Hybrid System Response Convergence (HSRC)

An Alternative Method for Durability Hybrid Simulation

Dave Fricke
Sr. Staff Engineer, Ground Vehicle Dynamics
MTS Systems Corporation

Introduction:

- **Hybrid Simulation** combines physical and virtual components, inputs and constraints to create a composite simulation system.

Modeling and HIL Technologies | System Integration | Mechanical Test Technologies

- Hybrid Simulation for <u>mechanical systems</u> integrates complex numerical calculations & models with the control & measurement of physical mechanical systems.

- **MTS Systems Corporation** has successfully applied Mechanical Hybrid Simulation methods for many years in the fields of Civil/Seismic, Aerospace, Biomedical, and Ground Vehicle testing. This presentation will cover the recent development & application of a new Hybrid Simulation method for Ground Vehicle durability.

Background: Ground Vehicle Product Development

Many OEMs target increased CAE utilization, reduced prototypes, and better prototypes to reach their goal of reduced development time and cost.

Process Goals

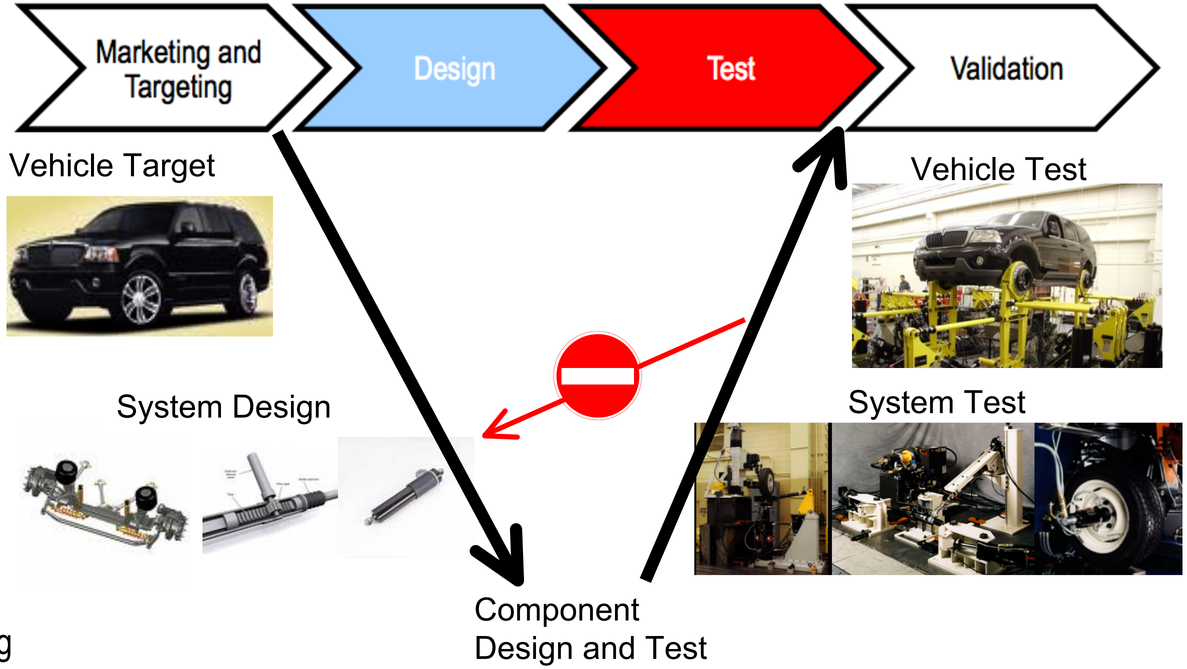
» Effective design

» Efficient test

Hybrid Simulation Roles

» Enable better choices sooner
  - Earliest possible test
  - Model only what is missing

» Fewer prototypes needed
  - For measuring & testing



» Enables accurate sub-system testing
  - when full prototypes are not available or possible (e.g. military, Tier-1 suppliers)

Hybrid Simulation: Ground Vehicle Applications

Hybrid Simulation methods can be applied to improve the vehicle development process from two different perspectives:

- **As a support tool for analytical simulation**
  - Physical components are added to the virtual system to improve the predictive accuracy of the simulation.
    - Hard-to-model components such as dampers, bushings, etc are replaced with physical components in a test system.
- **As a enabling tool for physical test development**
  - Virtual components and testing inputs are used to surround and complement physical components in a test system.
    - Physical components can be accurately tested before they can be assembled into a physical prototype vehicle to measure test loads on the road.

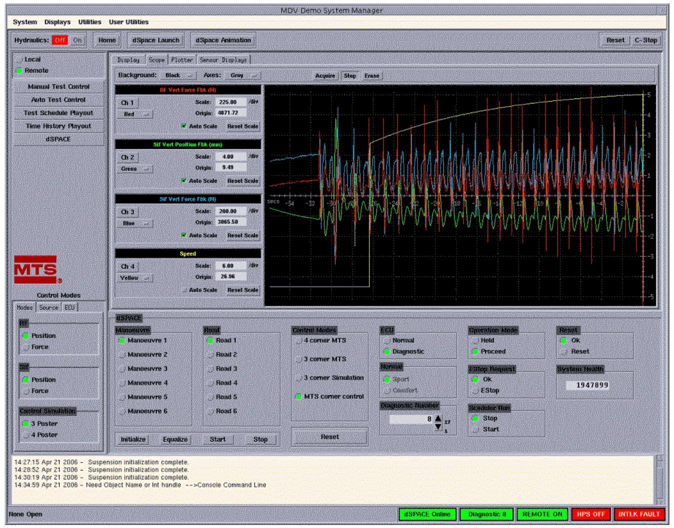
Most hybrid simulation systems are designed as “real-time” implementations

