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Task Implementation Plan - Final
February 20, 2019

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1 INTRODUCTION

Advancements in sensor and driver-assisted technologies may lead to future iterations of motor vehicles that are fully autonomous (no human intervention required), which could fundamentally change the design of vehicle interior and seating configurations. One study indicated that for 'short' trips, consumers preferred reclining the seat to a more comfortable position [1]. Occupant response in a reclined posture during motor vehicle accidents is not well understood, however the reclined occupant may be more prone to submarining of the lap belt, resulting in higher thoracic, lumbar and abdominal injuries [2, 3]. Analysis of CIREN crash data, showed that the occupants in fully reclined seats are at 77% higher risk of mortality [3]. Additionally, other anthropometries (obese and underweight) may be more susceptible to submarining than the 50th percentile male and represent a more vulnerable population in this loading scenario [4-6]. Historically the automotive community has conducted studies using Post Mortem Human Surrogates (PMHS) to develop Anthropomorphic Test Devices (ATD) and Human Body Models (HBM) as tools to improve occupant safety. The aim of the current study is to conduct PMHS sled tests in seating configuration(s) expected to be prevalent in vehicles with automated driving systems, with specific focus on collecting kinematics of vulnerable occupants. A similar study is simultaneously being conducted at the University of Michigan Transportation Research Institute (UMTRI) on 50th percentile male population. Similar methods will be used at both institutions to create harmonized data sets covering these occupants.

2 SCHEDULE

2.1 TASK 1: PROJECT MANAGEMENT

The schedule for Task 1 is shown in Table 1. Monthly meetings will be conducted via MCW WebEx services or via Polycom teleconferencing system (if necessary). Meetings are proposed on the 2nd Tuesday of every month in conjunction with the National Highway Traffic Safety Administration (NHTSA) and UMTRI.

Table 1: Task 1 Schedule

Item	Project Milestone/Deliverable	Target Date
1.01	Kickoff Meeting	10/11/2018
1.02	Midterm Review	05/2020
1.03	Final Review	09/2021
1.04	Monthly Web Conference/Progress Reports	2nd Tuesday of month

2.2 TASK 2: IMPLEMENTATION PLAN

The Task Implementation Plan (TIP) is presented in this document.

2.3 TASK 3: SLED BUCK FABRICATION

Industry feedback from the Public Meeting included a recommendation that MCW and UMTRI both use a generic spring-controlled seat similar to the one designed by The Laboratory of Accidentology and Biomechanics (LAB) in France [7] (Figure 1). Justification for this seat design is given in Section 4.1.2.1. We will work in conjunction with UMTRI using HMB simulations to determine if the design can be further simplified. It was also suggested that both bucks be fabricated at the same location to ensure consistency. We agree in part with this suggestion and think it makes sense to build the seat pan at either UMTRI or MCW. Due to differences in the sleds at MCW and UMTRI (acceleration versus rebound, sled hole patterns, etc.), it may not be practical to fabricate the entire buck in one shop and the remaining structures can be built/assembled locally.

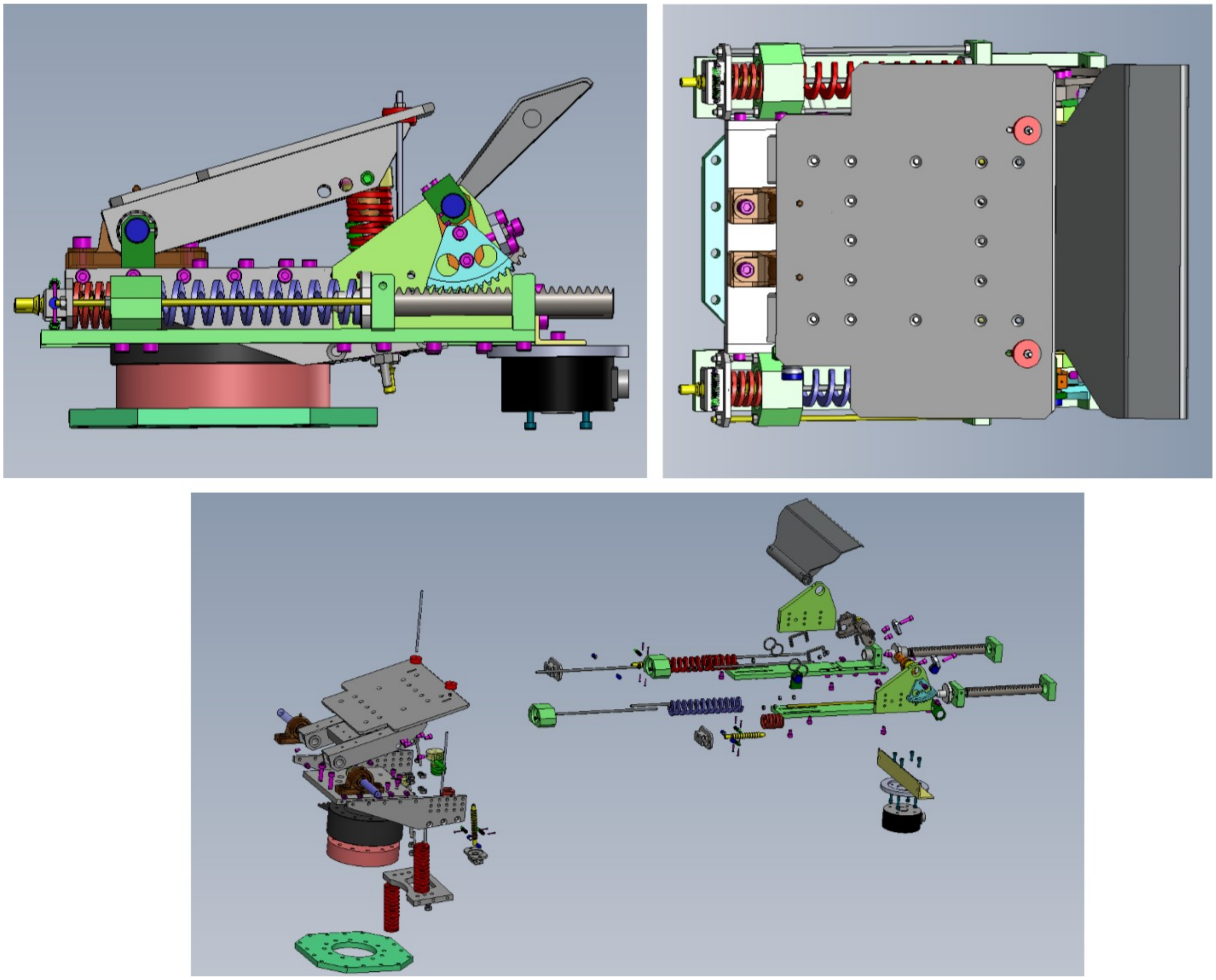


Figure 1: Generic spring-controlled seat CAD drawing obtained from LAB. Upper left is right-side view, upper right is overhead view, and lower is an exploded view.

Upon acceptance of final TIP, we will coordinate with UMTRI on the construction of the seat bottom. We anticipate one month for the construction of the seat bottom and another month for assembly of the remaining structures of the buck.

Table 2: Task 3 Schedule

Item	Project Milestone/Deliverable	Target Date
3.01	Preliminary Modeling	11/01/2018
3.02	Complete seat fabrication	2 months after accepted TIP
3.03	Hybrid III shakedown tests with Seat	2 weeks after completion of 3.02

2.4 Task 4: Frontal-impact Sled Tests (Biofidelity) PMHS—Vulnerable Occupant

The PMHS procured for this study will be representative of a vulnerable occupant population (described in Section 3). Based on our recent procurement schedule we expect to receive at least one PMHS per month for the obese population and one every other month for the small female population. Each specimen will undergo a two-test sequence consisting of a low-speed, non-injurious test followed by a high-speed failure test. The tests will be conducted on separate days and follow a Thursday (low-speed)-Tuesday (high-speed) schedule. In between the tests CT scans and x-rays will be obtained. A clinician will perform a manual examination of the specimen and evaluate the radiology to assess injury and determine specimen fitness for subsequent testing. The first three specimens will be tested at a rate of one specimen per month (one non-injurious test and one failure test per month). The extended interval between this initial set of PMHS tests will allow time for adjustments to test fixture(s), refinement of data processing pipeline, and generation of reports. Starting with the fourth specimen, our preparation and analysis techniques will have been optimized such that we can test up to two specimens/month (two non-injurious tests and two failure tests per month) for the remaining PMHS. The schedule for Task 4 is shown in Table 4. The Technical Data Package will be delivered to NHTSA within thirty days of the failure test.

