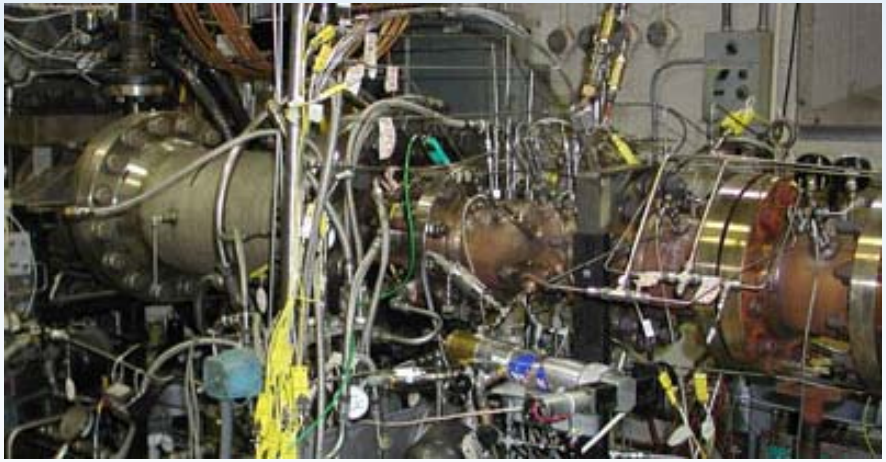
NASA Overview: Combustion Dynamics and Control for Ultra Low Emissions in Aircraft Gas-Turbine Engines



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OUTLINE

- Motivation: Low Emissions Combustors
- Associated Technical Challenges
  - Thermo-Acoustic Instability => Active Control
- Active Control Technical Challenges and Approach
- Current Efforts and Workshop Topics
- Future Directions and Opportunities for Collaboration

NASA Aeronautics Research

Technologies for simultaneous, dramatic improvements in noise, emissions, performance

NASA Subsonic Transport System Level Metrics

. . . . technology for dramatically improving noise, emissions, & performance

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption† (rel. to 2005 best in class)	-33%	-50%	-60%

Supersonics Technology Challenge Goals

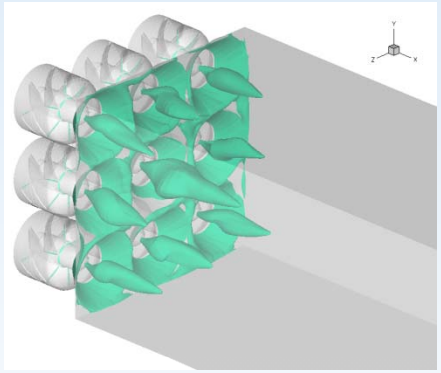
Balanced Goals for Practical Civil Supersonic Aircraft (Technology Available)	N+1 Supersonic Business Class Aircraft (2015)	N+2 Small Supersonic Airliner (2020)	N+3 Efficient Multi-Mach Aircraft (Beyond 2030)
Design Goals			
Cruise Speed	Mach 1.6-1.8	Mach 1.6 -1.8	Mach 1.3 - 2.0
Range (n.mi.)	4000	4000	4000 - 5500
Payload (passengers)	6-20	35-70	100 - 200
Environmental Goals			
Sonic Boom	65-70 PLdB	65-70 PldB	65-70 PLdB Low Boom flight 75-80 PldB Overwater flight
Airport Noise (cum below stage 4)	Meet with Margin	10 EPNdB	10-20 EPNdB
Cruise Emissions (Cruise NOx g/kg of fuel)	Equivalent to current Subsonic	< 10	< 5 & particulate and water vapor mitigation
Efficiency Goals			
Fuel Efficiency (pass-miles per lb of fuel)	1.0	3.0	3.5 – 4.5

