Overcoming the Environmental Challenges Facing Aviation

To: 32nd Annual Aviation Noise and Emissions Symposium

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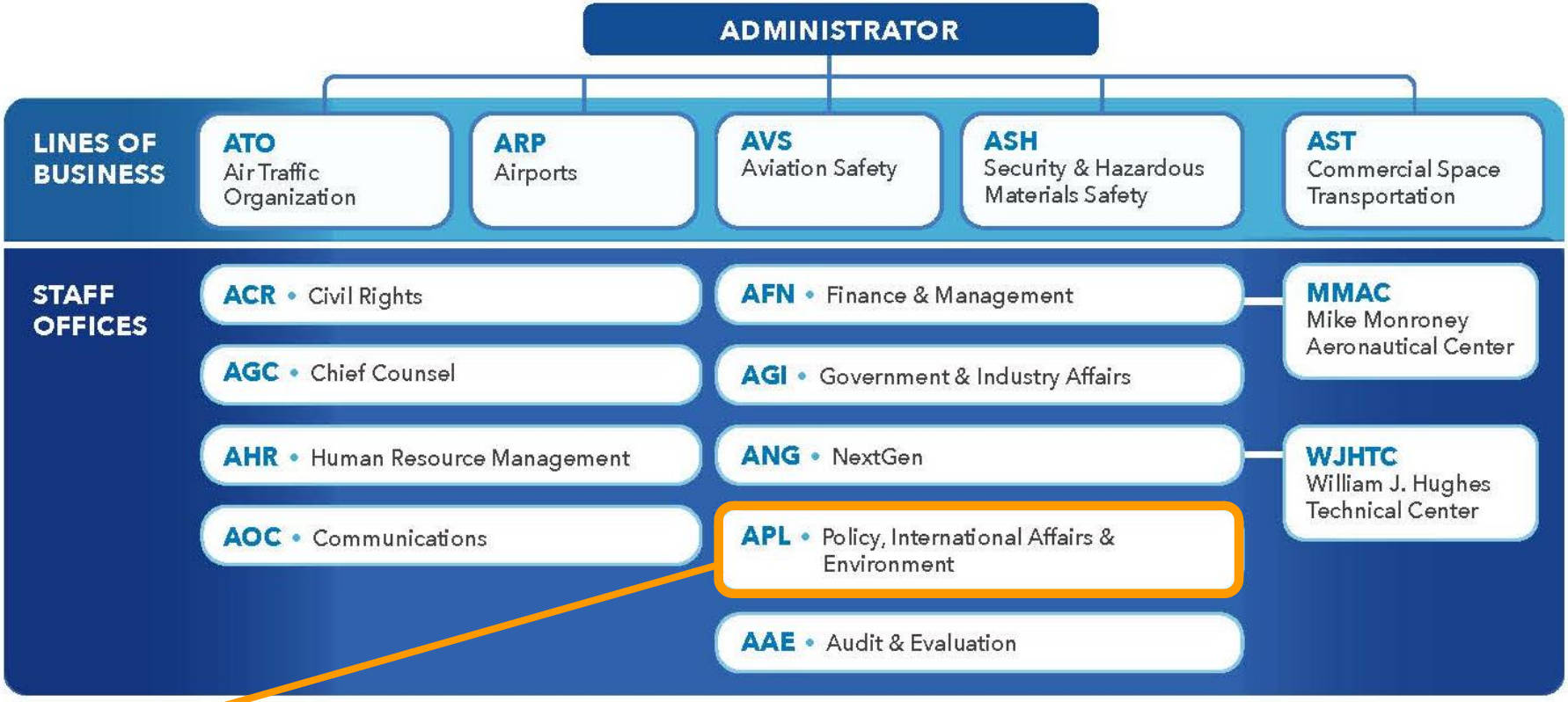
Federal Aviation Administration
Office of Environment and Energy

