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

Georgia Institute of Technology

Project Lead Investigators

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University Participants

Georgia Institute of Technology (Georgia Tech)

- P.I.s: Dr. Dimitri Mavris (P.I.), Dr. Jimmy Tai (co-P.I.)
- FAA Award Number: 13-C-AJFE-GIT–070
- Period of Performance: October 1, 2021 to September 30, 2022

Project Funding Level

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

Georgia Tech 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 sharing is also obtained for cost share.

Investigation Team

Georgia Tech

- P.I.: Dimitri Mavris
- Co-Investigator: Jimmy Tai
- Project Manager/Technical Lead: James Kenny
  - Primary technical developer, project manager, and student advisor
- Supporting Engineers: Jai Ahuja
  - Supporting technical developer, aerodynamics SME
- Students: Student technical support role involved completing various tasks to support completion of supersonic inlet code, actual tasks varied depending on timeframe support was provided

- o Noah Chartier: Graduate Research Assistant, provided technical support from 2021 to 2022, co-developed majority of the inlet code with James Kenny
- o Andrew Tai: Undergraduate Research Assistant, supported between late 2021 to early 2022
- o Sijan Tan: Graduate Research Assistant, supported inlet code development from mid-2022 to current year

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 would be assessed. The predictions would include consideration of the engine inlet, engine cycle, mixers and ejectors, and unsteady jet exhaust. Accurate prediction of the engine exhaust flow would enable the noise generated by the theoretical system to be computed. Predictions were to be assessed through comparison with available experimental measurements provided by Project 59 research partners focusing on experimental methods.

In discussion with the FAA, the overall direction of the project has been changed. Instead of developing and simulating jet noise reduction technologies, Project 59A will provide benefits for addressing the supersonic jet noise problem through a different approach—considering the supersonic inlet's effects. The Project 59a team will still be supported by experimental data provided by other Project 59 technical partners, including the work jet noise experimentation, led by Dr. Krishnan Ahuja at Georgia Tech, and system operating conditions for the initial experimental geometry, which will result from discussions with other Project 59 partners.

As a result of this change, Georgia Tech's research team will now be pursuing means to identify a thrust–noise break-even relationship for arbitrary and real nozzle-based jet noise reduction technologies. Collaboration with other Project 59 partners will allow models to be developed and studies to be performed for real, experimentally developed nozzle-based jet noise reduction technologies. Additionally, the Project 59a research team will facilitate exploration of how variable geometry for supersonic inlets can potentially recover thrust lost by the aforementioned nozzle technologies.

If successful, the ASCENT Project 59a research will develop a means for performing systems-level studies for supersonic propulsion systems to identify the break-even line for any given engine assembly (engine, inlet, nozzle) whose thrust impact cost outweighs the noise reduction benefit. Additionally, low-fidelity, low-speed aerodynamics models will be implemented for the supersonic inlet, as well as new variable-geometry models, to determine whether any thrust lost by the addition of the jet noise technology can be recovered by sole use of inlet variable geometry (including the external compression inlet ramps or cone, a variable-geometry cowl lip, and potentially blow-in doors), without further manipulation of the throttle. In future work, higher-fidelity modeling capabilities will be incorporated into the zeroth-order inlet performance tool. Additionally, if the hypothesis that thrust degradations due to nozzle devices can be recovered by variable geometries in off-design configurations, then a design tool that manually achieves an optimum design will be developed from the analysis capability. Essentially, the research team will identify a way to enable rapid identification and selection of nozzle-based jet noise technologies for a given installed engine configuration, to ensure that the jet noise technology is not degrading aircraft thrust to an extent that the technology is no longer beneficial, and to determine the effectiveness of off-design variable-geometry configurations for conditions of low speed/high inlet air demand conditions.

Project Introduction

The chief objectives of this research project are twofold: first, to facilitate the capability to perform thrust–noise break-even studies for arbitrary nozzle-based jet noise technologies, and second, to develop capabilities to identify the impacts of supersonic inlet configurations and designs on thrust recovery—thus ultimately determining whether off-design supersonic inlet configurations can recover the thrust detriment from noise technologies used for jet noise regulation compliance. As a consequence of the Georgia Tech research team's departure from being coupled with Pennsylvania State University (PSU) researchers, and the modification of the overall project direction, the major project milestones for Year 2 and beyond have been modified.

