Virtual Prototyping to predict the Vehicle Dynamics Performance of an Inter-City Bus

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Agenda

- About the Company
- Need for virtual prototyping
- Ride & Handling Target Book
- Modeling
  - Sub-System
    - Steer Axle and Suspension, Drive Axle
    - Body
    - Powertrain
  - Tire (Handling & F-Tire)
    - Measurement
    - Parametric Modeling
  - Full Vehicle assembly
  - Road Profile
- Analysis
  - Suspension Kinematics & Compliance
  - Full-Vehicle Level
    - Modal Analysis
    - Ride
    - Handling (Ramp Steer, Step Steer, ISO Double Lane Change)
- Conclusions

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About Mahindra Navistar

- **Mahindra Navistar Automotives Ltd**. is a 6 year old joint venture between - Mahindra & Mahindra Ltd. (M&M) and Navistar Inc. USA.
- The product range includes Rigid trucks, Tractor trailers, Buses and Tippers in the tonnage range of **3.5** to **49** ton.
- Over **600** people involved in the development and support of its Indian products.
- Vehicles are manufactured at M&M's new Greenfield Plant near Pune
- **Mahindra Engineering Services Ltd**. supports product development in Structural Analysis and Vehicle Dynamics, using high-end CAE tools.

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Need for Virtual Prototyping

- Demand for **high-speed** and **comfortable** inter-city luxury buses is growing at **~25% per annum**
  - Substantial investments planned in infrastructure
  - **Higher customer expectations** due to presence of **experienced global bus players**
  - ⇒ Results in a need to provide good ride and handling properties on buses

- Time and money constraints to carry out iterations on physical prototype
- Need for systematic methods for up-front prediction of various vehicle performance parameters

This presentation describes the virtual prototyping to predict the vehicle dynamics performance of such an inter-city bus.

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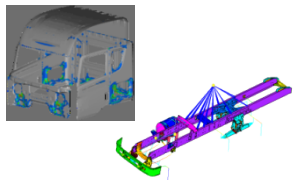
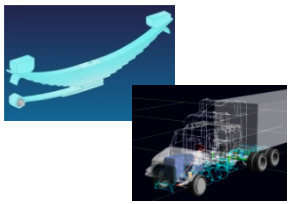
CAE for Commercial Vehicles

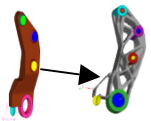


Durability

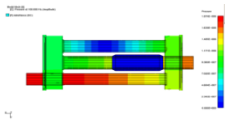


Ride & Handling

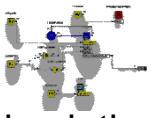
Crash



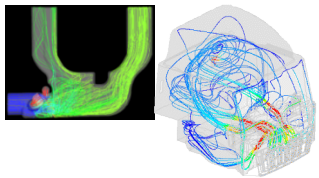
Optimization



NVH



1D Simulation



CFD

Benefits of Virtual Prototyping

- Better insight into the dynamics of suspensions with a new topology
- Vehicle performance can be *predicted from* or *cascaded to* suspension performance & chassis dynamics
- Reduction in iterations
- Models can be extended to measure forces on suspension components & chassis

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R&H Target Book

A ***full-vehicle*** level & ***suspension*** level target book drive the product development for achieving the requisite vehicle dynamics performance. Vehicle performance can be *predicted from* or *cascaded to* suspension performance & chassis dynamics.

Ride Targets
(Ride Quality Number & Index, Modal Separation, Transmissibility, …)

Handling Targets
(U/S gradient, Roll gradient, Roll over threshold
Overshoot, Response Times, Brake Veer …)

Suspension Targets
(Suspension Kinematics & Compliance parameters, Mobility)

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- **Modeling**
  - Sub-System
  - Tire (Handling & F-Tire)
  - Full-Vehicle Assembly
  - Road Profile
- Analysis
  - Suspension Kinematics & Compliance
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    - Modal Analysis
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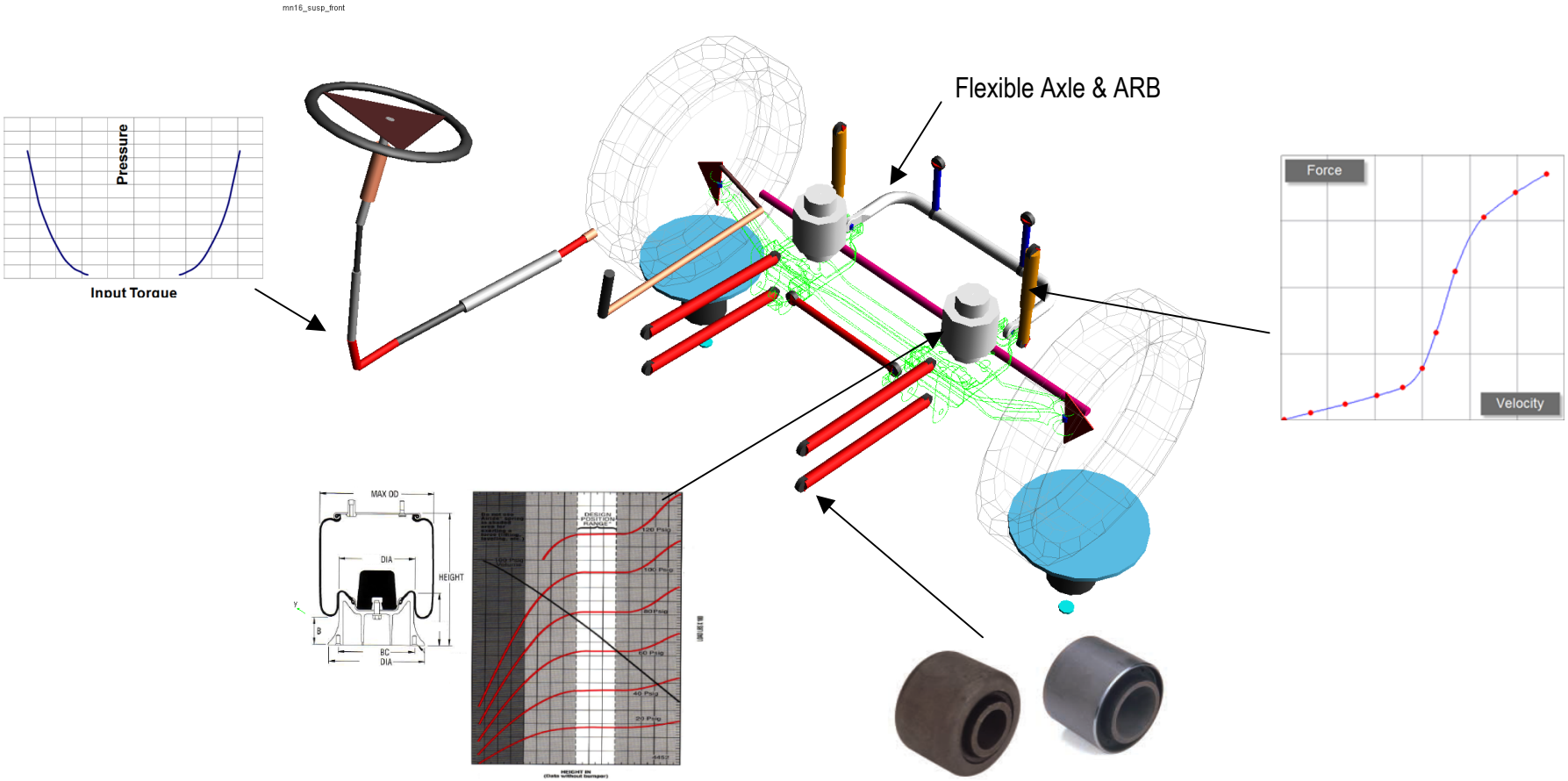
Modeling: Steer-Axle Suspension model

