Project 037 CLEEN II System Level Assessment

Georgia Institute of Technology

Project Lead Investigator

Dimitri Mavris (PI)
Regents Professor
School of Aerospace Engineering
Georgia Institute of Technology
Mail Stop 0150
Atlanta, GA 30332-0150
Phone: 404-894-1557
Email: dimitri.mavris@ae.gatech.edu

University Participants

Georgia Institute of Technology

- PIs: Dr. Dimitri Mavris (PI), Dr. Jimmy Tai (Co-PI)
- FAA Award Number: 13-C-AJFE-GIT-055
- Period of Performance: August 31, 2019 to August 31, 2020

Project Funding Level

FAA funding was distributed at the levels of $240,000. The Georgia Institute of Technology has agreed to a total of $240,000 in matching funds. This total includes salaries for the project director, research engineers, and computing, financial and administrative support, including meeting arrangements. The institute has also agreed to provide tuition remission for any students paid for by state funds.

Investigation Team

Georgia Institute of Technology
Principal Investigator: Dimitri Mavris
Co-Investigators: Jimmy Tai
Fleet Modeling Technical Lead: Holger Pfaender
Supporting Engineers: Greg Busch, Joshua Brooks

Project Overview

The objective of this research project is to support the FAA by independently modeling and assessing the technologies that will be developed under the Continuous Lower Energy, Emissions, and Noise Phase II (CLEEN II) program. This will involve direct coordination and data sharing with companies developing technologies under CLEEN II, in order to accurately model the environmental benefits of these technologies at the vehicle and fleet levels.

The Georgia Institute of Technology (GT) was previously selected to perform all of the system level assessments for the original CLEEN Phase I (CLEEN I) program under PARTNER Project 36 and ASCENT Project 10. As a result, GT is in a unique position from both a technical and programmatic standpoint to continue the system level assessments for CLEEN II. From a technical perspective, GT has significantly enhanced the Environmental Design Space (EDS) over the last five years to incorporate advanced, adaptive, and operational technologies targeting fuel burn, noise, and emissions. EDS was successfully applied to all CLEEN I contractor technologies including: GE open rotor, TAPS II combustor, FMS-Engine and FMS-Airframe; Pratt & Whitney geared fan; Boeing adaptive trailing edge and CMC nozzle; Honeywell hot section cooling and materials; and Rolls-Royce turbine cooling technologies. GT also gained significant experience in communicating system-level modeling requirements to industry engineers and translating the impacts to fleet-level fuel burn, noise, and emissions assessments.

This broad technical knowledge base covering both detailed aircraft and engine design and high-level benefits assessments puts GT in a unique position to assess CLEEN II technologies.

As the ultimate goal of this work is to conduct fleet-level assessments for aircraft representative of future "in-service" systems, GT will need to create system-level EDS models using a combination of both CLEEN II and other public domain N+1 and N+2 technologies. The outcomes of the technology and fleet assumptions-setting workshops conducted under ASCENT Project 10 will be heavily leveraged for this effort. Non-CLEEN II technologies for consideration along with potential future fleet scenarios will help to bound the impact of CLEEN II on future fleet fuel burn, emissions, and noise.

Since the FAA will also be performing a portion of the EDS technology modeling work, EDS training has been provided to the FAA in 2016 under ASCENT Project 10. The training has provided the requisite skill set required to use EDS.

In the prior year of this project, GT began modeling activities with Collins, GE, Honeywell, and Pratt & Whitney. This modeling process included validation of underlying EDS models, information and data exchange necessary to model the individual technologies, and related EDS modeling activities. In addition, GT has assisted the FAA with in-house modeling of GE combustion technologies. This process has increased the FAA's use of FAA personnel for EDS system level assessment modeling.

This year's work will focus on moving toward the end of the project by completing vehicle- and fleet-level assessments for CLEEN II. This includes final technology modeling details for each CLEEN II industry contractor generation of vehicle-level assessments of fuel burn, emissions, and noise compared to current best-in-class along with fleet-level estimates of fuel burn, emissions, and noise, including community noise impact estimates at multiple relevant airports. Quantifying this impact will provide understanding on the number of increased operations per day that CLEEN II technologies enable without worsening noise exposure to the surrounding community. While airports in the U.S. are not generally noise-constrained, there are European airports that do have limited capacity to meet noise constraints. Understanding the impact of technologies on the future U.S. fleet is critical to quantifying the interaction between economic growth (i.e., increased flight operations at a given airport) and community noise impacts.

