Development of Detailed Finite Element Dummy Models

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Summary:

Various numerical models of crash test dummies have been developed over the last decade ranging from rigid body models to deformable models. Today, these models have become an integral part of vehicle interior and restraint development. There is an ever increasing need for accurate and detailed finite element (FE) models of these crash test dummies in the academia, government and industry to further advance the performance of these models with respect to their physical counterparts. In addition, these numerical models can provide a means to further improve the bio-fidelity of the crash test dummies in various impact scenarios. To this end, the National Crash Analysis Centre (NCAC) recently started developing a suite of highly detailed public domain FE models of the crash test dummies. This paper presents the current status of the Hybrid III 50th percentile dummy model development. The methodology is based on the premise that the model must be based on the fundamentals of mechanics, focusing directly on component geometry and material mechanical properties. Furthermore, the model should be created and validated at the component level and then integrated and re-evaluated at a system level to ensure accuracy. All parts of the existing Hybrid III 50th percentile dummy are incorporated in their original manufacturer intended form and function.

Keywords:

Hybrid III, Finite Element, Dummy

1 Introduction

Motor vehicle travel is the primary means of transportation in the United States, providing an unprecedented degree of mobility. Yet for all its advantages, injuries resulting from motor vehicle crashes are the leading cause of death for persons of every age from 3 through 33 years old (based on 2003 FARS data). Traffic fatalities accounted for more than 90 percent of transportation-related fatalities. In 2005, 43,443 people were killed in the estimated 6,159,000 police reported motor vehicle traffic crashes, 2,699,000 people were injured, and 4,304,000 crashes involved property damage only. An average of 119 people died each day in motor vehicle crashes in 2005, one every 12 minutes [1].

The mission of the National Highway Traffic Safety Administration (NHTSA) is to reduce deaths, injuries, and economic losses from motor vehicle crashes by mandating safety requirements for all vehicles sold in the US. The automotive manufacturers are required to build cars, which meet or exceed these minimum safety requirements. To this end, Anthropomorphic Test Devices (ATDs) are used in crash testing of the vehicles as human surrogates to predict injury risks.

Fig. 1: Hybrid III 50th Percentile crash test dummy

The Hybrid III 50th Percentile crash test dummy (Fig 1), representing the average adult male, is the most widely used dummy in frontal crash and automotive safety restraint testing. Originally, the Hybrid III 50th male was developed by General Motors in the mid 70's for vehicle safety purposes. It has since been incorporated into the Code of Federal Regulations under Title 49, Part 572 subpart E, and is the required dummy in NHTSA's motor vehicle safety standards (http://www-nrd.nhtsa.dot.gov/vrtc/bio/adult/hybIII50dat.htm). Over the years, improvements have been made to the dummy to make it more human-like. This has been done in conjunction with the Society of Automotive Engineers' (SAE) Biomechanics Committee and NHTSA. The dummy has adequate instrumentation capability to evaluate different injury risks. The fundamental measurements include head and neck acceleration, chest acceleration, chest deflection, femur load etc. [2]. The Code of Federal Regulations sets guidelines for calibrating the dummy and its sensors to ensure the consistency of these measurements.

To assess and improve vehicle safety and crashworthiness, computer simulations using finite element (FE) methods are standard practice in the automotive industry as well as government agencies and academic institutions. This method has been proven efficient and cost effective over the original methods that were based solely on crash testing. Due to limitations in computational speed and costs, typically only the vehicle structure was analyzed and optimized using FE methods. Occupant injury risks and restraint performance evaluations were carried out separately. With recent advancements in computer hardware technology and software developments have made it possible to develop large and detailed finite element models that include vehicle structures as well as occupants, restraints, and interior components. As these integrated simulation approach are becoming more and more popular, the need for accurate, detailed and robust FE dummy models is increasing. To serve this purpose, the NCAC recently started developing a suite of highly detailed public domain FE models of the crash test dummies

2 Methodology

The primary objective of this research is to develop a highly detailed accurate and robust FE model of the Hybrid III 50th percentile dummy. To achieve this goal, the project was divided into 5 main phases as illustrated in the flowchart in Figure 2.

