# Hold Down Release Mechanism
# Team Stellar Hold

## Preliminary Proposal

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# DISCLAIMER

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# 1 BACKGROUND

## 1.1 Introduction

Satellites are typically in a folded/stowed away state until they are in their final position, usually orbit, and then they unfold to become operational. The mechanism that allows this operation is called a hold-down release mechanism, or HDRM. These devices need to be relatively small, hold a desired load, and then release the load upon receiving a command. These must be extremely reliable and non-destructive to the satellite, as if the mechanism fails, the entire satellite is likely to be non-functional and cannot be recovered. General Atomics – Electromagnetic Systems (GA-EMS) offers small scale satellites called CubeSats, ranging in size from a loaf of bread to a refrigerator. They typically source their HDRM's from other companies that have a reliable history of manufacturing these devices. Most HDRM's are single use, which eliminates the possibility to perform multiple tests on a single device.

GA-EMS has tasked the team at Northern Arizona University to begin a design process for their own HDRM. The goal of this project is to eventually have a device that is as advanced as state-of-the-art designs, that GA-EMS can manufacture themselves. Additionally, they need their HDRM to be resettable for multiple uses, to allow each individual device to be tested multiple times for reliability before attaching it to a satellite. This has many benefits for both GA-EMS and the industry.

One main outcome of this project will be GA-EMS saving money on their products. By vertically integrating these satellite components, they will be able to both save money by manufacturing their own product and be allowed to modify it with greater ease to fit their purposes more adequately. Another outcome of this project is potential improvements and advancements in current HDRM technology. As the industry moves away from pyrotechnic (combustible) designs, most HDRM's are still single-use and cannot be reset. By beginning development for a completely resettable HDRM design, it may open or widen a pathway towards safer, more cost-effective resettable HDRM's or lead the industry into an innovation for these mechanisms.

Additional beneficiaries of this project include the clients of GA-EMS satellites. If GA-EMS can provide a mechanism that guarantees greater success of their products, they would likely receive more business. This would also potentially drive down costs of the product due to the increase in reliability and decrease in component costs.

## 1.2 Project Description

The sponsor, GA-EMS, provided a brief introductory project description, reading as follows.

> "Students will develop and work toward a schedule with milestones including a Kickoff Meeting, SRR, PDR, CDR, etc. Performing a Trade Study will inform students of current retention methods of HDRMs and keep GA-EMS abreast of latest vendor technology. Current GA-EMS CubeSat designs will be used to help students develop requirements of HDRM to bound design. GA-EMS will support this project by supplying technical expertise and assisting with the purchase of COTS mechanical and electrical components, if needed. GA-EMS can support students further by allowing use of 3D printers for custom components. For this first year, the HDRM design should remain simple enough to result in an end of year demo."

# 2 REQUIREMENTS

This section will contain information describing what the client requires from the project, and how the team has interpreted and quantified those requirements. As GA-EMS has provided a group of their own engineers to collaborate with us throughout this project, many of the customer requirements they provided are already in the form of engineering requirements. Because of this, some customer requirements have been created based on an engineering requirement provided by GA-EMS. Once the customer requirements and engineering requirements have been introduced, a house of quality, or QFD, is generated and presented later in this section.

## *2.1 Customer Requirements (CRs)*

The following list is comprised of the requirements provided by GA-EMS and their weights, with some minor simplifications. The weights for each requirement are assumed after clarification and discussion with the team and the representatives from GA-EMS. The requirement weights are on a scale from 1-5, with 5 being of highest importance.