Table 3: Task 4 Schedule

Item	Project Milestone/Deliverable	Target Date
4.01	Specimen Procurement	12/01/2018
4.02	PMHS 1	12/2019
4.03	PMHS 2	
4.04	PMHS 3	
4.05	PMHS 4	
4.06	PMHS 5	
4.07	PMHS 6	
4.08	PMHS 7	
4.09	PMHS 8	
4.10	PMHS 9	
4.11	PMHS 10	
4.12	PMHS 11	
4.13	PMHS 12	
4.14	PMHS 13	07/2020
4.15	PMHS 14	
4.16	PMHS 15	
4.17	PMHS 16	
4.18	PMHS 17	
4.19	PMHS 18	
4.20	PMHS 19	
4.21	PMHS 20	
4.22	PMHS 21	
4.23	PMHS 22	
4.24	PMHS 23	
4.25	PMHS 24	
4.26	Draft Copy of PMHS Report	09/2020
4.27	Final Copy of PMHS Report	10/2020

2.5 Task 5: Biofidelity Corridor Creation

We will develop biofidelity corridors for occupant excursions, accelerations, seatbelt forces, and occupant-seat contact forces. Two sets of corridors will be created: one for the obese occupants, and one for the small female occupants. Intermediate corridors will be delivered in Monthly Reports.

Table 4: Task 5 Schedule

Item	Project Milestone/Deliverable	Target Date
5.01	Begin corridor creation	After 3rd PMHS test in a series
5.02	PMHS corridor obese occupants	01/2021
5.03	PMHS corridor small female occupants	01/2021
5.04	Draft Copy of report on biofidelity corridors	06/2021
5.05	Final Copy of report on biofidelity corridors	1 week from COR comments

2.6 Task 6: Dummy Matched Pair Tests [Optional Task]

Matched paired ATD tests will be conducted using boundary conditions of Task 4 using equivalent ATD described in 4.2.4. The schedule is shown in Table 5 and is referenced to the receipt of ATD. It was designed to minimize the ATD's time at our facility and recognizes the limited number of advanced ATD in NHTSA's inventory.

Table 5: Task 6 Schedule

Item	Project Milestone/Deliverable	Target Date
6.01	Fabrication of hardware for ATD	2 weeks from receipt of ATD
6.02	Matched pair condition 1	4 weeks from receipt of ATD
6.03	Matched pair condition 2	5 weeks from receipt of ATD
6.04	Matched pair condition 3	6 weeks from receipt of ATD
6.05	Matched pair condition 4	7 weeks from receipt of ATD
6.06	Draft copy of ATD report	3 months from receipt of ATD
6.07	Final copy of ATD report	1 week from COR comments

2.7 Task 7: Human Body Model Evaluation/Improvement—Vulnerable Occupant [Optional]

Table 6: Task 7 Schedule

Item	Project Milestone/Deliverable	Target Date
7.01	Simulations of PMHS sled tests	4 months from award
7.02	Model improvements/optimizations	10 months from award
7.03	Draft Report	11 months from award
7.04	Final Report	1 week of COR comments

2.8 Task 8: Frontal-impact Sled Tests—Injury Criteria [Optional]

Table 7: Task 8 Schedule

Item	Project Milestone/Deliverable	Target Date
8.01	Draft Copy of Report	6 months from completion of PMHS 24
8.02	Final Copy of Report	1 week from COR comments

2.9 Task 9: Additional Sled Tests (Biofidelity) – PMHS Vulnerable Occupant [Optional]

Table 8: Task 9 Schedule

Item	Project Milestone/Deliverable	Target Date
9.01	Begin PMHS tests	3 weeks from award
9.02	Finish PMHS tests	11 months from award
9.03	Draft Copy of Report	12 months from award
9.04	Final Copy of Report	1 week for COR comments

3 PMHS Selection Requirements

3.1 Vulnerable Occupant

We will be testing the PMHS according to the schedule specified in Section 2. The specific aim of this phase is to examine the effect of reclined seating positions on the response of vulnerable occupants in frontal impacts. The vulnerable population is defined as those occupants deemed more likely to submarine in a reclined position than the 50th percentile male population. Submarining is essentially the slipping of the lap belt above the anterior superior iliac spine (ASIS) of the pelvis in a frontal impact during occupant-to-belt loading. Submarining often results in serious abdominal injuries and, sometimes, spine fracture-dislocations. Industry feedback from the Public Meeting indicated three potential vulnerable occupant populations.

1. Obese occupants
2. Small female occupants
3. Elderly occupants

Given the number of PMHS allocated for this phase and number of parameters, testing all three of these vulnerable populations would leave little room for variations on parameters such as seat recline angle. Therefore, this study will examine the obese and small female populations directly, since these are distinct non-overlapping populations, and then analyze the elderly occupant population indirectly since it is not mutually exclusive from the obese and small female populations. To evaluate the elderly occupant population, bone mineral density of each specimen will be measured to indirectly determine the effect of age.

3.2 Inclusion Criteria

3.2.1 Obese Occupants

Male and female subjects with BMI > 30 will be used for the obese occupant population. A BMI greater than 30 is defined as obese according to the Center for Disease Control (CDC). We anticipate a procurement rate of at least one obese specimen per month

3.2.2 Small Female Occupants

We have defined small female occupants to include the first quartile of the female population by stature and mass. PMHS with a stature between 143-157 cm and mass between 38-62 kg will be included. Our previous experience in obtaining small female PMHS indicates that we can receive six specimens a year matching these criteria.

3.3 Procurement

We will follow standard protocols for screening (e.g. HIV and hepatitis B and C). Specimens with pre-existing thoracic injuries that might affect the kinematics and injury from the frontal test will be excluded. Such injuries will include, but will not be limited to:

1. Pre-existing rib fractures greater than five
2. Hip replacement(s)
3. Limb amputations †
4. Severe rib degenerations, as identified by the clinician using palpations, manipulations, and radiography
5. Severe and bridging osteophytes compromising the integrity of the intervertebral joint(s)
6. Severe lateral curvatures (scoliosis) present in the dorsal spine
7. Carcinomas such as bone cancer

†To accommodate next-of-kin requests for ashes, we may use PMHS without forearms to widen the searchable inventory. This increases the likelihood that we will receive enough PMHS to complete the task on time.

3.4 Preservation Method

PMHS meeting the criteria specified in 3.2 and 3.3 will be stored in our pathology laboratory, which has eight whole-body freezers (-40° C) for storage and three freezers (0° C) for temporary storage of specimens awaiting cremation. All freezers are locked, and keys are secured by a monitoring system that requires badge entry by designated lab personnel. All freezers are plugged into circuits that, in the event of power loss, switch power to an on-site natural-gas-powered generator. Freezers are also connected to a temperature monitoring station that automatically generates an e-mail and text alert to key personnel 24 hours a day if temperature is outside the threshold. The lab also contains a climate-controlled, nine-foot-by-seven-foot walk-in cooler for short-term storage of prepared whole-body specimens and specimens removed from storage for thawing.

4 Test Methodology

4.1 Hardware

4.1.1 Sled System

All tests will be conducted using a Seattle Safety 1.4 MN ServoSled. Relevant nominal characteristics of the system are shown in Table 9.

Table 9: ServoSled Parameters

Parameter	Units	Value
Peak Force	kN	1400
Stroke	m	2.0
Peak velocity	km/h	75
Peak acceleration	g	>80
Maximum jerk	g/s	20000
Maximum payload	kg	2500
Maximum energy	kJ	576
Sled dimensions	m (L X W)	3.0 X 1.2

Outrigger(s) will be placed on the side of the sled to accommodate on-board high-speed video (Figure 2).

