Environmental Control Systems (ECS) Door Redesign

Final Report

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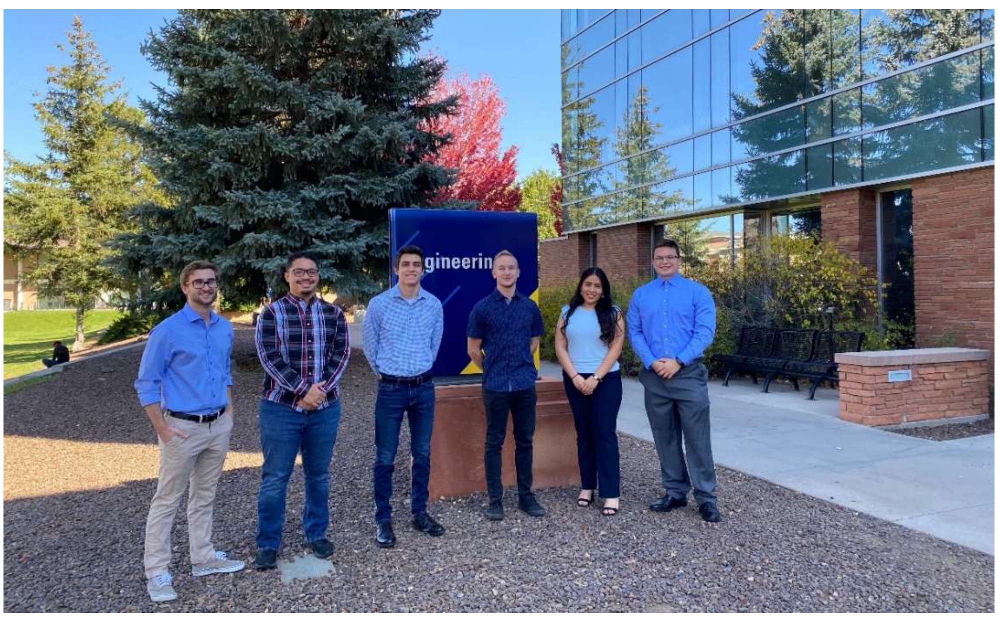

Figure 1: Northrop Grumman Capstone Team 2021

Project Sponsor: Northrop Grumman
Faculty Advisor: Sarah Oman and David Trevas
Sponsor Mentor: Daniel Johnson and Kaitlyn Barr
Instructor: Sarah Oman

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

For the Northrop Grumman teams final report, the team has gone over the final design developed during the semester, as well as laid out the next steps in order to have a working design by the end of the next semester. The team has been tasked by Northrop Grumman to redesign the Environmental control system door, specifically in relation to their Antares rocket. This door must close as the ECS nozzle is removed from the inlet in the fairing and stay properly sealed throughout the duration of the flight. The design needs to be lightweight, scalable, not interfere with other systems nearby. There are a variety of engineering requirements that must be met by specified factors of safety in order to be considered as a legitimate design to be implements on their systems.

The design that was chosen by the team was a twisting latch design. This design came out ahead of the other three major contenders as the final design, as it excelled in many of the requirements necessary. The latch functions using a torsion spring to twist a shaft with the latch on it. While open, the latch is out of the way of the door and is held in place by a retaining pin. As the door closes, the pin is pressed down by the door, allowing the shaft to freely spin 180 degrees, until the latch coves the bottom of the door. At this point, the latch is in tension, and the threads that drive the shaft have enough friction to prevent further rotation.

To test the design and make sure it can handle the conditions of an actual flight, the team has derived three tests for the device. These will test the Vibration load, temperature, and load that the system will be experiencing in flight. These tests will use the budget given to us by Northrop Grumman, to design and build test jigs in order to conduct test trials of the performance of our design. The budget will also be used to create full scale models of the device, both in 3D printed materials and in full metal. Basic tests and tolerances can be investigated with the 3D printed part, while the major tests with be on the full metal design.

ACKNOWLEDGEMENTS

Thank you to all those who have supported our Capstone project. Specifically, NAU Faculty Dr. Trevas and Dr. Oman as well as our client and sponsors Northrop Grumman with mechanical engineers Daniel Johnson and Kaitlyn Barr.

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1 BACKGROUND

1.1 Introduction

In this project, the Northrop Grumman capstone team from NAU will be designing a latching door to be implemented on Northrop Grumman's rockets. The rockets require an inlet on the fairing of the rocket, to allow airconditioned air to be pumped into the cabin of the vehicle. As the rocket launches, the inlet must be sealed shut in order to maintain the internal pressure of the cabin. The heritage design has had problems with maintaining a seal during flight, causing air the suddenly force open the door and lose some of the internal pressure. This sudden leak of air has potential to cause serious damage to the vehicle in flight and could even result in a mission failure. Solving this potential issue helps to eliminate risks of failure, which can cost millions of dollars put towards the project. Our teams' goal is to create a closing and latching system that effectively seals of the inlet and will remain closed throughout the entire flight.

While the team is currently designing the system based off Northrop Grumman's Antares rocket, one of the main goals is to allow the design to be scalable in order to be implemented onto other systems. One of the major problems that lead to the previous design to fail occurred when the rocket took new trajectories. It is important that the design will work in many different circumstances to allow for the design to be successful from different launchpads. Creating a design that is versatile, scalable and reliable will save Northrop Grumman valuable resources that can be used to develop and improve on other systems.

[Use this section to introduce the reader to your project. Describe what the project is, project objectives, why it is of interest to the sponsor (project relevance), and how the project benefits the sponsor and other stakeholders, upon completion. A large emphasis in the section should be on why this project is important. What contemporary issues does this project address?]

1.2 Project Description

Following is the original project description provided by the sponsor:

> *Most vehicles that Northrop Grumman Space Systems flies have a requirement to keep their payload air conditioned. This air is blown into the fairing through a specific door in the fairings of the vehicle prior to launch. In the past, the use of heritage designs to meet the needs of new or developing vehicles was relied upon for these doors. However, recently, there has been an undesirable side effect discovered largely due to this method. The main issue has been traced back to the way these doors are kept closed during flight. The latching method used has been discovered to be sensitive to different flight trajectories. The way we currently latch our ECS doors is to use hook and loop (Velcro) in combination with a hinge that is precisely shimmed to allow the mating halves to properly align. This ensures the strongest possible bond and has worked well in the past due to its simple nature. However, we have found that with steeper trajectories and higher-pressure differentials between the interior and exterior surfaces of the fairing, there can be a tendency for the door to "burp" or open during flight.*

> NGC is requesting that NAU select one team to design, analyze, and build a prototype door system that is insensitive to pressure differences that may be seen during flight.

[Provide the sponsor's original project description, as presented at the beginning of fall term. To credit the source, precede the description with text, such as "Following is the original project description provided by the sponsor." Set the Description in a block quote (i.e., indented from the surrounding text). If the description has been changed, provide an explanation of what has changed and why.]

2 REQUIREMENTS

The project requirement consists of customer needs and engineering requirement the team had to compile to define the goals and objects in qualitative and quantitative values for the design process. These characteristics of the design are then analyzed via a quality function deployment. Then, the overall needed functions of the design are visually shown in functional decomposition models. Lastly, the standards observed in the design are discussed.

2.1 Customer Requirements (CRs)

Various customer requirements have been discussed with the project sponsor, Northrop Grumman, and the team. These are all qualitative requirements that the ECS door design must fulfill as agreed upon by Northrop Grumman and the team. Majority of the customer requirements originated in the project proposal provided by Northrop Grumman. Additional customer requirements were added by the Capstone team as they were determined to be essential for a successful design.

Ease/Safety of Installation: The door design must be able to be easily installed into the vehicle fairing at the launch site. The installation shall not require any specialized, uncommon tooling and can be installed by no more than two people due to the limited access on site.

- Scalable: The design shall be able to be scaled for use across various launch vehicles. While the door is being initially designed for the Antares rocket, the goal is to create a design that can be implemented across the entire selection of Northrop Grumman's launch vehicles.
- Reopenable: The ECS door shall be able to be opened from the outside. There is potential for accidental closure of the door during installation and during insertion of the ECS nozzle. The installation team must be able to easily open the door on site.
- Withstand Pressure Differential: The design will potentially be implemented into various launch vehicles with different launch trajectories. These trajectories cause various pressure differentials, and the door must be able to remain closed when exposed to these various pressures.
- No Contaminates: The design materials shall not generate any foreign object debris (FOD) such as sparks, shavings, dust, or material off-gassing. The location of the door is close to sensitive satellites in which FOD can affect.
- Not Based on Gravity: The closure of the door design shall not rely solely on the force of gravity. Additional systems must be implemented for closure to ensure an accurate design.
- Door Closes on Launch: The design must automatically close upon removal of the ECS nozzle. It is acceptable for the ECS nozzle to hold the door open with direct contact.
- No Interference with Surrounding Systems: The components of the door shall not interfere with nearby systems or operation of the rocket fairing. Any system interference can create potential for mission failure.
- Professionalism: The team shall conduct themselves in a professional manner throughout their work with Northrop Grumman. The team recognizes that they not only represent themselves, but also the reputation of NAU's mechanical engineering program.
- Minimal Effect on Aerodynamics: The design must be externally flat and free of any major protuberant components to minimize potential effects on overall aerodynamics of the launch vehicle.
- Electrostatic Discharge Safe: The design shall not have any major potential electrostatic discharge (ESD) as any discharge can affect the performance of the sensitive satellite systems nearby.

- Door Status Indicator: This indicator is an optional stretch goal. An indicator that remotely communicates that status of the door as open or closed is an optional customer requirement that has been requested by Northrop Grumman.

