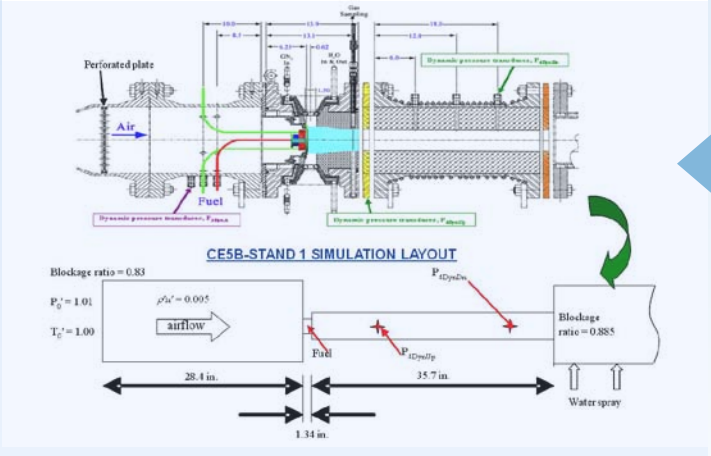
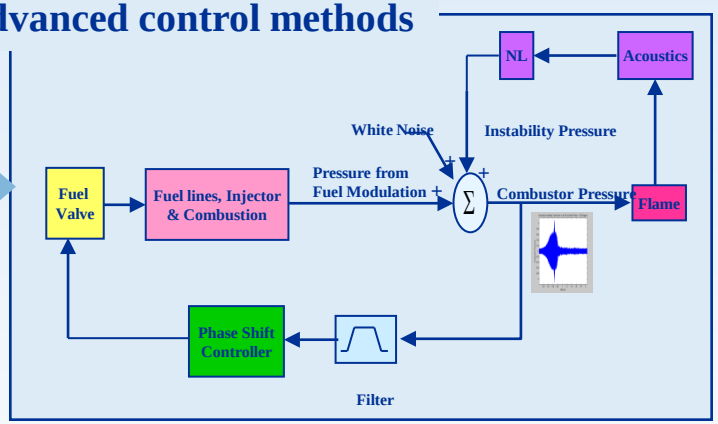
Simulink-Based Test-Bed for Combustion Instability Modeling and Control

Physics-based instability models



Advanced control methods



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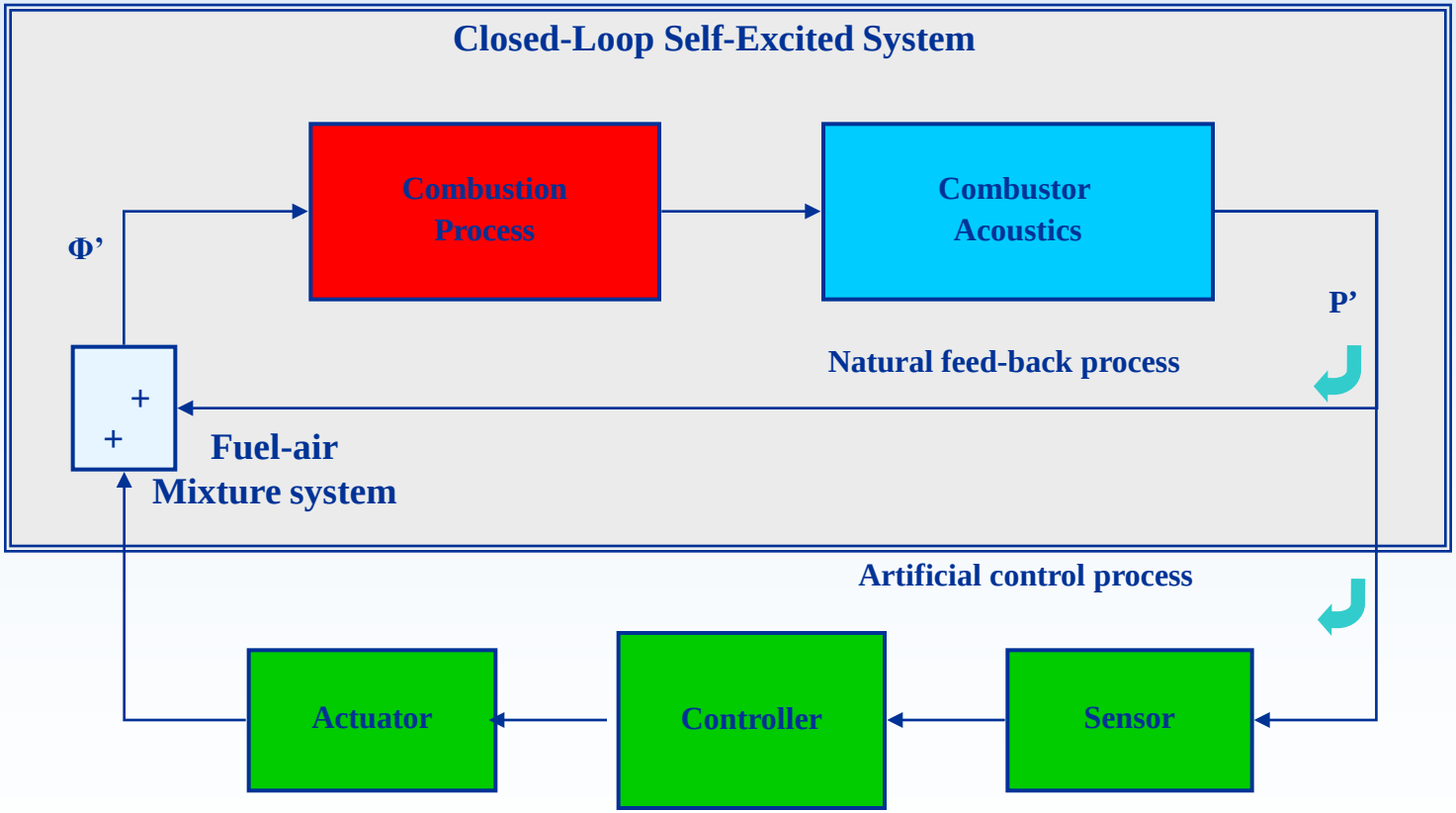
Outline

- Desired environment for combustion instability control development
- Past approach
- Current approach
- Software demonstration
- Discussion

