Model Based Engineering Approach in Aeronautical Fatigue and Structure Integrity Testing

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MTS Systems

Model Based Systems Engineering (MBSE) and Model Based Engineering (MBE)

Model-Based Systems Engineering is a methodology focused on leveraging and creating domain models as its main means of communication between engineers. MBSE uses formalized system elements to design, analyze, verify and validate the system design.

Model-Based Engineering is the creation and analysis of models of your system such that you can predict and understand its capacity and operational quality attribute.

MBSE and MBE are the Trends

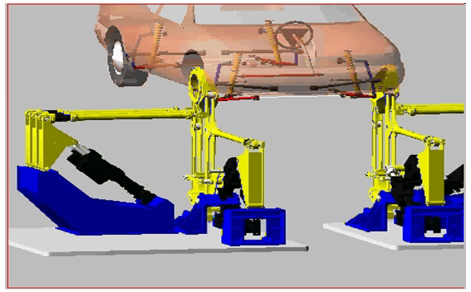
- When changes are made to a model, all the dependents are automatically updated.
- Improves understanding and allows for a more detailed level of communication.
- Fewer documents
- Fixed quality standards
- Consistency in information
- More efficient.
- Find deign issues early.

Challenges of MBSE and MBE

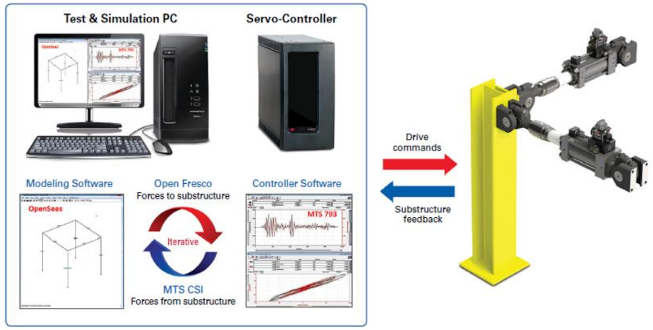
- MBSE and MBE require accurate models of system elements.
- Models can be confusing and overwhelming for those trying to understand them.
- Connection between different types of models could be difficult to setup.
- Model validation could be difficult.
- Version control could be an issue.
- Training needs to be conducted.

What Can MTS Provide

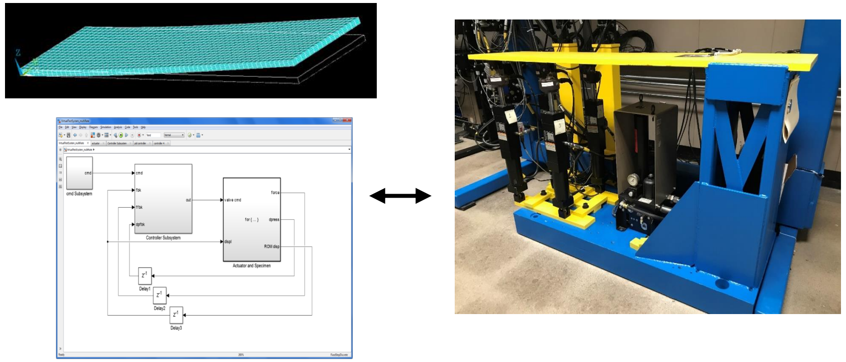
- MTS provides structure and material testing systems and solutions.
- MTS also provides MBE tools that integrate modeling and physical testing such as:
  - » Virtual testing (digital twin)
  - » Model assisted testing
- MTS can help its customers implementing MBSE and MBE approaches.
  - » Provide, validate, and maintain test system models
  - » Provide interfacing software to connect different types of models
  - » Create user interface so that the models are easy to use
  - » Provide consulting services to create special models and configurations
  - » Provide training services



Virtual Testing

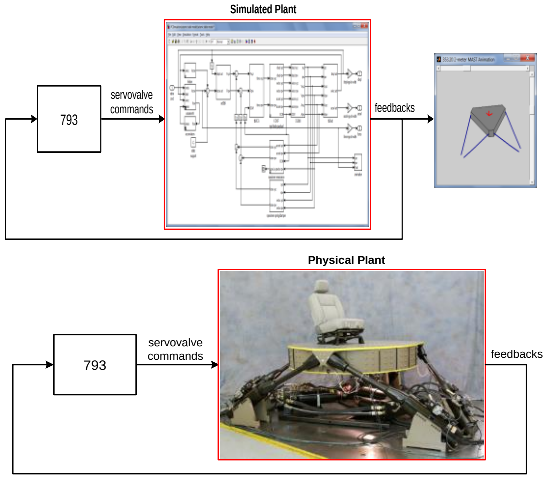


Hybrid Simulation

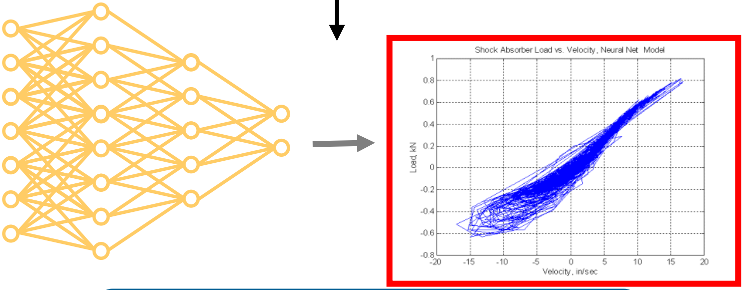


Model Assisted Testing

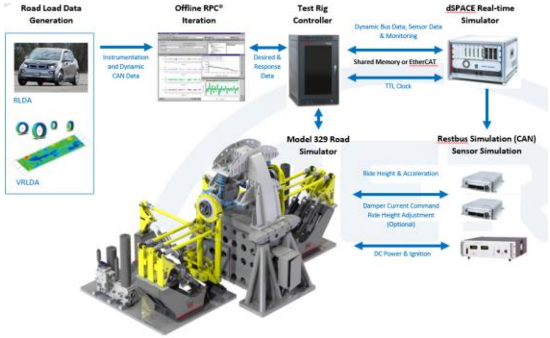
Model Based Engineering at MTS



Model Validation



Machine Learning



"Smart" system testing (active control implementation)

MBE at MTS

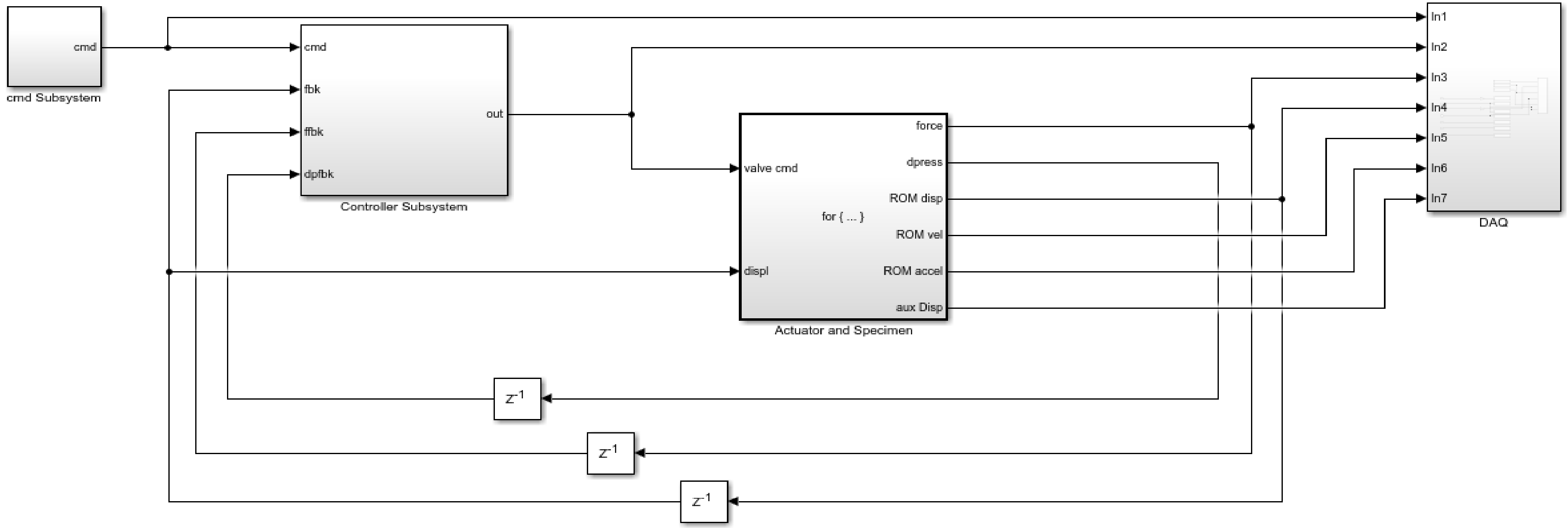
- MTS started to do virtual testing about 40 years ago and hybrid simulation about 30 years ago.
- MTS has over 160 virtual testing, hybrid simulation, model assisted testing customers in civil/structure, ground vehicle, and aero industries.
- MTS developed multiple standard and semi standard MBE tools.
- MTS MBE solutions helped our customers to accelerate their development process.
- In developing these solutions, MTS gained expertise in modeling mechanical, hydraulic, control, electric, and mechatronic systems. MTS also developed communication methods for connecting different types of models.
- MTS MBE tools can be used in MBSE approach.