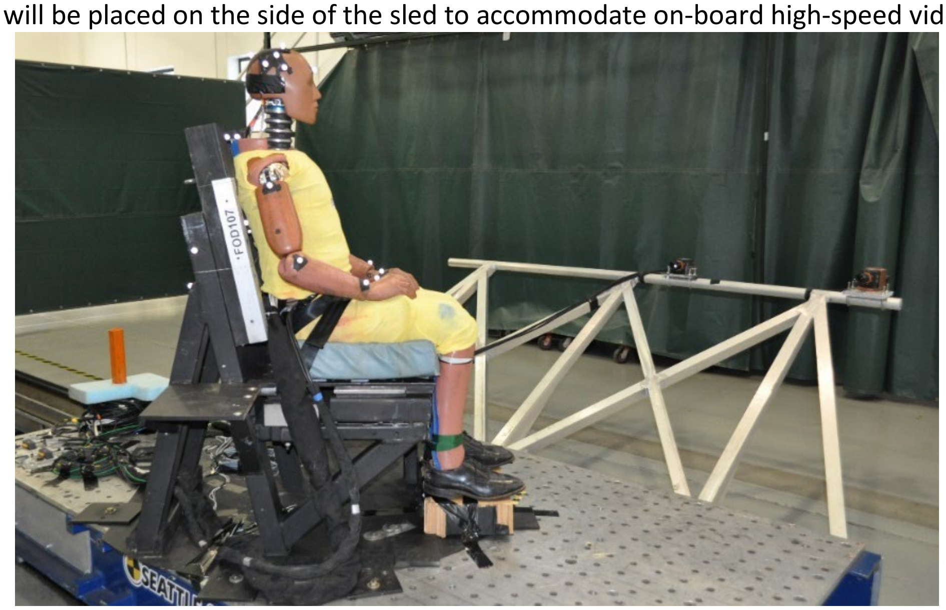


Figure 2: ServoSled with Outrigger and On-board High-speed Video

4.1.2 Test Buck

4.1.2.1 Seat bottom design

While OEM seats provide a realistic boundary condition, use of these seats can add model and experimental variability and be difficult to obtain. Generic/rigid seats are easier to characterize and help to “future-proof” the data for later studies. A set of HBM simulations were performed to compare occupant responses in OEM, semi-rigid, and spring-loaded seats to determine the appropriate test condition for the current study.

Two GHBMC female occupants (Figure 3), with BMI 25 and 35, in base and reclined posture were compared in the three different seats at 32 km/h. The reclined posture was obtained by morphing the occupant for 60-degree OEM seat back angle. The morphing was performed at UMTRI using the custom proprietary code. The three seats used for the study were an OEM seat (Toyota Yaris), a rigid seat with foam, and a spring-loaded seat developed at LAB and are shown in Figure 4.

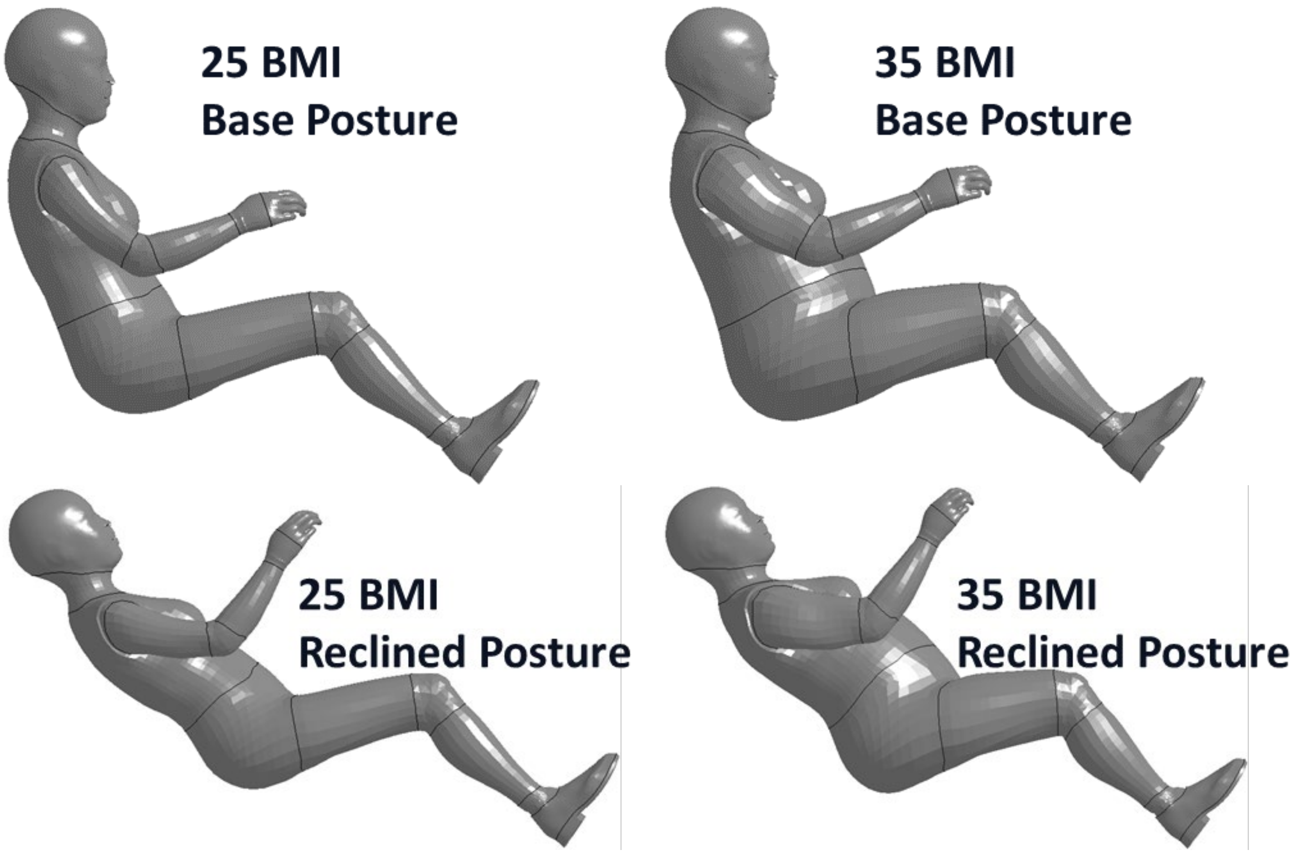
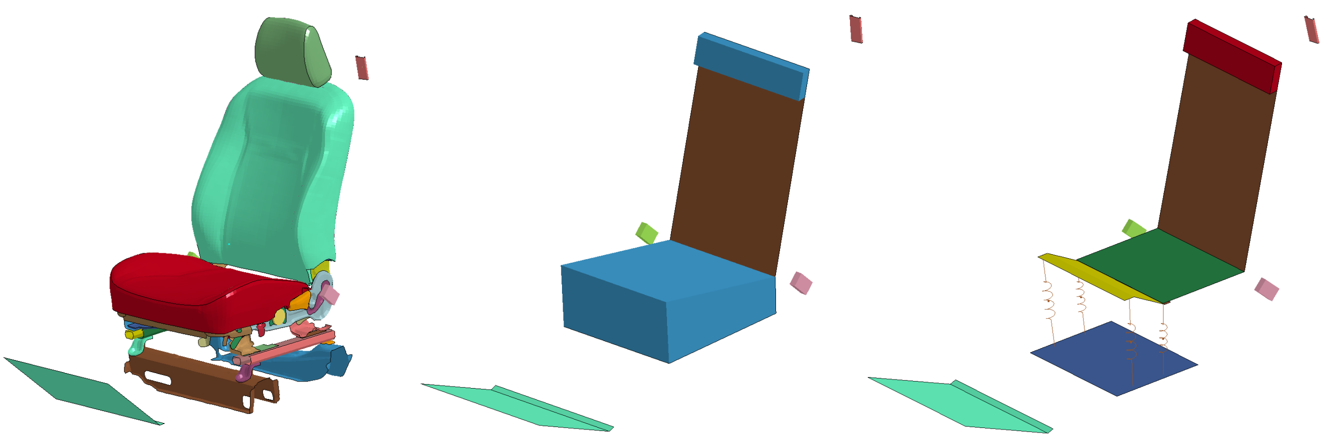


Figure 3: GHBMC Simplified Occupants in base and reclined postures (25 BMI and 35 BMI)



OEM Seat Rigid Seat Spring controlled seat

Figure 4: Finite element models of candidate seats for experiments

Twelve (12) simulations were performed with the candidate seats, and occupant anthropometries and postures. The lap belt did not slip above the anterior superior iliac spine (ASIS) in any of the simulations, and thus did not meet the criteria of 'submarining'. The suitability of the rigid seat with foam and spring-controlled seat was compared using the head and pelvis accelerations, pelvis excursion and rotation, retractor force and pull out, and lumbar spine forces during the event. Results demonstrated that occupants in the spring-controlled seat had a closer response to the occupants of the OEM seat. Some of the responses from the simulations are compared in Figure 5. Head accelerations were similar for the three seats, however the peak head acceleration of the occupant in the spring-controlled seat was more similar to the occupant in the OEM seat. Pelvis accelerations were similar for all three seats. The retractor pullout for the spring-controlled seat was also comparable with the OEM seat. The lumbar spine forces showed compression for the OEM and spring-controlled seat, and tension in the rigid seat. Results from this analysis further justifies the use of the spring-controlled seat for the experimental sled tests. The schematic diagram of the seat pan is shown in Figure 6.