GT has completed most of the technology modeling to date. Remaining items include updating technology models using the most recent data from contractors and conducting a final fleet assessment. The table in the next section shows the current status of technology modeling. Where work remains, a brief description is provided after the table.

Major Accomplishments

- The modeling for GE MESTANG is complete.
- The modeling for GE Flight Management System is complete.
- The modeling for Collins Slim Nacelle is complete.
- The modeling for Honeywell Blade Outer Air Seal is complete, awaiting contractor review.
- The modeling for Pratt & Whitney Compressor and Turbine Aero-Efficiency Technologies is complete, awaiting contractor review.
- Preliminary fuel burn assessment completed.
- The data exchange and assumptions were defined for Honeywell Compact Combustor.
- Ongoing effort to model Collins zoned liner technology.
- Ongoing effort to model GE LPR Advanced Acoustic technology.

Contractor	Technology / Model Impact Area	Initial Modeling Discussions Held with Contractor?	Modeling Underway	Percentage Complete	Might Require Update?
Aurora (Techs listed are sub-parts of Double Bubble Fuselage)	D8 configuration	✓	✓	100%	No
Boeing	Structurally Efficient Wing	✓	✓	100%	No
	Compact Nacelle	✓	✓	100%	No

Contractor	Technology / Model Impact Area	Initial Modeling Discussions Held with Contractor?	Modeling Underway	Percentage Complete	Might Require Update?
Delta/MDS/America's Phenix	Leading Edge Protective Fan Blade Coating	✓	✓	100%	No
GE	TAPS III Low NOx Combustor	✓	✓	100%	No
	More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG)	✓	✓	100%	Yes
	Flight Management System (FMS)	✓	✓	100%	Yes
	Low Pressure Ratio Advanced Acoustic	✓		15%	Yes
Honeywell	Compact Combustor	✓	✓	75%	Yes
	Turbine Blade Outer Air Seal	✓	✓	80%	No
Pratt & Whitney	Compressor and Turbine Aero-Efficiency Technologies	✓	✓	80%	Yes
Collins/Rohr/UTAS	Slim Nacelle	✓	✓	100%	Yes
	Noise Liner Technologies	✓	✓	75%	Yes
Rolls-Royce	Advanced Rich Quench Lean Low NOx Combustor	✓		25%	Yes

<u>Remaining Modeling Work</u>

- GE Low Pressure Ratio Advanced Acoustic
  - Waiting on information from GE.
  - Modeling not yet started. Modeling approach formulated.
- Honeywell Compact Combustor
  - Received preliminary combustor correlation estimates from Honeywell.
  - When Honeywell completes high pressure testing at NASA facility, correlations will be updated and model finalized. This only requires minor modeling changes.
- Honeywell Turbine Blade Outer Air Seal
  - Have received modeling impacts from Honeywell. Have modeled similar technology for CLEEN I from Honeywell. Will implement and confirm at same time as Compact Combustor validation.
- Pratt & Whitney Compressor and Turbine Aero-Efficiency Technologies
  - Have held several working meetings with Pratt & Whitney. Modeling approach agreed upon. Modeling data required has been provided by Pratt & Whitney. GT needs to run sensitivity studies and verify trends with Pratt & Whitney.
- Collins Noise Liner Technologies
  - GT has developed a new modeling approach based on feedback from Collins and is currently in the process of implementing this approach.
- Rolls-Royce Advanced RQL Low NOx Combustor
  - When Rolls-Royce completes testing, the same modeling approach as Honeywell will be used, but with empirical NOx model specific to Rolls-Royce.

Preliminary Fuel Burn Assessment

GT and FAA have completed a preliminary fleet-level fuel burn assessment. This does not include the entire set of CLEEN II technologies. The following technologies are included in this assessment:

- All relevant CLEEN I Technologies
- Aurora Double Bubble (fuselage weight reduction)
- Boeing SEW
- Boeing Compact Nacelle
- Delta/MDS/America's Phenix Leading Edge Protective Coating
- GE MESTANG
- Honeywell Turbine Blade Outer Air Seal
- Pratt & Whitney Compressor and Turbine Aero-Efficiency Technologies
- Collins Slim Nacelle

Figure 1 below depicts the estimated fuel burn (in billions of gallons) under the technology introduction scenarios considered by GT. These results are estimated for the fleet of U. S. domestic and internationally departing aircraft. The red and green shaded areas represent the estimated fuel burn savings enabled by the CLEEN Phase I and Phase II programs, respectively.