These various customer requirements were rated by the team on a scale of 1-10 to allow the team to prioritize the most important requirements. It has been determined that the highest priority customer requirements are withstanding pressure differentials, automatic closure upon vehicle launch, and no interference of surrounding systems. The customer requirement that is the lowest priority is the optional door status indicator. The rating of all customer requirements is shown below in Table 1.

Table 1: Rating of Customer Requirements

#	**Customer Requirement**	**Rating**
1	Ease/safety of installation	7
2	Scalable	8
3	Reopenable	4
4	Withstand Pressure Differential	10
5	No contaminates	8
6	Does not use gravity or acceleration	6
7	Activates on launch	10
8	Does not interfere with nearby systems	9
9	Professionalism	5
10	Does not influence aerodynamics	9
11	ESD safe	7
12	Indicates open/closed status	1

List and discuss all Customer Requirements and weightings. Customer Requirements must fully incorporate all the project requirements provided by the sponsor. Additionally, the Customer Requirements should fully specify and clarify the overall project objectives. The discussion of each CR should elaborate on how they meet the project objectives.]

2.2 Engineering Requirements (ERs)

The various engineering requirements are quantitative characteristics that were provided by Northrop Grumman. These requirements are necessary to successfully fulfill the intended use of the design. These engineering requirements help to ensure a high standard of design performance, reliability, durability, and safety. Many of these engineering requirements are directly related to customer requirements and give a quantitative measurement to fulfill the customer requirement.

- Safety Factor: All metal components shall meet the minimum safety factors of 1.6 to yield and 2.0 to ultimate. All plastic or composite components shall meet the minimum safety factors of 2.0 to ultimate and 2.3 to buckling. These safety factors help to prevent any potential failure of components that can potentially lead to door failure.

- Vibrations: The design shall withstand a vibration test with a load of 73 Gs while in the closed position. The vibration test helps to ensure the reliability of the latching mechanism during launch of the vehicle.

- Pressure Differential: The door shall withstand a pressure differential of up to 7.5 psi during flight. Failure to withstand this pressure differential was the main issue of the original design. The new design must be able to withstand the pressure differential that the previous design was not able to withstand.
- Budget: The team shall not exceed the allocated budget of $8,000. This budget includes all costs of materials, prototypes, and out-sourced manufacturing.
- Dimensions: The maximum inlet area shall not exceed 203 in^2. The design will be scaled for implementation on various launch vehicle. This is the maximum potential area required.
- Weight: The overall mass of the design shall not exceed 5 lbs. This weight limit is important as overall weight of the launch vehicle must not have major effects due to the door.
- Pressure Limit: The compressive stress applied to the surrounding fairing area of the door shall not exceed 810 psi. This compressive pressure limit ensures that the design will not cause any damage that can potentially compromise the integrity of the fairing structure.

2.3 Functional Decomposition

The functional decomposition of the door redesign is a visual representation that assists the team in understanding the use and results needed of the product. In this case the team needed to consider all the components necessary to have an effective prototype latching system on the ECS door of the Antares vehicle that will significantly reduce air escaping. Specifically, a Black Box Model approach was used to see a broad view of these inputs and outputs a system required to accomplish the tasks listed for the project. Then, a detailed breakdown of the main functions in a Functional Model Basis Functions chart was created to help the team clarify the project and updates as needed based on projects progress and feedback. The analysis from this section is strongly related to the customer needs thus extends through the engineering design process in the following sections as well.

2.3.1 Black Box Model

The black box model creates a visual description of the operations needed for product to perform the desired outcomes. The generalized goal of the project is to close a door and keep it closed despite forces acting on it. Therefore, the inputs and outputs break down into three flow categories: energy, material, and signal. Figure 2 shows the functions required for the overall redesign goal. For example, the team ultimately designed a system which solely realize on visual confirmation for the closed door. Therefore, the only signal in is visual in Figure 2.

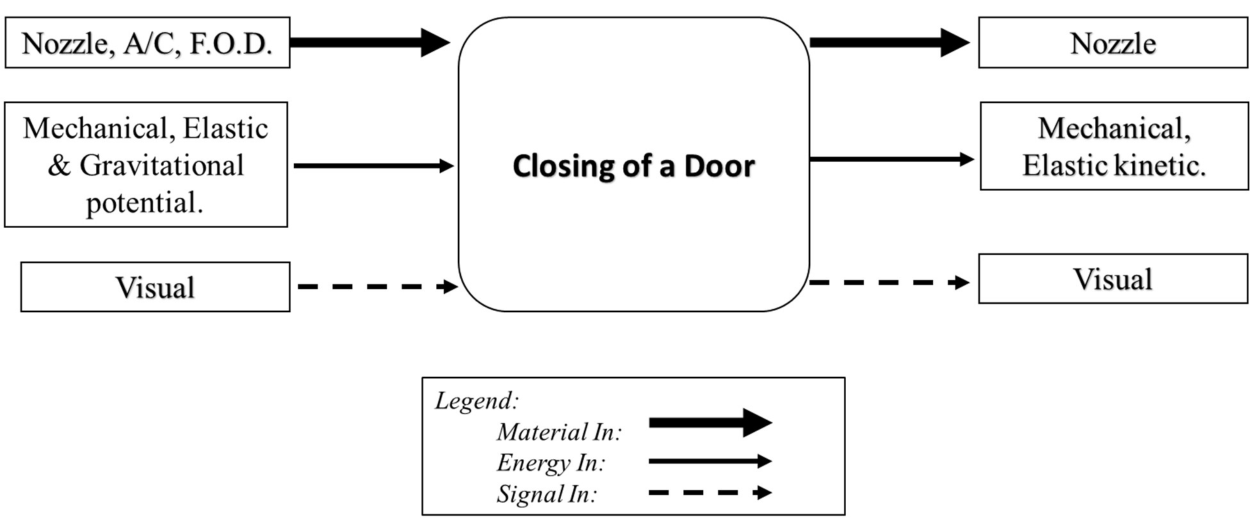

Figure 2: Black Box Model

This figure is updated to the most current requirements for the project objectives. Since the functions considered are simplified by only taking into account the beginning and end, the team formulated concepts that complete the objectives of the project without restricting creativity from specificity.

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

Further analysis on the black box model leads to functional decomposition. The outcome, Table 2, is a detailed look into the sub functions of each flow input and output of the black box model of Figure 2. The division gives emphasis on how functions were achieved throughout the use of the design and the results of the material, energy, or signal flow path.

Table 2: Functional Model Basis

Functional Model Basis			
Class			
Primary	**Secondary**	**Tertiary**	**Correspondents**
Material	Solid	object	nozzle
		particulate	F.O.D
	Gas		A/C
Energy	Mechanical	rotational	potential, closing system
		translational	potential, closing system
		elastic	potential and kinetic, closing system
	Elastic	potential	startup force, closing system
	Gravitational	potential	startup force, closing system
Signal	Status	visual	position, displacement

From Table 2 above, it is clear how the mechanical energy is related to a possible application the team can use to create a closing system, or electrical energy by use of a control system such as radio. Additionally, a material present in the system is the nozzle since it will interfere with any closing system the team designs. The team used the breakdown of the functions to clarify the categories needed for the morph matrix in concept generation since the derived sub functions of the design ensure the customer needs are satisfied.

2.4 House of Quality (HoQ)

The use of a house of quality ensures the customer requirements and engineering requirements are examined through a quality function deployment, QFD, which is an engineering technique used to make sure customer needs are correctly translated into specific design inputs of a device being designed. The proceed evaluates customer needs to quantifiable and measurable criteria. The team create the weighted values of each customer requirement from the project proposal and client input to prioritize design functions and qualities for the final concept. Then, relationships between requirements were compared on a scale of 9 (strong), 3 (moderate), 1(weak), or no value. Since the engineering requirements are based on customer needs for the design, there is at least one engineering requirement to one customer requirement.

In summary the results showed that the most important engineering requirement to keep in mind thought the design process will be the weight limitation. As we consider safety factors for yield, ultimate and bucking of a material we effect the weight of the system. Also, wanting to keep the design easy and safe to install, the team must review the weight value. Other factors such as cost, gravity, additional component for an ESD safe design can further add to the total design's weight. Detailed team results of the House of Quality can be seen in Appendix A.

2.4.1 Testing Procedures

The team formulated a range of testing procedures to ensure the design being considered does in fact satisfy the deliverables, specifically the engineering requirements. Therefore, the team will be conducting vibration, pressure, and load testing in the next steps of the engineering design process so verify the design is functional, reliable, and robust.

2.4.1.1 Vibrations Testing

The vibrations test will test how well our design can withstand the 24Gs for 9 seconds the new design needs to endure given the material change. Testing the vibrations determines how we change our design to handle the forces, and if it will open or close out of turn. Originally the team planned on Northrop's Grumman facilities in Chandler as they have mentioned we can do vibration testing there however there was restrictions that prevented that method. Thus, the team pursued other options. Ultimately, the design was tested via an off roading experience to simulate abrupt shaking on the device.

2.4.1.2 Temperature Testing

This testing was applied to study the design dimensions as drastic temperatures occur to the design. Functionality and overall area limitations will be compared to ranges in the QFD. We measured the dimensions before placing it in a freezer, then after it was cold, and lastly when it was heated int eh oven. The tolerances were all within +/- 0.001 in.

2.4.1.3 Load Testing

The design was examined through Solidworks to simulate the expected point of failure through FEA. Applying the load of 1050 lbf on the latch resulted in a maximum deformation of 0.01214mm or 0.000478 inches. The values deal with the yield FS and the ultimate FS int eh design as well as overall forces it must take on.

2.5 Standards, Codes, and Regulations

Northrop Grumman has company standards that the team's design must meet. The first standard provided is for tolerancing in which all parts must have a tolerance of ±1/1000 in. This is the standard company tolerance which must be met. Another important standard provided by Northrop Grumman is that all metal parts must have a safety factor of 1.2 to yield and 2.0 to ultimate. Additionally, all plastic or composite parts must have a safety factor of 2.0 to ultimate and 2.3 for buckling. These safety factors are essential to help mitigate potential failure of any parts or components.

