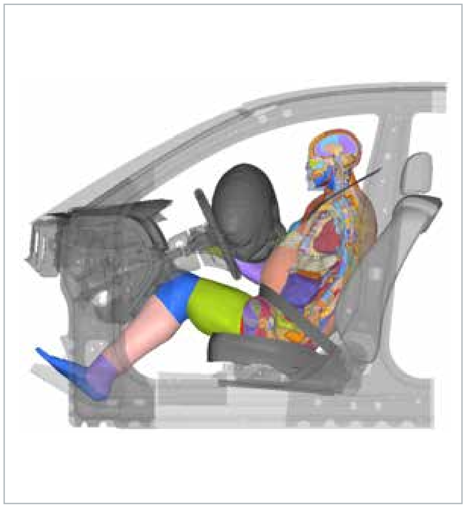
Application of HyperWorks to Develop Human Body Models to Assess Injury Potential for Vulnerable Populations in Vehicle Crashes



Key Highlights

Industry
University/Research

Challenge
Develop finite-element human body models that account for effects of age, gender, and obesity on injury risk in vehicle crash

Altair Solution
Apply HyperMesh and HyperMorph to develop parametric-based models

Benefits
Parametric-based finite-element models of the human body can enable population-based crash simulations to improve vehicle safety

The University of Michigan Transportation Research Institute (UMTRI) is a leading research center dedicated to achieving safe and sustainable transportation for a global society. UMTRI is committed to interdisciplinary research that focuses on increasing driver safety. Since its inception in 1965, UMTRI has earned a significant national and international reputation for its motor vehicle safety research related to injury biomechanics. This research, largely focused in UMTRI's Biosciences Group, involves research on the biomechanics of motor vehicle occupants, as it relates to occupant injury assessment, crash protection, and occupant accommodation. Under the direction of Dr. Matthew Reed, the scope of the biosciences work consists of three main areas: crash analysis and simulation, experimental impact biomechanics, and vehicle ergonomics.

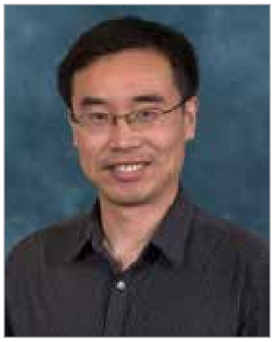
Develop Improved Parametric-Based Finite Element Human Models

Children, small female, the elderly, and obese occupants are at greater risk of serious injury from vehicle crashes than young, mid-size male occupants. Analysis of crash injury databases by UMTRI show that occupant characteristics, such as age, sex, and body mass index (BMI) significantly affect the risks for thoracic and lower extremity injuries in vehicle crashes. Thoracic injuries are disproportionately common for accidents involving older occupants. Obese individuals have also been shown to be more susceptible to lower extremity injuries.

While increased injury potential for these vulnerable populations in crashes is well established, current injury assessment

HyperMesh, HyperMorph, parametric human body models, crashworthiness simulation, biomechanics

UMTRI Success Story



"HyperMesh and HyperMorph were key enabling tools for the development of parametric-based human body computational models for injury assessment resulting from vehicle crash events"

Dr. Jingwen Hu
Associate Research Scientist
University of Michigan Transportation Research Institute

