Project 059(A) Jet Noise Modeling to Support Low-Noise Supersonic Aircraft Technology Development

Georgia Institute of Technology and Pennsylvania State University

Project Lead Investigators

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University Participants

Georgia Institute of Technology
- PI(s): Dr. Dimitri Mavris (PI), Dr. Jimmy Tai (Co-PI)
- FAA Award Number: 13-C-AJFE-GIT–070
- Period of Performance: October 1, 2020 to September 30, 2021

Project Funding Level

The project is funded at the following levels. Georgia Institute of Technology: $100,000. Cost-sharing details are below.

The Georgia Institute of Technology has agreed to a total of $100,000 in matching funds. This total includes salaries for the project director, research engineers, and graduate research assistants, as well as funds for computing, financial, and administrative support, including meeting arrangements. The institute has also agreed to provide tuition remission for the students, paid from state funds. During the period of performance, in-kind cost-sharing is also obtained.

Investigation Team

- PI: Dimitri Mavris (Georgia Institute of Technology)
- Co-Investigator: Jimmy Tai (Georgia Institute of Technology)
- Program Manager: Joshua Brooks (Georgia Institute of Technology)
- Students: Edan Baltman, James Kenny, Noah Chartier, Jeremy Decroix, Andrew Tai, and Madeline Bowne (Georgia Institute of Technology)

Project Overview

The original purpose of this project was to develop and assess computational tools to simulate the flow and noise of civil supersonic aircraft engines and to identify novel methods for noise reduction. In addition to noise predictions, the impact of the noise reduction methods on overall engine performance was planned to be assessed. The predictions were planned to include consideration of the engine inlet, the engine cycle, mixers and ejectors, and the unsteady jet exhaust. Accurate prediction of the engine exhaust flow would enable the generated noise to be computed. Predictions were planned to be assessed through comparison with available experimental measurements.

In discussion with FAA, the overall direction of the project has been changed. Instead of developing and simulating jet noise reduction technologies, Project 59A will be supported by experimental data provided by Project 59 (led by Dr. Krishnan Ahuja) at Georgia Institute of Technology (Georgia Tech). The operating conditions for the initial experimental geometry will be the result of discussions with other Project 59 performers.

This year's work will focus on moving toward the new end of the project. The work includes the assembly of zeroth-order methods for predicting supersonic inlet performance, as well as the deployment of these methods for the identification of competitive supersonic inlet designs for overcoming the performance impacts accompanying noise-reducing nozzle technologies across the flight envelope.

If successful, the ASCENT Project 59 research will develop methods to predict the noise generated and radiated by civil supersonic aircraft engines. The developed tools will enable airframe and engine manufacturers to assess the noise impacts of engine design changes and to determine whether particular designs will meet current or anticipated noise certification requirements. In future years, the assessment of jet noise reduction technologies as originally proposed will be reconsidered.

Project Introduction

The primary objective of this research project is to develop and assess computational tools to simulate the flow and noise of civil supersonic aircraft engines. In Task 1, Georgia Tech and Pennsylvania State University (Penn State) collaborated to select an initial jet nozzle geometry. In Task 2, Georgia Tech analyzed the engine cycle developed by ASCENT Project 10 to estimate the best operating conditions for takeoff and landing for minimizing certification noise levels (Mavris et al., 2015; Welge et al., 2010). The resulting mixer and nozzle conditions are being used to advise the researchers of ASCENT Project 59 on relevant test conditions. These test conditions for the initial geometry will also provide boundary conditions for Task 3. In Task 3, an internal and external flow simulation aimed at uncovering noise source information will be performed. In Task 4, a process for converting high-fidelity simulation results into jet noise sources will be developed, and Task 5 will yield a final report detailing this research effort.

In line with the updated project trajectory, the original leading Tasks 1 and 2.1 have been replaced with the coordination task with Project 59 performers and stakeholders.

Milestone(s)

The major milestones and planned due dates are as follows:

Task No.	Milestone	University	Planned Due Date
Task 1	Selection of initial geometry in coordination with other Project 59 investigators	Penn State and Georgia Tech	12/15/2020
Task 2.1	Assembly of zero-order methods to predict inlet performance	Georgia Tech	11/30/2021
Task 2.2	Determination of boundary conditions from "Vision SST Engine Cycle"	Georgia Tech	2/5/2021
Task 4	Script construction for generation of Aircraft Noise Prediction Program (ANOPP) custom jet noise source	Penn State and Georgia Tech	9/1/2022
Task 5	Submission of interim project report	Penn State and Georgia Tech	11/1/2022

Major Accomplishments

- To capture thrust recovery due to improved inlet performance, the Georgia Tech team must complete the supersonic inlet performance analysis.
  - Validation for zeroth-order supersonic inlet performance analysis for two-dimensional (2D) inlets against IPAC (Barnart, 1997).
  - A sensitivity study was performed to evaluate the thrust recovery potential of inlet variable geometric settings at takeoff and landing.

