Addressing Aviation Environmental Challenges through Technology and Fuels

Presented to: Aircraft Noise & Emissions Symposium

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Chief Scientific and Technical Advisor for Environment and Energy
Office of Environment and Energy
Federal Aviation Administration

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Outline

• Background
• Fuels
• Aircraft Technology
• Conclusion
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Efforts Relating to Aircraft Emissions

Understanding Impacts

- Particulate Matter (PM) measurements and modeling
- Improving atmospheric impact modeling capabilities
- Evaluating current aircraft, commercial supersonic aircraft, unmanned aerial systems, and commercial space vehicles

Mitigation

- Vehicle operations
- Alternative fuel sources
- Modifications to fuel composition
- Aircraft technologies and architecture
- Engine standard (CAEP PM standard)
- Policy measures (CORSIA)
Efforts Relating to Jet Fuel

Coordination
• Public-Private
• Interagency
• State & Regional
• International

Testing
• Support certification testing
• Improve certification process
• Emissions measurements

Analysis
• Environmental sustainability
• Techno-economic analysis
• Future scenarios
ASCENT Center of Excellence (COE)

Lead Universities:
Washington State University (WSU)*
Massachusetts Institute of Technology (MIT)

Core Universities:
Boston University (BU)
Georgia Institute of Technology (Ga Tech)
Missouri University of Science and Technology (MS&T)
Oregon State University (OSU)*
Pennsylvania State University (PSU)*
Purdue University (PU)*
Stanford University (SU)
University of Dayton (UD)
University of Hawaii (UH)*
University of Illinois at Urbana-Champaign (UIUC)*
University of North Carolina at Chapel Hill (UNC)
University of Pennsylvania (UPenn)
University of Tennessee (UT)*
University of Washington (UW)*

* Denotes USDA NIFA AFRI-CAP Leads and Participants & Sun Grant Schools

Advisory Committee - 58 organizations:
5 airports
4 airlines
7 NGO/advocacy
9 aviation manufacturers
11 feedstock/fuel manufacturers
22 R&D, service to aviation sector

For more information:
https://ascent.aero/
ASCENT COE Details

Timeline:
- In 2004, FAA established PARTNER Center of Excellence
- In 2013, FAA established Center of Excellence for Alternative Jet Fuels and Environment, a.k.a. Aviation Sustainability Center or ASCENT, continues PARTNER with expanded efforts on alt fuels

Budget Direction:
- FY2018 & FY2019 budget: FAA directed to use $15M in RE&D funds for ASCENT COE

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Where do we stand?

- Commercial flights on alternative jet fuels are expanding
- 1.5 million gallons in 2017 from two commercial producers, many commercial user, multiple U.S. airports

![Graph showing U.S. Alternative Jet Fuel Procurements](image)

Notes:
1. Includes procurements of fuel by U.S. government, U.S. airlines, manufacturers, and foreign carriers delivered to U.S. airports
Where are we headed?

Potential for 250 million gallons/year in five years

- 5 M gpy from 2016
  - 3 yr agreement 30/70 blend
  - 3 yr agreement Enabling LAX flts
- 375M usg
  - 90-180 M gpy Over 10 yrs
- 3 M gpy
- 3 M gpy
- 48 A350 deliveries 10% blend
  - Supply from 2018
- 10M gpy, 10 yrs
  - Up to 40M gal Over 5 yrs (MOU)
  - (Bioport on demand)
Commercial Aviation Alternative Fuels Initiative

A public – private coalition for commercial aviation to engage the emerging alternative fuels industry and government

- Communicate the Value Proposition of Sustainable Aviation Fuels (SAF)
- Enhance the Fuel Qualification Approach
- Implement Frameworks & Share Best Practices
- Develop the U.S. SAF Supply by Aligning Efforts to Enable Commercial Deployment

CAAFI Administrative Leadership Team:
- Steve Csonka, CAAFI Executive Director
- Chris Tindal, CAAFI Assistant Director
- Kristin Lewis (Volpe)
- Peter Herzig (Volpe)
- Nate Brown (FAA)
- Rich Altman, CAAFI Executive Director Emeritus

