REDAC Environment and Energy Sub-Committee

Aircraft Technology Research

By: Levent Ileri and Chris Dorbian
FAA CLEEN Program

Date: September 14, 2021

Federal Aviation Administration

Agenda

- **Continuous Lower Energy, Emissions & Noise (CLEEN) Program Overview**
  - CLEEN Phase I
  - CLEEN Phase II
  - CLEEN Phase III
- **Aviation Sustainability Center of Excellence (ASCENT) Technology Projects Update**

Continuous Lower Energy, Emissions & Noise (CLEEN) Program

- 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

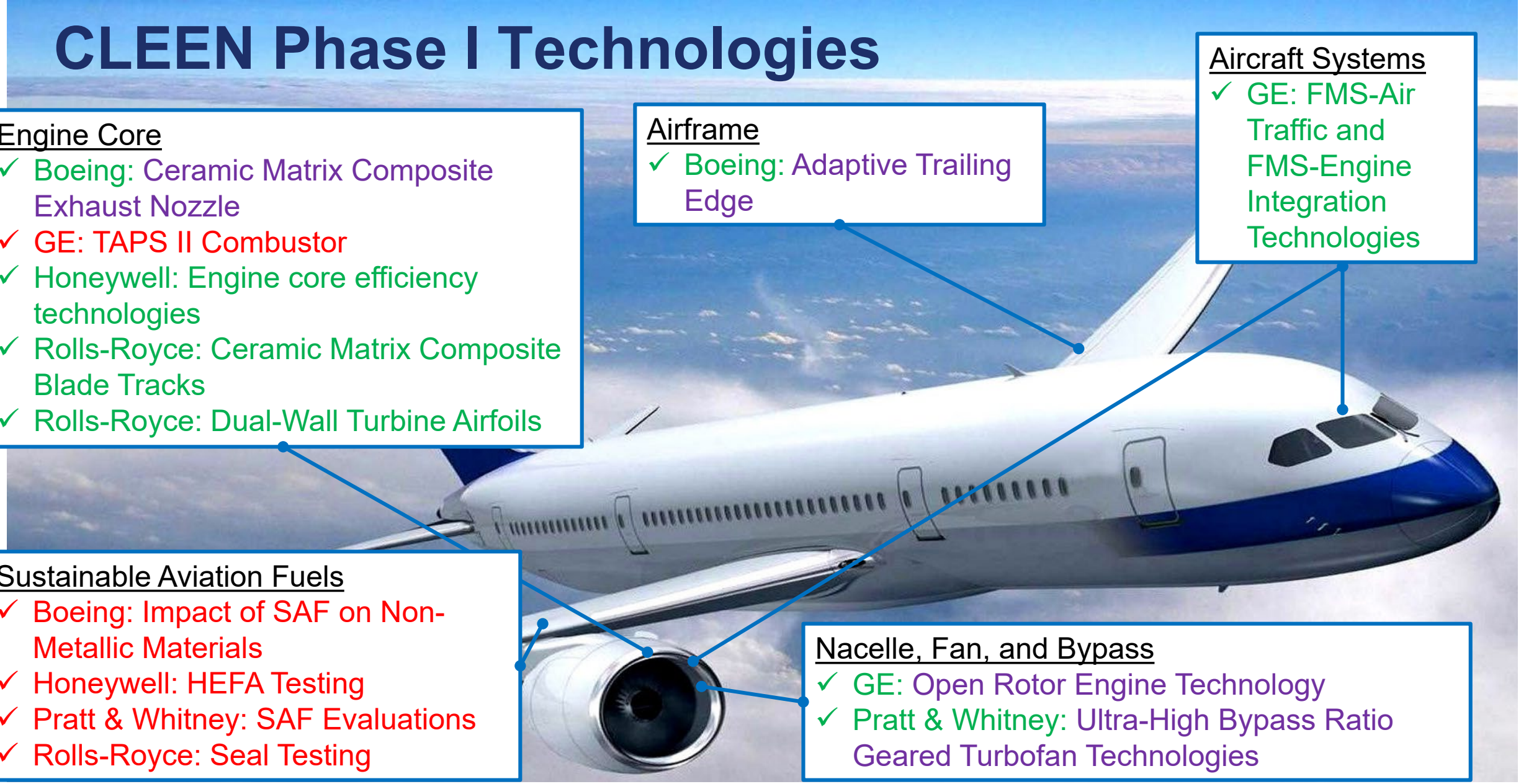
	Phase I	Phase II	Phase III
Time Frame	2010-2015	2016-2020	2021-2025
FAA Budget	~$125M	~$100M	~$100M+
Noise Reduction Goal	25 dB cumulative noise reduction cumulative to Stage 5 ***and/or reduces community noise exposure (new goal for Phase III)***		
Fuel Burn Goal	33% reduction	40% reduction	-20% re: CAEP/10 Std.
NO_X Emissions Reduction Goal	60% landing/take-off NO_X emissions (re: CAEP/6)	75% landing/take-off NO_X emissions (-70% re: CAEP/8)	
Particulate Matter Reduction Goal			Reduction relative to CAEP/11 Std
Entry into Service	2018	2026	2031

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

CLEEN III Industry Day: https://faaco.faa.gov/index.cfm/announcement/view/32134

CLEEN III Solicitation: https://faaco.faa.gov/index.cfm/announcement/view/31885

CLEEN Phase I Technologies



Engine Core
- ✓ Boeing: Ceramic Matrix Composite Exhaust Nozzle
- ✓ GE: TAPS II Combustor
- ✓ Honeywell: Engine core efficiency technologies
- ✓ Rolls-Royce: Ceramic Matrix Composite Blade Tracks
- ✓ Rolls-Royce: Dual-Wall Turbine Airfoils

Airframe
- ✓ Boeing: Adaptive Trailing Edge

Aircraft Systems
- ✓ GE: FMS-Air Traffic and FMS-Engine Integration Technologies

Sustainable Aviation Fuels
- ✓ Boeing: Impact of SAF on Non-Metallic Materials
- ✓ Honeywell: HEFA Testing
- ✓ Pratt & Whitney: SAF Evaluations
- ✓ Rolls-Royce: Seal Testing

