REDAC Environment and Energy Sub-Committee

Federal Aviation Administration

Aircraft Technology Research

By: Levent Ileri and Arthur Orton
FAA CLEEN Program Managers

Date: September 17, 2020

Agenda

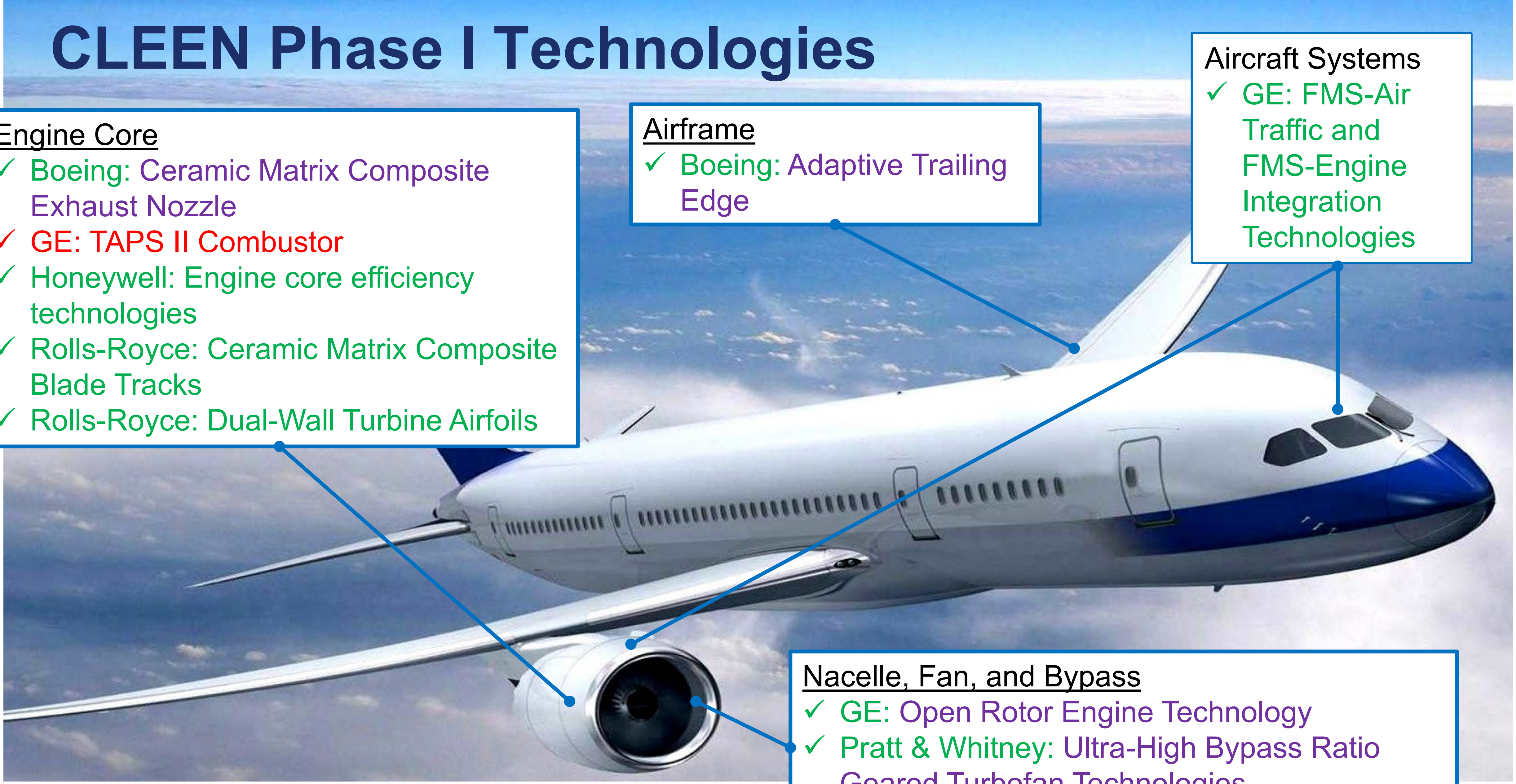
- **Continuous Lower Energy, Emissions & Noise (CLEEN) Program Overview**
  - CLEEN Phase II status
  - CLEEN Phase III update
- **Aviation Sustainability Center of Excellence (ASCENT) Technology Projects**
- **ICAO CAEP Long Term Aspirational Goal Support**

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 (Completed)	Phase II (Ongoing)
Time Frame	2010-2015	2016-2020
FAA Budget	~$125M	~$100M
Noise Reduction Goal	25 dB cumulative noise reduction cumulative to Stage 5	
Fuel Burn Goal	33% reduction	40% reduction
NO_X Emissions Reduction Goal	60% landing/take-off NO_X emissions	75% landing/take-off NO_X emissions (-70% re: CAEP/8)
Entry into Service	2018	2026

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

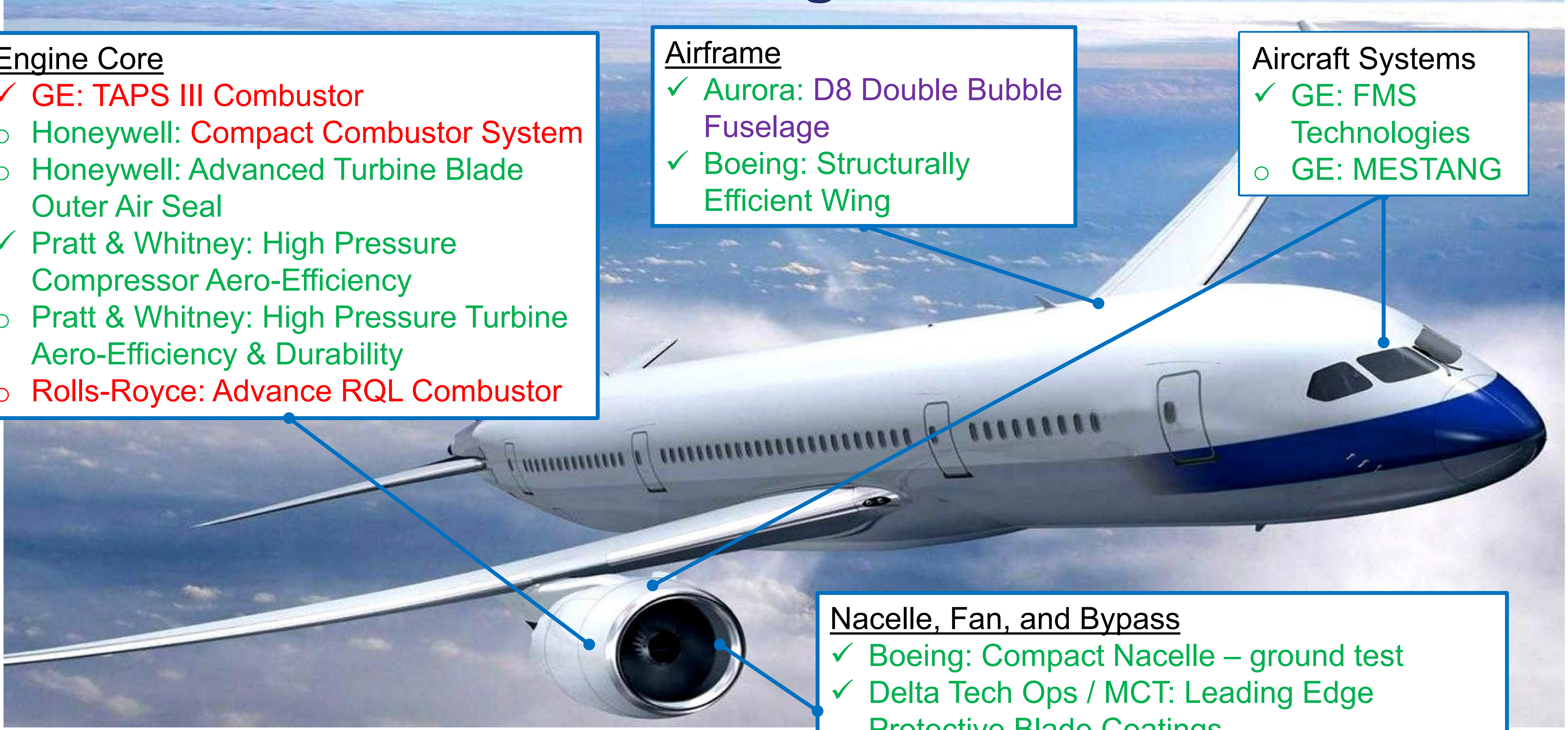
Aircraft Systems
- ✓ GE: FMS-Air Traffic and FMS-Engine Integration Technologies

