Project 063 Parametric Noise Modeling for Boundary Layer Ingesting Propulsors

Georgia Institute of Technology

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- Period of Performance: June 5, 2020 to June 4, 2021
- Tasks:
  - Task 1 – Literature Review and Problem Parameterization
  - Task 2 – Develop Parametric Noise Model
  - Task 3 – Model Validation Exercises
  - Task 4 – Tool Documentation

Project Funding Level

The project funding amount is $300,000 from the FAA and a cost share match from Georgia Tech of $300,000.

Investigation Team

Dr. Jonathan Gladin – Research Engineer II – CO-PI, Overall task lead (Tasks 1 and 4)
Dr. Miguel Walter – Research Engineer II – Technical Aero-acoustics lead, Task 2 and Task 3 lead
Mr. Greg Busch – Research Engineer II – Noise analysis lead
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Project Overview

Boundary layer ingestion (BLI) is a popular area of research by many entities in aerospace due to the potential for large fuel burn savings. However, the noise implications of this technology are not fully known at this time. The purpose of this project is to identify, develop, and validate a parametric fan noise module for a generic BLI propulsor based on the specifics of a given configuration and design. Parameters influencing the model will include aerodynamic distortion parameters along with others that may affect the noise of the propulsor. The module developed will be based on lower order methods but will seek to validate such methods against higher fidelity approaches and any publicly available experimental data sets. The goal is to quantify turbulence ingestion, mean flow distortion, and shielding in a generic enough way that multiple classes can be captured. Georgia Tech also expects that this module could be integrated into the NASA Aircraft Noise Prediction Program (ANOPP) in a future effort, especially if additional funding for supplementary experimentation or numerical solutions are provided within a future phase.

A recent study by Clark et al. attempted to demonstrate the impact on noise from the inlet distortion-fan interaction for the NASA D8 (ND8) concept and found it to be as much as a 15 EPNdB penalty on cumulative noise. While the study by Clark et al. is interesting in that it represents a first-cut approach for quantifying a BLI impact due to distortion based on experiment, there are several factors that may call such approaches into question. The first is the validity of the open rotor experiment for predicting the sound pressure level (SPL) impact for tonal noise impact on an embedded turbofan engine. The second is due to the fact that there are many ways to achieve BLI and the interaction may vary significantly depending on the kind and quantity of the distortion ingested, and for varying fan applications such as ducted electric fans, propellers, or turbofan engines. Georgia Tech therefore proposes to close the gap identified from this literature by developing a parametric fan noise module for a generic BLI propulsor based on the specifics of the BLI configuration and propulsor design. Parameters influencing the model would include distortion intensity, character (i.e., radial versus circumferential), frequency, multiple-per-rev, fan design parameters, location on the airplane, embedded versus flush mounted, and potentially other relevant physical parameters. The module will attempt to quantify the impact of BLI on turbulent ingestion and mean flow distortion noise based on lower-order methods but would seek to validate such methods against higher-fidelity approaches and any publicly available experimental data sets, such as those used in the above paper or others. The module will also seek to model the effects of ducted versus unducted shielding of BLI noise sources so as to quantify the validity of using “equivalent” experiment data sources for BLI approximations. A validation exercise will be conducted whereby the lower-order methods are tested against higher-fidelity analyses and compared against empirical approaches.

Task 1 – Literature Review and Problem Parameterization

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Objectives

The objective of this task is to research existing approaches for the quantification of noise sources related to BLI fans and to determine an appropriate modeling approach for the parametric modules. The approach should fit within the statement of work and numerical computational budget afforded to the project.

Research Approach

The approach for this task is to scan the literature associated with BLI and with distortion-related noise generation for ducted fans. Each reference will be ranked by relevance and appropriateness and its direct applicability and usefulness will be determined.

Literature Review Results

A literature review on BLI, noise generation and prediction, model validation, and other related topics was conducted. The topics and research goals covered within a subset of the review are shown in Table 1. Most of the researched literature involved BLI, noise prediction, experimental validation, and numerical modeling. One limitation was the difficulty in finding literature that dealt with turbofans instead of open rotor engines. The identified numerical models emphasized that having well-understood correlations between the upwash of different rotor blades and the turbulence space-time correlations are critical in accurate noise estimation. This is partly due to the widely used rapid distortion theory (RDT) not being as useful in cases of inhomogeneous flow distortion, in which case sampling this correlation function becomes essential as a substitute to RDT. There also may be situations in which using this correlation function as a sampling distribution considerably accelerates computational time.

Table 1. Literature review topics

Literature	Topic Covered: BLI	Topic Covered: Inlet Distortions	Research Goal: Noise Prediction	Research Goal: Performance Prediction	Validation Method: Experimental Validation	Validation Method: CFD Validation	Results: Numerical Model Created	Topics Covered: Turbofans	Topics Covered: Open Rotor
Modelling of a Boundary Layer Ingesting Propulsor	X			X			X	X	
Predicting the Inflow Distortion Tone Noise of the NASA Glenn Advanced Noise Control Fan with a Combined Quadrupole-Dipole Model		X	X		X		X	X	
Discretized Miller Approach to Assess Effects on Boundary Layer Ingestion Induced Distortion	X			X	X	X	X	X	
An Analytical Model for Predicting Rotor Broadband Noise Due to Turbulent Boundary Layer Ingestion	X		X		X		X		X
Noise Produced by Turbulent Flow into a Rotor		X	X				X		X
Noise from a Rotor Ingesting a Thick Boundary Layer and Relation to Measurements of Ingested Turbulence	X		X		X				X
Noise from a Rotor Ingesting a Planar Turbulent Boundary Layer	X		X		X				X
Rotor Inflow Noise Caused by a Boundary Layer: Inflow Measurements and Noise Predictions	X		X		X				X
Enhanced Fan Noise Modeling for Turbofan Engines			X		X		X	X	

Problem Parameterization and Approach

Based on the results of the literature review, an approach to parameterizing the problem was developed. In order to develop a noise module that accounts for the impact of BLI parametrically and across a range of different applications, it was decided to develop this module using a “delta” approach. This approach will utilize a baseline non-BLI fan noise prediction from NASA’s ANOPP tool and attempt to correct the noise based on a semi-empirical model that accounts for the impact of BLI on fan noise. In order to achieve this, the Georgia Tech team is proposing to use computational aeroacoustics (CAA) to capture the acoustic impact of BLI parametrically, starting with one BLI configuration / architecture. The chosen configuration is a BLI tail cone thruster, similar to NASA’s STARC-ABL concept. This will be accomplished by parametrizing the modeling approach according to Figure 1.