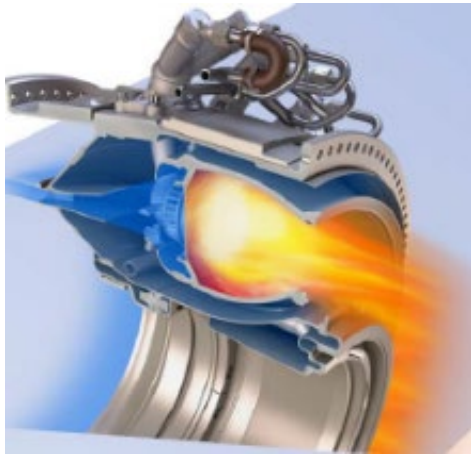
Nacelle, Fan, and Bypass
- ✓ GE: Open Rotor Engine Technology
- ✓ Pratt & Whitney: Ultra-High Bypass Ratio Geared Turbofan Technologies

Fuel
Emissions
Noise

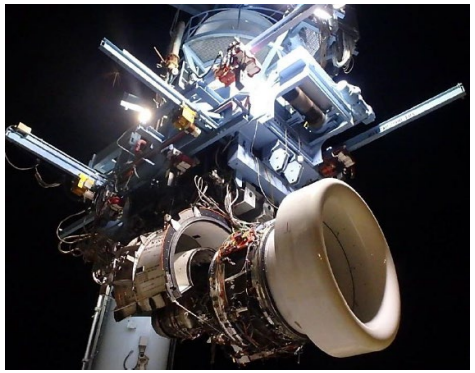
✓ Completed Effort

Success Stories from CLEEN I

- GE TAPS II Combustor entered fleet in 2016 on LEAP engine; installed on Airbus 320neo, Boeing 737 MAX, and COMAC C919
  Exceeds CLEEN Phase I NO_X Reduction Goal

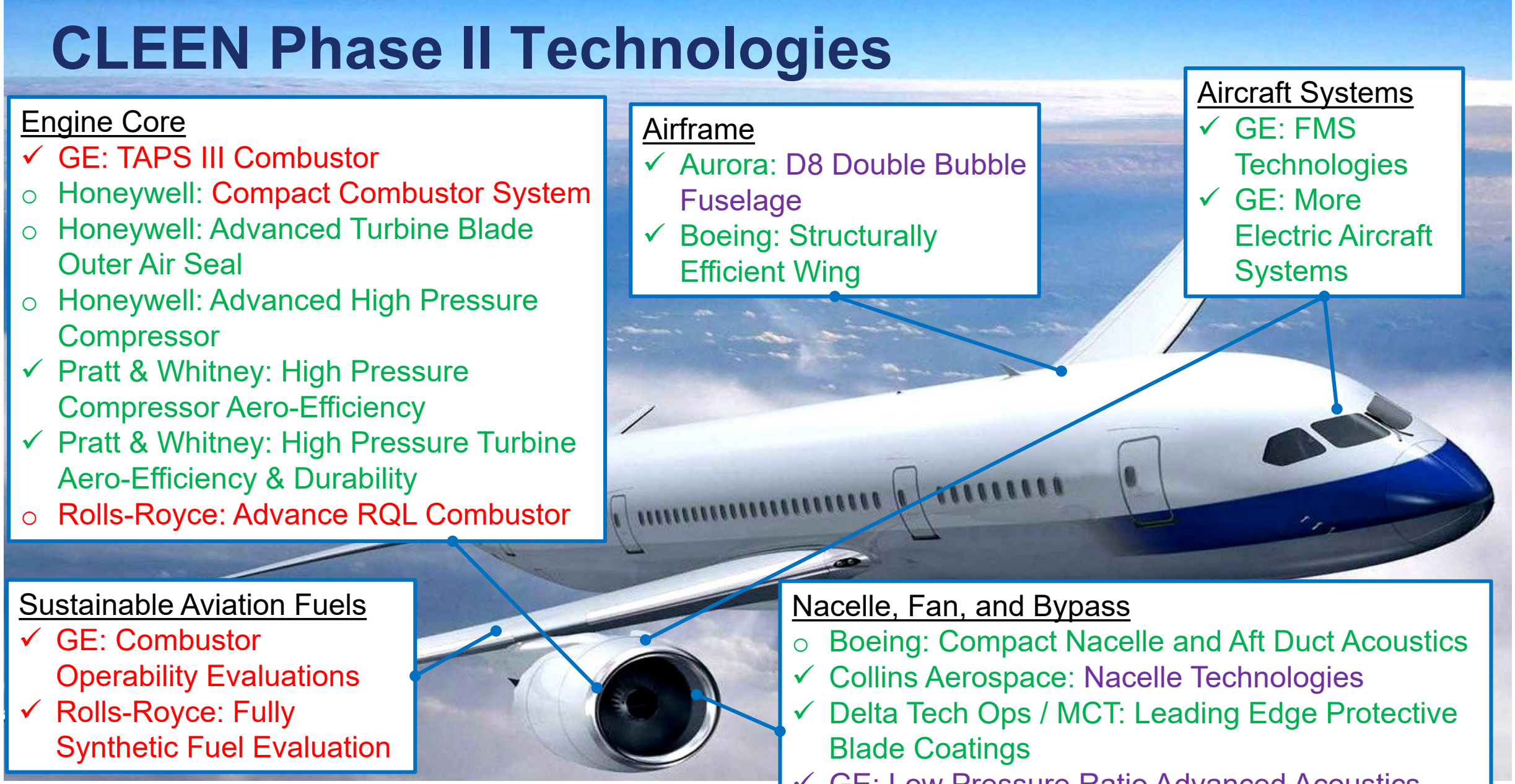


- Pratt & Whitney Gen 2 geared turbofan propulsor technology successfully engine tested
  Enables engine designs that provide 20% fuel burn reduction and 20 dB noise reduction