Fundamental Aeronautics, Supersonics
High Altitude Emissions

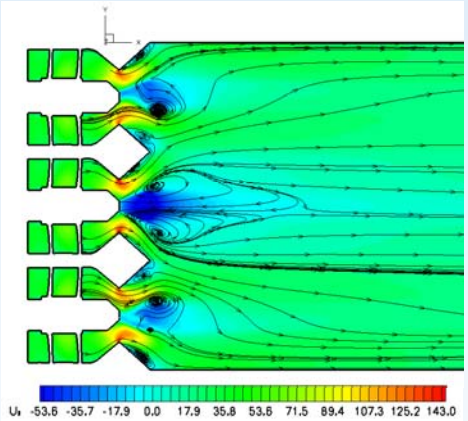
Objectives

- 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

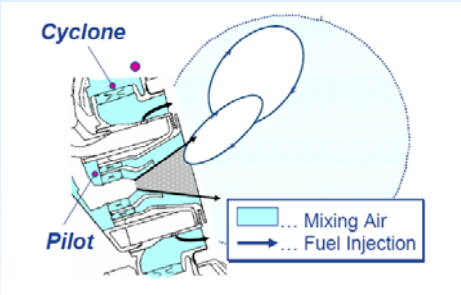
Also - Fundamental Aeronautics, Subsonics, Clean Energy and Emissions

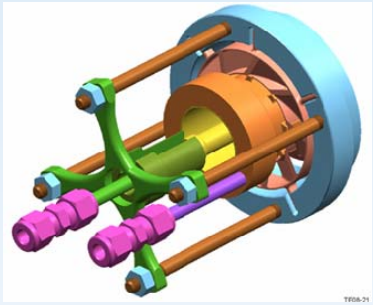
•Combustion Chemistry and Turbulence Modeling
•Particulates Sampling and Modeling
•Alternate Fuels

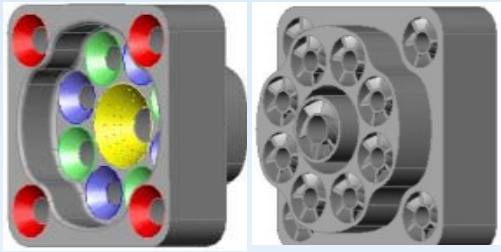
Integrated Systems Research

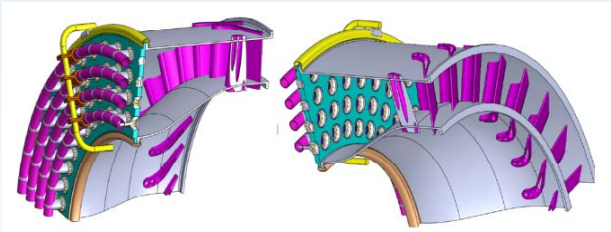
•Environmentally Responsible Aviation
- *•Airframe Technology*
- *•Propulsion Technology*
- *•Vehicle Systems Integration*

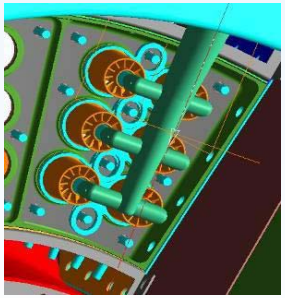
NASA Sponsored Low-Emissions Combustor Technology Development

