National Aeronautics and Space Administration

Advanced Concepts for Aircraft LTO NOx Reduction: A NASA Perspective

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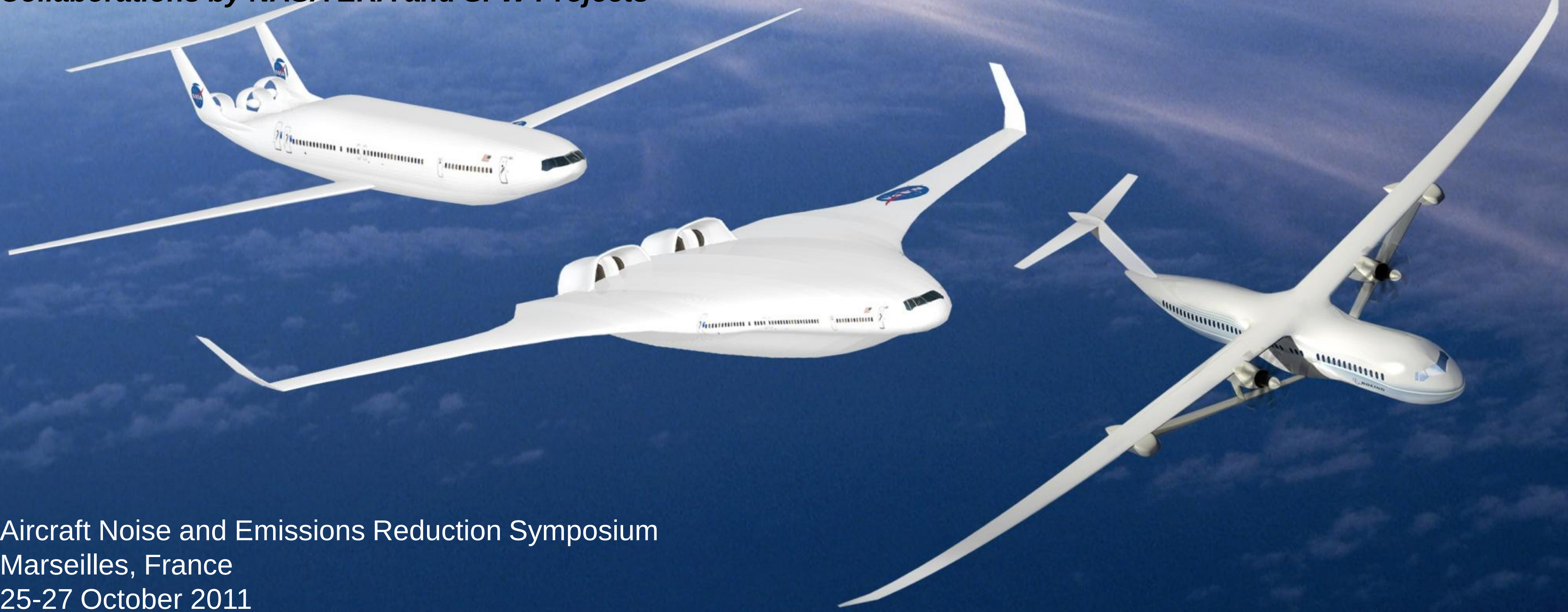
Collaborations by NASA ERA and SFW Projects



Aircraft Noise and Emissions Reduction Symposium
Marseilles, France
25-27 October 2011