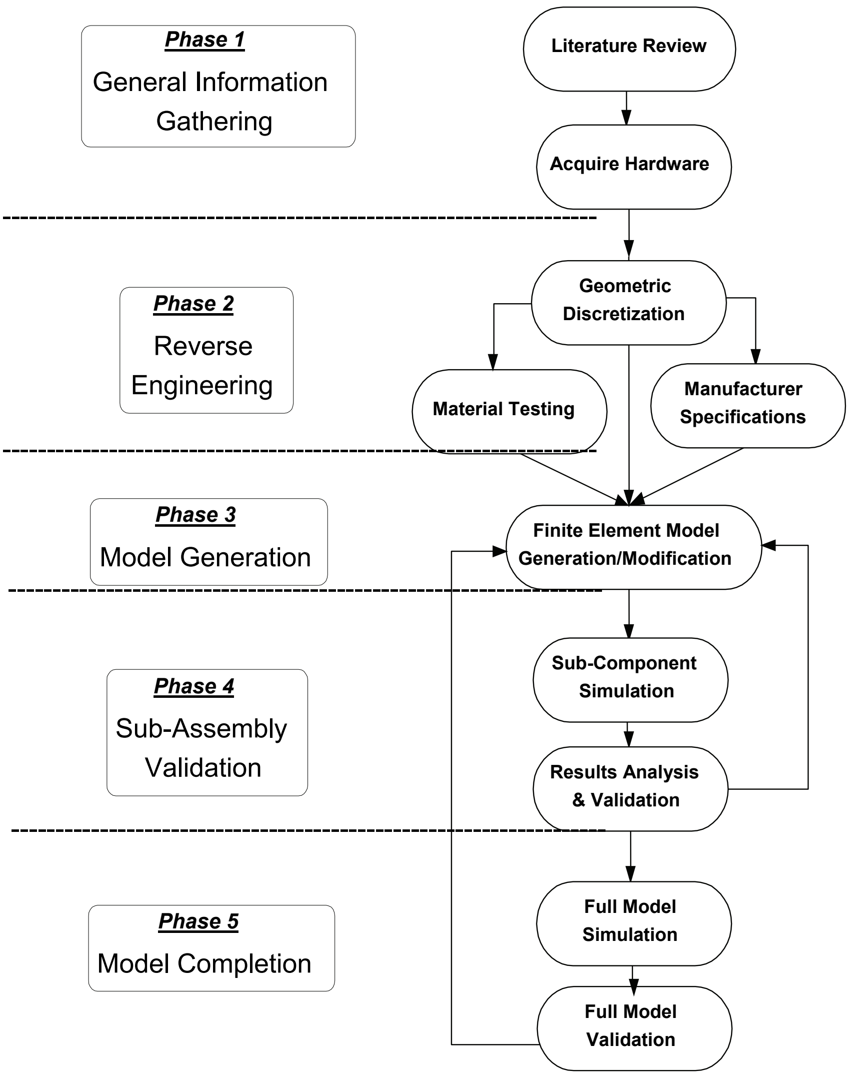

Fig. 2: Modeling Methodology [3]

2.1 General Information Gathering

In phase 1, extensive literature review was conducted to gather essential information on the design of the various components of the dummy. Much of this information was readily available from the SAE compendium [2] which has a collection of the landmark papers related to the development of the Hybrid III dummy. Part 572 of the Code of Federal Regulations (CFR) under Title 49 was consulted for additional information. The part and assembly drawings were obtained from the reference library of the Office of the Federal Register, National Archives and Records Administration in Washington DC. In addition, two functional dummies belonging to two major dummy manufacturers were obtained.

2.2 Reverse Engineering

As computer-aided design has become more popular, reverse engineering has become a viable method to create a 3 dimensional (3D) virtual model of an existing physical part for use in 3D CAD, CAM, CAE and other software. The reverse engineering process involves measuring an object and then reconstructing it as a 3D model. The physical object can be measured using 3D scanning technologies like coordinate measuring machines (CMM's), laser scanners, structured light digitizers or computed tomography. The measured data alone, usually represented as a point cloud, lacks topological information and is therefore often processed and modeled into a more usable format such as a CAD model.