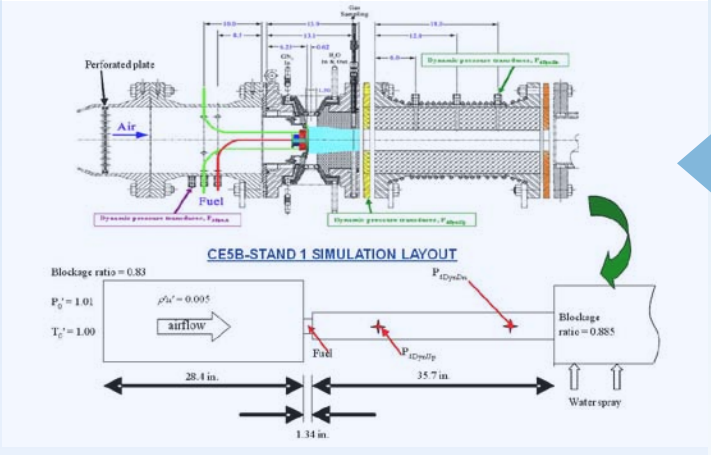
Combustion Instability Control Strategy

Objective: Suppress combustion thermo-acoustic instabilities when they occur

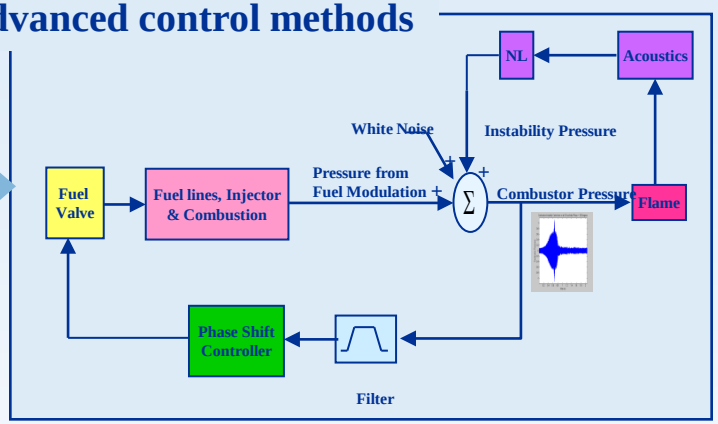


Desired Control Development Environment

Physics-based instability models



Advanced control methods



Integrates:

- Simulation with "enough" physics
- Controller in the form in which it will be experimentally validated

➢ In an environment that is familiar to the controls engineer

Motivation for Combustion Instability Simulation

- Successful active control design requires accurate modeling and simulation.
  - The essential physical phenomena should be correctly captured
    - (e.g. self-excitation).
  - Characterization and control design necessitate rapid simulation
    - (i.e. relative simplicity).
  - Simulation must lend itself to implementing a variety of sensing and actuation strategies.

- The developed simulation method must achieve these goals for combustor configurations:
  - in which the potential instabilities propagate axially
  - that contain abrupt changes in cross sectional area

Combustion Dynamics Modeling

Reduced-order oscillator models

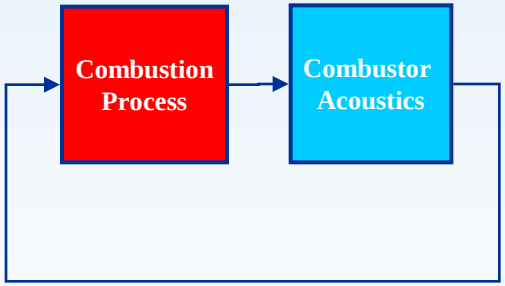
Run fast to allow parametric studies in support of control system development

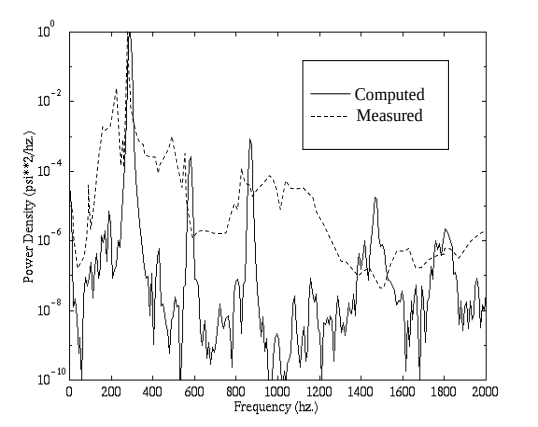
Simplified Quasi-1D dynamic models

Allow physics-based control method validation

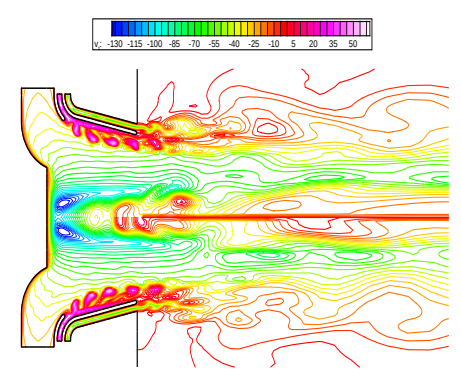
Detailed, physics-based dynamic models

Fundamental understanding of combustor dynamics to aid passive, active instability suppression





