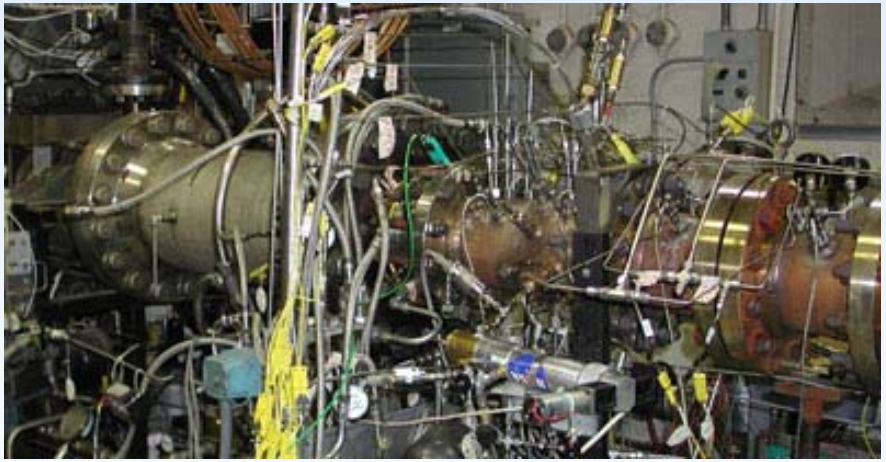
NASA Overview: Combustion Dynamics and Control for Ultra Low Emissions in Aircraft Gas-Turbine Engines



John DeLaat
Controls and Dynamics Branch
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email: jdelaat@nasa.gov

OUTLINE

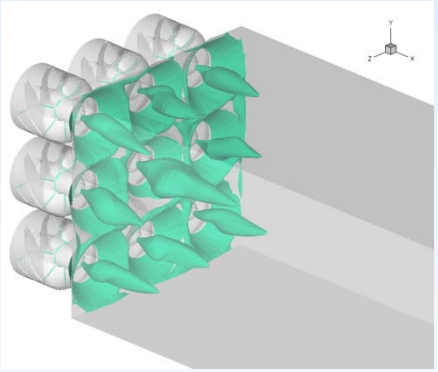
- NASA's Overall Combustors Effort
- Motivation: Low Emissions Combustors
- Thermo-Acoustic Instability => Active Control
- Technical Challenges and Approach
- Current Efforts
- Future Directions and Opportunities for Collaboration

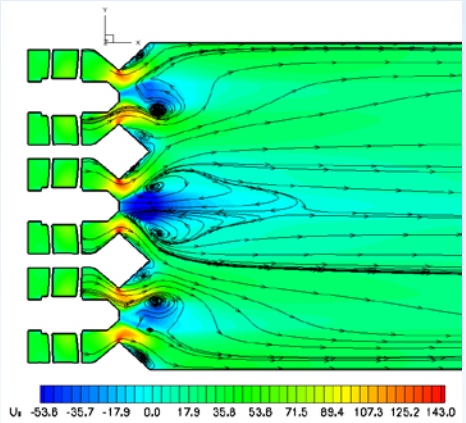
Fundamental Aeronautics, Supersonics
High Altitude Emissions

Objectives

- Develop the necessary technologies to enable low emissions (gaseous and particulate) combustion systems to be developed for supersonic cruise applications.
- Develop and validate physics-based models to enable quantitative emissions and performance predictions at supersonic cruise conditions using Combustion CFD simulations.
- Develop and validate high temperature sensors for use in intelligent engines.

