# Dynamic Modeling of Supersonic Propulsion Systems for AeroPropulsoServoElasticity Analysis

**AeroServoElasticity - AeroPropulsoServoElasticity**
**Fundamental Aeronautics – High Speed Project**


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**NASA Glenn Research Center**
**Cleveland, Ohio**



**Propulsion Control and Diagnostics (PCD) Workshop**
**Cleveland OH, Dec. 11 – 12, 2013**

# APSE Task Objective

**Develop appropriate vehicle models and controls to study the dynamic performance of supersonic vehicles**

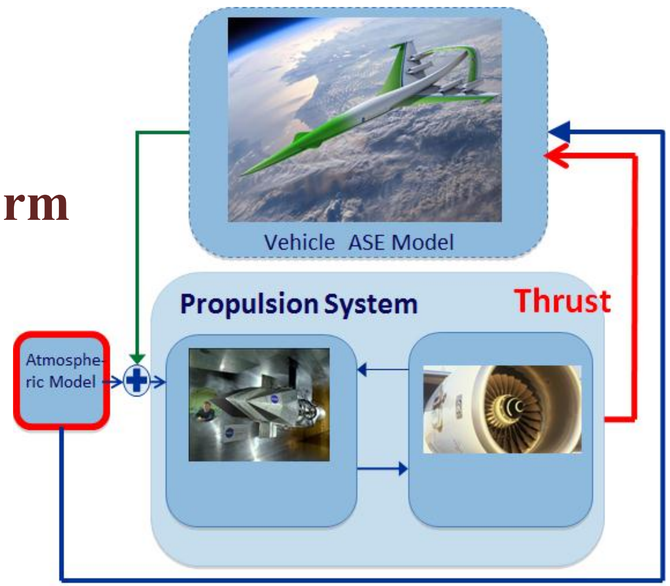
**<u>Team:</u>**

**NASA Langley – Develop the structural vehicle models**

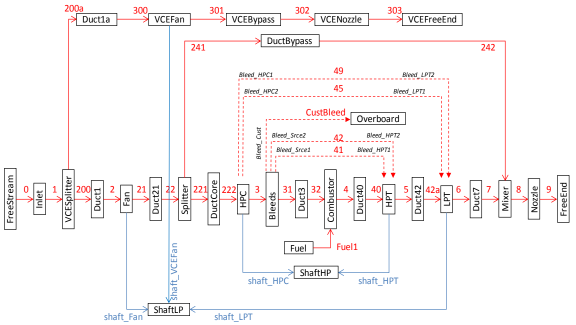
**NASA Glenn – Develop the propulsion system models**

- **Controls and Dynamics Branch (RHC):** George Kopasakis, Joseph Connolly
- **Inlet and Nozzle Branch (RTE):** David Friedlander
- **Multidisciplinary Design Analysis Optimization Branch (RTM):** Jonathan Seidel, Jeff Chin
- **Antenna and Optical Systems Branch (RHA):** Noulie Theofylaktos
- **Thermal Systems Branch (DET):** Xiao-Yen Wang
- **University of Colorado:** PhD Research Kyle Woolwine
- **Ohio State University:** PhD Research Joseph Connolly

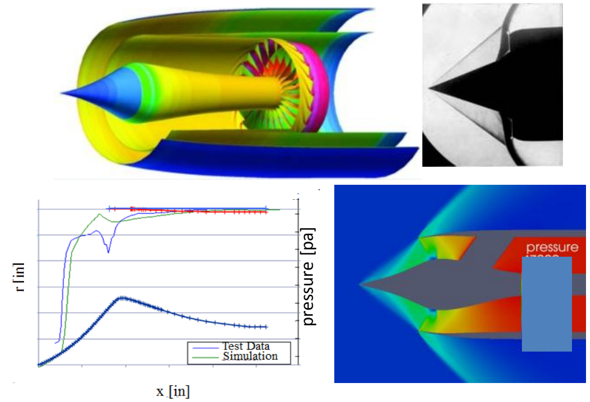
**Both – Develop integrated model and perform APSE studies**



