Tibia - Lower Right	Fx, Fy, Fz, Mx, My	N, Nm
42	Load cell	MIL-LX Tibia - Upper Left	Fx, Fy, Fz, Mx, My	N, Nm
47	Load cell	MIL-LX Tibia - Lower Left	Fx, Fy, Fz, Mx, My	N, Nm
50	Accelerometer	HIII Tibia - Right	Ax, Ay, Az	G
53	Accelerometer	MIL-LX Tibia - Left	Ax, Ay, Az	G
56	Accelerometer	MIL-LX Foot - Left	Ax, Ay, Az	G
57	Accelerometer	MIL-LX Heel - Left	Az	G

Test Procedure

- Perform trigger check for SLICE DAS, shock tube DAS and HS video cameras
- Confirm shock tube components are test ready
- Place surrogate in test position
- Perform still photography
- Assess lab security
- Confirm surrogate positioning
- Initiate filling of shock tube breech
- Fire shock tube

Data Acquisition Procedure

- DTS SLICE PRO
- Sampling rate = 500 kHz
- Built-in 4-pole Butterworth anti-aliasing filter
- 0.5 s of pre-trigger and 1.0s of post-trigger data
- Post acquisition filtration using SAE J211 CFC 60-1000

Test Measurements	**Channel Frequency Class (CFC)**
Head acceleration	1000
Neck forces	1000
Neck moments	600
Chest acceleration	180
Lumbar forces & moments	1000
Pelvic acceleration	1000
Femur & Tibia forces & moments	600
Tibia & Foot accelerations	1000

Data analysis algorithm

- Analyze the acceleration pulse and high speed video of the experiment simultaneously and identify acceleration pulse of interest.
- Calculate the velocity and displacement of the plate from the acceleration pulse using numerical integration.
- Calculate displacement of the plate from video analysis.
- Compare displacement obtained from measured pulse with the displacement obtained from video analysis. When displacements are close to each other it confirms that recorded data is accurate and calculations are correct.
- Analyze load cell data for trends and consistencies.
- The peak load recorded by the H-3 tibia load cells should occur when plate reaches common peak velocity.
- When separation takes place the load cell should read zero. Cross verify this from the video and pressure pad analysis.

Summary of tests

- The following full body instrumented dummy tests were conducted with the dummy seated on a rigid seat:
  – 3 repeat tests at low specific power input level.
  – 3 repeat tests at medium specific power input level.
  – 3 repeat tests at high specific power input level.
- Input pulse parameters are summarised in the next slide.

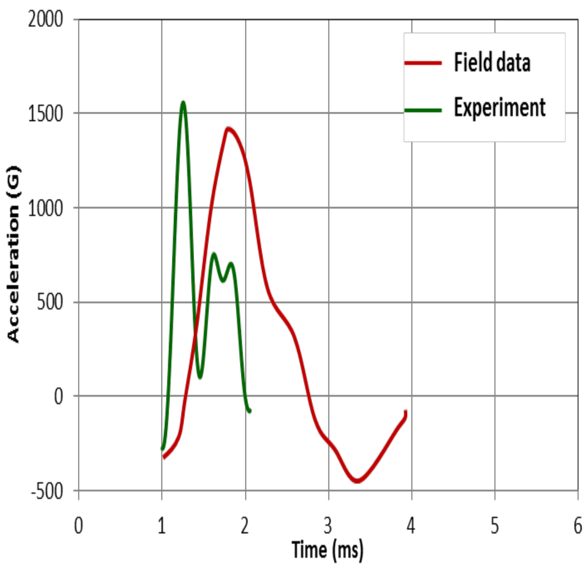
Center of plate

Membranes	Plate velocity, m/s	Time to peak, ms	Plate acceleration, g	Time to peak, ms
5	3.2	4.3	508	0.15
10	5	3.89	865	0.18
15	10	4.11	1600	0.24

Comparison with live fire test

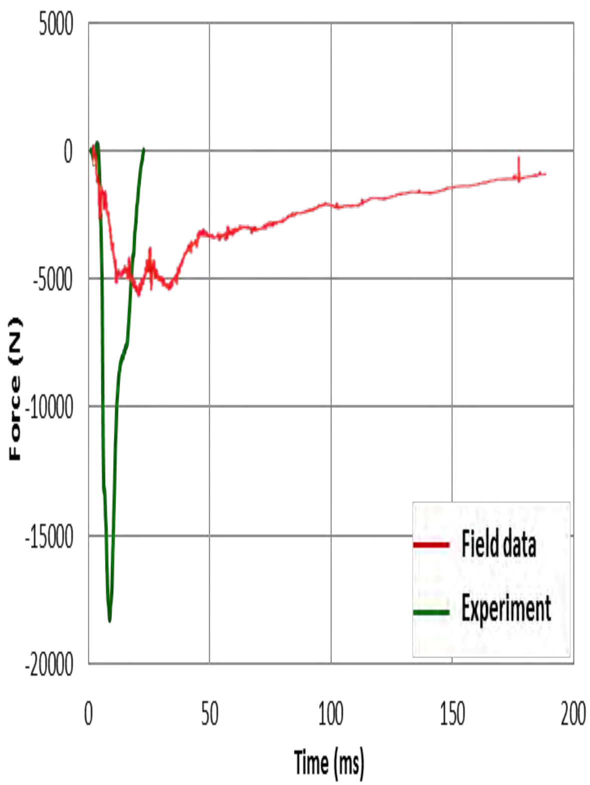
- In the next few slides, UNL experimental input pulse and selected dummy responses will be compared with appropriate data from live fire tests.

Comparison – plate center acceleration



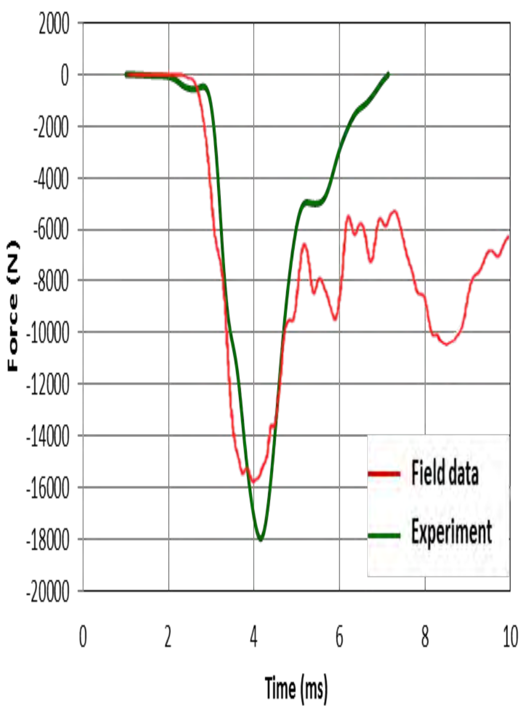
- Plot compares centre of plate acceleration in UNL tests [in Green] with live fire test plate acceleration [in Red].
- Experimental peak is higher but duration is lower. However, experimental acceleration continues to vary beyond 2 ms.

Lumbar spine load comparison



- Plot compares experimental H3 lumbar spine load in UNL high energy test with live fire test results.
- It is assumed that the occupant in live fire test was seated on a stroking seat.

Right tibia load comparison

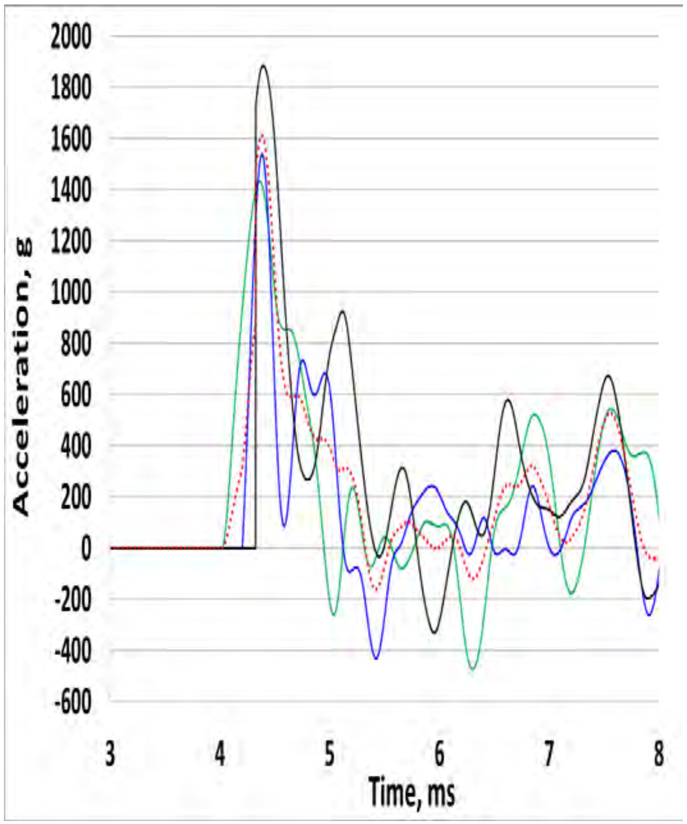


- Plot compares H3 lower tibia loads with live fire data.
- Peaks are comparable and it is possible that the occupant was seated on a stroking seat which caused loading beyond the point at which experimental data returns to zero.

Test results

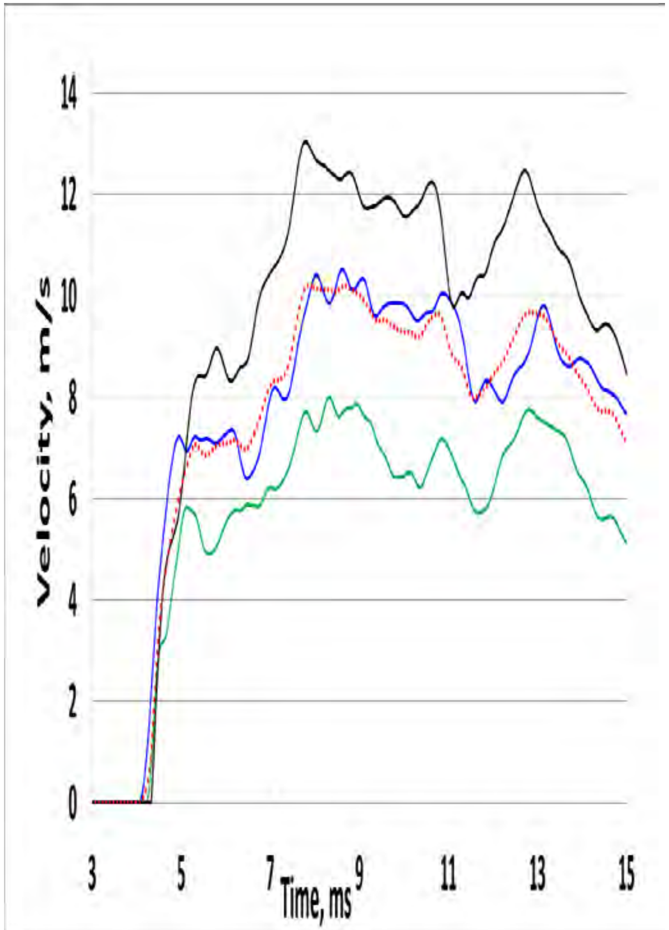
In the next few slides, test results from high energy [15 membrane] tests will be illustrated.

Plate center acceleration



- Plot shows plate acceleration pulse for 3 high energy pulses.
- Mean is shown in red.

Plate Center velocity



- Plot shows plate velocity profile for 3 high energy pulses.
- Mean is shown in red.

Load cell data from Test 13

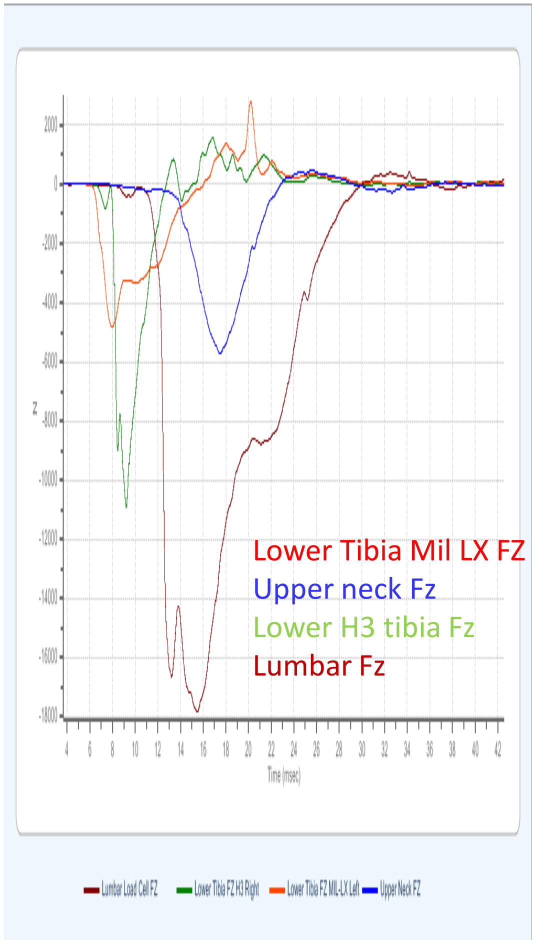
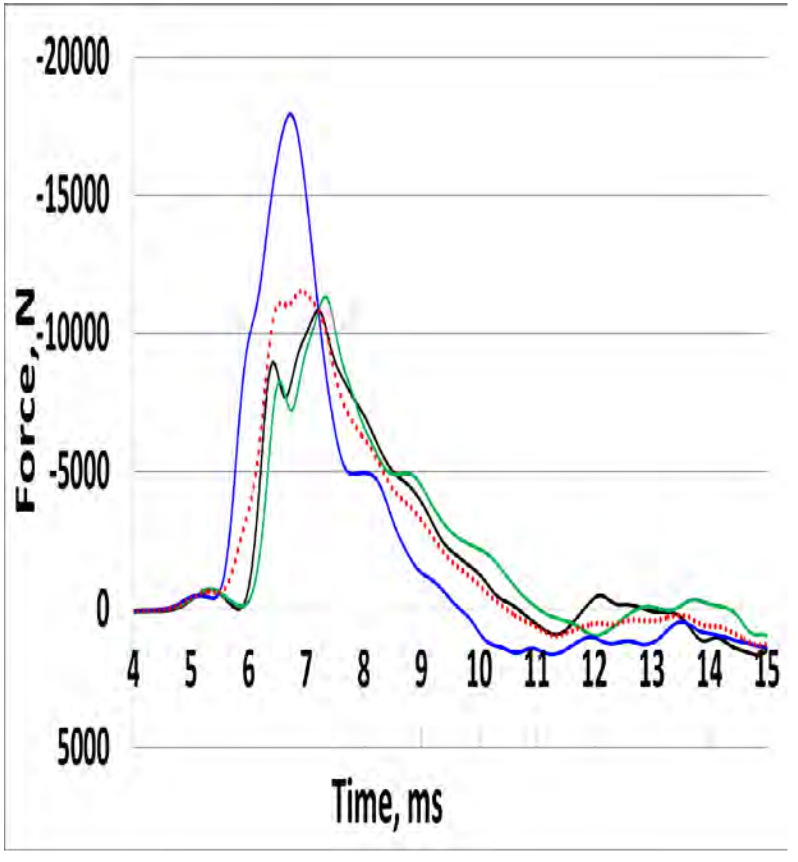


Figure shows load cell data from a 15 membrane test.

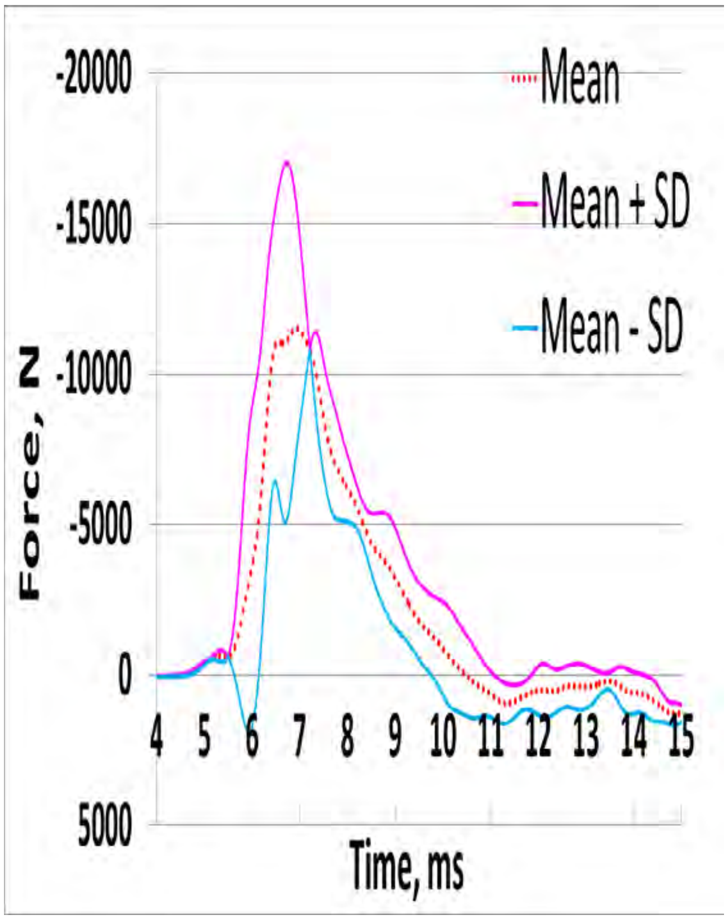
- Standard H3 tibia loads are shown
- The seat is connected rigidly to the loading plate.
- All loads exceed current IARV for H3.

H-3 lower tibia load



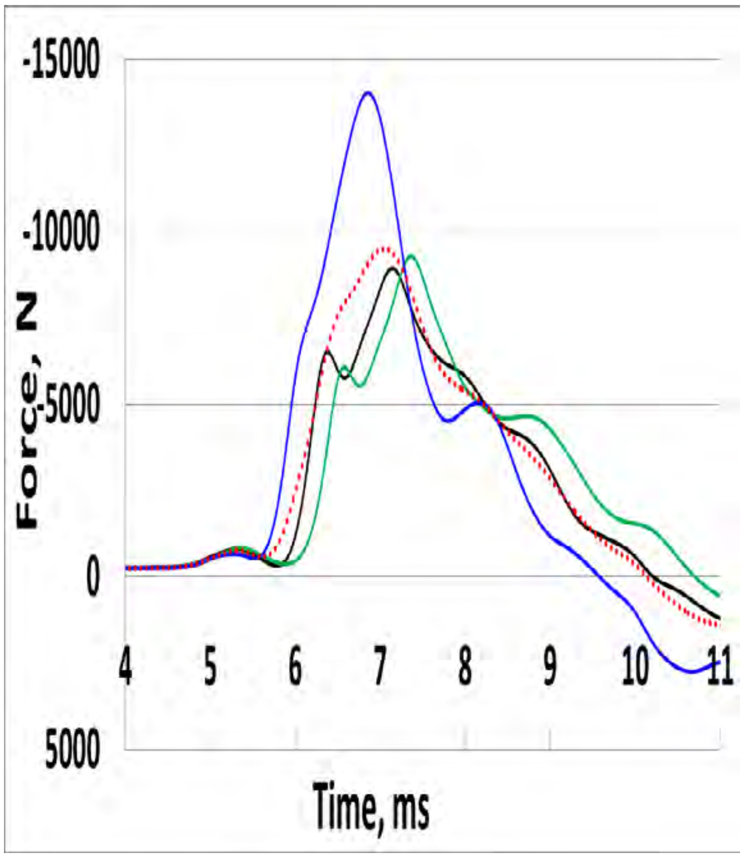
- The plot shows H3 lower tibia load cell from 3 high energy tests.
- Cause for large variation in one test is being investigated.

H-3 lower tibia load



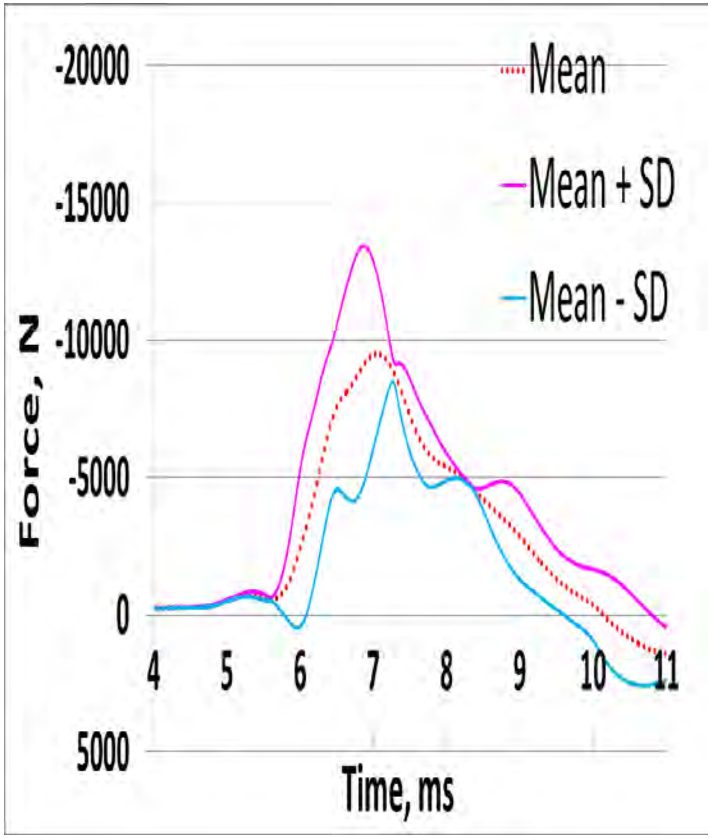
- Plot shows mean and standard deviation of H3 lower tibia loads.

H-3 upper tibia load



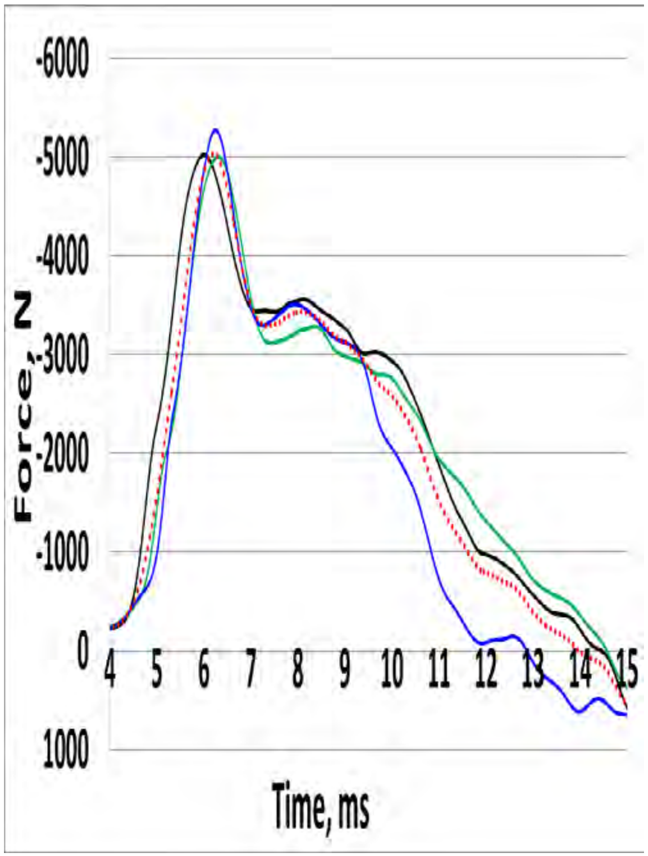
- H3 upper tibia loads from 3 tests and mean are shown.
- Cause of large variation in load in one test is being investigated.

H-3 upper tibia load



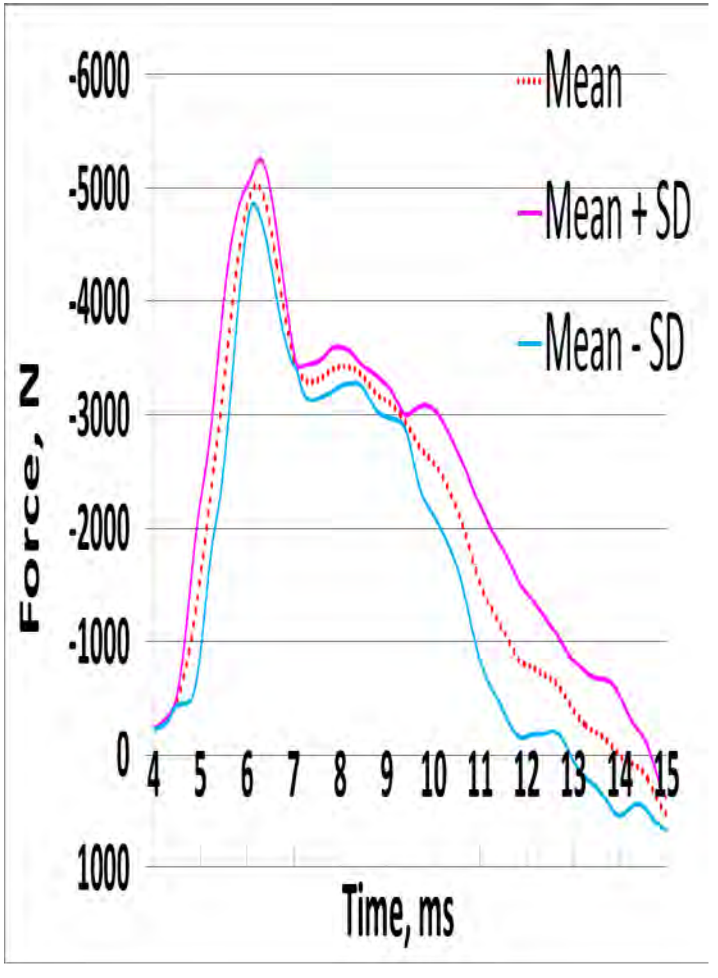
- Mean and standard deviation of H3 upper tibia load is shown in the plot.

MIL-LX lower tibia load



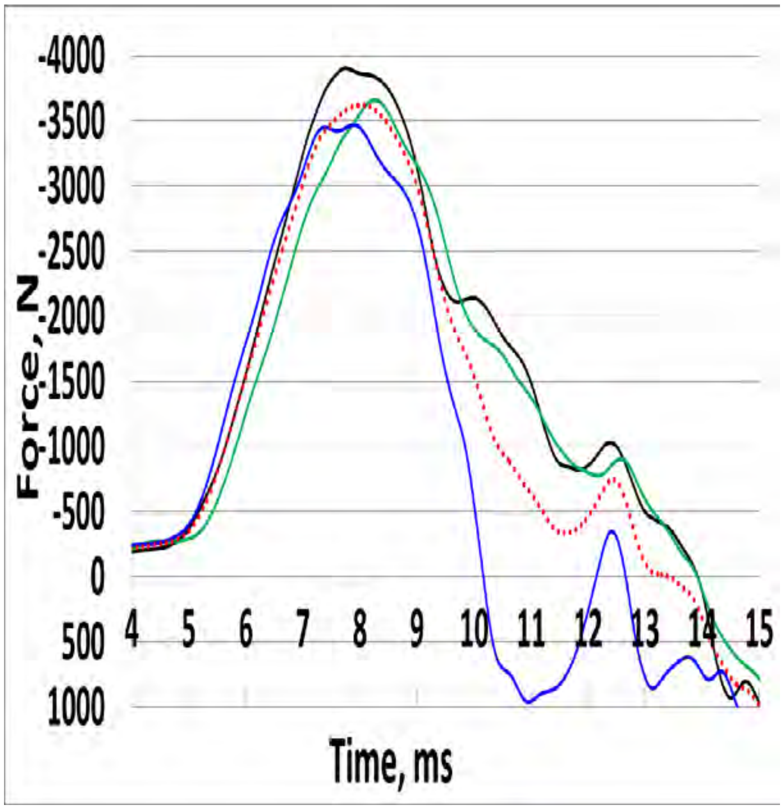
- MLX lower tibia loads indicate that test and response are repeatable.

MIL-LX lower tibia load



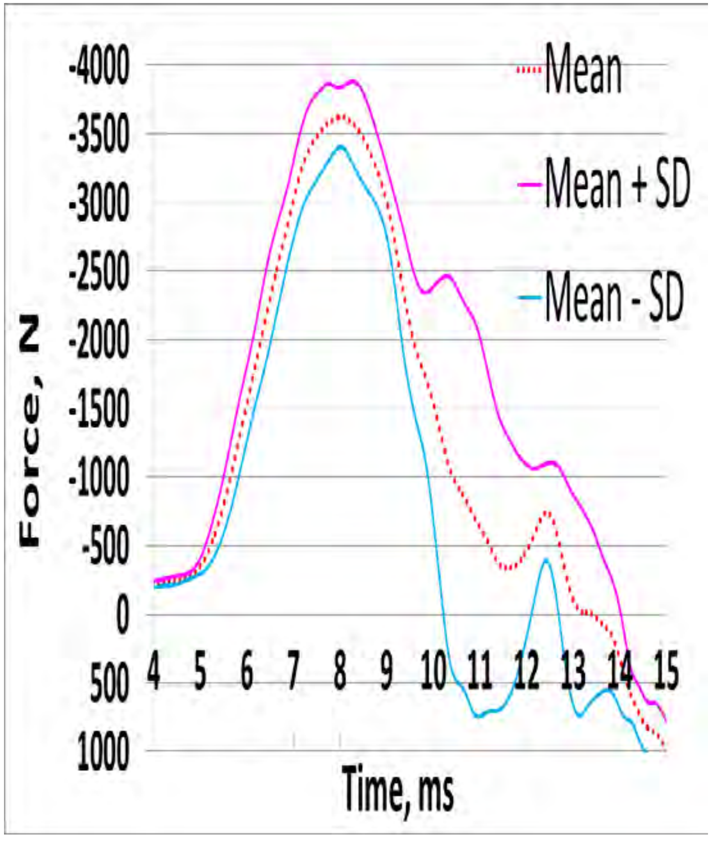
- Mean and standard deviation of MLX lower tibia indicate that response and tests are repeatable.

MIL-LX upper tibia load



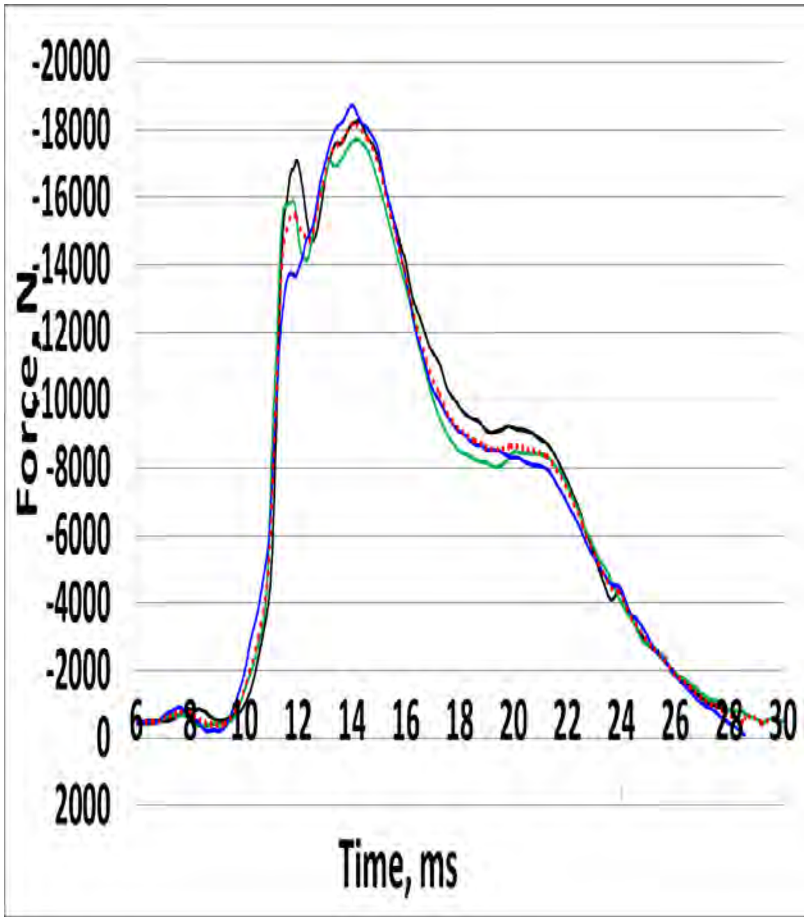
- MLX upper tibia loads from 3 high energy tests are shown.
- Response seems repeatable.

