Project 059B Jet Noise Modeling and Measurements to Support Reduced LTO Noise of Supersonic Aircraft Technology Development

Georgia Institute of Technology/Gulfstream

Project Lead Investigator

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University Participants

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- PI: Krishan K. Ahuja, Regents Professor
- FAA Award Number: 13-C-AJFE-GIT-060
- Period of Performance: June 5, 2020 to June 4, 2021
- Tasks:
  - Task 1: Form an Advisory Panel
  - Task 2: Identify a Baseline Nozzle Requirements and Design Tests
  - Task 3: Design and Fabricate a Baseline Nozzle
  - Task 4: Test Setup and Experimental Data Acquisition
  - Task 5: Data Dissemination
  - Task 6: Assess Readiness of Design Tools for a simple Baseline Nozzle Configuration
  - Task 7: Proposal for a Follow-on Effort for Years 2 and 3
  - Task 8: Reporting and Data Dissemination

Project Funding Level

$250,000 from FAA; $250,000 cost share from Gulfstream.

Investigation Team

- Dr. Krishan Ahuja, PI, Georgia Tech
- Dr. Dimitri Mavris (Co-PI) and Jimmy Tai (Co-PI), Georgia Tech
- Dr. Aharon Karon, Co-Investigator and Lead Experimentalist, Georgia Tech Research Institute (GTRI)
- Dr. Robert Funk, Experimentalist, GTRI
- David Ramsey, Graduate Research Assistant and Experimentalist, Georgia Tech

Project Overview

The overall goal of this project is to perform cost-effective supersonic transport (SST) jet noise research/technology experiments to enable low-, medium-, and high-fidelity jet noise prediction methods. The specific objective is to design the experiments in collaboration with industry, NASA, DOD, FAA and Modelers funded by FAA to help develop improved jet noise prediction methods that have reduced uncertainty such that industry can design quieter supersonic jet engines with higher confidence of the noise that will be generated. Working with Gulfstream as Georgia Tech's industry partner on this project, a representative baseline nozzle design will be selected for experiments at Georgia Tech. The data acquired will consist of farfield noise, high-speed flow visualization, source location, and detailed mean and unsteady flow measurements.

The experimental data acquired by Georgia Tech will be provided to key stakeholders and other computational teams funded by FAA to validate their computational simulations to confirm that jet noise predictions using semi-empirical and computational modeling approaches can be used reliably for jet noise evaluation.

Task Objectives, Research Approach, and Accomplishments

This project is new and has the following eight Tasks. The Task titles are self-descriptive and reflect the Task objectives. A short objective statement, research approach, and a summary of the accomplishments to date for each Task is provided below under each Task description.

Task 1 – Form an Advisory Panel

Georgia Institute of Technology

The objective of this task is to receive regular feedback from Industry and NASA subject matter experts (SMEs) in supersonic jet noise.

Dr. Liu, the FAA Project Manager for ASCENT 59, has already formed an advisory panel consisting of representatives of FAA, DOD, NASA, Aerion, GE, and Gulfstream and a kick-off meeting has already been held. Their feedback was used in the design of the test nozzle described below.

Task 2 – Identify Baseline Nozzle Requirements and Design Tests

Georgia Institute of Technology

The objective of this Task is to define the nozzle requirements and design the experiments.

The baseline nozzle and tests were based on a paper engine design created by the Georgia Tech Aerospace Systems Design Lab (ASDL) guided by ASCENT Project 10 on engine cycle selection for GT Medium SST (55 passenger class). The GT nozzle model to be to be tested under this project will not have a plug. For the purpose of calculating the area of the outer (secondary flow) duct, the annular areas of the paper engine will be used to calculate the area of the secondary flow duct in the model nozzle facility. The GTRI model is a 0.045 scale of the paper engine. The mixing length/exhaust nozzle exit diameter (L/D) will be: 0.7, 1, 2, and 3.

As described below, tests have been designed with variations in nozzle design and/or operating parameters in order to explore the accuracy of semi-empirical and computational tools for predicting jet noise. Methodologies, the test matrix, and nozzle designs are detailed in Appendix A.

Task 3 – Design and Fabricate a Baseline Nozzle

Georgia Institute of Technology

The objective of this Task is to design and fabricate a baseline nozzle that meets the requirements defined in Task 2 above and is also suitable for the tests needed to meet the objectives of the overall program.

