Overcoming the Environmental Challenges Facing Aviation

To: 32nd Annual Aviation Noise and Emissions Symposium

By: Dr. James I. Hileman
Chief Scientific and Technical Advisor for Environment and Energy
Federal Aviation Administration
Office of Environment and Energy

Date: February 26, 2018
FAA Organizational Structure

Environment and Energy R&D Portfolio
Economic Benefits of Aviation

5.1% of U.S. GDP

10.6 Million U.S. jobs

$1.6 Trillion in U.S. economic activity annually

$59.9 Billion of U.S. Trade Balance (exports-imports)

SOURCE: FAA Air Traffic Organization

Aviation equipment (aircraft, spacecraft, and related equipment) is largest export sector in U.S. economy accounting for over 8% of total exports.

SOURCE: U.S. International Trade Commission
Benefits to Regional and Local Economies

• Aviation is a critical link for people, goods and services coming in and out of communities

• Access to aviation can be a vital reason that some companies use when choosing to locate offices, manufacturing and/or distribution facilities; and

• Passenger and cargo service can be crucial for community access and time-critical delivery services ranging from mail and packages to pharmaceuticals, biotech devices and computer components.
Environmental Impacts of Aviation

- **CO₂:** 71%
- **Water:** 28%
- CO, HC, NOₓ, SOₓ, Primary PM₂.₅: < 1%

Atmospheric Chemistry and Physics

- **Primary PM₂.₅**
- **Secondary PM₂.₅**
- SOₓ
- NOₓ
- UHC
- CO
- Ozone
- Soot
- CO
- H₂O
- CH₄

Global Climate Change

- Cooling Effects
- Warming Effects

Combustion Emissions

Emissions from Fuel Production

Contrails & Cirrus Clouds

Land and Water Usage

Aircraft Noise

Population Exposure and Health Impacts
Environmental Protection that Allows Sustained Aviation Growth

ENVIRONMENT AND ENERGY GOALS

**NOISE**
Reduce the number of people exposed to significant noise around U.S. airports

**AIR QUALITY**
Reduce significant air quality impacts attributable to aviation

**ENERGY**
Achieve net fuel burn reduction by 2020 relative to a 2005 baseline and deploy sustainable aviation fuels.
Environmental & Energy Strategy

FAA VISION
Reach the next level of safety, efficiency, environmental responsibility and global leadership

GOALS
• Noise
• Air Quality
• Energy

PLAN
• Environment and energy policy statement
• U.S. Action Plan
• Research roadmaps

ADVANCE SCIENCE AND INTEGRATED MODELING
Source characterization → Propagation and dispersion
Health and welfare impacts → Aviation Environmental Tool Suite

IMPROVE
• Adapt roadmaps
• Fill research pipeline

EVALUATE
• Progress toward goals
• Mitigation opportunities

IMPLEMENT
- Technology
- Alternative Fuels
- Operations
- Policy

Notes:
3. Environment and Energy Website: http://www.faa.gov/go/environment
Addressing the Aircraft Noise Challenge

• **Understanding Impact of Noise**
  – Improving modeling capabilities
  – Examining relationship between noise and annoyance, sleep, cardiovascular health and children’s learning.
  – Evaluating current aircraft, helicopters, emerging civil supersonic aircraft and commercial space vehicles, and drones.

• **Outreach**
  – Increase public understanding
  – Community engagement

• **Mitigation**
  – Land use planning and related measures
  – Vehicle operations
  – Airframe and engine technology
  – Aircraft architecture
Multiple Strategies for Aviation Noise
(as presented to Oct 2017 ACI-AAAE Noise Symposium)

• Reduce noise at the source
• Maintain or update noise standards
• Advance Performance-Based Navigation (PBN)
• Noise Compatibility Planning (Part 150)
• Enhanced community involvement (e.g., community roundtables)
• Noise-based access restrictions (Part 161)
• Noise mitigation
Addressing Aircraft Emissions