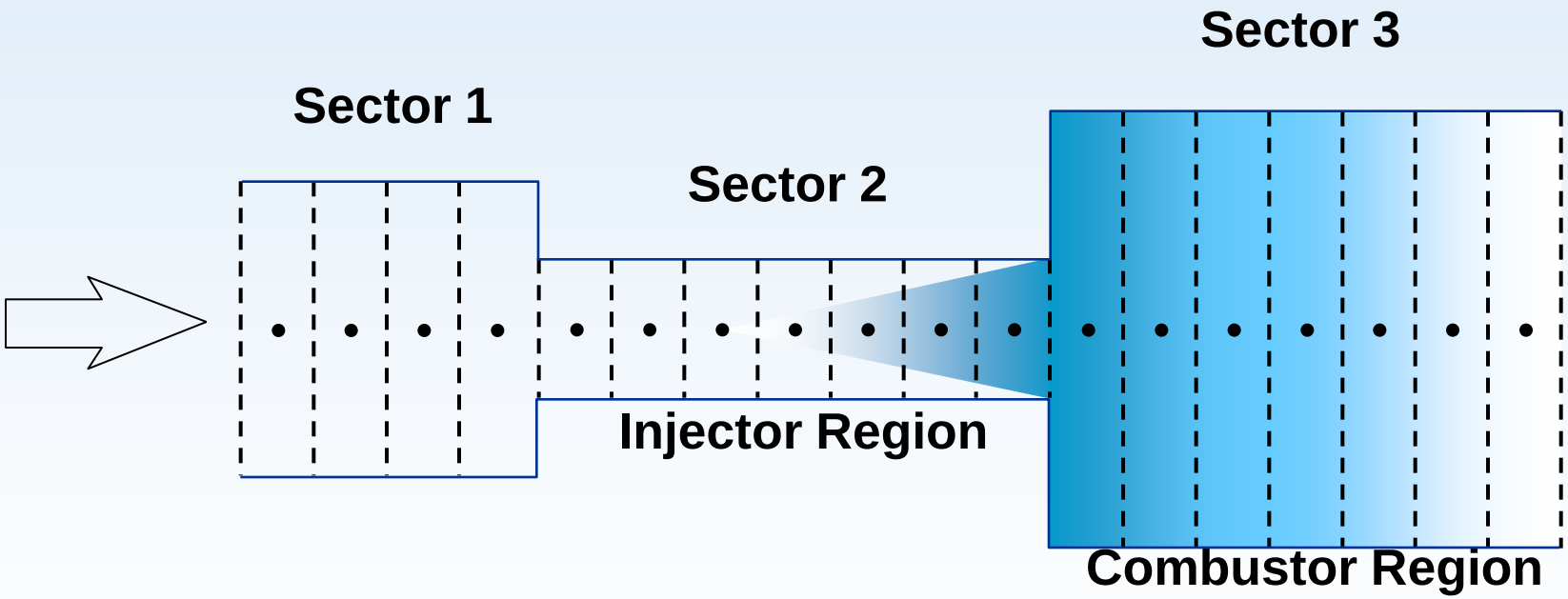
Results from NASA Sectored-1D Model of LPP Combustor Rig – D. Paxson



Penn State Injector Response Model Plot

Simulation Features

- Time-accurate
- Physics-based, Sectored 1-D, Reacting
- Computationally efficient area transitions
- Upstream and Downstream boundary conditions modeled to match rig

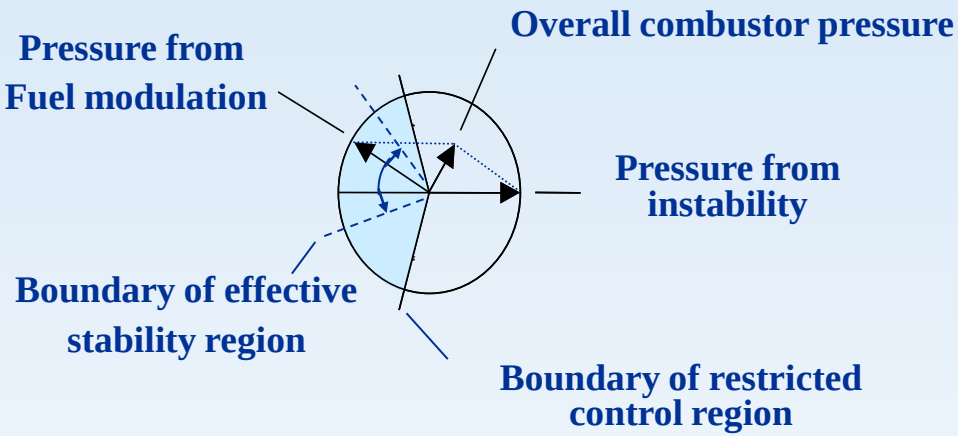


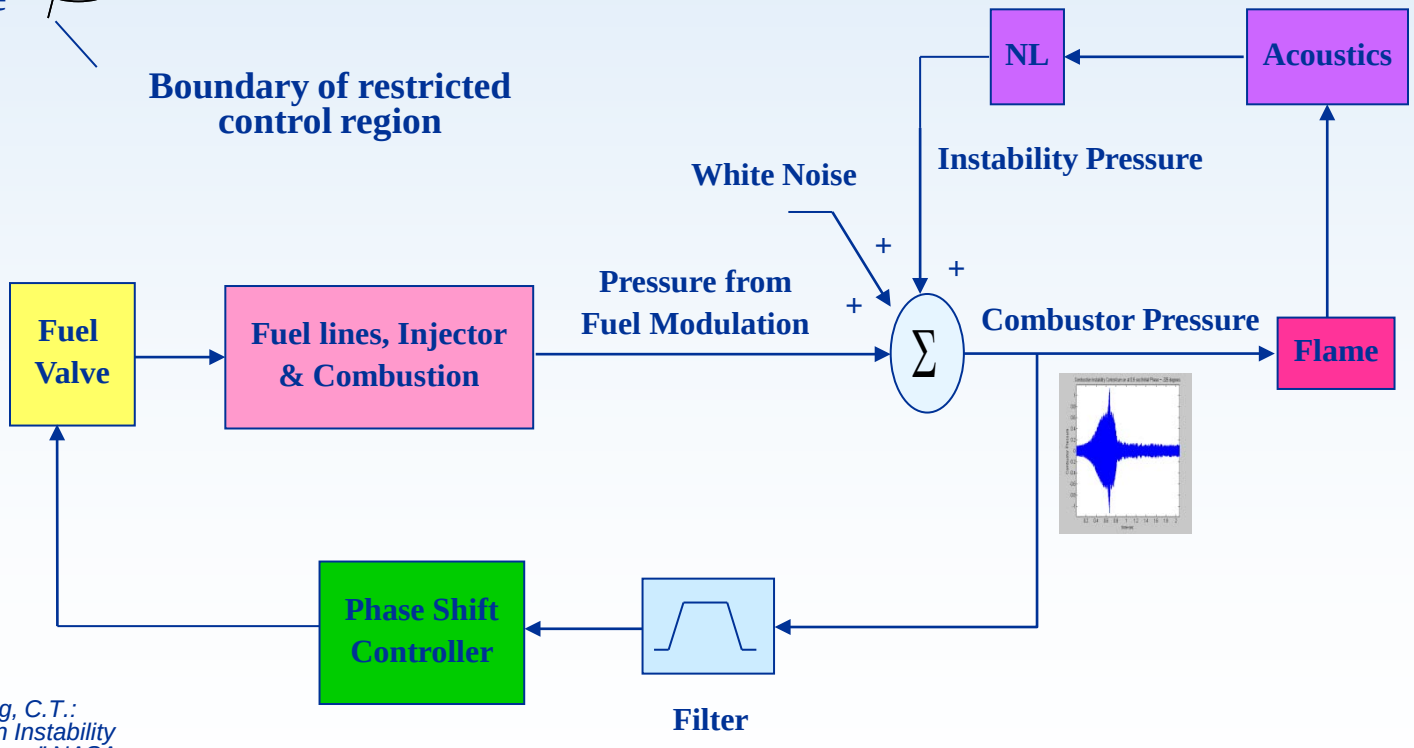
Within Each Sector:

- One-Dimensional
- Perfect Gas

Paxson, D.: "A Sectored-One-Dimensional Model for Simulating Combustion Instabilities in Premix Combustors," AIAA-2000-0313, NASA TM-1999-209771, January 2000.

Adaptive Sliding Phasor Averaged Control

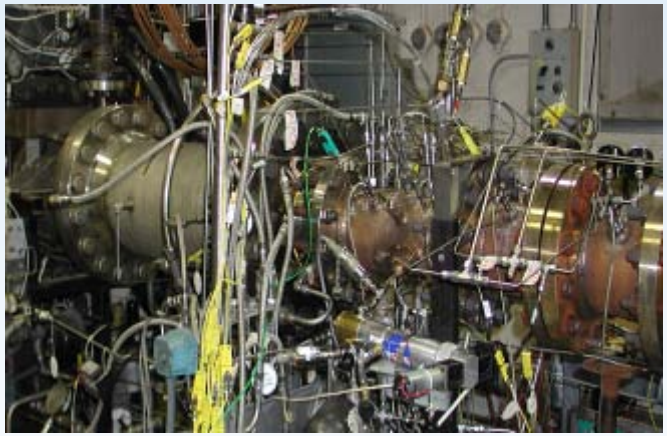


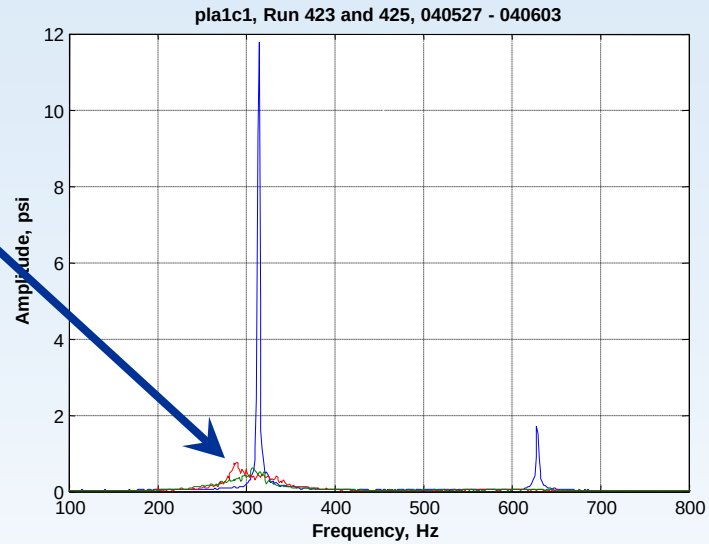


Kopasakis, G, DeLaat, J.C.; Chang, C.T.: "Validation of an Adaptive Combustion Instability Control Method for Gas-Turbine Engines." NASA TM-2004-213198, AIAA-2004-4028.

Active Combustion Instability Control Demonstrated Experimentally for a Conventional Combustor

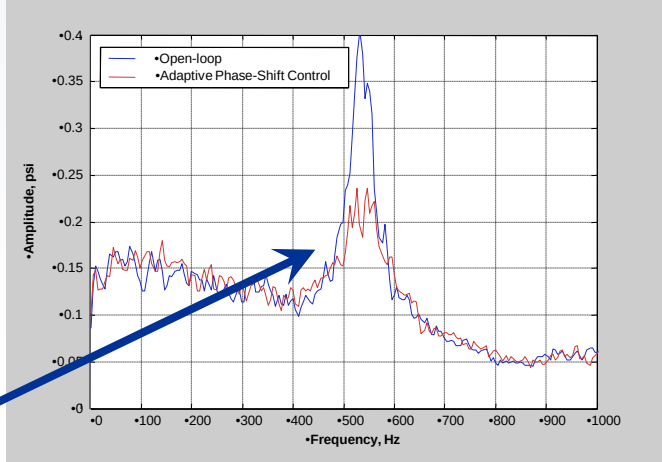
Large amplitude, low-frequency instability suppressed by 90%





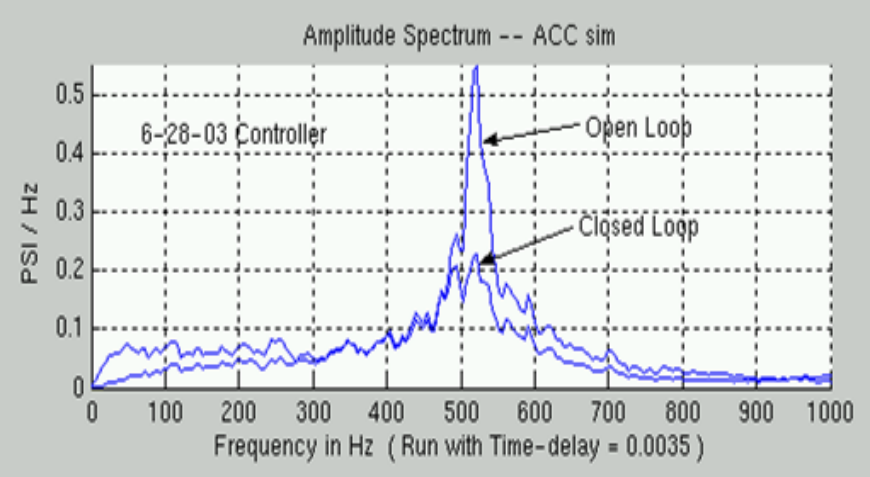
Liquid-fueled combustor rig emulates engine observed instability behavior at engine pressures, temperatures, flows

High-frequency, low-amplitude instability is identified, <u>while still small</u>, and suppressed almost to the noise floor.