Design has been completed and is shown in Figure 1. The model consists of the following parts: the primary nozzle with the collar to avoid any anomalous flow effects due to any geometrical protrusions/recesses, the secondary nozzle, mixer ducts, and the exhaust nozzle. There are three mixer ducts being fabricated to allow for different mixing length-to-nozzle-exit diameter ratios (L/D). The test model utilizes the coannular flow capabilities of the GTRI jet facilities. The primary and secondary flow streams converge into the mixer-duct and exhaust nozzle combination. The mixer-duct and exhaust nozzle combinations allow for L/Ds of 0.7 (exhaust nozzle mounted directly to the secondary nozzle), 1, 2, and 3. The jet stream is ultimately formed by the exhaust nozzle, which is a converging nozzle with geometry based on the converging section of the converging-diverging nozzle from the ASDL engine design.

The primary nozzle is ready to be used. The outer nozzle is being fabricated by Gulfstream. The COVID-19 situation has slowed down the availability of machinists.

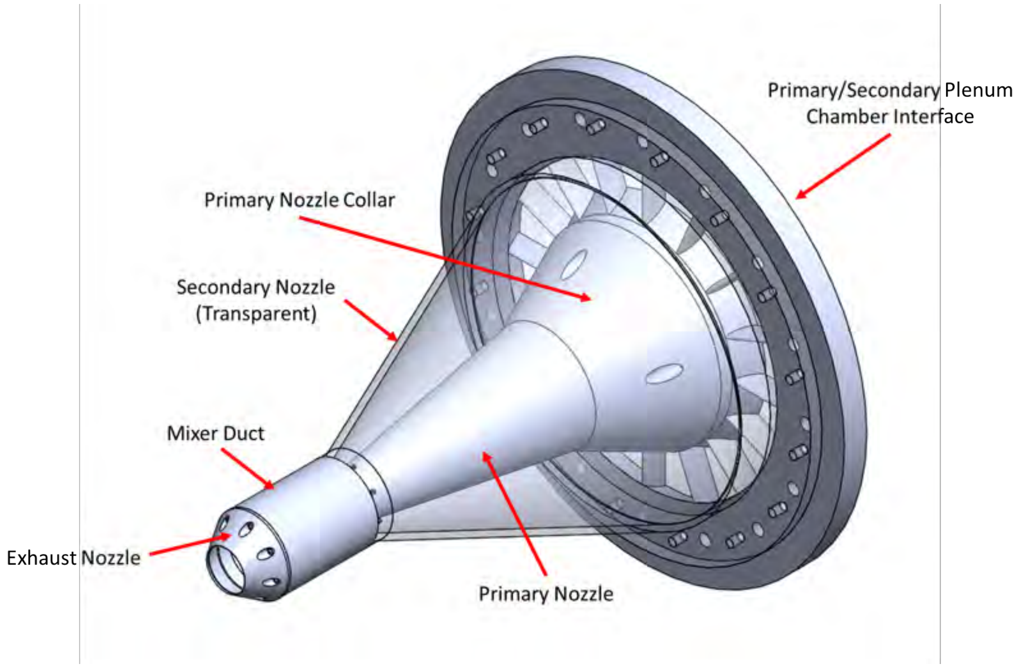


Figure 1. Experimental model design.

Task 4 – Test Setup and Experimental Data Acquisition

Georgia Institute of Technology

The objective of this Task is to get ready to conduct the tests and acquire and analyze the data.

Test setup has been initiated; experiments are being planned. Acoustic and flow measurements will be acquired for the experimental model for a range of primary and secondary total pressures for both cold and heated flows. The acoustic measurements will be acquired in the GTRI Anechoic Static Jet-Facility, which is anechoic above 250 Hz. A photographic view of the chamber appears in Appendix A. A detailed description of the facility can be seen in Burrin et al. [1], Burrin and Tanna [2], and Ahuja [3]. In addition to recording the acoustic pressure time histories, the acoustic measurements will be processed into loss-less power spectra. This will follow the procedure found in Karon [4]. The flow measurements will be acquired in the GTRI Flow Diagnostic Facility, which is a non-anechoic jet-facility that can produce jet flow identical to those in the GTRI Anechoic Static Jet-Facility. This facility is instrumented with high-speed flow visualization, beamforming, and particle image velocimetry (PIV) capabilities. All of the acoustic and flow measurements will be analyzed by the Georgia Tech team and will be compared to the simulation results as validation for those simulations.