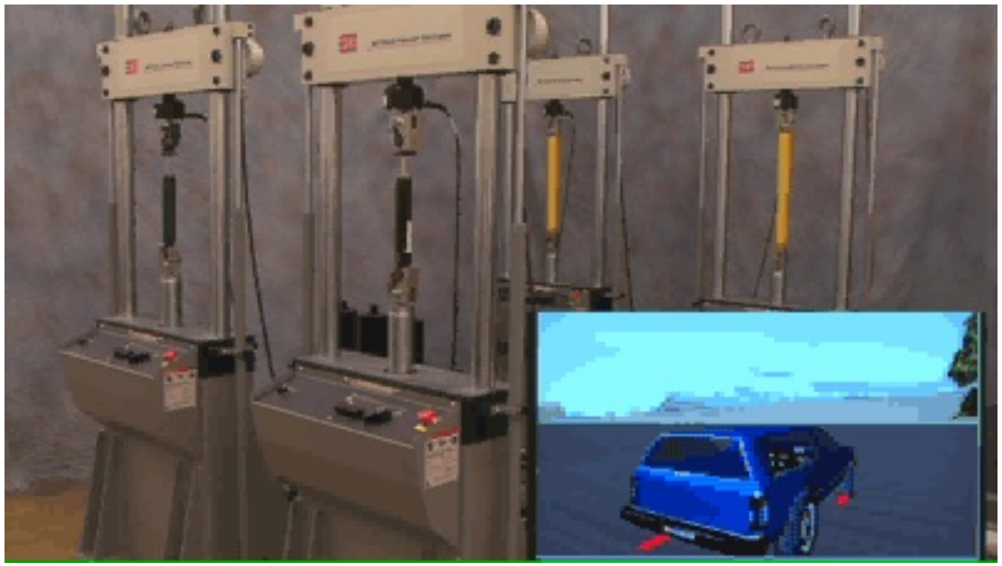
» Example: <u>MTS “Mechanical Hardware-in-the-Loop” (mHIL™)</u>

Four-Corner Vehicle Damper mHIL system (2008 Vehicle Dynamics Development Tool of the Year)

- Actual vehicle dampers are included in a virtual simulation to evaluate virtual vehicle performance and enable damper tuning.
  - mHIL test systems may also include active system ECU’s as well.

MTS mHIL™ Supervisor





Hybrid Simulation – Real-Time Systems

Characteristics of “real-time” hybrid simulations:

- Advantages: The hybrid system response will immediately adapt to any changes in the system, or to new system inputs.
  - Changes in component settings (e.g. ECU tuning adjustments)
  - Component degradation or failure, ECU faults, etc.
  - New or unexpected driver control inputs
- Limitations: The elements of the hybrid system must be optimized to allow for “real-time” operating speed
  - Model detail and complexity may need to be significantly reduced for some types of models
  - Physical test systems must be designed to operate with very low (near-zero) tracking control error

Some hybrid simulation applications demand more model and test system complexity, and cannot currently be optimized for real-time implementation.

Hybrid Simulation – MTS HSRC

To enable hybrid systems to utilize more detailed virtual models, MTS has developed an alternative "off-line" hybrid simulation method:

Hybrid System Response Convergence (HSRC)

HSRC uses an iterative convergence technique to develop a dynamically correct simulation for complex "mechanical" hybrid systems.

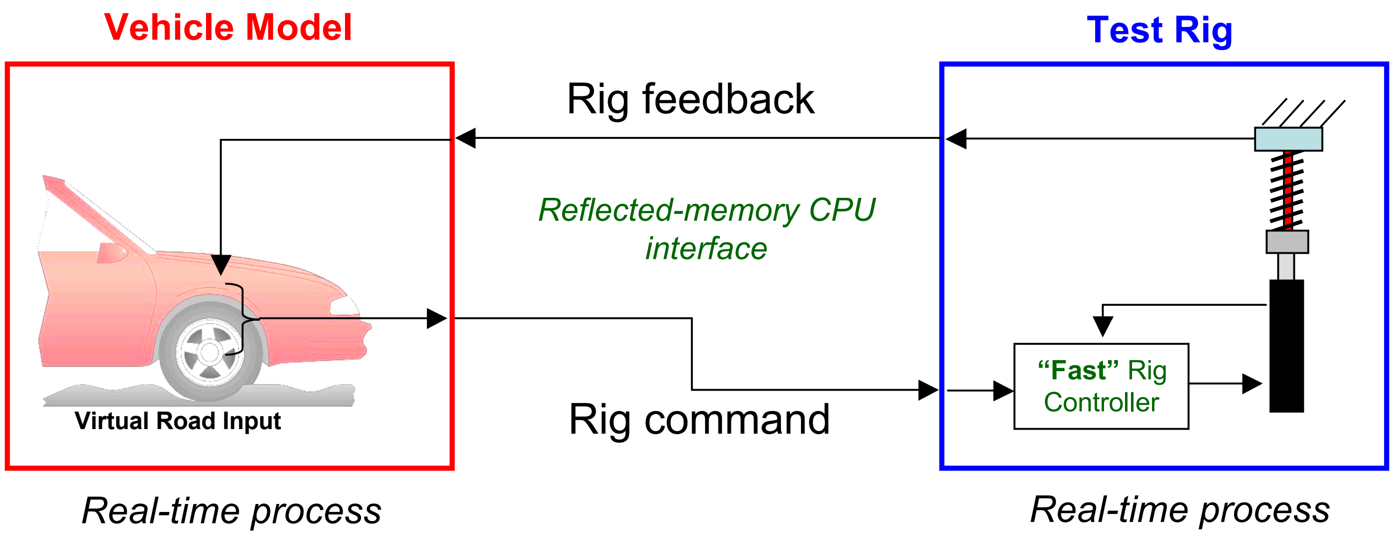
- Virtual components of the system do not have to be operated in real-time, and can therefore be developed using highly complex, industry-standard modeling tools.
- Physical test systems used in the hybrid simulation can be compensated off-line to correct for performance and cross-coupling characteristics that cannot be modeled in the control system.