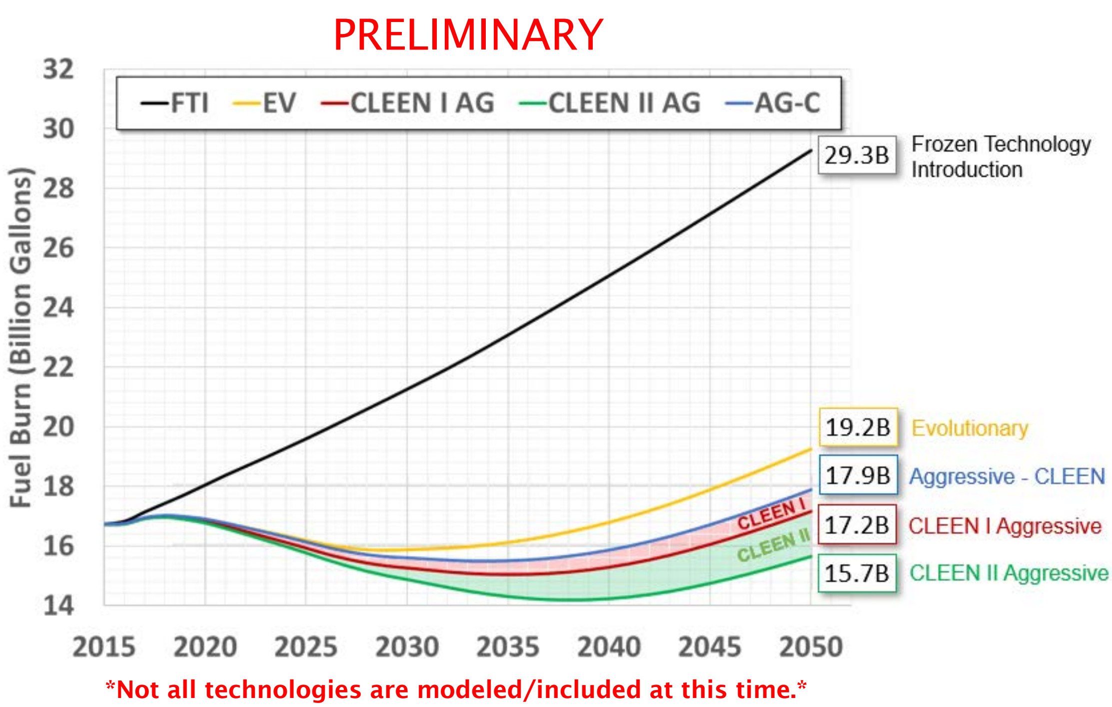

Figure 1. Preliminary fuel burn assessment.

