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 2019.**

NOMENCLATURE

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

I. INTRODUCTION

The project will be concerned with the design, fabrication, and experimentation of a cold gas propulsion system. This is a propulsion system that is solely based off momentum transfer with little to no heat considerations. The project should have a team consisting of 10 to 15 members willing to dedicate 5 to 10 hours a week to this project. The end result of the project will be a propulsion system, mounted on a test stand ready to test when the appropriate propellant is attached.

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 begin by informing new members on past projects. The team will discuss the events that went well, and the reasons some did not. The objective is to prevent the same problem occuring twice. Each team member will be instructed to read chapter 3 out of the *Rocket Propulsion Elements* book written by Sutton. Then the team will start with the nozzle design. The nozzle design process begins by defining the requirements, then using the analytical rocket equations, find the physical dimensions of the nozzle so it can be 3D modeled and sent to a manufacturer. During the nozzle design process, a second part of 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

There are seven phases of this project. subsection IV-B shows each phase in partial chronological order. The first phase is focused on getting the team acquainted with each other. This phase is when project management decisions will be made, such as meeting times and setting up members with the necessary software. The next phase will be dedicated to the nozzle design. Once that is complete, the test stand must be designed. After making a detailed BoM, the nozzle and test stand will be fabricated. The propellant must be procured with the necessary plumbing. Once the system is fully integrated the experiment will be conducted. Then all the data will be througohly organized to prevent any loss of data. The data

Proposed Timeline

Phase	Description
0	Team Introductions and project planning
1	Nozzle Design
2	Test Stand Design
3	Nozzle and Test Stand Fabrication
4	Experimentation
5	Data Collection and Organization
6	Data Analysis
7	Final Report

will be analyzed and made into a full report for SPEX. The schedule is partially chronological because some phases can be attacked simultaneously, such as phase one and two.

Phase Zero is estimated to last one week. Phase One is esitmated to last three to four weeks. Phase Two is esitmated to take three to four weeks. Phase Three is esitmated to take two to three weeks. Phase Four is estimated to take two to three weeks. Phase Five is estimated to take one week. Phase Six is estimated to take two to three weeks. Phase Seven is estimated to take three weeks. These esitmations are based on past experience and known manufacturing times. For a local Rochester machine shop, the part turn-around is one to two weeks.

V. Externalities

A. Prerequisite Skills

No skills are required. All necessary skills will be taught. These skills include; Differential & Integral Calculus (to a degree so understanding the rocket equations is possible), MATLAB coding, engineering decisions, machining design choices, and using the rocket equations. 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. The machining for this project will mainly concern the test stand, the nozzle will most likely be outsourced due to high machining complexity.

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 to $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 to 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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