be certain.

MTS®

Hybrid Simulation in Other Industries

Shawn You PhD, PE
Shawn Gao PhD, PE

Contents

- Background information
- Hybrid simulation in automotive industry
- Hybrid simulation in wind energy
- Hybrid simulation in aerospace

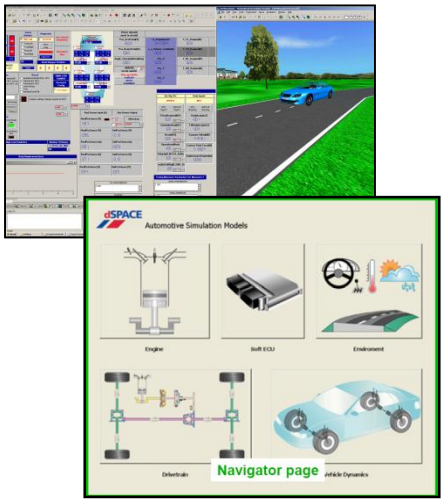
Background Information

Hybrid Simulation in Civil/Structure

- Hybrid simulation in civil/structure was started in 1973.
- Different hybrid simulation methods are developed including quasi static, real-time, and soft real-time hybrid simulation solutions.
- Hybrid simulation has been used in other industries such as ground vehicle, wind energy, and aerospace industries.

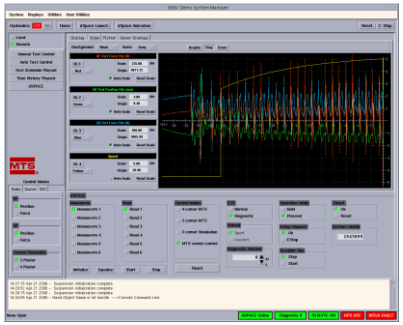
Hybrid Simulation in Ground Vehicle

Real-Time Hybrid Simulation with dSpace

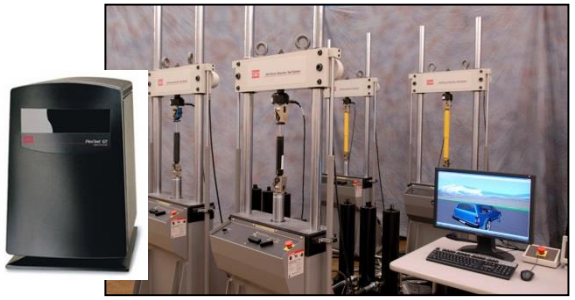


Vehicle Model

HIL Simulator



Integration
and User Application



Rig Control

Test Bench

Modeling and HIL Technologies

System Integration

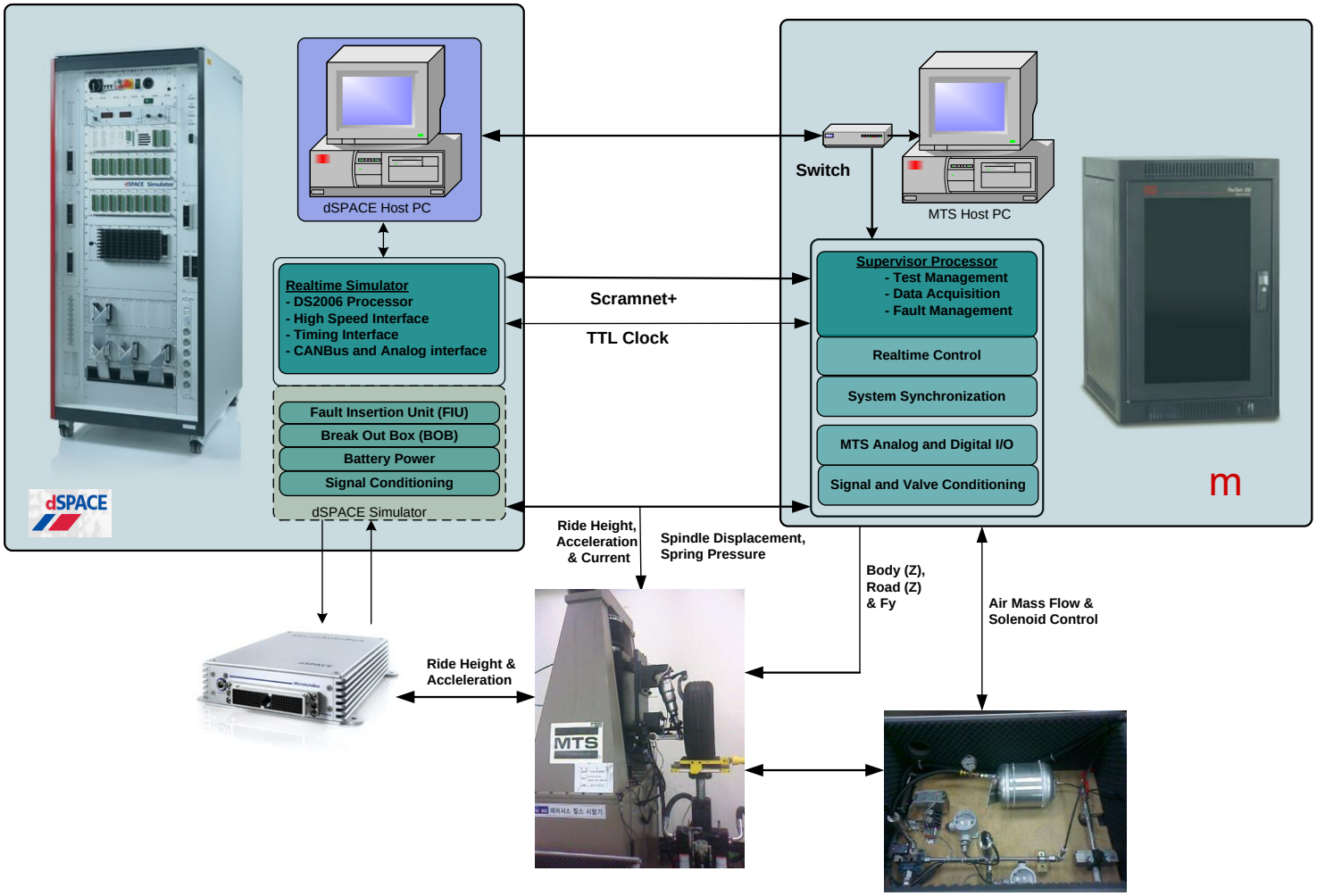
Mechanical Test Technologies

MTS Four–Corner Damper System

Quarter Car System

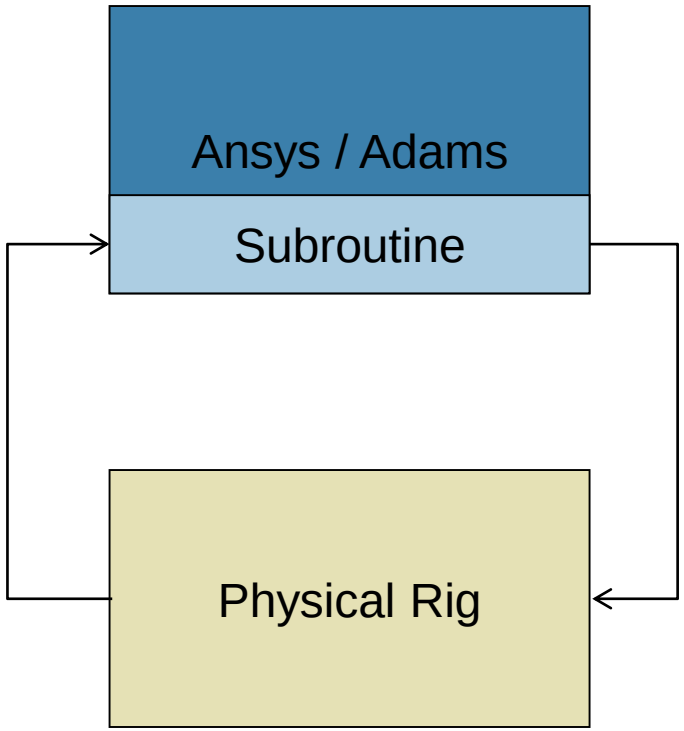
- Unsprung mass physically present
- Sprung mass simulated
- Actual sensors, solenoids, ECU.
- Proper suspension geometry exercised
- Tests component interaction
- Supports additional instrumentation