Axial Velocity Predictions of Lean Direct Injection Low NOx Emissions Concept





Zero Axial Velocity Contours *Side View through center*

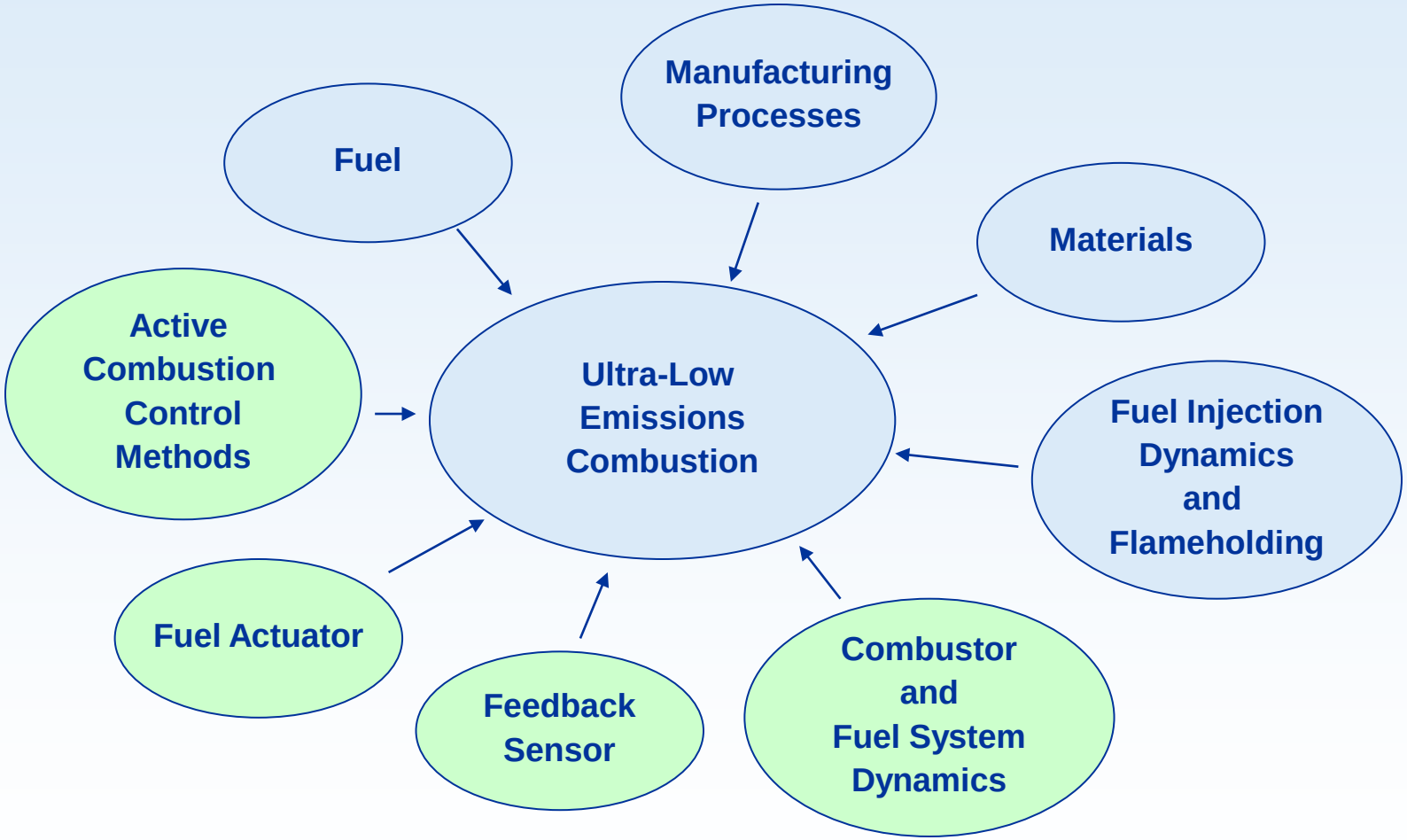
Also - Fundamental Aeronautics, Subsonics, Combustion

•Combustion Chemistry and Turbulence Modeling
•Particulates Sampling and Modeling
•Alternate Fuels

Integrated Systems Research

•Environmentally Responsive Aircraft

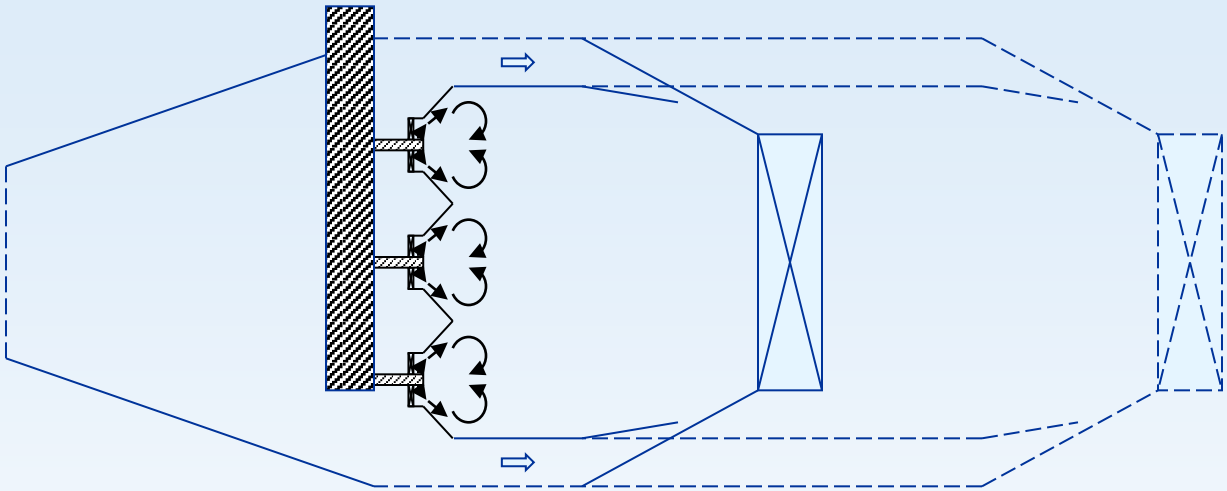
Synergistic Technologies to Enable Ultra-Low Emissions Combustion

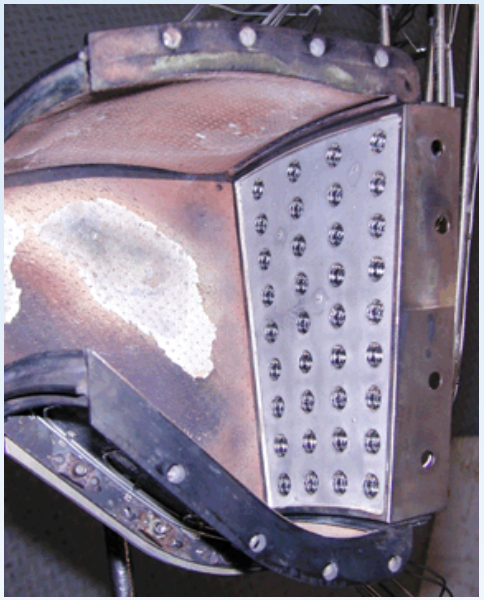


Team Members

- Controls and Dynamics Branch
  - Dan Paxson: Dynamic Models
  - George Kopasakis: Control Methods
  - Joe Saus: Actuators
- Combustion Branch
  - Clarence Chang: Combustion Science
- Engineering Directorate
  - Dan Vrnak: Control Software
- Supersonics Project
  - Dan Bulzan – Supersonics (and Subsonics) Combustion API
- Other NASA Participants
  - Sensors, Materials, Combustion and Flow Diagnostics, Experimental Staff,…
- NRA Participants
  - Georgia Tech, Penn State, Virginia Tech
  - Other NRA's associated with Combustion Science