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

Fuel
NO_x
Noise

✓ Completed Effort

CLEEN Phase II Technologies



Engine Core

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

Airframe

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

Aircraft Systems

- ✓ GE: FMS Technologies
- o GE: MESTANG

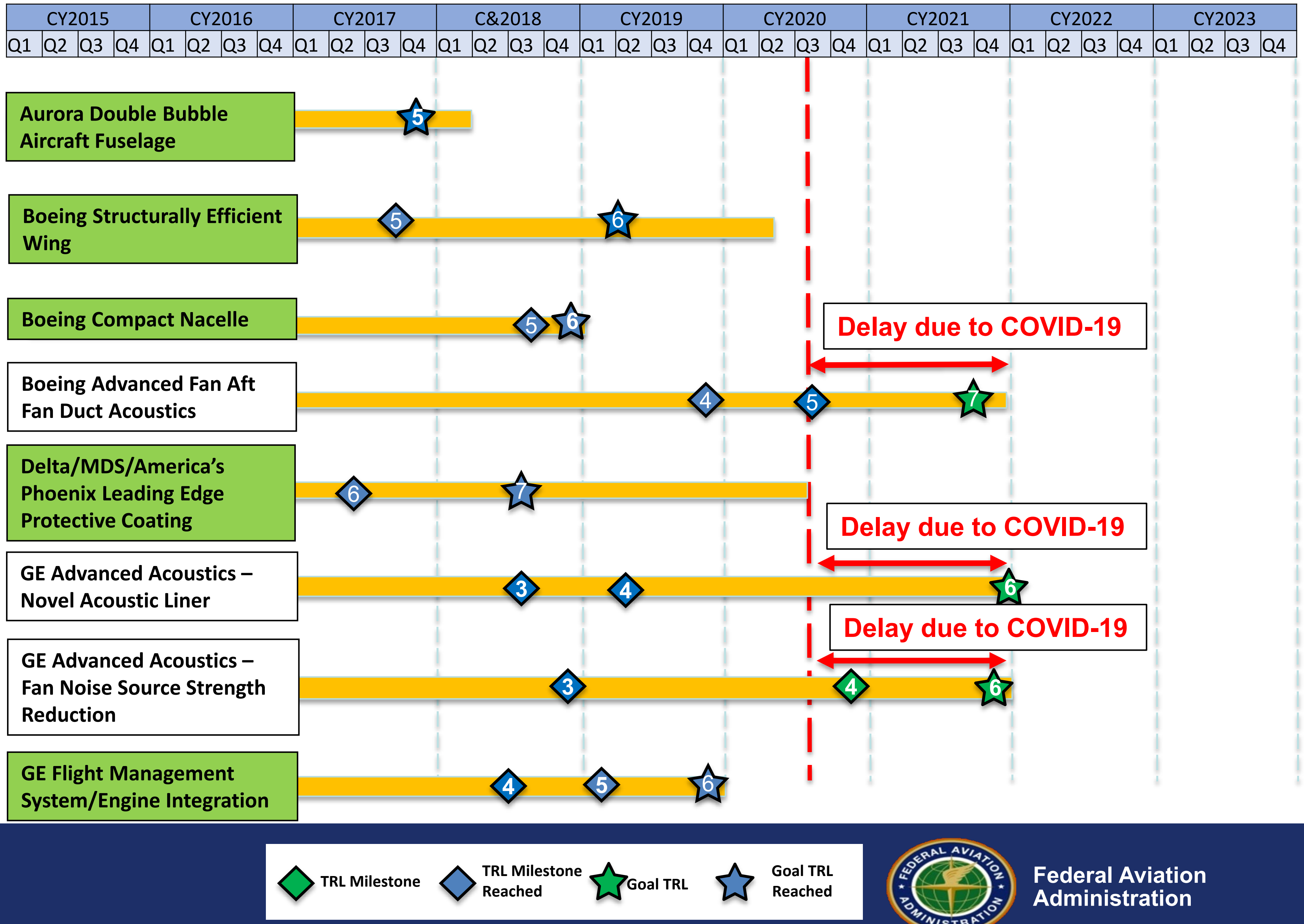
Nacelle, Fan, and Bypass

- ✓ Boeing: Compact Nacelle – ground test
- ✓ Delta Tech Ops / MCT: Leading Edge Protective Blade Coatings
- o GE: Low F[illegible]e Ratio Advanced Acoustics
- o Collins A[illegible]e: Nacelle Technologies

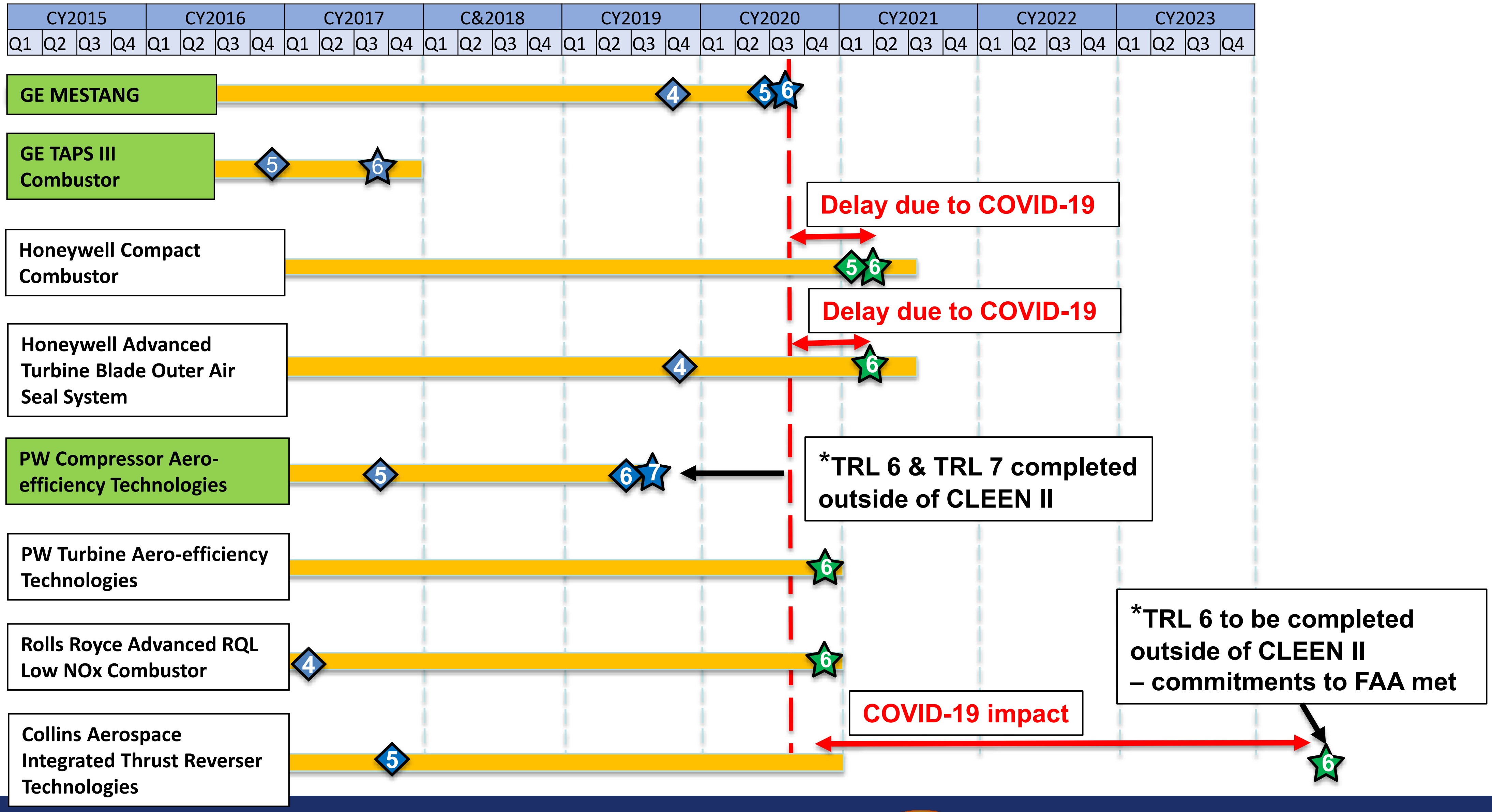
Fuel
NO_x
Noise

- ✓ Completed Effort
- o Continues in FY20

CLEEN Phase II Technologies – TRL Milestones



CLEEN Phase II Technologies – TRL Milestones (Continued)



