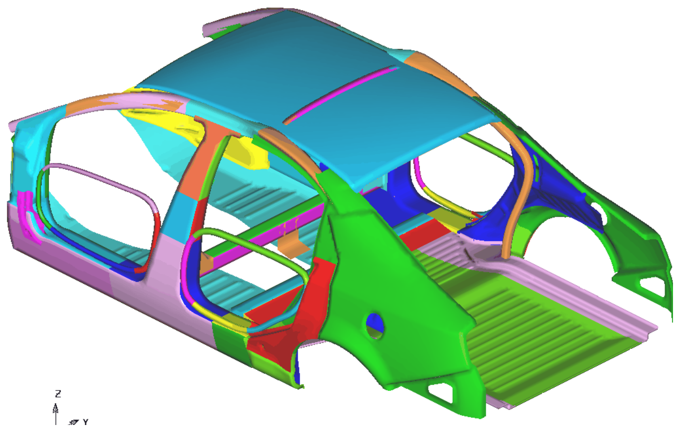
Multiphysics 2011, Barcelona, Spain

Multiphysics in Automotive Engineering



Basem Alzahabi

Mechanical Engineering Department

Kettering University

Flint, Michigan, USA

General Motors Institute

Kettering University

GMI

Founded in 1919

Cooperative Education

Industrial Partners

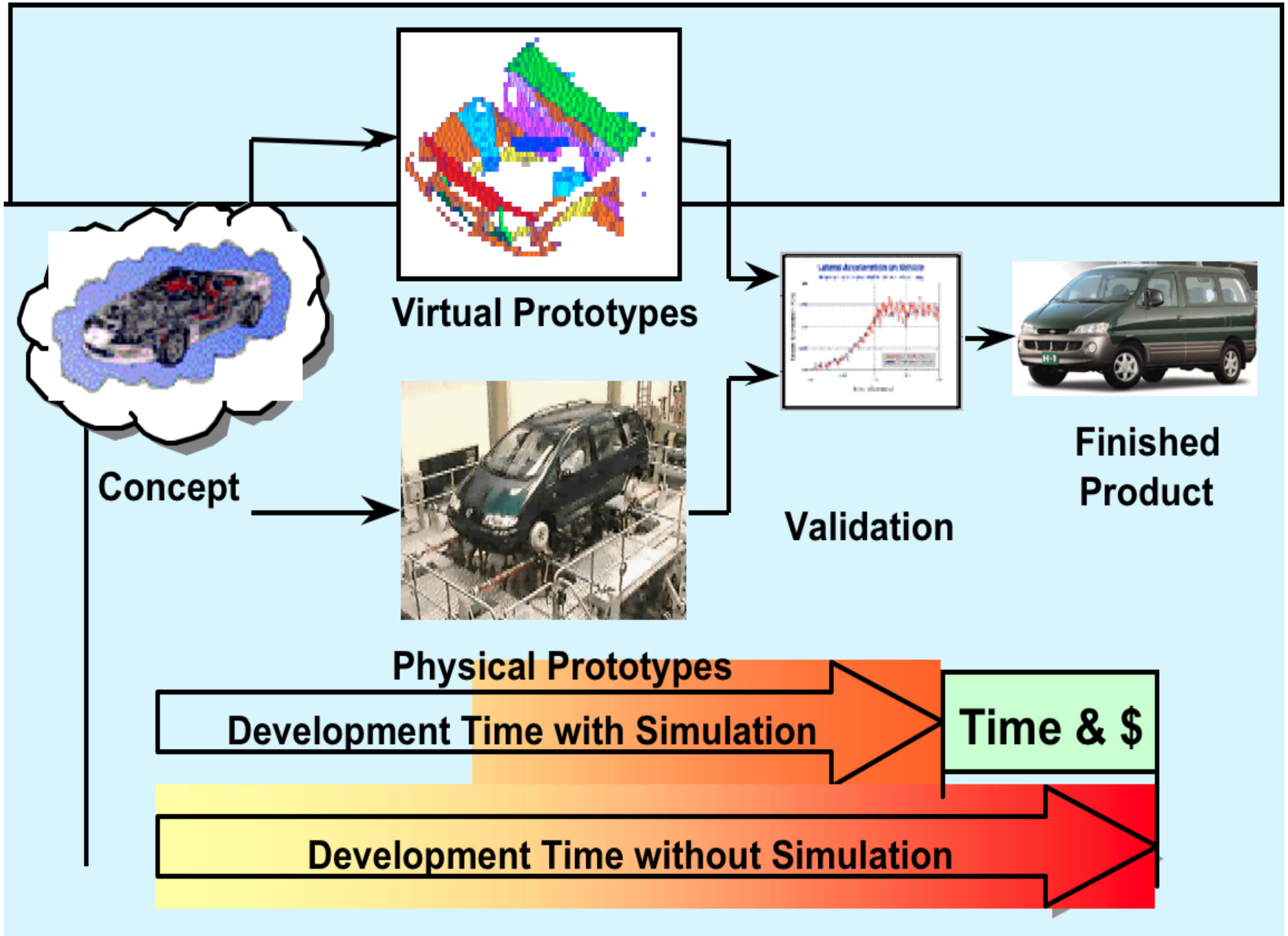
Today's Automotive Industry

- Worldwide Competition
- Customer Expectations
- Better Products
- Decreased Time-To-Market
- Cost Reduction

Industrial Necessities

- Incorporate interdisciplinary design and manufacturing constraints
- Development of virtual or digital environments for real-world design simulations

Industrial Necessities



Opportunity for Collaboration

Industries

- Identify Challenges
- Acquire tools & expertise
- Sponsor improvements

Engineering Providers

- Simulation Technology
- Process Improvement implementation

Educational Institutions

- Training of engineers
- Engineering research

Public Research

- Sponsor engineering research
- Define standards
- Regulation

Improved Product Development

Industries

- Acquire and develop the right tools
- Develop expertise to maintain their competitiveness
- Sponsor improvement programs where internal and external resources are brought together to collaborate

Educational Institutions

- Providing the core technical professionals
- Prepare multi-disciplinary technical professionals
- Ultimately, play a central role in our increasingly technologically based society

Engineering Providers

- Responding to the industrial needs by providing the right engineering software
- Providing people who can help implement new technology developed by the emerging engineering research

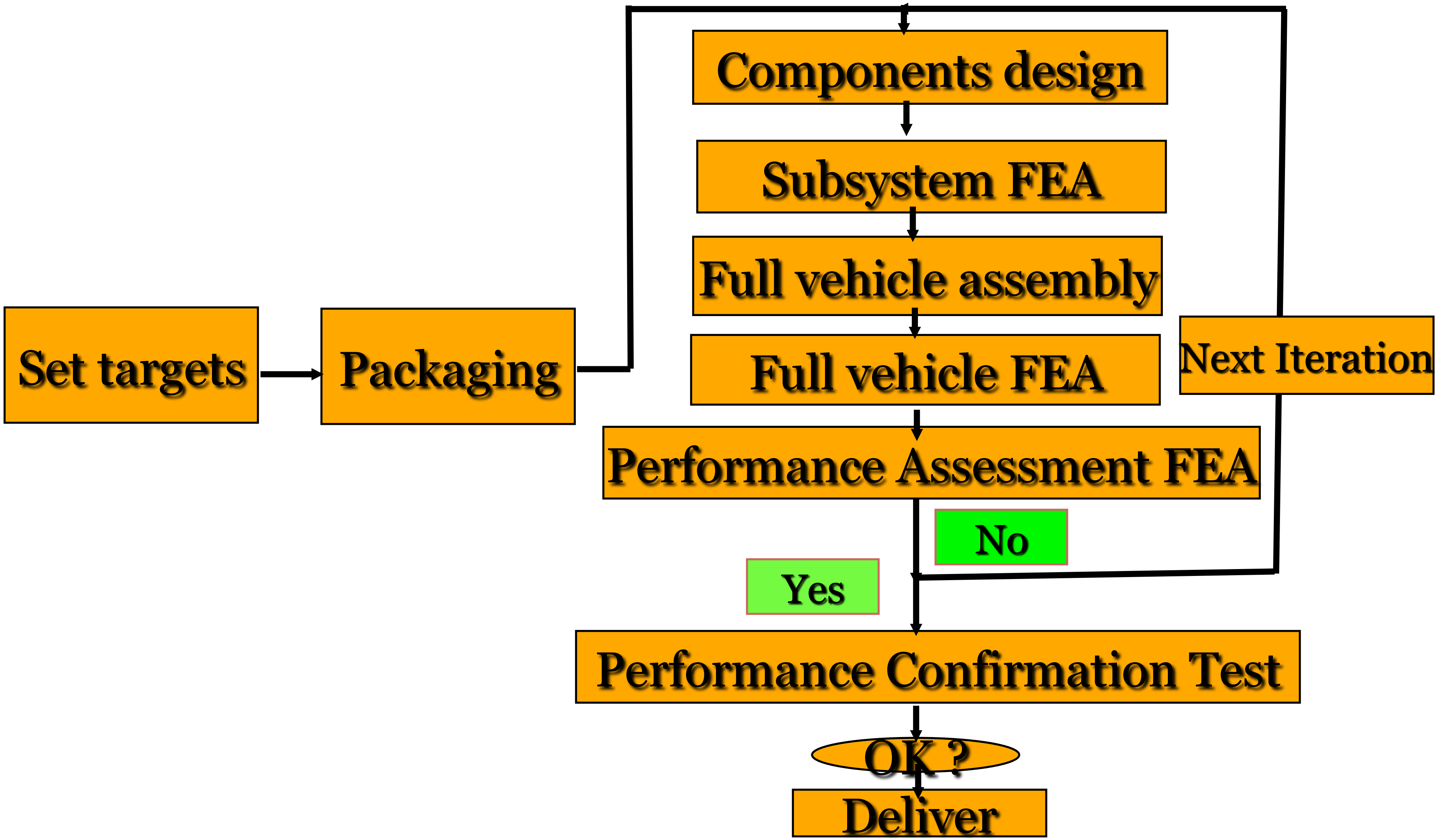
Governmental Agencies

- Investing funds to promote engineering research that lead to improved engineering for increased public safety
- Defines standards that help industries interact with each other
- Ensure that regulations are applied to serve the public good while not impairing the ability of industries to function with a reasonable level of business success

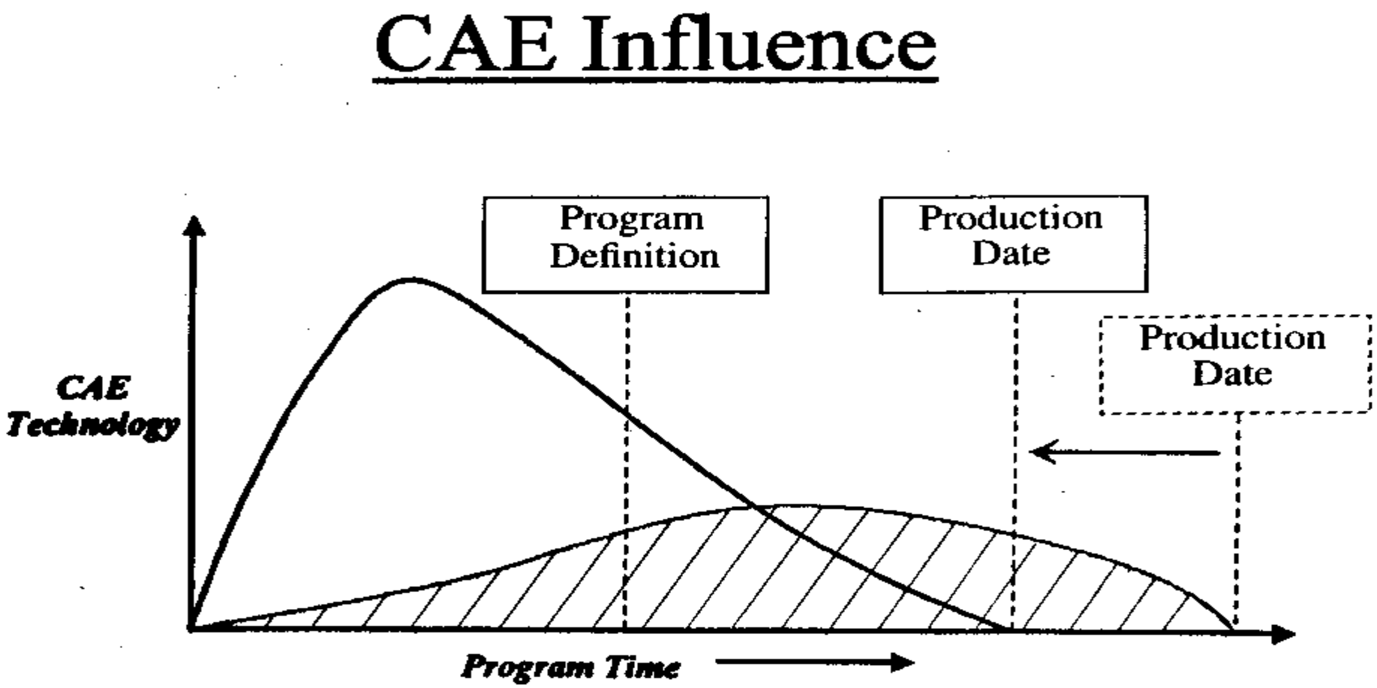
CAE in the Industrial Setting

- Qualitative & Quantitative relation
- CAE knowledge tools that correlate with physical testing
- Integration of design, simulation, and synthesis, to improve the product design process
- Integration of CAE driven design processes within a historically corporate culture devoted to 'build-n-test"

Automotive Design with Virtual Prototypes



Up-Front Computational Simulation



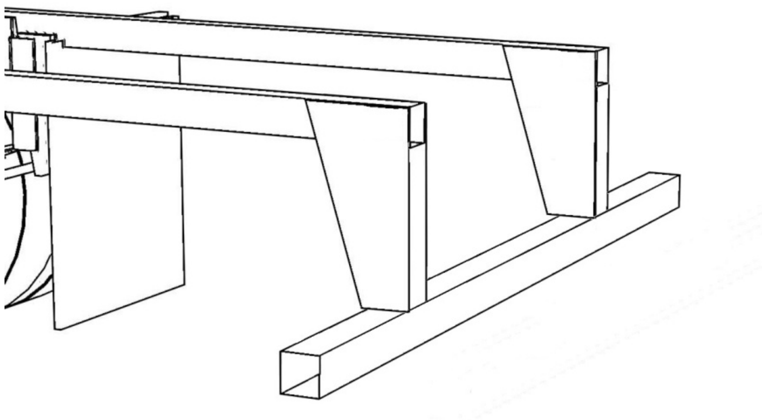
CAE

- Accuracy
  - Smaller meshes, more accurate physics, improved algorithms
- Speed
  - Design Validation
  - Optimisation

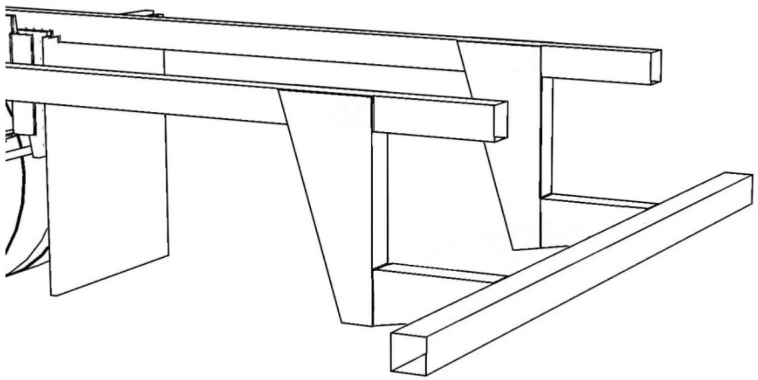
CAE Cycle

- Pre-processing
  - Meshing
  - Geometry simplification
  - Model assembly
  - Loading
  - Materials
- Solving
- Post processing
- Iteration – Optimisation