MIL-LX upper tibia load



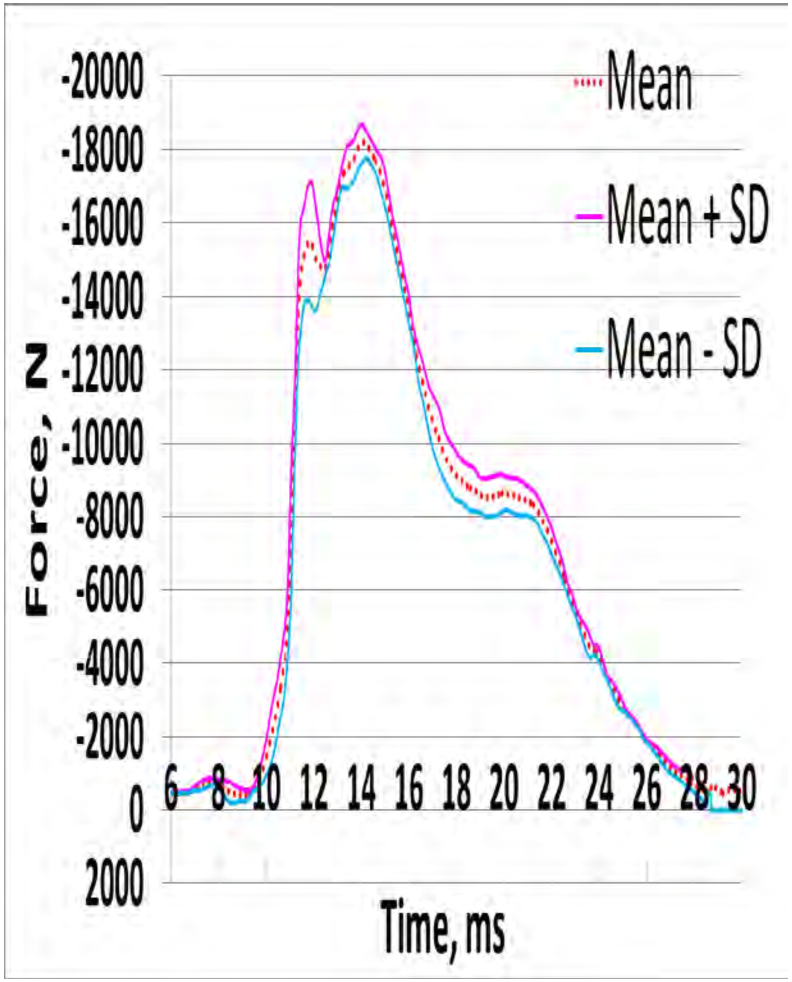
- Mean and standard deviation of MLX upper tibia loads are shown in the plot. Response seems repeatable.

Lumbar loads from 3 tests



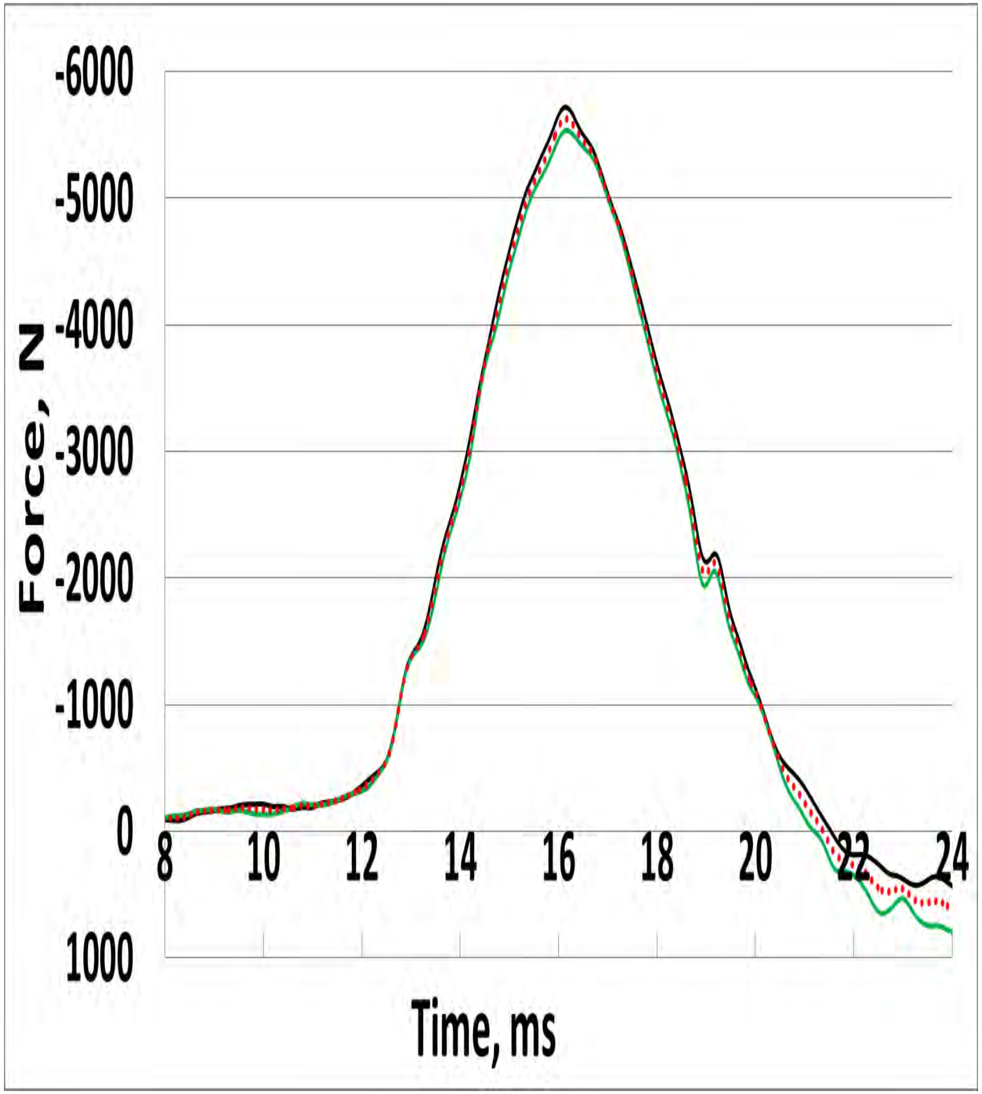
- Plot shows lumbar loads from three 15 membrane, high energy tests and the mean response.
- Data indicates that response and the test are repeatable.

Lumbar loads



- Mean and SD of lumbar loads in 3 high energy tests are shown.

Upper neck loads



- Plot shows upper neck load cell from 2 high energy tests.
- Data indicate that test and response are repeatable.

H-3 Lower tibia peak load

Membranes	Force (N)	Mean	Ratio wrt 5 membranes
5	-3,054	-3,151	1
	-2,860		
	-3,539		
10	-8,622	-8,235	2.61
	-6,022		
	-10,059		
15	-10,826	-11,355	3.66
	-11,322		
	-11,534		

MLX lower tibia peak load

Membranes	Force (N)	Mean	Ratio
5	-1,751	-1,812	1
	-1,540		
	-2,145		
10	-3080	-3248	1.79
	-2899		
	-3763		
15	-5022	-5096	2.81
	-4997		
	-5271		

Peak lumbar load

Membranes	Force (N)	Mean	Ratio
5	-5736	-5888	1
	-6395		
	-5535		
10	-12912	-12727	2.16
	-11974		
	-13294		
15	-18263	-18232	3.10
	-17714		
	-18719		

Peak upper neck load

Membranes	Force (N)	Mean	Ratio
5	-1,761	-1,932	1
	-2,103		
10	-4,172	-4,025	2.08
	-3,879		
15	-5,718	-5,626	2.91
	-5,535		

Conclusions - 1

- AENID produces foot plate acceleration pulses whose shape, time to peak, and width are very similar to those seen in Generic Hull test. Therefore, AENID is a very useful, low cost tool to study the effect of blast on vehicle occupants.
- Current design of AENID can accommodate one occupant.
- Multiple AENID tests can be conducted per day with a fully instrumented dummy.
- Plate pulse can be easily controlled.

Conclusions - 2

- The following full body instrumented dummy tests were conducted with the dummy seated on a rigid seat:
  - 3 repeat tests at low specific power input level.
  - 3 repeat tests at medium specific power input level.
  - 3 repeat tests at high specific power input level.

Conclusions - 3

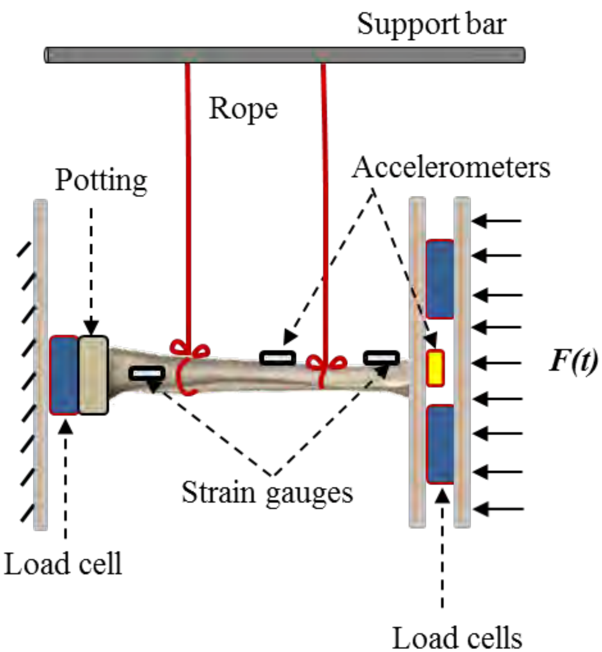
- The objective of these tests was to develop specifications for component level test parameters.

- Currently accepted IARV levels were exceeded for tibia loads, lumbar spine loads, pelvis acceleration, and neck compressive loads in the medium and high energy input level tests.

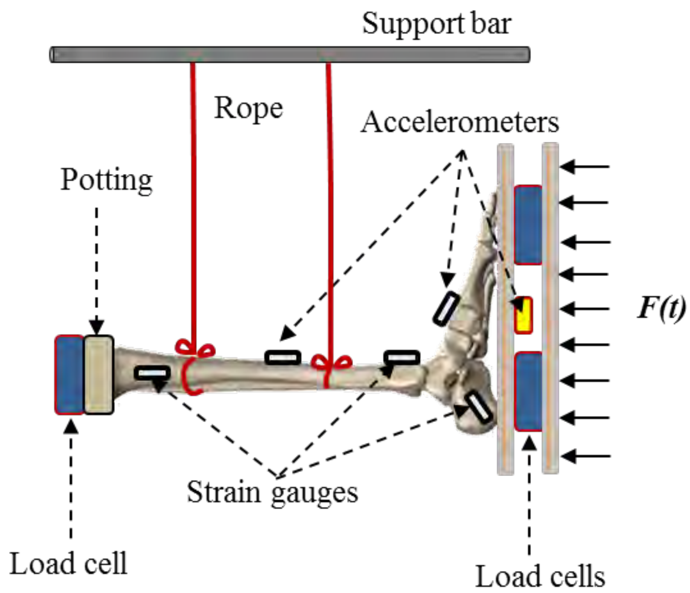
Conclusions - 4

- Results suggest that high acceleration levels even with low peak plate velocity might cause the dummy to exceed IARV levels.
- Preliminary analysis suggests that dummy response is related to specific power input level.
- Preliminary analysis also suggests that dummy response follows the “dosage” concept already seen in pelvis tests.

Proposed component testing



Proposed component testing



Appendix C

WHOLE BODY PMHS TESTING

Warrior Injury Assessment Manikin Injury Probability Curves Using AENID – Whole body tests (UNLWB-001/2013.)

Principal Investigator:

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Submitted to:

Biomechanics Product Team Lead

The Johns Hopkins University Applied Physics Laboratory

TABLE OF CONTENTS

1. WIAMan RESEARCH PLAN NUMBER – UNLWB-001/2013

2. RESEARCH PLAN TITLE - Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID) – Whole body tests

3. ABSTRACT

Majority of injuries sustained by United States warfighters in the current (and possibly the future) conflicts can be attributed to blasts. The response of the human body subjected to high-rate vertical under body blast (UBB) loading is not well understood and injury thresholds have not been established. The objective of this test series is to support the intent of the Warrior Injury Assessment Manikin (WIAMan) program to design and build a biofidelic dummy for UBB loading conditions. Both biofidelic response data and injury risk curves are needed to design the WIAMan dummy. UNL proposes to conduct whole body Post Mortem Human Subject (PMHS) tests to develop biofidelity data and injury thresholds. PMHS will be restrained by either a 4-point or a 5-point restraint system and will be tested with and without Personal Protective Equipment (PPE). Exact test configuration will be decided upon consultation with US Army/JHU-APL. A custom designed blast tube (Advanced ENergetic Impact Device – AENID) which can reproduce foot plate acceleration profiles seen in the field will be used to test instrumented PMHS under realistic UBB conditions. PMHS response data from non-injurious and injurious tests will be used to develop biofidelic response corridors, and injury risk curves.

4. STUDY PERSONNEL

Personnel Name	Responsibilities
Prof. Namas Chandra, PhD, PE	Principal Investigator
James Rinaldi, DC	Project Manager
Dr. Jayaraman Srinivasan, PhD	Laboratory Manager
Mr. Michael Bergen, MS BME	Biomedical Engineer
Mr. Nagarajan Rangarajan, PhD	Sub-contractor
Mr. Sailesh Ganpule, MSME	PhD Student Research assistant
Mr. Kurtis Palu, BSME	Test Engineer
Mr. Steve Gloor/Shawn Schumaker	Student Assistants

5. STUDY LOCATION

University of Nebraska, Lincoln, NE.

6. OBJECTIVES/SPECIFIC AIMS/RESEARCH QUESTIONS

Biofidelity and injury tolerance curves are needed to design the WIAMan dummy. Historically, biofidelity and response data to design automotive dummies have been developed through component and sub-system tests on a PMHS. However, since UBB loading is so different from loads imposed in occupants in the automotive environment, a new set of test protocols and loading conditions need to be developed. It is clearly understood that onset rates of loading under UBB conditions are much higher than those seen in the automotive environment even though how to characterize this type of loading is not well understood. Also, it is not known if and how response of the human skeletal system is modified by the high load onset rates. The first hypothesis is that loading rates will affect response of the human skeletal system.

The effects of Personal Protective Equipment (PPE) and restraint system on occupant response need to be evaluated under UBB loading conditions. Interaction between PPE and restraint system also needs to be evaluated.

Results from PMHS tests with 4- and 5-point restraint system can be used to design safer restraint systems. Interaction between PPE and restraint system can be evaluated from PMHS tests with and without PPE restrained by 4- and 5-point restraint systems. Results from PMHS tests with and without PPE can be used to design safer PPE.

UNL proposes to load whole body PMHS using the AENID system to understand and quantify the effect of loading rates, PPE and restraint system on the human skeletal system. Specific aims for the whole-body PMHS test series spanning five years are:

1. From the test series conducted at various input load-loading rate conditions, define loading (both injurious and sub-injurious) conditions for various body segments in sub-system and component tests,
2. Investigate the effects of 4- and 5-point restraint systems,
3. Investigate the effects of PPE,
4. Investigate the effect of interaction between PPE and restraint systems,
5. Develop biofidelity corridors for the lower extremities and lumbar spine based on whole body PMHS tests,
6. Develop injury thresholds for tibia, pelvis, and lumbar spine based on whole body PMHS tests,
7. Evaluate the effect of posture in PMHS response if tasked by the Army / APL, and
8. Develop metrics to compare PMHS response with WIAMan dummy response in matched pair testing.

Each whole-body test series will aim to resolve one or more of these specific aim; the number, type and timings of the tests will be determined based on the army requirements as well as the capabilities and deliverables assigned to other medical performers.

7. WIAMan/MILITARY RELEVANCE

The proposed research is designed to address the “Injury Prevention and Reduction” area of interest specified within BAA11-1. UNL will provide a data-driven, biomedical basis to determine injury mechanisms and injury risk functions, and to define appropriate loading conditions for sub-system and component PMHS tests by conducting whole body PMHS tests. Importantly, the proposed research recognizes that UBB loading environments are very different from other environments such as motor vehicle accidents.

Injuries and injury mechanisms seen under UBB loading differ from those seen in civilian settings. Occupant seating, restraints, and passenger postures in military vehicles are different from motor vehicles, and external loading in military vehicles is associated with higher loading/strain rates than in other environments. Biomechanical properties of human tissues are unknown at these high rates. Injury tolerance for different regions of the musculoskeletal system is unknown at military loading rates and modes.

Most importantly, a military-specific manikin has not been developed using military-specific loading modes, and load/strains rates. This study proposes to support the design of the WIAMan dummy which is intended to model a solider exposed to UBB loads. The new dummy will lead to design of "occupant-centric" vehicles resulting in lives saved and improvement in the quality of life for soldiers.

The proposed research effort will provide basic information needed to design the WIAMan dummy such as biofidelic response curves, and injury tolerance levels for various parts of the body under UBB loading conditions. In addition, this effort will also provide information on the effect of PPE on occupant response and the interaction between PPE and types of restraint systems. UNL's schedule for deliverables is structured to meet the requirements of dummy designers.

8. SCIENTIFIC BACKGROUND AND SIGNIFICANCE

8.1. Basis for the design of WIAMan dummy

The Hybrid III (H3) dummy is currently used to test armored vehicles under UBB loading conditions. H3 was developed to model vehicle occupants involved in frontal impacts, generally with negligible vertical acceleration. H3 dummy, in its original design, included tibias formed from steel tubes which are obviously much stiffer than the human tibia. H3 lumbar spine is kyphotic (convex backwards) whereas the human lumbar spine is lordotic (convex forwards). H3 lumbar spine is designed to provide human like response in frontal impact. Overall design of the H3 dummy was based on the much lower load onset rates than those seen in UBB events. Thus, there are a number of design features that make the H3 suitable for automotive testing but not for UBB loading.

The type and location of UBB injuries are quite different from those sustained in Motor Vehicle Accidents [MVA]. Injuries from MVAs are sustained in frontal, side or rear decelerative impacts in events lasting > 30 ms, while UBB events are primarily accelerative, high on-set vertical loadings lasting <10 ms. While occupants in MVAs range widely in age, size, gender, and health status wearing civilian clothes, UBB injuries involve healthy young men and women warriors with situational awareness wearing PPE. Design and construction of seats and restraint systems in military vehicles are different from civilian vehicles. Posture of military personnel in armored vehicles is likely to be different from those seen in civilian vehicles. Orientation of armored vehicle passengers to the load vector is likely to be different from those seen in civilian vehicles. These differences are substantial and require that a dummy be custom designed to be used for UBB testing.

The Army recognized the need for a dummy suitable to evaluate vehicle performance under UBB loading and this recognition is the basis for the WIAMan program.

8.2. Test equipment

Traditionally, acceleration and deceleration sleds, pendula, and linear impactors have been used to assess injuries resulting from MVA. In keeping with the level of impact in MVA, these test equipment are designed to load the human surrogate at acceleration levels far lower than those seen in UBB events. MVA events are also longer duration events than UBB events. Therefore, most test equipment designed to reproduce MVA events cannot be used to reproduce UBB events.

UNL has designed, developed, built, and tested a one-dimensional shock tube based system AENID. AENID has been proved to create floor accelerations and dummy responses similar to those seen in Generic Hull tests [1] and can be used to subject one occupant to inputs seen in UBB events. Figure 1 provides a schematic of the AENID loading system. AENID is designed to provide independent control over the rise time, magnitude, and duration of the loading pulse.

AENID can accommodate one occupant seated on a rigid seat with a rigid floor providing appropriate input pulse to the feet and buttocks of the occupant. Occupant position can be adjusted to meet program needs. AENID seat is designed to attenuate and delay, if needed, the pulse applied to the buttocks when compared with the loading pulse applied to the feet. Occupant restraint system can be configured to fit program requirements. The occupant can be tested with and without PPE.

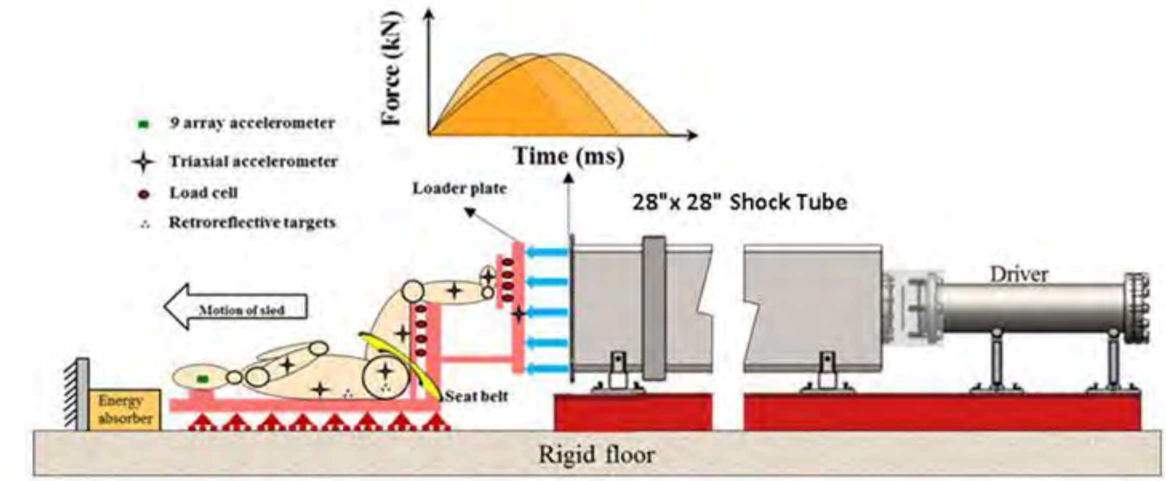

Figure 1: Schematic of AENID showing occupant and lap belt

8.3. Relevance of proposed study

The aims of whole body cadaver tests are: to establish loading conditions for sub-system and components as these are largely unknown; to estimate biomechanical PMHS response; and to develop injury tolerance criteria for various body segments. Some of these data are being developed from Generic Hull tests and other specialized tests being conducted by the Army as a part of their Live Fire Test and Evaluation (LFTE) program. UNL believes that the capability of AENID to reproduce LFTE test floor acceleration profiles and correlation between dummy segment responses in AENID and LFTE tests makes it possible to use AENID to develop loading conditions for cadaver sub-system and component tests. Also, whole body cadaver tests are needed to evaluate the effect of restraint systems on occupant response and also interaction between PPE and restraint systems. UNL believes that whole body tests on the AENID are therefore very relevant to WIAMan program goals.

8.4. Justification of test loading pulse

UNL recently conducted a number of shake down tests with the H3 dummy as the sole occupant of the seat. Details of dummy seating, data acquisition and results were presented at APL in late January, 2013 [1]. These tests with H3 revealed that:

- Dummy response in low energy tests [5 membranes] was very close to the IARV for the dummy. Higher energy tests [10 membrane and 15 membrane tests] indicated that dummy IARV for lower extremities, pelvis and lumbar spine would be exceeded under these loading conditions.
- In AENID, the seat is connected rigidly to the loading plate during the loading phase and the dummy lumbar loads and pelvis accelerations exceed the IARV for the dummy. We

interpret this to mean that at the lowest energy level input, even though the tibia is not likely to fractured, pelvis and lumbar spine are likely to be injured.

Based on our requirement to conduct the first few tests at non-injurious levels, we have decided to attenuate the seat bottom acceleration by attaching an elastomeric element to the stems that connect the seat bottom to the loading plate. This form of load attenuation has been successfully used in the design of MLX and the mine compatible version of the Thor-Lx. The elastomeric element will be used to attenuate the amplitude of the seat bottom acceleration pulse and extend it. Some energy will be used to deform the elastomer but we believe that there will be sufficient energy to load the pelvis and upper parts of the dummy adequately enough to cause injury.

- The use of elastomeric additions to the stems will allow us to separate loading on the feet and seat. This is similar to the strategy adopted in actual military vehicles where seats are attached to the walls or allowed to stroke to reduce the load on the lower torso and protect it. Please note that we compared the lumbar load in our tests with rigid stems with GH1 tests [1] and found that the lumbar spine load was much higher than that seen in GH1 tests even though AENID loading pulse for this test run was very similar to the foot plate acceleration seen in the GH1 test.
- It is hypothesized that the injury for the whole-body and/or components occurs during the loading phase (plate intrusion) when the maximum stress is experienced. Once the maximum load occurs (as a function of different loading rate and intrusion), further loading obscures the PMHS/H3 response. *These conditions are assured by the separation of both the legs and the buttocks from AENID*. These conditions are assessed by both the contact switches as well as the occurrence of peak loads in the lower legs as well as pelvis. Such separation is a necessary condition to evaluate the biomechanical response of the tested body (PMHS/H3) under those peak loads for different loading rates (rise times). These aspects were discussed during the APL meetings; for the sake of convenience, the slides are appended to this document

UNL's aim is to obtain as much useful information as possible from each cadaver for ethical and practical reasons. In practical terms, this means that UNL proposes to conduct multiple tests with each cadaver with the last test being conducted at an input level most likely to cause injury to the lower extremities, pelvis and lumbar spine which are of interest to UNL. UNL's proposed to estimate "safe" loading scenario by analyzing tests conducted by other test sites.

8.4.1: Analysis of others/AENID data in the selection of PMHS test conditions:

UNL analyzed data from other test sites to estimate a combination of seat peak acceleration and velocity that will be injurious. Table 1 shows the test data as supplied by USAARL. Based on our past analysis of H3 tests on MCW sled [2], UNL selected a variable tentatively called Maximum Specific Power Input to evaluate if it segregated pelvis injury adequately. The result of this analysis can be seen in Figure 2 which indicates that the selected variable adequately separates injury from non-injury. We understand that this is a preliminary and rough analyses but believe that it is sufficiently accurate for UNL to select loading parameters for the proposed tests.

Table 1: Pelvis test data from various institutions

Experiment	Seat Pan Peak G (Gs)	Seat PanTime to peak acceleration (s)	Seat Pan Peak Velocity (m/s)	Seat Pan Time to peak Velocity (s)	Injured (Y/N)	Max Sp. Input Pwr, m^2/s^3
MCW	158.9	0.0089	6.5	0.0145	1	10132
GH2	182.7	0.0029	5.1	0.0083	0	9141
GH2	183.1	0.0039	4.9	0.0071	0	8801
GH2	175.5	0.0046	7.4	0.0101	0	12740
UVA 1.1	750	0.0028	10.2	0.0057	1	75047
UVA 1.2	739.3	0.0029	10.5	0.0062	1	76152
UVA 1.3	292.2	0.0043	6.4	0.0084	0	18345
UVA 1.4	327.7	0.0044	7.6	0.0058	1	24432
UVA 1.5	310.2	0.0061	9.9	0.006	1	30126
wsu-gd9	375	0.0034	7	0.0052	1	25751
wsu-gd12	218	0.0065	8.1	0.0108	1	17322
wsu-gd14	200	0.0073	6.8	0.0122	1	13342
wsu-gd15	76	0.0069	5.2	0.0147	0	3877
wsu-gd16	139	0.0071	6.8	0.013	1	9272
wsu-gd17	175	0.008	7.8	0.0137	0	13391
wsu-gd18	137	0.0076	6.8	0.0142	1	9139
wsu-gd19	224	0.007	8.3	0.0129	1	18239
wsu-gd20	251	0.007	7.9	0.0124	1	19452

This table lists data supplied by USAARL. It is a compilation of results from whole body tests run at various institutions [MCW = Medical College of Wisconsin, GH = Generic Hull tests run at Aberdeen Proving Grounds, UVA = University of Virginia, WSU = Wayne State University]. These tests were run on a variety of test equipment such as horizontal sleds powered by a variety of systems. Generic Hull tests are the most representative of field conditions as a military vehicle with occupants was subjected to UBB loading conditions by exploding a bomb / mine under the vehicle.

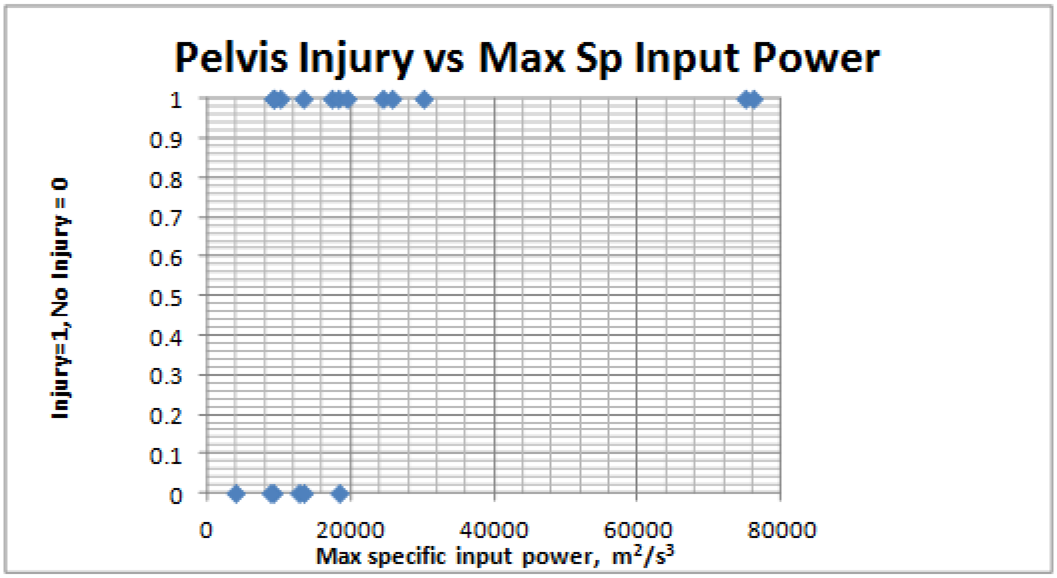

Figure 2: Segregation of Pelvis injury based on Max Sp Input Power

Figure 2 indicates that any test with Maximum Specific Input Power [MSIP] above 20000 m^2 / s^3 is likely to cause injury to the pelvis. Region of uncertainty lies between 10000 m^2 / s^3 and 20000 m^2 / s^3. Various probability distributions can be used to span this region of uncertainty. For ease of calculations, we will use a linear function to describe this distribution so that 50% probability of injury is likely to be around 15000 m^2 / s^3. This approach has been used in analyzing the relationship between probability of AIS3 injury and HIC. Though this approximation may seem rough, it might serve the purpose for now as all UNL wants to do is to identify a pulse or input conditions that can cause injury to pelvis.

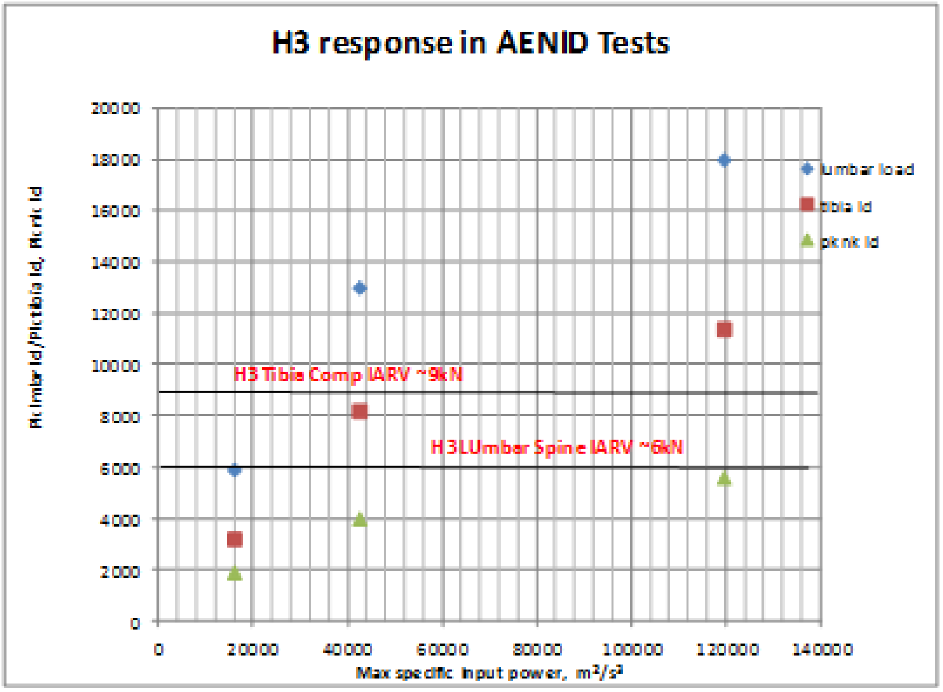

Figure 3: H3 response in AENID test showing IARV

Figure 3 indicates that the lowest energy level tests with 5 membranes is likely to cause lumbar injury and that moderate energy level tests with 10 membranes is likely to cause lumbar injury and possibly tibia injury.