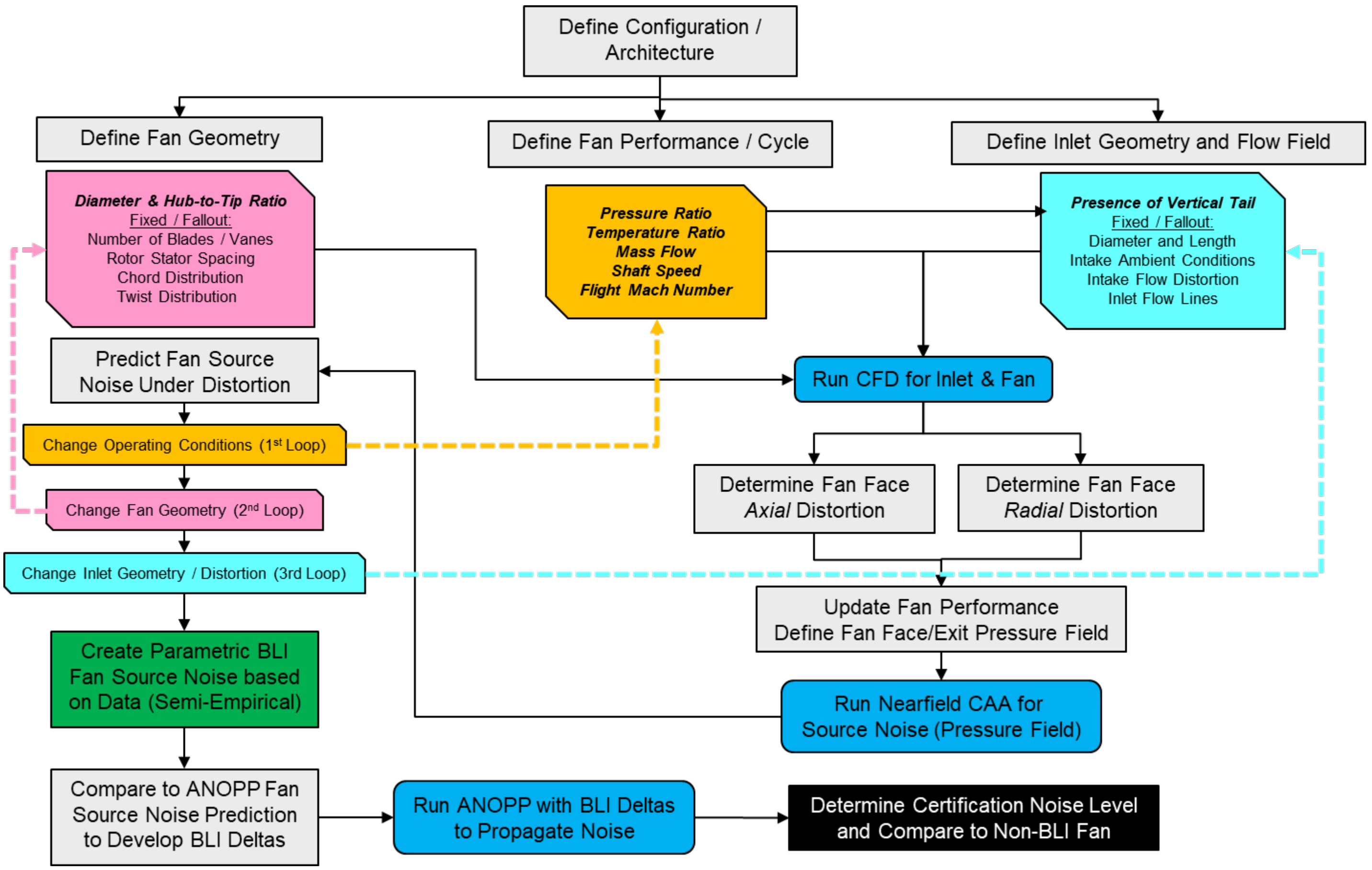

Figure 1. Proposed Modeling Approach to Create Parametric BLI Noise Module

To capture the sensitivity of the noise impact to a wide range of different BLI conditions, the acoustic impact of BLI will try to be captured at various fan geometries, operating conditions, and flow fields. To achieve the required number of runs needed to develop such a noise model, the scope of the varying parameters under each category was limited. The resulting proposed analysis cases needed to develop this initial parametric model are listed in Table 2. The analysis cases may change as the project progresses to accommodate computational resources and preliminary findings.

Table 2. Proposed analysis cases for modeling approach

Case Number	Operating Condition	Percent Power	Fan Diameter	Configuration
1	Takeoff	100%	Baseline	No Vertical Tail
2	Flyover / Cutback	65%	Baseline	No Vertical Tail
3	Approach	20%	Baseline	No Vertical Tail
4	Takeoff	100%	Baseline + 25%	No Vertical Tail
5	Flyover / Cutback	70%	Baseline + 25%	No Vertical Tail
6	Approach	35%	Baseline + 25%	No Vertical Tail
7	Takeoff	100%	Baseline - 25%	No Vertical Tail
8	Flyover / Cutback	70%	Baseline - 25%	No Vertical Tail
9	Approach	35%	Baseline - 25%	No Vertical Tail
10	Takeoff	100%	Baseline	With Vertical Tail
11	Flyover / Cutback	70%	Baseline	With Vertical Tail
12	Approach	35%	Baseline	With Vertical Tail
13	Takeoff	100%	Baseline + 25%	With Vertical Tail
14	Flyover / Cutback	70%	Baseline + 25%	With Vertical Tail
15	Approach	35%	Baseline + 25%	With Vertical Tail
16	Takeoff	100%	Baseline - 25%	With Vertical Tail
17	Flyover / Cutback	70%	Baseline - 25%	With Vertical Tail
18	Approach	35%	Baseline - 25%	With Vertical Tail

Takeoff
Mach Number: 0.24
Altitude: 1000 ft
Angle of Attack: 8.5 deg

Flyover / Cutback
Mach Number: 0.25
Altitude: 2000 ft
Angle of Attack: 4.5 deg

Approach
Mach Number: 0.20
Altitude: 400 ft
Angle of Attack: 6.5 deg

Milestone
Task completed.

