Newly Developed LS-DYNA® Models for the THOR-M and Harmonized HIII 50th Crash Test Dummies

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Abstract

Finite Element (FE) models of Anthropomorphic Test Device (ATD), commonly known as crash test dummies, have become increasingly applicable in automotive safety. A variety of ATDs models are widely used in many areas such as restraint development, automotive crashworthiness, occupant safety and other automotive environment related applications. With the increase in cost effectiveness of computational power, progressively complex and detailed computer models of ATDs have become more realistic in recent years. There has been growing demand for these models due to the inherent benefits of reduced cost and time in the product development cycle.

The presented paper highlights the development process of two of such highly detailed frontal impact ATD models namely: THOR-M 50th and Harmonized Hybrid III (HIII) 50th in the LS-DYNA FE code. Both these dummy models represent anthropometry of a 50th percentile adult male. The current work describes the model development process and a controlled loading case for each of the dummies to illustrate the predictive capabilities of both models.

The geometries and inertial properties for both dummy models are obtained from available drawings and hardware. The model connectivity and structural integrity are inspected by experiments and verified against hardware. Material tests have been conducted for all critical materials, enabling characterization using the latest material modeling techniques. The model's material properties are implemented from physical test data after numerical parameter extraction and verification through coupon simulations, using available material cards. All the injury output sensors and instrumentation in these models are developed and implemented based on all possible instrumentation information in hardware.

These models are then validated against a variety of component, sub-assembly, and full dummy level load cases, as a key for developing reliable models that meet industry expectations. A detailed validation case of the thorax is presented for the Harmonized HIII 50th and a neck validation case is presented for the THOR-M 50th dummy. The current development status has shown very reasonable predictive capabilities of these two models as evident in the illustrated loading conditions which range from component to full dummy level.

Introduction

In year 2011, 51% of passenger vehicle occupant fatalities occurred in vehicles that sustained frontal damage to the vehicles [1]. A large number of fatal and serious injuries will continue to occur in frontal crashes, and further improvements in crashworthiness in frontal crashes will be needed to address them.

The Hybrid III (3rd generation) 50th percentile adult male Anthropomorphic Test Device (ATD) commonly known as HIII 50th dummy [2] is the most widely used tool for occupant injury evaluation and automotive safety restraint testing in frontal crashes. The HIII 50th dummy was introduced into the Code of Federal Regulations by National Highway Traffic Safety Administration (NHTSA) in 1978. Since then it has been used in regulation for the frontal impact crash safety evaluation. During the past year, Humanetics (Humanetics Innovative Solutions, Inc.) has decided to consolidate the hardware development of the HIII 50th dummy from two manufacturers (First Technology Safety Systems, Inc. and Denton ATD, Inc.) into a single brand name of the Harmonized HIII 50th (referred as HH350 hereafter).

Currently, the Test device for Human Occupant Restraint–Metric (THOR-M) dummy [3] is under development as a possible successor to the HIII 50th. It is an advance frontal ATD that incorporates improved biofidelic features and significantly expanded instrumentation enabling crash test engineers to investigate injury pathways not included in the design of the HIII 50th.

For almost two decades, the Computer-Aided Engineering (CAE) group at Humanetics has been developing Finite Element (FE) models of a variety of crash test dummies. The demand for these models has grown significantly in recent years, as automotive manufacturers and their suppliers along with research institutions rely heavily on simulation models to accurately predict occupant injuries in a virtual environment. By using FE modeling, these organizations reduce both cost and development time by reducing the amount of physical testing required in achieving superior crash test results.

As with all FE models, crash test dummy models have three critical components: geometry, material modeling and structural connectivity. As part of the largest and most established manufacturer of physical ATDs, the Humanetics CAE group has access to the most up-to-date hardware which ensures that the delivered model incorporates the latest geometry. Material characterization and modeling in Humanetics FE dummies has become increasingly important over time as more accurate model responses are required. The use of advanced material models and extensive material testing has allowed for more representative non-linear and rate-dependent responses in a number of key components.

To validate each dummy model, Humanetics carries out an extensive amount of component, subassembly and full-dummy tests. Some of these tests are required to certify the dummy hardware while most are non-certification tests carried out specifically for model validation purposes. These validations are necessary to ensure the functionality of the models across a wide spectrum of loading conditions as well as to capture the responses of the physical dummy during various impact severities.

The presented work highlights development of two of the frontal impact ATD models namely: THOR-M V0.9 and HH350 V1.0 developed in LS-DYNA (Livermore Software Technology Corporation) FE code. Although both these dummies are validated against a variety of loading conditions, the current paper is limited to the thorax validation case for the HH350 V1.0 and the neck validation case for the THOR-M V0.9 that demonstrate the predictive capabilities of these models.