However, preliminary analysis relating pelvis acceleration to seat based MSIP [seat velocity in m/s multiplied by seat acceleration in m/s^2] indicates that for seat MSIP as low as 2300 can cause pelvic injury if the IARV for pelvic injury is set at 23G for vertical acceleration. There seems to be almost one order of magnitude difference in injurious level of loading when H3 is used as a surrogate with the current IARV for pelvis injury. In other words, with the current IARV, H3 dummy indicates that pelvic injury is feasible when seat based MSIP is around 2300 whereas cadaver tests indicate that injury is feasible when seat based MSIP is around 15000. This needs to be researched further as setting the IARV at 250G would yield a seat based MSIP value of about 12000. This is probably a reasonable value because setting the seat based MSIP at criterion would yield a H3 lumbar load of approximately 5kN which is lower than its IARV of approximately 6kN.

Since AENID is being modified to provide different input pulses at the feet and pelvis, we will aim to conduct tests tabulated below. Floor plate loading pattern will be different from seat loading pattern in these tests. Floor plate loading pattern is described in the research plan for the lower extremities in a separate document.

Table 2: Proposed Year 1 Test Description

Cadaver Number	Test Number	Estimated MSIP at Seat	Objective	Sensors on cadaver [see details in Table 3]
1 *(see note below)*	1	~4000	Biofidelity of : • Lower extremity • Pelvis • Lumbar spine	• Strain gauge • Video for displacement • 1 axis angular accel in pitch axis • Z axis linear accel
	2	~7000	Same as above	Same as above
	3	~4000	Same as above	Same as above
	4	~12000	Same as above	Same as above
	5	~14000	Same as above	Same as above
2 [test conditions will depend on results with cadaver 1] (see note below)	1	~5000	Biofidelity of : • Lower extremity • Pelvis • Lumbar spine	• Strain gauge • Video for displacement • 1 axis angular accel in pitch axis • Z axis linear accel
	2	~8000	Same as above	Same as above
	3	~5000	Same as above	Same as above
	4	~10000	Same as above	Same as above
	5	~15000	Same as above	Same as above
	6	~18000	If no Pelvis FX	Same as above

Note 1: Number of tests specified above is an optimistic estimate. Each test series will end when any injury is detected-see details in Section 9
Note 2: Cadaver#1 and #2 may be used to study the effect of PPEs. In such a case cadaver1 will be tested without PPE and identical loading conditions will be applied to cadaver 2.
Note 3: The current proposal calls for testing 2 cadavers in year 1 (up to June 2013, and 5 cadavers in year 2 (July 2013-June 2014). However, according to the accelerated test schedules a significantly increased number of cadavers will be tested, if additional funding is provided for.
Note 4: Actual test condition will be specified in Test readiness plan to be submitted prior to each test.

9. RESEARCH METHODOLOGY

9.1. Description of Research Approach

In the first year two whole body PMHS will be tested. AENID has been calibrated using an instrumented H3 and results of these tests have been used to develop the cadaver test matrix. A summary of year one testing is shown in Table 1.

Table 3. Year one testing summary

Task	Specimen	Assessment	Deliverables
Whole body testing	HIII	Calibration & Response	Demonstration of AENID loading capabilities
	PMHS 1	Response	Response corridors, injury risk curves and loading pathways (see notes below Table 2)
	PMHS 2	Response	

9.2. Exposures, Setup, and Data

Kinematic, acceleration, angular rate, strain, and input load data will be collected for each test series. All data will be collected at 500k Hz using the DTS SLICE PRO data acquisition system. Kinematic data will be captured using high speed video at a frame rate of at least 1000 frames/sec. Surface anatomical landmarks as defined in the ANSUR II Pilot study and the WIAMan-Med IPT Medical Research Integration Plan Test Requirements will be identified with targets.

9.3. Whole body testing

9.3.1. Hybrid III ATD

H3 tests have been completed and results presented at APL. Some salient features of the tests are summarized below. Results of these tests have been discussed at APL and summarized in Section 8.

Table 5. Hybrid III whole body instrumentation

Channel Count	Sensor Type	Sensor Location	Axis	Units(s)
3	Accelerometer	H3 Head	A_x, A_y, A_z	G
9	Load cell	H3 upper neck	F_x, F_y, F_z, M_x, M_y, M_z	N, Nm
12	Accelerometer	H3 chest	A_x, A_y, A_z	G
18	Load cell	H3 lumbar	F_x, F_y, F_z, M_x, M_y, M_z	N, Nm
21	Load cell	H3 pelvis	A_x, A_y, A_z	G
27	Load cell	H3 femur – right	F_x, F_y, F_z, M_x, M_y, M_z	N, Nm
32	Load cell	H3 tibia – upper right	F_x, F_z, F_z, M_x, M_y	N, Nm
37	Load cell	H3 tibia – lower left	F_x, F_z, F_z, M_x, M_y	N, Nm

Channel Count	Sensor Type	Sensor Location	Axis	Units(s)
42	Load cell	Mil-LX tibia – upper left	F_x, F_z, F_z, M_x, M_y	N, Nm
47	Load cell	Mil-LX tibia – lower left	F_x, F_z, F_z, M_x, M_y	N, Nm
50	Accelerometer	H3 tibia left	A_x, A_y, A_z	G
53	Accelerometer	Mil-Lx tibia left	A_x, A_y, A_z	G
56	Accelerometer	Mil-Lx foot left	A_x, A_y, A_z	G
57	Accelerometer	Mil-Lx heel left	A_z	G

The dummy was placed on a rigid seat specifically designed to mimic the seat and floor pan of a military vehicle (Fig. 1). Seating methodology will follow the procedure specified in the WIAMan-MED IPT Medical Research Integration Plan Test Requirements, V.1.3. 9 tests were performed and test matrix is provided in Table 6.

Table 6: Test variables for H3 whole body tests

# Membranes	No. of tests	Mean Plate Vel, m/s	Mean time to peak, ms	Mean plate accel, G	Mean time to peak, ms
5	3	3.2	4.3	508	0.15
10	3	5	3.89	865	0.18
15	3	8	4.11	1523	0.19

Data have been analysed and were presented at APL in January, 2013 [1]. Findings are summarized below:

- AENID produces foot plate acceleration pulses whose shape, time to peak, and width are very similar to those seen in Generic Hull test. Therefore, AENID is a very useful, low cost tool to study the effect of blast on vehicle occupants.
- Current design of AENID can accommodate one occupant.
- Multiple AENID tests can be conducted per day with a fully instrumented dummy.
- Plate pulse can be easily controlled.
- Currently accepted IARV levels were exceeded for tibia loads, lumbar spine loads, pelvis acceleration, and neck compressive loads in the medium and high energy input level tests [10 and 15 membrane tests].
- Results suggest that high acceleration levels even with low peak plate velocity might cause the dummy to exceed IARV levels.
- Preliminary analysis suggests that dummy response is related to specific power input level.
- Preliminary analysis also suggests that dummy response follows the “dosage” concept already seen in pelvis tests.

9.3.2. Post Mortem Human Surrogate

Platinum Training, LLC in Henderson, NV will supply all whole and subsystem PMHS. All specimens are routinely screened for HIV 1, HIV 2, HBsAg and HCV. Platinum Training donor consent forms are compliant with DOD language requirements. PMHS exclusion criteria include the following: history of HIV, Hepatitis B, or Syphilis; wasting disease; primary bone cancer or cancer that has metastasized to bone; and traumatic injury to the area of interest. All PMHS will be male between the ages of 18 – 60 years. Every effort will be made to approximate the target anthropometric values shown in Table 4. If this is not possible, the specimen stature will fall within the 10th and 90th percentile as published in the ANSUR II Pilot study with BMI less than 20-30.

Table 4. PMHS Anthropometric target values and ranges

Anthropometric measure	**Target Value**	**Range**
Stature	1725 mm	1666 – 1844 mm
Erect Sitting Height	918 mm	871 – 965 mm
Mass	84.2 kg	Depends on stature & BMI
BMI	----	< 20 - 30

Following procurement, the specimen will undergo radiographic examination to scan for exclusion criteria and determine appropriateness for inclusion in experimental testing. Additionally, the specimen will be subjected to a physical examination of the musculoskeletal system to evaluate for abnormalities that may not be readily identifiable in radiologic examination, e.g. joint hypermobility or instability. .

The identity of PMHSs will be protected by providing a unique UNL identification number for each specimen. The UNL ID number and the identification number provided by the supplier will be maintained in a password protected database accessible only to the project manager and the PI. The tissue supplier has assured UNL that they have a system in place to prevent unauthorized tracking of their PMHS ID number to the death certificate. Additionally, the head and face of the specimen will be covered by a stockinette prior to testing. No still or video photography demonstrating the head or face of the specimen will be permitted until the stockinette is in place.

Specimens will be stored in a locked chest freezer in a secured room accessible to laboratory staff only. After instrumentation is completed, the specimen will be maintained in a lockable mortuary cooler in a secure room until experimentation can commence. The specimen will be placed in a black disaster pouch during transport from preparation room to experimental room. The specimen will returned to Platinum Training for cremation following completion of the experimental series and injury documentation.

After anthropometric assessment the PMHS will be dressed in a long sleeve unitard garment with socks and cotton gloves. All seams at the ankles and wrists will be fully sealed with tape. The head and face will be covered with orthopaedic stockinet serving as both a barrier and a means to prevent specimen identification. The specimen will then be dressed in a heavy duty vinyl sauna suit.

A radiological examination of the specimen will be performed with a portable digital x-ray unit. The initial instrumentation step, to include accelerometers, angular rate sensors, and strain gages (Table 5), will be to create windows in the unitard and vinyl suit to allow access to the skin surface at the sites of sensor placement. As a rule, PMHS instrumentation fixation is achieved through incision in the skin with dissection of underlying soft tissues to expose boney fixation site. The bone will be prepared and instrumentation fixation will be achieved by means dictated by the anatomy involved. For example, accelerometers will be affixed to ribs via a clamp-type mechanism, strain gages will be glued directly to bone at required locations, and accelerometers will be attached to the sacrum and sternum via a screw system. Instrumentation fixation to other regions of the skeleton will employ one or a combination of these methods. Any void created by instrument fixation will be packed with gauze pads and the incision closed with super glue and skin staples allowing the instrumentation cable to exit. The window created in the unitard garment will be sealed with duct tape. The instrumentation cable will be routed appropriately between the unitard and vinyl suits. The outermost window will also be sealed with duct tape. The position of sensors relative to anatomical landmarks will be measured and recorded. Additional radiological examination may be required to document instrumentation positioning. The PMHS will be transported to the shock tube lab, in a double body bag.

Table 7 provides a list of sensors and data to be gathered during each test. All PMHS response data and input characterization data in the SAE J211 format will be gathered using a digital data acquisition system at 500 kHz. A hardware-based, 4-pole Butterworth antialiasing filter at 100KHz is applied to the data. High-speed video cameras are used to capture kinematic data.

Contact switches will be installed on the loading plate [under the feet of the test subject] and seat bottom [under the buttocks of the test subject] to indicate when the test subject has ceased to be in contact with the loading platform. This information will be useful in guiding analyses of data.

The instrumented whole body PMHS will be placed in the rigid seat of the test device as described above for ATD testing (Fig. 1). The postural scheme will reflect the 90°- 90°- 90° condition with torso/thigh angle of 90°, thigh/leg angle of 90°, and leg/foot angle of 90°.

An incremental scheme of loading progression will be utilized. The initial test with “Baseline” loading condition with MSIP is expected to be sub-injurious. The loading conditions then progress toward the “High” level with a “Baseline” test performed between each step. The test matrix is shown in Table 2. A baseline test will be conducted to establish cadaver response and to ensure that the set up and data analysis procedures are appropriate.

Table 7: List of sensors for cadaver whole body tests

Channel Count	Sensor Type	Sensor Location	Axis	Unit
2	Accelerometer	Head	Ax, Az	G
3	Angular rate	Head	ωy	rad/s
5	Accelerometer	T1	Ax, Az	G
6	Angular rate	T1	ωy	rad/s
8	Accelerometer	Sternum	Ax, Az	G
9	Strain gage	Rib 4 - Right	NUL	-
10	Strain gage	Rib 4 - Left	NUL	-
11	Strain gage	Rib 7 - Right	NUL	-
12	Strain gage	Rib 7 - Left	NUL	-
14	Accelerometer	L1	Ax, Az	G
15	Angular rate	L1	ωy	rad/s
16	Strain gage	L1	NUL	-
18	Accelerometer	Sacrum	Ax, Az	G
19	Angular rate	Sacrum	ωy	rad/s
20	Strain gage	Sacrum	NUL	-
23	Accelerometer	Distal Femur – Right	Ax,Ay,Az	G
25	Angular rate	Distal Femur – Right	ωx, ωy	rad/s
26	Strain gage	Distal Femur – Right	NUL	-
29	Accelerometer	Distal Femur - Left	Ax,Ay,Az	G
31	Angular rate	Distal Femur - Left	ωx, ωy	rad/s
32	Strain gage	Distal Femur - Left	NUL	-
35	Accelerometer	Tibia - Right	Ax,Ay,Az	G
36	Angular rate	Tibia - Right	ωy	rad/s
37	Strain gage	Tibia - Right	NUL	-
40	Accelerometer	Tibia - Left	Ax,Ay,Az	G
41	Angular rate	Tibia - Left	ωy	rad/s
42	Strain gage	Tibia - Left	NUL	-
43	Strain gage	Calcaneus - Right	NUL	-
44	Strain gage	Calcaneus - Left	NUL	-
45	Accelerometer	Navicular - Right	Az	G
46	Strain gage	Navicular - Right	NUL	-
47	Accelerometer	Navicular - Left	Az	G
48	Strain gage	Navicular - Left	NUL	-
52	Load cell	Seat Bottom x4	Fz	N
56	Load cell	Foot Plate x4	Fz	N
59	Accelerometer	Foot Plate	Ax,Ay,Az	G
62	Accelerometer	Center Plate	Ax,Ay,Az	G
63	Accelerometer	Seat Bottom	Az	G

Following each PMHS test data will be reviewed for indicators of injury. The specimen will undergo whole body orthopaedic and palpatory evaluation to assess for injury. Post-test radiology will also be performed to evaluate for injury. If the PMHS sustains an injury, the test series ends. If no injury is detected, the next step in the progression will be performed. Experimentation will continue until injury is detected. After injury detection the PMHS will undergo complete radiographic examination and autopsy to complete documentation of injuries.

9.4. GFE Required (supplied by Government based on specific tests)

- Appropriate upper body PPE including helmets
- PPE donning procedures
- Boots of various sizes with lacing instructions if any
- Location of restraint system anchors, type of anchors, anchors to be provided if feasible.
- Geometry of restraint systems
- Belt hardware and belt setup procedure
- PMHS seating procedures with PPE.
- Permission to modify PPE as required.

9.5. Potection of cadaver identity

The identity of PMHS will be protected by providing a unique UNL identification number for each specimen. The UNL ID number and the identification number provided by the supplier will be maintained in a password protected database accessible only to the Project Manager and the PI. The tissue supplier has assured UNL that they have a system in place to prevent unauthorized tracking of their PMHS ID number to the death certificate. Additionally, a stockinette will cover the head and face of the specimen prior to testing. Stockinette will be in place when still or video pictures of the cadaver are taken.

9.6. Safety of study personnel

Specimens will be stored in a locked chest freezer in a secured room accessible to laboratory staff only. After instrumentation is completed, the specimen will be maintained in a lockable mortuary cooler in a secure room until experimentation can commence. The specimen will be placed in a black disaster pouch during transport from preparation room to experimental room. The specimen will be cremated at a local crematorium following completion of the experimental series and injury documentation.

Study personnel will wear PPE including masks, gloves, and Tyvek suits when handling cadavers. Study personnel will also complete UNL Bloodborne pathogen and biosafety training prior to participating in experimentation. Additionally, the UNL Institutional Biosafety Committee has approved all safety procedures related to this protocol.

10. ANALYSIS PLAN

Our proposed data analysis procedure was developed in-house and codified in the form of a project document. The document was distributed to laboratory and analysis personnel to evaluate its applicability and usefulness. After several iterations, a unified data analysis approach was developed and is listed below.

1. All data and video pertaining to any one test are named according the convention specified in document WIAMan Medical Research Integration Plan, Ver. 5.0, chapter 6.4.2.
2. All test data are stored in 2 places, on the local server and on a separate multi-tera-byte storage device at another location.
3. Data analysis starts with the process of identifying all data and video pertaining to a test of interest and downloading them onto the analyst's computer. The analyst might develop a simpler naming convention for ease of use.
4. Calculate the velocity and displacement of the plate from the acceleration pulse using numerical integration.
5. Calculate displacement of the plate from video analysis.
6. Compare displacement obtained from measured pulse with the displacement obtained from video analysis. When displacements are close to each other it confirms that recorded data is accurate and calculations are correct.
7. Analyze load cell and acceleration data for trends and consistency.
8. When comparing responses from multiple tests, align the data first in time. The peak load recorded by the load cells should occur when plate reaches peak velocity.
9. When separation takes place the load cell should read zero. Cross verify this from the video and pressure pad analysis.

10.1. Development of response corridors

UNL will use mass scaling method proposed by Eppinger, 1984 to scale all response data using a standard mass of 76 kg for the 50th percentile male. As indicated in Table 2, UNL proposes to conduct 2 cadaver whole body tests in this period. We expect to record cadaver response variables such as linear accelerations, strain, and angular accelerations on various body segments. If all goes well, and the cadaver is not damaged early in the sequence, cadaver response data will be obtained for base line [2 tests], medium level [1 or perhaps 2 repeats] and one high or injurious level input loadings. These data can be pooled with data from other institutions to develop response corridors for various body segments. Alternatively, if the 2 cadavers yield results from 10 tests [optimistic], then, response will be plotted against an input variable such as MSIP after scaling the data. Since the proposed input loading pulses are not too different, it might be possible to develop average responses with the caveat that these averages should be compared with data from other institutions.

11. SCHEDULE, PRODUCTS, AND MILESTONES

The following summarizes the schedule for whole body PMHS experimentation and analysis during the April - July 2013 phase of this project (Table 8) with associated milestones. Table 9 shows a proposed timeline for additional whole body PMHS testing through October 2013.

1. An updated Research Plan for whole-body PMHS testing will be submitted. C*ompletion date: April 5, 2013*
2. Test Readiness Plan for whole-body PMHS testing will be submitted. C*ompletion date: Three weeks from the date of approval by Army/APL on Research Plan*
3. Whole-body PMHS 1 experimental series will be conducted using AENID. *Expected completion date: Two weeks after approval of TRP (expected May 24, 2013)*
4. Whole-body PMHS 2 experimental series will be conducted using AENID. *Expected completion date: (4 weeks after stage 3-June 28, 2013)*
5. Data reduction, analysis and scaling will follow each test series and culminate in a summary report. *Expected completion date: June 30, 2013*

Table 8: Experiment and deliverable timeline for whole body PMHS 1 and 2 series

Year		2013															
Task	Duration (days)	April				May				June				July			
		Week				Week				Week				Week			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Submit updated WB Research Plan	7	→															
Submit WB Test Readiness Plan	7		→														
PMHS 1 WB preparation & testing	10						→	→									
PMHS 1 Data Analysis	10									→	→						
PMHS 2 WB preparation & testing	10											→	→				
PMHS 2 Data Analysis	10													→	→		
PMHS WB report with IRC	14															→	→

Table 9 is an aggressive schedule to meet the requirements of ATD developers as articulated by JHU/APL. Some potential sources of delay are: approval of Research Plan/Test readiness plan; availability of PMHS; new contract; supply of right test specification (e.g restraint system); any new requirement that may require modification to AENID; test personnel/data analysis; supply of PPE; and coordination with other medical performers. Hence Table 9 should be viewed as an optimistic timeline.

Table 9: Proposed timeline for additional PMHS test series

Year		2013											
Task	Duration (days)	August				September				October			
		Week				Week				Week			
		1	2	3	4	1	2	3	4	1	2	3	4
PMHS 3 WB preparation & testing	10												
PMHS 3 Data Analysis	10												
PMHS 4 WB preparation & testing	10												
PMHS 4 Data Analysis	10												
PMHS 5 WB preparation & testing	10												
PMHS 5 Data Analysis	10												
PMHS 6 WB preparation & testing	10												
PMHS 6 Data Analysis	10												
PMHS 7 WB preparation & testing	10												
PMHS 7 Data Analysis	10												
PMHS 8 WB preparation & testing	10												
PMHS 8 Data Analysis	10												
PMHS WB report with IRC	7												

12. ASSUMPTIONS AND RISKS

The major risk in the proposed series of tests is that only 2 tests are being proposed and the loading condition to cause injury to the pelvis is unclear. Results of tests with H3 as the test subject indicate that pelvis injury is likely to occur at very low loading regimen. We have presented our analysis in support of the choice of input variables. However, since we do not have data from other institutions and GH tests comparing H3 and cadaver test results for rigid seat attached rigidly to the floor plate, pelvic injury early on in the test sequence remains a possibility. See also notes on Table 9 in Section 11.

We do not anticipate any technical or budget risks. UNL's sensor suite is a little limited, but we are attempting to buy and install more sensors and DAQ , with timely/additional funds from the army.

13. APPENDIX A – USAMRMC ORP Approval

From: Brosch, Laura R Dr CIV USA MEDCOM USAMRMC
<Laura.Brosch@us.army.mil>
Sent: Thursday, November 15, 2012 11:58 AM
To: Namas Chandra
Cc: Bennett, Jodi H Ms CIV USA MEDCOM USAMRMC; Brosch, Laura R Dr CIV USA MEDCOM USAMRMC; Donahue, Sarah L Dr CIV US USA MEDCOM USAMRMC; Brozoski, Frederick T Mr CIV USA MEDCOM USAARL; Starrs, Richard P COL MIL USA MEDCOM USAMRMC; Teyhen, John V COL MIL USA MEDCOM USAMRMC; Gupta, Raj K Dr DoD Af US USA MEDCOM USAMRMC; Chancey, Valeta C Dr CIV USA MEDCOM USAARL; Hall, LaMont J LTC MIL USA ASA ALT; McEntire, Barney J Mr CIV USA MEDCOM USAARL; Emerson, Jill D Ms CIV US USA MEDCOM USAARL; Rangarajan, Nagarajan (nranga@mcw.edu); James Rinaldi; Aaron Alai
Subject: A-17569.a Approval of Cadaver Activity, "Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID)," Namas Chandra, PhD, University of Nebraska, Year 1, Proposal Log Number 11201009, Award W81XWH-12-2-0056 (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE
SUBJECT: Approval of Cadaver Activity, "Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID)," Submitted by Namas Chandra, PhD, University of Nebraska, Lincoln, in Support of Year 1 activities in accordance with Proposal Log Number 11201009, Award Number W81XWH-12-2-0056, USAMRMC ORP Log Number A-17569.a

1. The U.S. Army Medical Research and Materiel Command (USAMRMC) Office of Research Protections (ORP) received documents in support of the Research Plan #1 activities to be done in year 1.

2. The Research Plan #1 (version 2012, received 4 September 2012) and associated documents have been reviewed for applicability of the U.S. Army Policy for Use of Human Cadavers for Research, Development, Test and Evaluation (RDT&E), Education, or Training (referred to herein as the "Army policy"). The involvement of cadavers in this activity constitutes
a sensitive use as defined within the Army policy.

a. Year 1 activities will be undertaken to develop injury risk curves for lower extremities and whole bodies. Specimens will be subjected to underbody blast (UBB) loading pressures using the newly developed Advanced Energetic Impact Device (AENID) and the resulting injuries measured. The existing test devices/protocols (e.g., impactors, sleds) do not adequately reproduce the extremely violent high onset and high accelerative vertical loading conditions necessary to generate the data required for injury assessment reference curves. The AENID is expected to produce more reliable curves.

b. Year 1 activities will use 2 sets of lower extremities and 2 whole body cadavers will be procured from the Platinum Training Services, LLC, provided donors mark the 'yes' checkbox for 'non-medical testing' on the International Institute for the Advancement of Medicine Consent/Authorization for Non-Transplant Anatomic Donation form or the 'I do authorize' checkbox for 'special non-medical projects' on the Willed Body to Science Consent Form for the Biological Resources Center (BRC).

c. NOTE: Activities that will involve cadavers to be conducted after year 1 using funds from this award must be reviewed separately. These activities may not be initiated until approval from this office is granted.

3. The USAMRMC ORP has determined that requirements of the Army policy have been satisfied. This activity is approved and may be implemented pending authorization by local authorities.

4. Please note the following reporting requirements and responsibilities. Send actions as described below to the hrpo@amedd.army.mil, referencing both the proposal log number and USAMRMC ORP log number listed in the "Subject" line above.

a. The activity must be conducted in accordance with the approved Research Plan #1 (version 2012, received 4 September 2012) and other governing documents.

b. In the event of activity modifications, the Principal Investigator must send a description of the change(s) to the USAMRMC ORP prior to implementation. A change to the approved SOW requires ORP approval prior to implementation.

c. Problems related to the conduct of the activity involving cadavers or the procurement, inventory, use, storage, transfer, transportation, and disposition of cadavers must be reported promptly to the USAMRMC ORP. Examples of problems include but are not limited to: loss of confidentiality of cadaveric donors, breach of security, significant deviation from the approved protocol, failure to comply with state laws and/or institutional policies, and public relations issues. The USAMRMC ORP will report the problem to the CG, USAMRMC and to TSG of the Army.

5. The Commander/Director/Head of the DA organization conducting or supporting the activity,
the USAMRMC ORP, or designees, must be permitted to observe the activity upon request and/or audit activity records to ensure compliance with the approved protocol or applicable regulatory requirements.

6. Do not construe this correspondence as approval for any contract funding. Only the Contracting Officer or Grants Officer can authorize expenditure of funds. It is recommended that you contact the appropriate contract specialist or contracting officer regarding the expenditure of funds for your project.

7. Further information regarding this review may be obtained by contacting Sarah L. Donahue, PhD, MPH, CIP, at 301-619-1118 or Sarah.L.Donahue@us.army.mil.

LAURA R. BROSCH, PhD
Director, Office of Research Protections Director, Human Research Protection Office U.S. Army Medical Research and Materiel Command

Note: The official copy of this approval memo is housed with the protocol file at the Office of Research Protections, Human Research Protections Office, 504 Scott Street, Fort Detrick, MD 21702. Signed copies will be provided upon request.

Classification: UNCLASSIFIED
Caveats: NONE

14. APPENDIX B – Shock Lab Checklist

University of Nebraska – Lincoln Trauma Mechanics Lab - Shock Lab Checklist
Project: ____
Test ID: ________________________ Test date: _____________________

Pre-Shot Checklist

- ☐ Record sensor serial number, location and DAQ channel
- ☐ Check all signal cables for correct routing to data acquisition board
- ☐ Inspect breech and bolts for defects
- ☐ Inspect Impact wrench for defects
- ☐ Take note of membrane supply and alert lab manager if it is getting low
- ☐ Check for a good breech shocktube mate
- ☐ Membranes installed with star tightening pattern
  - o Use of extended wrench arm and manual tightening of bolts is necessary for membrane stacks greater than 5 when using 28” shock tube
- ☐ Turn trigger on
- ☐ Turn PXI power strip and computer on
- ☐ Turn on appropriate signal conditioners (allow for necessary warm up time)
- ☐ Turn on sensor power supplies
- ☐ Open the emergency release gas valve
- ☐ Open appropriate gas lines
- ☐ Open driver gas bottle
- ☐ Check for sufficient gas pressure for experimentation
- ☐ Turn on gas system power unit
- ☐ Check end configuration units for proper installation
- ☐ Check specimens for proper installation
- ☐ Tighten down shock tube windows
- ☐ Reset trigger if red indication light is activated

Pre-Shot Control Room Checklist

- ☐ Turn on gas and DAQ remote access computers
- ☐ Turn on camera security system
- ☐ Open shot log and gas control program
  - o Confirm “fill time” is appropriate
- ☐ Open Data acquisition program for the appropriate shock tube
  - o Confirm recording rate and duration
  - o Select sensor serial number and type in description of its location
- ☐ Visually confirm all doors are shut and that there are no people present in the immediate vicinity of the shock lab walls

- ☐ Enter shock lab and close emergency gas release valve
- ☐ Shut and check lab door is locked upon exiting
- ☐ Arm the shock tube gas control system and confirm warning lights and siren are functioning before starting the fill process
- ☐ Save all data after the execution of the shot

  Camera Setup
  - ☐ Select appropriate viewing area for camera
  - ☐ Select recording speed
  - ☐ Adjust light source and F-Stop
  - ☐ Connect cameras to the trigger output of the DAQ

  Post-Shot Control Room Checklist
  - ☐ Enter atmospheric and temperature data into Shot Log
  - ☐ Confirm sensor data has been successfully recorded
  - ☐ If using high speed camera system select frame range of interest and save data
  - ☐ Turn off control room computers, remote DAQ computer, lights and security camera system
  - ☐ Lock door

  Post-Shot Lab Checklist
  - ☐ Turn off unit to the entire DAQ unit
  - ☐ Turn off gas control system
  - ☐ Turn off trigger systems
  - ☐ Close driver gas bottle
  - ☐ Open emergency gas release valve
  - ☐ Turn off power sensor power units
  - ☐ Lock all bay doors
  - ☐ Turn off lights
  - ☐ Confirms door locks behind you

15. APPENDIX C – Shock Lab Specimen and Data Sheet

University of Nebraska – Lincoln Trauma Mechanics Lab - Shock Lab Specimen and Data Sheet

Project: ____

Test ID: ____________________ **Test date:** _________________

Driver gas: He N_2 Other __________

Membrane material:

____

Membrane thickness: ________________ Membrane #:

____

Breech length: ___________

Specimen placement WRT membrane:

____

Mass on sled: Specimen: ____________ Ballast: ___________ Total:

____

Target peak acceleration: ________________ Target time to peak acceleration:

____

Actual peak acceleration: _______________ Actual time to peak acceleration:

____

Actual peak velocity: __________________ Actual time to peak velocity:

____

Specimen: PMHS ATD Animal: _________________

WB Region/Component: __________________________________

UNL specimen #: ____________________________________

ATD type: ___________________________ ATD serial #:

____

Specimen orientation:

____

Notes:

____

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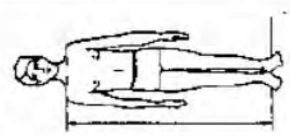
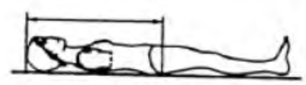
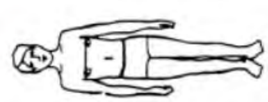
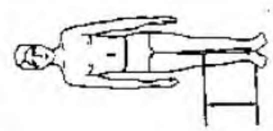
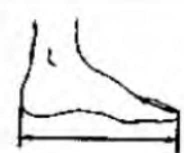
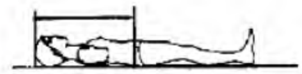
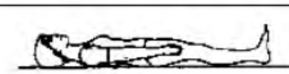
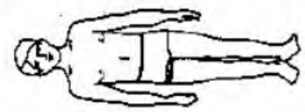
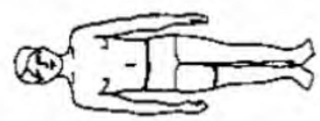
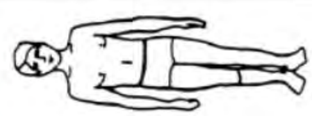
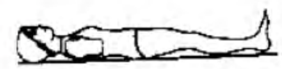
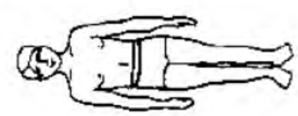
16. APPENDIX D – Anthropometry Data Sheets

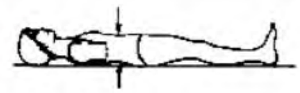
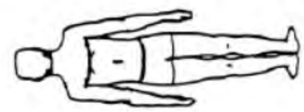
MEASUREMENT	DESCRIPTION	
Stature	Stature of the test subject, measured as the horizontal distance from the headboard of the measuring table to the most distal portion of the heel and taken as an average of the measurement from the left heel and the measurement from the right heel. The measurement is taken with an anthropometer, with the test subject supine, head in the Frankfort plane and firmly touching the headboard.	
Acromial Shoulder Height	Shoulder height of the test subject measured as the horizontal distance from the most distal portion of the heel to the most lateral point of the acromial process of the scapula. The measurement may be obtained by measuring either the distance to both the right and left heels and averaging the two values; or by measuring the distance from the vertex of the head to the acromial process and subtracting the value from STATURE.	
Vertex to Symphysion	Test subject's vertex-to-symphysion length, measured, using an anthropometer, from the headboard of the measuring table to the symphysion, with the test subject in a supine position, head oriented in the Frankfort plane and firmly touching the headboard	
Waist Height	Test subject's waist height, measured as the horizontal distance from the most distal portion of the heel to the anterior superior iliac spine. The measurement may be obtained by measuring either the distance to both the right and left heels and averaging the two values; or by measuring the distance from the vertex of the head to the anterior superior iliac spine and subtracting the value from STATURE.	
Shoulder Breadth	Breadth of the test subject's shoulder measured as the distance across the body between the lateral edge of the left and right acromions.	
Chest Breadth	Chest breadth of the test subject, taken as the average of two measurements of the horizontal breadth of the chest — one taken at the axilla and the other at the substernale, using a beam caliper.	
Waist Breadth	Waist breadth of the test subject, measured, using a beam caliper, as the horizontal breadth of the body at the level of the anterior superior iliac spine.	