Major Accomplishments
The Task was completed and an approach for defining the methodology was conducted and finalized with FAA sponsor approval.

Publications
No publications during this reporting period.

Outreach Efforts
No forms of outreach were performed during this reporting period.

Awards
No awards received during this reporting period.

Student Involvement

Two graduate students, Ross Weidman and Jose Zevala, are involved with this work. Both are graduate research assistants in their first year at Georgia Tech.

Plans for Next Period

None. Task 1 has been completed.

Task 2 – Develop Parametric Noise Model

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Objective

The objective of this task is to develop the parametric noise model, which will be the primary deliverable for the project. This module should be compatible with the ANOPP program.

Research Approach

After formulating the approach that was taken during the completion of Task 1, a more detailed Task schedule was defined and is shown in Table 3 below. The remaining Tasks 2, 3, and 4 and specific items relevant to each Task are broken down into a timeline through the end of the first year of the project. For Task 2, the baseline ANOPP, Fan, and computational fluid dynamics (CFD) models are the first items to have been worked and primarily accomplished during the current reporting period. Details on these items are shown below.

Table 3. Schedule for the implementation of Project 063's remaining Tasks (by month)

		S	O	N	D	J	F	M	A	M
Task 2	Baseline ANOPP Fan Model Development									
	Baseline Clean Fan Geometry w / SDT									
	Baseline Podded Fan CAA Cases									
	Baseline Distorted ANOPP Fan Model									
	Baseline STARC-ABL Geometry and Mesh									
	Parametric Perturbation Geometries and Mesh									
	Distorted CAA Cases									
Task 3	Reference ANOPP Fan Validation									
	Formulate Source Noise “Delta” Modules									
	Use Case Study, Single CAA Far Field Case									
T4	Documentation of Theory, Setup, Results									
	Documentation of Tool, Delta Modules, etc.									

Baseline Clean Fan Geometry with SDT Fan and Modifications Made

The baseline configuration chosen for the current project is based on the STARC-ABL geometry and the NASA Source Diagnostic Test (SDT) fan. The former is chosen due to its BLI effect on the rear electric propulsor, while the latter is chosen because it is a benchmark geometry for acoustic fan studies. These two geometries are integrated, with SDT fan geometry replacing the original STARC-ABL propulsor geometry. Some modifications are needed in order to accomplish such integration.

The first modification concerns the NASA SDT fan. The SDT is a 1/5 scale model of a representative high bypass turbo fan, with three different vane variants, which differ from the type of outer guide vane (OGV). A baseline OGV that has 54 radial vanes to reduce the blade passing frequency (BPF) rotor-interaction tone, a low-count OGV which has 26 radial vanes to reduce broadband noise, and a swept OGV which has 26 swept vanes with 30 degrees of sweep for reduced BPF noise. More information about the development of the SDT variants, can be found in the respective NASA program reports. The SDT provided by NASA for the current project is the first variant, and it is named SDT-A hereafter. SDT-A has a flat surface at the rear since it was developed to address fan noise only and thus it is not concerned with jet noise that would otherwise be generated from the rear part - core. In the current project, the chosen STARC-ABL utilizes an electric propulsor at the rear of the fuselage. Since the original STARC-ABL fan geometry is replaced with that of the SDT-A maintaining the concept of electric propulsor, then there is not core jet flow. Consequently, the SDT-A geometry is modified to have a plug shape at the rear so that it resembles the original STARC-ABL propulsor. The SDT-A geometry was modified in computer-aided design (CAD) to have a conical shape starting at the axial location of the trailing edge of the nacelle. A half-angle of the cone is 20º and the cone vertex is smoothed out with a small spherical cap. The resulting geometry is shown in Figure 2.

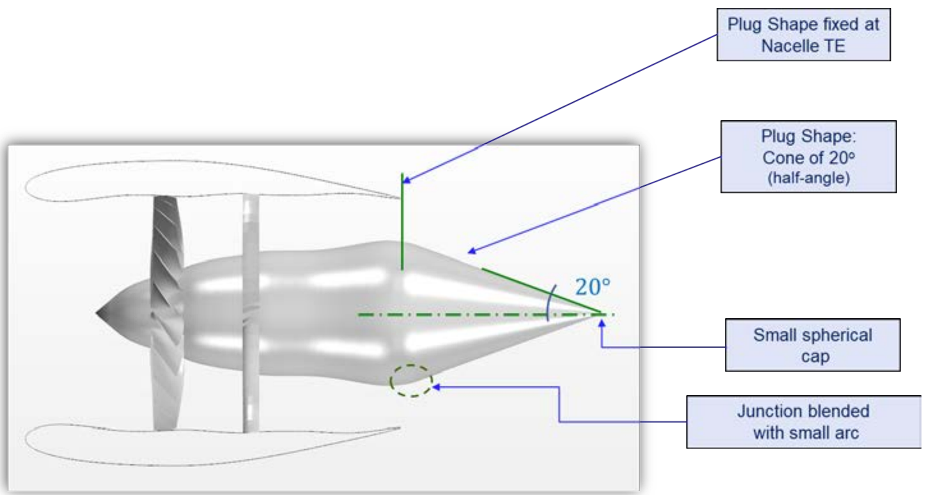

Figure 2. Modification to SDT-A geometry.

The second modification concerns changes at the STARC-ABL fuselage in order to integrate it with the modified SDT-A geometry. This integration uses two geometrical references in order to replace the original electric propulsor with that of the modified SDT-A. The first geometrical reference is the distance between the nose of the fuselage and the leading edge of the nacelle, which is maintained constant. The second geometrical reference, the axis of the original propulsor, is also maintained. These geometrical references are shown in Figure 3. Next, the modified SDT-A fan geometry is scaled up by a factor of 2.7272 so that it approximately meets the dimensions at the hub of the STARC-ABL propulsor. Then, the rear part of the fuselage is modified to allow a smooth transition with the scaled and modified SDT-A geometry. All of this is shown in Figure 4.