Table 3: Standards of Practice as Applied to this Project.

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASNI/AAMI HE 74:2001	Human Factors Design Process for Medical Devices	Helps in the design of how the device with interface with the user in a safe manner.
ANSI Y14.5	ASME Y14.5 2018	Authoritative guideline for the design language of Geometric Dimensioning and Tolerancing

3 DESIGN SPACE RESEARCH

3.1 Literature Review

The various sources our team found during literature review were: Electrostatic Discharge, Computation Fluid Dynamics, Geometric Dimensioning and Tolerancing, and Aerodynamic Protuberance. Electrostatic Discharge mainly focused on looking at what materials would transfer electrons that cause an electric shock. Considering that most rubbers have this effect we had to understand what materials could be used before considering the design of our device. Computation Fluid Dynamics was used to approximate simple flows using ANSYS. This was we could see what how certain geometries come into play when in flight, which allowed our team to brainstorm more aerodynamic shapes. Geometric Dimensioning and Tolerancing was used to help our team understand the symbols that are used and to check if a machined part fit our desired tolerances. This proved helpful since we created a loose tolerance to have an idea of what to design our assembly to. Aerodynamic Protuberance dealt with ways to minimize the aerodynamic effects on the door. This was beneficial since our device was designed to be on the outside which proved to not cause any significant aerodynamic effects that called for altering the design.

3.2 Benchmarking

Benchmarking did not take place in our previous reports, due to the information being inaccessible to us. However, we decided to look into other systems of which the same Antares door was used before it was used on rocket ships.

3.2.1 System Level Benchmarking

Figure 3: Pegasus Rocket [8]

Pegasus, shown in Figure 3, was the original target for the door. Once that door and latch design was proven to work, it was the applied to be used universally in Northrop Grumman's vehicles.

3.2.1.1 Existing Design #1: Pegasus Design

The Pegasus rocket was used to aid in deploying small satellites up to 1000 lbs. [8]. This aircraft flew in low-Earth orbit to deliver satellites in space. Due to the unique shape of the wing the Pegasus can put satellites into orbit in about 10 minutes. What Pegasus does is it assist satellites as shown just below the aircraft in the above figure to reach orbit with minimal ground support. The satellite then is dropped and falls then ignites its first stage rocket motor. Pegasus was the first privately developed space launch vehicle, the first winged vehicle to accelerate to eight times the speed of sound and first air-launched rocket to place satellites into orbit [8]. The concept for this door was then used in the Antares rocket shown below in Figure 4.

Figure 4: Antares Rocket [9]

3.2.2 Subsystem Level Benchmarking

3.2.2.1 Subsystem #1: Latch

The latch subsystem is important in the overall design due to the customer requirement of the door being able to secure tightly and allow for little to no air leakage. This latching system is restricted to having no ESD which can restrict ideas and designs our team can develop. The latching system also has a stretch goal of being able to indicate electrically if the door is in the closed/open position.

3.2.2.1.1 Existing Design #1: Velcro

The Velcro design is what was previously used by the Northrop Grumman engineers on the Antares rocket. This design did not secure correctly and allowed for "burping" while in flight. This design relates to the requirements by securing to the side of the rocket, while being compact and lightweight. The design closes properly at launch and does not create an electrostatic discharge.

3.2.2.1.2 Existing Design #2: Door Latch

The door latching system is similar to any generic door latching, it has a swinging arm that grabs onto the other latch that will hold the door tight to the door frame. This design relates to the requirements because it is simple and can be scaled up or down to match the customer requirements. This design also can be manufactured to be activated by the energy systems involved in the overall design.

3.2.2.1.3 Existing Design #3: Cabinet Latch

The cabinet latch consists of tight springs that are forced into a tight space like locks seen on cabinets. The idea of this design is when the door is closed, the springs will impact on an opposing lock and the springs will compress and enter the locking mechanism. The springs will be designed to stay secured and lock inside the mechanism. This design relates to the requirements by being simple and can be replicated throughout the perimeter to the door. The design also has the simplicity to be scaled up and down as desired.

3.2.2.2 Subsystem #2: Hinge

The hinge subsystem allows for the door to swing open or closed. This hinge system needs to be strong and consistent with the various vibrations and loads on our system. This subsystem is important to the overall project because it is what connects the rocket to the door system.

3.2.2.2.1 Existing Design #1: External Door Hinge

The external door hinge is a hinge on the exterior of the rocket that will allow for the door to be forced closed with a torsion spring. This design relates to our requirements because it allows for the door to close consistently and stay closed throughout launch. This design was used before in the past and has worked.

3.2.2.2.2 Existing Design #2: Sliding Door

The sliding door design has no hinge but is a door design used in closing the door. This sliding door is held open by the nozzle of the environmental control system. The door is forced shut by gravity and locked in place by the latching subsystem. This design relates to the requirements because it allows for the door to be closed and not affect any of the surrounding systems.

3.2.2.2.3 Existing Design #3: Internal Door Hinge

The internal door hinge is a torsion spring installed on the inside of the rocket that will pull down the door to close flush with the exterior of the rocket. This design relates to our requirements because it is unique and compact being on the inside of the rocket. The interior design allows for minimal aerodynamic interruption, meaning it can be more efficient for the rocket overall.

4 CONCEPT GENERATION

4.1 Full System Concepts

After the Morphological matrix was developed, three unique designs were generated from it. These three designs are the sliding door, the exterior hinge, and the interior hinge. Each design pulled different concepts for each subsystem. This produced functional designs with different pros and cons.

4.1.1 Full System Design #1: Sliding Door

The first full system design that the team analyzed was a sliding door design. The system was positioned on the inside of the fairing, in order to not have protrusion on the exterior of the vehicle that could affect the aerodynamics. The door rests on top of the nozzle that goes in the inlet, holding the door up while the nozzle is in place. As the rocket launches, the nozzle is removed, and the sliding door falls into place, with the help of several springs at the top to ensure it does not get stuck. As the door falls into place, a latching system, much like those seen on common doors, is activated as the door passes its threshold. These latches can be released from the outside fairing by a pull tab, in case the door prematurely closes and needs to be reopened. The system used the internal pressure to push the door against the fairing to keep a better seal. The bottom of the system uses a rubber pate to seal the bottom edge, and the top uses brushes that line the area between the top of the door and the fairing.

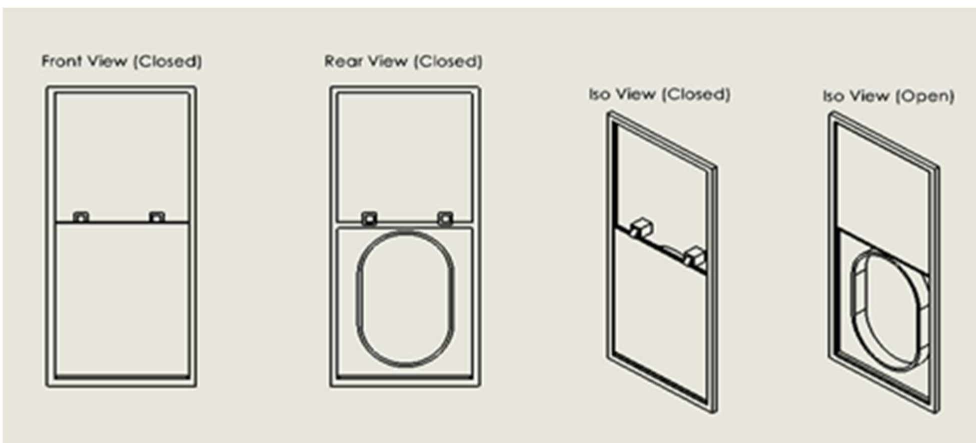

Figure 5: CAD Sketches of Sliding Door Design.

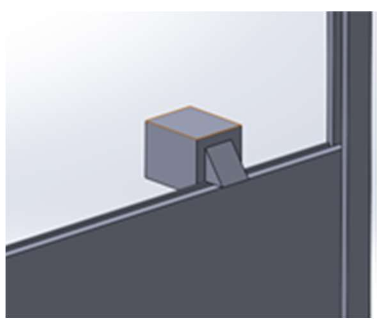

Figure 6: Close Look at Latching Mechanism

The sliding door design had several key criteria that made it a competitive design. One of the first things the design handled was maintaining a tight seal. This is achieved by the pressure pushing the door against the fairing. This design is also easily scalable to be implemented on other systems. The overall design has simple parts that can be easily manufactured and reproduced.

This design was not perfect and had several flaws that caused it to not be the team's first choice. The flaws of this design were that it did not cover the inlet hole from the outside, allowing a one-inch deep hole to be exposed to the exterior, possibly affecting the aerodynamics of the vehicle. The design was also difficult to reopen if prematurely closed and did not have a way to remain open if the nozzle was not placed in the inlet. The movement of the door relied almost entirely on gravity, with only some short springs to help with the initial movement. With the design being on the inside, there are tight restrictions on how large the design can be, since a diffuser plate is right behind the inlet area. With the inclusion of a rubber plate to form a stronger seal, the design may also have challenges grounding all the components to ensure it remains ESD safe. Finally, this design used more material than the others, causing the cost and weight to potential increase.

4.1.2 Full System Design #2: External Hinge Door

The next full system design that was developed from the Morphological matrix was the External hinge Door. This door can be seen open and closed in the figures below, as well as a back view of the design. This design consists of a simple hinge that is loaded with a torsion spring. This creates a force that pulls the door down into its closed state. Next, the door will be made of aluminum and be rectangular in shape with rounded edges. The door will fully cover the inlet seen in figure 7 and will lie flush with the rocket fairing. Moving on to the design's last component, it has a spring-loaded system. The latch piece is loaded with a compression spring to keep it popped out and is angled in shape so as it pushes against the inlet ring, the piece retracts. Once the piece clears the inlet thickness on the inside of the fairing, the latch will pop open again and hold the door shut.

