Using hybrid simulation tools to streamline development cycles

Tim Powell
MTS Ground Vehicle Application Engineer

ADVANCED
TEST AND
MEASUREMENT
SOLUTIONS

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MTS Systems Corporation Introduction and brief history

MTS has been a global supplier of high performance testing and simulation systems for over 55 years
Operations span across Americas, Europe and Asia
Deliver technology and engineering expertise to produce high quality, innovative testing solutions for our customers

1966 – MTS founded as spin-off from Research Incorporated.
1967 - Moved to current location in Eden Prairie, Minnesota, USA.
1989 – Acquired Sintech, PC based screw driven test machines.
2008 – Acquired SANS, testing equipment company in China.
2014 – Acquired Roehrig Engineering, US based vehicle component testing company.
2018 – Acquired E2M Technologies B.V., EU based simulation and testing company.
2020 – Acquired R&D, Denmark, simulation and testing company.
2021 – MTS Systems Corporation acquired by Illinois Tool Works (ITW).

MTS has approximately 1,700 employees worldwide, including a network of ~400 field engineers and technical specialists

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Materials ›

1500 degree Celsius — solutions for testing high-temperature alloys, composites, ceramics and polymers

Read the Article

Aerospace ›

20% increase — in testing speeds using state-of-the-art cross-coupling compensation technology

Read the Article

Automotive ›

320 kph — flat-belt roadway enables precise replication of motorsports cornering maneuvers

Read the Case Study

Civil Engineering ›

1.32 million pound — force capacity enables the testing of very large specimens all the way to failure

Read the Case Study

Biomedical ›

1 in 1,000 children — will need corrective scoliosis surgery

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Rail ›

550 kph — test system enables lab-based studies of high-speed rail operating environments

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Energy ›

56 MNm — overturning moment capacity enables testing of the largest wind turbine drivetrains

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Rock & Geomechanics ›

3x stronger — concrete materials make it possible to carry higher loads

Read the Case Study

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Content

- Industry Trends in the Ground Vehicle Market
- mHIL Technology & Applications
- HSRC (Hybrid System Response Convergence)

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Challenges facing development teams

- Accelerating vehicle development programs
  - Typically OEMs are striving to accelerate platform and variant development
  - Goal is to drive platform programs development to less than 20 months

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Challenges facing development teams

- » Accelerating vehicle development programs
- » Sharp reduction or elimination of prototypes for development
  - » Typically OEM’s reducing number of available development prototypes
  - » Suppliers provided no prototype for development
  - » Heavier reliance on simulation tools for design and validation

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Challenges facing development teams

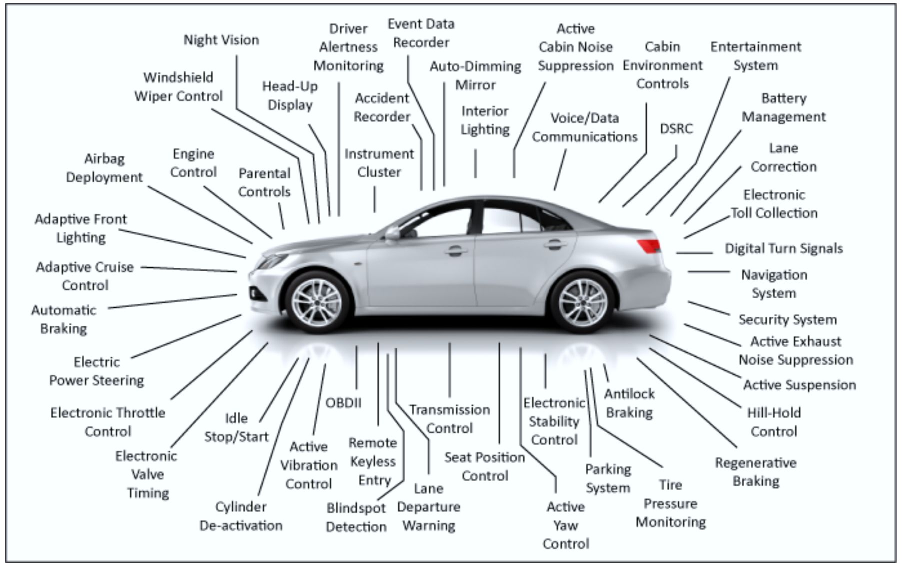
» Accelerating vehicle development programs

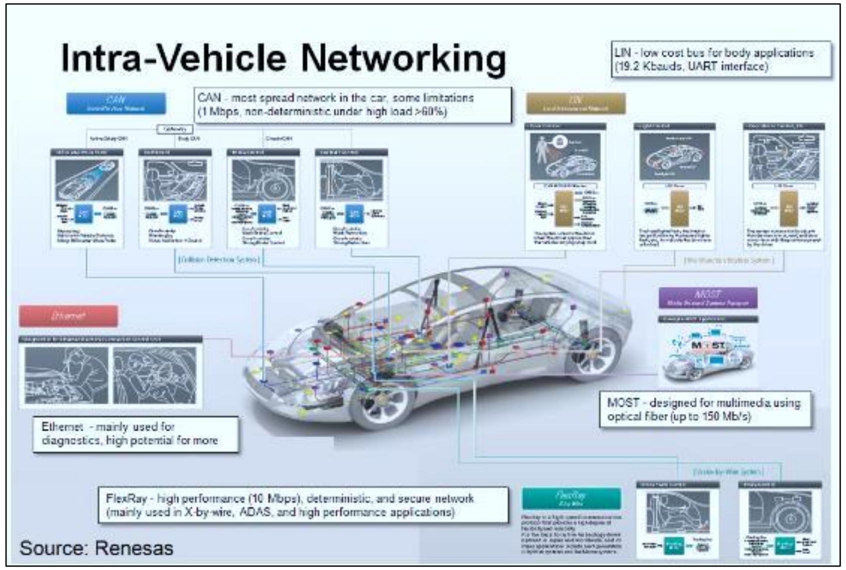
» Sharp reduction or elimination of prototypes for development

» Growth of mechatronic systems in the vehicle (Digital Revolution)

  » Active and semi-active components and subsystems are growing

  » Control by wire will grow with a fast pace.





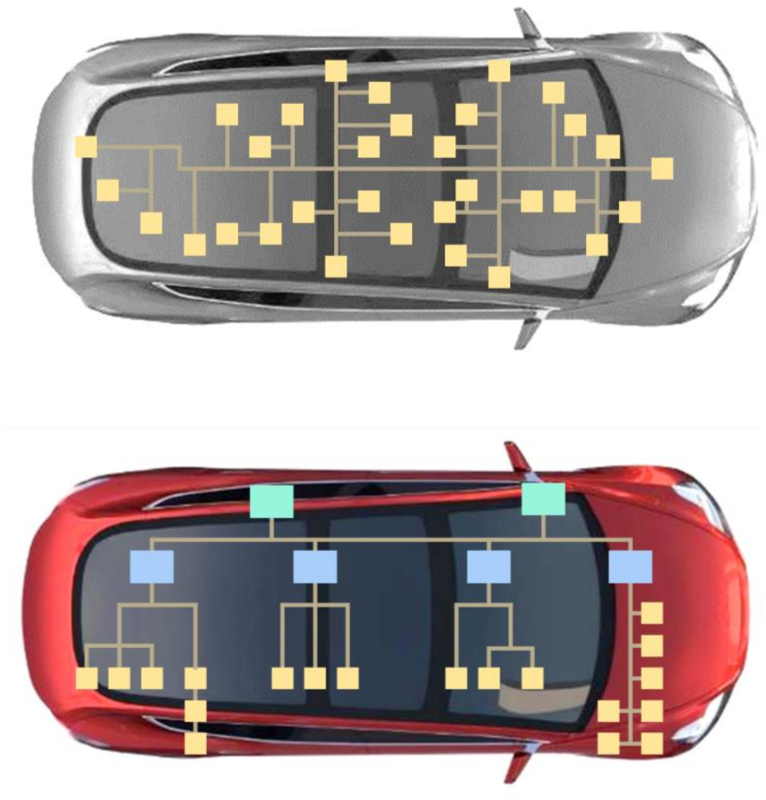
Challenges facing development teams

» Traditionally as the use of mechatronics grew a distributed architecture was utilized with each component or subsystem having their own controller with ECU counts exceeding 100 in a vehicle.

» As higher level functionality grows the trend is moving towards a highly integrated architecture taking advantage of and requiring processing power and higher bandwidth networks.