CAAFI Team Leads:
- C/Q: M. Rumizen (FAA)
- Sustainability: J. Hileman (FAA) & N. Young (A4A)
- Business: J. Heimlich (A4A)
- R&D: M. Lakeman (Boeing), S. Kramer (P&W), & G. Andac (GE)

CAAFI Steering Group: AIA, ACI-NA, A4A, GE, Boeing, P&W, ASCENT, DOE, USDA

CAAFI Website: http://caafi.org
Coordination Activities:
U.S. Agency Efforts Across the Supply Chain

Feedstock Production
- Agriculture: Biomass Crop Assistance Program & Crop Insurance Program
- Agriculture: Feedstock Development Center Grants
- Energy: R&D

Feedstock Logistics
- Energy & Defense: R&D grants

Fuel Conversion
- Agriculture & Energy: R&D grants

Conversion Process Scale-up/Integration

Fuel Testing / Approval
- FAA & Defense: C/Q Fuel testing
- FAA, Defense, & NASA: Enviro Analysis

Environment Assessment
- Agriculture, Navy, & Energy: Defense Production Act and Biorefinery Program

Enable Production
- EPA: Renewable Fuel Standard
- FAA: Guidance for Airports

End User/Buyer
- Airlines: fuel purchases
- Agriculture & Defense: Farm to Fleet
- FAA: ICAO CORSIA

All: Coordination with Other Federal Agencies
- Agriculture, Energy, FAA: Farm to Fly 2.0
Overview of FAA Testing Activities

Support ASTM International evaluation of alternative jet fuels and improve the evaluation process

- Support ASTM certification & qualification testing activities to develop data for new approvals (CAAFI, CLEEN, & ASCENT)
- ASTM Clearinghouse (CAAFI & ASCENT)
- OEM Review Process (ASCENT)
- Data Gathering & Library (ASCENT)
- Streamline approval process via the National Jet Fuels Combustion Program (ASCENT)

Testing Activities Resulting in Fuel Certification
Impact of FAA Testing Activities:

Alternative Jet Fuels are being Certified

- Created ASTM D7566 Specification (2009)
- 5 fuels added to the ASTM specification (2009-present)
  - Sixth approval Q2 2018
  - 6+ additional fuels under evaluation

- Created ASTM D4054 Process and D4054 Users Guide

- Filled “testing gap”
  - FAA funded testing of 7 fuels via first phase of CLEEN program
  - FAA funded testing of 5 fuels via second phase of CLEEN program

- D4054 Clearinghouse established via ASCENT to simplify and accelerate approval process (2016)
  - Facilitate funding from non-US government sources
  - Research report review support
  - Tier 1 & 2 testing for two fuels
  - EU, UK clearing houses in development
Overview of FAA Analysis Activities

Support better understanding of the environmental sustainability, economic costs, and potential supply of fuels from petroleum and alternative sources

- **ICAO Support** (ASCENT)
  - Greenhouse gas emissions life cycle analysis
  - Sustainability criteria
  - Alternative fuel production potential & policies

- **Supply Chain Development** (ASCENT, Volpe)
  - Opportunities & challenges for U.S. production
  - Regional supply chain studies (Pacific Northwest, Southeast, Hawaii)
  - Open source tools development (economic evaluation, environmental analysis, siting etc.)

- **Modeling Future Scenarios/Supply** (ASCENT, Volpe)

- **Reducing Emissions and Improving Performance through Fuel Composition Changes**

**Analyses Supporting Industry and Government Efforts**
Impact of FAA Analysis Activities:

Analyses being Used

- Inclusion of alternative jet fuels in DOE Argonne National Lab GREET model
- Renewable Fuel Standard (RFS) “opt in” for Alternative Jet Fuels
- California Low carbon fuel standard (LCFS) “opt in” for Alternative Jet Fuels
- Inclusion of Sustainable Aviation Fuels and Lower Carbon Aviation Fuels within CORSIA
  - Life cycle emissions methodology and values
  - Initial set of sustainability criteria
- Fuel production forecasts widely used by ICAO
- Support DOE funding activities for conversion process development
- Economic analyses being used by industry (e.g., High Freeze Point - HEFA)
- Complementing USDA regional activities
  - Increasing understanding of bottlenecks to production
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**Continuous Lower Energy, Emissions & Noise (CLEEN)**