Accomplishments – Since Spring REDAC Sub-Committee

Programmatic

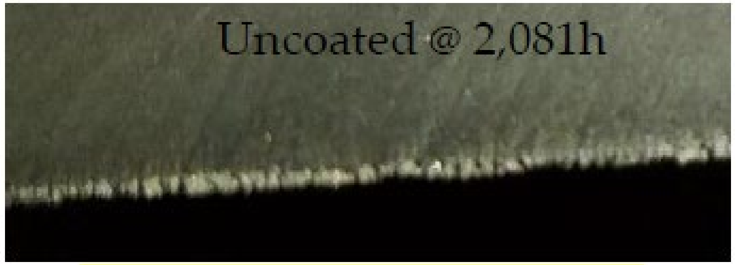
- Execution of CLEEN Phase II Options (initiated Spring 2019 – awarded August 2020):
  - Honeywell advanced acoustic fan module
    Expected 2.5 EPNdB cum. noise reduction with 3% fuel burn reduction
  - GE low pressure ratio acoustics (additional phase)
    Expected ~2 EPNdB cum. noise reduction

Technical

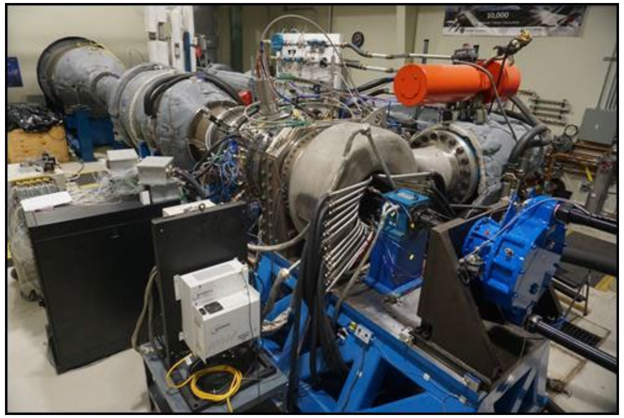
- Boeing completion of Structurally Efficient Wing project final report (May 2020)
  - Covers results of full development effort, concluding in full scale wing structural load testing
  - Successfully matured a suite of composite, materials and manufacturing technologies to TRL 6
  - Expected to deliver up to 3.5% fuel burn reduction in future applications

Accomplishments (contd.) – Since Spring REDAC Sub-Committee

- Delta Tech Ops / MDS Coating Technologies completion of flight service evaluation of leading edge protective blade coatings (March 2020)
  - Confirmed 1.1% fuel consumption improvement in engine test
  - Achieved TRL 7 with over 7,000 flight hours on wing to prove and quantify durability



- Pratt & Whitney testing of turbine technology blade at Penn State rig (March 2020)
  - Validated predictions for new turbine blade designs
  - Compared baseline and advanced aero/thermal technologies at representative operating conditions
  - Expected 0.8-1.0% fuel burn reduction (to be validated in final report)



- Rolls-Royce initiation of advanced rich-quench lean (RQL) combustor full annular rig (August 2020)

Upcoming CLEEN II Activities

Next 6 Months' Activities

- Honeywell to conduct TRL 6 engine test of blade outer air seal and combustor technologies
- Rolls-Royce completion of advanced RQL combustor rig testing
- Full-swing execution of GE and Honeywell options that are now in place

CLEEN Phase II Benefits Assessments

- Continue to work with Georgia Tech to model CLEEN Phase II technologies and assess benefits at vehicle and fleet level (via ASCENT Project 37)

- Preliminary fleet level benefits assessment expected Fall 2020
  - Includes a subset of technologies matured and modeled to date

- COVID-19 impacts to CLEEN Phase II development schedules pushes out data availability for final assessments
  - Requires additional time and funding (approx. 1 yr additional) to support conclusion of assessments

CLEEN Phase III

CLEEN Phase III Overview

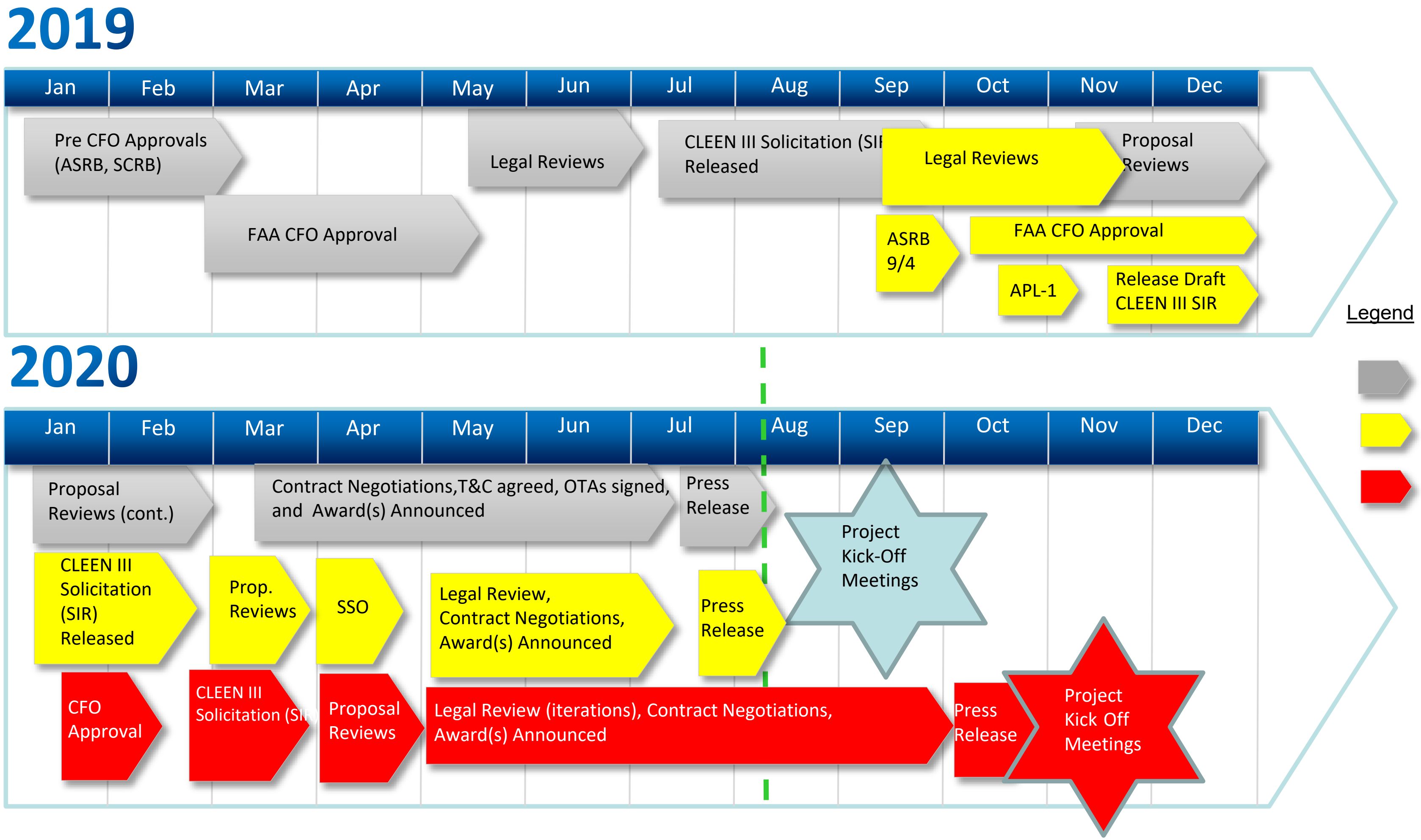
	Phase III*	
Time Frame	2021-2025	
Entry into Service	2031	
FAA Budget	TBD	
Vehicle Type	Subsonic	Supersonic
Noise Goal	25 dB cumulative noise reduction relative to Stage 5 and/or reduces community noise exposure	Reduction during landing and takeoff cycle (LTO)
Fuel Burn Goal	-20% re: CAEP/10 Std	-
NO_X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

