



EML 4905 Senior Design Project

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REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

**NANO-LAUNCH
REACTION CONTROL SYSTEM
25% Report**

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of David Dominguez, Gianni Jimenez, and Genesis Vasquez and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Table of Contents

| | |
|---|----|
| Table of Contents | 2 |
| List of Figures | 2 |
| Abstract | 3 |
| 1. Introduction | 3 |
| 1.1 PROBLEM STATEMENT | 3 |
| 1.2 MOTIVATION..... | 4 |
| 1.3 LITERATURE SURVEY..... | 5 |
| 1.4 PROJECT REQUIREMENTS | 5 |
| 2. Design Alternatives | 6 |
| 2.1 DESIGN ALTERNATE 1 | 6 |
| 2.2 PROPOSED DESIGN | 7 |
| 3. Organizational Components | 11 |
| 3.1 ORGANIZATION OF WORK AND TIMELINE..... | 11 |
| 3.2 BREAKDOWN OF RESPONSIBILITIES AMONG TEAM MEMBERS..... | 12 |
| 4. Major Components | 12 |
| 4.1 MANIFOLD | 12 |
| 4.2 VALVE | 12 |
| 4.3 STEPPER MOTOR..... | 13 |
| 4.4 ON/OFF VALVE | 13 |
| 4.5 RCS CONTROLLER..... | 13 |
| 5. Structural Design | 14 |
| 6. Prototype System Description | 14 |
| 7. CONCLUSIONS | 17 |
| REFERENCES | 18 |

List of Figures

| | |
|--|----|
| Figure 1 - NASA proposed RCS version 1 | 6 |
| Figure 2 - NASA proposed RCS version 2 (roll test) | 7 |
| Figure 3 – Rotating Valve System..... | 8 |
| Figure 4 – Rotary valve (red) that provides 4 different exit combinations..... | 8 |
| Figure 5 - Rocket cross section showing required firing combinations..... | 9 |
| Figure 6 - Rendered model shown in 3D printed enclosure | 9 |
| Figure 7- 3D print of the valve done at NASA | 10 |
| Figure 8 - Expanded view of parts..... | 10 |
| Figure 9 - Flow analysis in Solidworks | 11 |
| Figure 10 – Mockup of rocket stages..... | 14 |
| Figure 11 – Current NASA RCS Prototype..... | 16 |

Abstract

This project involves the design, analysis, manufacture, and testing of a reaction control system (RCS) for an orbital launch vehicle suitable for NASA's Nanolaunch program. The goal is a cheap, reliable RCS that will help lower the cost of entry into space experimentation for universities. Our design reduces the number of failure points of the current NASA design, is half the weight, and one-third the cost.

1. Introduction

1.1 PROBLEM STATEMENT

The goal of our project is to design a reaction control system that reduces cost, mass, volume, and complexity, to open up space experimentation to a larger number of universities. NASA's current RCS prototype for Nanolaunch uses four on/off solenoid switches with various pipe adapters to control four cold gas (CO₂) thrusters. Our concept revolves around one selector valve and one solenoid switch. The selector valve will be controlled by a stepper motor which will align the ports needed for proper RCS operation. Pitch, yaw, and bi-directional rotation are possible with the current port combination. The RCS has been designed with Solidworks and will be analyzed with SolidWorks Flow Simulator, ANSYS, and other software as resources become available.

A prototype made of delrin (acetal) and acrylic is currently being built and will be tested with compressed air. NASA will 3D-print the final version in titanium to be used with a carbon fiber 4500 PSI tank regulated down to 150-250 PSI. The required force per RCS activation is currently set at 10-15 Newtons. Our design can produce 106 Newtons at maximum pressure using 1/8" tubing, or 230 Newtons using 1/4" tubing. This allows for leeway in requirement changes, flow losses, and other unknown effects.

Our concept eliminates heavy pipe adapter fittings, reduces the failure points due to the elimination of pipe connection points and solenoid switches, and reduces the cost of parts. The incorporation of our design into the Nanolaunch250 will enable NASA to meet their budget requirements in offering universities more control and more affordable access to space for their orbital experiments.