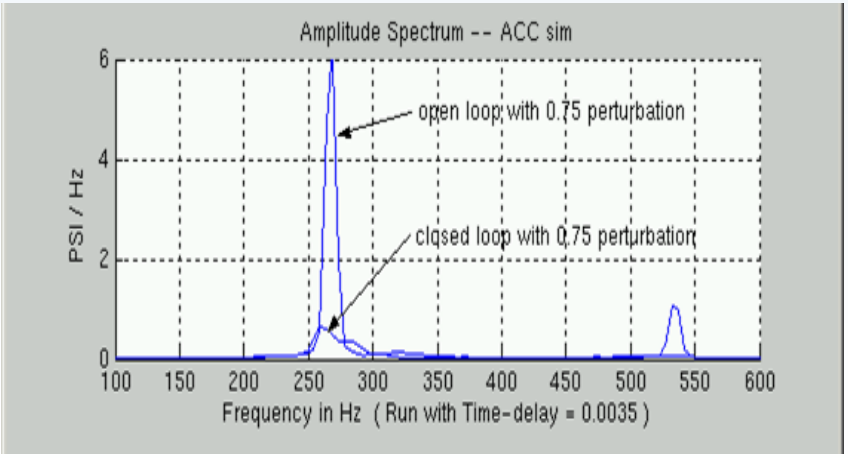


Predicted Instability Control Results: Sectored 1-D Model

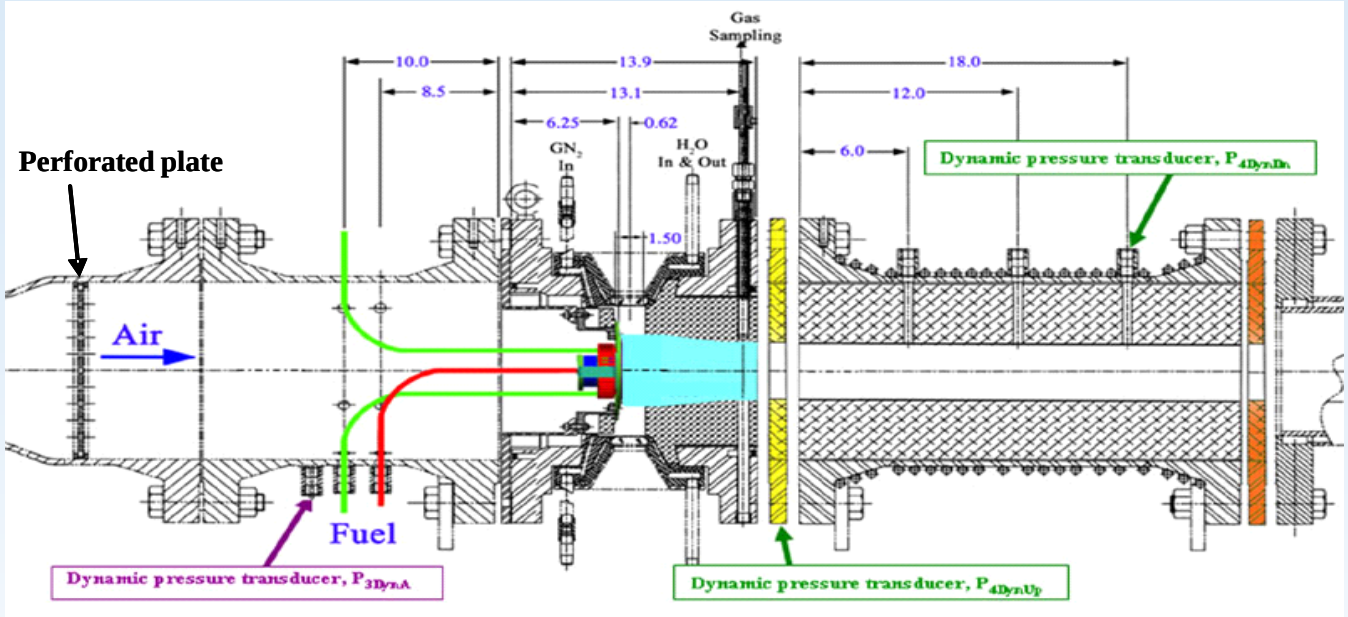
Baseline, high-frequency configuration



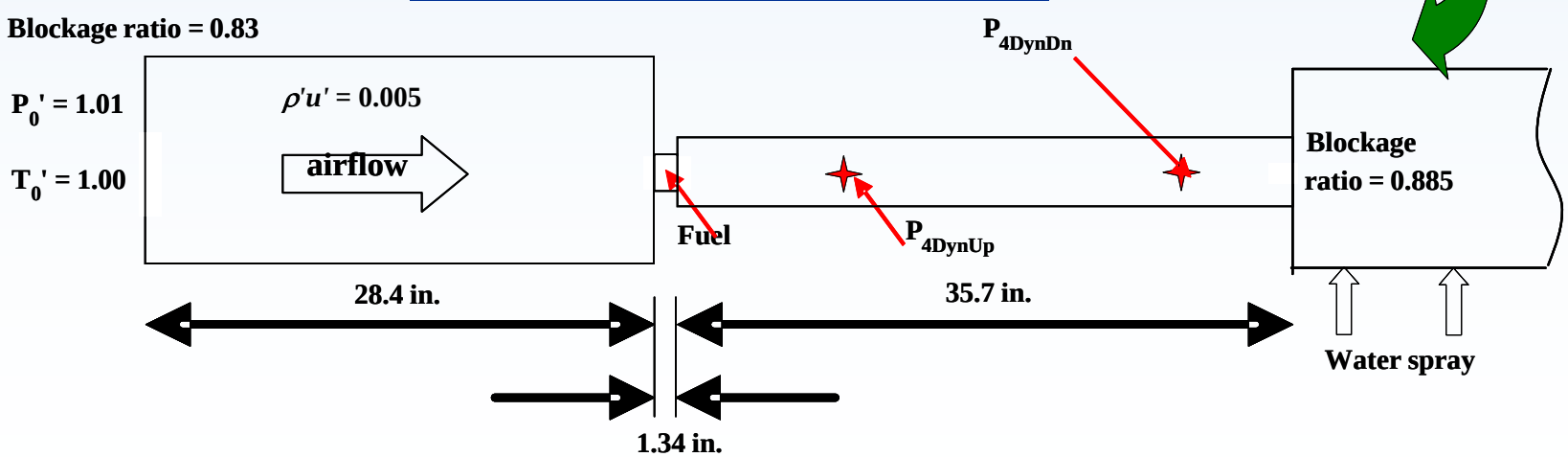
Extended, low-frequency configuration



Low Emissions Combustor Instability Model Development