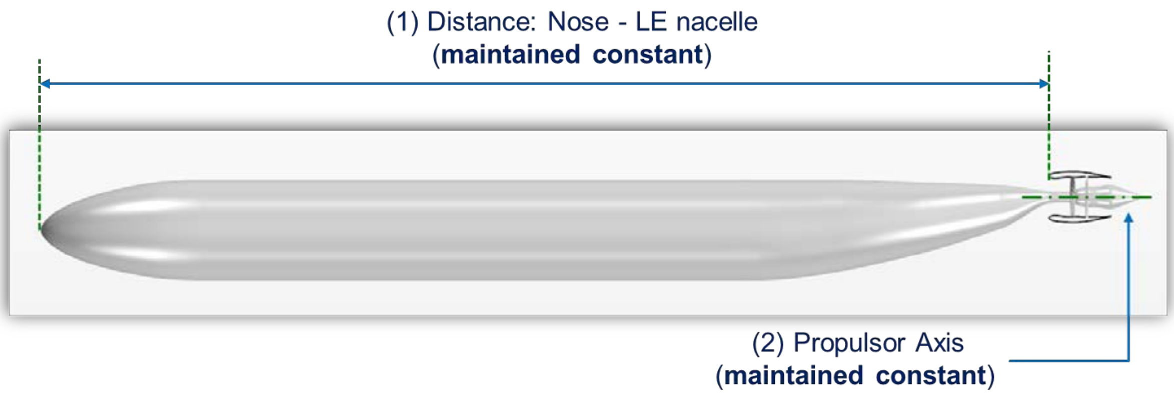

Figure 3. Geometry references for integration between the STARC-ABL and modified SDT-A.

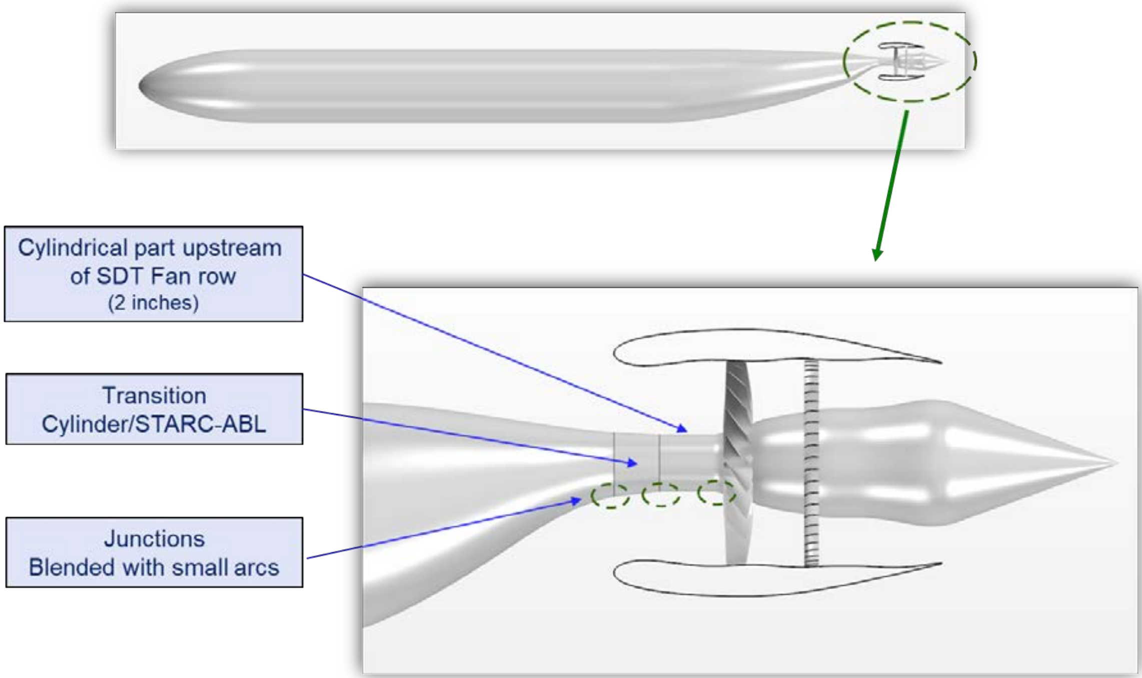

Figure 4. Modifications at the fuselage for integration.

Baseline Fan Performance Model for ANOPP

In order to create a baseline ANOPP noise model for the ducted SDT fan, it is necessary to model the performance of the fan over a range of flight conditions. To do that, a fan map was digitized from the reference material for the SDT fan and is shown below in Figure 5. The data points in the plots represent data digitized from the SDT test data, and the lines are the output of a computer code called CMPGEN, a NASA code that was used to approximately match the SDT fan map. This map is used to model the fan performance during off-design performance.

