A Triple-Flame, n+3 Generation Mixer

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Outline of Presentation

Motivation—Lower emissions and alternative fuels
Single annular combustors—Pre- and Low-emissions Combustors, LEC
Dual-annular combustors for the CFM56 and GE90 engines
Twin-Annular Premixing Swirl (TAPS) technology for the CFM56 and GE90 size engines
Emissions comparison
Triple-Flame Mixer
  Description and Analytical Design Status
  Preliminary data from NRCC

Future Plan
Motivation for the proposed work comes from:
2009 Copenhagen UN Framework Convention on Climate Change, UNFCC)
Aviation industry agreed:
   - Improve fuel efficiency of the world aircraft fleet by 1.5% per year
   - Cap aviation CO2 footprint at 2020 level
   - 50% of the 2005 CO2 level by 2050.

The challenges described well by:
Ted Thrasher, ICAO’s Activities on International Aviation and Climate Change
John Green, Climate change, fuel burn targets and the options and limitations facing the designer
Scott Hartman, Alternative Fuels in Air Transport — From Lab to World Scale Plant
Fayette Collier, Overview of the Environmentally Responsible Aviation Project
Dan Bulzan, NASA Emissions Reduction and Alternative Fuel Research

Let me therefore focus on developing aviation combustion technology for:
   - Further reducing NOx emissions for future energy efficient engines
   - Combustibility and increased operability with conventional & alternative fuels.
NO/CO/Operability Tradeoffs in a typical rich-dome combustor

Low-Power

High-Power

Triple-Flame Mixer for Low-NOx & Fuel Flexibility
CFM56 Combustion Technologies and Products

Single Annular Combustors
Pre-LEC & Low-Emissions Comb

Dual Annular Combustors
DAC I, DAC II and DAC II+

GE 90 Combustion Technologies and Products

DAC I, DAC II and DAC II+

Triple-Flame Mixer for Low-NOx & Fuel Flexibility
Twin-Annular Premixing Swirl (TAPS) stabilized Flames technology developed for potential applications in the CFM56 and GE90 engine models. Typical values quoted.
NASA GRC and GE Aviation supported the development of the CFM and GE90 TAPS technologies
Further reduction in TAPS CO emissions would be desirable for low pressure ratio engines.
GE90 TAPS technology demonstrated significant emissions reduction compared to current technology GE90 combustion system
Typical TAPS diagnostics data from Prof. Driscoll and his students
Show twin flames as hypothesized for TAPS mixers
Triple-Flame Mixer
“Optimized strain/vorticity /FAR distribution

TFM Goals
Reduce NOxEI by ~50%*
Simplify fuel injectors*
Reduce hot-streaking
Improve operability
Increase fuel flexibility

*Baseline combustors are CFM56 TAPS and GE90 TAPS
Triple-Flame Mixer with optimized strain, vorticity and $\phi$ distribution

RANS Non-reacting flow; DES/LES simulation continues
Takeoff: 45.7 atm, 918K, 0.0279 fuel/air ratio

$0 < \omega < 15000 \text{ s}^{-1}$

$0 < \phi < 1.6$

$-80 < u < 120 \text{ m/s}$

Progress Variable

$700 < T < 2600 \text{K}$
Cruise: 21.4 atm, 737K, 0.0287 fuel/air ratio

- $0 < \omega < 15000 \text{ s}^{-1}$

- $0 < \phi < 1.6$

- $-80 < u < 120 \text{ m/s}$

- $700 < T < 2600\text{K}$

Progress Variable
Preliminary Data and current status on 2-D RANS axial velocity normalized contours

Axial Velocity Contours Data

Reversed Flow

Reverse-flow

Work in progress on data and simulations including LES/DES

5/28/2010

Triple-Flame Mixer for Low-NOx & Fuel Flexibility
Preliminary Data and current status on 2-D RANS Total pressure coefficient contours

\[ \frac{P_0 - P_{si}}{P_{0i} - P_{si}} \] 

Total Pressure Coefficient Contours Data

Reversed Flow

Reverse-flow

5/28/2010

Triple-Flame Mixer for Low-NOx & Fuel Flexibility
Preliminary Data and current status on 2-D RANS Static pressure coefficient contours

\[ C_{p_s} = \frac{P_s - P_{si}}{P_{oi} - P_{si}} \]

Static Pressure Coefficient Contours Data

Reverse-flow

Reversed Flow

5/28/2010
Triple-Flame Mixer for Low-NOx & Fuel Flexibility
Axial Velocity Data 3mm downstream of mixer exit

Total Pressure Coefficient Data 3 mm downstream of mixer exit

Static Pressure Coefficient Data 3 mm downstream of mixer exit

Axial Vorticity Data 3 mm downstream of mixer exit

Excellent quality data for modeling and simulation
Axial Velocity Data 3 mm downstream of mixer exit

Axisymmetric quality of axial velocity contours improves with increased airflow rate.
Total Pressure Coefficient Data 3 mm downstream of mixer exit

Design Flow Rate

Twice Design Flow Rate

Reversed Flow

Axisymmetric quality of total pressure coefficient contours improves with increased airflow rate.

\[ C_{p0} = \frac{P_0 - P_{si}}{P_{0i} - P_{si}} \]
Future Plan for Triple-Flame Mixer

1. Continue design optimization for cold and reacting flows
2. Design, fabrication and preliminary testing at engine relevant conditions in collaboration with a fuel nozzle vendor and NRCC
3. Conduct comprehensive diagnostics at engine relevant conditions with “10 kHz” PIV/PLIF, kHz Dual-Beam CARS, Spray patternation (SETScan optical patternator) and X-Ray tomography (dense sprays)
4. Design, fabricate and test “5 lb/sec” TFM in a flame tube rig at inlet pressure and temperature approaching 25 bar and 600°C followed by testing on a three nozzle sector
5. Formulate and validate engineering correlations, 3-D modeling and simulation approach for combustion technology and design community.