MEASUREMENT	DESCRIPTION	
Hip Breadth	Hip breadth of the test subject, measured, using an anthropometer, between the right and left illocristale landmarks perpendicular to the mid-sagital plane.	
Shoulder Length	Length of the test subject's arm from shoulder to elbow, measured, with a beam caliper, as the distance from the top of the acromion process to the bottom of the elbow, with the arm flexed 90 degrees	
Forearm-hand length	Length of the test subject's forearm, measured, with a beam caliper, from the tip of the elbow to the tip of the longest finger, with the arm flexed 90 degrees.	
Tibia Height	Tibia Height is the knee height of the test subject, measured from the most distal portion of the heel to the proximal medial margin of the tibia. The measurement may be obtained by measuring either the distance to both the right and left heels and averaging the two values; or by measuring the distance from the vertex of the head to the proximal medial margin of the tibia and subtracting that value from STATURE.	
Ankle Height	Height of the test subject's ankle as measured, with sliding calipers, from the most distal portion of the heel to the level of the minimum circumference of the ankle (at the level proximal to the malleoli of the tibia and fibula perpendicular to the long axis of the lower leg).	
Foot Breadth	Breadth of the test subject's foot, measured with sliding calipers, at the level of the metatarsal-phalangeal joints along an axis perpendicular to the long axis of the foot. Measure the breadth of both feet and take the average to obtain Foot Breadth.	
Foot Length	Length of the test subject's foot, measured from the dorsal surface of the heel to the tip of the big toe by the use of a beam caliper. Measure the length of both feet and take the average to obtain Foot Length.	

MEASUREMENT	DESCRIPTION	
Head to Trochanterion	Horizontal distance from the test subject's head to the Trochanterion measured, using an anthropometer, from the headboard of the measuring table to the Trochanterion, with the test subject supine, head in the Frankfort plane.	
Seated Height	Test subject's seated height, measured as the vertical distance from the sitting surface to the top of the head. The measurement is taken with the test subject sitting erect, looking straight ahead. This measurement must be made in all cases where the test subject is seated during testing.	
Knee Height	Knee height of the test subject, taken as an average of the vertical distance from the floor to the uppermost point on the knee of both legs. The measurement is taken with the test subject sitting erect, knees and ankles at right angles. This measurement must be made in all cases where the test subject is seated during testing.	
Head Length	Head length of the test subject, measured as the maximum length of the head between the glabella and the occiput in the mid-sagittal plane.	
Head Breadth	Test subject's head breadth, measured, with spreading calipers, as the maximum horizontal breadth of the skull above the level of the ears, perpendicular to the mid-sagittal plane.	
Head Height	Test subject's head height, measured from the highest point on the head to the mentum landmark.	
Bicep Circumference	The circumference of the test subject's bicep, measured, with a tape, as the circumference of the upper arm at the level of the maximum anterior prominence of the biceps brachii, perpendicular to the long axis of the upper arm.	

MEASUREMENT	DESCRIPTION	
Elbow Circumference	The circumference of the test subject's elbow, measured with a tape passing over the olecranon process of the ulna and into the crease of the elbow, which is flexed at 125 degrees.	
Forearm Circumference	Circumference of the test subject's forearm, measured at the maximum circumference of the forearm, with a tape perpendicular to the long axis of the forearm.	
Wrist Circumference	Wrist circumference of the test subject, measured at the minimum circumference of the wrist proximal to the radial and ulnar styloid processes, with a tape perpendicular to the long axis of the forearm.	
Thigh Circumference	Circumference of the test subject's thigh, measured, with a tape, perpendicular to the long axis of the leg and passing just below the lowest point of the gluteal furrow.	
Lower Thigh Circumference	Circumference of the test subject's lower thigh, measured, just superior to the patella, with a tape perpendicular to the long axis of the thigh.	
Knee Circumference	Circumference of the test subject's knee, measured either with the leg extended or with the knee flexed 90 degrees. Only one measurement is needed for the test. For tests in which the test subject is seated with the leg flexed 90 degrees, measure the circumference of the knee across the antecubital crease and the most anterior superior margin of the patella. Measure the circumference of both knees and take the average to obtain Knee Circumference. For all other tests, the test subject is supine with the leg extended. Measure the circumference of both knees at the level of the mid-patella landmark and take the average to obtain Knee Circumference.	
Calf Circumference	Circumference of the test subject's calf, taken as the average measurement of the calf circumferences of both legs. The maximum circumference of the calf for each leg is measured by the use of a tape perpendicular to the long axis of the lower leg.	

MEASUREMENT	DESCRIPTION	
Ankle Circumference	Circumference of the test subject's ankle, measured as the average maximum circumference of the ankle perpendicular to the long axis of the lower leg at the level proximal to the malleoli of the tibia and fibula.	
Neck Circumference	Circumference of the test subject's neck, measured with a tape in a plane perpendicular to the axis of the neck and passing inferior, but tangent, to the laryngeal prominence.	
Scye Circumference	Test subject's scye circumference, measured by passing through the axilla over the anterior and posterior vertical scye landmarks and over the acromial landmarks.	
Chest Circumference	Test subject's chest circumference, taken as the average of two measurements, made perpendicular to the long axis of the trunk: one taken as the axilla circumference and the other as the substernale circumference.	
Waist Circumference	Waist circumference of the test subject, measured with a tape passing over the anterior superior iliac spine and perpendicular to the long axis of the trunk.	
Buttocks Circumference	Horizontal circumference of the buttocks of the test subject, measured at the level of the trochanterion surface landmarks.	
Chest Depth	Test subject's chest depth, taken as the average of two measurements: with an anthropometer, one is taken from the measuring table to the anterior surface of the body at the axilla and the other at the substernale.	

MEASUREMENT	DESCRIPTION	
Waist Depth	Waist depth of the test subject, measured as the vertical distance between the measuring table and the anterior surface of the body at the level of the anterior superior iliac spine.	
Buttocks Depth	Buttock depth of the test subject, measured as the anterior-posterior distance on the medial plane projection at the level of the maximum posterior protrusion of the buttocks.	
Inter Scye Distance	Horizontal distance across the back of the test subject, measured between the posterior scye point landmarks.	

17. APPENDIX E – Seating Procedure

PMHS seating procedure

The seat will be aligned to the loading plate such that the central longitudinal axis of the seat is orthogonal and centered to the plate.

The PMHS is centered on the seat so that the midsagittal plane coincides with the vertical longitudinal plane through the center of the seat.

The specimen will be placed so that there are no gaps between the posterior surface of the torso, with or without PPE, and the seat back.

The upper torso will be rocked laterally in a side to side motion three times through a ±5° arc to reduce friction.

The PMHS will be positioned so that the posterior surface of the pelvis and thighs will contact the seat bottom without gaps. The distance between the femoral lateral epicondyles will the 270 mm. The midpoint of the lateral epicondylar line will be on the midsagittal plane and coincide with the central longitudinal axis of the seat.

The specimen's feet will be placed flat against the loading plate and equidistant from the central longitudinal axis of the foot plate, while maintaining the 270 mm lateral epicondylar distance. The angle between the leg and the foot will be 90° in the sagittal plane and verified with a framing square. A single strip of masking tape may be required to maintain foot position against the plate.

The angle between the thigh and the leg will be 90° in the sagittal plane and verified with a framing square. Additionally, the leg will be horizontal with the center of the anterior knee coincident with the center of the ankle joint.

The head of the supine specimen will be positioned so that the Frankfort plane will be 90 ± 0.5° from the horizontal.

The lateral aspect of specimen wrists will be placed on the anterior surface of the superior thighs.

Testing position of the specimen will be documented through photography and radiographic examination, if required.

18. APPENDIX F – Detail of Specimen & File Numbering Schemes

The identity of PMHS will be protected by providing a unique UNL identification number for each specimen starting with PMHS_001. The UNL ID number and details regarding the specimen, e.g. age, specimen type (whole body, subsystem, or component), acquisition date and disposition date, will be maintained in a password protected database accessible only to the Project Manager and the PI.

File naming structure for data, high speed video, still images, and reports will follow the guidelines specified in WIAMan Medical Research Integration Plan Version 5.0. An example filename for raw data collected during a PMHS test using AENID follows.

UNL_0000000_YYYYMMDD_PMHS_ST0001_Raw_GD.txt

In this example "UNL" is the institution, "0000000" represents the last seven digits of the Cooperative Agreement task number, "YYYYMMDD" is the date of the test, "PMHS" is the surrogate tested, "ST0001" indicates AENID, "Raw" is the data signal status, and "GD" is a note.

Additionally, all data will include the header information specified in WIAMan Medical Research Integration Plan Version 5.0.

19. APPENDIX G – APL Presentation – January 30, 2013

Slide 1

Nebraska
Lincoln

Presentation outline

- Objectives of tests
- Description of test apparatus
- Description of seating procedure
- Data collection methodology
- Data analysis algorithm
- Summary of tests
- Comparison of high energy input test loading pulse and dummy response with live fire test
- Summary of dummy responses
- Conclusion

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Slide 2

Nebraska
Lincoln

Objectives of tests

- Conduct whole body tests using an instrumented H3 dummy.
- Dummy has Mil-LX on left side and standard H3 legs on the right.
- Expose dummy to realistic UBB pulses using AENID.
- Compare responses of Mil-LX with standard H3 leg under realistic UBB conditions.
- Summarise responses of the dummy, develop response corridors.
- Develop parameters for component tests.

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Slide 3

Nebraska Lincoln

Description of test apparatus

Medical College of Wisconsin

- Seat and loading plate design
- Seat instrumentation
- Loading plate design

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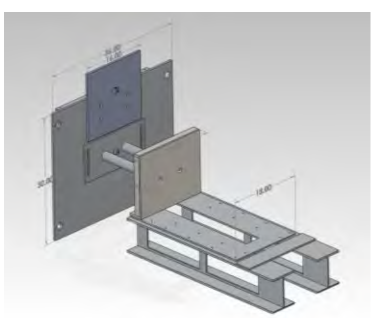
Slide 4

Nebraska Lincoln

Seat and Loading Plate Design

Medical College of Wisconsin



- Image at left shows the seat and loading plate. The loading plate is connected to the seat through 2 "stems." This design allows the seat to push away from the loading plate
- Seat weighs approximately 42 kg
- Loading plate weighs approximately 45 kg

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Slide 5

Nebraska Lincoln

Seat Instrumentation

Sensor Type	Sensor Location	Axis
Accelerometer	Seat bottom - centered between seat stems (red arrow)	Az

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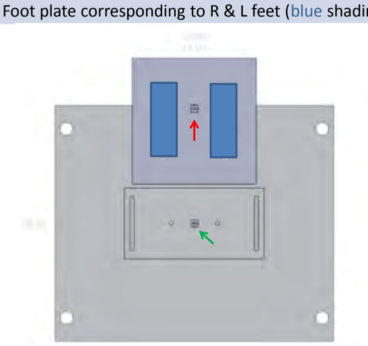
Slide 6

Nebraska Lincoln

Loading Plate Design

Sensor Type	Sensor Location	Axes
Accelerometer	Foot plate center at surrogate midfoot level (red arrow)	Ax, Ay, Az
Accelerometer	Loading plate center at seat stem level (green arrow)	Ax, Ay, Az
Contact switch	Foot plate corresponding to R & L feet (blue shading)	N/A



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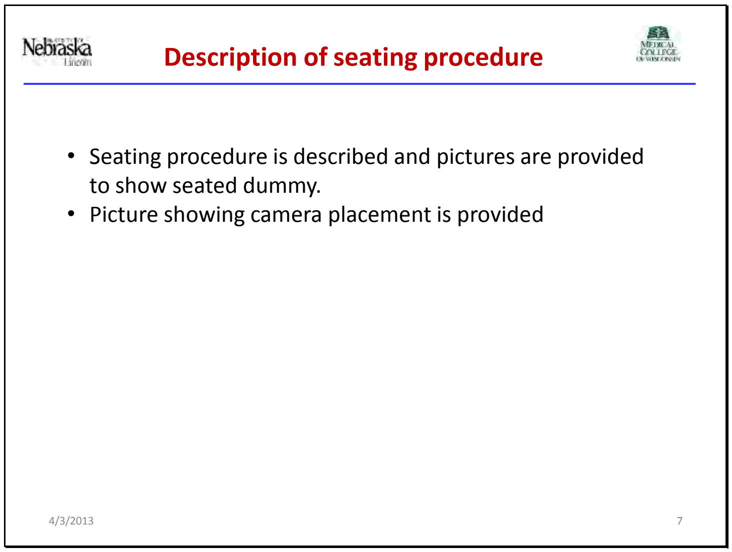
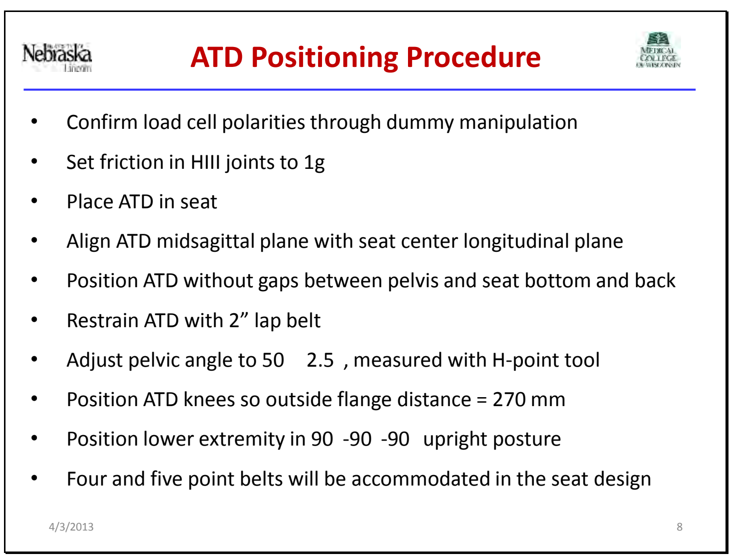
Slide 7



Slide 8



Slide 9

Nebraska Lincoln

ATD Initial Positioning

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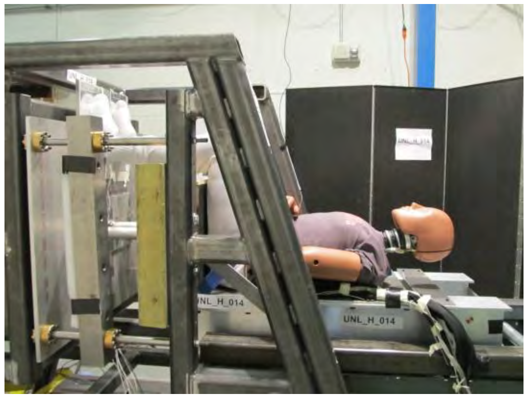

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Slide 10

Nebraska Lincoln

ATD and Seat on Rollers

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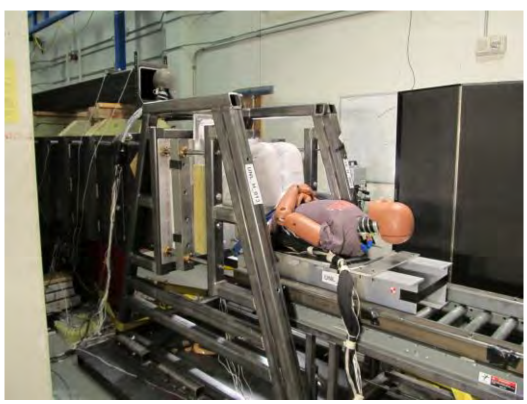

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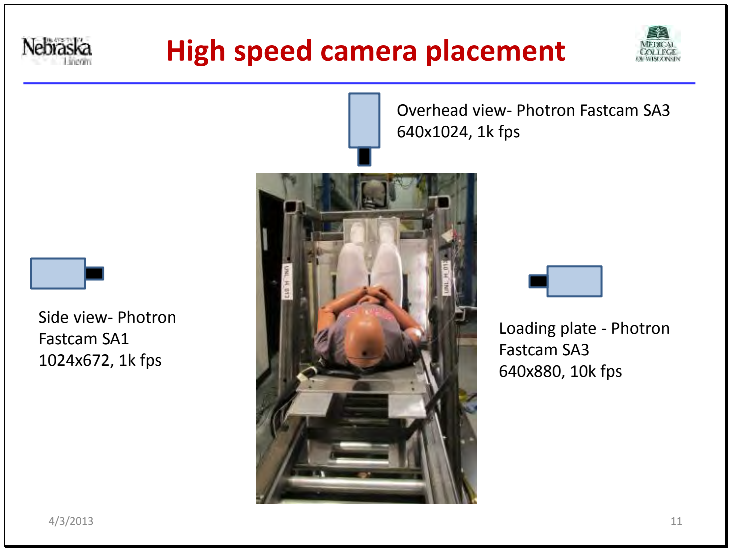

Slide 12

Data collection methodology

- List of H3 sensors is provided
- Test procedure is summarised
- Data acquisition procedure is summarised

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Slide 13

HIII Instrumentation

Channel count	Sensor Type	Sensor Location	Axis	Unit(s)
3	Accelerometer	HIII Head	Ax, Ay, Az	G
9	Load cell	HIII Upper Neck	Fx, Fy, Fz, Mx, My, Mz	N, Nm
12	Accelerometer	HIII Chest	Ax, Ay, Az	G
18	Load cell	HIII Lumbar	Fx, Fy, Fz, Mx, My, Mz	N, Nm
21	Accelerometer	HIII pelvis	Ax, Ay, Az	G
27	Load cell	HIII Femur - Right	Fx, Fy, Fz, Mx, My, Mz	N, Nm
32	Load cell	HIII Tibia - Upper Right	Fx, Fy, Fz, Mx, My	N, Nm
37	Load cell	HIII Tibia - Lower Right	Fx, Fy, Fz, Mx, My	N, Nm
42	Load cell	MIL-LX Tibia - Upper Left	Fx, Fy, Fz, Mx, My	N, Nm
47	Load cell	MIL-LX Tibia - Lower Left	Fx, Fy, Fz, Mx, My	N, Nm
50	Accelerometer	HIII Tibia - Right	Ax, Ay, Az	G
53	Accelerometer	MIL-LX Tibia - Left	Ax, Ay, Az	G
56	Accelerometer	MIL-LX Foot - Left	Ax, Ay, Az	G
57	Accelerometer	MIL-LX Heel - Left	Az	G

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Slide 14

Test Procedure

- Perform trigger check for SLICE DAS, shock tube DAS and HS video cameras
- Confirm shock tube components are test ready
- Place surrogate in test position
- Perform still photography
- Assess lab security
- Confirm surrogate positioning
- Initiate filling of shock tube breech
- Fire shock tube

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Slide 15

Data Acquisition Procedure

- DTS SLICE PRO
- Sampling rate = 500 kHz
- Built-in 4-pole Butterworth anti-aliasing filter
- 0.5 s of pre-trigger and 1.0s of post-trigger data
- Post acquisition filtration using SAE J211 CFC 60-1000

Test Measurements	Channel Frequency Class (CFC)
Head acceleration	1000
Neck forces	1000
Neck moments	600
Chest acceleration	180
Lumbar forces & moments	1000
Pelvic acceleration	1000
Femur & Tibia forces & moments	600
Tibia & Foot accelerations	1000

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Slide 16

Data analysis algorithm

- Analyze the acceleration pulse and high speed video of the experiment simultaneously and identify acceleration pulse of interest.
- Calculate the velocity and displacement of the plate from the acceleration pulse using numerical integration.
- Calculate displacement of the plate from video analysis.
- Compare displacement obtained from measured pulse with the displacement obtained from video analysis. When displacements are close to each other it confirms that recorded data is accurate and calculations are correct.
- Analyze load cell data for trends and consistencies.
- The peak load recorded by the H-3 tibia load cells should occur when plate reaches common peak velocity.
- When separation takes place the load cell should read zero. Cross verify this from the video and pressure pad analysis.

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Slide 17

Summary of tests

- The following full body instrumented dummy tests were conducted with the dummy seated on a rigid seat:
  - 3 repeat tests at low specific power input level.
  - 3 repeat tests at medium specific power input level.
  - 3 repeat tests at high specific power input level.
- Input pulse parameters are summarised in the next slide.

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Slide 18

Center of plate

Membranes	Plate velocity, m/s	Time to peak, ms	Plate acceleration , g	Time to peak, ms
5	3.2	4.3	508	0.15
10	5	3.89	865	0.18
15	10	4.11	1600	0.24

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Slide 19

Comparison with live fire test

- In the next few slides, UNL experimental input pulse and selected dummy responses will be compared with appropriate data from live fire tests.

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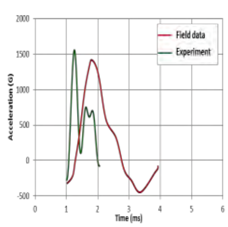
Slide 20

Comparison – plate center acceleration



- Plot compares centre of plate acceleration in UNL tests [in Green] with live fire test plate acceleration [in Red].
- Experimental peak is higher but duration is lower. However, experimental acceleration continues to vary beyond 2 ms.

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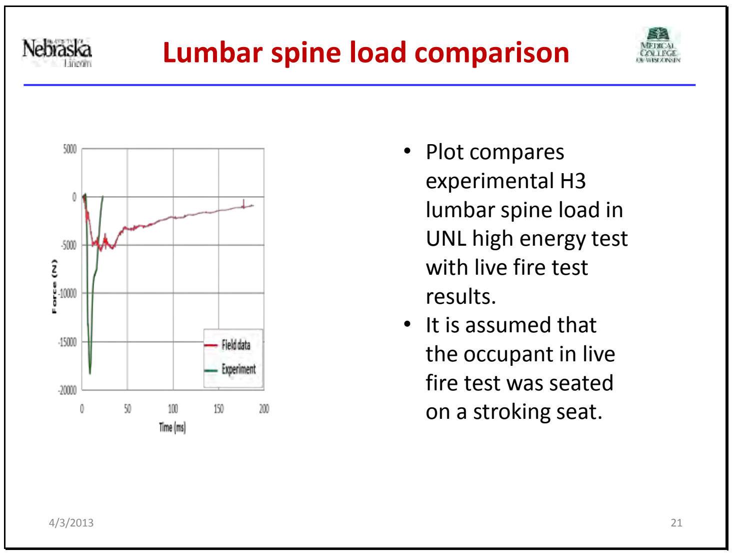
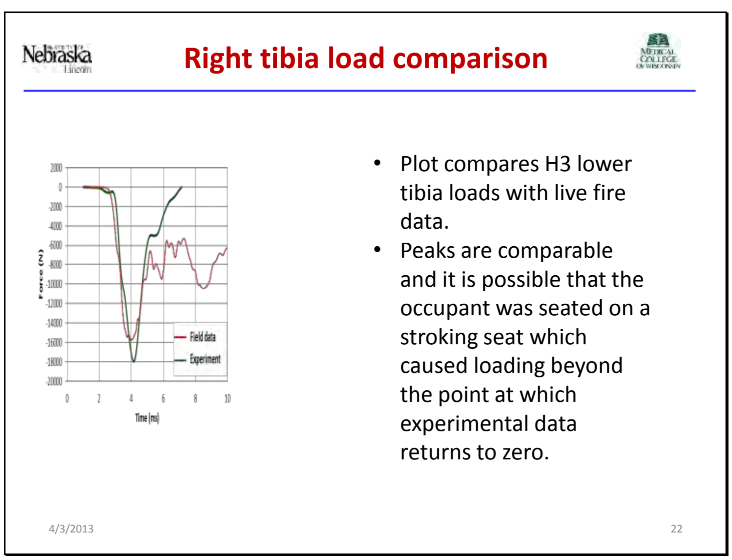
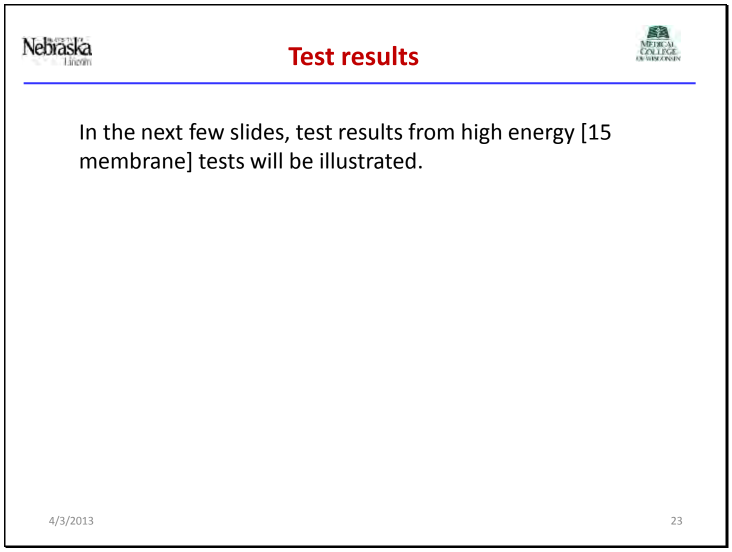
Slide 21



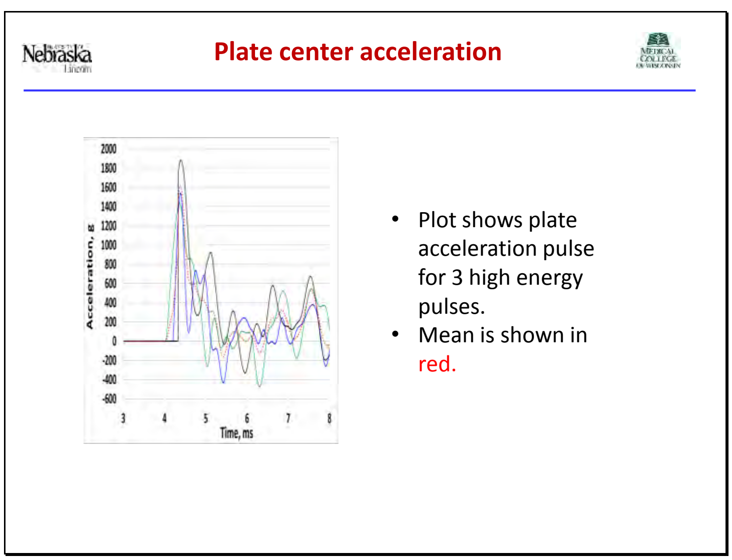
Slide 22



Slide 23



Slide 24



Slide 25

Nebraska Lincoln

Plate Center velocity

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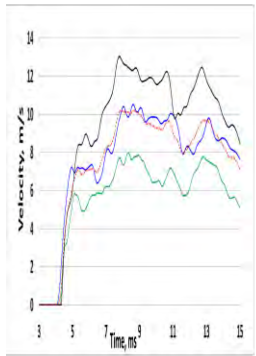

- Plot shows plate velocity profile for 3 high energy pulses.
- Mean is shown in red.

Slide 26

Nebraska Lincoln

Load cell data from Test 13

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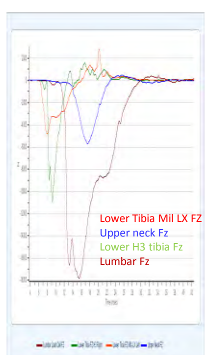

Figure shows load cell data from a 15 membrane test.

- Standard H3 tibia loads are shown
- The seat is connected rigidly to the loading plate.
- All loads exceed current IARV for H3.

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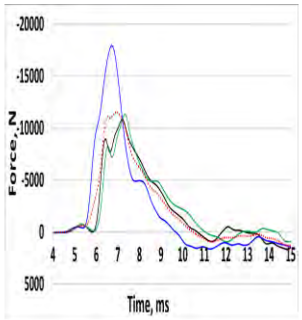
Slide 27

H-3 lower tibia load

Nebraska Lincoln



- The plot shows H3 lower tibia load cell from 3 high energy tests.
- Cause for large variation in one test is being investigated.

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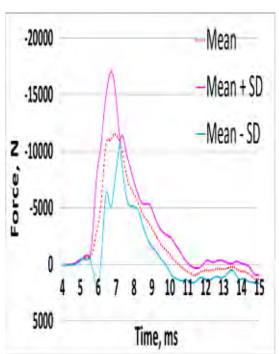
H-3 lower tibia load

Nebraska Lincoln



- Plot shows mean and standard deviation of H3 lower tibia loads.

