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High Altitude Emissions

Dan Bulzan, NASA Glenn Research Center

Fundamental Aeronautics 2007 Annual Meeting

New Orleans, LA

Oct 31, 2007

An overview of emissions related research being conducted as part of the Fundamental Aeronautics Supersonics Project is presented. The overview includes project objectives, milestones, and descriptions of major research areas. The overview also includes information on the emissions research being conducted under NASA Research Announcements.

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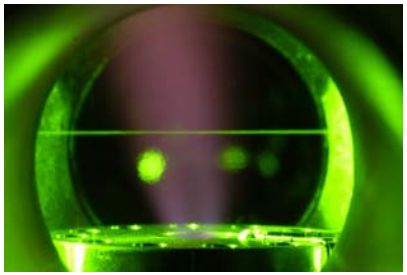
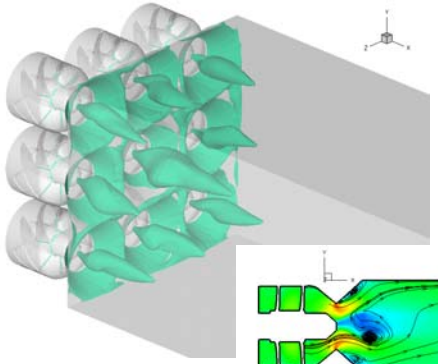
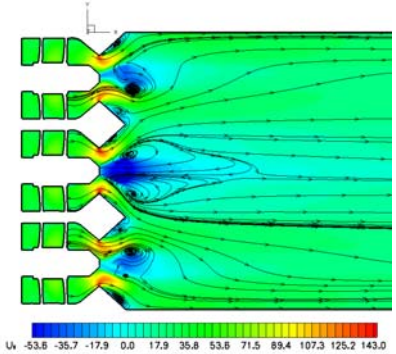
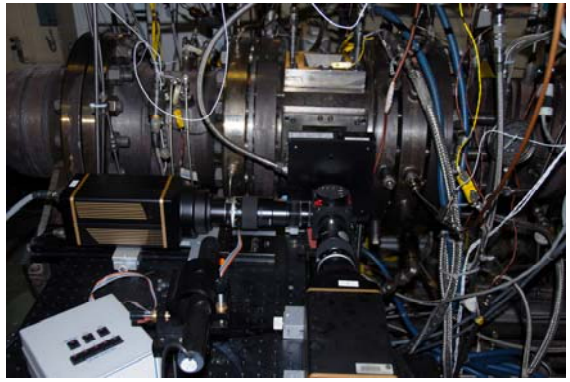








Supersonics

Technical Challenges

- Environmental impact of supersonic cruise emissions is greater due to higher flight altitudes which makes emissions reduction increasingly important.
- Accurate prediction tools to enable combustor designs that reduce emissions at supersonic cruise are needed as well as intelligent systems to minimize emissions.
- Combustor operating conditions at supersonic cruise are different than at subsonic cruise since inlet fuel and air temperatures are considerably increased.

Technical Approach

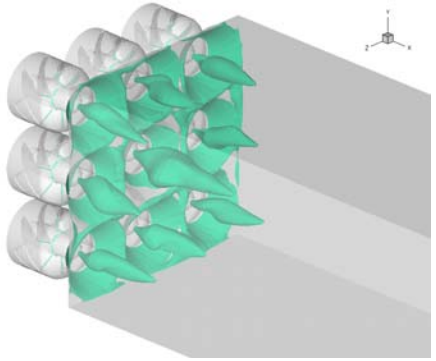
- NASA Research Announcement
- Emissions Prediction and Modeling
  - Physics-based model development for combustion CFD codes for improved supersonic cruise emissions predictions
- Diagnostics and Validation Experiments
  - Laser-based diagnostics development for quantitative major species and temperature measurements
  - CFD code validation experiments at supersonic cruise conditions
- Low Emission Concepts
  - Low NOx emission concept development
  - Active combustion control
- High Temperature Sensors
  - High temperature sensor development