- FAA led public-private partnership with 100% cost share from industry
- Reducing fuel burn, emissions and noise via aircraft and engine technologies and alternative jet fuels
- Conducting ground and/or flight test demonstrations to accelerate maturation of certifiable aircraft and engine technologies

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<th>Phase I</th>
<th>Phase II</th>
<th>Phase III*</th>
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<tr>
<td><strong>Time Frame</strong></td>
<td>2010-2015</td>
<td>2016-2020</td>
<td>2021-2025</td>
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<tr>
<td><strong>FAA Budget</strong></td>
<td>~$125M</td>
<td>~$100M</td>
<td>TBD</td>
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<td><strong>Noise Reduction</strong></td>
<td>25 dB cumulative noise reduction cumulative to Stage 5</td>
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<td><strong>Goal</strong></td>
<td><strong>and/or reduces community noise exposure</strong></td>
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<td><strong>NO\textsubscript{X} Emissions</strong></td>
<td>60% landing/take-off NO\textsubscript{X} emissions</td>
<td>75% landing/take-off NO\textsubscript{X} emissions (70% re: CAEP/8)</td>
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<td><strong>Reduction Goal</strong></td>
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<td><strong>Fuel Burn</strong></td>
<td>33% reduction</td>
<td>40% reduction</td>
<td>-20% re: CAEP/10 Std.</td>
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<tr>
<td><strong>Goal</strong></td>
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<td><strong>Entry into Service</strong></td>
<td>2018</td>
<td>2026</td>
<td>2031</td>
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*Notional

For more information on CLEEN program: [http://www.faa.gov/go/cleen](http://www.faa.gov/go/cleen)
CLEEN Details

Awardees:
- Aurora Flight Sciences (Phase II only)
- Boeing
- Delta Tech Ops, America’s Phenix, MDS Coating Technologies (Phase II only)
- General Electric (GE) Aviation
- Honeywell Aerospace
- Pratt & Whitney
- Rohr, Inc. / UTC Aerospace Systems (Phase II only)
- Rolls-Royce

Phase I Technologies:
- 9 Technologies focused on
  - Revolutionary Engine Design
  - Engine redesign
  - Wing technologies
  - Flight Management System Improvements
  - Improved Combustors

Phase II Technologies:
- 14 Technologies focused on
  - Fuselage redesign
  - Engine redesign
  - Wing technology
  - Flight Management System improvements
  - Improved combustion

For more information: http://www.faa.gov/go/cleen
CLEEN Highlights

CLEEN Phase I
• GE TAPS II Combustor entered fleet in 2016 on LEAP engine
• Pratt & Whitney Gen 2 geared turbofan propulsor technology successfully engine tested
• Boeing ceramic matrix composite nozzle flight tested on a 787 aircraft

CLEEN Phase II
• GE TAPS III Combustor has achieved CLEEN goals on NOx reduction
• Aurora Flight Sciences tested key structural subcomponent that enables mass-efficient double bubble fuselage
• America’s Phenix/Delta TechOps/MDS Coating Technologies currently conducting in-service flight evaluation of fan blade leading edge protective coating
• Boeing completed ground engine test of compact nacelle technology
• Rolls-Royce conducting full annular rig test for RQL low NOx combustion system
• Pratt & Whitney completed rig testing of advanced high pressure compressor technologies
## CLEEN Phase I Benefits:
Demonstrated technologies that reduce noise, emissions and fuel burn

### Boeing

<table>
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<tr>
<th>Technology</th>
<th>Reductions</th>
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<tr>
<td>Adaptive Trailing Edge</td>
<td>~2% fuel burn reduction</td>
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<td>~1.7 EPNdB cum in some single and twin aisles</td>
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<tr>
<td>CMC Acoustic Nozzle</td>
<td>~1% fuel burn reduction</td>
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<td>~2.3 EPNdB cumulative noise margin to Stage 4</td>
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### Honeywell

**Fuel Burn Technologies**
CLEEN technologies contributed to ~5% fuel burn reduction as part of a 15.7% fuel burn reduction engine package

### General Electric

**TAPS II Combustor** *(entered fleet in 2016)*
> 60% margin to CAEP/6 LTO NOx was achieved

**FMS/Engine and FMS/ATM Integration** *(Entered into service - LEAP engine on B737MAX, Airbus A320 Neo aircraft, and GE9X engine on 777X)*
0.7-1.0% fuel burn reduction

**Open Rotor**
~26% reduction in fuel burn (re: 737-800)
~15-17 EPNdB cumulative noise margin to Stage 4

### Rolls Royce

**Ceramic Matrix Composite Turbine Blade Track**
CMC blade tracks offer > 50% reduction in cooling flow and component weight.