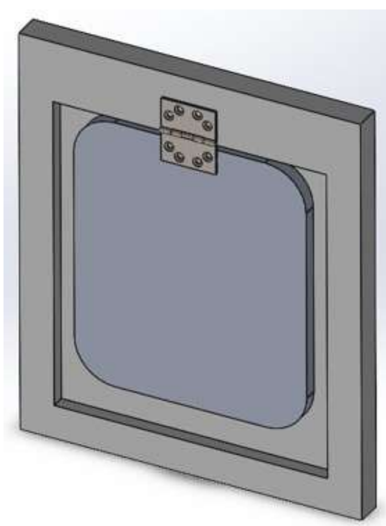

Figure 7: Closed Door View Exterior Hinge

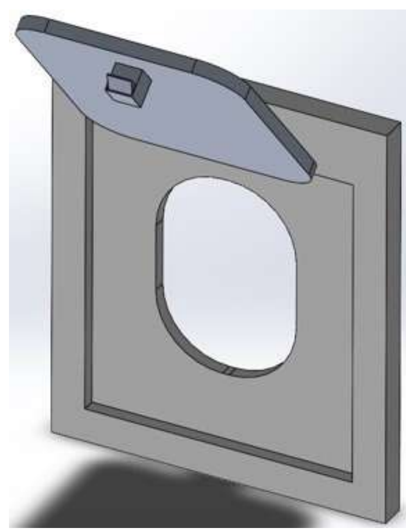

Figure 8: Open Door View Exterior Hinge

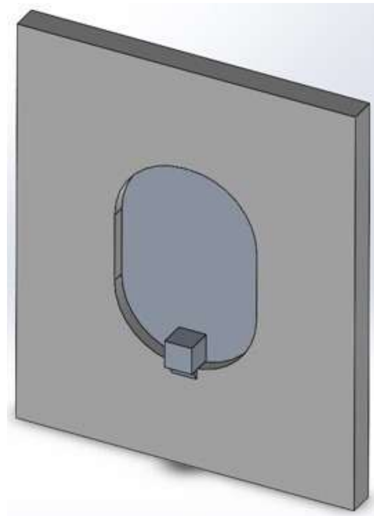

Figure 9: Back View Exterior

The main advantage of this design is that it is very simple and could be built to be very reliable. It is very similar to Northrop Grumman's heritage design so they could keep their door and hinge system and simply implement the latching system which would be very cheap. Another advantage to this design is the ease of scalability. NG wants a design that can be used on most of their rockets. This means the whole system must be able to change in dimension to properly fit each separate rocket. Because this design is so simple, it would be very easy for NG to scale it to fit any of their rockets.

The main disadvantages of this design are its ability to withstand the amount of vibrations it will experience, and its need to have a very strong latch so that it does not break. In the rockets process from launch to flight, it will experience a great deal of vibrations. With a simple compression spring latch, these vibrations could push the latch piece inside of its housing and therefore release the door, causing the system to fail.

4.1.3 Full System Design #3: Internal Hinge Door

The last full system design that was considered by the team is an interior hinge design with a pop-in roller latching system. The overall motion of this design is similar to the external hinge design. The main advantage of the interior hinge design is that it allows for a completely flat external door face. This provides minimal effects on the aerodynamics of the vehicle as there are no protruding components. However, this interior hinge is not as robust as an external hinge due to the increased moment force on the hinge. The latching system consists of a rounded knob on the lower interior section of the door. The latch relies on the closing force of the door to push through rounded rollers that are installed in the lower inlet area of the fairing. The exterior face of the rollers is rounded with a flat interior face. This prevents potential door opening during flight. The open position of the door can be viewed in Figure 10 and the closed position of the door is shown in Figure 11.

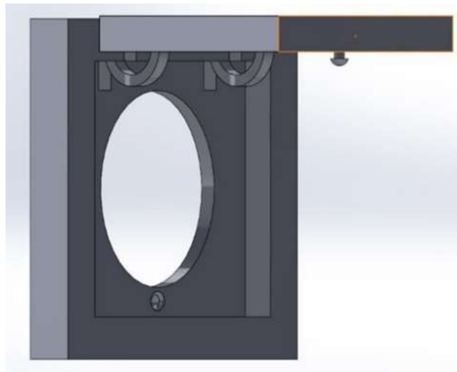

Figure 10: Open Position of Interior Hinge Design

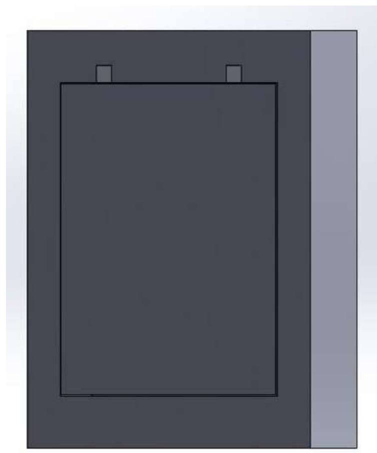

Figure 11: Closed Position of Interior Hinge Design

The main disadvantage of this design is the latching system. Since the system relies on the closing force of the door, this creates potential for failure to securely latch if the closing motion of the door is slowed due to removal of the ECS nozzle. Another potential issue is that when the design is scaled smaller, the weight and momentum of the door might not apply enough closing force to push through the rollers. While the design would likely be secure enough to withstand the pressure differential and vibrations during flight, the potential failure to properly close makes this design unreliable in small-scale applications.

4.2 Subsystem Concepts

The system concepts are distinct different full-system concepts. These subsystems have been used in our designs and have been selected using a morph matrix. The subsystems were generated using our engineering requirements and our customer requirements.

4.2.1 Subsystem #1: Opening/Closing

The opening and closing subsystem are what keep the door from opening on launch. This subsystem consists of different ways the door can maintain its closure while also ensuring there is no leakage from the inside of the rocket.

4.2.1.1 Design #1: Door Latch

The door latch consists of a mechanical swinging arm that will grab onto and latch the door into position. These latches are familiarly seen in U-Haul vehicles. The pros of this design are the simple swinging motion makes it easy to manufacture, the design can also be scaled up and down with minimal effort. The cons of this design are it can be bulky and heavy causing issues with our weight limit. The latch also will not be consistent and will not be as reliable as the other designs.

4.2.1.2 Design #2: Cabinet Latch

The cabinet latch is a spring that is compressed on impact with a latching system to hold the door into place. This design is commonly seen in ordinary kitchen cabinets. The pro of this design is it can be easily placed along the perimeter of the door to allow for complete coverage. The cons of this design consist of the latch coming undone on launch due to the high amounts of vibrations on the system.

4.2.1.3 Design #3: Spring Latch

The spring latch is a spring-loaded design that will compress on closure and expand once in place to create a tight seal on the door. The pros of this design are it is cheap and easy to make, with movable parts and a small area. The cons of this design are the consistency of closing and stay closed over a period of time, the spring has a potential to compress unwillingly and open the door.

4.2.1.4 Design #4: Velcro Latch

The Velcro latch is what was seen before in previous designs. This design is a Velcro perimeter on the door that will seal and close after launch. The pros of this design are the light weight and tight frame on the inside of the door. The cons of this design are the strength of the Velcro could allow for the door to reopen while in flight as well as give the not align properly after the launch.

4.2.1.5 Design #5: Hydraulic latch

The hydraulic latch is similar to the spring latch, but instead of a spring being used to shut the door the hydraulics take its place. The pro of this design is the consistency of the hydraulics over a period of time, the latch can be closed at wherever we design it. The cons are the heavy and large amount of area a hydraulic component will take, as well as an overall more complex design.

4.2.2 Subsystem #2: Door Movement

The door movement is important in the overall design due to it being the overall base to how we expand and design our other subsystems. If the door movement is not consistent or does not meet the desired requirements, it can lead to an overall failure of the system.

4.2.2.1 Design #1: Exterior Swing

The exterior swinging door movement uses one hinge to open and close the door. With the door moving away from the rocket, this design can get in the way of different subsystem. The pros to this design is the simplicity and the overall smaller volume required for the door. The cons are designing a way to keep the door open for long periods of time.

4.2.2.2 Design #2: Sliding Inside/Outside

The sliding door design is a door that falls down and locks on launch of the rocket. The door will be controlled by gravity and will have no used of outside energies to close. The pros of this design are it allows for a tight seal if approached correctly and does not require any precise tolerances to be made. The con of this design is creating a frame to guide the door into place and seal it properly.

4.2.2.3 Design #3: Pivoting Point

The pivoting point design is a swinging door that will pivot on one point of the rocket and will create a seal on the required area of the system. The pros of this door are it can be compact and flush with the exterior of the rocket and the swinging action will require it to not have too much extra energy put into the system. The cons of this door are it will not be reliable, closing the area completely might be hard to design and the swinging action could create a lot of extra momentum.

4.2.2.4 Design #3: Rolling Door

The rolling door is similar to the garage doors seen in most houses, the door will be flexible and able to roll onto itself to keep the area requirement low. The pros of this design is it will be compact and held tightly to the rocket, meaning it will have little room to move. The con of this device is it will be hard to scale the device up and down without creating too much bulking.

4.2.2.5 Design #3: Double Sliding

The double sliding door is the same concept of the sliding door design but has two doors meeting in the meeting of the covering area. This design is unique and has advantages of being compressed into different rockets and designs. The pros of this design are it is unique and has not been used before. The con of this design is it has to be locked in the center of the area to stay secured.