NASA Subsonic Transport System Level Metrics

… technology for dramatically improving noise, emissions, & performance

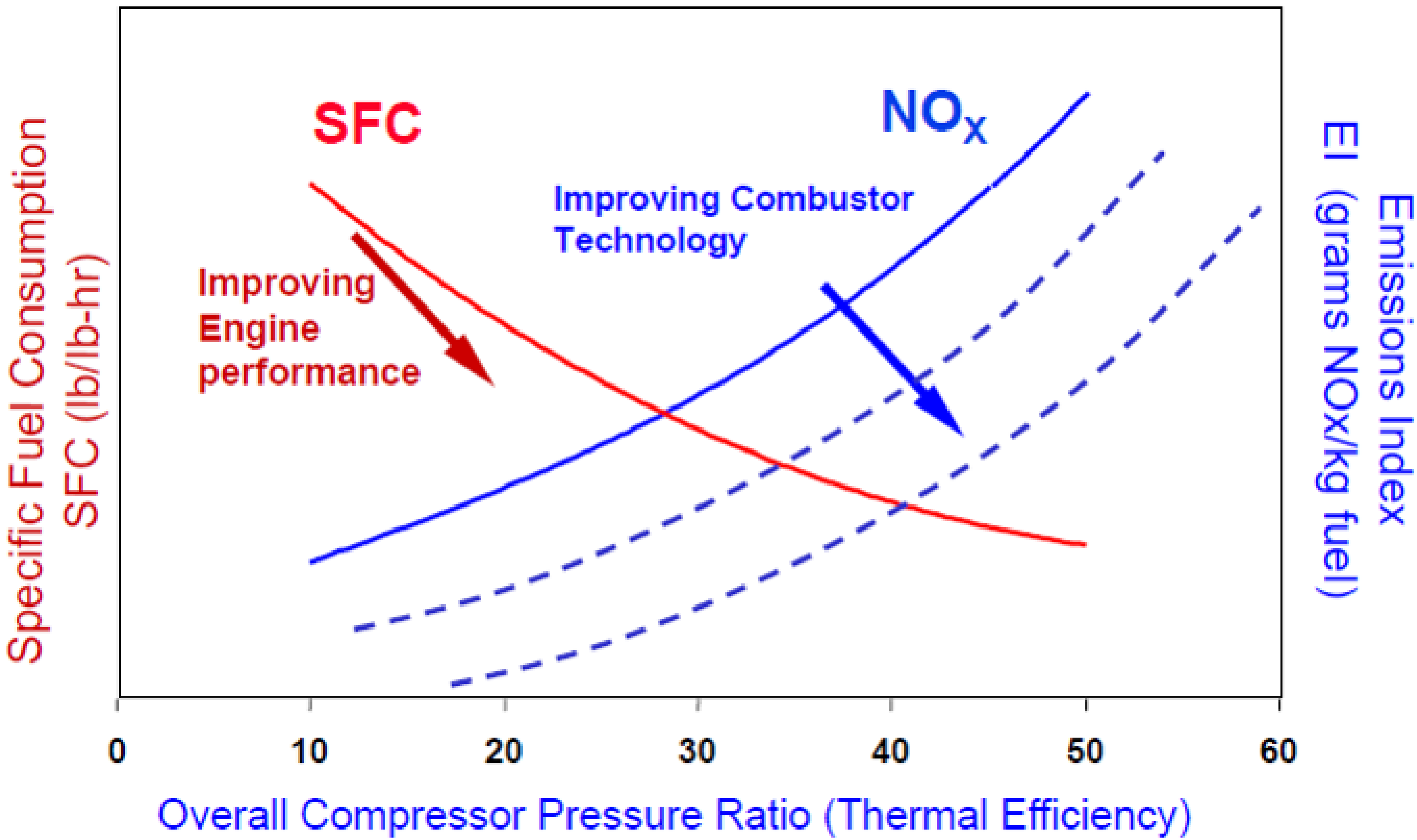
TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy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

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

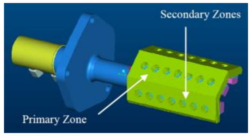
Trading Performance & NOx Reduction

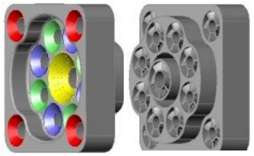


Addressing LTO NO_x Emissions

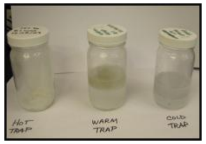
Low NOx, Fuel-Flexible Combustors

Innovative Injector Concepts





- High bypass ratio, high pressure smaller-core engines
- Superior alternative fuel properties

