

# Rocket Nozzle Design and Analysis

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**Abstract**—This project focuses on the design of a large-scale rocket nozzle capable of producing 100 Newtons of thrust. There will be a test stand used to measure the thrust force by method of a load cell. There will be sensors placed in strategic locations that will assist in the data analysis to allow the team to understand conditions of the fluid as it passes through the nozzle and exits. The results of the experiment will be summarized in a final report and presented at Imagine RIT, depending on the completion date.

## NOMENCLATURE

PDD Project Design Document  
RIT Rochester Institute of Technology  
SPEX RIT Space Exploration

## I. INTRODUCTION

Propulsion systems are very difficult to design and test. The SPEX propulsion team has worked for two semesters, Spring 2017 Fall 2017, to design and test a cold gas propulsion system. There was moderate success in the design and testing of this system. The successes included, nozzle design, nozzle fabrication, test stand fabrication, and experimentation. The nozzles were designed through the Aerospike software given to us by an advisor, Dr. Dorin Patru. The nozzles were fabricated by methods of additive manufacturing. The test stand was properly designed and fabricated to work with thrust levels up to 10 Newtons. The experimentation was successful because the team was able to test multiple nozzles with different operating characteristics. There developed a problem in the fabrication of conical nozzles that the team designed using the analytical rocket equations. The nozzles for the thrust levels were too small. The fabrication process would be inhibitive difficult. The solution to this is an increase in the thrust level. This project will focus on the design of a conical nozzle for a 100 Newton thrust force test.

## II. PRIMARY OBJECTIVE

The primary goal of this project is to use the analytical rocket equations to design a conical rocket nozzle to produce 100 Newtons of thrust. The team will design a new stand that is capable of securely fastening a propulsion test of 200 Newtons. Thus providing a factor of safety of 2.0. The tests will be performed with Air or Nitrogen so the extensive tabulated data can be used in the performance analysis of the nozzle.

## III. BENEFIT TO SPEX

The benefit to SPEX would be the further education in the design of rocket nozzles using the analytical rocket equations. The experiment platform would be a great exhibit for visiting companies or Imagine RIT where SPEX would be on display. This project would be the first time that the propulsion team has fully designed and operated a rocket nozzle. Using these equations correctly is very complicated and important for propulsion engineers to understand. The project would have a full life cycle which includes design, manufacture, test, and reporting the results.

## IV. IMPLEMENTATION

The project will start with a brief education of the rocket equations. The team will go through each one so everyone on the team is acquainted with them before we dive into the nozzle design. Then the team will start with the nozzle design. Once the nozzle design is complete the team will design the test stand that can adequately contain the propulsion system. Then the team will manufacture the nozzle and test stand. After testing, if time permits, the team will use a schlieren lensing setup to get a very good look at the fluid flowing out of the nozzle.

### A. Deliverables

The physical deliverables for this project are the test stand and rocket nozzle. The test stand and rocket nozzle can be shown to faculty and other bodies that could support SPEX in some fashion. The test stand and nozzle will be stored so it can be demonstrated when necessary, such as an introduction to SPEX engineering to students, faculty, or others.

The non-physical deliverables would be a poster that exhibits the work completed and the results of the experiment. There will be a final report that outlines the method used for designing the nozzle and manufacturing the nozzle and test stand. The report will be written in the IEEE standard and can be submitted to various organizations for funding other outreach opportunities.

### B. Milestones

The milestones for this project are, in chronological order; nozzle design, test stand design, nozzle fabrication, test stand fabrication, testing, and final report. The nozzle design and fabrication proceed the test stand because the test stand must be designed to fit the nozzle, the nozzle should not be designed

### Proposed Timeline

Week	Description
1	Team Introductions and project planning
2	Nozzle Design
3	Nozzle Design
4	Nozzle Design
5	Nozzle Design
6	Test Stand Design
7	Test Stand Design
8	Test Stand Design
9	Nozzle Fabrication
10	Test Stand Fabrication
11	Test Stand Fabrication
12	Order Gas
13	Setup experiment
14	Test #1
15	Test #2 & Schlieren Lensing

to fit the test stand. The following, is a proposed project schedule.

## V. EXTERNALITIES

### A. Prerequisite Skills

No skills are required. But the recommended skills are as follows; Differential & Integral Calculus and MATLAB coding. The rocket equations require a basic knowledge of calculus to understand. Rates of change and integration show up very regularly in this type of physics and mathematics. MATLAB is a very usefull resource. MATLAB will be used for the data collection and the data analysis. It's ability to handle vectors and large datasets is unparalleled. A very basic understanding of MATLAB would be great, but the team plans to host MATLAB training sessions so everyone can be brought to a rudimentary understanding level of MATLAB.

### B. Funding Requirements

The project will most likely require a budget of \$400. There will be material costs for the test stand and the nozzle. Then there will be the cost of a proper load cell. There will also be the cost of the necessary sensors to measure the proper characteristics of the fluid flowing through the nozzle.

Measuring the thrust is extremely important to this project. The accuracy of this measurement must be high enough that it can fully register the data output. This will entail a very high sampling rate and a appropriately sensitive load cell. The best contender for data acquisition is the National Instruments USB-6008. It is capable of a 48000 sampling rate. But they are slightly expensive, usually falling between \$150 - \$200. This DAQ is easy to setup with MATLAB and can easily and effectively pull the data and store the data.

### C. Faculty Support

Faculty support will be necessary for obtaining the necessary safety equipment and propulsion equipment, such as the bottle pressures. There may also be the need for faculty support during the data analysis and nozzle design.

Bottles can be pressurized to 3000 Psi. There is a method of using these bottles for quick propulsion tests. To use these bottles, the team must get faculty help for safely storing and

operating these bottles. The team may also have to get RIT Risk Management's approval for this testing.

### D. Long-Term Vision

The long-term vision of this project is provide experience of analytical nozzle design. Understanding what is happening in the computer that designs the better nozzles, is very important for propulsion engineers. This project will open a gateway to more complex projects. This project will show the team how properly contain a high thrust system. The data analysis experience is also very valueable as it will assist in connecting physical outcomes due to internal conditions. That kind of experience is invaluable for students in the learning process.

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