Project 037 CLEEN II System-level Assessment

Georgia Institute of Technology

Project Lead Investigator

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University Participants

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- PI(s): Dr. Dimitri Mavris (PI), Dr. Jimmy Tai (Co-PI)
- FAA Award Number: 13-C-AJFE-GIT-055
- Period of Performance: October 1, 2020 to September 30, 2021

Project Funding Level

FAA provided $240,000 in funding to Georgia Institute of Technology.

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

Investigation Team

PI: Dimitri Mavris
Co-Investigator: Jimmy Tai
Fleet Modeling Technical Lead: Holger Pfaender
Supporting Engineers: Joshua Brooks, and Brennan Stewart
Students: Joao De Azevedo, Madelyn Focaracci, and Sebastian Seubert

Project Overview

The objective of this research project is to support the FAA by independently modeling and assessing the technologies that are being developed under the CLEEN II and CLEEN III programs. This will involve direct coordination and data sharing with the CLEEN funded companies in order to accurately model the environmental benefits of these technologies at the vehicle and fleet levels.

Georgia Institute of Technology (GT) was previously selected to perform all system-level assessments for the CLEEN program under PARTNER Project 36 and ASCENT Project 10. As a result, GT is in a unique position from both technical and programmatic standpoints to continue the system-level assessments for CLEEN II. From a technical perspective, GT has significantly enhanced the Environmental Design Space (EDS) over the past 5 years to incorporate advanced, adaptive, and operational technologies targeting fuel burn, noise, and emissions. EDS has been successfully applied to all CLEEN I contractor technologies including the following: GE open rotor, twin annular premixing swirler (TAPS) II combustor, Flight Management System (FMS)-Engine, and FMS-Airframe; Pratt & Whitney geared fan; Boeing adaptive trailing edge and ceramic matrix composite (CMC) nozzle; Honeywell hot section cooling and materials; and Rolls-Royce turbine cooling technologies. GT has also gained extensive 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 detailed aircraft and engine design as well as high-level benefits assessments places GT in a unique position to assess CLEEN II technologies.

Because 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.

Because the FAA will also be performing a portion of the EDS technology modeling work, EDS training was provided to the FAA in 2016 under ASCENT Project 10. The training provided the requisite skill set for using EDS. In the prior year of this project, Georgia Tech continued modeling activities with Collins, Honeywell, Boeing, 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 EDS modeling. This process has increased the number of FAA personnel performing EDS system-level assessment modeling.

Next year's work will focus on moving toward the end of the project by completing vehicle- and fleet-level assessments for CLEEN II. This will include 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 values, along with fleet-level estimates of fuel burn, emissions, and noise, including community noise impact estimates at multiple relevant airports. Individual technology impacts to the vehicle airframe and engine will not be reported, to preserve contractor confidentiality. Quantifying this impact will provide an understanding of the number of increased operations per day that CLEEN II technologies enable without worsening the surrounding community's noise exposure. Although airports in the United States are not generally noise constrained, some European airports have limited capacity to meet noise constraints. Understanding the impact of technologies on the future U.S. fleet will be 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 by using the most recent data from contractors and conducting a final fleet assessment. The table in the next section shows the current status of the technology modeling. Where work remains, a brief description is provided after the table.

Milestone(s)

The major milestones and planned due dates are listed in the table below:

Task No.	Milestone	Planned Due Date
Task 1	Attend CLEEN II Contractor Kickoff Meetings	8/31/2022
Task 2	Identify Required EDS Modeling Enhancements	8/31/2022
Task 2	Develop CLEEN II 5-year System Modeling Roadmaps for Each Contractor	8/31/2022
Task 3	Document EDS Modeling Approaches	8/31/2022

Major Accomplishments

- The modeling for GE More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG) is complete.
- The modeling for the GE Flight Management System is complete.
- The modeling for the Collins slim nacelle is complete.
- The audit of CLEEN I and II technology impacts is complete.
- Updated fuel burn assessment is complete.
- The data exchange and assumptions were defined for the Honeywell compact combustor.
- Efforts to model Collins zoned liner technology are ongoing.
- Efforts to model GE low pressure ratio advanced acoustic technology are ongoing.
- Efforts to model the Boeing compact nacelle acoustic liner are ongoing.

- Efforts to model the Honeywell blade outer air seal are ongoing and awaiting contractor review.
- Efforts to model the Pratt & Whitney compressor and turbine aero-efficiency technologies are ongoing and awaiting contractor review.

Task 1 – Establish Working Relationship with CLEEN III Contractors

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Working relationships with CLEEN III contractors has been largely established through Georgia Tech's participation at contractor kickoff meetings held in the second half of 2021. Non-disclosure agreements where necessary are either standing or are in the initialization process.

Task 2 - Modeling of Aircraft Technologies and Advanced Configurations

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Objective(s)

In order to estimate the impact of CLEEN relevant technologies at the vehicle system-level, each of these technologies must be modeled regarding their impacts to aircraft fuel burn, noise, and emissions using EDS.