The model incorporates an accurate representation of **air-bag with height control** valve, **non-linear shocks** & **bushings**, structural **flexibility of axle** & **anti-roll bar** and a **power-assist steering** system



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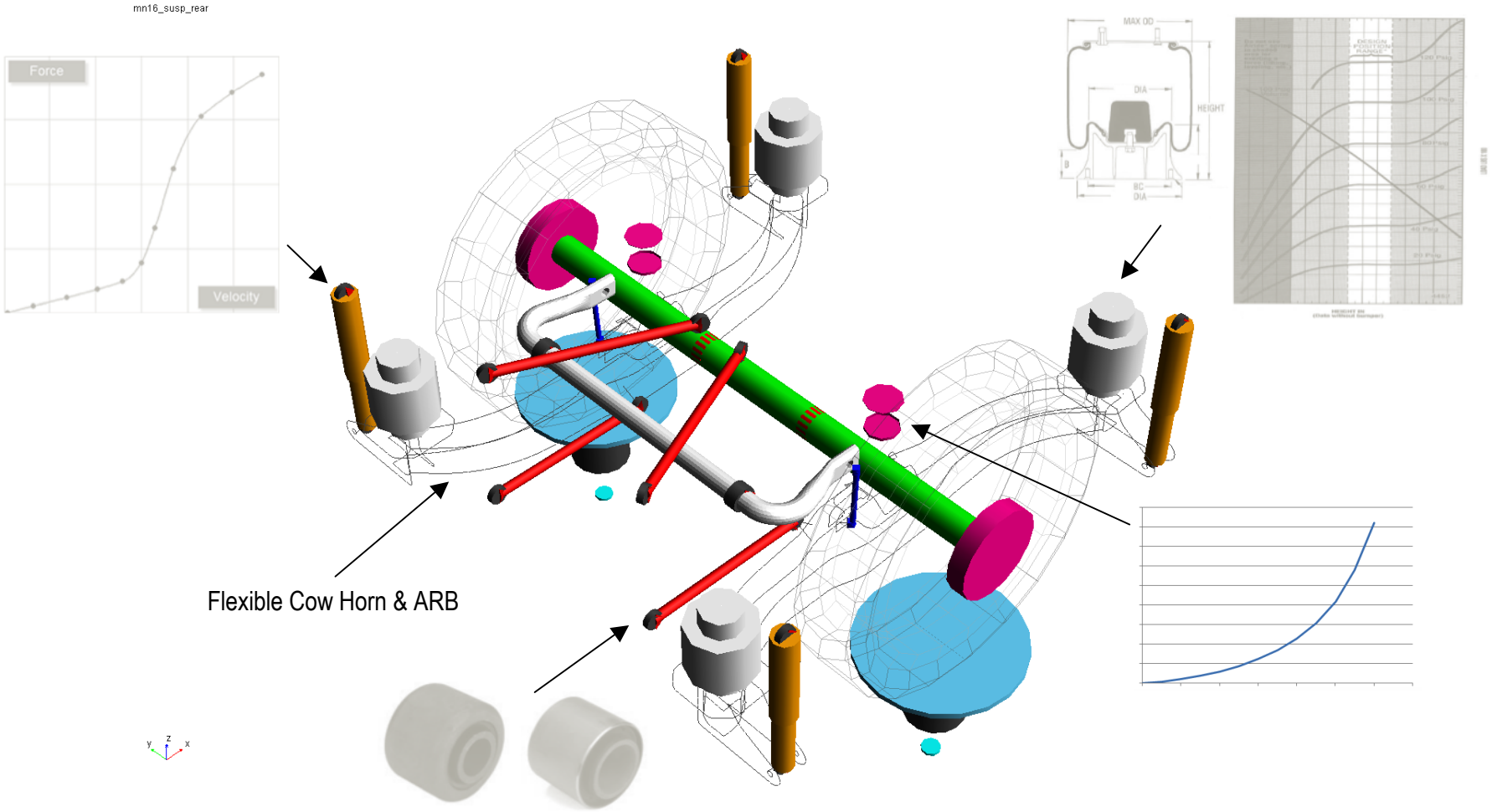
Modeling: Drive Axle Sub-System

The model incorporates an accurate representation of **air-bag with level control** valve, **non-linear shocks** & **bushings**, structural **flexibility of cow horns** and **anti-roll bar**



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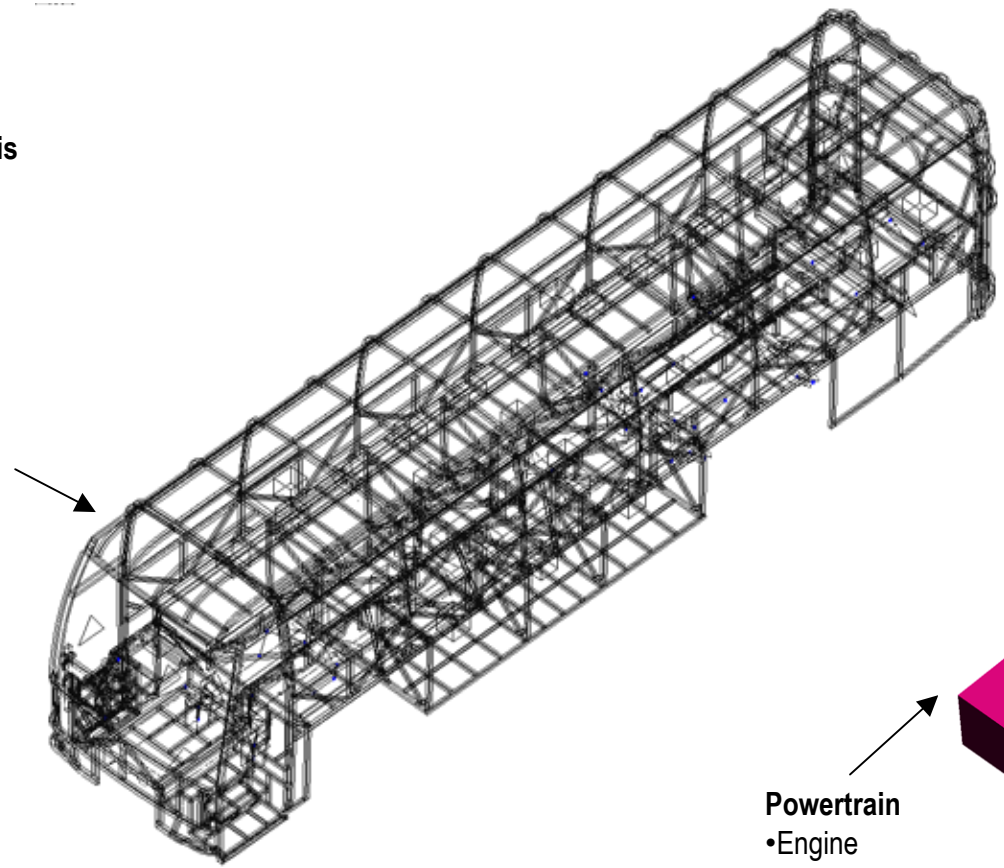
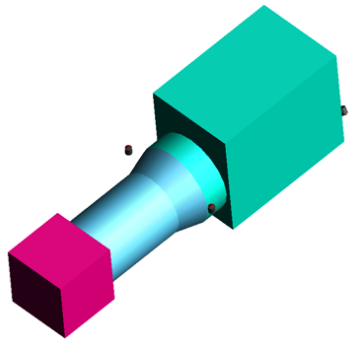
Modeling: Body & Powertrain Sub-System

