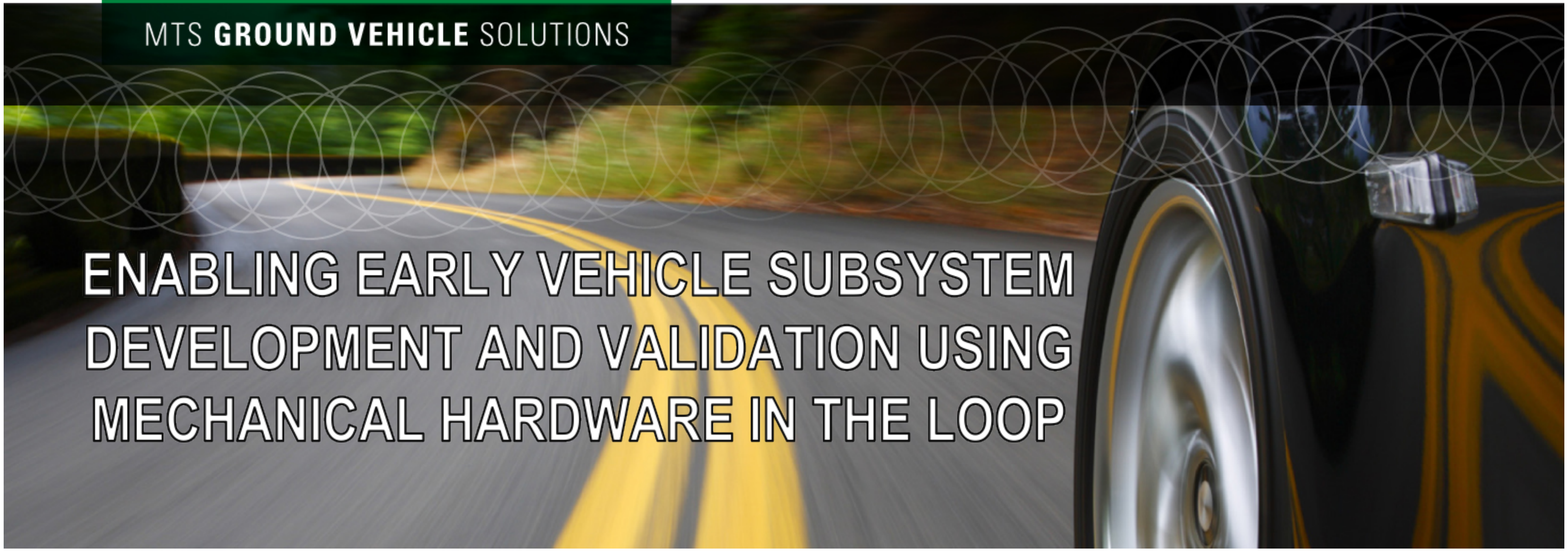


Juan Garcia

MTS Systems Corp

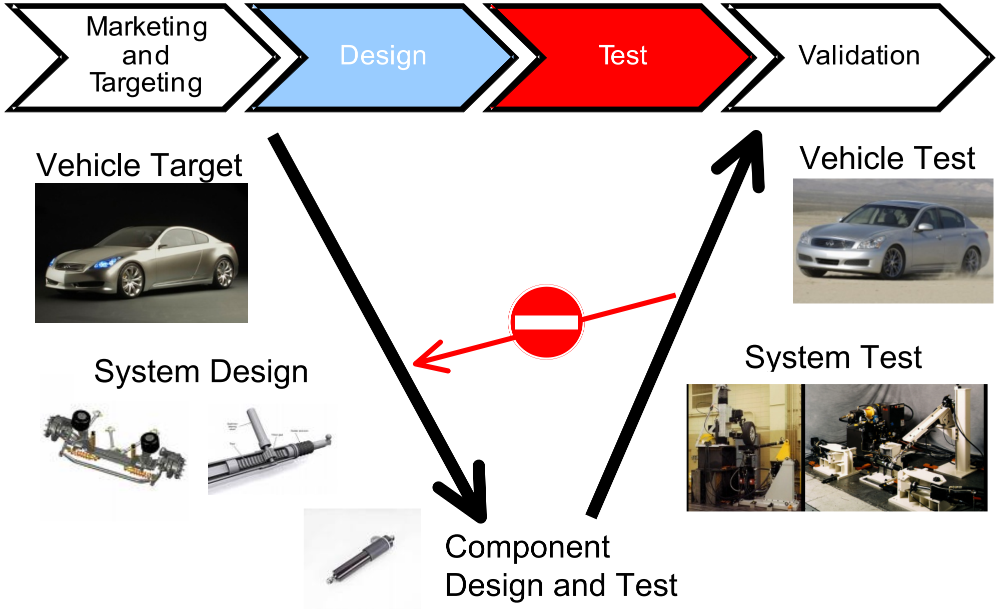
Testing Expo
Stuttgart, Germany
May 17-19, 2011

be certain.

Contents

- Motivation
- Hybrid simulation and mechanical hardware in the loop (mHIL)
- Four corner damper test system
- Steer test system
- Conclusions

Addressing Development Challenges

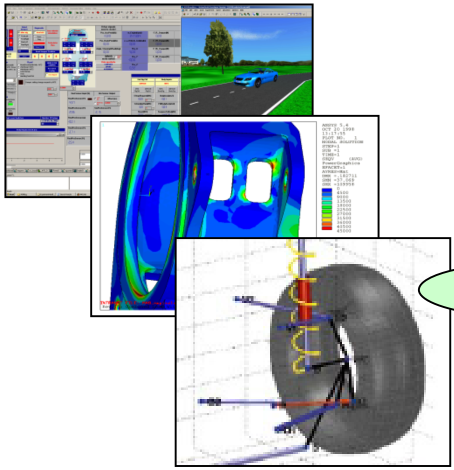


- Earlier evaluation and validation at both the component and vehicle level.
- Eliminate costly iterative cycles late in the development program.
- Effective use of prototypes for track validation.

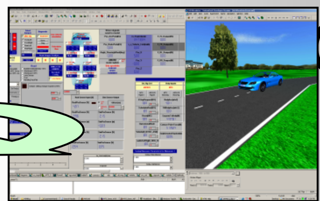
MTS GROUND VEHICLE SOLUTIONS

Accelerated Vehicle Development

CAE	Mechanical Hardware in the Loop (mHIL)	Track Testing



Real-time Vehicle Model



Real Components and Test Rig

Early and fast, but incomplete

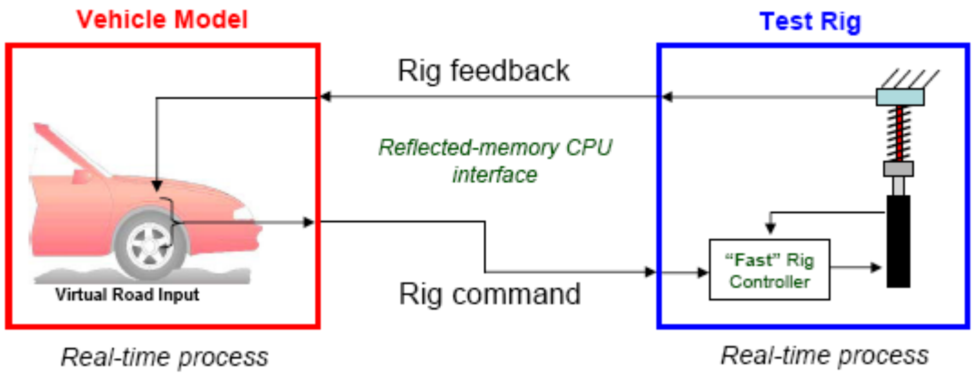
Early, fast, and more complete

Later and slower, but complete

mHIL Concept: Hybrid Simulation

- Combine virtual and real elements
- Hybrid Simulation is a technique that integrates dynamic simulation and physical measurements
- Why? Uncertainty about components

Real-time coupled hybrid system



mHIL: Bridge the Gap between CAE and Track Testing

Real Vehicle System

Maneuver

Road Surface

Driver

Vehicle Response

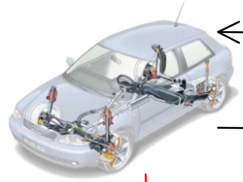
mHIL Vehicle System

Maneuver

Road Surface

Driver

Vehicle Model



Component and Loading Rig

Vehicle Response

Component Response

Role	CAE	mHIL	Prototype
Target Validation		√	√
Confirmation of Knowns	√ √	√ √	√
Identification of Unknowns		√ √	√