*** The information for the third phase of the CLEEN Program is notional as the FAA is in the process of developing the final solicitation.**

- **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 <u>civil subsonic and supersonic airplanes</u> 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 Acquisition Schedule



FAA CLEEN Phase III Contracting Specialist:
Stephen Mostow
Stephen.Mostow@faa.gov
(202) 267-8494

Legend

- Original Plan (grey)
- Slippage due to AFN (yellow)
- Actual (red)

In Summary

- CLEEN technology development and alternative fuels projects are progressing under CLEEN Phase II, managing COVID-19 impacts
- Next CLEEN II + CLEEN III Consortium Meetings:
  - October 26-30, 2020: Virtual
  - May 4-6, 2021: Phoenix, AZ (pending COVID restrictions)
  - Nov 2-4, 2021: Washington, DC (location TBD)
- In the process of executing CLEEN Phase III awards (2020-2025)
- For more on CLEEN https://www.faa.gov/go/cleen

ASCENT Technology Projects

- **Continue to expand our environmental technology research portfolio into our Center of Excellence**
- **Provides complementary venue for University-led research to advance industry state-of-the-art and expand knowledge broadly**
- **Themes:**
  - *New: Improved technology noise modeling*
  - System-level modeling and design considerations
  - Propulsion-airframe integration
  - Combustion
  - Turbomachinery
  - Supersonics (covered in separate session on supersonics)
- **Overview of projects now available on ASCENT website:**

  https://ascent.aero/topic/Aircraft-Technology/

Technology Projects Summary

Improved technology noise modeling

75	Improved Engine Fan Broadband Noise Prediction Capabilities
76	Improved Open Rotor Noise Prediction Capabilities

New since Spring sub-committee meeting

System-level modeling and design considerations

37	CLEEN Technology Modeling and Assessment
52	Comparative Assessment of Electrification Strategies for Aviation
64	Alternative Design Configurations to Meet Future Demand

Green = awarded since Spring meeting via grant approval memos 3 and 4

Propulsion-airframe integration

50	Over Wing Engine Placement Evaluation
63	Parametric Noise Modeling for Boundary Layer Ingesting (BLI) Propulsors

Combustion

51	Combustion Concepts for Next-Generation Aircraft Engines
55	Noise Generation and Propagation from Advanced Combustors
66	Evaluation of High Thermal Stability Fuels
67	Impact of Fuel Heating on Combustion and Emissions
68	Combustor Wall Cooling with Dirt Mitigation
70	Reduction in nvPM Emissions from Aero-Engine Fuel Injectors
71	Predictive Simulation of nvPM Formation in Aircraft Combustors

Technology Projects Summary (Contd.)

Turbomachinery

56	Turbine Cooling Through Additive Manufacturing

Supersonics

10	Aircraft Technology Modeling and Assessment
47	Clean Sheet Supersonic Engine Design and Performance
59	Jet Noise Modeling and Measurements to Support Low Noise Supersonic Aircraft Technology Development
74	Low Emissions Pre-Mixed Combustion Technology for Supersonic Civil Transport

Green = awarded since Spring meeting via grant approval memos 3 and 4

ASCENT Project 75: Improved Engine Fan Broadband Noise Prediction Capabilities

Institution / PI: Boston University / Sheryl Grace

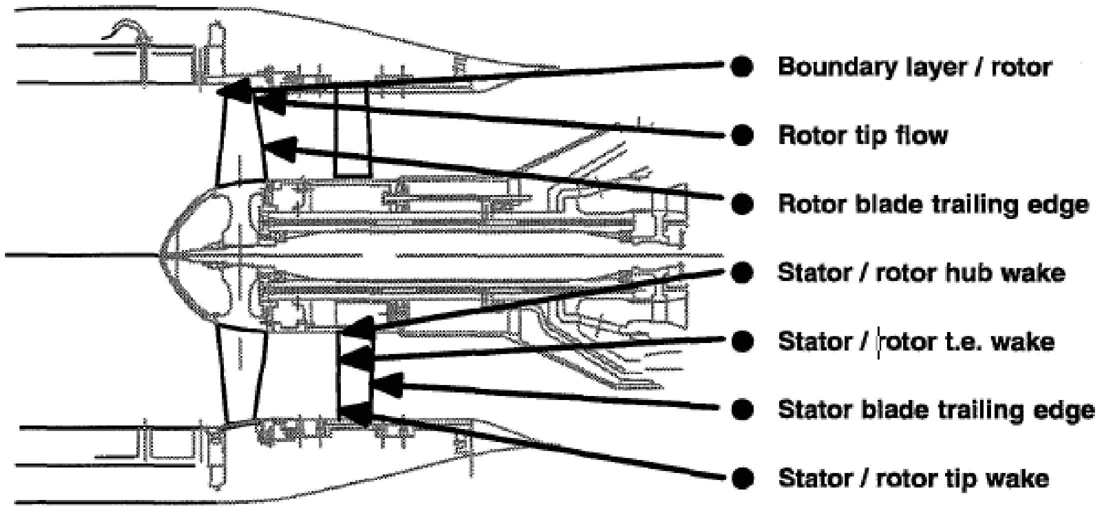
FAA PM: Chris Dorbian

Funding: $300,000/yr. for 3 years

Objective: Accepted methods for predicting, controlling, and treating fan tonal noise have existed for years, but less so for broadband noise. This work will develop a fan broadband noise prediction method that addresses the gaps in currently used lower-order models.

Approach: Researchers will leverage past experience with low-order model development, machine learning, and training data (some of which is on hand and some of which will need to be obtained/created) to build a fan-wake turbulence surrogate model. The team will also seek to make improvements to the low-order method. Rig testing at UTRC will be considered.

Expected Impact: Aft fan broadband noise is an increasingly significant noise source in modern engines. With a faster, more applicable fan broadband prediction method, engine designers will be able to include this outcome as a design variable, which will result in better engine designs.



(Ganz et al., 1998)

ASCENT Project 76: Improved Open Rotor Noise Prediction Capabilities

Institution / PI: Georgia Tech / Dimitri Mavris

FAA PM: Chris Dorbian

Funding: $300,000/yr. for 3 years

Objective: The Contra-Rotating Open Rotor (CROR) system has promising fuel/emissions, but may come with noise penalties. The researchers will perform a sensitivity study on the design parameters of a CROR configuration to enable system design improvements for noise reduction.

Approach: Build on past efforts to reduce size of parameter space, then carry out high-fidelity computational aeroacoustics analyses to assess impact of parameters on noise. GE Aviation is a cost-share partner.

Expected Impact: Provide both the FAA and industry key insights necessary for design optimization of the CROR system in the future.