Harmonized H350 V1.0 Model

Development of the HH350 V1.0 began shortly after the harmonization process for the HIII 50th hardware was completed and entered production. Since a significant amount of the dummy component geometry varied from the past HIII 50th models, the majority of the mesh had to be regenerated to reflect the changes in the new hardware. Several material manufacturing changes in the harmonization process necessitated re-testing and creating new material models for a number of key components including the lumbar spine, neck, ribs, skin vinyl, and pelvis and abdomen insert foams. Several new material level deformation modes were tested to assess the material response in more complicated loading scenarios. A complete set of component, sub-assembly and full dummy level testing was then carried out to validate the HH350 V1.0 model.

The HH350 V1.0 model consists of 270K nodes and 237K deformable elements. An initial time-step of 0.8 micro-second was achieved for the dummy model. The H350 V1.0 has been tested using the LS-DYNA solver version R6.1.1. Figure 1 shows the overall comparison of the HH350 V1.0 model to the hardware.

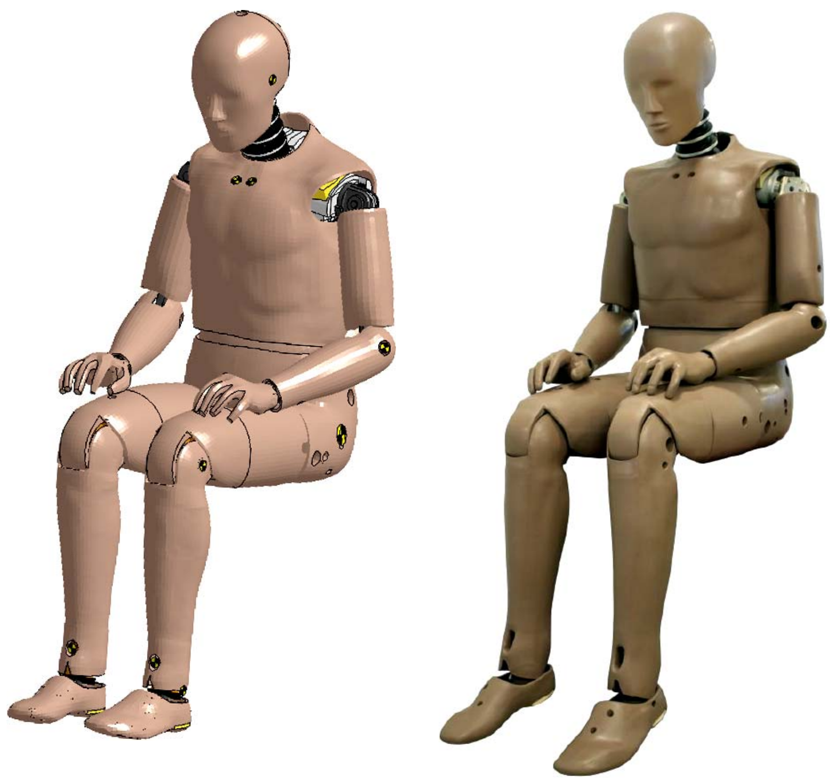


Figure 1: Harmonized H350: V1.0 LS-DYNA model (left) and the hardware (right)

HH350 V1.0 thorax validation case:

The HH350 thorax hardware consists of a complex structural aspect involving ribs, sternum, spine box, and a transducer to measure the chest deflection. The thorax has a jacket comprising of foams and rubber materials. The thorax can be instrumented with many sensors including accelerometers, load-cells and chest deflection transducer. The most important sensor from thorax injury prediction perspective in automotive safety is the chest deflection transducer. It is used to measure how much the sternum (front of the chest) compresses relative to the spine box. The HH350 V1.0 model accurately captures all structural, geometric and instrumentation aspects of its hardware counterpart. The materials in HH350 V1.0 model such as foams, rubbers, bib and ribs are modeled using the best available options from the LS-DYNA material library.

Figures 2 and 3 show the model validation process ranging from validating at the single rib (component), the thorax without jacket (sub-assembly) and full dummy pendulum certification levels. All these different level validations are carried out at different energy levels (initial velocities) to evaluate the model performance in rate sensitive dynamic loading environment.