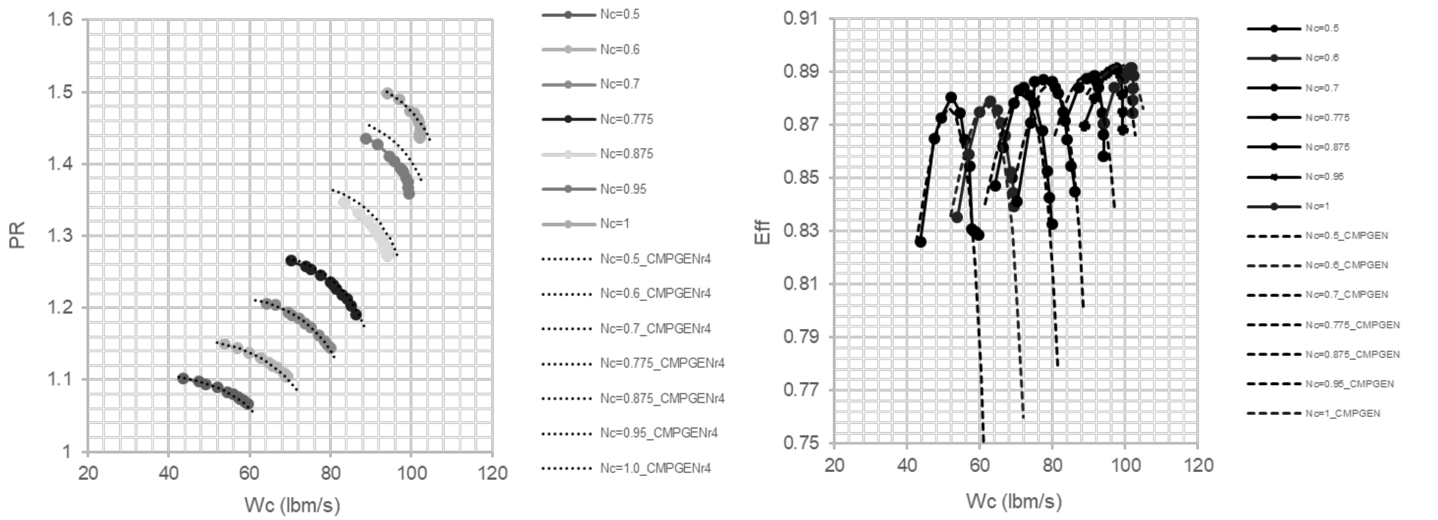

Figure 5. SDT fan map digitized from the SDT test data references and the lines representing the CMPGEN fan map performance that was matched to the SDT data set.

Next, the SDT fan needed to be scaled up to the size of the STARC-ABL geometry. The approach for doing this was to hold the fan shaft power constant at 3500 hp, which was taken from the STARC-ABL aircraft design. The criterion for scaling was to create a geometrically similar fan, but at the 3500 hp size. The scaling exercise results are shown below in Table 3. The scale factors for each of the main parameters of the fan are shown in the right column. The power of 3500 hp was used to determine the fan weight flow scale factor of 5.378. The square root of this number (2.31905) is therefore the geometric scale factor since the corrected flow is proportional to the area, which is in turn proportional to the radius of the fan squared. Therefore, the scale factor on the radii is 2.31905. The revolutions per minute (RPM) of the machine are also adjusted to keep the tip speed of the fan constant and maintain roughly constant aerodynamic performance. In this process, the stage pressure ratio and corrected specific flow are held constant. A numerical propulsion system simulation (NPSS) model of the ducted fan with these specifications and the fan map above was created. That model was then used to produce state tables to feed into the fan noise model.

Table 4. The parameters for the SDT and geometrically scaled SDT and the scale factors derived to scale the fan.

Parameter	SDT	Scaled SDT	Scale Factor
Tip Diameter	22 in.	51.0191 in.	2.31905
Hub Diameter	6.6 in. (Assuming 0.3 h/t ratio)	15.30573 in.	2.31905
Corrected Rotational Speed	12657 RPM	5457.83 RPM	1/2.31905
Corr. Tip Speed	1,215 ft/s	1,215 ft/s	1.0
Corrected Fan Weight Flow	100.5 lbm/sec	540.49	5.378 (2.31905^2)
Corrected Specific Flow	41.8 lbm/sec-ft^2	41.8 lbm/sec-ft^2	1.0
Stage Pressure Ratio	1.47	1.47	1.0

Baseline Fan Noise Model

The development of the baseline fan noise model for the parametric model plus the fan performance and geometry were used to create an ANOPP noise model. This ANOPP model was used to predict the hard-wall forward and aft fan noise based on the Heidmann fan noise module within ANOPP. It was decided to forego modeling of acoustic liners for the development of the BLI noise module to fully capture the impact of BLI and remove acoustic liner assumptions. The baseline noise model was run for three representative conditions for noise certification: sideline, flyover, and approach. The baseline noise model will be used in conjunction with computational aeroacoustics results for the non-BLI baseline case to create a set of “baseline deltas” between ANOPP and CAA. These deltas will eventually serve as a calibration for the BLI noise module so the application of the module in ANOPP is captured correctly and will ensure that the magnitude of the BLI impacts on noise are representative of BLI only, and do not include differences in the modeling methods. An outline of this process is shown in Figure 6.

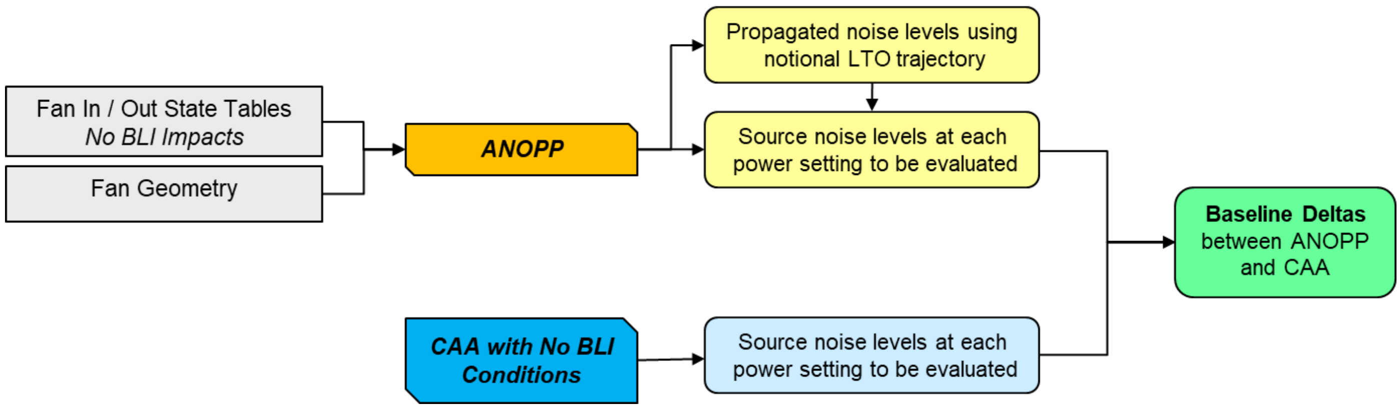

Figure 6. Modeling process to capture differences between ANOPP and CAA.

Baseline Fan RANS CFD Cases

In order to ensure that the modification to the rear part of the SDT-A geometry does not introduce undesired flow features, axisymmetric CFD simulations are carried out. These simulations are carried with the scaled-up geometry of the modified geometry. The scale factor is 2.31905, which is the first scaling performed and it is lower than the final scale factor used for the integration with the STARC-ABL geometry. Simulations with the final scale factor will be provided in the next report.