Task 1 - Select Jet Nozzle Geometry

Georgia Institute of Technology and Pennsylvania State University

Objective(s)

To unify and maximize the impact of work across relevant ASCENT projects, Georgia Tech and Penn State will coordinate efforts to select an initial jet nozzle geometry. Through collaboration with Dr. Krishnan Ahuja, the experimental data from this standard geometry (gathered in ASCENT project 59) will be used to inform the work of ASCENT project 59A.

Research Approach

The combined Penn State and Georgia Tech research team will work together to identify promising geometries for use across the ASCENT projects. The selected geometry must be relevant to the project goals while also being achievable in terms of experimental measurements, computational analysis, and other supporting tasks. Specific evaluation criteria may include jet velocity reduction and thrust loss.

Task 2 - Translate Installed Cycle Performance Requirements into Boundary Conditions

Georgia Institute of Technology

Objective(s)

Task 2 aims to leverage engine cycle modeling capabilities to determine the installed thrust for an engine of interest that is appropriate for commercial supersonic transport. The thermodynamic properties across this mixed flow turbofan engine, alongside the installed thrust value, are used to characterize the mixer exit, nozzle entrance, and nozzle exit operating conditions during takeoff. Because the initial testing and high-fidelity simulations are not yet representative of a mixed flow turbofan, these operating conditions (e.g., total pressure, total temperature, mass flow, and geometry) will inform the testing team regarding relevant testing conditions.

Research Approach (Georgia Tech)

Task 2.1 - Determine Installed Thrust

To ensure that minimum thrust is lost due to the implementation of potential jet noise reduction technology, the installed thrust requirement must be determined, because it is directly proportional to jet velocity. A major contributor to installed thrust is inlet performance, which is highly dependent on how the engine is integrated with the vehicle. Therefore, another element of this task is the investigation of zero-order methods to predict inlet performance for different inlet configurations.

Task 2.2 - Generate Boundary Conditions

Georgia Tech will analyze the engine cycle developed by ASCENT Project 10 to estimate the best operating conditions for takeoff and landing to minimize certification noise levels. The resulting mixer and nozzle conditions (i.e., total temperature, total pressure, and mass flow rate) will inform the researchers of ASCENT Project 59 regarding the relevant test conditions. These test conditions for the initial geometry will also provide boundary conditions for the high-fidelity simulations to be performed in Task 3. The inlet investigation will insure against any thrust loss due to any mixer or nozzle design to minimize noise.

Task 2.1 - Zero-order Methods to Predict Inlet Performance

Inlet performance, a major contributor to the installed thrust, is highly dependent on how the engine is integrated with the vehicle. To capture thrust recovery due to improved inlet performance, the Georgia Tech team must complete the supersonic inlet performance analysis.

In the past year, the Georgia Tech team has completed the model development for the 2D inlet case in Python. In addition, the team has completed an initial validation of a 2D inlet case with satisfactory preliminary results. Table 1 compares the developed tool's predicted total pressure recovery to that produced by IPAC across the mission-relevant range of freestream Mach number (Barnart, 1997). Here, the supersonic inlet was designed for a freesteam Mach number of 5 and has been evaluated across a range of lower "off-design" operating freestream Mach settings. The maximum and average error values were found to be 3.69% and 0.82%, respectively, across this range.

Table 2 compares the total drag coefficient predicted by the developed tool and that produced by IPAC across the mission-relevant range of freestream Mach number (Barnart, 1997). This drag term includes the contributions of spillage, bleed, and bypass drag upon the engine inlet. Again, the supersonic inlet was designed for a freesteam Mach number of 5 and was evaluated across a range of lower "off-design" operating freestream Mach settings. The maximum and average error values were found to be 9.88% and 1.19%, respectively, across this range.

Table 1. Validation case: total pressure recovery.