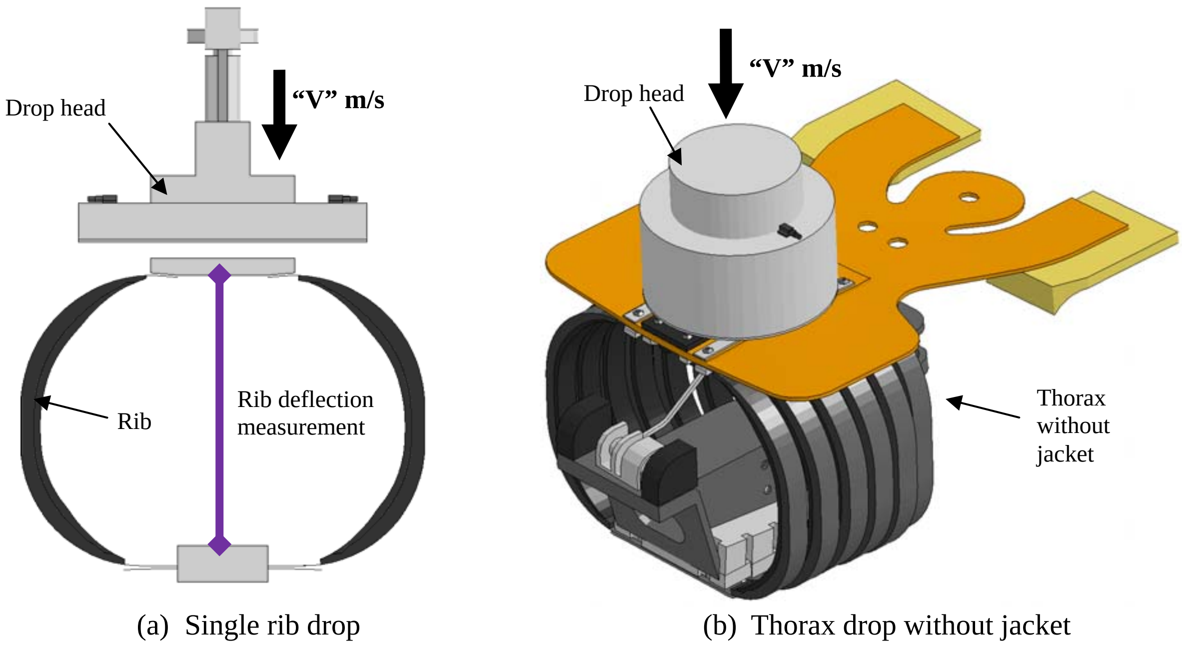


Figure 2: HH350 V1.0 validation setup for the component (a) and the sub-assembly (b)

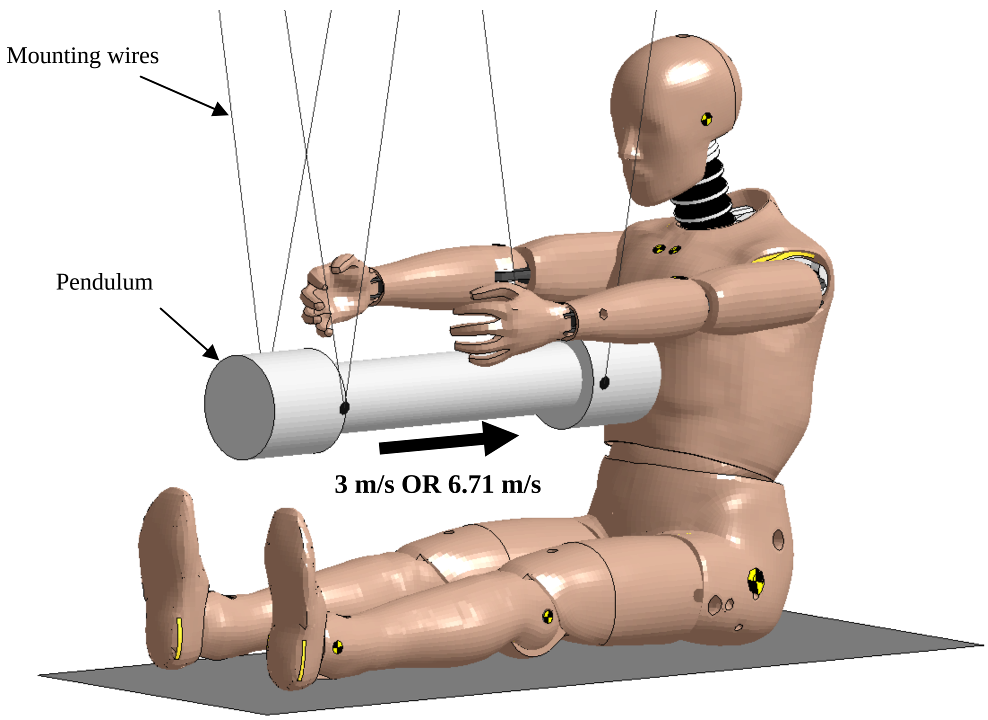
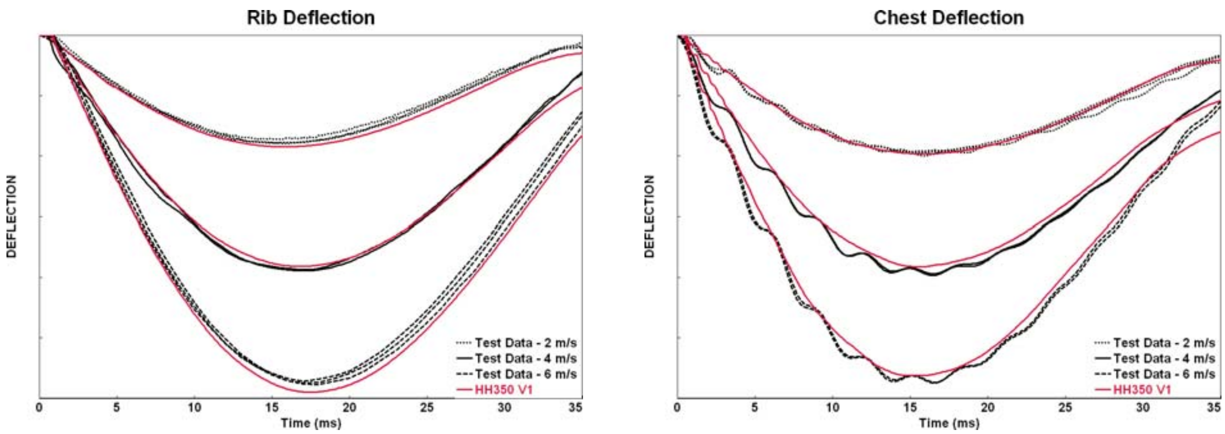


