LS-DYNA® Model Development of the Harmonized Hybrid III 05F Crash Test Dummy

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Abstract

Finite Element (FE) models of Anthropomorphic Test Device (ATD) commonly known as crash test dummies have become increasingly employed in automotive safety with the underlying benefits of cost and product development cycle.

The current paper highlights the development of the harmonized Hybrid III 5th percentile (small female) dummy model referred hereafter as the "HH305 V1.0" LS-DYNA FE model. To be compliant with Euro NCAP test requirements, the model has been incorporated with the SAE harmonized jacket and meets both the lower and higher velocity thorax pendulum impact certifications.

The development of HH305 V1.0 FE model particularly focused on accuracy of the thorax performance. The thorax performance of the model was evaluated for a variety of loading conditions such as single rib drop tests, thorax pendulum impact tests and the new aggressive seatbelt pretension tests on the thorax assembly. The seatbelt pretension tests were conducted in collaboration with Ford Motor Company and aimed to improve the thorax correlation for relatively smaller chest deflection at faster rate.

The HH305 V1.0 model performance is significantly better compared to its predecessor in all the simulated thorax load-cases. The HH305 V1.0 release for the LS-DYNA FE model is commercially available to customers.

Introduction

Occupant fatalities occurred in the vehicles that sustained frontal damage to vehicle in approximately 51% of passenger cars in year 2011 [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 5th (H305) percentile dummy is one of the regulated crash test dummies based on the characteristic size and weight measurements from anthropometry studies of the small adult female [2]. Its impact response requirements for the head, neck, chest, hip, knee and ankle are extrapolated from the biofidelity requirements of the Hybrid III mid-size male dummy. The Hybrid III-5th dummy is employed as front passenger in the full width US-NCAP regulatory testing. For the Euro NCAP full width frontal testing, it is used in the first and second row passenger positions. It is being used in the second row seat for the 40% offset deformable barrier (ODB) and full width frontal tests for the China-NCAP (C-NCAP) regulatory requirements.

For more than 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 not only reduce cost and development cycle but also amount of physical testing.

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 current study describes development of the harmonized H3-5th V1.0 LS-DYNA (Livermore Software Technology Corporation) model and its performance for the selected thorax validation cases in particular the aggressive seatbelt pretension test validation.

Harmonized H3-5th V1.0 Model

Harmonization:

Humanetics Innovative Solutions, Inc. (referred hereafter as Humanetics) is formed by the merger of First Technology Safety Solutions (FTSS) and Robert A. Denton, Inc. (Denton). In order to standardize the hardware dummy and reduce the variations in the test results due to dummy brand variation, harmonization was undertaken. Table 1 below shows the selection of various components for the harmonization of the H3-5th female dummy hardware.

Table 1: Harmonization of the H3-5th dummy

Head and Neck	Upper Torso	Jacket (new design)	Lower Torso	Legs and Feet	Leg flesh	Arms	Hands
Denton	FTSS	Harmonized	FTSS	FTSS	Denton	FTSS	Denton

Although the thorax ribcage is adopted from the FTSS brand of H3-5th dummy hardware, significant portion of performance change in the harmonized thorax can be attributed to implementation of the new harmonized jacket (SAE J2921, January 2013) [3].

Figure 1 compares all the three jackets from three different brands. The harmonized jacket has completely new design and geometry compared to the FTSS and Denton brand jackets. Additionally, the structural representation and location of breast cups and materials for the harmonized jacket are entirely different from the two former brand jackets. The new SAE harmonized jacket has become the only option offered by Humanetics since mid of 2013.

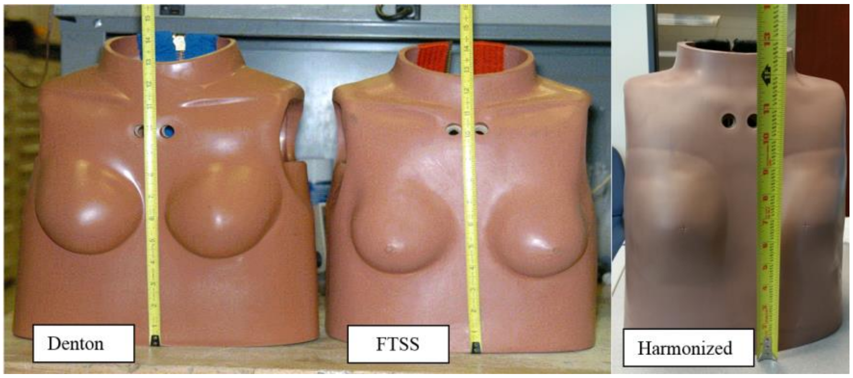


Figure 1: Comparison of different bands of jacket

Model development:

In order to assure the FE model to reflect the geometry of hardware, sophisticated 3D contouring methods, X-Ray Computed Tomography (CT) and 3D laser scanner were employed to capture details of inner and outer surfaces of flexible deformable parts, such as the jacket. Figure 2 illustrates steps of the new harmonized SAE jacket [3] modeling from the CT scan data. Jacket fit simulation was carried out to fit the jacket on the thorax model and then was verified against the laser surface data of the jacket model. All the metallic hardware structures were discretized and modeled based on available CAD data and verified against physical parts.

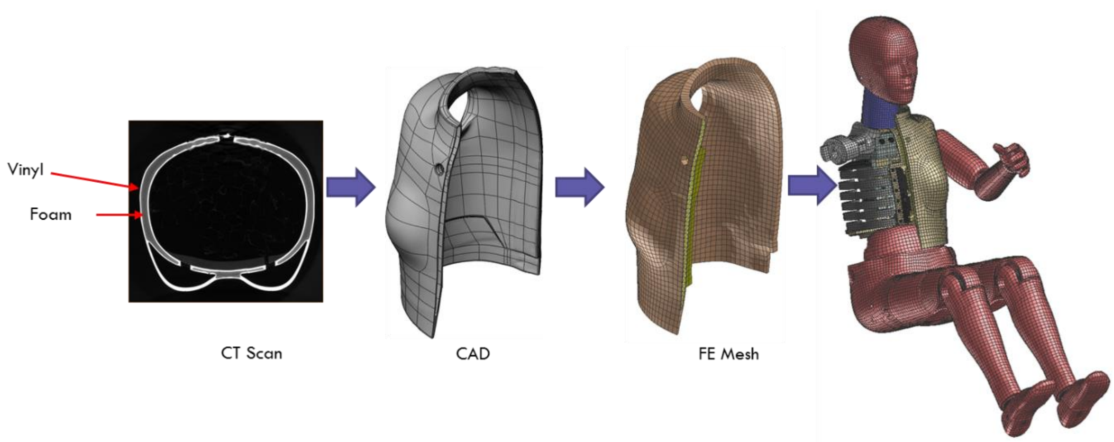


Figure 2: SAE Harmonized jacket mesh development and implementation

The HH305 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 new SAE harmonized 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 HH305 V1.0 model accurately captures all structural, geometric and instrumentation aspects of its hardware counterpart. The HH305 V1.0 model consists of 211K nodes and 186K deformable elements. The HH305 V1.0 has been tested using the LS-DYNA solver version R6.1.1 [4].

Material modeling:

The performance of HH305 V.0 model is strongly governed on the accurate representation of the nonlinear behavior of rubber, plastic, and foam materials. Material property of each deformable component were obtained from the material testing in a variety of loading modes. Material cards from the material test data were then adapted and optimized for the FE discretization and verified against coupon, component and sub-assembly level validations for the optimum performance of the model.

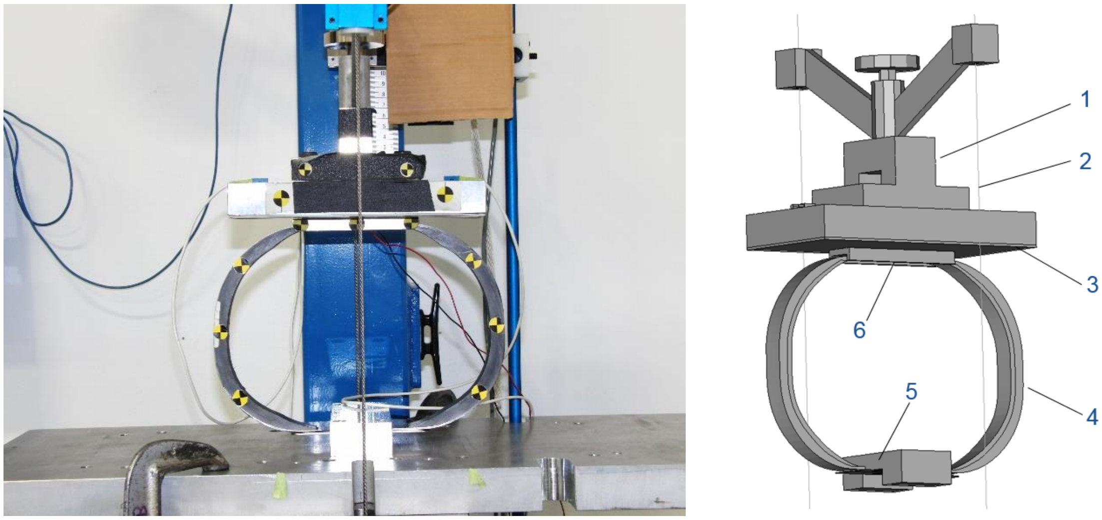
In particular for the thorax, it was found that the rib damping material plays important role in governing the performance. The rib damping material was tested under different loading speeds and modes and parameters were extracted by simultaneous fitting for different loading modes. Those parameters were then adapted and optimized to perform in a variety of thorax loading conditions. The materials in HH305 V1.0 model such as foams, rubbers, bib and ribs are modeled using the best available options from the LS-DYNA material library [4].