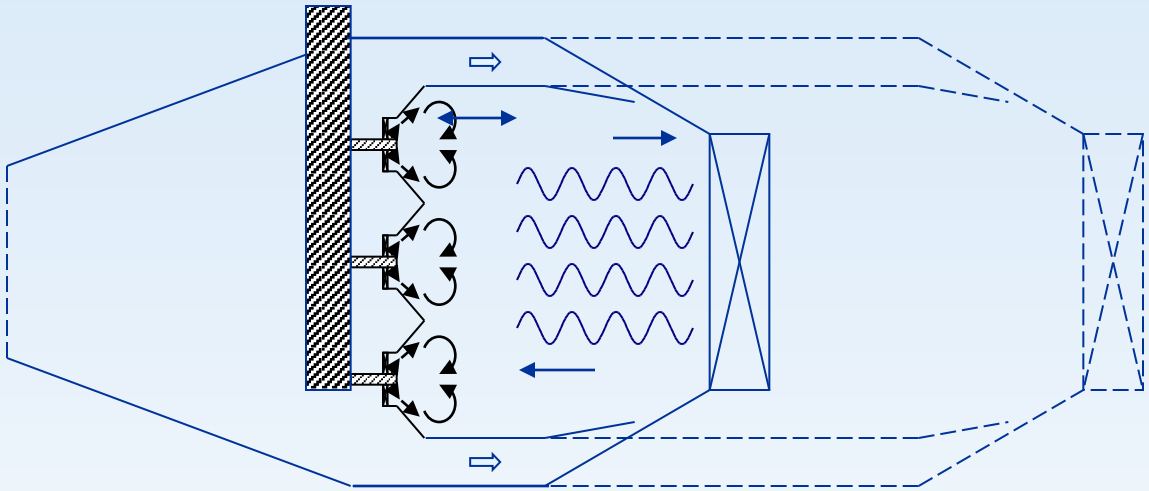
90% NOx Reduction Combustion: Multi-Point Lean Direct Injection





1. Energetic quick-mixing before auto ignition at high power condition
2. Lean and uniform front end makes less CO and NOx initially
3. Less CO initially, shorter combustor needed
4. Shorter combustor, shorter residence time, less additional NOx
5. Multiple injection points allow temporal and spatial fuel/air control
   - allows active fuel-shifting control to improve operability

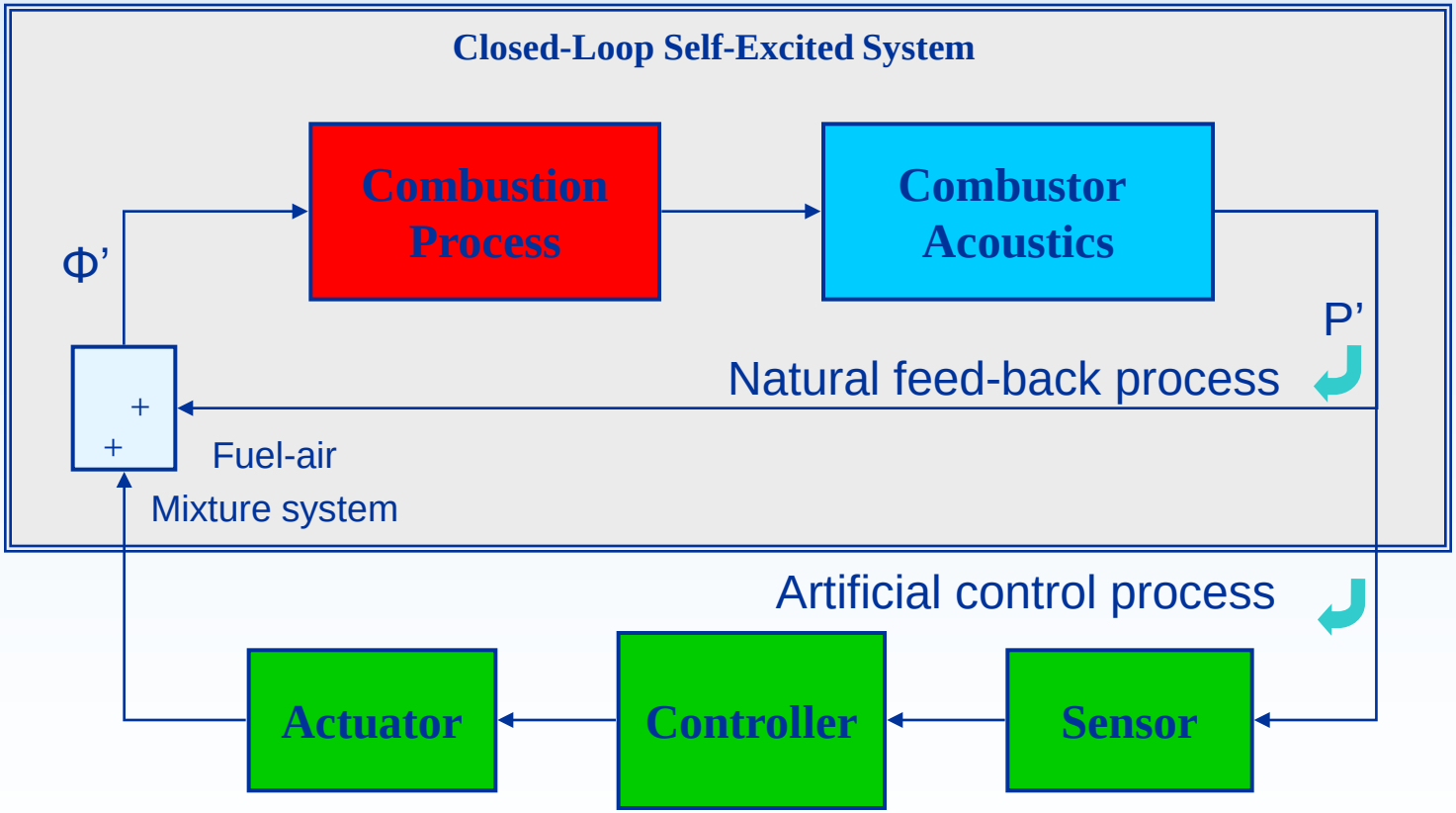
Ultra-Lean-Burning Combustors Are More Susceptible to Thermo-Acoustic Instabilities