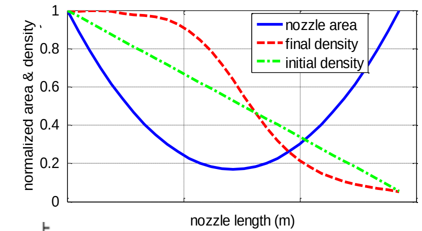

**Integrated APSE Model**

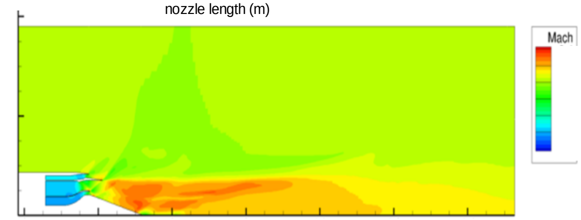



Variable Cycle Engine 1D Component Dynamic Model & NPSS Cycle Model

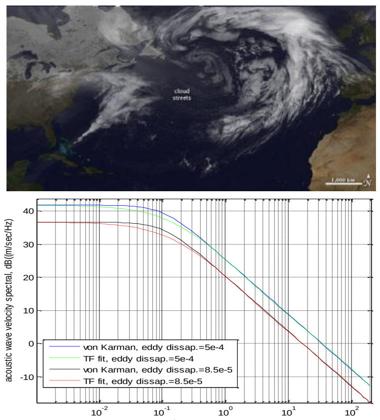



External Compression Inlet CFD Modeling for Dynamics

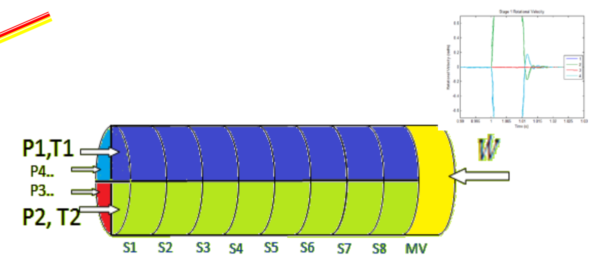


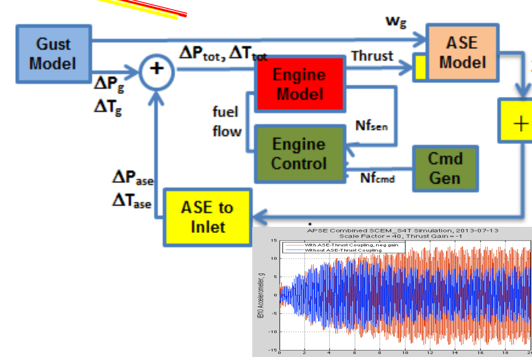

Nozzle Modeling – 1D & 2D for Dynamics



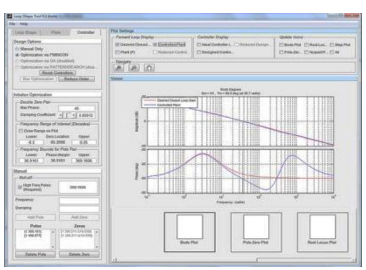