- Boeing CMC Nozzle flight tested on a 787 aircraft
  Up to 1% fuel burn reduction and 2.3 dB noise reduction

CLEEN Phase II Technologies



Engine Core

- ✓ GE: TAPS III Combustor
- ○ Honeywell: Compact Combustor System
- ○ Honeywell: Advanced Turbine Blade Outer Air Seal
- ○ Honeywell: Advanced High Pressure Compressor
- ✓ Pratt & Whitney: High Pressure Compressor Aero-Efficiency
- ✓ Pratt & Whitney: High Pressure Turbine Aero-Efficiency & Durability
- ○ Rolls-Royce: Advance RQL Combustor

Airframe

- ✓ Aurora: D8 Double Bubble Fuselage
- ✓ Boeing: Structurally Efficient Wing

Aircraft Systems

- ✓ GE: FMS Technologies
- ✓ GE: More Electric Aircraft Systems

Sustainable Aviation Fuels

- ✓ GE: Combustor Operability Evaluations
- ✓ Rolls-Royce: Fully Synthetic Fuel Evaluation

Nacelle, Fan, and Bypass

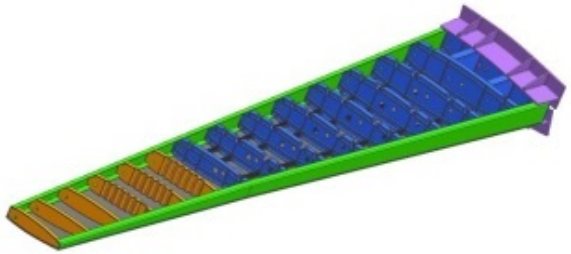
- ○ Boeing: Compact Nacelle and Aft Duct Acoustics
- ✓ Collins Aerospace: Nacelle Technologies
- ✓ Delta Tech Ops / MCT: Leading Edge Protective Blade Coatings
- ✓ GE: Low Pressure Ratio Advanced Acoustics
- ○ Honeywell: Advanced Acoustic Fan and Liners
- ○ Rolls-Royce: Compact Nacelle Flight Test

Fuel
Emissions
Noise

✓ Completed Effort
○ Ongoing Effort

Success Stories from CLEEN II

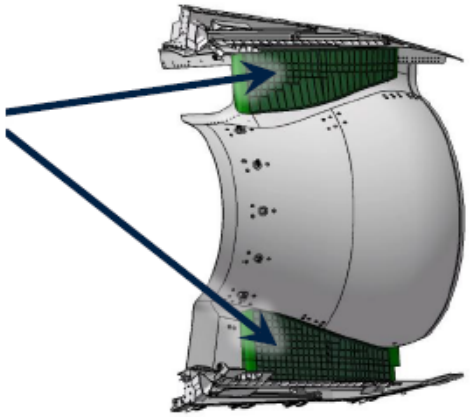
- Delta TechOps/MCT completed in-service flight evaluation of fan blade leading edge protective coating
  Retained efficiency equating to 0.4% to 1% fuel burn savings
- Boeing completed full scale ground test of Structurally Efficient Wing
  3.5% fuel savings through weight reduction
- Boeing completed ground engine test of Compact Nacelle technology
  1% fuel burn reduction; enables more efficient engine designs and improved acoustic treatments
- GE TAPS III combustion system will be implemented in the GE9X-powered Boeing 777X
  Enables NO_X emissions 30% below CAEP/8
- GE completed TRL 6 demonstration of Flight Management System optimization algorithms, including electronic flight bag prototype
  1% fleet-wide average improvement in fuel burn
- P&W high pressure compressor completed ground and flight tests—learnings integrated into GTF product line
  0.8-1.0% fuel burn reduction relative to a state-of-the-art engine



Recent Accomplishments – Since Spring REDAC Sub-Committee

CLEEN Phase II:

- Boeing Aft Fan Duct Acoustics
  - Flight test completed July 2021 in Glasgow, MT
  - Results under analysis; final reports expected by end of CY2021
- Project closeouts:
  - GE Advanced Acoustics – Final report delivered
  - RR Advanced RQL Combustor – Awaiting final report

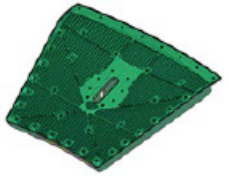


Thrust Reverser
Inner Wall

CLEEN Phase III Awards:

- America's Phenix, Delta TechOps, MDS Coating Technologies, GKN Aerospace
- Boeing
- Honeywell
- Pratt & Whitney
- GE Aviation
- Rohr (Collins Aerospace)

Two additional awards under negotiation

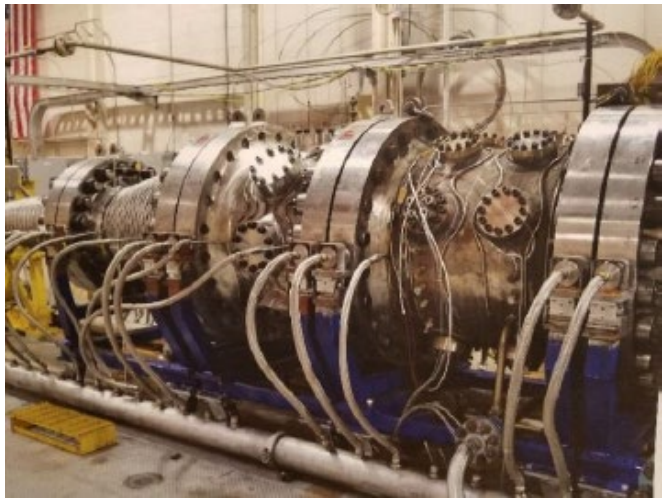


Treated Blocker
Doors

Upcoming CLEEN Activities

Next 6 Months:

- Remaining CLEEN Phase III awards and kickoffs
- Rolls-Royce CLEEN Phase II flight test of compact nacelle technology (Q4 2021)
- Honeywell CLEEN Phase II compact combustor test at NASA Glenn Advanced Subsonic Combustion Rig (Q4 2021)