1. Higher-performance fuel injectors: more turbulence
2. Reduced film cooling: reduced damping
3. More uniform temperature and composition
4. No dilution holes: reduced flame-holding

Combustion Instability Control Strategy

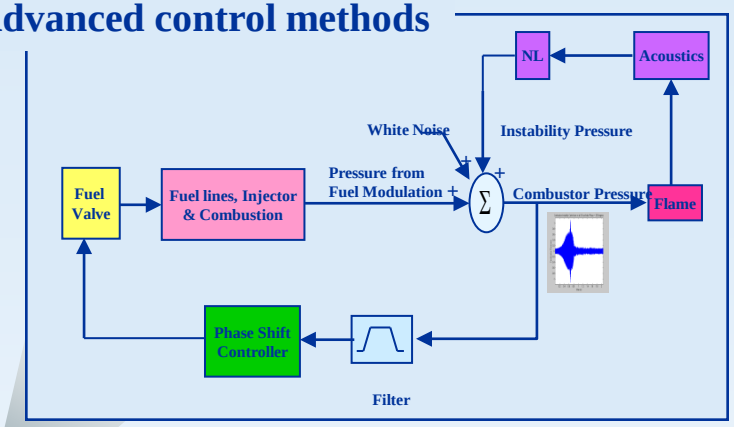
Objective: Suppress combustion thermo-acoustic instabilities when they occur



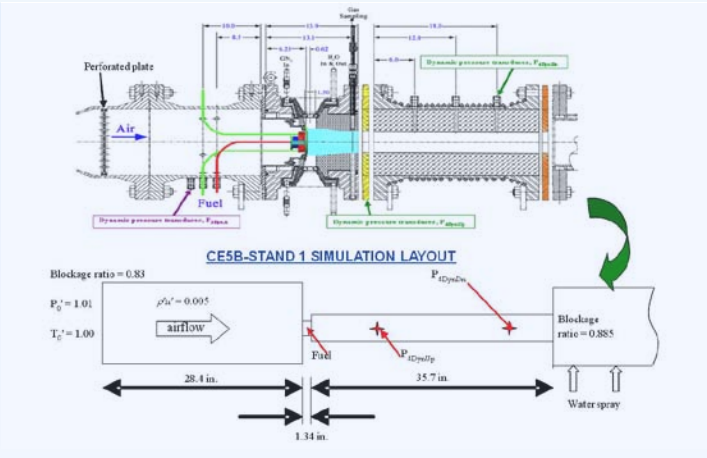
Active Combustion Instability Control Via Fuel Modulation