√ = Effective

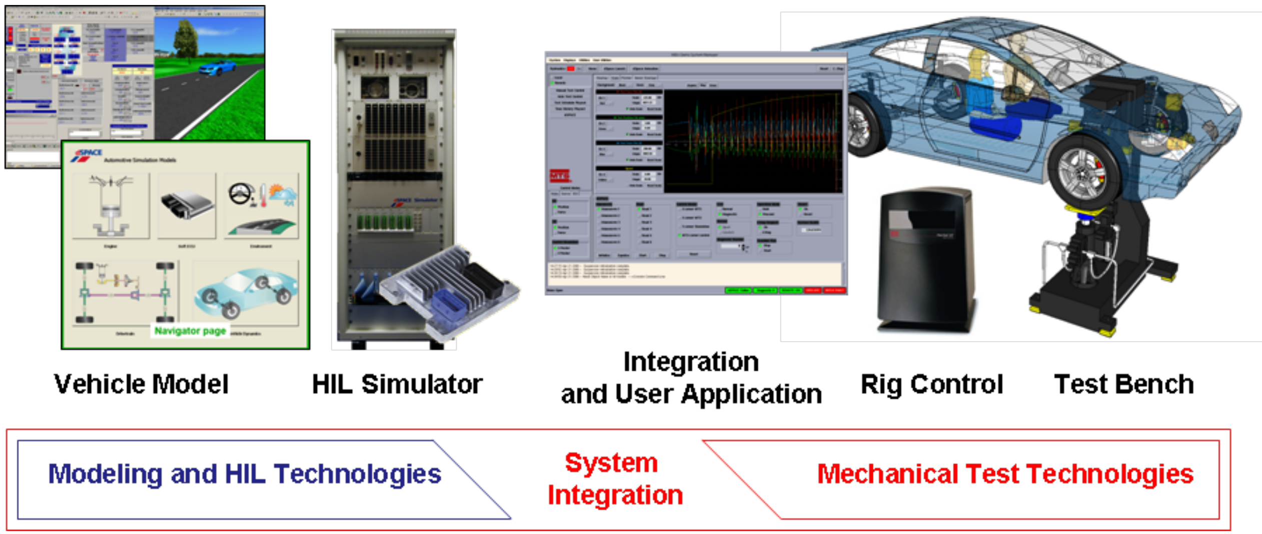
√ √ = Effective and Efficient

Benefits of Vehicle Development with mHIL

- Combining simulation with physical components provides more complete results earlier in the development process.
- Maneuver driven testing provides a development environment that allows for:
  - Enhanced characterization to support better model development.
  - Evaluation and validation at both the component and vehicle level.
  - Advanced test and method development to address increasing complexity.
  - Diagnostic tool to support a more efficient track program.
- Simple parameter or environment modifications allows rapid testing of platform and geographic variations.
- Expected and unexpected fault conditions can be easily and safely evaluated.

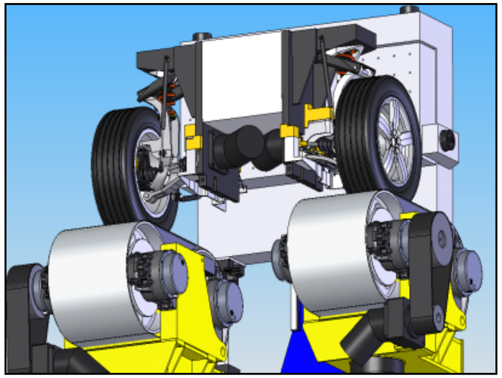
mHIL Requirements and Components

- Real-Time Vehicle Dynamic Model and Simulation Software
- Validated Vehicle Parameters
- Rig with Fast, Accurate Control
- Fast Communication Link

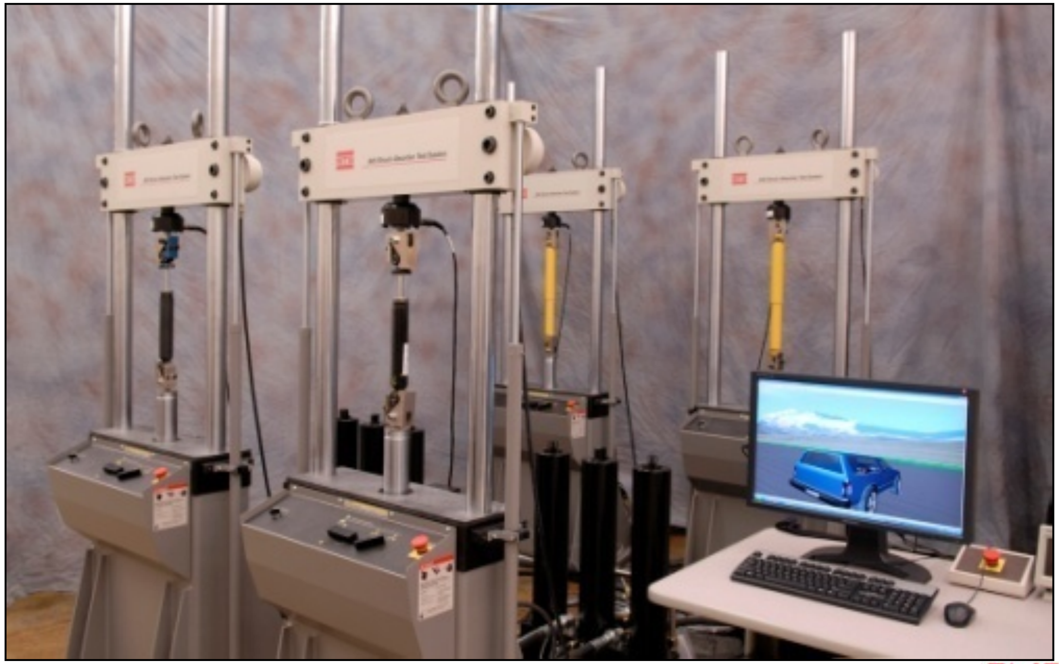


mHIL Test Systems

- Four Corner Damper
- Steer
- Quarter suspension
- K&C/DK&C
- Full Axle



Four Corner Damper System



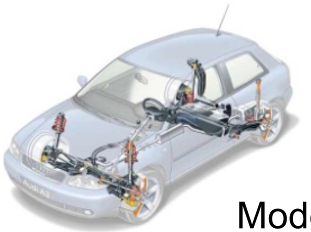
VEHICLE DYNAMICS INTERNATIONAL
WINNER
Development Tool of the Year 2008

mHIL FCD Description

- FCD combines a real-time vehicle dynamic model and physical dampers in loading rigs
- Physical dampers replace virtual dampers in the model
- Model calculates damper displacement command to rig
- Rig measures damper forces and feeds back to model
- *Model and rig function in closed loop, in real time*

Operation

Driver and Road Inputs



Model

Vehicle Response

Real-Time Model (HIL box)

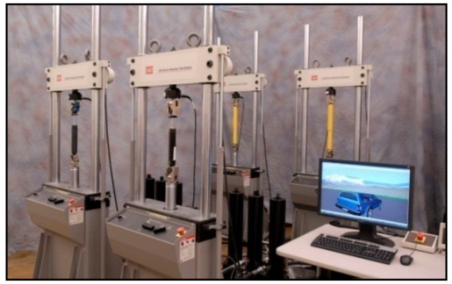
SCRAMNet

Displacement Command

Force Feedback

Component Response

Force Measurement



Displacement Control

Loading & Measurement Rig

FCD Features and Applications

- Advanced Control Techniques

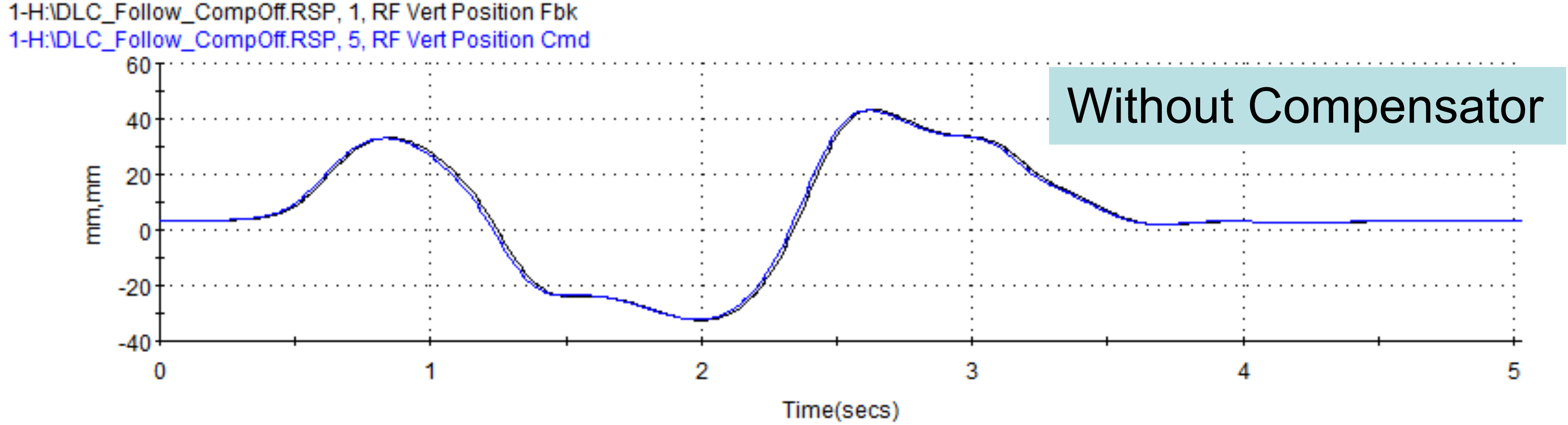
  Model-based, parametric compensator to minimize lag

