Continuous Lower Energy, Emissions and Noise (CLEEN) Aircraft Technology Maturation - Update

Federal Aviation Administration

Presented to: REDAC E&E Subcommittee

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Outline

- Action Items from May 2014
- CLEEN Overview and Goals
- Completed technology demonstrations
- CLEEN – Company by Company
- CLEEN II
- Summary

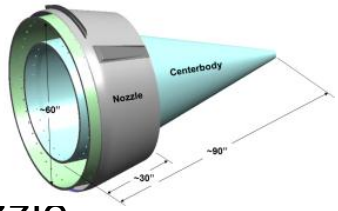
Action Items from May 2014

- **Develop CLEEN Communication Materials**
  - Update the CLEEN Fact Sheet – completed 8/1 http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=16814
  - Additional means of conducting outreach on CLEEN and its successes
    - FAA Focus, and interviews with the CLEEN companies
    - Journal Publication(s) by FAA and/or CLEEN companies
    - Conference Presentations
    - Briefings at ASCENT, CAAFI, VAATE, BioMass, etc
    - Boeing ecoDemonstrator
- **Roadmap of the CLEEN program with expected EIS (in progress)**
- **What was accomplished that would not have happened if there was no CLEEN funding**

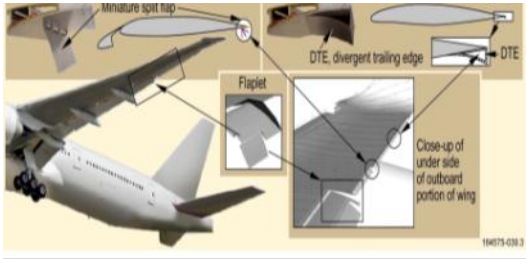
Continuous Lower Energy, Emissions and Noise (CLEEN)

- 5 year effort to accelerate technology maturation & AJF
- Reduces aircraft fuel burn, emissions and noise
- 50% cost share; total FAA budget: ~$125M

Boeing



- Ceramic Matrix Composite Nozzle



- Adaptive Trailing Edge

Rolls-Royce

- Ceramic Matrix Composite Blade Tracks
- Dual-Walled Turbine Airfoils

Honeywell

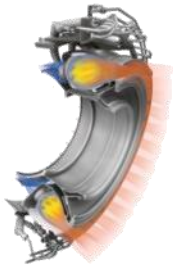
- Lighter weight, higher temp engine

Pratt & Whitney

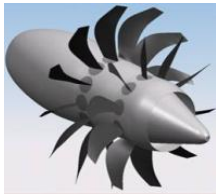
- Ultra-high Bypass Ratio Geared Turbofan

General Electric

- Flight Management System / Air Traffic Integration
- Flight Management System / Engine Integration



- Twin Annual Premixing Swirler (TAPS) II Low NOx Combustor
- Open Rotor Engine



CLEEN I Benefits So Far

Boeing

Adaptive Trailing Edge and CMC Acoustic Nozzle
~2% fuel burn reduction

Honeywell

Fuel Burn Technologies
CLEEN techs contributed to ~5% fuel burn reduction from CLEEN tech, 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, 25 EPNdB cumulative noise margin to Stg. 4

General Electric

TAPS II Combustor
CLEEN 60% margin to CAEP/6 LTO NOx was achieved

FMS/Engine and FMS/ATM Integration
Benefits are being assessed

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

Rolls Royce

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

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

CLEEN techs will provide ~1% fuel burn reduction

Completed Technology Demos (2011-2013)

Met CLEEN Goal

Landing and Takeoff NOx reduced 60% re CAEP 6

TAPS II Core Engine Test (TRL 6)

Open Rotor Wind Tunnel Tests (TRL 5)

Boeing 737 with Adaptive Trailing Edge

Ground Demonstration (TRL 6)

Flight Demonstration (TRL 7)

Ceramic Matrix Composite Nozzle Ground Test (TRL 6)

Dynamic Synchronization Simulation (TRL 6)

Dec Jan Jul Sep Jan Mar

2011 2012 2013

Completed Technology Demos in 2014

RR CMC Turbine Blade Track Engine Ground Testing

May

P&W Fan Rig Wind Tunnel Test

Jul

Boeing CMC Flight Test on ecoDemonstrator (TRL 7)

Jul

2014

Boeing CLEEN Technologies

Accomplishments:

- Adaptive trailing edge project complete (TRL 7), including 737-800 ecoDemonstrator flight test
- Ceramic matrix composite (CMC) nozzle ground test complete (TRL 6) in 2013
- CMC nozzle flight test on 787 ecoDemonstrator in July 2014 (TRL 7) – results are being assessed

Assessed at up to 2% fuel burn reduction.