Atmospheric Turbulence Modeling

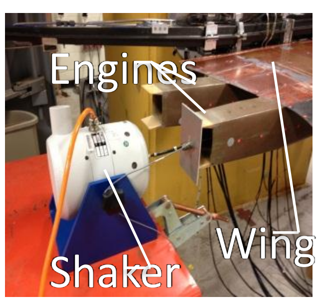

Parallel Flow Path modeling – 2D Dynamics



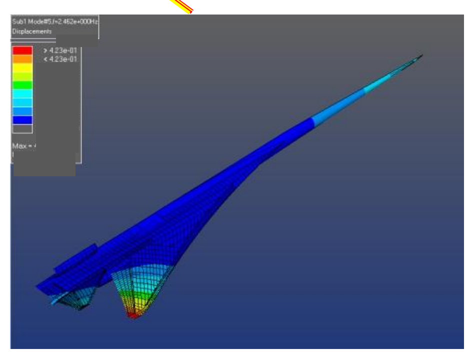

Integrated APSE



Feedback Controls GUI tool & Control Schedules




APSE System Interfaces – analytical & by testing



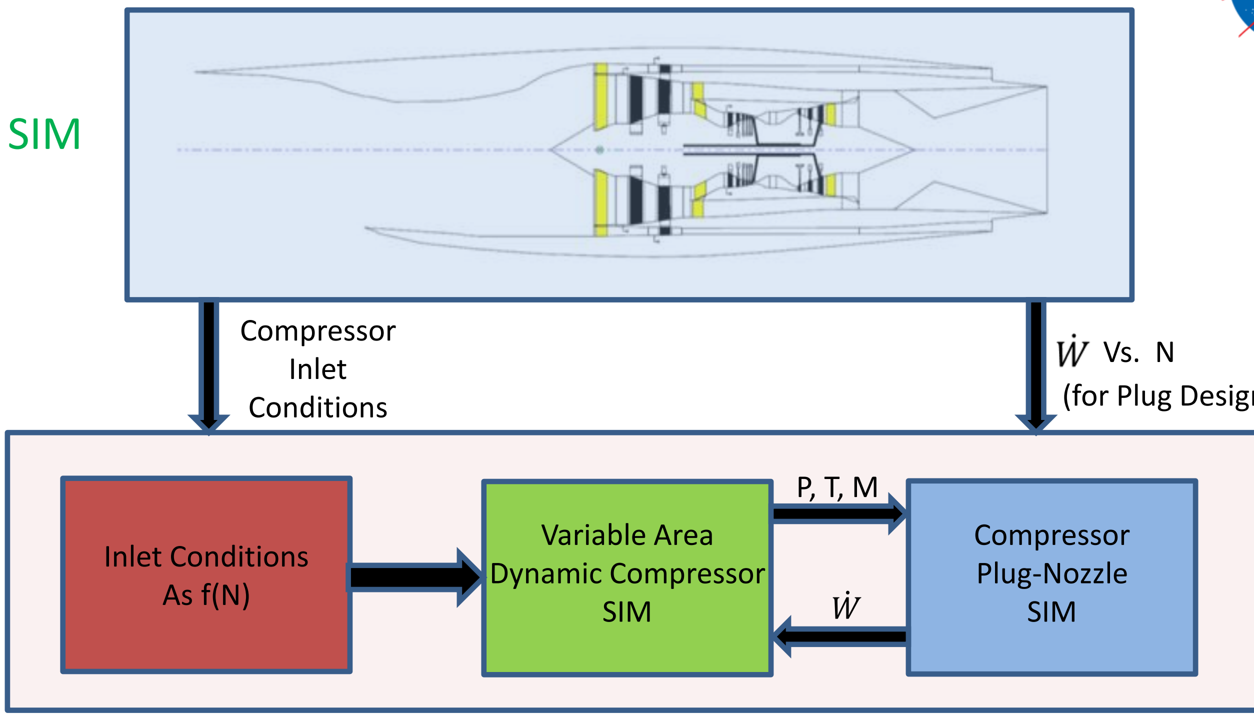
Vehicle Structure – CFL3D, FUN3D & State Space



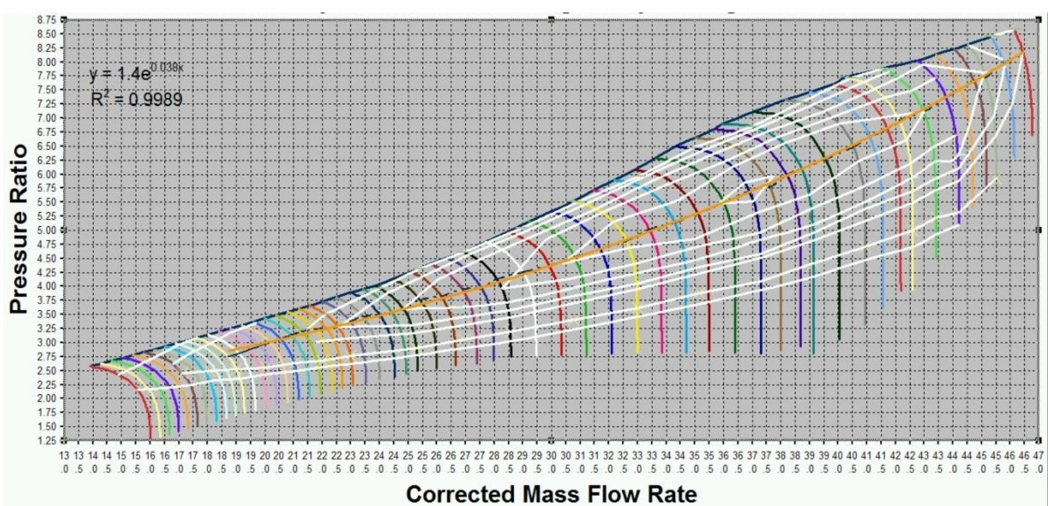
Note: Pictures manipulated to remove controlled information