Trailer Under-ride Guard

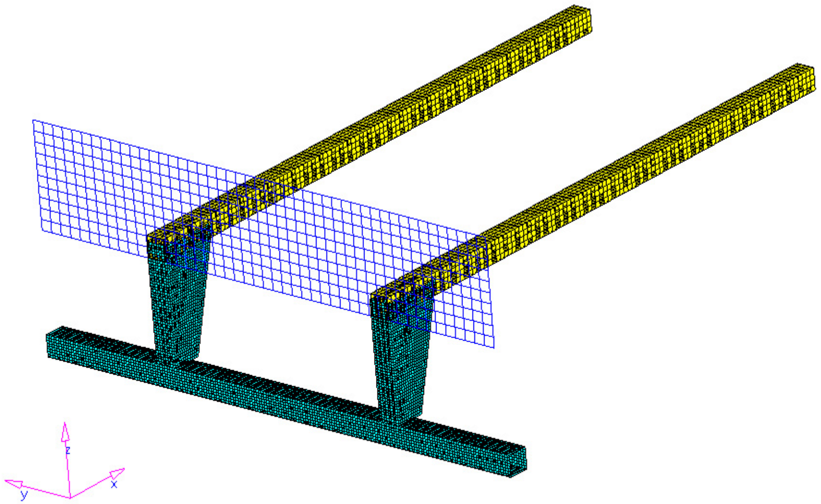


Conventional Underride Guard

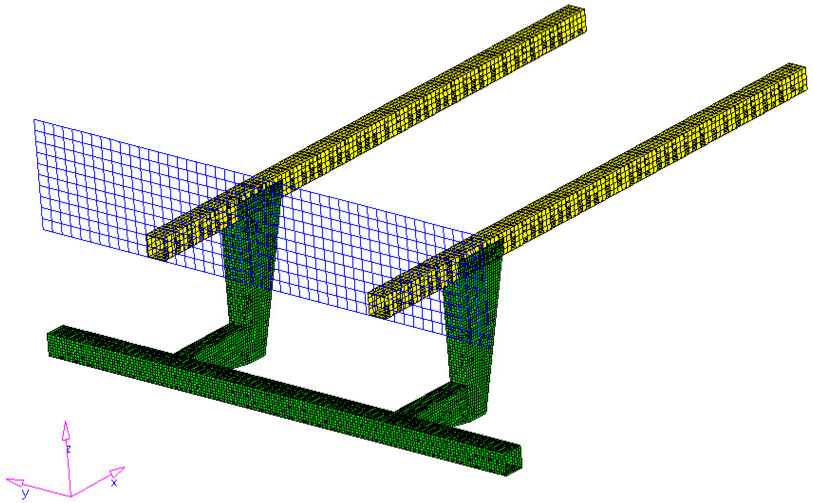


Offset Underride Guard

Trailer Under-ride Guard

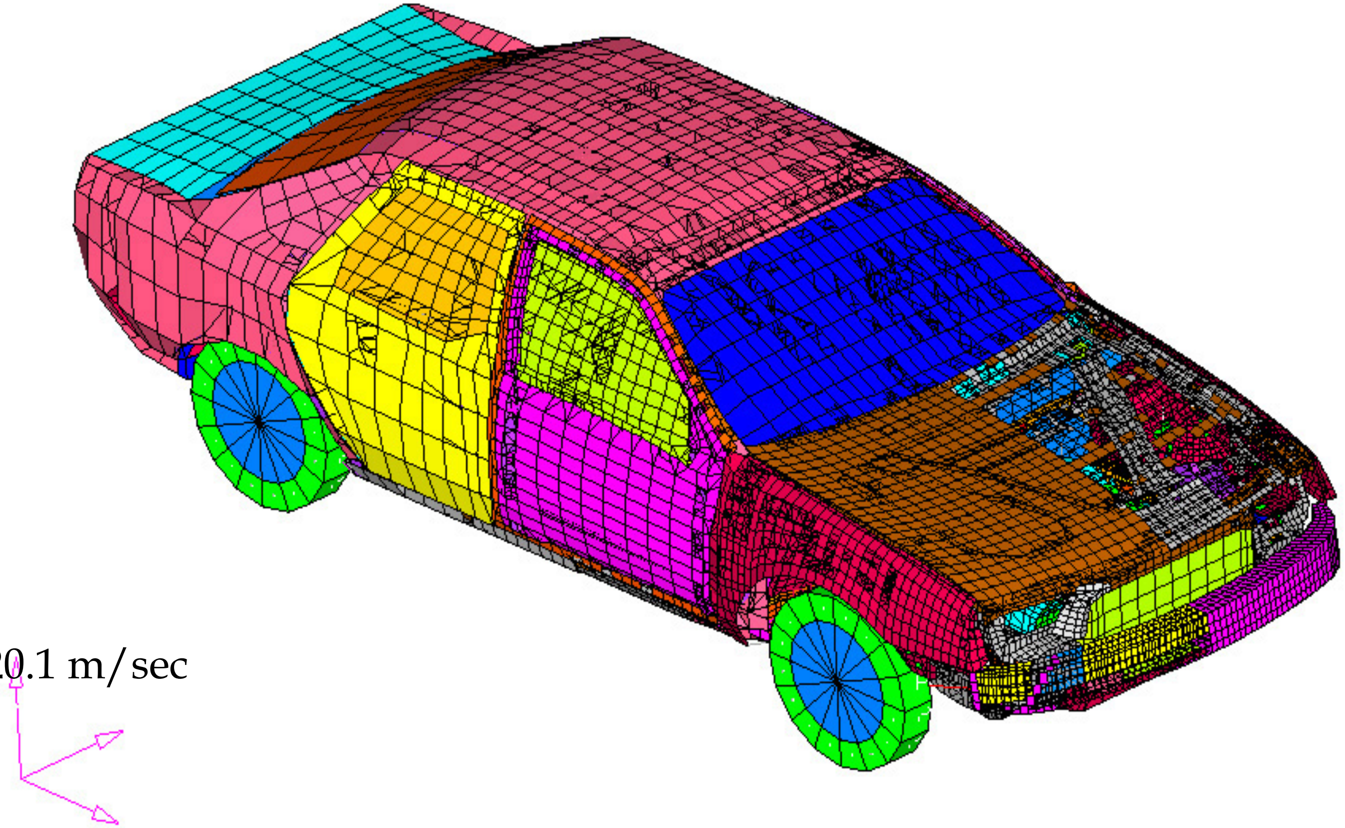


Conventional Bumper



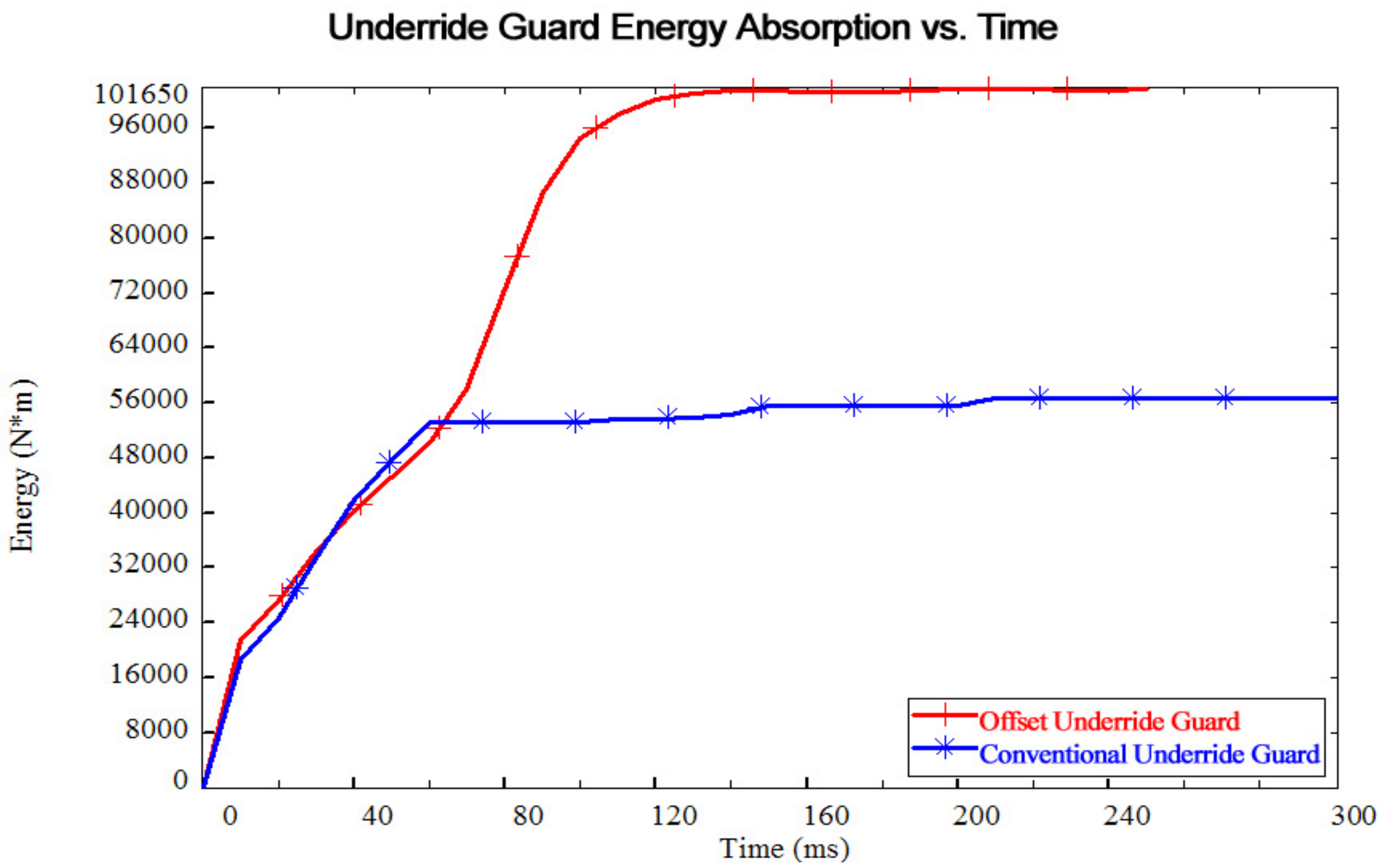
Offset Bumper

Finite Element of Striking Vehicle

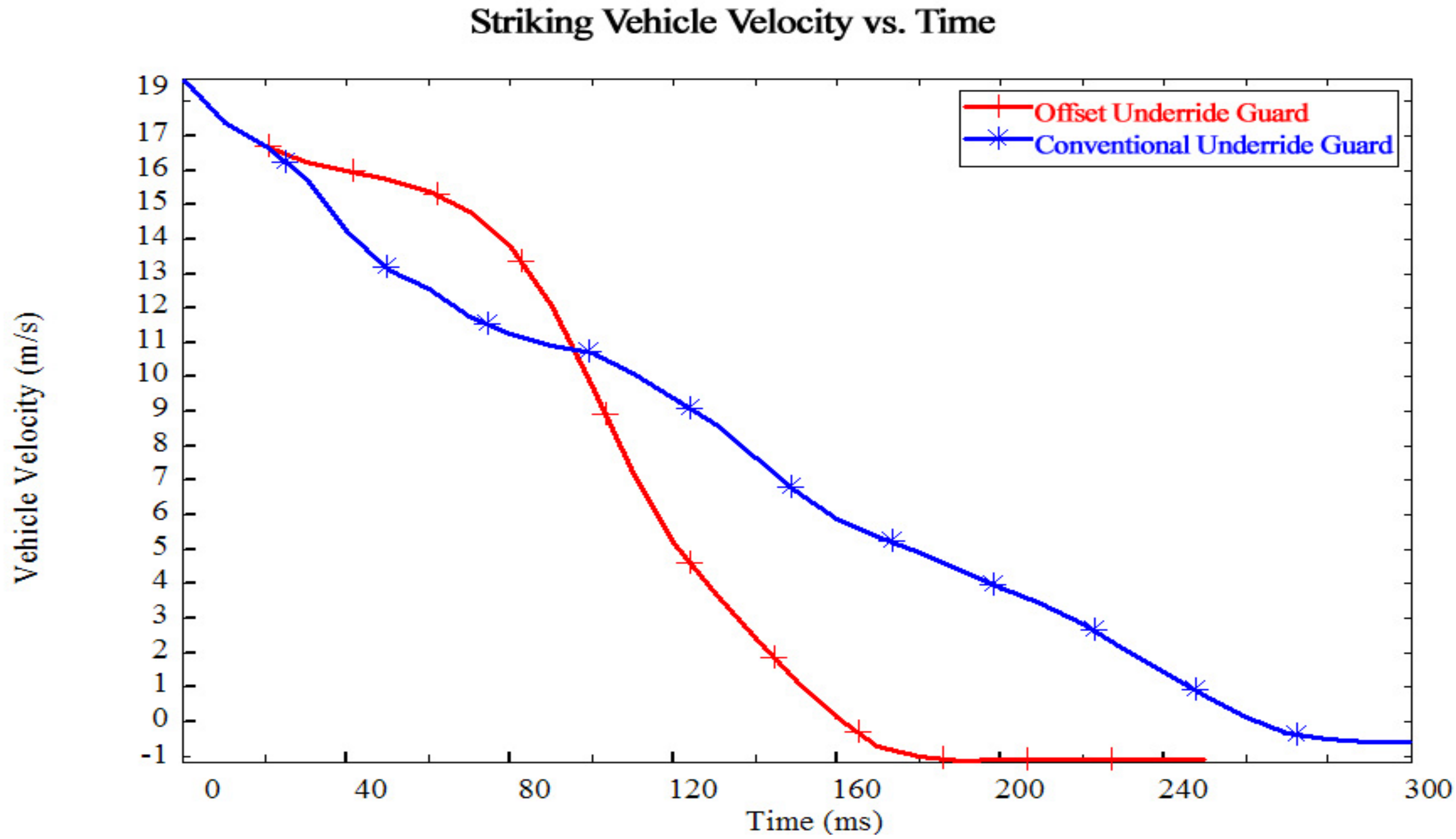


Velocity: 20.1 m/sec

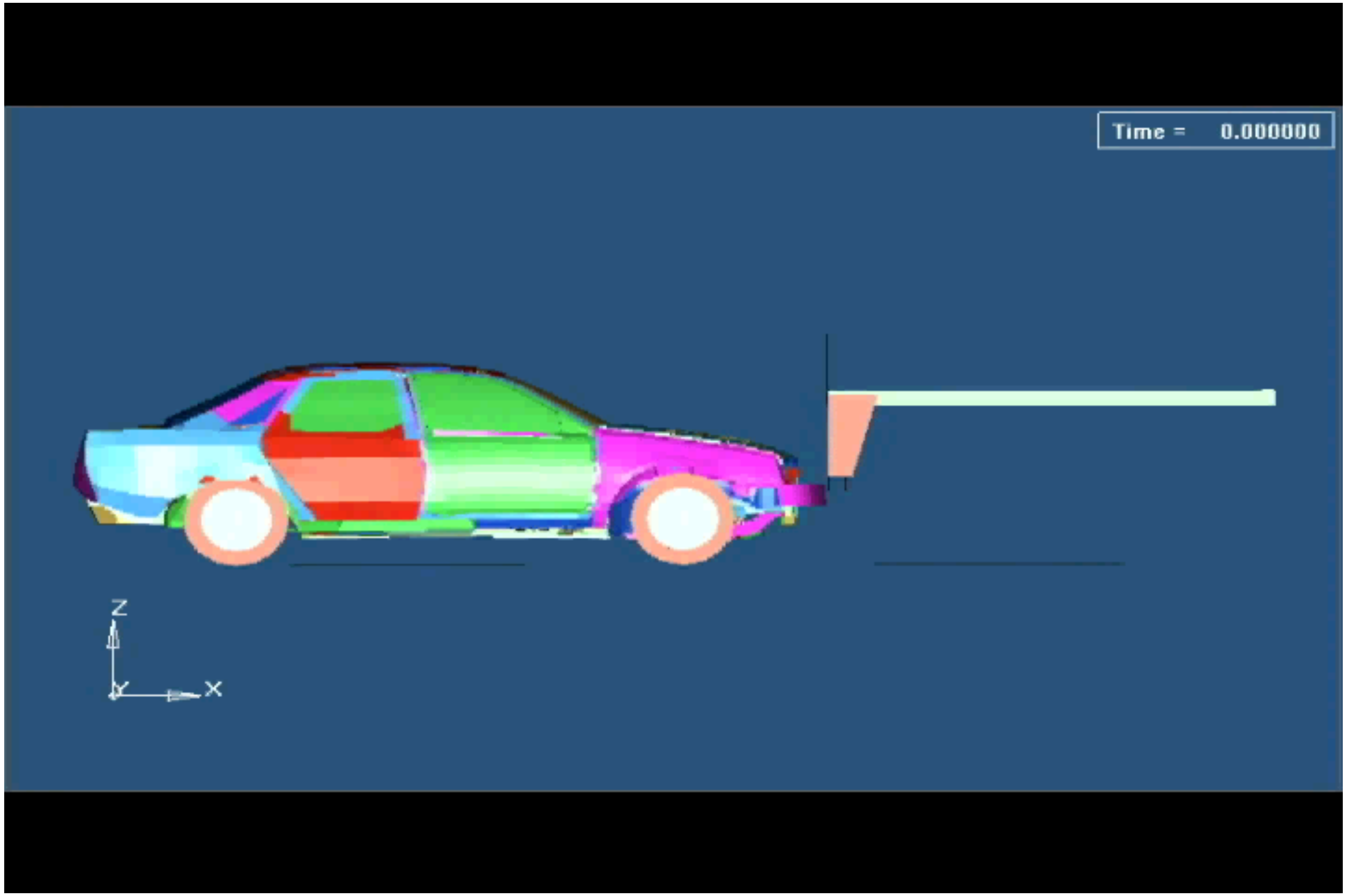