Why Virtual Testing?

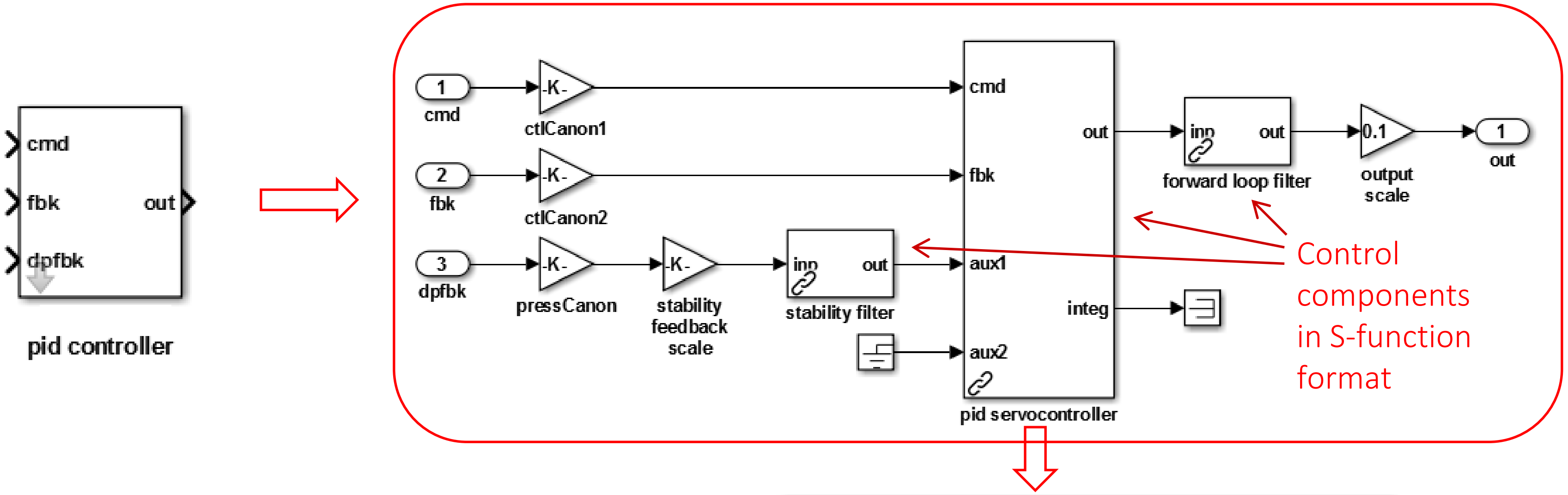
- Aerospace testing are complex:
  - Test specimens are expensive and often have underdamped modes in multiple directions causing stability issue when interacting with actuators
  - Significant cross-coupling exists between large number of actuators
- Models can help answer two important questions:
  - Capacity (choose the right component with right size)
  - Fidelity (predict how well can the test be performed)
- Test startup is always difficult
  - Modeling can help determine initial PID parameters
  - Modeling can help define hydraulic flow requirements.
- Virtual testing models can be connected to MBSE model
  - Most of the MBSE software can access the Simulink based virtual testing models.

What is Modeled?

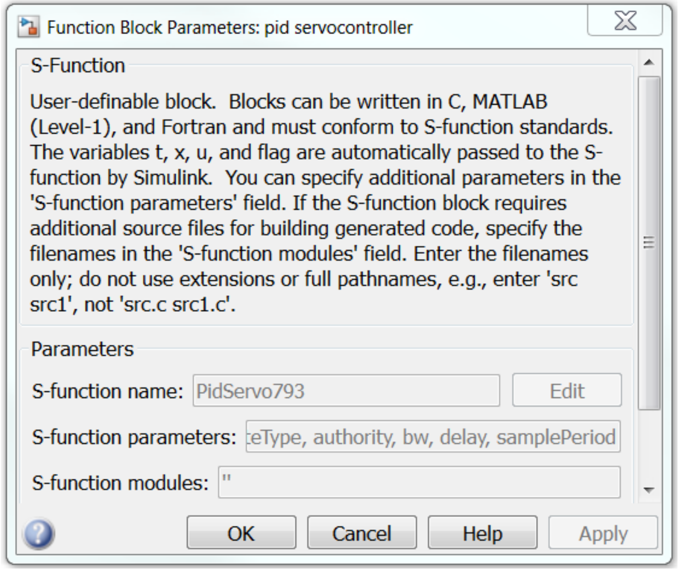
- MTS controller model (including PIDF and forward loop filters)
- MTS actuator model (including servo valve)
- Test specimen model



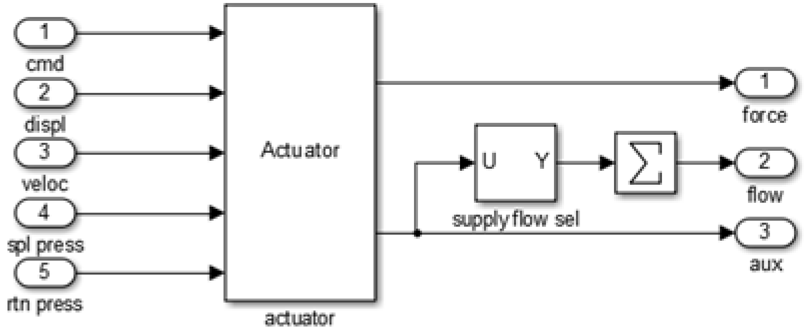
Controller Model

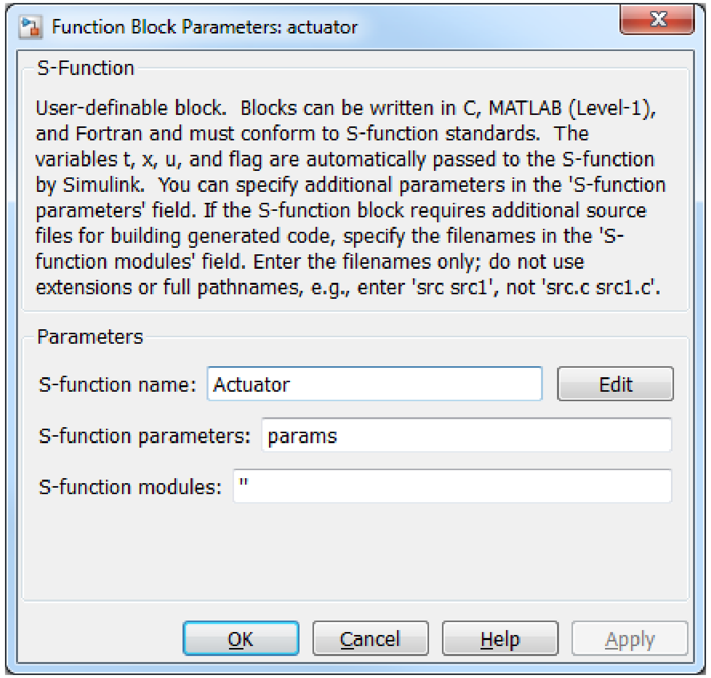


- Exact mimic of test controller including all parameters in the control software.
  - » S-function format for fast solving
  - » Real-time capability



Actuator Model





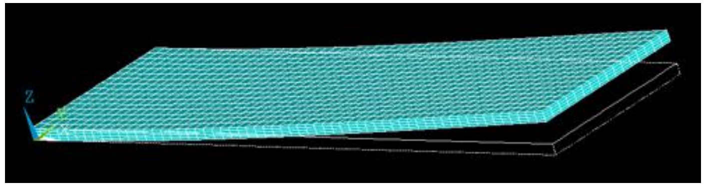
Actuator Dynamics
- Unequal area effects
- Variable volume effects with piston stroke
- Volumetric and compressibility flows
- Cross-piston leakage flow
- Parasitic damping
- Additional trapped oil volume
- End cushion profiling
- Seal friction
- Static support