High-frequency fuel delivery system and models

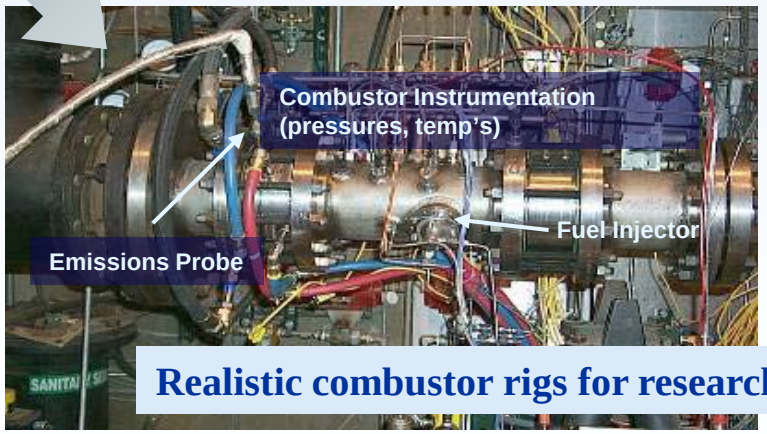
Advanced control methods



Physics-based instability models



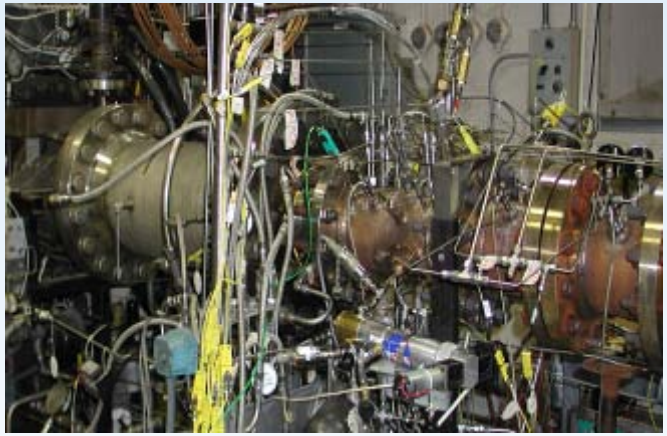
Related technologies: Harsh environment sensors, advanced materials, etc.



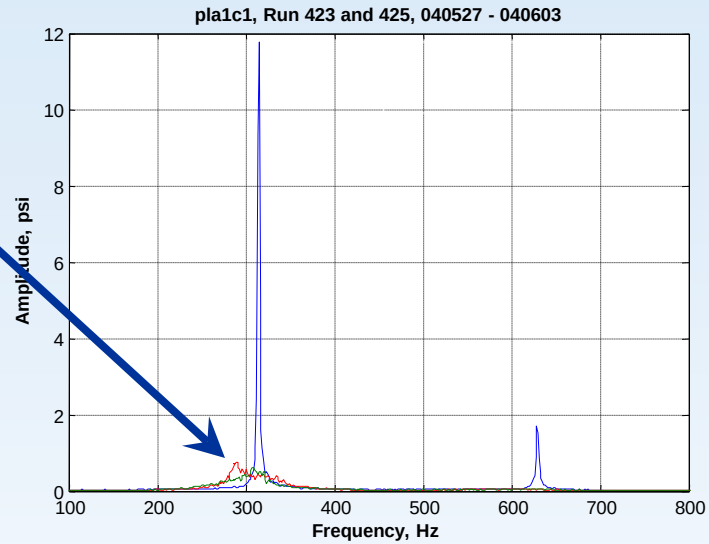
Realistic combustor rigs for research

Active Combustion Instability Control Demonstrated Experimentally

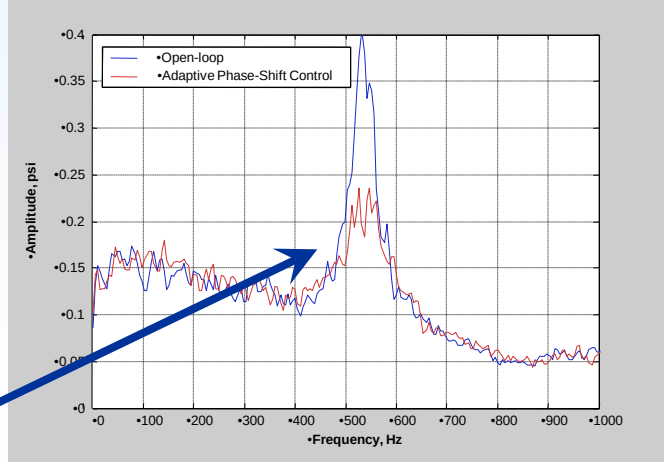
Large amplitude, low-frequency instability suppressed by 90%



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.



Current Directions and Future Plans

- Current platform - lean combustor concept (not LDI)
  - Actuator research for small “pilot” flows - Ongoing
  - Dynamic model validation - Ongoing
  - Instability control demonstration – Winter 2010
- Future platform - LDI Multi-point injection
  - Fundamentals rig in CE13
  - High pressure testing in CE5, ASCR
  - Control methods that exploit multipoint injection
  - Multidimensional models
- Incorporate technologies from NRA’s
- Harmonic, sub-harmonic models and control

Opportunities for Collaboration

- Requirements definition and feedback (engine, HW mfrs)
- Realistic testbeds for technology transfer
- Control methods integration and field testing
- Modeling methods field testing
- Multidimensional models development
- Actuator systems, associated models development, field testing

- **NRA's, SBIR – Future topics TBD - Watch announcements**
- **SAA's – Some in place, others welcome**

Concluding Remarks - Long Term Goal for Active Combustion Control

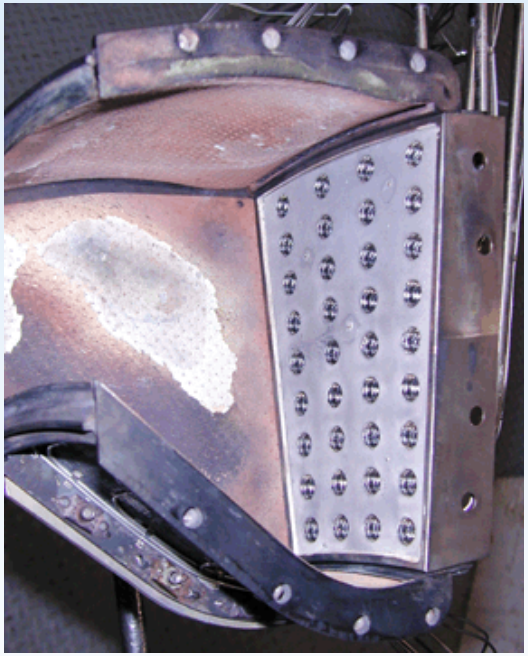
- **Improve fundamental understanding of the combustor processes**

in order to…

- **More effectively integrate multi-point combustor design, controls, sensor, and actuator technologies**

to provide…

  - **An intelligent fuel/air management system with temporal and spatial fuel modulation for**
    - **Instability avoidance/suppression**
      - **Thermoacoustics, blowout**
    - ***Pattern factor control***
    - ***Emissions minimization***



to enable…

➢ **Combustors with extremely low emissions throughout the engine operating envelope**