Honeywell CLEEN Technologies

Fuel Burn Reduction Technologies

- Achieved TRL 6 for alloy 10 turbine disk material

2014 Activities:

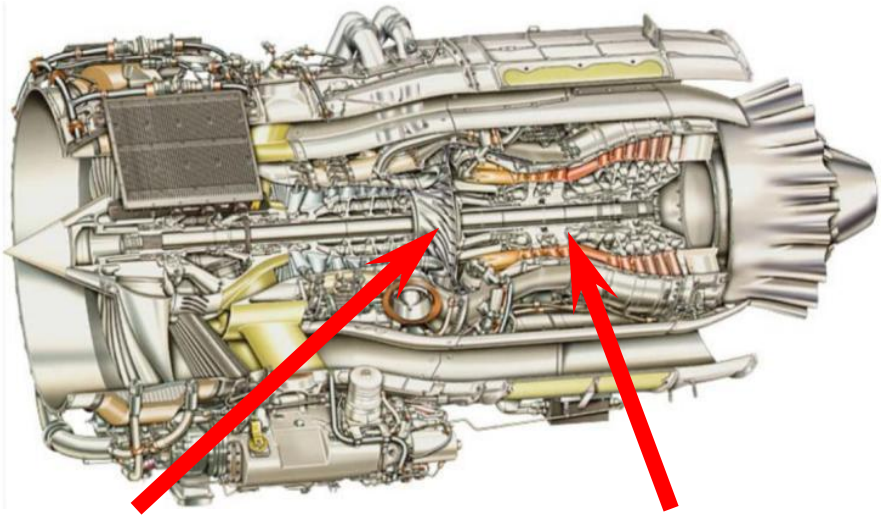
- Core and engine tests to bring other technologies to TRL 6

Alternative Jet Fuels

- Completed study on impact of aromatics on materials
- Completed biofuel life cycle analyses with MIT