4.2.3 Subsystem #3: Failsafe

The failsafe subsystem is what keeps the door from failing and not being able to reopen. The. failsafe is put into place to ensure that the door can close fluidly and stay closed throughout launch. This subsystem is important because if anything were to go wrong, we will be able to reopen the door without causing any problems.

4.2.3.1 Design #1: Torsion Spring

The torsion spring would be used to create a tight seal on the door to the rocket. The torsion spring also can be loaded to be easily opened by hand as well as stay tight when needed. The pros of this design are it can be compressed easily and reused for any focuses. The cons of this device are the overall thickness of the spring can cause issues with aerodynamics on the exterior of the rocket and if designed incorrectly, the door can close and not be able to open properly.

4.2.3.2 Design #2: Tension Spring

The tension spring can be used on the latching subsystem to keep the door locked and sealed during launch. The tensions can be designed to easily get undone and allow for the door to reopen if there are any failures. The pro of this design is it can be put into place on latches that need to be opened frequently. The con of this design is it can lose tension during flight if the vibrations cause any kind of unlatching.

4.2.3.3 Design #3: Compression Spring

The compression spring can also be used in the latching system to keep the door locked and sealed during launch. The pro of this design is it will be kept tight in position on launch and can be compressed in a closed area to theoretically not lose compression during flight. The con of this design is if we need the spring to be compressed too much, it can cause safety issues for the manufacturers.

4.2.3.4 Design #4: Hydraulics

The hydraulics of this design can be used like the previous springs but will require more maintenance than the springs. The pro of this design is it has unlimited force potential, allow for us to use it wherever we need it. The con of this design is it will need to maintain a certain weight and it will be hard to design a hydraulic system to maintain the weight requirement.

5 DESIGN SELECTED – First Semester

The design selected will provide a detailed design description that fully explains the final design the team is moving forward with into the spring semester, as well as an implementation plan. The design was a result of using a morphological matrix to generate concepts and a decision matrix and Pugh chart evaluate those concepts. Several analyses were performed like material weight and stress to justify the plausibility of the final design. In the design description there will be several CAD models to show and explain the design. The implementation plan will include the team's plan for prototyping in spring semester which covers the resources needed in a bill of materials.

5.1 Design Description

The final design the team chose was based on different subsystems from the morphological matrix. A simple exterior hinge and aluminum door were selected with a more complex twisting latch at the bottom of the system. The whole system can be seen in the open position in figure 12. This is before the rocket launches and a nozzle is resting in the opening which feeds conditioned air to the inside of the fairing for the satellite. The hinge is loaded with a torsion spring so as the nozzle is removed at launch, the door will shut closed, and the latch will turn and secure the door which is seen in Figure 13.

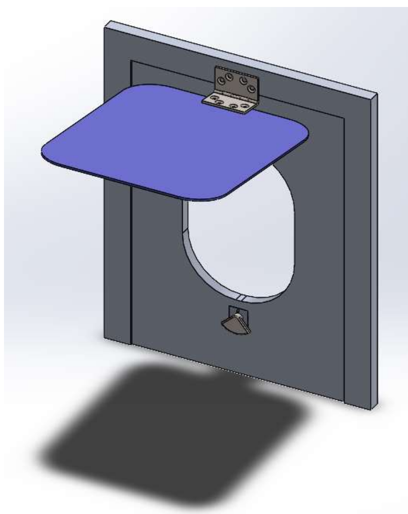

Figure 12: Open Position

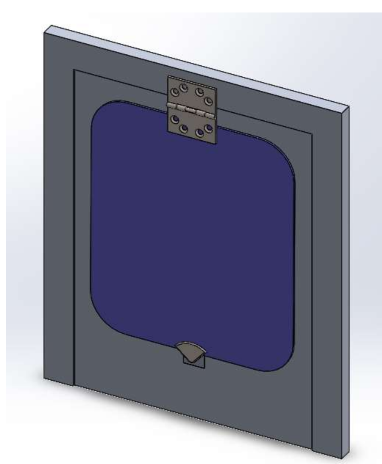

Figure 13: Closed Position

While consulting with the client, the team came to the conclusion that because the rocket already uses an exterior hinge and aluminum door, these components will not be further designed as the company already has working versions of these components. The team will move forward with purely designing the latching system which will satisfy the client's needs. Moving on to a more detailed overview of the latching system, it is shown below in figure 14 and a sectioned view is shown in figure 15. The components are a bottom plate, housing, bolt, shaft, torsion spring, pin compression spring and top plate. These can all be seen in Figure 15.

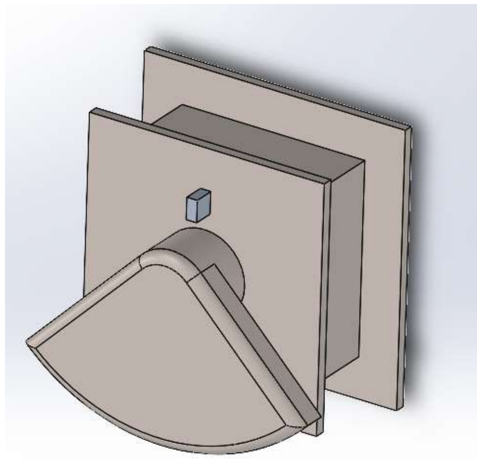

Figure 14: Latch System

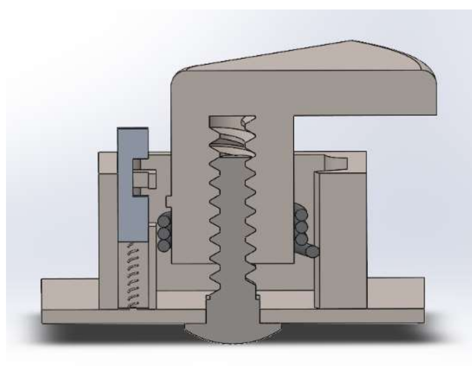

Figure 15: Latch System Section View

The system works through the torsion spring coiled around the shaft giving the shaft torsional tension. That tension is held by an extrusion on the shaft that is resting on the pin. Once the door shuts closed, it will push the pin down against the compression spring further into the housing. That pin will then reveal an opening that allows the extrusion to pass by which releases all the torsional tension. The shaft will spin 180 degrees down on the bolt causing it to lower slightly and cover the door. The housing has an addition shelf located on the right wall in Figure 15. This shelf will block the extrusion and prevent the shaft from rotating further than 180 degrees. The opened and closed views just as the door has shut can be seen below in Figures 16 and 17.

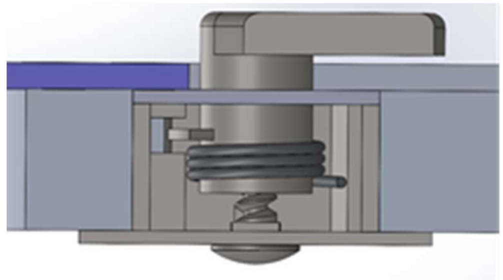
Figure 16: System Side View Opened

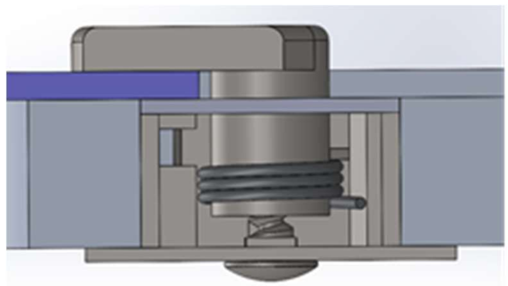
Figure 17: System Side View Closed

In Figure 16 above the door and just shut and the pin has been pushed down. At this time the shaft can now freely rotate. Figure 17 then shows the final closed view of the system after the shaft has turned 180 degrees and the latch portion of the shaft is now covering the door holding it shut. Between figure 16 and 17 the gap between the latch and the door reduces to nothing. This is because while the system is open the is clearing between where the door would lie and the latch. Once the system turned into its closed position, that clearance is removed because the shaft rotates down the threaded bolt. This provides a secure fit of the latch to the door which will increase the resistance to the internal pressure the team is designing for.
The parts will all be made of AISI 304 stainless steel except for the two springs which will be made from music wire. These materials have been selected because they are easily machinable, accessible, and strong. By the preliminary report the team had a very simple latch selected and based on feedback the team chose a much more complex and unique latching design. Now that the final design has been fully detailed, the team's next steps will be to begin prototyping which is discussed in the next section.

6 IMPLEMENTATION – Second Semester

6.1 Design Changes in Second Semester

6.1.1 Design Iteration 1: Change in Scalability discussion

At the beginning of the semester the first change to the design the team looked at was the device's ability to scale to any size rocket fairing. The team met up the first week of the semester to lay out the problems of the old design and start brainstorming new ideas. This issue was brought up in the preliminary design review held by Northrop Grumman last semester. Below are some pictures of the design process the team took to brainstorm new ideas.

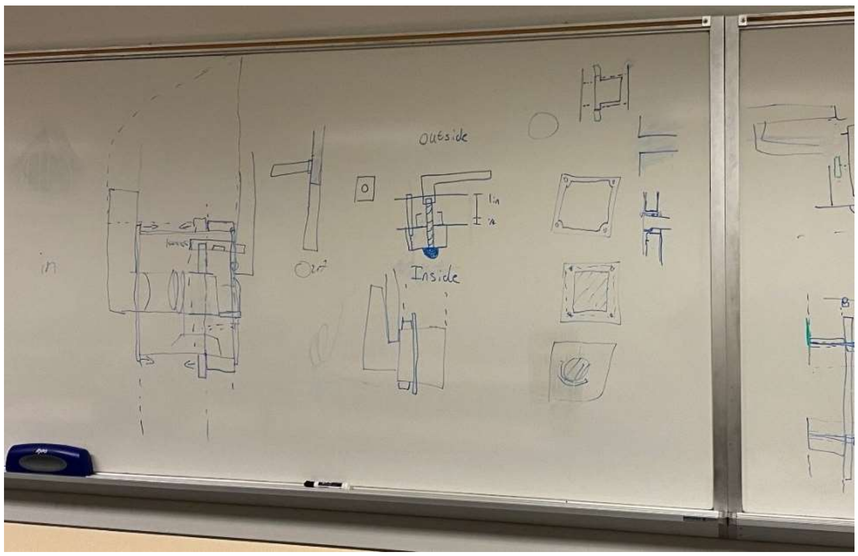

Figure 18: Whiteboard Drawings.