1. No space debris
    a. Weight 5. This is a major requirement, as the industry is leaning away from devices that release material into space.
2. Low outgassing
    a. Weight 3. This is important for a device that is being sent to space, however it is not within the budget or design scope for this portion of the project.
3. No pyrotechnics
    a. Weight 5. The HDRM industry is advancing enough to provide better options than pyrotechnic releases.
4. Deploy solar panels sized 20 by 30cm
    a. Weight 3. This is important for consideration, but the scope of the project considers generating a design that functions, with spatial considerations secondary.
5. Cannot protrude >1cm from external face of CubeSat
    a. Weight 4. This device cannot have any part that protrudes more than one centimeter from the outside of the satellite, as it would not be able to fit in its stowed configuration.
6. Deploy all panels simultaneously
    a. Weight 3. This design is primarily focused on HDRM mechanism itself. The team from GA-EMS allows the connection to the solar panels to be considered a secondary task, if necessary.
7. Easily resettable
    a. Weight 5. This is required for testing purposes, and to remain current with state-of-the-art designs.
8. Be able to retain stowed config prior to deployment
    a. Weight 5. The HDRM must reliably hold down any load it experiences through the turbulence and forces before deployment.
9. Release on command
    a. Weight 3. The team from GA-EMS considers the release input command a secondary task, as the primary focus is to develop the mechanism. The NAU team may take on this task if time and budget allow it.
10. Have rotational abilities
    a. Weight 2. This requirement would apply to the hinges on the satellite solar panels. This task may be taken on if time and budget allow it.

## *2.2 Engineering Requirements (ERs)*

The following table list of engineering requirements has been developed based on the customer requirements (Table 1). These are the criteria that the designs will be evaluated against when deciding and weighing unique design variants.

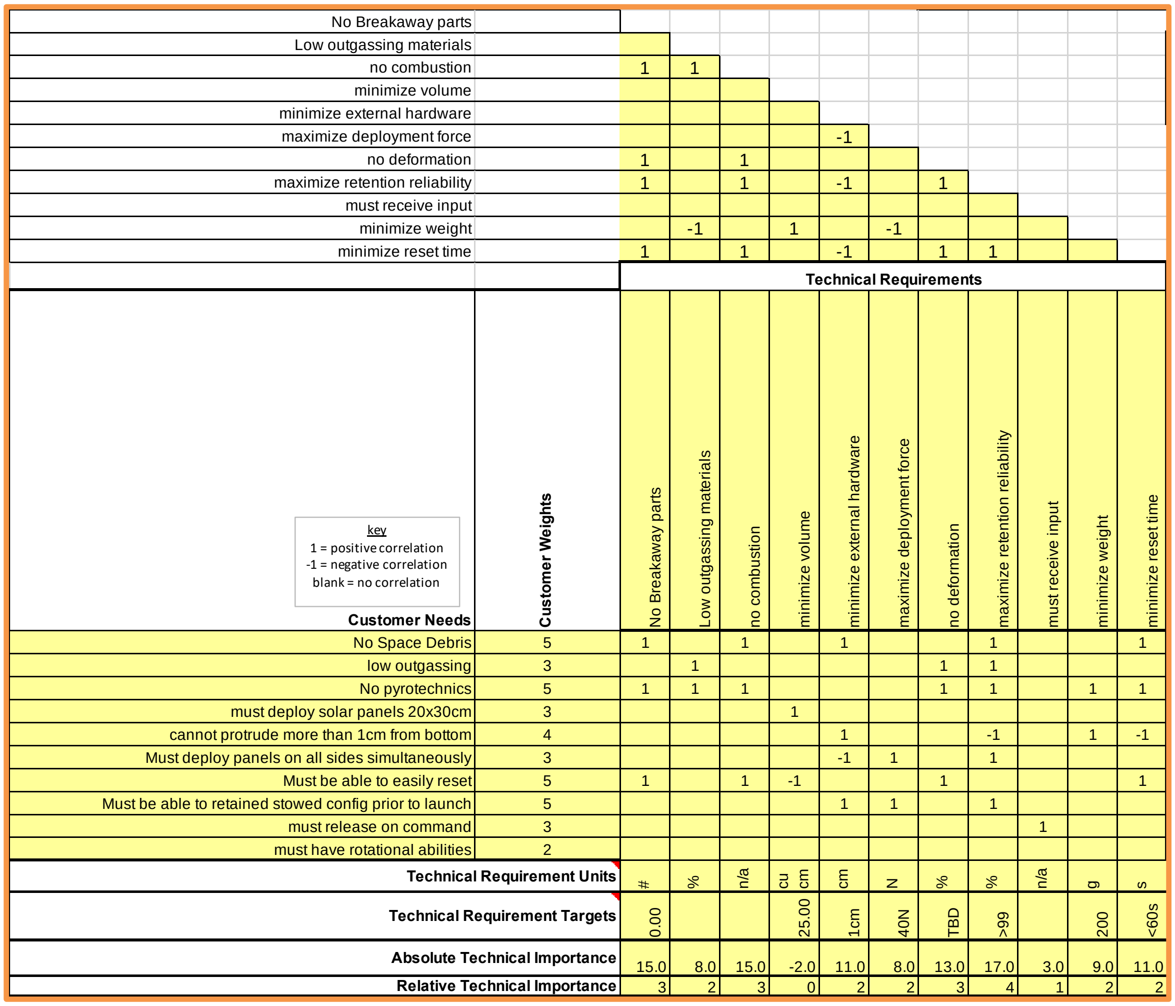
Table 1: Engineering Requirements & Target Values

