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 CO_2 footprint at 2020 level
- 50% of the 2005 CO_2 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

Chi-Ming Lee, Technical Challenges of Low Emissions and Fuel Flexible Combustors .

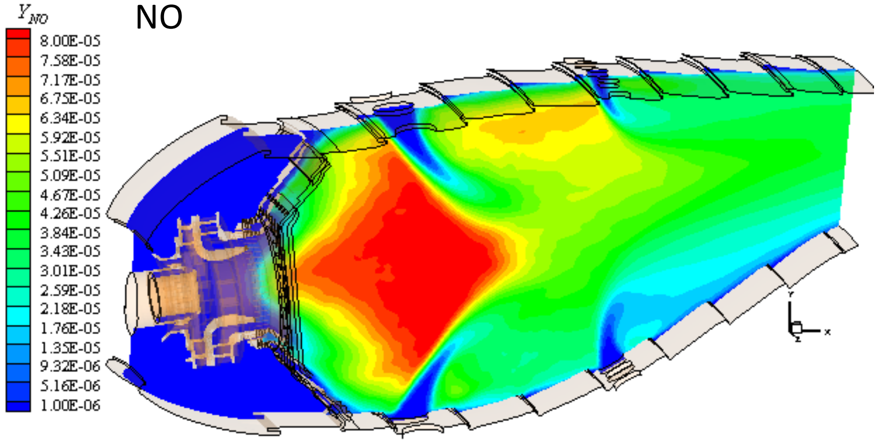
Let me therefore focus on developing aviation combustion technology for:

- Further reducing NOx emissions for future energy efficient engines
- Combustibility and increased operability with conventional & alternative fuels.

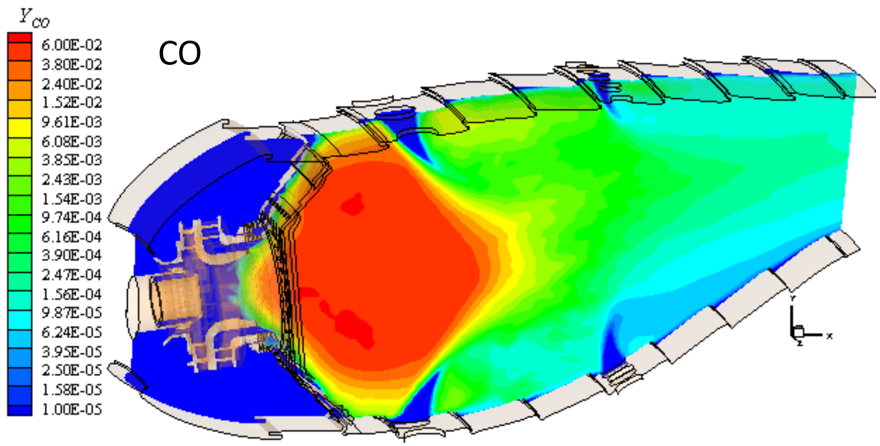
NO/CO/Operability Tradeoffs in a typical rich-dome combustor