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"NASA Combustion Test Capabilities"
– Clarence Chang, NASA GRC

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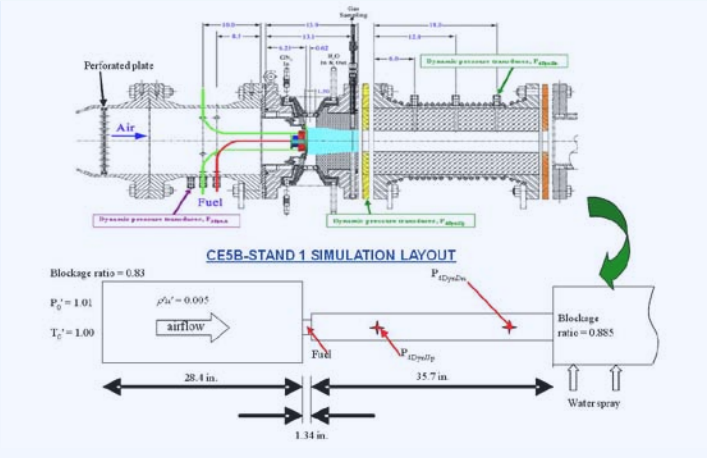

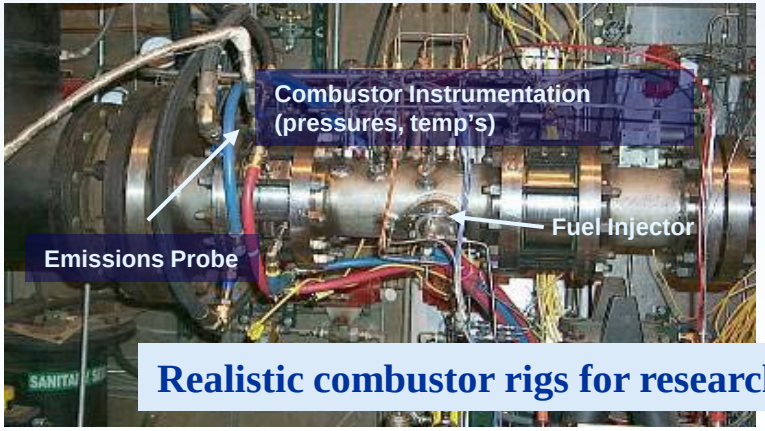

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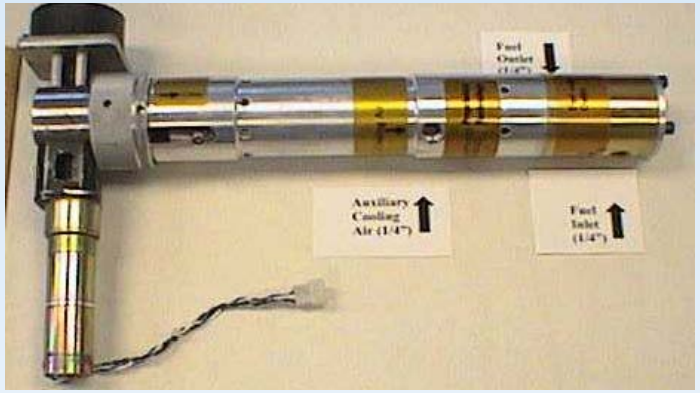

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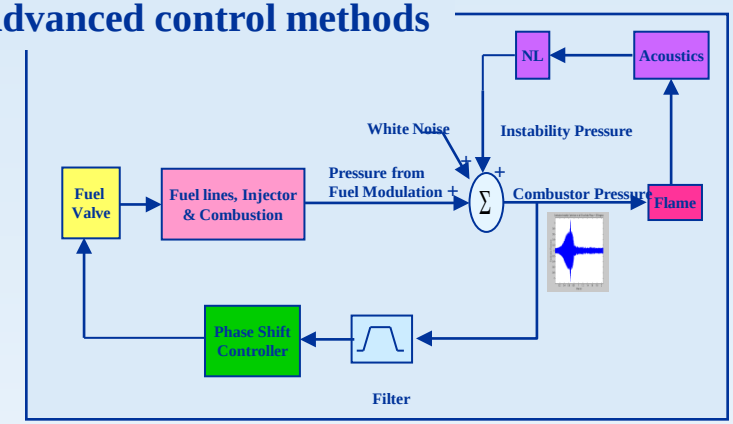