| **Engineering Requirement** | **Target Value** | **Units** |
|---|---|---|
| No breakaway parts | 0 | # Parts |
| Low outgassing materials | TBD | % |
| No combustion | n/a | n/a |
| Minimize volume | 25 | $cm^3$ |
| Minimize protruding material | 1 | cm |
| Maximize deployment force | 40 | N |
| No deformation | TBD | % |
| Maximize retention reliability | >99 | % |
| Receive input command | n/a | n/a |
| Minimize weight | 200 | Grams |
| Minimize reset time | 60 | Seconds |

## *2.3 House of Quality (HoQ)*

This subsection evaluates the customer and engineering requirements using a house of quality (figure 1) and describes its effectiveness, as well as how it has helped in the design process. This HoQ evaluates the weighted customer requirements and engineering requirements. The comparison sections use the values of -1, 0 (blank) or 1 to denote negative, zero, or positive correlation, respectively, between the two requirements being considered. This helped to determine which technical requirements are most important, with respect to the weight of the customer needs.

Based on this HoQ, the correlation matrix between technical requirements and the customer requirements proposes that reliability is the most important requirement. The requirements of no deformation, no combustion, and no breakaway parts (debris) closely follow reliability in importance. However, minimizing the reset time is not one of the most important technical requirements, according to this HoQ. While this is unexpected, the requirements that are previously mentioned (no deformation, combustion, or debris and max reliability) all positively correlate with minimizing the reset time. This verifies the strong importance on this requirement as imposed by the client, GA-EMS. This HoQ has aided in the design process by placing a strong importance and primary focus on generating a non-destructive design that is both reliable and easily resettable, while keeping volume and weight low are less important at this stage in the process.



| | No Breakaway parts | Low outgassing materials | no combustion | minimize volume | minimize external hardware | maximize deployment force | no deformation | maximize retention reliability | must receive input | minimize weight | minimize reset time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No Breakaway parts | | | | | | | | | | | |
| Low outgassing materials | | | | | | | | | | | |
| no combustion | 1 | 1 | | | | | | | | | |
| minimize volume | | | | | | | | | | | |
| minimize external hardware | | | | | | | | | | | |
| maximize deployment force | | | | | -1 | | | | | | |
| no deformation | 1 | | 1 | | | | | | | | |
| maximize retention reliability | 1 | | 1 | | -1 | | 1 | | | | |
| must receive input | | | | | | | | | | | |
| minimize weight | | -1 | | 1 | | -1 | | | | | |
| minimize reset time | 1 | | 1 | | -1 | | 1 | 1 | | | |

