Near Side Impact: Experience with Ansys Hans M50 - Human Body Model

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1 Introduction

Automotive safety testing has undergone a remarkable evolution since its beginning in the mid-20th century. Prior to the development of standardized anthropomorphic test devices (ATDs), commonly known as crash test dummies, safety evaluation relied on methods including cadaver testing, animal subjects, and volunteer studies under limited impact conditions [1].
The first purpose-built crash test dummy, Sierra Sam, was developed in 1949 by Sierra Engineering Co. for the United States Air Force to test aircraft ejection seats and restraint systems [2]. This pioneering effort laid the groundwork for automotive-specific ATDs, with General Motors introducing the Hybrid I dummy in 1971 [3]. The evolution continued with increasingly sophisticated designs: Hybrid II (1972), which offered improved durability, and the Hybrid III family (1976), which remains an industry standard for frontal impact testing [4].
Side impact protection emerged as a critical safety concern in the 1980s, as epidemiological data revealed the severity of lateral collisions. Early side impact dummies such as the SID (Side Impact Dummy) developed by the National Highway Traffic Safety Administration (NHTSA) and the EuroSID developed in Europe had significant limitations in biofidelity and measurement capabilities [5]. These limitations prompted an international collaboration to develop a more advanced side impact dummy.

1.1 Development of the WorldSID-50M

The WorldSID-50M represents a significant advancement in side impact dummy technology, developed through an international collaboration beginning in 1997. The WorldSID Task Group, comprising representatives from government agencies, automotive manufacturers, and research institutions across North America, Europe, and Asia, sought to create a single global standard for side impact testing.
The WorldSID-50M, representing a 50th percentile male, introduced several innovative features that distinguished it from previous side impact dummies [6]:

- An advanced shoulder design with improved range of motion and load sensitivity
- A more realistic thorax with ribs that better represent human thoracic deflection patterns
- A multi-segment abdominal insert with improved biofidelity
- A lumbar spine capable of realistic lateral bending
- A pelvis design with humanlike iliac wing geometry

Extensive validation testing against post-mortem human subject (PMHS) data demonstrated that the WorldSID-50M achieved significantly higher biofidelity ratings compared to its predecessors [7]. The dummy was subsequently incorporated into testing protocols, including Euro NCAP side impact assessment in 2015, representing a standardized physical model for safety evaluation [8].

1.2 Evolution of Computational Human Models

While physical ATDs continue to serve as regulatory tools, computational simulation has emerged as a powerful complement to physical testing. The development of Human Body Models (HBMs) represents a paradigm shift in safety assessment methodology, offering important insights into injury mechanisms at the tissue level [9].

The development of computational human body models has paralleled advancements in computing technology and numerical methods. Early models in the 1980s utilized multibody dynamics approaches, representing the human body as a series of rigid segments connected by simplified joints [10]. While computationally efficient, these models lacked the anatomical detail necessary to predict tissue-level responses.
Finite element (FE) human body modelling began in earnest during the 1990s, with pioneering work by researchers at Wayne State University who developed detailed models of the human head for impact

simulation [11]. As computational resources expanded, whole-body FE models emerged with increasing levels of anatomical detail.

The evolution of HBMs has been enabled by several technological advancements:

1. **Enhanced Anatomical Fidelity**: Modern imaging techniques, including computed tomography (CT) and magnetic resonance imaging (MRI), have enabled the development of highly detailed anatomical representations. Models now incorporate hundreds of distinct anatomical structures with appropriate geometric relationships [12].
2. **Advanced Material Modelling**: Sophisticated constitutive models have been developed to represent the complex mechanical behaviour of biological tissues, including viscoelasticity, anisotropy, and strain-rate sensitivity. These models are calibrated using experimental data from tissue testing [13].
3. **Active Musculature**: Recent HBM developments have incorporated active musculature using control systems that simulate reflexive and voluntary muscle activation, allowing for more realistic pre-crash positioning and bracing responses [14].
4. **Personalization Capabilities**: Tools for morphing standard HBMs to represent specific anthropometries have enabled studies of population variability and vulnerable populations .

1.3 Motivation and Research questions

The question of which approach, physical ATDs or computational HBMs, provides superior biofidelity requires consideration. Both methodologies present distinct advantages and limitations in representing human response to impact.