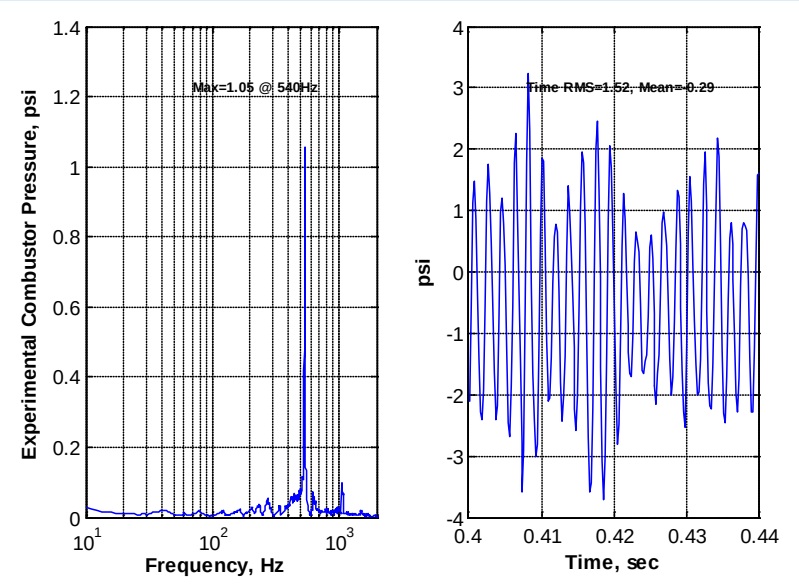


CE5B-STAND 1 SIMULATION LAYOUT



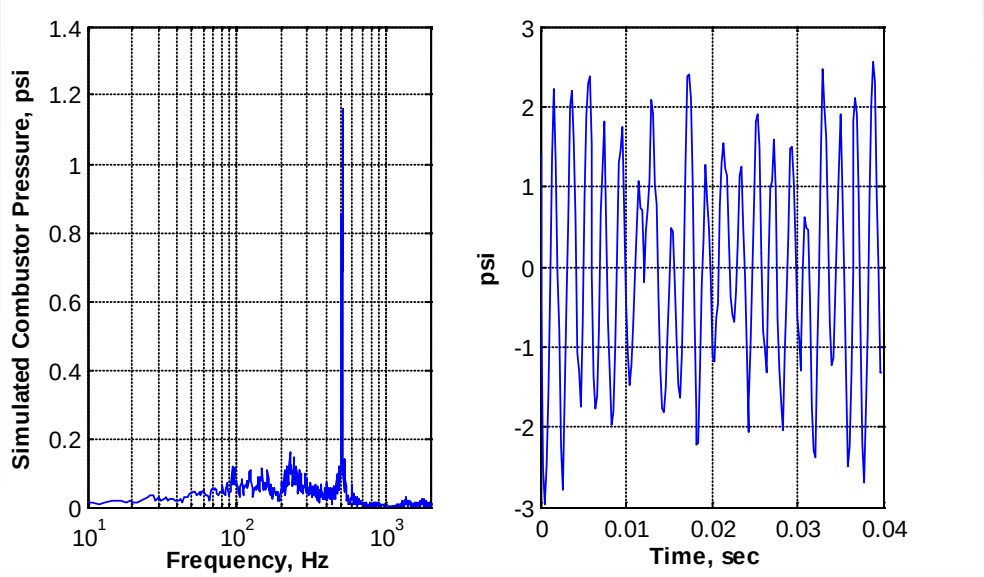
Combustion Instability Simulation Results

- Self-sustained instability simulated
- Instability frequency and amplitude closely match experimental values