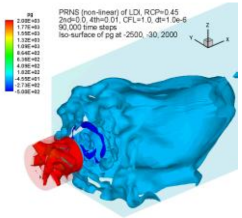


Alternative fuels

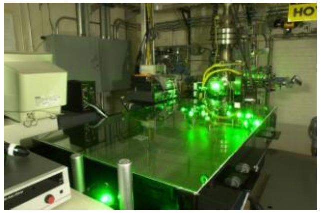
ASCR Combustion Rig

CFD Models and Validation Experiments

Validated CFD tools for emissions predictions



RANS, URANS, TFNS, LES CFD Modeling

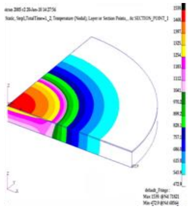


Validation Experiments - quantitative time resolved measurements of major species and temperature

CMC Combustor Liner

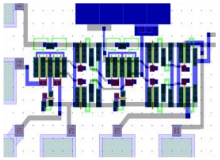
CMC combustor liner for higher engine temperatures and reduced cooling air flows

CMC combustor liner

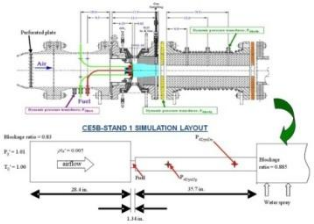


Active Combustion Instability Control

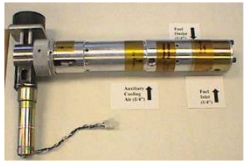
Capability to suppress combustor instabilities for low emission combustors



