Project 059A/E Jet Noise Modeling to Support Low Noise Supersonic Aircraft Technology Development

Georgia Institute of Technology and Pennsylvania State University

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University Participants

Georgia Institute of Technology
- PI: Dr. Dimitri Mavris (PI), Dr. Jimmy Tai (Co-PI)
- FAA Award Number: 13-C-AJFE-GIT–070
- Period of Performance: July 5, 2020 – December 31, 2020
- Task(s): 1,2,4,5

Pennsylvania State University
- PI: Dr. Philip Morris (PI)
- FAA Award Number: 13-C-AJFE-GIT–070
- Period of Performance: July 5, 2020 – December 31, 2020
- Task(s): 1,3-5

Project Funding Level

FAA provided $200,000 in funding. Matching funds are provided by the Georgia Institute of Technology ($100,000) and Pennsylvania State University ($100,000). Cost share 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 computing, financial, and administrative support, including meeting arrangements. The institute has also agreed to provide tuition remission for the students, paid for by state funds. During the period of performance, in-kind cost share is also obtained for cost share.

Pennsylvania State University provides matching support through salary support of the faculty PI, as well as computing and administrative support.

Investigation Team

Georgia Institute of Technology

- PI: Dimitri Mavris
- Co-Investigator: Jimmy Tai (Task(s) 1,2,4,5)
- Supporting Engineers: Greg Busch, Joshua Brooks
- Students: Edan Baltman, James Kenny, Madeline Bowne, Noah Chartier, Leon Chen, Jeremy Decroix

Pennsylvania State University

- Principal Investigator: Dr. Phillip Morris (Task(s) 1,3-5)
- Graduate Students: Dana Mikkelsen, Stephen Willoughby

Project Overview

During the reporting period, the Project 59A/E team focused on the assembly of 1) zeroth-order methods for predicting supersonic inlet performance, 2) introduction of an engine cycle modeling strategy, and 3) calculation of engine cycle boundary conditions. The last two tasks are closely tied to concurrent work in ASCENT Project 10. Preliminary steady simulations will be performed for the proposed nozzle geometries which involve grid generation and use of the STARCCM+ Computational Fluid Dynamics (CFD) solver. The operating conditions for the initial experimental geometry will be the result of discussions with other Project 59 performers.

If successful, the ASCENT Project 59 research will support development of methods to predict the noise generated and radiated by civil supersonic aircraft engines. The tools developed will enable airframe and engine manufacturers to assess the noise impacts of engine design changes and to determine if particular designs will meet current or anticipated noise certification requirements.

It should be noted that after discussions with FAA, the overall direction of this project was changed. The original purpose of Project 59A/E 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. The impact of the noise reduction methods on the overall engine performance also would be assessed. The predictions would 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 noise it generates to be computed. Predictions were to be assessed by comparisons with available experimental measurements. In future years, the assessment of jet noise reduction technologies, as originally proposed, will be re-considered as part of this project.

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, the Georgia Institute of Technology (Georgia Tech) and the Pennsylvania State University (Penn State) will coordinate to select an initial jet nozzle geometry. In Task 2, Georgia Tech will analyze the engine cycle developed by ASCENT Project 10 for best operating conditions for take-off and landing to minimize certification noise levels [1, 2]. The resulting mixer and nozzle conditions will advise the researchers of ASCENT Project 59 on relevant test conditions. The test conditions for the initial geometry will also provide boundary conditions for Task 3 which will perform an internal and external flow simulation aimed at uncovering noise source information. Task4 will develop a process for converting high fidelity simulation results into jet noise sources, and Task 5 will produce a final report detailing this research effort.

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

Task No.	Milestone	University	Planned Due Date
Task 1	Selection of initial geometry in coordination with other Project 59 Investigators	PSU & GIT	12/15/2020
Task 2.1	Assembly of zero-order methods to predict inlet performance	GIT	05/31/2021
Task 2.2	Determination of boundary conditions from "Vision SST Engine Cycle"	GIT	02/05/2021
Task 3.1	Completion of grid generation for internal flow calculations	PSU	03/05/2021
Task 3.2	Initial RANS Simulation of internal flow.	PSU	05/01/2021
Task 3.3	Preliminary grid generation for jet exhaust flow	PSU	04/01/2021
Task 4	Script construction for generation of ANOPP custom jet noise source	PSU & GIT	05/31/2021
Task 5	Submission of interim project report	PSU & GIT	05/31/2021

Major Accomplishments
The ASCENT 59A/E team has received the geometry from the ASCENT 59 team and is currently gridding the geometry.