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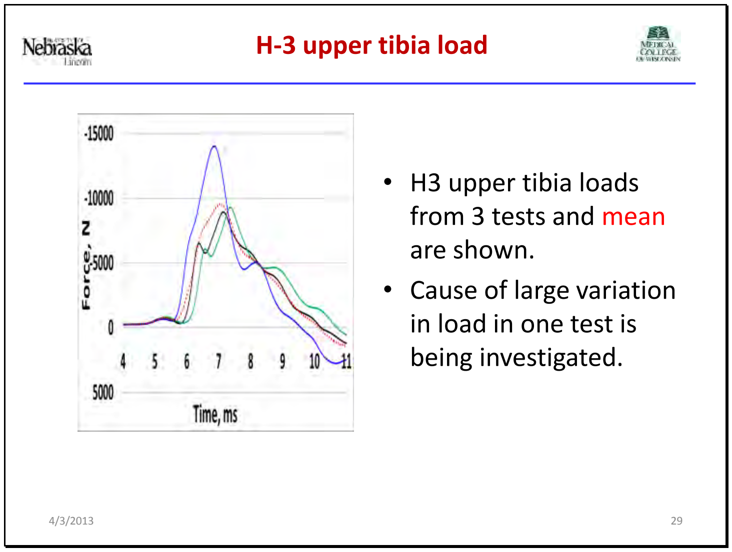
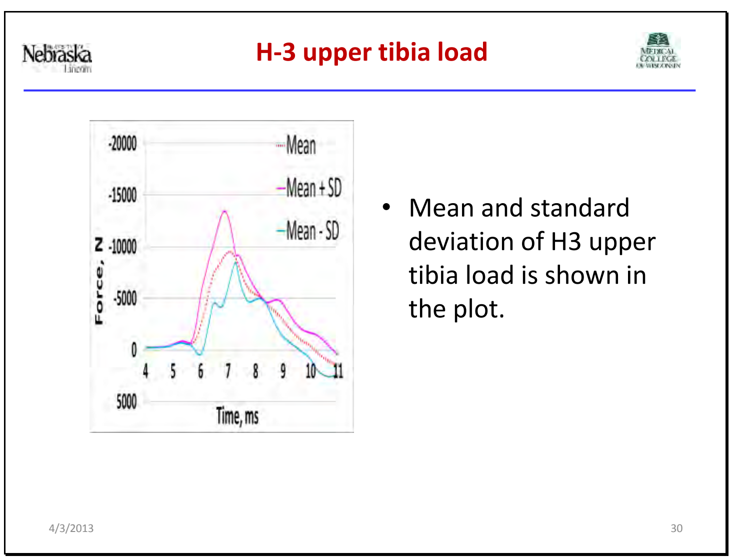
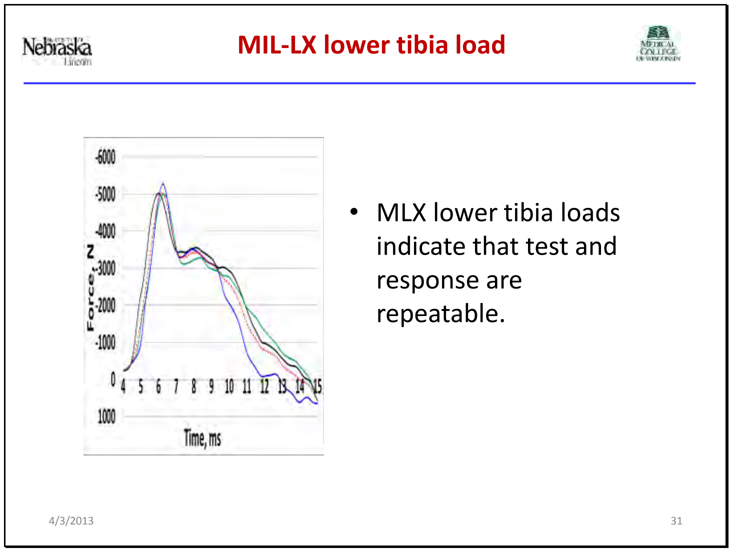


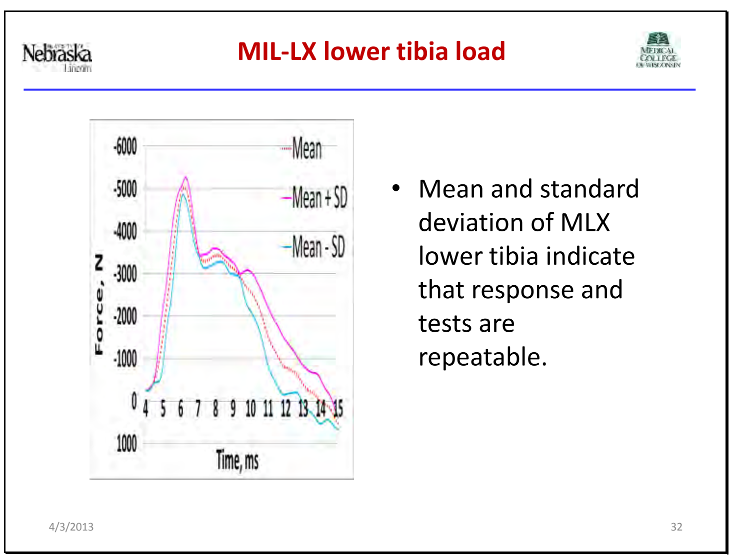
Slide 30



Slide 31



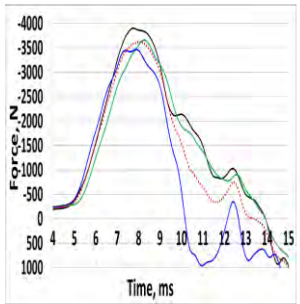
Slide 32



Slide 33

Nebraska Lincoln

MIL-LX upper tibia load



- MLX upper tibia loads from 3 high energy tests are shown.
- Response seems repeatable.

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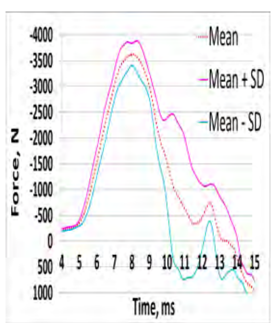
Nebraska Lincoln

MIL-LX upper tibia load



- Mean and standard deviation of MLX upper tibia loads are shown in the plot. Response seems repeatable.

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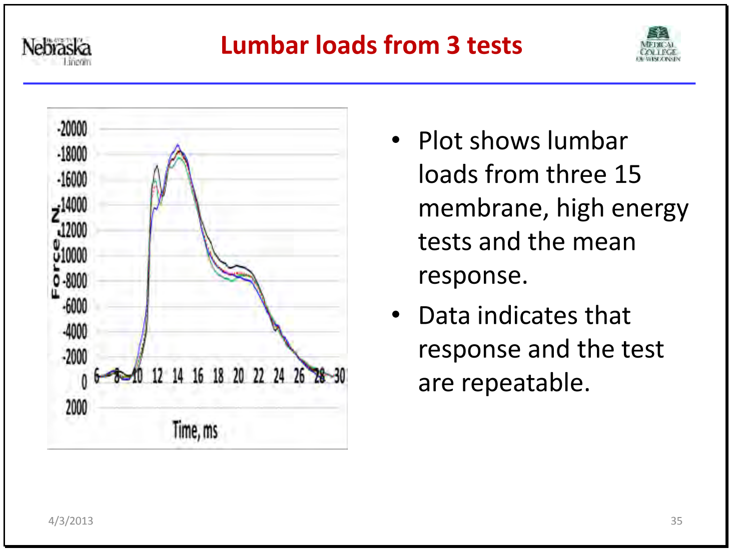
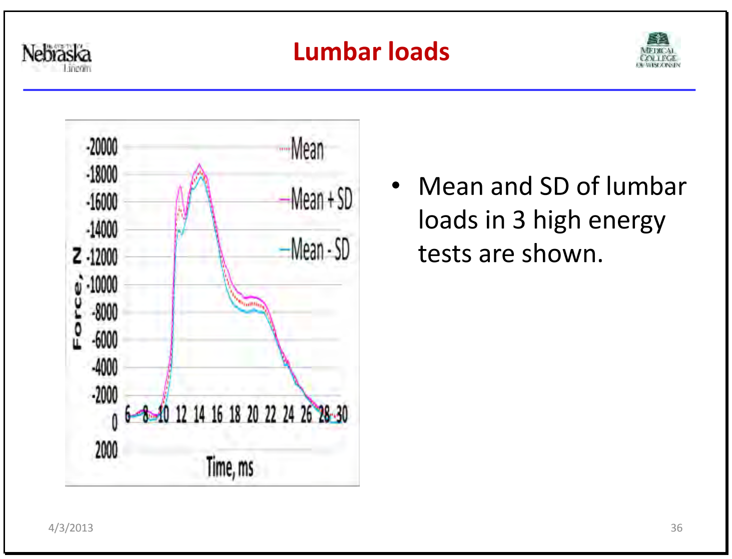
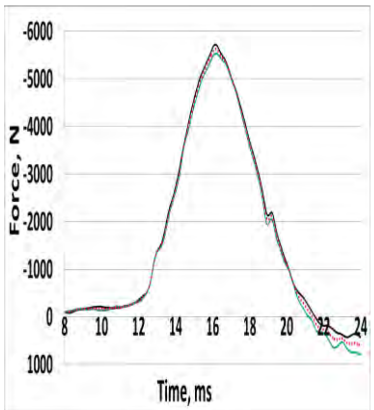


Slide 36



Slide 37

Upper neck loads



- Plot shows upper neck load cell from 2 high energy tests.
- Data indicate that test and response are repeatable.

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H-3 Lower tibia peak load

Membranes	Force (N)	Mean	Ratio wrt 5 membranes
5	-3,054	-3,151	1
	-2,860		
	-3,539		
10	-8,622	-8,235	2.61
	-6,022		
	-10,059		
15	-10,826	-11,355	3.66
	-11,322		
	-11,534		

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MLX lower tibia peak load

Membranes	Force (N)	Mean	Ratio
5	-1,751	-1,812	1
	-1,540		
	-2,145		
10	-3080	-3248	1.79
	-2899		
	-3763		
15	-5022	-5096	2.81
	-4997		
	-5271		

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Peak lumbar load

Membranes	Force (N)	Mean	Ratio
5	-5736	-5888	1
	-6395		
	-5535		
10	-12912	-12727	2.16
	-11974		
	-13294		
15	-18263	-18232	3.10
	-17714		
	-18719		

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Nebraska Lincoln

Peak upper neck load

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Membranes	Force (N)	Mean	Ratio
5	-1,761	-1,932	1
	-2,103		
10	-4,172	-4,025	2.08
	-3,879		
15	-5,718	-5,626	2.91
	-5,535		

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Nebraska Lincoln

Conclusions - 1

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- AENID produces foot plate acceleration pulses whose shape, time to peak, and width are very similar to those seen in Generic Hull test. Therefore, AENID is a very useful, low cost tool to study the effect of blast on vehicle occupants.
- Current design of AENID can accommodate one occupant.
- Multiple AENID tests can be conducted per day with a fully instrumented dummy.
- Plate pulse can be easily controlled.

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Conclusions - 2

- The following full body instrumented dummy tests were conducted with the dummy seated on a rigid seat:
  - 3 repeat tests at low specific power input level.
  - 3 repeat tests at medium specific power input level.
  - 3 repeat tests at high specific power input level.

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Conclusions - 3

- The objective of these tests was to develop specifications for component level test parameters.
- Currently accepted IARV levels were exceeded for tibia loads, lumbar spine loads, pelvis acceleration, and neck compressive loads in the medium and high energy input level tests.

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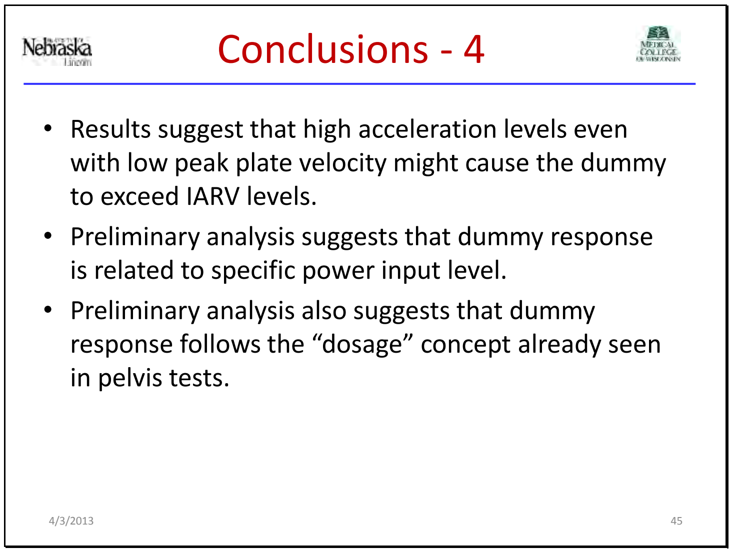
Slide 45


Conclusions - 4
• Results suggest that high acceleration levels even with low peak plate velocity might cause the dummy to exceed IARV levels.
• Preliminary analysis suggests that dummy response is related to specific power input level.
• Preliminary analysis also suggests that dummy response follows the “dosage” concept already seen in pelvis tests.
4/3/2013
45

20. REFERENCES

1. Eppinger, R, Marcus, J and Morgan, R. 1984. Development of dummy and injury index for NHTSA's thoracic side impact protection and research program. SAE Paper No. 840885. Society of Automotive Engineers, Warrendale, PA.
2. Rangarajan, N. and N. Chandra. 2013. Recreation of UBB loading patterns using AENID. Presented at Applied Physics Laboratory, January 30, 2013.

Appendix D

WHOLE BODY PMHS TEST READINESS PLAN

Biomechanics Product Team
Test Readiness Review

Whole Body Cadaver Test
UNLWB-001/2013

Michael Kleinberger, PhD
Technical Coordinator, Whole Body

Andrew Merkle
BIO PT Lead

Agenda

Biomechanics Product Team Test Readiness Review

WIAMan Project

Head Injury Mechanics for Under-Body Blast

University of Nebraska at Lincoln

19 April 2013

8:00 a.m.	Arrival at UNL
8:15 a.m.	Bio PT Technical Coordinator Introduction
8:30 a.m.	Presentation of Test Methods
10:30 a.m.	Demonstration
11:45 a.m.	Travel Time to East Campus for Tour of PMHS Storage and Prep Facilities
12:30 p.m.	Final Q&A & Adjourn

BIO PT Overview & Introduction

- Whole body testing being planned for multiple biomechanics performers
- UNL is the first to progress to the Test Readiness Review
  - Approval for PMHS use received from ORP on 15 November 2012 (Appendix 1)
  - Research Plan Review conducted on 31 January 2013
  - Research Plan Approval received 4 April 2013 (Appendix 2)
  - Test system fully operational and preliminary tests conducted with Hybrid III ATD
- Current test series includes only 2 tests under existing contract. Additional tests are being planned as a follow-on assuming successful completion of initial 2 tests.
- Test conditions based on latest priorities provided by the ATD PT. UNL will conduct tests under the following conditions:
  - WB 14: 7 m/s peak velocity; 5 ms time to peak; no PPE
  - WB 16: 7 m/s peak velocity; 5 ms time to peak; medium PPE
  - WB 18: 7 m/s peak velocity; 8 ms time to peak; no PPE (follow-on effort)
- Data to be integrated with other whole body test efforts to improve statistical power in developing BIO PT deliverables (pending comparative system assessment)
- Initial threshold whole body BRC scheduled to be delivered in November 2013.

For Consideration

- Current system design allows the seat to separate from the floor as the driving plate is stopped.
  - Performer requested by BIO PT to evaluate timing of occupant motion relative to seat separation from the floor to determine the potential effect on occupant response.
  - Initial analysis presented today
    - Regardless of TRR outcome, this consideration must be monitored for all PMHS tests
- There is inherent risk associated with a new system (AENID).
  - Initial checkout tests have demonstrated the capabilities of the AENID system to generate loading profiles consistent with the WBE.
    - However, magnitude of pelvis acceleration jumps with M10, M15. Need to determine why.
  - Tuning and possible system modification will be required to generate alternate profiles. Performer requested to describe potential strategies for pulse tuning.
- Conditions for planned test matrix (<u>velocity</u>) require consideration based on 4.2
- <u>BIO PT Assessment</u>: *Based on the approval of the research plan, awareness of the considerations, demonstrated performance of the AENID system to date, Army HRPO approval, and the readiness of the research team, and assuming the above considerations are satisfied as part of the TRR, the BIO PT recommends this test plan be approved.*

Whole Body Cadaver Test UNLWB-001/2013

Prof. N. Chandra, PhD, PE
University of Nebraska, Lincoln, NE

April 19, 2013

1. Objective and Requirements

Test Series Objectives

- Provide initial whole body data to help determine the effect of PPE on the whole body biomechanical response to UBB loading,
- Provide initial whole body data to help determine the effect of loading rate (time to peak) on the whole body biomechanical response to UBB loading (follow-on effort),
- Provide initial whole body data to help determine loading conditions (both injurious and sub-injurious) to be used for various body regions in sub-system and component tests,
- Provide initial whole body data to help determine biofidelic response corridors in combination with other whole body test efforts,
- Provide initial whole body data to help determine injury probability curves in combination with other whole body test efforts,
- Provide initial whole body data to help determine metrics to compare PMHS responses with WIAMan ATD responses in matched pair testing.

Targeted Requirements

ITM Mapping

- Testing initially mapped to test series WH04 in ITM version 1.0
  - Whole body PMHS tests to study the effects of posture and belt restraints
  - LR 4-9; MR 19; ATD N129 WB 1, 7-9
- Current testing to target re-prioritized requirements
  - Whole body PMHS tests to study the effects of PPE and loading rate (time to peak)
  - LR 4-9; MR 19 ; ATD N129 WB 14, 16, 18
  - Two tests to be conducted under current contract
    - WB 14 (7 m/s peak velocity, 5 ms time to peak, no PPE, rigid seat) – 1 specimen
    - WB 16 (7 m/s peak velocity, 5 ms time to peak, med PPE, rigid seat) – 1 specimen
- Matched pair testing with Hybrid III and WIAMan ATD to be performed under same test conditions as PMHS

2. Pre-Test Preparation

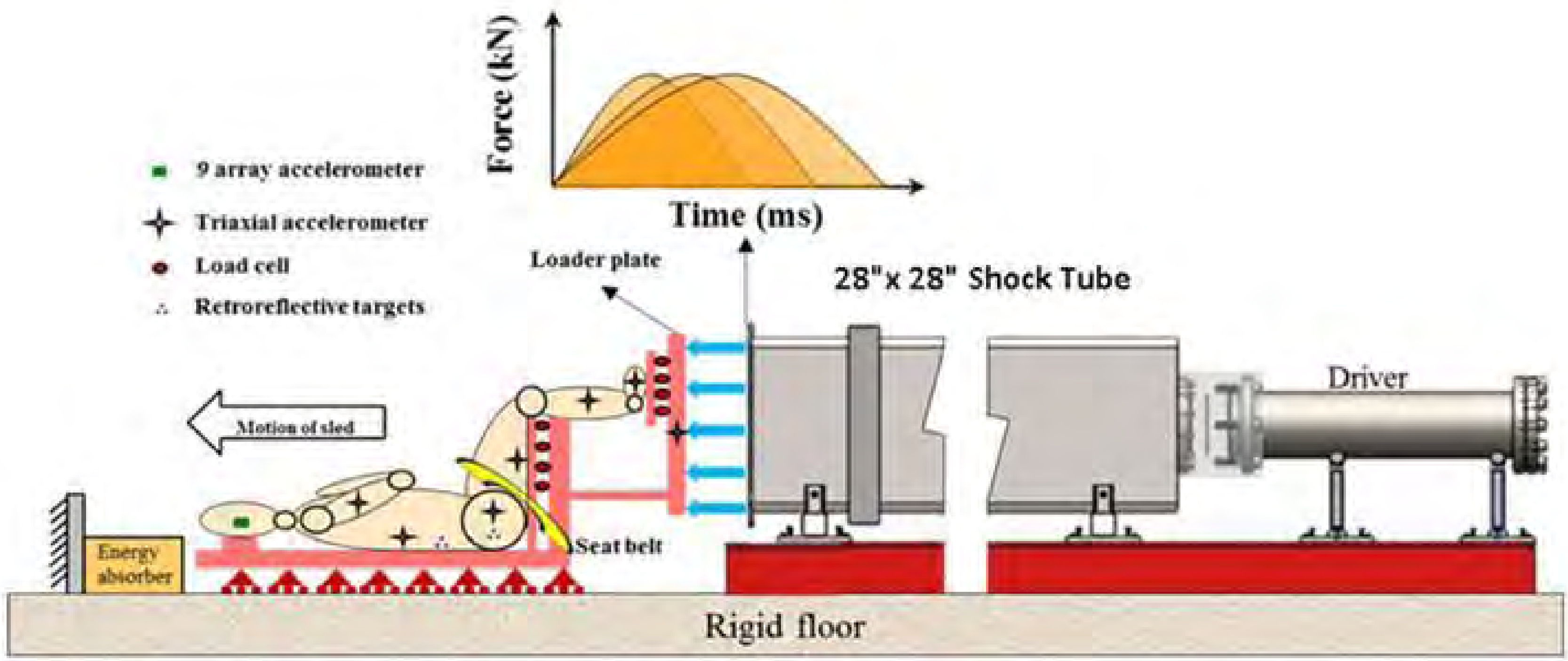
Pre-Requisites

- HRPO / ORP Approval – Received and transmitted to APL as a part of the test plan (see Appendix 1)
- Research plan submitted to APL and approved by BIO PT and PMO (see Appendix 2)

Test Method

- AENID will be used to apply UBB relevant loading conditions to PMHS as described in the ITM and other project requirements documents.
- List of planned instrumentation provided below.
  - Consists of linear accelerometers, angular rate sensors, and strain gauges attached to PMHS specimens.
  - Instrumentation to include standard set of core instrumentation for use with whole body testing as defined by the Biomechanical Parameters listed in the ITM.
  - Additional sensor channels included to document shock tube parameters and sled motion.
- Whole body kinematics captured using 3 high-speed video cameras providing overall left (BP 4,5,6), overall overhead (BP 4,49,54), and foot-plate close-up (BP 49,54) from right.
- All tests performed with PMHS positioned in 90-90-90 posture with 5-point restraint harness.
- Please see research plan and test matrix below for further details.

AENID



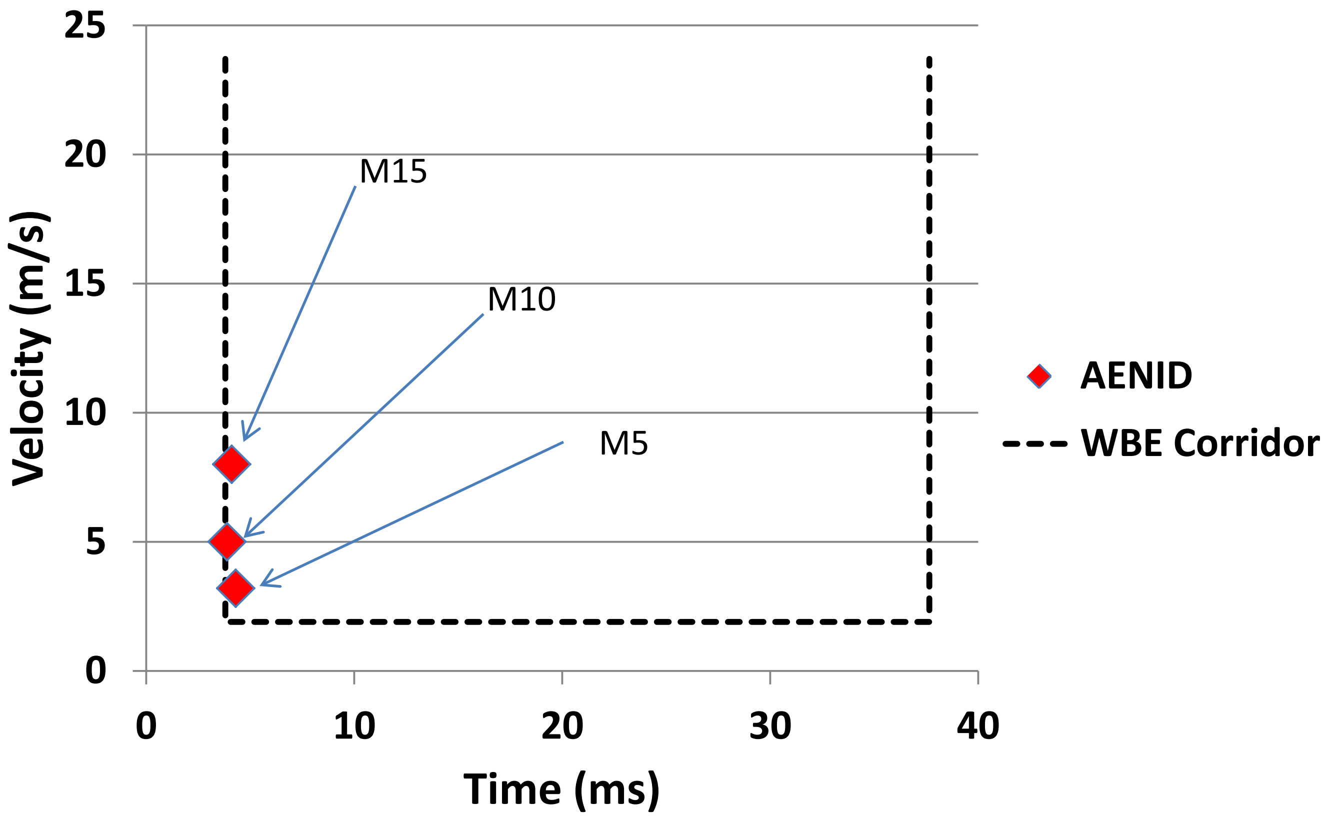
- Tunable loading profile for driving plate
  – Adjust number of diaphragms, driving pressure, length of shock tube
- Strategies to extend duration of loading pulse
  – Bleeding off flow by controlled opening on edge of the shock tube
  – Providing additional resistance on loader plate rod using elastomers or springs

System Performance

- Test variables for recently conducted H3 whole body tests are provided below. *Mn designates n Membranes used.*

# Mem-branes	No of tests	Mean Plate Vel, m/s	Mean time to peak, ms	Mean Plate Acc, G	Mean time to peak, ms
M5	3	3.2	4.3	508	0.15
M10	3	5	3.89	865	0.18
M15	3	8	4.11	1523	0.19

System Performance



Surrogate Response under AENID

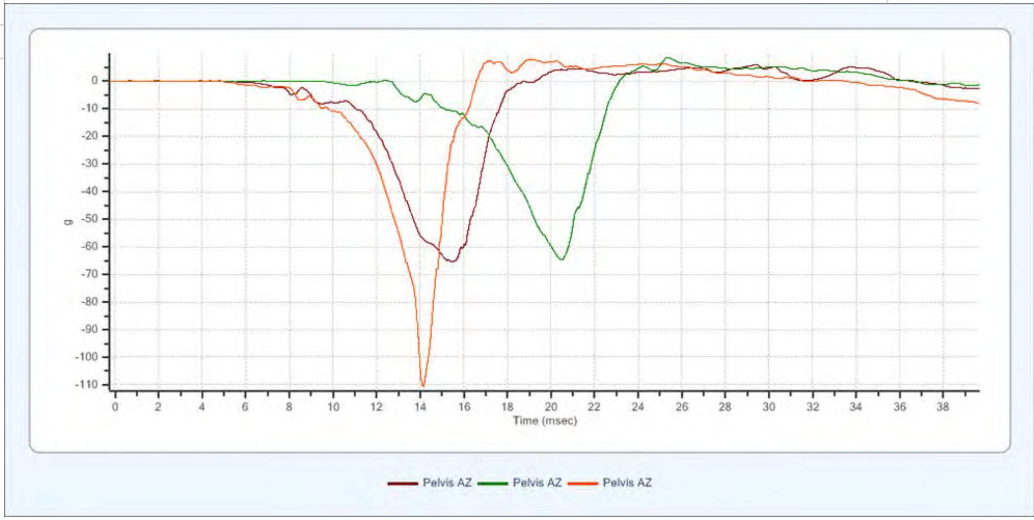
Sample H3 response – Peak tibia and lumbar spine load

# Membranes	Mean Peak Lumbar Spine Load, lbs	Mean Peak Tibia Fz, lbs	Mean Pelvis Accn, G
M5	1319	706	80
M10	2851	1845	413
M15	4084	2544	645

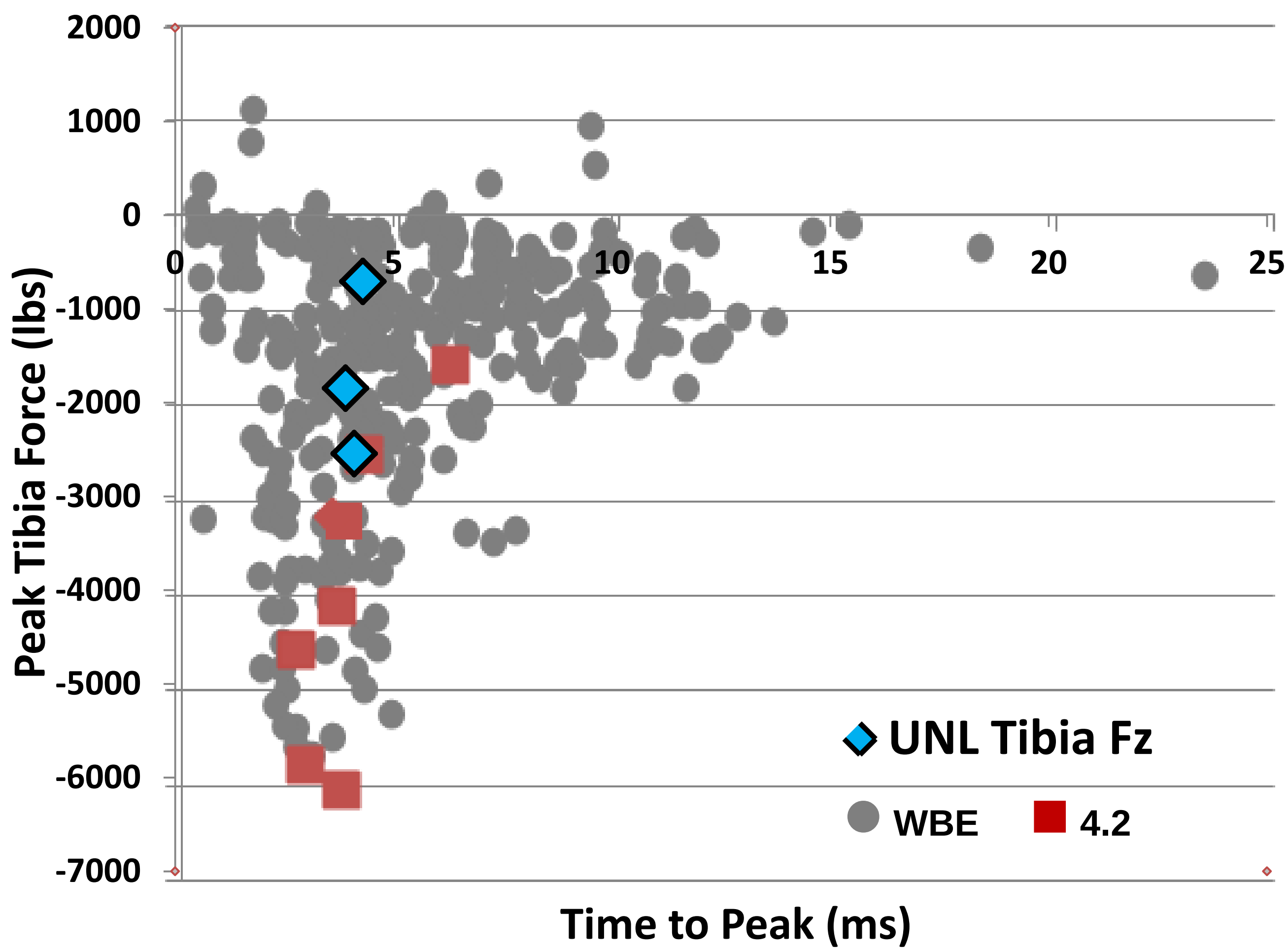
Seat Separation and Peak Accelerations

Separation Analysis - Does Pelvis Acceleration peak before dummy separates from Seat?								
Test No	#Mem-branes	Pk Pel Accn, G	Begin acc	Pk acc	Time to pk	Separat-ion Time	Seperat-ion after peak?	
5	5	65	6	15.5	9.5	15	Y	Separation at almost peak pelvis accel
8	5	65	12.5	20.5	8	17	N	Separation before peak but accn same as test 5, same energy. Please look at Figure 1 which shows essentially the same pelvis acceleration in 2 tests, one with and one without separation.
9	5	110	6	14.1	8.1	12.1	N	Dummy neck does not move till 15 ms, so perhaps no separation
6	10	320	10	14.5	4.5	17	Y	
10	10	450	9	12.2	3.2		Y	
11	10	375	8	11.25	3.25	13.4	Y	
7	15	450	10	13	3	13	Y	
13	15	640	10.2	12.7	2.5	15	Y	
14	15	650	8.5	11.2	2.7	17.9	Y	

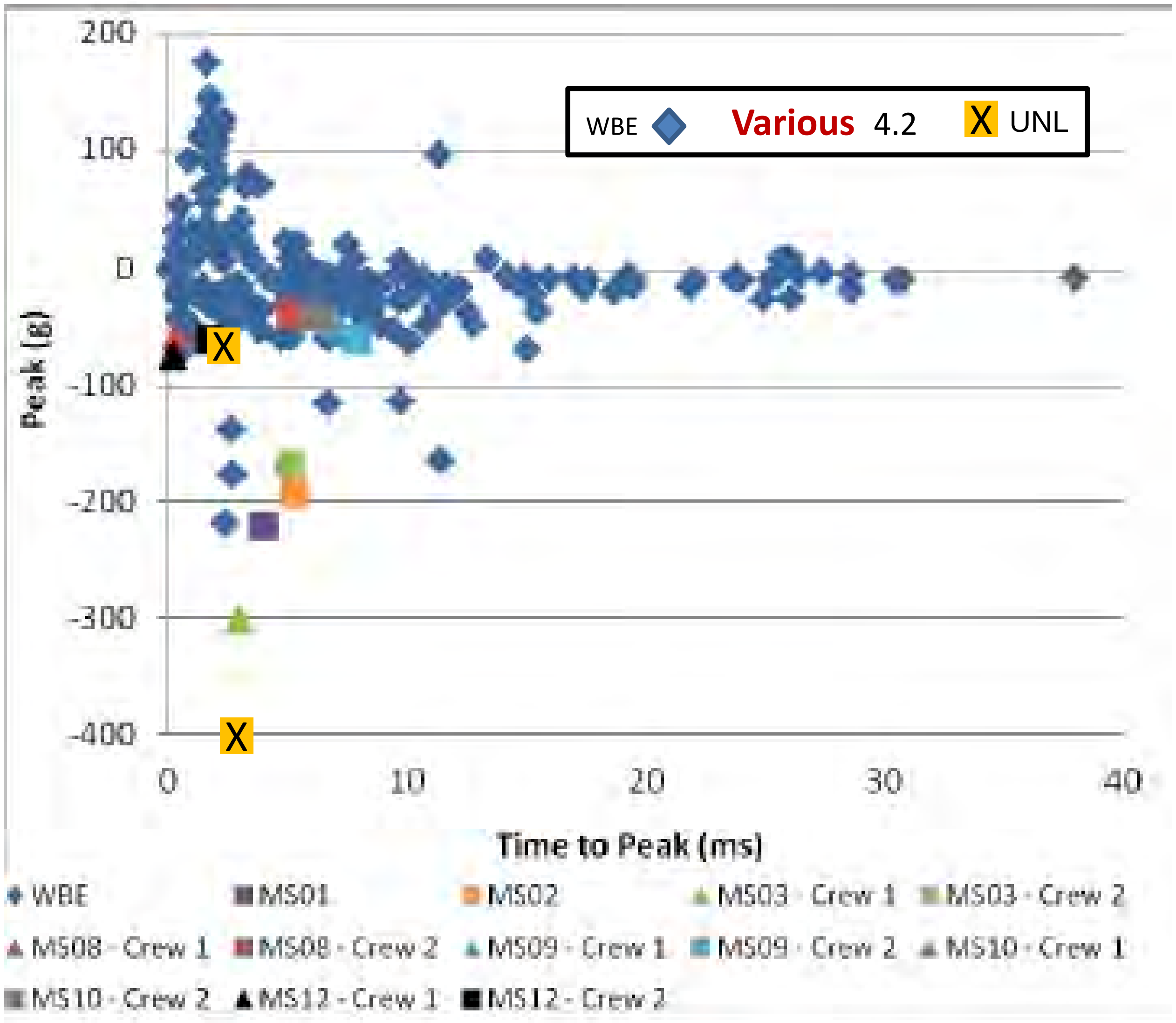
Peak pelvic accelerations occur before the separation of the pelvis from the seat.