Energy Absorption



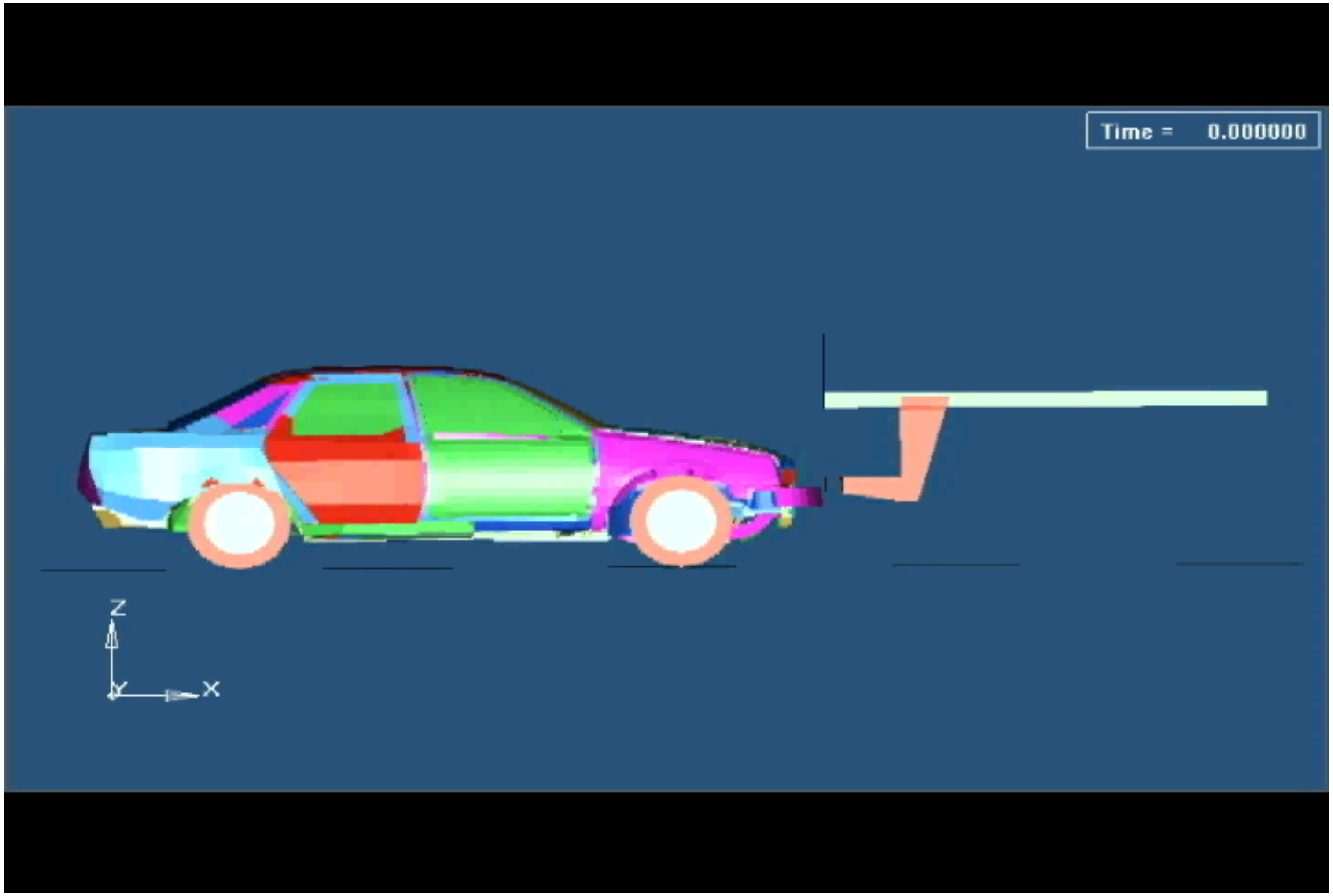
Striking Vehicle Deceleration



Conventional Bumper Simulation



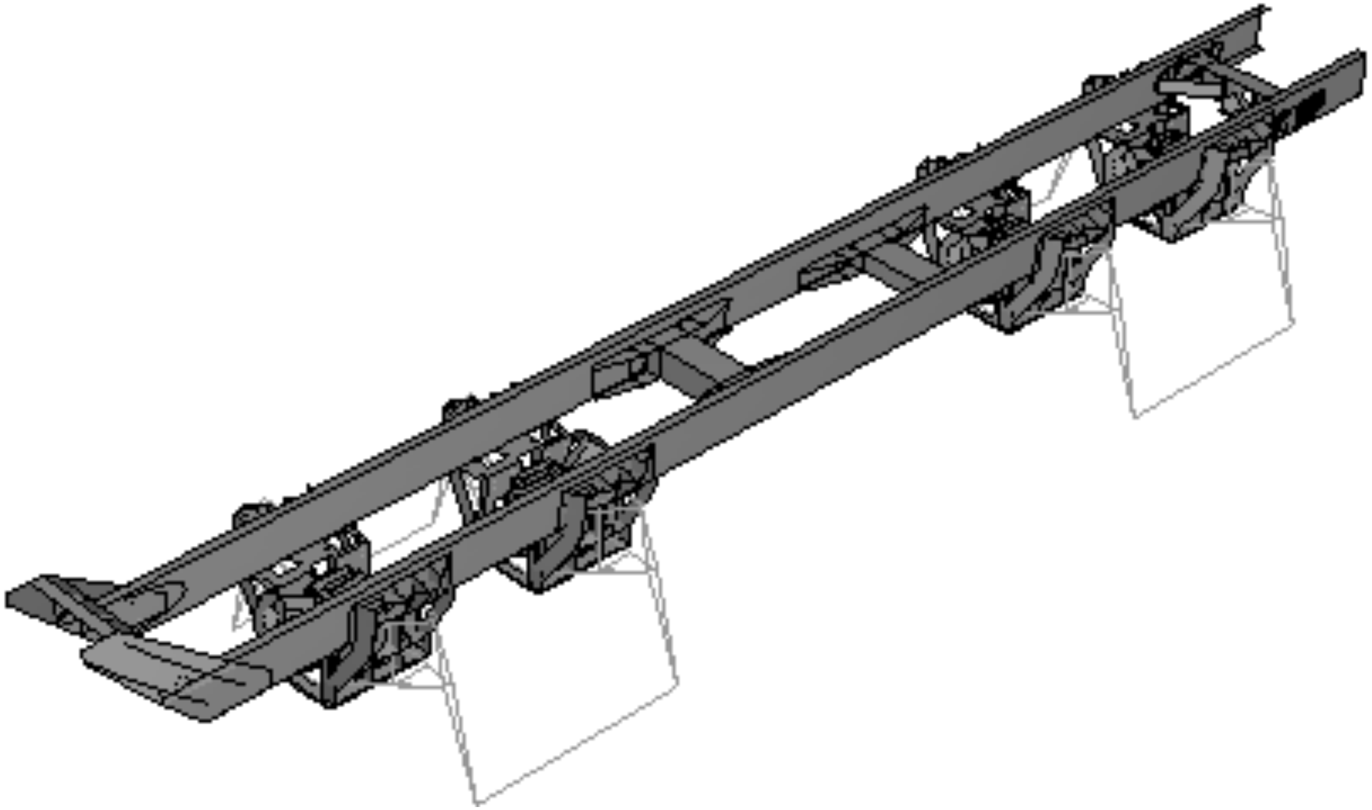
New Bumper Simulation



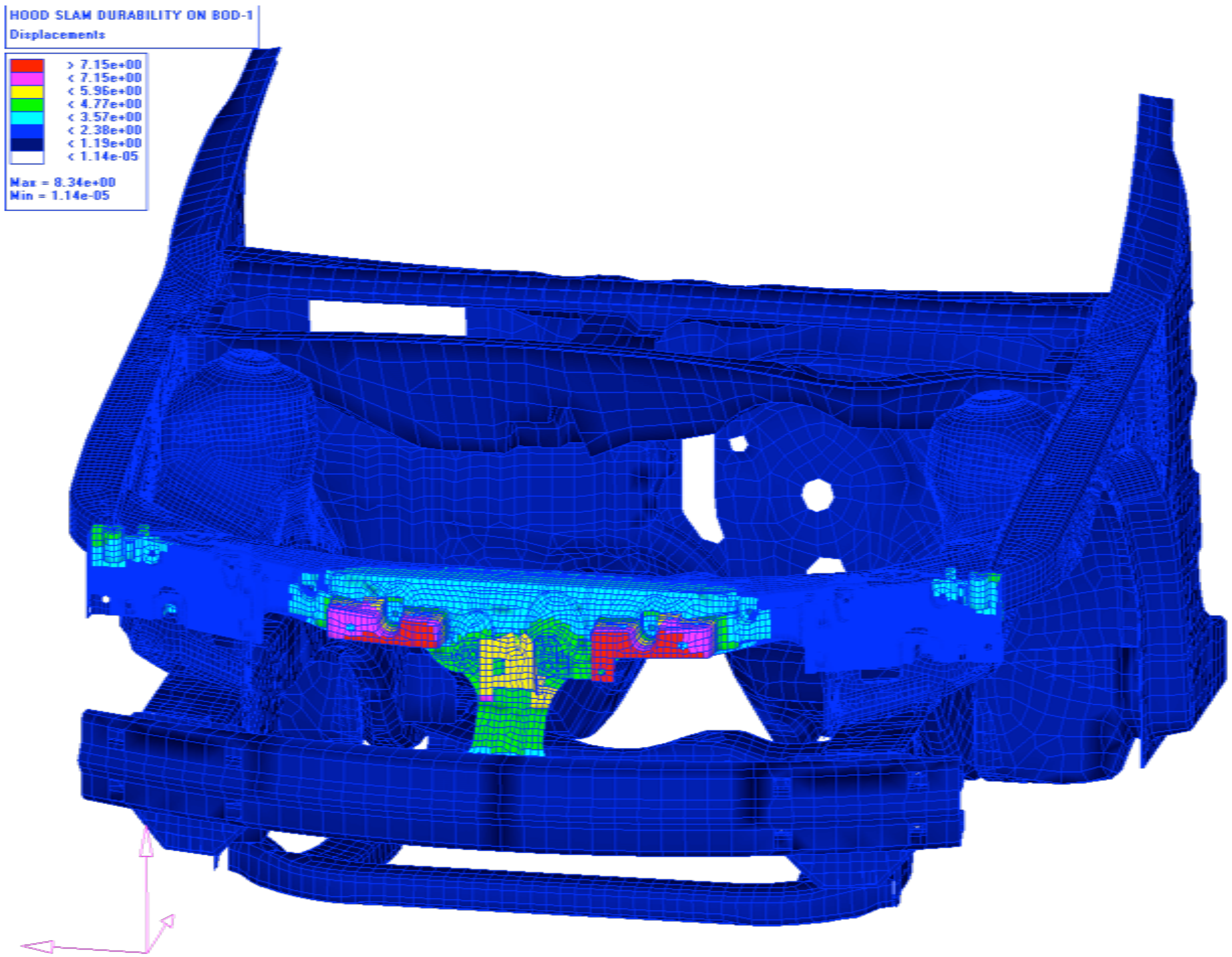
CAE in Automotive Engineering

- Strength and Durability
- Noise, vibration and harshness (NVH)
- Crashworthiness
- Occupant Safety
- Climate control
- Aero-thermal management
- Ride and Handling