The simulations consider that the flow is entirely axial at cruise condition with a flight Mach number of 0.8. Inlet and outlet boundaries are included slightly downstream of the vanes and slightly upstream of the rotor, respectively, in order to simulate the effect of the fan on the flow. These boundaries enforce thermodynamics conditions at the inlet and exit of the fan. The thermodynamic state at these boundaries is given by an engine NPSS model. At the inlet of the fan, outlet boundary conditions (BC) are enforced by prescribing static pressure and temperature so that they match the mass flow given by the NPSS model. At the exit of the fan inflow, boundary conditions are enforced by prescribing stagnation pressure and temperature. In an outer boundary far from the modified SDT-A fan, freestream conditions are imposed with a cruise flight Mach number of 0.8 and altitude of 35,000 ft.

Simulations are carried out with a Reynolds-averaged Navier-Stokes (RANS) solver provided by the commercial CFD solver, STAR-CCM+. Furthermore, the adopted turbulence model is $k-\omega$ *SST*. The computational mesh consists of prismatic cells and polyhedral cells. The former are used at the surface walls of the nacelle and center body, while the latter are used everywhere else. The mesh ensures that $y^{+} \approx 1$ at all walls while the entire boundary layer is simulated with 25 prismatic cells. The computational set up and geometry are shown in Figure 7.

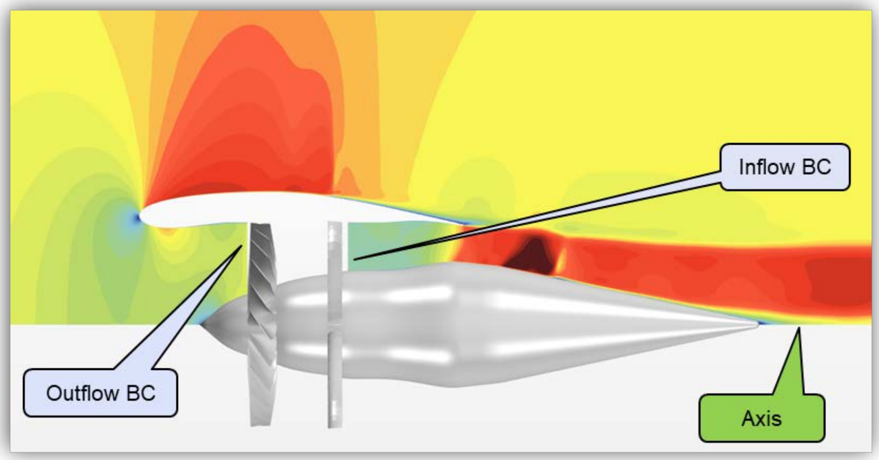

Figure 7. Axisymmetric CFD boundary conditions and geometry.

Flowfields of Mach number and magnitude of the density gradient are shown in Figure 8. It is observed that the resulting flow features of the modified SDT-A geometry are what would be typically expected for a turbofan at cruise conditions. Two relatively weak shock waves are observed at the nacelle, which is more evident in the gradient density flowfield. The flow exiting the fan undergoes expansion at the plug part, developing a relatively stronger shock wave. Immediately downstream of this shock, there is a very small separation of the flow; however, it reattaches at a very small distance downstream. All in all, no undesirable flow features such as strong separations and recirculations due to the plug shape geometry are observed.

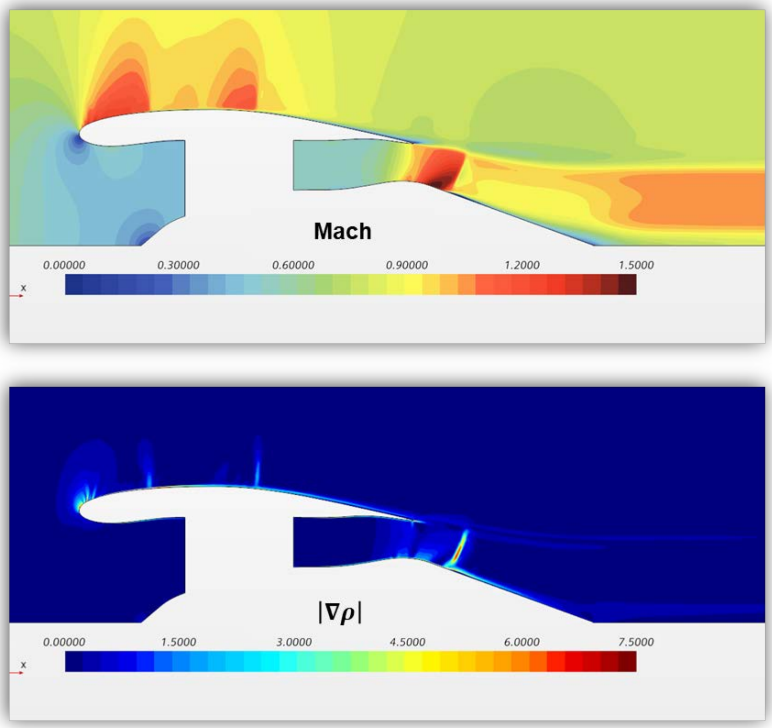

Figure 8. Flowfields of Mach and magnitude of density gradient

Milestones
No major milestones yet reached in this task.

Major Accomplishments
- SDT fan geometry and STARC-ABL aircraft geometry secured.
- Initial fan geometry run through RANS CFD codes.
- Geometry updated to baseline scaled model.
- Initial CAA meshes and test cases performed.

Publications
No publications during this reporting period.

Outreach Efforts
No forms of outreach yet performed during this reporting period.

Awards
No awards received during this reporting period.

Student Involvement
Two graduate students, Ross Weidman and Jose Zevala, are involved with this work. Both are graduate research assistants in their first year at Georgia Tech.

Plans for Next Period
The plan for the next reporting period is to finish all of the items specified in the research approach under Task 3 and to fully finish the first phase of the Task before the end of the current period of performance.

Task 3 – Model Validation Exercises
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Objective
The purpose of this task is to validate the creation of the parametric noise models with existing data or high-fidelity simulations.