Validations:

The HH305 V1.0 thorax validations include single rib drop test (Figure 3), the thorax pendulum impact test (Figure 4) and the newly developed seatbelt pretension tests (Figure 5).

The single rib drop test (Figure 3) is a controlled testing for characterizing the rib damping material performance at the material level. These tests are conducted at three different speeds to capture the dynamic rate effects in the material. The drop mass was guided to compress the single rib. High speed videography was used to capture the deformation of the rib and to validate the individual rib performance. The FE model setup is also shown in Figure 3 and mimicked the test.

The HH305 thorax impact test certification involves the whole dummy except shoes. This validation characterize the global response of the dummy. Chest deflection sensor output was used to obtain the chest compression and probe acceleration to compute the impact force of the pendulum probe. The FE model was setup exactly the same way as in the test and is depicted in Figure 4.



1. Impactor; 2. Guiding cable; 3. Teflon sheet; 4. Rib; 5. Rib mounting fixture; 6. Sternum plate

Figure 3: Test setup (left) and FE model setup (right) for the single rib drop test

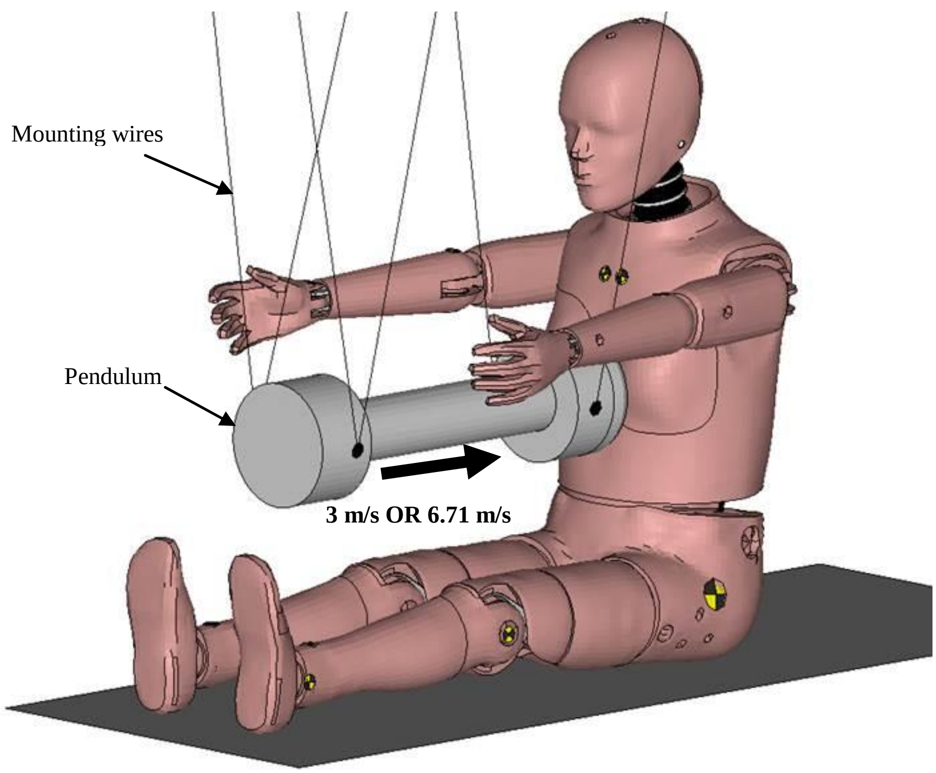


Figure 4: HH305 V1.0 model setup for the thorax pendulum impact test

The newly designed seatbelt pretension only tests, conducted in collaboration with Ford Motor Company, are introduced to enhance the performance of thorax at relatively small chest deflection and faster loading rates. Only the dummy thorax assembly was used with the spine box fixed to the test fixture. The shoulder belt was fixed at the buckle end in a typical 3-point seatbelt harness as shown in Figure 5. The seatbelt was equipped with a retractor pretensioner which was fired during the test to apply seatbelt pretension load to the dummy thorax.

