

## LSTC / NCAC Dummy Model Development

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### Abstract

*This paper presents the modeling and validation status of the most commonly used crash test dummies in the regulatory and consumer crash test programs, the Hybrid III family of crash test dummies. Systematic modeling and validation procedures are established and adopted to ensure the accuracy, efficiency, robustness, and ease of use of the models. The procedures are based on the premise that the model must be based on the fundamentals of mechanics, focusing directly on component geometry and material mechanical properties. The dummy models are created and validated at the component level. The models are then integrated and re-evaluated at the system level. The paper presents the component and system level validation results of the HIII 50<sup>th</sup> and 5<sup>th</sup> percentile dummy models.*

### Introduction

Crash test dummies are full-scale anthropomorphic test devices (ATD) that simulate the dimensions, weight proportions and articulation of the human body. They are instrumented to record data about their dynamic behavior in simulated vehicle impacts. The recorded data is then used to assess the human injury risk for different body regions in the simulated vehicle impact. The Hybrid III ATD family [1] is widely used in the current regulatory and consumer crash test programs to rate the effectiveness of the vehicle in reducing injury risks to its occupants.

CAE led product development is a standard practice in many industries including the automotive industry. This method has proven to be efficient and cost effective over the original methods that were based solely on physical prototype testing. Detailed finite element (FE) vehicle and dummy models verified against multitude of component and full system tests are now standard in the automotive industry. Continuing development of the crash codes coupled with sophisticated crash models have helped reduce the number of prototype vehicle testing in the product development phase. This has increased the demand on the simulation tools to be truly predictive.

Due to limitations in computational speed and costs, typically only the vehicle structure was designed, analyzed and optimized using FE vehicle models. The effectiveness of the restraint system to prevent/reduce injury risks to various size occupants for the optimized vehicle structure was subsequently analyzed and optimized using detailed sub-system sled models. Recent advancements in computer hardware and improved scalability of the crash codes 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 becomes the norm, there will be increasing need for accurate, detailed and robust FE dummy models. To serve this purpose, the NCAC/GWU in collaboration with LSTC is developing a suite of highly detailed public domain LS-DYNA<sup>®</sup> FE models of the crash test

dummies. The 50<sup>th</sup> percentile male, 5<sup>th</sup> percentile female and 95<sup>th</sup> percentile male FE models belonging to the Hybrid III ATD family are currently being developed at NCAC. Other dummy models (side impact dummy models and child dummy models) are being developed by LSTC in-house. The model development methodology and current validation results of the Hybrid III 50<sup>th</sup> and 5<sup>th</sup> percentile dummy models are presented in this paper.

### Dummy Model Description

The FE model of the dummy was developed using reverse engineering methodology. 3D scans were made of the assembled dummy and also for each of the components using a Faro Laser Scan Arm (Figure 1). The scan of the assembled dummy was used as a guide to position different components of the dummy. A Co-ordinate Measuring Machine (CMM) was utilized, when needed, to obtain accurate geometry for the parts which could not be scanned using the Laser Scan Arm. 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, like in the upper extremities, was reconstructed from the 2D drawings. In some cases, decommissioned dummy parts were made available by project partners. These parts were cut open and completely disassembled to obtain geometry of the molded parts (pelvis bone and joints).