Fundamental differences between ATDs and HBMs affect their response characteristics:

1. **Anatomical Simplification**: Physical ATDs necessarily simplify human anatomy for practical instrumentation and durability. While the WorldSID-50M represents a significant advancement with approximately 80 channels of instrumentation, it cannot match the thousands of output variables available in HBMs.
2. **Tissue Representation**: ATDs utilize engineered materials (steel, aluminium, rubber, vinyl) with properties optimized for durability and measurement rather than human tissue simulation. HBMs implement sophisticated material models based on actual tissue properties, allowing for more realistic deformation patterns [15].
3. **Kinematic Constraints**: ATD designs incorporate joint stops and simplified articulations that limit motion to prevent damage to the device. HBMs model anatomical joint structures with realistic ligamentous constraints and contact definitions, resulting in more natural kinematics, particularly in the spine and extremities [16].
4. **Regional Biofidelity**: Both ATDs and HBMs show varying levels of biofidelity across different body regions. The WorldSID-50M demonstrates excellent shoulder and thoracic response but has limitations in head-neck kinematics and extremity interactions. HBMs typically excel in spine kinematics but may have limitations in soft tissue interactions depending on model complexity [17].

This study examines ATD and HBM performance in near side impact evaluating linear and angular acceleration and consequently also DAMAGE [18]. By comparing responses between an industry-standard crash test dummy model and an anatomically detailed human body model with varying levels of biofidelity, we compare the tools available for injury prediction and evaluation of restraint and vehicle performance.

2 Model and Methods

2.1 Simulation Environment

To promote research reproducibility and accessibility, an open-source Honda Accord model was selected as the baseline vehicle platform for this study. The simulation methodology followed a two-stage approach. First, the complete vehicle model underwent an Advanced European Mobile Deformable Barrier (AE-MDB) lateral impact simulation to generate structural deformation patterns [19].

These deformations were subsequently extracted and applied as boundary conditions for the occupant simulations.

In the second stage, the vehicle model was reduced to simpler Body-in-White (BiW) components relevant to lateral impact scenarios, significantly reducing computational expense while maintaining mechanical response fidelity (Figure 1).

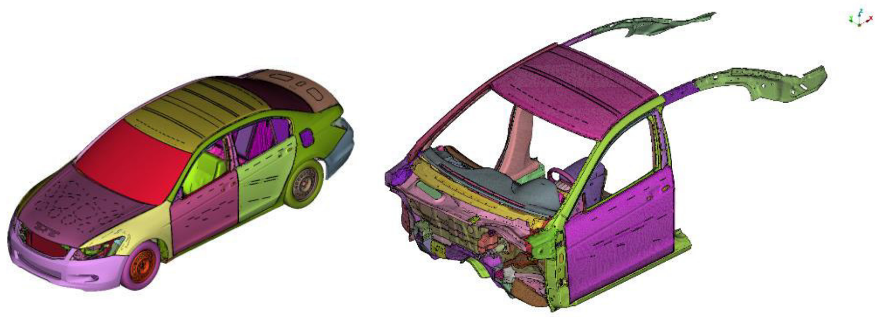

Figure 1: Honda Accord Open-Source Model implementation showing complete vehicle (left) and reduced BiW configuration (right).

2.2 Restraint System Configuration

Since the baseline vehicle model lacked side airbag systems, a foam structure (density: 3×10^{-8} kg/mm^3) was implemented to simulate the mechanical effect of a deployed side airbag. This approach was necessary to prevent computational instabilities in the WorldSID-50M model, which exhibited thoracic rib collapse and negative volume errors without this support structure (Figure 2).

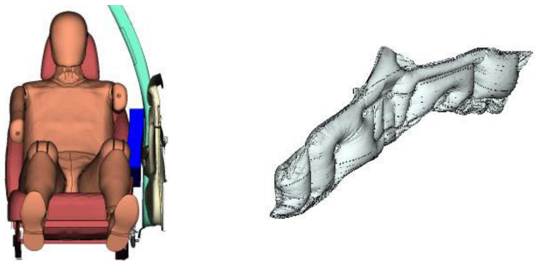

Figure 2: Restraint system configuration implemented in the simulation environment.

The restraint systems were parameterized with the following specifications:
- Curtain airbag deployment timing: 7 ms
- Seatbelt pre-tensioner force: 20 N
- Primary load limiter: 3 kN activation at 8 ms with 1000 mm payout distance
- Secondary load limiter: 10 kN threshold

2.3 Seat Model Implementation

The study incorporated the validated open-source driver seat model from Project VIRTUAL [20], which replicates a Toyota Auris (2010-2012) front passenger seat (Figure 3). This standardized seat model was selected based on three key criteria: comprehensive documentation, public accessibility, and robust validation against physical test data. All simulations maintained consistent seat geometry with a 25° seatback angle to ensure methodological consistency and comparative validity.