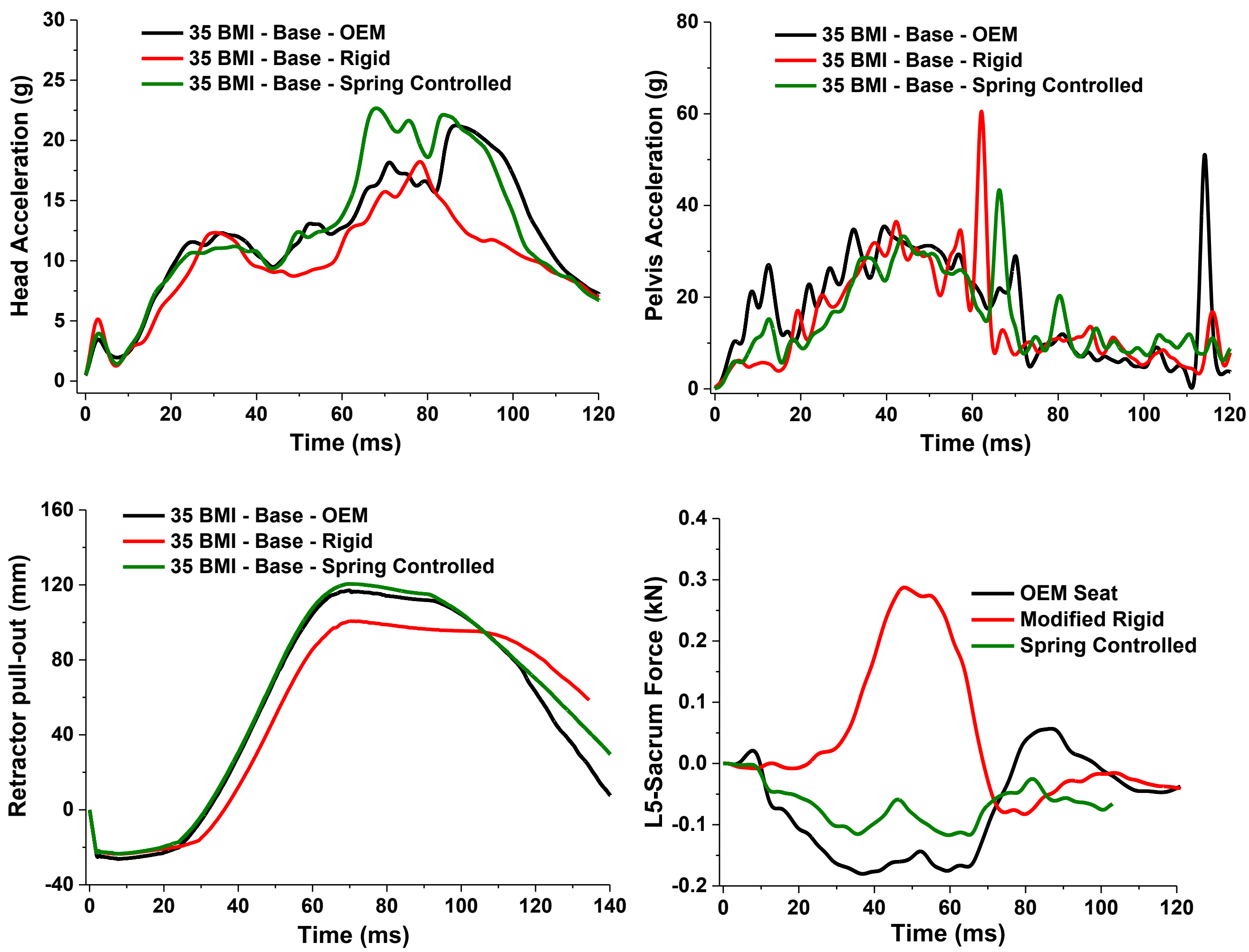


Figure 5: Comparison of the occupant responses for the three seats in the base posture

The seat pan will consist of a rigid aluminum plate articulated at its rear edge. Two sets of springs will be fixed under the front part of the plate, which will allow for downward movement of the pan. The second articulated aluminum plate will be positioned in front of the first plate and simulates the anti-submarining ramp in an OEM seat. The rotational motion of the plate will be controlled by two springs.

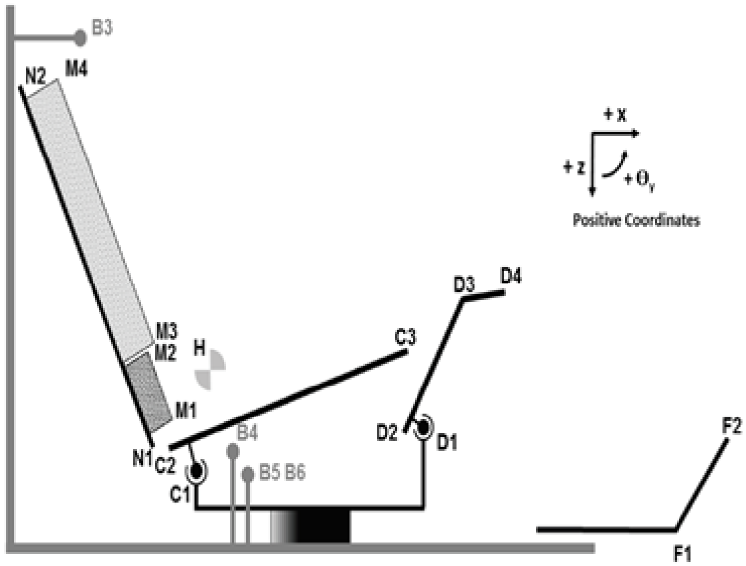


Figure 6: Representation of the spring-controlled seat

4.1.2.2 Seat back design

An open-back style torso support will be used to permit tracking of optical markers placed on the dorsal aspect of PMHS head, spine, and sacrum. The seat back will consist of two thin lateral support columns, which can be adjusted from upright to fully reclined. Thin steel cables will be connected between the two lateral posts to support the posterior thorax of the specimen. The cables will be attached to inertial blocks that release on the onset of sled acceleration to relieve the cable tension during the event and minimize potential interference with specimen instrumentation. The fore/aft and vertical positions of these cables are adjustable in order to achieve the prescribed posture.

4.1.2.3 Seatbelt restraint

The shoulder belt mount will be independent of the seat back but adjustable to simulate an integrated restraint. Lap belt anchors will be mounted to the floor of the buck and will be adjustable.

4.1.2.4 Pretensioner system

Previous PMHS frontal sled tests have simulated pretension in the seatbelt by manually retracting the shoulder belt 10 cm [8]. This method reduces the uncertainty of the seatbelt pretenioning due to different anthropometries and variability between pretensioning loads in different vehicles. The force required to pull the seatbelt for 10 cm will be recorded, and a new seatbelt will be used for each test.

4.1.2.5 Load limiter system

A custom load-limiting device will be used to limit the force to 3.5-4 kN. The seat belt load limiter (Figure 7) controls the magnitude of the shoulder belt force by applying a frictional force via three pistons to brake pad material fixed onto a steel bar. The shoulder belt is connected to the steel bar. The frictional force can be adjusted to a range of load limits by compressing a series of Belleville (disc) spring washers which are placed around the shaft of the piston. Compression of the pistons increases the frictional force on the brake pad material thus increasing the load limit on the shoulder belt.

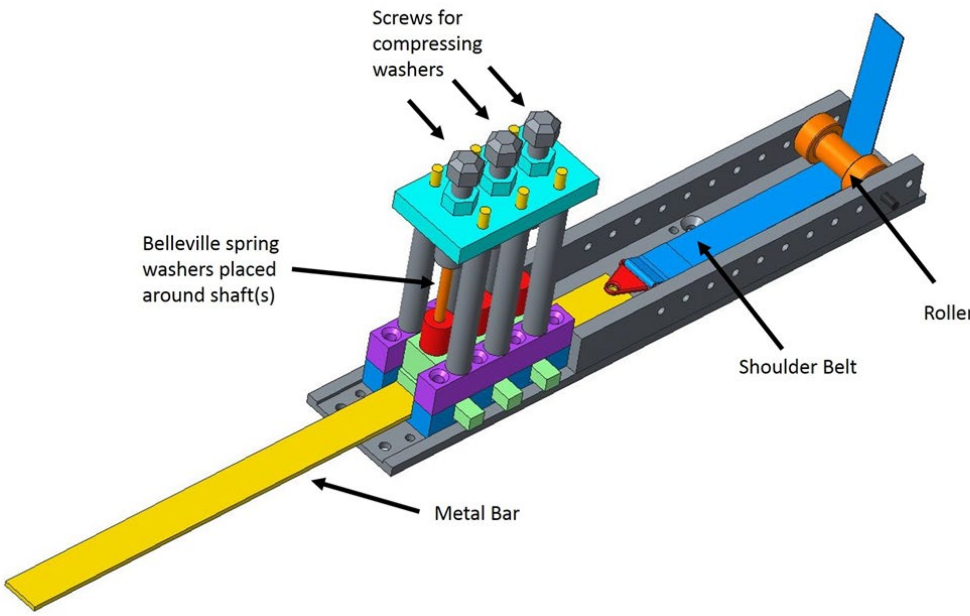


Figure 7: Schematic of load limiter system with shoulder belt attached to metal bar. Three pistons compress a block of aluminum onto brake pad material welded to the metal bar. This exerts a frictional force on the brake pad which acts as a load-limiter to the shoulder belt.