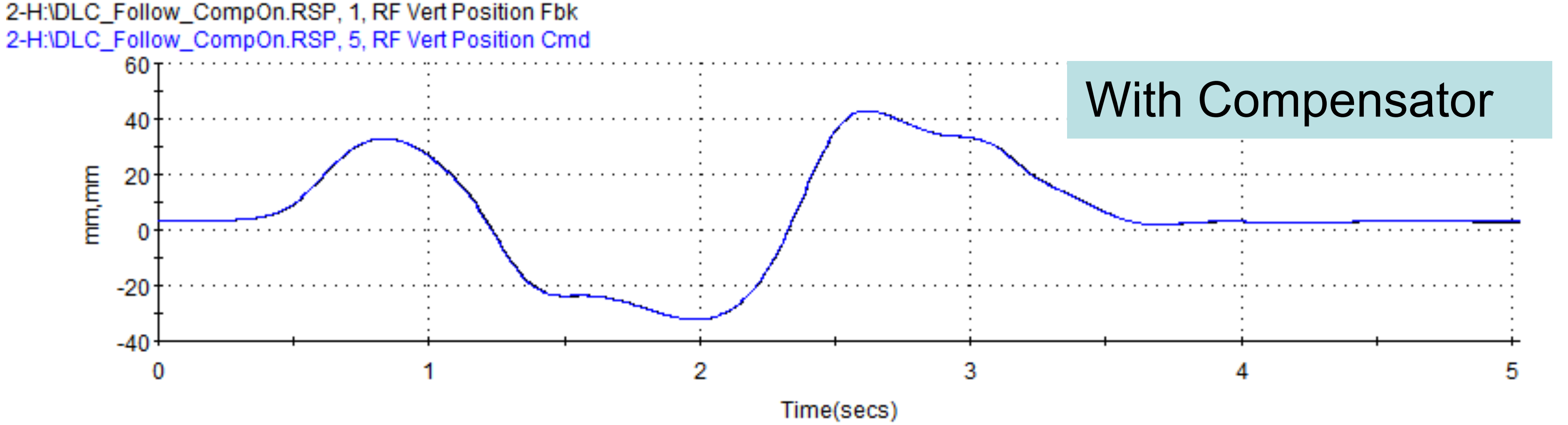
- Moment Input

  Provide lateral moment for strut configurations, more realistic boundary conditions

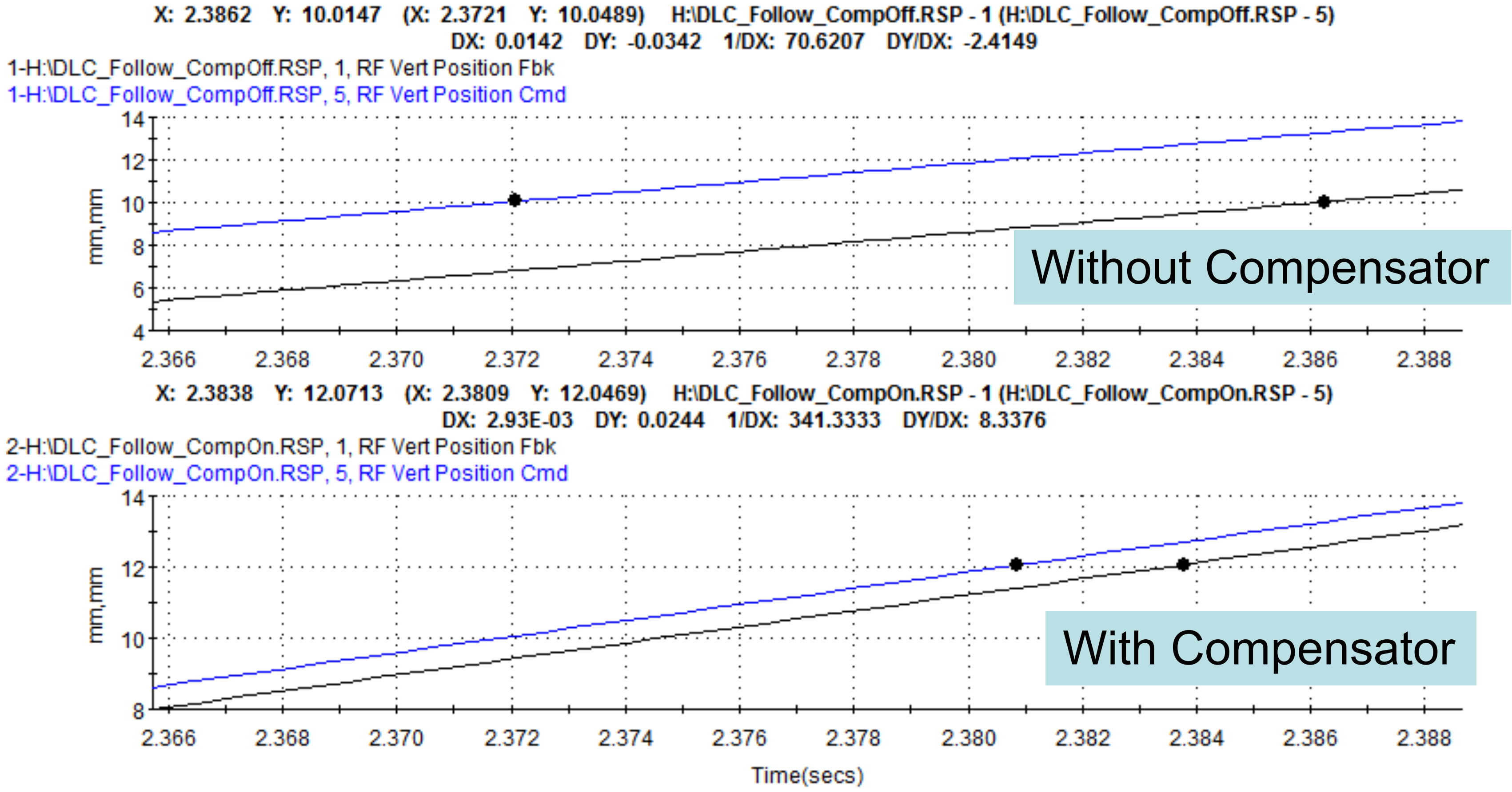
- Applications
  - Handling and primary ride simulation
  - Maneuver simulation
  - Four-poster simulation
  - Damper characterization (e.g.: friction evaluation, small amplitude motions)
  - ECU algorithm development