Whereas Task 2.2 previously was described as "Determination of boundary conditions from 'Vision SST Engine Cycle'," the replacement task for this period was to continue improvement of Task 2.1, "Assembly of zeroth-order methods to predict inlet performance." At the initially projected due date for Task 2.1, the supersonic inlet analysis tool developed during the first year, although functional, was found to lack many capabilities necessary to analyze the installed inlet performance across the entire supersonic transport (SST) mission profile. Some of these lacking capabilities included the abilities to predict

required inlet capture area, accurately calculate internal shocks and losses for mixed compression conditions for a supersonic 2D inlet; predict and determine additive (pre-entry) drags and cowl lip suction forces; predict the location and corresponding strength of the normal shock when swallowed; and accurately predict the low-speed losses associated with conditions of low speed and high air demand conditions (i.e. takeoff). Furthermore, the team used part of Year 2 to improve the supersonic inlet analysis tool's user interface and perform debugging to achieve highly robust performance across a variety of supersonic inlet geometries and mission profiles—from external compression to mixed compression inlets, as well as from transonic design Mach numbers to low hypersonic values (1.2 to 5) and off-design cases. The tool now functions well across many conditions. Additionally, the tool was integrated (currently as a first-iteration effort) with the team's internal supersonic aircraft and engine sizing and synthesis tool (FASST, also used for ASCENT Project 10), by converting the inlet code into a rapid-running executable.
From the first year of effort, a highly functional supersonic inlet analysis tool was found to be required to perform thrust recovery analyses, in accordance with the initial goal of the project. Therefore, the focus for the first and second years was on the robust development of this capability. However, during the third and final year of this project, continued development of the supersonic inlet tool will take a secondary role, and the execution and facilitation of the jet noise reduction-break-even study tool will become the chief priority.

Because the project vision has substantially changed since the end of Year 1 (and the previous annual report, for Project 59a), the milestones below have been updated (with removal of Task 4 and "Script construction for generation of Aircraft Noise Prediction Program (ANOPP) custom jet noise source"; modification of Task 2.2, "Determination of boundary conditions from 'Vision SST Engine Cycle'"; and modification of due dates) to reflect the current glide path for task completion and deliverables for the team, and ensure project completion by the end of the final period of performance in late September, 2023.

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	PSU and Georgia Tech	12/15/2020
Task 2.1	Final assembly of zero-order methods to predict inlet performance: Complete supersonic inlet analysis code and continue development	Georgia Tech	1/30/2023
Task 2.2	Determination of boundary conditions from "Vision SST Engine Cycle"—collaboration efforts: Identify engine and operating conditions for inlet studies to be performed	Georgia Tech	8/01/2023
~~Task 4~~	~~Script construction for generation of ANOPP custom jet noise source~~	~~PSU and Georgia Tech~~	~~9/1/2022~~
Task 5	Submission of interim project report	PSU and Georgia Tech	12/1/2022
Task 6	Extension of zeroth-order methods for inlet performance to include low-speed aerodynamics: Add low-speed viscous effects and ameliorating methods	Georgia Tech	4/15/2023
Task 7	Formulation and Execution of thrust–noise break-even study	Georgia Tech	8/15/2023
Task 8	Execution of the variable-geometry thrust recovery study	Georgia Tech	8/30/2023
Task 9	Submission of the final project report	Georgia Tech	9/31/2023

Major Accomplishments

The first and second years of work largely comprised creating and developing the supersonic inlet analysis code, and refining its capabilities, as described above. The first year of effort was focused primarily on the assembly of various zeroth-order methods to conduct this inlet analysis, whereas the second year of effort was focused primarily on making the tool useful and suitable for the Project 59a research goals. First-year accomplishments included the following:

- Completion of a simple parametric 2D analysis tool able to predict the following:
    - Pressure recovery between freestream and engine face
    - Oblique and normal shock predictions
    - Inlet geometry schematic for verification
    - Bleed, bypass, and spillage drags
- Validation of tool performance against several published 2D inlets
    - Good agreement with mixed compression, M_d= 5.0 inlet provided in IPAC (Inlet Performance Analysis Code) technical report, (Barnhart, 1997).
    - Good agreement with external compression, M_d= 2.3 inlet in *Fundamentals of Aircraft and Airship Design,* (Nicolai & Carichner, 2013)
    - Completed analysis and validation of Performance of Installed Propulsion Systems—Interactive (PIPSI) "R2DSST" $M_d = 2.3$ mixed compression inlet, (Kowalski & Atkins, 1979).