Comparison of Tibia Forces



Comparison of Pelvis Acceleration



Test Matrix

Test Number	# PMHS	Peak Velocity, m/s	Time to Peak, ms	PPE	Test Objective
1	1	7	5	None	ATD N129 WB 14, Support for whole body BRC and IPC
2	1	7	5	Medium	ATD N129 WB 16, Support for whole body BRC and IPC

Specimen

- Platinum Training, LLC will supply all whole body PMHS.
- Stature and mass will be confirmed and authorized by APL prior to specimen shipping.
- Platinum will notify UNL when a DOD compliant specimen becomes available.

Anthropometric measure	Target Value	Range
Stature	1725 mm	1666 – 1844 mm
Erect Sitting Height	918 mm	871 – 965 mm
Mass	84.2 kg	Depends on stature & BMI
BMI	----	< 20 - 30

Instrumentation

Channel Count	BP #	Sensor Type	Sensor Location	Axis	Unit(s)
3	BP-2	Accelerometer [1]	Head	Ax, Ay, Az	G
4	BP-3	Angular Rate Sensor [2]	Head	ωy	rad/s
6	BP-18	Accelerometer [1]	T1	Ax,Az	G
7	BP-19	Angular Rate Sensor [2]	T1	ωy	rad/s
9	BP-21	Accelerometer [1]	T4	Ax,Az	G
10	BP-22	Angular Rate Sensor [2]	T4	ωy	rad/s
11	BP-24	Accelerometer [1]	T12	Ax,Az	G
12	BP-25	Angular Rate Sensor [2]	T12	ωy	rad/s
15	BP-43	Accelerometer [1]	Sacrum	Ax, Ay, Az	G
16	BP-44	Angular Rate Sensor [2]	Sacrum	ωy	rad/s
18	BP-47	Accelerometer [1]	Distal Femur – R & L	Ax	G
22	-	Angular Rate Sensor [2]	Distal Femur – R & L	ωx, ωy	rad/s
24	BP-50	Accelerometer [1]	Tibia – R & L	Az	G
28	-	Angular Rate Sensor [2]	Tibia – R & L	ωx, ωy	rad/s
30	BP-53	Accelerometer*	Foot – R & L	Az	G
33	-	Accelerometer [3]	Foot Plate	Ax,Ay,Az	G
36	-	Accelerometer [3]	Center Plate	Ax,Ay,Az	G
37	-	Accelerometer [3]	Seat Bottom	Az	G

[1] Endevco 7264C-2k; [2] ARS: DTS ARS-12K; [3] Endevco 7270A

Strain gages to be added as specified by Instrumentation Working Group.

Data Collection and Processing

- All PMHS response data and input characterization data will be collected using a digital data acquisition system at a sampling rate of 500 kHz.
- A hardware-based, 4-pole Butterworth anti-aliasing filter at 100 kHz will be applied to the data.
- Spectral density plots will be used to evaluate the power and frequency content of each response signal. These plots will be evaluated to determine frequency range where most power is concentrated. This information in turn will be used to determine the characteristics of an appropriate filter. This information will be shared with other test institutions, the Army and APL and any committee that might be reviewing signal processing needs. An appropriate filter will then be chosen to filter the signals.
- Raw data and filtered data will be submitted for each test conducted.
- Three high-speed video cameras running at a minimum of 1,000 fps will be used to capture kinematic data (Higher speeds up to 5000 fps on two other cameras are possible).

3. Test Execution

Pre-Test Activities 1

- Complete specimen pre-test radiography.
- Examine musculoskeletal system for abnormalities.
- Photograph specimen.
- Collect anthropometric data as specified. (See Appendix D of Research Plan)
- Dress cadaver in long sleeve unitard garment with socks and cotton gloves. Tape all seams.
- Cover face and head with stockinet.

Pre-Test Activities 2

- Instrument cadaver – strain gauges will be glued; head, spine and sacrum mounts will be affixed with screws, long bone mounts will be affixed via clamps and adhesive; foot accelerometer will be glued.
- Photograph sensor locations
- Measure position of sensors relative to anatomical landmarks and record the findings.
- Pack void created with gauze pads, close incisions with super glue and skin staples ensuring sensor cables can exit appropriately.

Pre-Test Activities 3

- Move PMHS to test location.
- Position PMHS in 90-90-90 posture on sled. Use UMTRI developed pelvis positioning tool to orient the specimen.
- Measure and record position of anatomical landmarks. Take photographs to record position.
- Place contact sensors on the sled under feet and buttocks. Check to ensure that contact sensors are active.
- Connect all sensors to DAQ and confirm operation.
- Test trigger to DAQ and high speed cameras.

Test Activities 1

- Conduct shock tube safety and experiment checklist
- Conduct test as per test matrix. Initial two tests to be run with peak velocity of 7 m/s with 5 ms time to peak.
- Conduct initial “quick” data evaluation using DTS Sliceware software.
- Examine cadaver for indications of injury and confirm with radiography.
- Document all injuries. Use portable x-ray.
- Conduct initial data evaluation.

Immediate Post-Test Activities

- After each test, take photographs to record final position of cadaver, sled, etc.
- Download all data to storage device and to the master computer.
- Take final X-rays of cadaver segments. Store in storage device and master computer.
- Conduct final external examination and palpation of cadaver. Record all results in a standardized data sheet. Upload data to storage device.
- Conduct post-test autopsy of the cadaver and record all results on standardized injury score sheet.
- Describe all injuries in detail.
- Describe injuries in AIS scale. Follow Army format shown in GH2 test results.

4. Post-Test

Analysis and Reporting - 1

- Data from all sensor channels and video cameras will be downloaded to the analyst's computer for post-test analysis.
- A data quality check will be performed on all channels to verify that the collected data looks reasonable, without loss of signal, clipping of data, or excessive noise.
- Sensor responses will be combined with previous data collected under similar test conditions to establish a biofidelic response corridor for a specific biomechanical parameter (see list of BPs in ITM Appendix C). Data may be combined with data for similar test conditions conducted by other biomechanics performers.
- Data collected during injurious tests will be used to establish injury probability curves, which may be based on a single sensor measurement or a combination of multiple sensor channels. For example, head IPCs will most likely be based on three dimensional motion of the head, which would require the combination of at least 6 channels of data.

Analysis and Reporting - 2

Data Quality Assurance

UNL uses DTS Spliceware for preliminary analysis of data. As soon as the test is run, this software will be used to the following:

- Plots of acceleration, pelvis acceleration, thoracic acceleration and head acceleration as a function of time. Any irregularities in the data will be reported to the project manager as soon as possible.
- Contact switch data and tibia and pelvis acceleration curves will be evaluated to ensure that loading was completed before the body part lost contact with the sled.
- A preliminary spreadsheet will be designed for quick comparison between results from tests. For example, a data from a repeat test will be compared with 1st test in the series. Embedded formulae in the spreadsheet will calculate variance in response between tests.

Analysis and Reporting - 3

Data Quality Assurance

- Final data analysis will be conducted using spreadsheet program to analyze and plot data.
- Means and standard deviations in repeat test responses will also be calculated using the spreadsheet.
- When in doubt about quality of a signal, UNL staff will evaluate unfiltered data and, if need be, develop spectral density plots.
- Ensure that all data and video pertaining to any one test are named according the convention specified in document WIAMan Medical Research Integration Plan, Ver. 5.0, chapter 6.4.2.

Analysis and Reporting - 4

Analysis

- Data analysis starts with the process of identifying all data and video pertaining to a test of interest and downloading them onto the analyst's computer. The analyst might develop a simpler naming convention for ease of use.
- Calculate the velocity and displacement of the plate from the acceleration pulse using numerical integration.
- Calculate displacement of the plate from video analysis.
- Compare displacement obtained from measured pulse with the displacement obtained from video analysis. When displacements are close to each other it confirms that recorded data is accurate and calculations are correct.

Analysis and Reporting - 5

Analysis

- Analyze load cell and acceleration data for trends and consistency.
- When comparing responses from multiple tests, align the data first in time. The peak load recorded by the load cells should occur when plate reaches peak velocity.
- When separation takes place the load cell on the body segment should read zero. Cross verify this from the video and pressure pad analysis.

Analysis and Reporting - 6

Reporting

- UNL data can be provided in DTS format or excel format.
- Final data format will be developed in consultation with other laboratories, the Army and APL.
- Raw and filtered data will be submitted to the BIO PT, along with a quick look analysis report within 2 weeks of completing the test series.
- A final report with a more detailed analysis of the data will be submitted to the BIO PT within 4 weeks of completing the test series.

5. Schedule

Schedule

Year		2013															
Task	Duration (days)	April				May				June				July			
		Week				Week				Week				Week			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Submit updated WB Research Plan	7																
Submit WB Test Readiness Plan	7																
PMHS 1 WB preparation & testing	10																
PMHS 1 Data Analysis	10																
PMHS 2 WB preparation & testing	10																
PMHS 2 Data Analysis	10																
PMHS WB report	14																

6. Risk Mitigation

Risk Mitigation

Risks and mitigation strategies

Risk: Initial tests with Hybrid III ATD indicate that pelvis injury is likely to occur at 7 m/s loading rate. Multiple complex pelvic injuries may occur, which could make it difficult to generate biofidelity information or injury threshold.

Mitigation: Option 1: Conduct tests at lower severity level.

Option 2: To generate biofidelity and injury data, lower level non-injurious baseline test could be run with additional tests of incrementally higher severity being conducted on PMHS specimens until injury occurs. Baseline test would be run between higher increments to verify that no injury has occurred as per specimen re-use guidelines.

Risk Mitigation

Risks and mitigation strategies

Risk: Insufficient number of tests conducted to develop BRC, IPC, and IARC with any statistical significance.

Mitigation: Data collected by UNL will be combined with other whole body test data from other biomechanics performers to achieve the necessary significance. While the round robin activity is not complete, the system performance does fall within the current WBE which is an early indication that data generated from this system should be a candidate for integration.

APPENDICES

Appendix 1 – ORP Approval Letter

From: Brosch, Laura R Dr CIV USA MEDCOM USAMRMC
<Laura.Brosch@us.army.mil>
Sent: Thursday, November 15, 2012 11:58 AM
To: Namas Chandra
Cc: Bennett, Jodi H Ms CIV USA MEDCOM USAMRMC; Brosch, Laura R Dr CIV USA MEDCOM USAMRMC; Donahue, Sarah L Dr CIV US USA MEDCOM USAMRMC; Brozoski, Frederick T Mr CIV USA MEDCOM USAARL; Starrs, Richard P COL MIL USA MEDCOM USAMRMC; Teyhen, John V COL MIL USA MEDCOM USAMRMC; Gupta, Raj K Dr DoD Af US USA MEDCOM USAMRMC; Chancey, Valeta C Dr CIV USA MEDCOM USAARL; Hall, LaMont J LTC MIL USA ASA ALT; McEntire, Barney J Mr CIV USA MEDCOM USAARL; Emerson, Jill D Ms CIV US USA MEDCOM USAARL; Rangarajan, Nagarajan (nranga@mcw.edu); James Rinaldi; Aaron Alai
Subject: A-17569.a Approval of Cadaver Activity, "Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID)," Namas Chandra, PhD, University of Nebraska, Year 1, Proposal Log Number 11201009, Award W81XWH-12-2-0056 (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE
SUBJECT: Approval of Cadaver Activity, "Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID)," Submitted by Namas Chandra, PhD, University of Nebraska, Lincoln, in Support of Year 1 activities in accordance with Proposal Log Number 11201009, Award Number W81XWH-12-2-0056, USAMRMC ORP Log Number A-17569.a

1. The U.S. Army Medical Research and Materiel Command (USAMRMC) Office of Research Protections (ORP) received documents in support of the Research Plan #1 activities to be done in year 1.

2. The Research Plan #1 (version 2012, received 4 September 2012) and associated documents have been reviewed for applicability of the U.S. Army Policy for Use of Human Cadavers for Research, Development, Test and Evaluation (RDT&E), Education, or Training (referred to herein as the "Army policy"). The involvement of cadavers in this activity constitutes
a sensitive use as defined within the Army policy.

a. Year 1 activities will be undertaken to develop injury risk curves for lower extremities and whole bodies. Specimens will be subjected to underbody blast (UBB) loading pressures using the newly developed Advanced Energetic Impact Device (AENID) and the resulting injuries measured. The existing test devices/protocols (e.g., impactors, sleds) do not adequately reproduce the extremely violent high onset and high accelerative vertical loading conditions necessary to generate the data required for injury assessment reference curves. The AENID is expected to produce more reliable curves.

b. Year 1 activities will use 2 sets of lower extremities and 2 whole body cadavers will be procured from the Platinum Training Services, LLC, provided donors mark the 'yes' checkbox
for 'non-medical testing' on the International Institute for the Advancement of Medicine Consent/Authorization for Non-Transplant Anatomic Donation form or the 'I do authorize' checkbox for 'special non-medical projects' on the Willed Body to Science Consent Form for the Biological Resources Center (BRC).

c. NOTE: Activities that will involve cadavers to be conducted after year 1 using funds from this award must be reviewed separately. These activities may not be initiated until approval from this office is granted.

3. The USAMRMC ORP has determined that requirements of the Army policy have been satisfied. This activity is approved and may be implemented pending authorization by local authorities.

4. Please note the following reporting requirements and responsibilities. Send actions as described below to the hrpo@amedd.army.mil, referencing both the proposal log number and USAMRMC ORP log number listed in the "Subject" line above.

a. The activity must be conducted in accordance with the approved Research Plan #1 (version 2012, received 4 September 2012) and other governing documents.

b. In the event of activity modifications, the Principal Investigator must send a description of the change(s) to the USAMRMC ORP prior to implementation. A change to the approved SOW requires ORP approval prior to implementation.

c. Problems related to the conduct of the activity involving cadavers or the procurement, inventory, use, storage, transfer, transportation, and disposition of cadavers must be reported promptly to the USAMRMC ORP. Examples of problems include but are not limited to: loss of confidentiality of cadaveric donors, breach of security, significant deviation from the approved protocol, failure to comply with state laws and/or institutional policies, and public relations issues. The USAMRMC ORP will report the problem to the CG, USAMRMC and to TSG of the Army.

5. The Commander/Director/Head of the DA organization conducting or supporting the activity, the USAMRMC ORP, or designees, must be permitted to observe the activity upon request and/or audit activity records to ensure compliance with the approved protocol or applicable regulatory requirements.

6. Do not construe this correspondence as approval for any contract funding. Only the Contracting Officer or Grants Officer can authorize expenditure of funds. It is recommended that you contact the appropriate contract specialist or contracting officer regarding the expenditure of funds for your project.

7. Further information regarding this review may be obtained by contacting Sarah L. Donahue, PhD, MPH, CIP, at 301-619-1118 or Sarah.L.Donahue@us.army.mil.

LAURA R. BROSCH, PhD
Director, Office of Research Protections Director, Human Research Protection Office U.S. Army Medical Research and Materiel Command

Note: The official copy of this approval memo is housed with the protocol file at the Office of Research Protections, Human Research Protections Office, 504 Scott Street, Fort Detrick, MD 21702. Signed copies will be provided upon request.

Classification: UNCLASSIFIED
Caveats: NONE

Appendix 2 – Research Plan Approval Letter

You forwarded this message on 4/10/2013 9:31 PM.

From: Merkle, Andrew C. <Andrew.Merkle@jhuapl.edu>
Sent: Wed 4/10/2013 9:21 PM
To: Namas Chandra
Cc: Kleinberger, Michael; McEntire, Barney J Mr CIV USA MEDCOM USAARL; Brozoski, Frederick T CIV USARMY MEDCOM USAARL (US) (frederick.t.brozoski.civ@mail.mil)
Subject: Research Plan Approval Notification

Chandra-

I am writing to formally notify you that the research plan titled "Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID)" presented on January 31, 2013 was approved by the WIAMan PMO on 4 April 2013. As you are aware, a TRR must be planned in the near future. The tentative date for that TRR is 19 April 2013 which would include a presentation and a demonstration. Mike will work with you to finalize the agenda for that meeting. Please have a copy of it to me by COB 12 April 2013.

Thanks,
Andrew

Andrew C. Merkle
BIO PT Lead - WIAMan
The Johns Hopkins University
Applied Physics Laboratory
(o) 240.228.4832
(c) 240.501.1149

Appendix E

LOWER EXTREMITY PMHS TEST PROTOCOL

Warrior Injury Assessment Manikin Injury Probability Curves Using AENID – Lower Extremity tests (UNLLE-001/2013.)

Principal Investigator:

Prof. Namas Chandra, PhD, PE

University of Nebraska at Lincoln, NE

Mechanics and Material Engineering Department

900 North 16th Street

Lincoln, NE - 68588

Nchandra2@unl.edu

[402]472-8310

Submitted to:

Biomechanics Product Team Lead

The Johns Hopkins University Applied Physics Laboratory

TABLE OF CONTENTS

1. WIAMan RESEARCH PLAN NUMBER – UNLWB-001/2013

2. RESEARCH PLAN TITLE - Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID) – Whole body tests

3. ABSTRACT

Majority of injuries sustained by United States warfighters in the current (and possibly the future) conflicts can be attributed to blasts. The response of the human body subjected to high-rate vertical under body blast (UBB) loading is not well understood and injury thresholds have not been established. The objective of this test series is to support the intent of the Warrior Injury Assessment Manikin (WIAMan) program to design and build a biofidelic dummy for UBB loading conditions. Both biofidelic response data and injury risk curves are needed to design the WIAMan dummy. UNL proposes to conduct whole body Post Mortem Human Subject (PMHS) tests to develop biofidelity data and injury thresholds. PMHS will be restrained by either a 4-point or a 5-point restraint system and will be tested with and without Personal Protective Equipment (PPE). Exact test configuration will be decided upon consultation with US Army/JHU-APL. A custom designed blast tube (Advanced ENergetic Impact Device – AENID) which can reproduce foot plate acceleration profiles seen in the field will be used to test instrumented PMHS under realistic UBB conditions. PMHS response data from non-injurious and injurious tests will be used to develop biofidelic response corridors, and injury risk curves.

4. STUDY PERSONNEL

Personnel Name	Responsibilities
Prof. Namas Chandra, PhD, PE	Principal Investigator
James Rinaldi, DC	Project Manager
Dr. Jayaraman Srinivasan, PhD	Laboratory Manager
Mr. Michael Bergen, MS BME	Biomedical Engineer
Mr. Nagarajan Rangarajan, PhD	Sub-contractor
Mr. Sailesh Ganpule, MSME	PhD Student Research assistant
Mr. Kurtis Palu, BSME	Test Engineer
Mr. Steve Gloor/Shawn Schumaker	Student Assistants

5. STUDY LOCATION

University of Nebraska, Lincoln, NE.

6. OBJECTIVES/SPECIFIC AIMS/RESEARCH QUESTIONS

Biofidelity and injury tolerance curves are needed to design the WIAMan dummy. Historically, biofidelity and response data to design automotive dummies have been developed through component and sub-system tests on a PMHS. However, since UBB loading is so different from loads imposed in occupants in the automotive environment, a new set of test protocols and loading conditions need to be developed. It is clearly understood that onset rates of loading under UBB conditions are much higher than those seen in the automotive environment even though how to characterize this type of loading is not well understood. Also, it is not known if and how response of the human skeletal system is modified by the high load onset rates.

The effects of boots on occupant response need to be evaluated under UBB loading conditions. It is worth noting that the question of whether a cadaver should wear boots when being tested has been debated without conclusion in the automotive industry. The issue at hand is whether the biofidelity of the WIAMan dummy will be evaluated with or without boots. If the dummy is designed to be biofidelic without boots, it has to be assumed that its response with boots on (normal testing condition) is biofidelic with boots on. If cadaveric legs are tested with a certain type of boots on and the dummy is designed to be biofidelic for this type of response condition, an assumption has to be made that the dummy legs will continue to be biofidelic if the boots are changed. It is not clear how often boot types are changed by the Army. Therefore, it is not possible to make a reasoned decision on the topic of cadaver wearing boots.

Testing without boots makes it possible to observe foot flesh compression. Foot flesh compression plays an important part in the impact response of the lower leg. The effect of foot flesh compression was observed during the design and testing of the mine compatible Thor Lx. Initially, efforts were made to modify the elastomeric response element (puck) at the top of the tibia in an effort to obtain biofidelic response under UBB conditions. Redesigning the puck did modulate the response but it was found that insertion of an energy absorbing pad into the foot flesh moulding produced much more biofidelic response in terms of amplitude and peak time of the tibia compressive force. This effect was confirmed through lumped mass modeling.

With the concurrence of the Army and APL, UNL proposes to test lower extremities without boots. UNL is contracted to test 2 lower extremities in the 1^{st} year of the program. Taking into consideration the number of specimens to be tested, we propose to evaluate the biofidelic response of the lower extremity to compressive loading through the nominal axis of the tibia. UNL will submit plans to test ankle response in the future.

Results from cadaver tests can be used to design the foot, ankle and tibia of the WIAMan dummy.

UNL proposes to load cadaver lower extremity (foot, ankle, and tibia) using the AENID system to understand and quantify the effect of loading rates on the human skeletal system. Specific aims for lower extremity test series spanning all the five years are:

1. From the test series conducted at various input load-loading rate conditions, define loading (both injurious and sub-injurious) conditions for various parts of the lower extremity.
2. Investigate the effect of boots on tibia and ankle responses.

3. Investigate the effect of loading on non-nominal tibia axis. These tests will serve to characterize ankle response at various loading rates.
4. Develop biofidelity corridors for the lower extremities.
5. Develop injury thresholds for tibia.
6. Develop metrics to compare PMHS response with WIAMan dummy response in matched pair testing.

Each lower extremity test series will aim to resolve one or more of these specific aim; the number, type and timings of the tests will be determined based on the army requirements as well as the capabilities and deliverables assigned to other medical performers.

7. WIAMan/MILITARY RELEVANCE

The proposed research is designed to address the “Injury Prevention and Reduction” area of interest specified within BAA11-1. UNL will provide a data-driven, biomedical basis to determine injury mechanisms and injury risk functions, and to define appropriate loading conditions for sub-system and component PMHS tests by conducting whole body PMHS tests. Importantly, the proposed research recognizes that UBB loading environments are very different from other environments such as motor vehicle accidents.

Injuries and injury mechanisms seen under UBB loading differ from those seen in civilian settings. Occupant seating, restraints, and passenger postures in military vehicles are different from motor vehicles, and external loading in military vehicles is associated with higher loading/strain rates than in other environments. Biomechanical properties of human tissues are unknown at these high rates. Injury tolerance for different regions of the musculoskeletal system is unknown at military loading rates and modes.

Most importantly, a military-specific manikin has not been developed using military-specific loading modes, and load/strains rates. This study proposes to support the design of the WIAMan dummy which is intended to model a solider exposed to UBB loads. The new dummy will lead to design of “occupant-centric” vehicles resulting in lives saved and improvement in the quality of life for soldiers.

The proposed research effort will provide basic information needed to design the WIAMan dummy such as biofidelic response curves, and injury tolerance levels for various parts of the lower extremity under UBB loading conditions. UNL’s schedule for deliverables is structured to meet the requirements of dummy designers.

8. SCIENTIFIC BACKGROUND AND SIGNIFICANCE

8.1. Basis for the design of WIAMan dummy

The Hybrid III (H3) dummy is currently used to test armoured vehicles under UBB loading conditions. H3 was developed to model vehicle occupants involved in frontal impacts, generally with negligible vertical acceleration. H3 dummy, in its original design, included tibias formed from steel tubes which are obviously much stiffer than the human tibia. H3 lumbar spine is kyphotic (convex backwards) whereas the human lumbar spine is lordotic (convex forwards). H3 lumbar spine is designed to provide human like response in frontal impact. Overall design of the H3 dummy was based on the much lower load onset rates than those seen in UBB events. Thus, there are a number of design features that make the H3 suitable for automotive testing but not for UBB loading.

The type and location of UBB injuries are quite different from those sustained in Motor Vehicle Accidents (MVA). Injuries from MVAs are sustained in frontal, side or rear decelerative impacts in events lasting > 30 ms, while UBB events are primarily accelerative, high onset vertical loadings lasting <10 ms. While occupants in MVAs range widely in age, size, gender, and health status wearing civilian clothes, UBB injuries involve healthy young men and women warriors with situational awareness wearing PPE. Design and construction of seats and restraint systems in military vehicles are different from civilian vehicles. Posture of military personnel in armored vehicles is likely to be different from those seen in civilian vehicles. Orientation of armored vehicle passengers to the load vector is likely to be different from those seen in civilian vehicles. These differences are substantial and require that a dummy be custom designed to be used for UBB testing.

The Army recognized the need for a dummy suitable to evaluate vehicle performance under UBB loading and this recognition is the basis for the WIAMan program.

8.2. Test equipment

Traditionally, acceleration and deceleration sleds, pendula, and linear impactors have been used to assess injuries resulting from MVA. In keeping with the level of impact in MVA, these test equipment are designed to load the human surrogate at acceleration levels far lower than those seen in UBB events. MVA events are also longer duration events than UBB events. Therefore, most test equipment designed to reproduce MVA events cannot be used to reproduce UBB events.

UNL has designed, developed, built, and tested a one-dimensional shock tube based system AENID. AENID has been proved to create floor accelerations and dummy responses similar to those seen in Generic Hull tests [1] and can be used to subject one occupant to inputs seen in UBB events. Figure 1 provides a schematic of the AENID loading system. AENID is designed to provide independent control over the rise time, magnitude, and duration of the loading pulse.

AENID will be used in the proposed lower extremity tests.

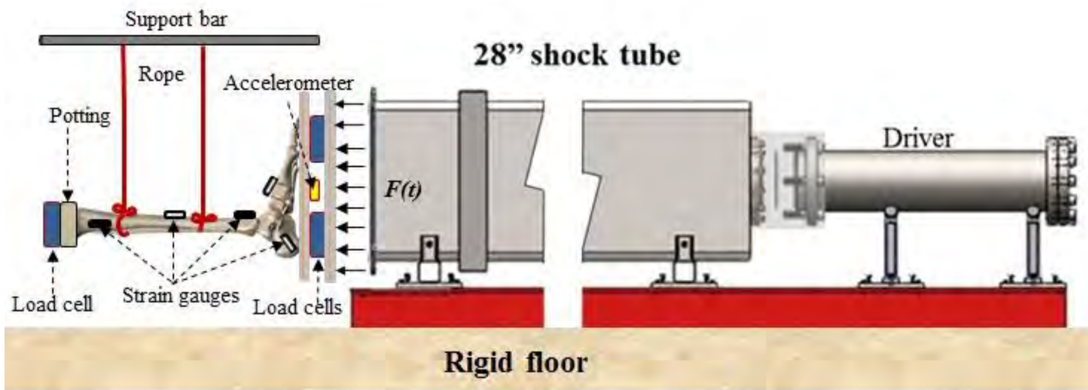


Figure 1: Schematic of AENID showing lower extremity test setup

8.3. Relevance of proposed study

The aims of lower extremity/whole body cadaver tests are to develop biofidelity corridors for tibia response to axial impact and injury criteria for the tibia. Some of these data are being developed from Generic Hull tests and other specialized tests being conducted by the Army as a part of their Live Fire Test and Evaluation (LFTE) program. UNL believes that the capability of AENID to reproduce LFTE test floor acceleration profiles and correlation between dummy segment responses in AENID and LFTE tests makes it possible to use AENID to develop loading conditions for cadaver sub-system and component tests. Figures 2 and 3 indicate that preliminary tests at UNL with H3 dummy reveal that the tibia loading and response patterns are almost exactly like the one recorded in a LFTE test [1]. Therefore, UNL believes that proposed tests are very relevant to the WIAMan program goals.