2014 Activities:

- Ongoing alternative jet fuel testing



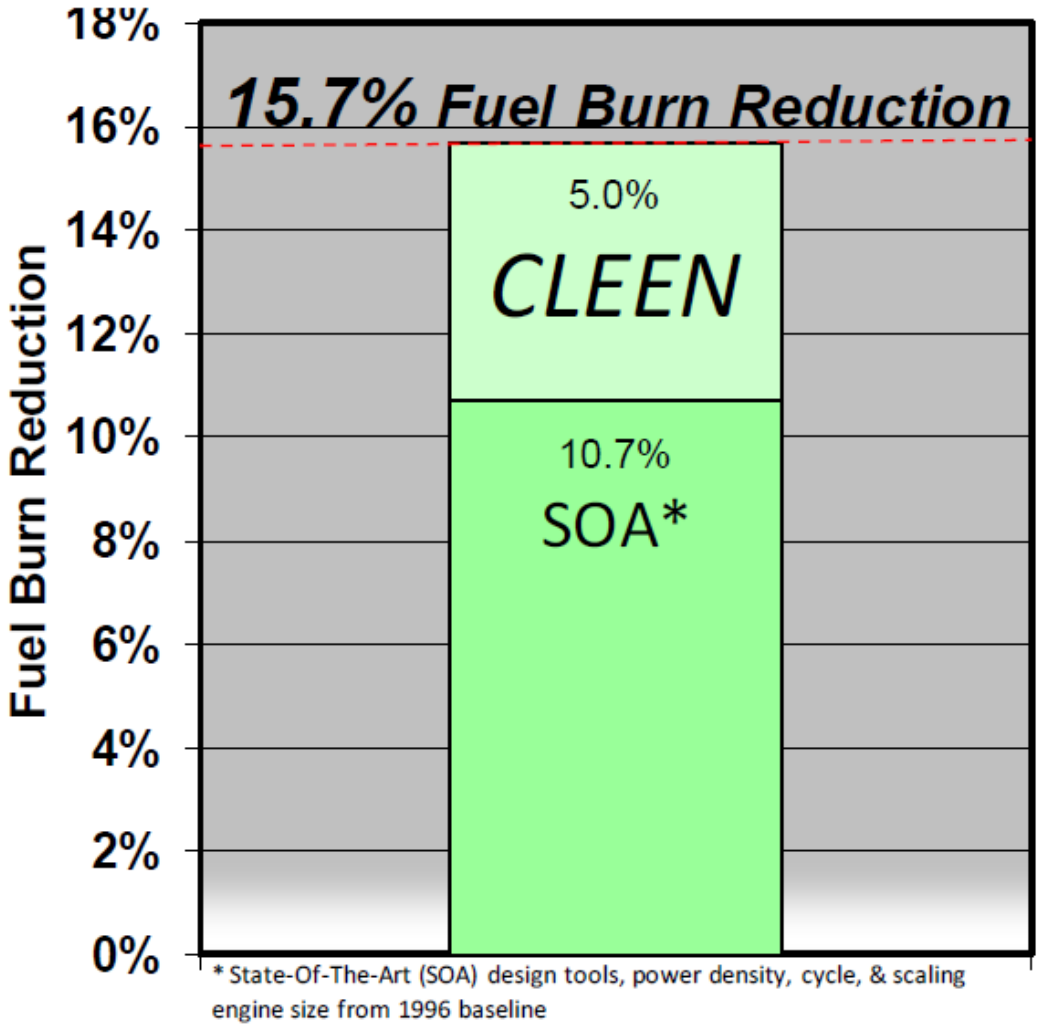
High T3 Impeller

- **Low leakage air-air seals**
- **Advanced materials**

Assessed at 5% fuel burn reduction from CLEEN tech, as part of a 15.7% fuel burn reduction engine package

Images courtesy of Honeywell

Honeywell CLEEN Program Reduces Carbon Foot Print



Benefits of FAA CLEEN Life Cycle Analysis of 100% Renewable Jet Fuel to National Climate Objectives

Support US Climate Action Plan

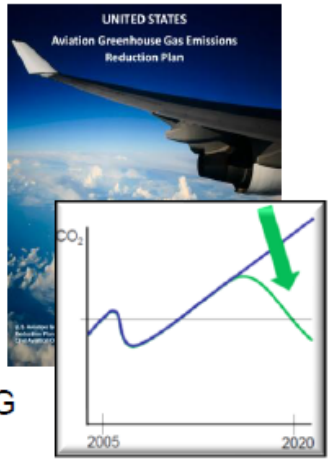
- Alternative Fuels Development & Deployment is key to reducing greenhouse gas (GHG) emissions

Support FAA Destination 2025

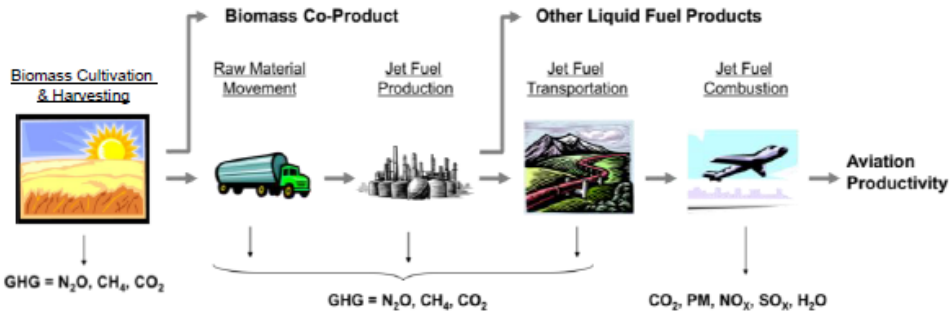
- Trajectory for carbon neutral growth using a 2005 baseline

Renewable Fuels Standard (RFS2)