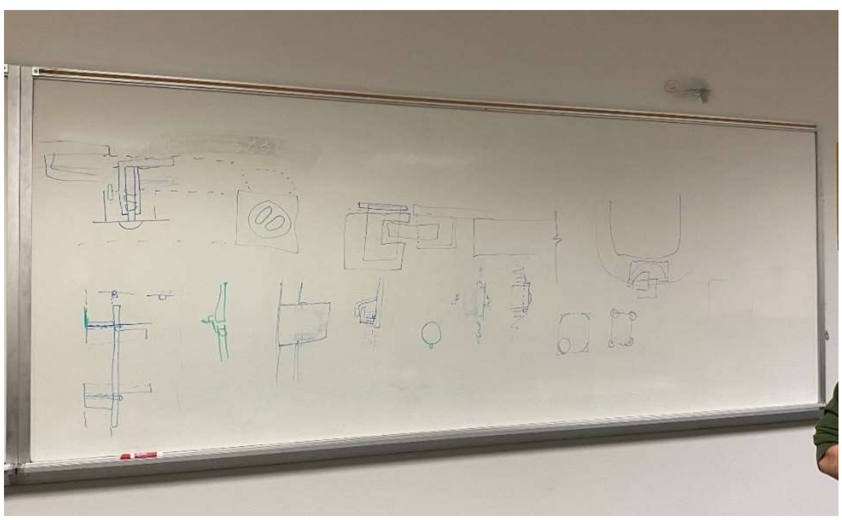

Figure 19: Continuation of Whiteboard Drawings.

While many different designs were suggested and thought of, the design the team moved forward with was adding a shoulder to the housing and adding an adjustable plate that would sandwich any size fairing in between the device. This provided the solution to the scalability problem with changing as little of the design as possible. Below are two figures, comparing the original design to the new design.

Figure 20: Original Design

Figure 21: New Design.

It can be seen in Figure 20 above, that the original design had no system to scale to different fairing sizes. The design on the right had that shoulder with the adjustable plate under it. The fairing will fit in between the shoulder and the plate will be adjusted accordingly, then tightened with bolts and nuts on the corners.

6.1.2 Design Iteration 2: Change in Material discussion

The next design the team looked at was a material change from stainless steel for every part in the design to aluminum 7075-T7. This material was suggested to the team during the preliminary design review with NG. This material provided a much lighter weight as well as stronger ultimate and yield strengths. Both properties are directly related to our engineering requirements. The first is to stay under 5.0 pounds while being encouraged to make it as light as possible. The second is to meet a 1.6 yield factor of safety and 2.0 ultimate factor of safety. With the change in material there was a decrease in weight of over 50% while adding more material to the design. This can be seen below in the table.

Table 4: Weight decrease

Mass Properties	Twisting Latch 1.0	Twisting Latch 2.0
Surface Area	54.06	65.35
Volume	3.33	4.12
Mass	0.96	0.45

As shown above the weight of the whole system went from 0.96 pounds to 0.45 pounds. The changes in strength resulted in an increase of both factors of safety changing them from around 2.0 to 4.5. The increase in strength makes the part that is taking the load over engineered, and its size might be reduced in the future because of this.

6.1.3 Design Iteration 3: Change for Manufacturing discussion

The team wanted to work on making the design as easy to manufacture as possible, without sacrificing important design details. This was done by making changes to sizes of fillets and bolts. Our original design included many square edges in internal components, which would be difficult to manufacture. There were several key locations that warranted a redesign to allow for easier manufacturing, mainly the housing and pin.

The housing has all of the internal corners now match standard bit sizes, to allow for easy corners to be made in a CNC or with a vertical mill. All the corners now use a 0.125in radius to easily cut the aluminum material at the necessary depth. The design also removed fillets on the exterior, which can be added later onto the final design, but are not necessary for testing.

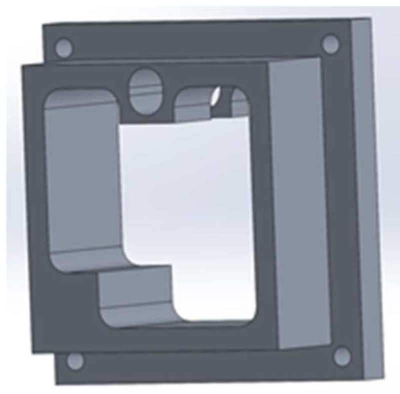

Figure 22: New Housing Design.

Figure 23: Comparison of Housing Designs from Original (left) to Newest (right) design.

The pin changed from being completely rectangular, to more circular in shape. The design required the use of the 0.125-inch radius in both the housing and the pin, so the design had to include these rounded edges. Two of the sides still include flat faces, to make sure the pin cannot rotate in its slot. Another change made here was including a small hole for the compression spring to sit in. This allows the pin to be comfortably placed on top of the spring. The top of the pin now includes a smaller diameter, that matches the hole in the top plate. This confines the pin in the housing, allowing only the top of the pin to peek out from the top of the plate. Lastly, the pin now included a small ramp in the cut, which allows for easier resetting of the device after it has activated.

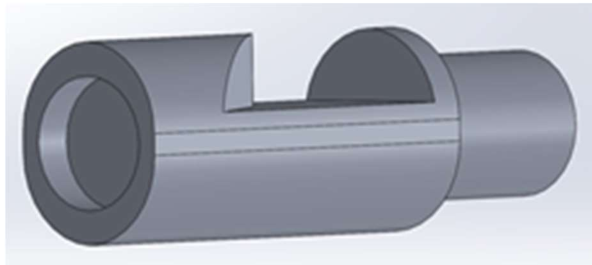

Figure 24: New Pin Design.

Figure 25: Comparison of New Pin (top) and Original Pin (bottom).

6.1.4 Design Iteration 4: Change in activation discussion

An additional design change made was to change the distance that the shaft needs to rotate for closing. We reduced the travel angle from 180 degrees to 90 degrees so the device will catch the door faster. This change reduces the potential for failure if the door bounces during closure. This rotational change also reduces the risk of overloading the torsion spring due to only being a 90-degree rotation of the shaft.

The extrusion tab on the shaft was also reinforced with fillets to help support the extrusion. The extrusion rests against the pin when the device is set, and breakage of the extrusion would result in premature actuation and the door would not properly latch shut. This extrusion change also makes manufacturing easier by reducing the risk of tooling breaking the extrusion during the milling process. Figure 26 shows a comparison of the latest shaft design and the original shaft design.

Figure 26: Comparison of new (left) and original (right) shaft designs.

7 RISK ANALYSIS AND MITIGATION

This section will cover how the team approached risk mitigation. While the team never created a failure modes and effects analysis (FMEA), risk mitigation was accounted for through the extensive prototyping with 3D printers. Once the team finalized the design last fall, a plan was made to 3D print all the parts and assemble the device to better understand the design and to identify any possible failures. The team followed through with this plan during this semester and created a metal prototype in the machine shop.

7.1 Potential Failures Identified First Semester

As stated above, the team did not perform an FMEA but simply brainstormed and considered ways potentials for our device to fail. These included the pin falling out of the assembly before activation, the device activating before the door comes down, the torsion spring not providing enough torque and the latch and threads not being able to sustain the applied loads. Once these potential failures were identified, the team planned to prototype the full design to test these concepts and brainstorm solutions.

7.2 Potential Failures Identified This Semester

This semester the main failures identified were surrounding the device's tolerancing. Engineers at Northrop Grumman were concerned that once the latch closes on the door there might be too much space in between the latch and door. This could cause server chatter due to the vibrations during and after launch. This chatter could cause the door to burp again which is the original problem the team was designing to avoid, and the chatter could potentially damage the device. In addition to this the team identified the failure of the tolerancing being too tight and the latch would not have enough room to cover the door on activation with the bounce of the door rebounding off of the fairing.

7.3 Risk Mitigation

The risks of failures that were identified during both semesters of this project were resolved through 3D printing prototypes and creating a tolerance stack up. Once the team 3D printed the first design, it became apparent that the pin could easily fall out of the assembly before launch causing the device to fail. The team then altered the design of the pin to be trapped inside of the housing by changing the size of the top plate. The figures below show the changes made to the pin.

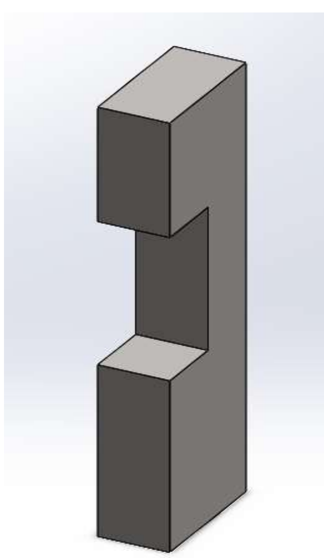

Figure 27: Original Pin

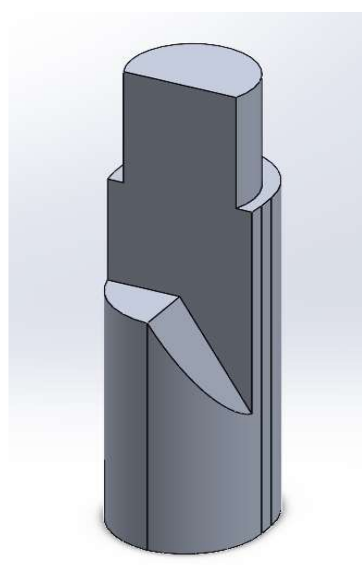

Figure 28: New Pin

It can also be seen in the above images the pin was changed from a rectangular form to a circular form.