During the second year of the Project 59a efforts, capability gaps were closed, and several capabilities were improved:

- Many capability gaps between the Year 1 supersonic inlet analysis tool and needs were identified and improved:
- Inlet–engine airflow matching → bypass mass flow determination
- Inlet capture area sizing
- Cowl lip suction and additive drag predictions
- Nacelle wave drag predictions
- Improved mixed compression inlet performance prediction
- Improved accuracy of location and strength of internal oblique shock train
- Improved accuracy of location and strength of internal terminal normal shock
- Completed initial integration of supersonic inlet tool and supersonic engine and aircraft analysis and design tools (FASST)

Task 1 - Select Jet Nozzle Geometry

Georgia Institute of Technology and Pennsylvania State University

Objective

To unify and maximize the impact of work across relevant ASCENT projects, Georgia Tech and PSU will coordinate efforts to select an initial jet nozzle geometry. In work 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. This work did not utilize the efforts of the A59a team at the Georgia Tech Aerospace Systems Design Laboratory (ASDL), but rather the nozzle and noise researchers from GT (Dr. Ahuja) and PSU.

Research Approach

The combined PSU 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, and also achievable regarding experimental measurement, computational analysis, and other supporting tasks. Specific evaluation criteria may include jet velocity reduction and thrust loss.

This task was completed during the first year of work. Although the results of this effort were not used to complete the inlet analysis code, it was helpful in identifying and converging upon the ultimate objective of the project, and establishing cooperative working relationships with other Project 59a partners.

Milestones(s)

As this task was accomplished in the first year, no update is possible for the current year's report.

Major Accomplishments
None.

Publications
None.

Outreach Efforts
None.

Awards
None.

Student Involvement
None.

Plans for Next Period
None.

Task 2 - Translate Installed Cycle Performance Requirements into Boundary Conditions

Georgia Institute of Technology

Objective
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 install 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 (i.e., total pressure, total temperature, mass flow, geometry, etc.) 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 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, the primary element of Task 2 is to investigate zeroth-order methods to predict inlet performance for different inlet designs and off-design configurations.

Task 2.2: Generate Boundary Conditions
Initially, the objective of this task was for Georgia Tech to analyze the engine cycle developed by ASCENT Project 10 to estimate the best operating conditions for takeoff and landing to minimize certification noise levels. This task was updated to reflect the required boundary condition/experimental data generated by project partners, to be used in Tasks 7 and 8. Additionally, the timeline was updated to reflect when these data were required by the Project 59a research team. Some beneficial data for modeling will include mixer and nozzle conditions, i.e., total temperature, total pressure, and mass flow rate, as well as measured thrust vs. noise for each tested jet noise reduction technology or mixer type.

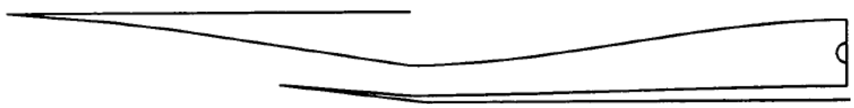
Task 2.1 - Zero-order Methods to Predict Inlet Performance
A major contributor to installed thrust is inlet performance, which is highly dependent on how the engine is integrated with the vehicle. To capture thrust recovery due to improved inlet performance, the Georgia Tech team must develop a means to predict inlet performance across the SST flight envelope, particularly at low-speed conditions during which jet noise is most prominent (i.e., landing and takeoff).

During the first year, the Georgia Tech team completed an initial the model development for the 2D inlet case, by developing a modular 2D supersonic inlet anlaysis tool. In addition, the team has completed an initial validation of the 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 (Barnhart, 1997). Here, the supersonic inlet is designed for a freesteam Mach number of 5, and 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.