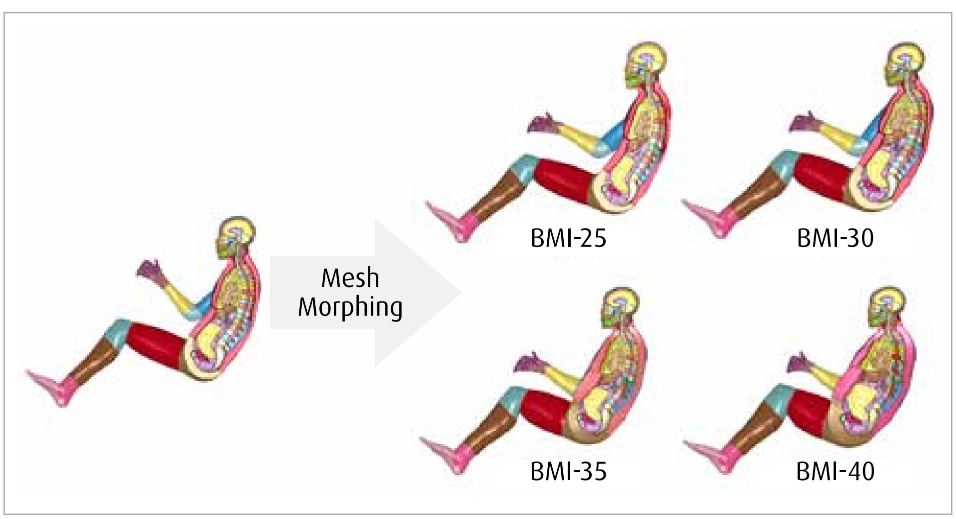
tools, including finite-element human models, do not account for different body shape and composition variations among the population. An opportunity exists to broaden vehicle crash protection to encompass all vehicle occupants by developing detailed, parametric-based finite element human body models that represent a wide range of human attributes.

Development of Parametric-Based Finite Element Human Body Models

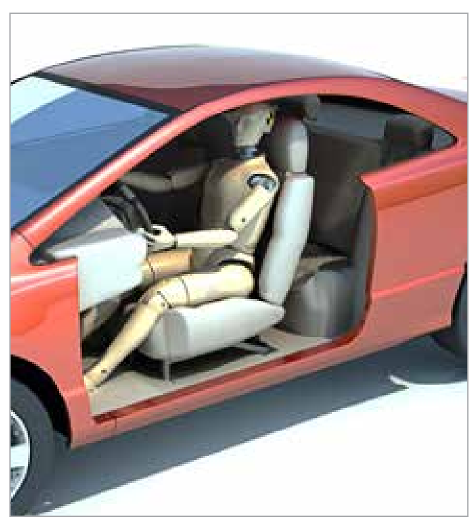
UMTRI has developed a computational framework to build parametric finite element whole-body human models for crash simulation. The framework consists of three modeling steps:

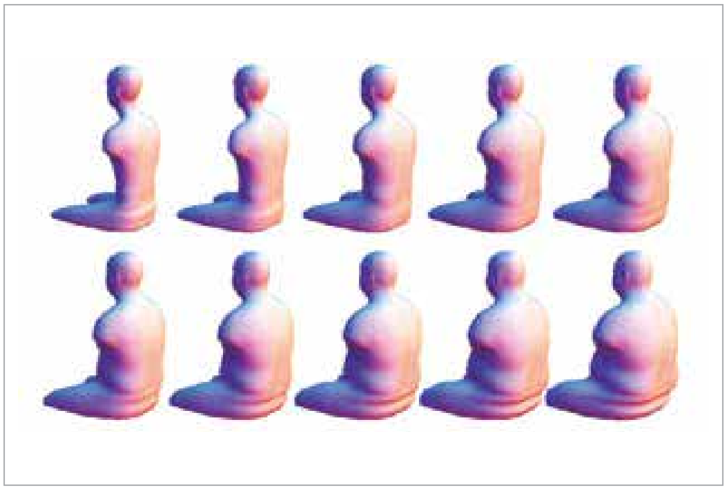
1. statistical model development of human anthropometry to characterize human population variability for size, age, gender, and obesity
2. mesh morphing based on body landmarks; and
3. stochastic material model assignment to characterize age and gender variation of bone and soft tissue properties.

Fundamental to statistical model development of human anthropometry are the establishment of sub-models: the sitting posture model, the body surface contour model, and the bone geometry model. UMTRI's Biosciences researchers have developed a method to build human skeletal geometry models based on radiological images. The modeling steps include CT image segmentation, landmark identification and registration, and statistical analyses. These statistical approaches have been applied to each of the sub-models. The posture model can predict the skeletal joint landmarks that characterize orientation of human body segments as functions of occupant characteristics. These landmark locations and associated occupant characteristics serve as inputs to the body surface contour model and the bone geometry model. The combined