CLEEN Phase III

Press Release and Website

www.faa.gov/go/CLEEN

- Press release on Phase 3 was released on Sept 10, 2021
  Website: https://www.faa.gov/newsroom/faa-awards-100m-develop-next-generation-sustainable-aircraft-technology
- Comprehensive report on CLEEN Program accomplishments has been uploaded as an FAA Fact Sheet
  Website: https://www.faa.gov/newsroom/continuous-lower-energy-emissions-and-noise-cleen-program?newsId=22534
- Materials should aid communications about the CLEEN Program

United States Department of Transportation

Federal Aviation Administration

Home / Newsroom

Newsroom
Press Releases
Fact Sheets
Speeches
Testimony
Conferences & Events
Daily Air Traffic Report
FAA Safety Briefing
Subscribe to FAA News

Continuous Lower Energy, Emissions, and Noise (CLEEN) Program

Friday, September 10, 2021

Continuous Lower Energy, Emissions and Noise (CLEEN) Program Summary and Status Report

Executive Summary

In partnership with industry, the FAA's Continuous Lower Energy, Emissions and Noise (CLEEN) program is developing certifiable aircraft and engine technologies that reduce noise and emissions while increasing fuel efficiency. Technologies developed by the CLEEN Program will result in a fleet of aircraft that have lower noise, use less fuel, and produce fewer emissions, thus supporting the overarching environmental performance goal for NextGen to remove environmental constraints on aviation growth by achieving quiet, clean, and efficient air transportation.

The CLEEN Program is implemented in five year phases and has goals for noise, fuel burn, and emissions. The first phase of CLEEN was executed from 2010 to 2015. Based on the success of this program, the second phase of CLEEN was initiated in 2015 for a five-year term. The third phase of the CLEEN Program is included in the FY2020 and FY2021 enacted budgets, with cooperative agreements awarded in 2021. To receive funding from CLEEN, industry partners need to contribute at least 100% cost share to the program.

The goals of the CLEEN Program are tied to the environmental standards that aircraft and engines are required to meet as a part of airworthiness certification. As industry meets the goals, the FAA has made the goals increasingly more stringent. Further, additional goals have also been added over time. The third phase of CLEEN plans to target reductions in aviation noise, emissions, and fuel burn. However, the third phase of the CLEEN Program will also target community noise exposure as well as aircraft engine particulate matter emissions.

The CLEEN Program has matured technologies that have entered the fleet, and industry anticipates that additional technologies will enter into service in the coming years as opportunities arise for their insertion into new aircraft and engine designs. Additionally, the knowledge gained from the development of these technologies is leading to improved design codes and fabrication methods that are being applied throughout these companies' product lines, leading to improved environmental performance across the industry.

Cumulatively, CLEEN Phase I and II are estimated to save the aviation industry 36.4 billion gallons of fuel by 2050, reducing airline costs by 72.8 billion dollars and lowering CO2 emissions by 424 million metric tons. These CO2 reductions are equivalent to removing 3.05 million cars from the road from 2020 to 2050. The technologies from the first phase of CLEEN are estimated to decrease land area exposed to noise by 14%. These technologies, as well as the use of sustainable aviation fuels, will also dramatically reduce nitrogen oxide and soot emissions from aircraft operations.

The CLEEN program demonstrates the continued commitment of the FAA toward reducing the noise, emissions, and fuel burn from the fleet. The FAA looks forward to the additional fuel burn, noise, and emissions reductions which the third phase of the program will yield as it partners with the industry to develop new technologies through 2025.

Federal Aviation Administration

Press Release

For Immediate Release

Date: September 10, 2021
Contact: pressoffice@faa.gov

You are subscribed to News updates for the Federal Aviation Administration. A new Press Release is now available. We've included a copy of the release in this email.

FAA Awards $100M to Develop Next Generation of Sustainable Aircraft Technology

WASHINGTON –The U.S. Department of Transportation's Federal Aviation Administration (FAA) has awarded more than $100 million for companies to help develop technologies that reduce fuel use, emissions and noise. The award is part of a series of steps President Biden is taking to coordinate leadership and innovation across the federal government, aircraft manufacturers, airlines, fuel producers and more to position American aviation to soar towards net zero emissions by 2050. This FAA announcement is part of those efforts.

"Across the country, communities have been devastated by the effects of climate change – but, if we act now, we can ensure that aviation plays a central role in the solution," **said Transportation Secretary Pete Buttigieg**. "These awards will help America lead the world in sustainable aviation."

The Continuous Lower Energy, Emissions and Noise (CLEEN) Program is a public-private partnership that began in 2010 and is a key part the FAA's overall strategy to tackle the global challenge of climate change and lower the impact aviation has on communities. The program requires the companies receiving the contracts to match or exceed the FAA's investment, bringing the total to at least $200 million over a five-year period. The awards are the third phase of the FAA's CLEEN program.

CLEEN Phase III Overview

	Phase III	
Time Frame	2021-2025	
Entry into Service	2031	
FAA Budget	~$100M+	
Vehicle Type	Subsonic	Supersonic
Noise Goal	25 dB cumulative noise reduction relative to Stage 5 and/or reduces community noise exposure	Reduction during landing and takeoff cycle (LTO)
Fuel Burn Goal	-20% re: CAEP/10 Std	-
NO_X Goal	-70% re: CAEP/8 Std (LTO)	Reduction in absolute NO_X emissions
Particulate Matter Goal	Reduction rel: CAEP/11 Std (LTO)	-

- **CLEEN Phase III: Follow-on to CLEEN Phase I and Phase II Programs focusing on aircraft noise, emissions and energy**
- **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 provide reductions in emissions or improvements in efficiency, including fuels that enable advancements in aircraft and engine design. This includes both conventional and alternative fuels.

The third phase of the CLEEN Program also aims to advance the development and introduction of hydrocarbon jet fuels for aviation that could enable improvements in fuel efficiency and reductions in emissions. This includes fuel blends. The CLEEN Program is interested in fuels that are drop-in compatible with the existing pipeline and airport fueling infrastructure, but have changes in their composition that could help an aircraft meet these CLEEN Program goals.