Geometry was considered the most important aspect of the physical dummy that needed to be gathered in order to create an accurate FE model. In this study, a CMM and a laser scanner were used to capture the 3D geometry of the dummy components. The portable CMM, manufactured by FARO Technologies (Figure 3a), used in the digitizing process had a single point accuracy of 0.005 inches. The FARO Arm is an instrumented articulated arm with six degrees of freedom (DOF). It uses proprietary hybrid analog/digital rotational transducers, which provide good accuracy measurements in a compact and extremely lightweight package. The Laser Scanner, also manufactured by FARO Technologies (Figure 3b), is a seven-axis contact/non-contact measurement device with a fully integrated Laser Line Probe. The FARO ScanArm's hard probe and FARO Laser Line Probe can digitize interchangeably without having to remove either component. The Laser Line Probe has an accuracy of 0.002 inches. It scans at a rate of 30 frames/second and has a spatial resolution of 640 points/line.

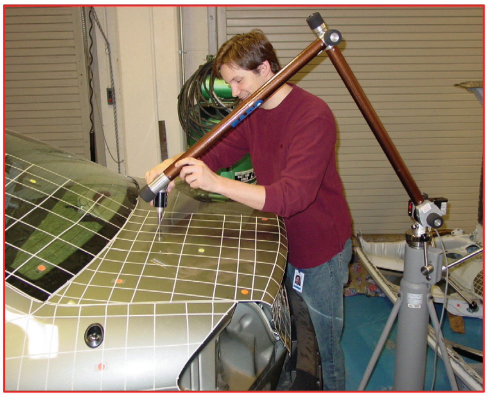


Fig. 3: a) 6 DOF Coordinate Measuring Machine b) Laser Scanner

3D scans were made for each of the dummy component using the Laser Line Probe. The CMM was used as needed to obtain accurate geometry for the parts which could not be scanned using the Laser Line Probe. Each component was scanned completely without assuming symmetry condition through out the modeling process. Engineering drawings were consulted to cross check the digitized geometry from the physical dummy. The 3D geometry of the interior components of the molded parts such as the upper extremities was reconstructed from the 2D drawings. Autoliv North America provided a de-commissioned pelvis which was cut open to scan the pelvis bone and hip joints.

2.3 Model Generation

Once the geometry of the dummy part was captured in sufficient detail, the IGES data for each component was imported into a pre-processor for mesh generation. Each of the dummy components was modeled explicitly to ensure accurate inertia and mass distribution. A uniform mesh size with a global element size of 6 mm was used in the model for two main reasons, one, to ensure a time step of at least 1 microsecond and two, to have good contact interaction with the vehicle interior which are also typically modeled using an element size of 6 mm. The fully assembled FE model is shown in figure 4. The model consists of six main assemblies, head, neck, torso, pelvis, arms, and legs. Each of these components will be described in more detail in the next several sections.

Every component in the dummy that appeared to function as a flexible body was incorporated in the model as a deformable body. This led to fewer assumptions in the modeling of the physical dummy. In other words, every effort was made to put the physical dummy directly into a FE model without any assumptions. These FE components will replicate the behaviour of their physical counterparts since they have accurate geometry and material properties. In addition, by including all flexible components, no limitations are imposed on the use of this dummy, hence increasing its functionality.