Task 5 – Data Dissemination

Georgia Institute of Technology

The objective of this Task is stay in touch with the modelers being funded by FAA under Project 59 and provide them the nozzle design and both the acoustic and flow data from the current project.

The modelers were all informed of our preliminary design during the first Advisory Panel discussion. We have now provided the finalized design to the modelers. The data will be provided as it becomes available.

Task 6 – Assess Readiness of Design Tools for a simple Baseline Nozzle Configuration

Georgia Institute of Technology

Whereas Task 5 just provides the data to the modelers, the objective of this Task is to interact with the modelers in terms of verification of their codes with the measurements made under this project at Georgia Tech. Partners Gulfstream and ASDL will also be comparing their low-fidelity codes with our data.

Task 7 – Proposal for a Follow-on Effort for Years 2 and 3

Georgia Institute of Technology

Proposals for follow-on efforts will be prepared under this Task.

This Task has not been initiated yet.

Task 8 – Reporting and Data Dissemination

Georgia Institute of Technology

This being a new project, so far only the first quarterly report has been submitted.

Milestones

The experimental model design was completed and approved by the FAA. The primary nozzle is ready to be tested. The outer nozzle is now being fabricated.

Major Accomplishments

The experimental model design was completed and approved by the FAA. This model design was passed along to the machine shops for fabrication and the simulation teams for use in their predictions. The microphones have been setup to start acquiring the data.

Publications

N/A

Outreach Efforts

N/A

Awards

None

Student Involvement

David Ramsey assisted with the design of the experimental model and put together the documents that were sent to the machine shop. He will continue to be the graduate research assistant on this project.

Plans for Next Period

Acquire jet noise data for the primary nozzle alone. In parallel, complete the fabrication of the outer nozzle duct sections and start acquiring the data.

References

[1] Burrin, R. H., Dean, P. D., and Tanna, H. K. "A New Anechoic Facility for Supersonic Hot Jet Noise Research at Lockheed-Georgia," *The Journal of the Acoustical Society of America* Vol. 55, No. 2, 1974, p. 400.

[2] Burrin, R., and Tanna, H. "The Lockheed - Georgia coannular jet research facility," *The Journal of the Acoustical Society of America* Vol. 65, No. S1, 2005, pp. S44-S44.
[3] Ahuja, K. "Designing clean jet-noise facilities and making accurate jet-noise measurements," *International Journal of Aeroacoustics* Vol. 2, No. 3, 2003, pp. 371-412.
[4] Karon, A. Z., "Potential factors responsible for discrepancies in jet noise measurements of different studies," Ph.D. Dissertation, Daniel Guggenheim School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, 2016.

Appendix A: Details of the Nozzle design

FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Appendix A

Project 59

Lead investigators: Krishan Ahuja (PI), Dimitri Mavris (Co-PI) and Jimmy Tai (Co-PI)
Georgia Institute of Technology

Lead Experimentalists: Aharon Karon and Robert Funk, GTRI
Industry Collaborator: Brian Cook (Gulfstream)

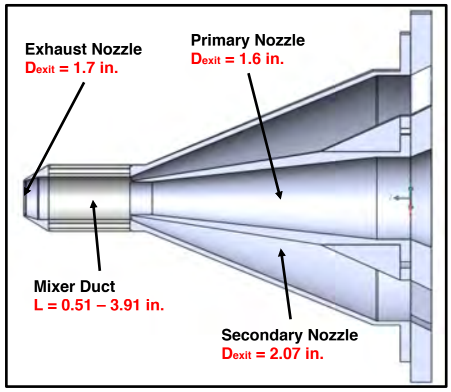
Project manager: Sandy Liu, FAA

Introduction

- Supersonic transports need small-sized engines to minimize drag when cruising at supersonic speeds.
- This requires higher jet exhaust velocities during landing and take-off (LTO), which will increase the noise at these conditions.
- The goal of this project is to improve jet noise prediction methods for supersonic transports at LTO conditions.
- This is to be done by acquiring high-quality acoustic data and the relevant flow data and providing that to separately-funded computational teams for validation using low, medium, and high fidelity codes.