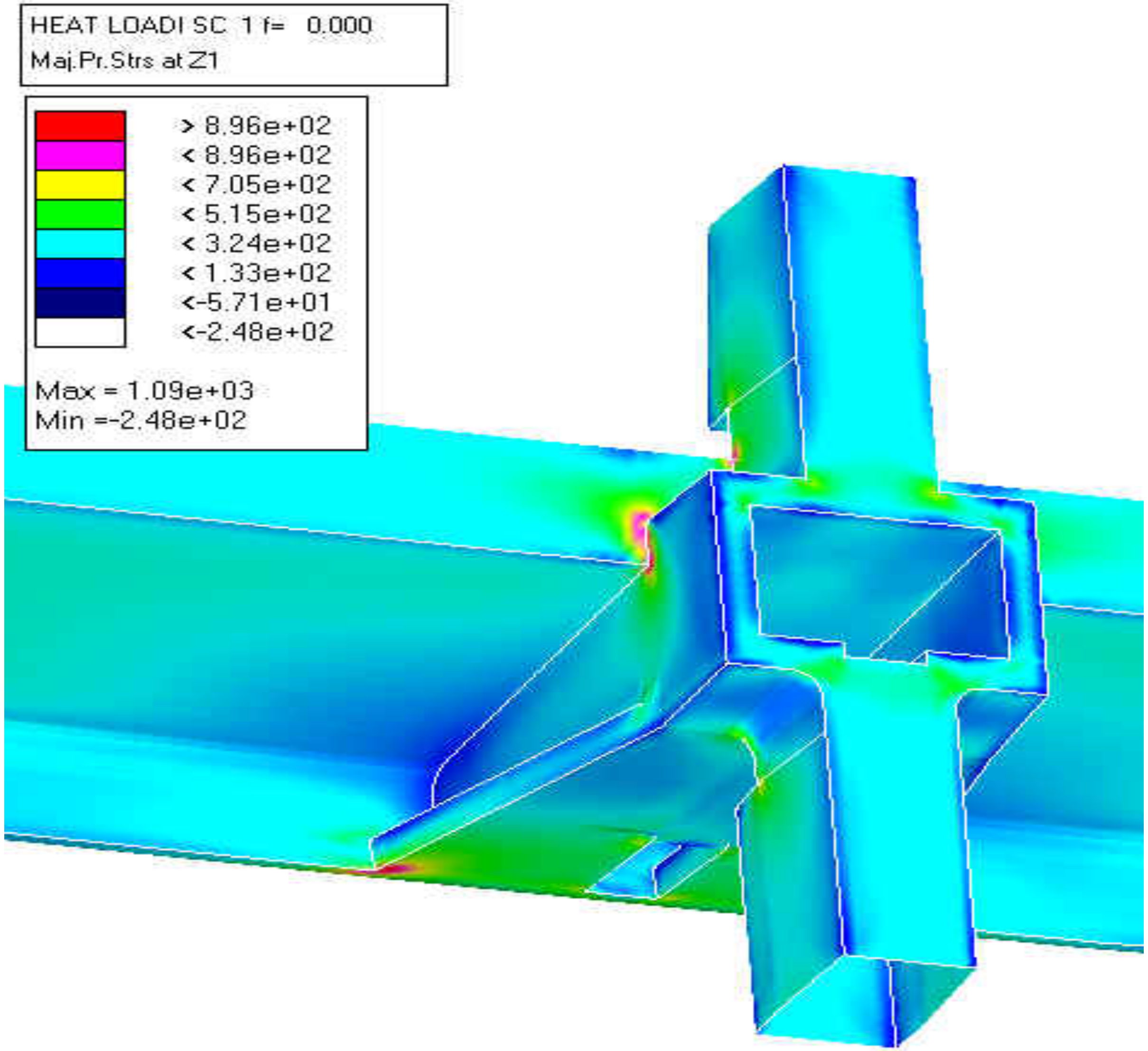
Frame Torsional Stiffness



Hood Slam Fatigue Simulation



Thermal Analysis Grille Chrome



The "Multi" World

- MULTIPHYSICS: problem divided into partitions
  per physical domains

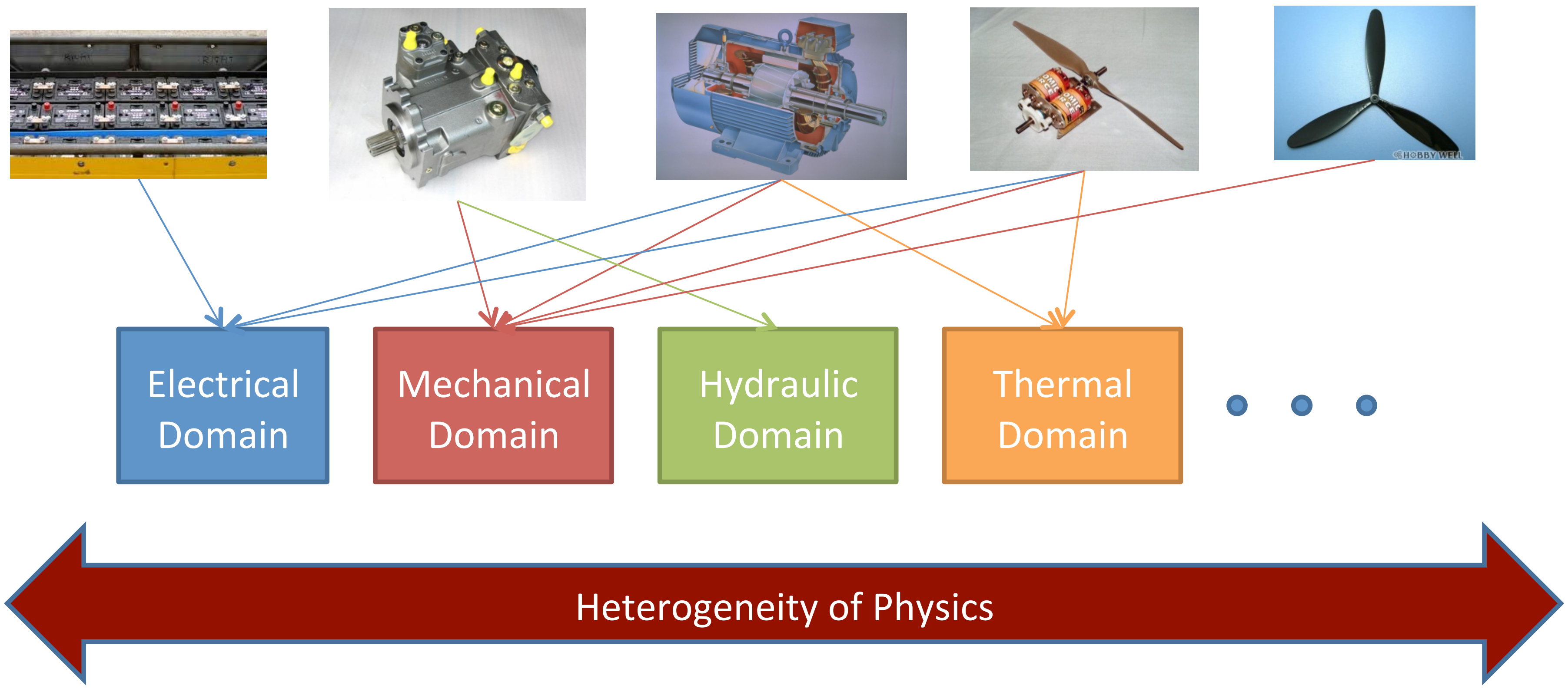
- MULTISCALE: problem divided into partitions
  per represented scales

- MULTIPROCESSING: distributed representations
  per computational resources

Multiphysics

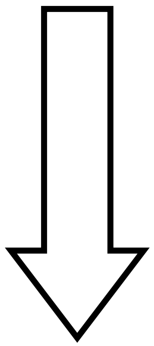
Multiphysics: the interaction of physically heterogeneous coupled system modeled at similar spatial / time domains

Integration Challenge: Multiphysics



Multiphysics Coupling

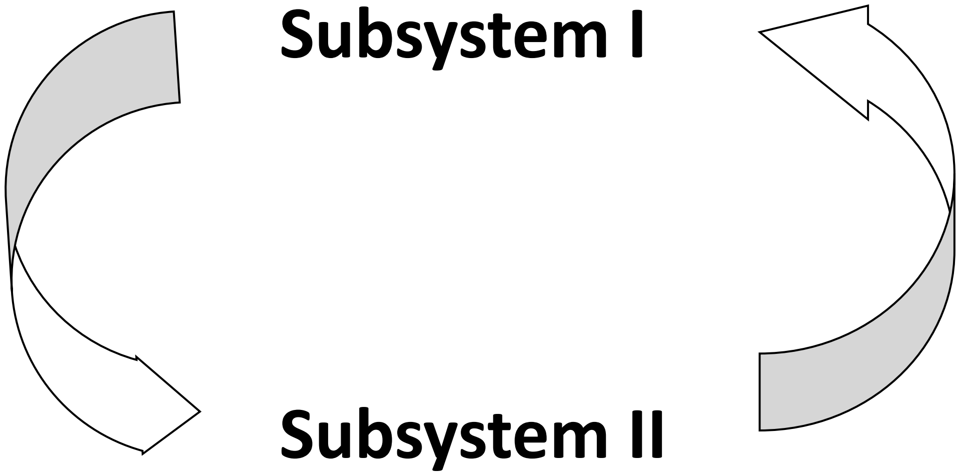
Subsystem I



Subsystem II

Weak Coupling (One-way)
Sequentially updated over interacting subsystems

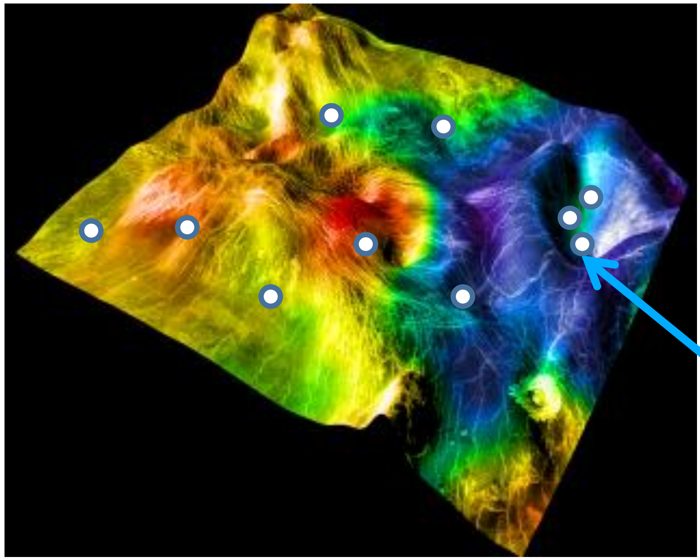
Multiphysics Coupling

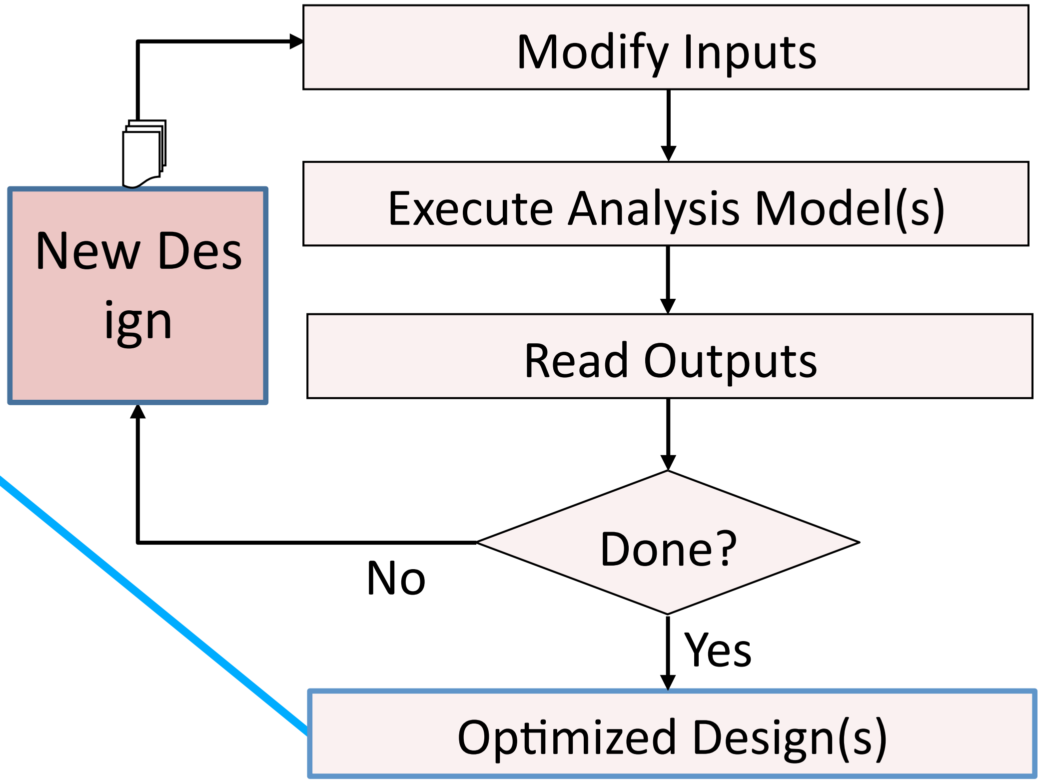


Strong Coupling (Two-way)
simultaneously updated over interacting subsystems

HEEDS MDO

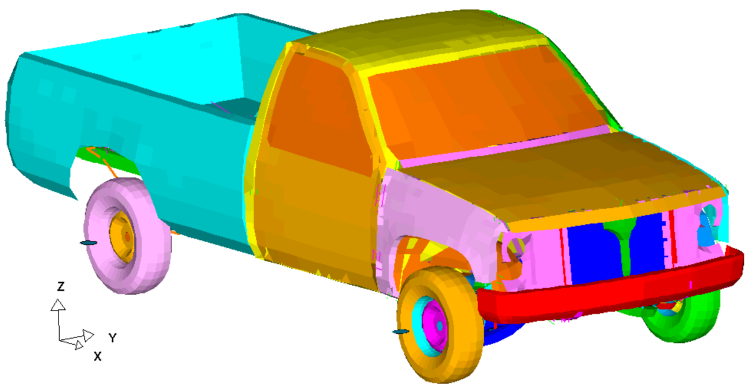
- A multi-disciplinary design optimization (MDO) software product that:
  - Automates the design evaluation process
  - Performs *parametric* design studies – MDO, DOE, Stochastic

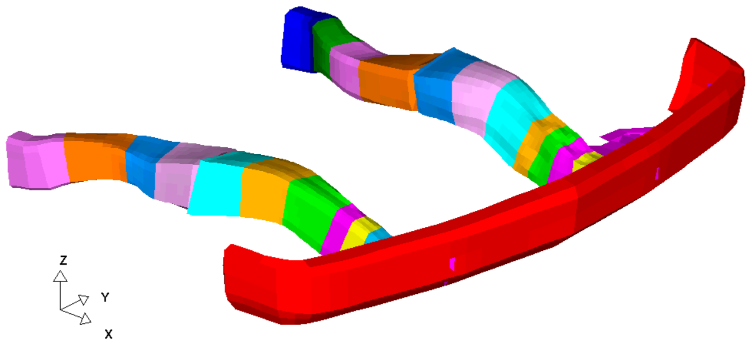




HEEDS COMPOSE

- COMPOSE – **COMP**onent **O**ptimization within a **S**ystem Environment
- New method for enabling high-fidelity design of subsystems in highly coupled complex systems





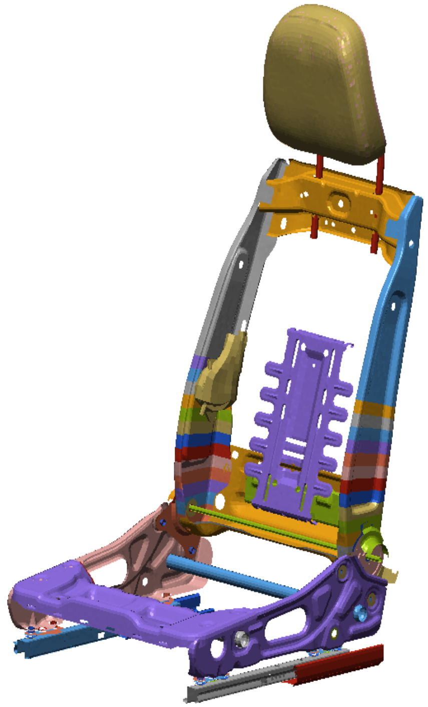
HEEDS MDO – Modules

- **CAE Portals**
  - Provide direct interfaces to major CAE tools:
    - Abaqus
    - Adams
    - ANSYS WB
    - LS-DYNA
    - Nastran
    - Excel
    - SolidWorks
    - SW Simulation
    - NX
    - Moldflow
    - *…and others*
  - Simplify development of design study models
- **PARALLEL**
  - Performs multiple analyses in parallel
  - Speeds up optimization runs linearly with extra computing resources
  - Interfaces with existing queuing software

    (PBS, LSF, MS Server and more)
- **HEEDS Q**
  - A job submission and management environment

Seat Frame Optimization

- **Loading**: Rear Impact, Modal
- **Two Objectives** (Pareto optimization problem)
  - Minimize Mass of the side members
  - Minimize Cost (material and manufacturing)
- **Constraints**
  - Peak avg. dynamic angular deflection < 30º
  - Maximum Twist < 15º
  - Max Recliner Torque < 1800 Nm
  - Natural Frequency 1st mode > Baseline
- **Design Variables** (TWB)
  - Thickness: 2 variables
  - Material: 2 variables
  - Shape: 7 variables



Compared to baseline/nearest optimizati on competitor:

- Reduced Mass by 25% / 10%
- Reduced Cost by 33% / 12%

Aero-acoustics

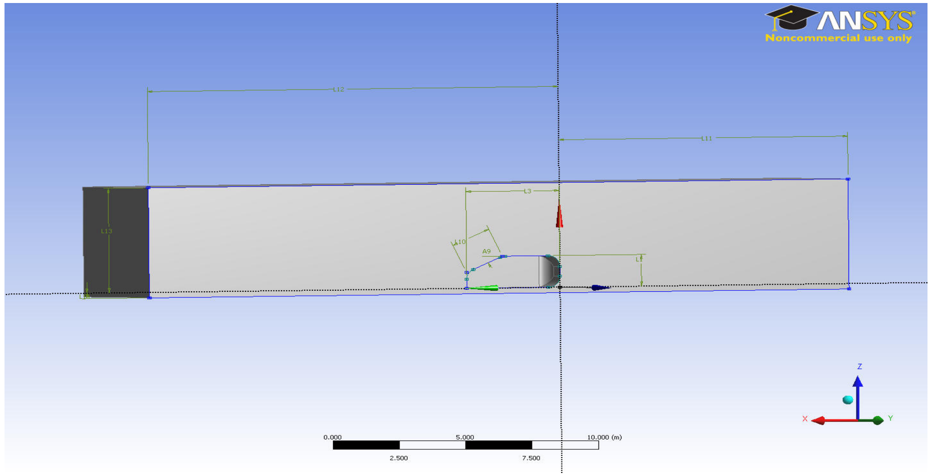
Wind Noise

Objectives

- To predict the aerodynamic noise generated by a vehicle.
- To find the region of the vehicle where the high noise source so that the NVH performance of the vehicle is improved by further modification of its geometry.

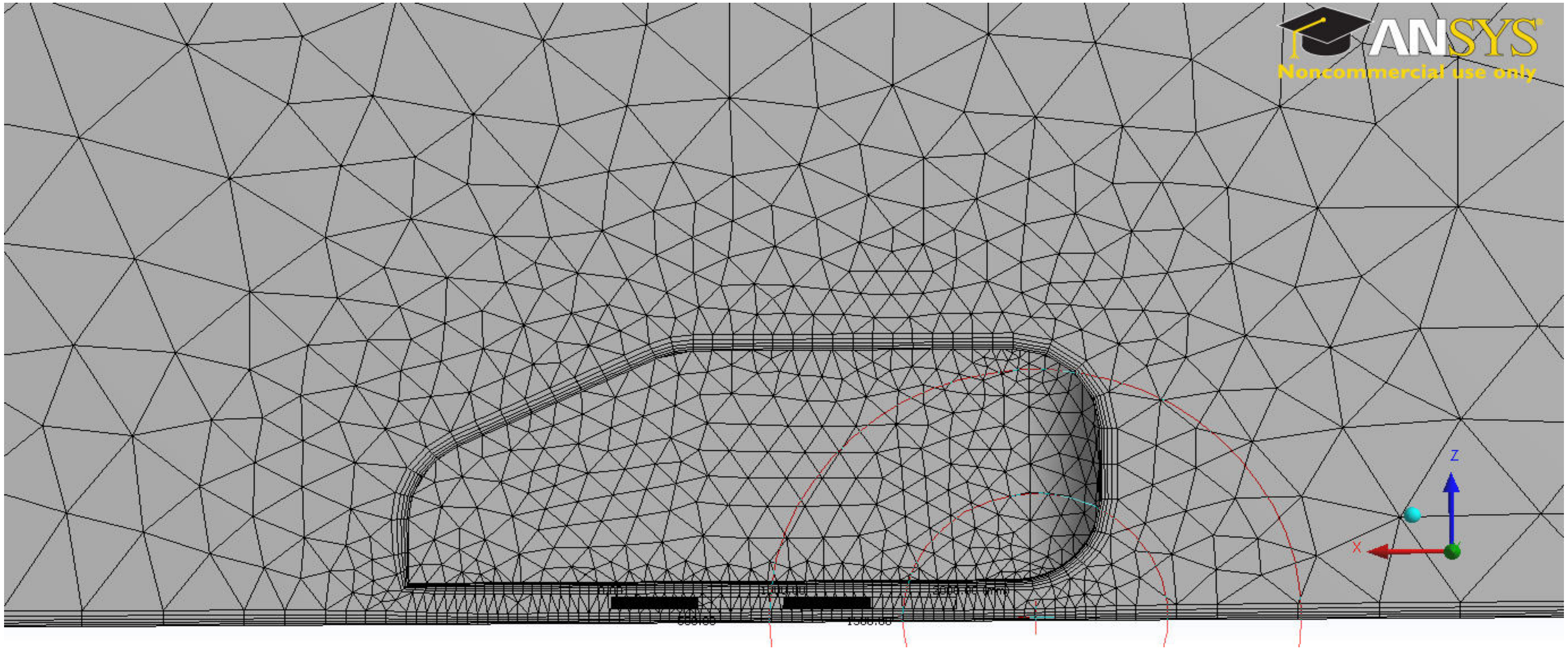
Approach

- A van type of the simplified vehicle is modeled
- The box around the vehicle is created for fluid flow simulation.
- The half of the vehicle is mounted on the box.