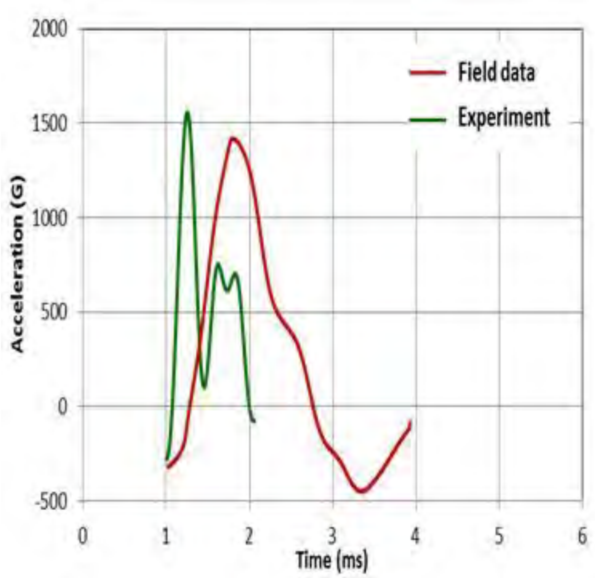


Figure 2: Comparison of field and AENID floor acceleration pulses

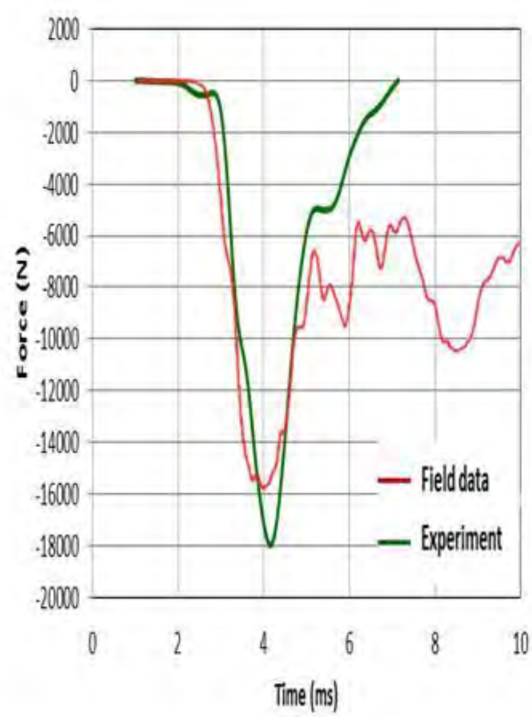


Figure 3: Comparison of field and AENID tibia response forces

8.4. Justification of test loading pulse

UNL recently conducted a number of shake down tests with the H3 dummy as the sole occupant of the seat. Details of dummy seating, data acquisition and results were presented at APL in late January, 2013 [1]. These tests with H3 revealed that:

- Medium and high energy tests (10 membrane and 15 membrane tests) indicated that dummy IARV for lower extremities would be exceeded under these loading conditions.
- It is hypothesized that the injury for the whole-body and/or components occurs during the loading phase (plate intrusion) when the maximum stress is experienced. Once the maximum load occurs (as a function of different loading rate and intrusion), further loading becomes device dependent and not relevant to our goals. *These conditions are assured by the separation of both the legs and the buttocks from AENID*. These conditions are assessed by both the contact switches as well as the occurrence of peak loads in the lower legs as well as pelvis. Such separation is a necessary condition to evaluate the biomechanical response of the tested body (PMHS/H3) under those peak loads for different loading rates (rise times). These aspects were discussed during the APL meetings; for the sake of convenience, the slides are appended to this document

UNL's aim is to obtain as much useful information as possible from each cadaver for ethical and practical reasons. In practical terms, this means that UNL proposes to conduct multiple tests with each lower extremity with the last test being conducted at an input level most likely to cause injury to the lower extremities. UNL proposes to estimate "safe" loading scenario by analyzing preliminary H3 tests conducted at UNL.

8.4.1: Analysis of others/AENID data in the selection of PMHS test conditions:

Figure 4 illustrates H3 response plotted against loading plate maximum specific input power. Figure 4 indicates that tests at moderate energy levels (10 membrane tests) are likely to possibly cause tibia injury. Tests also indicate that lower tibia loads on the MIL-Lx are 1812 N, 3248 N, and 5096 N in low (5 membrane), medium (10 membrane) and high (15 membrane) tests respectively. However, biofidelity of the MIL-Lx has not been established at high onset loading rates. Therefore, UNL's testing program shown in Table 1 is based on standard H3 tibia response and IARV.

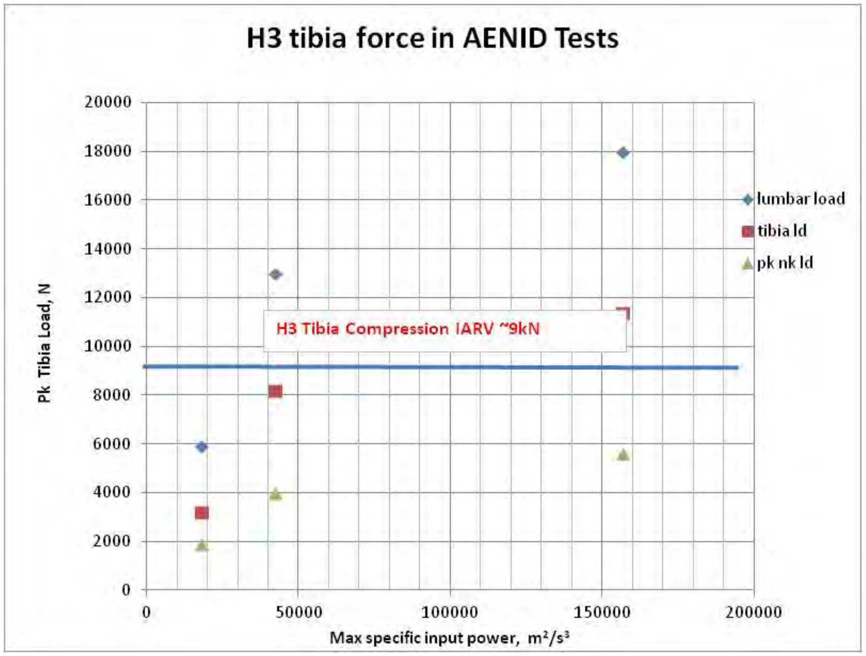


Figure 4: H3 response in AENID test showing tibia IARV

Table 1: Proposed Year 1 Test Description

Lower extremity Number	Test Number	Estimated MSIP at loading plate	Objective	Sensors on cadaver [see details in Table 3]
1 *(see note below)*	1	~20000	Biofidelity of : • Lower extremity	• Strain gauge • Video for displacement • 2 axis angular accel in Pitch and Yaw axes • Z and Y axes linear accel
	2	~40000	Same as above	Same as above
	3	~30000	Same as above	Same as above
	4	~50000	Same as above	Same as above
	5	~30000	Same as above	Same as above
2 [test conditions will depend on results	1	~25000	Biofidelity of : • Lower extremity • Pelvis • Lumbar spine	• Strain gauge • Video for displacement • 1 axis angular accel in pitch

Lower extremity Number	Test Number	Estimated MSIP at loading plate	Objective	Sensors on cadaver [see details in Table 3]
with cadaver 1] (see note below)				axis • Z axis linear accel
	2	~45000	Same as above	Same as above
	3	~25000	Same as above	Same as above
	4	~60000	Same as above	Same as above
	5	~75000	Same as above	Same as above
	6	~25000	If no Pelvis FX	Same as above

Note 1: Number of tests specified above is an optimistic estimate. Each test series will end when any injury is detected-see details in Section 9.

Note 2: The current proposal calls for testing 2 lower extremities in year 1 (up to June 2013, and 5 lower extremities in year 2 (July 2013-June 2014). However, according to the accelerated test schedules a significantly increased number of cadavers will be tested, if additional funding is provided for.

Note 3: Actual test condition will be specified in Test readiness plan to be submitted prior to each test.

9. RESEARCH METHODOLOGY

9.1. Description of Research Approach

In the first year two cadaver lower extremities will be tested. AENID has been calibrated using an instrumented H3 whole body and results of these tests have been used to develop the lower extremity test matrix. A summary of year one lower extremity testing is shown in Table 3.

Table 3. Year one testing summary

Task	Specimen	Assessment	Deliverables
Lower extremity testing	HIII whole body	Calibration & Response	Demonstration of AENID loading capabilities
	PMHS 1	Response	Response corridors, injury risk curves and loading pathways (see notes below Table 2)
	PMHS 2	Response	

9.2. Exposures, Setup, and Data

Kinematic, acceleration, angular rate, strain, and input load data will be collected for each test series. All data will be collected at 500k Hz using the DTS SLICE PRO data acquisition system. Kinematic data will be captured using high speed video at a frame rate of at least 1000 frames/sec. Surface anatomical landmarks as defined in the ANSUR II Pilot study and the WIAMan-Med IPT Medical Research Integration Plan Test Requirements will be identified with targets.

9.3. Whole body testing

The whole body test results with Hybrid III are included here just to guide us into the type and magnitude of loading expected in the lower extremity component/sub-system testing.

9.3.1. Hybrid III ATD

H3 tests have been completed and results presented at APL. Some salient features of the tests are summarized below. Results of these tests have been discussed at APL and summarized in Section 8.

Table 5. Hybrid III whole body instrumentation

Channel Count	Sensor Type	Sensor Location	Axis	Units(s)
3	Accelerometer	H3 Head	A_x, A_y, A_z	G
9	Load cell	H3 upper neck	F_x, F_y, F_z, M_x, M_y, M_z	N, Nm
12	Accelerometer	H3 chest	A_x, A_y, A_z	G
18	Load cell	H3 lumbar	F_x, F_y, F_z, M_x, M_y, M_z	N, Nm
21	Load cell	H3 pelvis	A_x, A_y, A_z	G
27	Load cell	H3 femur – right	F_x, F_y, F_z, M_x, M_y, M_z	N, Nm
32	Load cell	H3 tibia – upper right	F_x, F_z, F_z, M_x, M_y	N, Nm
37	Load cell	H3 tibia – lower left	F_x, F_z, F_z, M_x, M_y	N, Nm
42	Load cell	Mil-LX tibia – upper left	F_x, F_z, F_z, M_x, M_y	N, Nm
47	Load cell	Mil-LX tibia – lower left	F_x, F_z, F_z, M_x, M_y	N, Nm
50	Accelerometer	H3 tibia left	A_x, A_y, A_z	G
53	Accelerometer	Mil-Lx tibia left	A_x, A_y, A_z	G
56	Accelerometer	Mil-Lx foot left	A_x, A_y, A_z	G
57	Accelerometer	Mil-Lx heel left	A_z	G

The dummy was placed on a rigid seat specifically designed to mimic the seat and floor pan of a military vehicle (Fig. 1). Seating methodology will follow the procedure specified in the WIAMan-MED IPT Medical Research Integration Plan Test Requirements, V.1.3. 9 tests were performed and test matrix is provided in Table 6.

Table 6: Test variables for H3 whole body tests

# Membranes	No. of tests	Mean Plate Vel, m/s	Mean time to peak, ms	Mean plate accel, G	Mean time to peak, ms
5	3	3.2	4.3	508	0.15
10	3	5	3.89	865	0.18
15	3	8	4.11	1523	0.19

Data have been analysed and were presented at APL in January, 2013 [1]. Findings are summarized below:

- AENID produces foot plate acceleration pulses whose shape, time to peak, and width are very similar to those seen in Generic Hull test. Therefore, AENID is a very useful, low cost tool to study the effect of blast on vehicle occupants.
- Current design of AENID can accommodate one occupant.
- Multiple AENID tests can be conducted per day with a fully instrumented dummy.
- Plate pulse can be easily controlled.
- Currently accepted IARV levels were exceeded for tibia loads, lumbar spine loads, pelvis acceleration, and neck compressive loads in the medium and high energy input level tests [10 and 15 membrane tests].
- Results suggest that high acceleration levels even with low peak plate velocity might cause the dummy to exceed IARV levels.
- Preliminary analysis suggests that dummy response is related to specific power input level.
- Preliminary analysis also suggests that dummy response follows the "dosage" concept already seen in pelvis tests.

9.3.2. Post Mortem Human Surrogate

Platinum Training, LLC in Henderson, NV will supply all whole and subsystem PMHS. All specimens are routinely screened for HIV 1, HIV 2, HBsAg and HCV. Platinum Training donor consent forms are compliant with DOD language requirements. PMHS exclusion criteria include the following: history of HIV, Hepatitis B, or Syphilis; wasting disease; primary bone cancer or cancer that has metastasized to bone; and traumatic injury to the area of interest. All PMHS will be male between the ages of 18 – 60 years. Every effort will be made to approximate the target anthropometric values shown in Table 4. If this is not possible, the specimen stature will fall within the 10^{th} and 90^{th} percentile as published in the ANSUR II Pilot study with BMI less than 20-30.

Table 4. PMHS Anthropometric target values and ranges

Anthropometric measure	Target Value	Range
Stature	1725 mm	1666 – 1844 mm
Erect Sitting Height	918 mm	871 – 965 mm
Mass	84.2 kg	Depends on stature & BMI
BMI	----	< 20 - 30

Following procurement, the specimen will undergo radiographic examination to scan for exclusion criteria and determine appropriateness for inclusion in experimental testing. Additionally, the specimen will be subjected to a physical examination of the musculoskeletal system to evaluate for abnormalities that may not be readily identifiable in radiologic examination, e.g. joint hypermobility or instability. .

The identity of PMHSs will be protected by providing a unique UNL identification number for each specimen. The UNL ID number and the identification number provided by the supplier will be maintained in a password protected database accessible only to the project manager and the PI. The tissue supplier has assured UNL that they have a system in place to prevent unauthorized tracking of their PMHS ID number to the death certificate.

Specimens will be stored in a locked chest freezer in a secured room accessible to laboratory staff only. After instrumentation is completed, the specimen will be maintained in a lockable mortuary cooler in a secure room until experimentation can commence. The specimen will be placed in a black disaster pouch during transport from preparation room to experimental room. The specimen will returned to Platinum Training for cremation following completion of the experimental series and injury documentation.

All specimens will undergo radiological examination using a portable digital x-ray unit. As a rule, PMHS instrumentation fixation is achieved through incision in the skin with dissection of underlying soft tissues to expose boney fixation site. The bone will be prepared and instrumentation fixation will be achieved by means dictated by the anatomy involved. For example, accelerometers will be screwed onto the tibia, strain gages will be glued directly to bone at required locations. The position of sensors relative to anatomical landmarks will be measured and recorded. Additional radiological examination may be required to document instrumentation positioning.

Table 7 provides a list of sensors and data to be gathered during each test. All PMHS response data and input characterization data in the SAE J211 format will be gathered using a digital data acquisition system at 500 kHz. A hardware-based, 4-pole Butterworth antialiasing filter at 100KHz is applied to the data. High-speed video cameras are used to capture kinematic data.

Contact switches will be installed on the loading plate [under the feet] to indicate when the test subject has ceased to be in contact with the loading platform. This information will be useful in guiding analyses of data.

An incremental scheme of loading progression will be utilized. The initial test with “Baseline” loading condition with MSIP is expected to be sub-injurious. The loading conditions then progress toward the “High” level with a “Baseline” test performed between each step. The test matrix is shown in Table 2. A baseline test will be conducted to establish cadaver response and to ensure that the set up and data analysis procedures are appropriate.

Table 7: List of sensors for cadaver lower extremity tests

Channel Count	Sensor type	Sensor Location	Axis	Units
2	Linear Accelerometer	Lower tibia	Y and Z	G
2	Linear Accelerometer	Upper tibia	Y and Z	G
2	ARS	Lower tibia	$\omega_{z,}$ ω_y	Rad/s
6	Strain gauge	Lower and upper tibia	X, Y and Z	N/A
1	Linear Accelerometer	Foot	Z	G

Following each test data will be reviewed for indicators of injury. The specimen will undergo orthopaedic and palpatory evaluation to assess for injury. Post-test radiology will also be performed to evaluate for injury. If the lower extremity sustains an injury, the test series ends. If no injury is detected, the next step in the progression will be performed. Experimentation will continue until injury is detected. After injury detection the lower extremity will undergo complete radiographic examination and autopsy to complete documentation of injuries.

9.4. GFE Required (supplied by Government based on specific tests)

- Boots of various sizes with lacing instructions (if needed)
- Permission to modify boots as required.

9.5. Protection of cadaver identity

The identity of PMHS will be protected by providing a unique UNL identification number for each specimen. The UNL ID number and the identification number provided by the supplier will be maintained in a password protected database accessible only to the Project Manager and the PI. The tissue supplier has assured UNL that they have a system in place to prevent unauthorized tracking of their PMHS ID number to the death certificate.

9.6. Safety of study personnel

Study personnel will wear PPE including masks, gloves, and Tyvek suits when handling cadavers. Study personnel will also complete UNL Bloodborne pathogen and biosafety training prior to participating in experimentation. Additionally, the UNL Institutional Biosafety Committee has approved all safety procedures related to this protocol.

10. ANALYSIS PLAN

Our proposed data analysis procedure was developed in-house and codified in the form of a project document. The document was distributed to laboratory and analysis personnel to evaluate its applicability and usefulness. After several iterations, a unified data analysis approach was developed and is listed below.

1. All data and video pertaining to any one test are named according the convention specified in document WIAMan Medical Research Integration Plan, Ver. 5.0, chapter 6.4.2.
2. All test data are stored in 2 places, on the local server and on a separate multi-tera-byte storage device at another location.
3. Data analysis starts with the process of identifying all data and video pertaining to a test of interest and downloading them onto the analyst's computer. The analyst might develop a simpler naming convention for ease of use.
4. Calculate the velocity and displacement of the plate from the acceleration pulse using numerical integration.
5. Calculate displacement of the plate from video analysis.
6. Compare displacement obtained from measured pulse with the displacement obtained from video analysis. When displacements are close to each other it confirms that recorded data is accurate and calculations are correct.
7. Analyze load cell and acceleration data for trends and consistency.
8. When comparing responses from multiple tests, align the data first in time. The peak load recorded by the load cells should occur when plate reaches peak velocity.
9. When separation takes place the load cell should read zero. Cross verify this from the video and pressure pad analysis.

10.1. Development of response corridors

UNL will use mass scaling method proposed by Eppinger, 1984 to scale all response. Standard mass will be chosen in consultation with APL based on data used by other laboratories. As indicated in Table 2, UNL proposes to conduct 2 lower extremity tests in this period. We expect to record response variables such as linear accelerations, strain, and angular accelerations on the lower extremity. If all goes well, and the leg is not damaged early in the sequence, cadaver response data will be obtained for base line [2 tests], medium level [1 or perhaps 2 repeats] and one high or injurious level input loadings. These data can be pooled with data from other institutions to develop response corridors for the lower leg. Alternatively, if the legs yield results from 10 tests (optimistic), then, response will be plotted against an input variable such as MSIP after scaling the data. Since the proposed input loading pulses are not too different, it might be possible to develop average responses with the caveat that these averages should be compared with data from other institutions. We also hope to obtain data which can be used to define injury thresholds for the lower leg.

11. SCHEDULE, PRODUCTS, AND MILESTONES

The following summarizes the schedule for lower extremity (knee to foot) subsystem PMHS experimentation and analysis during the April - July 2013 phase of this project (Table 8) with associated milestones.

1. An updated Research Plan for PMHS lower extremity testing will be submitted. C*ompletion date: April 12, 2013*
2. Test Readiness Plan for PMHS lower extremity testing will be submitted. C*ompletion date: Three weeks from the date of approval by Army/APL on Research Plan*
3. PMHS 1 lower extremity experimental series will be conducted using AENID. *Expected completion date: July 12, 2013*
4. PMHS 2 lower extremity experimental series will be conducted using AENID. *Expected completion date: July 19, 2013*
5. Data reduction, analysis and scaling will follow each test series and culminate in a summary report. *Expected completion date: July 30, 2013*

Table 8: Experiment and deliverable timeline for lower extremity PMHS 1 and 2 series

Year		2013															
Task	Duration (days)	April				May				June				July			
		Week				Week				Week				Week			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Submit updated LX Research Plan	7		→														
Submit LX Test Readiness Plan	7						→										
PMHS 1 LX preparation & testing	5													→			
PMHS 1 LX Data Analysis	4														→		
PMHS 2 LX preparation & testing	5														→		
PMHS 2 LX Data Analysis	4															→	
PMHS WB report with IRC	7																→

12. ASSUMPTIONS AND RISKS

We do not see any major risks in these tests. UNL might have to wait till the end of 2nd year to draw robust conclusions about lower leg response and injury threshold as only 2 legs are being tested in the 1st year. We will attempt to combine our data with data from other institutions in order to develop an injury model. However, the assumption here is that the Army and other institutions will be willing to share the data.

We do not anticipate any technical or budget risks. UNL's sensor suite is a little limited, but we are attempting to buy and install more sensors and DAQ , with timely/additional funds from the army.

13. APPENDIX A – USAMRMC ORP Approval

From: Brosch, Laura R Dr CIV USA MEDCOM USAMRMC
<Laura.Brosch@us.army.mil>
Sent: Thursday, November 15, 2012 11:58 AM
To: Namas Chandra
Cc: Bennett, Jodi H Ms CIV USA MEDCOM USAMRMC; Brosch, Laura R Dr CIV USA MEDCOM USAMRMC; Donahue, Sarah L Dr CIV US USA MEDCOM USAMRMC; Brozoski, Frederick T Mr CIV USA MEDCOM USAARL; Starrs, Richard P COL MIL USA MEDCOM USAMRMC; Teyhen, John V COL MIL USA MEDCOM USAMRMC; Gupta, Raj K Dr DoD Af US USA MEDCOM USAMRMC; Chancey, Valeta C Dr CIV USA MEDCOM USAARL; Hall, LaMont J LTC MIL USA ASA ALT; McEntire, Barney J Mr CIV USA MEDCOM USAARL; Emerson, Jill D Ms CIV US USA MEDCOM USAARL; Rangarajan, Nagarajan (nranga@mcw.edu); James Rinaldi; Aaron Alai
Subject: A-17569.a Approval of Cadaver Activity, "Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID)," Namas Chandra, PhD, University of Nebraska, Year 1, Proposal Log Number 11201009, Award W81XWH-12-2-0056 (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE
SUBJECT: Approval of Cadaver Activity, "Injury Probability Curves Using the Advanced ENergetic Impact Device (AENID)," Submitted by Namas Chandra, PhD, University of Nebraska, Lincoln, in Support of Year 1 activities in accordance with Proposal Log Number 11201009, Award Number W81XWH-12-2-0056, USAMRMC ORP Log Number A-17569.a

1. The U.S. Army Medical Research and Materiel Command (USAMRMC) Office of Research Protections (ORP) received documents in support of the Research Plan #1 activities to be done in year 1.

2. The Research Plan #1 (version 2012, received 4 September 2012) and associated documents have been reviewed for applicability of the U.S. Army Policy for Use of Human Cadavers for Research, Development, Test and Evaluation (RDT&E), Education, or Training (referred to herein as the "Army policy"). The involvement of cadavers in this activity constitutes
a sensitive use as defined within the Army policy.

a. Year 1 activities will be undertaken to develop injury risk curves for lower extremities and whole bodies. Specimens will be subjected to underbody blast (UBB) loading pressures using the newly developed Advanced Energetic Impact Device (AENID) and the resulting injuries measured. The existing test devices/protocols (e.g., impactors, sleds) do not adequately reproduce the extremely violent high onset and high accelerative vertical loading conditions necessary to generate the data required for injury assessment reference curves. The AENID is expected to produce more reliable curves.

b. Year 1 activities will use 2 sets of lower extremities and 2 whole body cadavers will be procured from the Platinum Training Services, LLC, provided donors mark the ‘yes’ checkbox for ‘non-medical testing’ on the International Institute for the Advancement of Medicine Consent/Authorization for Non-Transplant Anatomic Donation form or the ‘I do authorize’ checkbox for ‘special non-medical projects’ on the Willed Body to Science Consent Form for the Biological Resources Center (BRC).

c. NOTE: Activities that will involve cadavers to be conducted after year 1 using funds from this award must be reviewed separately. These activities may not be initiated until approval from this office is granted.

3. The USAMRMC ORP has determined that requirements of the Army policy have been satisfied. This activity is approved and may be implemented pending authorization by local authorities.

4. Please note the following reporting requirements and responsibilities. Send actions as described below to the hrpo@amedd.army.mil, referencing both the proposal log number and USAMRMC ORP log number listed in the “Subject” line above.

a. The activity must be conducted in accordance with the approved Research Plan #1 (version 2012, received 4 September 2012) and other governing documents.

b. In the event of activity modifications, the Principal Investigator must send a description of the change(s) to the USAMRMC ORP prior to implementation. A change to the approved SOW requires ORP approval prior to implementation.

c. Problems related to the conduct of the activity involving cadavers or the procurement, inventory, use, storage, transfer, transportation, and disposition of cadavers must be reported promptly to the USAMRMC ORP. Examples of problems include but are not limited to: loss of confidentiality of cadaveric donors, breach of security, significant deviation from the approved protocol, failure to comply with state laws and/or institutional policies, and public relations issues. The USAMRMC ORP will report the problem to the CG, USAMRMC and to TSG of the Army.

5. The Commander/Director/Head of the DA organization conducting or supporting the activity,
the USAMRMC ORP, or designees, must be permitted to observe the activity upon request and/or audit activity records to ensure compliance with the approved protocol or applicable regulatory requirements.

6. Do not construe this correspondence as approval for any contract funding. Only the Contracting Officer or Grants Officer can authorize expenditure of funds. It is recommended that you contact the appropriate contract specialist or contracting officer regarding the expenditure of funds for your project.

7. Further information regarding this review may be obtained by contacting Sarah L. Donahue, PhD, MPH, CIP, at 301-619-1118 or Sarah.L.Donahue@us.army.mil.

LAURA R. BROSCH, PhD
Director, Office of Research Protections Director, Human Research Protection Office U.S. Army Medical Research and Materiel Command

Note: The official copy of this approval memo is housed with the protocol file at the Office of Research Protections, Human Research Protections Office, 504 Scott Street, Fort Detrick, MD 21702. Signed copies will be provided upon request.

Classification: UNCLASSIFIED
Caveats: NONE

14. APPENDIX B – Shock Lab Checklist

University of Nebraska – Lincoln Trauma Mechanics Lab - Shock Lab Checklist
Project: ____
Test ID: ____________________________ Test date: ________________________

Pre-Shot Checklist

- ☐ Record sensor serial number, location and DAQ channel
- ☐ Check all signal cables for correct routing to data acquisition board
- ☐ Inspect breech and bolts for defects
- ☐ Inspect Impact wrench for defects
- ☐ Take note of membrane supply and alert lab manager if it is getting low
- ☐ Check for a good breech shocktube mate
- ☐ Membranes installed with star tightening pattern
    - o Use of extended wrench arm and manual tightening of bolts is necessary for membrane stacks greater than 5 when using 28" shock tube
- ☐ Turn trigger on
- ☐ Turn PXI power strip and computer on
- ☐ Turn on appropriate signal conditioners (allow for necessary warm up time)
- ☐ Turn on sensor power supplies
- ☐ Open the emergency release gas valve
- ☐ Open appropriate gas lines
- ☐ Open driver gas bottle
- ☐ Check for sufficient gas pressure for experimentation
- ☐ Turn on gas system power unit
- ☐ Check end configuration units for proper installation
- ☐ Check specimens for proper installation
- ☐ Tighten down shock tube windows
- ☐ Reset trigger if red indication light is activated

Pre-Shot Control Room Checklist

- ☐ Turn on gas and DAQ remote access computers
- ☐ Turn on camera security system
- ☐ Open shot log and gas control program
    - o Confirm "fill time" is appropriate
- ☐ Open Data acquisition program for the appropriate shock tube
    - o Confirm recording rate and duration
    - o Select sensor serial number and type in description of its location
- ☐ Visually confirm all doors are shut and that there are no people present in the immediate vicinity of the shock lab walls

- ☐ Enter shock lab and close emergency gas release valve
- ☐ Shut and check lab door is locked upon exiting
- ☐ Arm the shock tube gas control system and confirm warning lights and siren are functioning before starting the fill process
- ☐ Save all data after the execution of the shot

Camera Setup

- ☐ Select appropriate viewing area for camera
- ☐ Select recording speed
- ☐ Adjust light source and F-Stop
- ☐ Connect cameras to the trigger output of the DAQ

Post-Shot Control Room Checklist

- ☐ Enter atmospheric and temperature data into Shot Log
- ☐ Confirm sensor data has been successfully recorded
- ☐ If using high speed camera system select frame range of interest and save data
- ☐ Turn off control room computers, remote DAQ computer, lights and security camera system
- ☐ Lock door

Post-Shot Lab Checklist

- ☐ Turn off unit to the entire DAQ unit
- ☐ Turn off gas control system
- ☐ Turn off trigger systems
- ☐ Close driver gas bottle
- ☐ Open emergency gas release valve
- ☐ Turn off power sensor power units
- ☐ Lock all bay doors
- ☐ Turn off lights
- ☐ Confirms door locks behind you

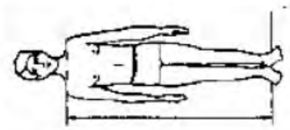
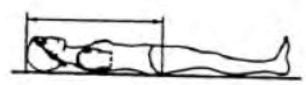
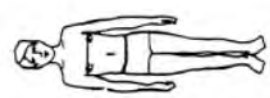
15. APPENDIX C – Shock Lab Specimen and Data Sheet

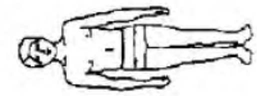
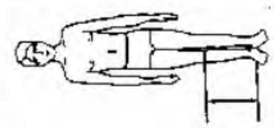
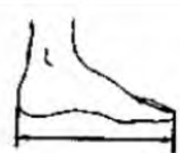
University of Nebraska – Lincoln   Trauma Mechanics Lab - Shock Lab Specimen and Data Sheet

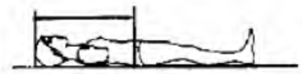
Project: ____
Test ID: ____________________________   Test date: ________________________
Driver gas: He N_2 Other _____________
Membrane material:
____
Membrane thickness: _______________________   Membrane #:
____
Breech length: _______________
Specimen placement WRT membrane:
____
Mass on sled: Specimen: _________________ Ballast: ________________ Total:
____
Target peak acceleration: _______________________ Target time to peak acceleration:
____
Actual peak acceleration: ______________________ Actual time to peak acceleration:
____
Actual peak velocity: __________________________ Actual time to peak velocity:
____

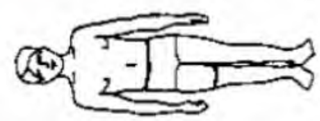
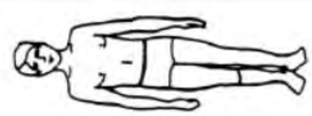
Specimen: PMHS   ATD   Animal: ________________________
WB   Region/Component: ____
UNL specimen #: ____
ATD type: ______________________________________ ATD serial #:
____
Specimen orientation:
____
Notes:
____
____
____
____
____
____
____
____
____

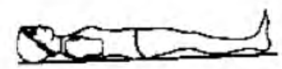
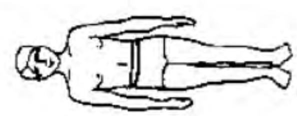
16. APPENDIX D – Anthropometry Data Sheets

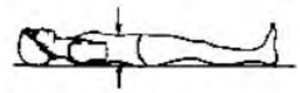
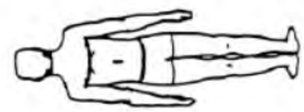
MEASUREMENT	DESCRIPTION	
Stature	Stature of the test subject, measured as the horizontal distance from the headboard of the measuring table to the most distal portion of the heel and taken as an average of the measurement from the left heel and the measurement from the right heel. The measurement is taken with an anthropometer, with the test subject supine, head in the Frankfort plane and firmly touching the headboard.	
Acromial Shoulder Height	Shoulder height of the test subject measured as the horizontal distance from the most distal portion of the heel to the most lateral point of the acromial process of the scapula. The measurement may be obtained by measuring either the distance to both the right and left heels and averaging the two values; or by measuring the distance from the vertex of the head to the acromial process and subtracting the value from STATURE.	
Vertex to Symphysion	Test subject's vertex-to-symphysion length, measured, using an anthropometer, from the headboard of the measuring table to the symphysion, with the test subject in a supine position, head oriented in the Frankfort plane and firmly touching the headboard	
Waist Height	Test subject's waist height, measured as the horizontal distance from the most distal portion of the heel to the anterior superior iliac spine. The measurement may be obtained by measuring either the distance to both the right and left heels and averaging the two values; or by measuring the distance from the vertex of the head to the anterior superior iliac spine and subtracting the value from STATURE.	
Shoulder Breadth	Breadth of the test subject's shoulder measured as the distance across the body between the lateral edge of the left and right acromions.	
Chest Breadth	Chest breadth of the test subject, taken as the average of two measurements of the horizontal breadth of the chest — one taken at the axilla and the other at the substernale, using a beam caliper.	
Waist Breadth	Waist breadth of the test subject, measured, using a beam caliper, as the horizontal breadth of the body at the level of the anterior superior iliac spine.	

