BiPROP Rocket Competition Team

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This document was prepared for the Region II AIAA Student Conference to discuss the design and testing process of BiPROP, a 2022-2023 Aerospace Engineering senior design project. The main motivation of this design project is to create a liquid bipropellant rocket, that shall be successfully recovered, for the Friends of Amateur Rocketry (FAR) competition that reaches 5,000 feet. The FAR organization and the competitions it hosts, span decades of experimental rocket development much like BiPROP is doing with this project. As the competition has continued to gain exposure, universities from all over the country have traveled to Mojave, California to compete. In addition to the benefits of attending the FAR competition, BiPROP holds special importance which stems from the lack of liquid bipropellant rockets designed by the university. If the project is successful, the team will be the first team in Florida Tech history to design a successful liquid bipropellant rocket. To achieve the main objectives of this project, the team has been divided into three technical subsystems: Chamber/Injector, Structures/Avionics/Recovery, and Ground Systems. In addition, some team members have assisted in a fourth subsystem, Safety, to ensure the team meets the extensive safety requirements for such a project. The team shall complete a variety of tests before the design showcase in April of 2023 to include a hydro-static pressure test, a nitrogen pressure test, an avionics test, a static test fire, and a test launch. These tests are designed to validate the design, manufacturing, and construction of the final product as soon as possible to allow for revisions as necessary.

I. Nomenclature

A^*	=	Throat Area
A_e	=	Exit Area
h	=	Heat Transfer Coefficient
R_{conv}	=	Convection Thermal Resistance
R_{cond}	=	Conduction Thermal Resistance
v	=	Fuel Velocity
t	=	Time to Heat
q	=	Heat Transfer
D_r	=	Diameter of Drogue Parachute
D_m	=	Diameter of Main Parachute
A_m	=	Main Parachute Area
F_s	=	Parachute Snatch Force
H_l	=	Piping Head Loss
P_{loss}	=	Piping Pressure Loss
K	=	Loss Factor
P_{op}	=	Operational Pressure
P_{proof}	=	Proof Pressure

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II. Introduction

Liquid bipropellant rockets are the most common rocket used in industry currently, for both commercial and scientific use. Though this is the case Florida Institute of Technology lacks a student-built bipropellant rocket that has been successfully launched. Since the industry is filled with liquid bipropellant rockets it is important that the students graduating from the university understand the design challenges and full workings of the rockets. By using the information taught in the many classes taken by both aerospace and mechanical engineering majors the team has decided to put it to the test by building a single stage rocket that will fly up to 5,000 ft in the Friends of Amateur Rocketry (FAR) 51025 competition. This competition is held every year for university students to be able to put their knowledge from the classroom into a design. The "51025" stands for the altitude options for each section of the competition, with 5 meaning 5,000 feet and so on with 10 and 25. The team has chosen the 5,000-foot category as it is the most attainable with the budget and with the goal of a successful launch and recovery, it is the safest option.

For the rocket's propulsion system design the propellants chosen were Isopropyl Alcohol and Nitrous Oxide, due to the large amount of thrust created when mixing them. One of the most notable pieces of the design of this rocket is the tank for these propellants. Instead of dealing with the extra fluid systems needed for two tanks and the increased weight, a nested tank was chosen where the Isopropyl Alcohol tank is inside the Nitrous Oxide tank. The injector will utilize coaxial shear using needles as that will give the best mix for the two propellants. The rocket also consists of a fluid system that has multiple valves all used to ensure the liquid propellants are where they need to be when stationary and during launch/flight. The structures and recovery design are to ensure all of the parts in the propulsion and fluid systems have a housing and a way to be successfully reused after every flight. Lastly, the ground systems design is to ensure the rocket vehicle can be fueled properly while at the launch pad. All these subsystems will have a more in-depth explanation in the design decisions section.