Low-Power

NO

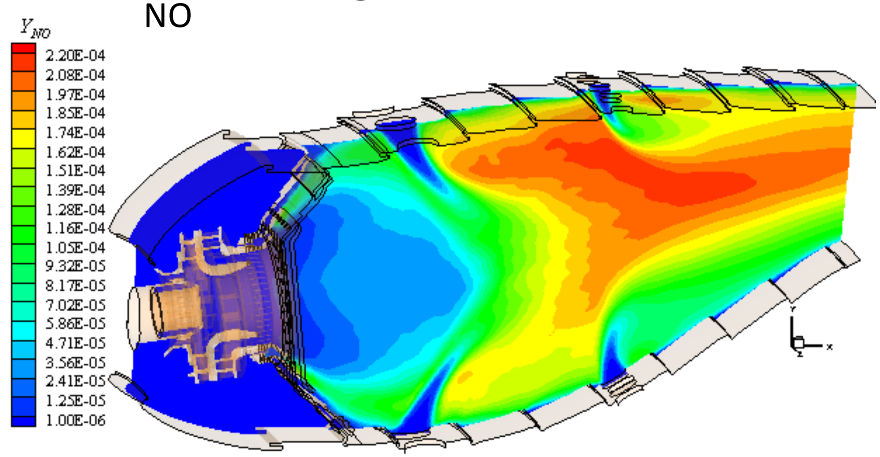


CO

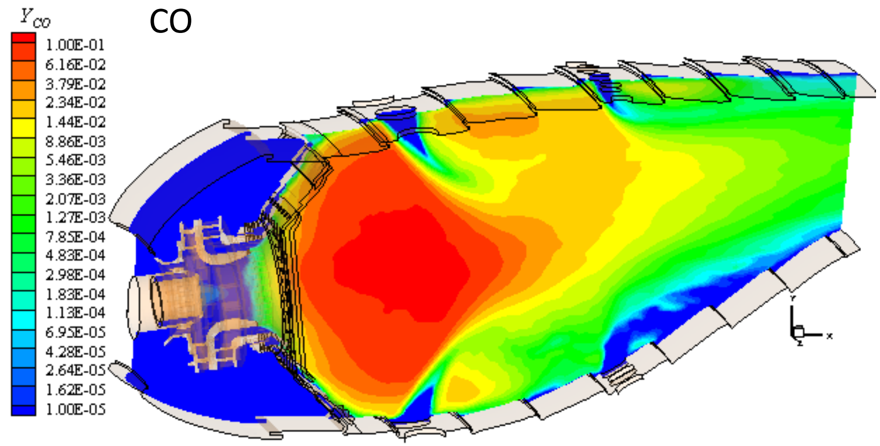


High-Power

NO



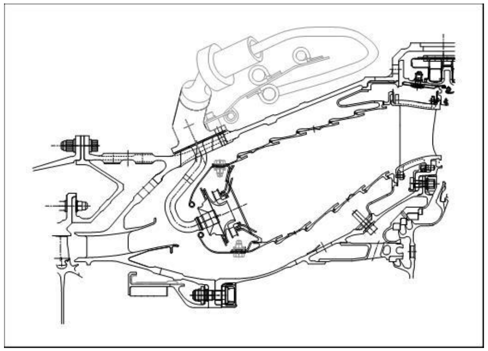
CO



CFM56 Combustion Technologies and Products

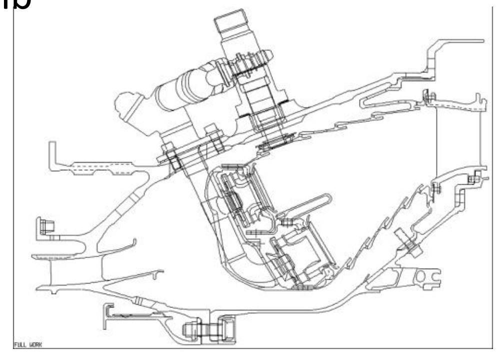
Single Annular Combustors

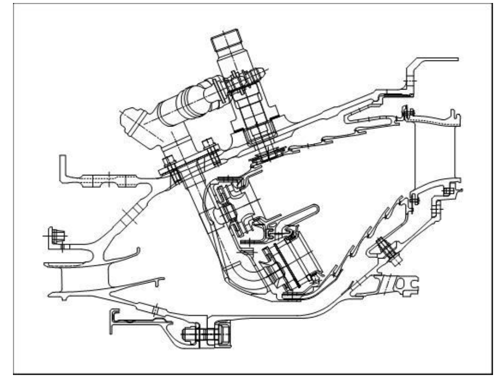
Pre-LEC & Low-Emissions Comb



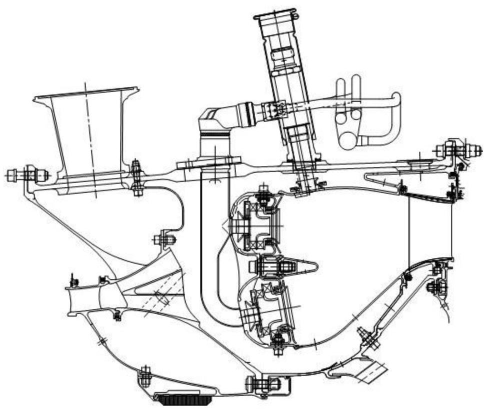
Dual Annular Combustors

DAC I, DAC II and DAC II+

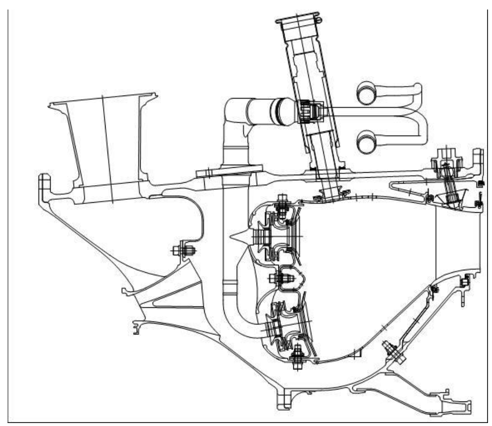


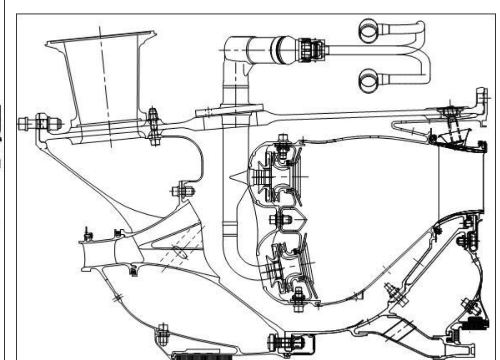


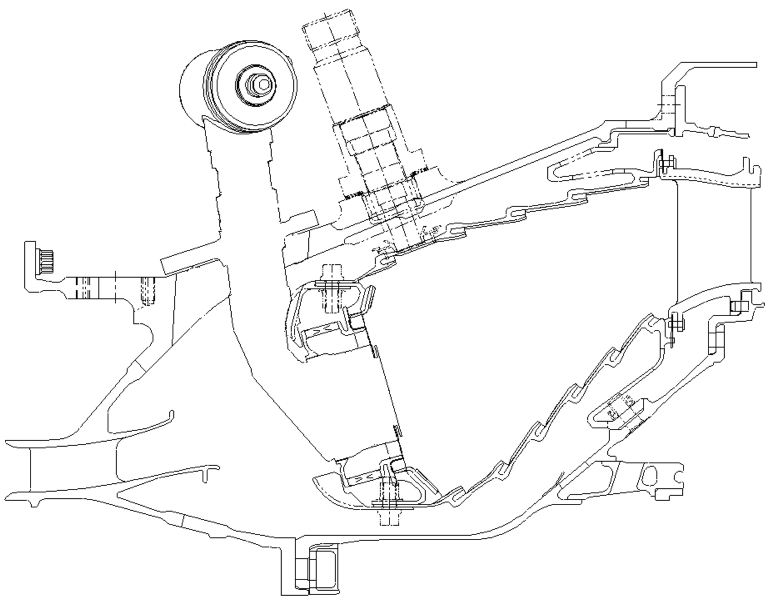
GE 90 Combustion Technologies and Products