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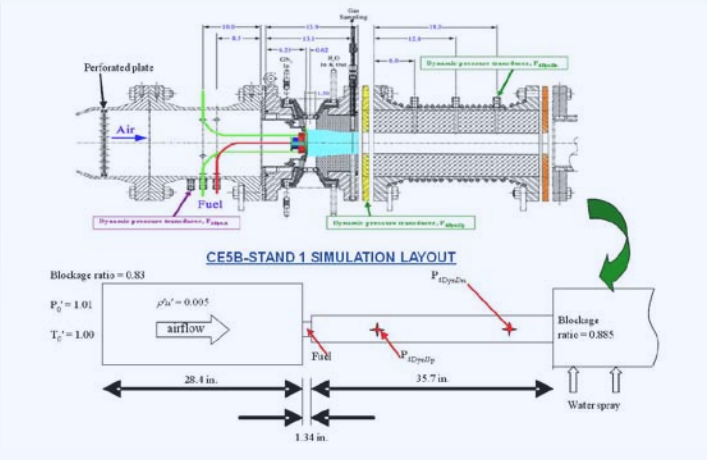

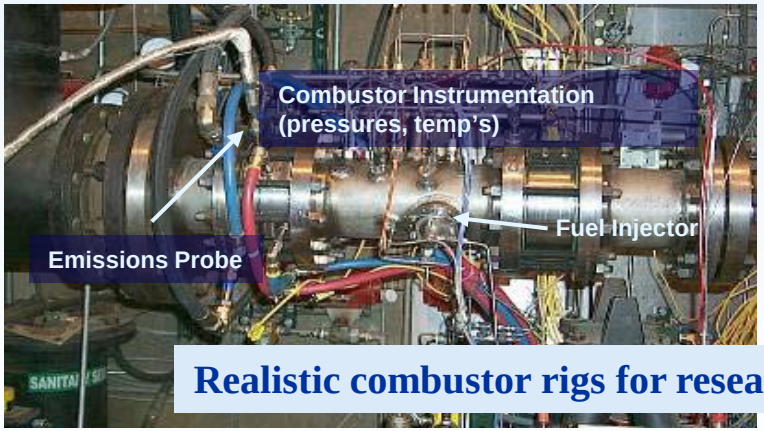

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– Tongxun Yi, Penn State

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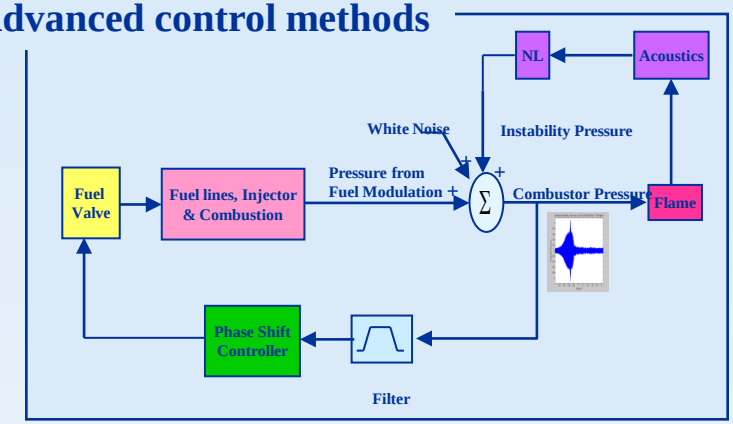

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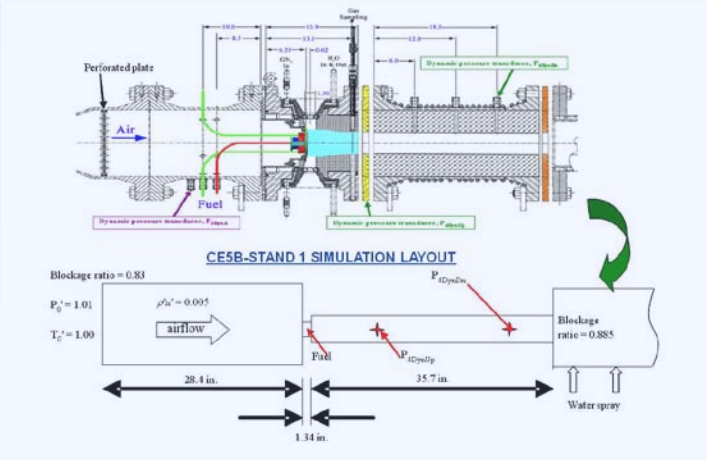

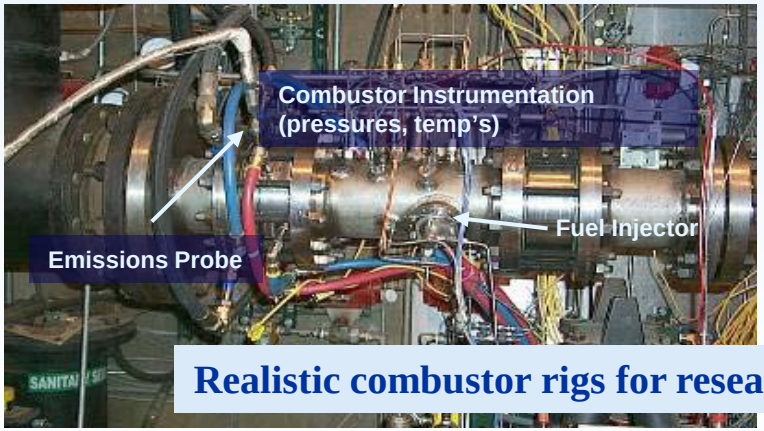

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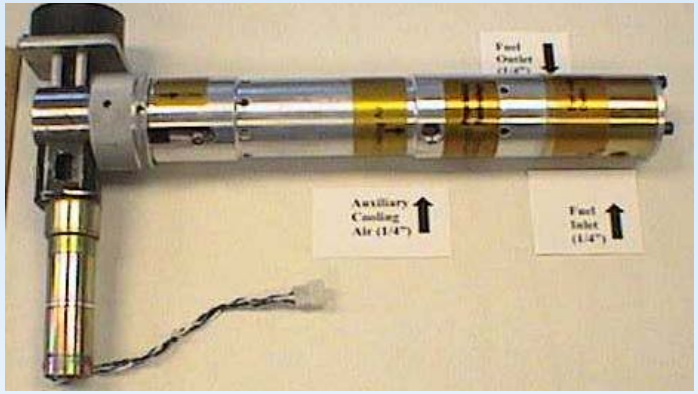

