Advanced Concepts for Aircraft LTO NOx Reduction: A NASA Perspective

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Collaborations by NASA ERA and SFW Projects
# NASA Subsonic Transport System Level Metrics

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

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS*</th>
<th>TECHNOLOGY GENERATIONS</th>
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<tbody>
<tr>
<td></td>
<td>(Technology Readiness Level = 4-6)</td>
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<tr>
<td>Noise (cum margin rel. to Stage 4)</td>
<td>-32 dB</td>
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<tr>
<td>LTO NOx Emissions (rel. to CAEP 6)</td>
<td>-60%</td>
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<tr>
<td>Cruise NOx Emissions (rel. to 2005 best in class)</td>
<td>-55%</td>
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<tr>
<td>Aircraft Fuel/Energy Consumption† (rel. to 2005 best in class)</td>
<td>-33%</td>
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* 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.

† CO₂ emission benefits dependent on life-cycle CO₂e per MJ for fuel and/or energy source used.
Trading Performance & NOx Reduction

![Diagram showing the relationship between Specific Fuel Consumption (SFC), NOx, and Overall Compressor Pressure Ratio (Thermal Efficiency). The diagram illustrates the trade-off between SFC and NOx emissions, with improvements in Combustor Technology leading to reduced NOx emissions at the cost of increased SFC.](image)
Addressing LTO NOx Emissions

**Low NOx, Fuel-Flexible Combustors**
- Innovative Injector Concepts
  - Alternative fuels
  - ASCR Combustion Rig
- High bypass ratio, high pressure smaller-core engines
- Superior alternative fuel properties

**CMC Combustor Liner**
- CMC combustor liner for higher engine temperatures and reduced cooling air flows

**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

**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

<table>
<thead>
<tr>
<th>TRL</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
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<td>Comple</td>
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<td>3</td>
<td>Combustor Concept Studies</td>
<td>Single-Injector Flametube Screening</td>
<td>ASCR activation 01/12</td>
<td>Complete sector test</td>
<td>Complete sector evaluation</td>
<td>Proposed core engine Test 2015</td>
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<tr>
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Benefits:
- Injector concept valid
- Flame stabilized
- Feasible fuel staging

Benefits:
- Stable flame propagation
- Injector-injector interaction
- Combustor cooling
- Radial and axial stability
- Fuel-flexibility

Benefits:
- Full envelope operability
- System integration
- Durability (liner temps)
- Pattern Factor/Radial Profile
- Real engine environment

Goal

Combustor concept validated – full Annular or core test

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 and alternative fuels
- Primary/Secondary Atomization models
- 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 CO₂
- 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
**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

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**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.

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**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

Flight Experiment planned for late FY12 using multiple fuels

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.
Questions?