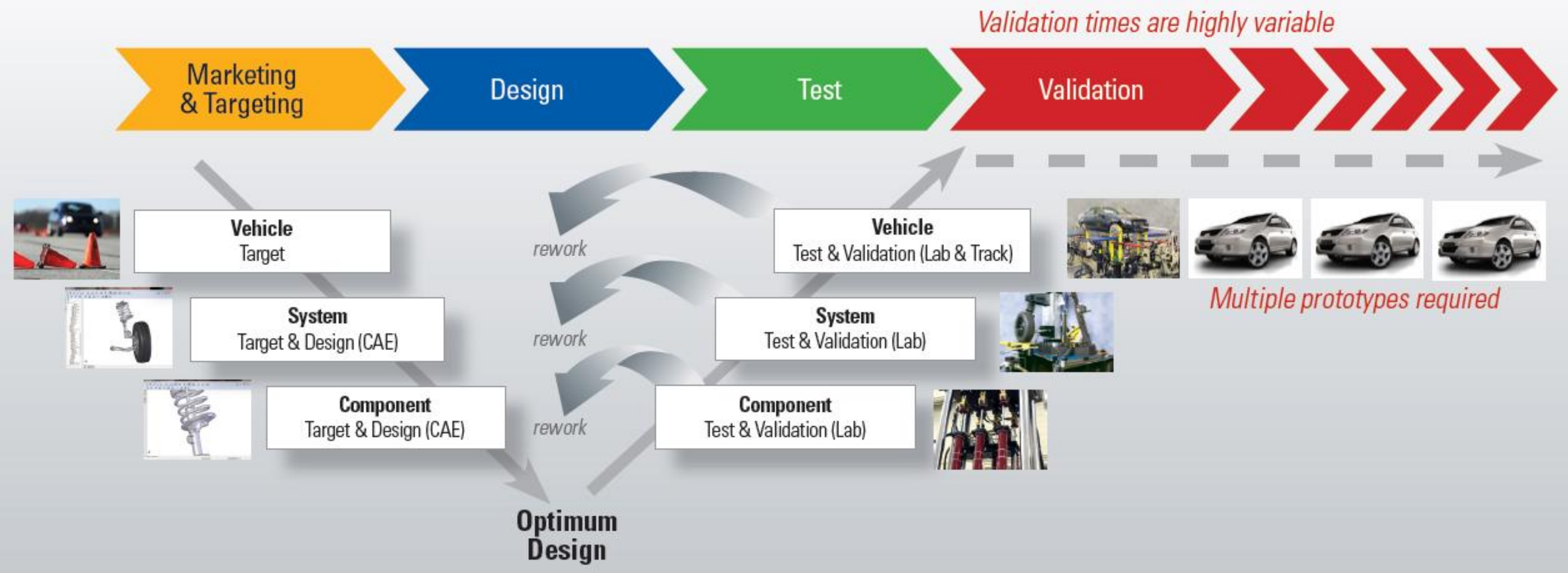
» This trend is driving OEMs and a few tier suppliers to take on the role of systems developer and integrator.

» This trend and the challenges it presents has lead to the need for an integrated mHIL lab



Challenges facing development teams

- Traditional V-shaped approach to vehicle development



» High vehicle complexity, decreased time-to-market, and parallel development requirements push physical test as validation only—no time for rework!

» Design refinements and multiple variants invalidate measured loads. Prototypes available too late to make meaningful design changes.

Hybrid Simulation Enabler: Deliver accurate lab testing before prototype is available and **without** loads measurement. CAE flexibility with the confidence of physical testing!

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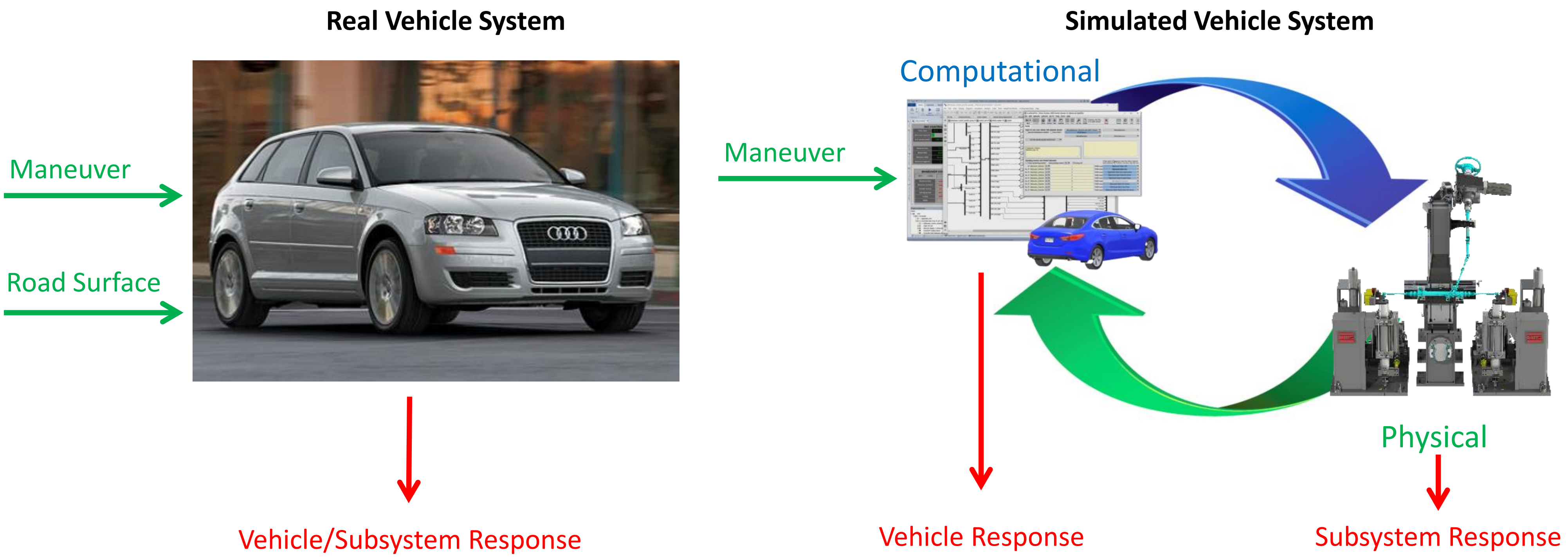
Content

- Industry Trends in the Ground Vehicle Market
- mHIL Technology & Applications
- HSRC (Hybrid System Response Convergence)

Hybrid Simulation Solution: Mechanical Hardware-in-the-Loop (mHIL)