Seatbelt forces were measured at three belt locations as described in Figure 5. Retractor pay in was recorded with a payout sensor and the chest deflection transducer recorded the chest deflection of the dummy. Table 2 depicts the four seatbelt pretension loading conditions achieved by combination of two different pretension levels and two different seatbelt routing. The FE model of the seatbelt pretension test mimicked the physical test as shown in Figure 5.

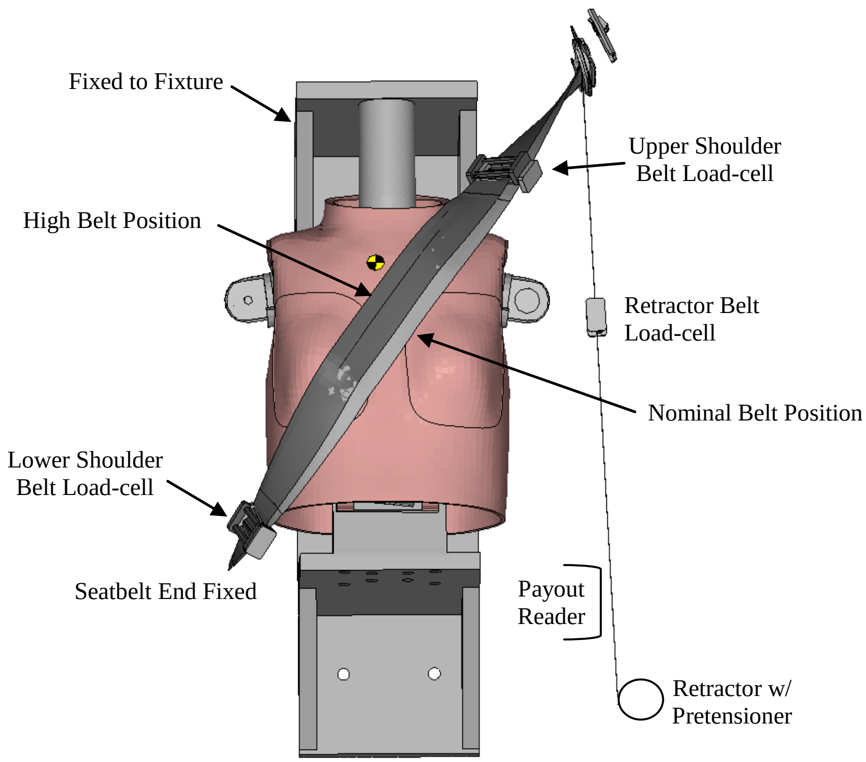


Figure 5: HH305 V1.0 model setup for the seatbelt pretension test

Table 2: Seatbelt pretension only loading conditions

Load-case	Belt Position	Pretension Level
1	Nominal	Low
2	Nominal	High
3	High	Low
4	High	High

Results

Figure 6 shows the FE results of single rib drop test compared to test at three different speeds of the drop mass: 1 m/s, 2m/s and 3m/s, respectively. The thorax pendulum impact results from HH305 V1.0 model simulation and tests are compared in Figure 7. The upper row of plots shows results for the 3 m/s impact velocity and the lower row shows results for the 6.71 m/s.