- **Understanding Impacts**
  - Particulate Matter (PM) measurements and modeling
  - Improving air quality and climate modeling capabilities
  - Evaluating current aircraft, commercial supersonic aircraft, unmanned aerial systems, and commercial space vehicles

- **Mitigation**
  - Vehicle operations
  - Alternative fuels
  - Airframe and engine technology
  - Aircraft architecture
  - Engine standard (CAEP PM standard)
  - Policy measures (CORSIA)
Aviation Sustainability Center (ASCENT)

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)

In operation since Sept 2013
- Continuing work of PARTNER COE
- $10+ million annual funding
- 50+ ongoing research projects
- 110+ publications per year
- 110+ students involved
- 70 industry research partners

ASCENT Website: http://ascent.aero
## Improved Scientific Knowledge for Solution Development

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Key Research Questions</th>
<th>Research Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise</td>
<td>How do we define significance in regards to aircraft noise?</td>
<td>ASCENT COE</td>
</tr>
<tr>
<td></td>
<td>What are the public health and welfare impacts of aircraft noise?</td>
<td>Tech Center</td>
</tr>
<tr>
<td></td>
<td>How do we certify “low-boom” supersonic aircraft?</td>
<td>Volpe Center</td>
</tr>
<tr>
<td>Air Quality</td>
<td>How do we define significance in regards to aircraft emissions that degrade air quality?</td>
<td>ASCENT COE</td>
</tr>
<tr>
<td>Energy</td>
<td>How do we characterize annual variations in system-wide fuel efficiency?</td>
<td>ASCENT COE</td>
</tr>
<tr>
<td></td>
<td>How do we define sustainability of alternative jet fuels?</td>
<td>CAAFI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CLEEN Program</td>
</tr>
<tr>
<td>Climate</td>
<td>What is the incremental impact of non-CO2 aircraft emissions on global and regional climate?</td>
<td>ASCENT COE</td>
</tr>
</tbody>
</table>
Aviation Environmental Tool Suite

Modeling range of solutions and their consequences on fuel use, noise and emissions (basket of measures for CO$_2$ and balanced approach for noise)

Policy and Scenarios
Including outputs from other tools and analyses as appropriate

Rapid Fleet-Wide Environmental Assessment

Alternative Fuels
Source and Composition

Aircraft Design
Existing Aircraft, New Aircraft, and/or Generic Fleet

Operations

Fleet Evolution, Economics Estimation & Evaluation (FOM, APMT-E, FLEET-BUILDER)

Cost Benefit Analysis

Aviation Environmental Design Tool (AEDT)

Single Flight/Airport
Regional
Global Studies

Integrated Noise, Emissions, and Fuel Burn Analyses

Aviation Environmental Impacts Analysis (APMT-I)

Emissions & Noise

Climate Impacts
Air Quality Impacts
Noise Impacts

Monetized Impacts

Emissions, Noise, & Fuel Burn

Collected Costs
Science and Analysis to Support Decision-Making

- Aviation environmental policies impact noise, climate and air quality. Using the aviation environmental tool suite to assess the impacts of noise and emissions for policy assessment.

- Tool suite informing decision making:
  - CAEP/11 PM Std (2019)
  - CAEP/10 CO$_2$ Std (2016)
  - CAEP/9 Noise Std (2013)
  - CAEP/8 NOx Std (2010)

- FAA uses cost/benefit analysis elements to supplement cost-effectiveness analysis in CAEP

- Tool suite provided analytical support to CORSIA development
- Developing capabilities to support NextGen business case evaluation

Additional information on APMT-Impacts and its use is available at: http://partner.mit.edu/projects/valuation-and-trade-offs-policy-options
FAA Activities

• Testing
  ▪ Support Certification/Qualification testing
  ▪ Improve Certification/Qualification process
  ▪ Emissions measurements

• Analysis
  ▪ Environmental sustainability
  ▪ Techno-economic analysis
  ▪ Future scenarios