Methodology

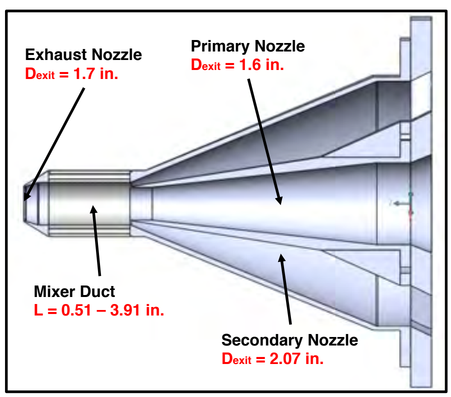
- The Georgia Tech team will collaborate with FAA-funded CFD teams from Stanford, Penn State and University of Illinois as well as Gulfstream.
- A common model-scale nozzle will be used by both the experimental and the computational teams.



- This model will initially be a simpler geometry to gain confidence in the noise prediction of the codes.
- In year 1, the mixer will be a straight duct as shown here.

Methodology

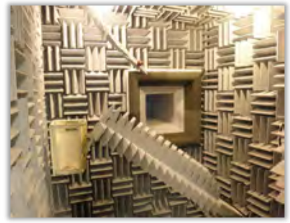
- Measured noise and related flow data by the Georgia Tech team will be used by the computational teams to validate the noise prediction codes
- The final exhaust model will be a conical nozzle



- The scaled dimensions are based on an engine cycle design from the Georgia Tech Aerospace Systems Design Laboratory (GT ASDL). This is still to be finalized.
- A selected mixer nozzle (design TBD) will be added to the primary stream in years 2 and 3

Data to Acquire

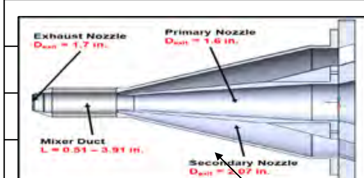
- Acoustic data will be acquired in GTRI's anechoic chamber



The following measurements will be made using model-scale nozzles

- Farfield noise
- Primary and secondary mass flow rates
- Primary and secondary total temperatures and pressures
- Ambient humidity and temperature
- Mean and turbulence velocities at the nozzle exits via PIV

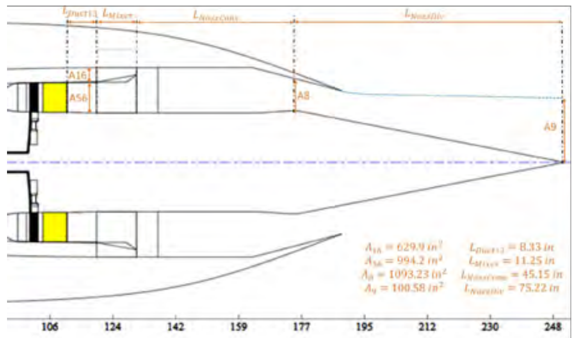
Test Matrix



Configuration	M1	M2	Primary Temp
Primary Nozzle Alone	0.2 - 0.9	N/A	Unheated
Primary Nozzle Alone	0.2 - 0.9	N/A	Heated
Primary + Secondary	0.2 - 0.9	0.2 - 0.9	Unheated
Primary + Secondary	0.2 - 0.9	0.2 - 0.9	Heated
Primary + Secondary + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Unheated
Primary + Secondary + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Heated
Primary + Secondary + Mixer Duct of Length L1 + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Unheated
Primary + Secondary + Mixer Duct of Length L1 + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Heated
Primary + Secondary + Mixer Duct of Length L2 + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Unheated
Primary + Secondary + Mixer Duct of Length L2 + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Heated
Primary + Secondary + Mixer Duct of Length L3 + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Unheated
Primary + Secondary + Mixer Duct of Length L3 + Exhaust Nozzle	0.2 - 0.9	0.2 - 0.9	Heated

Test Model Reference

- The model used is based on the paper engine design by ASDL
- The GTRI model will not have a plug
  - Annular areas will become circular areas using area-equivalent diameters