Hybrid Simulation comparison: Real-Time vs HSRC

"Real-Time" Hybrid System

- » Synchronously coupled hybrid simulation system
- » Models, data interface, servo-loop control: <u>all highly optimized for speed</u>

"Real-time" hybrid system

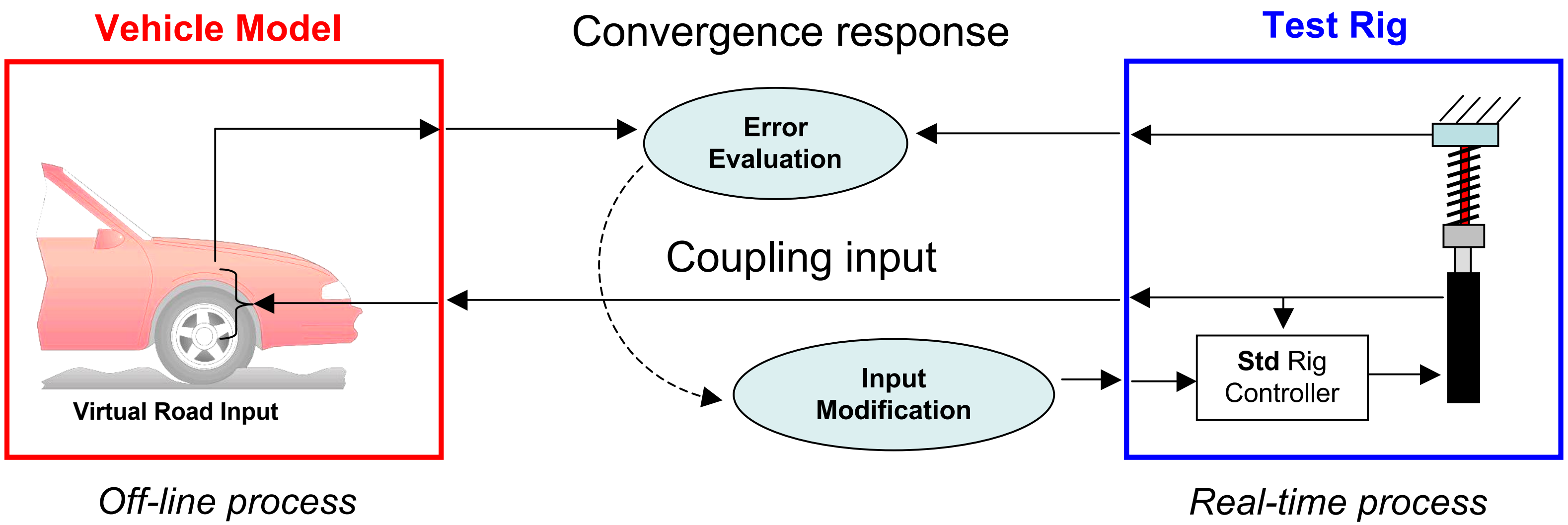


HSRC Hybrid System

» Asynchronously coupled hybrid system

» Models, data interface, servo-loop control: conventional & complex

"Off-line" hybrid system



Hybrid Simulation – MTS HSRC

MTS HSRC hybrid systems are not required to operate in "real-time".

» Advantages: Allows more detailed and complex elements to be included in the simulation.
  - Modeled elements can be represented with detailed multi-body dynamic or finite-element models, to meet the needs of the simulation application (e.g. ADAMs Car, etc)
  - Physical components can be tested with complex, but industry-standard MDOF test systems (e.g. MTS 329 + FlexTest ™ control).

» Limitations: HSRC simulations must be re-adapted to new simulation conditions.
  - Changes in component response to the same input (component degradation, modified ECU control algorithm, etc).
  - Changes in the simulation input (new road surface, new driver inputs, etc)

The HSRC simulation method, if applied to the elements of an identical, real-time system, will be able to generate the same system responses as the as the real-time system, for the same driver + road conditions.

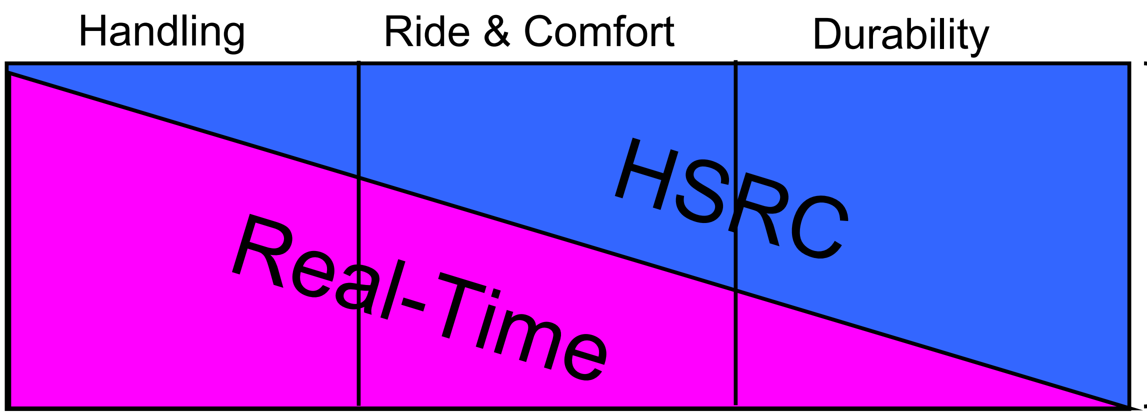
Application Comparison: mHIL™ vs HSRC

Application domain differences

» Real-Time systems react instantly to changes in system input or component behavior
- Important for human “driver-in-the-loop”, fault initiation testing, etc
- Important for efficient evaluation of multiple component variations (“tuning” mechatronic components, etc)

» HSRC systems can simulate broader system dynamic behavior.
- Supports models which can represent greater structural fidelity and bandwidth
- Works with test systems which rely on iterative compensation for loop control accuracy