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

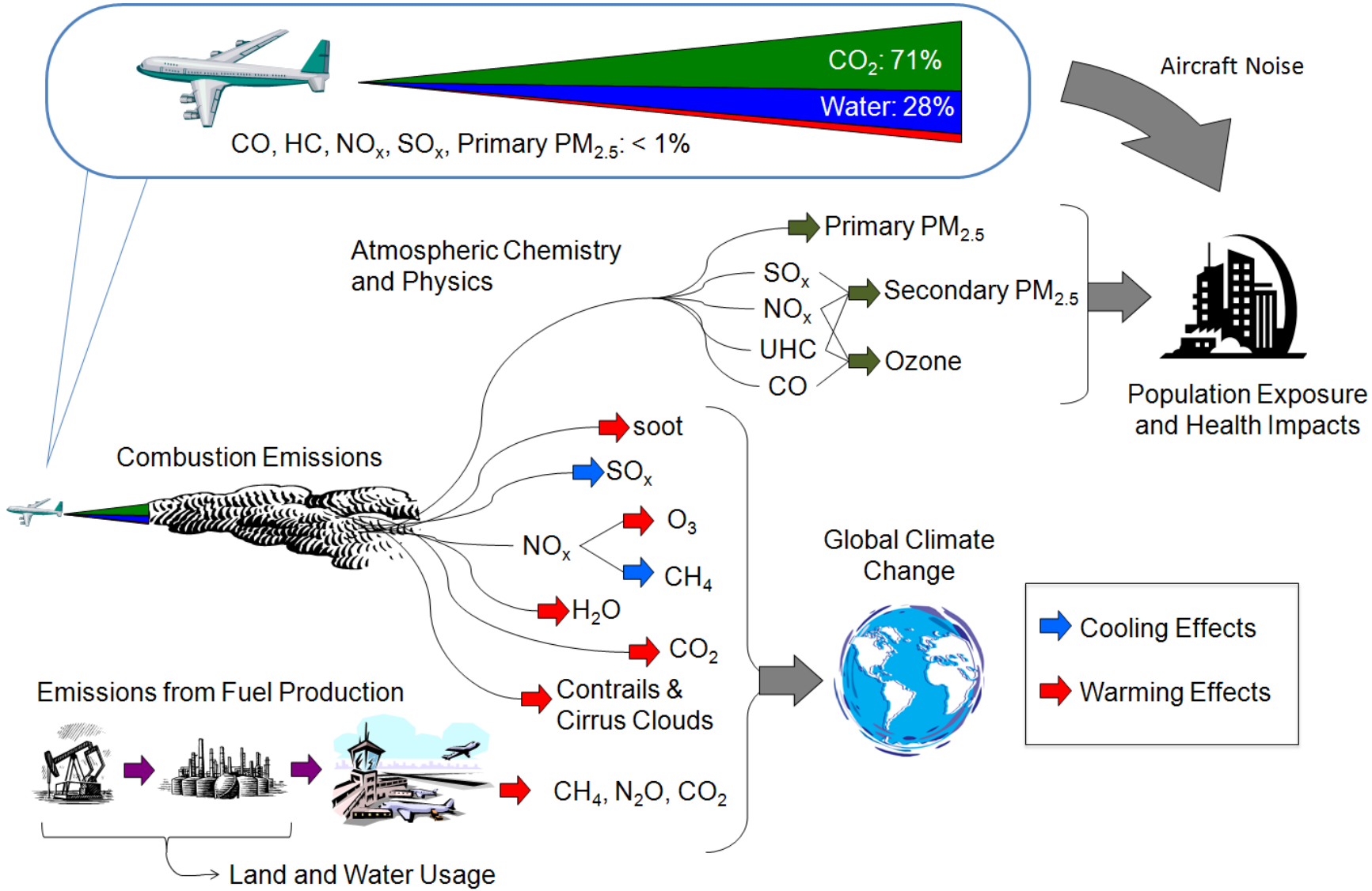
Aviation equipment (aircraft, spacecraft, and related equipment) is largest export sector in U.S. economy accounting for over 8% of total exports.