"Independent Dynamic Actuation of Spray Parameters with the SARA Gen II Nozzle"
– Uri Vandsburger, Virginia Tech

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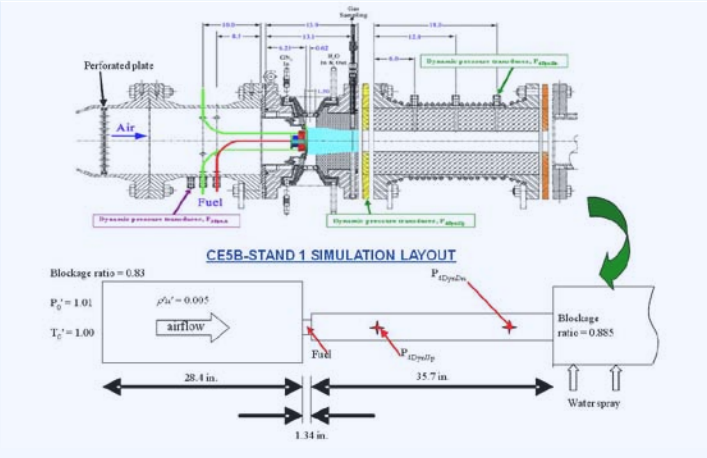

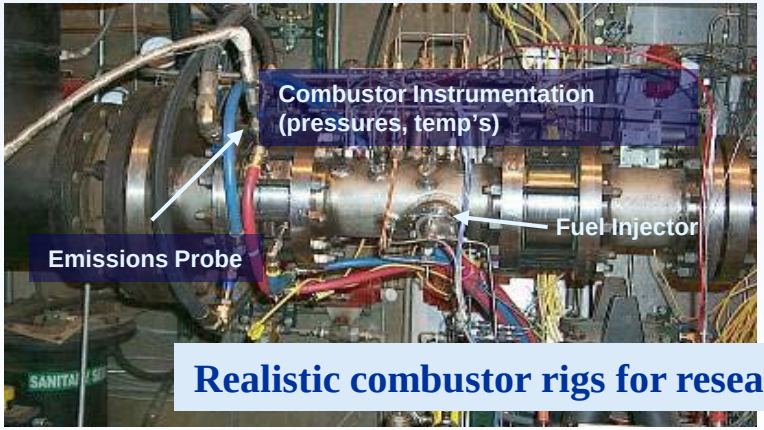

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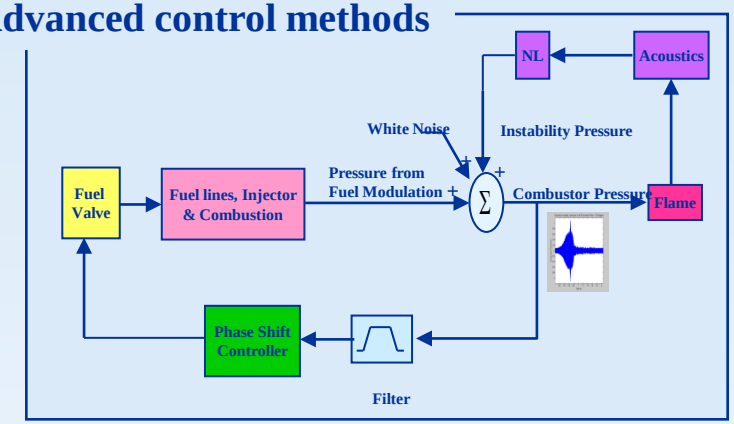
"Simulink Based Test-Bed for Combustion Instability Modeling and Control"
- John DeLaat, NASA GRC
(tomorrow)

Advanced control methods



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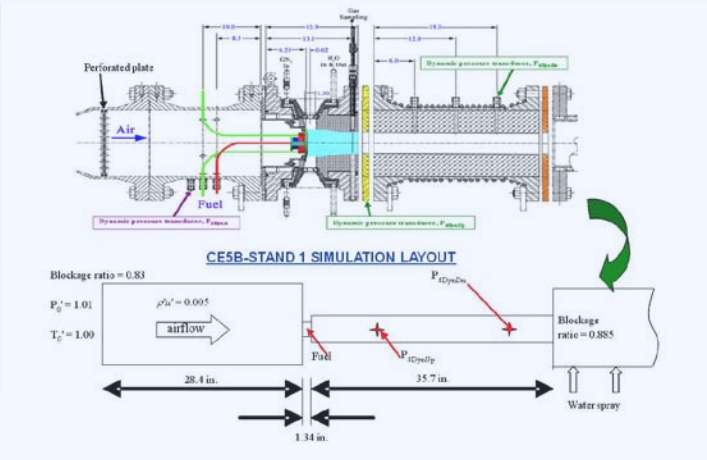

Combustion Instability Control

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