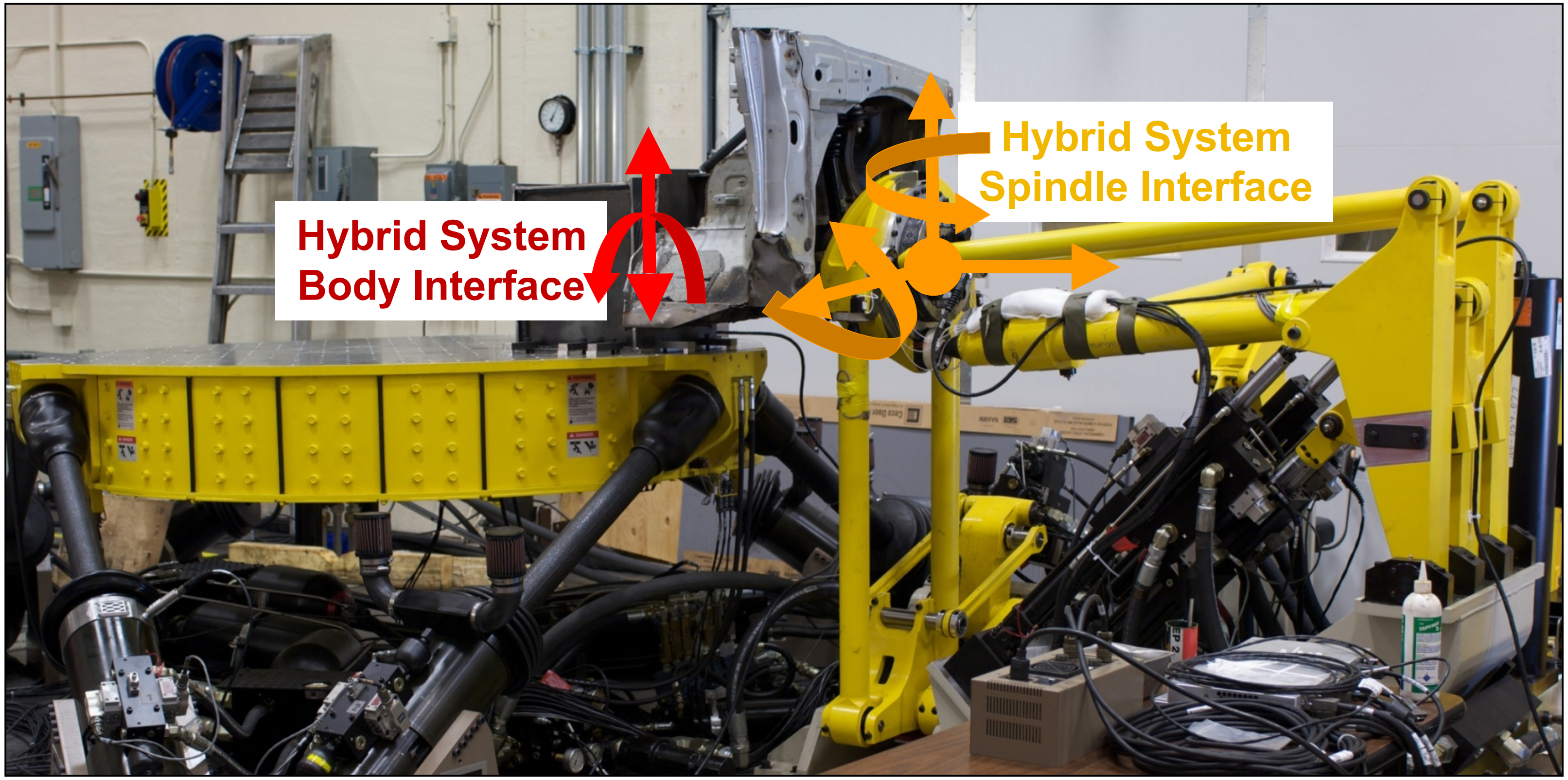
- Lower bandwidth
- Simpler vehicle dynamics models
- 1-2 axis test rig control
- Primarily rig motion control



- Higher control bandwidth (50 Hz+)
- Increased model complexity (MBD & FEM)
- Rig multi-axis cross coupling
- Rig force and motion control

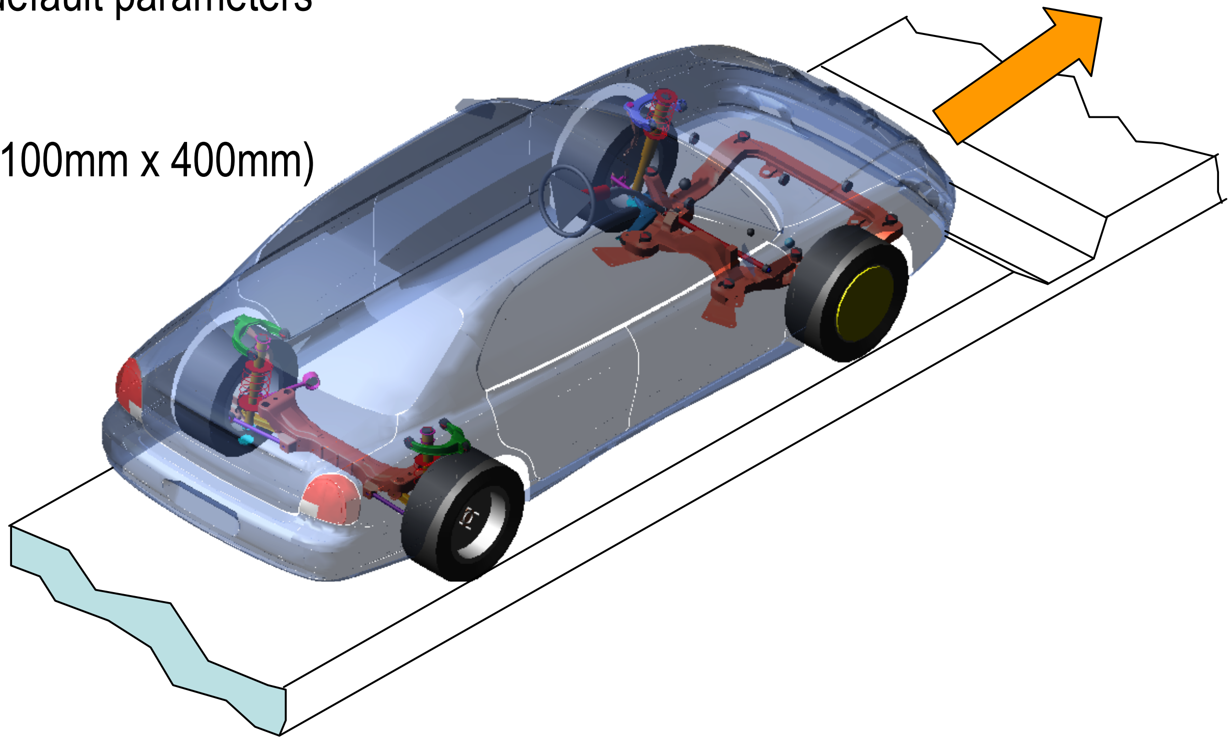
HSRC Demonstration Simulator

- Vehicle ¼-car suspension and body structure
- MTS 329 suspension test rig with FlexTest™ controller (5DOF spindle simulation)
- MTS 353 MAST system (2DOF body simulation)