1.2 MOTIVATION

Since the program's inception, the Nanolaunch initiative has always been a side project within NASA, and work for the project has mostly been carried out during employees' personal time. Interest in the program has grown within Marshall's administration and among other engineers, gaining the program more funding and manpower as this interest grew.

Recently NASA has made Nanolaunch an official, fully-funded program with dedicated full-time employees. As part of the Nanolaunch program, NASA allows for universities to participate by submitting ideas for various aspects of the launch vehicle which can potentially be used if proven to work reliably with minimal cost. As senior engineering students, we have decided to participate in this historical NASA opportunity to use our skills and experiences to help bring space exploration to the masses.

1.3 LITERATURE SURVEY

The designed survey will guide the team members on the theory of such operations and functions of the desired project's system and components necessary to create a reaction control system.

1.4 PROJECT REQUIREMENTS

- a. The reaction control system shall fit in a cylindrical body with the following measurements: Diameter of 8 inches and length of 24 inches.
- b. Although mass is a major metric in the design of rockets; no mass value has been provided by NASA. This value is still being worked on. An estimated value should be available by summer 2014.
- c. Logos: NASA official logo will be used when presenting posters, papers, and final build. No written permission was granted, but the project was advised and approved by David Dominguez's internship advisor early this year to proceed with David's idea of a rotary valve system for the senior design course.
- d. Testing: The design process includes having the final valve system built by the end of the spring semester where David will take such design for testing at Marshal Space Center during his employment with NASA over the summer, with such data and results we will make modifications during the fall semester in which we will carry our own testing, complying with NASA testing codes for safety.
- e. Competition: The design is new and unique. No existing system or patents were found related to our design. There is no need to compete with other universities as

our only task is to prove if such system is feasible for NASA's Nanolaunch program.

2. Design Alternatives

2.1 DESIGN ALTERNATE 1

NASA engineers are currently using one on/off valve for each of the four thrusters. This design is heavier, due to the tube interfaces; is more prone to failure with four times the chance of a valve failing, in addition to extra interfaces; and costs four times as much. Each valve costs \$363.