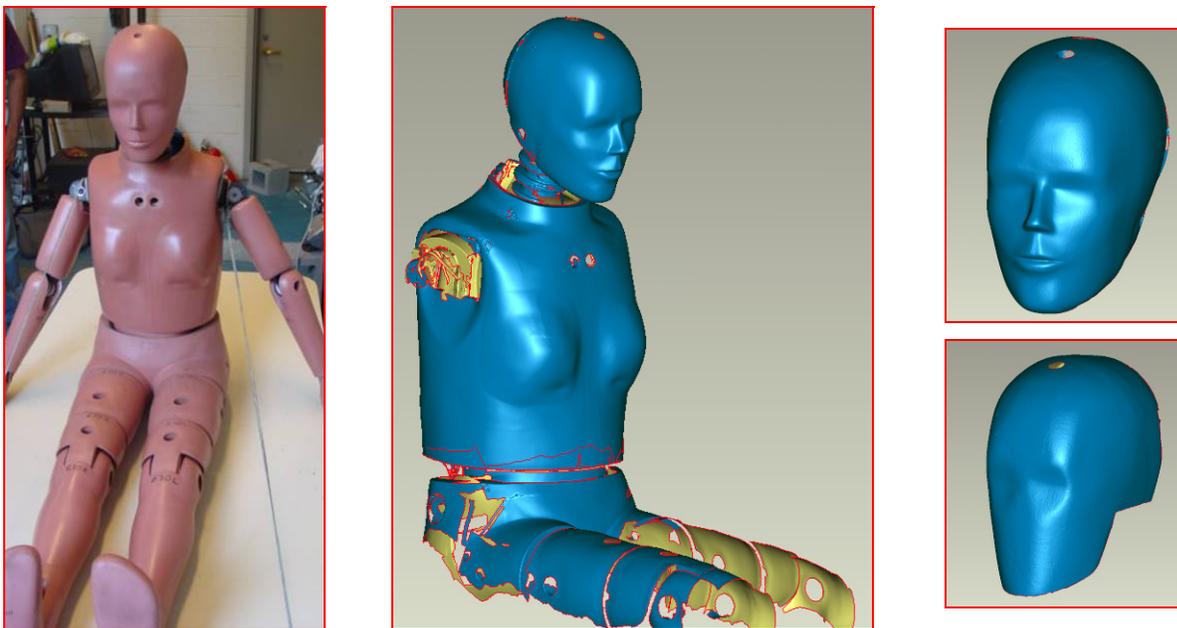


Figure 1: Hybrid III 5<sup>th</sup> percentile dummy 3D scans

Once the geometry of the dummy 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. This element size was chosen to ensure good contact interaction with the dummy surroundings (restraints and vehicle interior are also typically meshed with a 6 mm element size) during impact analysis. The dummy models consist of six main assemblies, head, neck, torso, pelvis, arms, and legs [2, 3].

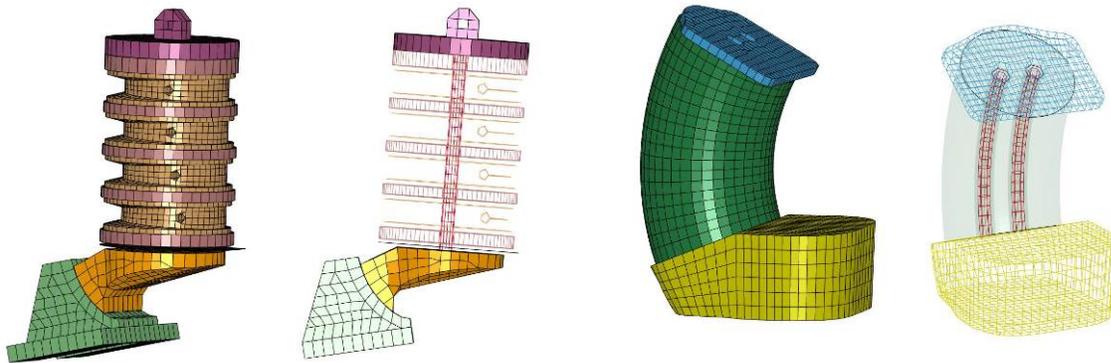
Every component in the dummy that appeared to function as a flexible body was incorporated in the model as a deformable body. Every effort was made to translate the physical dummy directly into an FE model with minimal assumptions. These FE components having accurate geometry and material properties would then closely replicate the behavior of their physical counterparts. The fully assembled FE model of the Hybrid III 50<sup>th</sup> and 5<sup>th</sup> percentile dummies is shown in Figure 2.



*Hybrid III 50<sup>th</sup> percentile FE model – 255000 elements*      *Hybrid III 5<sup>th</sup> percentile FE model – 200000 elements*

**Figure 2: FE model of the Hybrid III 50<sup>th</sup> and 5<sup>th</sup> percentile dummy**

The wire rope used in the neck and lumbar assembly for both the Hybrid III 50<sup>th</sup> (Figure 3) and 5<sup>th</sup> percentile dummy is 5/16 inch diameter (7.9 mm) 7x19 galvanized cables. These wire ropes are modeled as beam elements in the FE model. The point to note here is that the strength of the wire rope is not the same as a solid steel bar of the same diameter as represented by the beam elements. The elastic stretch in the wire rope is dependent on its "metallic cross section area". The metallic cross section area of the wire rope was calculated (based on wire rope manuals) as, diameter squared multiplied by the "independent wire rope core (IWRC)" factor. The IWRC for the 7x19 wire rope was found to be 0.466. This resulted in a metallic cross section area of 30 mm<sup>2</sup>. Hence a beam diameter of 6.18 mm was used to model the neck and lumbar cables. The elastic modulus for the beam elements was set to 96,000 Mpa (nearly half that of steel). The moment of inertias in r, s & t directions were scaled down by a factor of 10 to simulate the cable behavior.



*Hybrid III 50<sup>th</sup> percentile Neck FE model*

*Hybrid III 50<sup>th</sup> percentile Lumbar FE model*

**Figure 3: FE model of the Neck and Lumbar Assembly**

The non-deformable metal parts of the dummy, mainly the dummy skeleton, are modeled as elastic material, type 1 in LS-DYNA [4, 5]. The visco-elastic material type 6 is used to model the polyvinyl skin. The material type 7 (Blatz-ko\_rubber) is used to model some of the rubber components and material type 62 (viscous foam) is used to model the foam components. The standard dummy instrumentation (accelerometers, load cells, potentiometer) is represented in the FE model and the polarities are set according to the SAE J211 recommendation. The dummy models are assembled based on a modular approach. This approach will facilitate easier integration of assemblies between the LSTC's rigid dummy models and the new detailed models.