The model incorporates an accurate representation of structural **flexibility of the chassis and body** (with **seats and payloads**). The powertrain sub system contains and **engine**, **clutch**, **transmission**, and **differential**.

Flexible Body over Chassis
- Frame
- Body
- Body Mounting
- Closures
- Glazing
- Seats
- HVAC system loading
- Payload
- Fuel Tanks
- Air Tanks
- Cooling Module structure





Powertrain
- Engine
- Clutch
- Transmission

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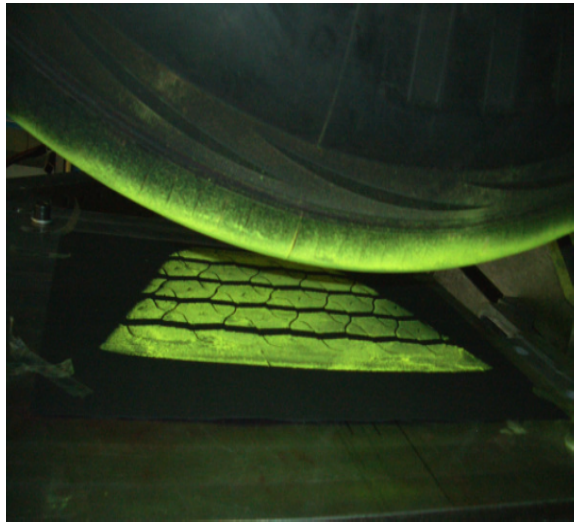
Modeling: Tire Model

Various tests are conducted to create **high-fidelity** Tire Models that describe the complex force-transfer characteristics of tires realistically in MBD software

- Tire Properties
- Steady-State and Handling Characteristics
- Cleat Tests
- Footprints

Conducted for Steer Tires (Rib) and Drive Tires (Lug)



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Modeling: Tire Model

Parameter identification exhibits high level of correlation for both, the Ride/Durability model & the Handling model.

Ride/Durability

F-Tire →

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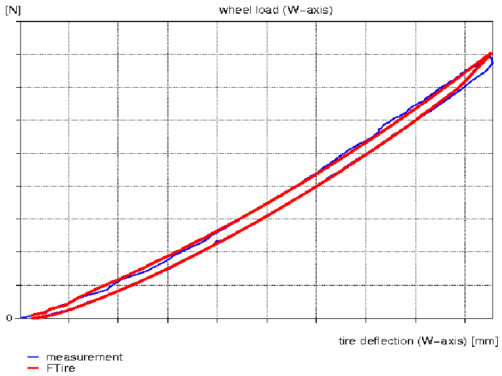
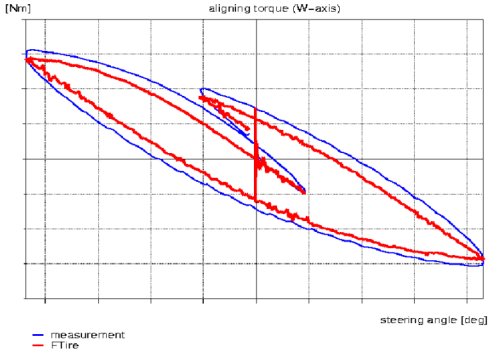
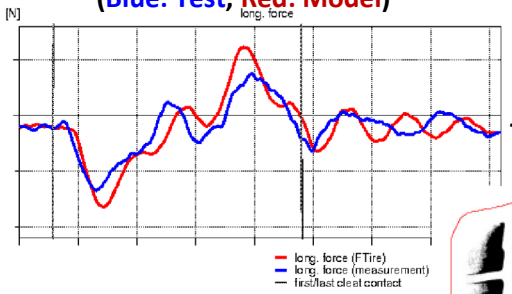
Wheel Load Curve Fit
(Blue: Test, Red: Model)



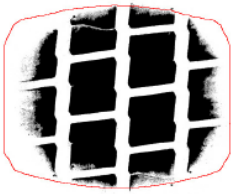
Aligning Torque Fit
(Blue: Test, Red: Model)



Cleat Test Fit
(Blue: Test, Red: Model)



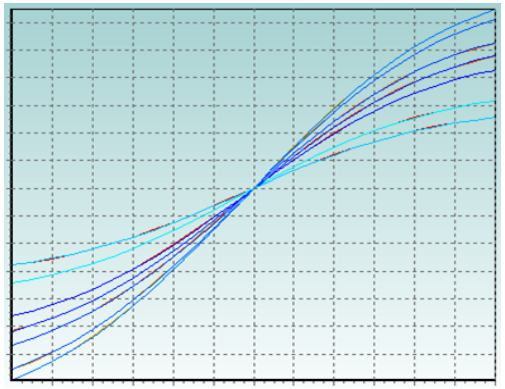
Tire Foot Print



Handling

MF Tire →

Lateral Force Fit
(Blue: Test, Red: Model)



Longitudinal Force Fit
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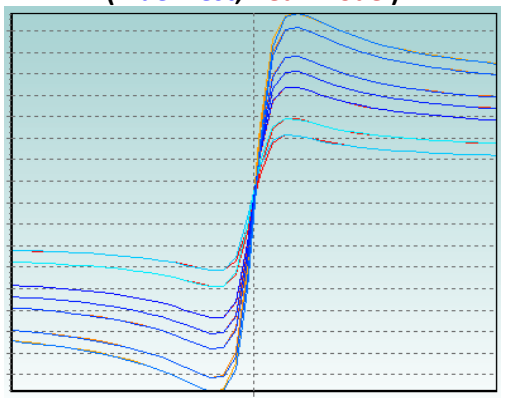
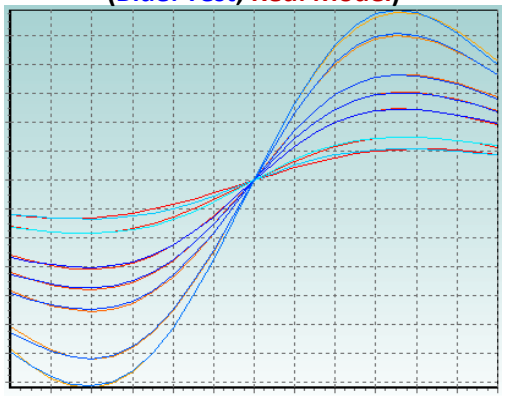