Task 1 – Select Jet Nozzle Geometry
Georgia Institute of Technology and Pennsylvania State University

Objective(s)
In order 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. Working with Dr. Krishnan Ahuja, the experimental data from this standard geometry (gathered in other ASCENT Project 59 research) will be used to inform the work of ASCENT project 59A/E.

Research Approach
The 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 achievable regarding experimental measurement, 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

Objectives
Task 2 aims to leverage engine cycle modeling capabilities to determine installed thrust for an engine of interest that is appropriate for civil supersonic transport. The thermodynamic properties across this mixed flow turbofan engine, with the install thrust value, are used to characterize the mixer exit, nozzle entrance, and nozzle exit operating conditions during take-off. Because the initial testing and high-fidelity simulations are not currently representative of a mixed flow turbofan, these operating conditions (i.e. total pressure, total temperature, mass flow, geometry, etc.) will advise the testing team on relevant testing conditions.

Research Approach

Task 2.1: Determine Installed Thrust

In order to ensure minimum thrust is lost, due to implementing potential jet noise reduction technology, the installed thrust requirement needs to be determined because it is directly proportional to jet velocity. One of the main contributors to installed thrust is inlet performance which is highly dependent on how the engine is integrated with the vehicle. This task will also investigate 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 for best operating conditions for take-off and landing to minimize certification noise levels. The resulting mixer and nozzle conditions, i.e. total temperature, total pressure, and mass flow rate, will advise the researchers of ASCENT Project 59 on relevant test conditions. 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 represent an insurance plan on any thrust loss due to any mixer or nozzle design to minimize noise.

Task 3 – High Fidelity Simulation of Jet Noise Reduction Technology

Pennsylvania State University

Objectives

The objective of this task is to develop methodologies to accurately simulate the noise generated by jet nozzles of the type likely to be used on civil supersonic aircraft. A commercial computational fluid dynamics application, STARCCM+, will be used to perform both steady and unsteady flow simulations. The unsteady simulations will be coupled with an acoustic analogy solution to predict the radiated noise.

Research Approach

Internal and external flows will be simulated in order to provide noise source information for Task 4.

Following discussions with FAA, it was decided to focus on a relatively simple geometry consisting of a dual stream jet followed by a mixing duct and a nozzle. The selected geometry is shown in Figure 1. The stages of the simulations follow those in the original work plan.

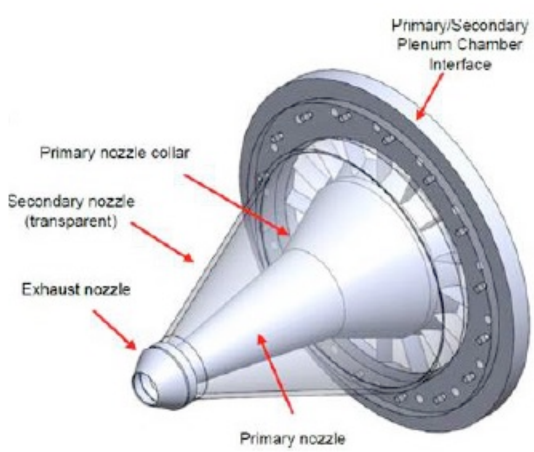

Figure 1. Schematic of proposed model geometry

Task 3.1: Grid generation for internal flow simulations

The selected geometry was only made available close to the end of the calendar year, therefore an existing dual-flow nozzle geometry was used to train the new students in the use of STARCCM+ for grid generation and simulations., This geometry was previously studied experimentally [3]. A grid was only generated for the inner nozzle. Figure 2 shows a grid for the inner nozzle. The nozzle includes a centerbody that can be seen in the grid.

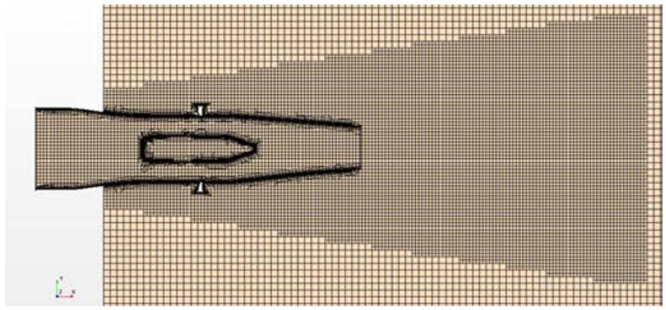

Figure 2. Grid generated for the inner nozzle

It is planned to use Reynolds-averaged Navier-Stokes (RANS) simulations for the internal flow. These simulations will provide boundary conditions at the nozzle exit. STARCCM+ will continue to be used to generate both the internal and external grid. The grid generator uses an extruder to generate the grid in the near wall regions and fills external regions with an unstructured mesh.