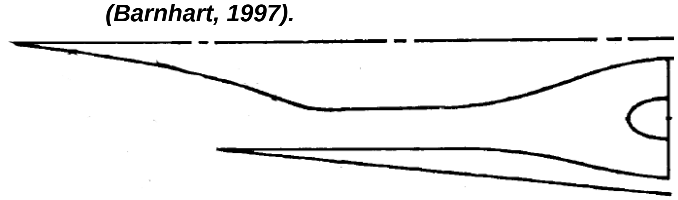
Table 2 compares the developed tool's predicted total drag coefficient and that produced by IPAC across the mission-relevant range of freestream Mach number (Barnhart, 1997). This drag term includes the contributions of spillage, bleed, and bypass drag on the engine inlet. Again, the supersonic inlet is designed for a freesteam Mach number of 5 and is 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.

$\{\theta, \ell\}$: per ramp segment
$\{\theta, x\}$: per ext. cowl segment
$\{\theta\}$: per int. cowl segment
cloff: engine vertical offset from local
ℓ_{th}: throat length
ℓ_{in}: total inlet length
t_c: cowl thickness (above engine face)
htr: hub to tip ratio
D_2: engine diameter
W_c: cowl width
W_{th}: throat width

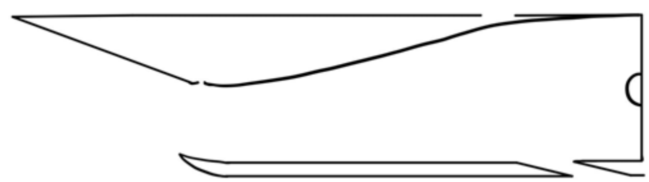
Figure 1. Geometry inputs to define inlet in Year 1 supersonic inlet analysis code.



$M_d = 5.0$ ***Mixed Compression Inlet from IPAC (Barnhart, 1997).***



$M_d = 2.3$ ***Mixed Compression Inlet from PIPSI, "R2DSST" (Kowalski & Atkins, 1979)***



$M_d = 2.3$ ***External Compression Inlet from Nicolai & Carichner (2013)***

Figure 2. Three 2D supersonic inlets used to validate the Year 1 inlet analysis tool; top inlet performance results are displayed below.

Table 1. Validation case: total pressure recovery.

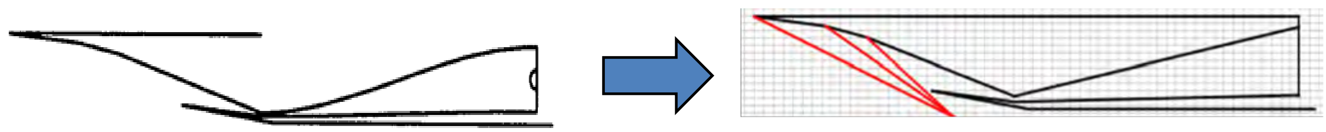
Freestream Mach number	Modeled	Reference	Error (%)
0.01	0.9586	0.9608	−0.23
0.2	0.9586	0.9608	−0.23
0.4	0.9586	0.9608	−0.23
0.6	0.9586	0.9608	−0.23
0.8	0.9586	0.9608	−0.23
1.0	0.9586	0.9608	−0.23
1.2	0.9517	0.9539	−0.23
1.4	0.9404	0.9456	−0.55
1.6	0.9233	0.9285	−0.56
1.8	0.8767	0.8816	−0.55
2.0	0.8107	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 noise reduction nozzle technologies across the flight envelope, as well as identifying the resulting behaviors associated with low-speed performance and off-design ramp (and other variable geometry) configurations of the inlet. 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, landing).

For the second year, the inlet performance tool was extended to include several capabilities for performance modeling. One simple capability added for the second year was a schematic showing the user where the external oblique shocks are located with respect to the external portion of the supersonic inlet (Figure 3). This schematic allows users of the supersonic inlet analysis script as a standalone tool (i.e., not coupled to an engine/airframe sizing and synthesis tool) to quickly identify whether an external shock system is attached to the inlet, or a detached shock system has been formed. In work for Year 3, the normal shock system, whether external or internal, will be included in the schematic. Additionally, the subsonic diffuser portion (the internal inlet section closest to the engine face) will reflect the actual curvature reflected in the model (here, it is straight, without curvature).



IPAC M_d= 5.0 Inlet Design

Modeled in Inlet Performance Analysis Tool

Figure 3. Inlet and shock schematic enabled in supersonic inlet tool during Year 2 work.