Aligning Torque Fit
(Blue: Test, Red: Model)



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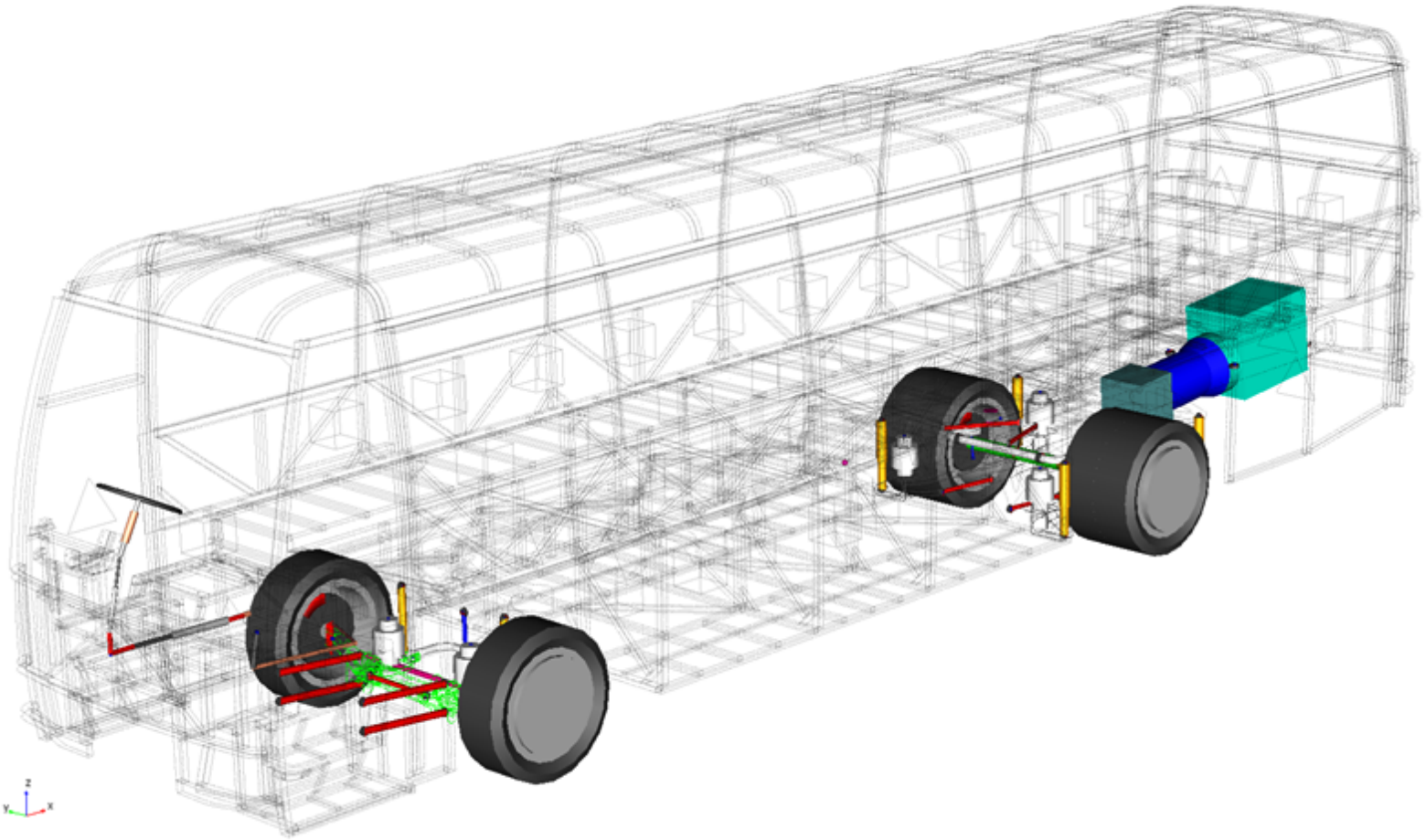
Modeling: Full-Vehicle Assembly

Sub-Systems are assembled to create Full-vehicle models in a **proprietary customized** version of **MSC.ADAMS/Car**



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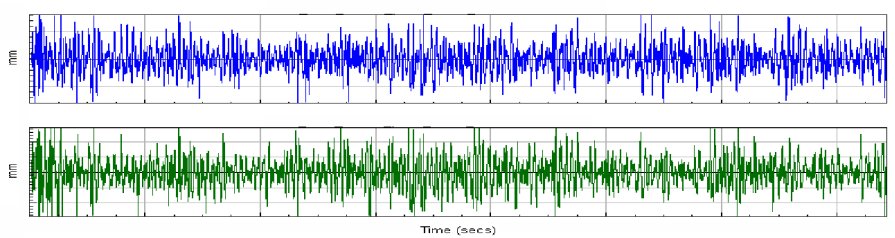
Modeling: Road Profile Measurement

A **high speed optical** vehicle mounted system is used to road surface test data at approx. 60 km/h

Large number of Public Roads and Test tracks were identified.

Data was collected for these roads:

- *Express Highway ~ Class A+*
- *National Highway ~ Class A*
- *State Highway ~ Class B/C*
- *Intra-City Roads ~ Class B/C*
- *Rural Roads ~ Class D*