Quarter Car System Overview

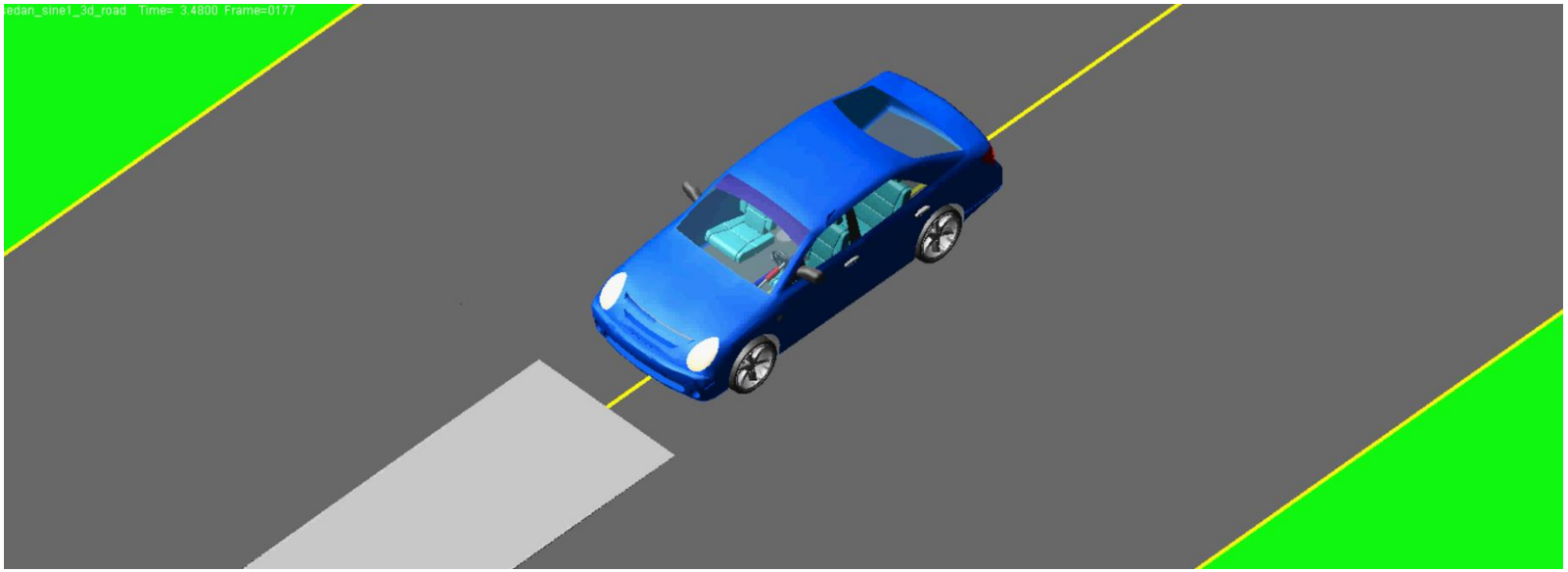


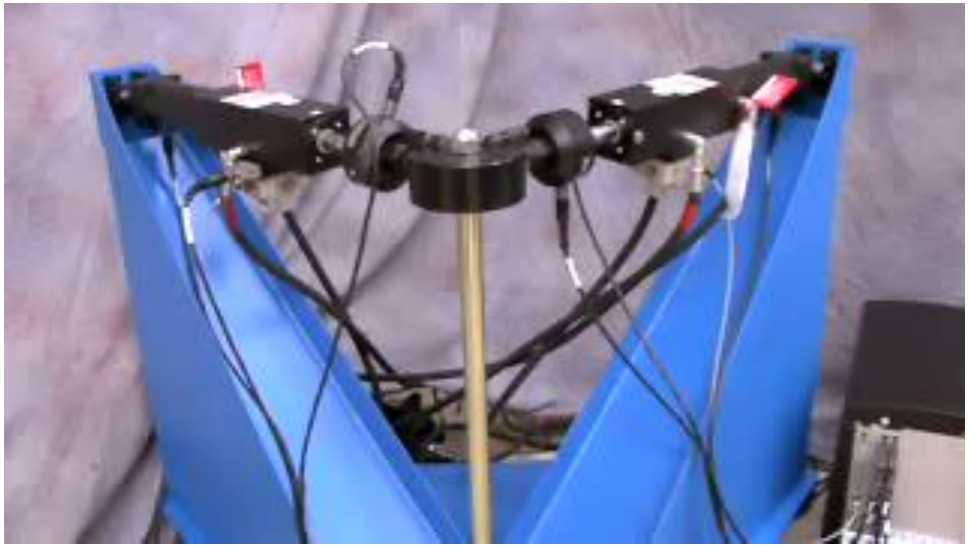
Hybrid Simulation with ADAMS

- Evaluate Adams model states (disp, and/or vel, accel), then use them to drive the physical rig
- Take physical force measurements then feed back to Adams and form the closedloop hybrid system
- OpenFresco is the communication middleware (tcp/ip approach is used in current development)
- C++ and Fortran Compilers are needed for developers to modify subroutine, but not necessary for end users