Supersonics

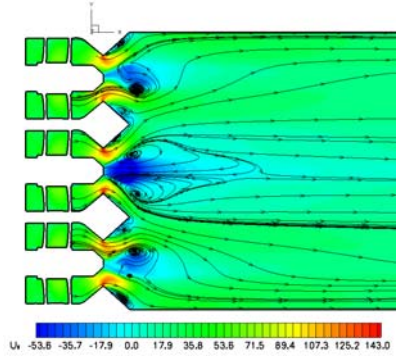
Emissions Prediction and Modeling

- Superheated atomization and vaporization modeling
- Conjugate heat transfer modeling including radiation
- Particle chemical and microphysics modeling
- Implementation of stator-rotor capabilities into NASA NCC v1.1.8

- NRA's
  - Validated Computational Tools for Low Emissions Injector Design using Superheated/Supercritical Fuels, United Technologies Research Center/University of Massachusetts, Amherst
  - Emissions Prediction and Modeling of Supersonic Vehicle Combustion Systems, Stanford University



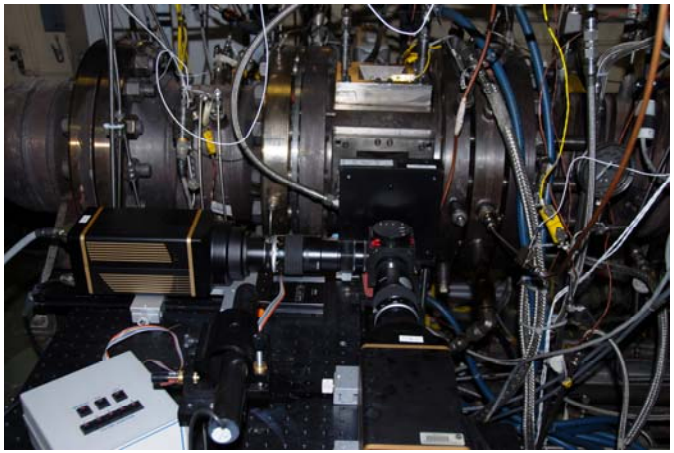
Axial Velocity Predictions in NASA 9-Point LDI Concept



Diagnostics and Validation Experiments

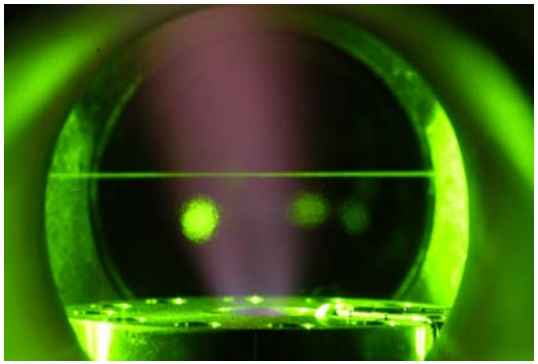
- Non-Intrusive laser diagnostics development for quantitative measurements of major species and temperature
- Fundamental experiments conducted in SE-5 facility at elevated pressures and temperatures
  - Perform a series of experiments of increasing flow complexity using gaseous methane, gaseous Heptane, liquid Heptane, and multi-component Jet-A surrogate liquid fuels.
- High-pressure flametube code validation experiments conducted in CE-5 for emissions and laser-based measurements at supersonic cruise conditions
  - NASA 9-point Lean Direct Injection concept
  - GE Complex multi-swirler mixer configurations
  - Others
- NRA's
  - Time Resolved Laser Raman Spectroscopy for Scalar Measurements of Swirl-Stabilized Liquid-Fueled Combustion at Elevated Pressures and Temperatures: Toward Combustion Code Validation, Ohio Aerospace Institute
  - Coherent Anti-Stokes Raman Scattering (CARS) for Quantitative Temperature and Concentration Measurements in a High Pressure Gas Turbine Test Rig, Purdue University/Rolls Royce Liberty Works