**Rolls-Royce – Dual Wall Turbine Airfoil**
Dual Wall turbine airfoils provide > 20% reduction in cooling flow and increased operating temperature capability.

CLEEN tech will provide ~1% fuel burn reduction

For more information: [http://www.faa.gov/go/cleen](http://www.faa.gov/go/cleen)
CLEEN Phase II Technologies

- Aurora Flight Sciences: D8 Double Bubble Fuselage
- Boeing: Structurally Efficient Wing (SEW)
- Boeing: Compact Nacelle – Short Inlet / Acoustic Liners
- Delta Tech Ops/MDS Coating Technologies/America’s Phenix: Leading Edge Protective Blade Coatings
- GE: TAPS III Combustor
- GE: FMS Technologies
- GE: More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG)
- GE: Low Pressure Ratio Advanced Acoustics & Liners
- Honeywell: Compact Combustor System
- Honeywell: Advanced Turbine Blade Outer Air Seal (BOAS) System
- Honeywell: Advanced Acoustic Fan Module (TBC)
- Pratt & Whitney: High Pressure Compressor Aero-Efficiency Techs
- Pratt & Whitney: High Pressure Turbine Aero-Efficiency & Durability Techs
- Rolls Royce: Advanced RQL Low NOx Combustion System
- UTAS: Nacelle Technologies

✓ Completed technologies
Technology & Emissions Reduction

- Visible smoke emissions have been eliminated

- 50% reduction in CAEP Nitrogen Oxides (NOx) emissions standard since 1995

- CLEEN Program - Low NO\textsubscript{X} Combustors
  - GE TAPS II Combustor, LTO Nox: 55% below most recent CAEP std PM: 90% below CAEP visibility smoke limit
  - CLEEN II combustor development ongoing with GE, Honeywell, RR
Assessment of CLEEN Technologies

Analytical Evaluation:
• Conducted by Georgia Tech
• Evaluating impact on fuel burn and noise out to 2050
• Modeled most, but not all, Phase I and II CLEEN Technologies
• Evaluation of Phase I captured in two technical reports – results below

Key Results:
• 22 billion gallons of cumulative jet fuel saved - equivalent to 1.7 million cars taken off road between 2025 and 2050
• Contributes to 14% decrease in the land area exposed to DNL 65 dB and greater

Figure 40: Potential Fuel Burn Savings Provided by CLEEN Technologies Modeled in this Study
CLEEN Phase III Overview

- **CLEEN Phase III**: Follow-on to CLEEN Phase I and Phase II Programs focusing on aircraft noise, emissions and energy (five year program with 100% cost share)

  - **Purpose**:
    - Mature previously conceived noise, emissions and fuel burn reduction technologies for civil subsonic and supersonic airplanes from TRLs of 3-5 to TRLs of 6-7 to enable industry to expedite introduction of these technologies into current and future aircraft and engines
    - Assess jet fuels that could be compatible with the current fleet of aircraft (i.e., they are “drop-in” fuels) that could provide reductions in emissions or improvements in efficiency, including fuels that enable advancements in aircraft and engine design. This includes both conventional and alternative jet fuels.

- CLEEN Phase III technologies expected to be on a path for introduction into commercial aircraft in the 2025-2031 timeframe
CLEEN Phase III Outlook

- Notional CLEEN Phase III timeline (actual timeline in flux due to budget uncertainty)
- Industry Day Follow up: [https://faaco.faa.gov/index.cfm/announcement/view/32134](https://faaco.faa.gov/index.cfm/announcement/view/32134)

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Conclusion

• Utilizing a comprehensive approach to address environmental challenges

• Working with a broad range of stakeholders to understand issues and develop solutions

• Placing more focus on innovation to overcome noise and emissions challenges

• Continue to seek partnerships for our R&D efforts