Image Source: NASA

ICAO CAEP Long Term Aspirational Goal (LTAG) Support

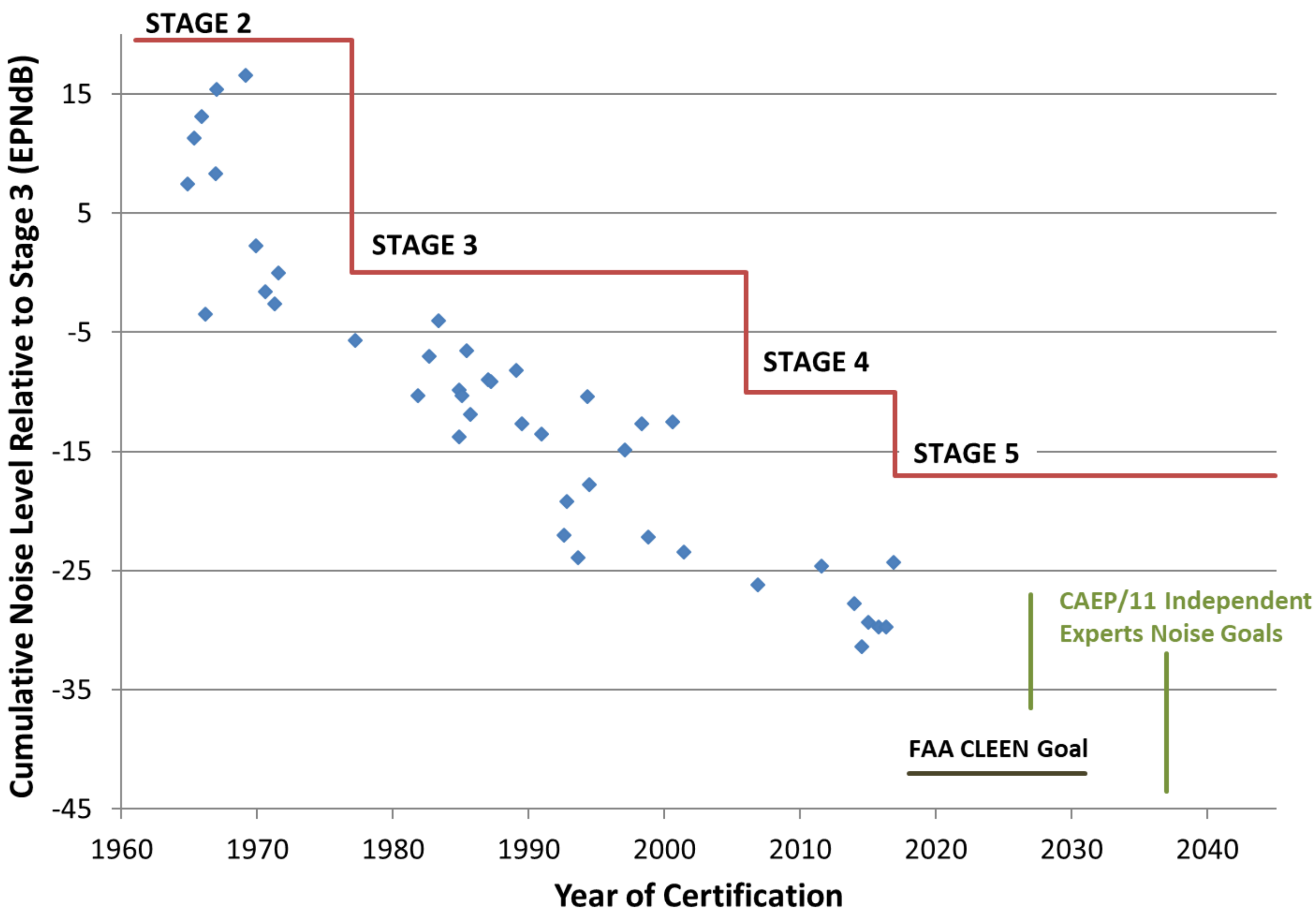
- FAA is providing staffing and researchers to support CAEP exploration of feasibility of a long term aspirational goal for CO_2 emissions from international aviation
- Engaging directly across all aspects of this work to support assessment of current, foreseen, innovative measures to contribute to CO_2 reduction under various future scenarios
- Plan to leverage ASCENT Project 64 to provide analysis support for modeling/analysis/assessment
  - Feeds into larger assessment of feasibility of an aspirational goal

Conclusions

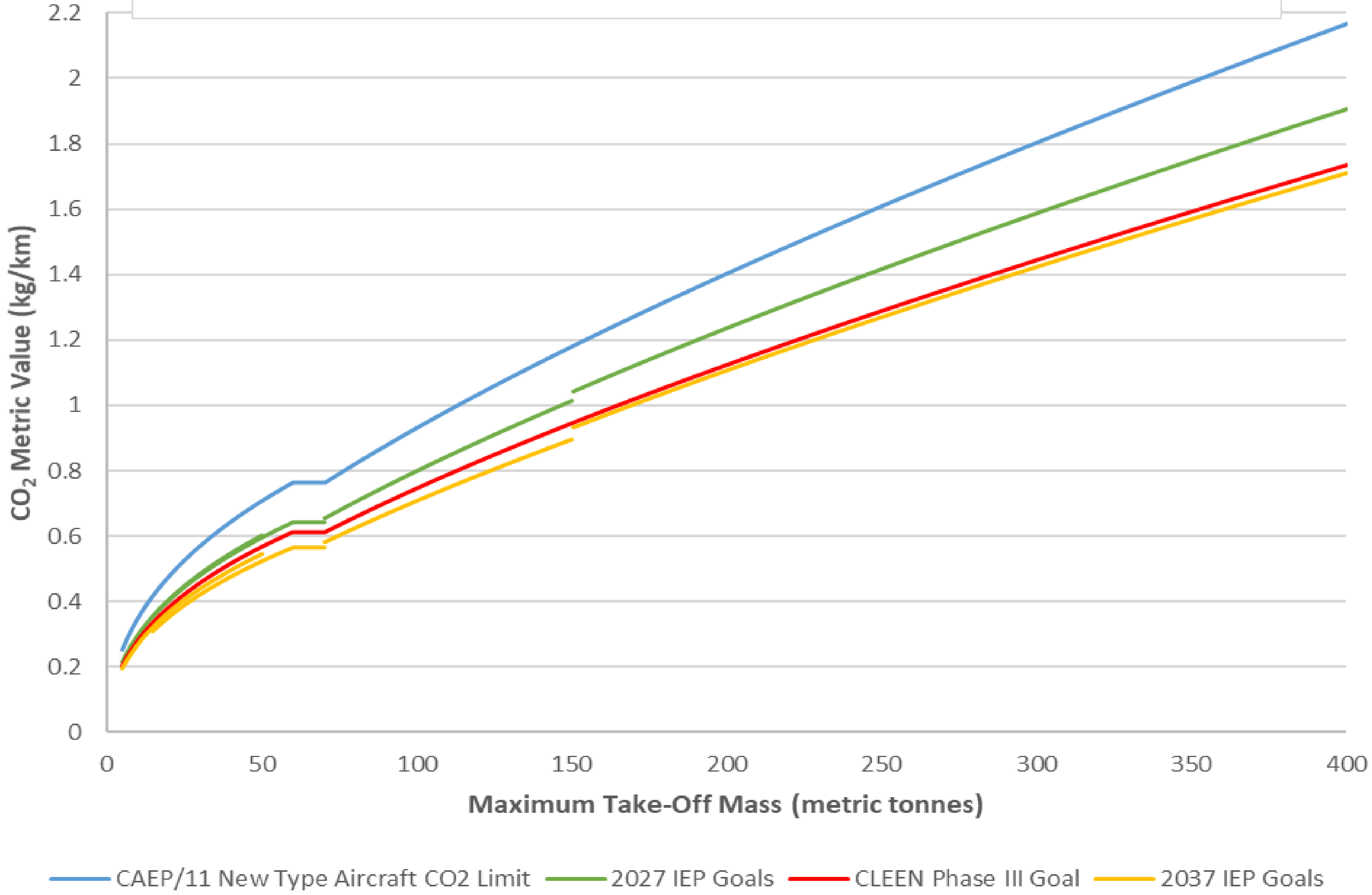
- **CLEEN Phase II is executing its fifth successful year**
  - Six technology projects have reached their maturation goals, with many more expected in the next year, even after COVID impacts
- **CLEEN Phase III will continue our efforts to accelerate maturation of environmental aircraft technologies into the fleet (2020-2025)**
  - Awards planned Q4 CY2020
- **New ASCENT projects continue to expand our aircraft technology research portfolio**
- **Supporting CAEP LTAG work across all elements**

Backup Slides

CLEEN Noise Goal in Context



CLEEN Phase III Fuel Burn Goal in Context



System-Level Modeling and Design Considerations

ASCENT Project 37: CLEEN Technology Modeling and Assessment

Institution / PI: Georgia Tech / Dimitri Mavris

FAA PM: Roxanna Moores

Funding: $240,000

Objective: Independently model and assess the benefits of the technologies that are being developed under the CLEEN program.

Approach: Directly coordinate, capture, and share data with the CLEEN II companies in order to accurately model the environmental benefits of each technology. Use these technology models in vehicle and fleet-level assessments of fuel burn, emissions and noise benefits from CLEEN.

Impact: Quantifies the benefits of the CLEEN Program's technology investments as they propagate into the fleet.