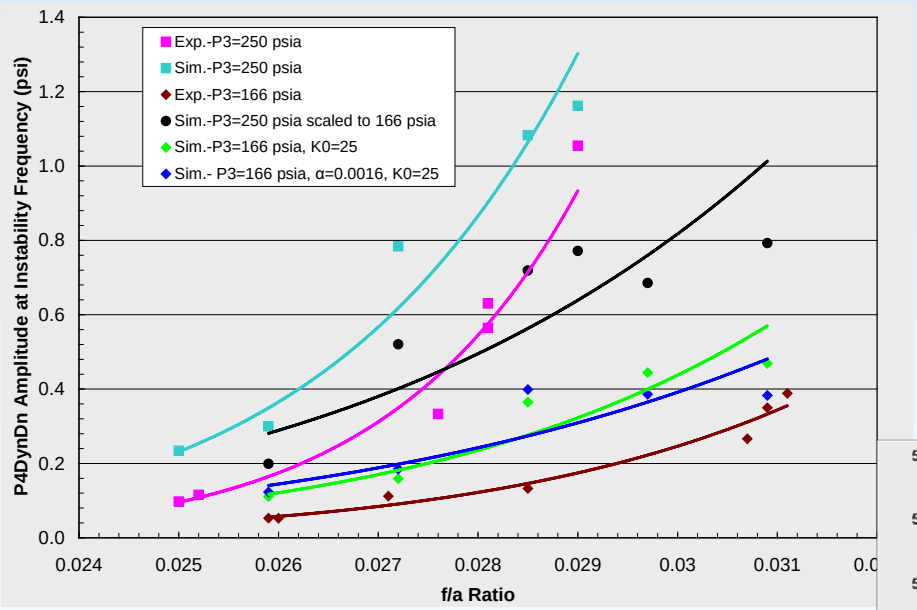


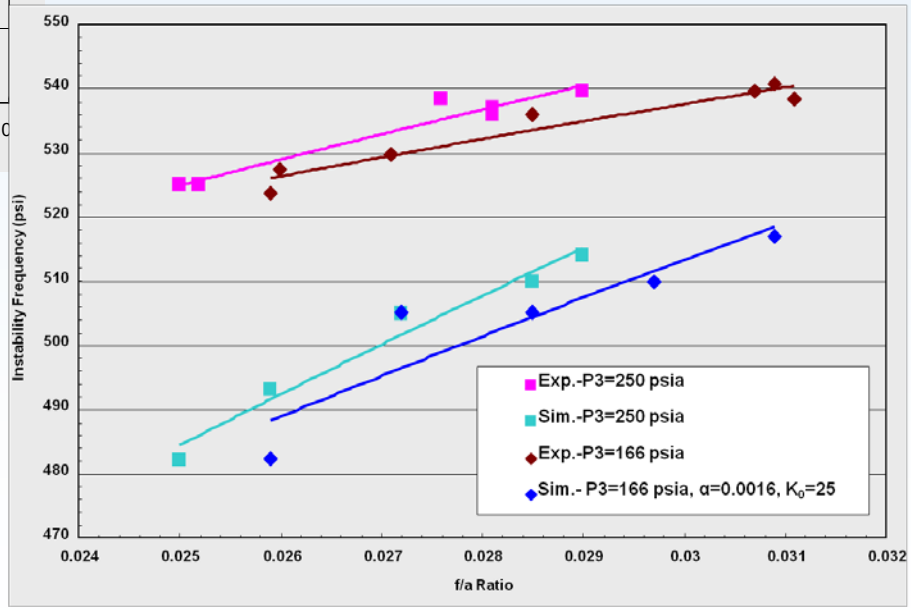
0.04 seconds of <u>rig data</u> with f/a=0.029

0.04 seconds of <u>simulation data</u> with f/a=0.029



Combustion Instability Simulation Results for Multiple Operating Conditions – Amplitude and Frequency Trends Replicated

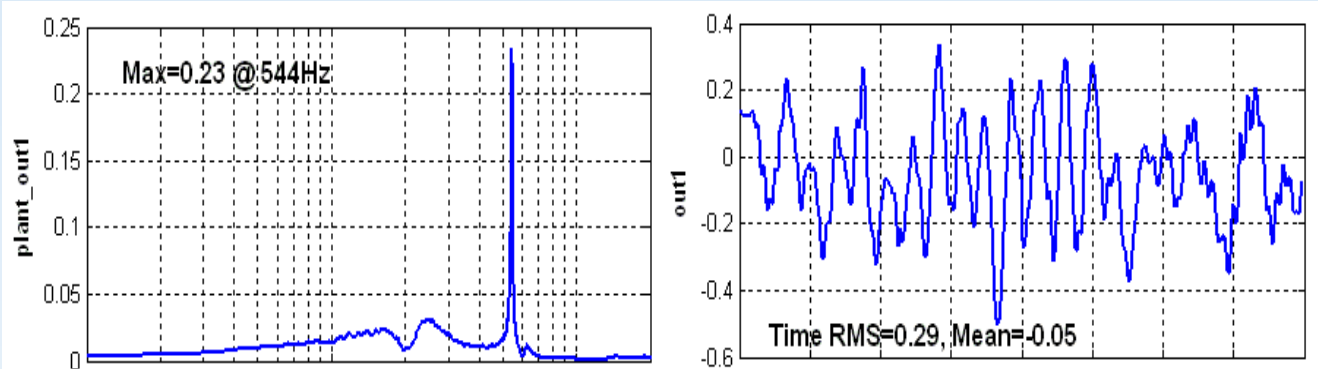




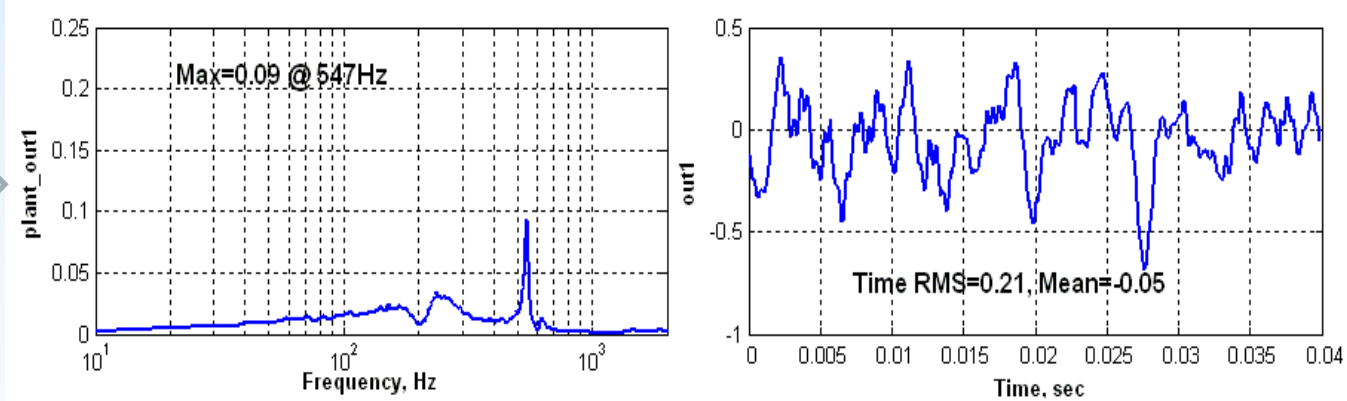
DeLaat, J.C.; Paxson, D.E.: "Characterization and Simulation of the Thermoacoustic Instability Behavior of an Advanced, Low Emissions Combustor Prototype." AIAA-2008-4878, NASA/TM—2008-215291

Results (cont'd)