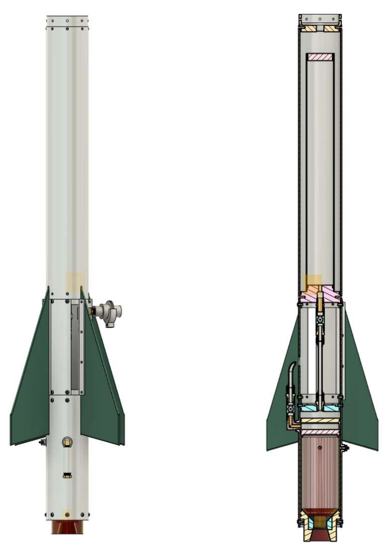

Figure 1: Complete Rocket Manufacturing Assembly

III. System Objectives

A. Deliverables

With the given budget of roughly $3,500 and the time restriction of late April 2023, there will be three deliverables achieved. The first deliverable consists of all documentation and analysis necessary to build and test the bipropellant rocket. This consists of reports required by the senior design class, and all the analysis needed to have confidence in particular design choices like material choice. The second deliverable will include all the hardware and software products needed to build the rocket vehicle completely. Examples of this can be seen with the manufacturing of the tank and the control software written for propellant loading during launch. The third deliverable consists of all the safety documentation needed for both testing and launch, as well as the procedures needed to operate the components of the rocket vehicle.

B. System Requirements

To achieve the needed design requirements of the rocket vehicle the project has been divided into a total of four subsystems, as seen in Fig. 2. These subsystems include a propulsion system, fluid system, ground system, and structure/recovery system. The propulsion system includes the injector, combustion chamber and the nozzle design. The fluid system includes all the piping within the rocket including the design of all the valves needed to move the propellants successfully through the rocket. The ground system includes everything needed for the propellant loading and transportation of the Nitrous Oxide. The structure/recovery system includes all the housing for the propulsion system, fluid system and avionics. The structures system in particular focuses on the design of the propellant tank as well.

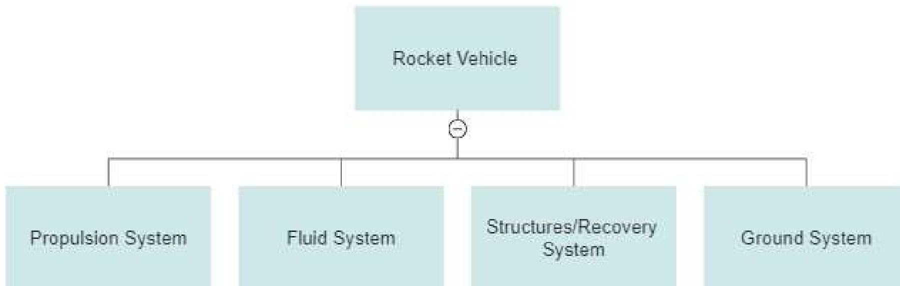

Figure 2: Flow Chart of Project Teams

For this project to be counted as a success, overall system requirements were created as well as specific requirements for each of the subsystems. From these requirements key performance parameters were created to state the goal of the entire assembly. The first is that the motor shall create 500 pounds of thrust using a bipropellant liquid design. The second encompasses the purpose of the payload in saying that it shall transmit live video from launch to recovery as well as store the footage via memory card. The third is what is expected from the flight in that the rocket shall go no higher or lower than 5,000 feet, which will be achieved through specific fuel amount and shown by altimeters. The last encompasses the overall goal of the recovery in which it will have a two-stage recovery and ensure the rocket vehicle does not exceed 100 feet per second. All these requirements will be proven through the necessary tests before the competition flight.

IV. Design Decisions

C. Combustion Chamber and Nozzle

The target thrust for the rocket to produce is 500 lbs and the design of the nozzle will help achieve this goal. The designed nozzle will be conical to simplify manufacturing, assume constant mass flow rate, and isentropic flow. Using CEA, a NASA program for combustion and rockets, a parametric study was conducted to analyze the relationship between the oxidizer to fuel ratio (O/F) and the exit velocity and combustion temperature. The results were plotted and the O/F was chosen to be 1.74 as it corresponds to an exit velocity of 1,788.5 m/s (and mass flow rate of 1.2436 kg/s) which is acceptable for the thrust and a combustion temperature of 1,476.72 K which will be manageable for heat transfer concerns to prevent melting.