Funded

ASCENT Project 52: Comparative assessment of electrification strategies for aviation

Institution / PI: MIT / Steven Barrett

FAA PM: Cecilia Shaw

Funding: $300,000

Objective: Compare the operational and economic feasibilty of “electro fuels” vs an all electric aircraft. Additionally, compare life-cycle emissions to conventional jet fuel powered aircraft.

Approach: Develop a system level engineering and economic model to estimate the lifecycle cost of each option.

Impact: Identify the conditions under which battery-powered aircraft or electrofuels are the more desirable electrification strategy for aviation from an economic and environmental perspective.

ASCENT Project 64: Alternative Design Configurations to meet Future Demand

Institution / PI: Georgia Tech / Dimitri Mavris

FAA PMs: Fabio Grandi and Maryalice Locke

Funding: $250,000

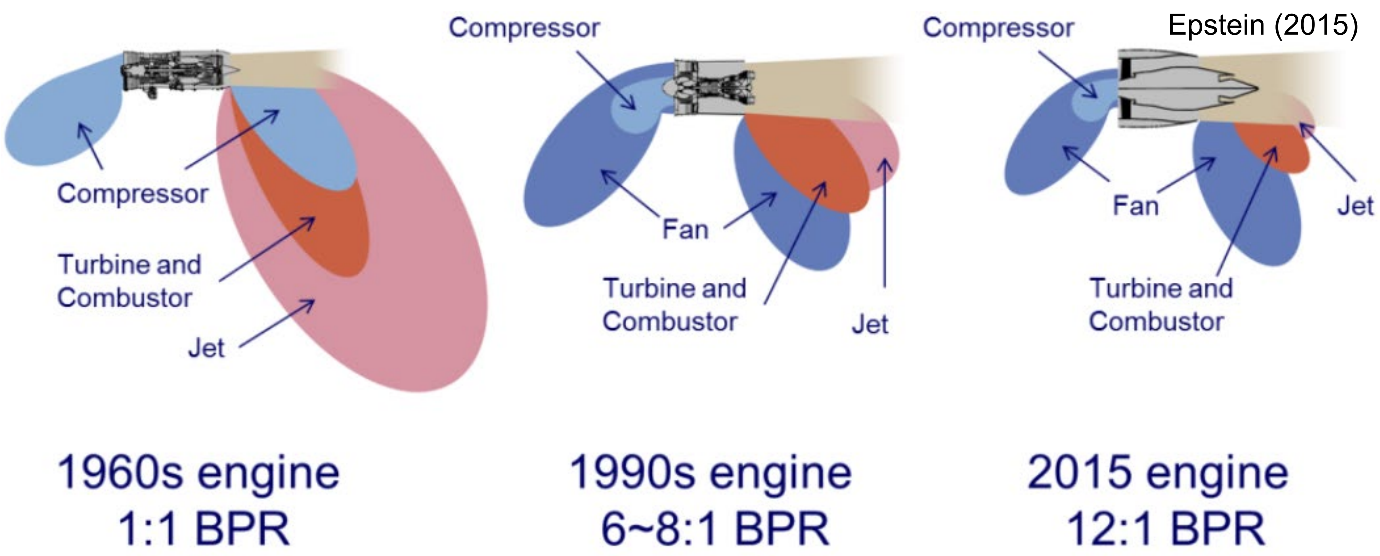
Objective: Investigate alternative aircraft design approaches to meeting future air transportation demand while taking into consideration a variety of constraints.

Approach: Consider constraints including real-world issues such as airport capacity constraints and desires for increased sustainability, while accounting for potential changes in aircraft design that result from advances in technology and changes in mission specifications and up-gauging.

Impact: Provide an understanding of the impacts of fleet turn-over trends and potential alternative design choices by the aircraft manufacturers to meet the growing passenger demand of the future. This project will identify the appropriate design requirements for new aircraft with available technologies of the future and assess how the use of these new aircraft designs will impact fuel burn, noise, and emissions.

Propulsion-Airframe Integration

ASCENT Project 50: Over-Wing Engine Placement Evaluation



Institution / PI: Georgia Tech / Dimitri Mavris

FAA PM: Chris Dorbian

Funding: $590,000 over two years;

Objective: Over-wing nacelle (OWN) concept has potential noise benefits due to shielding and reduced landing gear height, but there is potential for fuel penalties from wing/propulsor aerodynamic interactions if not optimized. Project will deliver method to assess tradeoffs and optimize OWN configuration.

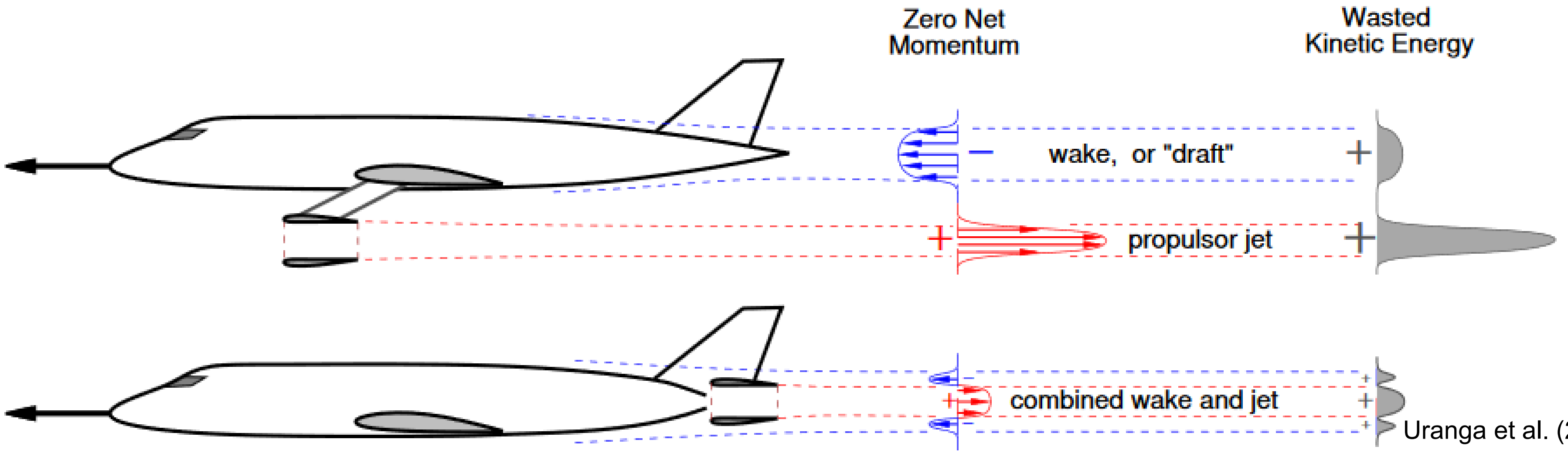
Approach: Leverage Georgia Tech experience with OWN, multidisciplinary analysis and optimization, and adaptive sampling to reduce computational cost of analysis. Build on past efforts to include noise shielding effects and analyze multiple flight conditions.

Expected Impact: Optimization of an OWN aircraft configuration over a mission with noise constraints will enable accurate tradeoffs between noise benefits and fuel burn. Informs FAA and industry on viability of OWN technology.

Funded

ASCENT Project 63: Parametric Noise Modeling for Boundary Layer Ingesting (BLI) Propulsors

Institution / PI: Georgia Tech / Dimitri Mavris
FAA PM: Chris Dorbian
Funding: $300,000



Uranga et al. (2014)

Objective: Identify, develop, and validate a parametric fan noise module for a generic BLI propulsor. Provide assessment of noise implications of advanced vehicle concepts that employ BLI (e.g., D8, STARC-ABL).

Approach: Utilize lower order methods but seek to validate against higher fidelity approaches and any publicly available experimental data sets. Quantify turbulence ingestion, mean flow distortion, and shielding in a generic enough way that multiple classes can be captured.

Expected Impact: Tool that allows propulsor designers to identify potential noise related problem areas for BLI propulsion concepts early in the conceptual design process to further define solutions for mitigation of noise impacts. Integrate with ANOPP in the future.

Combustion

ASCENT Project 51: Combustion Concepts for Next-Generation Aircraft Engines

Institution / PI: MIT / Steven Barrett
FAA PMs: Roxanna Moores & Rangasayi Halthore
Funding: $300,000 (with additional year planned)

Objective: The purpose of this project is to identify future aircraft engine designs which increase the efficiency of future aircraft, while simultaneously reducing emissions.