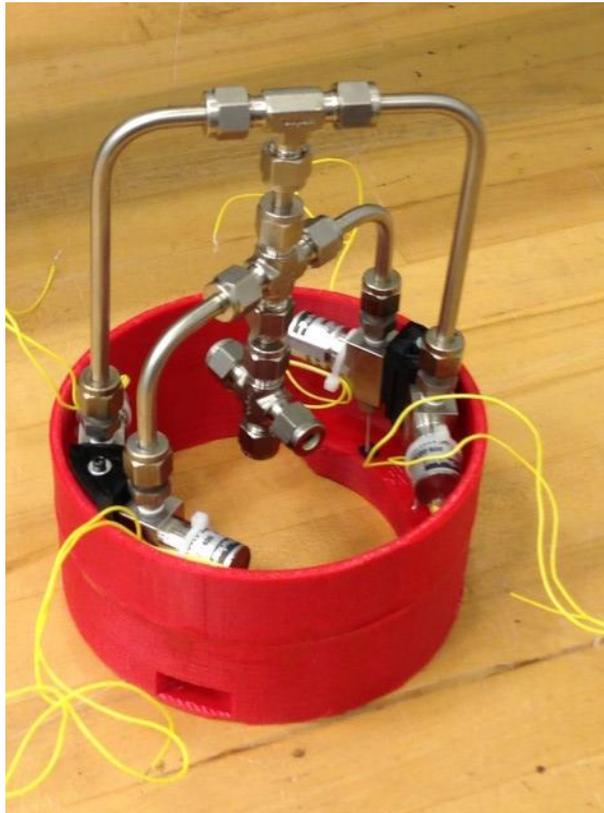


Figure 1 - NASA proposed RCS version 1

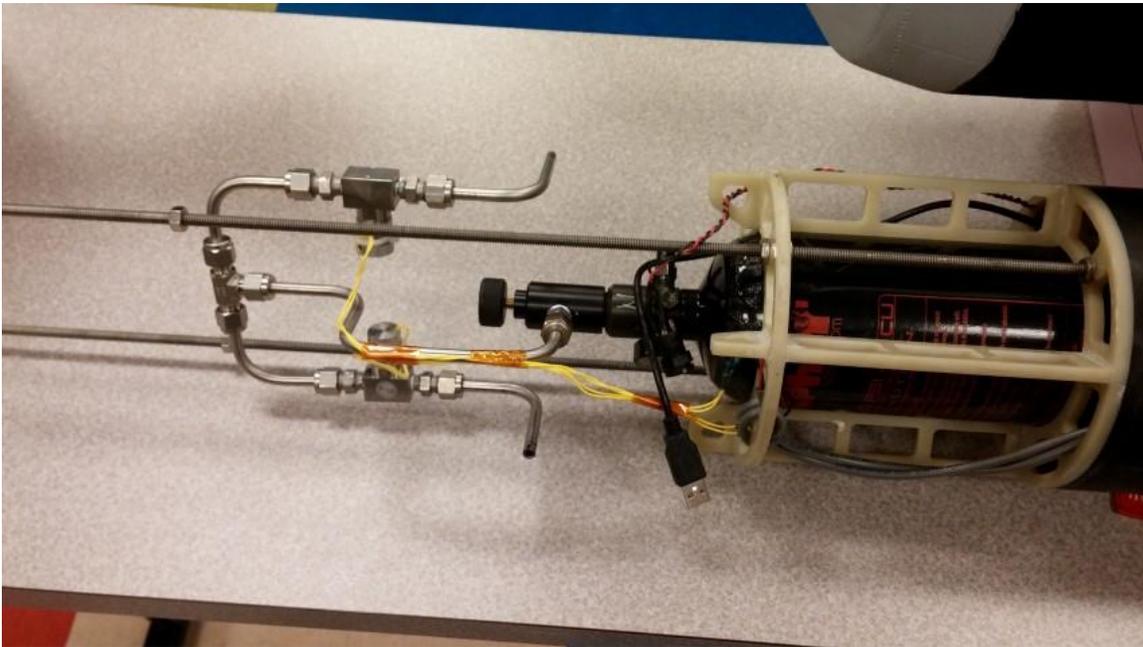


Figure 2 - NASA proposed RCS version 2 (roll test)

2.2 PROPOSED DESIGN

Our system consists of a rotating valve (seen below in red) within a manifold. The valve will be rotated by a stepper motor to align the ports according to the desired thrust mechanics and an on/off valve will then open briefly to pulse the high-pressure cold gas through the nozzles to roll or pitch the vehicle. The rotary valve was designed to have four different combinations for the exit nozzles that will control the rocket during after phase 1 of the launch. The figures can be seen in the following page.

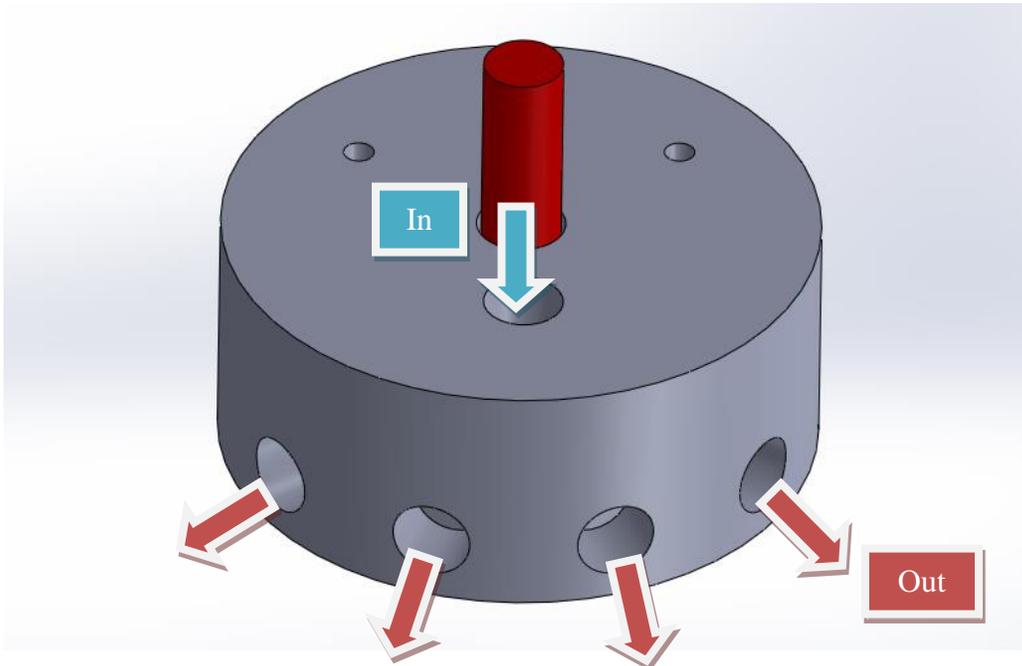


Figure 3 – Rotating Valve System.