High Temperature SiC electronics circuits and dynamic pressure sensors

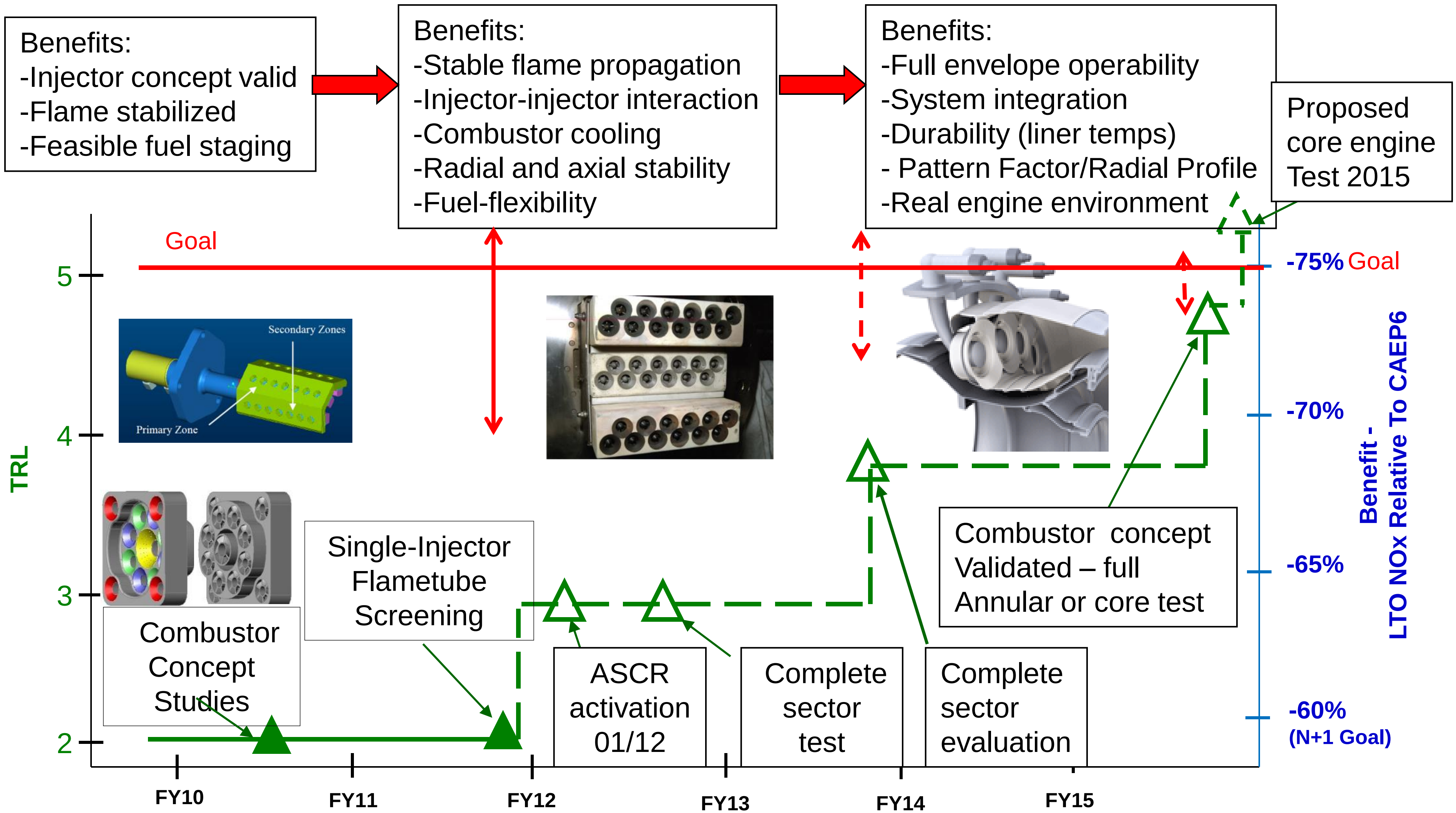


Fuel Modulation – high frequency fuel delivery systems



Instability Models and Control Methods

Ultra-Low Nox, Fuel Flexible Combustor
Objective: Reduce LTO NOx 75% from CAEP6



ERA: Ultra-Low NOx Combustor Technology Maturation Roadmap

New Combustor concepts required to meet the Goal

Low Emissions Combustors for N+3

Subsonic Fixed Wing Project

- Combustion CFD Model Development and Application
- Validation Experiments
- Low Emissions Combustion Concepts
  - N+3 Goals (Subsonic Fixed Wing and Supersonics Projects)
- Active Combustion Control
- Alternative Fuels

Combustion CFD Modeling

- Chemical Kinetics for conventional a alternative fuels
- Primary/Secondary Atomization moc
- Turbulent combustion modeling
- RANS/URANS/TFNS(VLES)/LES models
- Radiation Heat Transfer
- Combustion Dynamics
- Soot Modeling
- Spray Vaporization
- Coupled Combustor/Turbine calculations

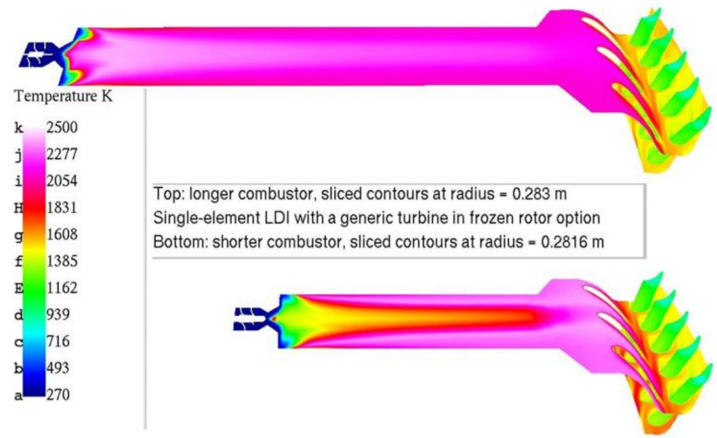
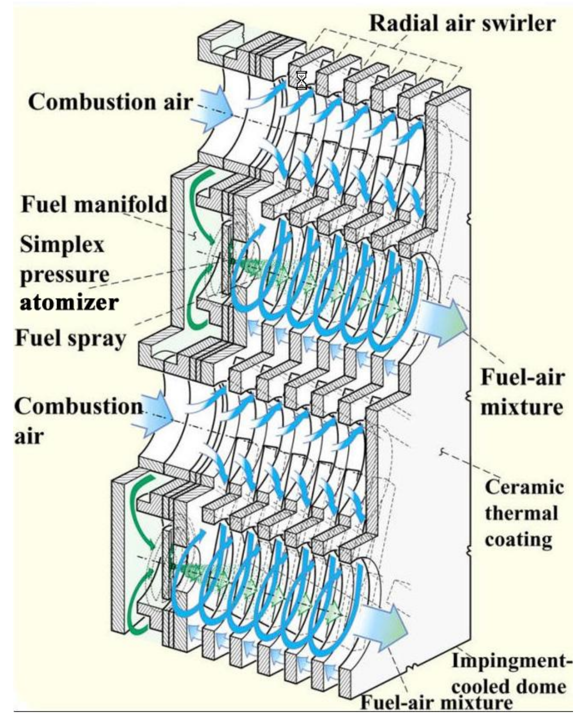
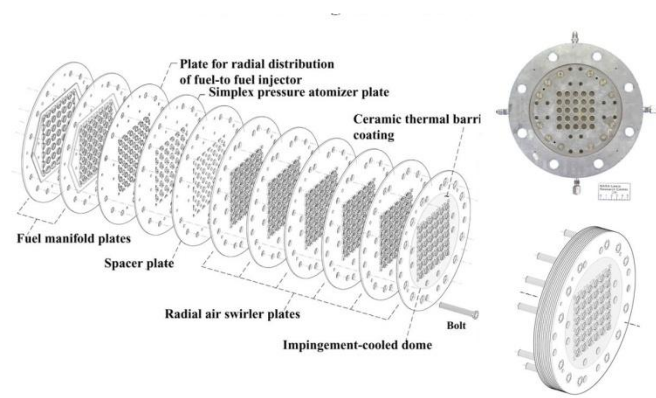