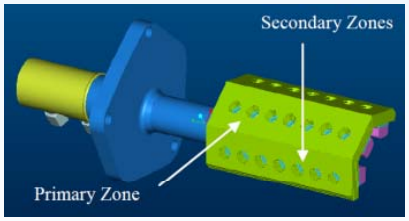


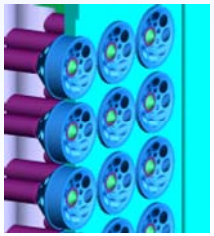








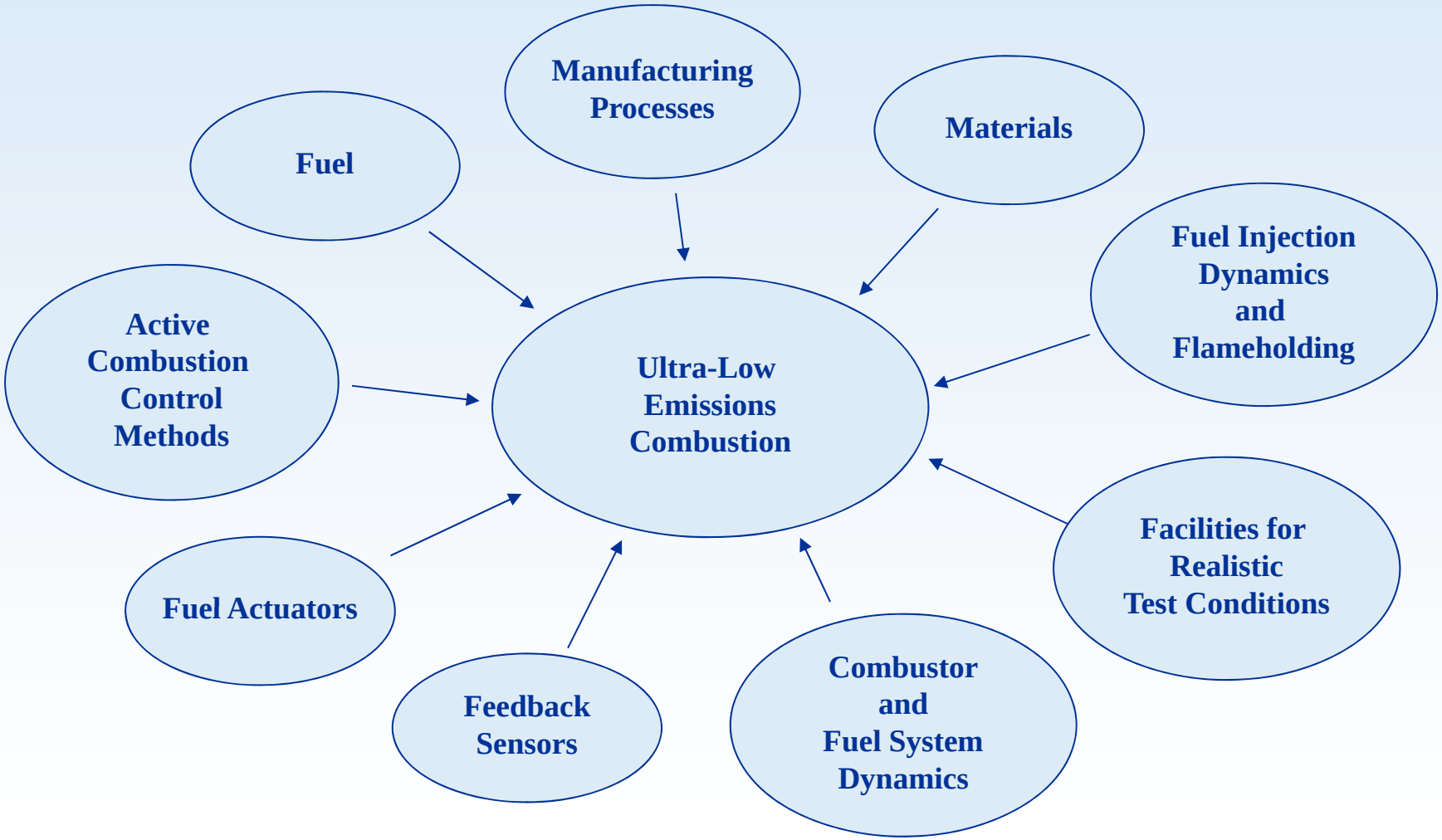




Lean-burning => lower flame temperatures => lower NOx

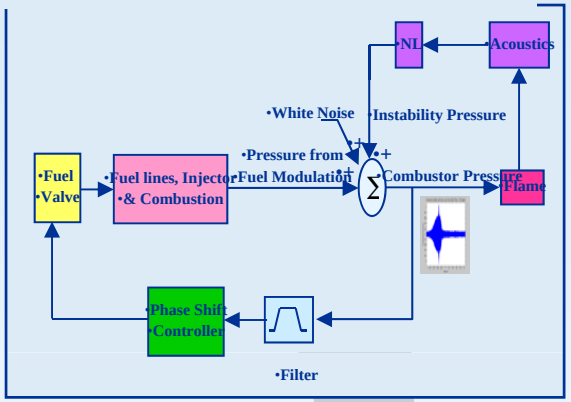
However lean, low-emissions combustors are more susceptible to instabilities