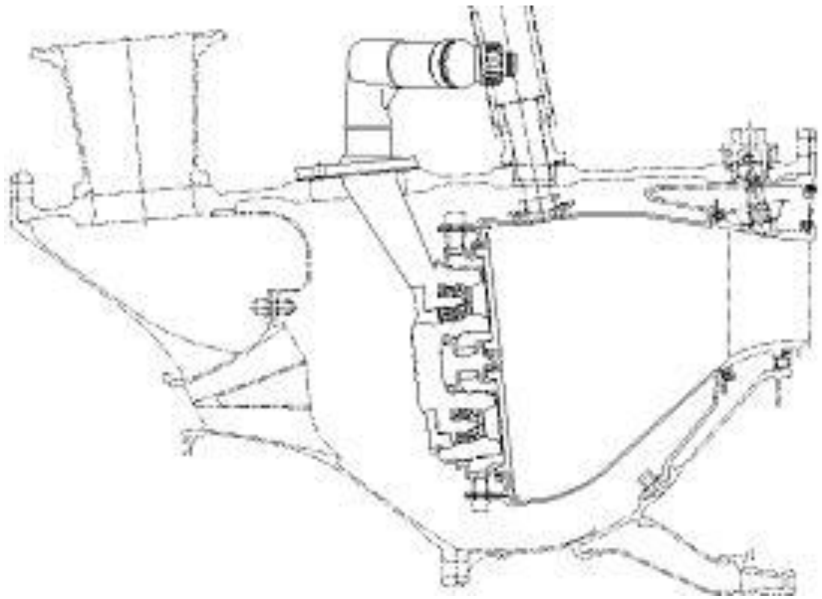


DAC I, DAC II and DAC II+

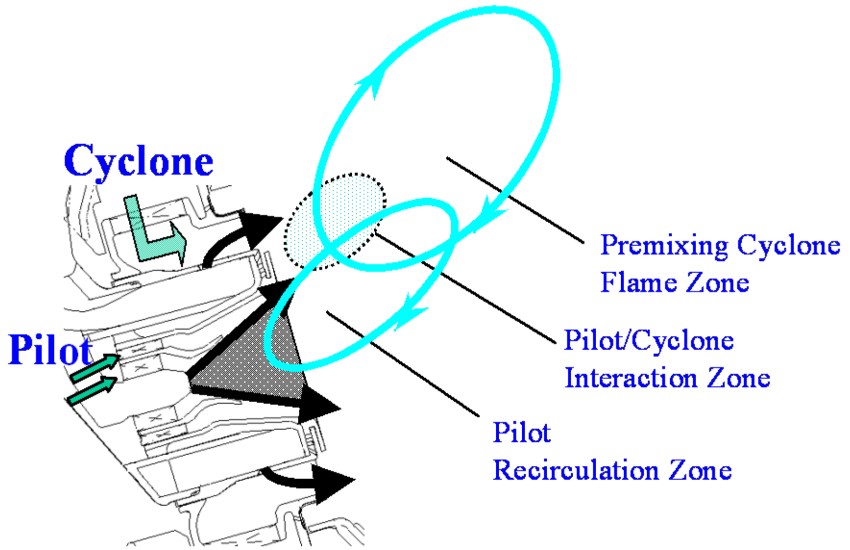


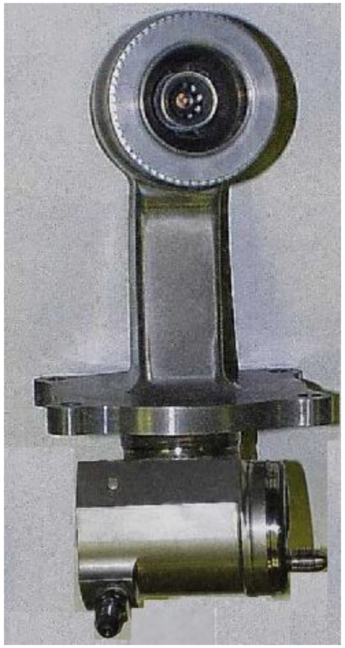


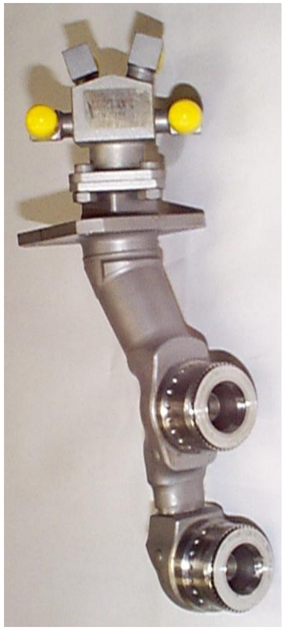




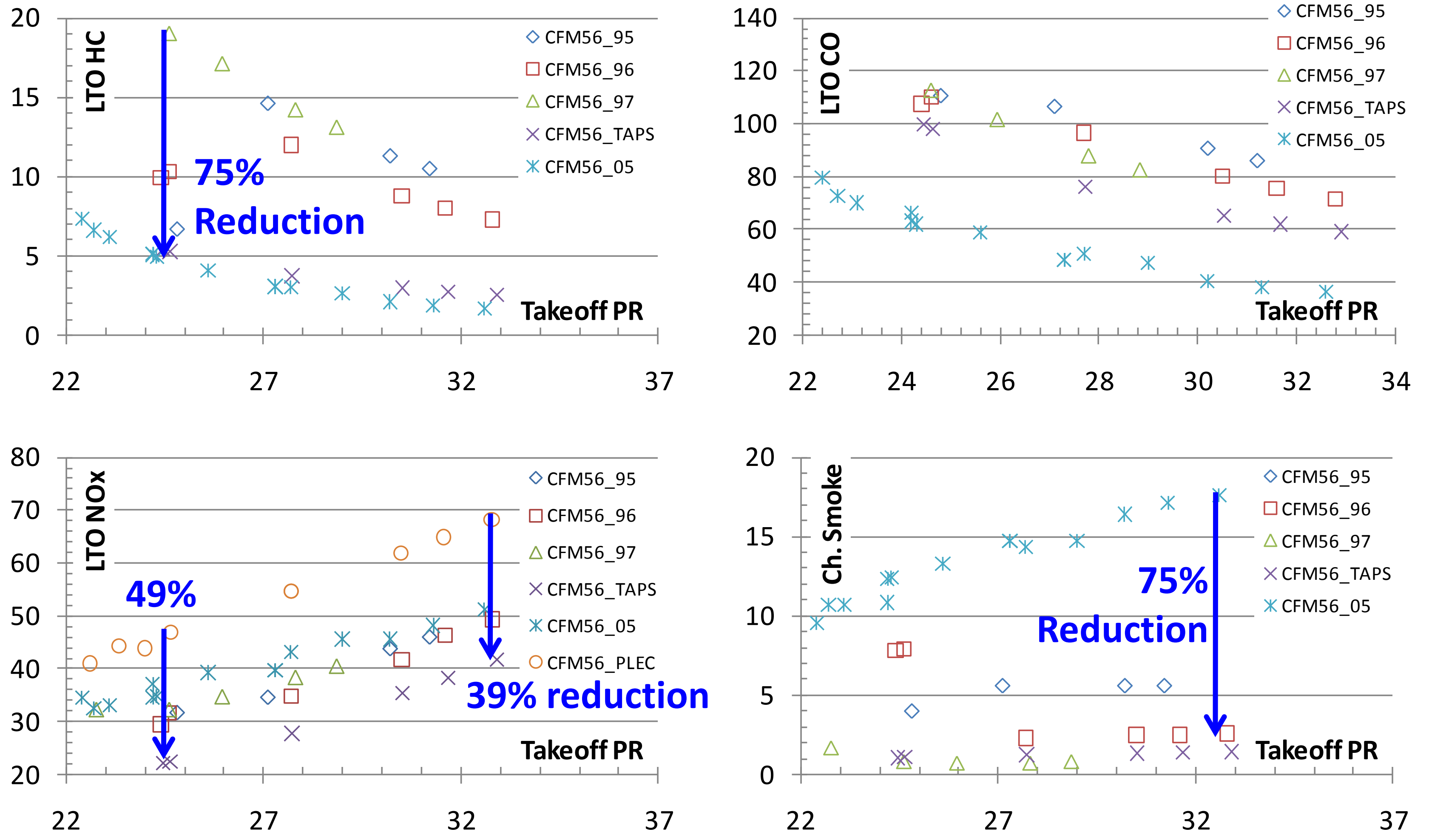
Twin-Annular Premixing Swirl (TAPS) stabilized Flames technology developed for potential applications in the CFM56 and GE90 engine models. Typical values quoted.