Freestream Mach Number	Modeled	Reference	Error (%)
0.01	0.9586	0.9608	−0.23
0.2	0.9586	0.9608	−0.23
0.4	0.9586	0.9608	−0.23
0.6	0.9586	0.9608	−0.23
0.8	0.9586	0.9608	−0.23
1.0	0.9586	0.9608	−0.23
1.2	0.9517	0.9539	−0.23
1.4	0.9404	0.9456	−0.55
1.6	0.9233	0.9285	−0.56
1.8	0.8767	0.8816	−0.55
2.0	0.8107	0.8153	−0.57
2.5	0.8591	0.8760	−1.97
3.0	0.7873	0.7875	−0.03
4.0	0.6618	0.6427	2.88
5.0	0.5349	0.5152	3.67

Table 2 Validation case: total drag coefficient.

Freestream Mach Number	Modeled	Reference	Error (%)
0.01	0.0000	0.0000	0.00
0.2	0.0000	0.0000	0.00
0.4	0.1976	0.1799	9.88
0.6	0.3086	0.3024	2.05
0.8	0.3831	0.3811	0.53
1.0	0.4809	0.4797	0.25
1.2	0.6537	0.6617	−1.21
1.4	0.3953	0.3855	2.53
1.6	0.3264	0.3265	−0.01
1.8	0.3245	0.3250	−0.15
2.0	0.3426	0.3411	0.45
2.5	0.3007	0.3000	0.23
3.0	0.2994	0.2987	0.23
4.0	0.2315	0.2307	0.35
5.0	0.0175	0.0175	0.00

The developed inlet performance analysis tool is intended to help identify competitive supersonic inlet designs for overcoming negative performance impacts accompanying the use of noise reduction nozzle technologies across the flight envelope. To this end, a sensitivity study was performed to evaluate inlet variable geometry settings that may be capable of recovering thrust across off-design flight segments (takeoff and landing).

The inlet performance tool will be extended to include the axisymmetric configuration, which will then be integrated into an inlet design tool capable of identifying competitive inlet designs for overcoming thrust losses due to adjustment to the nozzle.

Task 4 - Source Integration and Propagation

Georgia Institute of Technology and Pennsylvania State University

Objective(s)

The knowledge acquired through the simulations performed within Task 3 must be translated into functional noise sources for use in onboard aircraft analyses. These noise sources will allow for the assessment of observer-perceived noise and therefore the ability to assess the specific impacts of each of the promising noise technologies. The aim is to perform these analyses in terms of both certification noise levels and noise contours.

Research Approach

The combined research team will develop a process for converting high-fidelity simulations (i.e., computational aeroacoustics [CAA]) results into jet noise sources by using ANOPP2's custom noise source feature. After the process is developed and verified, the research team will be able to input CAA-simulated jet noise sources and propagate the noise to the observer by using ANOPP2's propagation module to assess the perceived noise levels. The latter step will require the research team to also establish a baseline case with no active technology to assess the level of jet noise reduction. Furthermore, the combined research team will also coordinate with ASCENT Project 10 to integrate the jet noise source results from the proposed research with other noise sources captured by the ASCENT Project 10 team, to examine the impact of the jet noise reduction technology in terms of both certification noise levels and noise contours.

Publications

None

Outreach Efforts

ASCENT Advisory Board Meeting

Awards
None

Student Involvement
The Georgia Tech student team consists of five graduate research assistants (GRAs). Over the past performance period, all five GRAs engaged in formulating the approach being pursued for the inlet modeling activity. The team is divided into supersonic inlet aerodynamic and thermodynamic performance, and mechanical and structural analysis. Each student is involved with multiple topics, and GRA leads are identified for each topic. Mr. James Kenny is the student lead for aerodynamic and thermodynamic performance, and Mr. Noah Chartier is the student lead for mechanical and structural analysis.

Plans for Next Period
Georgia Tech

The Georgia Tech team plans to complete the indicated tasks listed in Table 3. Work will continue toward completion of the assembly of a zero-order inlet design and analysis environment, including the following:
- Completion of validation of the first iteration of a zeroth-order inlet performance analysis environment
- Conversion of the developed inlet analysis tool into a supersonic inlet design tool
- Implementation of on-design single-ramp compressible flow analysis capability for axisymmetric inlets
- Implementation of on-design multi-ramp compressible flow analysis capability for axisymmetric inlets
- Implementation of off-design multi-ramp compressible flow analysis capability for axisymmetric inlets

Table 3. Anticipated milestones for the next research period.

Milestone	University	Planned Due Date
Zero-order methods to predict inlet performance	Georgia Tech	11/30/2021
Script for generation of ANOPP custom jet noise source	Penn State and Georgia Tech	9/1/2022
Annual report submission	Penn State and Georgia Tech	11/1/2022

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