The throat area of the nozzle is crucial as it is the location where the flow becomes choked, or reaches sonic speed, and helps the subsonic flow through the converging section become supersonic as it travels through the diverging section. The throat area is calculated with Eqn 1 below and resulted in an area of 1.148 in^2. The throat area is used to directly find the outlet area as seen in Eqn 2 below which results in an area of 2.945 in^2. The inside diameter of the rocket is 3.5 inches and the inlet is designed to match it evenly leaving it with an area of 9.621 in^2. The nozzle converges at a forty-five degree half angle because it is easy to manufacture and produces a contraction ratio of 8.25. This ratio is acceptable because a minimum ratio of 3 is typically required to prevent energy losses from the exhaust. The diverging section will have a 15-degree half angle, again for manufacturing ease, and to prevent flow separation from the nozzle wall.

$$Throat\ Area \qquad A^* = \frac{\dot{m}\sqrt{T_o R}}{P_o\sqrt{\gamma\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}} \qquad 1$$

$$Outlet\ Area \qquad A_e = \frac{A^*}{M_e}\sqrt{\left(\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M_e^2\right)\right)^{\frac{\gamma+1}{(\gamma-1)}}} \qquad 2$$

The injector is designed as a coaxial shear injector which promotes the mixing of the propellants before combustion. The first propellant, the nitrous, is passed through a shower head-like plate. A second injector plate, above the first, passes the second propellant, the alcohol, through needles that go through the holes of the first plate. There shall be eighteen injector elements (holes) total. Each plate injects the fluids at a different angle to further increase mixing. Assuming the same constant mass flow rate from the nozzle, 1.2436 kg/s and the O/F of 1.74, the nitrous oxide and isopropyl alcohol have a mass flow rate of 0.7897 kg/s and 0.4539 kg/s, respectively. The pressure across the inlet and outlet of the injector is 750 psi and 300 psi, respectively. Using Eqn 3 below, the velocity of each propellant can be found assuming a contraction ratio of 0.5. The velocity of the nitrous and alcohol are 41.145 ft/s and 51.415 ft/s, respectively. Dividing this result by the mass flow rate and density of each propellant results in an area of 0.039 in^2 for the oxidizer and 0.013 in^2 for the alcohol.

$$Fuel\ Velocity \qquad v = \sqrt{\frac{2(P_1 - P_2)}{\rho + \frac{K}{g}}} \qquad 3$$

As seen before, the combustion temperature is 1,476.72 K so the rocket needs to be designed to handle such heat. The main concern is the aluminum which melts at 855 K and begins to lose structural strength at 475 K. The aluminum cannot exceed the latter temperature as it must be reusable and recoverable. The most challenging scenario for the rocket heat transfer-wise will be during the static fire test where the outside air is relatively static, or not moving, which means the rocket will have difficulty in transferring heat out of itself into the surroundings, making it more likely to melt. The main concern is the integrity of the aluminum walls, so the heat transfer through the rocket and expected temperature the aluminum can reach must be determined. To simplify this heat transfer problem, the exhaust gasses will be simplified as one gas, the one with the greatest heat transfer coefficient as it will be able to transfer the most amount of heat into the rocket walls, in order to create a conservative, ‘worst-case-scenario’ to analyze. The heat transfer coefficient is necessary to determine the convection thermal resistance of fluids in this problem and is found using Eqn 3 below. The convection and conduction thermal resistance is found using Eqn 4 and 5, respectively. When assuming steady, 1-D, constant property heat transfer, it begins to resemble the physics of an electrical circuit where the temperature difference is similar to the potential difference, heat transfer to the current, and thermal resistance to electrical resistance. Using this analogy, the heat transfer through the exhaust to the rocket walls and then to the outside air resembles a series circuit. Therefore, the heat transfer is the same through each component which is found using Eqn 6. Then, by analyzing the heat transfer up until the aluminum wall with Eqn 7, the temperature can found which is 1,475 K. With a melting point of 855 K and the point where its structural strength diminishes being 475 K, the rocket is clearly expected to fail. However, it takes time for the walls of the rocket to heat up and the static fire test is only for two seconds. To verify if the rocket can survive, the integral of Eqn 8 is used to determine the time it takes for the rocket to reach 475 K. The result is that it will take about thirty seconds for the aluminum wall to reach 475 K, meaning the rocket can be expected to survive the static fire test.