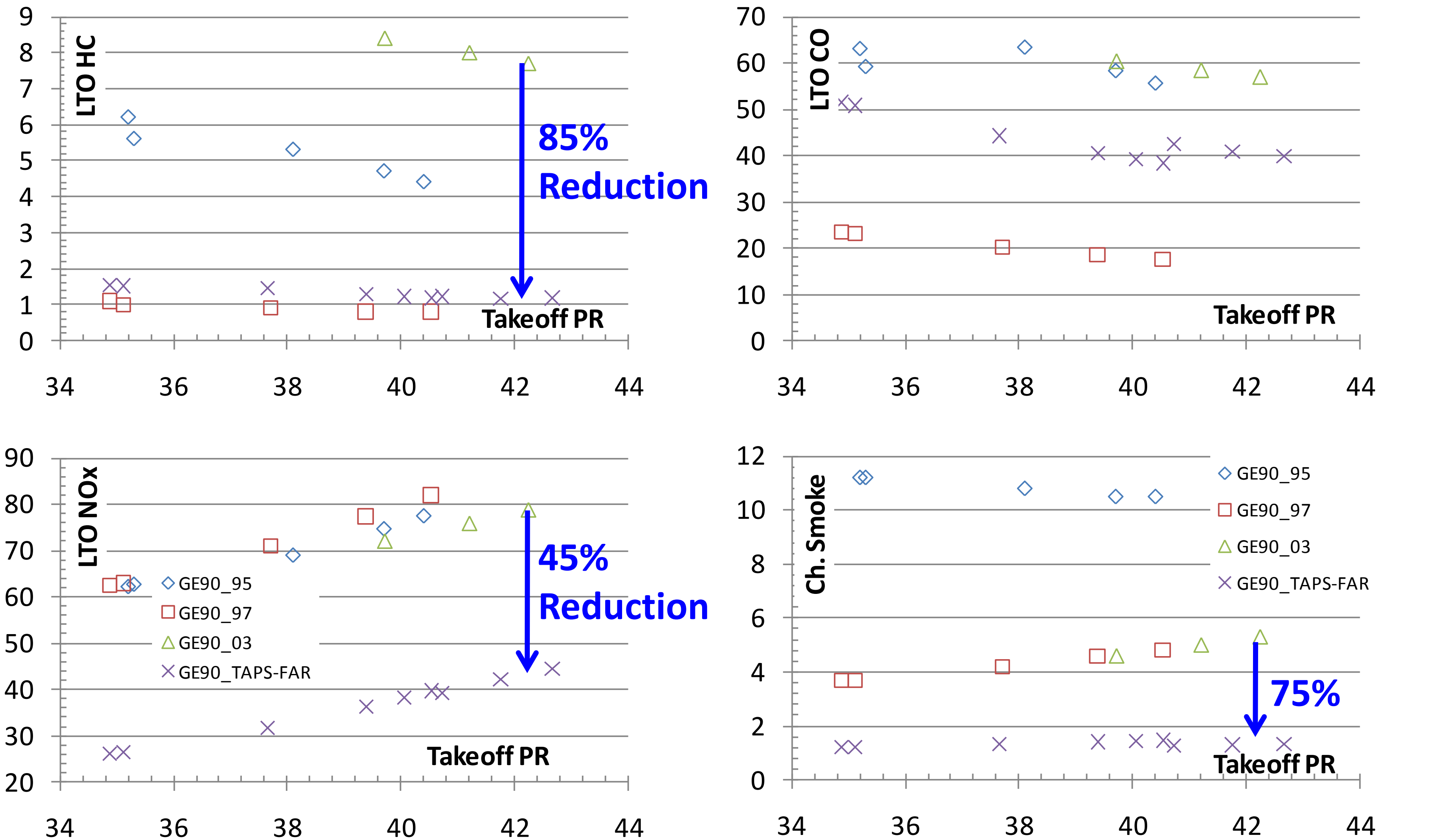




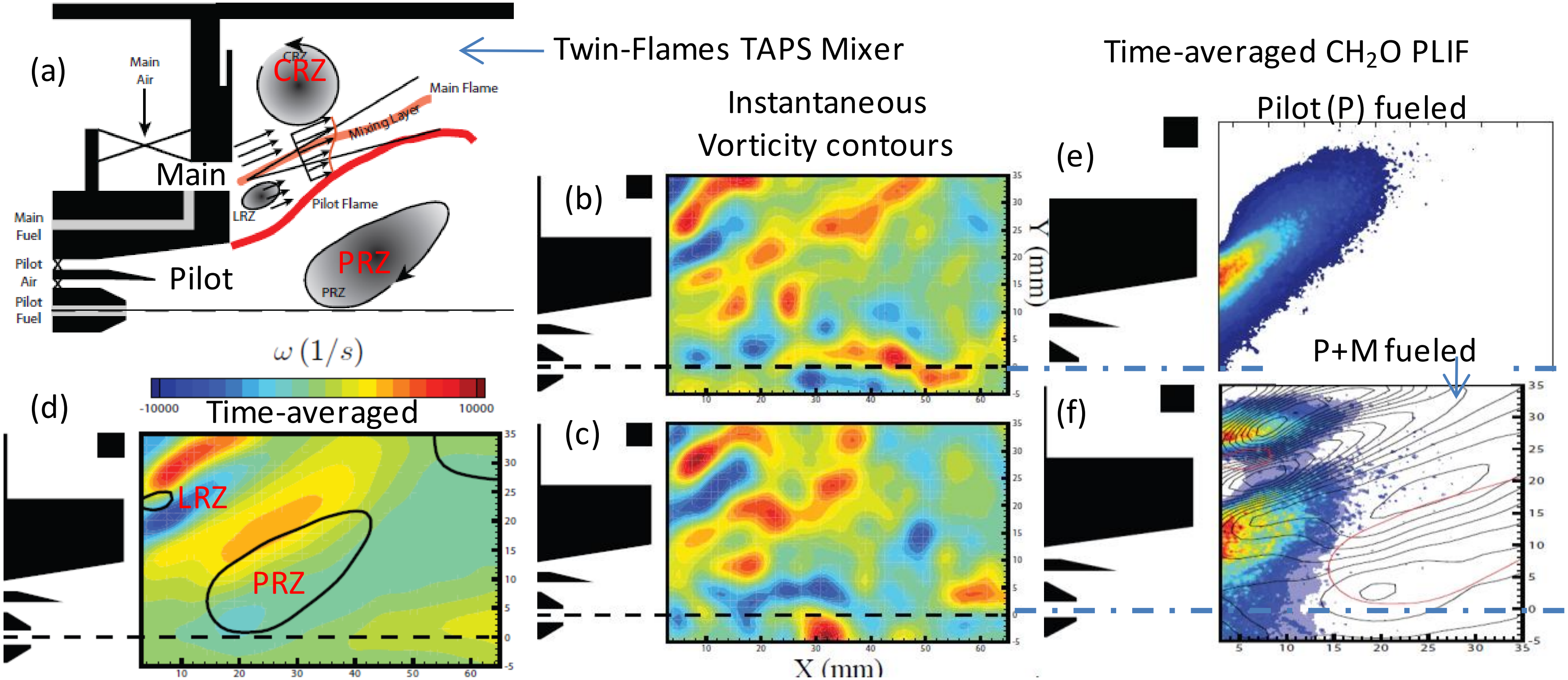
NASA GRC and GE Aviation supported the development of the CFM and GE90 TAPS technologies



Further reduction in TAPS CO emissions would be desirable for low pressure ratio engines



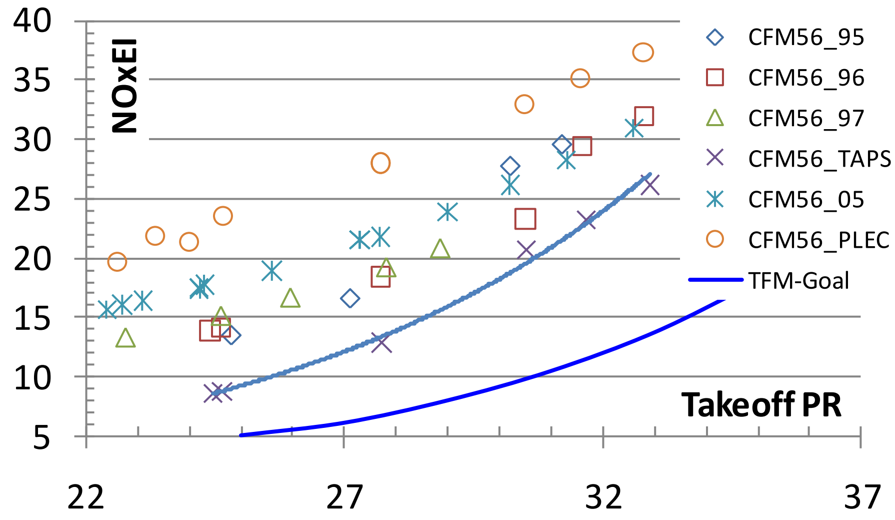
GE90 TAPS technology demonstrated significant emissions reduction compared to current technology GE90 combustion system



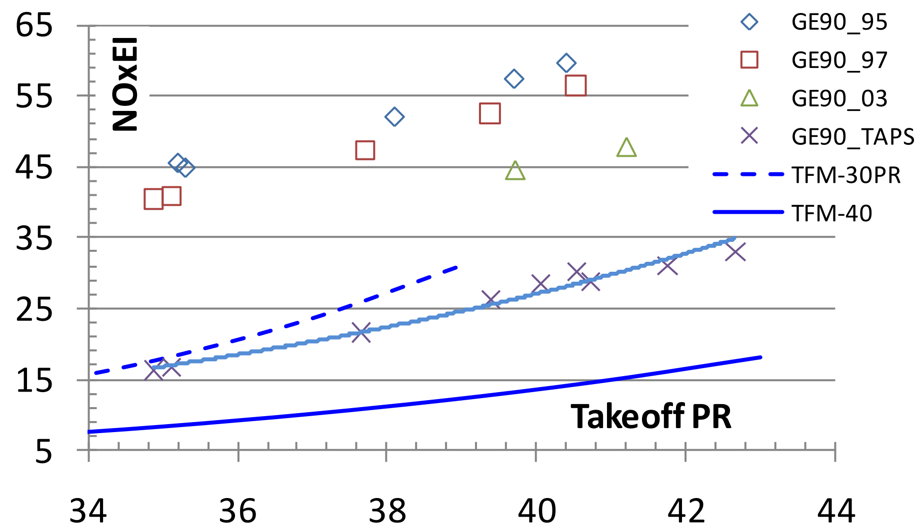
Typical TAPS diagnostics data from Prof. Driscoll and his students
Show twin flames as hypothesized for TAPS mixers

Triple-Flame Mixer

"Optimized strain/vorticity /FAR distribution

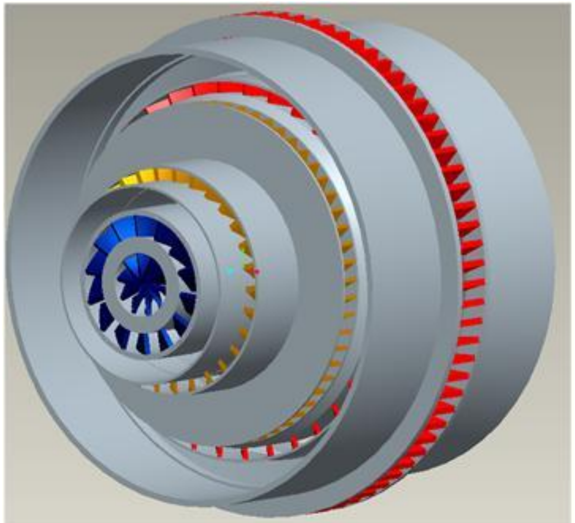


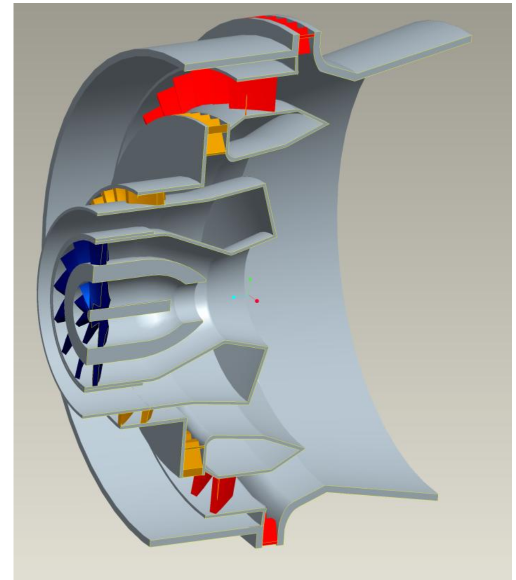
TFM Goals
Reduce NOxEI by ~50%*
Simplify fuel injectors*
Reduce hot-streaking
Improve operability
Increase fuel flexibility

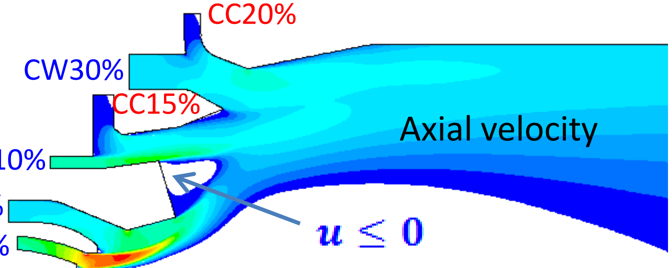


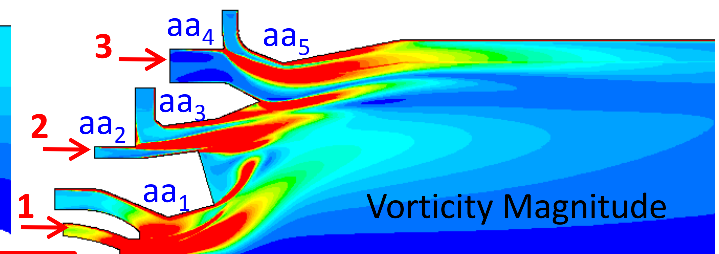
*Baseline combustors are CFM56 TAPS and GE90 TAPS