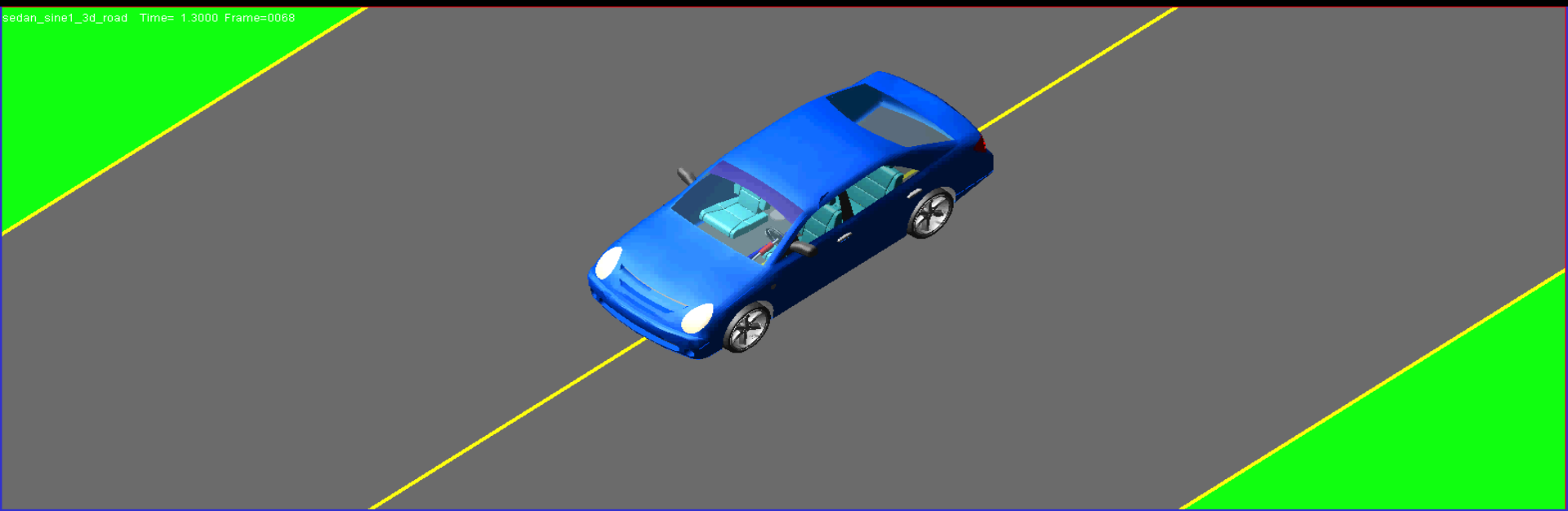


Demo Example 1 – Car on the Road Model

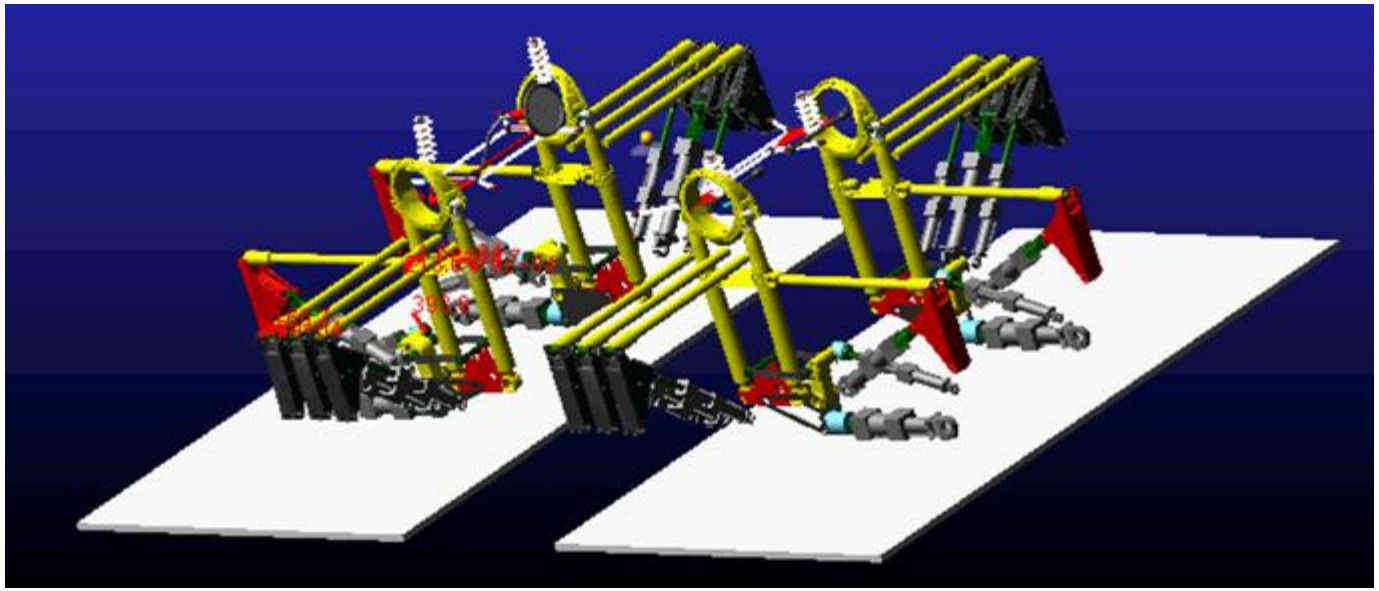


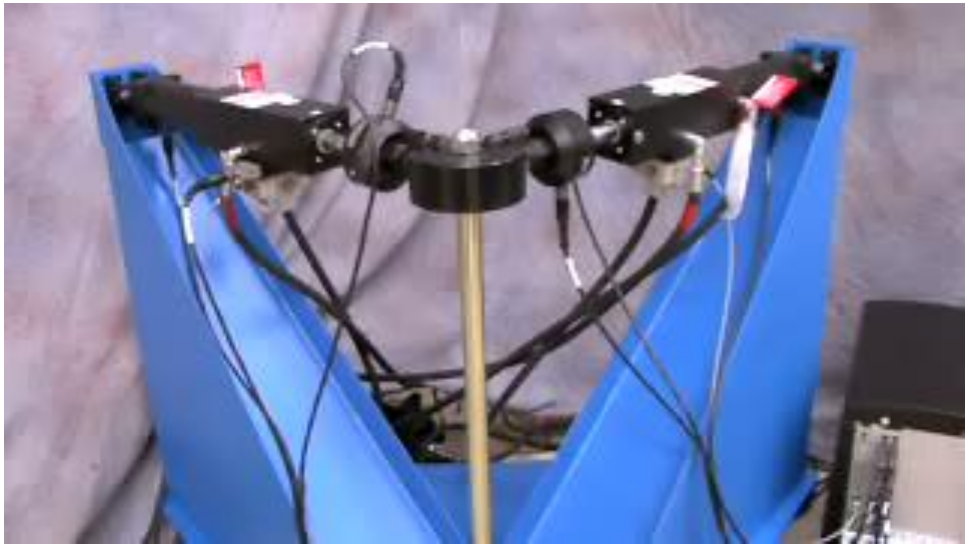


Demo 1 – Video

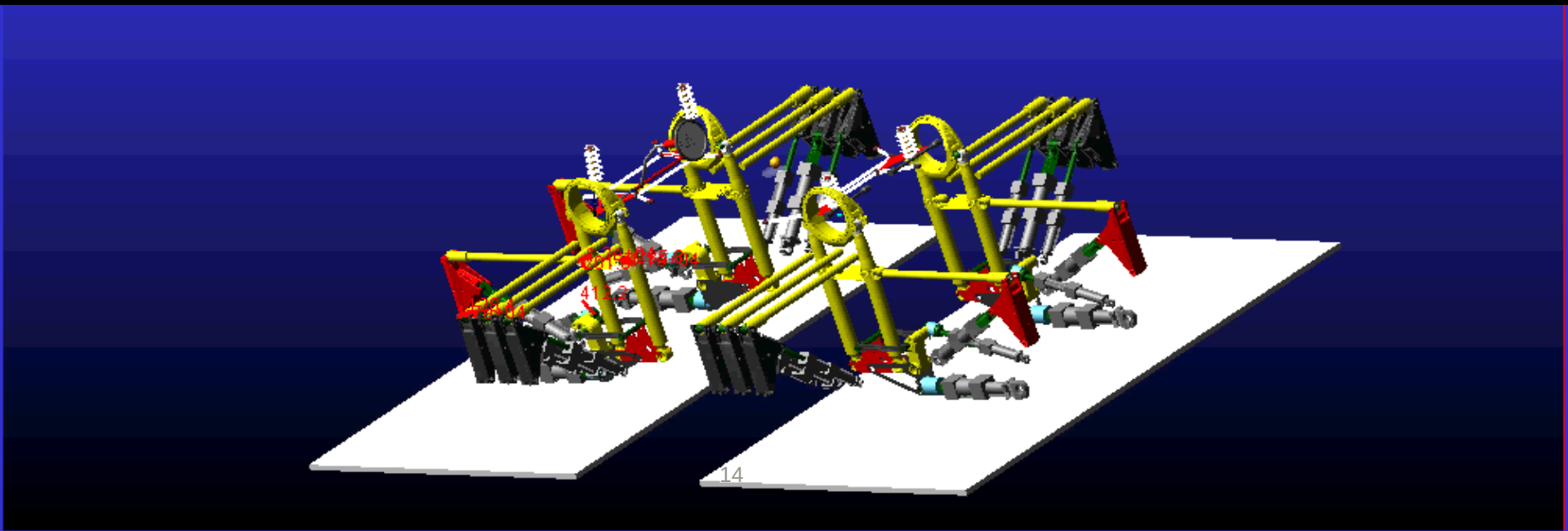


Demo Example 2 – MTS 329 with Car Model





Demo 2 – Video

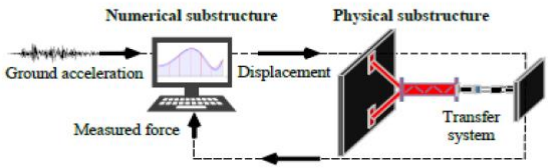


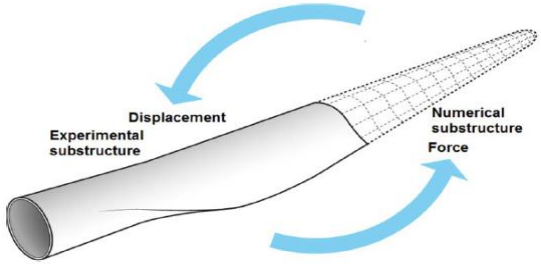
Hybrid Simulation in Wind Energy

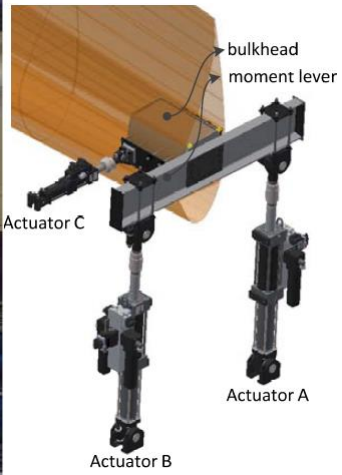
Hybrid Simulation with ANSYS

- ANSYS is widely used in many areas. Hybrid simulation with ANSYS can help spreading hybrid sim in other industries.
- There have been several requests to do hybrid simulation with ANSYS.