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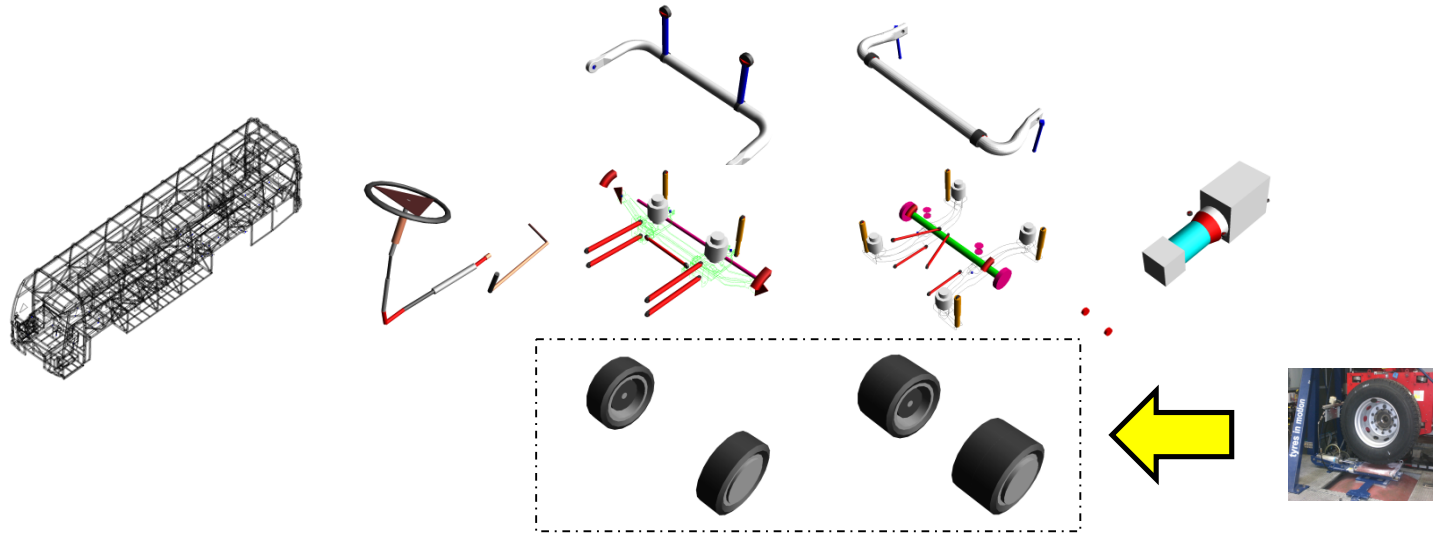
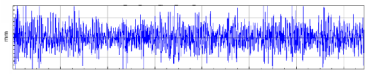
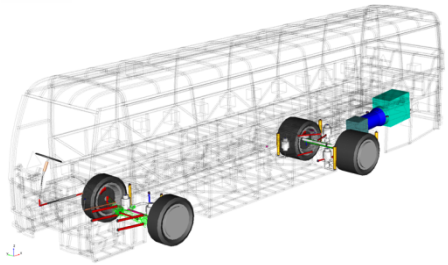
Modeling: Approach







<u>Better Accuracy</u>:

- **Flexible body modeling**
- Air Spring representation: Pressure variation & Level control
- Non-linear bushings
- **High-Fidelity Ride & Handling Tire models**
- **Accurate 2D road representation**

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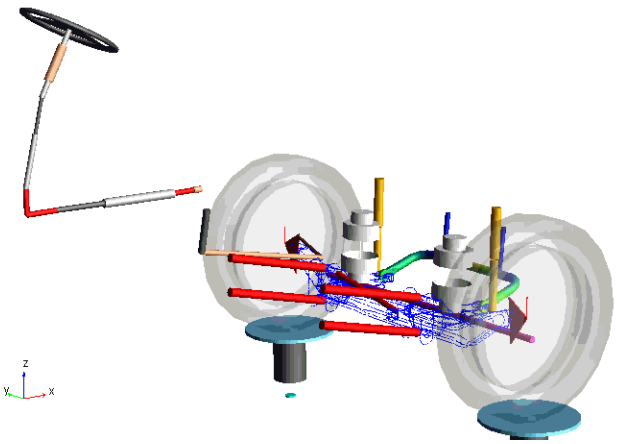
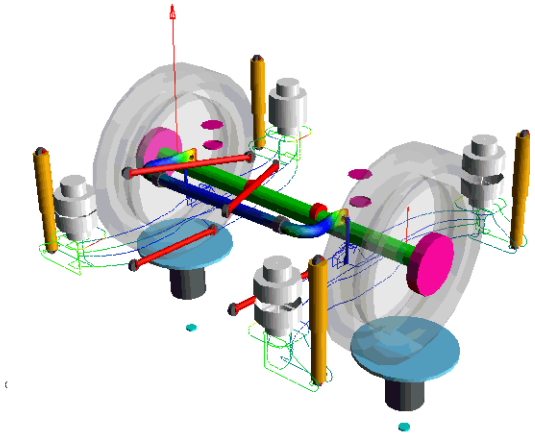
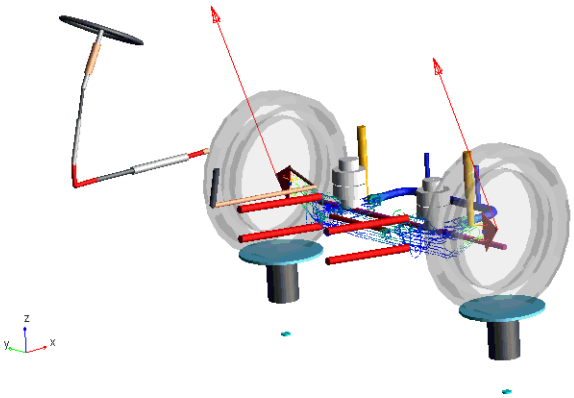
Analysis: Suspension K&C

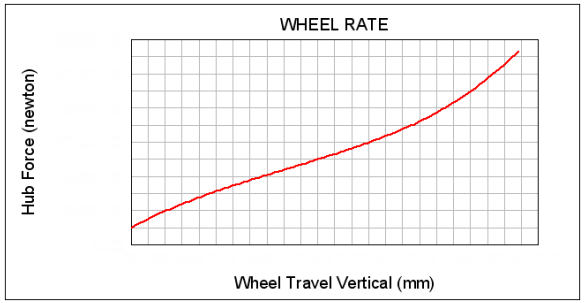
Measurement of Suspension **Kinematics** & **Compliance** for Steer Axle & Drive Axle

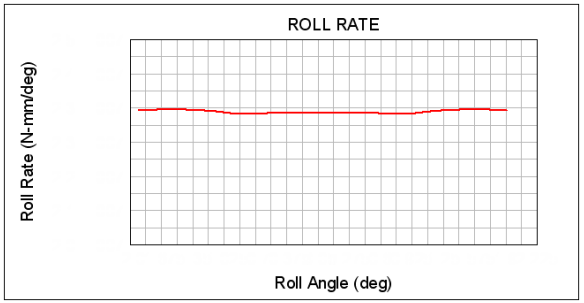
Derivation of suspension characteristics like
- Wheel rate,
- Roll rate,
- Wheel recession stiffness,
- Contribution of ARB, etc…