Figure 3: HH350 V1.0 validation setup for the full dummy thorax pendulum at 3 and 6.71 m/s

The HH350 V1.0 model performances are evaluated based on comparison of the chest deflection responses from the test. Figure 4 shows the model response comparison with test data for the component and the sub-assembly levels at three different speeds. Figures 5 and 6 compare the full dummy model response with test data at 3 m/s and 6.71 m/s, respectively. Comparisons of results illustrate very promising predictive capabilities of the HH350 V1.0 model.



(a) Single Rib Drop Validation (b) Thorax Drop Validation

Figure 4: Component (a) and sub-assembly (b) level deflection validation performances

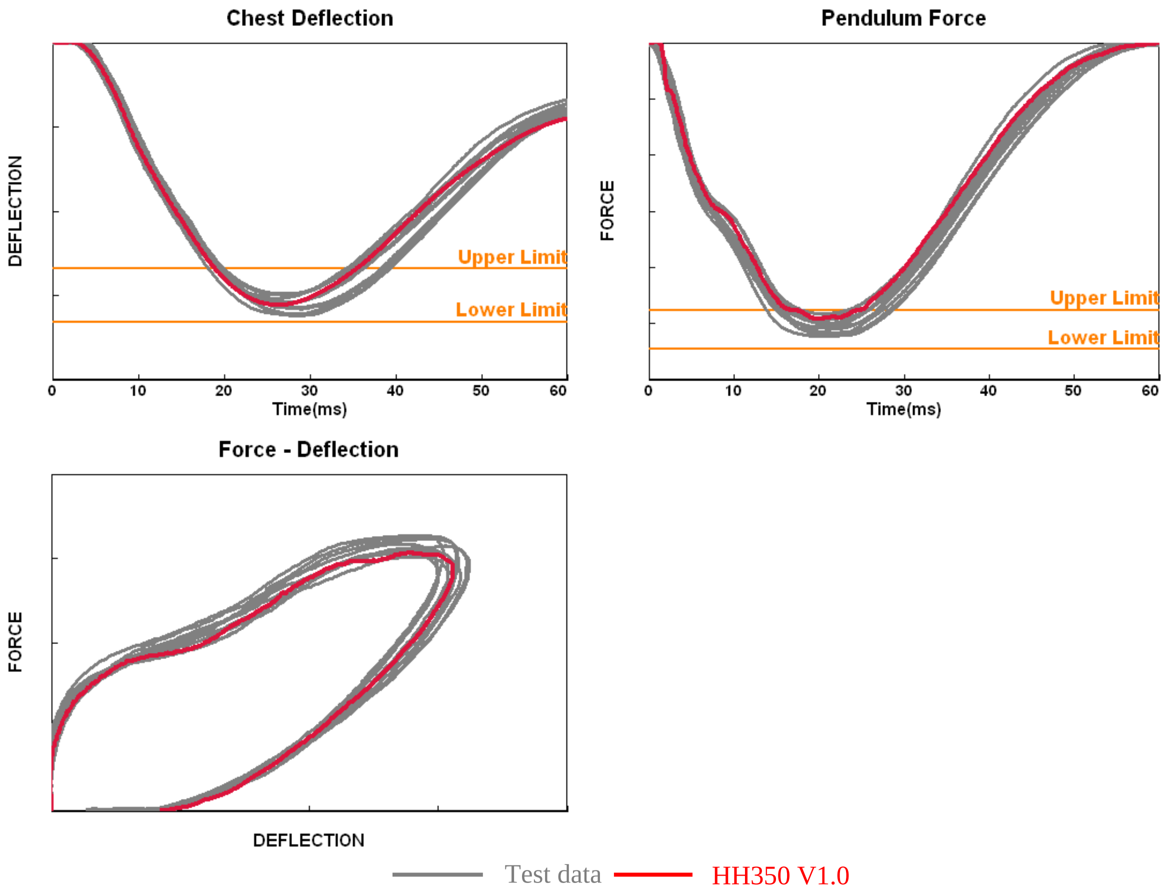


Figure 5: Full dummy thorax pendulum validation performance at 3 m/s

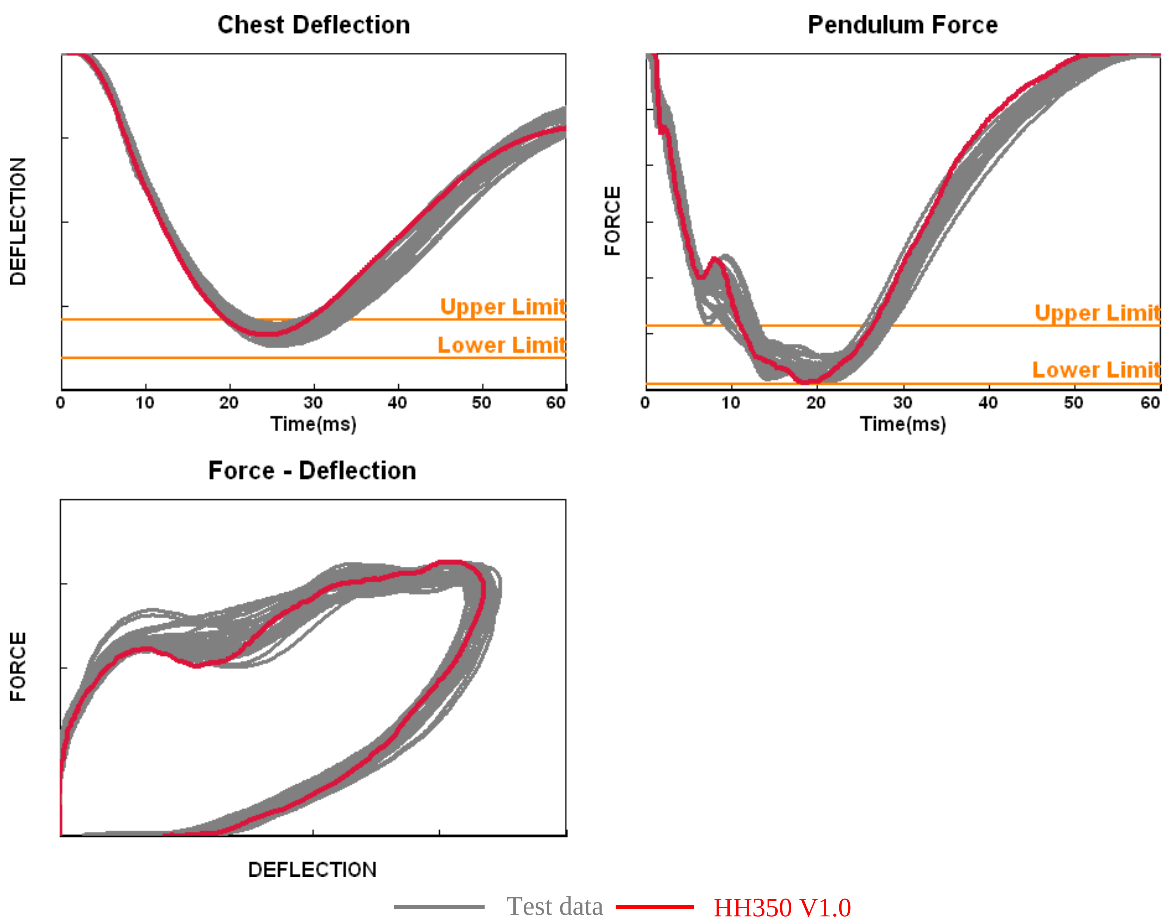


Figure 6: Full dummy thorax pendulum validation performance at 6.71 m/s

THOR-M V0.9 Model

The THOR-M model development has been carried out concurrently with the development of the dummy hardware. This has allowed the model developers to ensure that the latest hardware changes are represented in the model in the most physical way. Throughout the course of the THOR-M model development, a number of customers have been consulted to collect the requirements pertaining to the level of model detail and computational efficiency. A variety of material tests have been conducted to allow material characterization of all essential THOR-M hardware materials.

The THOR-M model V0.9 is currently being validated using the most essential certification tests and a set of key component tests. A detailed test plan containing component, sub-assembly and full dummy level validations for a wide variety of loading conditions at various levels of complexity is under way to ensure the model's predictive capabilities are as high as possible.

The total THOR-M V0.9 model element count is more than 0.6 million with a time step greater than 0.7 micro-second which is in line with the user expectations. The THOR-M V0.9 model development process is using the LS-DYNA solver version R6.1.1. Figure 7 compares the THOR-M V0.9 LS-DYNA model with its hardware counterpart.