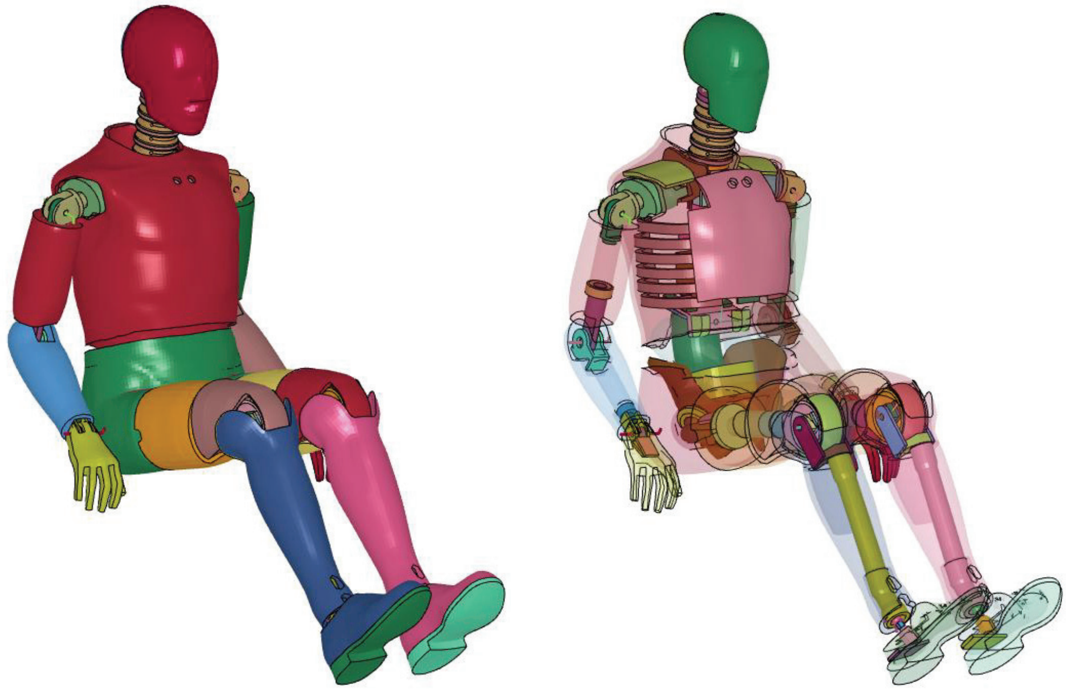

Fig. 4: Hybrid III 50th Percentile FE Model

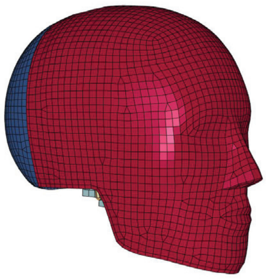

Fig. 5: Head Model

Head Model: The head assembly shown in figure 5 consists of vinyl skin, aluminium skull, ballast plates and neck connection bracket. All components were modeled as solid elements to ensure accurate inertia and mass distribution. The calculated principal moments of inertia were compared to the data from the literature [2] and found to be within 2%. The outer vinyl skin is connected to the skull using the "contact tied nodes to surface" [4, 5] option. The tri-axial accelerometer is represented using the standard LS-DYNA accelerometer feature and is positioned at the centre of gravity of the head.

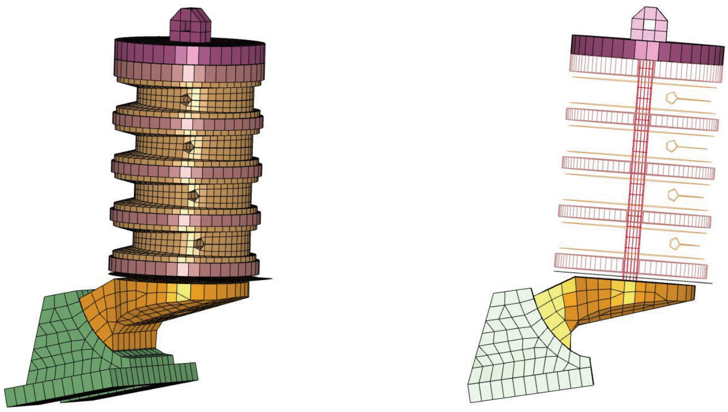

Fig. 6: Neck Model

Neck Model: The neck assembly shown in figure 6 is composed of head to neck connection bracket, four rubber discs molded between 5 metal discs, steel cable at the center, chest bib simulator and an upper neck bracket to spine mount. The rubber discs have a partial depth horizontal slit on the anterior side to simulate a less stiff response in neck extension than in flexion. Each of these slit have different depths (figure 6) to match the response of the human neck. The rubber components are modeled as solid elements and have the holes and slits incorporated as in the physical dummy. The rubber discs were attached to the metal discs using "contact tied nodes to surface" [4, 5]. After testing the improved contact algorithm in the recent release of LS-DYNA, the contact between the slits was included in the global "automatic single surface contact" [4, 5]. The metal discs were modeled as a single layer of fully integrated solid elements. The steel cable is modeled using beam elements and is covered with a layer of null shell elements for better contact interaction with the metal and rubber discs. The steel cable is under tension in the assembled physical dummy. This pre-stress is incorporated using the "initial stress beam" [4, 5] option which provides a means to apply the stress in the local co-ordinate system.

<u>Thorax Model:</u> The thorax assembly shown in figure 7 is composed of chest jacket, bib assembly, ribs, clavicles and thoracic spine. Most of the components, where feasible, are modeled as solid elements to ensure accurate mass and inertia distribution. The chest jacket is modeled with a fully integrated single layer of solid elements. The steel ribs were modeled with three layers of shell elements across their width to capture the correct bending behavior. The damping material attached to the ribs is modeled as solid elements. The individual components were connected to each other using joints, spot welds and constrained nodal rigid bodies as represented in the physical dummy. The tri-axial accelerometer is represented using the standard LS-DYNA accelerometer feature and is positioned in the spine box. The chest deflection potentiometer is modeled realistically as can be seen in figure 7. A translational and spherical joint at the front end allow the beam to slide up and down the sternum assembly as the chest compresses. A revolute joint at the back end attaches the beam to the spine. The measured rotation in this joint can be converted using a scale function to obtain the chest deflection.