$$Heat\ Transfer\ Coefficient \qquad h = \frac{k\,Nu}{L} \qquad 4$$

$$Convection\ Thermal\ Resistance \qquad R_{conv} = \frac{1}{2\pi rLh} \qquad 5$$

$$Conduction\ Thermal\ Resistance \qquad R_{cond} = \frac{\ln\left(\frac{r_{out}}{r_{in}}\right)}{2\pi Lk} \qquad 6$$

$$Heat\ Transfer \qquad q = \frac{T_{exhaust} - T_{air}}{R_{Tot}} \qquad 7$$

$$Finding\ T_{aluminum} \qquad q = \frac{T_{exhaust} - T_{aluminum}}{R_{exhaust} + \cdots + R_{aluminum}} \qquad 8$$

$$Time\ to\ Heat \qquad mC_P\frac{dT_s}{dt} = q - \frac{T_s - T_\infty}{R_{total}} \qquad 9$$

D. Tanks and Bulkheads

The primary structure of the rocket is constructed of the tanks and supporting upper and lower bulkheads. The driving parameter for the structure's design was the operational pressure of the gaseous nitrous oxide at 950 pounds per square inch. Given a necessity to deliver a product with a factor of safety of 1.5, the tank and bulkheads were sized such that they could withstand a proof pressure of 1,425 pounds per square inch. Given these requirements, hoop stress formulas, material properties, and allowable formulas were used to obtain minimum design conditions [1].

The most cost-effective considerations were made, and 0.125 inch thick, 3.75-inch diameter tubing made of multipurpose Aluminum 6061 was chosen for the outer tank. Since the concentric, inner tank does not have experience and pressure differential, the thin enough tube was selected to maintain sturdiness while being as light weight and cost effective as possible.

The design of the top bulkhead was driven by the thickness being sufficient for not yielding under load. The thickness requirement was determined using Roark's Formulas for Flat Circular Plates of Constant Thickness [2]. Case 2a is for outer edge, simply supported outer edge, free inner edge case which best reflects the bulkhead being bolted to the rocket while there is a concentric, free edge hole in the center for a 3/8-inch NPT tube to be inserted for filling nitrous oxide into the tank.

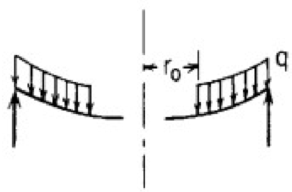

Figure 3: Roark Bending Diagram

Utilizing the set of formulas from Roark's Formulas in addition to iterative numerical analysis, an inner radius deflection of 0.303 degrees, outer radius deflection of 0.211 degrees, and a distributed pressure of 1437.7 pounds per square inch were calculated for a minimum thickness of 0.6 inches for the bulkhead.

Steel fasteners were used to attach the bulkheads to the tank structure and were sized based on the loads calculated above. The load was distributed evenly across all six of the bolts and a conservative size for the bolts, 10-32 Class 2A, was selected to ensure a significant margin to compensate for shearing as well as to be able to purchase a more standard size bolt.

The bottom bulkhead supports both the quarter-inch NPT nitrous through hole in addition to the three-eighths inch NPT through hole for the isopropyl alcohol. Since Roark's formulas do not exist for a uniformly loaded circular plate with two holes, the analysis must be simplified to the same top bulkhead shear calculations. To ensure the design was sufficient, a bulkhead thickness of one inch was chosen in addition to a bottom flange being added with eight fasteners as opposed to six.