# Compressor/Fan Test-Bed SIM for Derivation of Control Schedules

Dynamic Engine SIM




Isolated Compressor Rig SIM
- Variable Guide Vane angle as a function of rotor speed



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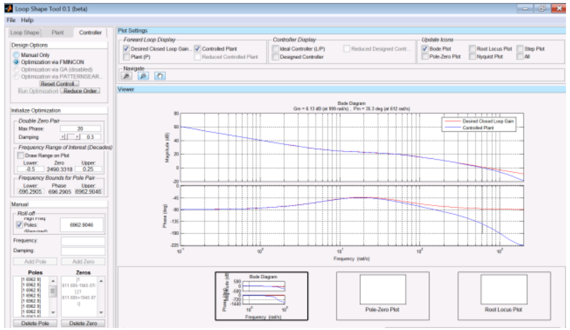
# Feedback Control Design GUI



-- Purpose of new control design GUI is to maximize control system performance (stability vs. disturbance rejection & response time).

-- Only information needed is plant transfer function and how fast the plant is driven (plant actuation system response)

-- Robust feedback control designs obtained with couple clicks (normally in the first try) – Robustness also due to auto GUI design of 2 dominant natural controller frequencies.

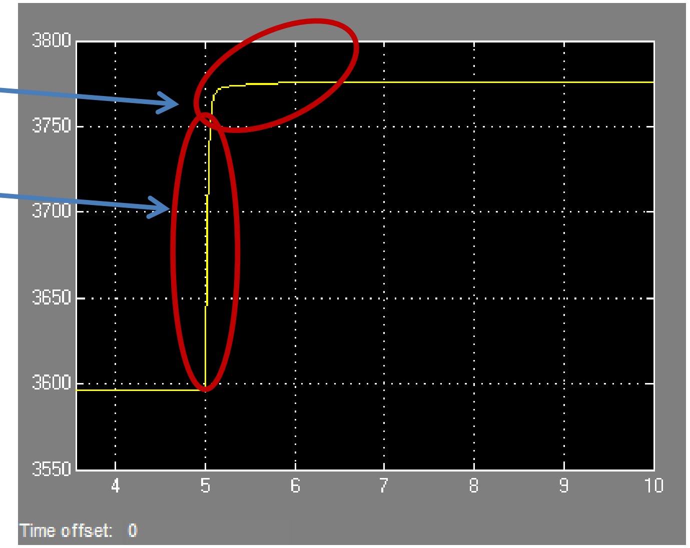
--- Low natural frequency for stability/robustness & for high disturbance rejection in mid frequency range

--- High natural frequency for fast response & for high disturbance rejection

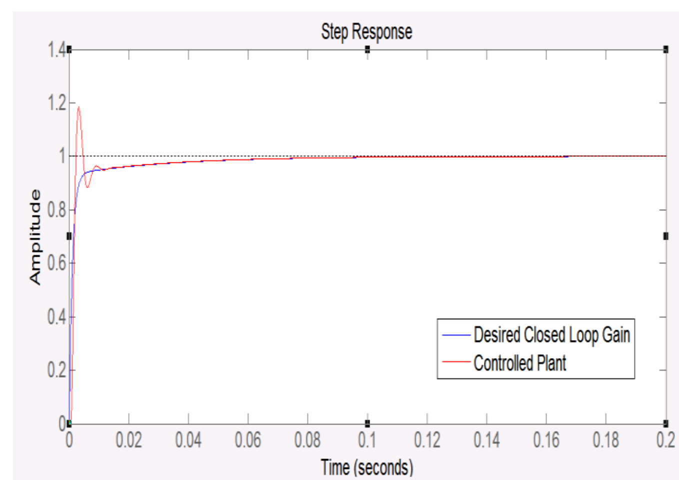
-- GUI control design more tolerable to unmodeled dynamics and tighter stability margins

Low natural freq. of control system

High natural freq.