Research Approach

Georgia Institute of Technology (GT) was previously selected to perform all system-level assessments for the CLEEN program under ASCENT Project 10. Because 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. Vehicle system-level modeling for all relevant CLEEN II technologies will be performed using EDS.

Table 1 presents an update on the vehicle system-level modeling effort regarding each of the CLEEN II relevant technologies.

Table 1. Update on CLEEN II technology modeling.

Contractor	Technology/Model Impact Area	Initial Modeling Discussions Held with Contractor?	Modeling Underway	Percentage Complete
Aurora (Technologies Listed are Sub-parts of Double Bubble Fuselage)	D8 configuration	✓	✓	100%
Boeing	Structurally efficient wing	✓	✓	100%
	Compact nacelle	✓	✓	100%
	Compact nacelle (noise liner)	✓	✓	50%
Delta/MDS/America's Phenix	Leading edge protective fan blade coating	✓	✓	100%
GE	TAPS III low NOx combustor	✓	✓	90%
	More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG)	✓	✓	100%
	Flight Management System (FMS)	✓	✓	100%

Contractor	Technology/Model Impact Area	Initial Modeling Discussions Held with Contractor?	Modeling Underway	Percentage Complete
	Low pressure ratio advanced acoustic	✓		15%
Honeywell	Compact combustor	✓	✓	75%
	Advanced acoustic fan rotor/liner			0%
	Advanced high-pressure compressor		✓	5%
	Turbine blade outer air seal	✓	✓	85%
Pratt & Whitney	Compressor and turbine aero-efficiency technologies	✓	✓	85%
Collins/Rohr/UTAS	Slim nacelle	✓	✓	100%
	Noise liner technologies	✓	✓	85%
Rolls-Royce	Advanced rich-quench-lean low NOx combustor	✓		25%

Remaining Modeling Work

- GE low pressure ratio advanced acoustic
  - We are awaiting information from GE.
  - Modeling has not yet started. The modeling approach has been formulated.
- Boeing compact nacelle noise liner
  - We have held several working meetings with Boeing. The modeling approach has been agreed upon. The required modeling data have been provided by Boeing.
  - Baseline aircraft modeling results have been reviewed by Boeing.
  - Technology modeling study is underway, and results will be presented to Boeing for verification.
- Honeywell compact combustor
  - We have received preliminary combustor correlation estimates from Honeywell.
  - When Honeywell completes high-pressure testing at NASA, correlations will be updated, and the model will be finalized. Only minor modeling changes will be required.
- Honeywell turbine blade outer air seal
  - We have received modeling impacts from Honeywell. Preliminary sensitivity studies have been completed, and the results have been communicated to Honeywell. Work with Honeywell to verify trends is ongoing.
- Honeywell advanced high-pressure compressor
  - The GT modeling approach formulation has begun. We will initiate modeling conversations with Honeywell before proceeding to results generation.
- Honeywell advanced acoustic fan rotor/liner
  - Modeling has not yet started.
- Pratt & Whitney compressor and turbine aero-efficiency technologies
  - We have held several working meetings with Pratt & Whitney. The modeling approach has been agreed upon. The required modeling data have been provided by Pratt & Whitney. Preliminary sensitivity studies have been completed, and the results have been communicated to Pratt & Whitney. Work with Pratt & Whitney to verify trends is ongoing.
- 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. Preliminary results have been generated.
- Rolls-Royce advanced rich-quench-lean (RQL) low nitrogen oxides (NOx) combustor
  - When Rolls-Royce completes testing, we will use the same modeling approach as that with Honeywell, but with an empirical NOx model specific to Rolls-Royce.

Task 3 - Finalize CLEEN II Analysis

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Objective(s)

To evaluate the impact of CLEEN relevant technologies as propagated forward into the United States civil fleet of domestic and international departing aircraft. Specifically interested in the impact of CLEEN technologies to fleet-level noise, fuel burn, and NOx emissions.

Research Approach

Vehicle system-level modeling for all relevant CLEEN II technologies will be performed using EDS. Fleet benefit assessments for aircraft fleet fuel burn, oxides of nitrogen (NOx), and noise through the year 2050 will be performed using the information delivered by the vehicle system-level modeling effort alongside fleet replacement matrices, technology integration scenarios, and projected aviation demand schedules.

Updated Fuel Burn Assessment

GT and FAA have updated the preliminary fleet-level fuel burn assessment from 2020. This update includes the results of an audit of the previously presented study, with the objective of ensuring the traceability of all relevant technology impacts and the repeatability of the fleet benefit assessment. Technologies included in the fuel burn assessment update include:

- All relevant CLEEN I technologies
- Aurora double bubble (fuselage weight reduction)
- Boeing structurally efficient wing (SEW)
- Boeing compact nacelle
- Delta/MDS/America's Phenix leading edge protective coating
- GE MESTANG
- GE FMS
- Honeywell turbine blade outer air seal
- Pratt & Whitney compressor and turbine aero-efficiency technologies
- Collins slim nacelle

The fuel burn assessment update does not represent the entire set of CLEEN II technologies. It is important also to note that this analysis only includes domestic US flights and US departures, which may represent lower growth rates than a more global analysis. The applied fleet analysis definition and underlying assumptions have remained consistent throughout the CLEEN program.