Image: Gas-phase temperatures for two different length Single-element LDI Combustors coupled to the 1st stage of a High Pressure Turbine consisting of Stator and Rotor

N+3 Low Emissions Combustor Concepts

- Smaller Higher Pressure Engine Cores for Advanced Airframe Concepts: BWB, Hybrid Propulsion, etc.
- Emissions Goals may be expanded to include particulates and CO_2
- Fundamental Combustion Research
  - Fuel-Air Mixing
  - Combustion Dynamics
  - Passive Damping
- Advanced Concepts
  - Multipoint Lean Direct Injection, other advanced Lean Burn Concepts
  - Pressure Gain Combustion Feasibility

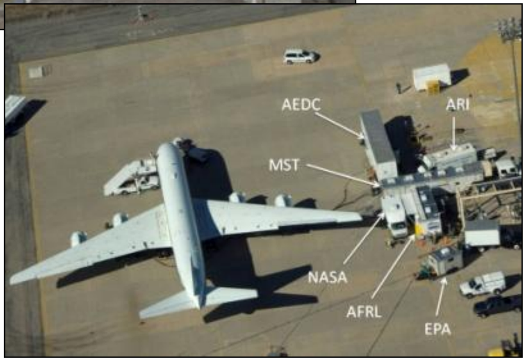




Alternative Fuels Research Effort

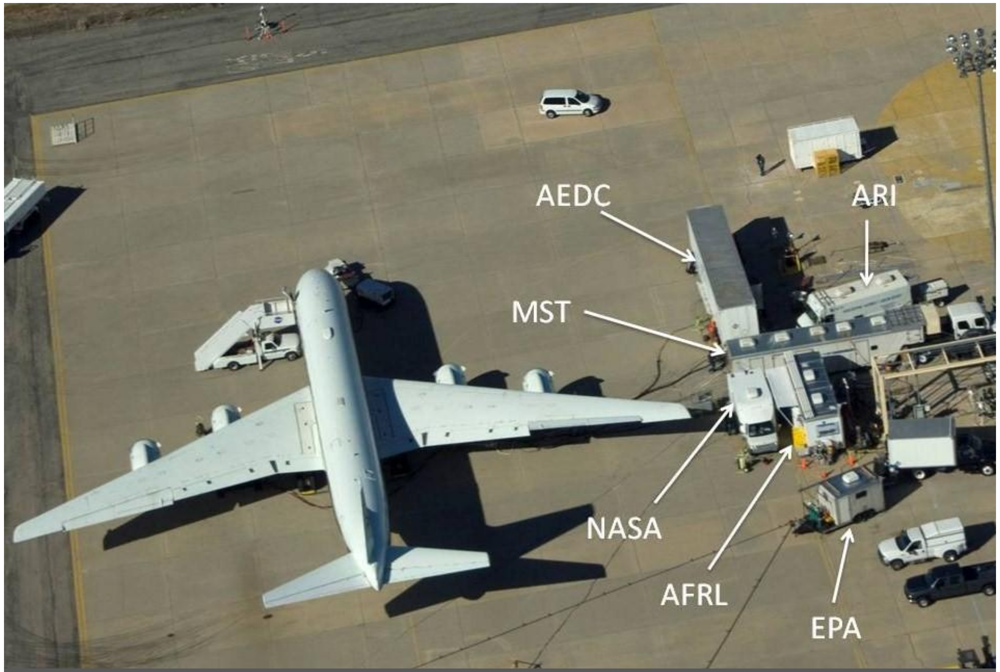
National Plan Goals:
Energy and Environment Goal 1: Enable new aviation fuels
Energy and Environment Goal 3: Technologies and operational procedures to decrease Environmental Impact of Aviation