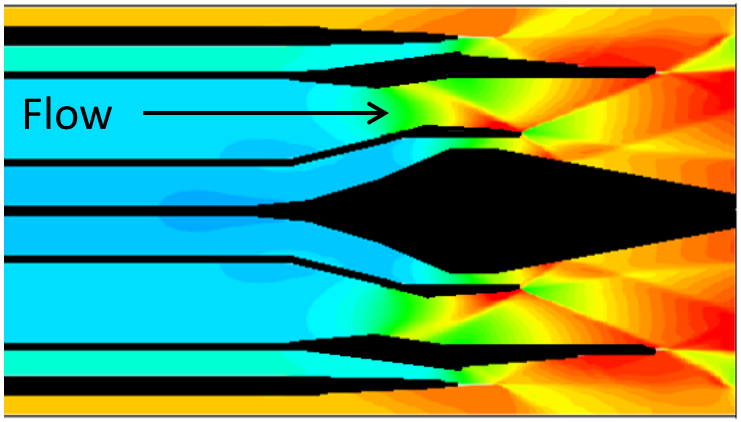

**Step response of CMAPPS fan control system designed using the GUI**



# Nozzle Dynamic Characterization

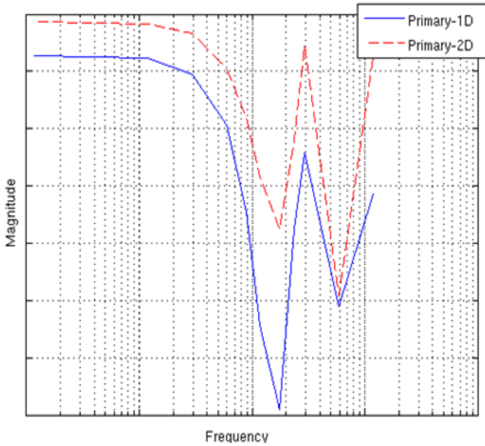
**Objective:**
Develop a dynamically accurate nozzle model to integrate with the rest of the propulsion system

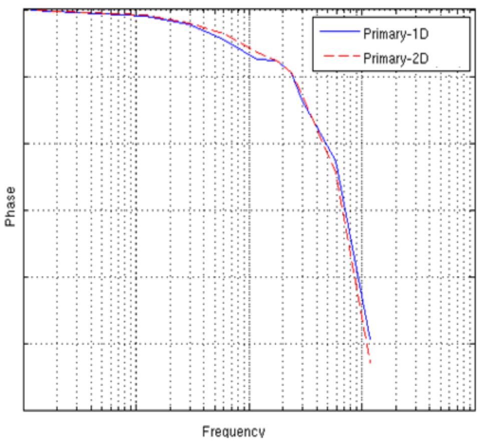
**Approach:**
-- Develop CFD model to capture shock dynamics
-- Determine the minimum grid resolution necessary for dynamic accuracy based on developed dynamic accuracy criteria