Advanced Control Techniques: Example – DLC Maneuver

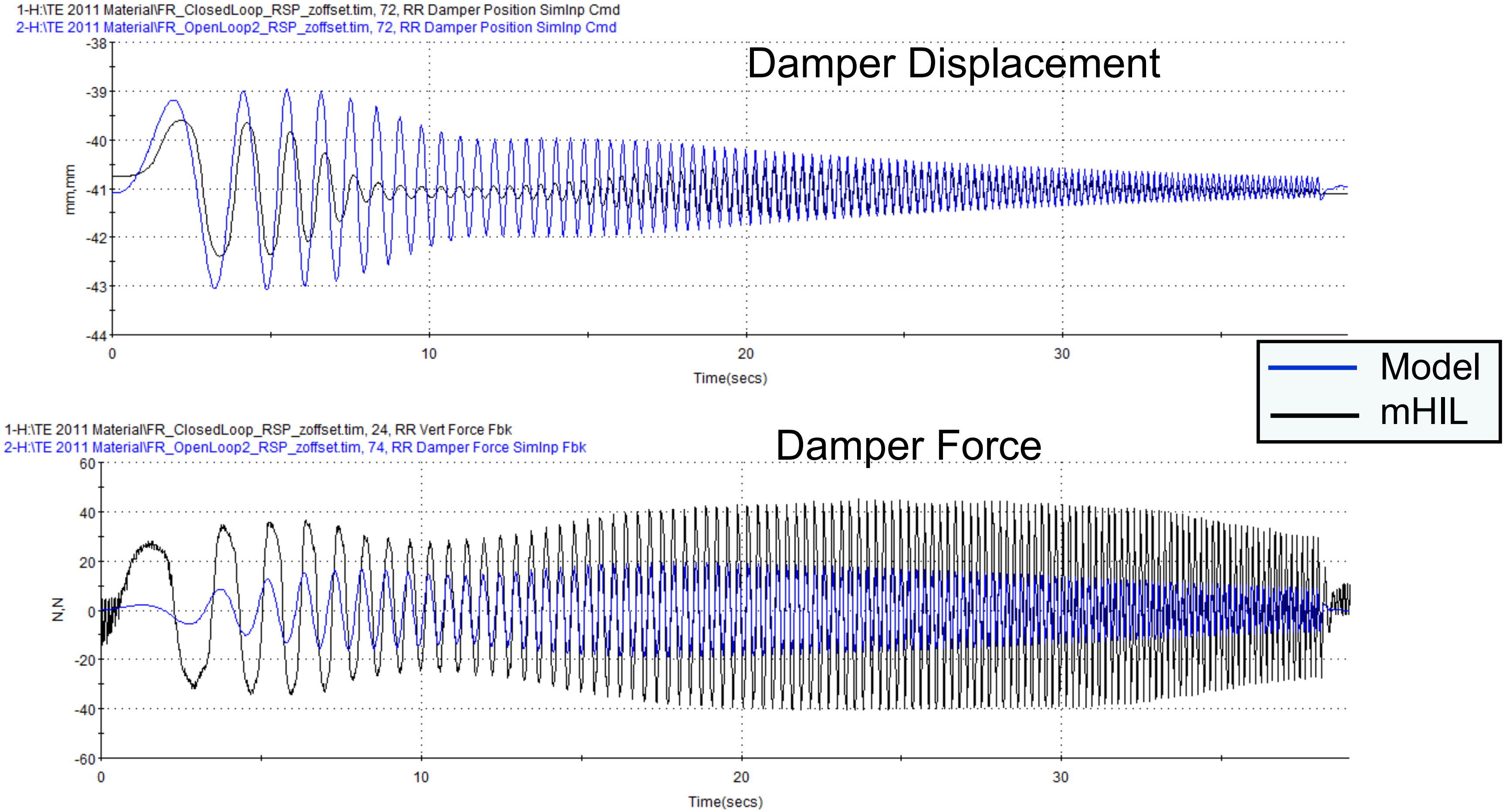




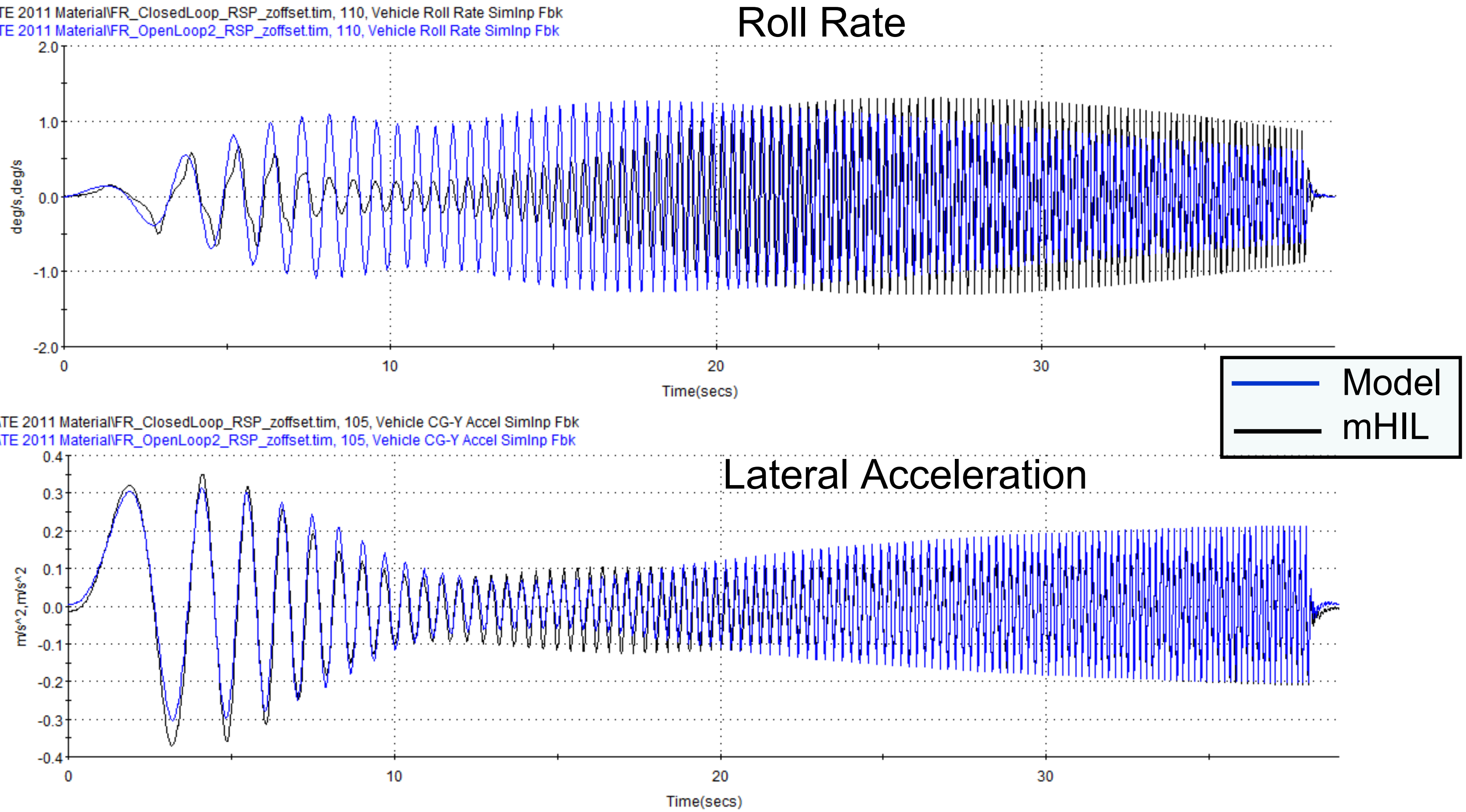
Advanced Control Techniques: Example – DLC Detail