CLEEN Phase III Technologies

Engine Core
- GE: Compact Core – Low Emissions Combustor
- GE: Advanced Thermal Management
- GE: Hybrid Electric Integrated Generation
- Honeywell: Efficient Green High Pressure Core
- Honeywell: Compact High Work High Lift Low Pressure Turbine (LPT)
- Pratt & Whitney: TALON X+ Combustor

Airframe
- Boeing: Quiet Landing Gear
- Boeing: Quiet High-Lift System

Aircraft Systems
- GE: MESTANG III
- Boeing: Intelligent Operations

Sustainable Aviation Fuels
- Boeing: Higher Blend SAF Qualification
- GE: Higher Blend SAF Qualification

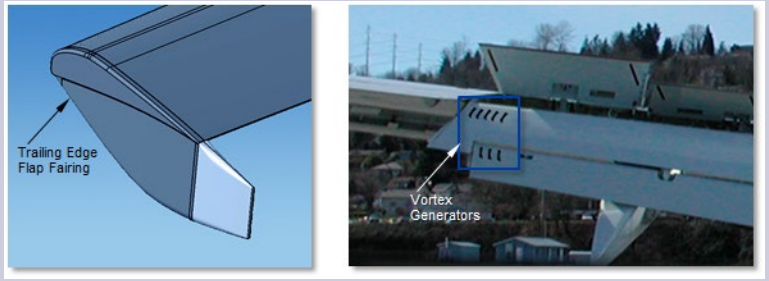
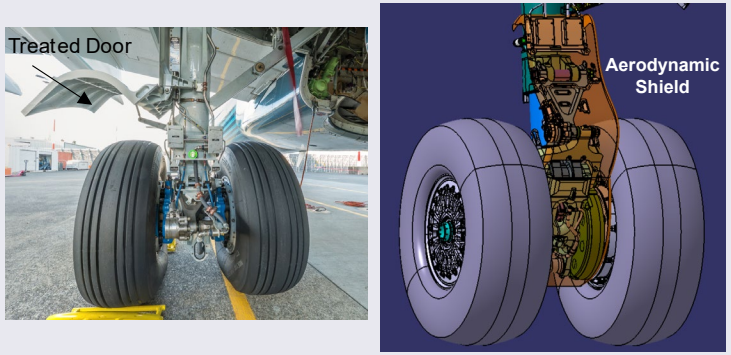
Nacelle, Fan, and Bypass
- America's Phenix: Erosion-Resistant Fan Blade Coating
- Boeing: Advanced Nacelle Next Generation Inlet
- Collins: Large Cell Exhaust Acoustic Technology
- GE: Open Fan
- GE: Advanced Acoustics
- Honeywell: Highly Efficient Fan Module
- Pratt & Whitney: Ultra-Quiet Reduced-Loss Fan Stage

Fuel
Emissions
Noise

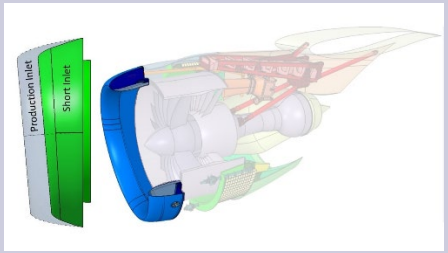
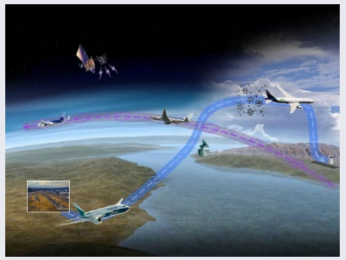
America's Phenix, Delta TechOps, MDS Coating Technologies, GKN Aerospace

Technology	Description	Benefits
Particulate & Fluid Erosion-Resistant Fan Blade Coating for Expanded Applications 	The team of Delta TechOps, GKN Aerospace, MDS Coating and America's Phenix, is developing erosion resistant fan blade coatings for various engine applications. The coatings protect the fan blade's leading edge against particulate and fluid erosion; thus, retaining engine performance, reducing fuel consumption and lowering emissions over an engine's operational tour.	Fuel: 1% or greater fuel burn reduction and corresponding reduction in greenhouse gas emissions via retaining engine performance over an engine's operational tour.

Boeing (1 of 2)

Technology	Description	Benefits
Quiet High-Lift System 	Boeing is developing flap edge fairings and vortex generators for wing high-lift devices in order to minimize noise.	Noise: Up to 0.5 EPNdB noise reduction
Quiet Landing Gear 	Boeing is developing landing gear door noise treatment and aerodynamic shields to reduce aircraft noise.	Noise: Up to 0.5 EPNdB noise reduction

Boeing (2 of 2)

Technology	Description	Benefits
Advanced Nacelle: Next Generation Inlet 	Boeing is developing a new inlet architecture that will reduce weight, drag and noise.	Noise: Up to 1.5 EPNdB Fuel: 2% fuel burn reduction
Intelligent Operations 	Boeing is developing noise-optimized flight path algorithms with integration into the Air Traffic Management System.	Noise: 3-5 dBA peak noise reduction Fuel: 2% fuel savings during take-off; 5% during approach phase
Sustainable Aviation Fuels 	Under CLEEN Phase III, Boeing is supporting qualification of Sustainable Aviation Fuels through lab material compatibility evaluations and flight demonstration. This program will characterize selected new alternative fuel blends and provide test data in support of future ASTM International specifications. Through this effort, Boeing will support continued expansion of certified alternative fuel pathways to promote uptake and sustainability.	Supports > 50% blend levels