ANSYS







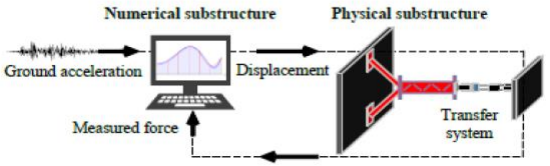
ANSYS is the desired finite element analysis software for DTU blade hybrid simulation.

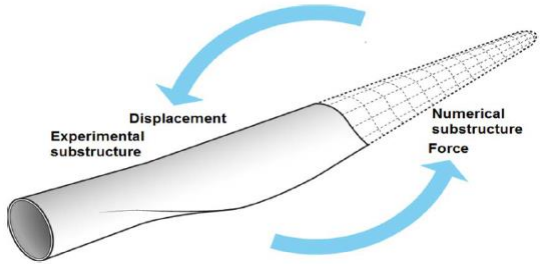
Specimen Aging During the Lifetime

- Many specimen could last for a long time.
- There are many factors that can cause specimen aging, such as corrosion, mechanical loading, delamination, joint loosing, and oxidization.
- For some composite materials, under same working environment, the load on the parts could change significantly during the lifetime due to material aging induced property change.
- It is important to consider specimen aging during fatigue tests.

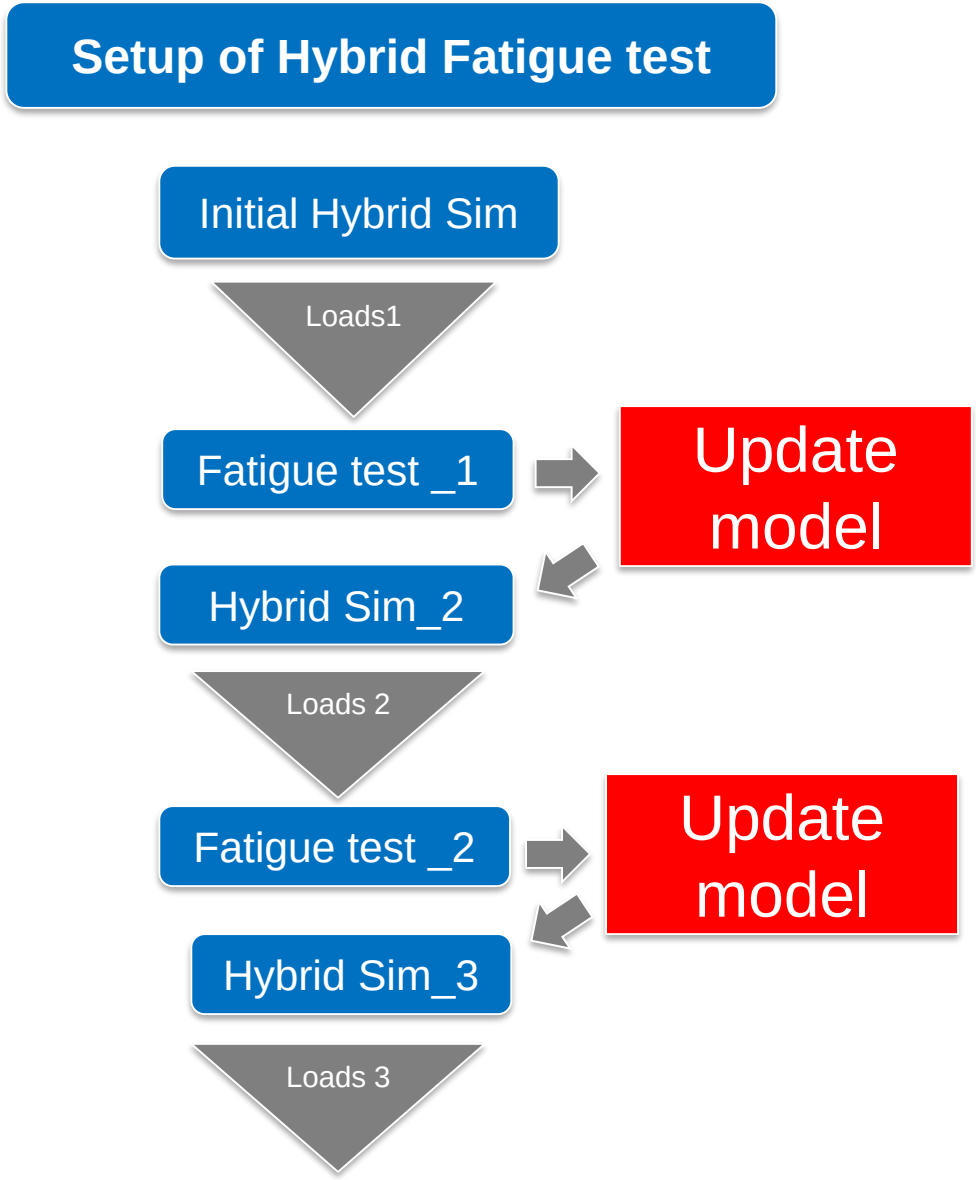
Hybrid Simulation Provides Commands for Fatigue Testing

- During hybrid simulation, ANSYS output interface load to a file in global coordinate in MTS Profile Command format.
- Fatigue testing can be easily setup by repeating the load file.





Hybrid Fatigue Test Method



Europe – Wind Energy

Engineering Structures 126 (2016) 417–431

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Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Performance evaluation of full-scale tuned liquid dampers (TLDs) for vibration control of large wind turbines using real-time hybrid testing

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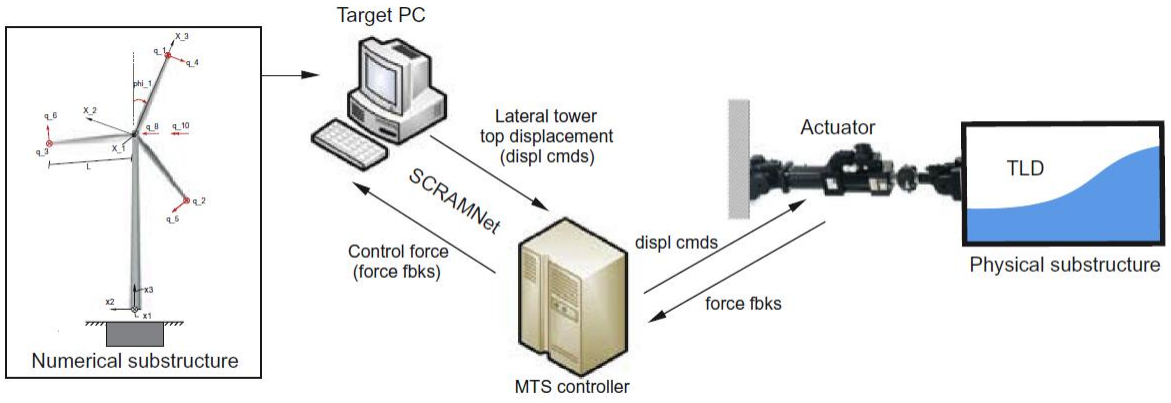

Fig. 2. Conceptual view of the RTHT for the TLD-wind turbine system.

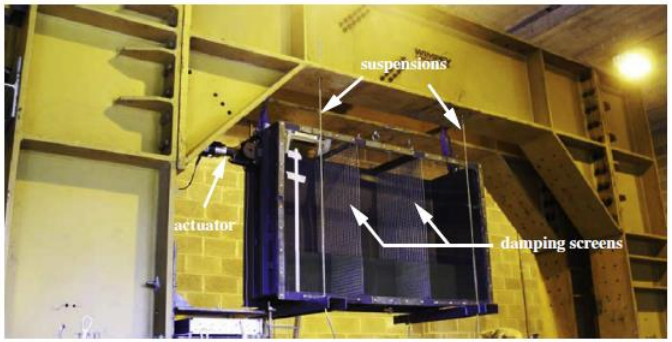

Fig. 5. Test setup and the physical substructure (the TLD).

Research carried out using MTS real-time hybrid simulation system at Trinity College Dublin, Ireland.