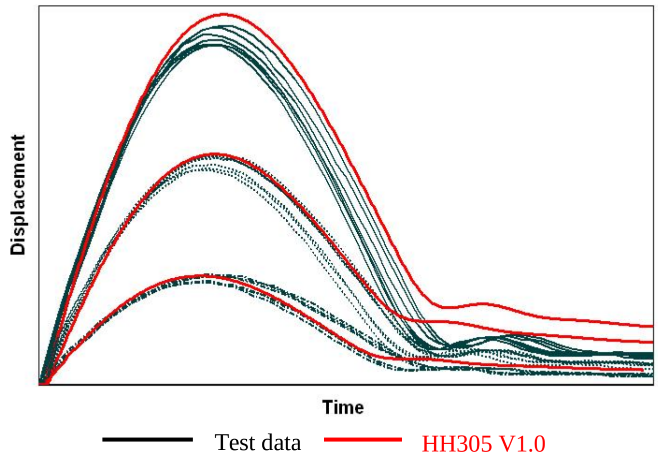


Figure 6: Single rib drop validation results

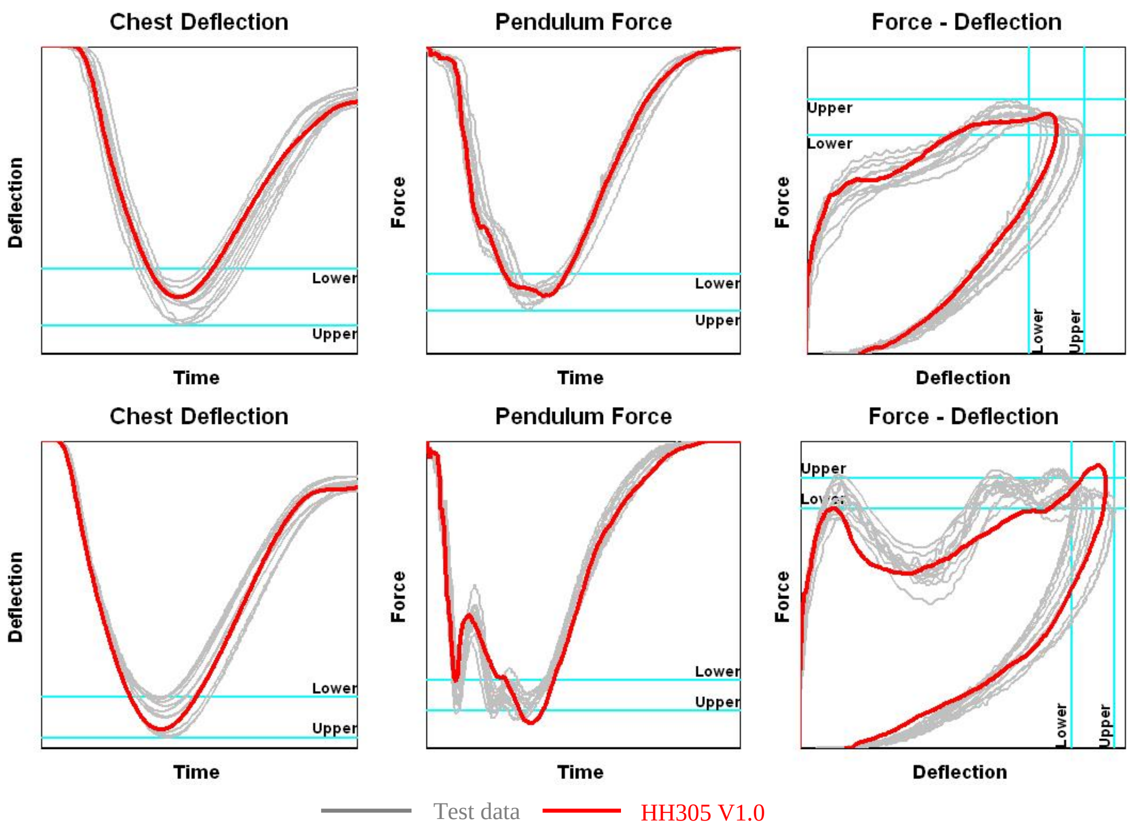


Figure 7: Thorax pendulum impact validation results at 3 m/s (top row) and 6.71 m/s (bottom row)

Figure 8 shows seatbelt pretension loading for seatbelt routing to the nominal position and low pretension level as illustration from all the four loading conditions (Table 2). Similar performance for the remaining three seatbelt pretension cases are evaluated. Figure 9 presents the chest deflections for all the four seatbelt pretension loading conditions mentioned in Table 2.