This change was made for ease of manufacturing. In addition, an angled slit was cut into the pin to allow the device to be reset by simply twisting the shaft back in place.

The other risks identified in the first semester were resolved through 3D printing the whole assembly. This can be seen in the figure below.

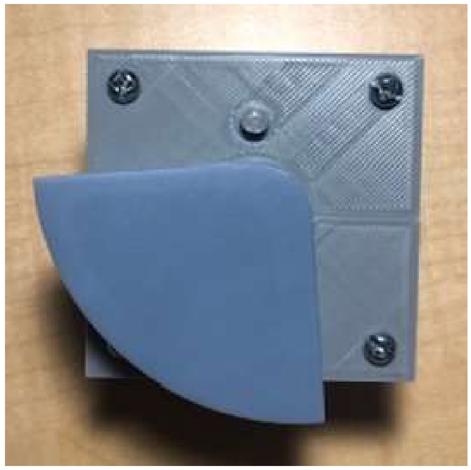

Figure 29: 3D Printed Assembly.

Through prototyping, it became apparent that the device would work as intended and the risks identified were resolved. The team then resolved the current semesters identified risks by creating a tolerance stack up.

Table 5: Tolerance Stack Up

Part	LMC (in.)	MMC (in.)
Shaft	+0.005	-0.005
Door	+0.001	-0.001
Velcro	+0.01	-0.01
Installation	+0.0156	+0.0156*2
Gap (total)	+0.0316	+0.0152

This tolerance stack up shows that if the machining tolerances are correct, the gap would be at 0.03 or 0.025 inches which is enough that the latch will close over the door upon activation and that the tolerance is tight enough so that there will be little to no chatter. The team identified several risks of the design during this project and resolved those risks with slight design changes and testing.

8 ER Proofs

This section will include how we addressed our engineering requirements using software or equations. We will elaborate on each engineering requirement to state how we proved them within our project. By proving these requirements, we are validating our design and if it works to our client's expectations.

8.1 ER Proof #1 – Safety Factors of 1.6 yield and 2.0 ultimate.

This engineering requirement was based around have a 1.6 yield and 2.0 ultimate factors of safety if we used metal components which we did. From there our team was able to calculate the factor of safety for yield and ultimate using the following equation:

$$\sigma_B = \frac{My}{I}$$

Here we found of bending stress, σ, bending moment, M, the vertical distance away from the neutral axis, y, and the moment of inertia around the neutral axis, I. We did this analysis on the latch of our device to determine if a thickness of 0.3" was able to satisfy our safety factors. Using excel we calculated the yield and ultimate and found that our yield was 1.65 and the ultimate was 3.89 which both are within the desired safety factors.

8.2 ER Proof #2 – Vibrations of 24 Gs for 9 seconds.

We could not perform this vibration test to the accuracy of what Northrop Grumman would have done. We did brainstorm ways of using the shaker table that Dr. Penado has but after consulting with him he did not agree his shaker table would yield usable data for vibrations. Also due to Covid our device could not have vibration testing performed unless it was deemed necessary by Northrop Grumman. Due to this, we did visual vibration tests to confirm is the device stayed active as well as did not accidentally activate before the door closes by going out to a bumpy road on Lake Mary Rd. Visuals were noted as our device did not false activate and also kept our mock door closed when activated once vibrations were put onto it.

8.3 ER Proof #3 – Pressure Differential of 7.5 psi.

The team was unable to properly fulfill this engineering requirement due to not being able to use Northrop Grumman's facilities. If we were to use, there mock and installed our device we could then run a pressure differential to see if our door will stay closed. The following equation would have then been used: $P = \frac{F}{A}$ where P is the pressure in psi, F is the force applied in lbs. and A is the area of the latch on the door. Here we would know the area of our latch on the door and with a large amount of force being applied we could determine if the pressure differential is met.

8.4 ER Proof #4 – Budget within $8,000.

After our project concluded our budget was not broken. We only used $1848.16 of the $8,000 given which left us with $6,151.86. We kept track of all the expenses within an excel file to make sure we stayed within budget.

8.5 ER Proof #5 – Dimensions within 203 in^2.

For this engineering requirement we had to not be over the inlet area of 203 in^2. Our device was around 2 in^2. These dimensions did not come close to what we were allotted and therefore we kept measurements of our device as we went along but no equations or software was needed.

8.6 ER Proof #6 – Weight Within 5 lbm

For our weight engineering requirement, we weighed our device as well as used solid works to get an estimate of the weight which was around 0.45lbm. In the end we took our full assembly to a food scale to get the weight which was 0.594 lbm. Some difference in our solid works were that the pin was made of the Aluminum 7075, but our actual pin was made of brass. We also did not account for the nuts and bolts in the assembly which is why solid works estimated it to be lighter.

8.7 ER Proof #7 – Pressure Limit within 810 psi.

We attempted to perform a load test on our device using an Instron at the Machine Shop. However, we consulted with Dr. Ciocanel and he felt our device was over-engineered to where our device would be able to withstand our pressure limit. Due to this, we did not prove this worked since our device was designed to be well over based on our safety factors. If we did prove this engineering requirement it would consist of doing a compressive load test on our device to make sure it does not comprise the integrity of the fairing. If the data displayed that our device does not exceed 810 psi this requirement would be successful.

9 LOOKING FORWARD

9.1 Future Testing Procedures

9.1.1 Testing Procedure 1: Vibrations Testing

9.1.1.1 Testing Procedure 1: Objective

The device will be implemented in the Antares rocket which experiences significant vibrational loads on launch and during flight. To ensure the device will survive the duration of the flight and test its functionality it needs to be tested against the required vibration loads. It should be checked that not parts break or fail, and that the intention use goes uninterrupted during flight.

9.1.1.2 Testing Procedure 1: Resources Required

Northrop Grumman will need to use its shaker table to analyze the device for a max of 24 Gs for 9 seconds. The device will likely need to have accelerometers attached to recorded Gs experienced during the test.

9.1.1.3 Testing Procedure 1: Schedule

This test could be conducted within several hours, as the testing time itself will take less than 10-15 seconds. It is recommended to run the test multiple times, as well as change up the frequency and durations of vibrations.

9.1.2 Testing Procedure 2: Additional Function Testing

9.1.2.1 Testing Procedure 2: Objective

For this test, the device should be inserted into the rocket fairing and allow for testing with the intended door and hinge system. The objective is to ensure that the device works as intended for the entire system.

9.1.2.2 Testing Procedure 2: Resources Required

This test will require the rocket fairing, hinge, door, ESC nozzle, and device.

9.1.2.3 Testing Procedure 2: Schedule

This test should be conducted as soon as possible to identify any changes needed to the design. This will require the team to cut a correct size hole in the fairing just below the inlet.

9.2 Future Work

While the team is close on the design there is still further testing and analysis to be done. One of the main things that needs to be done is to fit in the torsion spring to the shaft. The problem encountered before was that the torsion spring would deform inside the housing. The team has identified a new torsion spring that has a smaller wire diameter but will still fit over the shaft. The modifications necessary to allow this to work in the haft will be to cut both ends short, with one bent inward to fit into a small hole drilled at an angle into the shaft. The other end will be long enough to catch on the shoulder inside the housing, holding the spring in place when rotated.

The next aspect of future would be to reduce the thickness of the latch. According to the team analysis, the thickness gives a current factor of safety of about 3-5. This can be reduced to decrease the weight of the device. It is recommended that reduce would take place by shaving down the top of the shaft and/or filleting the edges to reduce any potential drag. This would most likely warrant further analysis and potentially load testing to failure on the part.

The last aspect of the project that needs to be analyzed is vibrational testing. The team was able to do some very basic vibrations tests, but it was not to the necessary standards or guidelines needed. This project requires the part to withstand 24Gs for 9 seconds, which is the max vibrations load during Antares launch. This needs to be done on a vibration table that can handle and produce that load to the part.

10 CONCLUSIONS

For this project, the team was tasked with designing a door that covers the environmental control system inlet in the Antares rocket for Northrop Grumman. The door was designed to close as the rocket launches and remain closed during the entire flight. During flight, the system will experience great variances of temperature, high vibrations, and a large pressure differential that it must overcome. The overall design is also designed to be reopenable and scalable to other systems across client vehicle designs. The team met the overall goal of meeting the objectives designated by NAU and client. And further summary on learning outcomes and reflection are covered in following sections.

10.1 Reflection

The team's highest priority was to have a working design, but it was very important for us to design for safety and environmental concerns. The device needed to be safe to handle by operators, and not cause any damage to the vehicle. It was important that the device did not interfere with any surrounding systems, so we designed it to be ESD safe, not contain contaminants, and be small enough not to interfere with nearby systems.

Our team was able to quickly adapt to the new climate and standards of education during covid. We were able to meet virtually as well as in person when necessary. The team was able to finish all deliverables despite the situation of the world. Most of the design was done in the first semester, with few in person meetings to collaborate on ideas. During the second semester, the team had access to the NAU machine shop to fully manufacture our design. Any times that the team met, in the machine shop we would follow health and safety standards.

10.2 Postmortem Analysis of Capstone

In reflection of the team's work in the past 9 months, there are positive and negative aspects which affected capstone design project performance. We reviewed technical lessons and organizational actions as well as conducted tool, methodology, or practice evaluations as we ended the semester.