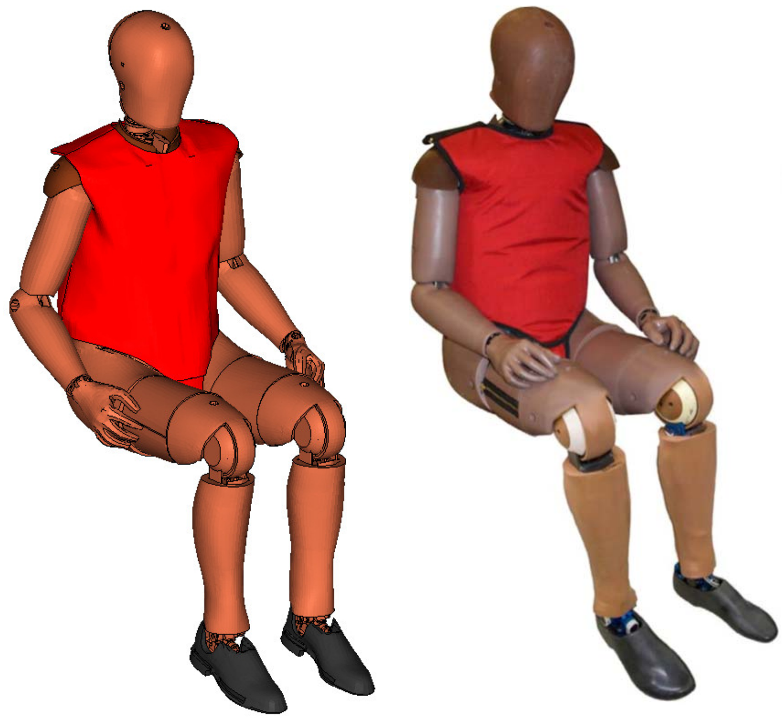


Figure 7: THOR-M: V0.9 LS-DYNA model (left) and the hardware (right)

THOR-M V0.9 neck validation case:

The THOR-M head-neck assembly consists of complex structures. The mid sagittal section of the THOR-M V0.9 model assembly is shown in Figure 8. It comprises of a series of aluminum disks and rubber pucks. The elliptical rubber pucks along with all the three cables (center, front and rear) provide the desired frontal and lateral bending responses for the neck. Fore and aft springs located in the skull and connected to front and rear cables enhance the biofidelic behavior in the THOR-M neck. The rubber soft stops (flexion and extension stops) attached at the base of the neck provide desired bending characteristics in both front and rear motion. The instrumentation for the THOR-M hardware neck assembly includes - a pair of load cells to measure the compression at the fore and aft spring locations, upper and lower neck load cells to measure the forces and moments developed at these locations, and a rotary potentiometer at the condyle pin to measure the relative rotation between the head and top of the neck. The THOR-M V0.9 LS-DYNA model captures all the structural complexity, material characteristics and instrumentation details with a high level of accuracy.

The THOR-M V0.9 neck is validated in a variety of neck loading conditions. For illustration purpose the current discussion is limited to the THOR-M neck validation for the neck flexion loading. The neck pendulum flexion test for THOR-M resembles the current test for the HIII 50th head-neck assembly. For the neck pendulum validation, a rotating pendulum arm is raised to achieve the desired initial impact velocity of 3.8 m/s before it is decelerated using the honeycomb block (Figure 9). A stepwise approach was adapted to validate the neck assembly performance considering the structural complexity of the THOR-M neck. First, only rubber materials were validated (no cables case). Next, the full neck with all the structures was validated with the same test configuration. Figure 9 shows the neck pendulum validation setup for the

THOR-M V0.9 full neck model in the frontal flexion configuration. Typical signals important in predicting the neck injury are the upper neck load-cell moment y, shear force x, and axial force z. Figures 10 and 11 show the model performance response in frontal flexion neck pendulum compared to the test data for the no cable neck and the full neck cases, respectively.