Hydraulic System Dynamics
- Pump flow limits
- Pressure losses
  - Pump droop
  - Piping resistive losses
- Line accumulators
- Blowdown accumulators

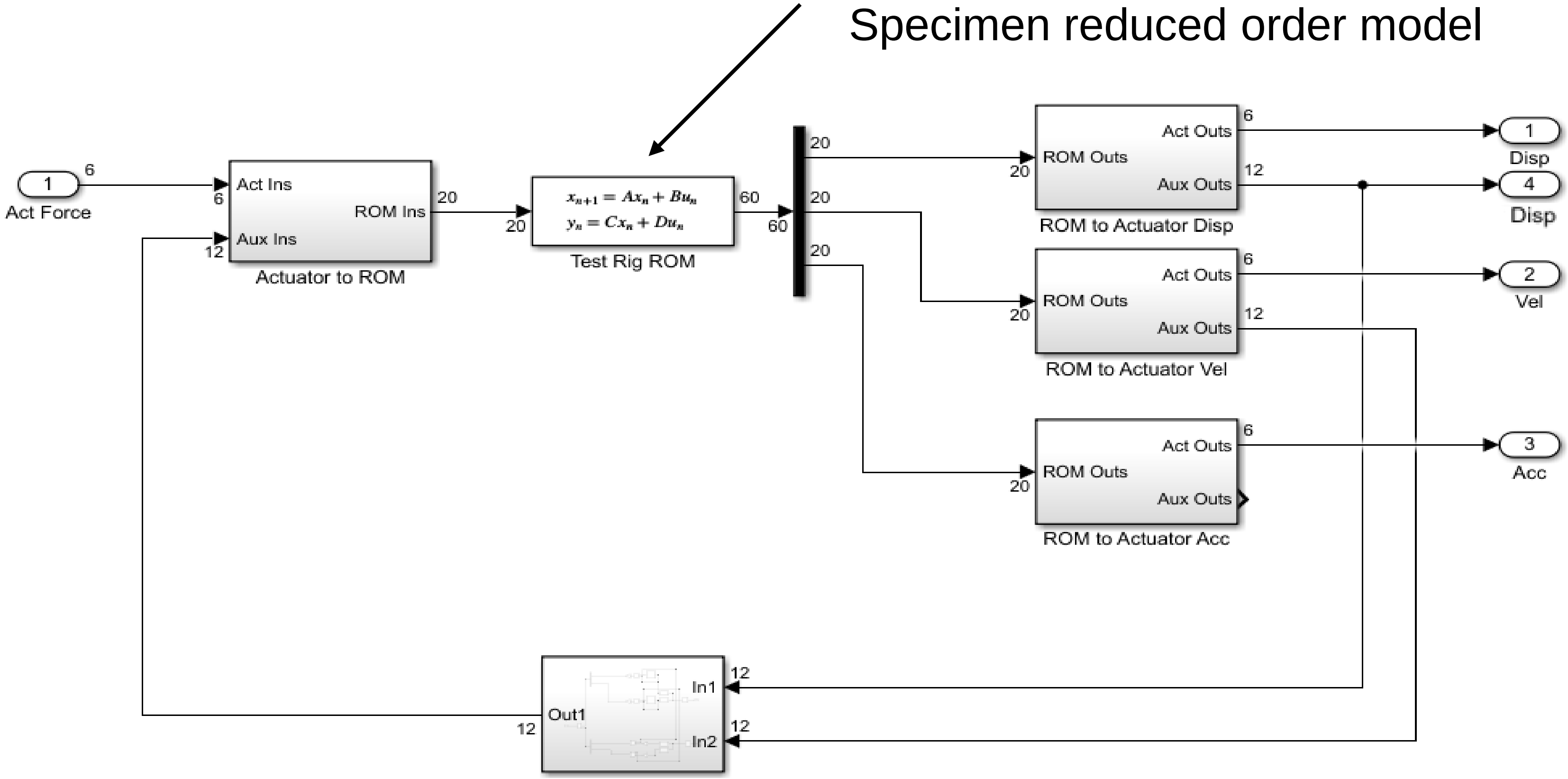
Servo valve Dynamics
- Bandwidth limitations
- Spool overlap and underlap
- Flow gain variation due to
  - Flow saturation
  - Supply/return pressure variations
  - Pressure switching

Scalability
- Any number of DOFs (including just one)
- Any number of actuators (incl. just one)
- Any number of accelerometers (incl. none)
- Actuators can be any of five types
  - in any combination