Approach: conducting simulations on new jet engine combustor technologies

Expected Impact: This project will provide novel capabilities to efficiently evaluate the performance of aircraft engine designs, which involve co-optimization of fuel, combustor, and engine cycle.

In this project, MIT plans to develop numerical models for engine concepts with promising new technologies

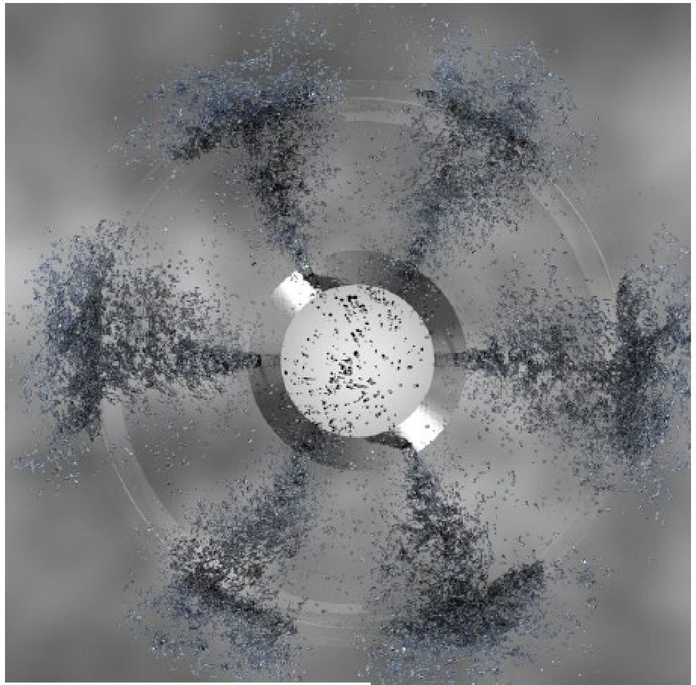
ASCENT Project 55: Noise Generation and Propagation from Advanced Combustors

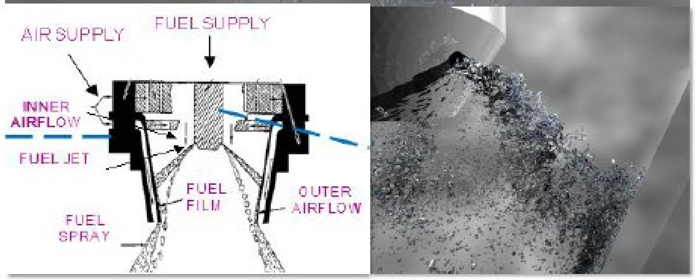
Institutions / PIs: Timothy Lieuwen (Georgia Tech) and Jeffrey Mendoza (UTRC)
FAA PM: Roxanna Moores
Funding Level: $1,499,984 (with additional year planned)

Objective: There is a need to reduce Jet engine combustor noise. This program will improve understanding of how combustion noise is generated, develop tools to predict noise levels and guide design decisions, and ultimately enable quieter aircraft engines.

Approach: Project will conduct simulations in various portions of the combustor. The project will conduct testing to validate the modelling results as well as create benchmark data.

Expected Impact: from this work are reduced noise pollution in the vicinity of airports and reduced development time/cost of new engines that meet future noise targets.





Accurate prediction of liquid fuel atomization is crucial for Large Eddy Simulation combustor noise prediction.

ASCENT Project 66: Evaluation of High Thermal Stability Fuels

Institution / PI: University of Dayton / Josh Heyne
FAA PM: Anna Oldani
Funding: $184,997

Objective: Investigate potential improvements in jet engine fuel burn when fuels with high thermal stability are used as coolants or subjected to engine temperatures higher than currently realizable with typical conventional fuel thermal stability.

Improve understanding of what fuel components drive thermal stability properties.

Approach: Identify engine components that could benefit from cooling using high thermal stability fuels. Apply heat transfer models to these components to estimate energy recovery. Identify optimum cooling sequence to maximize heat recovery. Estimate resulting fuel efficiency gains from combined impacts of cooling improvement, heat recovery maximization, and reduced engine component weight.

Impact: Provide analysis of the benefits deriving from the usage of high thermal stability fuels as engine coolant.

ASCENT Project 67: Impact of Fuel Heating on Combustion and Emissions

Institution / PI: Purdue / Robert Lucht

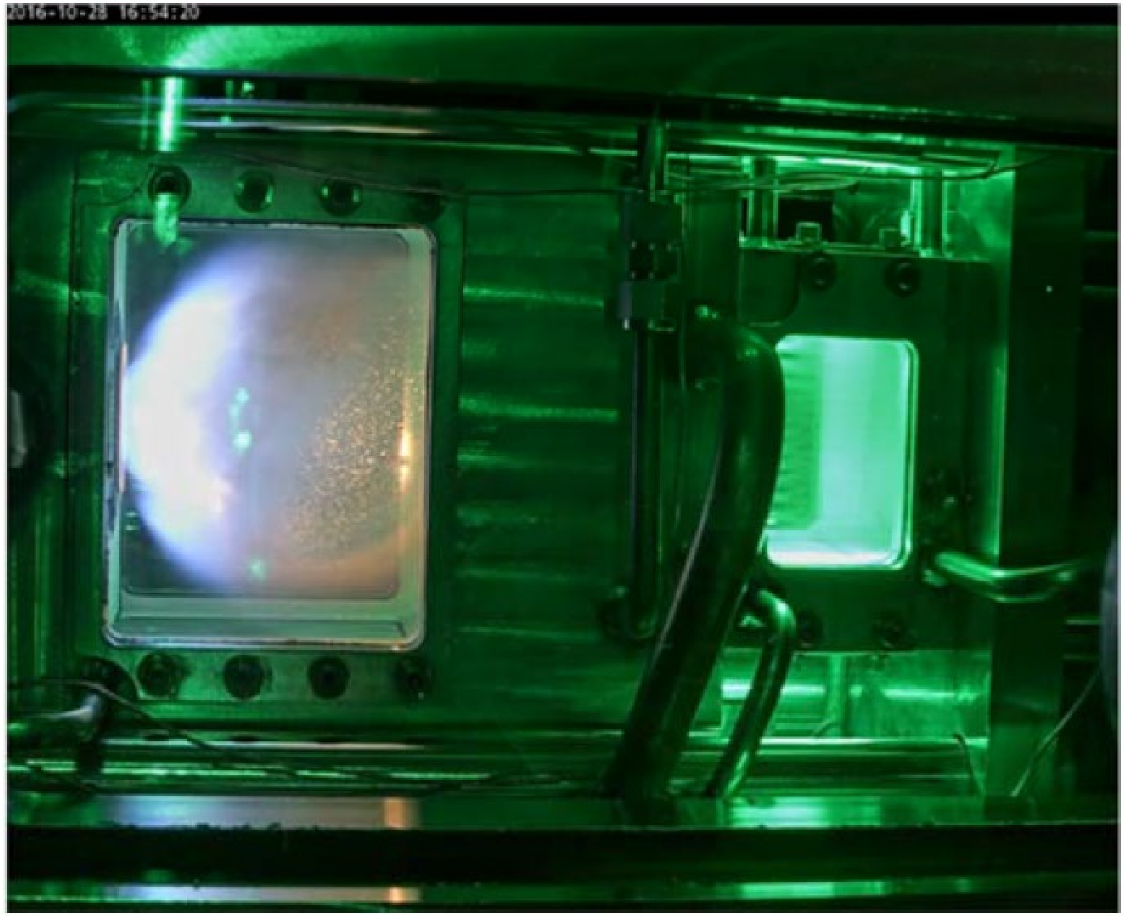
FAA PM: Cecilia Shaw

Funding: $250,000

Objective: Investigate the effects of hot fuel on combustion performance and the level of emissions for a lean burn combustor

Approach: The effects of heated fuel will be investigated using nonintrusive laser diagnostic methods and by physical probe sampling to monitor emissions and combustion efficiency.

Impact: Fuel can be used to support the increased thermal management load, enabling higher flight speeds.