- Identify fuels with 50% reduction in GHG



Lifecycle Greenhouse Gas (GHG) Emissions calculated by "well-to-wake" analysis

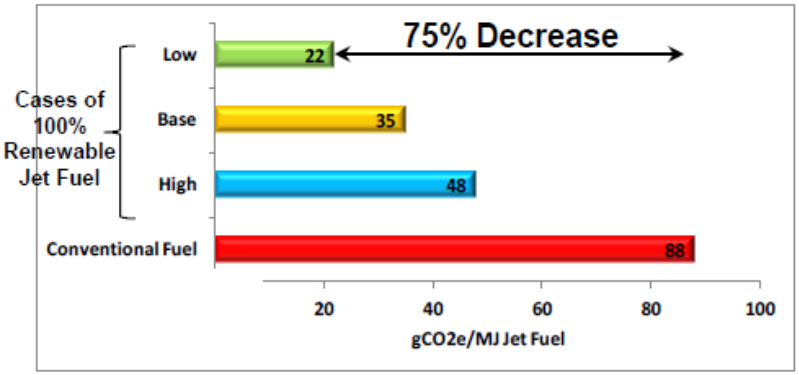


Highlights

- First Lifecycle Analysis (LCA) for 100% Renewable Jet Fuel based on blends of pyrolysis-derived kerosene and HEFA (hydroprocessed esters and fatty acids)
- Downselected four feedstocks from 51 analyzed: Camelina, Tallow, Sawmill / forest residue, Sugarcane bagasse
- High, low, and base cases were calculated based on ranges of feedstock mix, transportation costs, and efficiency of the fuel production process
- Modeled lifecycle steps using GREET (Argonne Nat'l Lab), SimaPro, published HEFA production data, and proprietary Honeywell-UOP data for pyrolysis processing
- Trained next generation of scientists and engineers at MIT

100% Renewable Jet Fuels will Meet Renewable Fuels Standard (RFS2)

- Total GHG emissions when all the emission scenarios are considered along with different HEFA production schemes range from 22 to 48 gCO2e/MJ, which is a 45-75% GHG reduction from conventional jet fuel using EPA methodology



P&W CLEEN Technologies Updates

Ultra High Bypass Geared Turbofan with Advanced Fan System

- Completed technology and demonstrator engine detailed design

2014 Activities:

- Hardware fabrication, test planning for demonstrator engine
- Fan rig tests

Alternative Jet Fuels

- Engine and combustor testing of alternative jet fuels from multiple production pathways

Ultra High Bypass Geared Turbofan (GTF)

Wind Tunnel Tests

Ground Test

Engine application projected at 20% fuel burn reduction re: CFM56-7 and 25 EPNdB cumulative margin to Stage 4