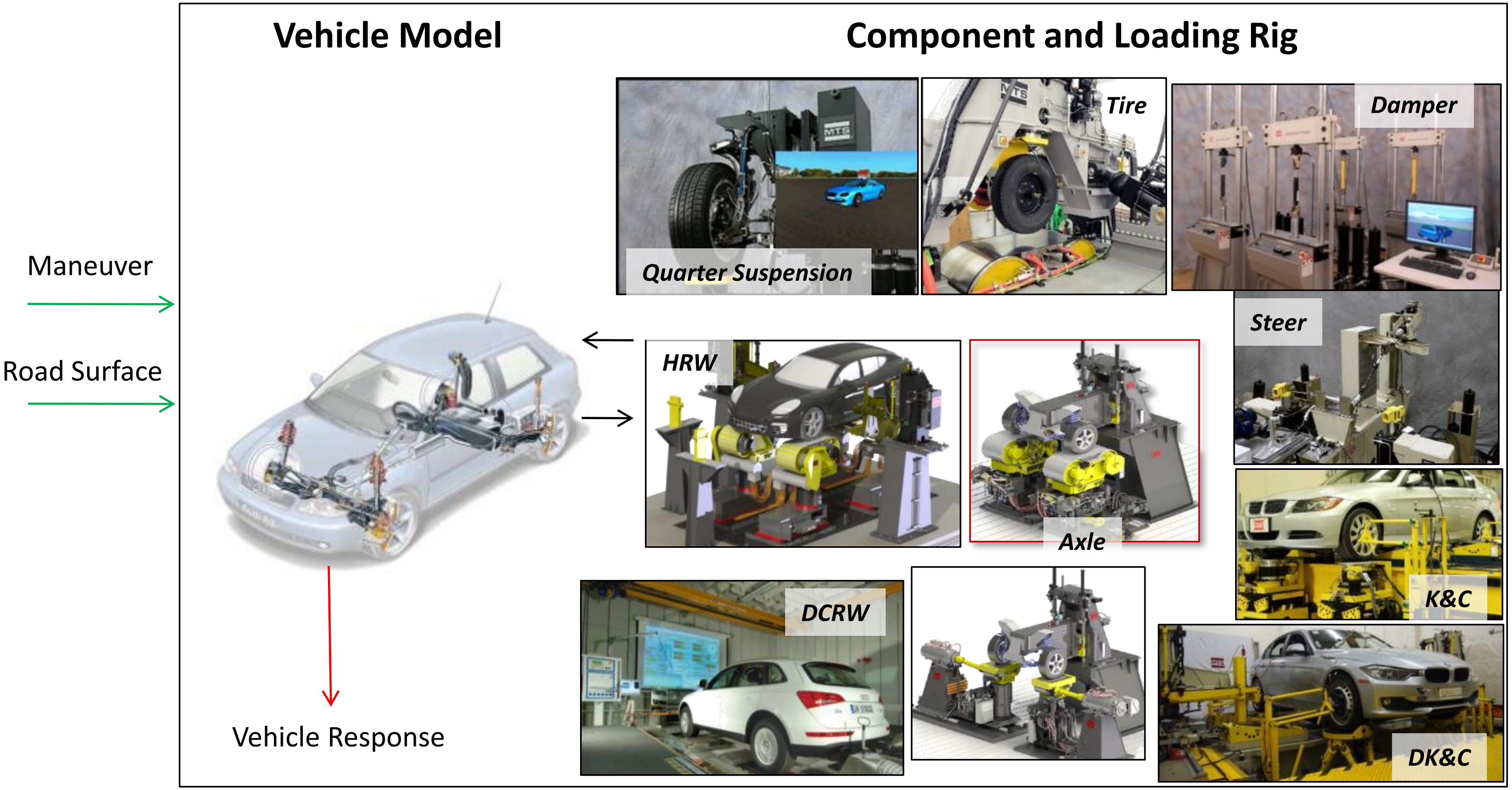


- mHIL: Mechanical Hardware In-the-Loop, physical vehicle mechanical component(s) in closed loop with an adapted vehicle real-time simulation model
- Application: Use the simulation maneuver environment to drive the component or sub-system as it would be driven in real-world driving or proving ground events

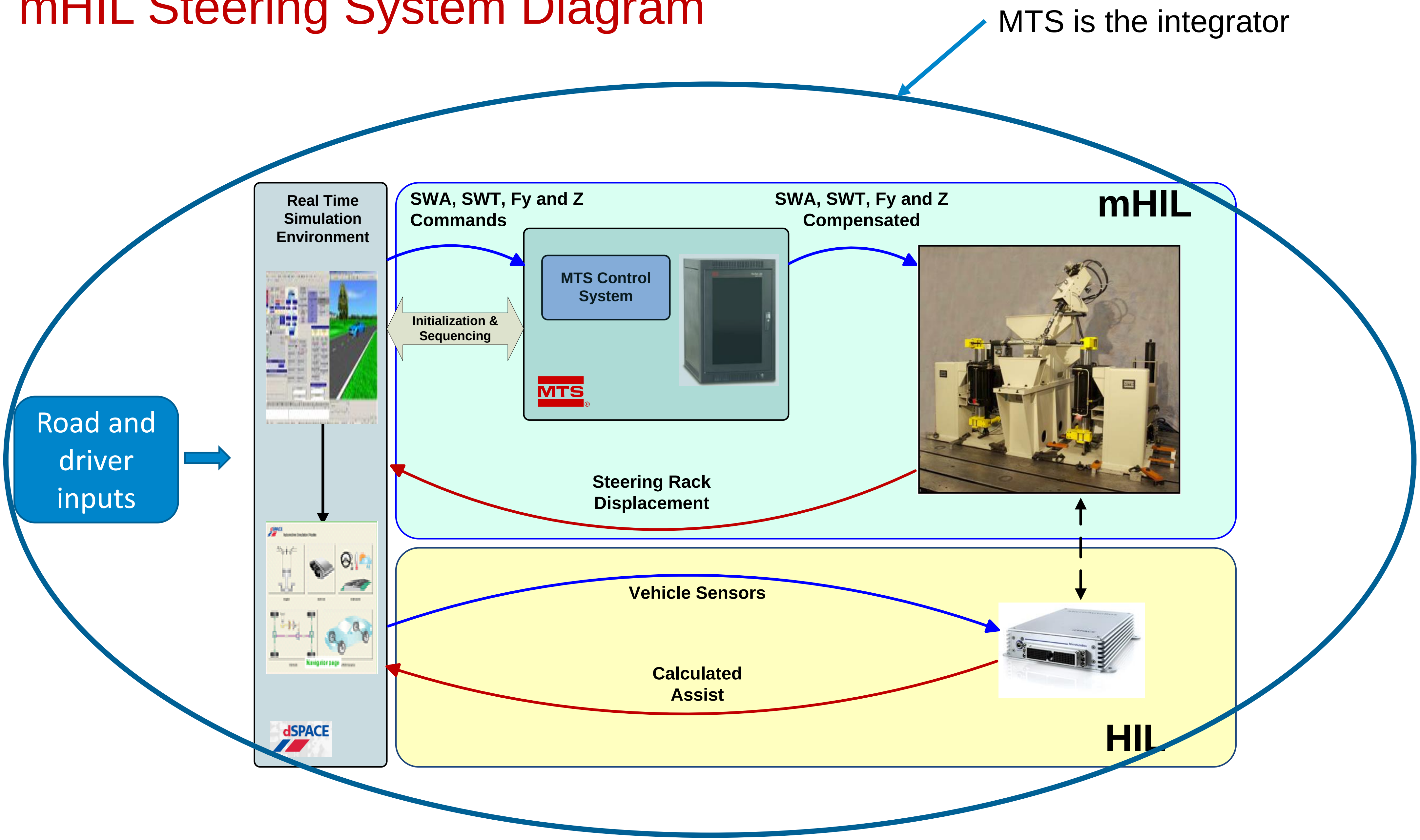
MTS mHIL Applications

UNDERSTAND MORE, FASTER with MTS in-the-loop

Simulated Vehicle System



mHIL Steering System Diagram



MTS®

Damper mHIL Simulation

HYBRID SIMULATION

» System Capabilities
  » Maneuver-based tests for vehicle level & subsystem evaluation
  » Active/passive damper & strut development
  » Comprehensive force & friction evaluation
  » Ride road & 4 poster simulation
  » Noise mitigation
  » Environmental evaluation
  » Damping algorithm development
  » Early supplier evaluation
  » Fault & limit handling events
  » Complement track evaluation program

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The Evolved Damper mHIL Solution

HYBRID SIMULATION

Ride Road

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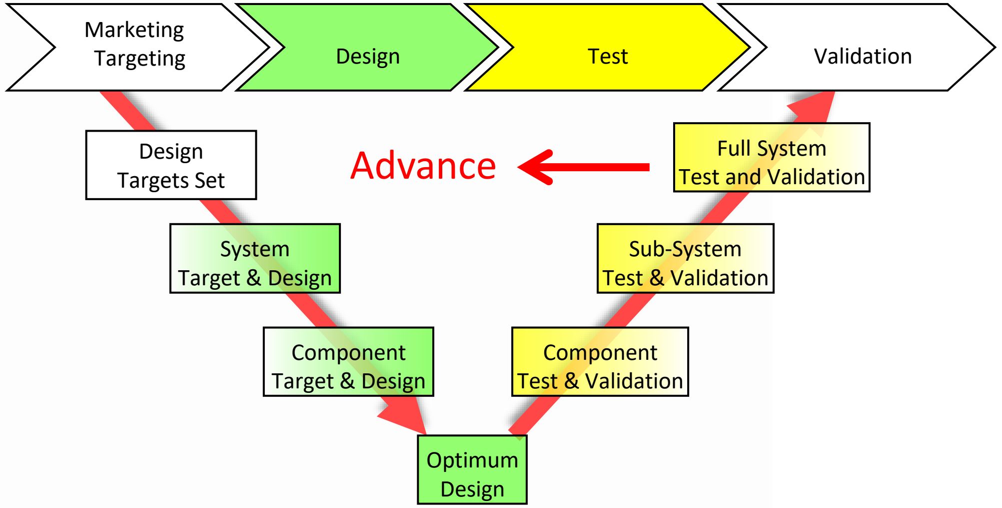
be certain.