Europe – Wind Energy

Proceedings of the 35th International Conference on Ocean, Offshore and Arctic Engineering
OMAE2016
June 19-24, 2016, Busan, Korea

OMAE2016-54435

REAL-TIME HYBRID MODEL TESTING OF A BRACELESS SEMI-SUBMERSIBLE WIND TURBINE. PART I: THE HYBRID APPROACH

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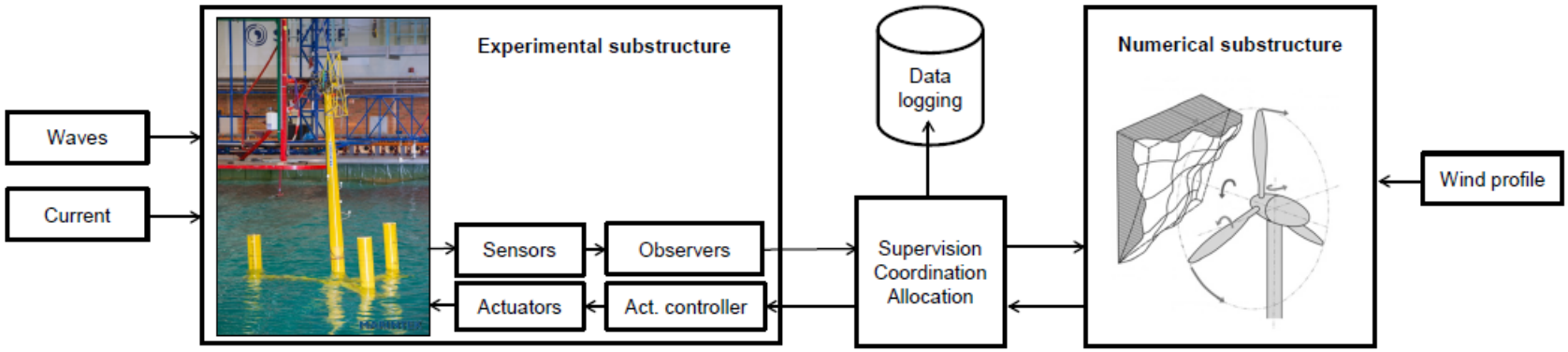
NTNU is the Norwegian University of Science and Technology, 7491 Trondheim, Norway

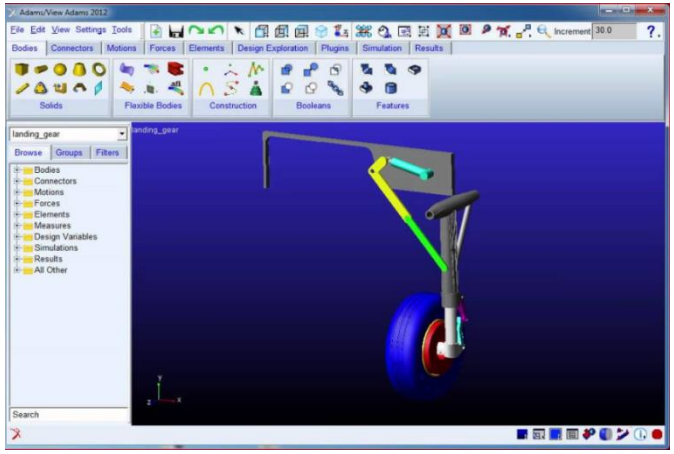


Hybrid Simulation in Aerospace

Hybrid Simulation in Aerospace

- Hybrid simulation to study sub structure and components, such as dampers.
- Model assisted testing is used more and more.
- Virtual testing has become more and more popular.

MTS Soft Real-Time Hybrid Simulation Solution



Target PC

OpenFresco

ADAMS model

Flextest Controller

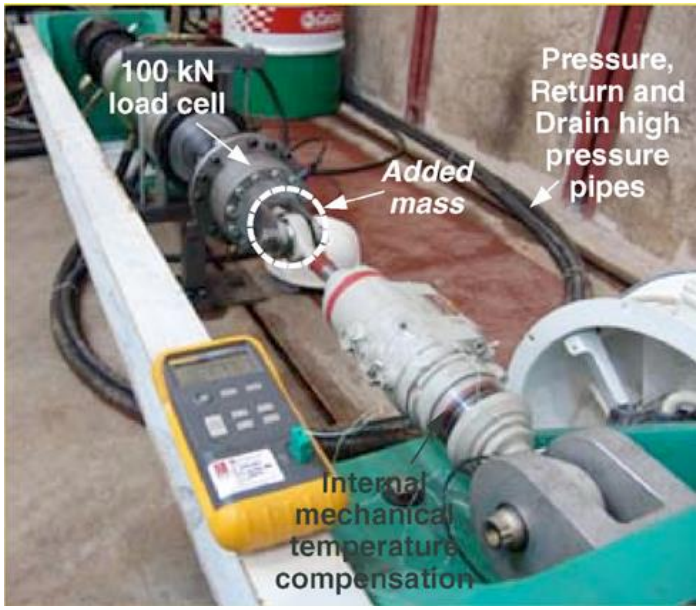
Scramnet Interface

Target PC with Predictor-Corrector

Test Rig

Helicopter Blade Hybrid Test At University of Bristol

Lag damper



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Journal of Sound and Vibration 307 (2007) 737–754

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Testing coupled rotor blade–lag damper vibration using real-time dynamic substructuring

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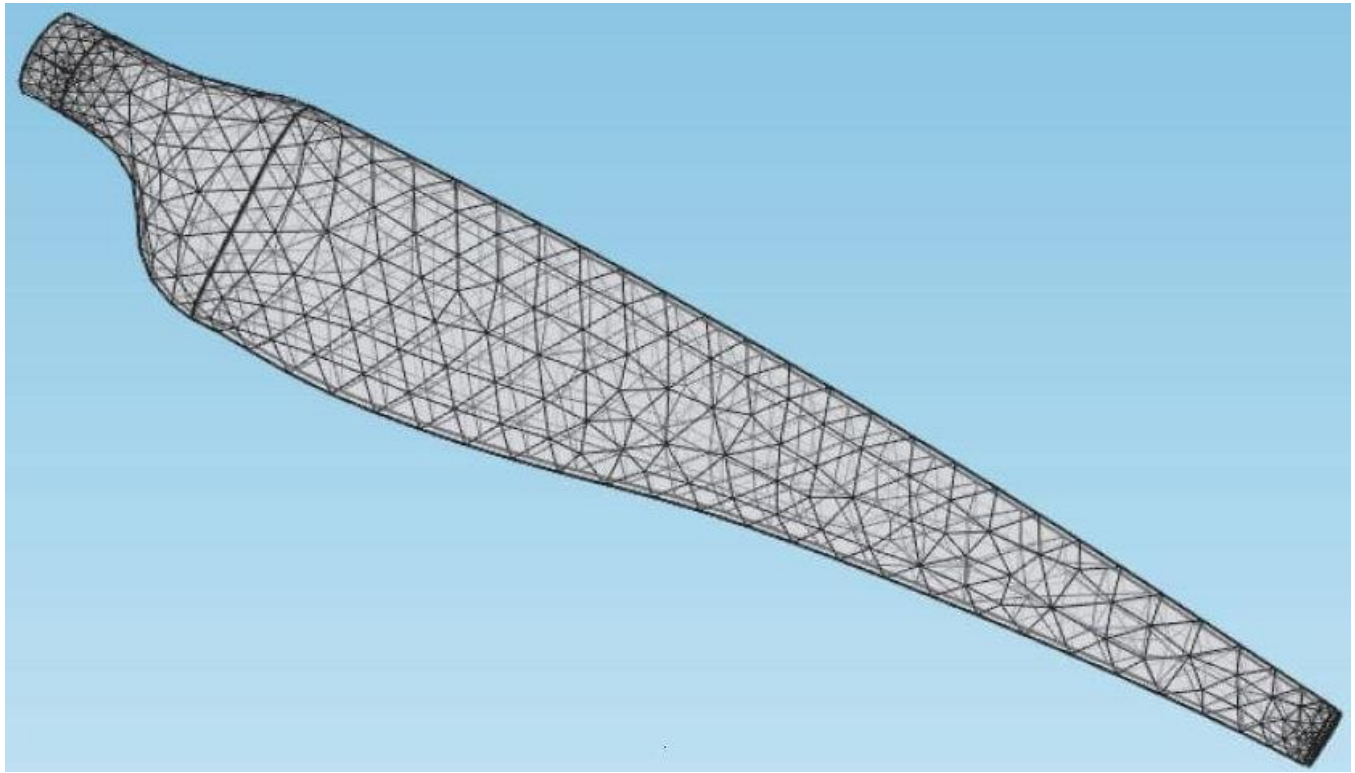
Hybrid Simulation with ROM

- In many cases, FEA models are too complicated to run in real-time. However, the specimens are rate dependent. Therefore, real-time hybrid simulation is a must. The solution is ROM.