	H (m)	W (m)	L (m)
Vehicle	1.44	0.9	4
Box	5	5.15	30

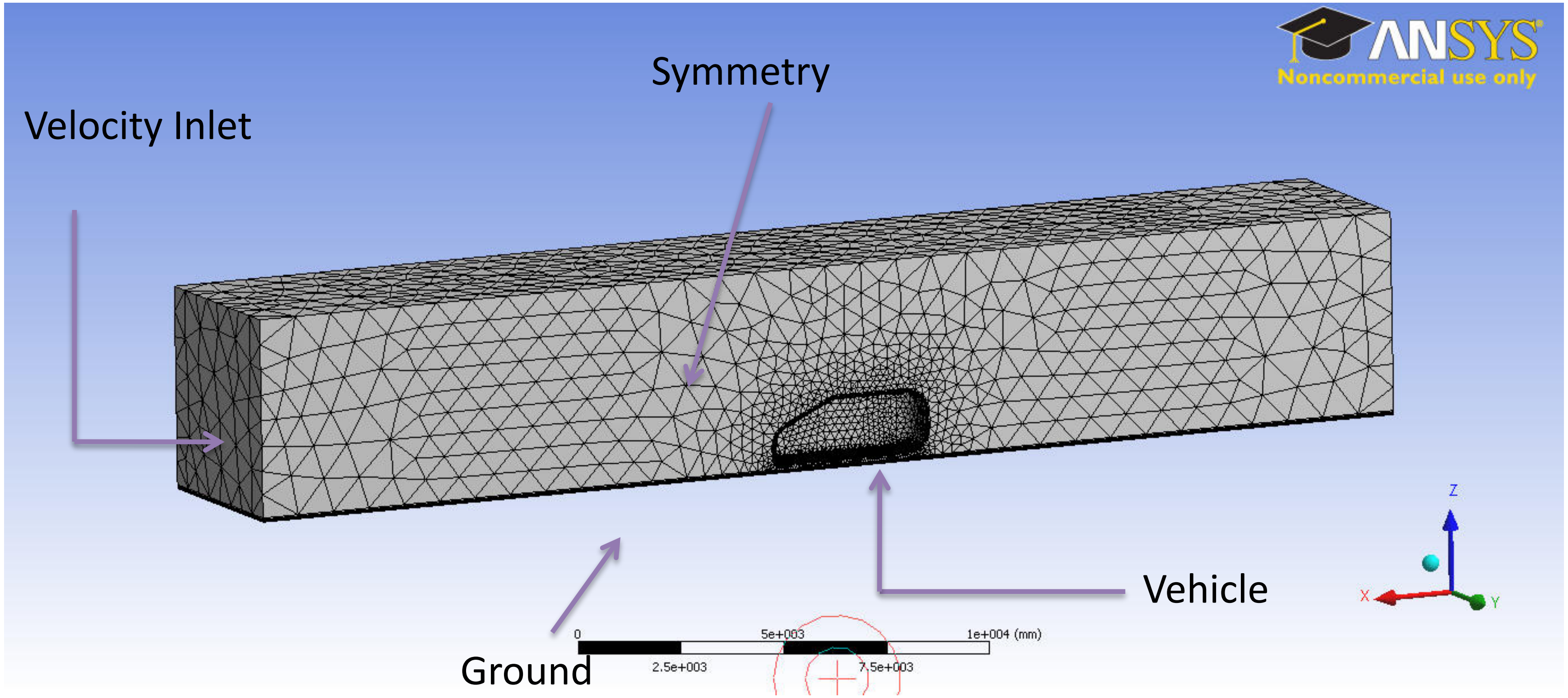
FE Model



Nodes	Elements
27152	93590

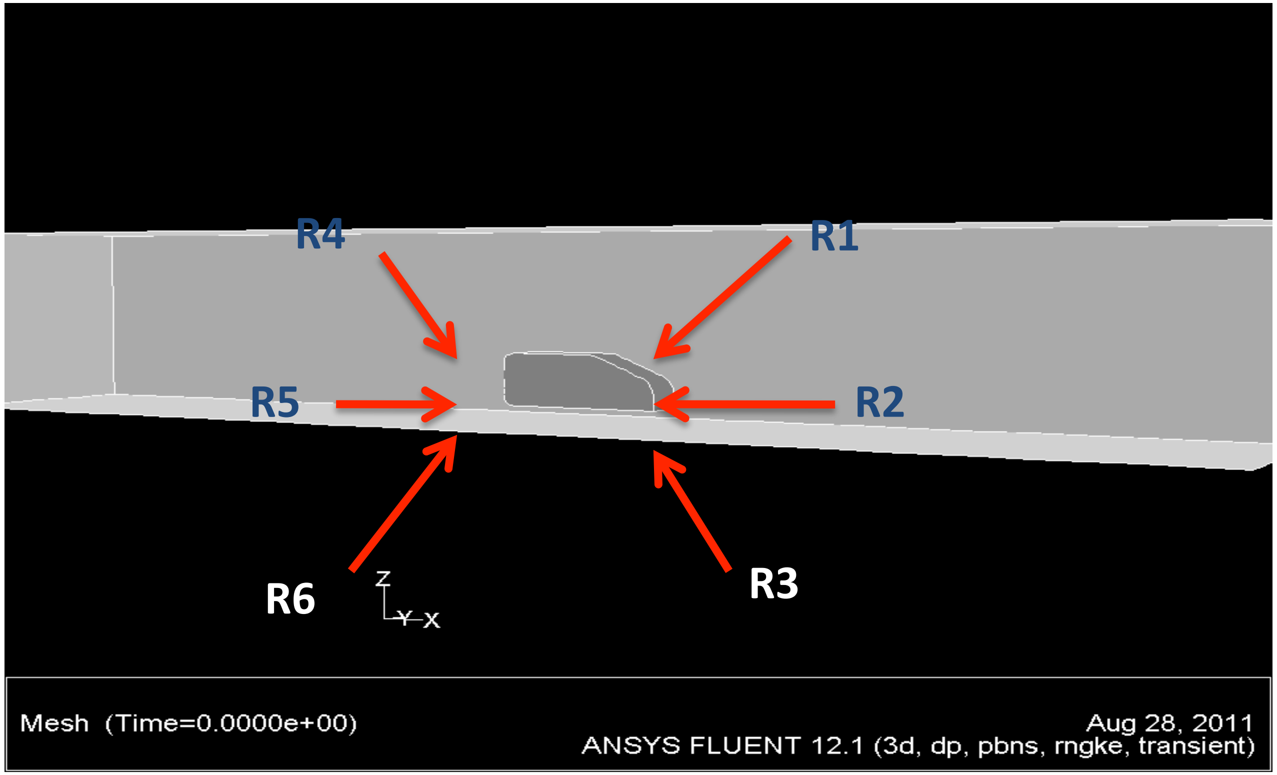
Boundary Conditions

Inlet Velocity: 200 kph
Vehicle, Ground: No slip wall



Boundary Conditions

Six receivers are located at bottom, middle, and top of the edge of the front and the rear of the vehicle.



Results

❑ **Flow velocity**

- The faster air flow observed at the bottom of the frontal area of the vehicle.
- Wake region behind of the vehicle can be seen.

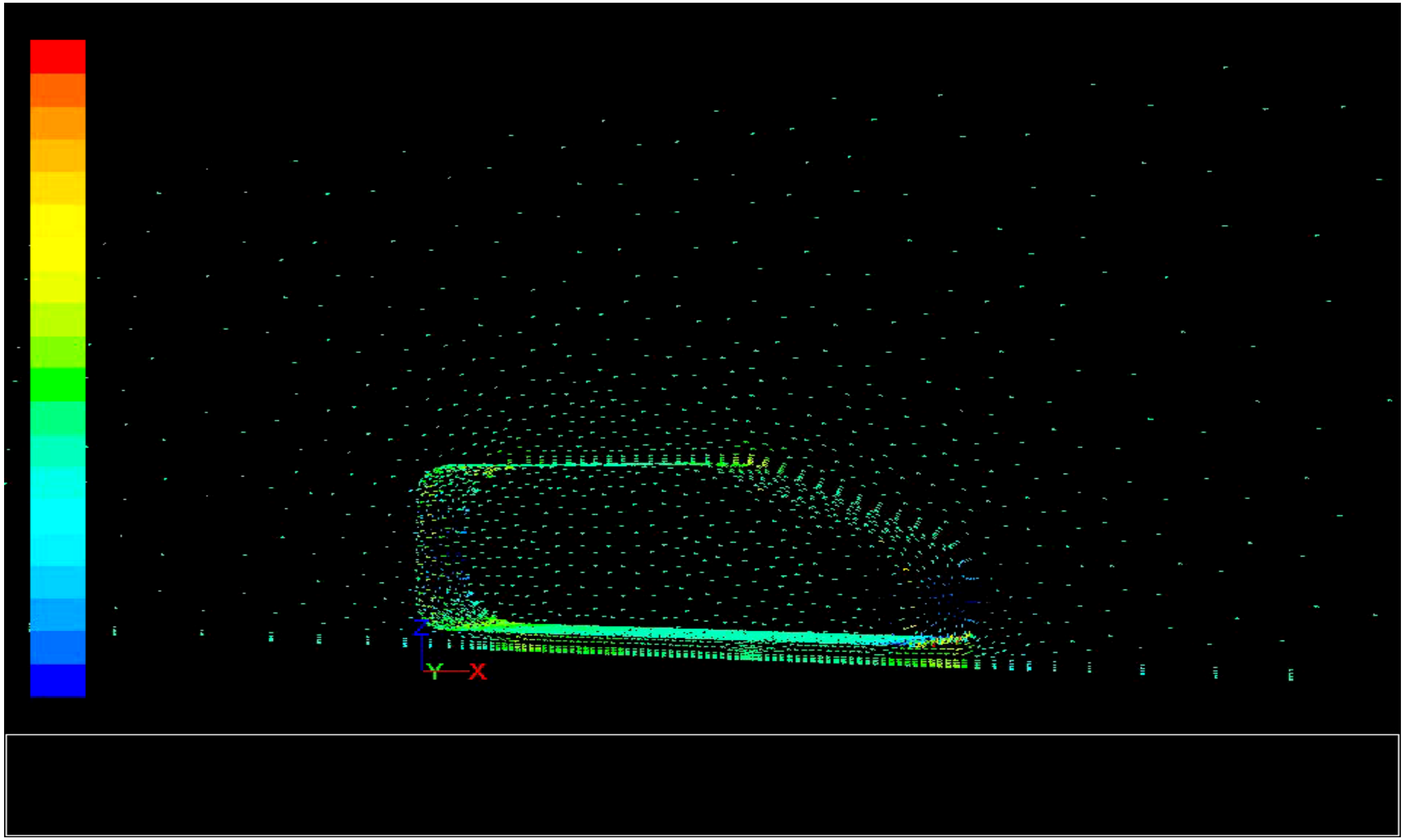
❑ **Flow Pressure**

- High pressure at the front and low pressure at the rear area of the vehicle

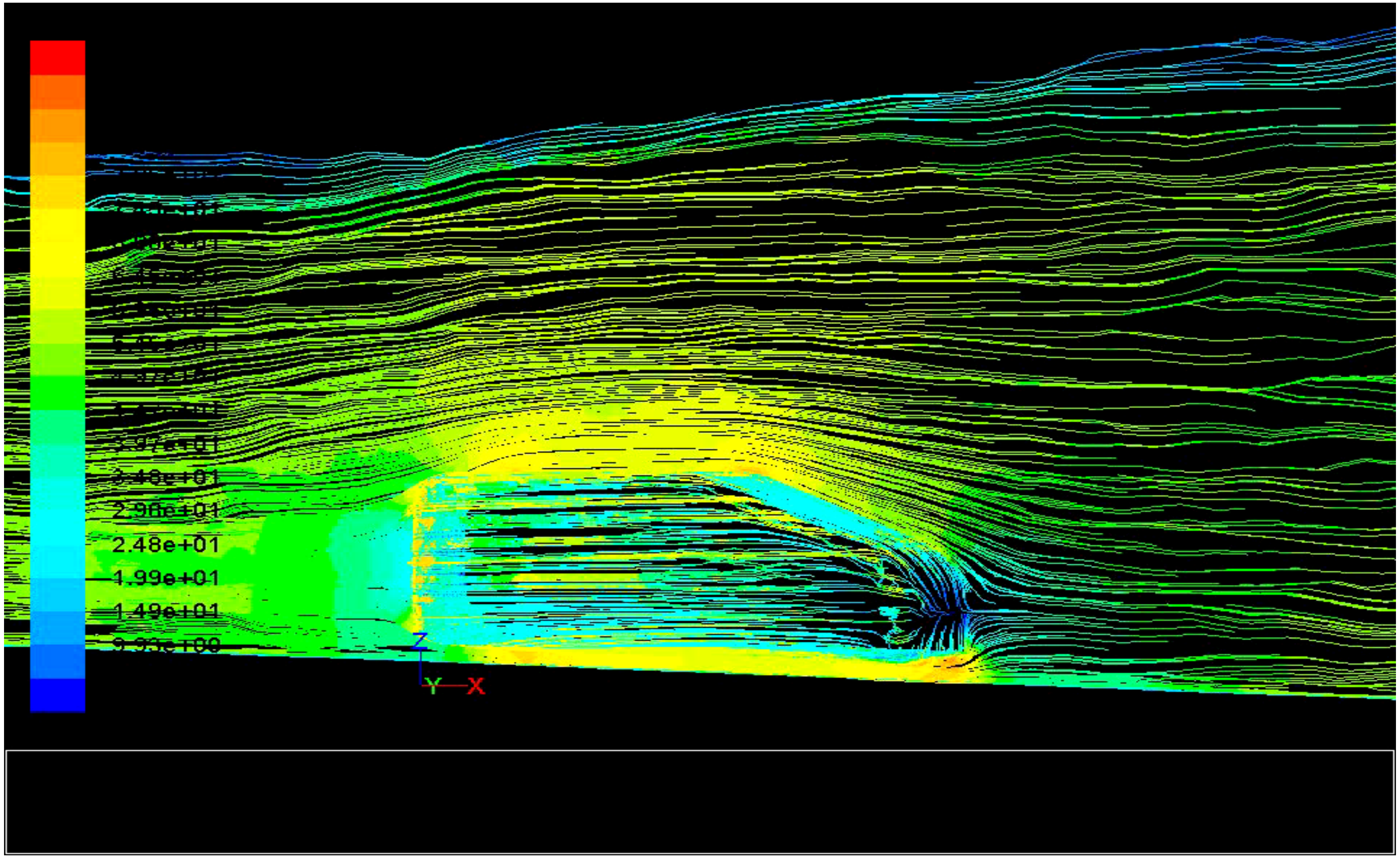
❑ **Noise Generation**

- Bottom and a-pillar region of the vehicle radiate most of noise.