Advantage of mHIL

- **Allow system level evaluation with a subsystem test!!!**
  - Tests can be done earlier – save development time and money.
  - Hard to model subsystems are represented by real components - accurate.
  - Reduce rework in the later stage.
  - Substructure test – less expensive.



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Hybrid System Response Convergence (HSRC):

A Hybrid Simulation Method for Vehicle Development

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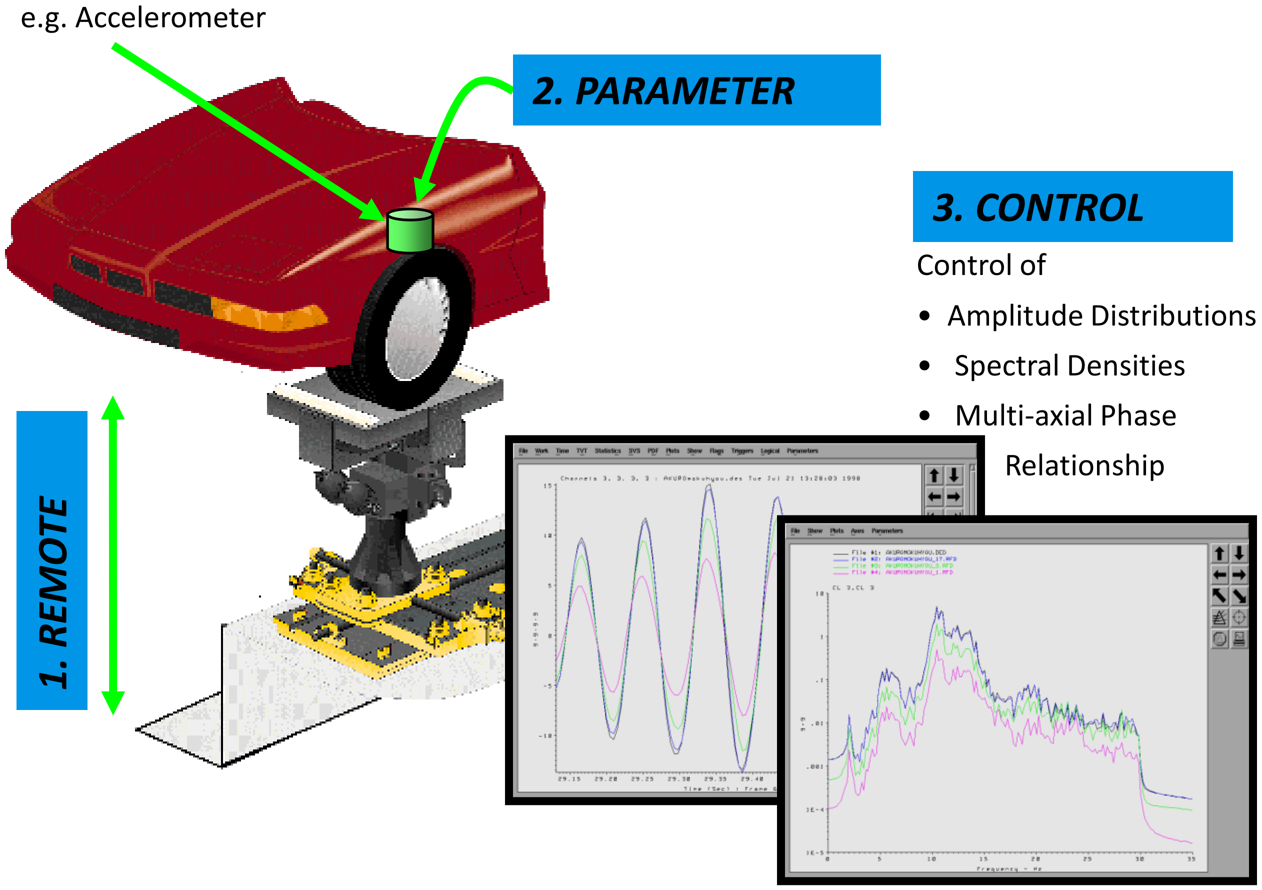
Remote Parameter Control (MTS RPC)



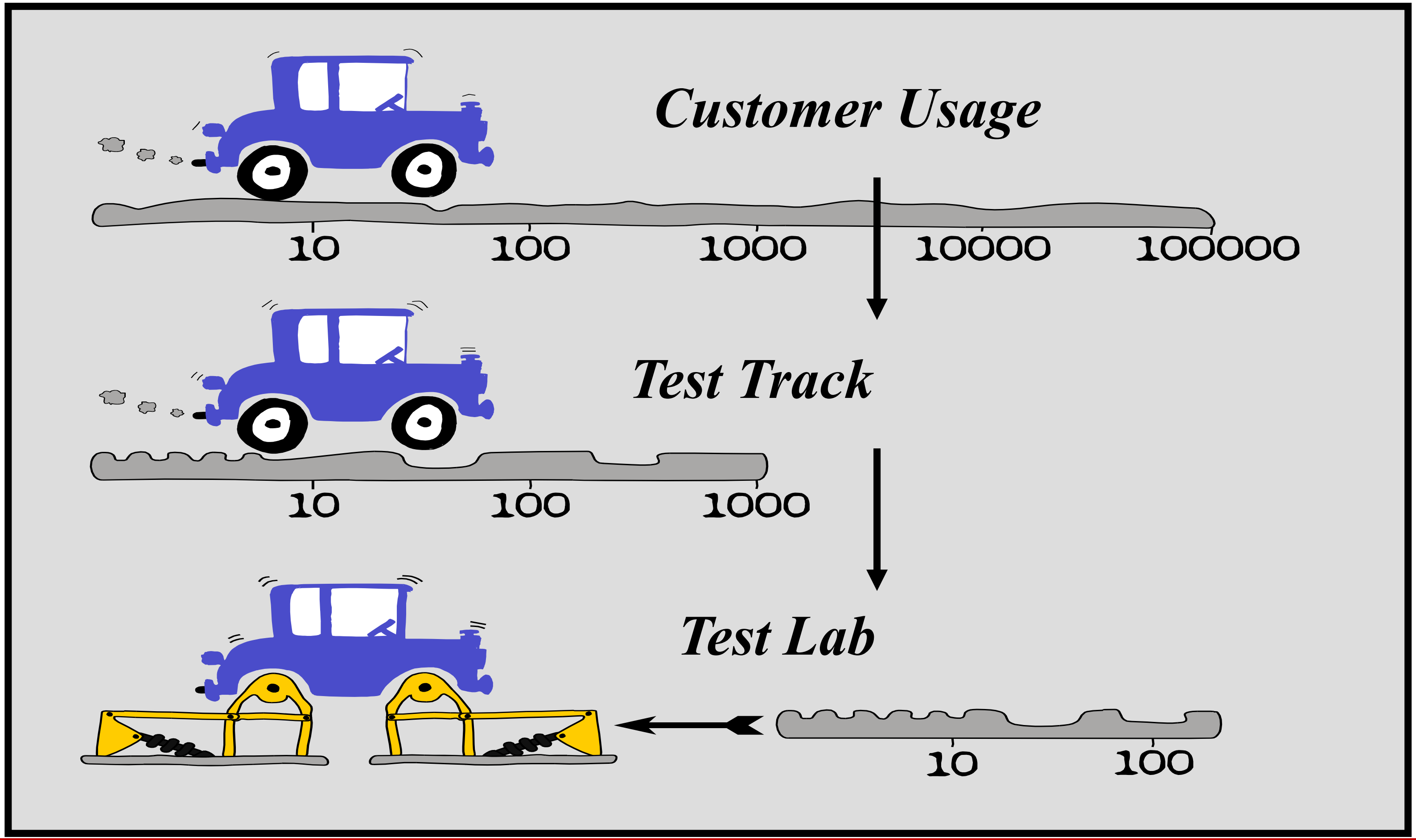
Control of

- Amplitude Distributions
- Spectral Densities
- Multi-axial Phase Relationship

- Remote Parameter Control (RPC) is an advanced simulation technique used to repeatedly replicate and analyze “in service” vibrations and motions of a specimen using a dynamic mechanical system in a controlled laboratory environment.

Remote Parameter Control (MTS RPC)

RPC – Accelerating durability tests by reproducing damage caused by the road in the lab.