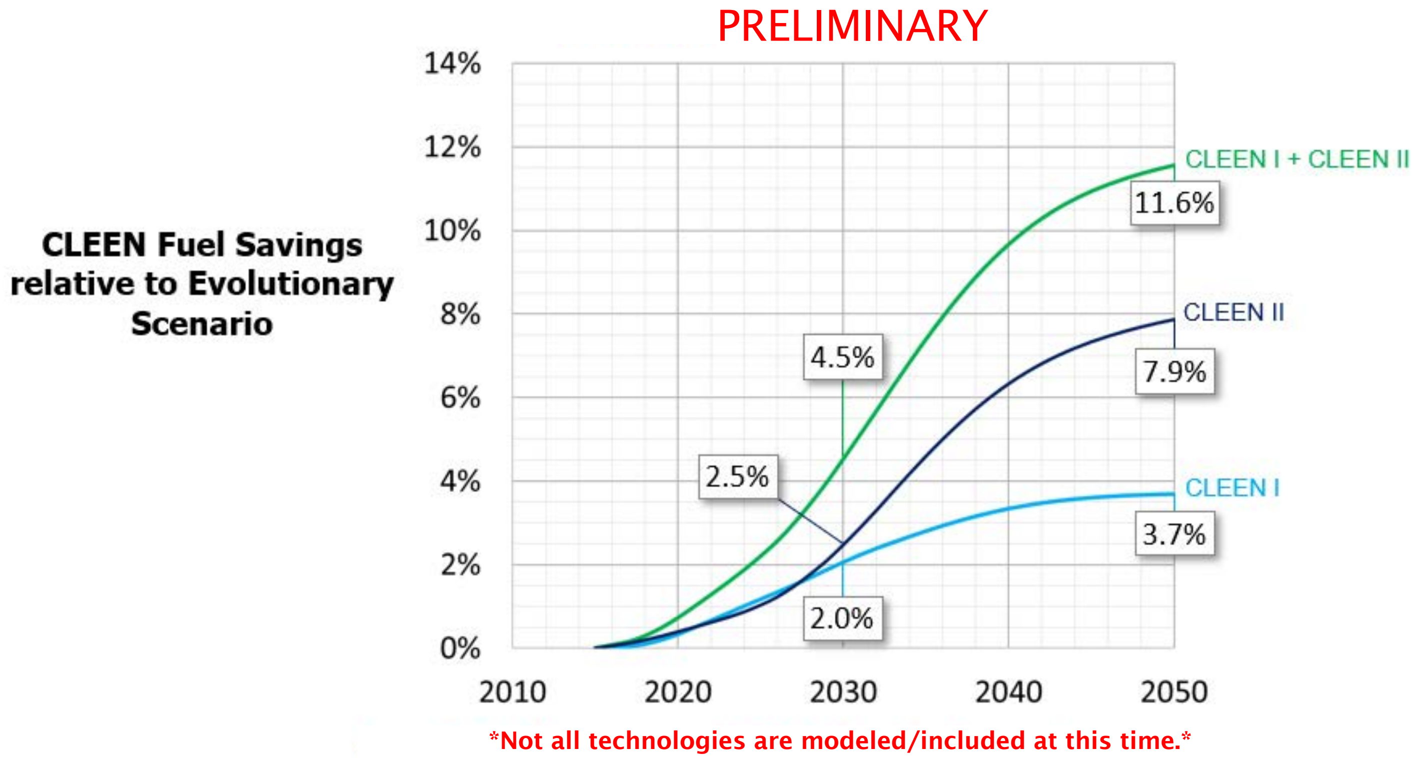

Figure 2. Preliminary fuel burn assessment: savings relative to evolutionary scenario.

Figure 2 has been provided to display fuel savings (%) relative to the evolutionary scenario.

According to the analysis performed above, the technologies matured in the first five-year phase of CLEEN will reduce U.S. fleet-wide fuel burn by 2 percent by 2030 and 3.7 percent by 2050 relative to the evolutionary scenario, providing a cumulative savings of 13.2 billion gallons of jet fuel. The CO_2 savings are the equivalent of taking 1.11 million cars off of the road from 2020 to 2050.

This preliminary analysis projects the technologies matured in the CLEEN Phase II program to reduce fuel consumption 2.5 percent by 2030 and 7.9 percent by 2050 relative to the evolutionary scenario, bringing the contribution of CLEEN Phase I and II to 11.6 percent fuel burn reduction in the fleet by 2050.

Cumulatively, CLEEN Phase I and II are estimated to save 36.4 billion gallons of fuel by 2050, worth approximately 72.8 billion dollars in savings for airlines, and resulting in a reduction in CO_2 emissions of approximately 424 million metric tons. These CO_2 reductions are equivalent to removing 3.05 million cars from the road from 2020 to 2050.

Assessment of CLEEN Phase II's other benefit areas are ongoing. Quantification of the program's fleet-level noise benefits is expected to be complete in 2022.

Publications
None

Outreach Efforts
CLEEN Consortium

Awards
None

Student Involvement
None currently, anticipated in 2021.

Plans for Next Period
Future work will focus on completing technology modeling and updating fleet analysis assessments with remaining technologies. The next period will also include the transition of efforts toward the incoming CLEEN III initiative (e.g., NDAs).

This work will also support attendance at CLEEN consortium meetings and contractor preliminary and detailed design reviews to identify any updates required to technology models developed in prior years.

References
None