Images courtesy of Pratt & Whitney

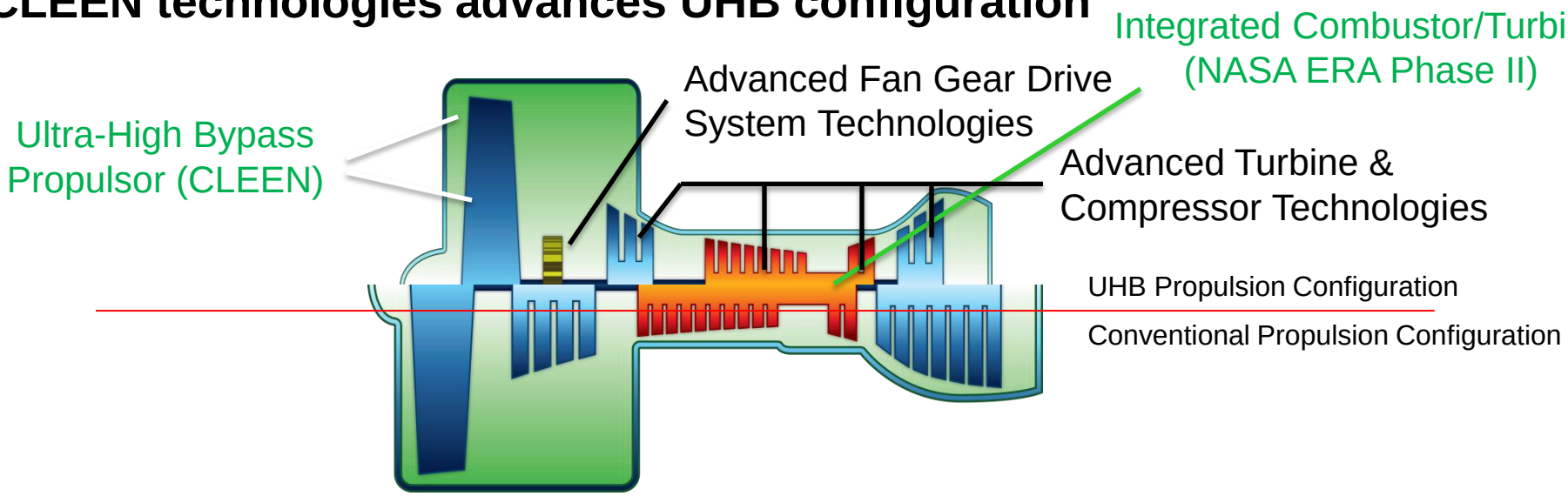
FAA CLEEN UHB Propulsion System

UHB propulsion system provides significant step towards CLEEN goals

Company	Technology	Goal Impact	CLEEN Goals	Projected System Performance
P&W	UHB Propulsion System	Fuel-burn	33% Reduction	> 20% Reduction
		Emissions	60% Reduction in NOx (re: CAEP 6)	>60% Reduction in NOx (re: CAEP 6)
		Noise	32 EPNdb Reduction	25 EPNdb Reduction (re: Stage 4)

FAA CLEEN Technologies – P&W

CLEEN technologies advances UHB configuration



				CLEEN Rig and Engine Demonstrator Programs and Technologies	
Company	Technology	Goal Impact	CLEEN Goals	Very High-Bypass (2015 - 2020 EIS)	Ultra High-Bypass (2020 - 2025 EIS)
P&W	UHB Propulsion System	Fuel-burn	33% Reduction	15% Reduction	20% Reduction
		Emissions	60% Reduction in NOx (re: CAEP 6)	50% Reduction in NOx (re: CAEP 6)	>60% Reduction in NOx (re: CAEP 6)
		Noise	32 EPNdb Reduction	20 EPNdb Reduction (re: Stage 4)	22 EPNdb Reduction (re: Stage 4)

CLEEN II

- **Program model based on successful CLEEN I**
  - Requires cost share and tech maturation from TRL 3-5 to demonstration at TRL 6-7
  - Program work conducted 2015-2020
  - Requires industry to show path to commercial product so tech realizes benefits in the fleet with EIS 2020-2025
- Milestones:
  - ✓ Market survey conducted May-July 2013
  - ✓ Draft solicitation released publicly November 2013
  - ✓ Industry day held in Washington D.C. December 2013
  - ✓ Obtained internal approvals for program and solicitation Spring 2014
  - ***Preparing solicitation for release soon!***
  - Contract award and work planned to begin summer of 2015

CLEEN vs. CLEEN II Program Goals

Develop and demonstrate (TRL 6-7) certifiable aircraft technology

	CLEEN	CLEEN II	
Noise (cum below Stage 4)	-32 dB	-32 dB	and/or reduces the noise contour area in absolute terms
LTO NOx Emissions (below CAEP 6)	-60%	-75%	and/or reduces absolute NOx production over the aircraft's mission
Aircraft Fuel Burn	-33%	-40%	and/or supports the FAA's goal to achieve a net reduction in climate impact from aviation