Figure 3: Validated seat model from Project VIRTUAL.

2.4 Impact Configuration

The near-side impact simulations replicated Euro NCAP AE-MDB test procedures, featuring a moving deformable barrier impacting the target vehicle at 50 km/h with a 90° angle of incidence. The simulated occupant, either a WorldSID-50M ATD or HBM, was positioned in the driver seat adjusted to mid-track position with a 25° seatback angle. No side airbag deployment mechanics were modelled; instead, a pre-deployed foam structure represented the final airbag state.

2.5 Occupant Models

Two different occupant surrogates were evaluated in this study:

- **WorldSID-50M:** Industry-standard 50th percentile male side impact test dummy implemented across major automotive safety assessment protocols,
- **Hans-M50-v1.21:** An average-sized male model developed by DYNAmore GmbH (an ANSYS Company) with standing and seated configurations.

2.5.1 Positioning Methodology

A standardized positioning protocol was implemented to minimize variability between occupant models. The WorldSID-50M was initially positioned according to Euro NCAP side impact testing protocols [21], establishing the reference configuration. Hans-M50-v1.21 was subsequently positioned to match the WorldSID-50M's head center of gravity and H-point coordinates as closely as possible, using Oasis Primer pre-processing software.
The Marionette positioning method was employed both models, utilizing tension cables with model-specific parameters:

- WorldSID-50M: 4000 N cable force, 0.1 cable damping, 20 global damping
- Hans-M50-v1.21: 500 N cable force, 50 damping

These parameters demonstrated stable and realistic behaviour in pre-simulation testing. Pre-simulation computational times varied significantly: 3.4 hours for WorldSID-50M, and approximately 7 hours for the Hans-M50-v1.21.

Ladmark / Model	WorldSID-50M	Hans-M50-v1.21
Head CoG	x: 2528 y: -396 z: 1138.3	x: 2521 y: -392 z: 1148
H-point	x: 2332.2 y: -396 z: 475.6	x: 2332 y: -396 z: 475

Table 1: Head centre of gravity (CoG) and H-point coordinates of both models (mm)

Hand positioning differed between model types: Hans-M50-v1.21 hands were positioned on the steering wheel, while the WorldSID-50M's arm was positioned at a 90° angle to represent the intended position following side airbag deployment (Figure 4).

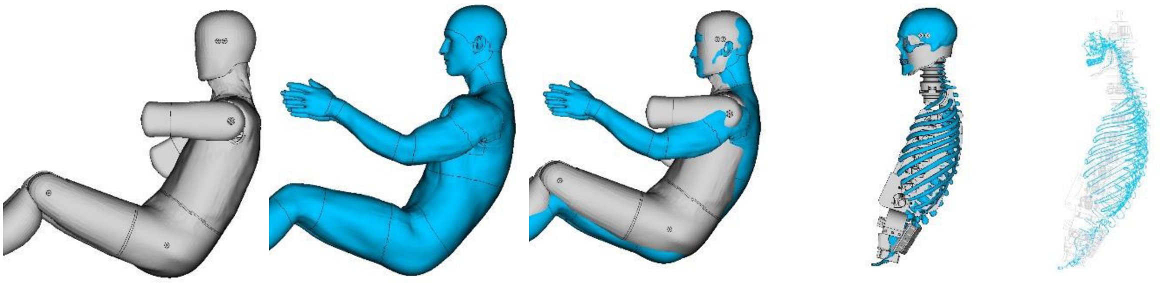

Figure 4: ATD: Grey - WorldSID-50M, Blue - HANS-AM50-v1.21

2.6 Simulation Parameters

WS simulation was executed using LS-DYNA R9.3.1, except for the Hans-M50-v1.21 model, which required LS-DYNA R12.2.2 due to compatibility constraints. The simulation duration was set to 140 ms to capture the complete occupant kinematic response through both maximum intrusion and rebound phases. Contact interactions between the occupant and vehicle interior components were defined with material-specific friction coefficients derived from characterization data. The computational timestep was maintained at 7×10^{-7} seconds throughout all simulations.