10.2.1 Contributors to Project Success

Effective actions the team followed throughout the semester were constant communication and adaptability. These contributors allowed the team to meet initial expectations such as professionalism and accountability. Examples such as these helped ensure the team was on track to meet our purpose to finalize a design, analyze new addition, build a functional prototype, and complete testing. With the implementation of Microsoft Teams and Zoom communication platforms, the team participated in weekly staff meetings, biweekly client meetings to effectively present multiple deliverables virtually. These programs were beneficial since the team was able to schedule times that worked for everyone to attend and allowed for more productive interactions. Additionally, there were ground rules and various strategies that also benefitted our team.

The team practiced the original set ground rules and coping strategies agreed upon for the Team Charter mostly throughout the past semester. For instance, to stay organized we used MS Teams to host documents since it provides flexible access across all devices and in a collaborative fashion. In view of potential conflicts arising from major decisions in a long-term project such as this capstone assignment, we agreed to hold discussions and decisions in a democratic manner to ensure all individuals voice their opinions on the topic at hand. When strong opposing views came up, individuals then shared their rationale followed by a compromise if needed. Ultimately, a majority vote dictated action. Nevertheless, reevaluation of final decisions was also a part of the process to make sure the decision provided the best results in the process to an approved final design. In moments that conflict arose in scheduling all members were quick to respond with availability or last-minute changes to their day as needed in our MS Team chat thus all were aware of what was going on. We had created an action plan if any member showed a lack of participation or failure

to meet tasks, he or she were responsible for, however, we were able to not have this issue due to constant honest communication with reminders, keeping each other accountable, and critical feedback.
Other positive aspects of project performance to highlight as contributors to the success of the project is meeting and sustaining design quality to our client. The final latching design we presented at the Preliminary Design Review to a range of professional engineers received high remarks from the attendees as well as our mentor. This level of feedback continued to our following review at the Critical Design Review when we shared the progress on the action items from the previous semester, 3D proof of concept, and detail breakdowns on testing planned. Then in relation to our coursework, the team managed time well as all deadlines were met with the help of project managers making sure members of the team completed necessary tasks. Our two team leads always delegate roles and tasks making responsibility clear so that the team can assess and resolve for future efficiency towards completing objectives.

The team gained valuable technical lessons, including understanding the engineering process, technical writing, professional deadlines, professional development, and hands on experience in the fabrication shop. Each student was also tasked with a self-learning assignment allowing the students to research and develop a new technical skill. These skills included advanced CAD trainings, electrostatic discharge, mechanical drag and dynamic force analyses.

Another strong technical lesson we learned as a team was how to present a professional technical presentation. We had a lot of presentations for Dr. Trevas, Dr. Oman, and our peers, however the PDR and CDR presentations with our client and experienced engineers are what helped us the most this past year. Not only did we get useful information from the engineering panel, but we also got were given experience on how to properly present in a professional environment as we start our professional careers in the summer as recent graduates.

Overall, observation of the past year showed clearly how the influential elements towards the team's success for our design project were organization, honest communication, and well-fitting team dynamics.

10.2.2 Opportunities/areas for improvement

While the team had great success for most of the project during the past two semesters, there were areas that could be improved upon. The only main goal that was previously stated in the Team Charter that the team did not consistently meet was completing deliverables 24 hours prior to the due date. This goal was set so that members of the team could provide quality work and not feel pressured or rushed to meet a due date. It mainly served to set early deadlines in general and avoid procrastinating. Although each team member agreed on this goal and saw the benefits, it was not consistently met. This led to may late nights trying to make up for lost time, more commonly in the second half of the semester as deadlines numbers increased in conjunction to other course loads. One instance was the team preparing for the Northrop Grumman preliminary design review. Few contributions were made to this presentation until the week before the deadline. This led to the team working consistently for multiple days in a row to get all the content we needed at a high standard of professional work. Because the team has strong communication and high standards the outcome was still high quality, but the stress could have been avoided if the team had a better schedule to uphold earlier deadlines.

Not only were there deadline complications but also communication with our client was not as strong until the end of the first semester. In the beginning our team was under the impression that our goal in the project was to redesign the entire Antares door. However, after asking more specific questions to our client about what we were doing we determined that it was the latching system that we are designing. Understanding this helped our team dial in to latches and allowed us to work cohesively on one latch design rather than looking into the door design as well. Also, during our client meetings and staff meeting there was a misunderstanding to the expectations from our capstone mentor and client. At first our capstone mentor felt are design should encompass a redesign of the door while the client wanted us to focus solely on the latching system. This could have been avoided if as a team we knew what we were responsible for sooner and communicated that to our mentor.

Other learning moments arose in manufacturing and order time management. Since the team utilized the NAU machine shop to complete the design there were delays given unexpected COVID changes and scares, then once we did receive the parts there were slight defects. Given the budget of $8,000 the team realized in reflection we took a conservative approach when it was not required to have our design manufactured at no cost rather outsource the order. After the learning moment, the team outsourced one of the final parts of the design to have it in the assembly in time for testing with the full, final assembly as well as for the team to present at the client handoff meeting. Due to extended timelines for purchase orders and reimbursements there were issues waiting for items to arrive for the team to continue working. This overall affected out time frames to meet deadlines within our projected dates. While all deliverables were met within professional standards, there was added stress and pressure to complete the work which we learned how to address given experienced delays earlier in the process.

Potential for improvement from our team reflection are based off constructive criticism as a team reviewing what worked well and what did not. One method in particular we could build on would be the vibrational testing configuration. The limitations and restriction that COVID presented to our project's client led to the team designing another approach to simulate the movements the assembly could encounter in flights and launch. With the initial thought of having access to a faculty shaker table there was not much additional detailed methods pursed until it was late in the semester. This led to formulating a procedure that would fulfill the requirement given circumstances nevertheless there is room for improving the set to be closer to original ranges and measures.

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12 APPENDICES

12.1 Appendix A: House of Quality/QFD

System QFD

Project: **NG: ECS Door Redesign**
Date: 11/15/2020
Input areas are in yellow

		1	2	3	4	5	6	7
1	Decrease weight							
2	Increase vibrational resistance	-9						
3	Increase yield strength (all hardware)		9					
4	Increase ultimate strength (all hardware)		9					
5	Increase buckling resistance (P/C hardware)	-1	9					
6	Maintain Area Limitations	3		3	3	3		
7	Decrease Crush Ratings (pressure differential)		1					
8	Meets NG Design GD&T	1					9	

Legend	
9	strong relation
6	moderate
3	weak
(blank)	none

moderate	3	
weak	1	

	Customer Needs	Weight	Engineering Requirement	Decrease weight	Increase vibrational resistance	Increase yield strength (all hardware)	Increase ultimate strength (all hardware)	Increase buckling resistance (P/C hardware)	Maintain Area Limitations	Decrease Crush Ratings (pressure differential)	Meets ESD safety	Meets NG Design GD&T
1	Ease /Safety of Installation	7		3								9
2	Scalable	8		1					3			9
3	Re-operable	4		1					1			
4	No Contaminates (FOD)	8									3	
5	Does not soley use gravity	6		3								
6	Activates on launch	10		3	1						3	
7	No interference on nearby systems	9							9		3	9
8	No influence on aerodynamics	9		9					9			
9	ESD safe material	7		3	1				1	1	9	3
10	indicates open/closed status	1									9	
11	Affordable	8		3	3	3	3	3	3	3	3	1
12	Lightweight	10		9		3	3	3		1	3	
13	Reliability	8			9	9	9	9		9	9	
14	Durability	7		3		3	3	3				
	Units of Engineering Requirements			lbm	G	#	#	#	in^2	psi	Y/N	N/A
	Target ER Values			<= 5	Max 70	Min 2	Min 2	Min 2.3	Max 203	7.5	Yes	N/A
	Tolerances			1.00	5.00	0.20	0.20	0.20	0.03	0.50	n/a	n/a
	Absolute Technical Importance (ATI)			318	113	147	147	147	221	113	279	245
	Relative Technical Importance (RTI)			9	2	4	4	4	6	2	8	7
	Testing Procedures (TP#)			#2	#1	#3	#3			#3		#2

Legend	
9	strong relationship
3	moderate
1	weak

Approval

Team member 1: Sam Manglalardi 11/15/2020
Team member 2: Jake West 11/15/2020
Team member 3: Michael Wilson 11/15/2020
Team member 4: Timothy Anderson 11/15/2020
Team member 5: Alex Soto 11/15/2020
Team member 6: Andrea Hernandez 11/15/2020

Client Approval: 11/12/2020

12.2 Appendix B: Budget Analysis

Material	Date	Price ($)
Aluminum 12x12x2"	1/16/2021	313.34
Torsion Springs	1/29/2021	63.48
Machine Shop Tooling	2/17/2021	778.36
1/8" aluminum plate	3/1/2021	54.66
Wood / Power tools	3/5/2021	210.76
Resin / Aluminum Door	3/23/2021	216.11
Saw / Aluminum Sheets	3/20/2021	63.28
Nuts / Washers / Bolts	3/29/2021	29.27
Pin from Xometry	3/31/2021	118.88
	Total	1,848.14

12.3 Appendix C: BOM

Part	Material	Description	Quantity	Unit Cost ($)
Aluminum Stock (Shaft & Housing)	Aluminum 7075 T7	12”x12”x2"	1	100
Aluminum Stock (Plates)	Aluminum 7075 T7	12”x12”x1/8"	1	54.66
Compression Spring	Music Wire ASTM A228	0.1x.75”	1	1
Torsion Spring	302 Stainless Wire	1.131”x6 coils	1	15.87
Steel Bolt	Zinc coated Stainless Steel	3/8”x1”	1	4
Steel Bolts & Nuts	Zinc coated Stainless Steel	1/8”x1”	4	30
			Total	205.53