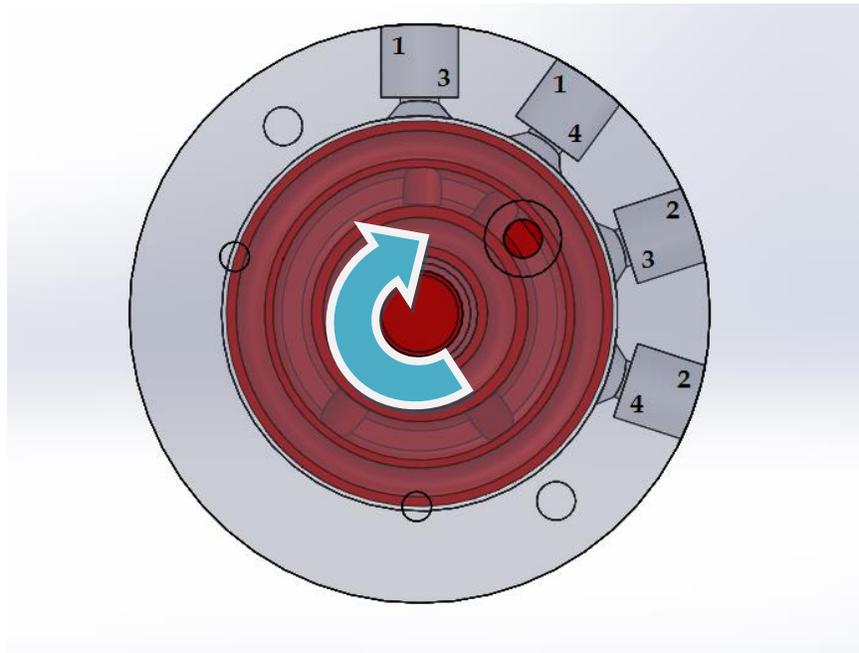


Figure 4 – Rotary valve (red) that provides 4 different exit combinations.

The figure below shows the combinations of thruster firing (numbered arrows outside circles) and the effect of the firing (arrows inside circles). The left two are the two roll directions and the right two are the pitch directions. For yaw, the vehicle rolls to one side and a pitch combination is then used.

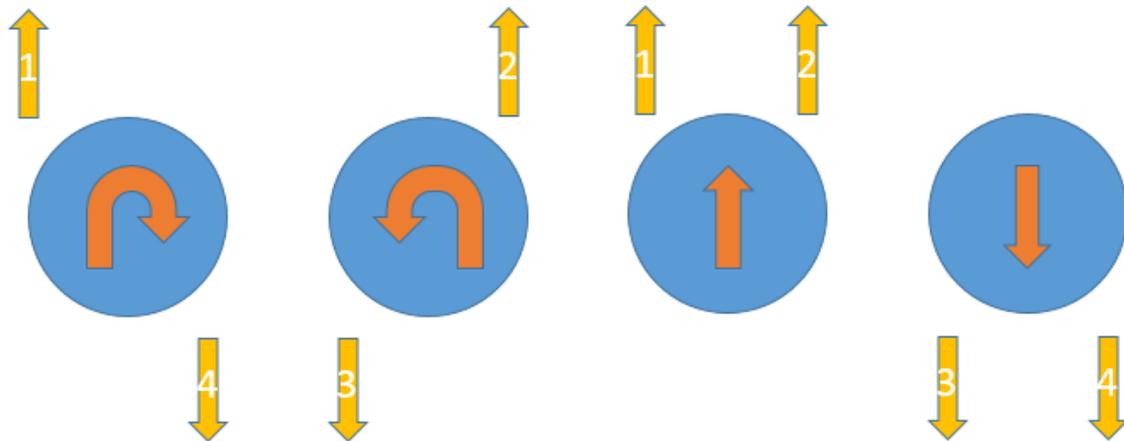


Figure 5 - Rocket cross section showing required firing combinations

The figure below shows the RCS valve system installed in the 8 inch 3D printed fuselage with built in nozzles, for mounting on a test vehicle consisting of a Wildman Ultimate Class III amateur rocket.