3 Results

3.1 Kinematic Response Comparison

Kinematic analysis revealed fundamental differences in how the two models respond to lateral impact:

- WorldSID-50M: Exhibited pivoting motion of the head around T1 vertebra with minimal spinal deformation, resulting in a more rigid body-like rotation of the head, consistent with previous observations in [22]
- Hans-M50-v1.21: Showed significant spinal lateral bending and translation in addition to rotation, allowing for more complex head movement patterns as noted in. [23]

These differences comes from the WorldSID's simplified spine design optimized for instrumentation versus the anatomically accurate vertebral column in the Hans-M50-v1.21 model that allows for more realistic deformation patterns.

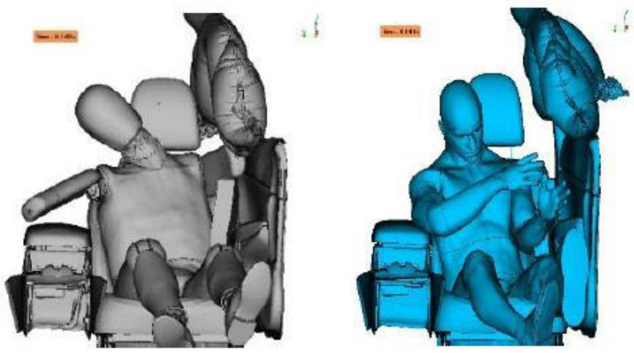

Figure 5: CAE simulations (Grey - WorldSID-50M, Blue - Hans-M50-v1.21) at 140ms.

3.2 DAMAGE Metric Response

Despite kinematic differences described in Section 3.1, DAMAGE time histories showed remarkably consistent characteristics across both models:

1. Initial peak occurring at approximately 40-60ms for both surrogates.
2. Secondary peak during rebound phase at 90ms for WorldSID-50M and Hans-M50-v1.21 is not showing relevant rebound values.
3. Similar slope patterns during loading phase.

Interestingly, for the Hans-M50-v1.21 model, the rebound phase produced lower DAMAGE values than the initial impact, while the WorldSID-50M showed a more prominent second peak. This highlights the importance of considering the entire impact event when assessing injury risk, but more importantly to verify the neck stiffness in all axes, particularly when using human body models.

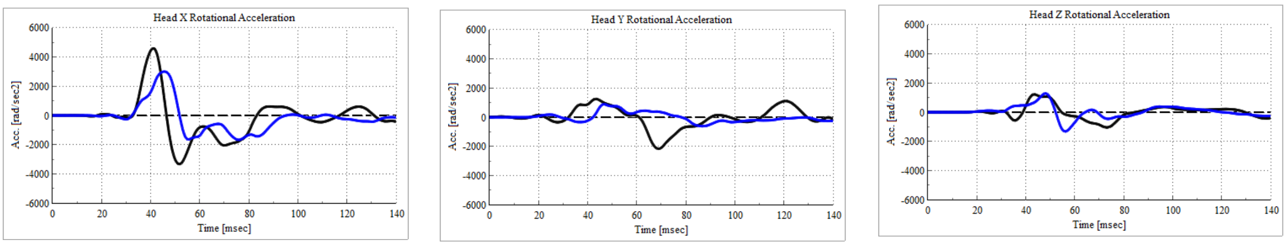

Figure 1: Head angular acceleration (left: X direction, middle: Y direction, right: Z direction).

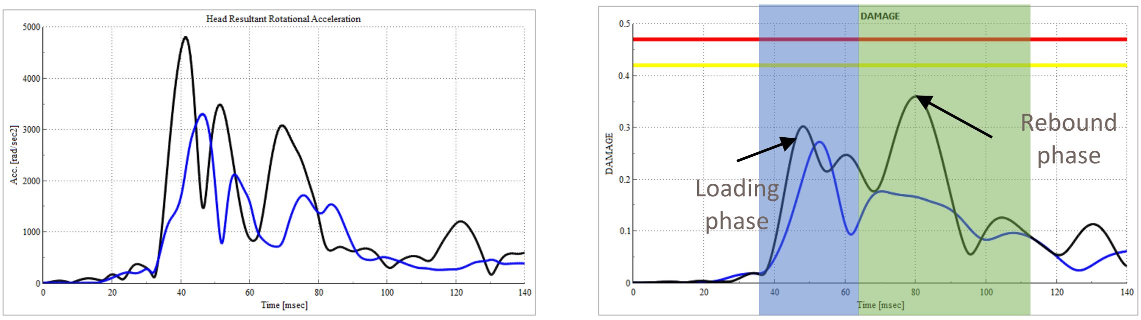

Figure 8: Head Resultant Rotational (left side), Damage (right side).