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



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 [1]
- U.S. Action Plan [2]
- Research roadmaps [3]

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:
1. Aviation E&E Policy Statement (Federal Register 77-141, 2012): http://www.faa.gov/about/office_org/headquarters_offices/apl/environ_policy_guidance/policy/media/FAA_EE_Policy_Statement.pdf
2. U.S. Aviation GHG Emissions Reduction Plan: http://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx
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)

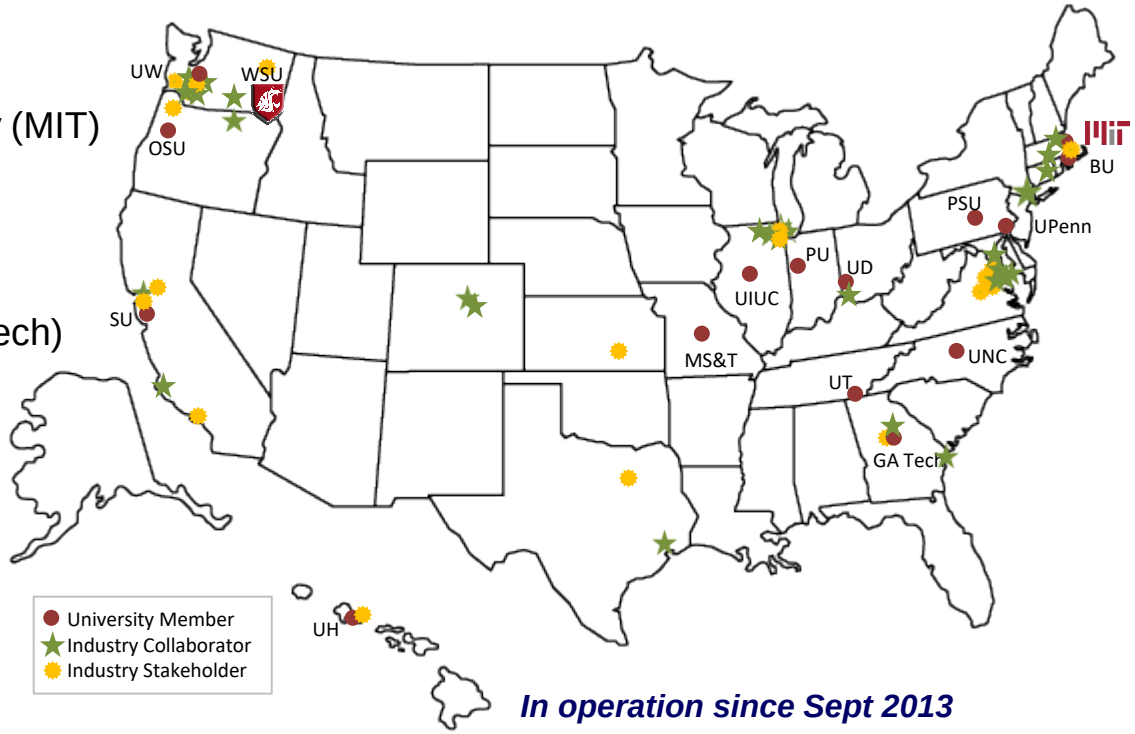
Aviation Sustainability Center (ASCENT)