MEASUREMENT	DESCRIPTION	
Hip Breadth	Hip breadth of the test subject, measured, using an anthropometer, between the right and left illocristale landmarks perpendicular to the mid-sagital plane.	
Shoulder Length	Length of the test subject's arm from shoulder to elbow, measured, with a beam caliper, as the distance from the top of the acromion process to the bottom of the elbow, with the arm flexed 90 degrees	
Forearm-hand length	Length of the test subject's forearm, measured, with a beam caliper, from the tip of the elbow to the tip of the longest finger, with the arm flexed 90 degrees.	
Tibia Height	Tibia Height is the knee height of the test subject, measured from the most distal portion of the heel to the proximal medial margin of the tibia. The measurement may be obtained by measuring either the distance to both the right and left heels and averaging the two values; or by measuring the distance from the vertex of the head to the proximal medial margin of the tibia and subtracting that value from STATURE.	
Ankle Height	Height of the test subject's ankle as measured, with sliding calipers, from the most distal portion of the heel to the level of the minimum circumference of the ankle (at the level proximal to the malleoli of the tibia and fibula perpendicular to the long axis of the lower leg).	
Foot Breadth	Breadth of the test subject's foot, measured with sliding calipers, at the level of the metatarsal-phalangeal joints along an axis perpendicular to the long axis of the foot. Measure the breadth of both feet and take the average to obtain Foot Breadth.	
Foot Length	Length of the test subject's foot, measured from the dorsal surface of the heel to the tip of the big toe by the use of a beam caliper. Measure the length of both feet and take the average to obtain Foot Length.	

MEASUREMENT	DESCRIPTION	
Head to Trochanterion	Horizontal distance from the test subject's head to the Trochanterion measured, using an anthropometer, from the headboard of the measuring table to the Trochanterion, with the test subject supine, head in the Frankfort plane.	
Seated Height	Test subject's seated height, measured as the vertical distance from the sitting surface to the top of the head. The measurement is taken with the test subject sitting erect, looking straight ahead. This measurement must be made in all cases where the test subject is seated during testing.	
Knee Height	Knee height of the test subject, taken as an average of the vertical distance from the floor to the uppermost point on the knee of both legs. The measurement is taken with the test subject sitting erect, knees and ankles at right angles. This measurement must be made in all cases where the test subject is seated during testing.	
Head Length	Head length of the test subject, measured as the maximum length of the head between the glabella and the occiput in the mid-sagittal plane.	
Head Breadth	Test subject's head breadth, measured, with spreading calipers, as the maximum horizontal breadth of the skull above the level of the ears, perpendicular to the mid-sagittal plane.	
Head Height	Test subject's head height, measured from the highest point on the head to the mentum landmark.	
Bicep Circumference	The circumference of the test subject's bicep, measured, with a tape, as the circumference of the upper arm at the level of the maximum anterior prominence of the biceps brachii, perpendicular to the long axis of the upper arm.	

MEASUREMENT	DESCRIPTION	
Elbow Circumference	The circumference of the test subject's elbow, measured with a tape passing over the olecranon process of the ulna and into the crease of the elbow, which is flexed at 125 degrees.	
Forearm Circumference	Circumference of the test subject's forearm, measured at the maximum circumference of the forearm, with a tape perpendicular to the long axis of the forearm.	
Wrist Circumference	Wrist circumference of the test subject, measured at the minimum circumference of the wrist proximal to the radial and ulnar styloid processes, with a tape perpendicular to the long axis of the forearm.	
Thigh Circumference	Circumference of the test subject's thigh, measured, with a tape, perpendicular to the long axis of the leg and passing just below the lowest point of the gluteal furrow.	
Lower Thigh Circumference	Circumference of the test subject's lower thigh, measured, just superior to the patella, with a tape perpendicular to the long axis of the thigh.	
Knee Circumference	Circumference of the test subject's knee, measured either with the leg extended or with the knee flexed 90 degrees. Only one measurement is needed for the test. For tests in which the test subject is seated with the leg flexed 90 degrees, measure the circumference of the knee across the antecubital crease and the most anterior superior margin of the patella. Measure the circumference of both knees and take the average to obtain Knee Circumference. For all other tests, the test subject is supine with the leg extended. Measure the circumference of both knees at the level of the mid-patella landmark and take the average to obtain Knee Circumference.	
Calf Circumference	Circumference of the test subject's calf, taken as the average measurement of the calf circumferences of both legs. The maximum circumference of the calf for each leg is measured by the use of a tape perpendicular to the long axis of the lower leg.	

MEASUREMENT	DESCRIPTION	
Ankle Circumference	Circumference of the test subject's ankle, measured as the average maximum circumference of the ankle perpendicular to the long axis of the lower leg at the level proximal to the malleoli of the tibia and fibula.	
Neck Circumference	Circumference of the test subject's neck, measured with a tape in a plane perpendicular to the axis of the neck and passing inferior, but tangent, to the laryngeal prominence.	
Scye Circumference	Test subject's scye circumference, measured by passing through the axilla over the anterior and posterior vertical scye landmarks and over the acromial landmarks.	
Chest Circumference	Test subject's chest circumference, taken as the average of two measurements, made perpendicular to the long axis of the trunk: one taken as the axilla circumference and the other as the substernale circumference.	
Waist Circumference	Waist circumference of the test subject, measured with a tape passing over the anterior superior iliac spine and perpendicular to the long axis of the trunk.	
Buttocks Circumference	Horizontal circumference of the buttocks of the test subject, measured at the level of the trochanterion surface landmarks.	
Chest Depth	Test subject's chest depth, taken as the average of two measurements: with an anthropometer, one is taken from the measuring table to the anterior surface of the body at the axilla and the other at the substernale.	

Measurement	Description	
Waist Depth	Waist depth of the test subject, measured as the vertical distance between the measuring table and the anterior surface of the body at the level of the anterior superior iliac spine.	
Buttocks Depth	Buttock depth of the test subject, measured as the anterior-posterior distance on the medial plane projection at the level of the maximum posterior protrusion of the buttocks.	
Inter Scye Distance	Horizontal distance across the back of the test subject, measured between the posterior scye point landmarks.	

17. APPENDIX E – Seating Procedure

PMHS seating procedure
The seat will be aligned to the loading plate such that the central longitudinal axis of the seat is orthogonal and centered to the plate.

The PMHS is centered on the seat so that the midsagittal plane coincides with the vertical longitudinal plane through the center of the seat.

The specimen will be placed so that there are no gaps between the posterior surface of the torso, with or without PPE, and the seat back.

The upper torso will be rocked laterally in a side to side motion three times through a ±5° arc to reduce friction.

The PMHS will be positioned so that the posterior surface of the pelvis and thighs will contact the seat bottom without gaps. The distance between the femoral lateral epicondyles will the 270 mm. The midpoint of the lateral epicondylar line will be on the midsagittal plane and coincide with the central longitudinal axis of the seat.

The specimen's feet will be placed flat against the loading plate and equidistant from the central longitudinal axis of the foot plate, while maintaining the 270 mm lateral epicondylar distance. The angle between the leg and the foot will be 90° in the sagittal plane and verified with a framing square. A single strip of masking tape may be required to maintain foot position against the plate.

The angle between the thigh and the leg will be 90° in the sagittal plane and verified with a framing square. Additionally, the leg will be horizontal with the center of the anterior knee coincident with the center of the ankle joint.

The head of the supine specimen will be positioned so that the Frankfort plane will be 90 ± 0.5° from the horizontal.

The lateral aspect of specimen wrists will be placed on the anterior surface of the superior thighs.

Testing position of the specimen will be documented through photography and radiographic examination, if required.

18. APPENDIX F – Detail of Specimen & File Numbering Schemes

The identity of PMHS will be protected by providing a unique UNL identification number for each specimen starting with PMHS_001. The UNL ID number and details regarding the specimen, e.g. age, specimen type (whole body, subsystem, or component), acquisition date and disposition date, will be maintained in a password protected database accessible only to the Project Manager and the PI.

File naming structure for data, high speed video, still images, and reports will follow the guidelines specified in WIAMan Medical Research Integration Plan Version 5.0. An example filename for raw data collected during a PMHS test using AENID follows.

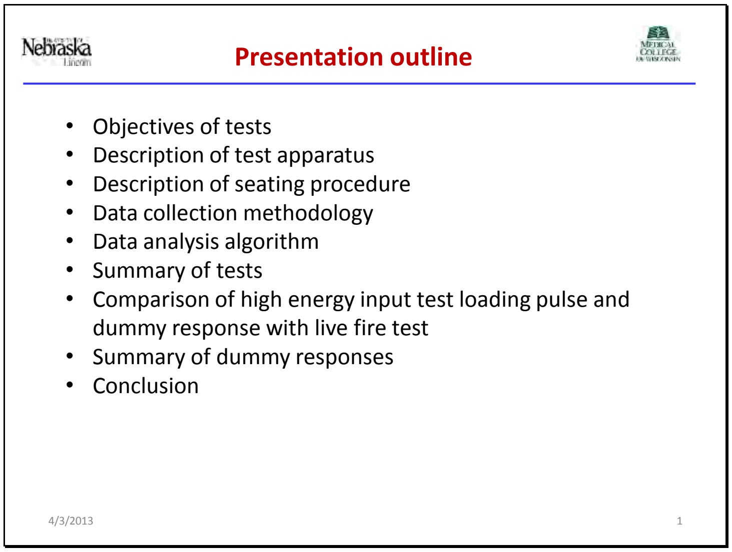
UNL_0000000_YYYYMMDD_PMHS_ST0001_Raw_GD.txt

In this example “UNL” is the institution, “0000000” represents the last seven digits of the Cooperative Agreement task number, “YYYYMMDD” is the date of the test, “PMHS” is the surrogate tested, “ST0001” indicates AENID, “Raw” is the data signal status, and “GD” is a note.

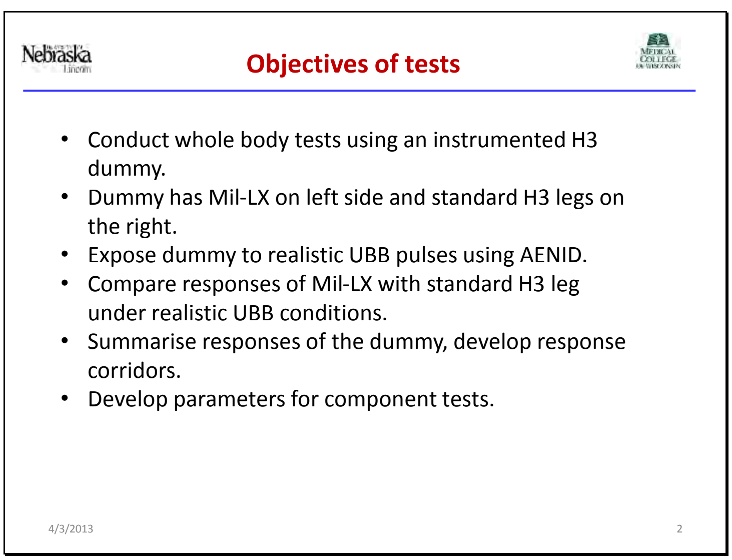
Additionally, all data will include the header information specified in WIAMan Medical Research Integration Plan Version 5.0.

19. APPENDIX G – APL Presentation – January 30, 2013

Slide 1



Slide 2



Slide 3

Description of test apparatus

- Seat and loading plate design
- Seat instrumentation
- Loading plate design

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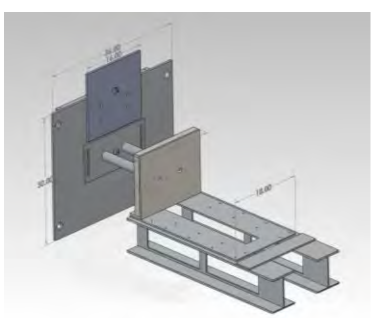
Slide 4

Seat and Loading Plate Design



- Image at left shows the seat and loading plate. The loading plate is connected to the seat through 2 “stems.” This design allows the seat to push away from the loading plate
- Seat weighs approximately 42 kg
- Loading plate weighs approximately 45 kg

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Slide 5

Seat Instrumentation

Sensor Type	Sensor Location	Axis
Accelerometer	Seat bottom - centered between seat stems (red arrow)	Az

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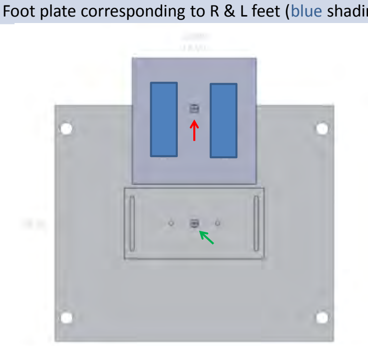
Slide 6

Loading Plate Design

Sensor Type	Sensor Location	Axes
Accelerometer	Foot plate center at surrogate midfoot level (red arrow)	Ax, Ay, Az
Accelerometer	Loading plate center at seat stem level (green arrow)	Ax, Ay, Az
Contact switch	Foot plate corresponding to R & L feet (blue shading)	N/A



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Slide 7

Nebraska Lincoln

Description of seating procedure

- Seating procedure is described and pictures are provided to show seated dummy.
- Picture showing camera placement is provided

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Slide 8

Nebraska Lincoln

ATD Positioning Procedure

- Confirm load cell polarities through dummy manipulation
- Set friction in HIII joints to 1g
- Place ATD in seat
- Align ATD midsagittal plane with seat center longitudinal plane
- Position ATD without gaps between pelvis and seat bottom and back
- Restrain ATD with 2” lap belt
- Adjust pelvic angle to 50 2.5 , measured with H-point tool
- Position ATD knees so outside flange distance = 270 mm
- Position lower extremity in 90 -90 -90 upright posture
- Four and five point belts will be accommodated in the seat design

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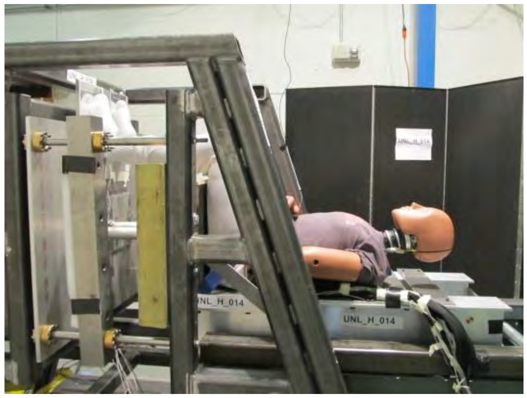
Slide 9

ATD Initial Positioning



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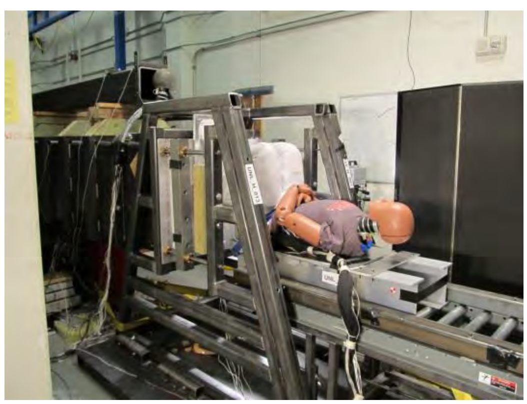
Slide 10

ATD and Seat on Rollers



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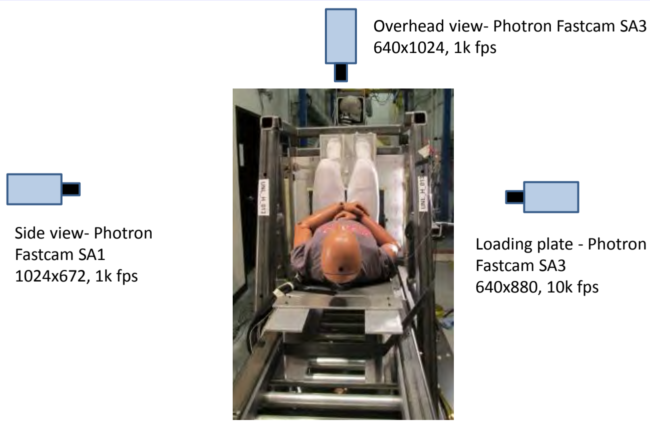
Slide 11

High speed camera placement



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Slide 12

Data collection methodology

- List of H3 sensors is provided
- Test procedure is summarised
- Data acquisition procedure is summarised

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Slide 13

HIII Instrumentation

Channel count	Sensor Type	Sensor Location	Axis	Unit(s)
3	Accelerometer	HIII Head	Ax, Ay, Az	G
9	Load cell	HIII Upper Neck	Fx, Fy, Fz, Mx, My, Mz	N, Nm
12	Accelerometer	HIII Chest	Ax, Ay, Az	G
18	Load cell	HIII Lumbar	Fx, Fy, Fz, Mx, My, Mz	N, Nm
21	Accelerometer	HIII pelvis	Ax, Ay, Az	G
27	Load cell	HIII Femur - Right	Fx, Fy, Fz, Mx, My, Mz	N, Nm
32	Load cell	HIII Tibia - Upper Right	Fx, Fy, Fz, Mx, My	N, Nm
37	Load cell	HIII Tibia - Lower Right	Fx, Fy, Fz, Mx, My	N, Nm
42	Load cell	MIL-LX Tibia - Upper Left	Fx, Fy, Fz, Mx, My	N, Nm
47	Load cell	MIL-LX Tibia - Lower Left	Fx, Fy, Fz, Mx, My	N, Nm
50	Accelerometer	HIII Tibia - Right	Ax, Ay, Az	G
53	Accelerometer	MIL-LX Tibia - Left	Ax, Ay, Az	G
56	Accelerometer	MIL-LX Foot - Left	Ax, Ay, Az	G
57	Accelerometer	MIL-LX Heel - Left	Az	G

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Slide 14

Test Procedure

- Perform trigger check for SLICE DAS, shock tube DAS and HS video cameras
- Confirm shock tube components are test ready
- Place surrogate in test position
- Perform still photography
- Assess lab security
- Confirm surrogate positioning
- Initiate filling of shock tube breech
- Fire shock tube

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Slide 15

Nebraska Lincoln

Data Acquisition Procedure

Medical College of Wisconsin

- DTS SLICE PRO
- Sampling rate = 500 kHz
- Built-in 4-pole Butterworth anti-aliasing filter
- 0.5 s of pre-trigger and 1.0s of post-trigger data
- Post acquisition filtration using SAE J211 CFC 60-1000

Test Measurements	Channel Frequency Class (CFC)
Head acceleration	1000
Neck forces	1000
Neck moments	600
Chest acceleration	180
Lumbar forces & moments	1000
Pelvic acceleration	1000
Femur & Tibia forces & moments	600
Tibia & Foot accelerations	1000

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Nebraska Lincoln

Data analysis algorithm

Medical College of Wisconsin

- Analyze the acceleration pulse and high speed video of the experiment simultaneously and identify acceleration pulse of interest.
- Calculate the velocity and displacement of the plate from the acceleration pulse using numerical integration.
- Calculate displacement of the plate from video analysis.
- Compare displacement obtained from measured pulse with the displacement obtained from video analysis. When displacements are close to each other it confirms that recorded data is accurate and calculations are correct.
- Analyze load cell data for trends and consistencies.
- The peak load recorded by the H-3 tibia load cells should occur when plate reaches common peak velocity.
- When separation takes place the load cell should read zero. Cross verify this from the video and pressure pad analysis.

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Summary of tests

Nebraska Lincoln — Medical College of Wisconsin

- The following full body instrumented dummy tests were conducted with the dummy seated on a rigid seat:
  - 3 repeat tests at low specific power input level.
  - 3 repeat tests at medium specific power input level.
  - 3 repeat tests at high specific power input level.
- Input pulse parameters are summarised in the next slide.

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Center of plate

Nebraska Lincoln — Medical College of Wisconsin

Membranes	Plate velocity, m/s	Time to peak, ms	Plate acceleration , g	Time to peak, ms
5	3.2	4.3	508	0.15
10	5	3.89	865	0.18
15	10	4.11	1600	0.24

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Comparison with live fire test

- In the next few slides, UNL experimental input pulse and selected dummy responses will be compared with appropriate data from live fire tests.

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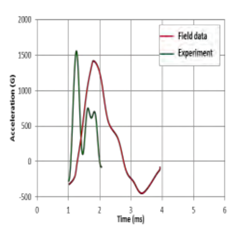
Nebraska Lincoln

Comparison – plate center acceleration



- Plot compares centre of plate acceleration in UNL tests [in Green] with live fire test plate acceleration [in Red].
- Experimental peak is higher but duration is lower. However, experimental acceleration continues to vary beyond 2 ms.

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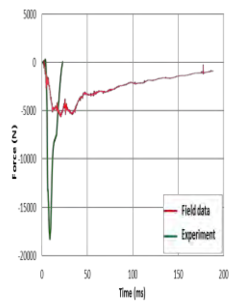
Lumbar spine load comparison



- Plot compares experimental H3 lumbar spine load in UNL high energy test with live fire test results.
- It is assumed that the occupant in live fire test was seated on a stroking seat.

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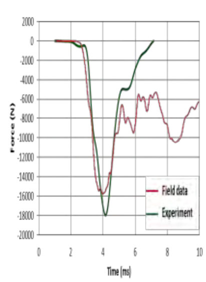
Right tibia load comparison



- Plot compares H3 lower tibia loads with live fire data.
- Peaks are comparable and it is possible that the occupant was seated on a stroking seat which caused loading beyond the point at which experimental data returns to zero.

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Test results

In the next few slides, test results from high energy [15 membrane] tests will be illustrated.

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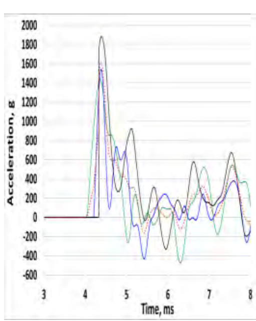
Plate center acceleration



- Plot shows plate acceleration pulse for 3 high energy pulses.
- Mean is shown in red.

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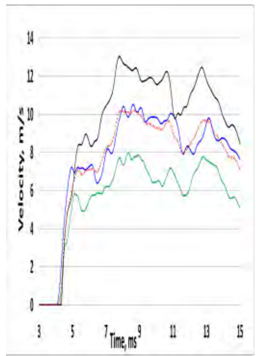
Plate Center velocity



- Plot shows plate velocity profile for 3 high energy pulses.
- Mean is shown in red.

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Load cell data from Test 13

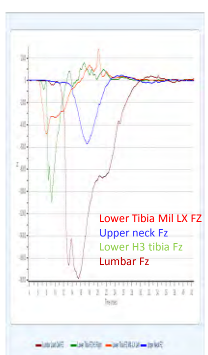

Figure shows load cell data from a 15 membrane test.

- Standard H3 tibia loads are shown
- The seat is connected rigidly to the loading plate.
- All loads exceed current IARV for H3.

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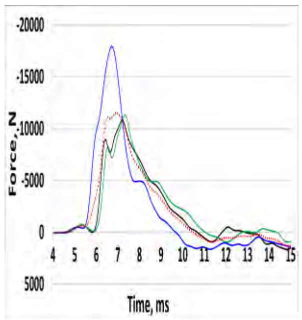
H-3 lower tibia load



- The plot shows H3 lower tibia load cell from 3 high energy tests.
- Cause for large variation in one test is being investigated.

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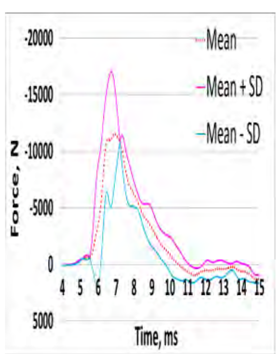
H-3 lower tibia load



- Plot shows mean and standard deviation of H3 lower tibia loads.

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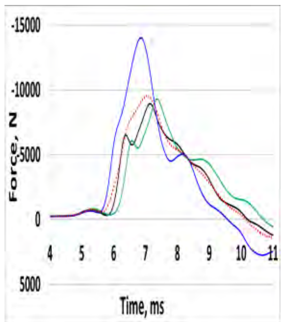
H-3 upper tibia load



- H3 upper tibia loads from 3 tests and mean are shown.
- Cause of large variation in load in one test is being investigated.

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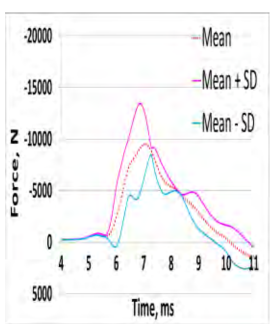
H-3 upper tibia load



- Mean and standard deviation of H3 upper tibia load is shown in the plot.

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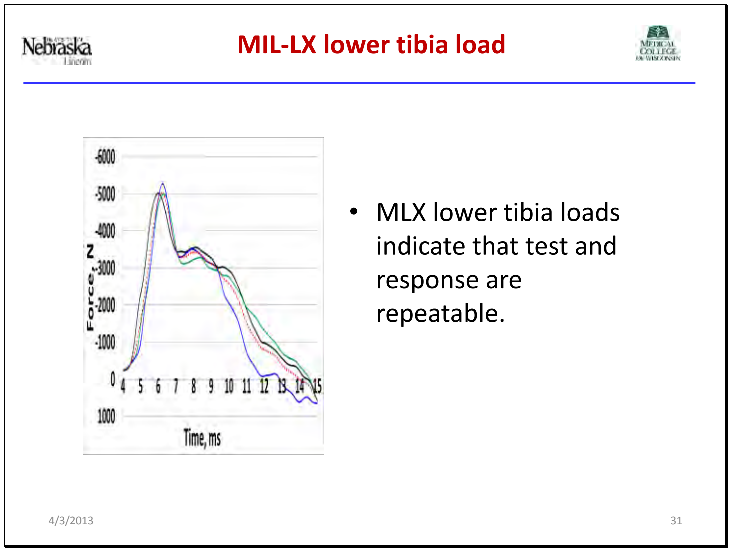

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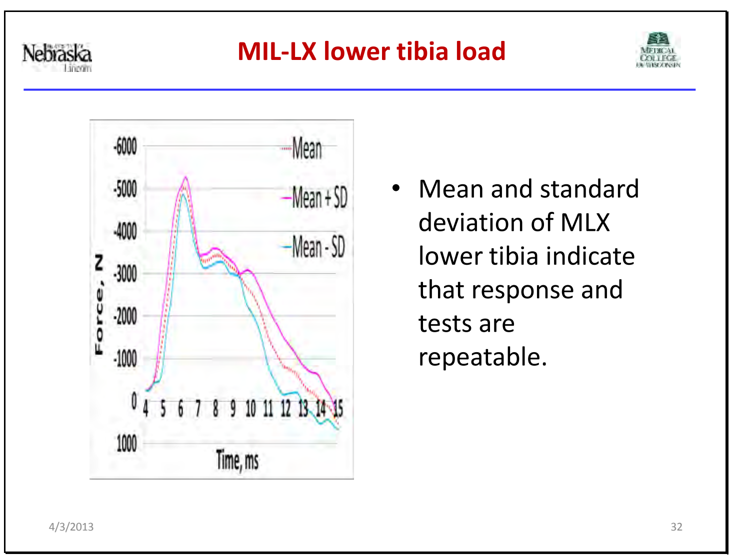

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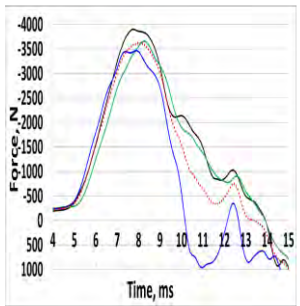
MIL-LX upper tibia load



- MLX upper tibia loads from 3 high energy tests are shown.
- Response seems repeatable.

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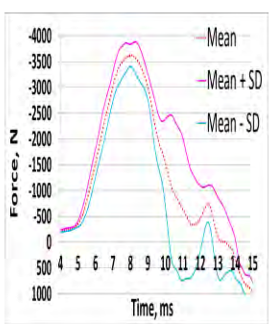
MIL-LX upper tibia load



- Mean and standard deviation of MLX upper tibia loads are shown in the plot. Response seems repeatable.

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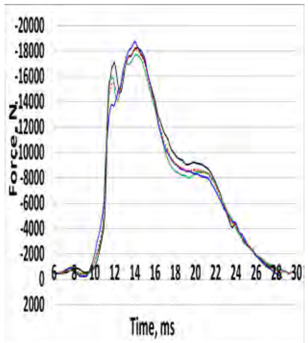
Lumbar loads from 3 tests



- Plot shows lumbar loads from three 15 membrane, high energy tests and the mean response.
- Data indicates that response and the test are repeatable.

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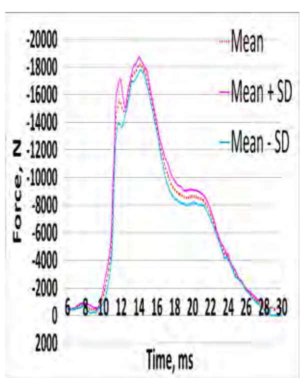
Lumbar loads



- Mean and SD of lumbar loads in 3 high energy tests are shown.

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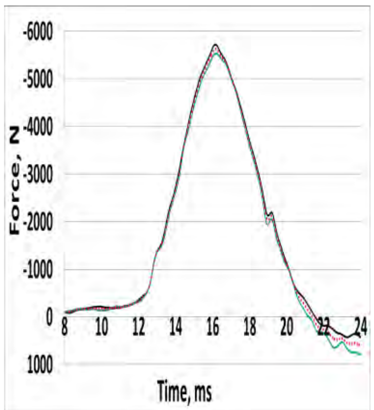
Upper neck loads



- Plot shows upper neck load cell from 2 high energy tests.
- Data indicate that test and response are repeatable.

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H-3 Lower tibia peak load

Membranes	Force (N)	Mean	Ratio wrt 5 membranes
5	-3,054	-3,151	1
	-2,860		
	-3,539		
10	-8,622	-8,235	2.61
	-6,022		
	-10,059		
15	-10,826	-11,355	3.66
	-11,322		
	-11,534		

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MLX lower tibia peak load

Membranes	Force (N)	Mean	Ratio
5	-1,751	-1,812	1
	-1,540		
	-2,145		
10	-3080	-3248	1.79
	-2899		
	-3763		
15	-5022	-5096	2.81
	-4997		
	-5271		

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Peak lumbar load

Membranes	Force (N)	Mean	Ratio
5	-5736	-5888	1
	-6395		
	-5535		
10	-12912	-12727	2.16
	-11974		
	-13294		
15	-18263	-18232	3.10
	-17714		
	-18719		

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Peak upper neck load

Membranes	Force (N)	Mean	Ratio
5	-1,761	-1,932	1
	-2,103		
10	-4,172	-4,025	2.08
	-3,879		
15	-5,718	-5,626	2.91
	-5,535		

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Conclusions - 1

- AENID produces foot plate acceleration pulses whose shape, time to peak, and width are very similar to those seen in Generic Hull test. Therefore, AENID is a very useful, low cost tool to study the effect of blast on vehicle occupants.
- Current design of AENID can accommodate one occupant.
- Multiple AENID tests can be conducted per day with a fully instrumented dummy.
- Plate pulse can be easily controlled.

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Conclusions - 2

- The following full body instrumented dummy tests were conducted with the dummy seated on a rigid seat:
  - 3 repeat tests at low specific power input level.
  - 3 repeat tests at medium specific power input level.
  - 3 repeat tests at high specific power input level.

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Conclusions - 3

- The objective of these tests was to develop specifications for component level test parameters.
- Currently accepted IARV levels were exceeded for tibia loads, lumbar spine loads, pelvis acceleration, and neck compressive loads in the medium and high energy input level tests.

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Nebraska Lincoln

Conclusions - 4

- Results suggest that high acceleration levels even with low peak plate velocity might cause the dummy to exceed IARV levels.
- Preliminary analysis suggests that dummy response is related to specific power input level.
- Preliminary analysis also suggests that dummy response follows the “dosage” concept already seen in pelvis tests.

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20. REFERENCES

1. Eppinger, R, Marcus, J and Morgan, R. 1984. Development of dummy and injury index for NHTSA's thoracic side impact protection and research program. SAE Paper No. 840885. Society of Automotive Engineers, Warrendale, PA.
2. Rangarajan, N. and N. Chandra. 2013. Recreation of UBB loading patterns using AENID. Presented at Applied Physics Laboratory, January 30, 2013.