### Dummy Model Calibration

The FE models of the Hybrid III 50<sup>th</sup> and 5<sup>th</sup> percentile dummy were validated to Head Drop, Neck Extension and Flexion and the Thorax impact certification tests recommended in the Code of Federal Regulations under Title 49, Part 572 subpart E [3, 6]. These certification tests ensure that the response of various assemblies of the dummy fits the predefined response corridor.

**Head Drop test** - The dummy head certification test requires a free drop of the head assembly onto a rigid surface from a height of 376 mm, such that the initial contact with the rigid plate occurs at the forehead. The peak resultant head acceleration has to be within the defined biomechanical corridor based on the size of the dummy.

**Neck Extension & Flexion test** - The Neck certification test is a pendulum drop with specified length, mass and moment of inertia in the vertical plane. The head-neck assembly attaches to the lower extremity of the pendulum bar in two configurations to simulate extension and flexion motions, respectively. The pendulum impact energy is absorbed by an aluminum honeycomb block which decelerates the pendulum to pre-defined ranges for extension and flexion, respectively. A load cell is mounted at the head-neck joint to measure the moment-time response about the lateral axis through the occipital condyle. The head rotation is measured by the rotation of "D" plane (horizontal surface at the base of the skull) rotation with respect to the pendulum's longitudinal centerline. The "D" plane angle and the moment measured at the occipital condyle have to be within the defined biomechanical corridor based on the size of the dummy.

**Thorax Impact test** - The dummy is seated on a flat bench with its upper and lower legs horizontal to the bench surface. The thorax is subjected to an impact using a pendulum. The centerline of the pendulum is lined up with the centerline of the 3<sup>rd</sup> rib. The sternum displacement measured relative to the spine and the peak resistive force (mass of the pendulum x acceleration) should be within the defined biomechanical corridor based on the size of the dummy.

The current model validation results for the Hybrid III 50<sup>th</sup> and 5<sup>th</sup> percentile dummies are shown in Appendix. The dummy models are undergoing massive testing and are in a state of continuous improvement. The paper reflects the status of model validation at the time of submission for printing (Mar 31, 2010). When all testing and calibration is complete, a final validation report will be provided along with the dummy model.

### AORC Sled Test Validation

The Automotive Occupant Restraints Council (AORC) System Performance and Numerical Analysis (SPNA) committee consists of representatives from the following companies Autoliv, Key Safety Systems, Takata, Toyoda Gosei & TRW. With the support of the AORC organization, the SPNA committee is developing advanced and common tools of operation which will be beneficial to its members in the long run and yet, reduce the cost of such development for each organization. One of the goals the SPNA committee set in 2008 was to verify the quality and efficiency of some of the occupant related CAE tools generally used for analysis, including the dummy FE models. The broader objective was to encourage the improvement of the various engineering software and dummy models through this scrutiny. LSTC welcomed the committee's idea and is supporting their effort to evaluate the LSTC tools and dummies.

In order to generate data for model validation, the SPNA committee has conducted a series of controlled sled tests at Wichita State University, Kansas. In order to reduce test-to-test variability, the seat foam, knee-bolsters and airbags were not included in the tests (Figure 4). These sled tests were conducted with only a belted occupant with an energy managing retractor (EMR). The force level of the EMR was reduced for the 25mph sled pulse tests.

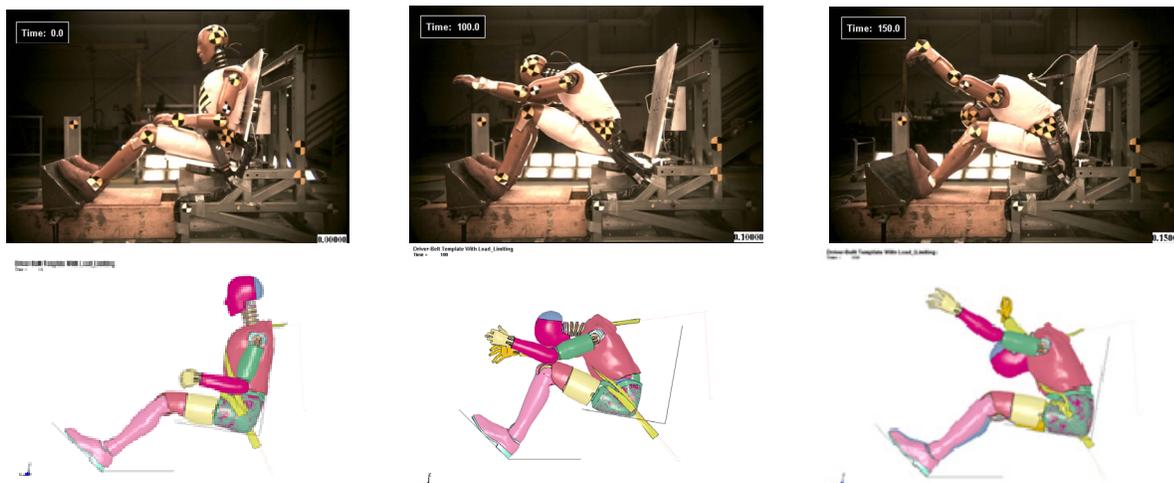


Figure 4: AORC Sled Test Set-up

The sled series consisted of the following tests:

1. Hybrid III 50<sup>th</sup> percentile - 35mph sled pulse (3 Tests)
2. Hybrid III 50<sup>th</sup> percentile - 25mph sled pulse (3 Tests)
3. Hybrid III 5<sup>th</sup> percentile - 35mph sled pulse (3 Tests)
4. Hybrid III 5<sup>th</sup> percentile - 25mph sled pulse (3 Tests)

Each of the test series was consistent with respect to the dummy & seatbelt responses. In this paper the model validation results for the first AORC test series (35 mph sled pulse) with the Hybrid III 50<sup>th</sup> percentile dummy are presented. The dummy kinematics comparison between the sled test and the simulation is shown in Figure 5. The vastly improved version of the Alpha release (June 2009 - LSTC.NCAC\_H3\_50th.090616\_Alpha.zip) dummy model was used in this study. One of the primary areas of improvement has been the Thorax. The thorax calibration is shown in Figure 20 (Appendix: Dummy Calibration - Hybrid III 50th Percentile). Other areas that have been improved are the upper neck and the limb joints. A Beta version of this dummy with all of these improvements will be released soon.



**Figure 5: Hybrid III 50<sup>th</sup> Percentile Dummy Kinematics Comparison**

The time history response of the various channels of data between the test and simulation are shown in Figures 6 through 17. The CAE model showed good correlation to majority of the channels except for the upper neck moment. The thorax deflection and resultant acceleration matched well both in magnitude and timing. The pelvis resultant acceleration and the left and right femur forces also showed good correlation. The shoulder and lap belts showed similar trends in the CAE model but the magnitude was little bit lower than the test results. The LSTC\_NCAC dummy models are in a state of continuous development. The upper neck will be revisited and the response will be improved in future releases.