ROM for Analytical Structural Dynamic EOMs

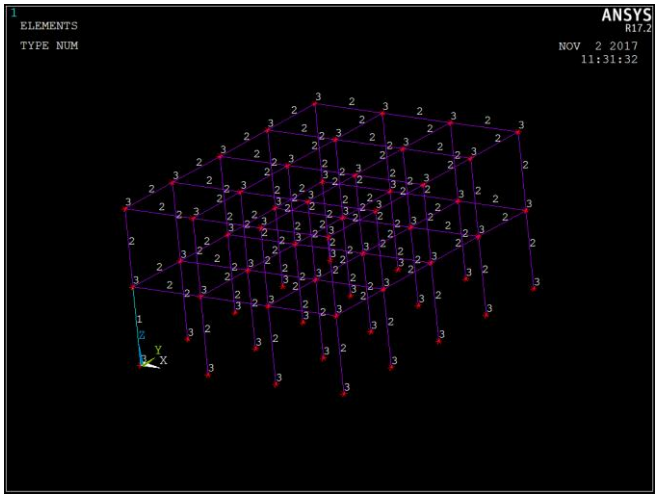
$$M_p\ddot{X}_p + C_p\dot{X}_p + K_pX_p = K_p\Gamma x_n + C_p\Gamma\dot{x}_n.$$

$$\begin{bmatrix}\dot{X}_p\\ \ddot{X}_p\end{bmatrix} = \begin{pmatrix}0_{p\times p} & I_{p\times p}\\ -M_p^{-1}K_p & -M_p^{-1}C_p\end{pmatrix}\begin{bmatrix}X_p\\ \dot{X}_p\end{bmatrix} + \begin{pmatrix}0_{p\times 1} & 0_{p\times 1}\\ -M_p^{-1}K_p\Gamma & -M_p^{-1}C_p\Gamma\end{pmatrix}\begin{bmatrix}x_n\\ \dot{x}_n\end{bmatrix}$$

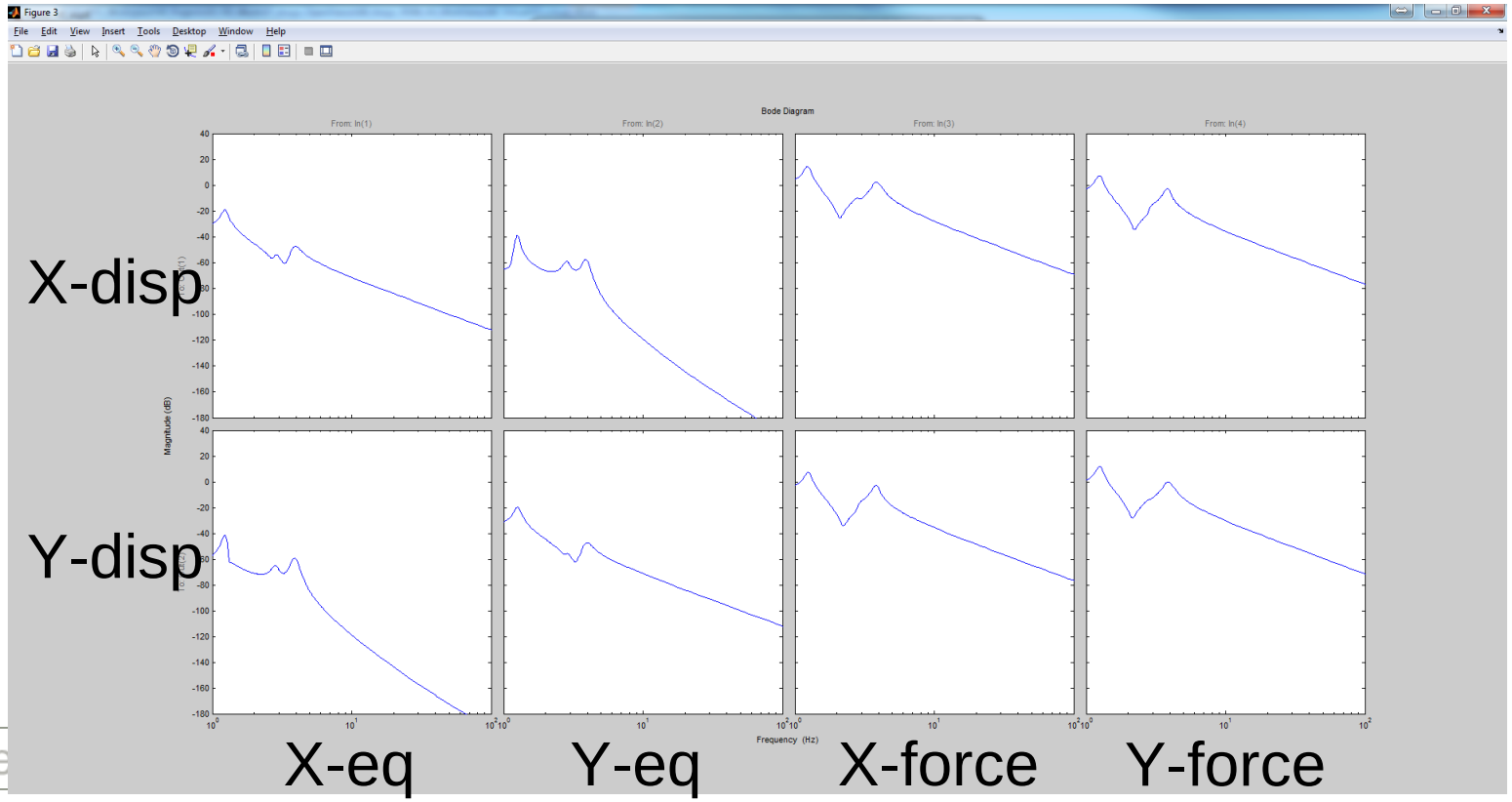
$$F_p = \begin{pmatrix}k_{n+1} & 0_{1\times p-1} & c_{n+1} & 0_{1\times p-1}\end{pmatrix}\begin{bmatrix}X_p\\ \dot{X}_p\end{bmatrix} + \begin{pmatrix}-k_{n+1} & -c_{n+1}\end{pmatrix}\begin{bmatrix}x_n\\ \dot{x}_n\end{bmatrix}$$

- Convert structural dynamic model (2nd order ODE) into state space model (1st order ODE)
- State space model allows utilization of vast resources of dynamical system analysis and control design tools

ROM for FEA Models (Ansys)