Virtual Test Components:

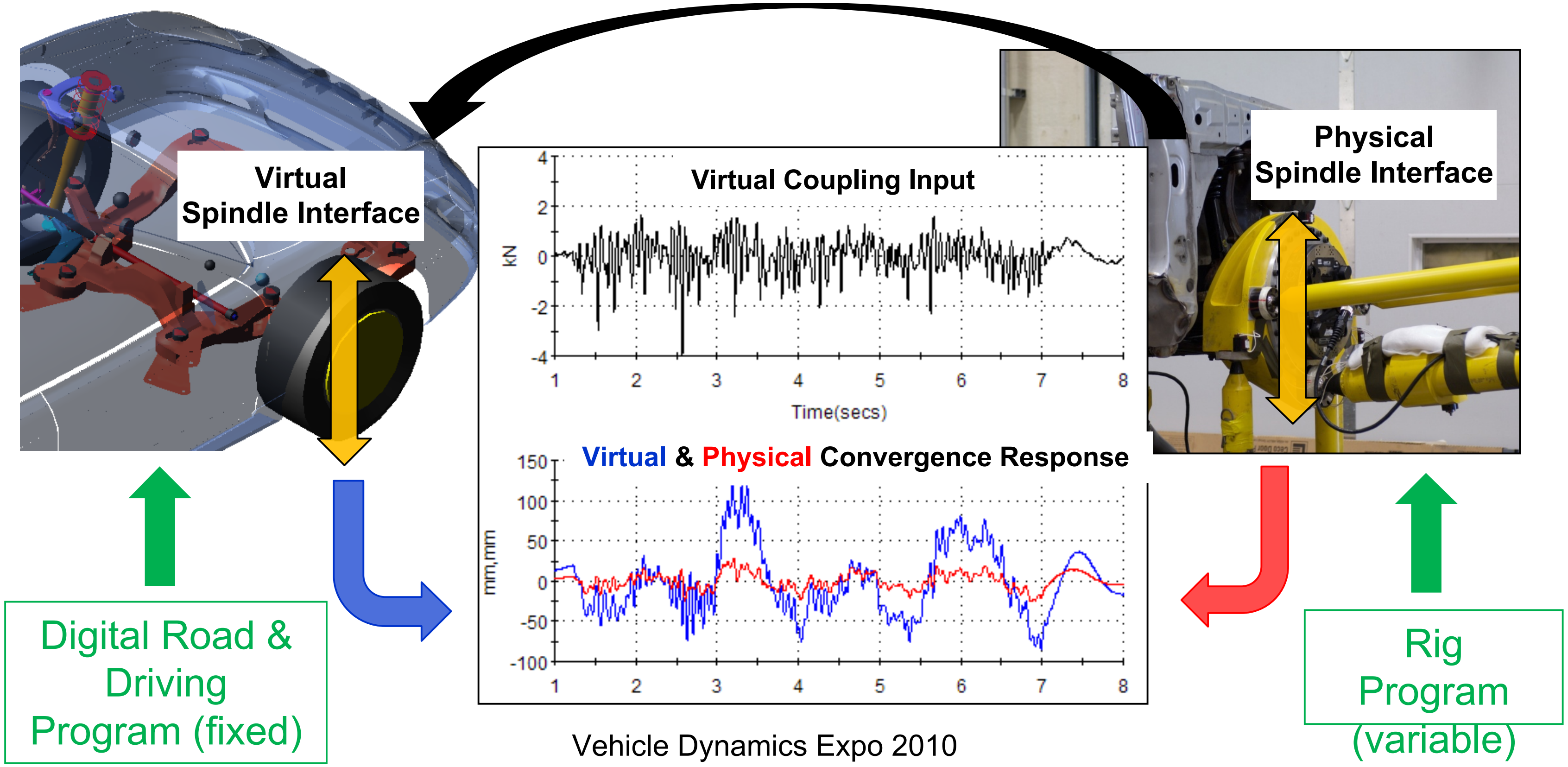
- ADAMs-CAR vehicle model
  - Modified model for HSRC
    - right front suspension replaced with motion and force generators
- ADAMs F-Tire tire model
  - 205-55R16 tire with default parameters
- Virtual test events
  - 40 kph potholes (3 x 100mm x 400mm)
  - 25 kph pavé
- ADAMs Driver Control



Hybrid System Response:

» Significant response differences exist at the interface between the coupled physical and virtual systems.