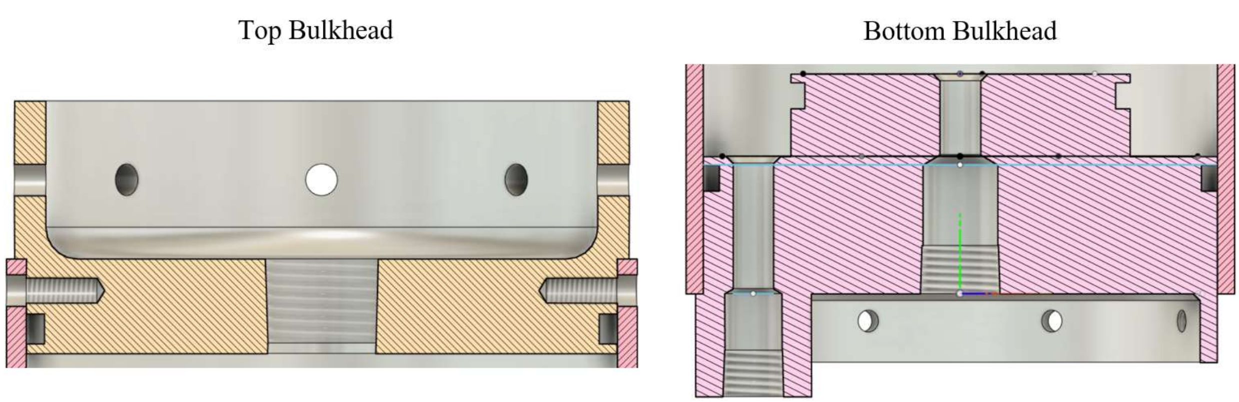

Figure 4: Cross-Section of Bulkheads

In addition to thickness sizing for yield, the tank and bulkhead assembly were analyzed for various failure conditions – bolt shear failure, tank walls bending around the O-ring, and bolt ripping downwards through the outer tank. These failure modes were analyzed with a conservative factor of safety of 1.7 to ensure that there was no risk of failure in the design – bolt shear failure, the tank walls bending around the O-ring and releasing pressure, and the bolt ripping downwards through the outer tank. Given the results of these calculations, none of the three failure conditions analyzed will be subject to occurrence in normal or proof pressure operations with additional margin for unknown parameters that cannot be simplified into calculations.

E. Avionics and Recovery

The avionics and recovery system for the rocket were chosen strictly from a need to meet the requirements set by the FAR 51025 competition. The most notable of them to discuss are the following:

- There shall be two altimeters or flight computers.
- There shall be two GPS tracking units.
- The rocket shall have a dual parachute deployment with a main deployment 500 to 1500 feet above ground level.
- The rocket shall not accelerate beyond 100 feet per second during descent.

The first two requirements for this section are met by utilizing commercial flight computers which provide altimeter readings in addition to redundant GPS capabilities in the event of an anomaly with one of the systems during flight. The second two requirements are met by performing calculations to determine the parachute sizing requirements and cord properties. This process ensures that the rocket descends at acceptable rates as well as does not endure forces beyond the capabilities of the materials chosen. To accomplish this, certain preliminary assumptions must be made:

- The rocket weight is approximately 50 pounds.
- The maximum speed of the rocket in flight is approximately 500 feet per second.
- The coefficient of drag for the drogue parachute is 0.5 and for the main parachute is 0.75.

Failure of the recovery system would be detrimental to the possibility of success of the project due to time and budget constraints. Thus, a factor of safety of two was applied to the calculations to increase confidence for successful descent.

$$D_r = \sqrt{\frac{8mg}{\pi \rho c_d V_d^2}} \qquad 10$$

$$A_m = \frac{2mg}{\rho C_d V_i^2} - \frac{\pi D_r^2}{4} \qquad 11$$

$$D_m = \sqrt{\frac{4A_m}{\pi}} \qquad 12$$

$$F_s = \frac{\rho V_d^2 C_d A_m}{2} \qquad 13$$

Utilizing the above equations, the parachute diameters (D_r,D_m), area of the main parachute, A_m, and snatch force, F_s, can be calculated and used to determine the necessary sizing for the rocket. Given the factor of safety, a drogue parachute with a 3.5-foot diameter was chosen and will be attached by eight ropes. The main parachute will have a diameter of ten feet and will be secured to the rocket via twelve ropes.

F. Fluid Systems

To create combustion, we must combine both an oxidizer and fuel, to accomplish this they must be moved from the tanks to the injector and combustion chamber. The fluid systems accomplish that via the use of pipping and valves connecting the tanks and injector together. Another critical function of the fluids system is to ensure that the mass flow of the fluids is kept constant at the required value to facilitate proper atomization and eventual combustion at the injector and combustion chamber. To manage this several sizes of pipes were investigated and through calculated values it was determined that 3/8-inch lines would be sufficient to maintain an acceptable mass flow.

Due to the small size of the rocket the selection of nitrous oxide was important as it allowed for simplification of many fluid systems. This is due to the fact nitrous oxide has a vaporization pressure of around 925psi at room temperature, meaning it continually pressurizes itself as it turns into a vapor from a liquid as stored. Due to this we do not need any sort of pressurization system or need to store other inert gases such as nitrogen to push fluids out of our tanks.