4.1.2.6 Padded rigid Wall

Simulations were performed for 35 BMI female GHBMC occupant at 56 km/h. Figure 8 shows the positions of the pelvis, knees and toes at 100 ms into the event. The lapbelt engaged with the anterior superior iliac spine (ASIS) (no submarining), and the knees were fully extended. In the experiments, however, we are anticipating submarining in the reclined posture [3]. To avoid catastrophic injury to the specimen and damage to instrumentation, the forward motion of the occupants will be limited to prevent the occupant from sliding out of the seat.

To arrest the motion of lower extremities and the motion of the occupant after submarining a padded wall will be placed at a predetermined distance from the occupant's toes, as shown in Figure 9. The distance of the padded wall from the toes will be estimated from simulations based on occupant BMI, stature, and impact speed. The inclination angle of the padded wall was the same as the tibial angle. The angle of the wall will be adjustable to accommodate different specimen anthropometry. To illustrate the effect of the padded wall, a simulation was performed. In the simulation without the wall the lower extremities (toes) demonstrated forward excursion of approximately 225 mm until 65 ms after which the knees extended. To arrest the rotation of the tibias, the padded wall was placed at 225 mm forward from the close point of the feet. The response of the simulation with the padded wall is shown in Figure 9. The occupant knee extension was arrested, maintaining the same frontal excursion and enough room for further excursion if the occupant submarines. Thus, the padded wall will stop the extension of the knees, at the same time allowing the occupant to submarine. It will also prevent the occupant from sliding out and falling off the sled and minimize the chance for catastrophic injuries.

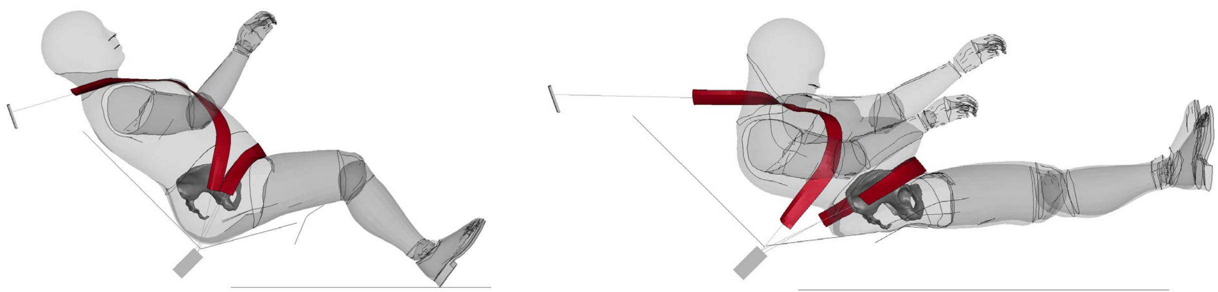


Figure 8: The position of the pelvis at t=0 (left) and t=100 ms (right) into the impact at 56 km/h

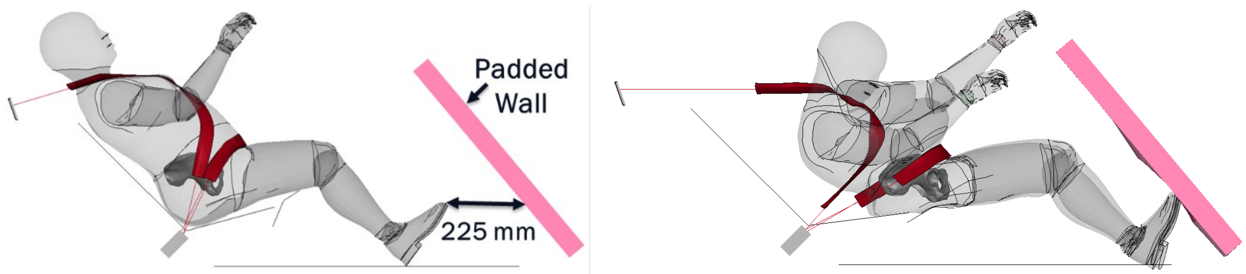


Figure 9: Representation of the vertical wall at t=0 (left) and occupant lower extremities restrained by the padded wall at t=100 ms (right) (Delta V – 56 km/h)

The seat and restraint system will be mounted to a separate aluminum plate and fixed to the top of the ServoSled. Holes will be drilled in the aluminum mounting plate to permit rotation of the buck relative to the impact vector. This will simulate loading in oblique directions; although oblique angles are not proposed in the current test matrix, they may be included in Optional Task 9.

4.1.3 Input pulse

4.1.3.1 High-speed test

The high-speed test will be a generic pulse representative of an NCAP frontal crash with a delta-V of 56 km/h. We will work with UMTRI to develop a pulse which can be easily reproduced by both sled systems.

4.1.3.2 Non-injurious test

Our unpublished small female frontal oblique tests have demonstrated a mix of injured and non-injured specimens at 30 km/h and no injuries for specimens at 15 km/h. Therefore, our non-injurious pulse will scale the high-speed pulse in magnitude to 15 km/h.

4.1.3.3 Medium-speed test

Depending on the outcomes of the first set of twelve PMHS tests, a 32 km/h pulse may be used. If the high-speed test proves to be too severe or if more overlap with the Phase 1 subjects would be beneficial, a 32 km/h pulse similar to that of Phase 1 can be achieved by scaling down the pulse in 4.1.3.1.

4.2 INSTRUMENTATION

4.2.1 Equipment

4.2.1.1 Data acquisition system

All analog data (acceleration, angular velocity, and load) will be recorded at 20 kHz using Slice Pro (Diversified Technical Systems Inc, Seal Beach, CA), according to standard practices. Data will be windowed to 100 ms pre-impact and 500 ms post impact.

4.2.1.2 High-speed video

On- and off-board high-speed video will be recorded at 1000 Hz. At minimum, all tests will have the following three views:

1. Overhead camera: view of superior aspect of PMHS
2. Inboard camera: right sagittal plane of PMHS
3. Outboard camera: left sagittal plane of PMHS.

4.2.1.3 Three-dimensional motion-capture system

Three-dimensional motion of the PMHS will be recorded using a combination of a 28-camera motion-capture system (Vicon, Oxford, UK) at 1000 Hz and images from the high-speed video using Digital Image Correlation (DIC) software.

4.2.2 Sled

A uniaxial accelerometer will be fixed to the base of the sled.

4.2.3 PMHS Instrumentation

The head will be instrumented with a Nine-Accelerometer Package (NAP) with three angular rate sensors (ARS). Six degree-of-freedom sensors (three linear accelerations and three angular velocities) will be mounted dorsally on the spine at T1, T8, T12, and L4-5, iliac wings (bilaterally), femurs (bilaterally), and tibiae (bilaterally). Retroreflective targets will be placed at the head, spine at T1, T8, T12, and L4-5, shoulders (bilaterally), arms (bilaterally), forearms (bilaterally), femurs (bilaterally), tibiae (bilaterally), and ribs 4 and 7 (bilaterally)). Rib markers will be secured lateral to the costal cartilage using custom designed mounts which align the markers to the coronal plane. At least three markers will be used at each location, and they will be used in a noncollinear fashion. Figures 10 and 11 depict the proposed sensor and target locations, Figure 12 the strain gauge locations, and Figure 13 the rib mounts.