Task 3.2: Perform RANS simulations for the internal flow
RANS simulations will be performed using STARCCM+. Important outputs will be the degree of mixedness at the exit, which is expected to be an important factor in determining the radiated noise. The flow predictions will be assessed by comparison with available experimental data. The comparisons will be for both subsonic and supersonic nozzles and will include both flow and noise measurements.

Task 3.3 Grid generation for Large Eddy Simulations of the jet exhaust flow
The simulation of the jet exhaust flow will be performed using Large Eddy Simulation (LES). A key element in obtaining accurate and efficient simulations is the structure of the computational grid. The grid will be generated based on previous experience of the PI and his co-workers for supersonic nozzles. The simulations, once completed, will provide the unsteady flow properties in the exhaust and in the jet near-field. It is proposed to use the permeable surface Ffowcs Williams – Hawkings (FWH) acoustic analogy solution [4, 5] to determine the amplitude, spectral content, and directivity of the radiated noise, assuming noise radiating into a uniform stationary medium. The commercial CFD solver, STARCCM+ will be used for both the internal and external flow and noise simulations.

Task 4 – Source Integration and Propagation

Georgia Institute of Technology and Pennsylvania State University

Objective(s)

The knowledge acquired through the simulations performed in Task 3 must be translated into functional noise sources for use onboard aircraft analyses. These noise sources will allow for the assessment of observer perceived noise and the ability to assess the specific impacts of each of the promising noise technologies. The goal 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 using the Aircraft Noise Prediction Program (ANOPP2) custom noise source feature. Once 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 using the ANOPP2 propagation module to assess the perceived noise levels. The latter step will require the research team to establish a baseline case with no active technology to assess the level of jet noise reduction. Furthermore, the combined research team will coordinate with ASCENT Project 10 (A10) to integrate the jet noise source results from the proposed research with other noise sources captured by the A10 team in order 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 (GRA). 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, with each student taking on multiple topics. GRA leads are identified for each topic. Mr. James Kenny is the student lead for aerodynamic and thermodynamic performance and Mr. Jeremy Decroix is the student lead for mechanical and structural analysis.

For the first year, the Penn State team consists of two graduate research assistants. Ms. Dana Mikkelsen is the lead on the CFD simulations. Mr. Stephen Willoughby will assist with CAD work as well as the grid generation.

Plans for Next Period
Georgia Tech

The Georgia Tech team plans to complete the tasks listed in Table 1 with GT designation. Having completed Task 1, the team may use the selected nozzle geometry to assist in determining the relevant boundary conditions, based on the "Vision SST Engine Cycle". Work will continue to completion in parallel on the assembly of a zero-order inlet design and analysis environment.

Penn State

The Penn State team plans to complete the tasks listed in Table 1 with PSU designation. Now that the geometry has been selected, Penn State researchers can continue with refining the grid generation and internal flow simulations. The jet exhaust flow will also be gridded and simulated using RANS. Unsteady simulations are planned for the second project year.

Table 1 shows the anticipated list of Milestones for the next research period:

Table 1. List of anticipated milestones for the next research period.

Milestone	Owner	Planned Due Date
Zero-order methods to predict inlet performance	GIT	05/31/2021
Determination of boundary conditions from "Vision SST Engine Cycle"	GIT	02/05/2021
Grid generation for internal flow calculations completed	PSU	03/05/2021
Initial RANS internal flow simulations completed	PSU	05/01/2021
Preliminary grid generated for jet exhaust flow	PSU	04/01/2021
Script for generation of ANOPP custom jet noise source	PSU & GIT	05/31/2021
Annual report will be submitted	PSU & GIT	05/31/2021

References

[1] Mavris, D., Tai, J., Kirby, M., Roth, B., "Systems Analyses of Pneumatic Technology for High Speed Civil Transport Aircraft," NASA Funded Grant NAG-1-2015, NASA document ID: 19990105723.

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[3] Auhl, R. R., Willoughby, S. P., McLaughlin, D. K. and Morris, P. J., "Acoustic Measurements of Co-annular Jets at High Subsonic-Low Supersonic Jet Velocities," AIAA Paper 2020-0264, 2020.

[4] Ffowcs Williams, J. and Hawkings, D. L., "Sound generation by turbulence and surfaces in arbitrary motion," *Phil. Trans. Roy. Soc. A*, **264**(1151) 1969, 321–342.

[5] Farassat, F. and Succi, G. P., "The prediction of helicopter rotor discrete frequency noise," *Vertica*, *7*(4), 1983, 497–507.