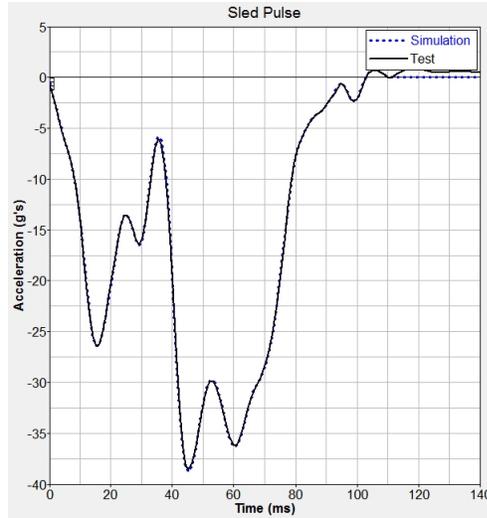


Figure 6: Test and Simulation Sled Pulse

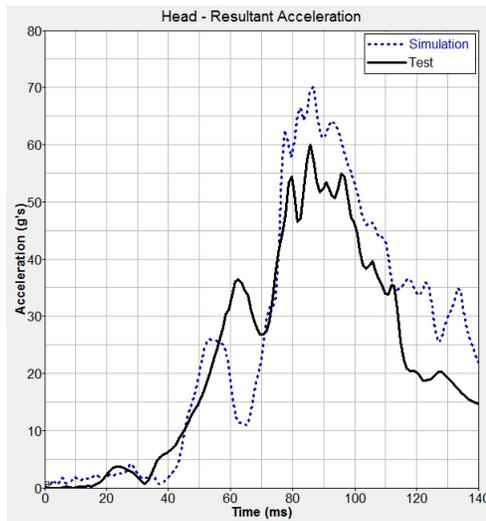


Figure 7: Head Resultant Acceleration

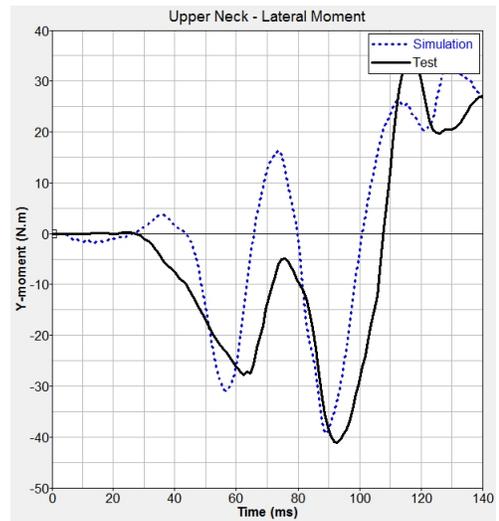


Figure 8: Upper Neck Moment

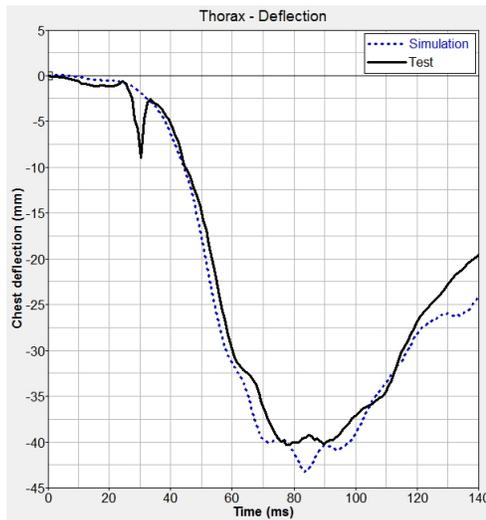


Figure 9: Thorax Deflection

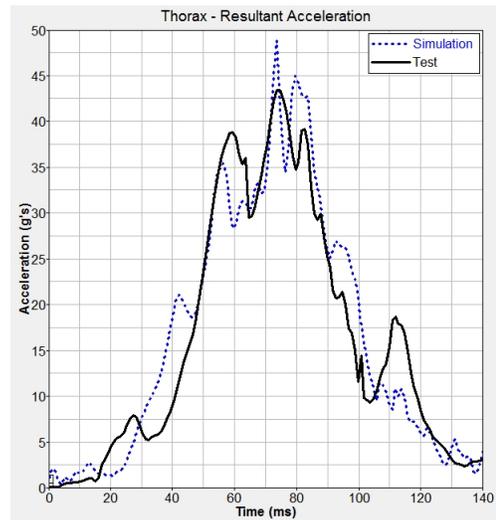


Figure 10: Thorax Resultant Acceleration

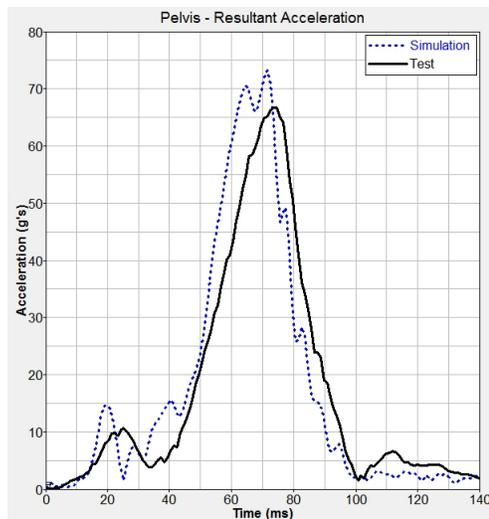


Figure 11: Pelvis Resultant Acceleration

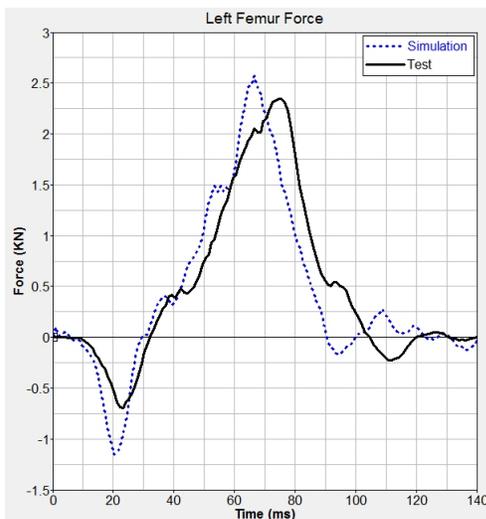


Figure 12: Left Femur Force

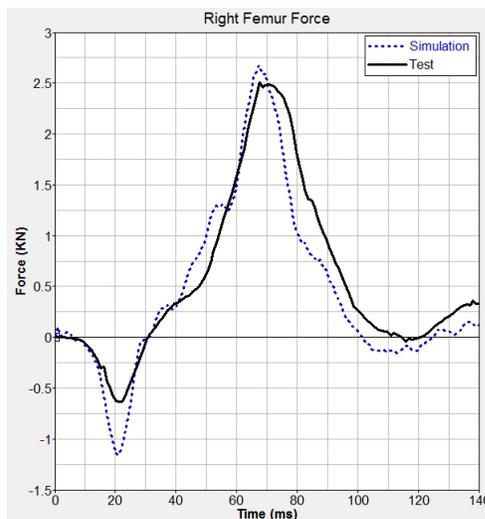


Figure 13: Right Femur Force

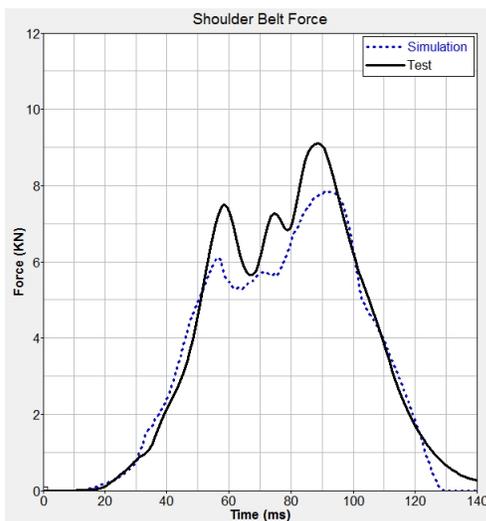


Figure 14: Shoulder Belt Force

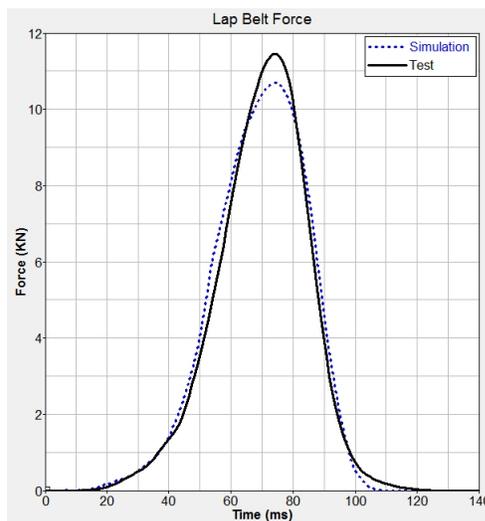


Figure 15: Lap Belt Force

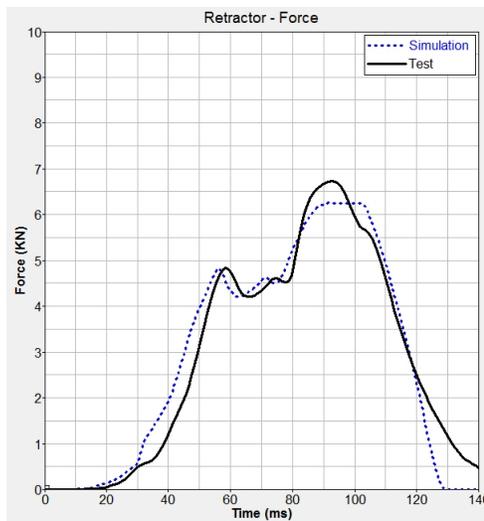


Figure 16: Retractor Force

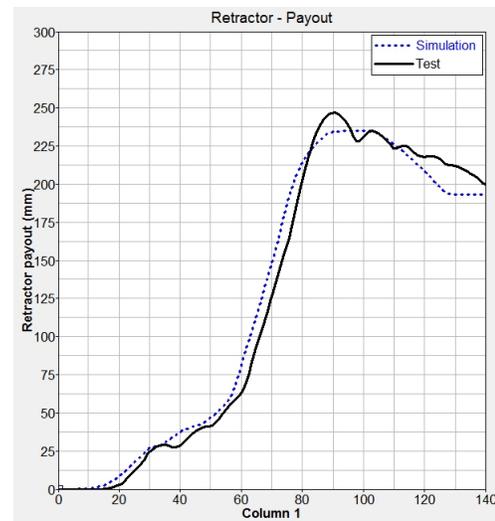


Figure 17: Retractor Payout

## Summary

The current status of the Hybrid III 50<sup>th</sup> and 5<sup>th</sup> percentile dummy model development and validation is presented in this paper. Material parameters were optimized by requiring the model response to match corresponding experimental data, mainly the certification tests. The dummy models show reasonable correlation to the calibration tests. In addition, the Hybrid III 50<sup>th</sup> percentile dummy was validated to a sled test. The simulation results show good correlation to the sled test. The LSTC\_NCAC dummy models are in a state of continuous improvement. The beta release of these dummy models will be publicly available later this year.

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- AORC for taking the step to conduct controlled sled tests at WSU and providing access to the test results. We would like to thank Dr. Olivares and Luis Manuel Gomez Valbuena of WSU for taking the time to answer our many questions related to interpretation of test data.
- AUTOLIV of Auburn Hills, Michigan, USA – We would like to thank Russ Morris and Fred Shokoohi for welcoming us to their site and giving access to the dummy laboratory whenever we had the need to check anything.
- Mazda of Japan for their valuable feedback in this development effort. Special thanks go out to Ueno Masaki-san and Asahi Ryusuke-san for going through the details of the dummy, pointing out potential problem areas and even conducting tests in their laboratories to improve these models.
- Last but not the least, special thanks to all the users worldwide for using LSTC dummy models and for any feedback that an individual might have given us.