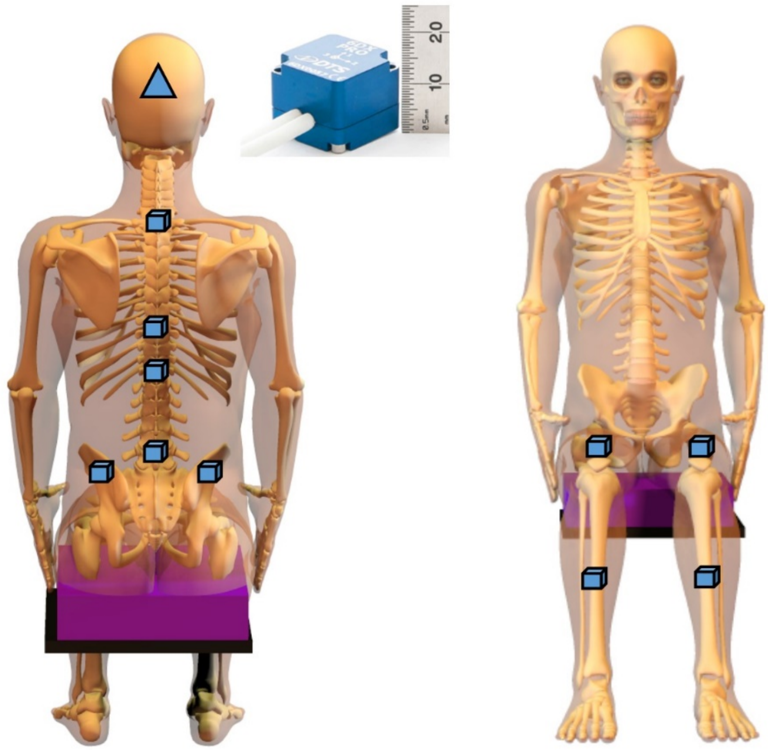


Figure 10: PMHS sensor mounts; tetrahedral NAP with 3 ARS at the head; 6 DOF sensors at T1, T8, T12, L4-5, iliac wings (bilaterally), femurs (bilaterally), and tibias (bilaterally).

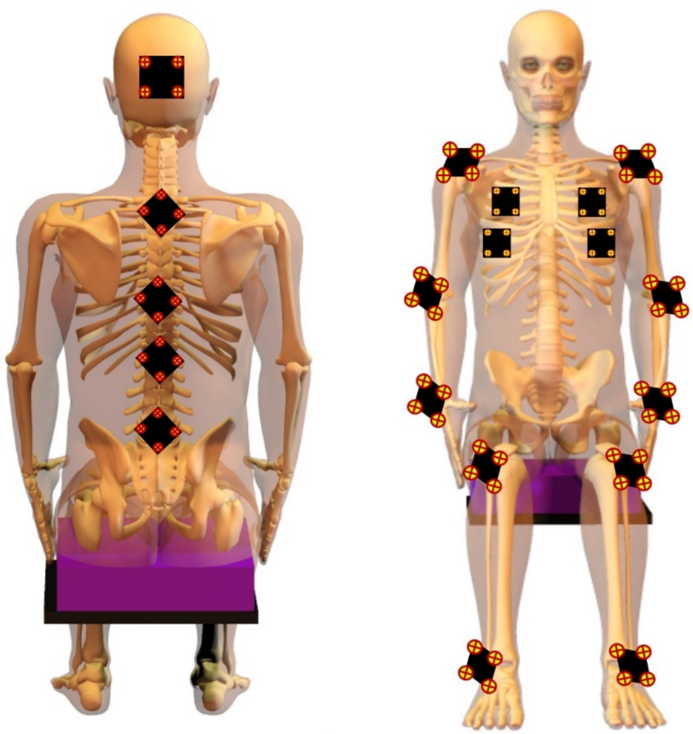


Figure 11: PMHS kinematic target locations at the head, T1, T8, T12, L4-5, shoulders (bilaterally), arms (bilaterally), forearms (bilaterally), femurs (bilaterally), tibias (bilaterally), ribs 4 and 7 (bilaterally).

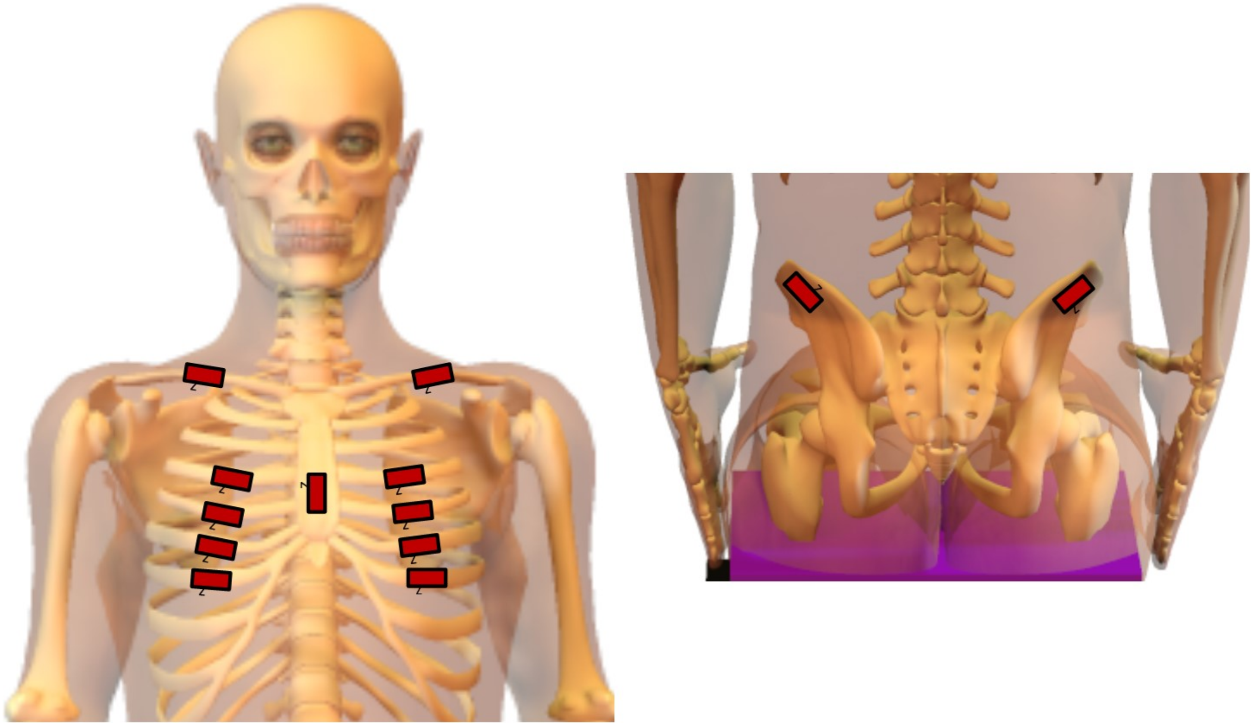


Figure 12: Left shows strain gauge locations on the anterior thorax (Ribs 4-7 bilaterally, clavicle bilaterally, and sternum). Right shows the strain gauges on iliac wings.

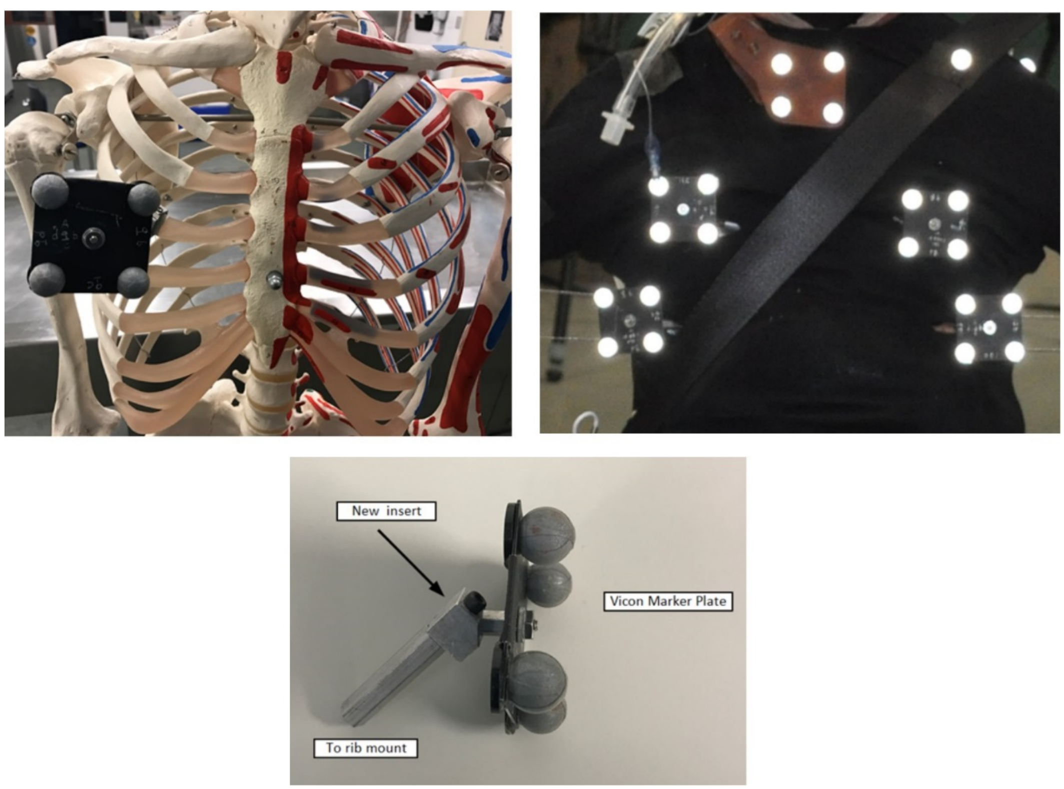


Figure 13: Rib marker mount (lower) shown on model skeleton (upper left) and PMHS (upper right).