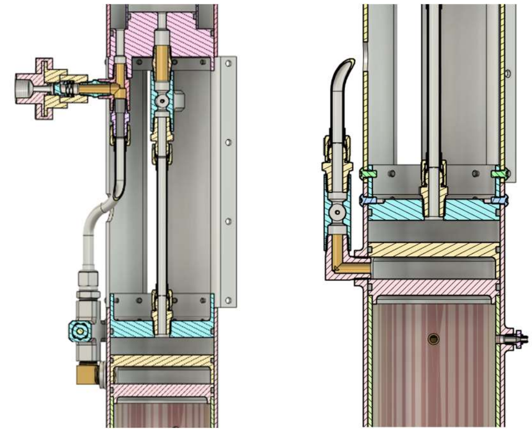

Figure 5: Cross-section of Rocket Fluid System

The last significant portion of the fluid systems are the valves. These valves allow for the flow or lack of, to the injector. To accomplish this, custom designed valves were created and allowed for a loss of less than 10% in flow while being smaller in size compared to commercial applications. These valves use E-matches or small pyro-charges to open, once open they cannot be closed, however, with our design these valves will only be opened when starting the engine until the tanks are empty. These charges are controlled by the ground systems and are being used as a way to lower costs for the overall project.

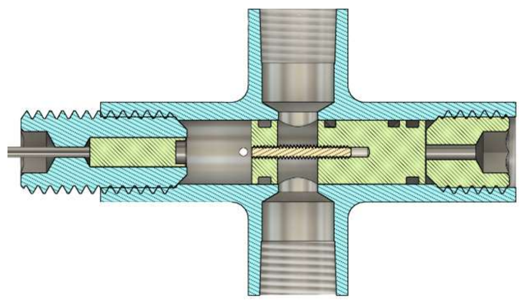

Figure 6: Cross-Section of Valve

G. Ground Systems

The Launch and Ground Controls System are divided into two different areas: the Launch System and the Fill System. The main parts of these two systems include the control module box, switch boxes, and the ball valve motor drive. These systems will be powered with the ground system equipment and will be controlled with simple logic, relays, and a micro-controller. The primary function of these systems is for proper propellant loading of the rocket. To achieve this an umbilical utilizing a quick disconnect, a fill valve, and a propellant tank holder needed to be designed. The second function of the ground systems is to ensure the rocket gets ignited while on the launch pad. This will be done by a control system that is a part of the one that will also control the fill valve of the rocket.

As stated before, to ensure proper propellant loading is possible the bottle that holds the oxidizer needs to be secured to ensure nothing goes wrong in the loading process. This holder will also double to transport the bottle safely between where it is being filled and where it is being used. The design of the bottle holder can be seen in figure X, however there will also be straps attached to the back supports so that the bottle has no way of moving during transport. The design utilizes Aluminum 6061 T6511 for the back supports because it's easy to machine, commonly used, strong, and corrosion resistant. The bottom plate, however, was made from steel, because when the bottle is filled the chosen aluminum was not strong enough. Given the material considerations, the holder design has significant margin of safety to ensure that the nitrous oxide bottle will be securely attached during both transportation as well as during use on the launch site.

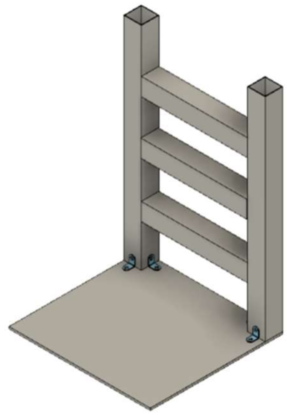

Figure 7: Isometric View of NOS Bottle Holder

The umbilical used to perform the propellant loading of the Nitrous Oxide has many parts to it, including a fill valve, flow tube, and quick disconnect. The fill valve and flow tube serve the purpose of getting the Nitrous Oxide to the rockets tank. When determining the material needed for the flow tube, brass and a variety of stainless steels were the two most looked at. However, due to the possibility of brass reacting to the Nitrous Oxide and its inability to seal as well as stainless steel it was not chosen. The final decision for the flow tube was a line made up of 304 stainless steel with polytetrafluoroethylene (PTFE), due to its durability and greater chemical resistance. The valve chosen to act as the fill valve is an actuated ball valve as it will ensure there is a lack of back flow into the Nitrous bottle during loading.