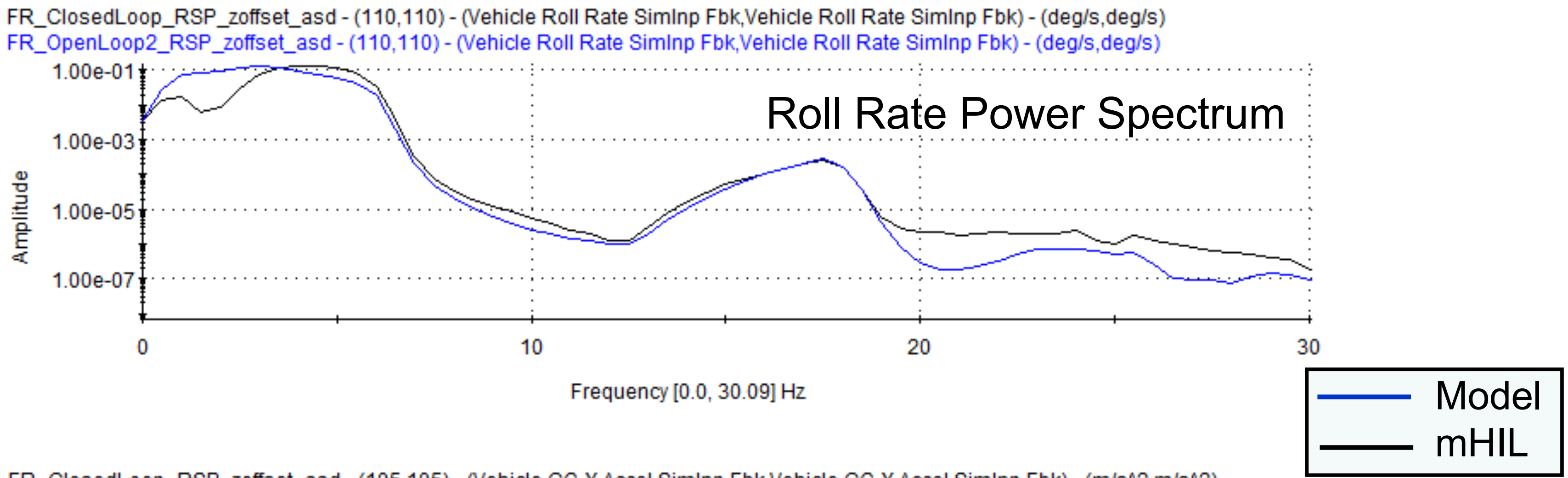
Sine Sweep: Model vs. mHIL

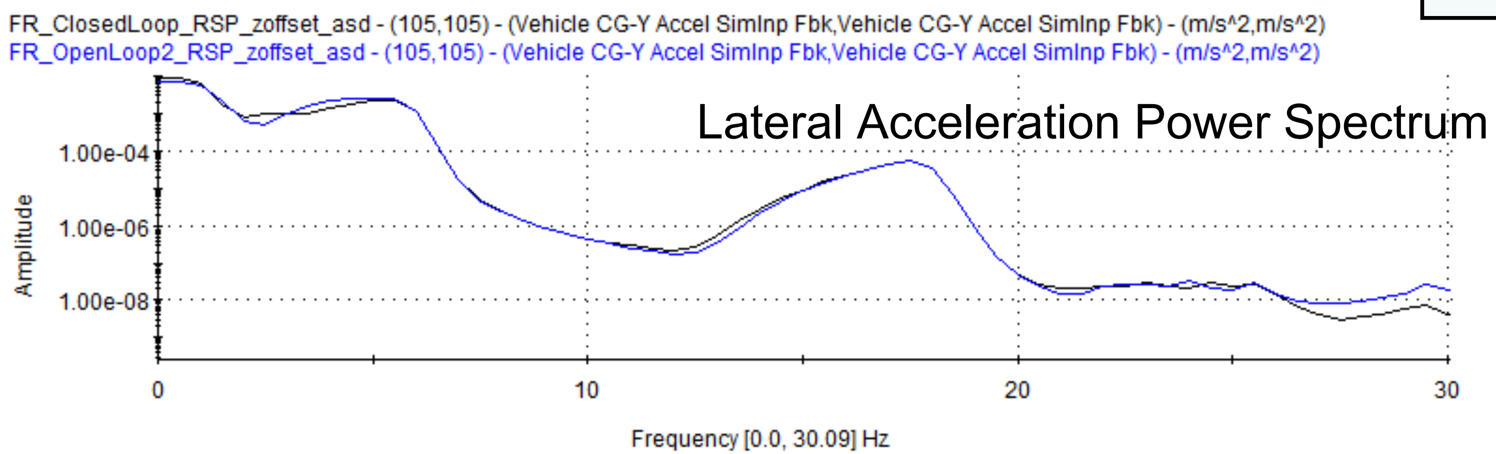


Sine Sweep: Model vs. mHIL

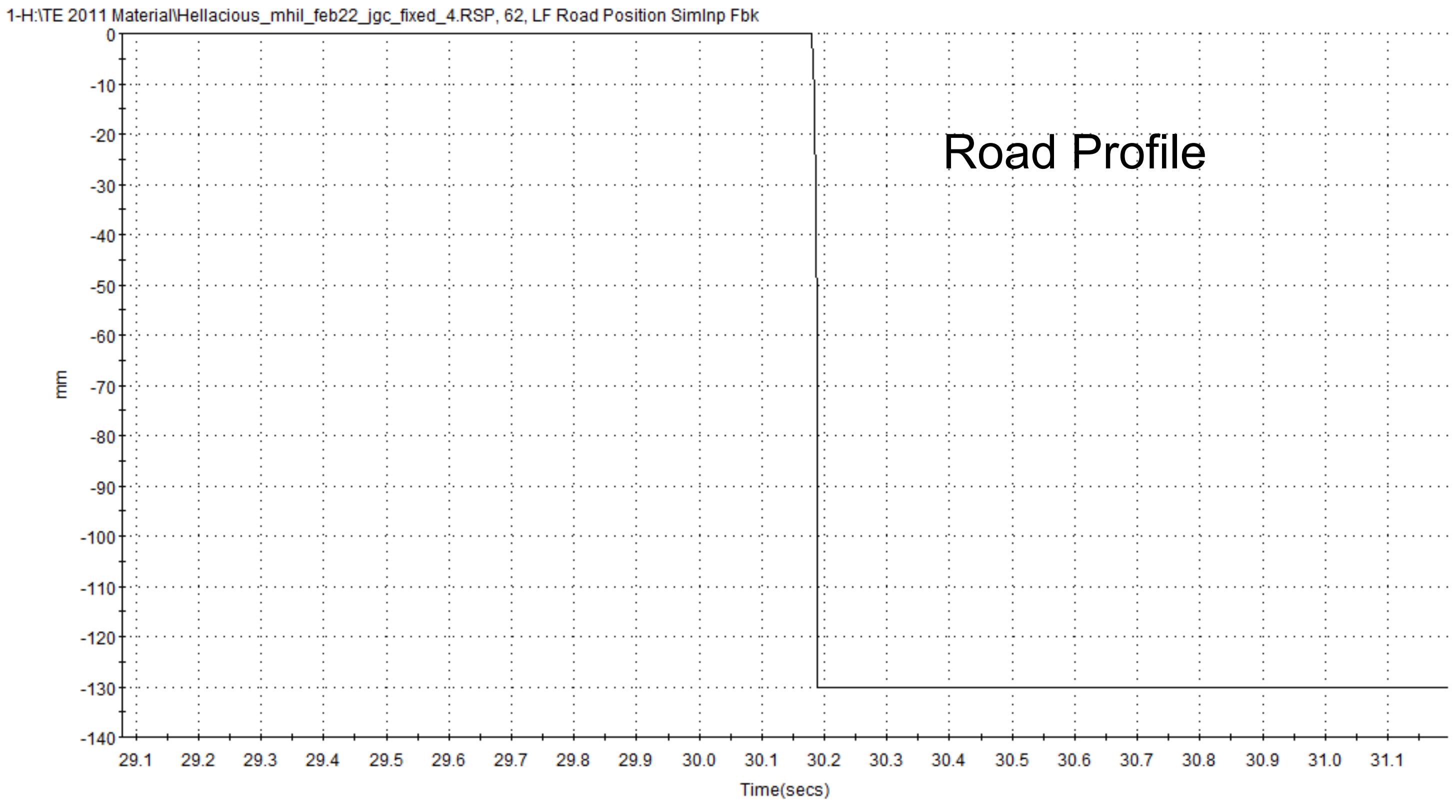


Sine Sweep: Model vs. mHIL

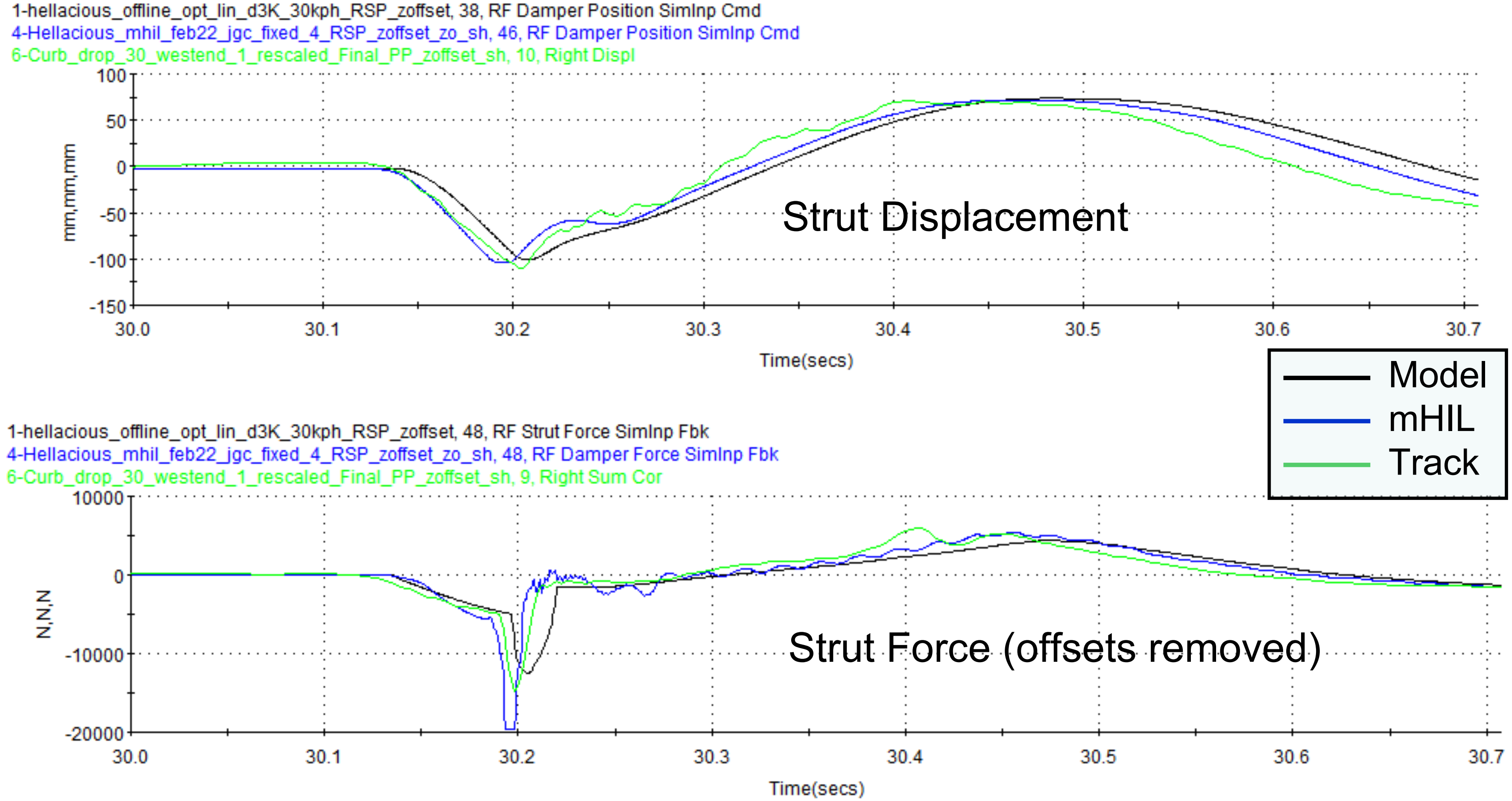




Curb Drop: Track Comparison



Curb Drop


1-hellacious_offline_opt_lin_d3K_30kph_RSP_zoffset, 38, RF Damper Position SimInp Cmd
4-Hellacious_mhil_feb22_jgc_fixed_4_RSP_zoffset_zo_sh, 46, RF Damper Position SimInp Cmd
6-Curb_drop_30_westend_1_rescaled_Final_PP_zoffset_sh, 10, Right Displ
mm,mm,mm
100
50
0
-50
-100
-150
30.0
30.1
30.2
30.3
30.4
30.5
30.6
30.7
Time(secs)
Strut Displacement
Model
mHIL
Track
1-hellacious_offline_opt_lin_d3K_30kph_RSP_zoffset, 48, RF Strut Force SimInp Fbk
4-Hellacious_mhil_feb22_jgc_fixed_4_RSP_zoffset_zo_sh, 48, RF Damper Force SimInp Fbk
6-Curb_drop_30_westend_1_rescaled_Final_PP_zoffset_sh, 9, Right Sum Cor
N,N,N
10000
0
-10000
-20000
30.0
30.1
30.2
30.3
30.4
30.5
30.6
30.7
Time(secs)
Strut Force (offsets removed)

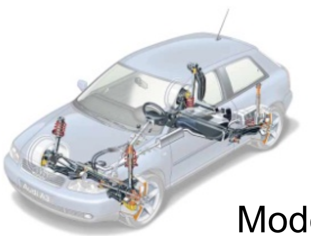
Five-Channel Steer System

mHIL Steer Rig Description

- mHIL steer rig combines a real-time vehicle dynamic model and a physical steer rack in a loading rig
- Physical steer rack replaces virtual rack in the model
- Model calculates lateral rack force and vertical displacement commands to rig
- Rig measures rack displacement and feeds back to model
- *Model and rig function in closed loop, in real time*

Operation

Driver and Road Inputs



Model

Vehicle Response

ECU

Real-Time Model (HIL box)