4.2.4 Government furnished ATD

Matched-pair data does not exist for ATDs in reclined postures, however, it is anticipated that the THOR and other new ATDs may be more biofidelic than the Hybrid III in this loading scenario. The following ATDs are possible surrogates that may be used to evaluate the vulnerable occupant populations described in 3.1.

4.2.4.1 Small female population

The THOR 5th ATD is designed to represent the 5th percentile (small) female automotive occupant [9] and improve on the biofidelity and capabilities of the Hybrid III [10]. Modifications to the lumbar spine may be necessary to achieve the matched-pair reclined posture of the PMHS. A Hybrid III 5th percentile ATD will be used for shakedown tests for the small female population PMHS tests.

4.2.4.2 Obese population

Either the First Generation Obese ATD (FGOA) [11] or the Elderly ATD (EATD) [12] will be considered for matched-pair tests for the obese population. The FGOA represents a 124 kg male with a BMI of 35 and is based on the THOR-50M design. This anthropometry is more representative of an obese occupant than the Hybrid III 95th which has a BMI of 27 and does not account for mass distribution characteristics of obese occupants. The EATD represents a 70-year-old female with a BMI of 28 and is the only ATD that represents a larger female occupant. Similar to 4.2.4.1 it is not known if either ATD can achieve the reclined posture defined in 4.4.2. A Hybrid III 95th percentile ATD will be used for shakedown tests for the obese population PMHS tests.

4.3 Test Procedure

A tentative test matrix for the tests—which will be performed in the first half of the task—is presented in Section 5. Prior to each test, a non-injurious test will be performed at 15 km/h, which will allow for interval censoring in Survival Analysis methods, producing better goodness of fit measures for the risk curves. The proposed test matrix will give a good estimation of the kinematics of the occupants in the reclined posture at 56 km/h. The delta-V of the non-injury and injury tests may be adjusted to a lower or higher severity depending on the outcome of the first group of tests.

4.3.1 Preparation

A PMHS that satisfies the procurement requirements in Section 3.3 and inclusion criterion in Section 3.2 will be thawed in the walk-in cooler (described in Section 3.4). Once the subject is sufficiently mobile, standard anthropometry measurements will be made according to the requirements for electronic data submission. The specimen will then be transported to the VAMC imaging suite for pre-test functional x-rays and CT scan and then returned to the Pathology Lab. Next, we will perform surgical-style dissections to mount PMHS hardware that minimizes disruption to the musculoskeletal system and soft tissues. All preparations are conducted on a stainless-steel elevating-pedestal autopsy table. Photographs of the specimen will be taken at instrumentation locations both prior to and after installation. Additionally, we will use worksheets with anatomic sketches to further document the serial numbers and orientations of the sensors. The specimen will be placed prone on the table, and dissection will begin from the posterior approach, where instrumentation will be mounted at T1, T8, T12, L4-5, and the pelvis. Cables will be strain-relieved and routed out the dorsal surface contralateral to the impact vector. The specimen will then be clothed in tight-fitting leotards, gloves, socks, and a face-mask. A tetrahedral nine-accelerometer package with three angular sensors will be secured to the posterosuperior aspect of the cranium. Three reference screws will be inserted into the anterosuperior cranium. Following this, the specimen will be placed on its back, and instrumentation will be mounted to the extremities and ribs 4 and 7. Finally, a set of instrumented CT scans will be obtained at the VAMC imagining suite.

4.3.2 Test Day: Non-injurious Test

A non-injurious test will be conducted using the pulse described in 4.1.3.2.

4.3.2.1 Pre-test position

The PMHS will be placed on the buck described in Section 4.1.2. It will be seated on the centerline of the seat bottom with the torso positioned against the seat back cables. These cables will be adjusted to achieve the required test posture (see Section 4.4). The head, torso, and femur angles will be measured at the corresponding anatomic locations. The seatbelt will be routed across the specimen and the lab belt vertical position will be adjusted to its relative position to ASIS predicted by the statistical model (Section 4.4). The pre-test position of the specimen will be documented in multiple ways:

1. Using a complete set of pre-test photographs
2. Using select anatomic points recorded using CMM including
    a. Pubic symphysis
    b. C7 spinous process
    c. Lateral femoral condyle (bilaterally)
    d. Lateral malleolus (bilaterally)
    e. Patella (bilaterally)
    f. Frankfurt plane
    g. Acromion (bilaterally)
    h. Epicondyle of humerus (bilaterally)
3. Using two seconds of Vicon static trial data to ensure visibility of all retroreflective targets and record the anatomic position of landmarks described in 4.2.3
4. Using a three-dimensional scan of the occupant using a FARO scanner (see Figure 14)

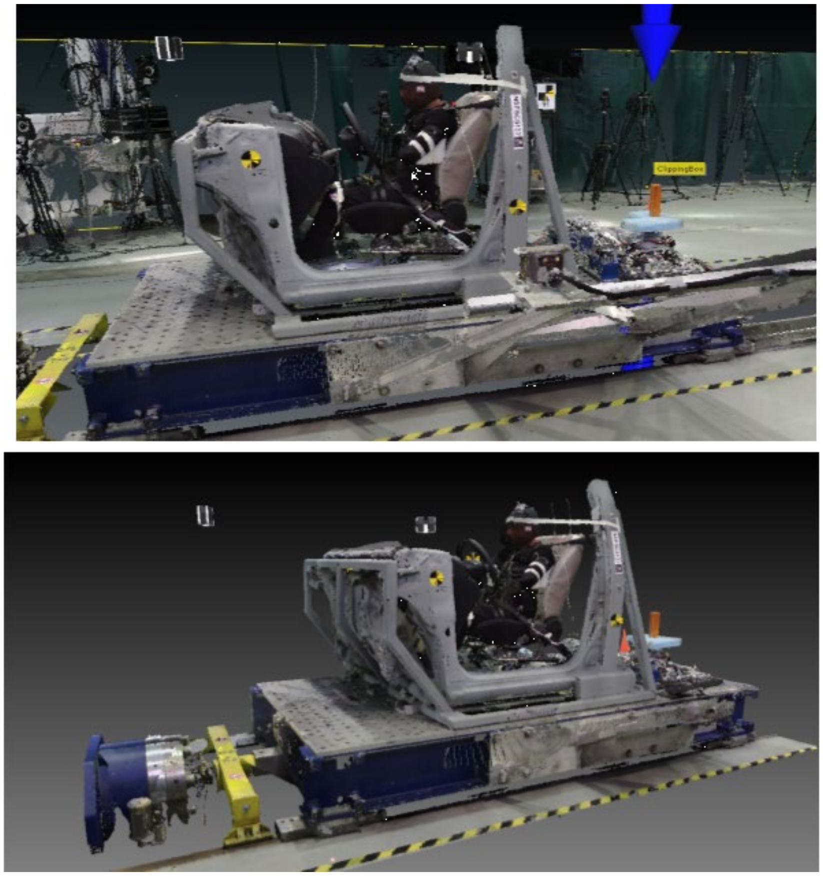


Figure 14: Pretest three-dimensional position scan of PMHS sled test including complete scan of specimen and lab area (upper), close-up of area around the sled buck (lower).

4.3.2.2 Sled test

Sensor checks will be performed to ensure proper function. A pretest checklist will be used to ensure that all test protocols and procedures are followed to minimize data loss.

4.3.2.3 Post-test

Following the test, the PMHS will be photographed on the sled, and the clinician will make an initial assessment using manual palpations prior to removal of the PMHS from the test fixture. Instrumentation will be unplugged one channel at a time, and its DAS channel location will be recorded in the laboratory notebook. These notes will then be compared to the DAS setup file to ensure the data was collected correctly. Vicon data will be reconstructed, and markers will be assigned labels corresponding to their anatomic locations. All analog, high-speed video, and Vicon data will be uploaded to a remote secured server. The specimen will then be transported to the VAMC for a full set of CT scans to determine injury.

4.3.2.4 Injury Assessment

A clinician will conduct a manual examination of the specimen and evaluate radiological images to assess injury. Generally, a specimen with three rib fractures or less will be considered as fit for the subsequent failure test. If injuries are determined to appreciably affect occupant kinematics (more than five rib fractures, and/or spine dislocations), another test will not be conducted.

4.3.2.5 Specimen storage

The specimen will be stored in the autopsy lab's walk-in cooler in between the non-injurious and failure tests.