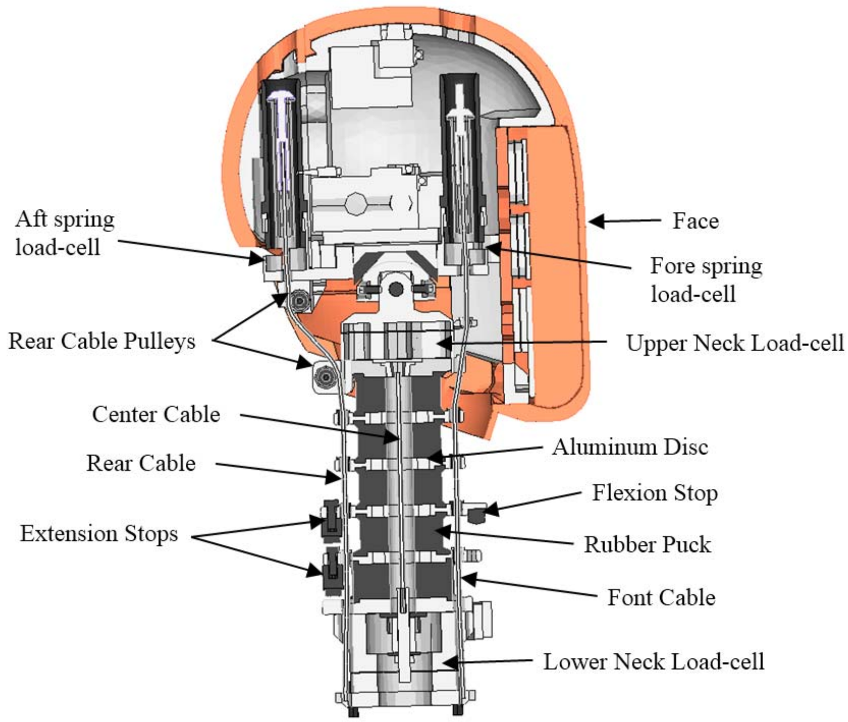


Figure 8: Mid sagittal sectional view of THOR-M V0.9 head-neck assembly

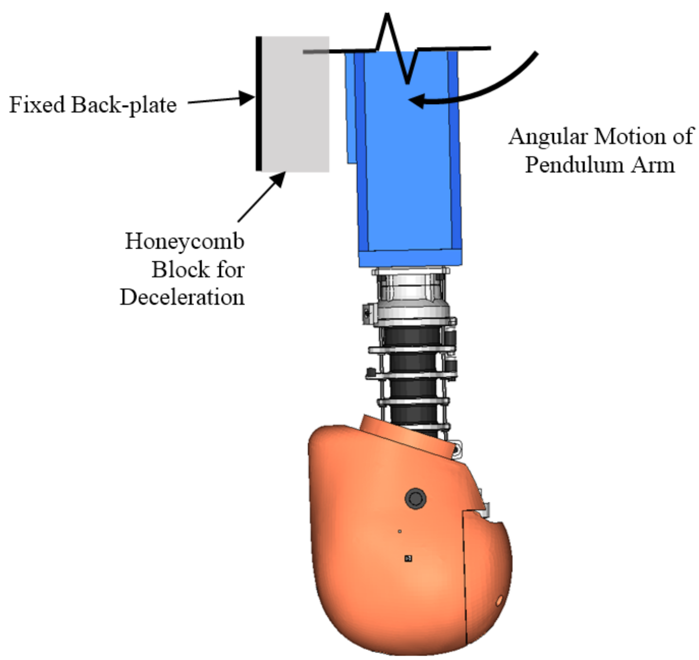


Figure 9: THOR-M V0.9 model neck pendulum validation setup for the frontal flexion