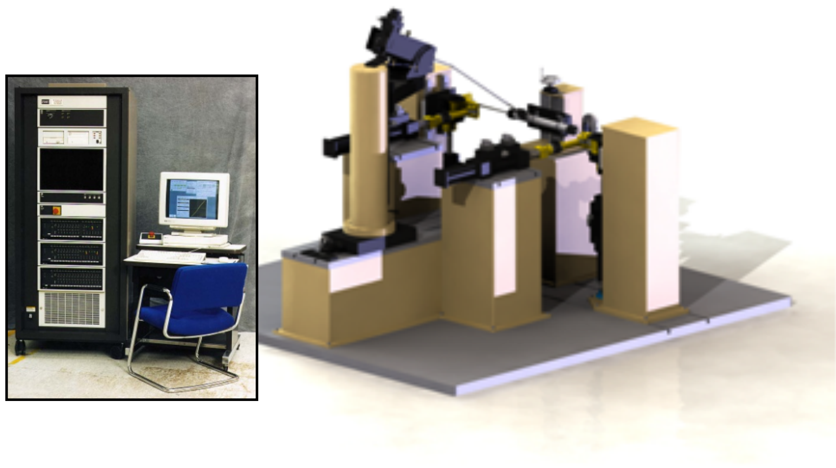
ECU Signals

SCRAMNet

SWA/SWT Cmd
Lat Force Cmd
Vert Disp Cmd

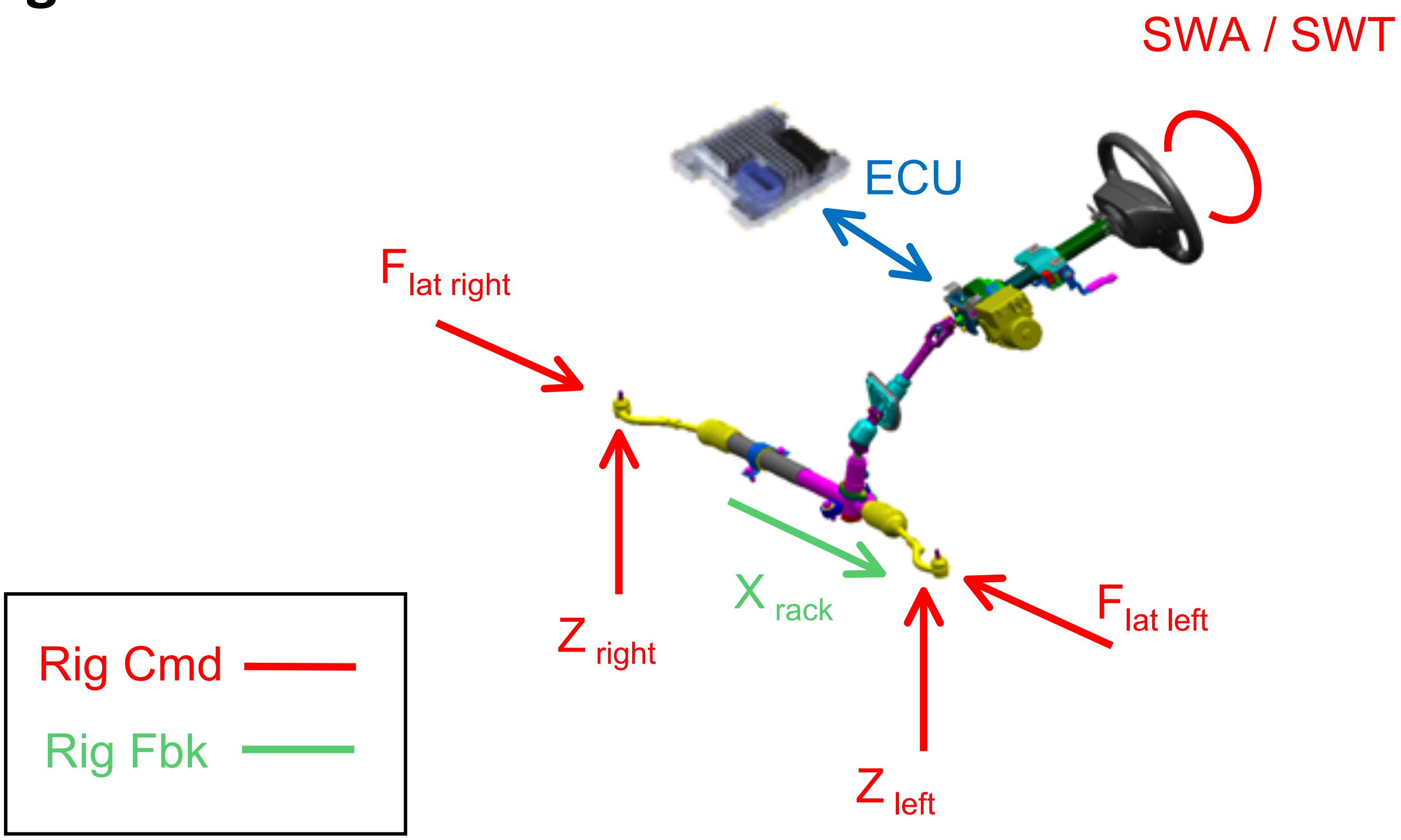
Rack Disp Fbk

Component Response



Loading & Measurement Rig

Rig Commands and Feedbacks

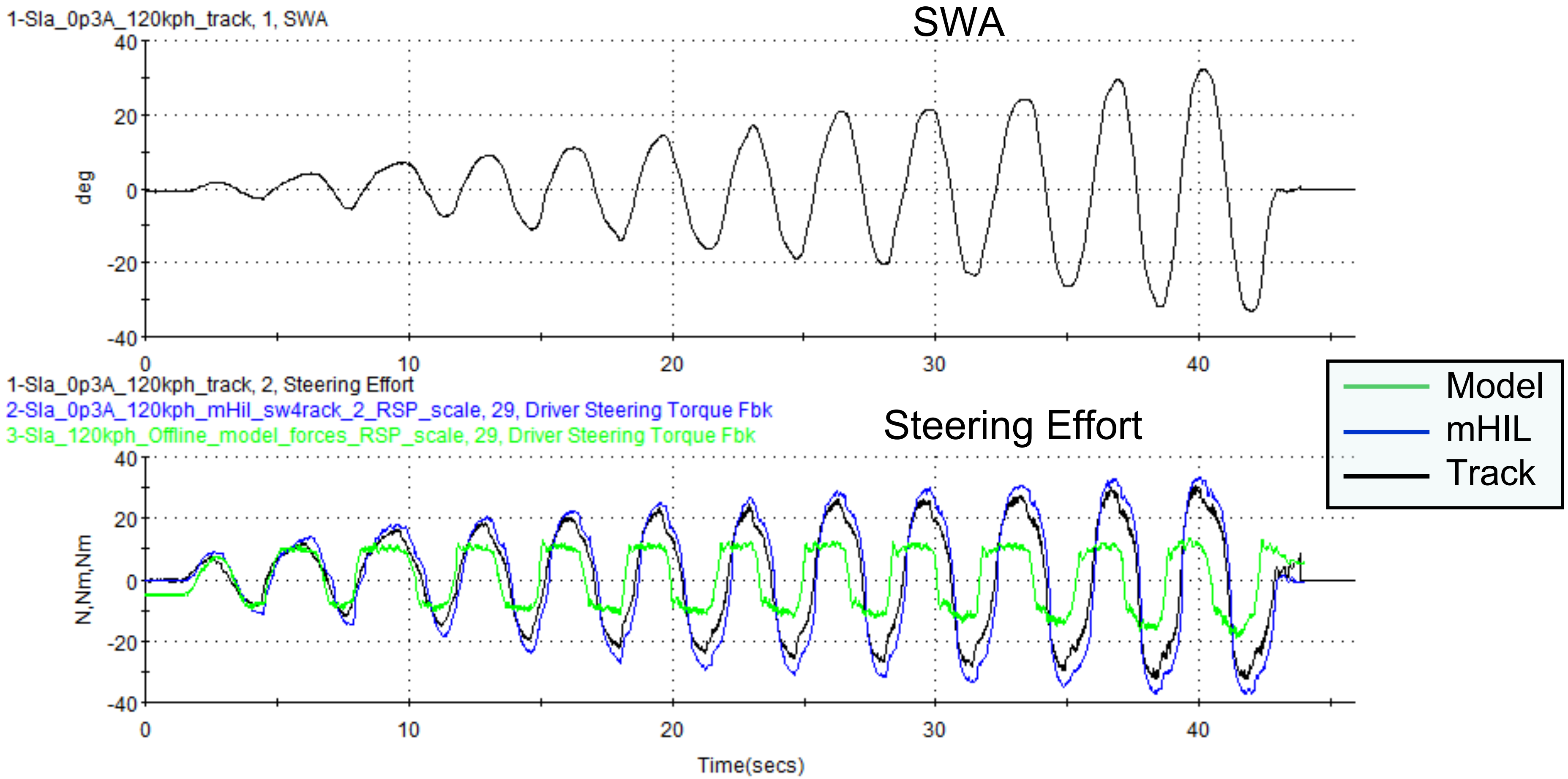


mHIL Steer Features and Applications

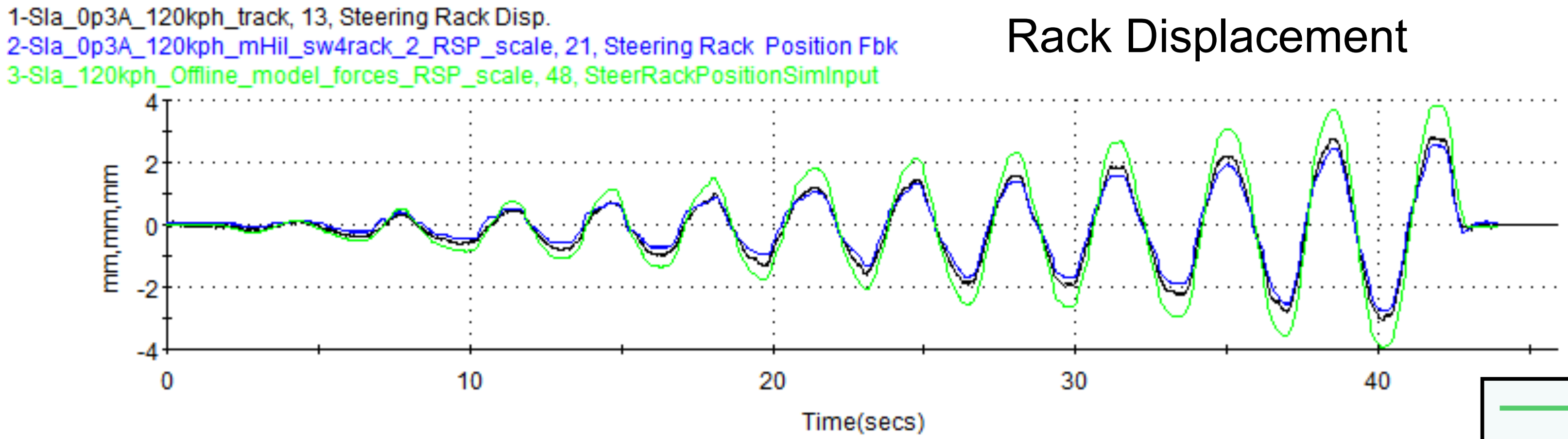
- Advanced Control Techniques
  - Model based, parametric rig dynamics compensation
  - Geometric transformation of force and displacement
  - Cross-coupling kinematics compensation

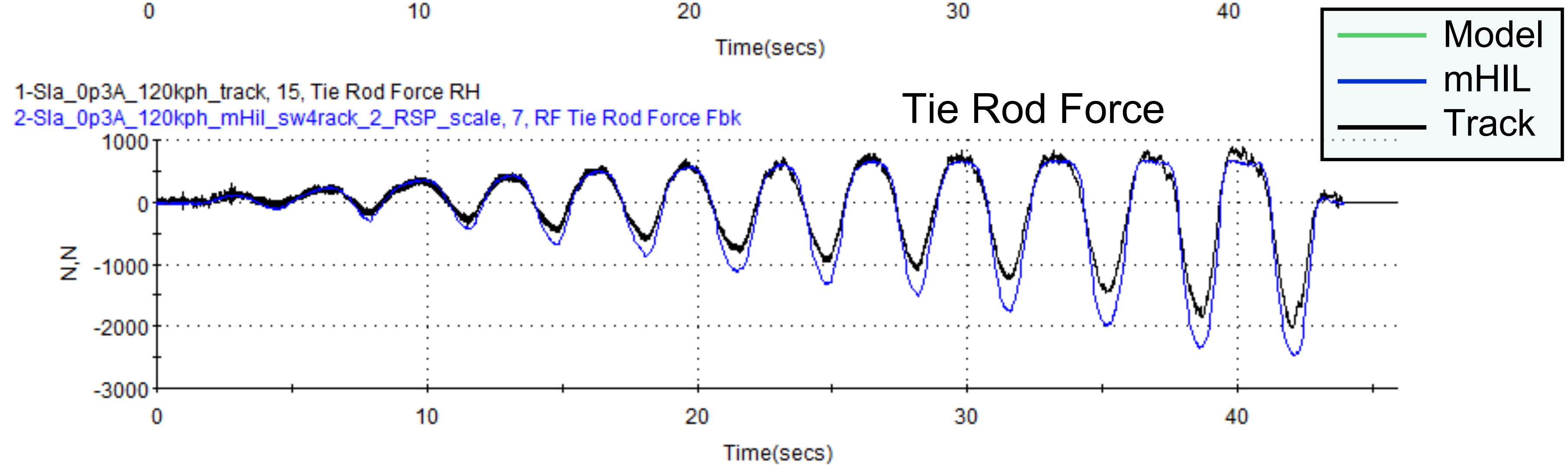
- Applications
  - Open and closed loop handling tests
  - Steering effort
  - Safety and fault condition evaluation
  - Return-to-center and on-center evaluation
  - Human-in-the-Loop