Research Approach

Baseline Validation Approach

To validate the baseline fan noise, the predicted fan noise from the ANOPP model will be compared to published acoustic results of the SDT fan and the differences will be documented. If there is a significant difference in the ANOPP prediction and published data, a correction function in the ANOPP model can be introduced to minimize these differences. In order to account for differences between the CAA results generated for the study and ANOPP, the proposed method is described in section 1.2, Figure 6. Further validation exercises may be needed depending on the results of the parametric model. The module will be used to generate both BLI and non-BLI noise results at various flight / operating conditions and compared to the CAA results at the corresponding conditions.

High-Fidelity Computational Aero-Acoustics Modeling

Since the objective is modeling the effect of BLI on noise, then the effect of distortion on noise must be addressed. BLI as well as other flow perturbations upstream of the fan lead to lack of uniformity in the axial flow ingested by the fan. This in turn causes variations of the blade loading in the azimuthal direction. Consequently, aeroacoustics performance is degraded.

In order to capture the effects of non-uniformities in the ingested flow, the aerodynamics analysis necessarily needs to be unsteady. In this study, the adopted analysis for performing CAA is a hybrid approach, consisting of unsteady CFD and integral method based on the Ffowcs Williams and Hawkings (FW-H) equations. The unsteady CFD simulates the aerodynamic flowfield, which in turn provides noise sources. The FW-H approach is then used to propagate the noise sources to the farfield.

For the aforementioned CAA approach, unsteady Reynolds-averaged Navier-Stokes (uRANS), detached eddy simulations (DES,) and Lattice Boltzmann methods (LBM) are suitable approaches for unsteady aerodynamics. However, only the latter two can provide multi-scale noise sources that allow broadband noise assessment. In terms of computational cost, DES is the most computationally expensive, whereas uRANS and LBM have been reported to be more affordable. A summary of computational cost for similar applications is shown in Table 5. These costs suggest that uRANS and LBM have similar cost, which are between 60,000–66,000 CPU-hr, and thus they are considered for use in the current project.

Table 5. Computational cost for unsteady CFD in turbomachinery applications

Application	Purpose	Method	Cost (CPU-Hr)	Noise characteristics	Source	Remark
BLI Fan	Acoustics	LBM	62,000	Tonal & Broadband	Romani *et al.*, Aerospace Sci & Tech, 2020	Whole geometry
Turbo Fan	Acoustics	LBM	60,000	Tonal & Broadband	Casalino *et al.*, Vol 56, No 2, AIAA J. 2018	Whole geometry
Open-Rotor	Aerodynamics	uRANS	65,280	Tonal	Stuermer, AIAA paper 2008-5218 2008	Whole geometry
Turbo Fan	Acoustics	DES	1’080,000	Tonal & Broadband	Arroyo *et al.*, *J. Sound and Vibration* 2019	Sector (1/11) domain

The high-fidelity analysis workflow for the CAA approach considered in this study is shown in Figure 9. This process consists of the following:

- Initialization: This step refers to an initial solution for starting unsteady CFD simulations. For this purpose, a steady RANS simulation is performed and then used as an initial solution to uRANS.
- Unsteady Aerodynamics: This step refers to the unsteady CFD analysis. Initially, the unsteady CFD solver needs to be run long enough so that the initial solution is washed-out, i.e. convected down by the incoming flow from the geometry of interest. For the BLI turbo-fan application in this project, it is estimated that the time it takes for the rotor to undergo 2–5 revolutions is enough. After this initial step, unsteady CFD is executed along with the FW-H solver as described below.
- CAA: This step addresses the farfield aeroacoustics calculation using the FW-H model. Noise propagation is carried out from FW-H surfaces, where noise sources are captured, to FW-H receivers, where the acoustic pressure is recorded. It is pointed out that the FW-H solver is executed simultaneously with the unsteady CFD—after the initial solution is washed-out—and it is run long enough to collect acoustic pressure time histories. It is estimated that the run time for this step is about the time the fan rotor takes to undergo 10–12 revolutions.

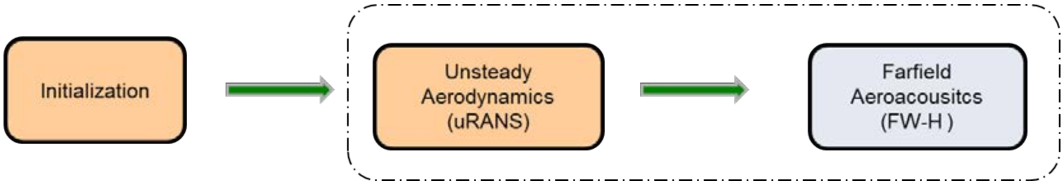

Figure 9. Workflow analysis chart.

In order to test the above workflow analysis, this process is applied to a simplified geometry based on the SDT-A turbofan. The main idea of this is to simplify the SDT geometry so that computational cost is reduced - reducing the total number of cells. As such, the geometry is simplified by removing the nacelle, vanes, and 20 blades from the SDT-A geometry. The resulting geometry resembles a two-blade propeller. The computational domain is divided into two regions. The first region simulates the motion of the rotor and spinner by undergoing rigid body rotating motion with the same angular speed as that of the rotor. The second region is static and surrounds the inner regions and the rest of the geometry. The simplified geometry along with the inner region is shown in Figure 10.