Triple-Flame Mixer with optimized strain, vorticity and ϕ distribution









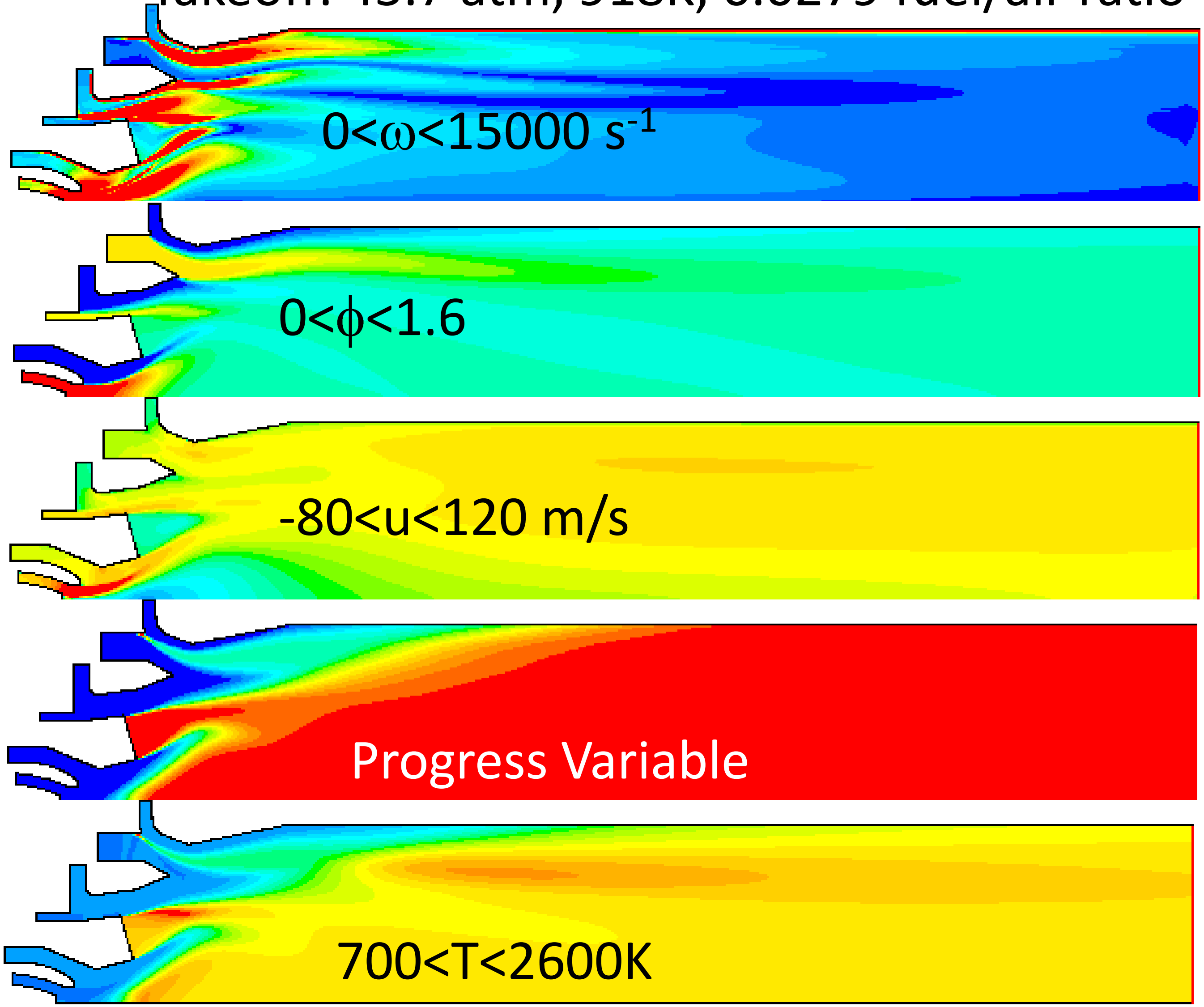
45°-vane angles →

Direct Fuel Injection, DFI, No premixing or liquid fuel jets in cross-flow. DFI_1 & DFI_2 fuel flow continuously

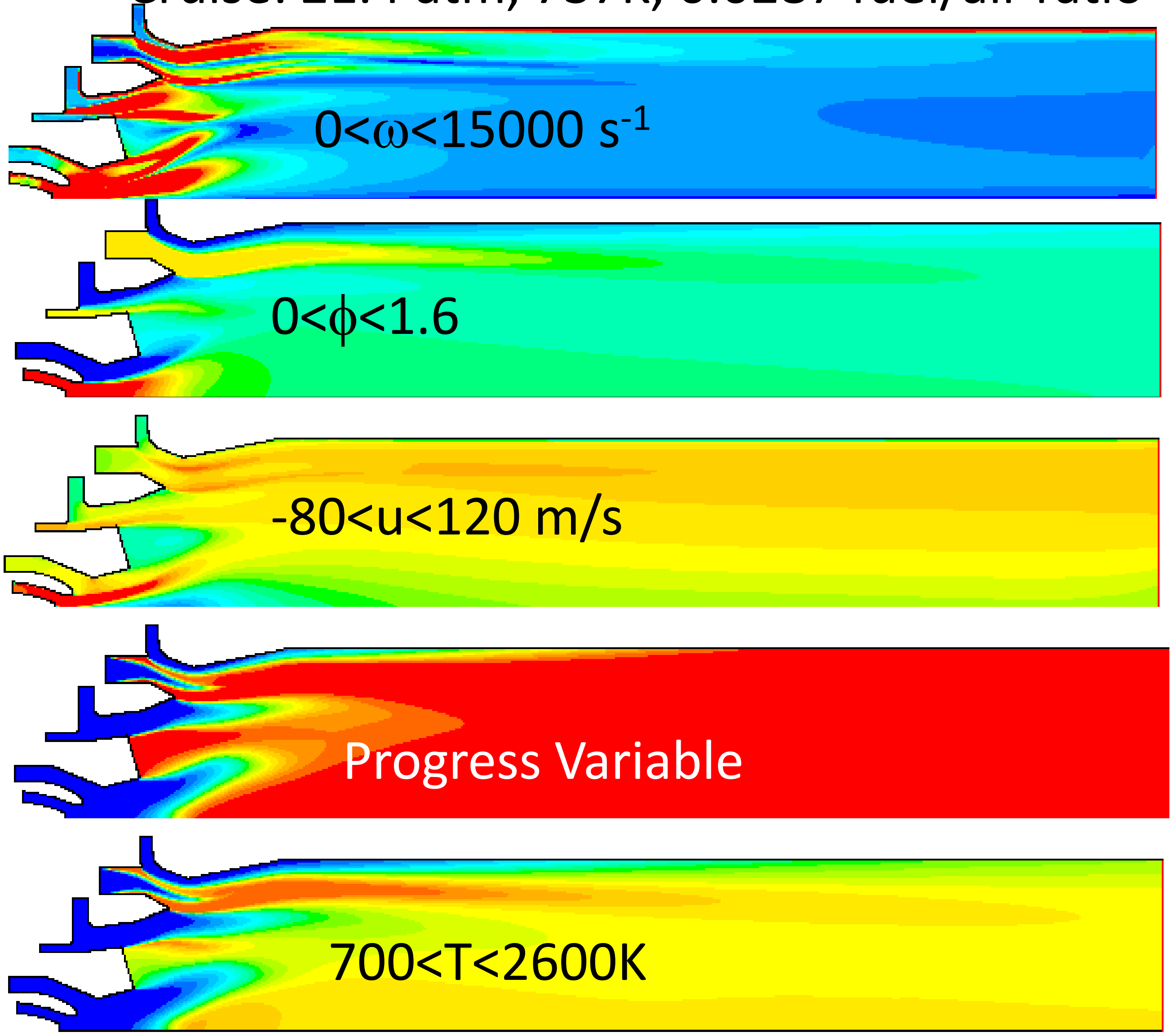
aa_1, aa_2 ----and aa_5 are the potential air atomizing locations