A technology impact matrix (TIM) has been introduced to rigorously, transparently, and reproducibly manage the impacts of all technologies included in GT's CLEEN program assessment. The TIM was implemented across all five vehicle classes considered in this assessment.

In addition, a comprehensive review was conducted of technology impacts and all the associated design of experiments (DoEs) considered, to date. Based on this review, updates were made within vehicle analysis DoE.

Figure 1 is provided to display the percentage fuel savings relative to the evolutionary scenario. Results are estimated for the fleet of U.S. domestic and internationally departing aircraft.

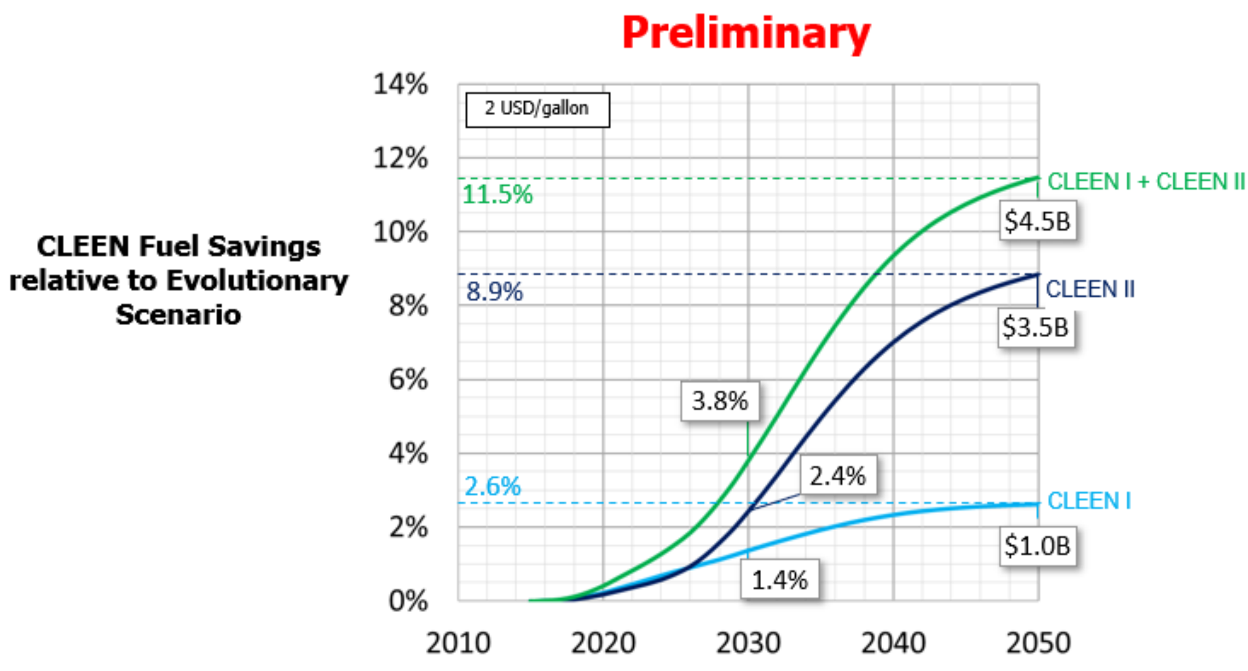

Figure 1. Preliminary fuel burn assessment: savings relative to evolutionary scenario (updated).

According to the analysis performed above, the technologies matured in the first 5-year phase of CLEEN will reduce U.S. fleet-wide fuel burn by 1.4% by the year 2030 and 2.6% by the year 2050 relative to the evolutionary scenario, thus providing a cumulative savings of 9.3 billion gallons of jet fuel. The CO_2 savings are the equivalent of taking 781,000 cars off the road in the years 2020–2050.

This preliminary analysis projects the technologies matured in the CLEEN Phase II program to reduce fuel consumption 2.4% by 2030 and 8.9% by 2050 relative to the evolutionary scenario, thus bringing the contribution of CLEEN Phase I and II to 11.5% fuel burn reduction in the fleet by 2050.

Cumulatively, CLEEN Phase I and II are estimated to save 34.7 billion gallons of fuel by 2050, with a savings worth approximately 69.5 billion dollars for airlines, and resulting in a reduction in CO_2 emissions of approximately 404 million metric tons. These CO_2 reductions are equivalent to removing 2.9 million cars from the road in the years 2020–2050.

Assessment of other areas of benefit of CLEEN Phase II 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

Three graduate students are currently receiving funding from this effort.

Plans for Next Period

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

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

References

None