In addition to the modeling fidelity improvements listed in the "Major Accomplishments" section above, many more stations and the physical properties of airflow at those stations can be modeled as a consequence of the Year 2 work. Instead of simply considering the total pressure recovery and drags, as displayed for the Year 1 work in Tables 1 and 2, the work of Year 2 enabled a much closer examination of the supersonic inlet performance at each station. The performance of the inlet at each of these additional stations was compared with those from the published results of the M_d=5.0 mixed compression inlet from IPAC (shown at top in Figure 2). Detailed results for the M = 3.0 off-design case of this inlet are shown in Table 3; the design case and other off-design cases down to M = 0.01 had similar performance results with respect to the validation error. As described previously, a greater level of fidelity regarding flow station performance, as well as improvements in the accuracy of the model was achieved. Using the Year 2 inlet analysis tools, the team had found an improvement in accuracy regarding total pressure recovery (total pressure ratio across the entire inlet) as a consequence of the improvement in shock location predictions and internal reflected shock quantities.

Table 3. Validation results for IPAC M_d= 5.0 inlet and M = 3.0 off-design case.

Outputs	**Local calculated**	**Local reference**	**Error (%)**	**Cowl lip calculated**	**Cowl lip reference**	**Error (%)**	**Throat calculated**	**Throat reference**	**Error (%)**
Flow area (ft²)	0.6905	0.6905	0.0000	0.3953	0.3955	0.0594	0.1600	0.1598	−0.1126
Mach number	3.0000	3.0000	0.0000	2.3982	2.3990	0.0335	1.3149	1.3140	−0.0700
Static pressure (lbf/ft²)	156.7630	156.3000	−0.2962	390.6043	389.5000	−0.2835	1,960.9823	1,959.0000	−0.1012
Static temperature (R)	389.9700	390.0000	0.0077	508.6205	507.7000	−0.1813	812.6533	811.5000	−0.1421
Density (slg/ft³)	0.0002	0.0002	−0.2490	0.0004	0.0004	−0.2472	0.0016	0.0014	−13.3433
Velocity (ft/s)	2,905.4154	2,904.0000	−0.0487	2,650.0449	2,649.0000	−0.0394	1,838.3284	1,835.0000	−0.1814
Total pressure (lbf/ft²)	5,753.6784	5,743.0000	−0.1859	5,694.5814	5,684.0000	−0.1862	5,545.0869	5,534.0000	−0.2003
Total temperature (R)	1,093.6709	1,092.0000	−0.1530	1,093.6709	1,092.0000	−0.1530	1,093.6709	1,092.0000	−0.1530
Mass flow (lbm/s)	21.8556	21.8200	−0.1630	15.0913	15.0700	−0.1411	13.2882	13.2700	−0.1370
$\frac{P_{T_1}}{P_{T_L}}$	$\frac{P_{T_1}}{P_{T_{L REF}}}$	$\frac{P_{T_{TH}}}{P_{T_1}}$	$\frac{P_{T_{TH}}}{P_{T_1 REF}}$	$\frac{P_{T_2}}{P_{T_{TH}}}$	$\frac{P_{T_2}}{P_{T_{TH REF}}}$	$\frac{P_{T_X}}{P_{T_Y}}$ **(across normal shock)**	$\frac{P_{T_X}}{P_{T_{Y REF}}}$ **(across normal shock)**	**Number of internal shocks**	**Number of internal shocks (reference)**
0.9897	0.9900	0.9737	0.9740	0.8164	0.8174	0.897	.8952	3	3

During Year 3 work, low-speed viscous loss prediction models will be integrated, as will a variable-geometry cowl lip configuration to enable the exploration of potential airflow maximization at low speeds. If time allows, the modeling of blow-in doors will also be completed toward this same end.