Test Specimen Model



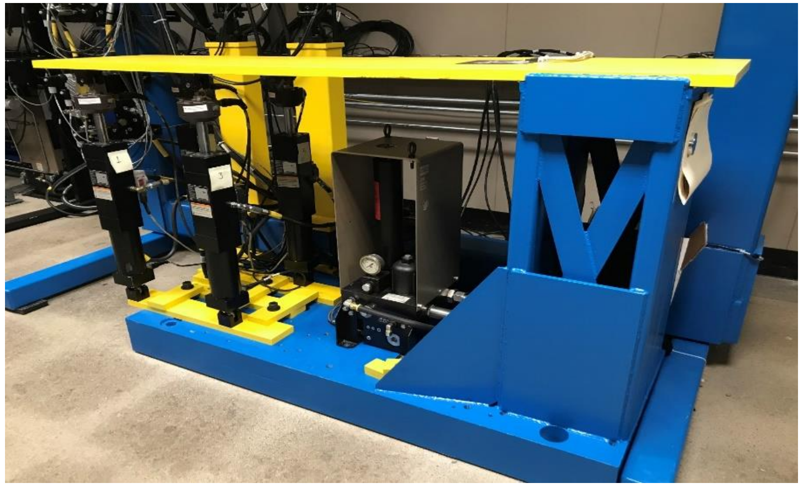
Specimen reduced order model

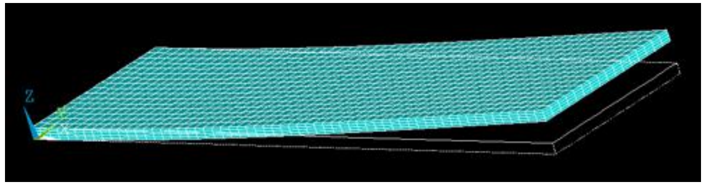


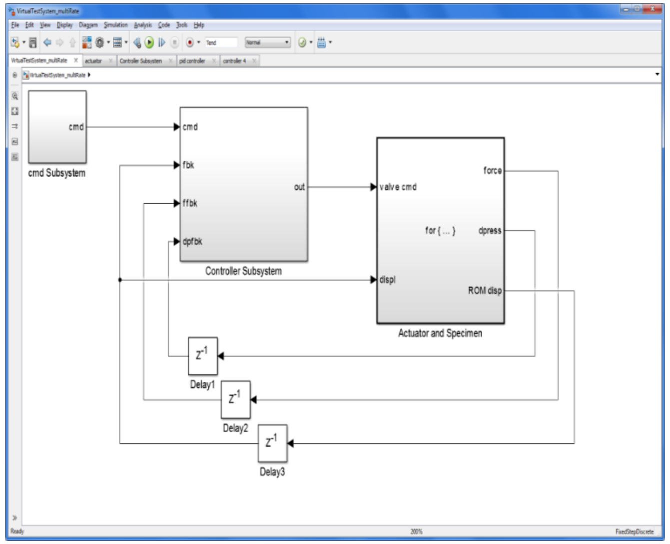
Specimen nonlinear stiffness

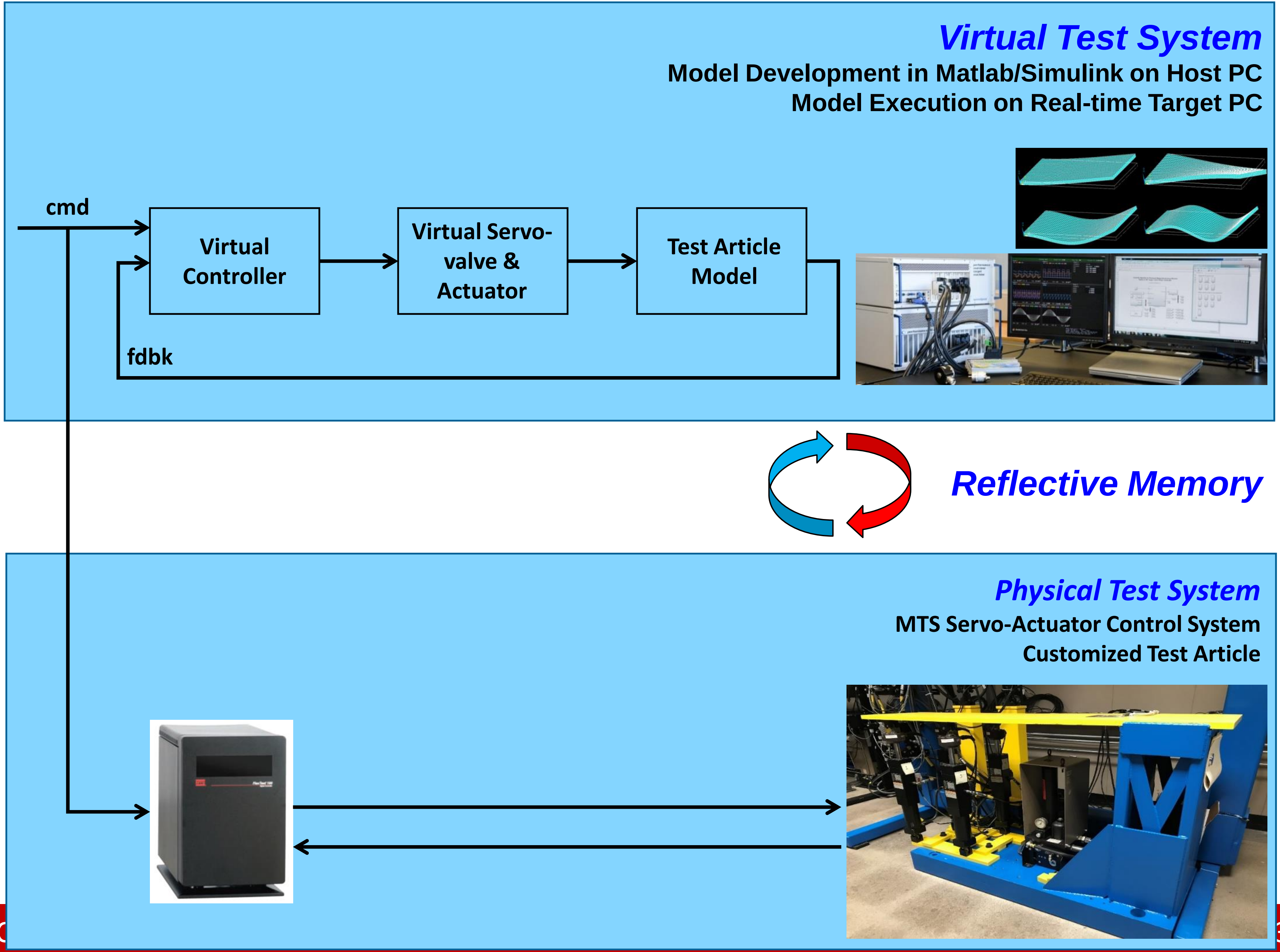
Simulink Model of the 4-Channel Demo System

- MTS controller model (PIDF and forward loop filters)
- MTS actuator model (including servo valve)
- Reduced order model for the test specimen



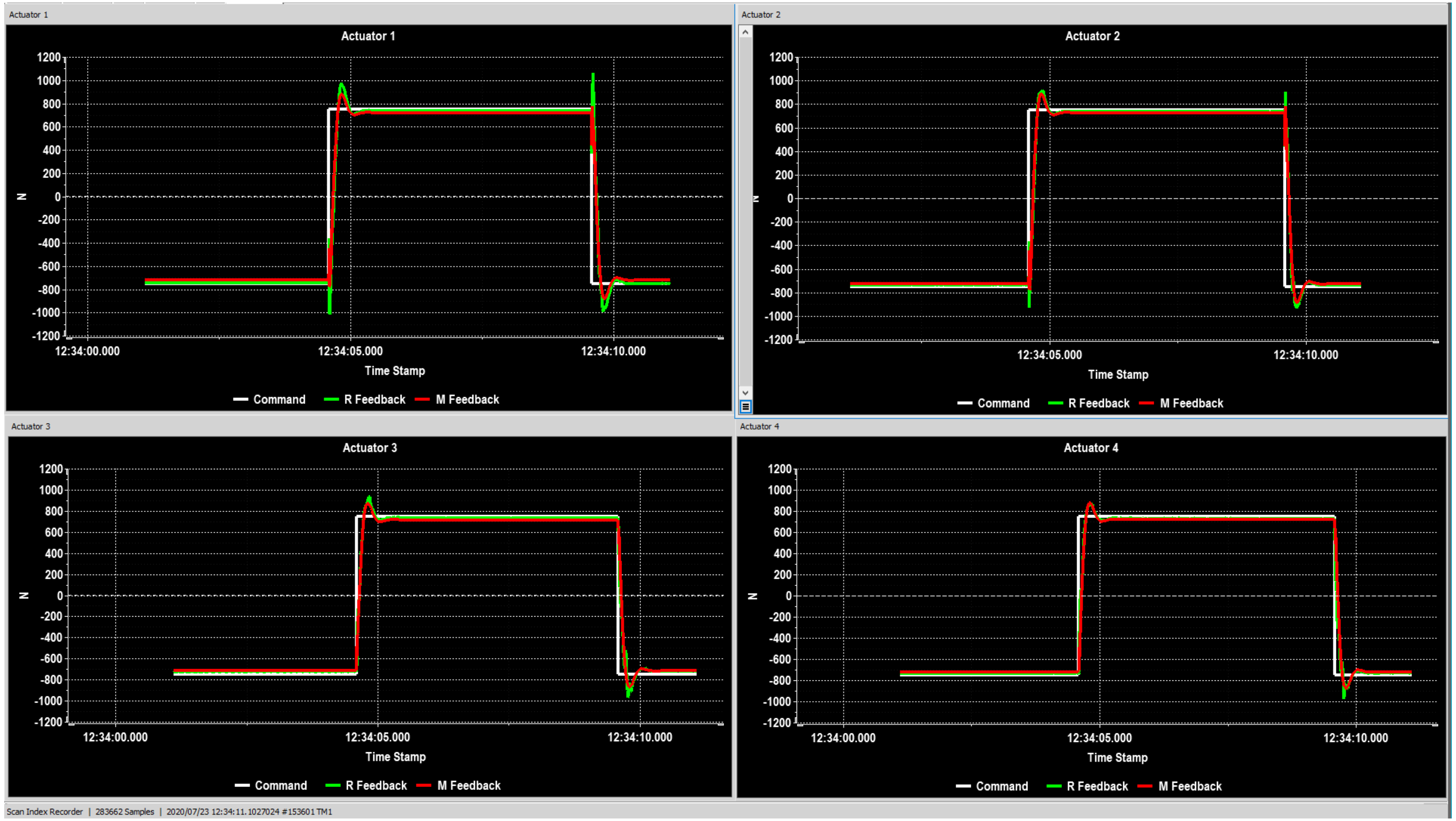





Virtual Test System
Model Development in Matlab/Simulink on Host PC
Model Execution on Real-time Target PC
cmd
Virtual Controller
Virtual Servo-valve & Actuator
Test Article Model
fdbk
Reflective Memory
Physical Test System
MTS Servo-Actuator Control System
Customized Test Article

Actuator Square Wave Response

P gains for both physical system and virtual system are 3.0.