RANS Non-reacting flow; DES/LES simulation continues

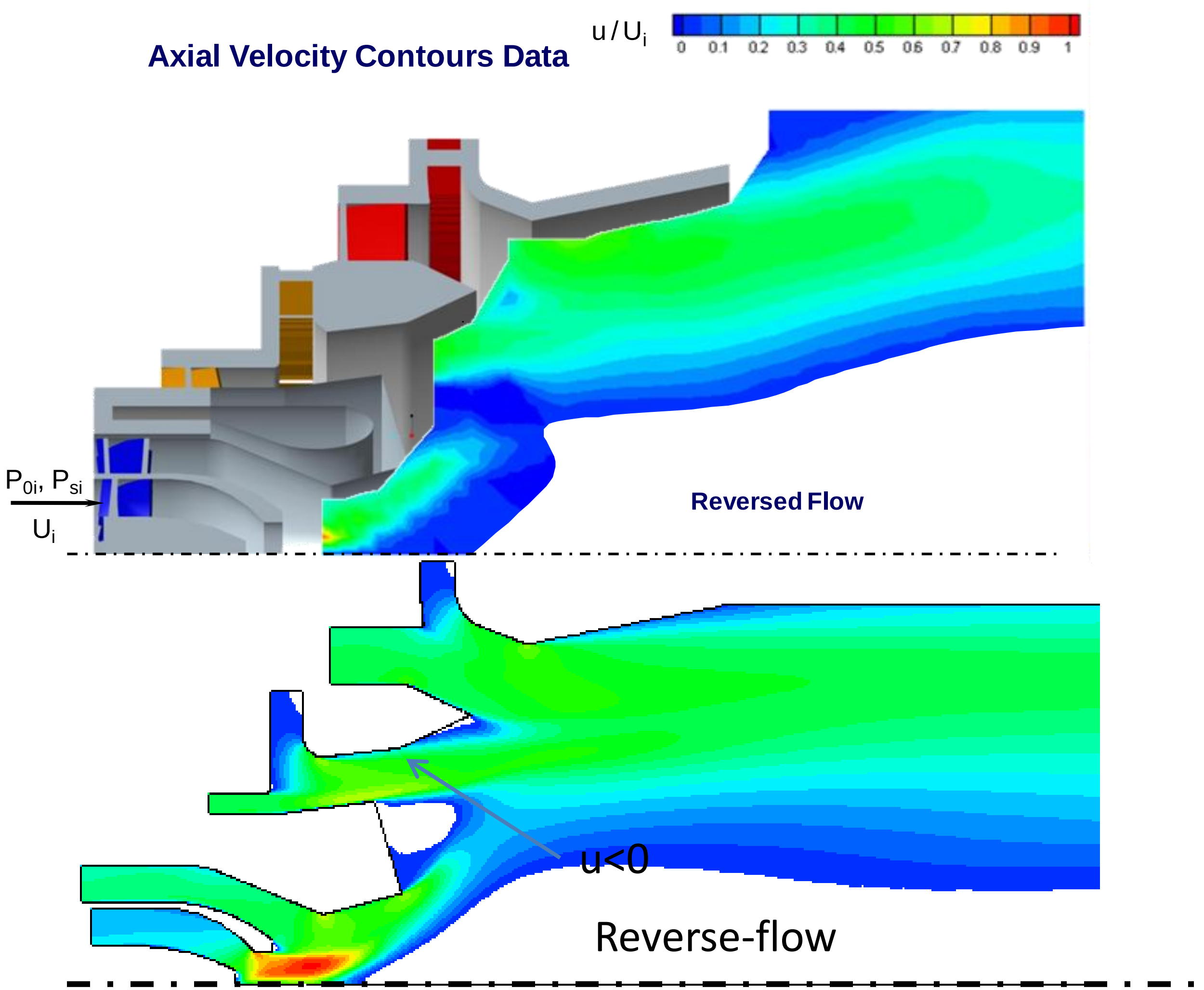
Takeoff: 45.7 atm, 918K, 0.0279 fuel/air ratio



Cruise: 21.4 atm, 737K, 0.0287 fuel/air ratio

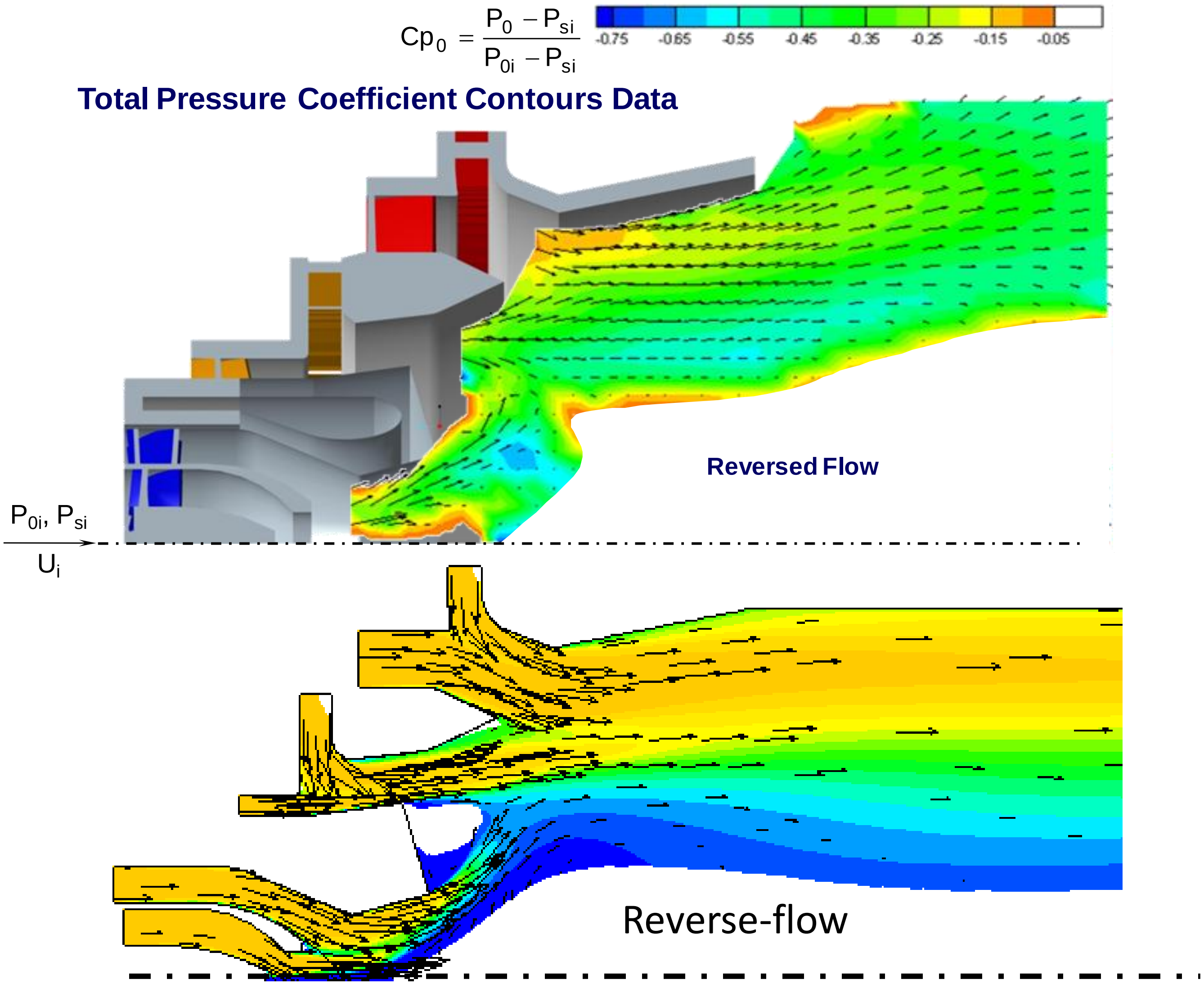


Preliminary Data and current status on 2-D RANS axial velocity normalized contours