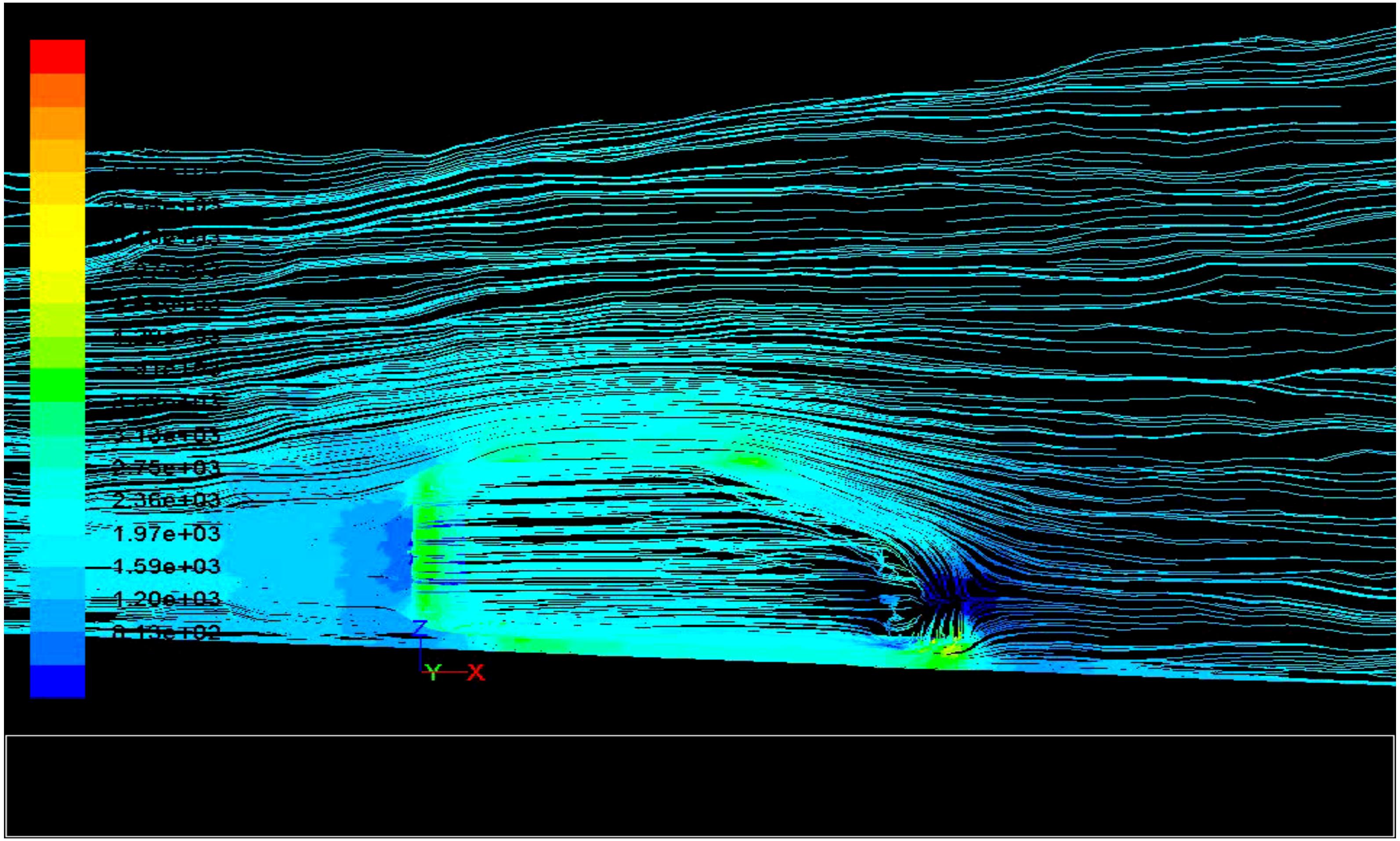
Velocity Vectors



Velocity Paths



Dynamic Pressure



Sound Pressure Level

Receiver	Overall sound pressure level (dB)
1	94.71697
2	105.3221
3	107.5347
4	103.1495
5	118.7685
6	101.9685

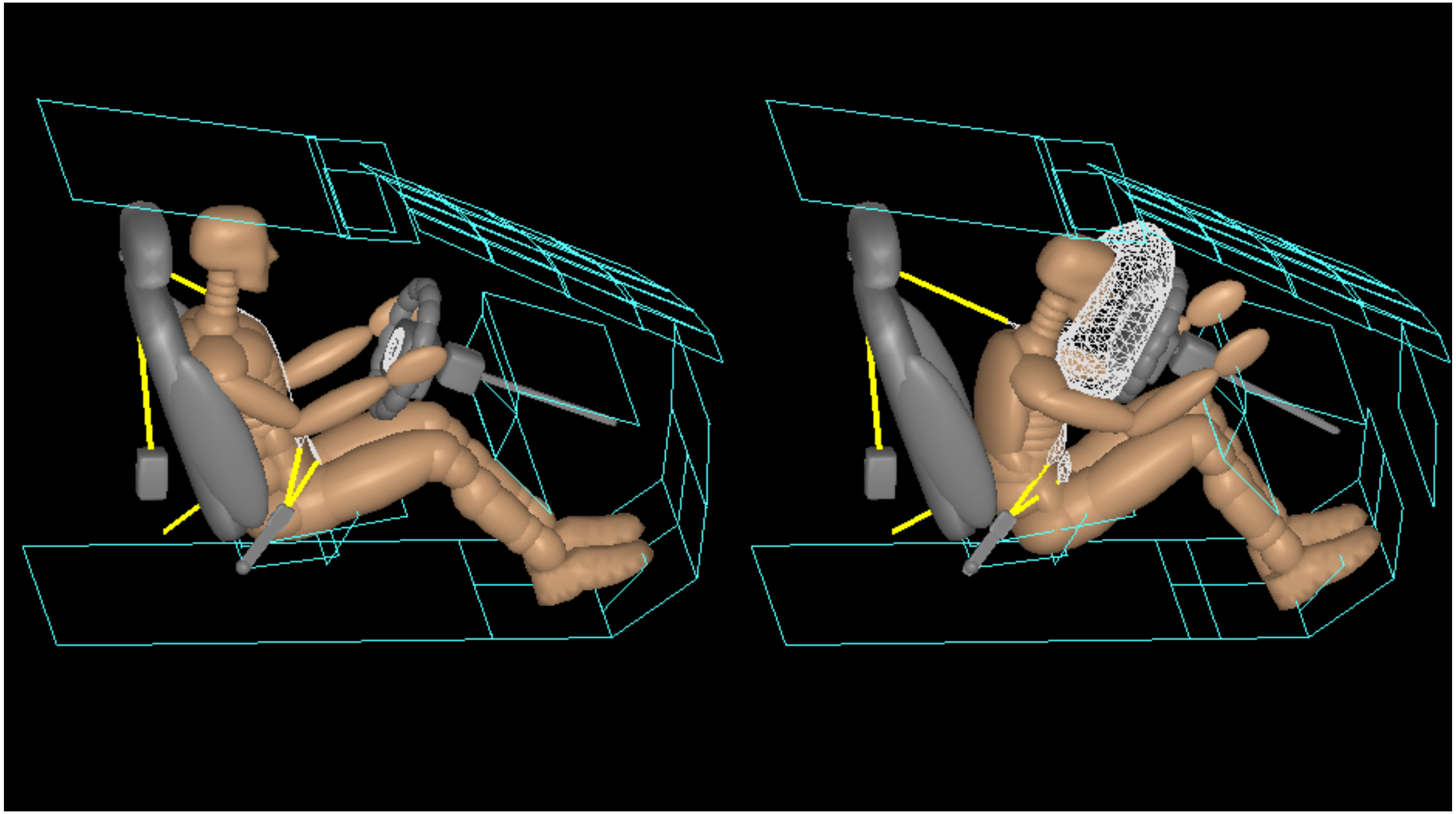
Conclusion

- The bottom of the frontal area and the rear area of the vehicle are predicted to generate most of the wind noise when the vehicle cruising at high speed.
- At frontal region, receiver 3 located at the bottom shows high sound pressure level.

Conclusion

- Highest sound pressure level observed at receiver 5.
- Due to turbulence created at the wake regions that are sources of sound (unsteady pressure variation).
- High noise source regions can be modified to improve NVH performance in design-wise.

Virtual Testing for Crash Safety



Testing with Virtual Prototypes

Early Design Cycle

- Packaginging vehicle front-end structure
- Restraint system selection
- Model correlation
- Component design

Middle Design Cycle

- Model updating
- Restraint system design

Late Design Cycle

- Model updating
- Fine tuning restraint system design
- Lessons learned

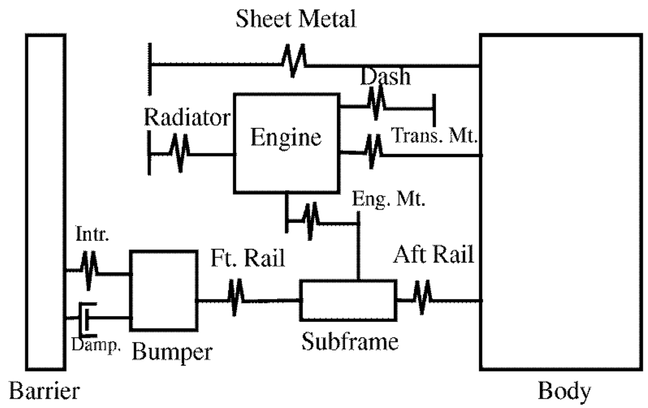
Optimize with CAE:

Early Design Cycle Modeling

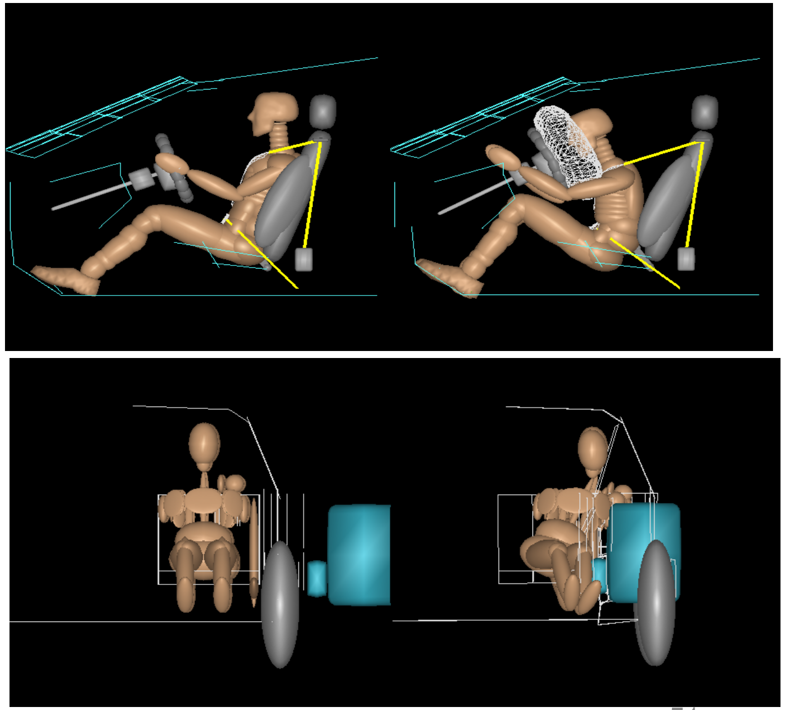
* Lumped-mass models for packaging studies

* Madymo models for restraint system selection

* Non-linear beam models for structural section selection



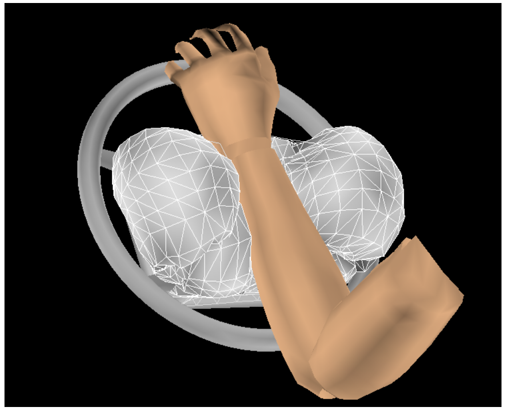
Ex: Frontal & Side Impact S tudies



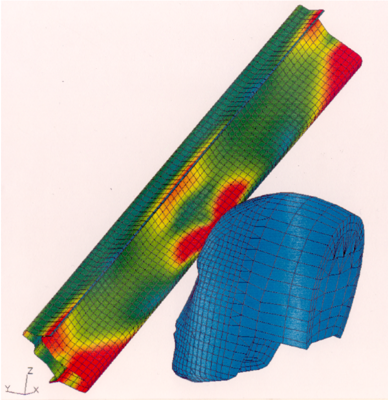
Mid-Cycle Design Modeling

* Madymo/Non-linear FE Coupling
* Madymo/Fluid Coupling
* Hybrid - Lumped mass / FE
* Component FEA

Ex: Driver/Airbag Interaction Studie

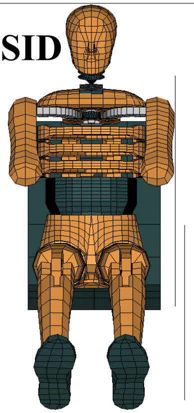


Ex: Head Impact Studies



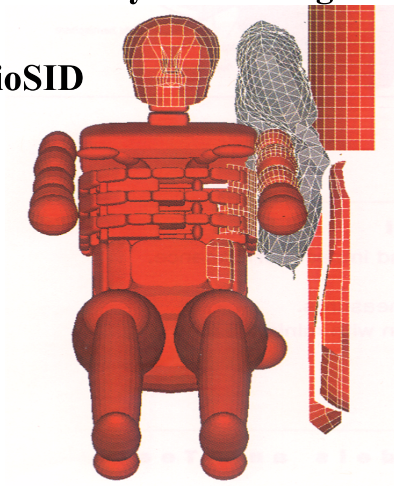
FE Dummy Model

EuroSID

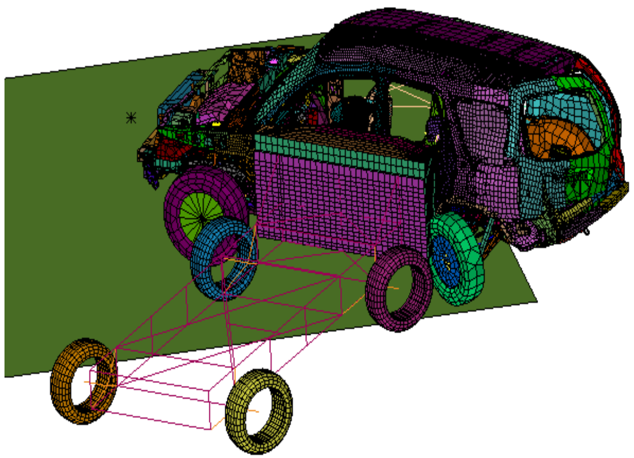


LM Dummy/ FE Airbag Model

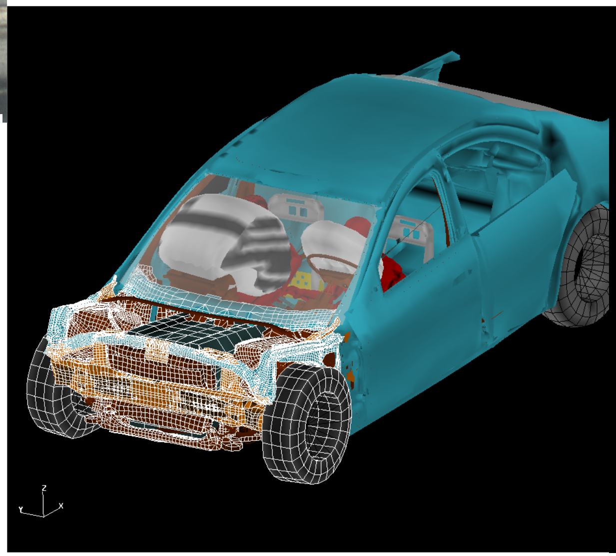
BioSID



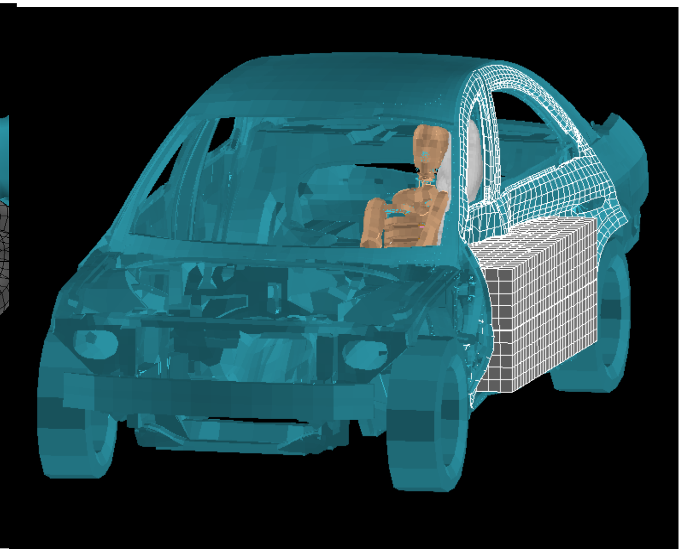
Late-Cycle Design Modeling



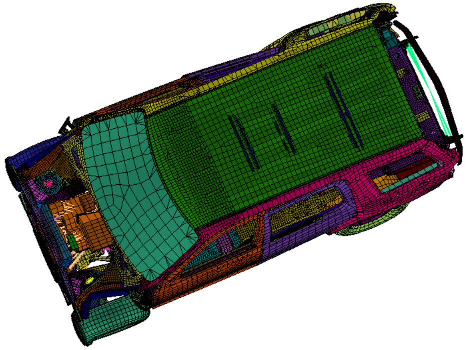
Ex: Frontal, Rigid Fixed Barrier Studies