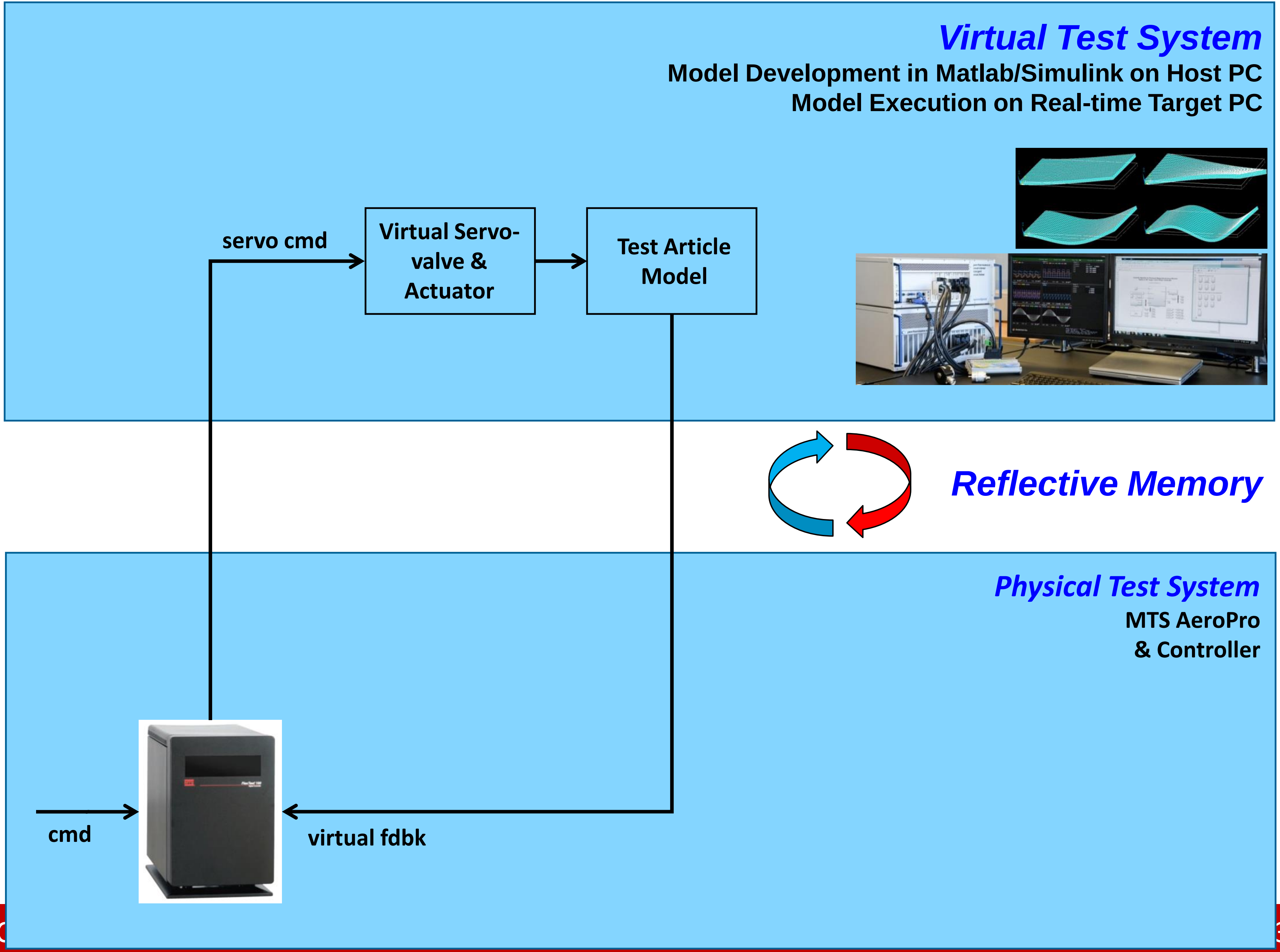


White: Command

Green: Physical Measurement

Red: Model Prediction

- Model prediction matches well with physical measurement.
- Systems are stable with some overshooting.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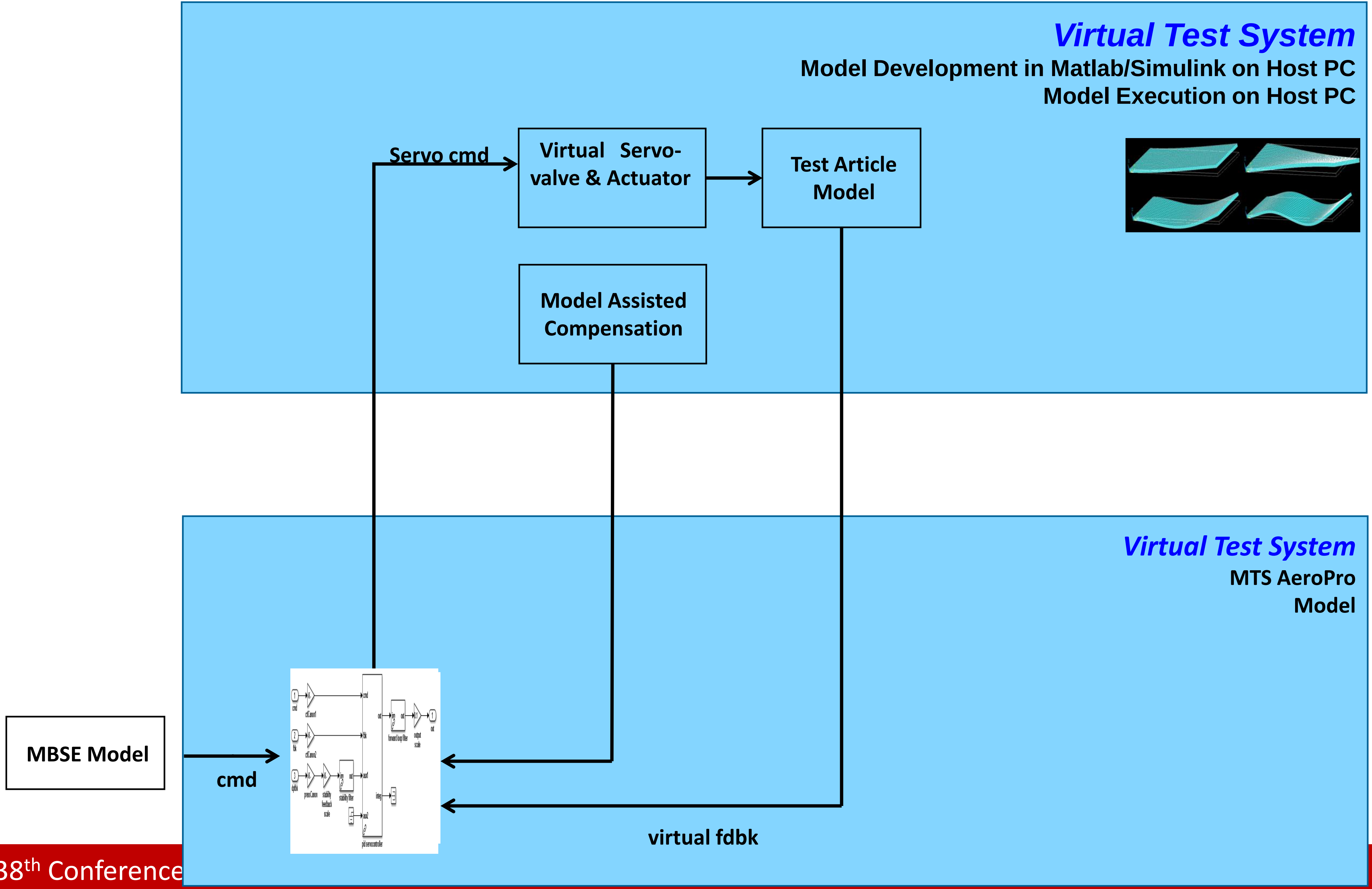
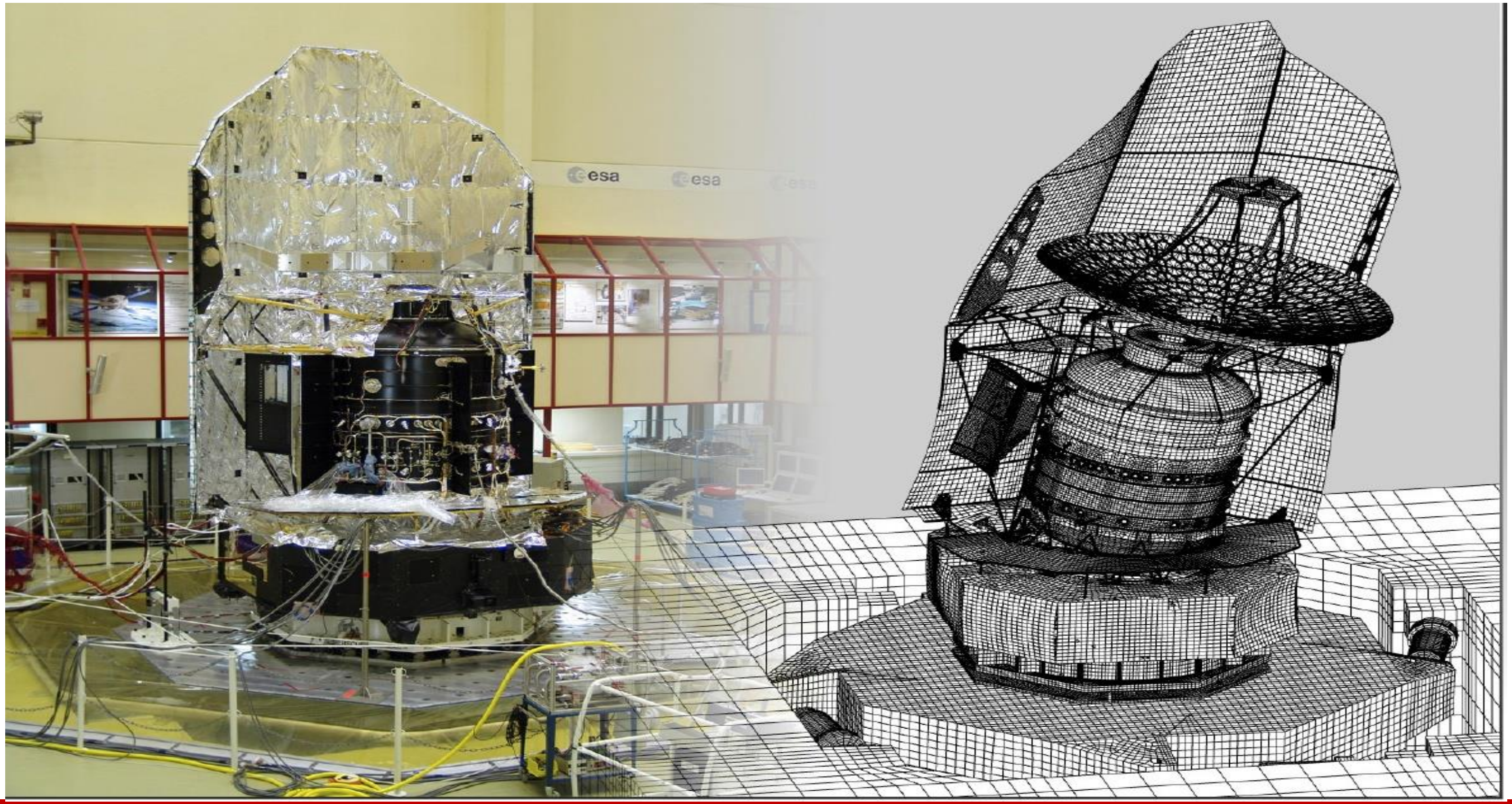
MTS AeroPro
& Controller
cmd
virtual fdbk


