Continuous Lower Energy, Emissions and Noise (CLEEN) Program

Aircraft Technology - CLEEN Update

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Outline

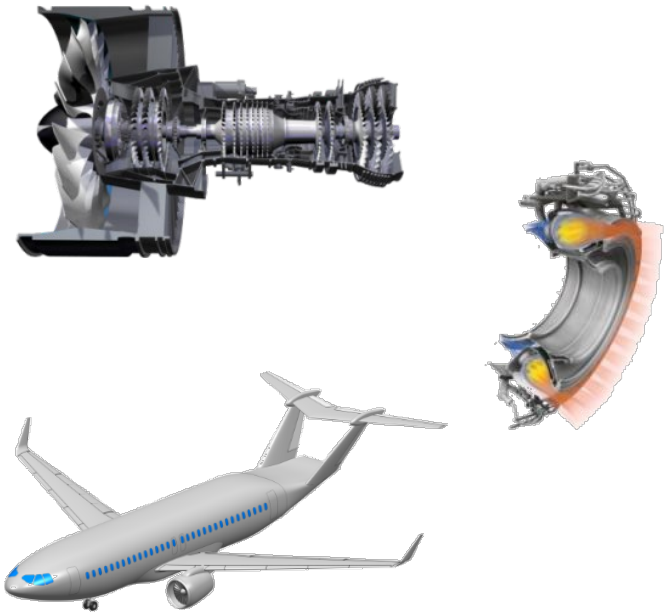
- CLEEN Phase I & II Program Overview
- CLEEN Program Benefits
- CLEEN Phase III Overview
- Summary

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

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

*Notional



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 II – Options for FY19

Options	Boeing	GE	Honeywell
Project Description	Acoustic improvements in the aft fan duct in support of the Boeing Compact Nacelle	Inlet Liner Flight Noise Test / Novel Acoustic Liner	Advanced Acoustic Fan Module
FAA Budget (based on availability of funds)	~$4M	~$3.9M	$4.95M
CLEEN Noise Reduction Goal	0.2 to 0.6 EPNdB for 737Max, and 0.4 to 1.2 EPNdB for airplanes entering into service in the 2025 timeframe	Developing innovative acoustic liner using state-of-the-art additive manufacturing technologies to increase acoustic efficiency of liners with the goal of demonstrating ~ 2+ EPNdB cumulative noise reduction relative to current Single Degree of Freedom (SDOF) honeycomb liners	Developing a blisk fan and booster configuration that significantly lowers overall engine fuel burn and noise. Reduce fan tone and broadband noise. Increased fan efficiency at lower weight. Improved noise source identification, leading to new concepts for noise source reduction and optimized acoustic treatment. Benefit: 2.5 EPNdB and 3% fuel burn improvement.
Duration of Project	1.5 years	1.5 years	2.25 years
TRL	TRL 7 in 2020	TRL 7 in 2020	TRL 7 in early 2021
Entry into Service	2025	2026	2026

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
Flight tested on a 787 aircraft
~ 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
Successfully engine tested
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 on LEAP engine)
> 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 Expected Benefits (1 of 2):

Technologies that reduce noise, emissions and fuel burn

Aurora Flight Sciences

D8 Aircraft Fuselage (completed)
Tested key structural subcomponent
~ 29% fuel burn reduction
~ 16 EPNdB cum

Boeing

Structurally Efficient Wing
Up to 3.5% fuel burn reduction

Compact Nacelle (CN) - completed
Completed ground engine test of CN tech
1.0% fuel burn reduction

Acoustic improvements in the aft fan duct in support of the Boeing Compact Nacelle **(NEW)**

Collins Aerospace

Integrated Propulsion System Nacelle Technology Demonstrator
~1.0% fuel burn reduction
~2.0 EPNdB Noise Reduction

Delta/MDS/America's Phenix

Leading Edge Protective Coating for Turbofan Blades
Conducting in-service flight evaluation of fan blade
~1% fuel savings for Mainline and Regional Commercial carriers

Rolls-Royce

Advanced Rich Quench Lean (RQL) Low NOx Combustion System
Conducting full annular rig test
~LTO NOx emissions 65 below CAEP/8

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

CLEEN Phase II Expected Benefits (2 of 2):

Technologies that reduce noise, emissions and fuel burn

Pratt & Whitney

Compressor Aero Efficiency Technologies
Completed rig testing of advanced high pressure compressor tech
~0.8-1.0% fuel burn reduction

Turbine Aero Efficiency and Durability Technologies
~0.8-1.0% fuel burn reduction

Honeywell

Advanced Turbine Blade Outer Air Seal (BOAS) System
>2% Fuel Burn Reduction

Compact Low Emissions Combustor
>50% CAEP/8 NOx Margin
~0.1% fuel burn reduction

Advanced Acoustic Fan Module (NEW)

General Electric

Low Pressure Ratio (LPR) - Fan Advanced Acoustics
Improved Acoustic Liner
~ 2 EPNdB cum, Neutral Performance

Improved Fan Source Strength
~ 1 EPNdB cum, Neutral Performance

Inlet Liner Flight Noise Test / Novel Acoustic Liner (NEW)

Flight Management System (FMS) – Engine Integration
~3.5% fuel savings

More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG)
~3% Fuel Burn Savings for Single-Aisle aircraft

Twin Annular Pre-Swirler (TAPS) III Combustion System (completed)
~ 35% margin to CAEP/8 (55 OPR) LTO NOx was achieved. CLEEN NOx goal has been achieved.