- The GTRI Model of a 0.045 scale of the paper engine

Notes on the Test Model Design

- The GTRI Model is a 0.045 scale of the paper engine
- The mixing length/exhaust nozzle exit diameter (L/D) will be: 0.7, 1, 2, and 3

Complete Model

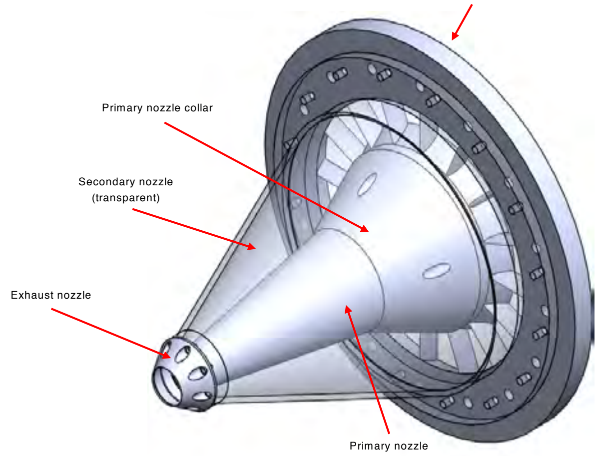


Figure 01. Isometric view of complete model with secondary nozzle shown as transparent

Complete Model Exploded View

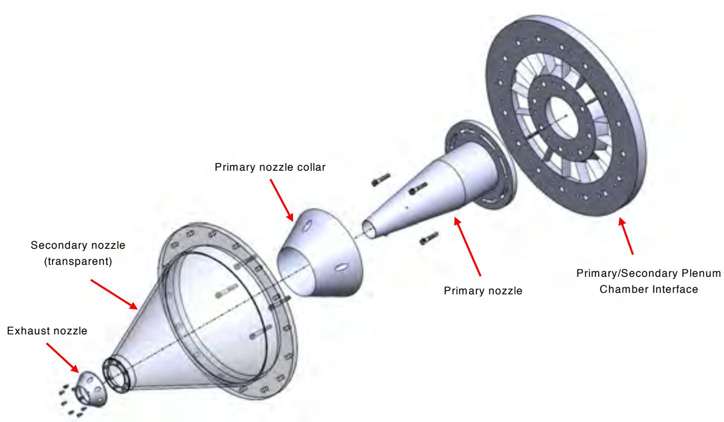


Figure 02. Isometric, exploded view of complete model with secondary nozzle shown as transparent

Exhaust nozzle spacer length used to set L/D

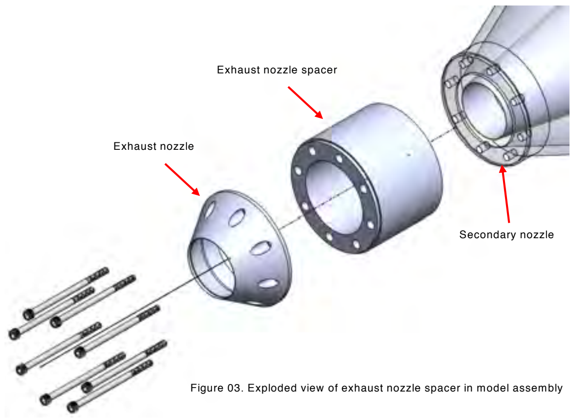


Figure 03. Exploded view of exhaust nozzle spacer in model assembly

L/D convention shown with section view of exhaust nozzle

$$\frac{L_e}{D_e}$$

L_e: Exhaust nozzle length after primary/secondary nozzle exit plane

D_e: Exhaust nozzle exit diameter

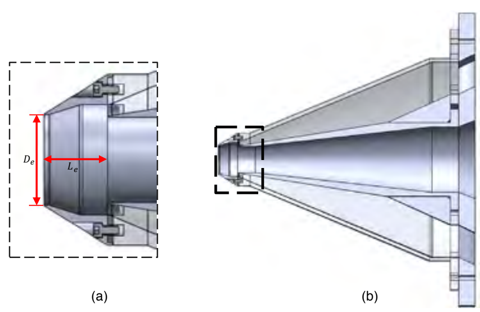


Figure 04. Section view of (a) exhaust nozzle with critical dimensions labeled and (b) region of view shown within context of model, both with secondary nozzle shown as transparent