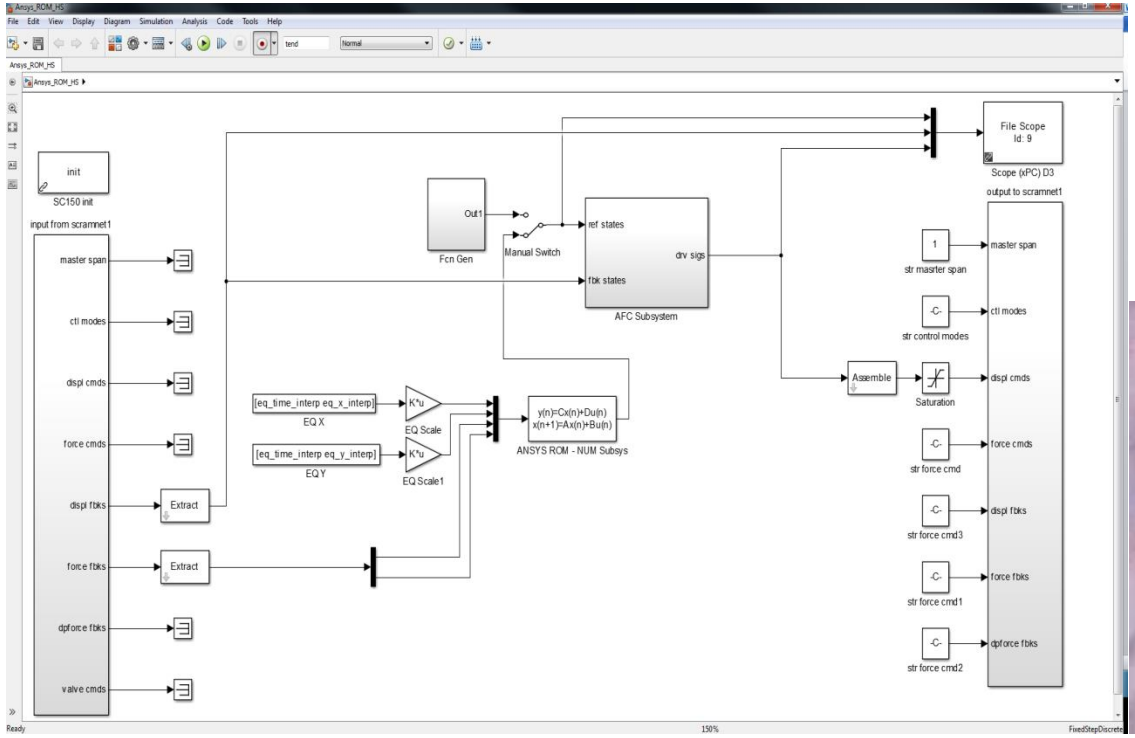


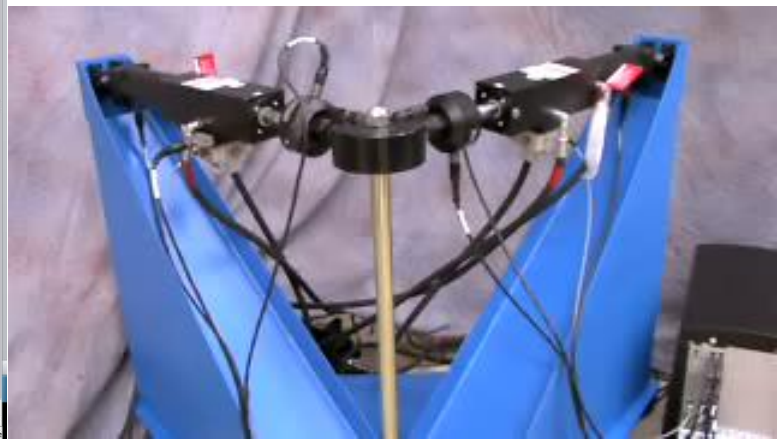
- Use modal superposition approach to construct state space ROM
- Hybrid simulation - analytical substructure ROM 4 inputs, 2 outputs



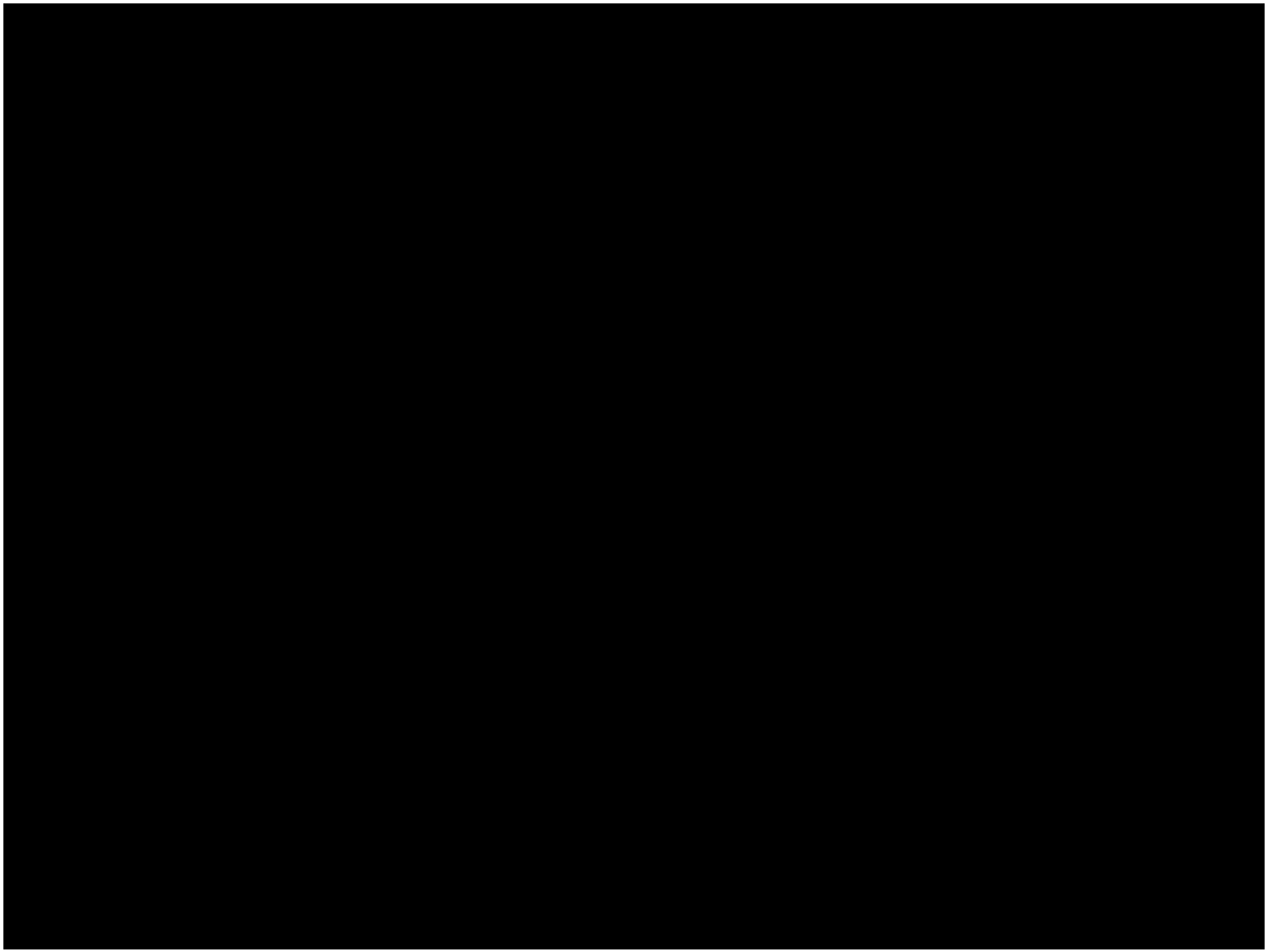
Ansys ROM Realtime Hybrid Simulation Demo

- State space ROM constructed offline
- Hard realtime hybrid simulation, 1024 Hz simulation rate
- No OpenFresco needed





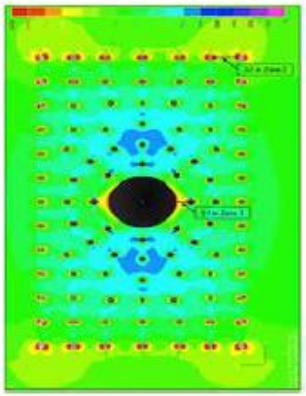
Ansys ROM Realtime Hybrid Simulation

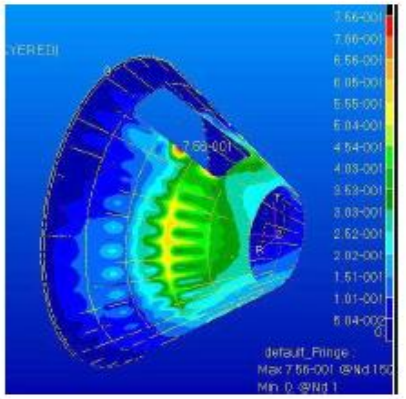


Achieving Calculated Stress Distribution

- Development of simplified process to introduce CAE model stress calculations to apply load input distribution
  - CAE model and wanted stress distribution
  - MTS test rig, static testing of fuselage panel
  - Import stress distribution, MTS controls, iterate loads to achieve correct stress distribution
  - MTS s/w has the tools to identify the matrix, and iteratively apply it to improve the load case input until the stress state for all locations is optimized.
  - Validate and execute test
  - Export test data for comparison
- Method development project

Example of present methods:
"When developing loads we start with a desired response, stress, at a certain location on the specimen. Then we back-calculate through the Aircraft model and the model for the testing system to arrive on an input load for the control system."