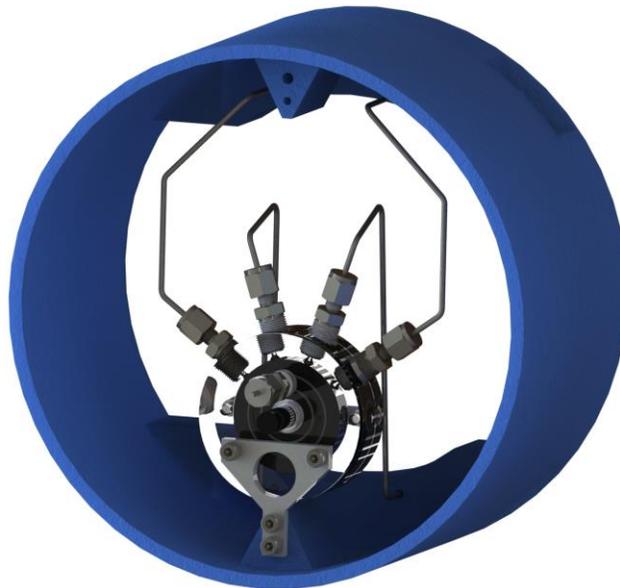


Figure 6 - Rendered model shown in 3D printed enclosur

The valve was 3D printed as NASA in March to have a physical prototype to help analyze the design.



Figure 7- 3D print of the valve done at NASA

The valve itself consists of 19 parts as seen below.

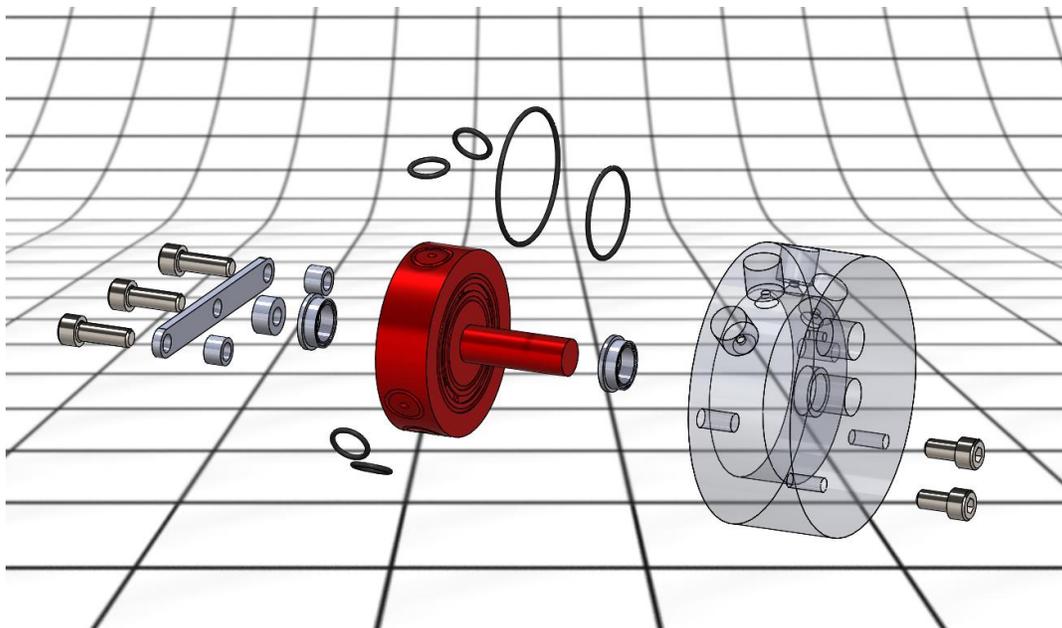


Figure 8 - Expanded view of parts

An initial simple flow analysis was done in Solidworks to ensure the gas would flow out of both ports equally in a vacuum.