Exhaust nozzle spacers shown for each L/D value

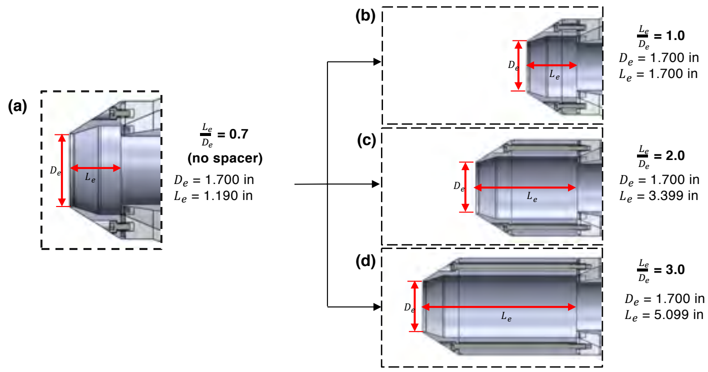


Figure 05. Section view of exhaust nozzle (a) with no spacer, (b) with L/D = 1.0 spacer, (c) with L/D = 2.0 spacer, and (d) with L/D = 3.0 spacer. Note that screws used for L/D = 2.0 and L/D = 3.0 must be cut to length.

Complete Model for Hand-off to Simulation Engineers

No fasteners or fastener holes included. All fastener holes will be sealed with clay/plaster during experimentation.

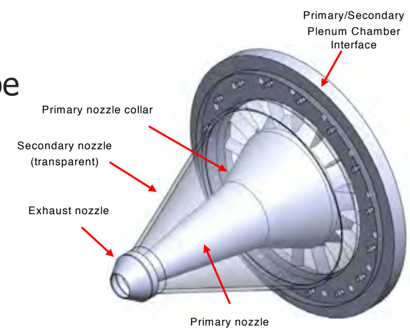


Figure 06. Isometric view of complete model as will be passed to simulation engineers with secondary nozzle shown as transparent

Primary/Secondary Plenum Chamber Interface (Slide 1 of 2)

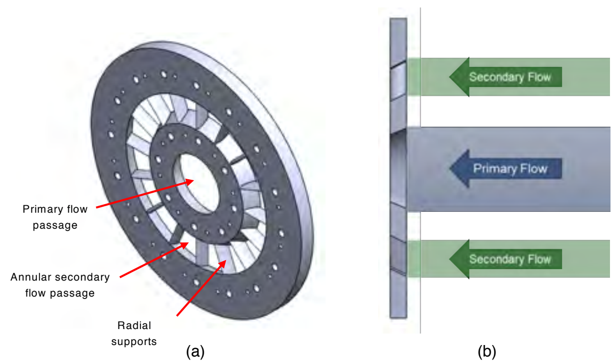


Figure 07. Primary/secondary plenum chamber interface (a) isometric view and (b) cross section view with primary and secondary flow shown

Primary/Secondary Plenum Chamber Interface (Slide 2 of 2)

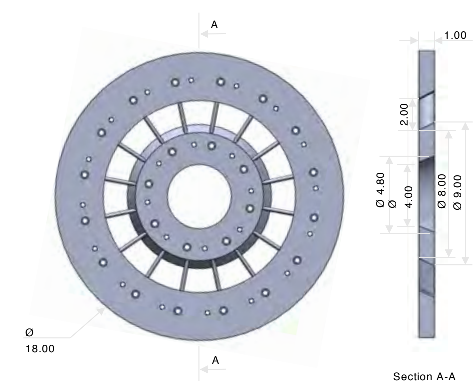


Figure 08. Primary/secondary plenum chamber interface dimensions (all dimensions are in inches)

Primary Nozzle

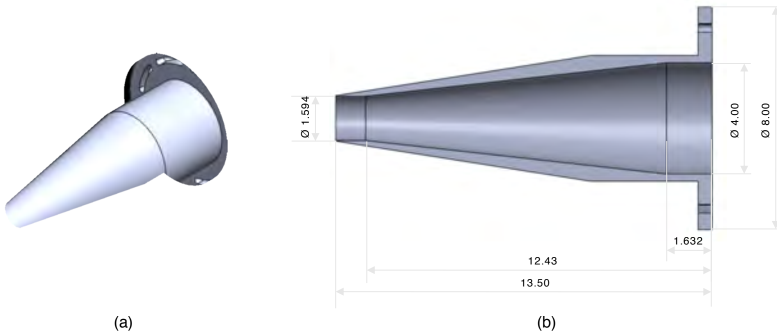


Figure 09. Primary nozzle (a) isometric view and (b) dimensioned cross section view (all dimensions are in inches)