**References**

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3. Pradeep Mohan, Dhafer Marzougui, Steve Kan, “Development and Validation of Hybrid III Crash Test Dummy”, SAE Paper No 2009-01-0473, Detroit, 2009.
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6. [http://www.access.gpo.gov/nara/cfr/waisidx\\_02/49cfr572\\_02.html](http://www.access.gpo.gov/nara/cfr/waisidx_02/49cfr572_02.html)
7. Product Validation Report, Dummy Serial Number 516, First Technology Safety Systems, June 2007.
8. T B Khalil & T C Lin, “Simulation of the Hybrid III Dummy Response to Impact by Nonlinear Finite Element Analysis”, SAE Paper No 942227.

Appendix

Dummy Calibration - Hybrid III 50<sup>th</sup> Percentile

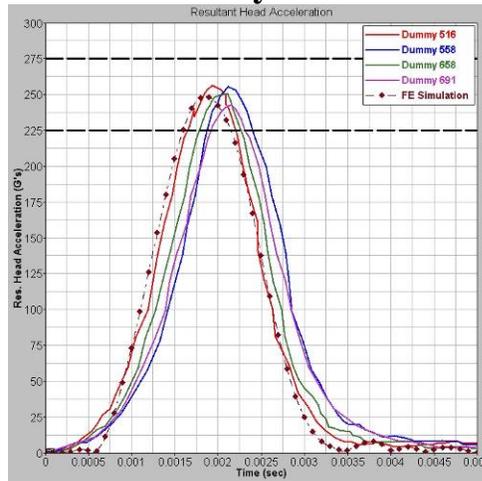


Figure 18: Head Assembly Validation Results

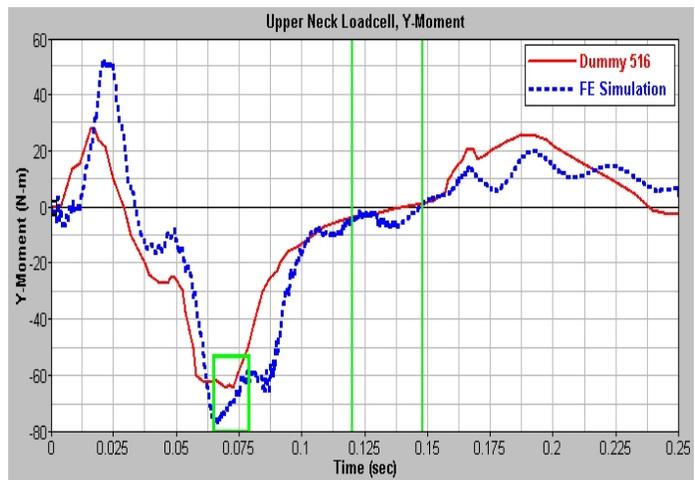
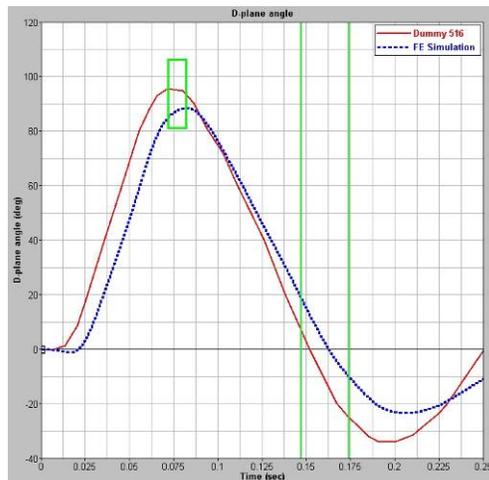