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

CLEEN Phase III Outlook

- Notional CLEEN Phase III timeline (actual timeline in flux due to budget uncertainty)
- Market Survey: https://faaco.faa.gov/index.cfm/announcement/view/31002
- Industry Day: https://faaco.faa.gov/index.cfm/announcement/view/31885
- Industry Day Follow up: https://faaco.faa.gov/index.cfm/announcement/view/32134

CLEEN Phase III Overview

- **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 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 Overview (cont.)

- **Planned Funding**
  - FAA contribution: $100M over 2020-2025 timeframe
  - 1:1 Minimum cost share requirement
    - $200M(+) Program with cost share included
- **Five year duration: 2020-2025**
- **CLEEN Phase III technologies expected to be on a path for introduction into commercial aircraft in the 2025-2031 timeframe**

Draft Statement of Work (SOW): Goals

1. Tier 1: Certifiable aircraft technology that reduces noise levels by 25 dB cumulative, relative to the Stage 5 standard for civil subsonic airplanes and/or reduces community noise exposure

    - *the reduction of community noise exposure is to be measured relative to a 2000 best-in-class in-service baseline aircraft and mission (e.g., Embraer E-190, Boeing 737-800, Boeing 777-200LR).*

2. Tier 2: Certifiable aircraft technology that improves aircraft fuel efficiency by 20% relative to the International Civil Aviation Organization (ICAO) new type fuel efficiency standard for civil subsonic airplanes adopted in 2016 (Committee on Aviation Environmental Protection, CAEP/10)

Draft SOW: Goals (cont.)

3. Tier 3: Certifiable engine technology that reduces landing and takeoff cycle (LTO) nitrogen oxide emissions for civil subsonic airplanes by 70% over the ICAO standard adopted in 2010 (CAEP/8), and/or reduces absolute NOx production over the aircraft's mission. This must be achieved while limiting or reducing other gaseous and particulate matter emissions.

- *The absolute NOx production over the aircraft's mission is to be measured relative to a 2000 best-in-class in-service baseline aircraft and mission.*
- *The 70% margin to CAEP/8 LTO NOx pertains to an engine overall pressure ratio (OPR) of 30. This goal targets a commensurate reduction across the OPR range.*

Notional Goal: Reductions in nvPM mass and number are expected to compliment NOx reductions.

4. Tier 4: Certifiable aircraft technology that reduces noise levels during the landing and takeoff cycle (LTO) for civil supersonic airplanes or reduces landing and takeoff cycle (LTO) nitrogen oxide emissions for civil supersonic airplanes

Draft SOW: Goals (cont.)

- **Includes consideration of the extent to which new airframe and engine technologies may be used to retrofit or re-engine aircraft so as to increase the level of penetration into the commercial fleet**

- **"Certifiable" means:**
  - the technology has been demonstrated to TRL 6-7, and
  - there are no issues regarding the technology that would prevent noise, emissions, and airworthiness certification to existing certification standards

Draft SOW: Goals (cont.)

The third phase of the CLEEN Program is also aiming at developing and demonstrating:

5. The feasibility of use of novel jet fuels in aircraft and engine systems that are drop-in compatible with the existing fleet, or a defined subset of the existing fleet, but come from alternative sources or have changes in their composition. This includes support for fuel testing and evaluation, and support for procurement of pre-production jet fuels intended to advance the maturity of these fuels.

To advance the development and introduction of "drop in" jet fuels for aviation, with particular focus on options that could reduce the emissions from aviation, including greenhouse gas footprint. This includes fuel blends.

Efforts under CLEEN Phase III on jet fuels are limited to demonstration and assessment of the fuels, including assessment of the testing required to support fuel qualification and specification development and production potential.

CLEEN Phase III jet fuels efforts do not include funding for development of fuel production capabilities, except that which may be needed to support ASTM approval

In Summary

- CLEEN technology development and alternative fuels projects are progressing under CLEEN Phase II
- Next CLEEN II Consortium Meetings:
  - May 7-9, 2019: Cleveland, OH (NASA Glenn)
  - Nov 19-21, 2019: Washington, DC (location TBD)
  - May 5-7, 2020: Phoenix, AZ (Honeywell)
  - Nov 17-19, 2020: Washington, DC (location TBD)
- In the process of initiating CLEEN Phase III (2020-2025)
  - Market Survey was conducted in summer of 2018
  - Industry day took place on December 10, 2018
- For more on CLEEN https://www.faa.gov/go/cleen