Primary Nozzle Collar

- This part is used to prevent a circulation zone from the backwards step in the secondary flow path

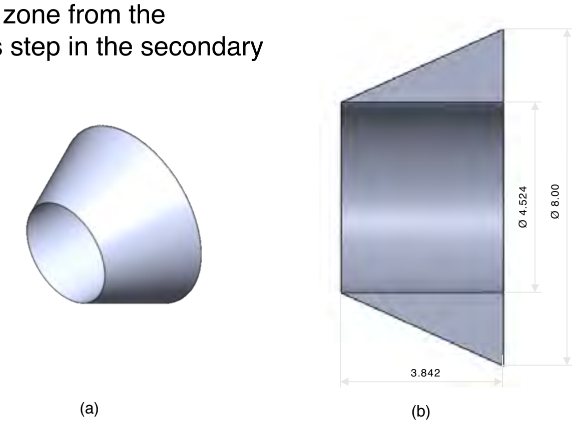


Figure 10. Primary nozzle collar (a) isometric view and (b) dimensioned cross section view (all dimensions are in inches)

Secondary Nozzle

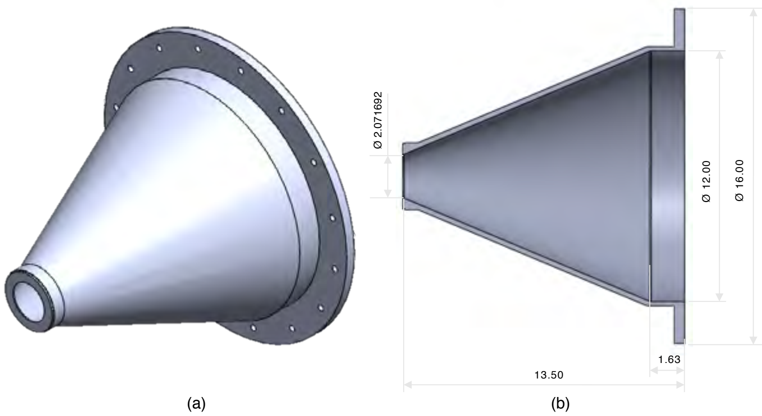


Figure 11. Secondary nozzle (a) isometric view and (b) dimensioned cross section view

Exhaust Nozzle

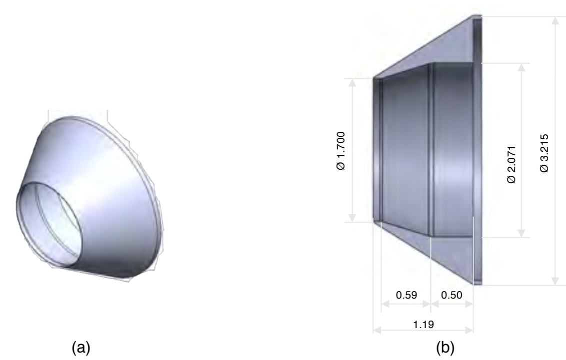
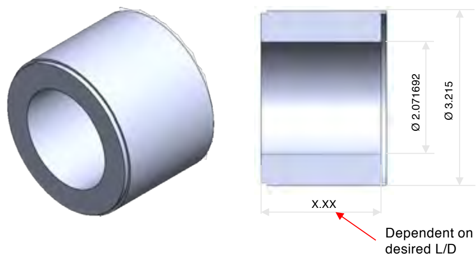


Figure 12. Exhaust nozzle (a) isometric view and (b) dimensioned cross section view (all dimensions are in inches)

Exhaust Nozzle Spacer



(a) (b)

L/D	Spacer Length
0.7	No spacer
1	0.510 in
2	2.210 in
3	3.910 in

(c)

Figure 13. Exhaust nozzle (a) isometric view and (b) dimensioned cross section view (all dimensions are in inches) and (c) spacer length as a function of desired L/D