Synergistic Technologies to Enable Ultra-Low Emissions Combustion



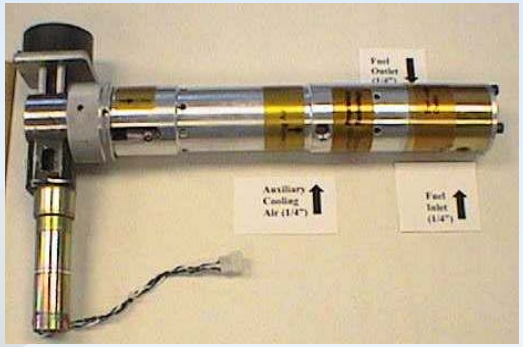
Active Combustion Instability Control Via Fuel Modulation

Advanced control methods

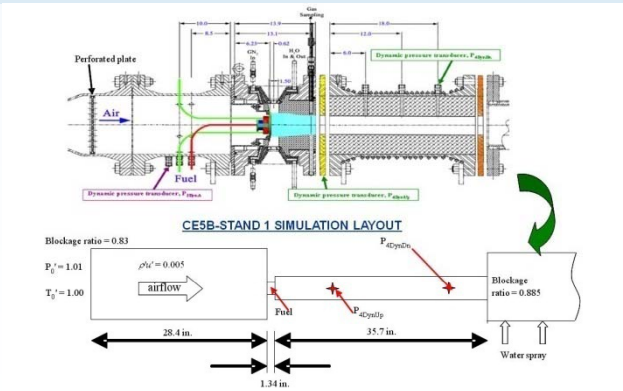


High-temperature sensors and electronics

High-frequency fuel delivery system and models



Physics-based instability models



Realistic combustors, rigs for research

Synergistic Technologies to Enable Ultra-Low Emissions Combustion

- Low Emissions Combustors Development and Test
- Modeling of combustion dynamics
  - Simplified physics-based
    - Sectored 1-D
    - Simulation benchmarking
  - Detailed, physics-based
    - NRA's: Purdue, GaTech
- Combustion Control Methods
  - Experimental results with NASA Adaptive Sliding Phasor Averaged Control
  - Controls design benchmarking
  - NRA – GaTech: Instability and LBO precursor detection and control
- Fuel Actuators
  - Fuel actuator development and testing
  - NRA: Active Signal magnetostrictive valve
  - SBIR Phase II: JASC electromagnetic rotary valve
  - NRA/GSRP: VaTech Variable spray properties fuel nozzle
- Sensors
  - 600ºC pressure sensor
  - 500ºC signal conditioning electronics

Posters
Presentations

Active Combustion Control

Agenda

- "NASA Overview – Combustion Dynamics and Control for Ultra Low Emissions in Aircraft Gas-Turbine Engines"
  John DeLaat, NASA GRC Controls and Dynamics Branch
- "Low-Emissions Combustors Development and Testing"
  Clarence Chang, NASA GRC Combustion Branch
- "Recent Combustion Control Test Results"
  John DeLaat, NASA GRC Controls and Dynamics Branch
- "Fuel Actuator Development and Testing"
  Joe Saus, NASA GRC Controls and Dynamics Branch
- "Sensors for Intelligent Engines"
  Gary Hunter, NASA GRC Sensors and Electronics Branch
- Discussion – All

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
- Sensor systems field testing

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

Long Term Goals for Active Combustion Control

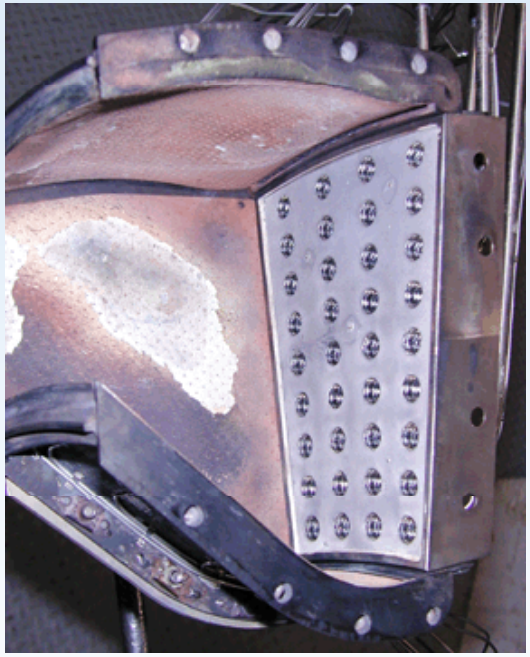
- **Improve fundamental understanding of the combustor processes**

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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