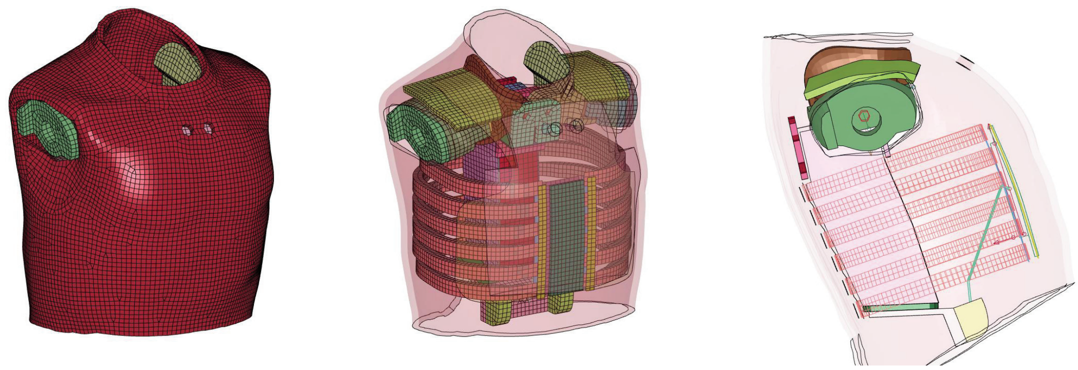

Fig. 7: Thorax Model

<u>Lumbar Spine Model:</u> The lumbar spine assembly shown in figure 8 is composed of curved lumbar spine, two steel cables and brackets. The lumbar spine is molded with the top metal bracket and connected to the bottom bracket with two steel cables. All components are modeled as solid elements. The lumbar spine is attached to the top bracket using "contact tied nodes to surface" [4, 5]. The steel cables are modeled using beam elements and are covered with a layer of null shell elements for better contact interaction with the lumbar spine. The steel cable is under tension in the assembled physical dummy. This pre-stress is incorporated using the "initial stress beam" [4, 5] option which provides a means to apply the stress in the local co-ordinate system.

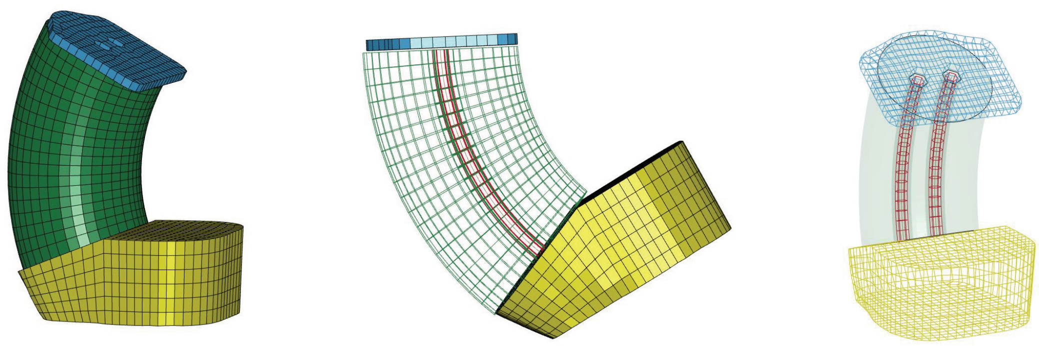

Fig. 8: Lumbar Spine Model

Pelvis and Abdomen Model: The pelvis assembly shown in figure 9 is composed of cast aluminum pelvis bone, foam and upper femur joints. The abdomen is a molded foam component covered with vinyl skin. All components are modeled as solid elements to ensure accurate inertia and mass distribution. The pelvis bone is connected to the foam and vinyl skin using "contact tied nodes to surface" [4, 5]. A spherical joint is added between the pelvis bone and upper femur castings to simulate the ball and socket hip joint.