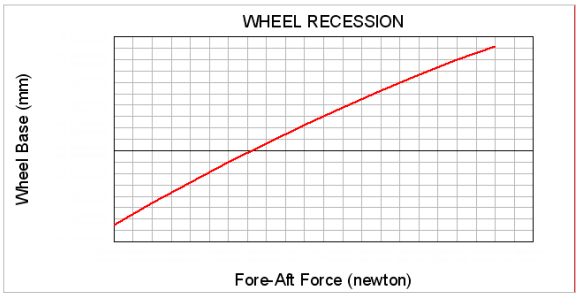












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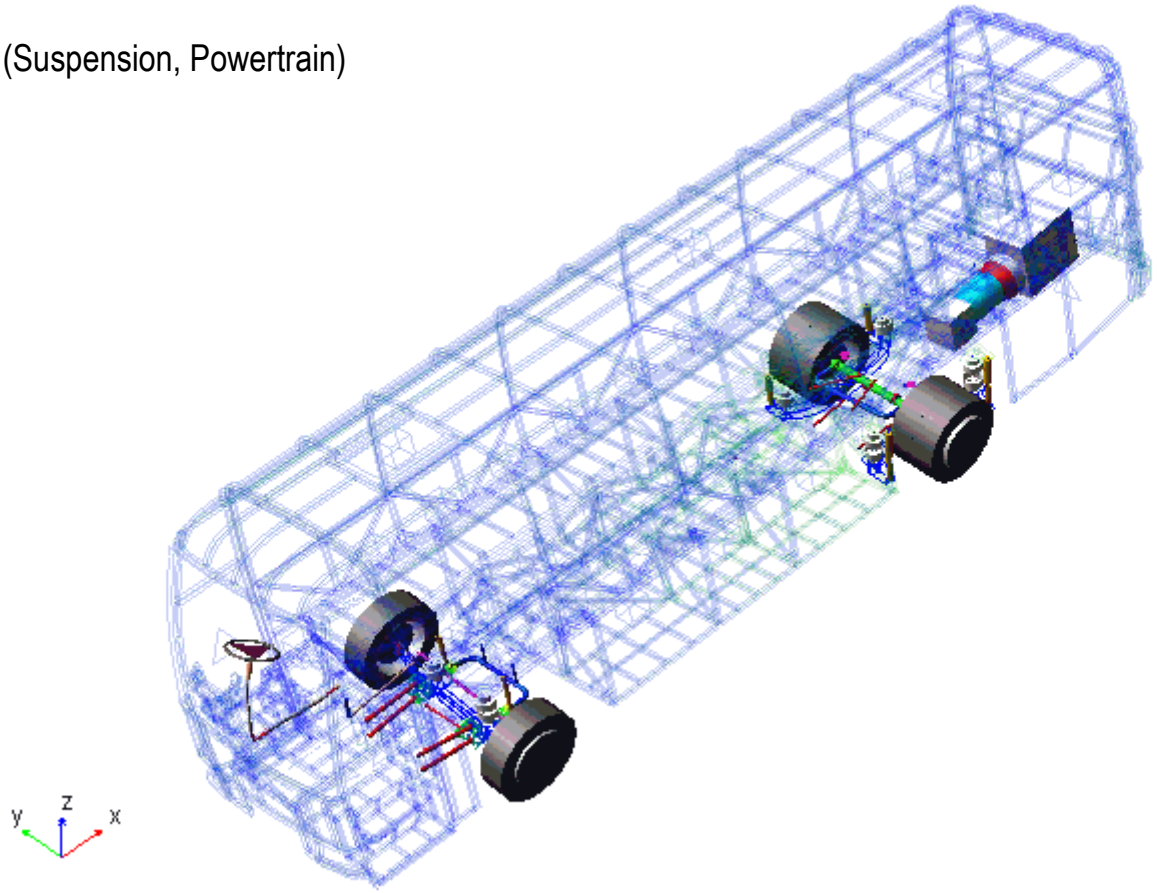
Analysis: Eigen-value Analysis

Analysis to achieve proper **modal stack up** and proper **decoupling** of modes

- Sub-Systems (Suspension, Powertrain)
- Full-Vehicle



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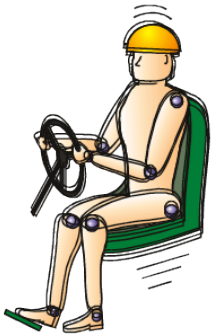
Analysis: Ride

- Vehicle driven over specified roads at various speeds
- Acceleration levels measured at driver & passenger seats
- Ride quality algorithm allows computation of human discomfort
  - In-house proprietary **ride quality meter**
  - Provides an objective metric for ride discomfort in a **multi-axis vibration** environment (longitudinal, pitch, roll, lateral, vertical)
  - Each axis is evaluated in the frequency domain, **human sensitivity weighting functions** are applied, giving 5 discomfort components
  - The five discomfort component go thru a series of nonlinear equations that represent human response to combined vibration environments, producing a final **Total Discomfort number**
- Results translate into a subjective discomfort level index
- **Design directions given for suspension, structure, etc…**



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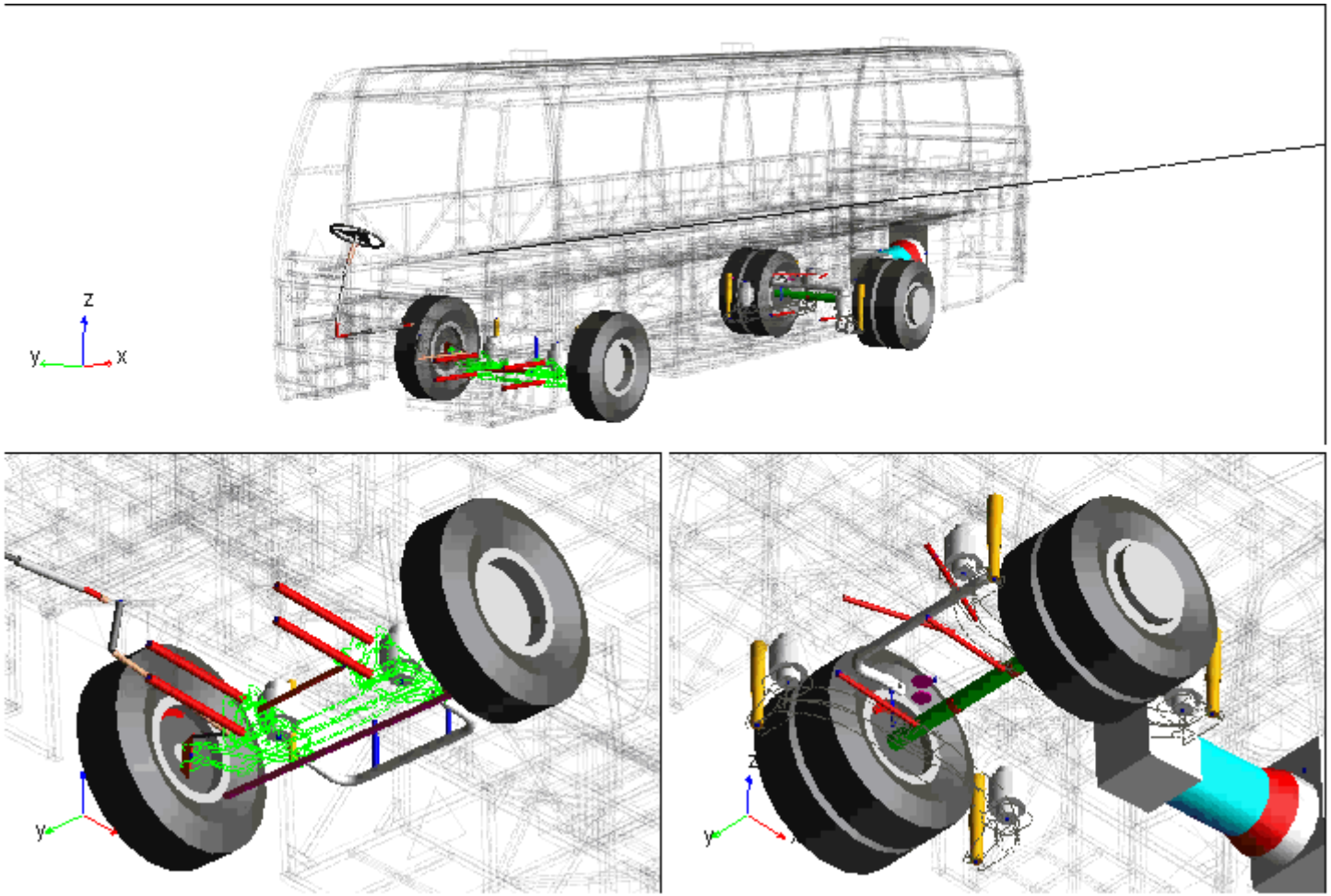
Analysis: Ride (contd.)