Virtual Test System
Model Development in Matlab/Simulink on Host PC
Model Execution on Host PC
Servo cmd
Virtual Servo-valve & Actuator
Test Article Model
Model Assisted Compensation
Virtual Test System
MTS AeroPro Model
MBSE Model
cmd
virtual fdbk

Offline Tuning Example

European Space Agency HYDRA shake table with Herschel satellite

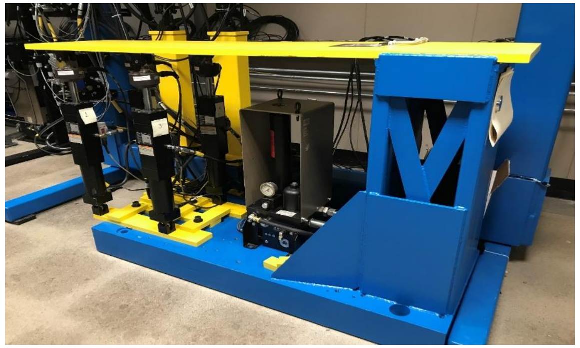
Modeling test system and specimen
Tune the virtual system and determine tuning parameter
Apply the tuning parameters to real test system and run the test

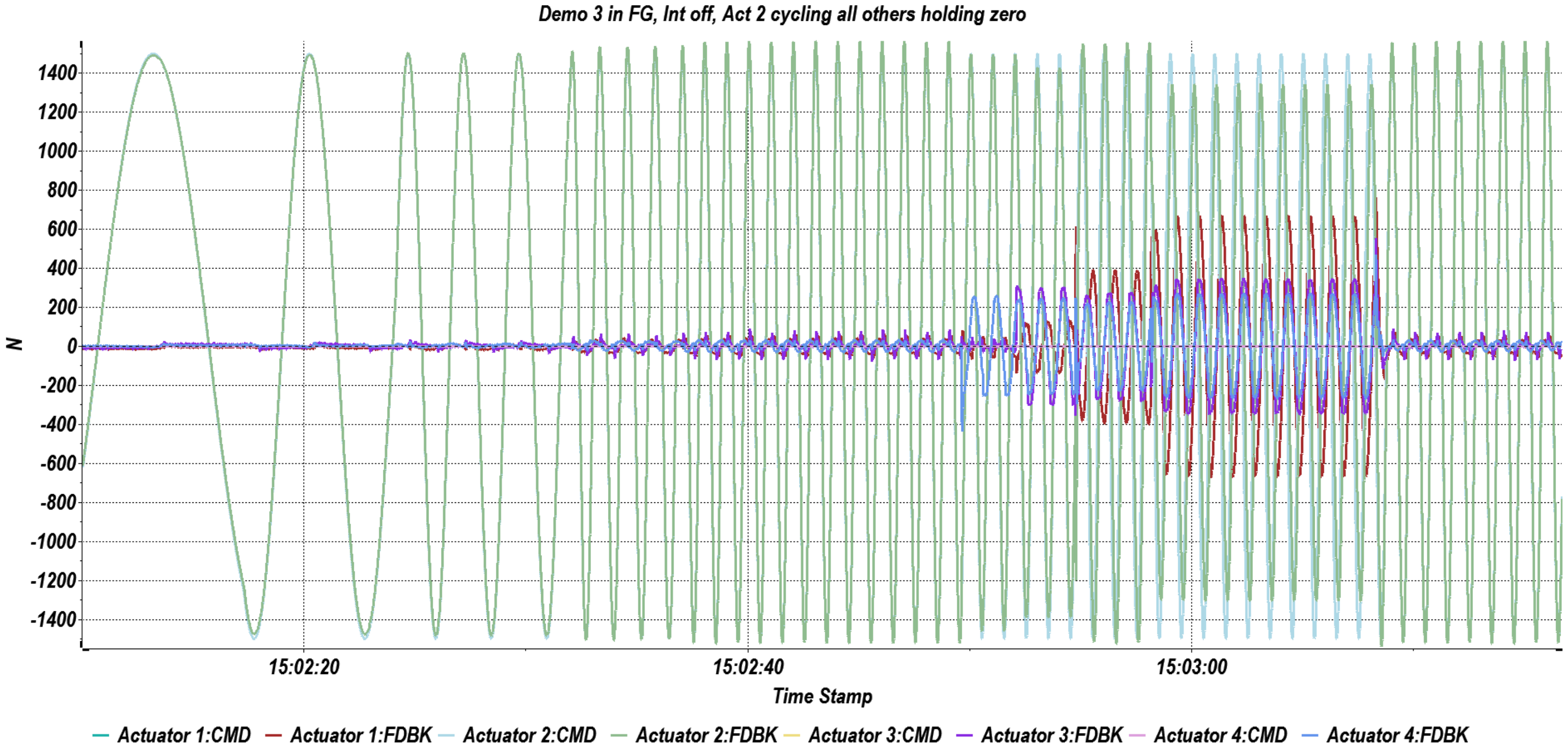


Model Assisted Compensator (MAC)

- A test system model running in real-time target PC.
- The test system model predicts system behavior of the next control step and calculates the compensation signals to cancel out the nonlinear behavior.
- The compensation signals are sent to the controller on the next controller clock tick.