Milestones(s)

- Completion of the initial inlet analysis code

- Addition of additive drag prediction
- Addition of bleed and bypass drag models
- Addition of normal shock position predictions
- Addition of internal shock train predictions (starting conditions)
- Addition of angle of attack effects
- Validation against published data
- Integration with engine model

Major Accomplishments

First-year accomplishments included the following:

- Completion of a simple parametric 2D analysis tool able to predict the following:
    - Pressure recovery between freestream and engine face
    - Oblique and normal shock predictions
    - Inlet geometry schematic for verification
    - Bleed, bypass, and spillage drags
- Validation of tool performance against several published 2D inlets
    - Good agreement with mixed compression, M_d= 5.0 inlet provided in IPAC (Inlet Performance Analysis Code) technical report, (Barnhart, 1997).
    - Good agreement with external compression, M_d= 2.3 inlet in *Fundamentals of Aircraft and Airship Design,* (Nicolai & Carichner, 2013)
    - Completed analysis and validation of Performance of Installed Propulsion Systems—Interactive (PIPSI) "R2DSST" $M_d = 2.3$ mixed compression inlet, (Kowalski & Atkins, 1979).

During the second year of the Project 59a efforts, capability gaps were closed, and several capabilities were improved:

- Many capability gaps between the Year 1 supersonic inlet analysis tool and needs were identified and improved:
- Inlet-engine airflow matching → bypass mass flow determination
- Inlet capture area sizing
- Cowl lip suction and additive drag predictions
- Nacelle wave drag predictions
- Improved mixed compression inlet performance prediction
- Improved accuracy of location and strength of internal oblique shock train
- Improved accuracy of location and strength of internal terminal normal shock
- Completed initial integration of supersonic inlet tool and supersonic engine and aircraft analysis and design tools (FASST)

Publications

No manuscripts or works have been submitted for publication at this time of this report.

Outreach Efforts

None.

Awards

None.

Student Involvement

The progress of this project has been possible due to the involvement of and technical work by students. All graduate research assistants, as well as the undergraduate research assistant who worked on this task individually enabled the progress and near-completion of the inlet analysis tool, to be used in future tasks. Additionally, the project manager, James Kenny, served as a graduate research assistant during the first year of the project, and he continues to provide technical and management work towards the completion of this task.

Plans for Next Period

The next period of this task requires the final completion and validation of the zeroth-order inlet analysis tool and the finalized integration with the supersonic engine analysis and design code, FASST. Completion of both of these steps will facilitate the completion of the following tasks.

Task 6 - Extension of Zeroth-Order Methods for Inlet Performance to Include Low-Speed Aerodynamics

Georgia Institute of Technology

Objective

To enable the completion of Tasks 7 and 8, low-speed aerodynamics modeling must be facilitated for the supersonic inlet, including the viscous effects encountered by supersonic inlets during landing and takeoff conditions. The current supersonic inlet analysis model uses a simple viscous loss relationship, which is scaled depending on the freestream air Mach number and the sharpness and radius of the inlet cowl lip, taken from the IPAC publication's equations (Barnhart, 1997). This loss cannot account for the potential improvements achieved by modulating the variable geometry of the inlet to maximize airflow, and minimize the viscous effects incurred by incoming air when pulling around the cowl lip and sidewalls.

Research Approach

Several approaches will be followed to identify computationally low-cost methods for determining low-speed aerodynamics over the supersonic inlet ramps, cowl lip, or compression center cone:

- Perform literature review to identify analytical methods for modeling low-speed viscous flow over a flat ramp with varying angles of attack or incidence
- Implement these methods within the script, and compare results for validation against published sources as well as published experimental data
- Perform flat-plate loss approximations, and compare them with experimental data and the results achieved above
- Select the method yielding the best results with reasonable computation execution time

Milestones(s)

Major milestones for this project in the second year of the project had not been accomplished at the time of initial submission of this report, with the exception of an in-depth literature review of low-fidelity approaches for low speed aerodynamics modeling. As of the time of this report, a preliminary low-speed aerodynamics model has been developed and tested, and is currently being validated by the team against experimental data.

- Literature review to understand how low-speed aerodynamics is currently modeled analytically
- Development of models for each segment of the inlet
- Integration of each part of the inlet low-speed aero model
- Validation against of overall model against published data

Major Accomplishments

Major accomplishments include completion of a lengthy literature review into the topic of low-fidelity low-speed aerodynamics modeling, and the initial development of the modeling code.

Publications

None.

Outreach Efforts

None.

Awards

None.

Student Involvement

This task has been primarily worked on by graduate research assistant, Sijan Tan.