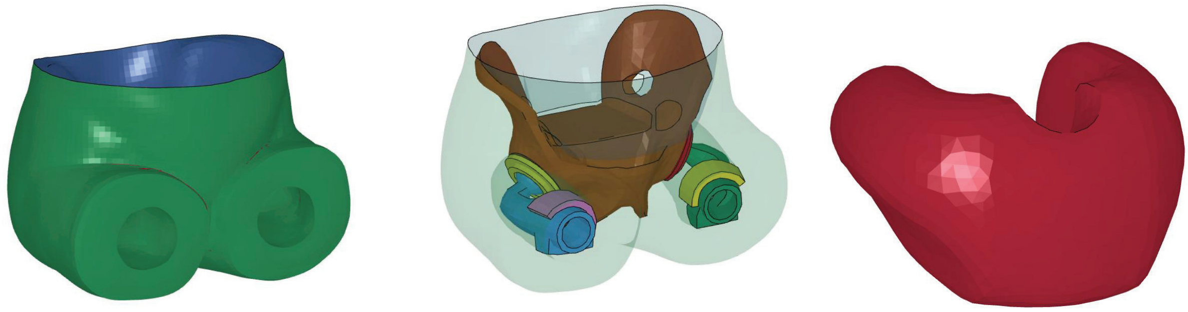

Fig. 9: Abdomen and Pelvis Model

Fig. 10: Lower Extremity Model

Lower Extremity Model: The lower extremity shown in figure 10 is composed of upper leg, knee, lower leg and foot. It is attached to the pelvis at the hip through a spherical joint. Most of the components, where feasible, are modeled as solid elements to ensure accurate mass and inertia distribution. The outer surface of the upper leg and lower leg flesh is covered with shell element for contact purposes. The knee is connected to lower leg through two slider blocks. The slider blocks allow for both rotational and translational motions between the knee and lower leg. These motions are represented with translational and revolute joints in the model. The lower leg is connected to the foot through a "soft-stop" ankle assembly. A spherical joint is defined between the ankle components to replicate the motion between the lower leg and the foot. The foot consists of an inner steel plate and an outer soft vinyl. The steel plate is modeled with shell elements and the vinyl is modeled with solid elements. The foot model incorporates the heel insert, which is modeled with solid elements. The Hybrid III dummy is always tested with regulation shoes, and these are included in the model.

Upper Extremity Model: The upper extremity shown in figure 11 is composed of the upper arm, lower arm and hand. The upper arm is made of a metallic inner piece modeled as shell elements and an inner solid vinyl pad. The lower arm is modeled similar to the upper arm and the two are connected through a revolute joint at the elbow. The hand is modeled as solid elements and is attached to the lower arm by means of a revolute joint at the wrist. The outer surface of the upper arm, lower arm and hand flesh is covered with shell element for contact purposes.

Fig. 11: Upper Extremity Model

The non-deformable part of the dummy, mainly the dummy skeleton, is modeled as elastic material, type 1 in LS-DYNA [4, 5]. The visco-elastic material type 6 [4, 5] in LS-DYNA is used to model the vinyl skin. The material type 7 [4, 5] (Blatz-ko_rubber) is used to model some of the rubber components and material type 62 [4, 5] (viscous_foam) is used to model the foam components. The standard dummy instrumentation was incorporated in the model and the polarities were set according to the SAE J211 recommendation. Table 1 summarizes the model statistics mainly the number of parts, nodes and elements in each assembly. The joint beams and nodes are not included in this table.

Table 1: Model Summary

Assembly	Number of Parts	Number of Nodes	Number of Elements
Head	9	15515	9394
Neck	8	12015	7902
Thorax	38	58750	40485
Lumbar Spine	5	7144	5830
Abdomen	2	4511	25346
Pelvis	6	21886	63440
Upper legs	22	31234	34819
Lower legs	24	24788	28346
Feet	18	9472	11444
Shoes	4	4502	3450
Shoulders	4	858	438
Upper arms	12	22190	25166
Fore arms	14	16432	19114
Hands	10	4244	5308
Totals	**176**	**233541**	**280482**

3 Conclusion

The current status of the FE model development of the 50th percentile Hybrid III dummy has been presented. The FE model is currently completing the Phase 3 of the methodology presented in the earlier section. Further work will focus on component and sub-system validation. Once the parameters required for the material models are optimized for the sub-system validation, the dummy model will be validated against full scale sled tests.

4 Acknowledgements

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