Figure 19: Head & Neck Assembly Extension

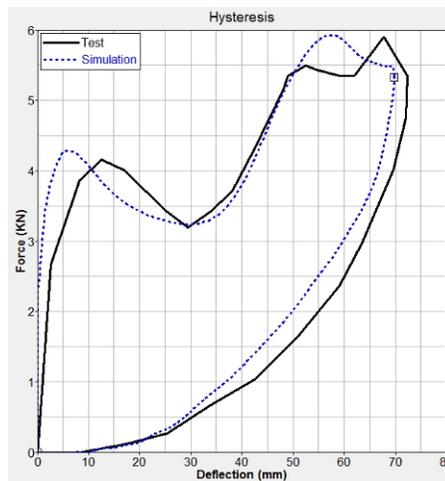


Figure 20: Thorax Calibration

### Dummy Calibration - Hybrid III 5<sup>th</sup> Percentile

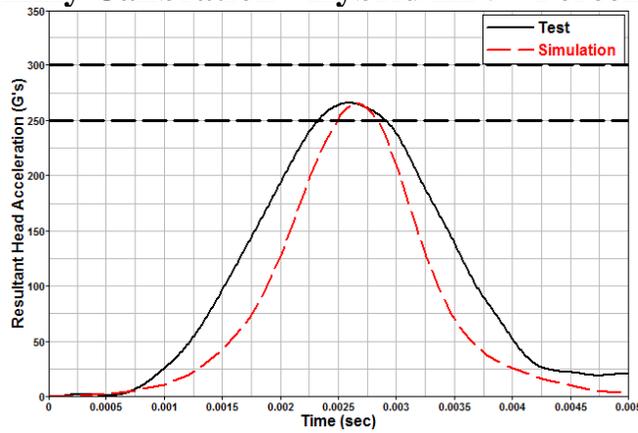


Figure 21: Head Assembly Validation Results

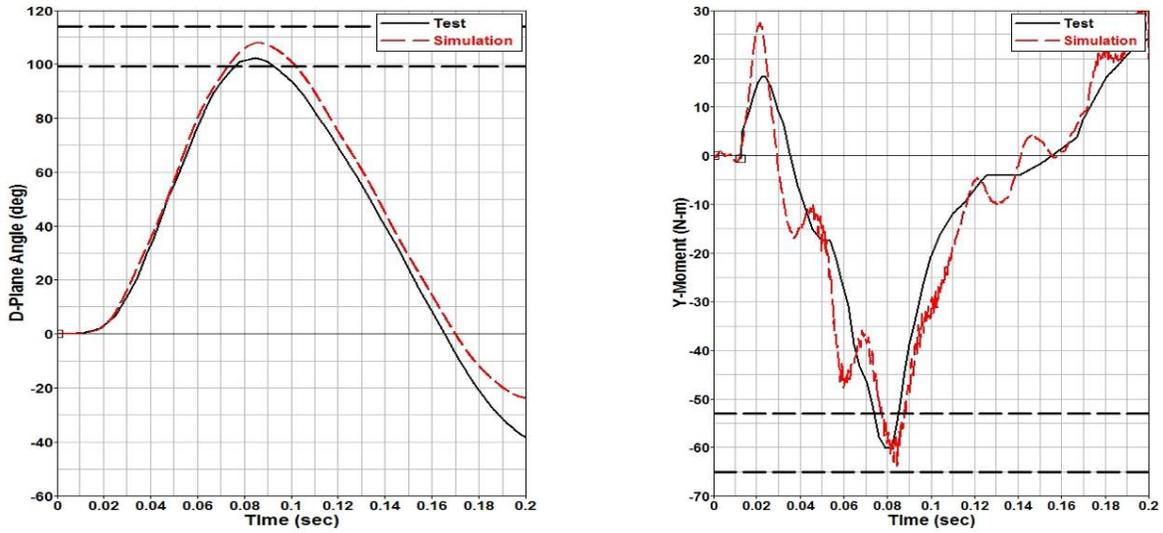


Figure 22: Head & Neck Assembly Extension

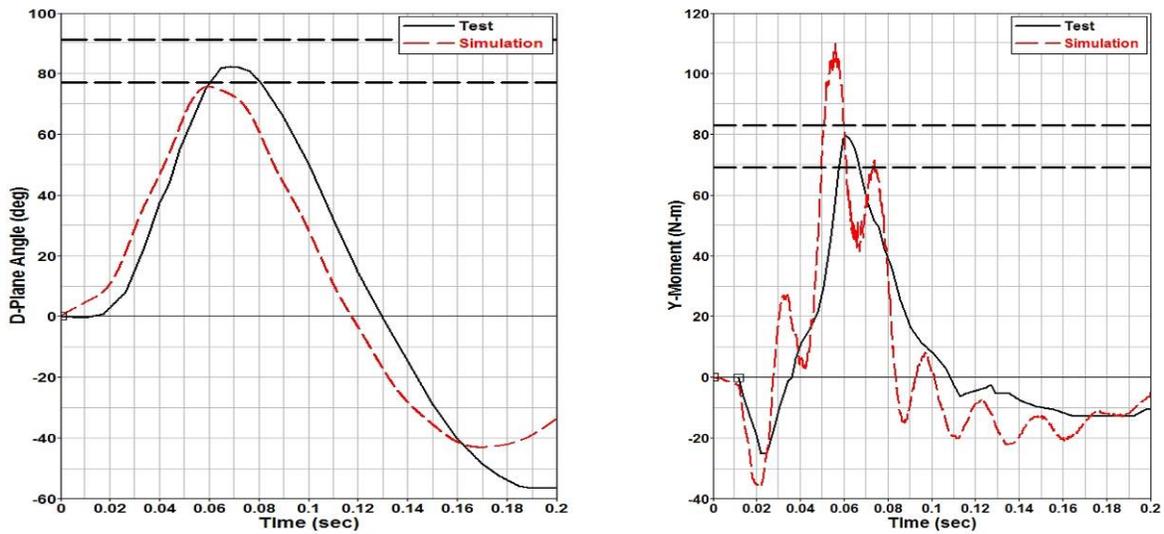


Figure 23: Head & Neck Assembly Flexion