4 Discussion

The comparative analysis of WorldSID-50M and Hans-M50-v1.21 responses revealed fundamental differences in head kinematics during near-side impacts, with some implications for brain injury assessment. The WorldSID-50M exhibited a characteristic pivoting motion around the T1 vertebra with minimal spinal deformation, essentially producing a rigid-body-like head rotation. In contrast, the Hans-M50-v1.21 demonstrated more complex head kinematics characterized by significant lateral bending and translation throughout the spine. This discrepancy comes from the inherent structural design differences between the two models.

The WorldSID-50M, designed for measurement repeatability and instrumentation accommodation, employs a simplified spinal column with constrained articulation to ensure consistent performance across multiple impact events [24]. Conversely, the Hans-M50-v1.21 anatomically detailed vertebral structures, complete with realistic ligamentous connections and intervertebral discs, permit more biofidelic deformation patterns [25]. These differences significantly influence the resulting head acceleration profiles that drive brain injury metrics.

The greater lateral head displacement observed in the Hans-M50-v1.21 compared to the WorldSID-50M underscores the importance of spinal kinematics in lateral impacts. This finding aligns with observations by Pipkorn et al. [26], who noted that ATD spine simplifications can lead to underestimation of head excursion in complex loading scenarios.

Despite the differences in biomechanical response, the DAMAGE time histories exhibited consistent characteristic patterns across both occupant models. This consistency suggests that the DAMAGE metric captures fundamental aspects of head kinematics relevant to brain injury prediction regardless of the surrogate model employed.
The observation that the rebound phase produced lower DAMAGE values than the initial impact in the Hans-M50-v1.21 model is especially noteworthy for validation purposes. Current industry practices often focus computational resources on the primary impact phase, potentially stopping simulations before the full rebound response develops. Our results indicate that comprehensive brain injury assessment requires extended simulation times to capture the complete kinematic response, with important implications for computational resource allocation and job scheduling in large-scale simulation campaigns.

From a software implementation perspective, several key insights emerge from this comparative study that directly impact CAE workflow development for brain injury assessment. The significant computational cost differential between occupant models (longer runtime for Hans-M50-v1.21 versus WorldSID-50M) presents a critical trade-off between biofidelity and computational efficiency. This disparity necessitates thoughtful model selection strategies based on specific analysis objectives. For parameter studies and early design evaluations, the more computationally efficient WorldSID-50M may be appropriate, while detailed injury mechanism investigations would benefit from the higher biofidelity of the Hans-M50-v1.21, despite increased computational demands.

5 Limitations

Several limitations should be considered when interpreting the results of this study. The open-source vehicle model, while enabling reproducible research, represents older vehicle architecture without modern side impact protection systems. The simplified representation of the deployed side airbag using a foam structure, while necessary for simulation stability, may not fully capture the complex interaction between occupant and airbag during deployment phases.

Future work should address these limitations through integration of more sophisticated vehicle models with advanced restraint systems, particularly focusing on the interaction between side airbags and different occupant models. Additionally, parameter sensitivity studies exploring the effects of impact angle, velocity, and occupant positioning would enhance understanding of DAMAGE metric robustness across a broader range of impact scenarios.

6 Conclusion

This study investigated the performance of the DAMAGE brain injury metric across different occupant models in near-side impact scenarios, comparing responses between the industry-standard WorldSID-50M dummy and the Hans-M50-v1.21 human body model. Our findings yield several significant conclusions with direct relevance for computational safety assessment methodologies:

1. Significant differences in head kinematics between WorldSID-50M and Hans-M50-v1.21 comes primarily from their distinct spinal configurations, with the anatomically detailed spine of the Hans-M50-v1.21 model permitting more complex deformation patterns that influence head acceleration profiles.
2. Rebound phases can produce DAMAGE values equal to or exceeding those from initial impact, highlighting the necessity of extended simulation durations that capture the complete kinematic response for comprehensive brain injury assessment.
3. Software implementations of injury assessment workflows should incorporate robust positioning algorithms and standardized signal processing protocols to ensure consistent injury prediction across different occupant models.

These conclusions have significant implications for automotive safety assessment, particularly as the industry transitions toward greater integration of computational methods in the development process. The complementary strengths of physical ATDs (regulatory alignment, computational efficiency) and computational human body models (anatomical detail, tissue-level injury prediction) suggest that hybrid approaches incorporating both methodologies will provide the most comprehensive safety assessment framework.

7 Literature

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