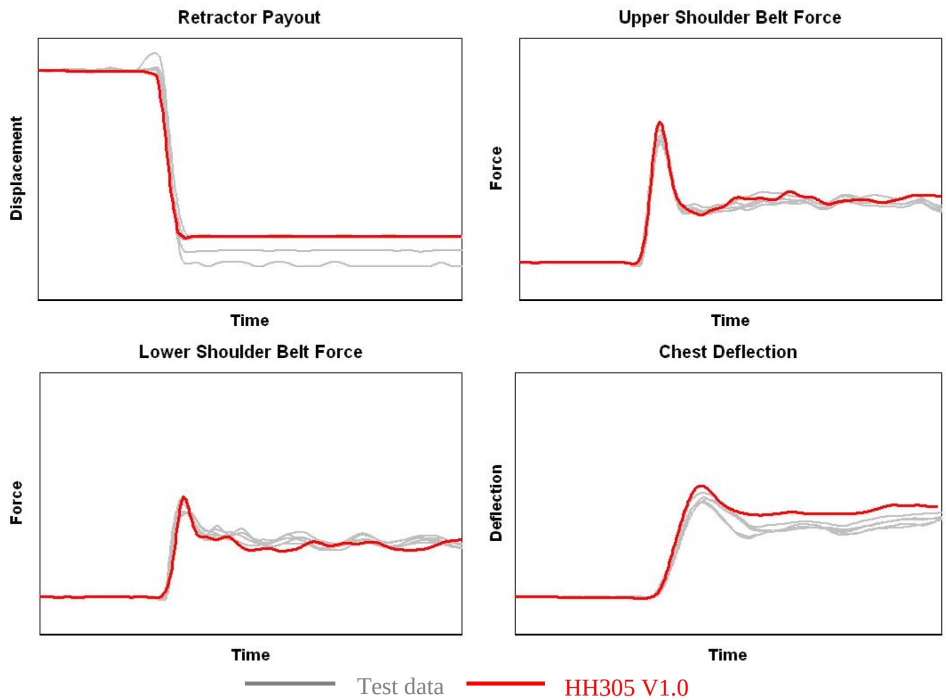


Figure 8: Seatbelt pretension validation results (Nominal belt position and low pretension level)

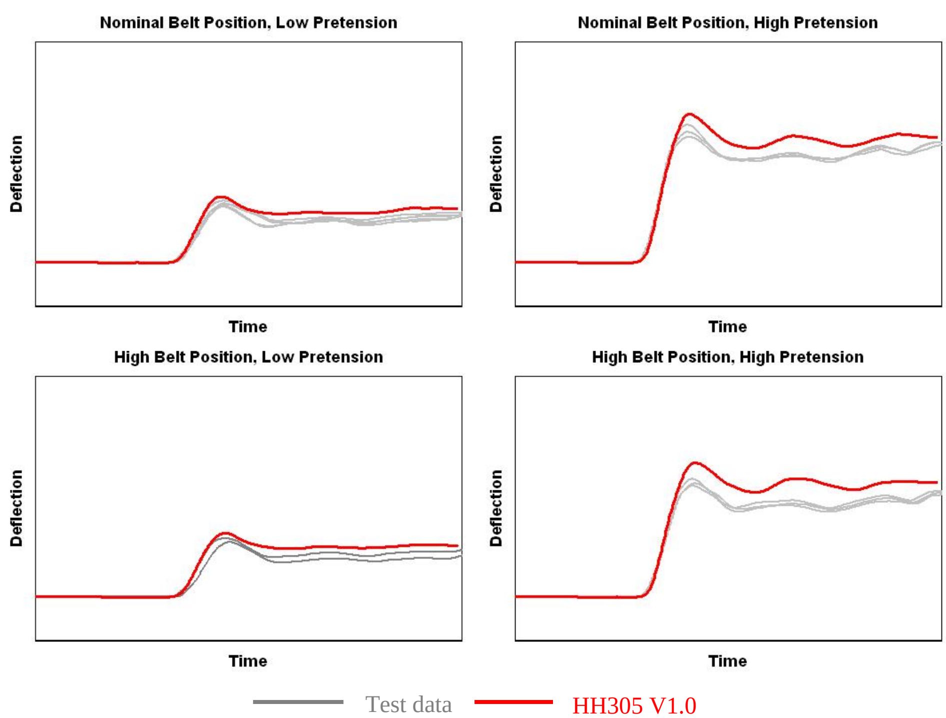


Figure 9: Chest deflections of four load cases in seatbelt pretension test

Conclusions

The following conclusions can be drawn from the presented work:

- Very detailed Harmonized H305 (HH305) V1.0 is 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.
- The new additional seatbelt tests enhanced HH305 V1.0 model predictive capabilities at more realistic loading rates.
- The HH305 model demonstrates 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) “Hybrid III 5th Female User’s Manual”, Humanetics Innovative Solutions, Inc.
[3] SAE J2921 (2013) “H-III5F Chest Jacket Harmonization”, SAE International.
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