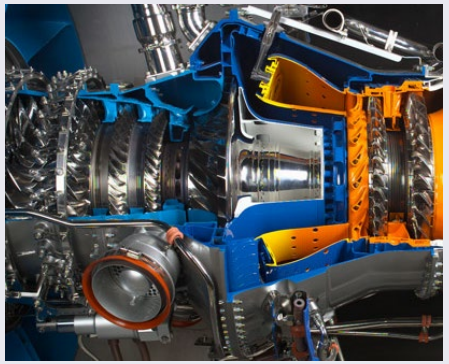
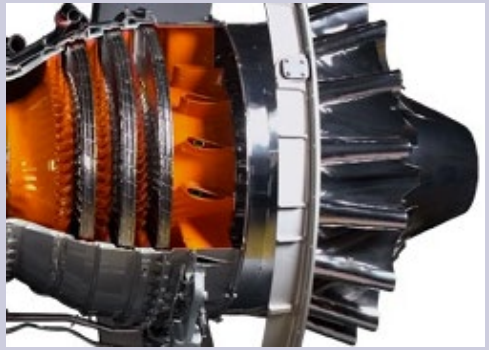
GE Aviation (1 of 2)

Technology	Description	Benefits
Open Fan	GE Aviation is developing an unducted single fan architecture optimized for noise and fuel burn reduction.	Noise: 13 EPNdB cum margin relative to Stage 5 Fuel: 10+% reduction relative to current LEAP engine
Compact Core – Low Emissions Combustor	GE Aviation is developing combustor technology that will result in reduced NOx emissions.	NOx: Targeting NOx reduction for a future high overall pressure ratio engine cycle, equivalent to 70% margin to the CAEP/8 standard at 30 OPR.
Advanced Thermal Management	GE Aviation is developing advanced thermal management and waste heat recovery systems to facilitate compressor and turbine temperature increases, thereby improving cycle efficiency and reducing fuel burn.	Fuel: Up to 3% reduction relative to traditional architectures

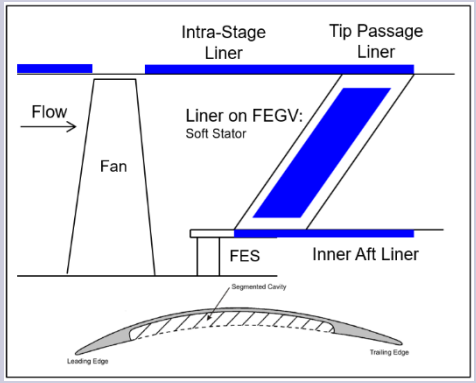
GE Aviation (2 of 2)

Technology	Description	Benefits
Advanced Acoustics	GE Aviation is developing advanced fan duct acoustic liners and fan/outlet guide vane (OGV) technologies to reduce noise.	Noise: 2 EPNdB cum. reduction from novel liners, 1 EPNdB cum. reduction from fan/OGV designs
MESTANG III	GE Aviation is developing more electric aircraft systems that will reduce fuel burn by requiring reduced engine bleed air.	Fuel: 3-6% reduction for mid-size aircraft
Hybrid Electric Integrated Generation	GE Aviation is developing an integrated electric-power generation system within the engine to enable flexibility in electric power generation and optimize engine performance.	Fuel: 3-4% reduction
Sustainable Aviation Fuels	GE will support qualification efforts for alternative jet fuels with unique compositions, including highly cycloparaffinic fuels. Cycloparaffins may provide sufficient seal swell unlike other alternative jet fuels which lack aromatics. GE testing will characterize combustor operability and emissions impact of the fuels.	Supports > 50% blend levels

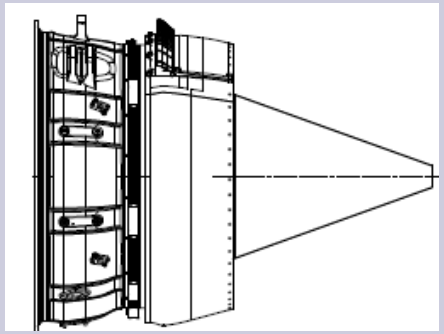
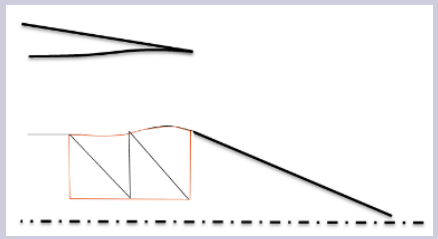
Honeywell Aerospace

Technology	Description	Benefits
Highly Efficient Fan Module 	Honeywell is developing over-the-rotor acoustic treatment, a high efficiency booster, and optimizing the fan exit guide vanes and booster stators for combined noise and efficiency benefits.	Noise: 1.5 EPNdB Fuel: 1.5% fuel burn reduction
Efficient Green High Pressure Core 	Honeywell is developing advanced high pressure compressor, low emission combustor, and efficient high pressure turbine technologies for next generation business jet aircraft.	Noise: 3 EPNdB reduction Fuel: 8.3% fuel burn reduction Emissions: 70% margin to CAEP/8 NOx; 70% reduction in nvPM
High Work High Lift Low Pressure Turbine (LPT) 	Honeywell is developing technologies for a reduced weight, more efficient and quieter low pressure turbine for future business jet class aircraft.	Noise: 0.5 EPNdB Fuel: 2.5% fuel burn reduction

Pratt & Whitney

Technology	Description	Benefits
Ultra-Quiet Reduced-Loss Fan Stage 	Pratt & Whitney is developing a quieter, more efficient fan module including additively manufactured low-loss acoustic liners and reduced solidity, reduced-loss, lower noise fan exit guide vanes. Areas of interest for the advanced acoustic treatment are highlighted in blue.	Noise: Target 3 EPNdB noise reduction combined with P&W combustor technology Fuel: 0.8% fuel burn as part of package with P&W combustor technology
TALON X+ Combustor 	Pratt & Whitney is developing an advanced combustion system based on the TALON X that will simultaneously reduce noise and emissions, while improving temperature pattern factor and enabling improved high pressure turbine design and efficiency.	Noise: Target 3 EPNdB noise reduction combined with P&W fan technology Fuel Burn: 0.8% fuel burn as part of package with P&W fan technology Emissions: deliver 50% margin to CAEP/8 NOx

Rohr, Inc. (Collins Aerospace)