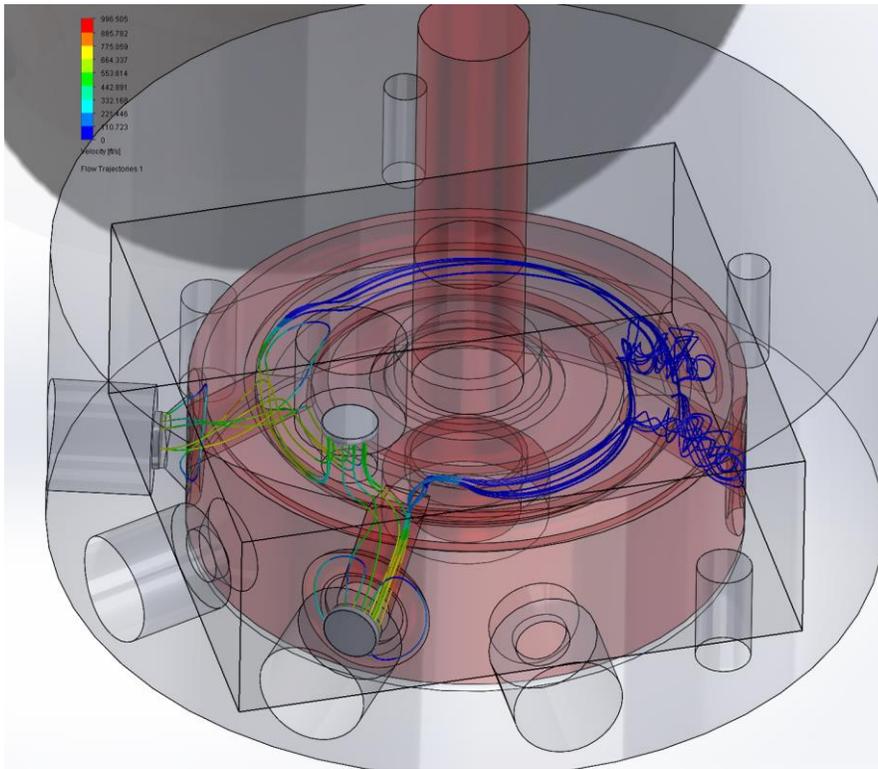


Figure 9 - Flow analysis in Solidworks

3. Organizational Components

3.1 ORGANIZATION OF WORK AND TIMELINE



3.2 BREAKDOWN OF RESPONSIBILITIES AMONG TEAM MEMBERS

- David Dominguez: CAD design, manufacturing, testing, NASA contact
- Gianni Jimenez: CAD design, manufacturing, testing, dynamic analysis
- Genesis Vasquez: Flow simulations, dynamic analysis

4. Major Components

4.1 MANIFOLD

The purpose of the manifold is to hold the valve system in position (two bolt mount) and to provide a point of entry for the compressed cold gas and multiple points of exit for proper nozzle firing.

The manifold will be 3D printed in titanium using the laser sintering method at NASA's Marshall Space Flight Center.

The ports and walls of the manifold shall withstand a 150 pound cold gas pressure with equal to or greater than 1.2 safety factor. It will be anchored to the inner fuselage of the rocket with two ¼ inch steel hex bolts. The manifold will be 5 inches in diameter and 3 inches tall and weigh 5.7 pounds.

4.2 VALVE

The valve shall provide one entry and two exit points for the cold gas. It shall move freely within the manifold and direct the pressure to the proper nozzle ports. It shall

be oriented within the manifold through a shaft with a stepper motor when unpressurized. The valve will also be 3D printed in titanium.

4.3 STEPPER MOTOR

The stepper motor shall be a standard NEMA 11 motor. It will be connected to the valve shaft with a coupler. The stepper motor shall receive input from the flight controller to align the valve with the proper ports.

4.4 ON/OFF VALVE

The on/off valve shall open to enable the flow of 150 PSI of cold gas once given the signal from the flight controller. The proper valve for 250 psi is still under procurement.

4.5 RCS CONTROLLER

The RCS controller is a circuit that shall control both the stepper motor and the on/off valve. It shall receive input from the inertial measurement unit and decide the proper outputs based on the flight profile programmed before flight. This aspect is beyond the scope of this project as NASA has not finalized the details of the flight profile and RCS activations.