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Traditional RPC Steps

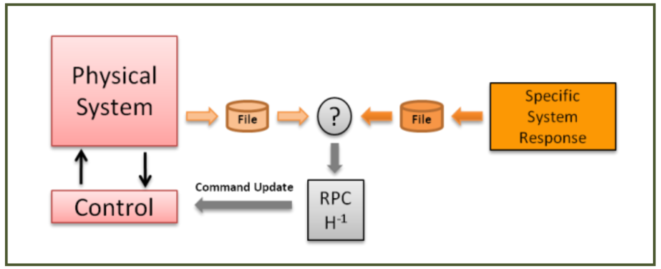
- Step 1: Acquire data
- Step 2: Digitize Edit & Analyze
- Step 3: Measure the System FRF
- Step 4: Invert & Prepare the FRF
- Step 5: Iterate
- Step 6: Run the Test

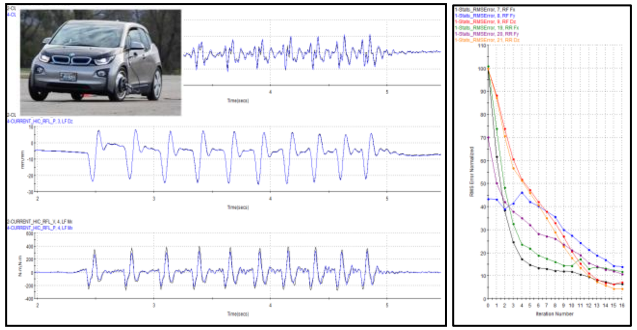
How is HSRC Different?

- HSRC avoids the limitations of traditional RPC and Real-Time hybrid simulation:

RPC Simulation

(Needs a measured target)

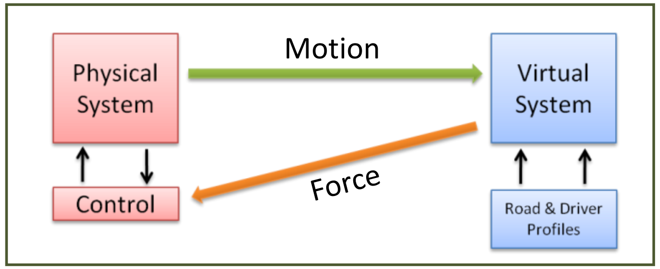


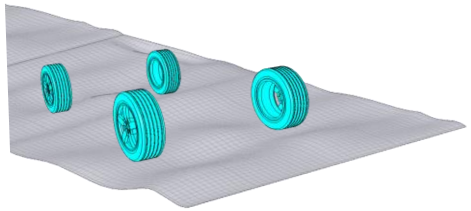


- Drivable prototype required
- Long instrumentation and acquisition time
- Uncontrollable variability in test conditions
- Remeasure for variants and loaded condition

Hybrid Simulation

(Needs real time coupling)





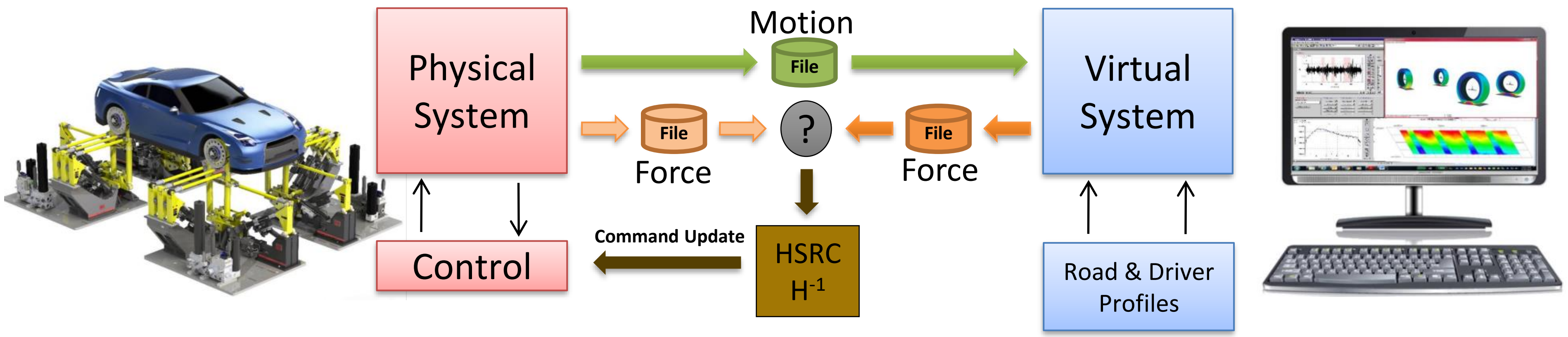
- Need minimal communication/control delay
- Multi-axis, cross-coupled system
- Force control with compliant specimens
- 50+ Hz control performance required

How is HSRC Different? (cont.)

» The solution -- a decoupled, iterative hybrid simulation approach:

MTS HSRC: **H**ybrid **S**ystem **R**esponse **C**onvergence (patented)

– Combines RPC and hybrid simulation techniques for laboratory durability testing



- HSRC converges on the 6 Degree of Freedom (DOF) force & motion solution at each corner that simultaneously solves for the unique solution of the complete, coupled system at each hybrid interface.

How Full Vehicle HSRC Works

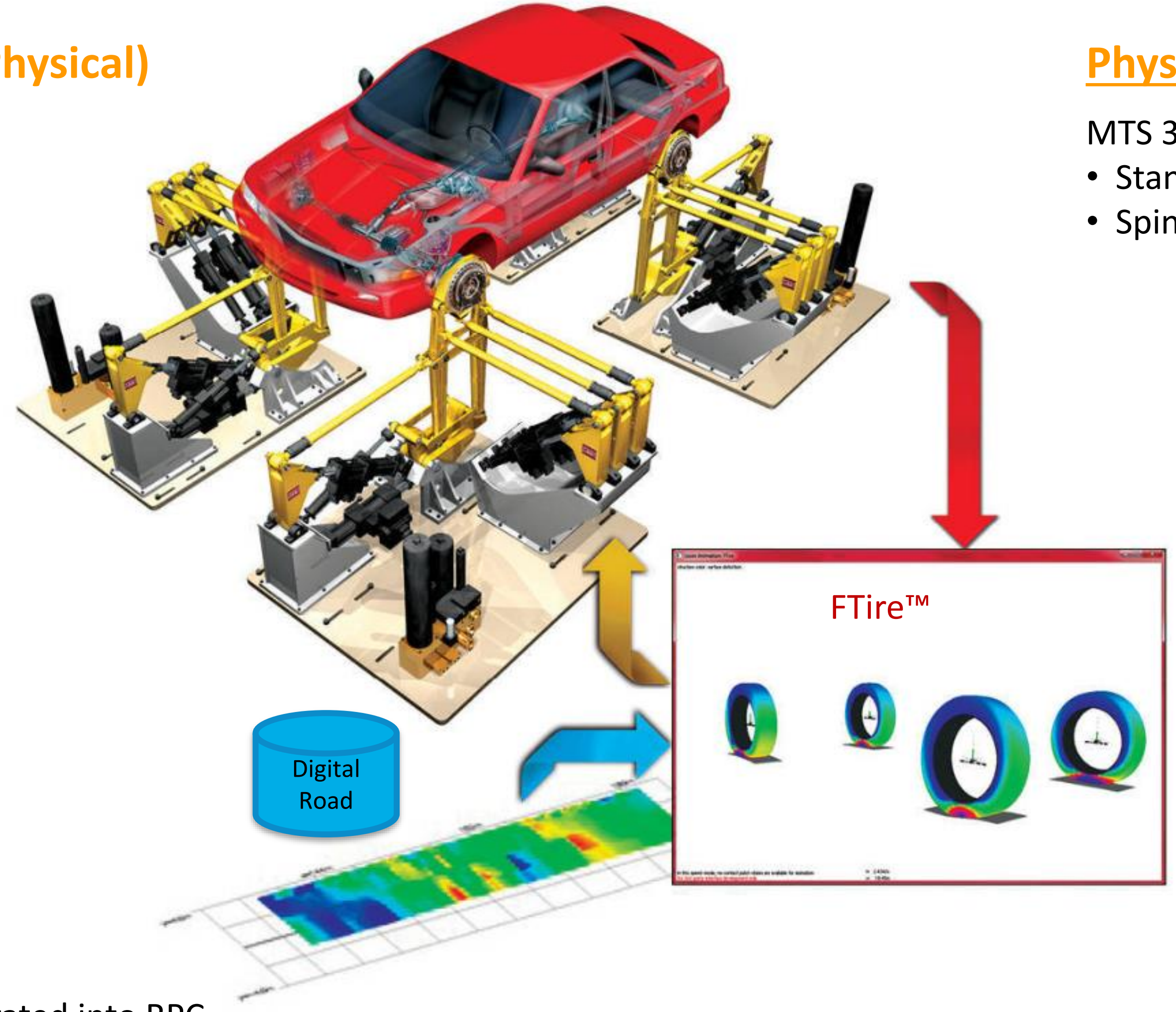
Spindle Convergence (Physical)