The quick disconnect is designed to be a connection between the loading system and the rocket vehicle itself. The main goal of this part is to be able to assist in proper loading of the rocket and act as a disconnection during launch. The design chosen for the quick disconnect stems from a check valve, more specifically a poppet check valve. However, due to the high pressure expected from the Nitrous Oxide the valve will utilize a flat plate and wave string instead of a ball bearing and a traditional spring. To ensure the valve can withstand the pressure placed on it a hoop stress calculation using a factor of safety of 1.7 was used. As the valve needs to be able to separate it was designed to have a male and female piece. To keep the two pieces together a clip was developed to fit perfectly around the two sections which will be 3D printed from PLA filament. The final assembly of the quick disconnect can be seen in the figure below.

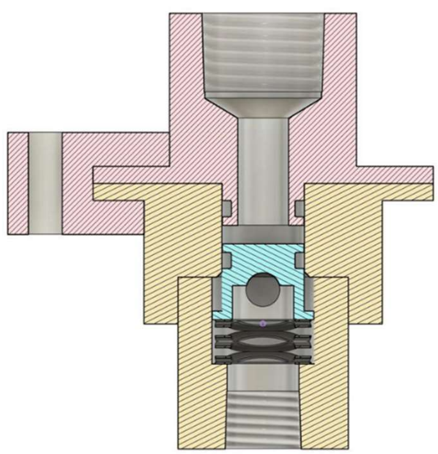

Figure 8: Cross-Section of Propellant Quick Disconnect

H. Flight Simulation Validation

To ensure that the design of the project will perform as expected, flight simulation software was used to compare the design to what should be expected in flight. This analysis was done by using OpenRocket, a six degree of freedom simulator which uses the Barrowman method to estimate aerodynamic forces and RK4 numerical integration to calculate the flight path of the rocket [3]. OpenRocket is a recommended simulation program by the Friends of

Amateur Rocketry and has consistently been proven to provide accurate simulations for various rockets launched by Florida Tech students. The simulation was run with the rocket launched vertically, a 15mph cross wind, and atmospheric conditions consistent with those found in June at the FAR launch site. With full propellant tanks the rocket reached a simulated altitude of 8700ft. After hot fire testing, we will perform more simulations with hot fire data to determine the final tank size or fill level.

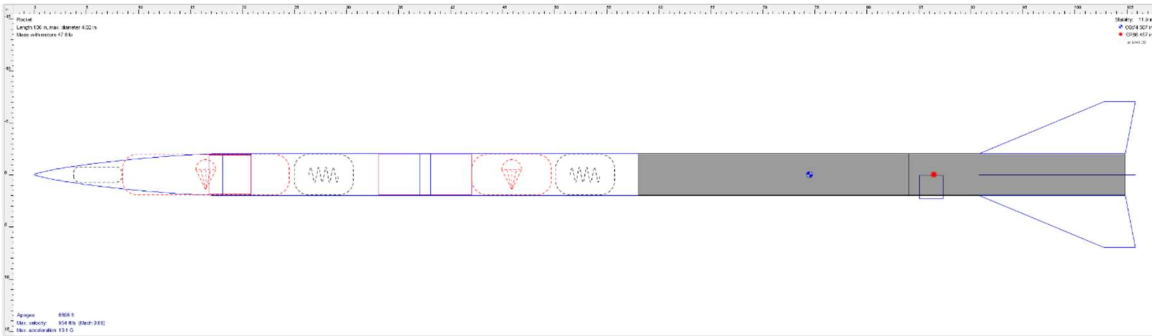

Figure 9: OpenRocket Analysis Diagram

The results of the simulation show that the rocket can maintain its stability requirements of maintaining a damping ratio between 0.05 and 0.3 as well as staying within ± 20 degrees during boost. The results show that for a full propellant tank, the rocket should be able to achieve an altitude of 8700 feet, which provides us with margin for increased weight, decreased engine performance, and the option of reducing the amount of propellant used for flight.

V. Manufacturing and Testing

I. Fluid Systems Testing

Performed before hydro-static testing, manufactured fluid lines and valves were tested to confirm their viability and performance in comparison to hand calculated values. This test was necessary to confirm that continuation to hydro-static testing of the tank assembly could be accomplished successfully.