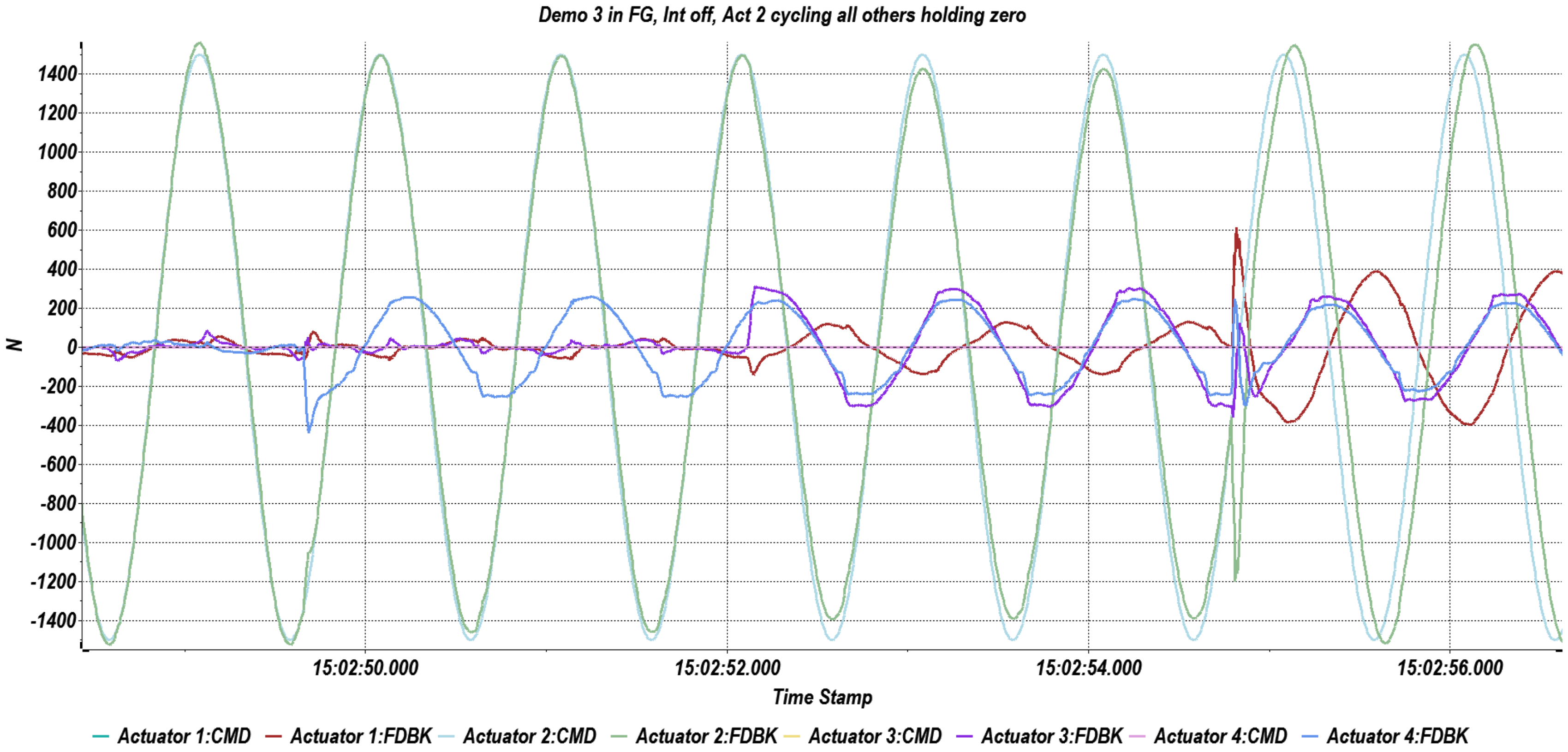
MAC and Function Generator





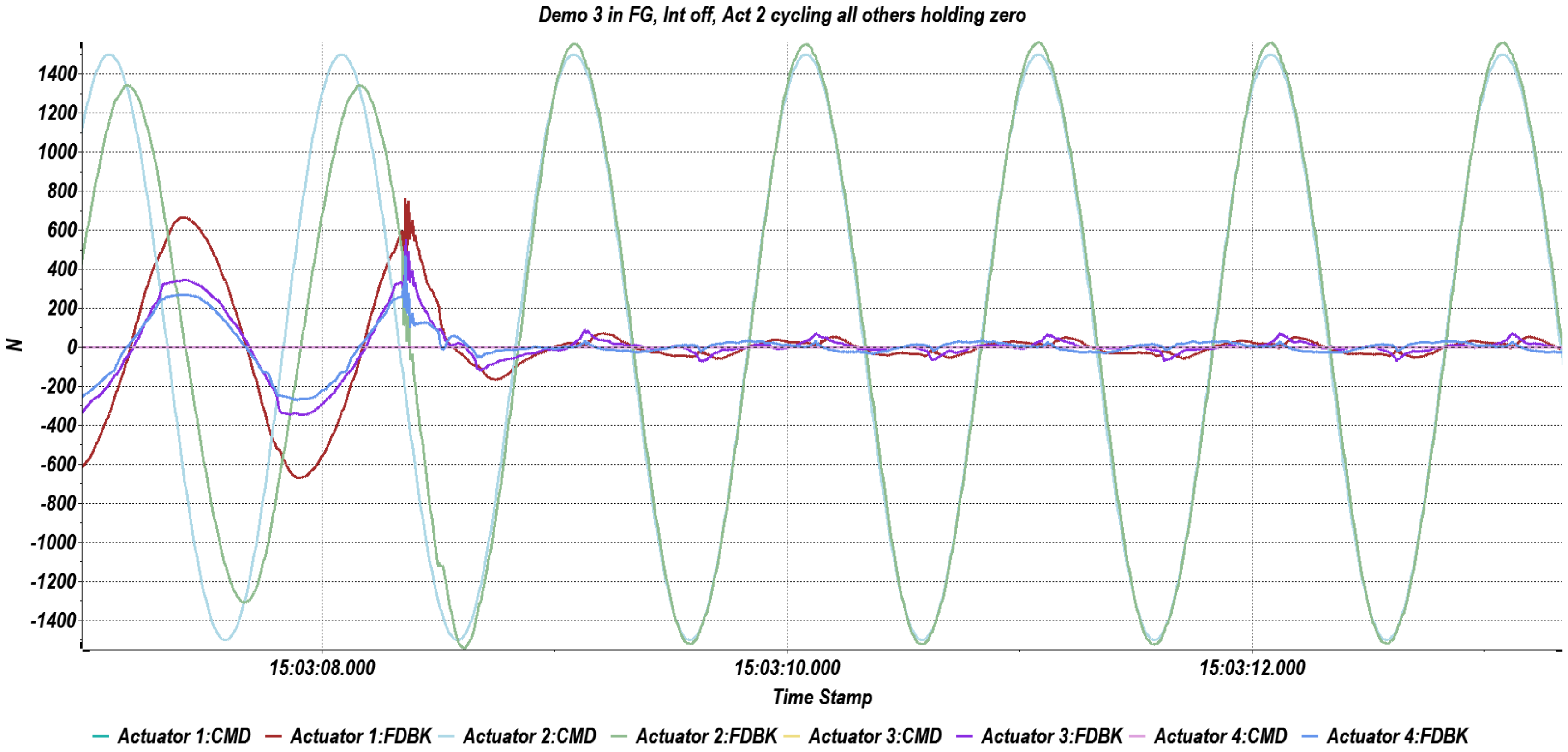
Only move one actuator and keep others at zero force. Start slow then increase speed. Then turn ‘off’ the MAC channel per channel. Finally, all channels MAC ‘on’.

MAC and Function Generator



MAC 'on' for all. The 'off' for channel 4, 'off' for 3, 'off' for 2, 'off' for 1. (All off)

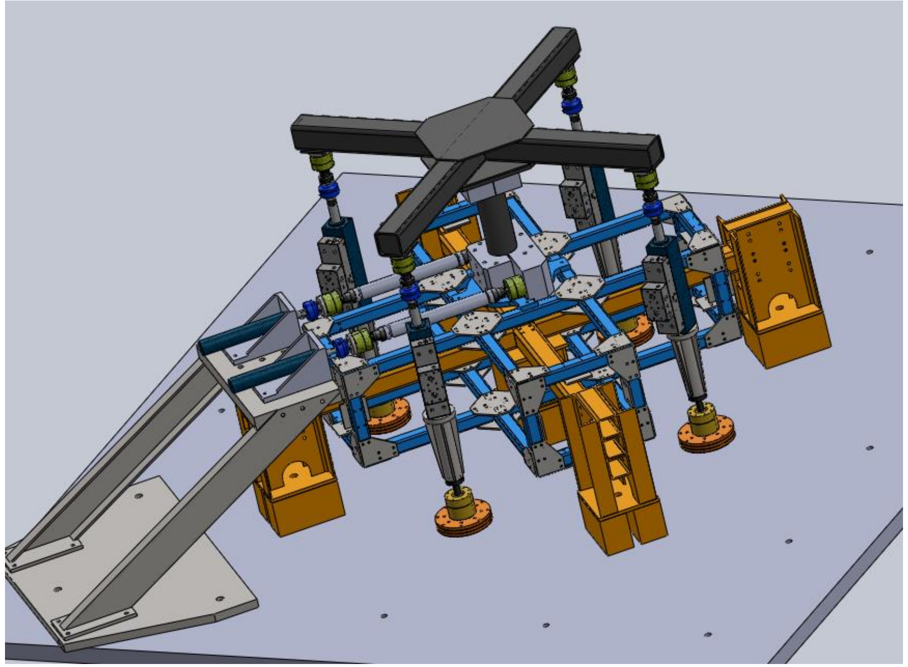
MAC and Function Generator



All ‘off’. Then all ‘on’. It is a step function for all channels. But MAC behave very stable and robust.