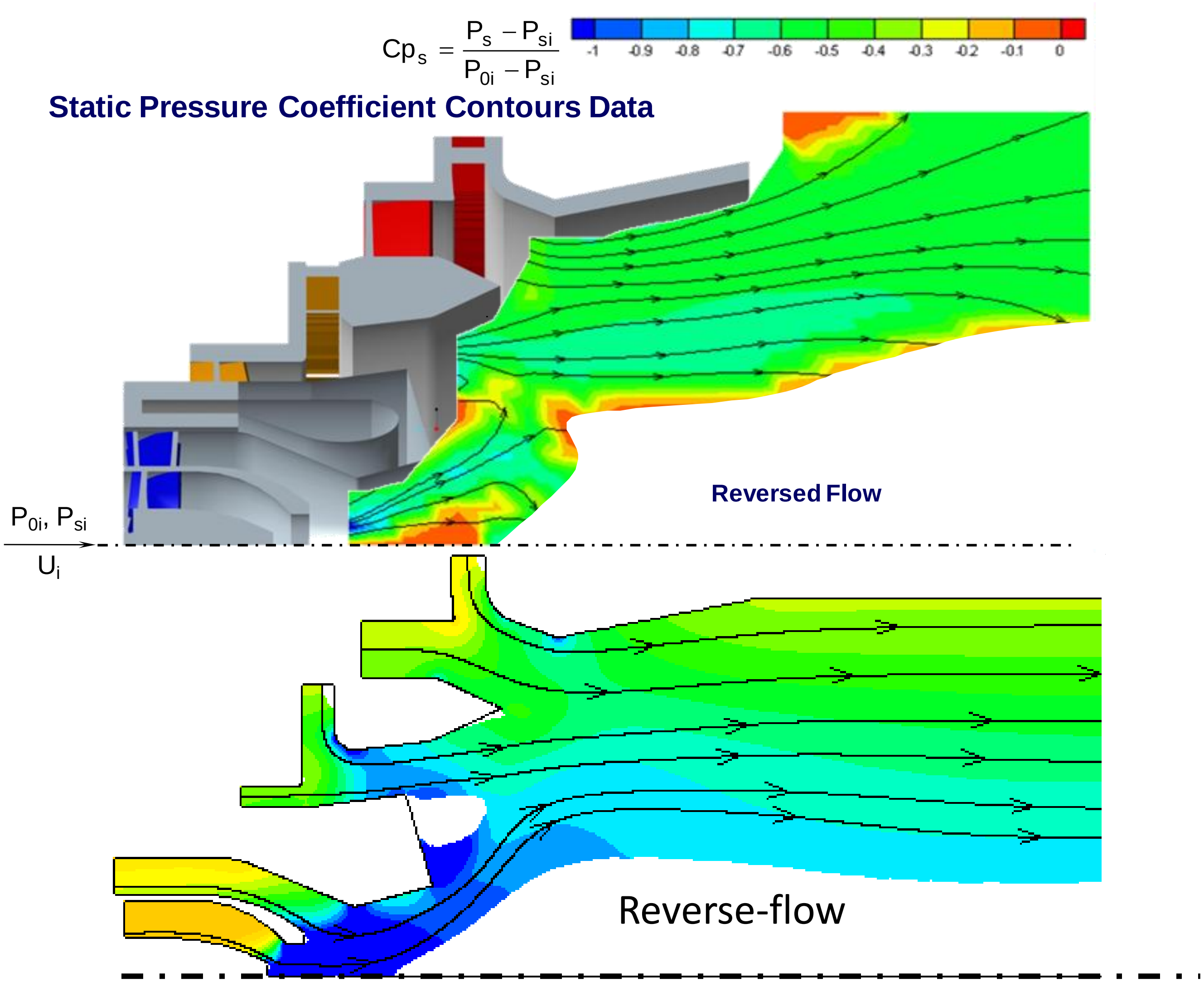


Work in progress on data and simulations including LES/DES

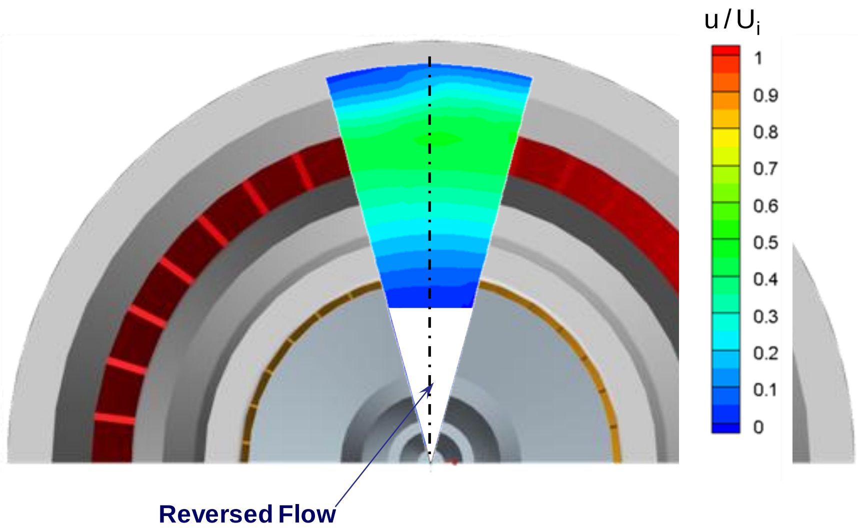
Preliminary Data and current status on 2-D RANS Total pressure coefficient contours



Preliminary Data and current status on 2-D RANS Static pressure coefficient contours



Axial Velocity Data 3mm downstream of mixer exit



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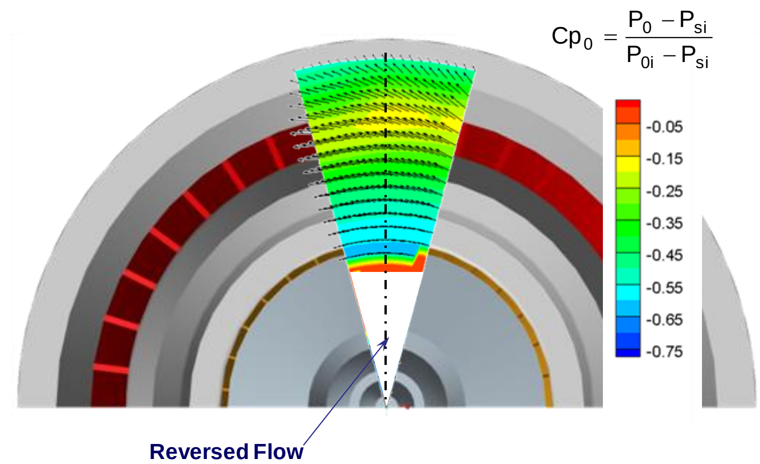
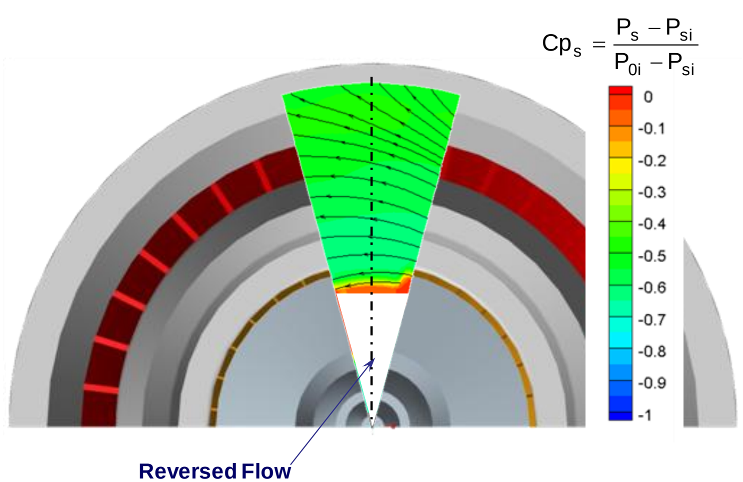
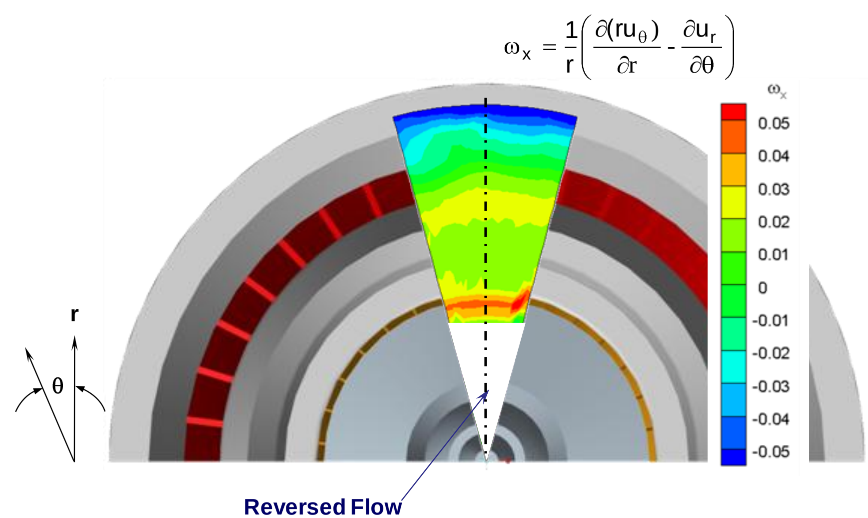