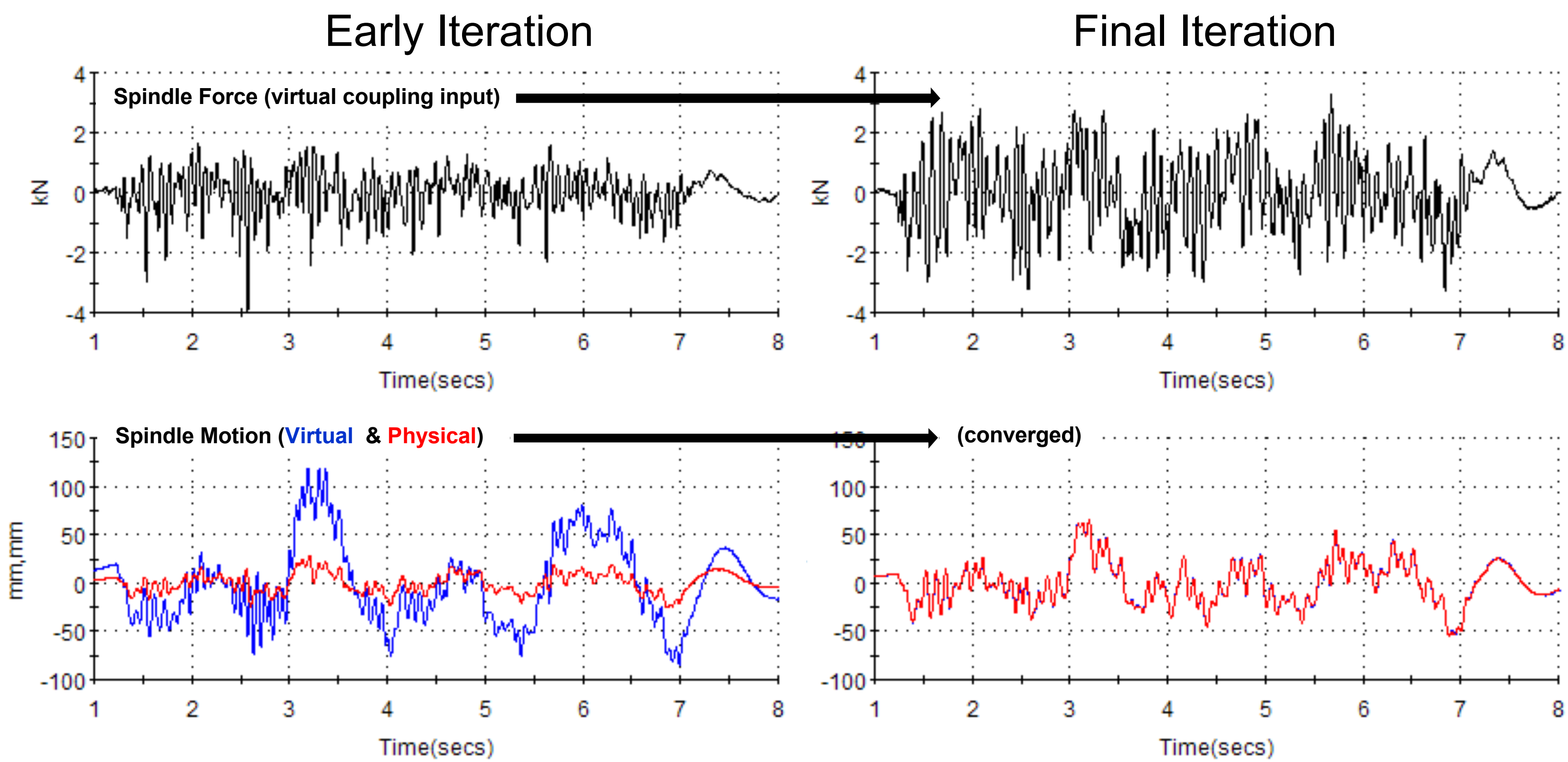
- Indicates that the current physical rig program is incorrect for the combination of the hybrid system dynamics and the programmed virtual test event.



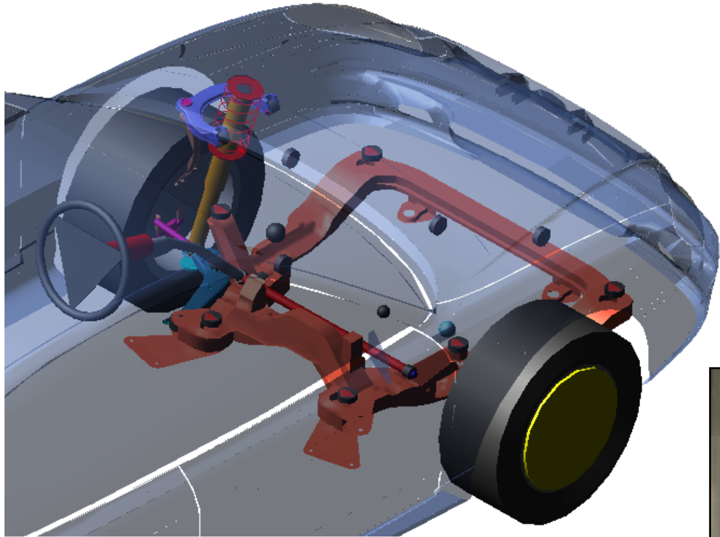
HSRC ¼ Suspension Simulation

Hybrid System Response Convergence:

- » The physical rig program is modified until the non-coupled interface response error is eliminated.
  - Both the coupling input and the convergence response are iteratively adapted.