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

CAAFI: http://caafi.org
CLEEN Program: http://www.faa.gov/go/cleen/
ASCENT: http://ascent.aero
Commercial Aviation Alternative Fuels Initiative

- Communicate the Value Proposition of SAJF
- Enhance the Fuel Qualification Approach
- Implement Frameworks & Share Best Practices
- Develop the U.S. SAJF 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, C/Q
- Sustainability: J. Hileman & N. Young,
- Business: J. Heimlich
- R&D : M. Lakeman, S Kramer, & G. Andac

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

CAAFI Website: http://caafi.org
Where We Stand Today

- Commercial flights on AJF are taking place
- 1.5 million gallons in 2017 from two commercial producers, many commercial users

**U.S. Alternative Jet Fuel Procurements**

Notes:
1. Includes procurements of fuel by U.S. government, U.S. airlines, manufacturers, and foreign carriers delivered to U.S. airports
Continuous Lower Energy, Emissions & Noise (CLEEN)

- FAA led public-private partnership with 50-50 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

For More Information, please visit CLEEN Fact Sheet and Website:
- [http://www.faa.gov/go/cleen](http://www.faa.gov/go/cleen)

<table>
<thead>
<tr>
<th>Technology</th>
<th>CLEEN I</th>
<th>CLEEN II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Frame</td>
<td>2010-2015</td>
<td>2016-2020</td>
</tr>
<tr>
<td>FAA Budget</td>
<td>~$125M</td>
<td>~$100M</td>
</tr>
<tr>
<td>Noise Reduction Goal</td>
<td>32 dB cumulative noise reduction</td>
<td>32 dB cumulative noise reduction</td>
</tr>
<tr>
<td>NO$_X$ Emissions Reduction Goal</td>
<td>60% landing/take-off NO$_X$ emissions</td>
<td>75% landing/take-off NO$_X$ emissions</td>
</tr>
<tr>
<td>Fuel Burn Goal</td>
<td>33% reduction</td>
<td>40% reduction</td>
</tr>
<tr>
<td>Entry into Service</td>
<td>2018</td>
<td>2026</td>
</tr>
</tbody>
</table>
CLEEN Phase I Overview

CLEEN Phase 1 Program Details:
• Reducing environmental impacts via aircraft technology and alternative jet fuels
• Five year effort to accelerate technology maturation (2010-2015)
• 50% cost share; total FAA budget: ~$125M

CLEEN Phase 1 Program Goals:
• 32 dB cumulative noise reduction
• 60% landing/take-off NOx emissions reduction
• 33% fuel burn reduction

Conducting ground and/or flight test demonstrations of certifiable aircraft technologies with entry into service by 2018

Based on 5-year cost share agreements with industry

Awardees:

Boeing
Ceramic Matrix Composite Nozzle
Adaptive Trailing Edge

Honeywell
New coatings, higher temperature impeller, advanced seals and improved turbine cooling.

Pratt & Whitney
Ultra-high Bypass Ratio Geared Turbofan

Rolls-Royce
Ceramic Matrix Composite Blade Tracks and Dual-Walled Turbine Airfoils

General Electric
Flight Management System / Air Traffic Integration
Flight Management System / Engine Integration
Twin Annular Premixing Swirler (TAPS) II Low NOx Combustor
Open Rotor Engine

For more information: http://www.faa.gov/go/cleen
CLEEN Phase I Benefits: Demonstrated technologies that reduce noise, emissions and fuel burn

**Boeing**

Adaptive Trailing Edge
~ 2% fuel burn reduction
~ 1.7 EPNdB cum in some single and twin aisles

CMC Acoustic Nozzle
~ 1% fuel burn reduction
~ 2.3 EPNdB cumulative noise margin to Stage 4

**Honeywell**

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

**Pratt & Whitney**

Geared Turbofan Technologies
CLEEN techs expand design space for engine with ~20% fuel burn reduction, > 20 EPNdB cumulative noise margin to Stage 4