Technology	Description	Benefits
Large Cell Exhaust Acoustic Technology  	Collins Aerospace is developing a novel exhaust noise attenuation feature involving a “large cell” cavity treatment in the exhaust structure.	Noise: Lower noise by 0.9 to 1.5 EPNdB

CLEEN Program - In Summary

- Remaining CLEEN Phase II technology development projects are on track

- Awarded six CLEEN Phase III agreements
  - Additional two under negotiation

- Next CLEEN II + CLEEN III Consortium Meetings:
  - Nov 1-5, 2021 (virtual)

- For more on CLEEN https://www.faa.gov/go/cleen

ASCENT Technology Projects

- **Now 1.5 years into execution of the portfolio of environmental technology research projects in our Center of Excellence**
- **Originally set up as an experiment a the direction of the prior Administration to conduct innovation activities in our CoE**
- **Themes:**
  - Noise reduction technology modeling and development
  - System-level modeling and design considerations
  - Propulsion-airframe integration
  - Combustion
  - Turbomachinery
  - Supersonics
- **Overview of projects now available on ASCENT website:** https://ascent.aero/topic/Aircraft-Technology/

ASCENT Aircraft Technology Innovation Portfolio

ASCENT Aircraft Technology Innovation Projects

- 010- Aircraft Technology Modeling and Assessment
- 037 - CLEEN II System Level Assessment
- 047 - Clean Sheet Supersonic Aircraft Engine Design and Performance
- 050 - Over-Wing Engine Placement Evaluation
- 051 - Combustion concepts for next-generation aircraft engines to reduce fuel burn and emissions
- 052 - Comparative Assessment of Electrification Strategies for Aviation
- 055 - Noise Generation and Propagation from Advanced Combustors
- 056 - Turbine Cooling Through Additive Manufacturing
- 059 - Jet Noise Modeling to Support Low Noise Supersonic Aircraft Technology Development
- 063 - Parametric Noise Modeling For Boundary Layer Ingesting Propulsors
- 064 - Alternative Design Configurations to Meet Future Demand
- 066 - Evaluation of High Thermal Stability Fuels
- 067 - Impact of Fuel Heating on Combustion and Emissions
- 068 - Combustor Wall Cooling Concepts for Dirt Mitigation
- 070 - Reduction of nvPM emissions via innovation in aero-engine fuel injector design
- 071 - Predictive Simulation of Soot Emission in Aircraft combustors
- 074 - Low Emissions Pre-Mixed Combustion Technology for Supersonic Civil Transport
- 075 - Improved Engine Fan Broadband Noise Prediction Capabilities
- 076 - Improved Open Rotor Noise Prediction Capabilities
- 077 - Measurements to Support Noise Certification for UAS/UAM Vehicles and Identify Noise Reduction Opportunities
- 079 (In Development) - Novel Noise Liner Development Enabled by Advanced Manufacturing

ASCENT's aircraft technology innovation research advances the industry state-of-the-art and expands the technical knowledge base.
https://ascent.aero/topic/Aircraft-Technology/

Key Outcomes Thus Far

While many projects were planned as multi-year from the start, we are seeing positive outcomes already:

- **ASCENT 37** has captured the projected fuel burn and CO2 emission benefits of CLEEN Phase II through 2050, helping us understand and communicate the benefits of CLEEN.

- **ASCENT 52** has demonstrated the significant energy requirements and infrastructure investments needed to support hydrogen aircraft. The team also evaluated the intense energy needs and environmental impact of Power-to-Liquid (PtL) fuels. This work has been critical in conversations at ICAO and within the U.S. Government to educate aviation experts on key challenges that must be addressed for both hydrogen and PtL technologies.

- **ASCENT 64** has provided invaluable modeling and analysis support to our work to inform a long term aspirational goal for CO2 from international aviation at ICAO.

ASCENT Connections to CLEEN Phase III

- **ASCENT 55** – Georgia Tech / RTRC research is improving understanding of combustor noise generation
  - ➢ CLEEN Phase III P&W TALON X+ Combustor
- **ASCENT 68** – Penn State / P&W investigating dirt resistant combustor cooling holes
  - ➢ CLEEN Phase III P&W TALON X+ Combustor
- **ASCENT 76** – GE is providing Georgia Tech with open rotor geometry for parametric noise analysis
  - ➢ CLEEN Phase III GE Open Fan
- **ASCENT 79** – Penn State / RTRC investigating novel noise reduction liners enabled by Advanced Manufacturing
  - ➢ CLEEN Phase III P&W Ultra-Quiet Reduced-Loss Fan Stage

Conclusions

- **CLEEN Phase II is executing its sixth successful year**
  - Twelve technology projects have reached their maturation goals, with many more expected in the next year, even after COVID impacts
- **CLEEN Phase III now underway to continue our efforts to accelerate maturation of environmental aircraft technologies into the fleet (2021-2026)**
  - Eight awards in total, with six now underway
- **ASCENT projects showing promising initial outcomes as part of our expanded technology research portfolio**

Backup Slides

Assessment of CLEEN Technologies

Analytical Evaluation:

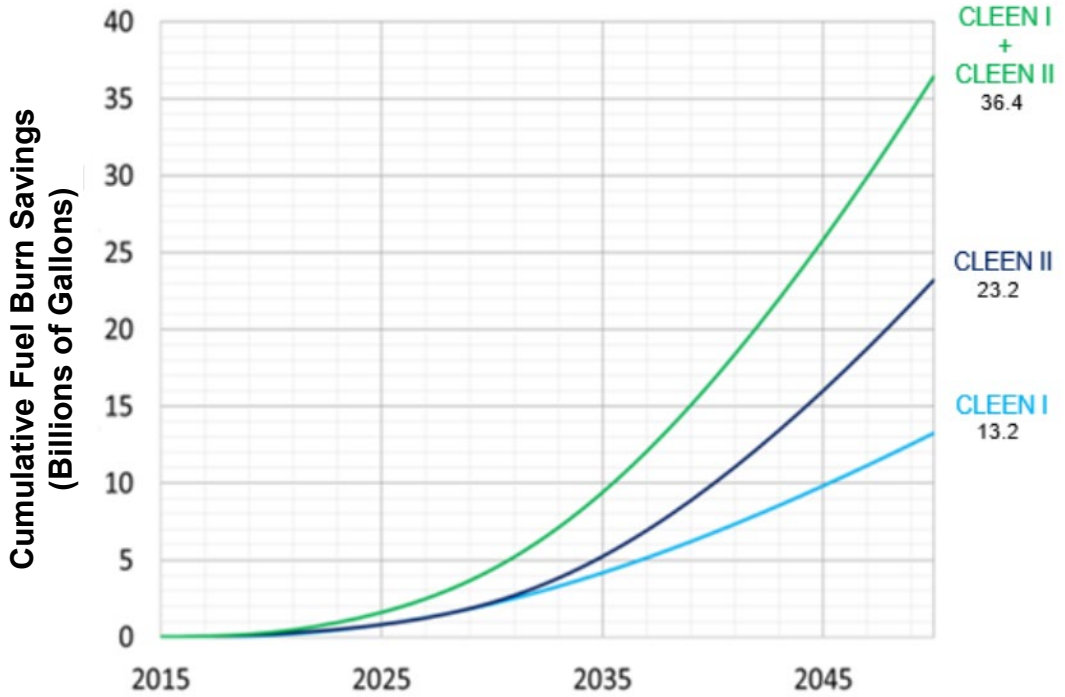
- Conducted by Georgia Tech through ASCENT COE Project 37
- Evaluating impact on fuel burn and noise out to 2050
- Have completed modeling of CLEEN Phase I technologies and all CLEEN Phase II fuel burn reduction technologies

Fuel Burn Benefit:

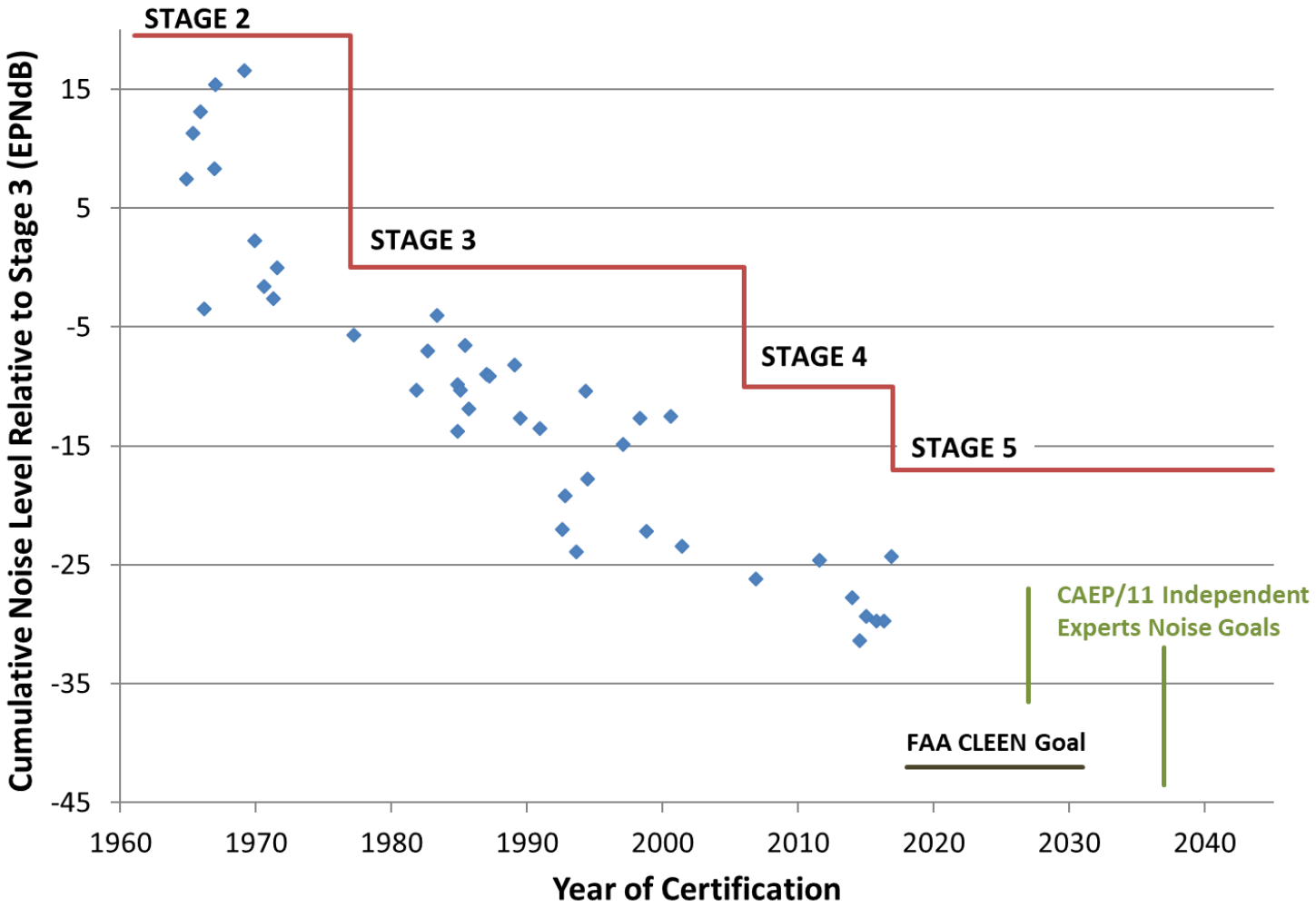
- 36.4 billion gallons of fuel saved cumulative by 2050 from CLEEN Phase I and II
- CO_2 emissions reduced by 424 million metric tons over this time period – the equivalent to removing 3 million cars from the road from 2020 to 2050

Noise Benefit:

- CLEEN Phase I Contributes to 14% decrease in the land area exposed to DNL 65 dB and greater
- CLEEN Phase II noise benefits assessment ongoing



CLEEN Noise Goal in Context



CLEEN Phase III Fuel Burn Goal in Context