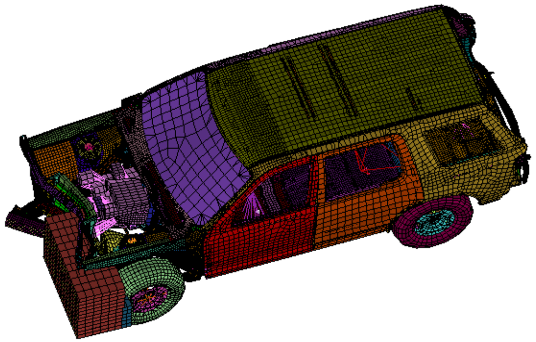
Ex: Side Impact Studies



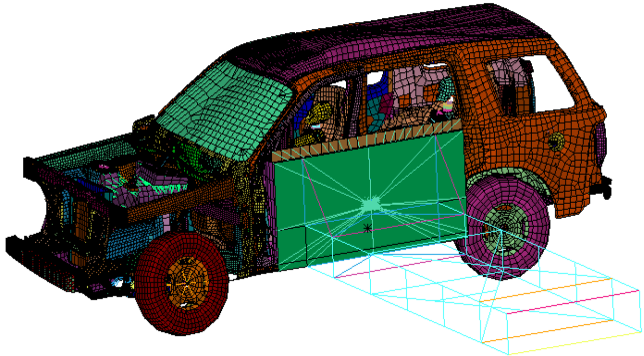
Examples of Vehicle Crash Modes



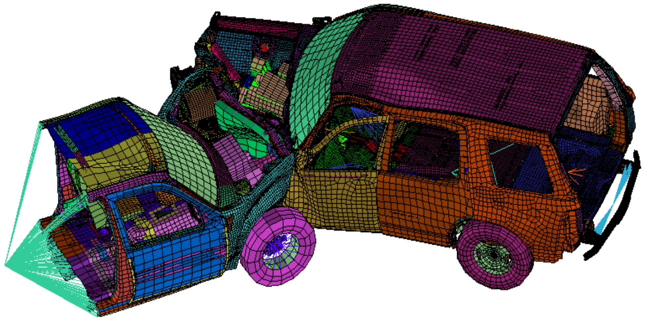
Frontal impact



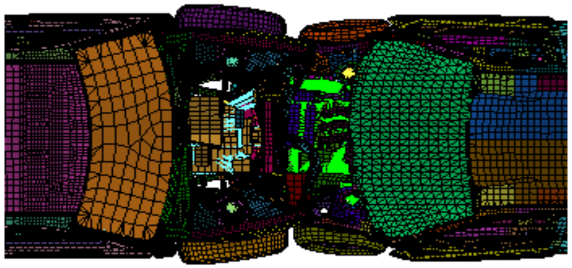
IIHS 40% offset impact



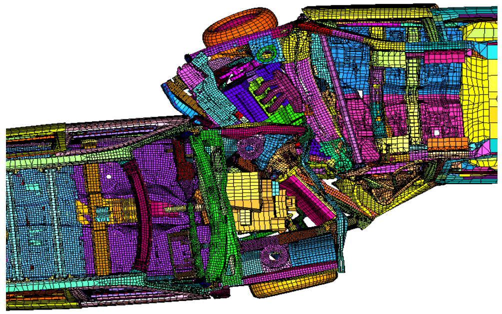
Side impact



Oblique impact



Full frontal collinear impact



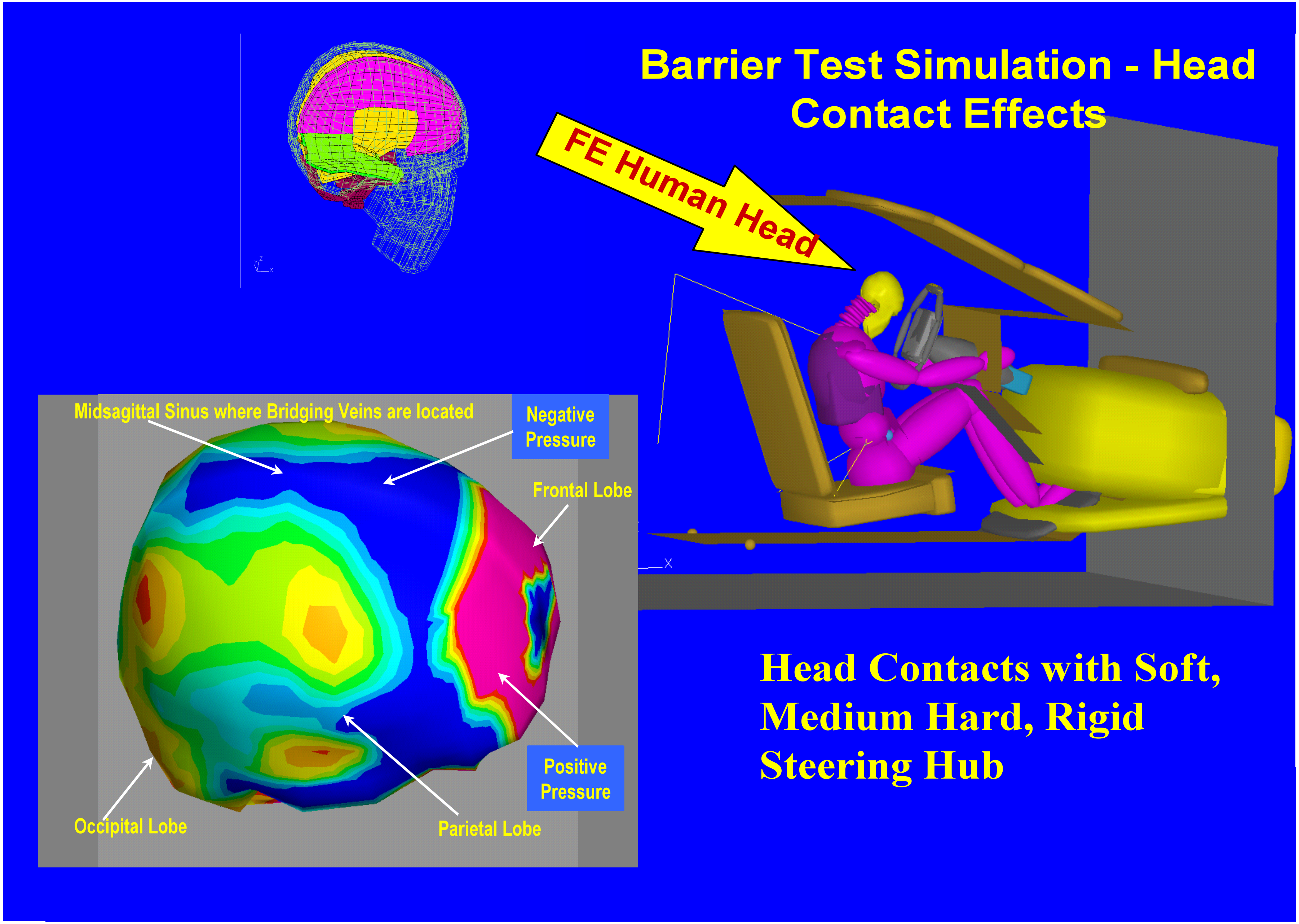
50% offset collinear impact

Biomechanics

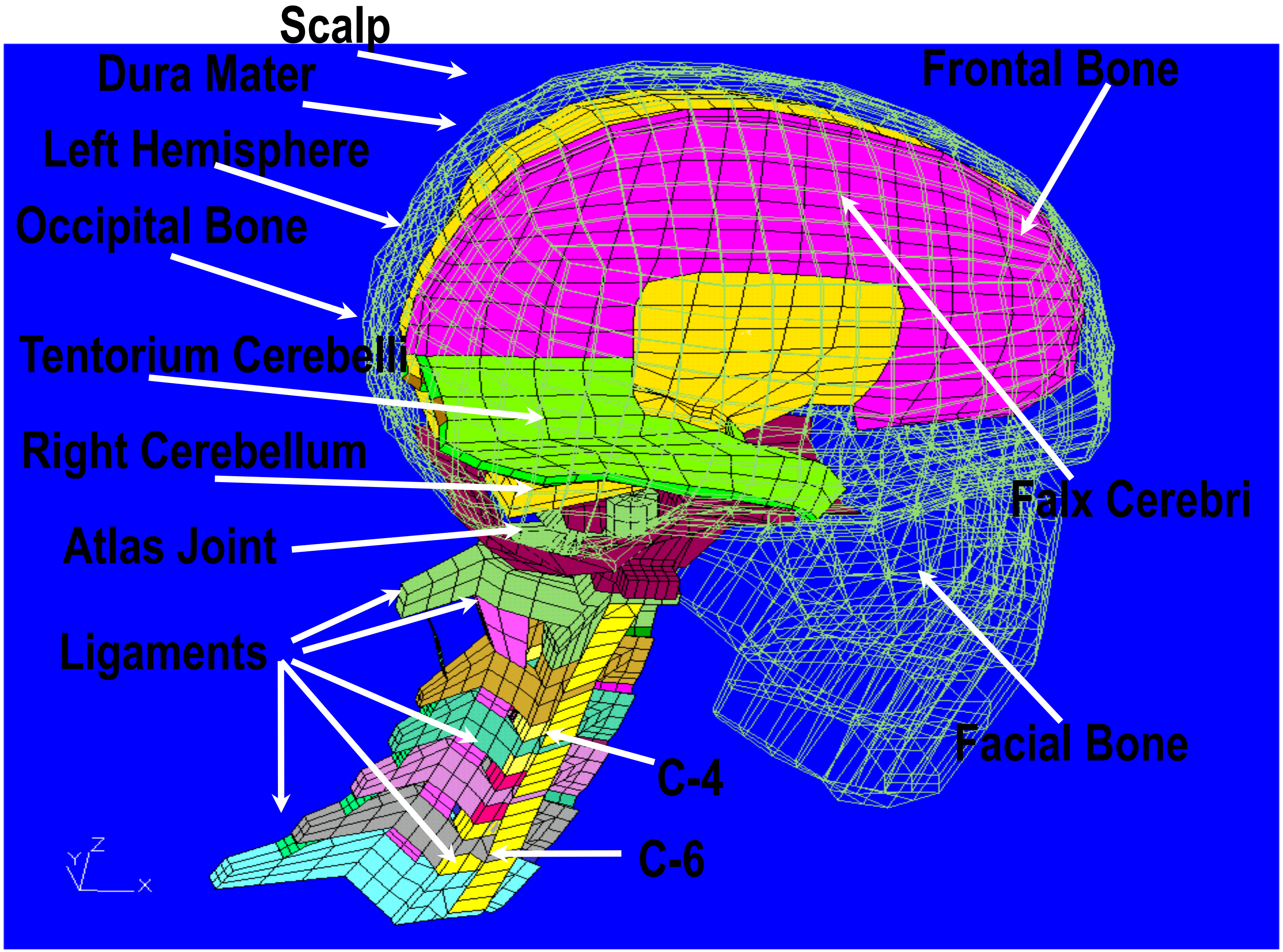
- Growing Multiphysics area
- Made possible by FEA techniques
- Can lead to refined injury criteria based on tissue level injuries rather than forces and moments
- Currently used for hypothesis testing
- Example: human skull/brain, Total Human Body Model

Human Head/Brain Modeling

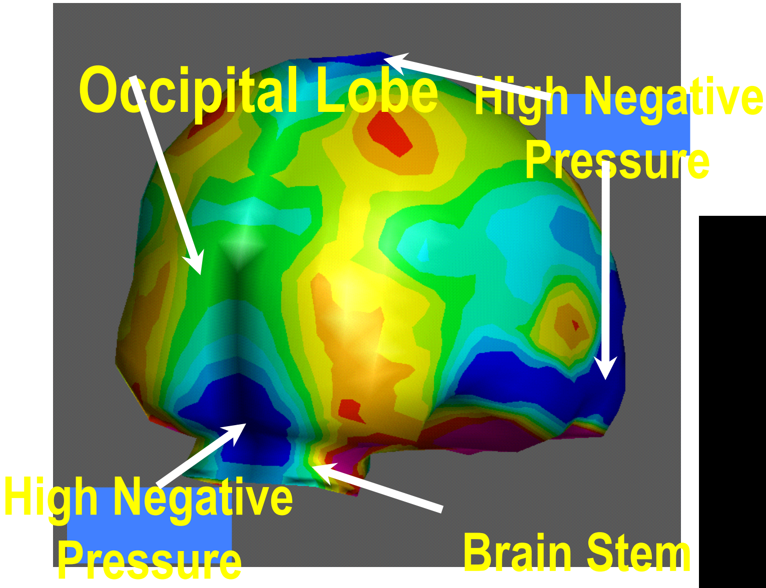
- FE model for the human head and brain has been developed and validated against frontal impact cadaver test data. The model has been used for various impact conditions in automotive environment
- Experimental and theoretical studies of human skull fracture risks and tolerance
- Modeling the boundary between the CSF and brain with Solid-Fluid Coupling technique

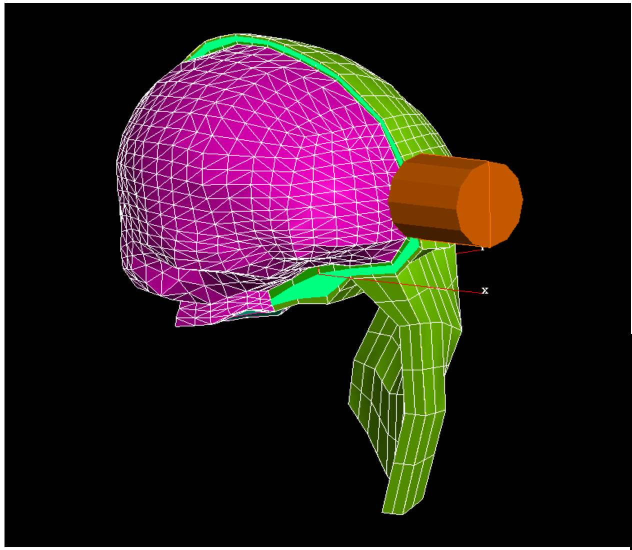

Barrier Test Simulation - Head Contact Effects
FE Human Head
Midsagittal Sinus where Bridging Veins are located
Negative Pressure
Frontal Lobe
Positive Pressure
Occipital Lobe
Parietal Lobe
Head Contacts with Soft, Medium Hard, Rigid Steering Hub

Human Body Head and Neck



Response, Tolerance, and Mechanisms of Brain Injury

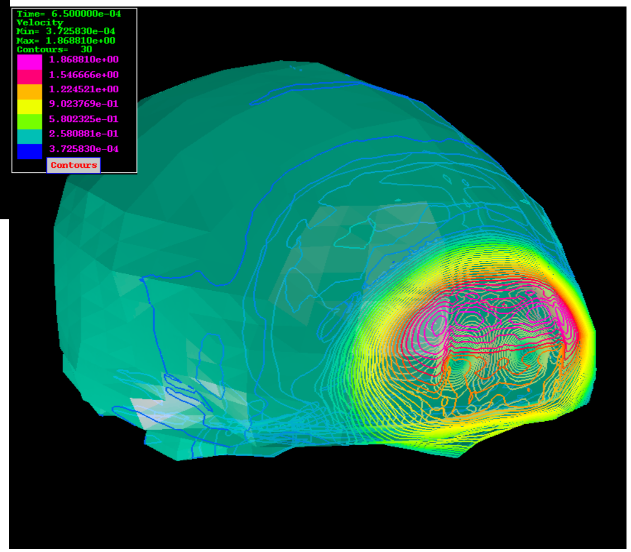




Rigid Cylinder Impact

(PAM-Solid/Flow Coupling)