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

Physical System:

MTS 329 6 DOF Road Simulator

- Standard FlexTest controller
- Spindle force & motion sensors



Virtual System:

Tire Model Simulation

- Industry standard Ftire integrated into RPC
- High fidelity tire models and road scans
- Curved/elevated roads
- Trajectory managed from HSRC application

Spindle Coupling (Virtual)

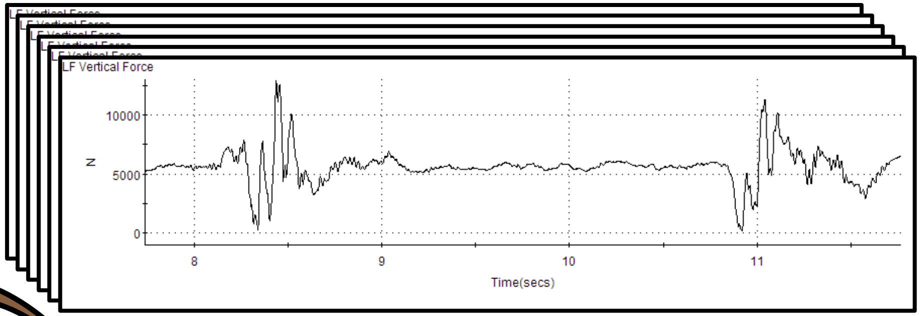
- Vertical force (Fz)
- Longitudinal displacement (Dx)
- Lateral displacement (Dy)
- Camber angle (@x)
- Steer angle (@z)

HSRC Full-Vehicle Hybrid Simulation

- Iterative convergence: Vertical Spindle example

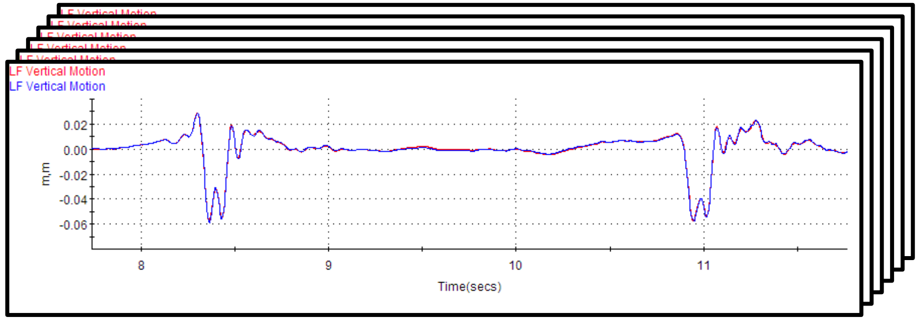
Update Rig Drive

Hybrid Interface Coupling Mode

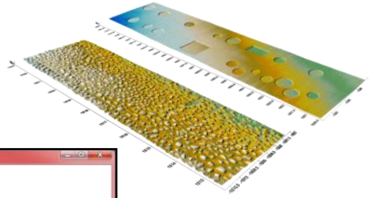


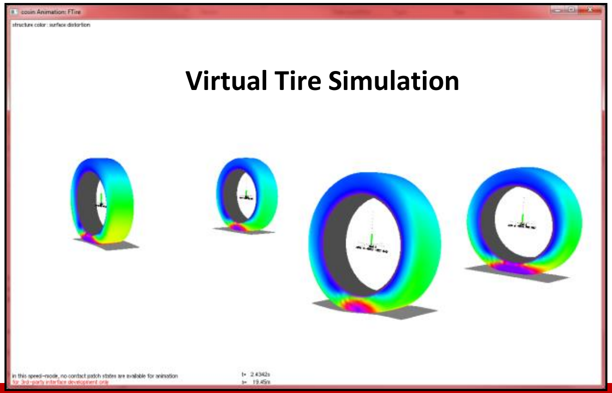
Vertical Spindle Force_5

Hybrid Interface Convergence Mode
Physical / Virtual



Vertical Spindle Motion_5

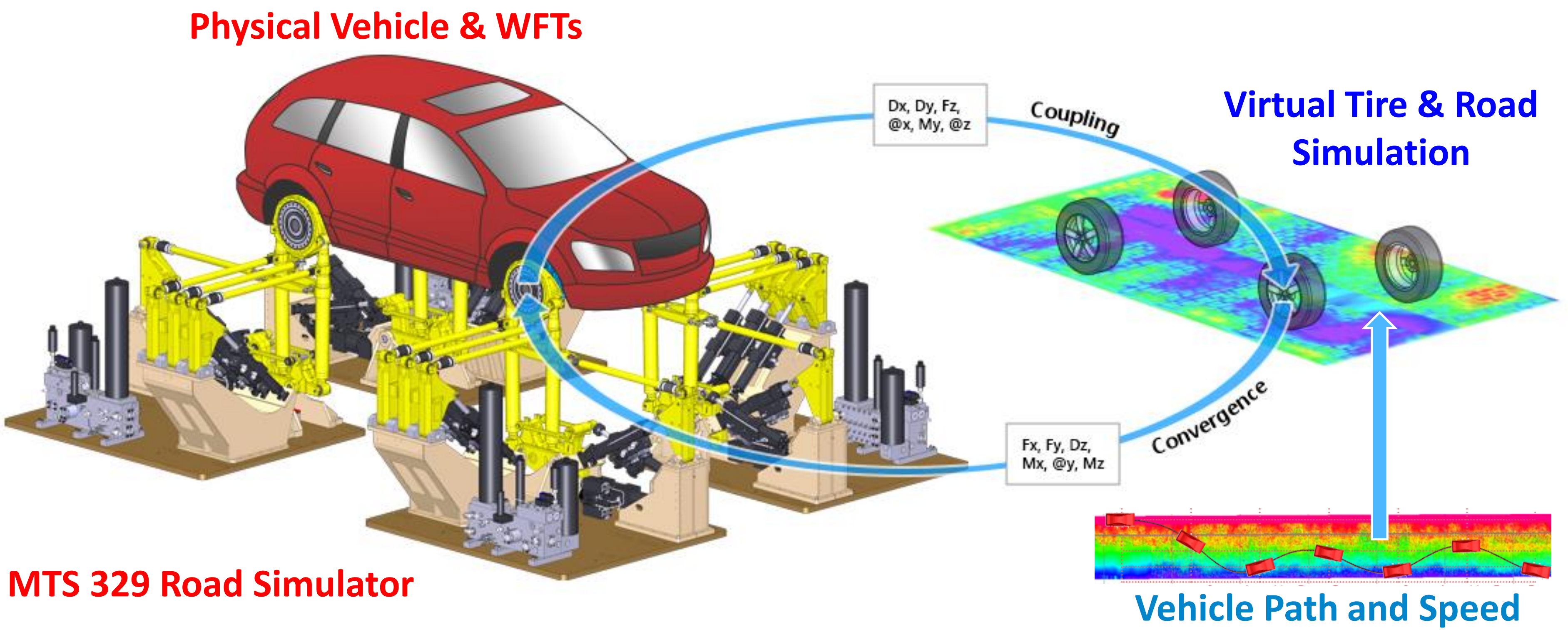




Driving Profile (vehicle path)

Final HSRC solution will be identical to that of the same Real-Time Coupled System!