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

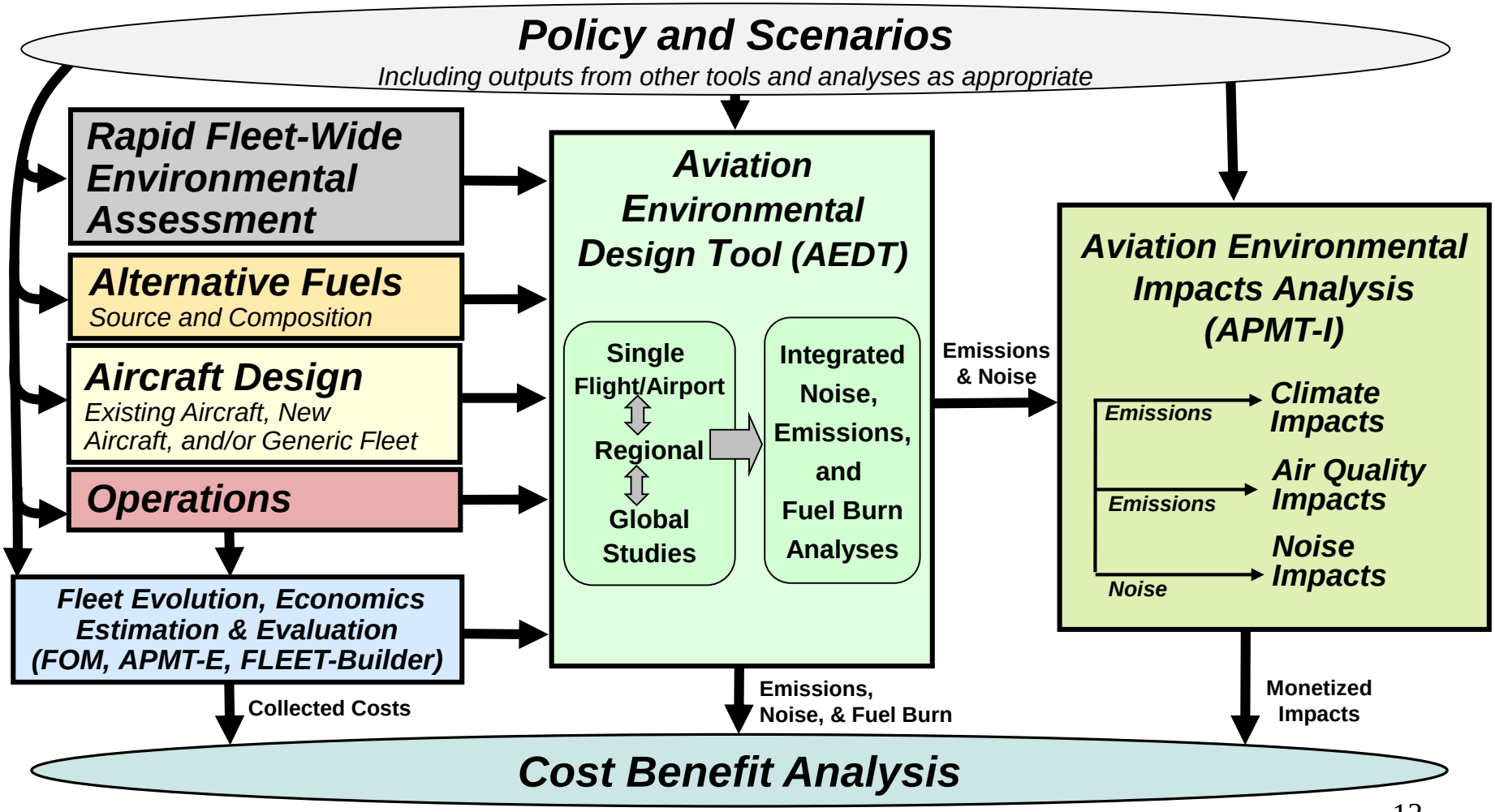
- ***Continuing work of PARTNER COE***
- ***$10+ million annual funding***
- ***50+ ongoing research projects***
- ***110+ publications per year***
- ***110+ students involved***
- ***70 industry research partners***

Improved Scientific Knowledge for Solution Development

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

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)