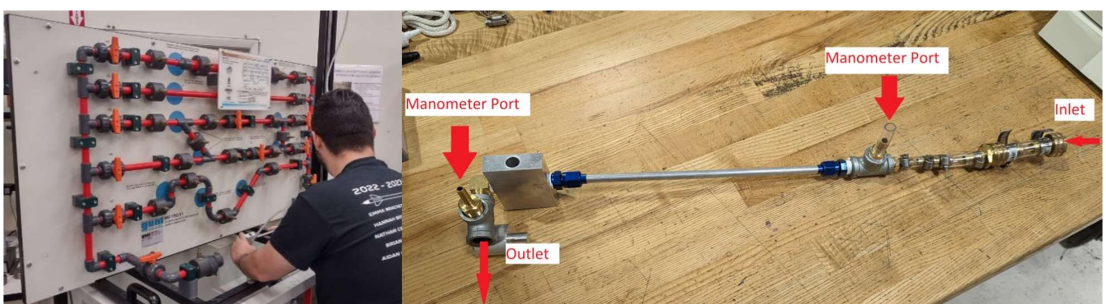

Figure 10: Prototype Piping Loss Test

Testing of the lines and valves was accomplished utilizing a pipe flow apparatus that allowed for a "K" value to be found or the dimensionless value of pressure lost through the assembly. To accomplish this multiple water velocities were utilized along with manometers at two points along the fluid system. Due to the modifications of the system an increase of the K factor was expected compared to calculated values, however when tests were run, the experimental values determined from the fluids testing were very high. After much analysis it was determined that this sharp increase compared to calculated values of 4.12 for Nitrous Oxide and 2.46 for Isopropyl Alcohol was mainly cause by the adjustments made to conform to the testing apparatus and slow flow of water. Velocities in the lines will be 5.68 m/s when in operation. Following the test hand calculations were confirmed and allowed for continuation to future testing.

J. Hydro-Static Testing

The first major test performed on manufactured parts for the project is the hydro-static testing of the tank assembly. The FAR competition requires that experimental tanks must be tested to the following requirements before they can be flown at the competition:

- The proof pressure shall be 1.5 times to expected operational pressure (P_{proof} = 1425 psi)
- There shall be three successful tests performed
- During each test, the proof pressure shall be maintained for three minutes

The hydro-static test is completed by filling the tank entirely with water including a few inches of the fill line. Then, the tank is securely grounded in place and connected to the nitrogen fill lines provided by Florida Tech's Mobile Engine Testing Apparatus (META). Once the area is secured and evacuated, the regulator and relief valves are checked to ensure they are in the proper position before opening the nitrogen bottle.

Figure 11: Hydro-Static Testing Setup

When ready to perform the test, the relief valve is closed, and the fill line is opened to begin. Various camera streams around the testing site are used to check for signs of deformation, problems with the testing equipment, leaking, and to monitor the pressure reading at the bottle and within the tank. After each test, the testing lines are purged to atmospheric pressure and the camera streams are utilized to assess the assembly before continuing with additional tests.

K. Hot Fire Testing

The final test before attending the Friends of Amateur Rocketry competition is to complete a full static hot fire of the rocket. This test will take advantage of the engine testing capabilities of the META trailer which was used for the hydro-static testing, as well. This time, however, the trailer will only be used for its ability to safely mount a high-thrust engine and monitor conditions from a safe distance. Various ground systems and controls will be used to monitor and perform the fill and testing necessary to complete a full three-second burn of the engine using the intended fuel, isopropyl alcohol, and oxidizer, nitrous oxide.

In addition to re-assessing the capabilities of the tank structure, this test is critical to quantifying the performance of the various parts which were manufactured for this project including components for the ground, fluid, chamber, and injector systems. The test will allow for qualitative analysis of the project progress including structural capabilities while also allowing for quantitative results, such as thrust, weight, and system pressures to be assessed and used in further development in preparation for attending the FAR 51025 competition.

VI. Future Work and Considerations

For this project, there are various avenues for future work. First, the FAR 51025 competition provides the opportunity for increased altitude goals of 10,000 and 25,000 feet. Each higher goal sets a new challenge for the project which will involve significant consideration of the rocket design and the various systems which impact performance. The project can also be expanded to perform experimental design testing once the rocket platform is proven to be a reliable system to work off. Different types of injector systems, nozzles, or any variety of changes can be made to the project to create experimental comparisons to research and innovation purposes.

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