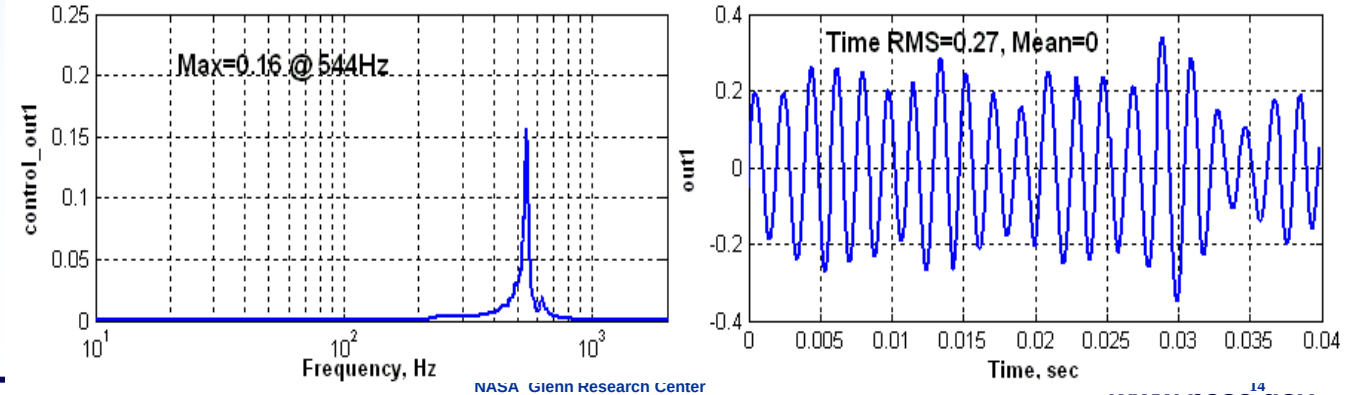
No Controller



With Controller



Controller Output



Past Approach

- Controller developed and evaluated in MATLAB/Simulink
  - Simplified instability model (non-linear oscillator)

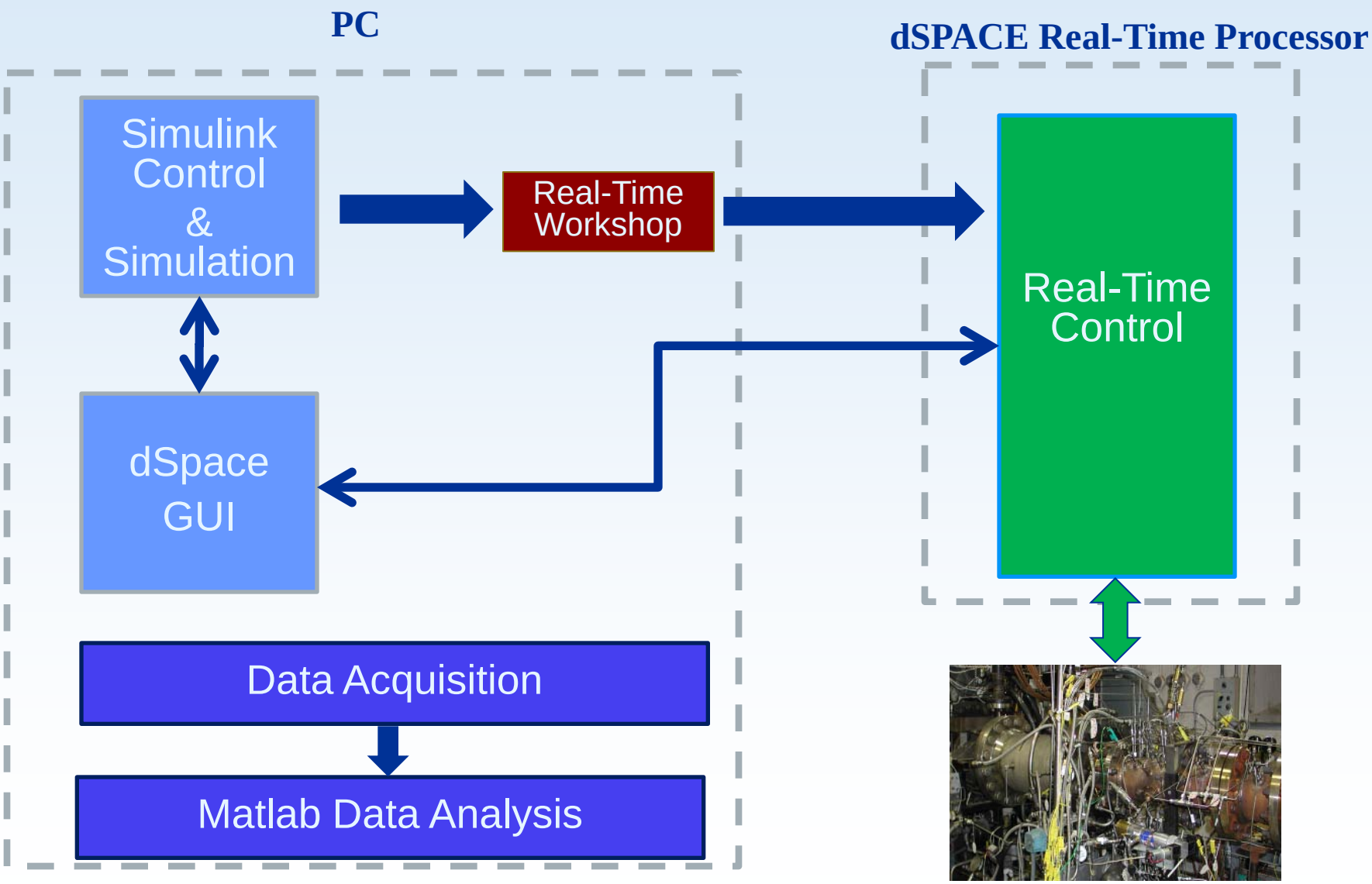
- Very limited physics-based simulation evaluation
  - Simulation developed and evaluated in FORTRAN
  - Code generated from controller and linked to simulation
  - Batch runs to test controller functionality
    - Limited opportunities for interaction with simulation while running
    - Limited opportunities for controller tuning while simulation is running
  - Modify controller parameters and re-run simulation

Current Approach

- Controller developed and evaluated in MATLAB/Simulink
  - Simplified instability model (non-linear oscillator)

- More extensive use of physics-based simulation evaluation
  - Simulation developed and evaluated in FORTRAN
  - Simulation inserted into Matlab/Simulink as FORTRAN S-function
  - Interactive runs to test controller functionality
    - Increased opportunities for interaction with simulation while running
    - Increased opportunities for controller tuning while simulation is running
  - Can directly port controller to experimental combustor
  - User interface is identical to that used with experimental combustor

Details of Current Approach



Software Demonstration

Discussion

- Similar approaches
- Value of this approach to NASA's partners
  - Simulation
  - Controller
  - Integrated software
  - Integrated software/hardware
- Other discussion