5. Structural Design

The RCS must fit within the designated space in the craft, and all components must be able to withstand the force of the pressurized gas. The RCS must also be securely anchored to the craft in order to rotate it as needed.

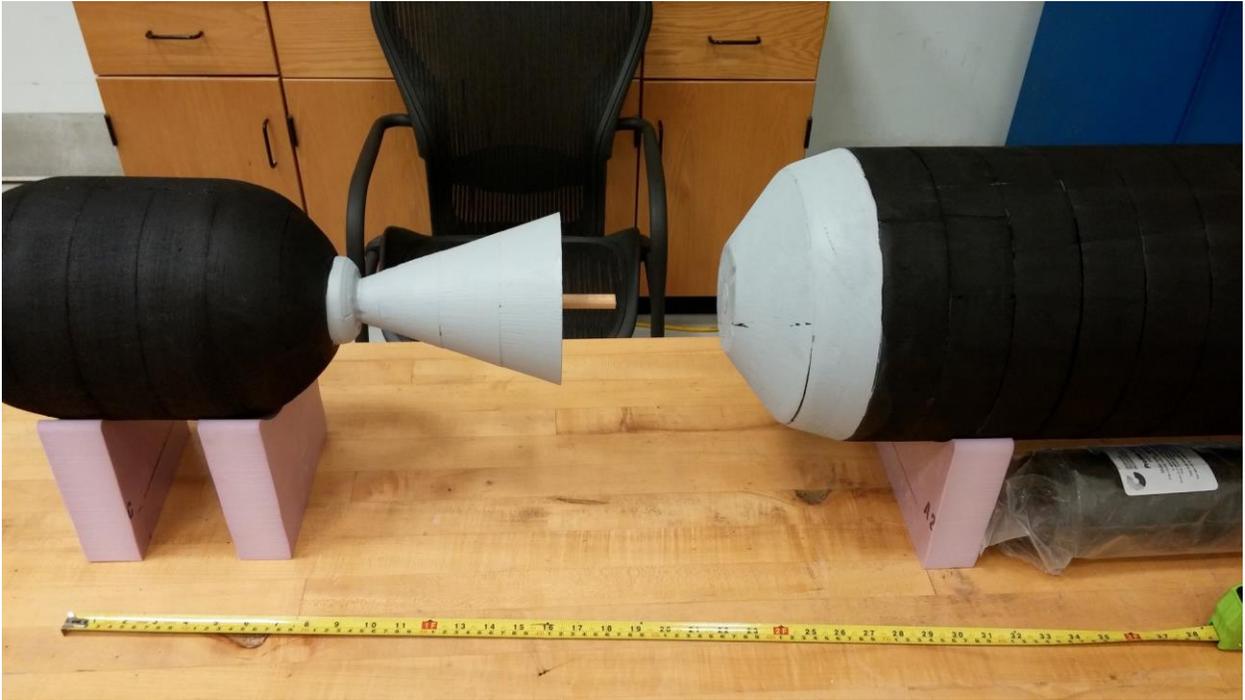


Figure 10 – Mockup of rocket stages

6. Prototype System Description

The prototype system will consist of:

- ABS 3D printed valve and manifold assembly
- Swagelok pipe fittings
- Swagelok 0.245 ID pipes
- 150 PSI supply from scuba tank system
- NEMA 11 motor for turning the valve

- Force measuring device to measure exhaust force

The system will be connected to a 3D printed shroud to provide support and ports for the tubes coming out of the manifold. This system will then be hung vertically to test the translation and rotational effects of the RCS. Thrust capacity will be measured while the system is fixed on a scale and compared to the angular maximum reached during the vertical hang testing.

6.1 PROTOTYPE COST ANALYSIS

Rapid prototyping the RCS in titanium by selective laser melting (SLM) was estimated by NASA to cost \$413.74. The NEMA 11 stepper motor required to turn the rotary valve will cost \$24.95. The input valve, as previously mentioned, will cost \$363. The Swagelok piping is estimated to cost around \$150. A scuba tank system is currently owned by one of the team members, saving the cost of purchasing a new one. This leaves the current running total as \$951.69 at the current design iteration. Future changes to the design, however, will increase the cost, since the new pieces will have to be produced.