Slalom Maneuver: Model vs mHIL vs Track

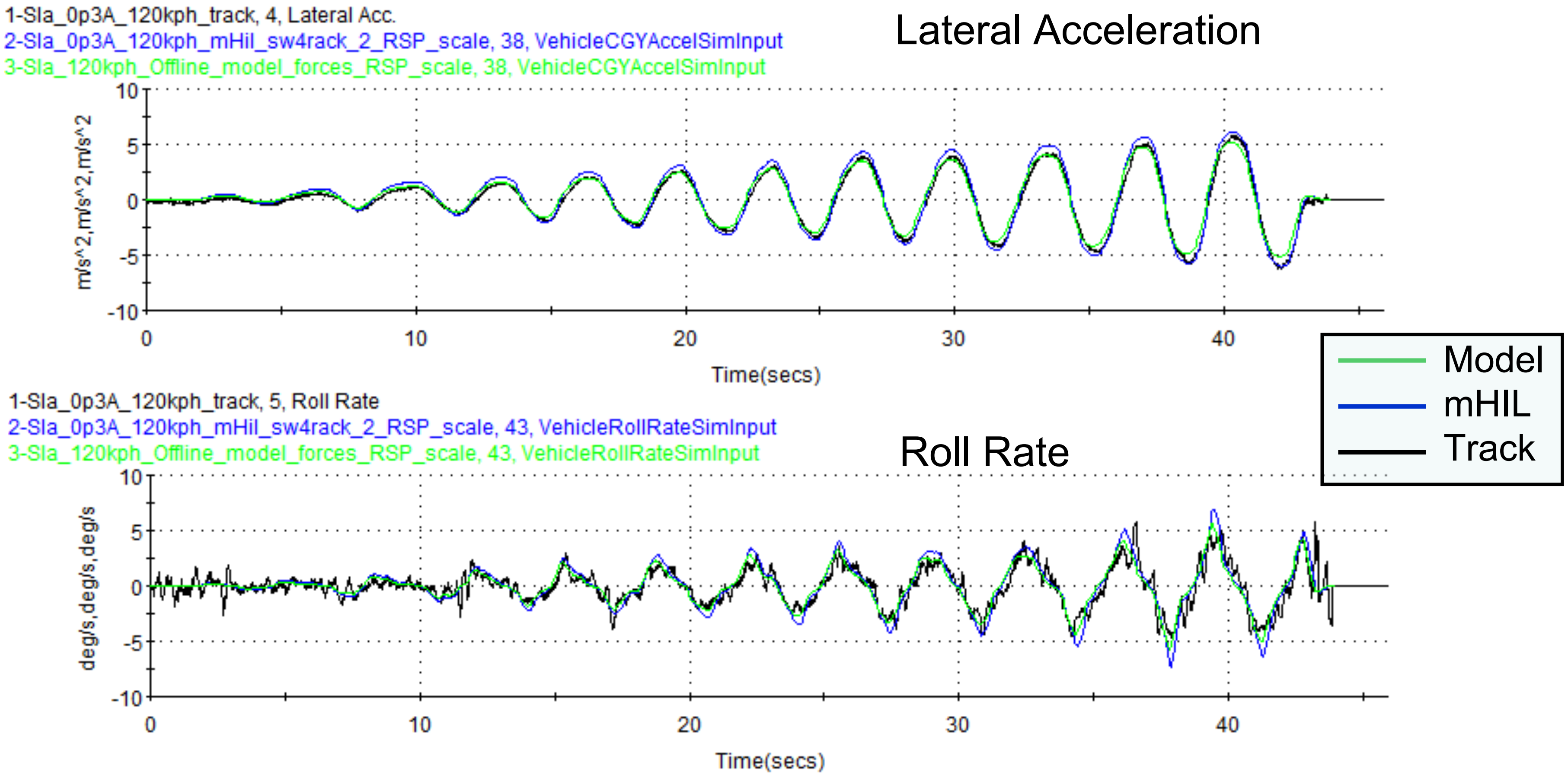


Slalom Maneuver

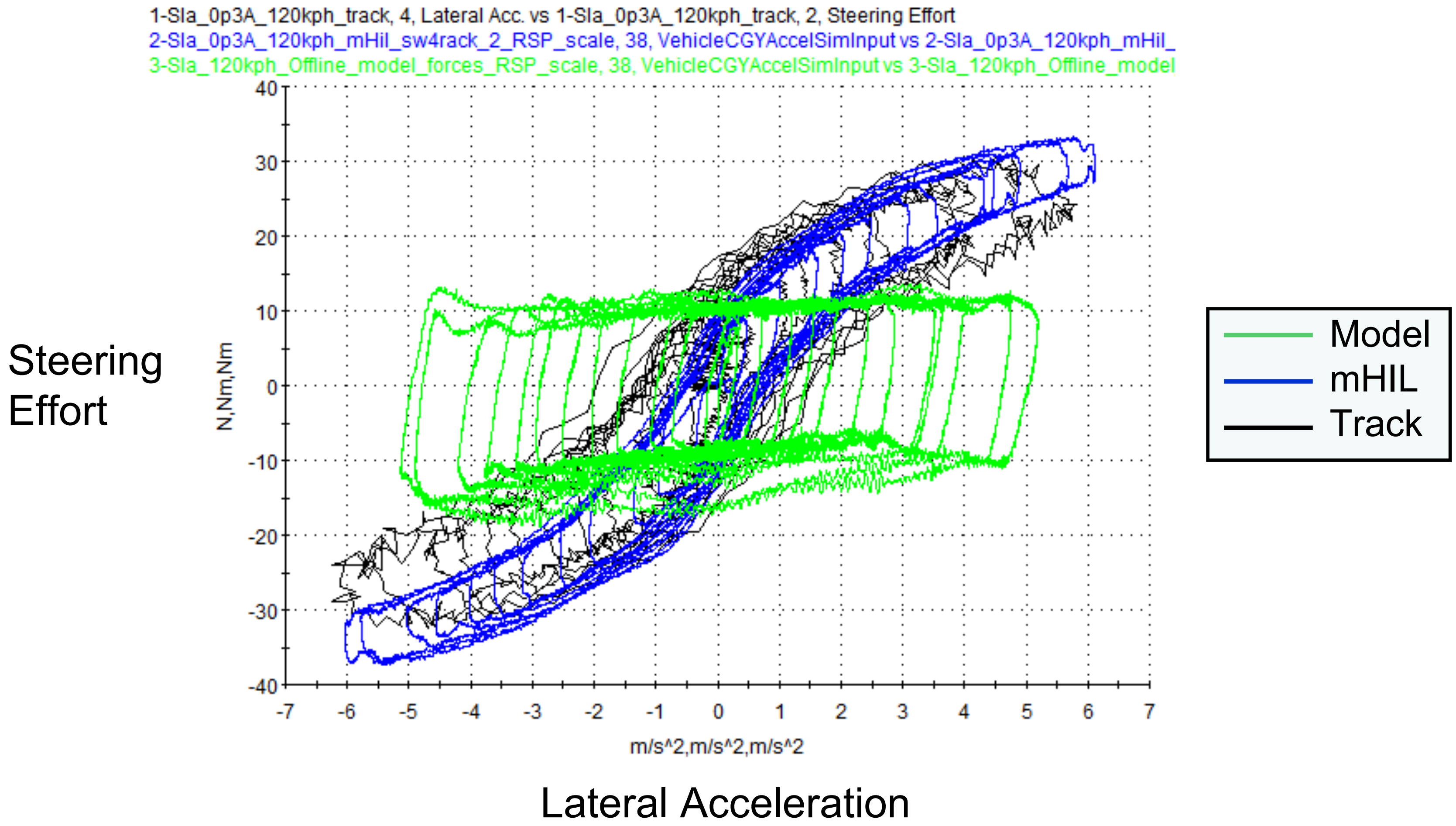




Slalom Maneuver



Slalom Maneuver



Conclusions

- *"Model what you know, test what you don't"*
- Drive components earlier in a virtual vehicle
- Benefits
  - Timely, repeatable, available sooner
  - Save time
    - ✓ Learning: Quickly confirm knowns
    - ✓ Awareness: Discover / visualize problems earlier
    - ✓ Result: Reduced development time