Static Pressure Coefficient Data 3 mm downstream of mixer exit

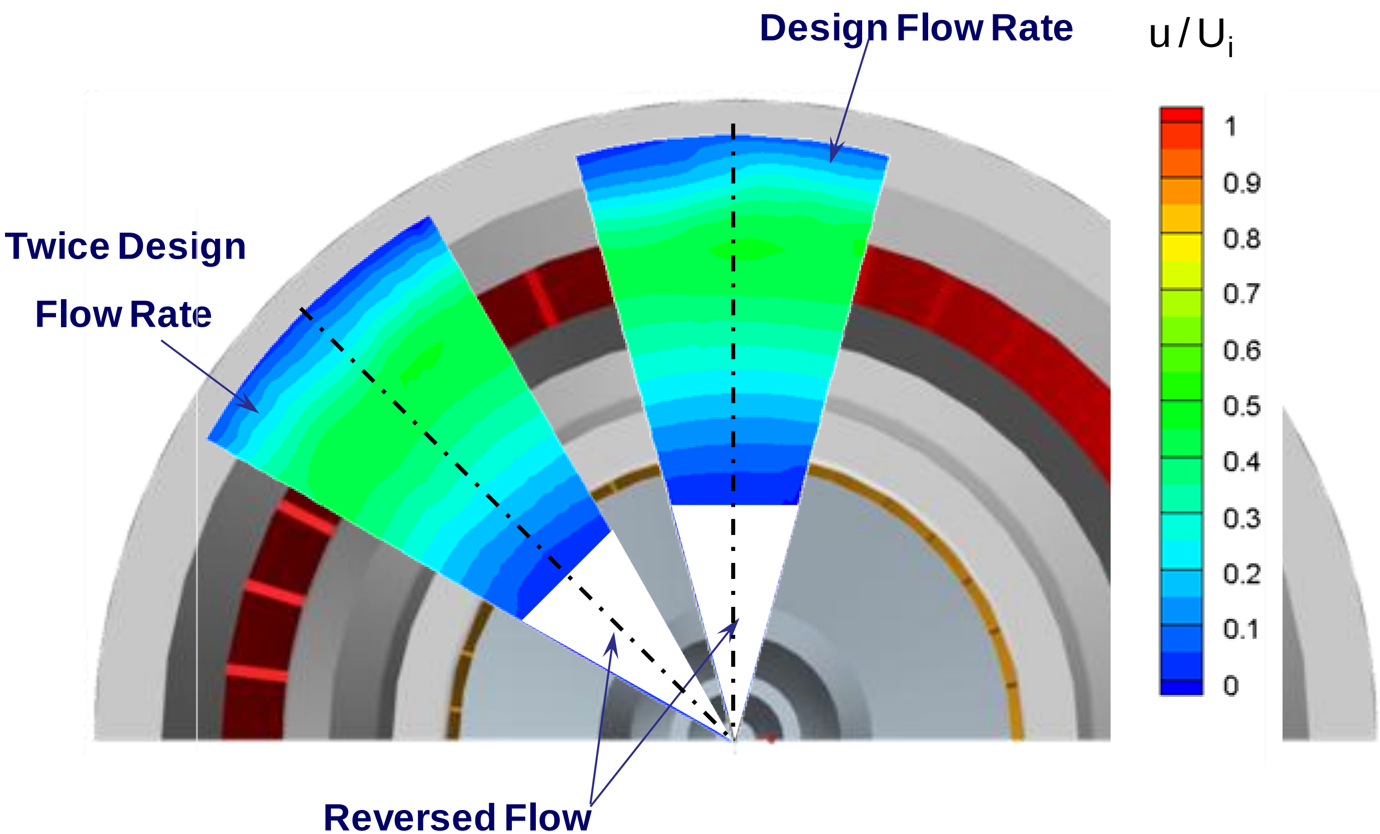


Axial Vorticity Data 3 mm downstream of mixer exit



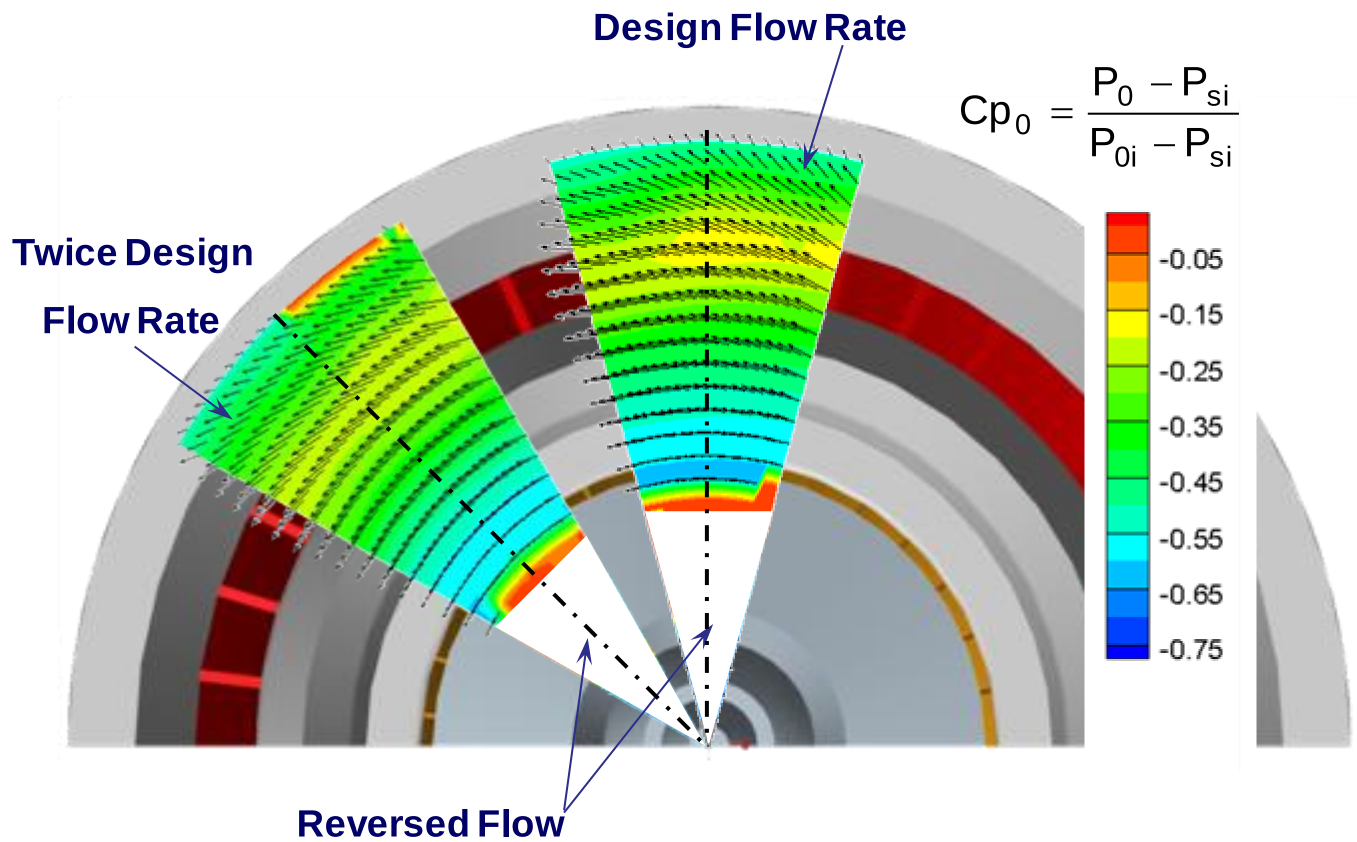
Excellent quality data for modeling and simulation

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



$$Cp_0 = \frac{P_0 - P_{si}}{P_{0i} - P_{si}}$$

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

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^{o}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.