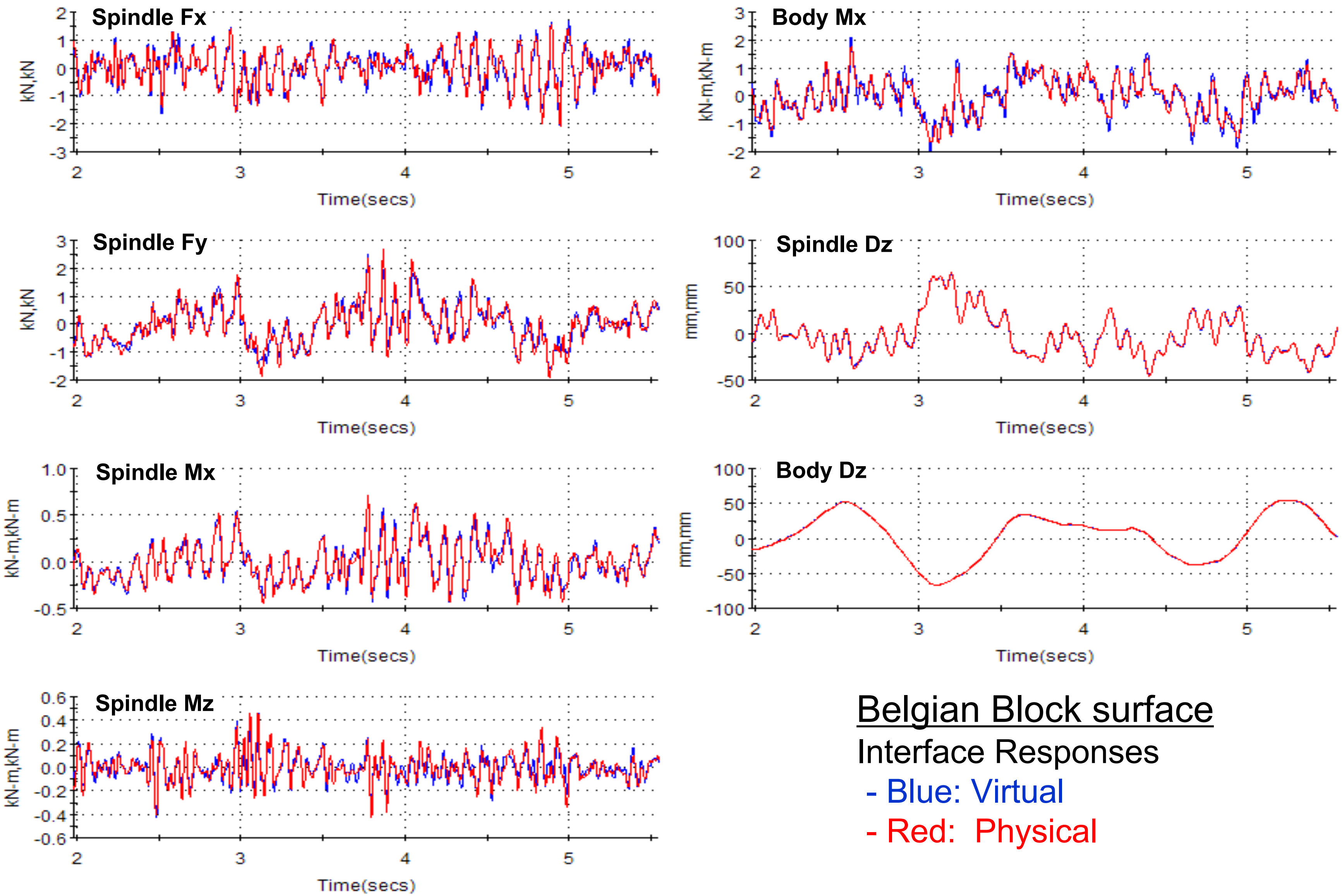


HSRC Simulation Results - Video



5DOF Hybrid System Response Convergence at the suspension/wheel interface (no braking)

2DOF Hybrid System Response Convergence at the body/suspension interface (body heave & roll)



<u>Belgian Block surface</u>

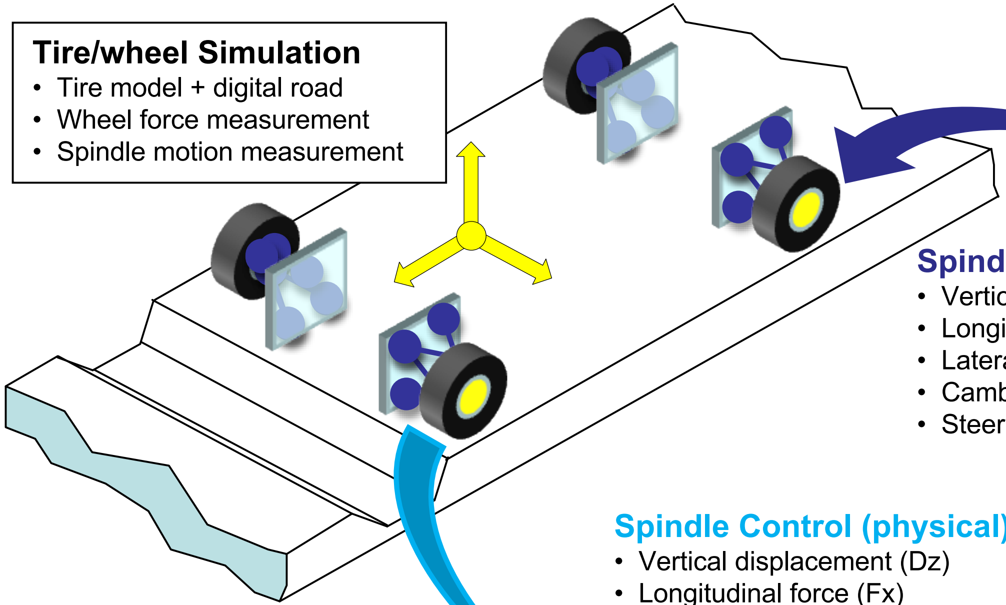
Interface Responses

- Blue: Virtual
- Red: Physical

HSRC Full Vehicle Simulation Application

Tire/wheel Simulation
- Tire model + digital road
- Wheel force measurement
- Spindle motion measurement

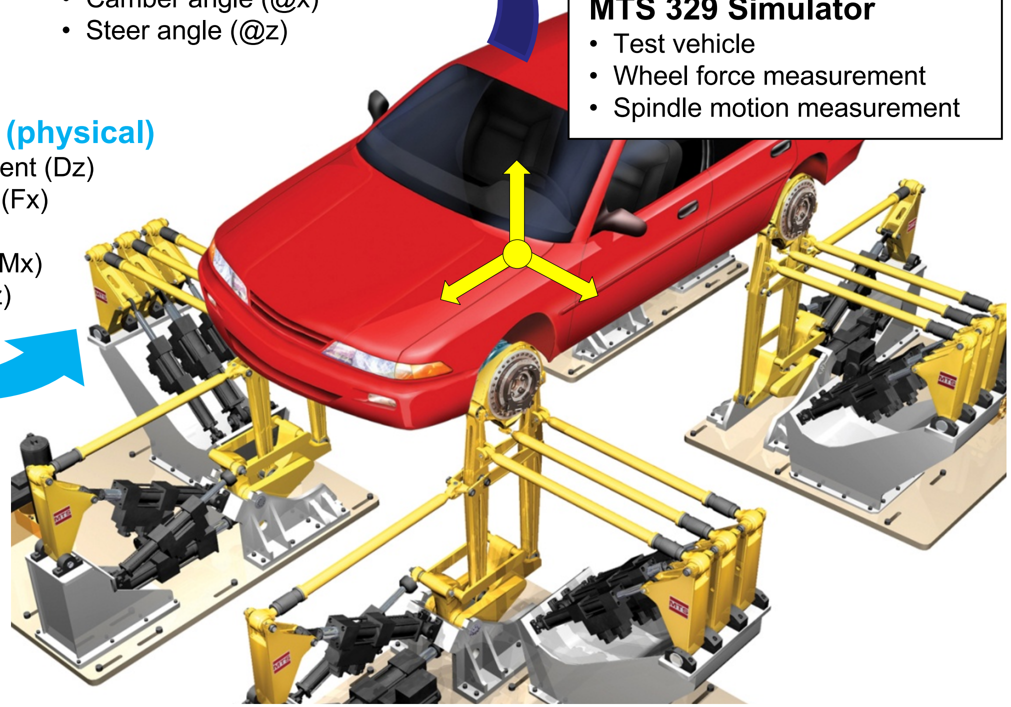
Virtual Simulation Method
- Physical rig response is applied to a set of virtual tires.
- Virtual spindles are simultaneously translated over digital road surface.
- Spindle loads not supplied by the rig are calculated and added to the virtual input.