Plans for Next Period

During the final period of the project, the low-fidelity, low-speed aerodynamics model will be fully integrated into the model and utilized to complete the final tasks of the project.

Task 7 - Execution of Thrust–Noise Breakeven Study

Georgia Institute of Technology

Objective

Because supersonic engines are likely to be throttled back at takeoff, any loss of thrust due to the implementation of noise technologies could theoretically be offset by simply pushing the throttle forward. However, doing so may reduce or completely offset any noise benefits achieved by the technology in the first place. In that case, another approach to recovering the lost thrust may be warranted. Although each technology is unique in the amount of noise reduction and thrust loss, the breakeven line (the point at which pushing the throttle forward to recover thrust completely offsets the noise benefits of the technology) can nonetheless be evaluated. The concept of this proposed study is illustrated in Figure 4.

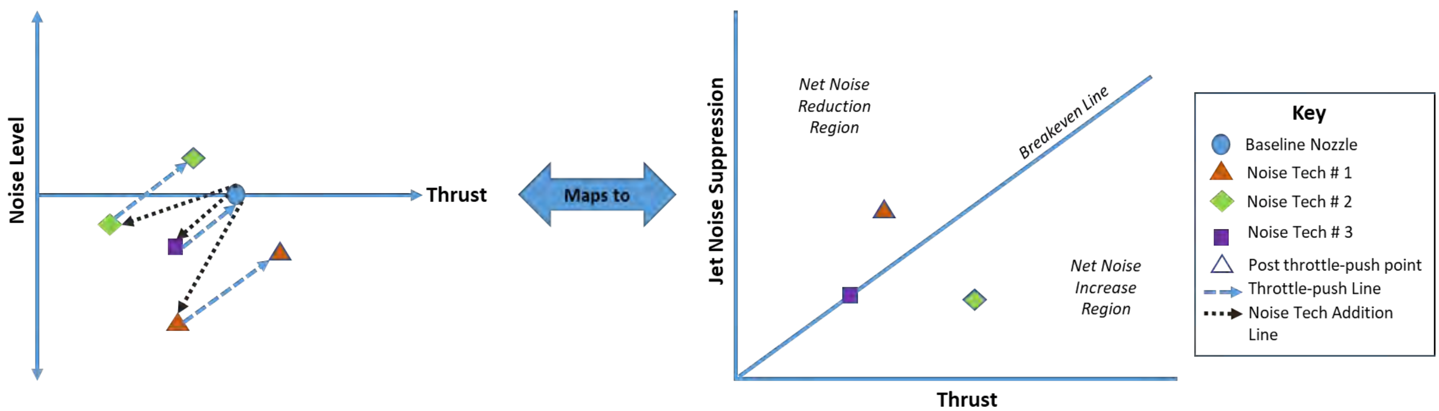


Figure 4. Thrust–noise break-even study concept.

Research Approach

To perform this study, we propose examining different levels of noise reduction through the jet suppression factors within ANOPP; thrust loss will be simulated by a reduction in the gross thrust coefficient in the engine analysis which will utilize the Numerical Propulsion System Simulation (NPSS).

The first step will be to establish a baseline with no noise technology. Second, the resulting thrust loss and noise benefit will be computed by using the jet suppression factors and gross thrust coefficient. Third, the aircraft will be flown again with an increase in throttle to offset the thrust loss, and the noise will be evaluated. For a range of jet suppression factors, the C_{fg} resulting in the noise benefit being offset will be identified to construct a break-even line (as shown in the figures). The goal is to determine the line of jet suppression and gross thrust, C_{fg}, simulating an arbitrary noise technology that, owing to a throttle push to recover lost thrust, yields no net change in noise with respect to the baseline design without noise technology. Until this study is performed, this line is unknown, so we will need to simulate multiple possible combinations of Jet suppression and C_{fg}. As can be seen on the left in Figure 4, Technology 1 yields a large initial reduction in noise (orange triangle), and the throttle push to recover thrust reduces the benefit but maintains an overall net reduction in noise. However, Technology 2 (green diamond) yields a small reduction in noise and a large reduction in thrust. Therefore, when the throttle is pushed forward, the result is a net increase in noise. Technology 3 (purple square) “breaks even” when the throttle is pushed and is therefore a point on the line. In accordance with Task 2.2 in the milestones table above, experimental thrust and noise data will be obtained from Project 59 research partners, then used in this effort to validate the approach and determine a realistic thrust–noise break-even line.