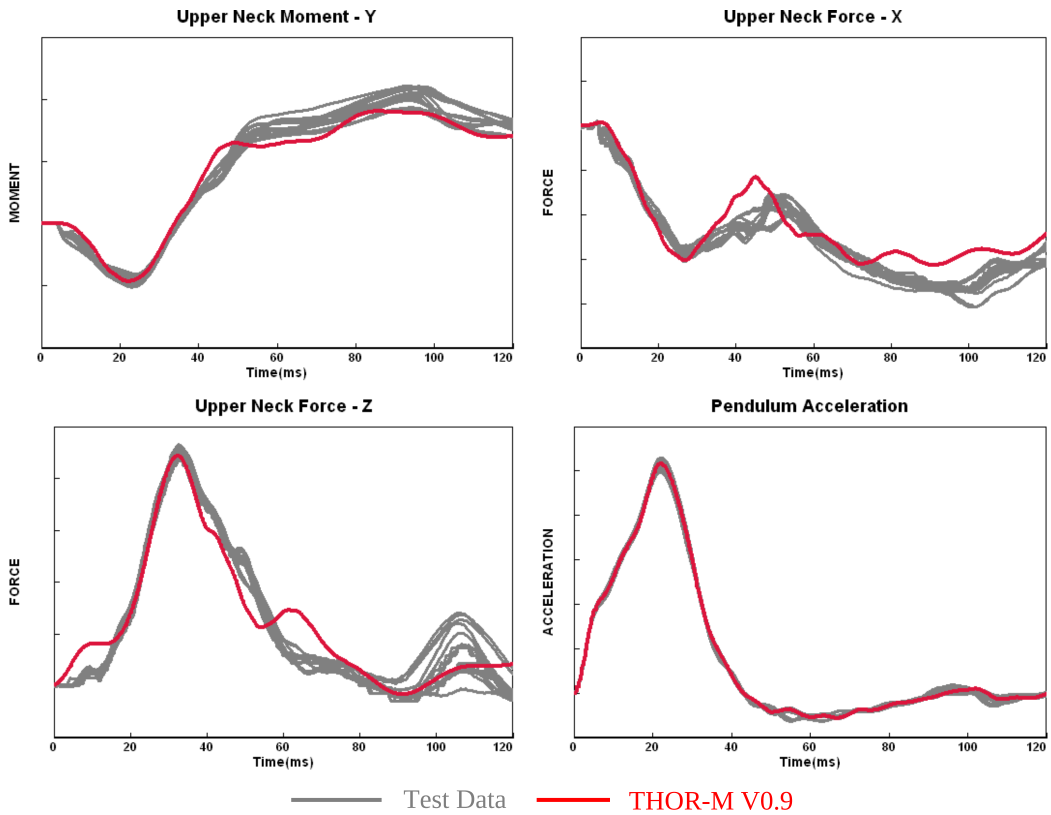


Figure 10: THOR-M V0.9 neck pendulum frontal flexion validation for the no cable case

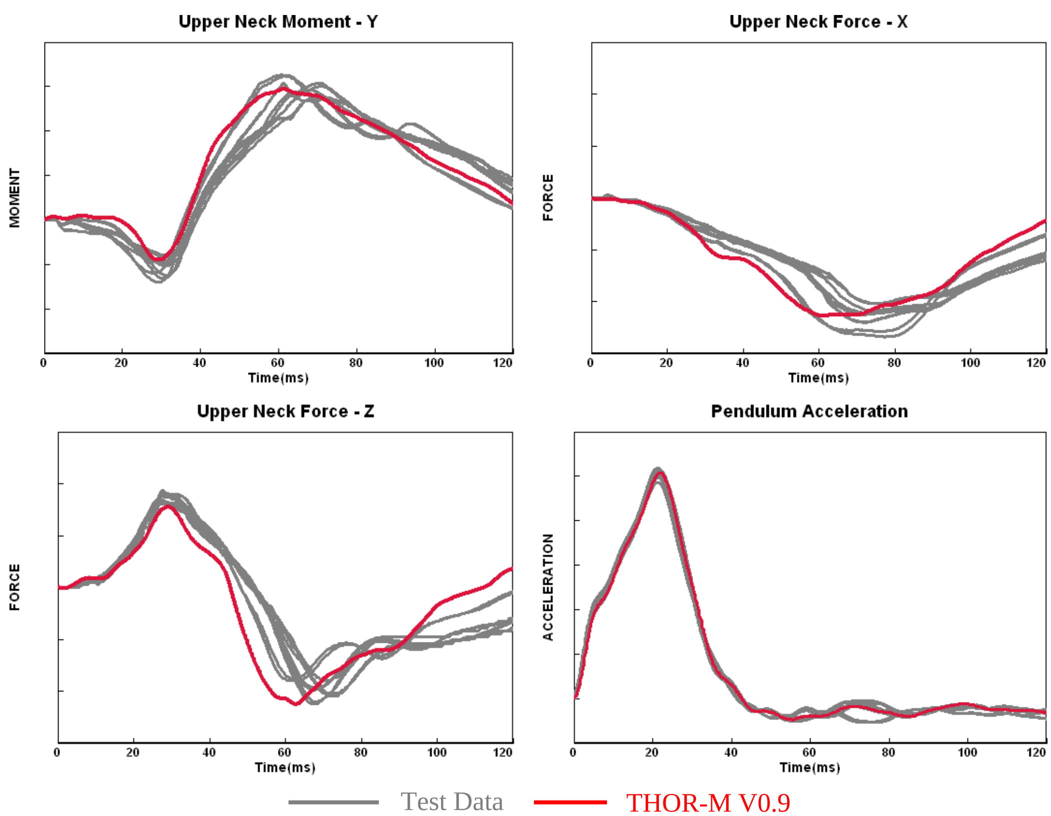


Figure 11: THOR-M V0.9 neck pendulum frontal flexion validation for the full neck case

Conclusions

The following conclusions can be drawn from the presented work:

- Very detailed Harmonized H350 (HH350) V1.0 and THOR-M V0.9 dummy models are developed using the LS-DYNA FE solver.
- All the hardware complexities of the structure, material, and instrumentation of the dummies are reasonably captured using the best possible features in the LS-DYNA.
- Both models demonstrate extremely promising predictive capabilities while computationally being very cost-effective.

References

[1] NHTSA (2011) “Traffic Safety Facts 2011 Data”, DOT HS 811 753.

[2] User’s manual (2012) “HIII 50th Percentile Dummy User’s Manual”, Humanetics Innovative Solutions, Inc., Plymouth, MI (USA).

[3] User’s Manual (2012) “Test Device for Human Occupant Restraint – Metric (THOR-M) with mod kit User’s Manual” Humanetics Innovative Solutions, Inc., Plymouth, MI (USA).