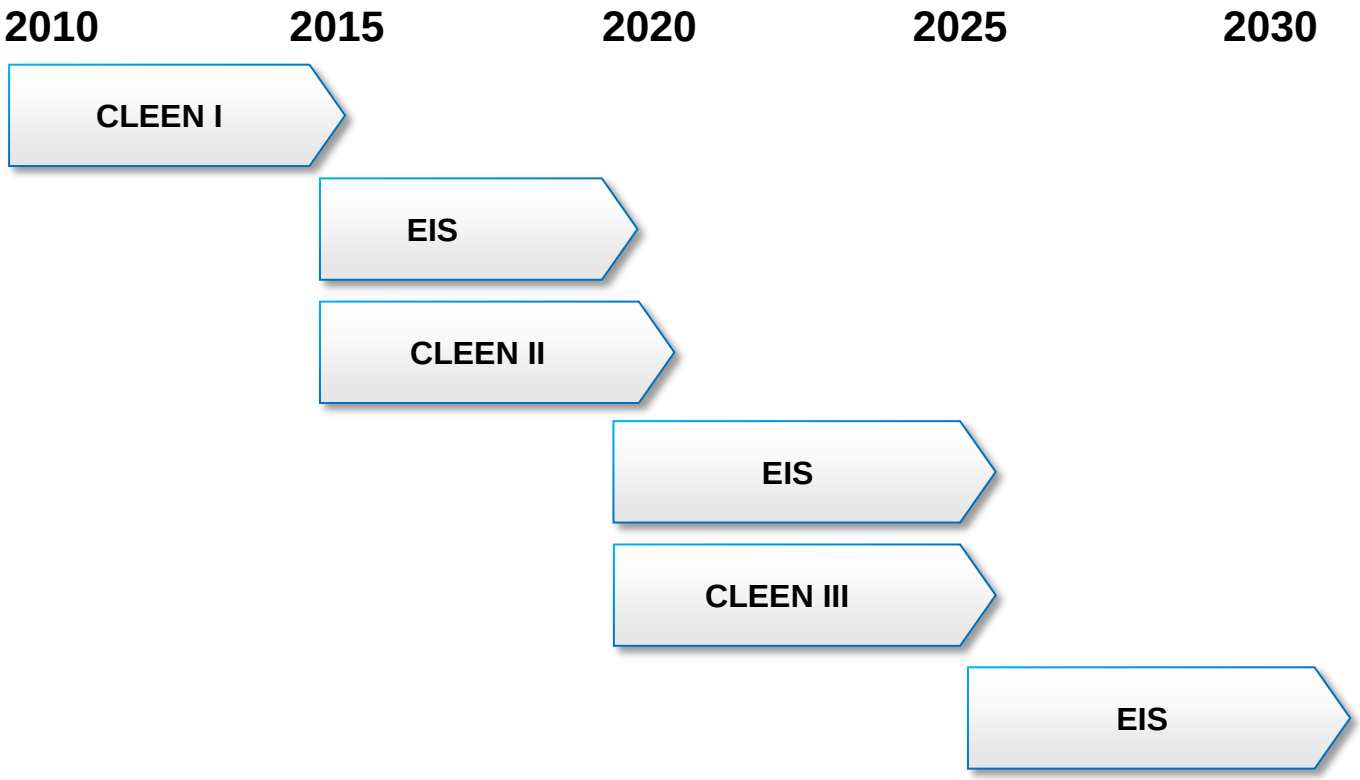
Advance use of "drop-in" renewable alternative fuels

Bio feedstock

Fuel Production

Jet fuel

CLEEN Timeline



CLEEN functions on five year cycle so a 10+ year vision could cover both CLEEN II & III. What do you see as being the needs to be addressed by the CLEEN Program?

In Summary

- CLEEN has already successfully accelerated aircraft technology development to reduce fuel burn, emissions and noise
- Technology assessment continues to play an important role in our aircraft technology activities
- CLEEN has helped and is helping to accelerate alternative jet fuel development
- CLEEN II is coming

Backup Slides:

Additional CLEEN Project Information

GE CLEEN Technologies

Flight Management System (FMS) /Air Traffic Management Integration

- Completed Dynamic Quiet Climb & Wind Input Optimization
- Completed Trajectory Sync Simulation (TRL 6)