6.2 PLAN FOR TESTS ON PROTOTYPE

Extensive ground tests will be carried out on the RCS before subjecting it to a flight test on an amateur rocket. The valve, manifold, and fittings will first be assembled and tested to ensure the required minimum force of 10N is produced. Our calculations estimate a theoretical force of 31 N with 150 PSI and 52N with 250 PSI. A maximum pressure of 1100 PSI is available should more force be needed which would give a force of 230N. The required longevity of the RCS system is not yet established in the

requirements. Once those guidelines are available, the maximum pressure to meet the requirements can be estimated then tested.

The second stage of prototype testing will commence. This second stage of testing will consist of mounting the prototype in an amateur rocket with an internal 6 inch diameter.

The amateur rocket, designated “Nanolaunch 1D”, will be flown by NASA once the valve has proven successful in ground tests. The scuba tank system will be replaced with one used for paint guns to enable the system to fit. It will be a similar setup to the NASA one shown below.

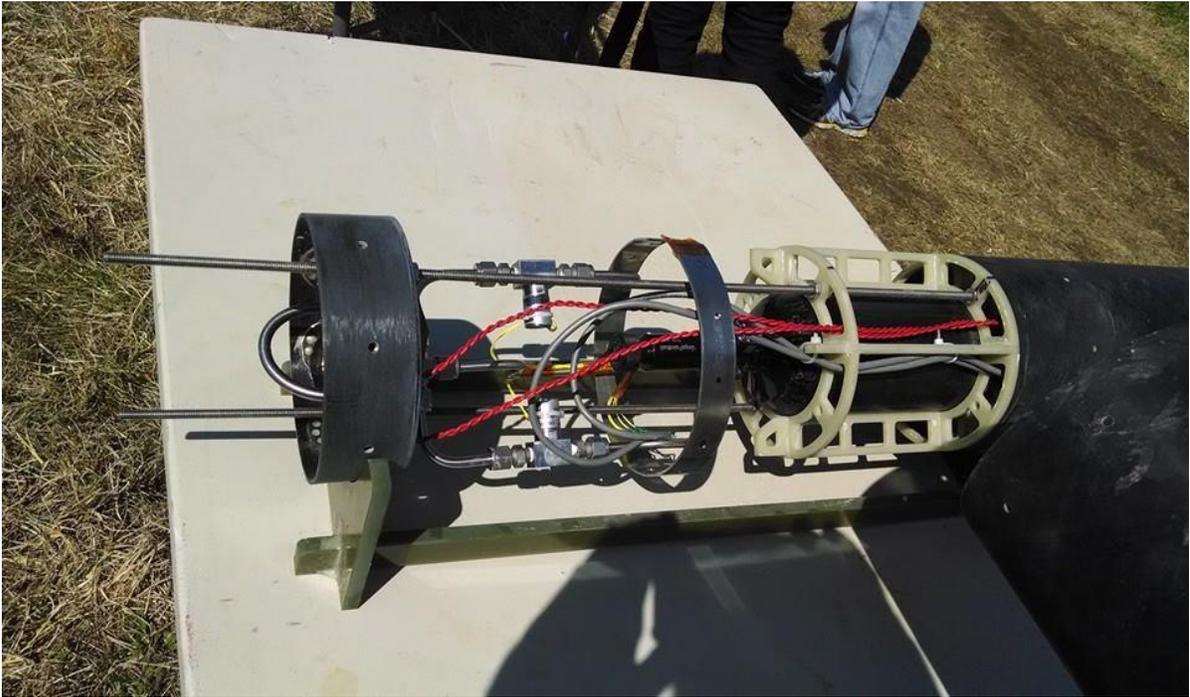


Figure 11 – Current NASA RCS Prototype

7. CONCLUSIONS

The proposed RCS design under development for use in NASA's Nanolaunch initiative is very promising. It should turn out to be cheaper and more reliable than the current mechanism in testing, primarily due to its reduction of input valves necessary. Further work is needed to produce a working physical prototype for testing so that the results can be used in the next iteration of the design until the product has reached all of its objectives in terms of reliability, performance, and low cost. If successful, this project will make space more and more accessible for the academic and scientific community for learning and experimentation purposes.

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