Science and Analysis to Support Decision-Making

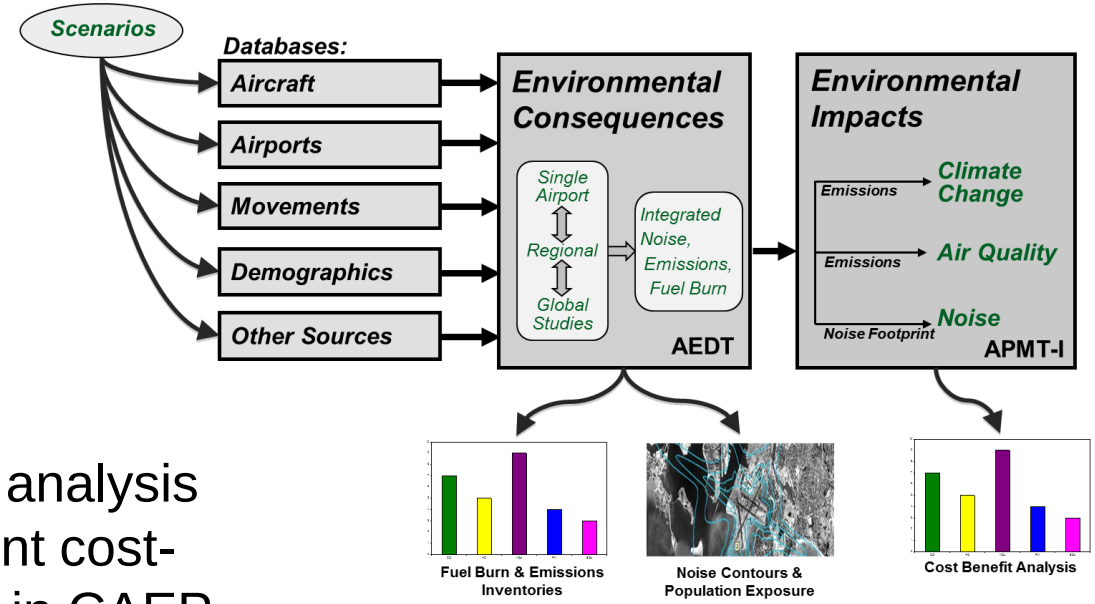
- Aviation environmental policies impact noise, climate and air quality. Using the aviation environmental tool suite to assess the impacts of noise and emissions for policy assessment.
- Tool suite informing decision making:

  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

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®
COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