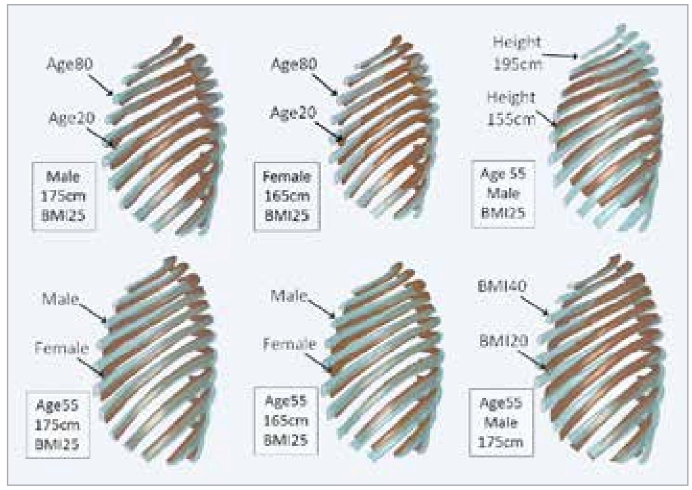


Mesh Morphing Results: Baseline Model to Four Targets





Male Torso Surface Shape for BMI Ranges 18 to 45



Effects of Age, Sex, Stature, and BMI on Rib Cage Geometries

output of these sub-models are a few thousand data points that define body posture, the size and shape of the external body surface, and skeletal geometry associated with a specific set of occupant characteristics.

The mesh morphing technique developed by UMTRI is based upon the assumption that the finite element model mesh from a human model can be changed smoothly into other geometries without developing new finite element meshes. Thus, the basic concept for developing a parametric human finite element model is to morph a baseline model into different geometries associated with the aforementioned sub-models. In this way, multiple models with different combinations of human body characteristics can be generated rapidly, which in turn enables large-scale design optimization accounting for population variance. Altair HyperMesh and its morphing module (HyperMorph) were used throughout the whole process of developing the parametric whole-body human models, including baseline model development, landmark identification, mesh smoothing, and simple morphing. Once the baseline model and geometry targets were set, they then applied landmark-based mesh morphing methods based on radial basis functions (RBFs).

Once the finite element mesh based on these morphing procedures is generated, material properties for occupants with different characteristics (age, gender, BMI) need to be assigned to different body components. The property assignments developed by Dr. Jingwen Hu are based on stochastic material models that comprehend not only the mean but also the standard deviations of the material parameters. These stochastic models of human body tissue were developed using a combination of tissue testing, specimen-specific finite element modeling applying HyperMesh, and stochastic optimization methods.

Studies Using the Parametric Models Illustrate Effects of Obesity on Occupant Response in Frontal Collisions

The effects of obesity on occupant responses in frontal collisions were investigated using the UMTRI whole-body human finite element models. A modeling approach was developed and applied that allowed for rapid change of a baseline human body model into geometries representing adults with different BMIs without the need for re-meshing the models. The previously described mesh morphing methods were then used to effectively morph a seated human body model into other BMI target geometries while maintaining high geometric accuracy and good mesh quality. The morphing techniques relied on landmark-based RBF interpolation. For a final step, calibration of the morphed models was completed by simulating cadaver tests with a range of BMI values. The morphed models were used for a parametric study of crash simulations using a previously developed and validated frontal-crash vehicle model. The finite element human models were positioned in a driver compartment model containing a standard front airbag and a three-point seat belt. The frontal crash pulse applied in the simulations was based on crash test data corresponding to an impact velocity of 48 km/hour. The parametric study was based on a Taguchi orthogonal array. Selected array levels resulted in 16 total simulations.

Simulation results for occupant kinematics show that even with the airbag, obese occupants tend to undergo larger excursions than non-obese occupants. The results also predict that obese occupants are at significantly higher risk of sustaining injuries to the thorax and lower extremities in frontal crashes compared to non-obese occupants, which is consistent with UMTRI field data analysis. These higher injury risks are mainly due to increased body mass and relatively poor fit of the belt restraints caused by obese occupant soft tissues around the abdomen. This study successfully demonstrated the feasibility of applying parametric finite element human-body models to investigate the obesity effects of occupant responses during frontal crashes. Altair HyperWorks played a significant role in providing fundamental finite element meshing tools for generating baseline models, identifying landmarks, and mesh quality evaluations for the study.

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