Technical Challenge:
Reduced Emission of Aircraft – Enable concepts and technologies to dramatically reduce or eliminate harmful emissions affecting local air quality/health and global climate change attributable to aircraft energy consumption.



Alternative Fuels Research Objectives:
- Characterize the performance and emissions of alternative & bio-fuels in aircraft propulsion systems.
- Predict the combustion performance and emissions characteristics to enable more effective design of combustors utilizing alternative fuels and bio-fuels.

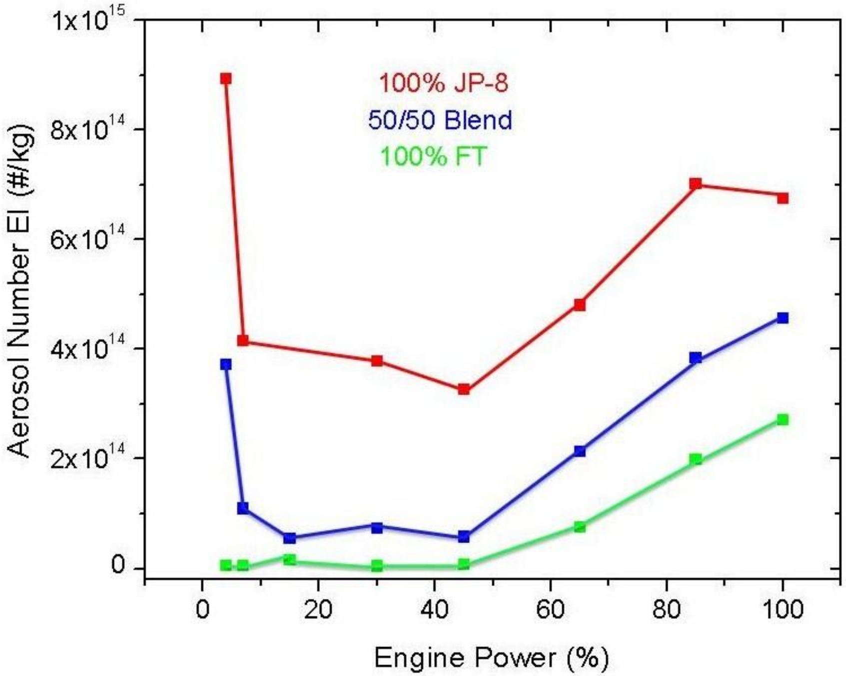
Alternative Aviation Fuel Experiments (AAFEX 1 and 2)



Boeing, GE, Pratt & Whitney, CMU, Harvard, MSU, UCSD, and UTRC

AAFEX1 - 2009
2 FT fuels pure and 50-50 mix

AAFEX2 – 2011
Tallow fuel, FT Low and High Sulfur both neat and 50-50 mix



Nonvolatile Aerosols @ 1m
Differences in emissions greatest at idle, less at higher engine powers.

Flight Experiment planned for late FY12 using multiple fuels

Questions?