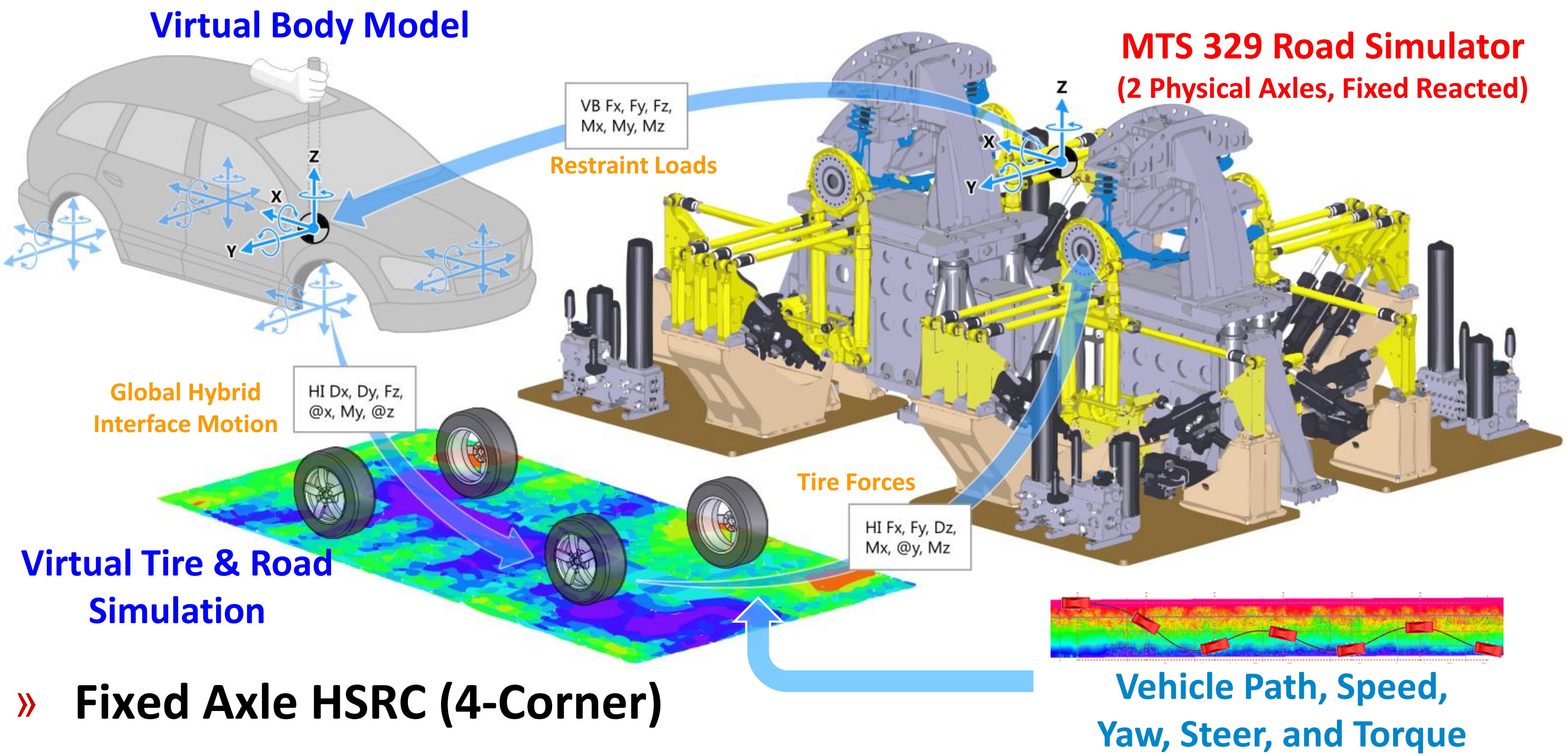
Full Vehicle HSRC: Floating Body HSRC



» **4-Corner Floating Body**

- Inertially reacted 329—Wheel Force Tranducers, Spindle Accelerometers, and specimen correlation channels
- Prototype need not be driveable—no road load data acquisition (RLDA) required
- Handling, accel, and braking can be simulated but rig translation is high-passed filtered
- Terrain pitch and roll is preserved to 0 Hz—correct body attitude compared to RLDA

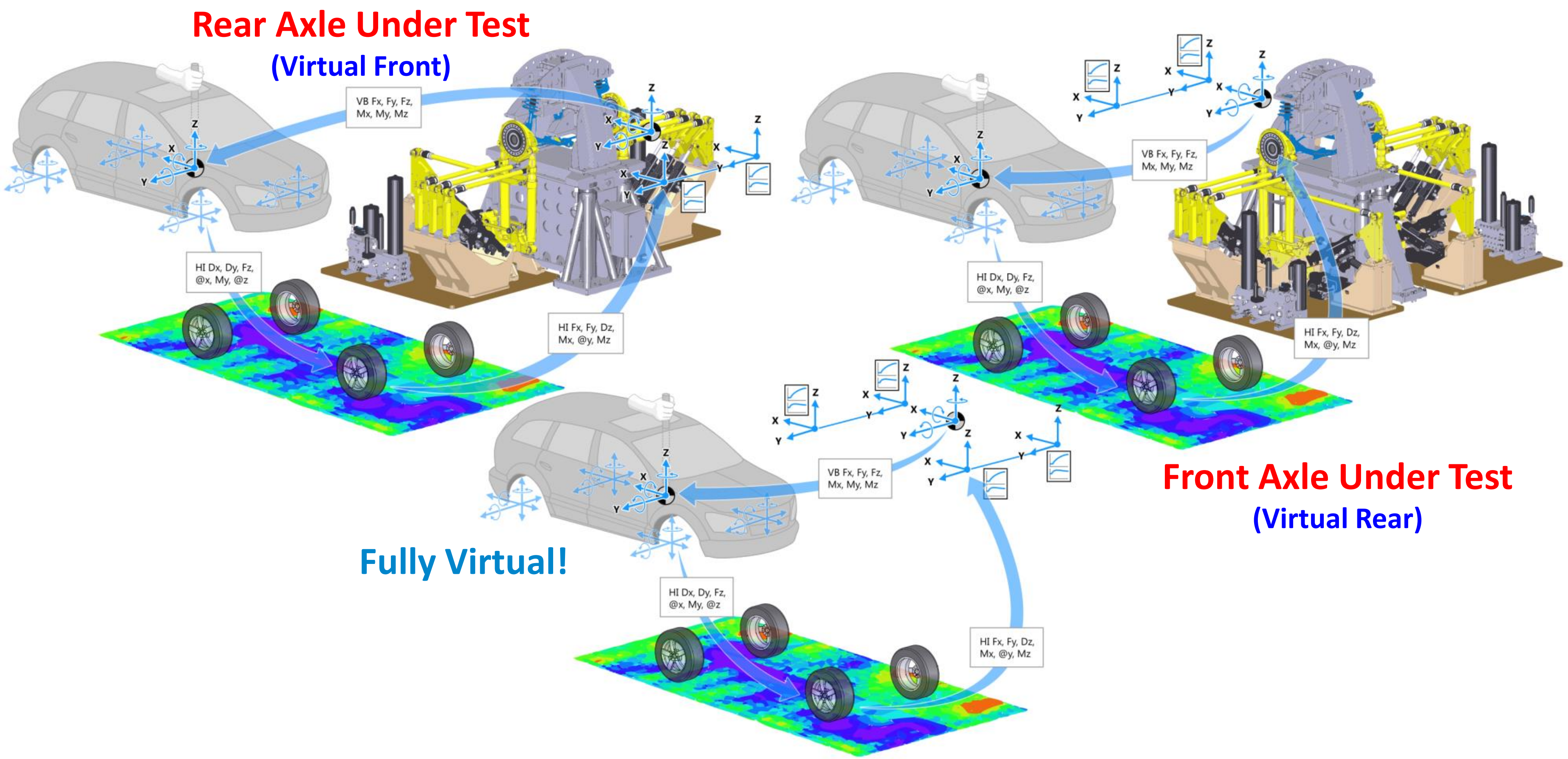
Fixed Axle HSRC (4-Corner)



» **Fixed Axle HSRC (4-Corner)**

- Two half-rig 329s with suspension connected to restraint fixtures
- Measured suspension restraint forces are relayed to virtual body model
- Body guidance controller allows suspension forces to create natural body motion
- Handling, acceleration, and braking maneuvers all possible

Fixed Axle HSRC (2-Corner) – 3 Axle Variations:



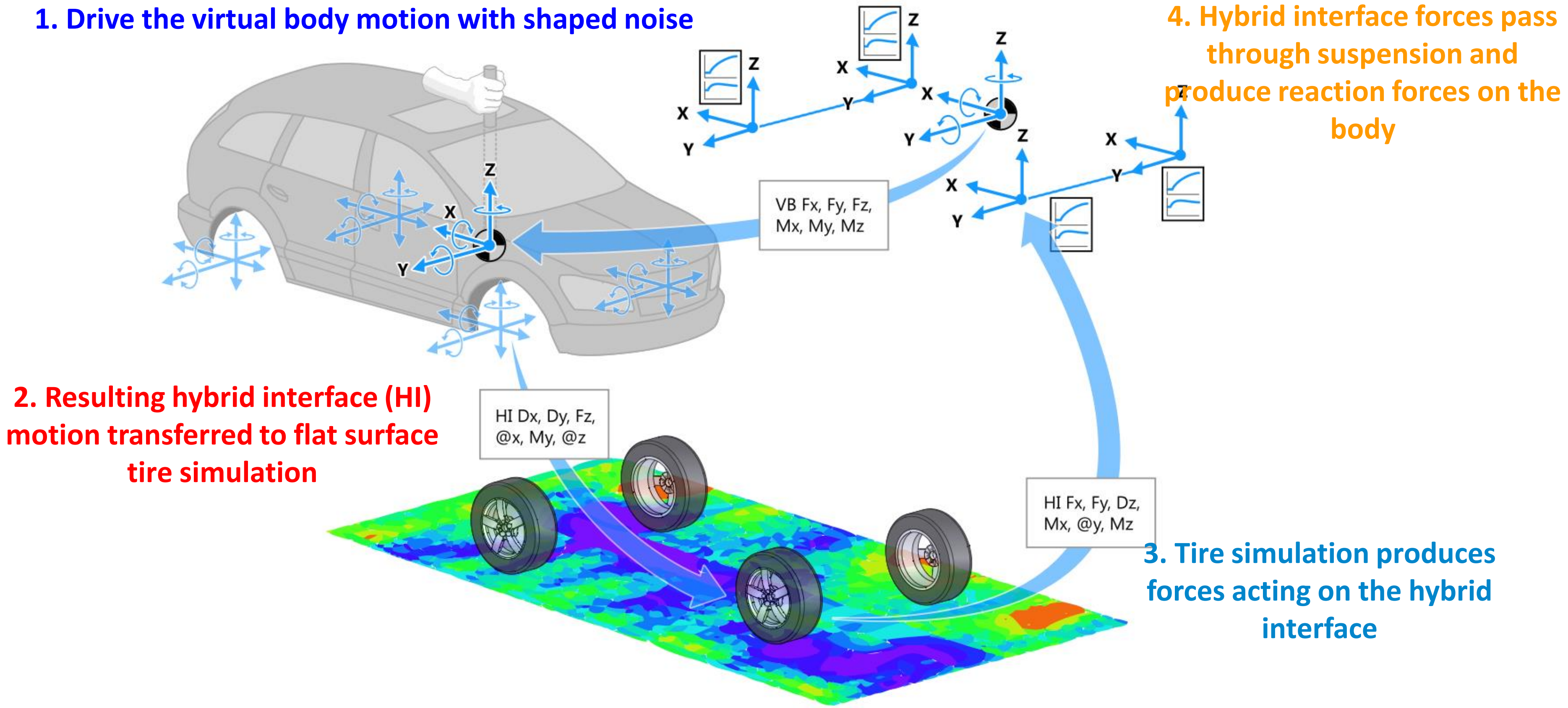
» **Fixed Axle HSRC (2-Corner)**

– Same as 4 corner fixed (full vehicle simulation) but with a single physical axle under test

– Untested axle identified from MBD model or internal 2nd order spring/mass/damper model

Virtual Body Guidance FRF – Fixed Axle

- **Virtual Body Guidance FRF Wizard**—create control FRF for the virtual body motion drive in all 6 DOF + driver steer and drive/brake torque input



» **Objective:** All forces causing motion on the body arise from the suspension– the virtual "hand" moving the body contributes zero force!

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HSRC — Accuracy compared to Measured Loads

- With accurate tyre models and road scans, HSRC produces loads statistically consistent with measured road data → Accurate tests without RLDA!

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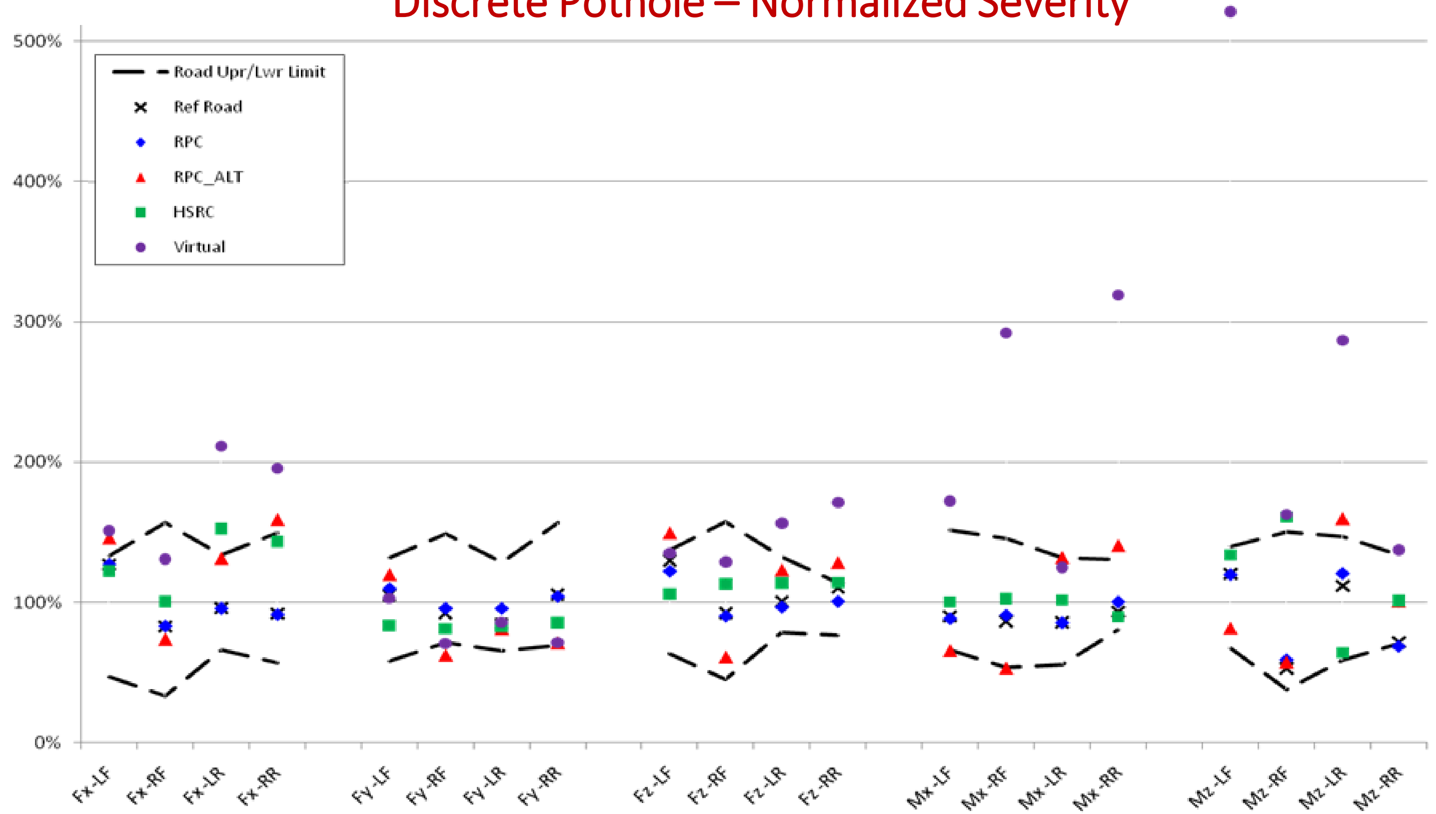
HSRC versus Analytical and Conventional RPC

» Statistical severity comparison of Wheel Force Tranducer loads normalized to an average of 23 road measurements of a single pothole event (**Blue** is RPC, **Black** dashed lines are max and min of measured)

» Compare to bookshelf loads (**Red**), fully analytical modeling (**Purple**), and HSRC (**Green**)

Discrete Pothole – Normalized Severity



- HSRC results fall within range of measured road data – generally better than bookshelf loads, and much less spread than the completely virtual model

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Using hybrid simulation tools to streamline development cycles

Thanks for your attention!

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