**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 Overview

CLEEN Phase II Program Details:
- Reducing environmental impacts via aircraft technology and alternative jet fuels
- Five year effort to accelerate technology maturation *(2015-2020)*
- 50% cost share; total FAA budget: ~$100M

CLEEN Phase II Program Goals:
- 32 dB\(^1\) cumulative noise reduction
- 70%\(^2\) landing/take-off NOx emissions reduction
- 40%\(^1\) fuel burn reduction

Conducting ground and/or flight test demonstrations of certifiable aircraft technologies with entry into service by 2026

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

Based on 5-year cost share agreements with industry

\(^1\) Common baseline with CLEEN I goals

\(^2\) 70% reduction in landing and take-off NOx relative to CAEP/8 standard. Relative to CLEEN I baseline of CAEP/6 this is a 75% reduction.

For more information: 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
- 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
- Honeywell: Compact Combustor System
- Honeywell: Advanced Turbine Blade Outer Air Seal (BOAS) System
- 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: Thrust Reverser Technology
Assessment of CLEEN Technologies

PARTNER Project 36 (Georgia Tech)

- Environmental Design Space (EDS) used to provide independent assessment of technologies (leveraged PARTNER Project 14 and NASA efforts)
- Modeled most, but not all CLEEN Technologies. Did not model all GE technologies
  - Open rotor engine
  - Engine control/flight management system integration
  - Flight management system/air traffic management integration

Follow-on Efforts

- ASCENT Project 10 (GeorgiaTech-Stanford-Purdue) – evaluating all CLEEN technologies for $\text{CO}_2$, $\text{NO}_x$ and noise
- ASCENT Project 37 (GT) CLEEN II Technology Evaluation

**Figure 40: Potential Fuel Burn Savings Provided by CLEEN Technologies Modeled in This Study**

22 billion gallons of cumulative jet fuel saved
- 1.7 million cars off road between 2025 and 2050
- $2.75$ billion annual savings to airlines

PARTNER Project 36 report can be downloaded at:
Aircraft Evolution – 1947 to Today

• Every large jet aircraft today is a descendant of the Boeing B-47\(^1\)

• Need a change in aircraft configuration to “solve” the aircraft noise challenge

Source:

The Jet as Art by Jeffrey Milstein\(^2\)
A Step-Change in Environmental Performance

• A step change in noise reduction will only be achieved if it is accompanied by a step change in fuel burn while ensuring safe operation

• Need to integrate engine, airframe and operations
  – Change configuration to allow larger bypass ratio engines
  – Shield engine noise with lifting fuselage
  – Flush mount engines to allow for boundary layer ingestion
  – Reduce cruise Mach with unswept wings

• Multiple Programs:
  – CMI Silent Aircraft Initiative
  – NASA Environmentally Responsible Aviation and N+3 Projects

• NASA New Aviation Horizons Initiative
  – Need flight demonstrations to mature new concepts
  – Critical to solving the noise challenge facing aviation

More Information:
• NASA ERA: http://www.aeronautics.nasa.gov/isrp/era/index.htm
• NASA SFW Project: http://www.aeronautics.nasa.gov/fap/sfw_project.html
• CMI SAI: http://silentaircraft.org/
Closing Observations

• Environmental and energy constraints are significant.
• Aviation noise causing considerable challenges today.
• Need a balanced approach to address aviation environmental impacts and energy concerns.
• Alternative fuels and technology will be key to overcoming environmental constraints.
• New users of NAS will present additional challenges (Unmanned Aerial Systems, Commercial Space Vehicles, Civil Supersonic Aircraft).
• We are advancing understanding, but not waiting; we are using best available methods to seek solutions now.
Dr. Jim Hileman
Chief Scientific and Technical Advisor for Environment and Energy
Federal Aviation Administration
Office of Environment and Energy
Email: james.hileman@faa.gov