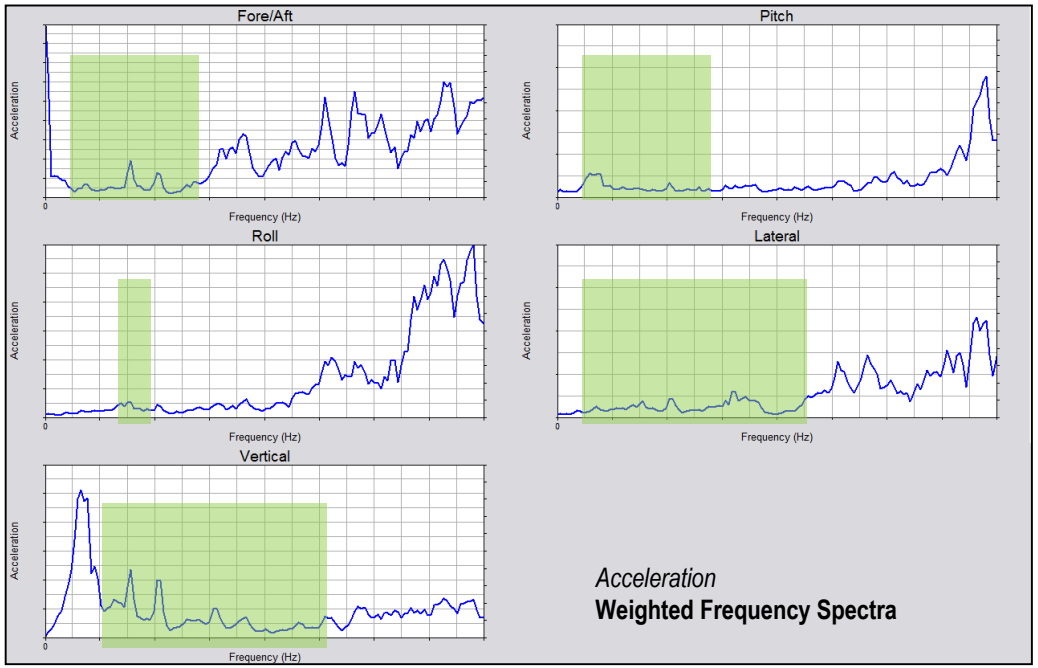


Analysis: Ride (contd.)

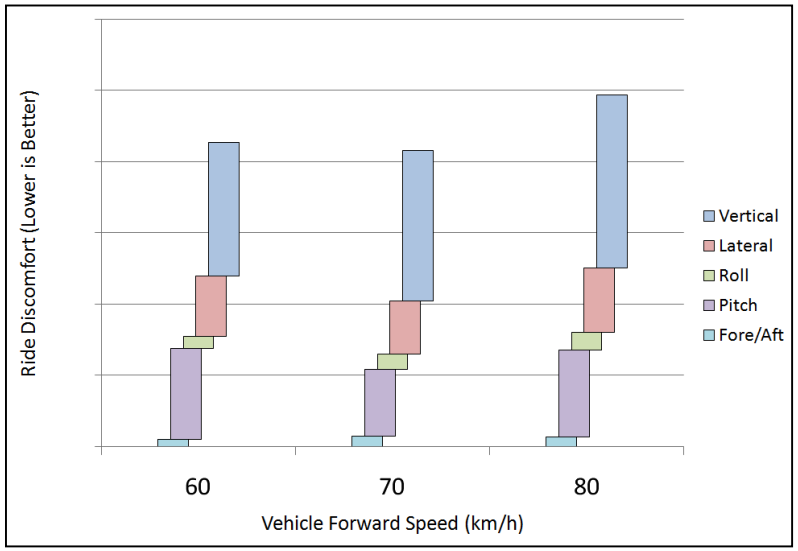
Simulation data analyzed to show:

- Human-sensitivity weighted Frequency Spectra of seat accelerations
- Directional components of Ride Quality Number
- Variation of ride with speed *(not shown)*

Checked for Driver, LH & RH seated Passenger (Front Row, Rear Row)



Acceleration
Weighted Frequency Spectra



Ride Discomfort
Components

Approximate peaks of weighting bands

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Analysis: Handling

Handling Analysis:

- Ramp Steer or Steer Sweep
- Step Steer
- ISO Lane Change

Calculation of handling metrics as per ISO norms

- Under Steer Gradient
- Steering Hand wheel Sensitivity
- Roll & pitch Gradients
- Roll over threshold
- Roll overshoot
- Time lags