Milestones(s)
No milestones for this task have been accomplished for the current year.
- Establish baseline for noise and thrust with baseline supersonic engine with no noise technology
- Develop nozzle noise technology models and implement to determine thrust and noise effects for them
- Determine thrust-noise breakeven line

Major Accomplishments
None.

Publications
None.

Outreach Efforts
None.

Awards
None.

Student Involvement
None.

Plans for Next Period
The completion of this task will take place in the third year, and the next reporting period.

Task 8 - Execution of the Variable Geometry Thrust Recovery Study
Georgia Institute of Technology

Objective
After low-speed aerodynamics can be approximated, and additional variable-geometry configuration options are enabled (variable-geometry cowl lip (VGCL)), studies will be performed to determine whether the off-design inlet configurations can assist in overcoming the thrust losses incurred by using nozzle-based jet noise technologies. That is, the objective is to enable greater thrust at landing and takeoff conditions without requiring a higher throttle setting, thus expanding the net noise decrease region, illustrated on the right in Figure 4.

Research Approach
For this task, a sensitivity study to determine the effects of the variable geometry at low speeds will be completed first. If the variable geometries are shown to have an effect on the overall low speed installed engine performance, they will then be modulated to identify a potential thrust recovery for several arbitrary nozzle-based jet noise technologies.

Milestone(s)
- Development of the VGCL model
- Validation of VGCL model
- Completion of study to determine if VGCL can allow the installed engine to perform better than the thrust-noise breakeven line established in Task 7
- Completion of studies for several notional nozzle technologies

Major Accomplishments
None.

Publications
No literature was written or published during Years 1 or 2. However, upon the completion of the studies proposed for the Year 3 tasks, a manuscript will be written for submission to AIAA Aviation 2024.

Outreach Efforts
Research Engineer James Kenny attended, and presented progress for this project at, the 2022 ASCENT Advisory Board Meeting in Alexandria, Virginia.

Awards
None.

Student Involvement
The Georgia Tech student team currently consists of one graduate research assistant and two full-time research engineers. Over the past performance period, all members have been engaged in formulating the approach being pursued for the inlet modeling activity. Graduate research assistant Sijan Tan has worked on developing the inlet modeling tool to more accurately reflect cowl lip suction benefits at low speeds and to improve other parts of the code. Previous students on the project during the performance period include Noah Chartier, who was pivotal in creating the skeleton of the inlet code, as it currently stands, and Andrew Tai, an undergraduate researcher, who helped improve the internal shock prediction model over one semester. Research engineers James Kenny and Jai Ahuja have been engaged in improving the inlet performance analysis tool to be more robust for all desired example model inlet geometries and configurations, as well as extending the capabilities of the tool to predict shock locations, as well as improve spillage accuracy and many other capabilities.

Plans for Next Period
Georgia Tech

The Georgia Tech team plans to complete the tasks listed in Table 1 with Georgia Tech designation. Work will continue toward completion on the assembly of a zeroth-order inlet design and analysis environment, and the completion of the milestone table below:

- Complete final assembly of zeroth-order methods to predict inlet performance
- Identify potential collaboration efforts to use experimental data from other Project 59 members
- Complete and submit a Year 3 interim project report
- Extend zeroth-order methods for inlet performance to include low-speed aerodynamics
- Perform thrust–noise break-even study
- Perform variable-geometry thrust recovery study
- Submit the final project report

Table 4. Anticipated milestones for the next research period.

Milestone	Owner	Planned due date
Final assembly of zeroth**-order methods to predict inlet performance**	Georgia Tech	1/30/2023
Determination of boundary conditions from "Vision SST Engine Cycle"—collaboration efforts	Georgia Tech	5/31/2023
Submission of interim project report	PSU and Georgia Tech	12/1/2022
Extension of zeroth-order methods for inlet performance to include low-speed aerodynamics	Georgia Tech	4/15/2023
Execution of thrust–noise break-even **study**	Georgia Tech	7/1/2023
Execution of the variable-geometry thrust recovery study	Georgia Tech	8/1/2023
Submission of the final project report	Georgia Tech	9/31/2023

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