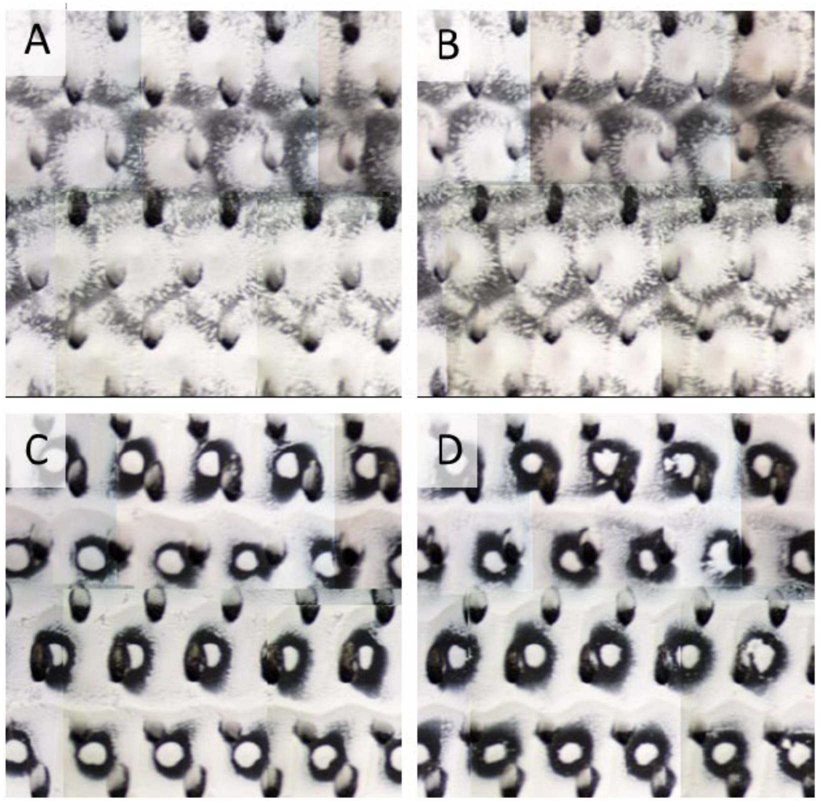
ASCENT Project 68: Combustor Wall Cooling with Dirt Mitigation

Institution / PI: Penn State University / Karen Thole
FAA PM: Cecilia Shaw
Funding: $150,000

Objective: Develop new design to reduce dirt accumulation in the combustor cooling liner during operating conditions

Approach: Study a cooling design for combustor walls that is insensitive to dirt accumulation, as well as an improved understanding of why it is insensitive

Impact: Dirt mitigations will result in fuel burn reductions over a longer time period as well as allowing continued turbine operations while reducing turbine maintenance.



ASCENT Project 70: Reduction of nvPM emissions from aero-engine fuel injectors

Institution / PI: Georgia Tech / Wenting Sun

FAA PMs: Daniel Jacob and Cecilia Shaw

Funding: $500,000 for two years

Objective: Investigate how jet fuel atomization affects the formation and oxidation of non-volatile particle matter (nvPM) in operating conditions and develop a model of novel fuel injector to reduce nvPM formation.

Approach: PI will use optical diagnostics to measure nvPM volume and flow field for a set of Honeywell injectors. Data will be used to develop CFD model to simulate nvPM formation oxidation

Impact: Enable the development of fuel injectors that have improved fuel atomization and reduced nvPM formation

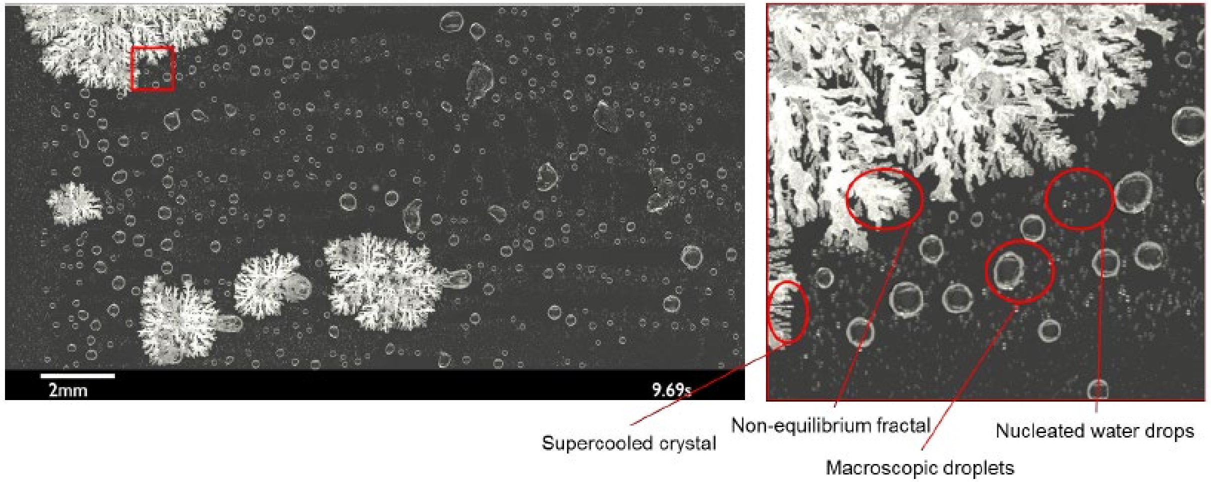
ASCENT Project 71: Predictive Simulation of Sooting Flames

Institution / PI: Georgia Tech / Suresh Menon
FAA PMs: Roxanna Moores and Daniel Jacob
Funding Level: $500,000

Objective: This project will establish a new multiscale approach to predict soot formation in aircraft combustors. All modeling tools already exist with this GT team but a systematic coupling of these tools in multi-scale, multi-physics strategy has yet to be accomplished by anyone.

Approach: The project will conduct simulations for chemical kinetics mechanisms, will include new chemistry and new subroutines. Additionally CFD modelling will be conducted to assess the impact of turbulence.

Expected Impact: Improve knowledge of emissions formation should enable development of improved combustors with lower emissions characteristics.



Snapshot of results using Metaphysics icing simulation capability which will be leveraged for a Monte Carlo simulation of post-inception mechanisms associated with soot formation and growth

Turbomachinery

ASCENT Project 56: Reduced Fuel Burn through Double-Wall Cooling of Turbine Airfoils Made Possible through Additive Manufacturing

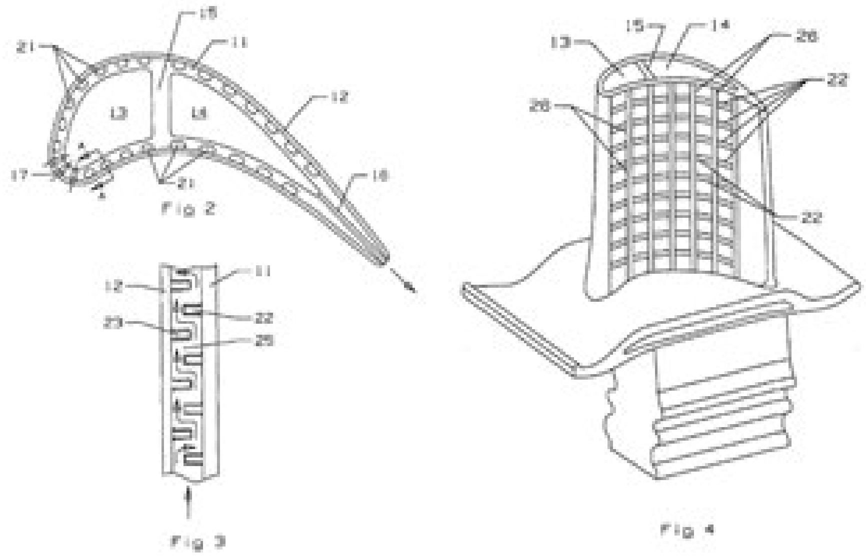
Institution / PI: Penn State University / Karen Thole

FAA PM: Cecilia Shaw

Funding: $400k for three years

Objective: Develop and fabricate potential thermal performance improvements to turbine airfoils using metal-based additive manufacturing.

Approach: PI will investigate the potential gains possible by manufacturing turbine airfoils using three-dimensional metal-based additive manufacturing (AM) and comparing them to traditional metal cast turbine airfoils



Impact: AM can improve cooling efficiency by exploring more complex cooling geometries. Can lead to decrease in fuel burn and reduce thermal stresses.