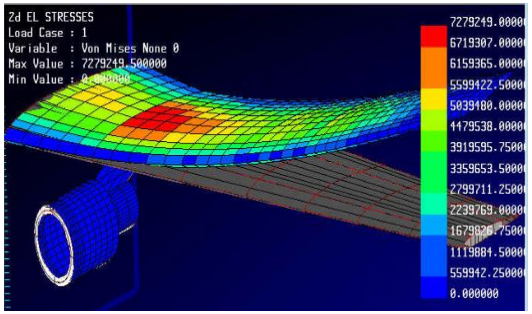




Some examples of stress calculations on A/C structures

Achieving Calculated Stress Distribution

Desired strain field



Real Test

Least Square Error

Optimization Process to Minimize the Error

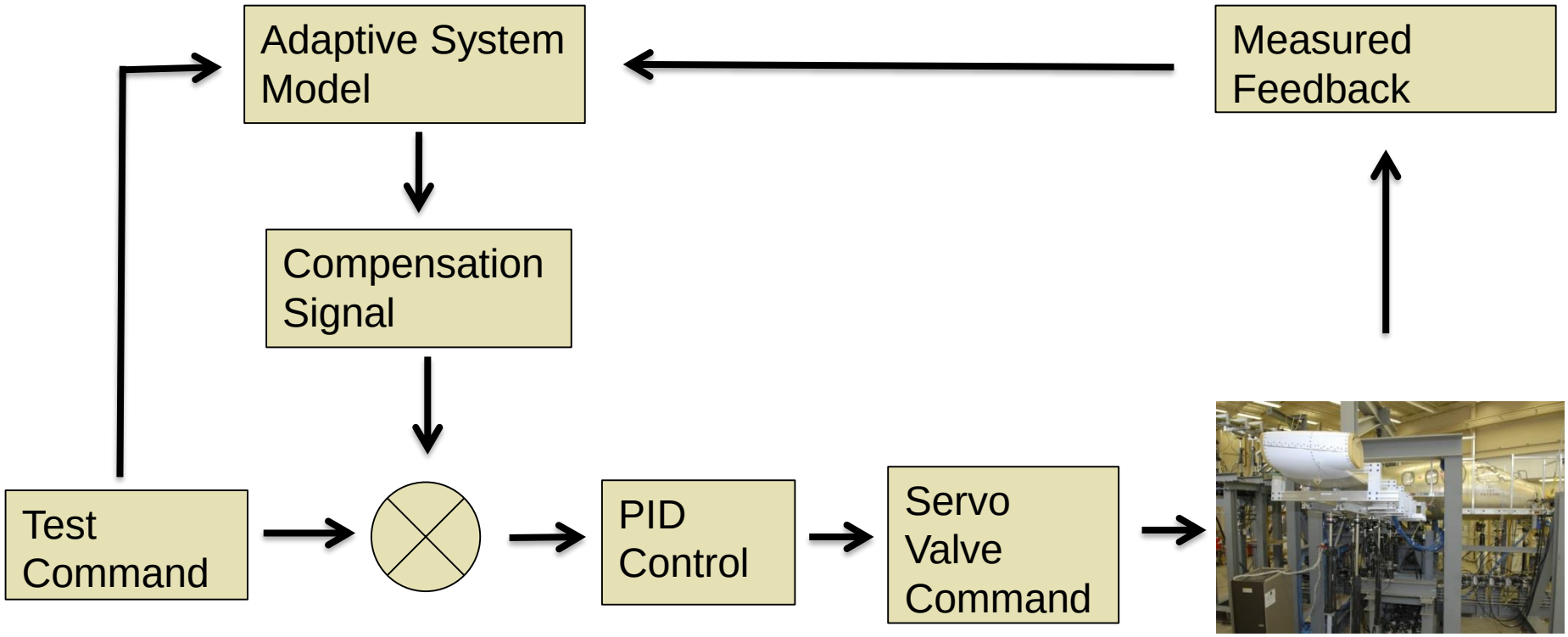
Actuator Command

Measured Stain signals

Model Based Compensation

- Real test system has system roll off, delay, cross coupling, resonance that cause control issue that have negative impact on test accuracy and test speed
- Model based compensation method predicts the impact of these effects and compensates the command or control output
- MTS offers different compensation method to improve performance of physical tests
- The result is better tracking, improved stability, and fast tests

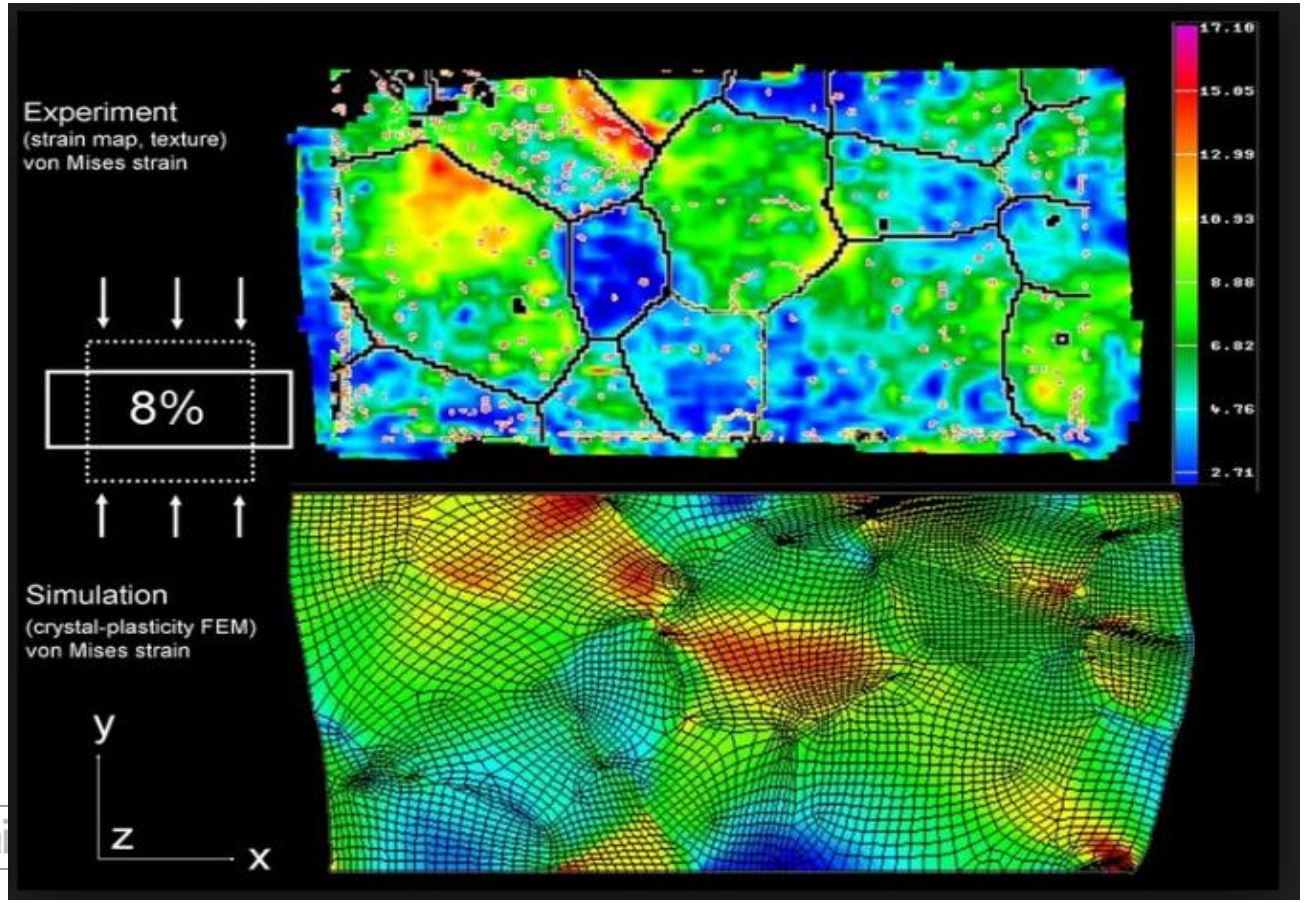
Feed Forward Compensation



Real Test

Digital Imaging Correlation (DIC) System

- 2D or 3D displacement or strain field measurement through image registration
- DIC signals can be imported into Flextest in form of analog input for correlation and control purpose



Discussion