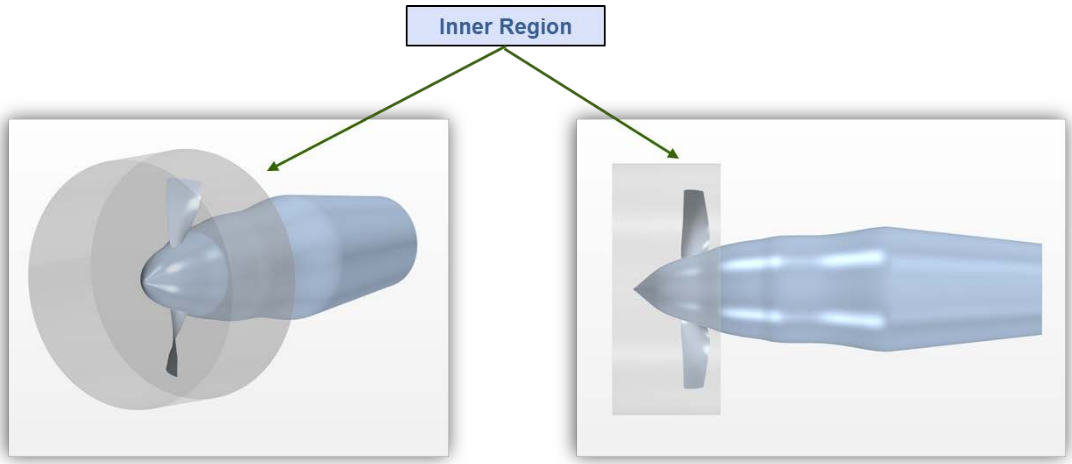

Figure 10. Simplified geometry

The CFD solver is uRANS with a $k - \omega$ *SST* turbulence model, provided by STAR-CCM+. The assumed operating conditions for this test are free-stream Mach number of 0.25 and tip Mach number of 0.6, which lead to a rotational speed of 742 rad/s. The time step is 10^{-5}, which approximately accounts for a half degree in the rotation of the fan rotor. The computational mesh has approximately 20 million cells and ensures $y^+ \approx 1$ at all solid walls – blade and center body surface. Also, the mesh in the near field—between geometry and FW-H surface—is fine enough to resolve frequencies up to 6000 Hz.

The FW-H solver is executed with the same time step as the unsteady solver. The FW-H surface where the noise sources are captured is a permeable surface in the near field surrounding the simplified geometry. The receivers are located in a line parallel to the geometry axis and at a distance of five meters. All of this is shown in Figure 11.

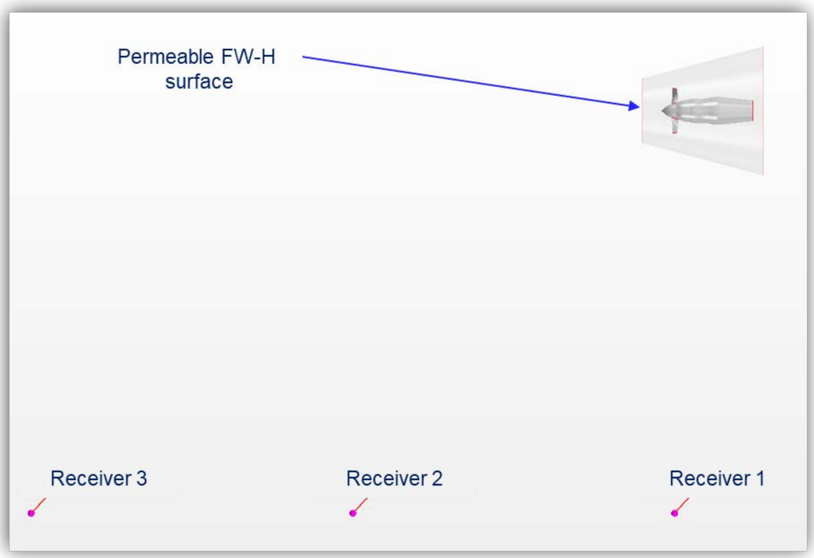

Figure 11. FW-H surfaces and receivers.

The acoustic pressure-time histories recorded in the receivers are shown in Figure 12. They have been recorded for approximately 1.5 revolutions of the simplified fan. Once run long enough, these pressure-time data can be used for assessing noise metrics such as spectrum and overall pressure sound level. It is noted that these pressure-time data will need to be recorded for a longer time—about 10 to 12 revolutions—in order to assess noise metrics. Nevertheless, the main purpose of this sample is to demonstrate the analysis workflow.

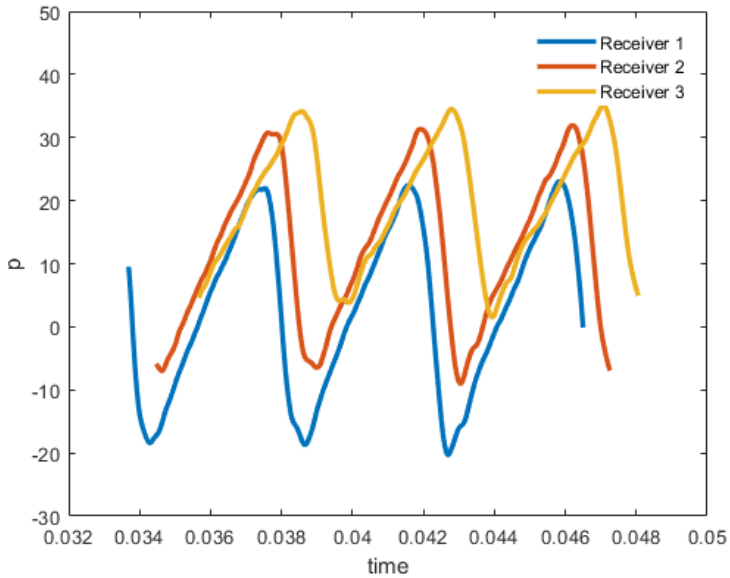

Figure 12. CAA results for the initial SDT fan test geometry.

Milestones
No major milestones achieved.

Major Accomplishments
Initial test cases for the SDT fan setup in CAA, including mesh, simulation, and unsteady CFD results.

Publications
No publications during this reporting period.

Outreach Efforts
No forms of outreach yet performed during this reporting period.

Awards
No awards received during this reporting period.

Student Involvement
Two graduate students, Ross Weidman and Jose Zevala, are involved with this work. Both are graduate research assistants in their first year at Georgia Tech.

Plans for Next Period
The plan for the next reporting period is to finish all of the items specified in the research approach under Task 3 and to fully finish the first phase of the Task before the end of the current period of performance.

Task 4 – Tool Documentation

Georgia Institute of Technology

Objective
The purpose of this task is to create documentation of the parametric noise tool created.

Research Approach
Georgia Tech will thoroughly document the tool and each of its modules including parameters involved, theoretical approach, algorithms utilized, output structure, and example use cases. This resulting theory manual will be in addition to the validation results which will be documented as a separate report.

Milestones
None. This Task has not started yet.

Major Accomplishments
None. This Task has not started yet.

Publications
No publications during this reporting period.

Outreach Efforts
No forms of outreach yet performed during this reporting period.

Awards
No awards received during this reporting period.

Student Involvement
Two graduate students, Ross Weidman and Jose Zevala, are involved with this work. Both are graduate research assistants in their first year at Georgia Tech.

Plans for Next Period
The documentation for the modules will be completed during the next annual period of performance.