DSTG Complex Loading System

- Six actuators controlling 5 DOF's
- Force control on all channels
- Variable stiffness
- Variable loading amplitudes & frequencies

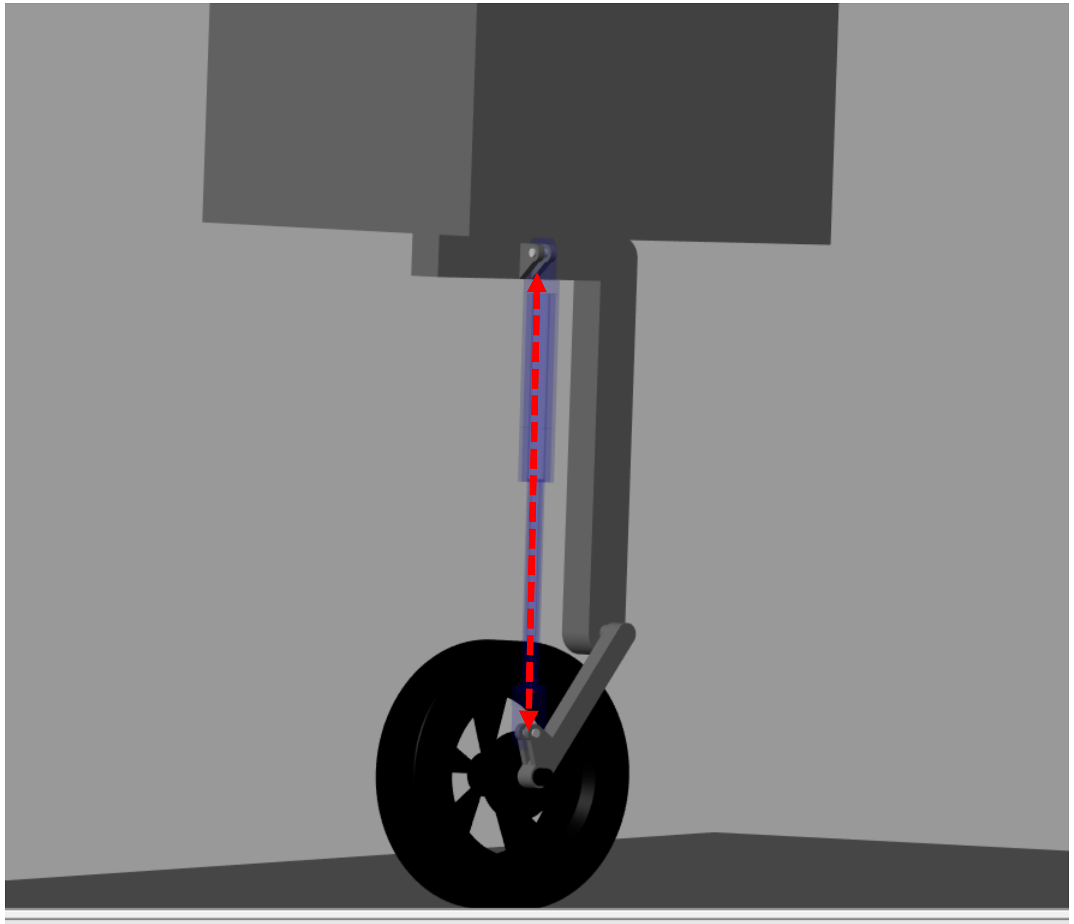


- Without MAC, the test was difficult to reach 1 Hz loading rate with acceptable error.
- With MAC, the test could reach at least 3.5 Hz loading rate at better than 1% accuracy

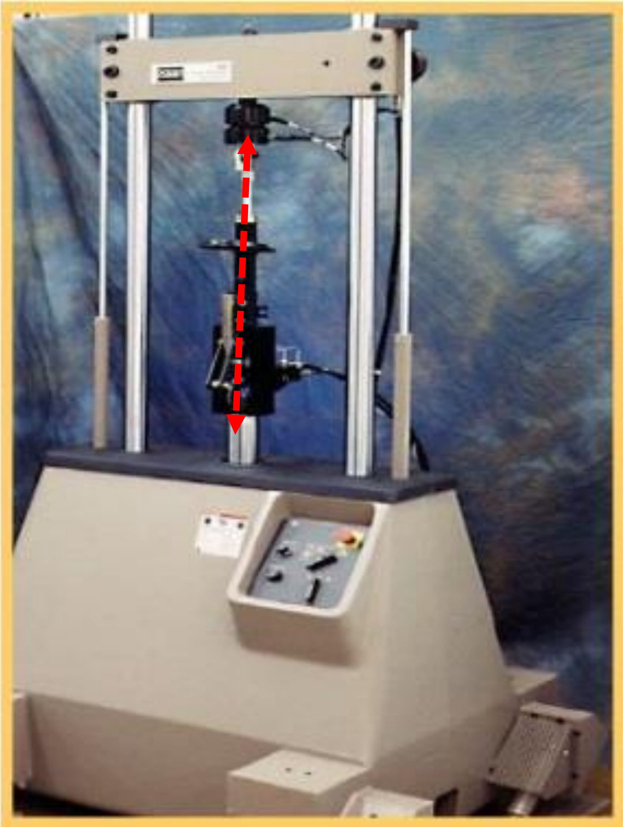
Landing Gear Oleo Hybrid Simulation

- This endeavor was to develop an iterative hybrid testing method for use in landing gear drop tests.
- Accurately predicting the performance of an Oleo is difficult, and performing the drop test is expensive.
- If the drop test results in the need for Oleo redesign this will require further drop testing and cost.
- By modelling the rest of the landing gear and testing the physical Oleo within a load frame, a hybrid testing method can be used to simulate drop conditions for Oleo performance testing.
- An iterative approach was developed thus not requiring a target pc or real-time solving.

Setup

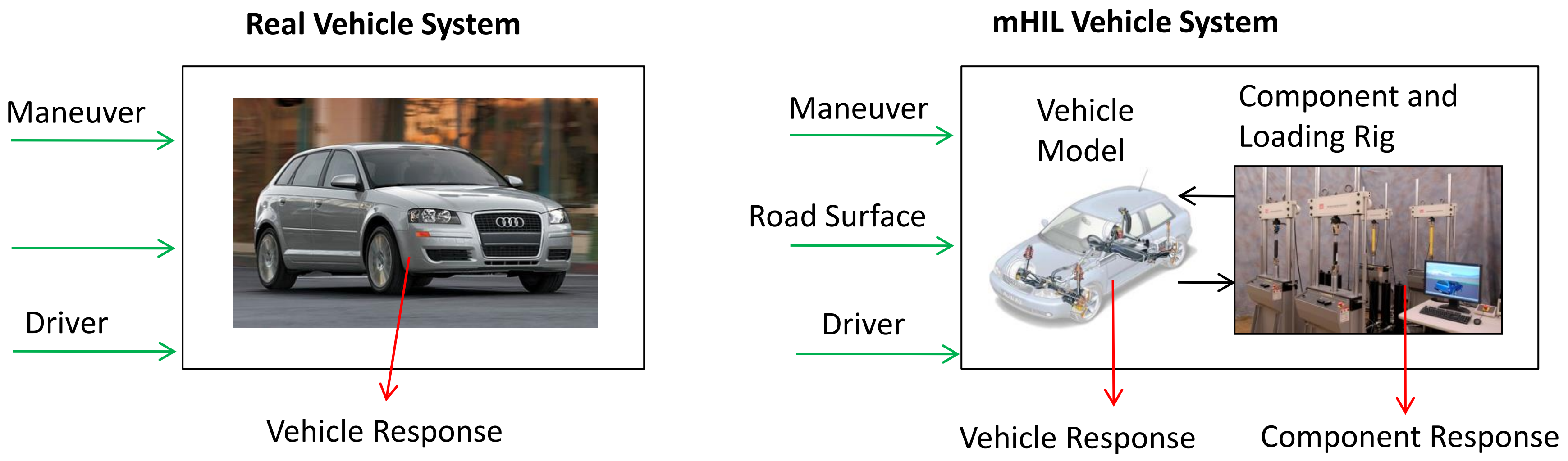


Model (numerical Substructure)



Test Frame With Specimen
(physical Substructure)

System Level Evaluation with a Sub-System Test



- Mechanical Hardware in the Loop (mHIL} provides more complete results earlier in the development process.
- Maneuver driven testing provides a <u>development environment</u> that allows:
  - Enhanced characterization to support better model development.
  - Evaluation and validation at both the component and vehicle level.
  - Advanced test & method development to address increasing complexity.
  - Diagnostic tool to support a more efficient track program.
- Simple parameter environment modifications allows rapid testing of platform for specific geographic variations.

Summary

- MTS provides accurate virtual testing models that can accurately predict the physical test.
- The virtual testing models can be linked to MBSE models.
- MTS provides compensators, such as MAC, that allows a model to run in real time to enhance actuator performance.
- MTS can provide engineering services to help its customers implementing MBSE and MBE approach.