2014 Activities:

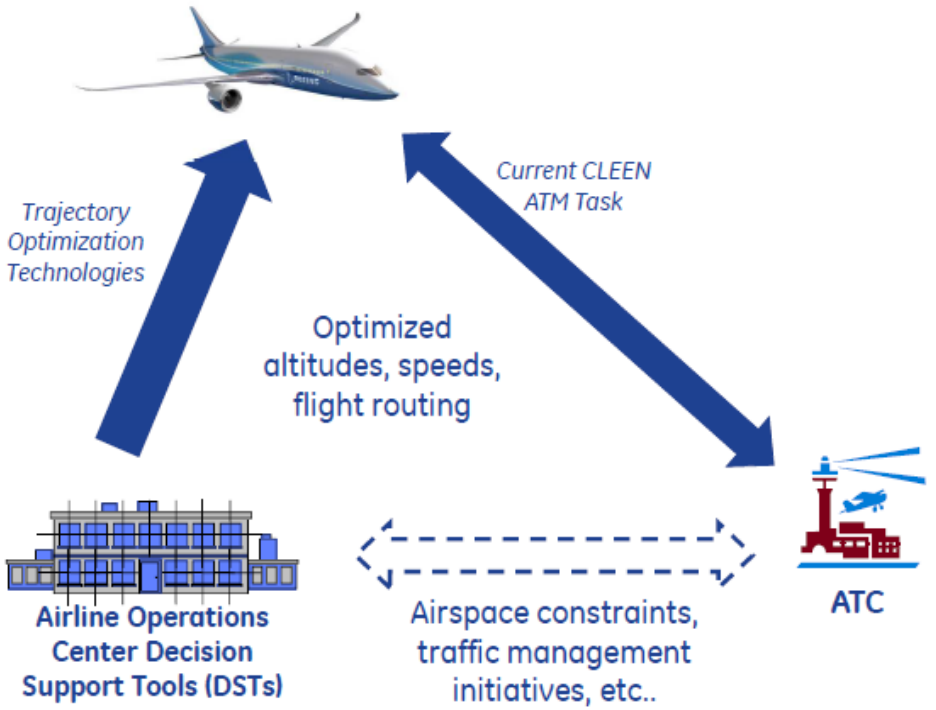
- Trajectory optimization

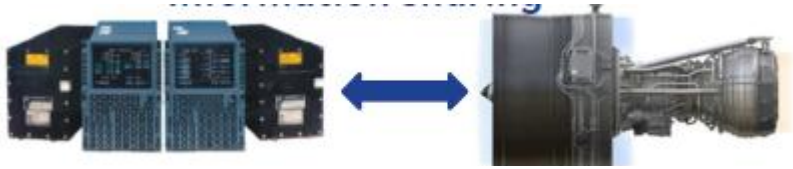
FMS/Engine Integration

- Adaptive engine control
- Vehicle health management
- Flight-propulsion control

2014 Activities:

- Further development, preparation for engine testing





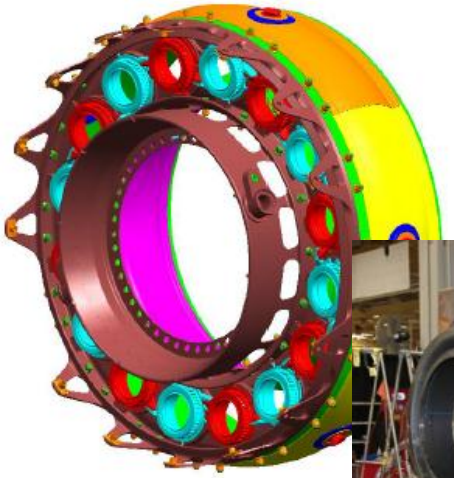
Fuel burn and noise reductions being assessed.

Images courtesy of GE Aviation and Aviation Systems

GE CLEEN Technologies

Twin Annular Premixing Swirler (TAPS) II Combustor

- Completed design, manufacture, lab rig, sector, full combustor rig, and engine core test (TRL 6)
- ***Demonstrated in rig and core engine test > 60% NOx margin to CAEP/6, exceeding CLEEN goal.***
- ***Technology transitioning on LEAP turbofan engine***



Open Rotor

- Completed design, fabrication, and wind tunnel testing of modern scaled blades in partnership w/ NASA
- ***Rig results assessed on single aisle aircraft design show 26% fuel burn reduction vs. 737/CFM56-7B and up to 15 EPNdB cumulative noise margin to Stage 4***

Images courtesy of GE Aviation

Rolls-Royce CLEEN Technologies Updates

Dual Wall Turbine Airfoils
- Completed casting trials
- Completed preliminary design

2014 Activities:
- Detailed design
- Initial hardware delivery

Ceramic Matrix Composite Blade Tracks
- First ground engine test complete

2014 Activities:
- Further engine testing

Novel Alternative Jet Fuels Project
- Lab, rig, and auxiliary power unit testing complete

Blade tracks/shrouds and dual wall turbine airfoils
- Increased temp
- Reduced weight
- Improved specific fuel consumption

Assessed at up to 1% fuel burn reduction

Images courtesy of Rolls-Royce