Spindle Control (virtual)
- Vertical force (Fz)
- Longitudinal displacement (Dx)
- Lateral displacement (Dy)
- Camber angle (@x)
- Steer angle (@z)

MTS 329 Simulator
- Test vehicle
- Wheel force measurement
- Spindle motion measurement

Spindle Control (physical)
- Vertical displacement (Dz)
- Longitudinal force (Fx)
- Lateral force (Fy)
- Camber moment (Mx)
- Steer moment (Mz)



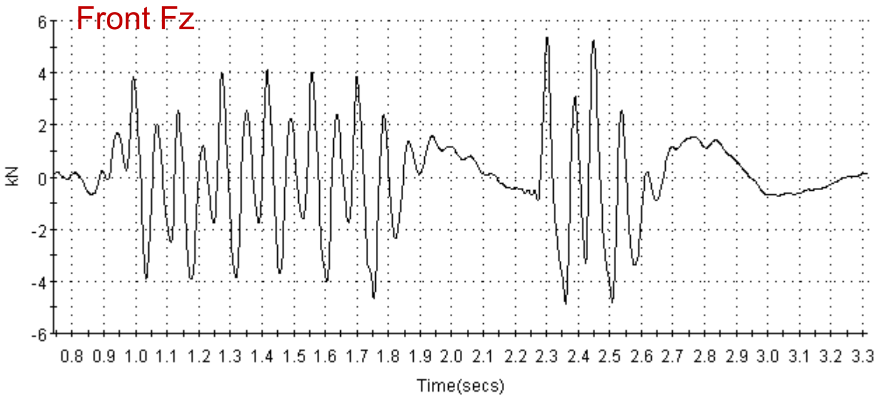
Physical Simulation Method
- HSRC uses proprietary compensation methods to achieve spindle control objectives on the rig in an iterative manner.
- HSRC simulation is complete and accurate when the current spindle control objective equals the previous rig spindle response.

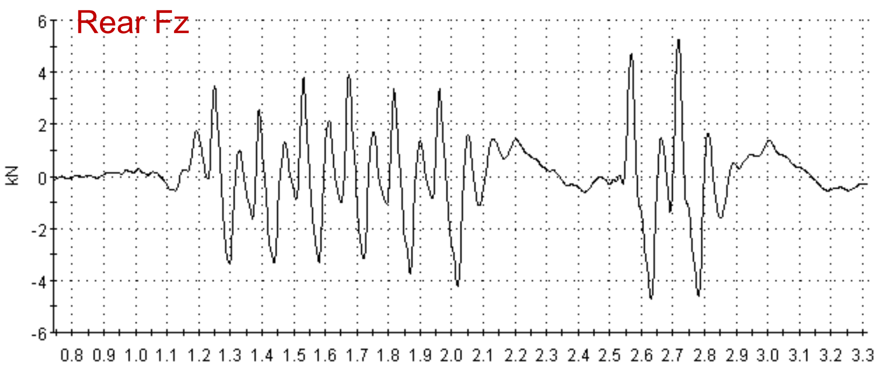
HSRC Full Vehicle Simulation Application

Correlation of HSRC full-vehicle simulation results to road vehicle measurements

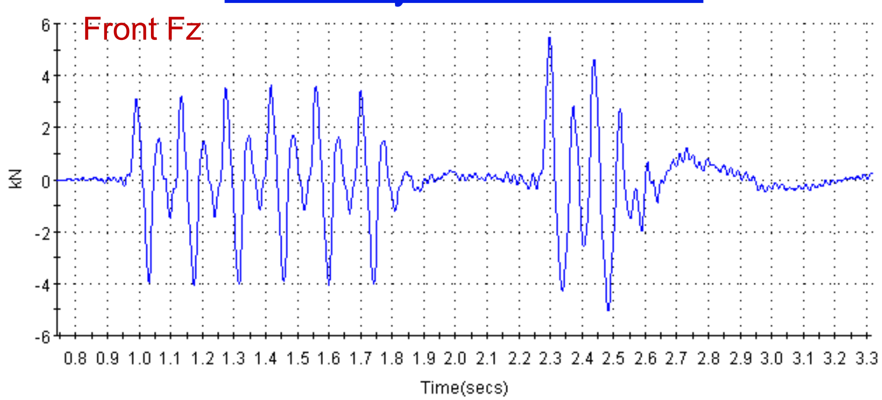
- » Test surface – perpendicular road cleats
- » Vertical spindle force correlation:

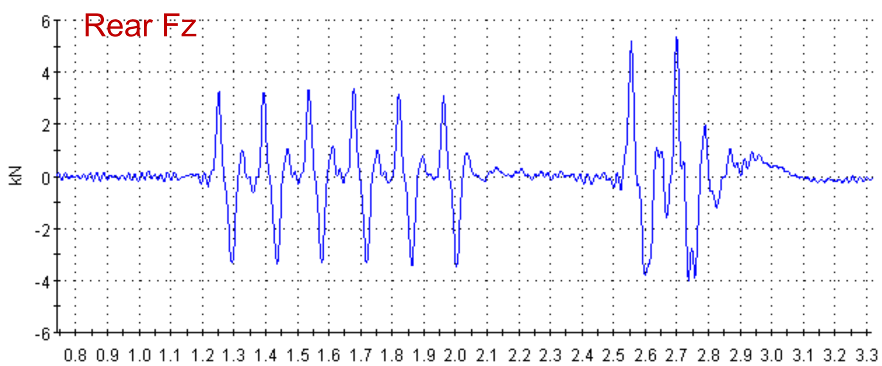
Road Measurements





HSRC Hybrid Simulation





Hybrid System Response Convergence

Summary:

» Hybrid simulation methods enable faster, more efficient vehicle development:

- Test earlier than is possible using conventional measure-&-test methods
- Test results are more accurate than 100% virtual methods

» HSRC is new hybrid simulation method

- HSRC allows complex analytical modeling and physical testing tools to be combined into a hybrid simulation system without requiring real-time operation.

» For most applications, HSRC hybrid simulations will achieve the same dynamic accuracy for the coupled system components as would be generated with real-time methods.

» HSRC can be applied to vehicle sub-systems and full vehicles with accurate results

- If the modeled components are accurate, the HSRC solution will match the equivalent road measurements.

Questions?