CSF velocity



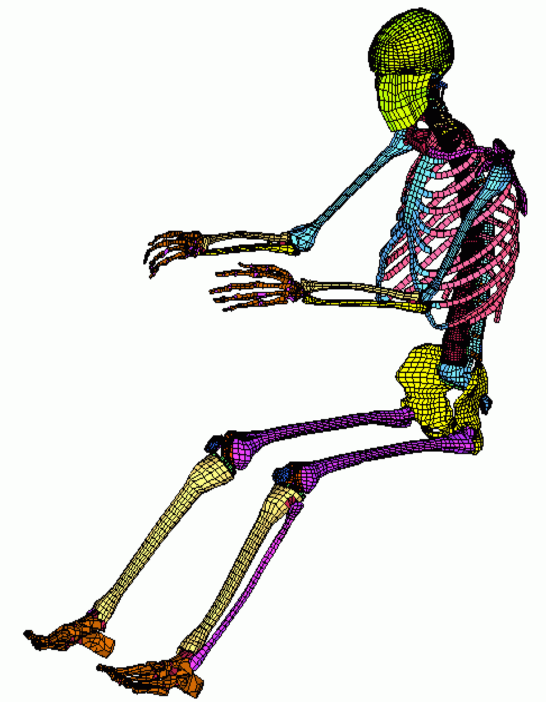
Human Body Modeling (HBM)

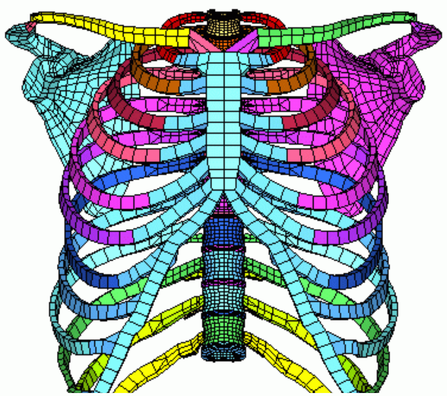
- Worldwide crash regulations have differences in crash dummies and divergence in injury criteria
- Regulatory injury criteria is based on the biofidelity and measurement capability of crash dummies
- Tissue level injuries as opposed to forces, moments, acceleration, etc. with dummies
- New advanced Restraint System evaluation
- Drives human like dummy development with an optimum goal to replace crash dummies with HBM
- Mild Traumatic Brain Injury (MTBI), predictions through strain and strain rate of the brain tissue

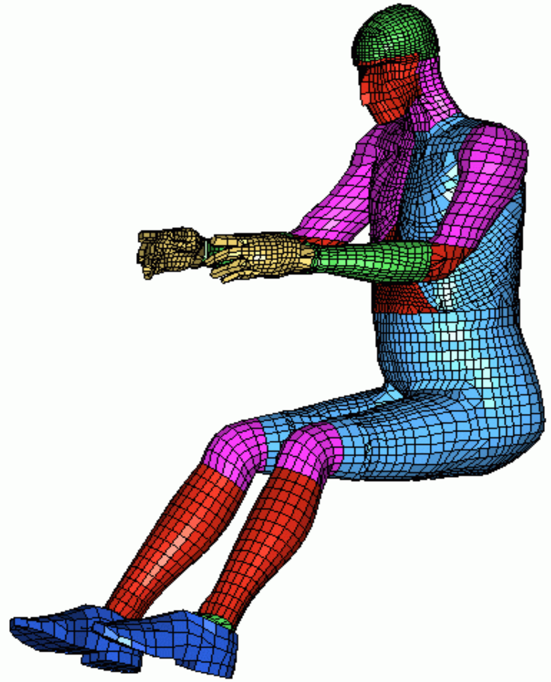
Descriptions of the HBM

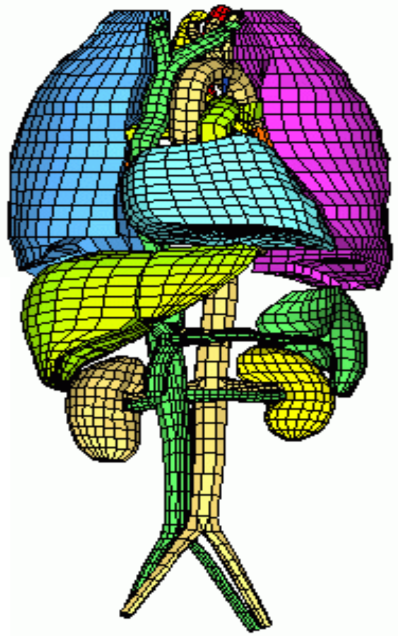
- The model is fully deformable, no rigid body defined for any body part.
- The synovial joints are defined by contact interfaces with synovial fluid in between.
- Long bones were characterized by elastic-plastic material and soft tissues were characterized as visco-elastic.
- Used as a research tool in assessing new restraint system

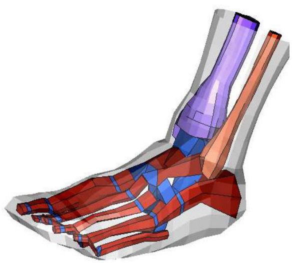
Total Human Body Modeling

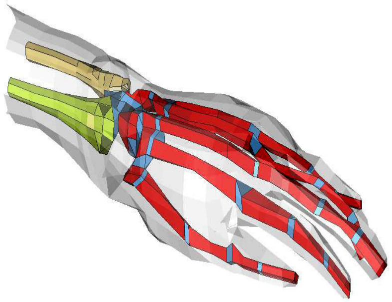


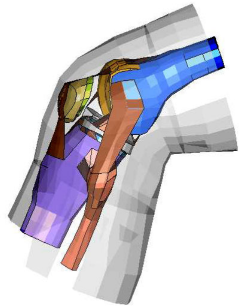




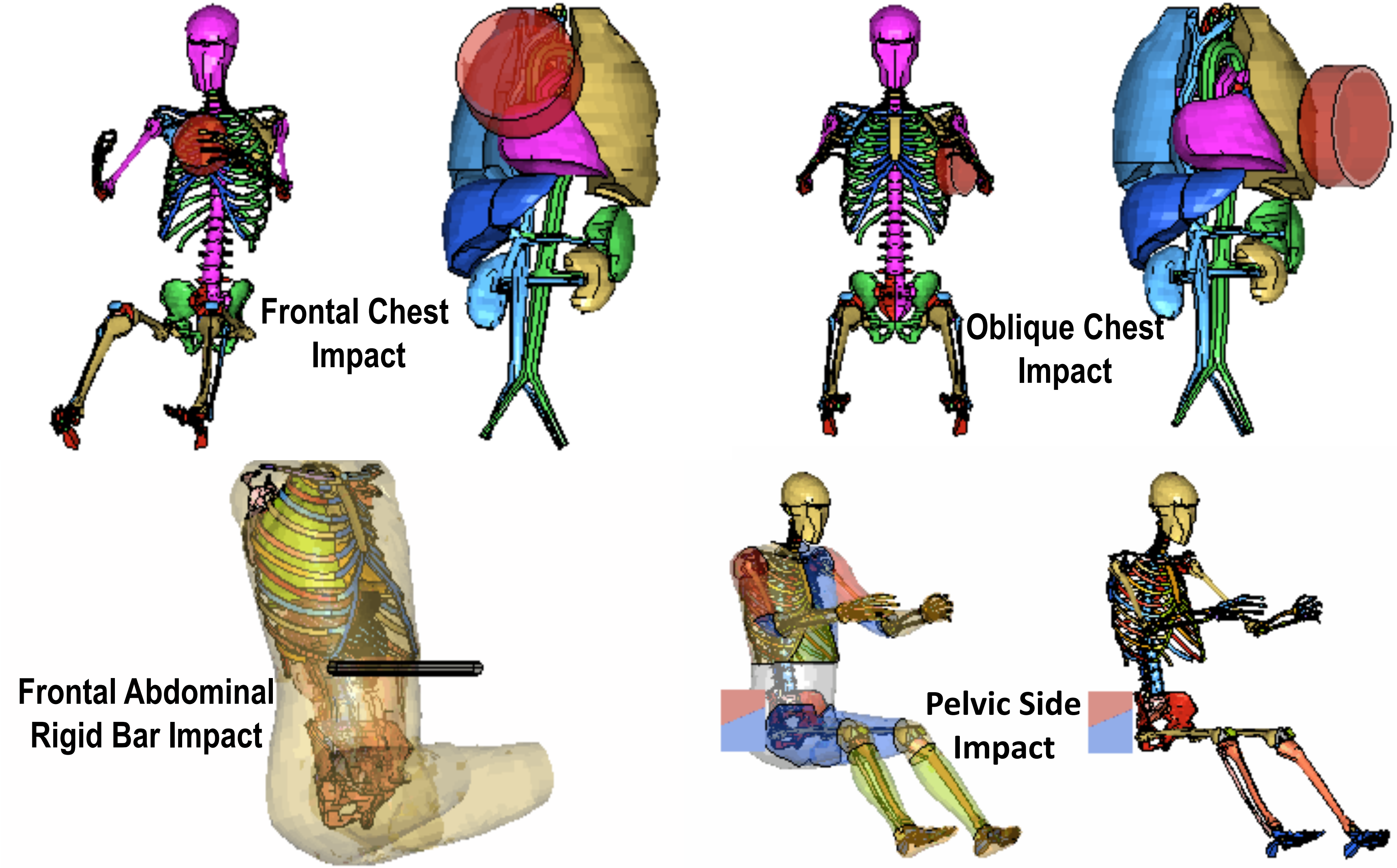








Blunt Impact Test/Simulation Validations



Challenges to Crash Safety Simulation

Damage and Rupture Modeling

- Rupture of sheet metal
- Rupture of cast components such as suspension arms, transmission housing, etc.
- Rupture of engine mounts and other joints

Challenges to Multiphysics Simulation

- An Automated Process to evaluate a family of crashes covering all critical speeds, impacts conditions, occupant size/age/seating position
- Integrated Structure-Occupant-Restraint analysis and Cross-Attribute Optimization
- Biomechanics Modeling:
  - Replace dummy models with human models - can lead to refined injury criteria
- Stochastic and robustness analysis

Automotive Industry Recalls

In 2004, the Auto Industry recalled 30,556,064 million cars, pickups, SUVs and vans in 598 separate actions.

An average recall takes 250 days and costs $1 million a day.

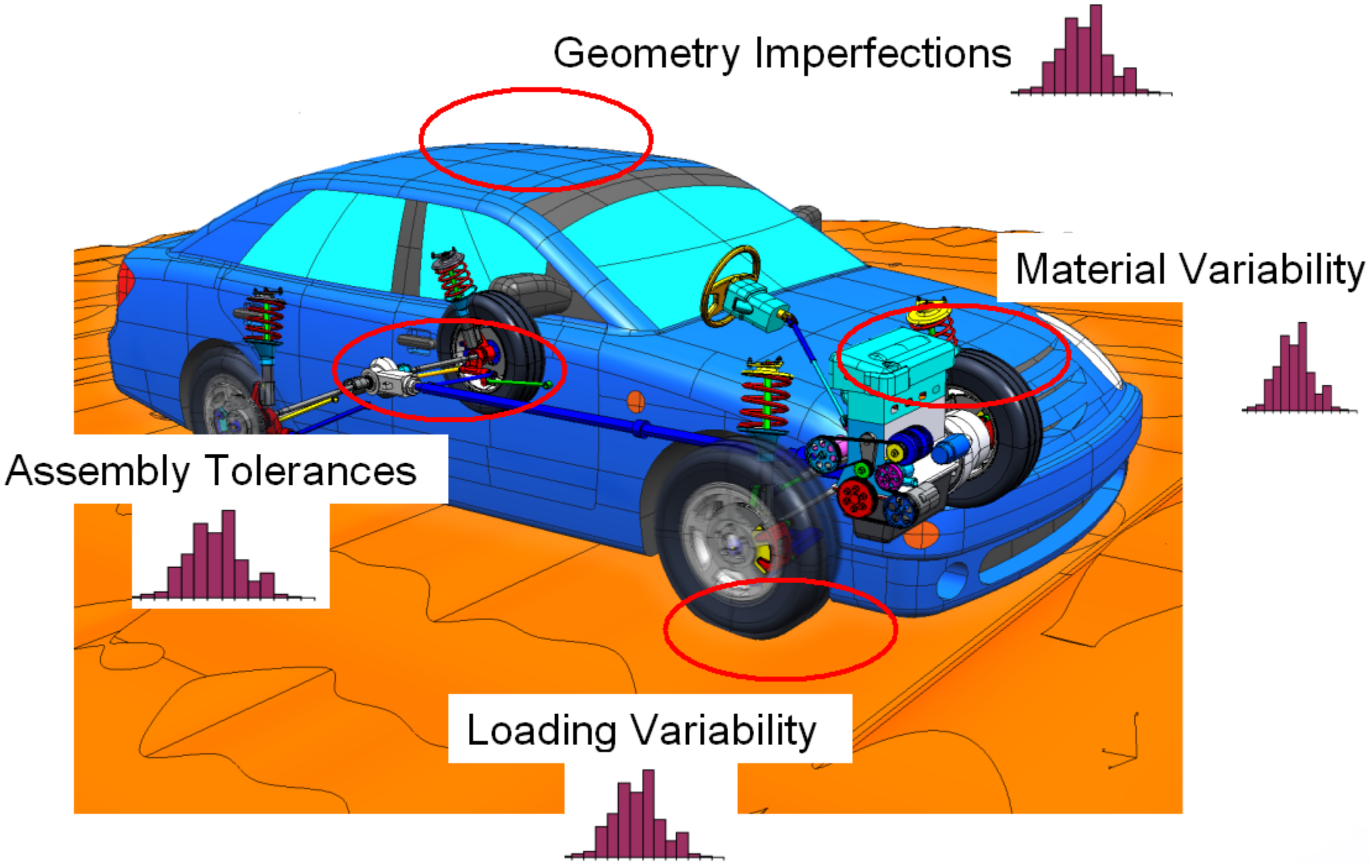
Average Cost = $250 million.

Source: Automotive Industry Action Group

http://www.applesforhealth.com/HealthySurvival/ararl6.html

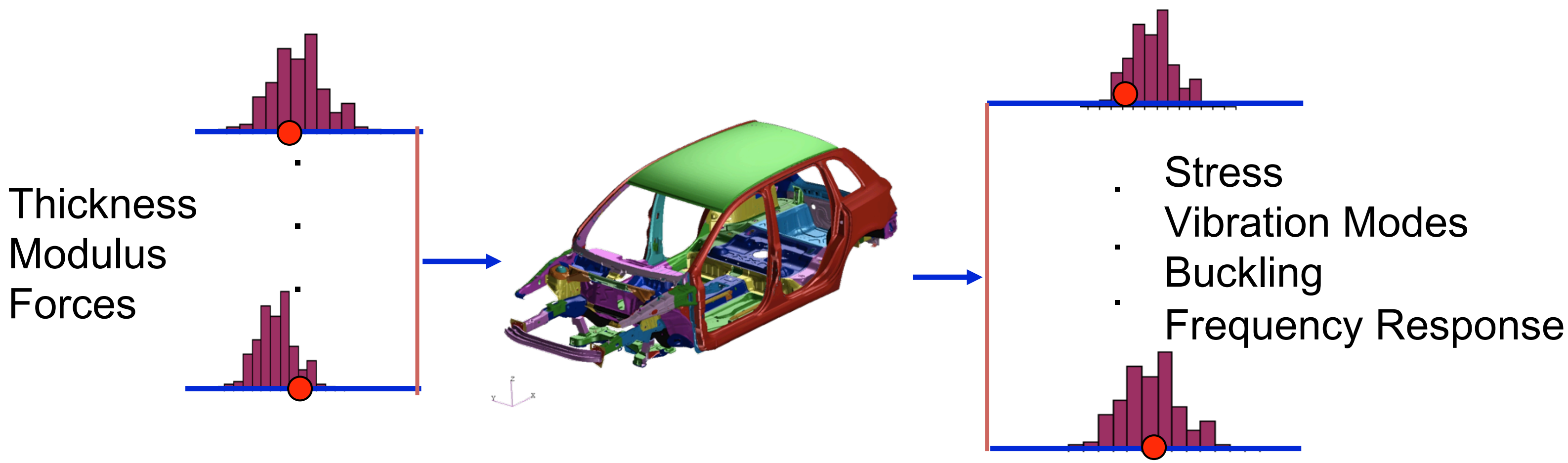
Automotive Industry Recalls

To be able to evaluate designs in a realistic environment, one that includes uncertainties

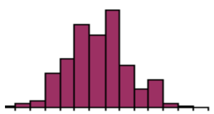


MSC.Robust Design

MSC.Robust Design is a tool which enables one to perform stochastic simulation, i.e. to evaluate and understand the behaviour of systems in the presence of uncertainty.



Nominal Performance – Focus of traditional analysis



Performance scatter – Focus of Robust Design analysis

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