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

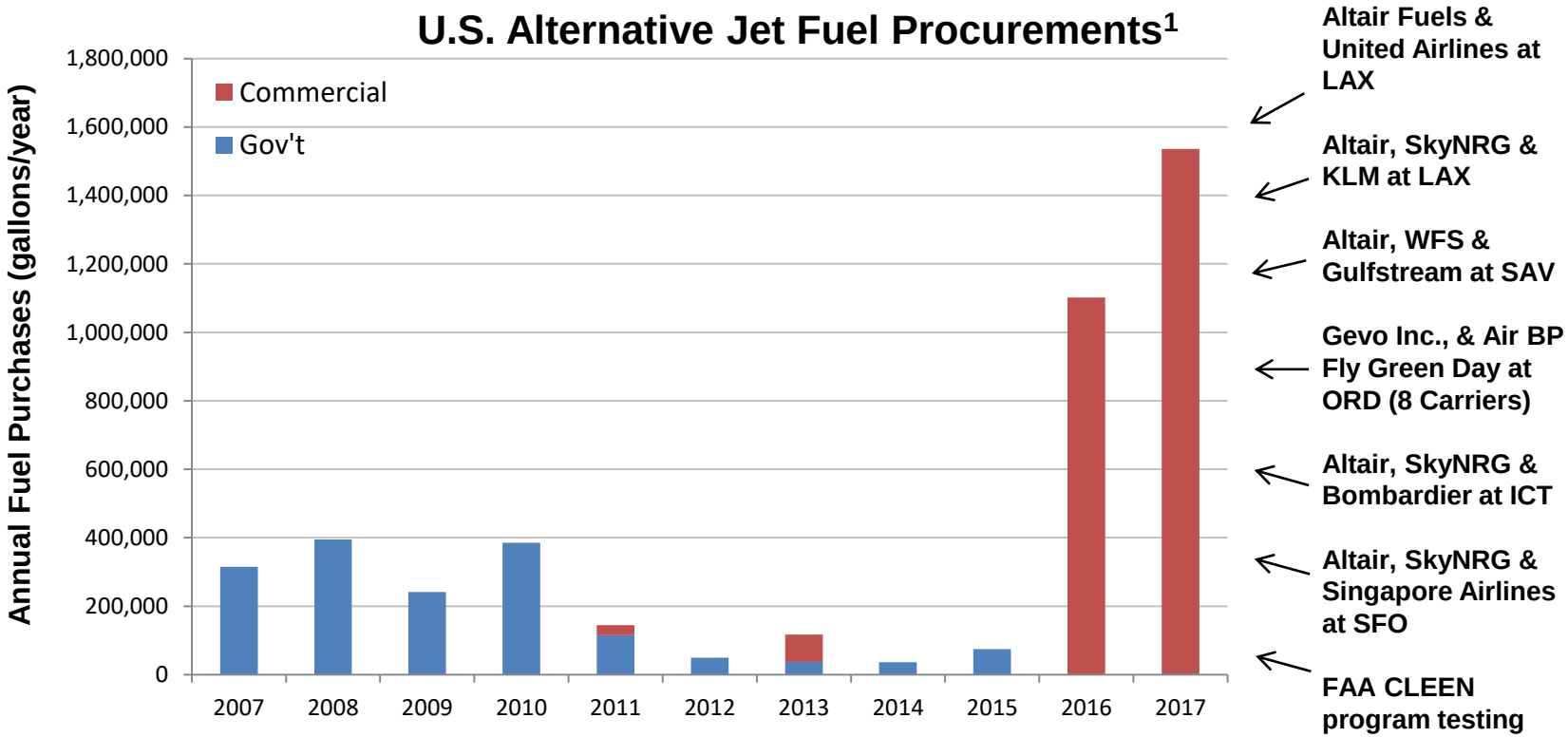
CAAFI Team Leads:

- 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

Where We Stand Today

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

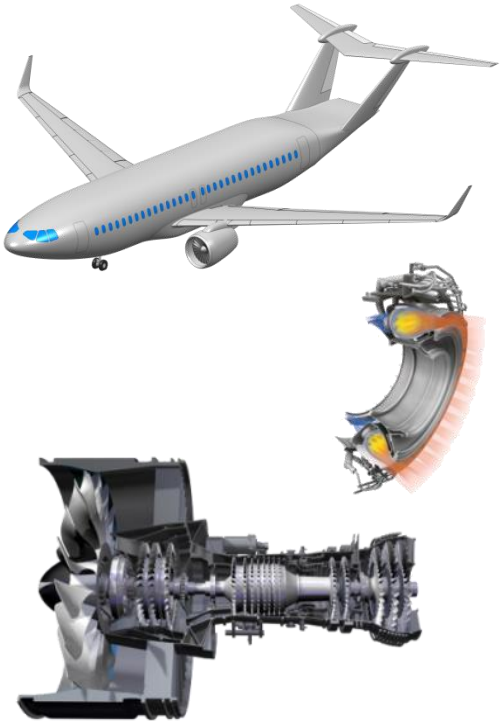


Notes:
1. Includes procurements of fuel by U.S. government, U.S. airlines, manufacturers, and foreign carriers delivered to U.S. airports

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

	CLEEN I	CLEEN II
Time Frame	2010-2015	2016-2020
FAA Budget	~$125M	~$100M
Noise Reduction Goal	32 dB cumulative noise reduction	32 dB cumulative noise reduction
NO_X Emissions Reduction Goal	60% landing/take-off NO_X emissions	75% landing/take-off NO_X emissions
Fuel Burn Goal	33% reduction	40% reduction
Entry into Service	2018	2026