Nozzle CFD flow field

Nozzle frequency domain response characterization



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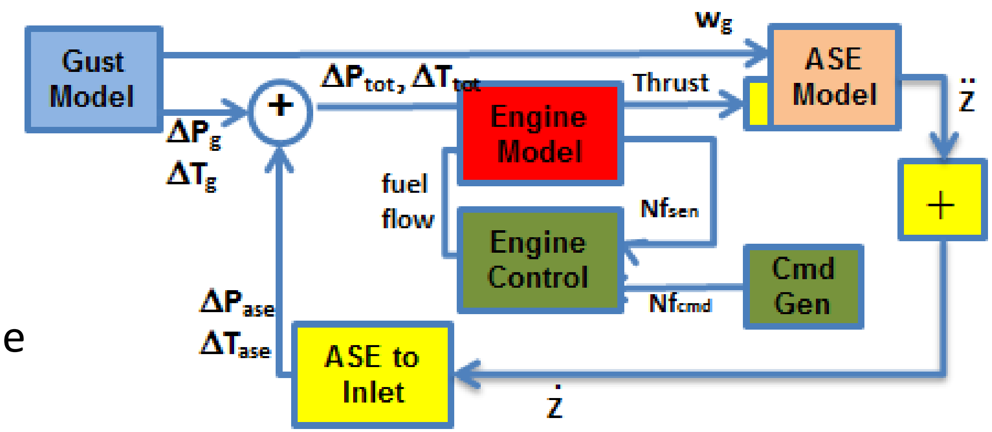
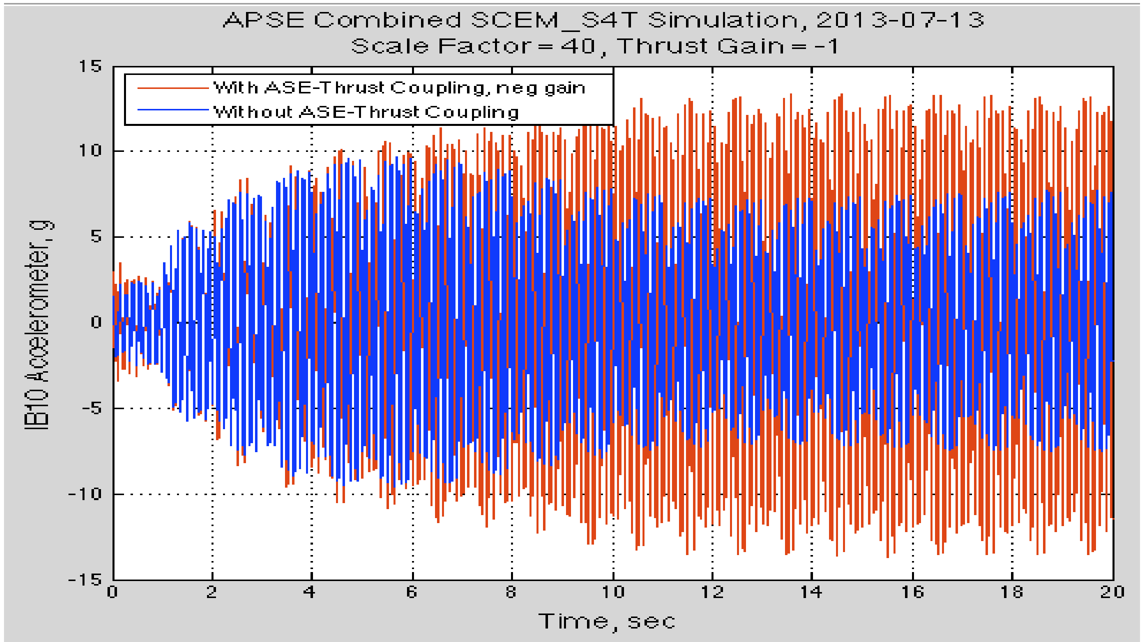
# Integrated AeroPropulsoServoElastic (APSE) Model




Early assessments indicate that closed loop coupling of propulsion and vehicle AeroServoElastic dynamics could be significant enough, that it may not be possible to ignore.



# Dynamic Propulsion System Modeling and Other Potential Applications

- Assessments of Compressor Stability Margin – realistic dynamics of stall
- Test-bed to validate engine **Cycle Deck** designs, geometry sensitivity due to flow impedances and compressor/turbine dynamic feedback loop, and choked dynamics.
- Test-bed to derive exit nozzle area control schedule and design controls to stabilize exit nozzle feedback loop
- Test-bed for isolated compressor/plug system to derive compressor IGV control schedules
- Perform assessments of the effect of flow distortion on dynamics

**Using dynamic engine models as test-beds can substantially reduce costs by performing early design validation studies and by reducing test time of real engine hardware**

# Future Work

Increasingly develop more detailed APSE simulations towards developing in the near future dynamic test-beds in simulation of component systems and a complete integrated vehicle model to conduct APSE performance studies such as ride quality, flight dynamics and vehicle stability, and flight efficiency.