NASA Facilities for Diagnostics and Validation Experiments



CE-5 Laser Diagnostics for Stand 2 Flametube

NASA 9-Point LDI operating in CE-5



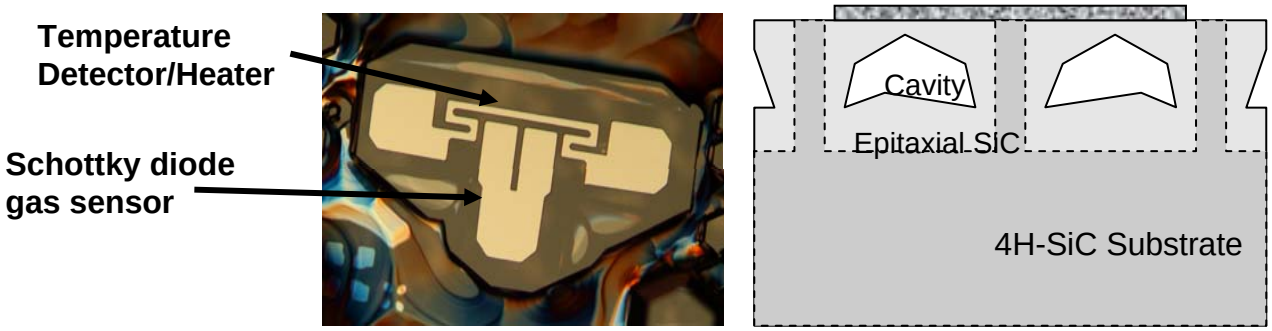
SE-5 Laboratory Scale Flametube

Low Emissions Concepts

- Fabricating smaller lower pressure(60 psi) flametube in CE-7 facility for fundamental studies of low-emission concepts and active combustion control
  - Perform fundamental studies using single element LDI to better understand and improve fuel/air mixing process
  - Perform fundamental studies with downstream flow choked for active combustion control experiments with well-defined boundary conditions
- Modeling of combustion dynamics in low and high-pressure flametubes
- Experimental studies of low-emissions concepts in high-pressure CE-5 flametube to measure gaseous and particulate emissions at supersonic cruise
  - NASA 9-point LDI, GE complex multi-swirler mixer configurations, others
- Experimental studies in high-pressure CE-5 flametube using open and closed-loop fuel modulation for active control of combustion instability
  - NASA 9-point LDI concept with spatial variation of fuel injection
  - GE complex multi-swirler mixer configuration
- NRA's
  - Detection and Control of Instabilities and Blowoff for Low Emissions Combustors, Georgia Institute of Technology
  - Active Combustion Control for Supersonic Low-Emission Combustors, Penn State/Virginia Tech

High Temperature Sensors

- High Temperature SiC (500 C) Junction Field Effect Transistor (JFET) Chip Fabrication and Evaluation
  - Demonstration at 500 C for 2000 hrs
- High Temperature NOx sensor(500 C) for emissions monitoring
  - Demonstration at 500 C for 1000 hrs
- High Temperature SiC Pressure Sensor(500 C) for active combustion control applications
  - Demonstration at 500 C for 1000 hrs
- High Temperature SiC amplifier(500 C) for high frequency and temperature pressure sensor
  - Demonstration at 500 C for 1000 hrs



Complete Atomically Flat SiC Gas Sensor and Cross-Section Schematic

Partnerships

- General Electric, SAA3-260-25, “Investigation of Complex Multi-Swirler Mixers.”

FY08 Key Activities

•NRA anticipated for Supersonic Cruise Low Emission Concepts for NASA testing in CE-5 high pressure flametube facility

•Code validation experiments in CE-5 of GE Complex Multi-Swirler configuration

•Gaseous and Particulate measurements of NASA 9-point LDI configuration with Jet-A and Fischer-Tropsch Synthetic Fuel at supersonic cruise conditions

•Raman calibration matrix completed, fundamental experiments completed using calibration burner and gaseous fuel, and UV Raman system designed for measurements in liquid fueled experiments

•Evaluation of open and closed loop fuel modulation on GE Complex Multi-Swirler configuration for active combustion control

•Low pressure CE-7 flametube facility completed and Gen 1 hardware experiments started

•Continued development of reacting RANS/VLES/LES CFD Codes for improved emissions predictions at supersonic cruise

•Demonstrate SiC NOx sensor and integrated circuit amplifier at 500 C for 1000 hrs

Agenda

- Overview of High Altitude Emissions Research - Dr. Dan Bulzan NASA GRC
- Status of Superheated Spray and Post Combustor Particulate Modeling for NCC - Dr. Nan-Suey Liu NASA GRC
- Prediction of Jet Fuel Properties for Superheated Injection - Drs. Jeremiah Lee/Catalin Fotache United Technologies Research Center
- Single-Shot Scalar-Triplet Measurements in High-Pressure Swirl-Stabilized Flames for Combustion Code Validation - Dr. Jun Kojima Ohio Aerospace Institute