For More Information, please visit CLEEN Fact Sheet and Website:

- https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=22534
- http://www.faa.gov/go/cleen

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

Rolls-Royce

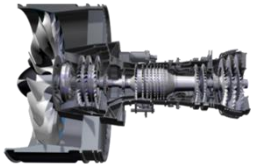
Ceramic Matrix Composite Blade Tracks and Dual-Walled Turbine Airfoils

Honeywell

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

Pratt & Whitney

Ultra-high Bypass Ratio Geared Turbofan

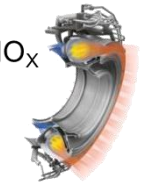


General Electric

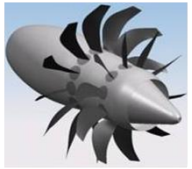
Flight Management System / Air Traffic Integration

Flight Management System / Engine Integration

Twin Annular Premixing Swirler (TAPS) II Low NO_X Combustor



Open Rotor Engine



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)
~15-17EPNdB 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

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***

Based on 5-year cost share agreements with industry

Awardees:

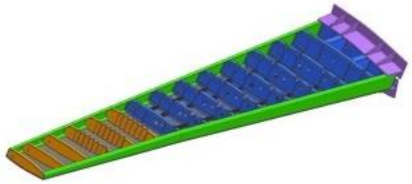
- Aurora Flight Sciences
- Boeing
- Delta Tech Ops, America's Phenix, MDS Coating Technologies
- General Electric (GE) Aviation
- Honeywell Aerospace
- Pratt & Whitney
- Rolls-Royce
- Rohr, Inc. / UTC Aerospace Systems

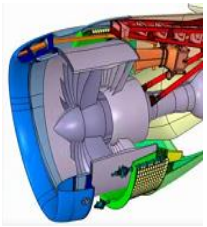
[1] Common baseline with CLEEN I goals

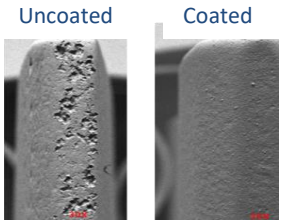
[2] 70% reduction in landing and take-off NOx relative to CAEP/8 standard. Relative to CLEEN I baseline of CAEP/6 this is a 75% reduction.

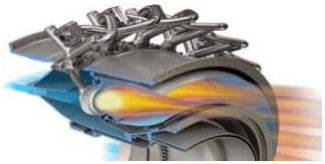
CLEEN Phase II Technologies

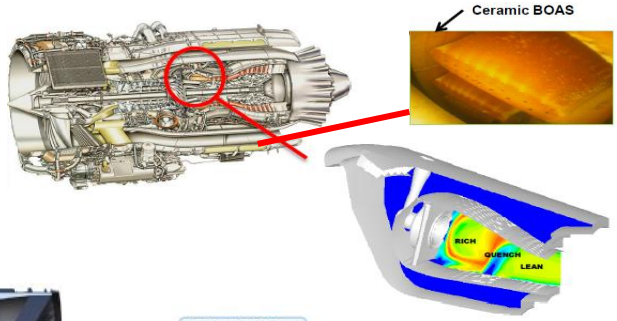
- Aurora Flight Sciences: D8 Double Bubble Fusela
- Boeing: Structurally Efficient Wing (SEW)
- Boeing: Compact Nacelle – Short Inlet
- Delta Tech Ops/MDS Coating Technologies/America's Phenix: Leading Edge Protective Blade Coatings
- GE: TAPS III Combustor
- GE: FMS Technologies
- GE: More Electric 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

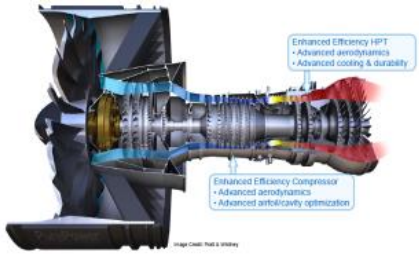












Assessment of CLEEN Technologies

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


PARTNER

Partnership for AIR Transportation Noise and Emissions Reduction
An FAA/NASA/Transport Canada-sponsored Center of Excellence