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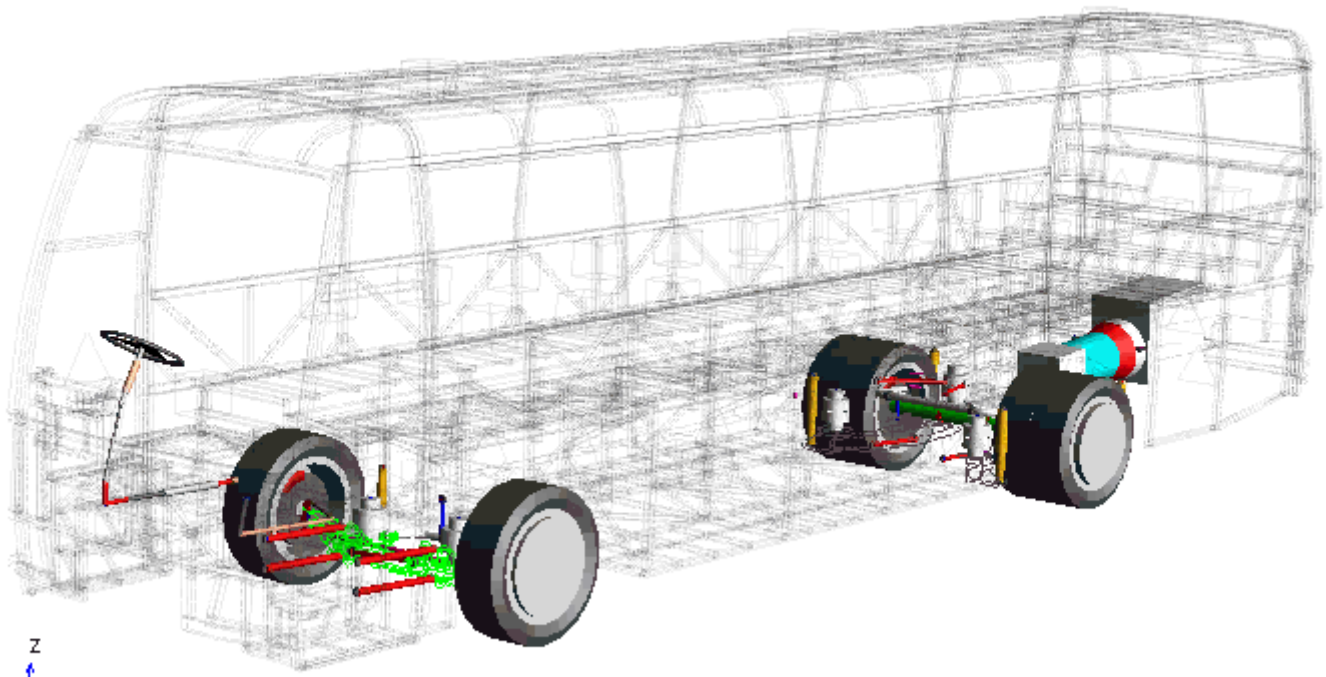
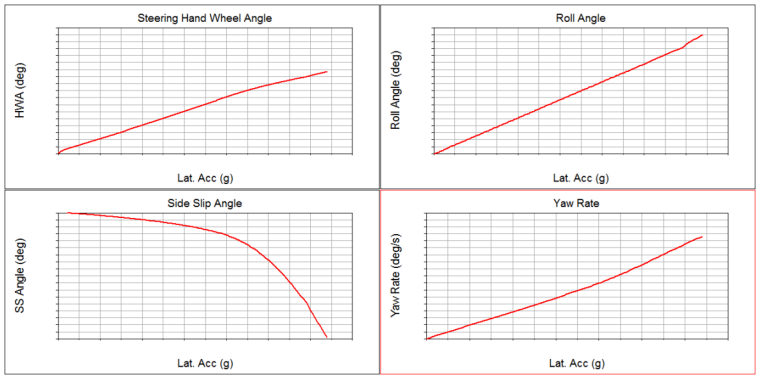
Analysis: Handling - Ramp Steer

ramp_ramp Equilibrium Frame=001

Ramp Steer (or Steer Sweep) is used to calculate **quasi-static gradients** e.g. Under Steer gradient, Roll gradient, etc.





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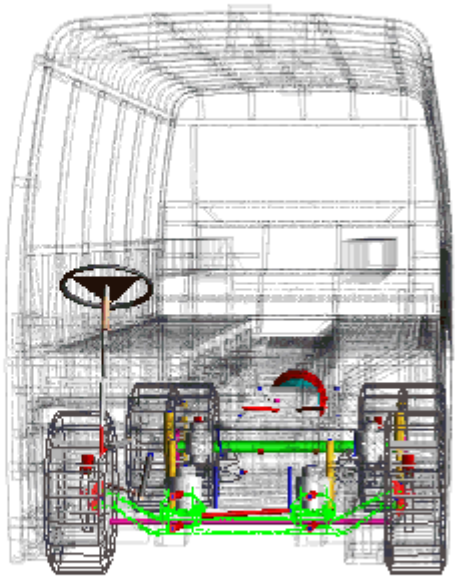
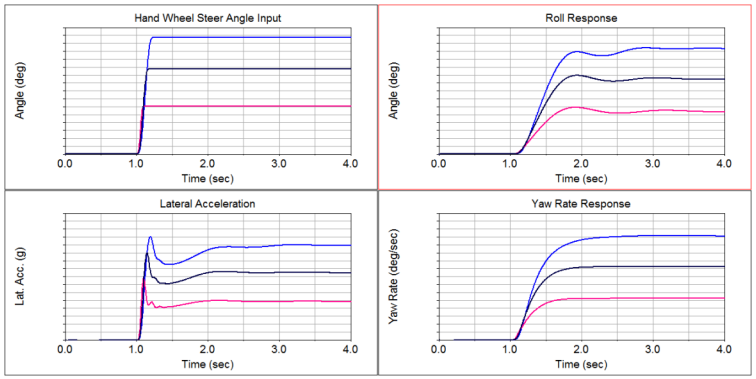
Analysis: Handling - Step Steer

Step Steer is used to calculate **transient characteristics** like Roll over shoot, Roll response time, etc.





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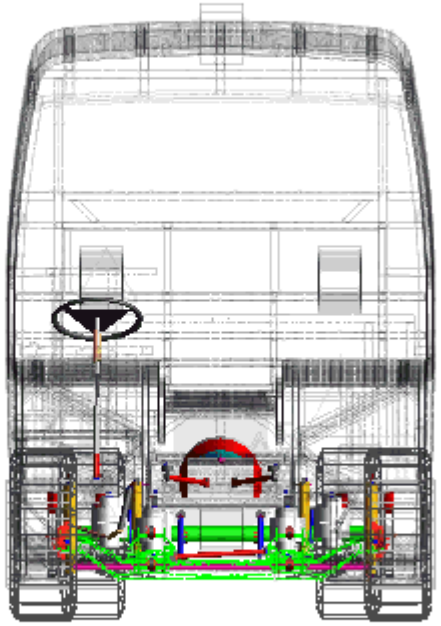
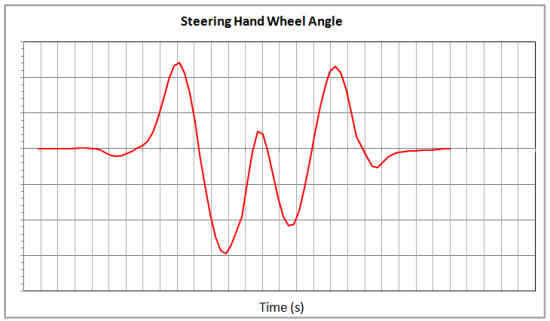
Analysis: Handling - Lane Change

ISO Lane Change is used to check **over all driver control and vehicle response** functions when traversing a lane change event





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Conclusion

Use of Virtual Prototyping techniques to predict the vehicle dynamics performance allows us to:

- Assess the ride comfort & handling quality
  - **Improved accuracy** over traditional models due to
    - Flexible body modeling
    - Air Spring representation: Pressure variation & Level control
    - Non-linear bushings
    - High-Fidelity Ride & Handling Tire models
    - Accurate 2D road representation
- Gain better insights into suspension performance
- Directionally predict the effects of design changes
- Efficiently support sub-system level specifications

Next Steps:

- Review & refine simulation results with testing results
- Connect objective simulation results with subjective performance

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Thank You!

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