4.3.3 Test Day: Failure Test

A subsequent failure test will be conducted using the pulse described in 4.1.3.1 or 4.1.3.2. This test will be conducted on a separate day from the non-injurious test.

4.3.3.1 Pre-test position

See 4.3.2.1.

4.3.3.2 Sled test

See 4.3.2.2.

4.3.3.3 Post-test

See 4.3.2.3.

4.3.3.4 Injury documentation

Upon completion of the 56 km/h test, a detailed autopsy will be conducted at the Milwaukee County Medical Examiner's Office, with special attention paid to skeletal and internal contents of the thoracic cage and abdominal and pelvic cavities. Organ (such as spleen and kidney) and soft tissue (such as lung, pleura and diaphragm, ligaments, and mesentery) traumas will be of particular note. The mass of each organ will be noted. Pre-existing conditions such as atherosclerosis will also be documented. All relevant musculoskeletal regions/components will be evaluated for joint abnormalities, which sometimes are less explicit on x-ray and CT scans. Fractures to bones and soft tissue injuries (such as ligament tears and disc and joint disruptions) will be classified. Rib fracture locations will be measured from the center of the sternum along the rib. Other injuries will be described and quantified based on local and regional anatomical characteristics. The head will be removed, and its mass and moment of inertia will be measured. After autopsy, more detailed dissection will be conducted as necessary to better photograph injuries. This will be conducted in our Pathology Lab. Using these images and photographs, we will be able to identify and document any abnormalities, and all pathologies will be graded using the AIS, 2005-2008 update.

4.3.3.5 Deliverables

The Technical Data Package will be submitted within thirty days of the failure test and shall consist of the following

1. Pre-test and post-test photographs
2. Pre-test and post-test radiology
3. Raw (instrumentation) data in EV5 format
4. Processed data including anatomic kinematics and chest deflections in excel format
5. High speed videos
6. Test summary document

4.4 Specimen Posture

PMHS pre-test posture will use a statistical model developed by UMTRI to calculate anatomically equivalent postures based on stature, mass, and sitting height for a given seat back angle. MCW will follow UMTRI's PMHS seating protocol where the occupant will be positioned with the following priority:

1. Pelvis position and angle
2. T1 fore-aft position relative to hips
3. Head angle and fore-aft position relative to T1
4. Upper and lower extremity position

4.4.1 Upright posture
The statistical model will be used to predict the anatomical position of the occupant for a nominal 24-degree seat back angle with the head ‘unsupported’.

4.4.2 Reclined posture
The statistical model will be used to predict the anatomical position of the occupant for a 45-degree seat back angle with the head ‘supported’.

4.5 Data processing

4.5.1 Kinematics
All sensor data will be aligned to a local anatomic coordinate system using pretest CT scan information. Similarly, marker time-history data will be combined with CT measurements to calculate the three-dimensional kinematics at the head, T1, T8, T12, L4-5, ribs 4 and 7 (bilaterally), and upper and lower extremities.

4.5.2 Chest deflection
Chest deflection will be calculated using marker data from the ribs and T8. Relative motion of a point on ribs 4 and 7 with respect to T8 will be used to measure chest deflection time-history.

4.5.3 Fracture timing
Strain gauges on the ribs, sternum, clavicles, and iliac wings may be used to determine the timing of fractures.

5 Test Matrix

5.1 Task 4: Frontal-impact Sled Tests (Biofidelity) PMHS—Vulnerable Occupant

5.1.1 Upright Posture Tests—Obese Occupants
It is estimated that nine Hybrid III 95th ATD tests will be conducted with a GFE ATD for this series. Six will be conducted during the initial shakedown tests to verify test equipment. Additionally, one ATD test will be run prior to each PMHS test.

Table 10: Upright posture tests with Obese Occupants

Parameter	**Description**
Number of PMHS	3
Delta-V	15 km/h and if no injury 56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2 and 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Upright posture (4.4.1)
HIII Shakedown Tests	9

5.1.2 Reclined Posture Tests—Obese Occupants

It is estimated that nine Hybrid III 95th ATD tests will be conducted with a GFE ATD for this series. Six will be conducted during the initial shakedown tests to verify test equipment. Additionally, one ATD test will be run prior to each PMHS test.

Table 11: Reclined posture 1 tests with Obese Occupants

Parameter	Description
Number of PMHS	3
Delta-V	15 km/h and if no injury 56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2 and 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Reclined posture (4.4.2)
HIII Shakedown Tests	9

5.1.3 Upright Posture Tests—Small Female Occupants

It is estimated that nine Hybrid III 5th ATD tests will be conducted with a GFE ATD for this series. Six will be conducted during the initial shakedown tests to verify test equipment. One ATD test will be run prior to each PMHS test.

Table 12: Upright posture tests with Small Female Occupants

Parameter	Description
Number of PMHS	3
Delta-V	15 km/h and if no injury 56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2 and 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Upright posture (4.4.1)
HIII Shakedown Tests	9

5.1.4 Reclined Posture Tests—Small Female Occupants

It is estimated that nine Hybrid III 5th ATD tests will be conducted with a GFE ATD for this series. Six will be conducted during the initial shakedown tests to verify test equipment. One ATD test will be run prior to each PMHS test.

Table 13: Upright posture tests with Small Female Occupants

Parameter	Description
Number of PMHS	3
Delta-V	15 km/h and if no injury 56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2 and 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Reclined posture (4.4.2)
HIII Shakedown Tests	9

5.1.5 Additional PMHS Tests

Other parameters for the Obese and Small Female Occupants may include the medium velocity pulse (4.1.3.3) and other postures. These parameters may be explored in the 2nd set of twelve specimens pending the outcomes of the first twelve.

5.2 TASK 6: DUMMY MATCHED PAIR TESTS [OPTIONAL TASK]

5.2.1 Upright Posture Tests 15 km/h —Obese ATD

Table 14: Upright posture tests - 15 km/h with Obese ATD

Parameter	Description
Occupant	Described in 4.2.4.2
Number of Tests	3
Delta-V	15 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2
Restraints	Described in 4.1.2
Pre-test Position	Upright posture (4.4.1)
HIII Shakedown Tests	3

5.2.2 Upright Posture Tests 56 km/h —Obese ATD

Table 15: Upright posture tests - 56 km/h with Obese ATD

Parameter	Description
Occupant	Described in 4.2.4.2
Number of Tests	3
Delta-V	56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Upright posture (4.4.1)
HIII Shakedown Tests	3

5.2.3 Reclined Posture Tests 15 km/h —Obese ATD

Table 16: Reclined posture tests - 15 km/h with Obese ATD

Parameter	Description
Occupant	Described in 4.2.4.2
Number of Tests	3
Delta-V	15 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2
Restraints	Described in 4.1.2
Pre-test Position	Reclined posture (4.4.2)
HIII Shakedown Tests	3

5.2.4 Reclined Posture Tests 56 km/h —Obese ATD

Table 17: Reclined posture tests - 56 km/h with Obese ATD

Parameter	Description
Occupant	Described in 4.2.4.2
Number of Tests	3
Delta-V	56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Reclined posture (4.4.2)
HIII Shakedown Tests	3

5.2.5 Upright Posture Tests 15 km/h—Small Female ATD

Table 18: Upright posture tests – 15 km/h with Small Female ATD

Parameter	Description
Occupant	Described in 4.2.4.1
Number of Tests	3
Delta-V	15 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2
Restraints	Described in 4.1.2
Pre-test Position	Upright posture (4.4.1)
HIII Shakedown Tests	3

5.2.6 Upright Posture Tests 56 km/h —Small Female ATD

Table 19: Upright posture tests – 56 km/h with Small Female ATD

Parameter	Description
Occupant	Described in 4.2.4.1
Number of Tests	3
Delta-V	56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Upright posture (4.4.1)
HIII Shakedown Tests	3

5.2.7 Reclined Posture Tests 15 km/h —Small Female ATD

Table 20: Reclined posture tests -15 km/h with Small Female ATD

Parameter	Description
Occupant	Described in 4.2.4.1
Number of Tests	3
Delta-V	15 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.2
Restraints	Described in 4.1.2
Pre-test Position	Reclined posture (4.4.2)
HIII Shakedown Tests	3

5.2.8 Reclined Posture Tests 56 km/h —Small Female ATD

Table 21: Reclined posture tests - 56 km/h with Small Female ATD

Parameter	Description
Occupant	Described in 4.2.4.1
Number of Tests	3
Delta-V	56 km/h
Buck	Described in 4.1.2
Pulse	Described in 4.1.3.1
Restraints	Described in 4.1.2
Pre-test Position	Reclined posture (4.4.2)
HIII Shakedown Tests	3

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