Environmental Design Space Assessment of Continuous Lower Energy Emissions and Noise (CLEEN) Technologies

PARTNER Project 36 Final Report

prepared by
Dimitri Mavris, Jimmy C. Tai, Christopher Perullo

March 2016

REPORT NO. PARTNER-COE-2016-001

Follow-on Efforts

- ASCENT Project 10 (GeorgiaTech-Stanford-Purdue) – evaluating all CLEEN technologies for CO_2, NO_X and noise
- ASCENT Project 37 (GT) CLEEN II Technology Evaluation

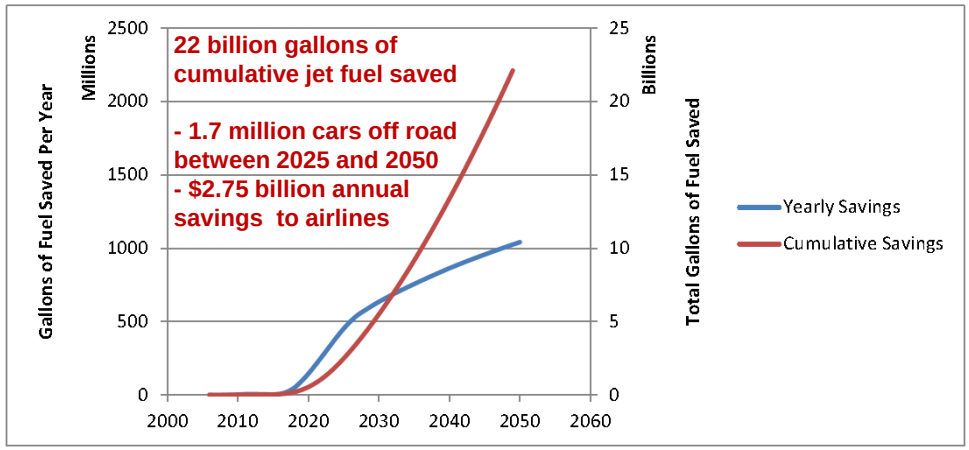


FIGURE 40: POTENTIAL FUEL BURN SAVINGS PROVIDED BY CLEEN TECHNOLOGIES MODELED IN THIS STUDY

PARTNER Project 36 report can be downloaded at:
http://partner.mit.edu/sites/partner.mit.edu/files/PARTNER-Project-36-final-report.pdf

Aircraft Evolution – 1947 to Today

- Every large jet aircraft today is a descendant of the Boeing B-47[1]

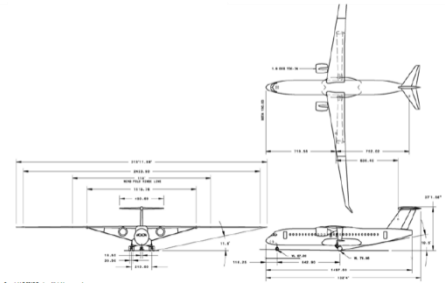
- Need a change in aircraft configuration to “solve” the aircraft noise challenge

The Jet as Art by Jeffrey Milstein[2]

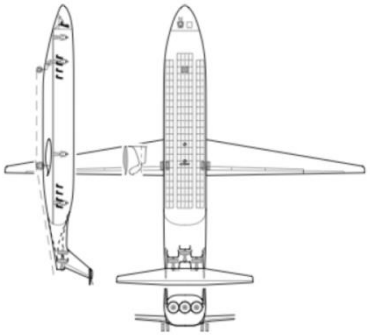
Source:
1. http://www.boeing.com/history/products/b-47-stratojet.page
2. http://www.jeffreymilstein.com/index/aircraft.html#grid

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

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Office of Environment and Energy

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