**Technical Requirements**

key
1 = positive correlation
-1 = negative correlation
blank = no correlation

| **Customer Needs** | **Customer Weights** | No Breakaway parts | Low outgassing materials | no combustion | minimize volume | minimize external hardware | maximize deployment force | no deformation | maximize retention reliability | must receive input | minimize weight | minimize reset time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No Space Debris | 5 | 1 | | 1 | | 1 | | | 1 | | | 1 |
| low outgassing | 3 | | 1 | | | | | 1 | 1 | | | |
| No pyrotechnics | 5 | 1 | 1 | 1 | | | | 1 | 1 | | 1 | 1 |
| must deploy solar panels 20x30cm | 3 | | | | 1 | | | | | | | |
| cannot protrude more than 1cm from bottom | 4 | | | | | 1 | | | -1 | | 1 | -1 |
| Must deploy panels on all sides simultaneously | 3 | | | | | -1 | 1 | | 1 | | | |
| Must be able to easily reset | 5 | 1 | | 1 | -1 | | | 1 | | | | 1 |
| Must be able to retained stowed config prior to launch | 5 | | | | | 1 | 1 | | 1 | | | |
| must release on command | 3 | | | | | | | | | 1 | | |
| must have rotational abilities | 2 | | | | | | | | | | | |
| **Technical Requirement Units** | | # | % | n/a | cu cm | cm | N | % | % | n/a | g | s |
| **Technical Requirement Targets** | | 0.00 | | | 25.00 | 1cm | 40N | TBD | >99 | | 200 | <60s |
| **Absolute Technical Importance** | | 15.0 | 8.0 | 15.0 | -2.0 | 11.0 | 8.0 | 13.0 | 17.0 | 3.0 | 9.0 | 11.0 |
| **Relative Technical Importance** | | 3 | 2 | 3 | 0 | 2 | 2 | 3 | 4 | 1 | 2 | 2 |

Figure 1: House of Quality for the HDRM

# 3 DESIGN SPACE RESEARCH

Designing a technical product, like a hold down and release mechanism, requires extensive research into a variety of areas. Important topics to take into consideration include existing HDRM designs and the different approaches to designing an HDRM. An overview of the sources each team member used for design research and benchmarking will be provided in this section.

## *3.1 Literature Review*

Each team member has conducted preliminary research on aspects of the project that are relevant to their role in the team and the success of the project. This research aids in initial design and benchmarking processes. Additionally, this benefits the team in understanding basic limitations for designs, as this research leads into a greater understanding of current state-of-the-art products described in section 3.2. As the project progresses further into design iterations and prototyping, further research will be conducted to continually ensure feasibility and guide the team through the project.

### 3.1.1 Valentin Gamez

Valentin is leading both the CAD and Manufacturing development of the project. The resources that benefit Valentin will include company websites that have existing HDRM CAD designs, shape memory alloy research papers, and several patents.

1. EBAD Website [1]

EBAD is a supplier that manufactures and sells HDRMs to aerospace companies. Their website includes data sheets, specifications on designs, and CAD models. This website will be a crucial source of information for the design process. EBAD will be able to provide specific dimensions, materials, and inspiration for designs.

2. Shape Memory Alloys Behavior: A Review [2]

Shape memory alloy will be a key material in the team’s design. Knowing the material’s properties and behaviors will be important as the team will be aiming to manipulate the material’s properties however, they can. This peer-reviewed paper goes into detail about the materials properties and behaviors. The most important area this paper covers is the relationship between SMA and temperature. Valentin will need to know this information since the design will involve changing the temperature of the material to change its shape.

3. NASA/GSFC Design References [3]

This Nasa design reference resource contains numerous documents regarding material specifications, drafting and drawing standards, and other useful information for manufacturing. This will be a great resource for CAD models, drawings, and for the manufacturing process. It will also be extremely helpful for finding the correct materials to use for building the HDRM.

4. HDRM with Integral Sensing Patent [4]

Referencing other HDRM designs can help spark inspiration for unique designs. This patent is for an HDRM that contains integral sensing. This sensor is configured to sense a parameter of interest. This concept could potentially inspire future design changes.

5. HDRM for a Deployable Satellite Solar Panel Patent [5]

Another patent that has proven useful is the HDRM for a deployable satellite solar panel. Since the team's goal is to design an HDRM for a CubeSat it shares a similar concept to this patent. There are plenty of drawings to reference that help visualize how an HDRM works. These drawings can help with creating a prototype with a satellite as they show where the HDRMs are placed on the satellite.

### 3.1.2 Nathan Olson

Nathan's roles include leading testing processes and procedures for the prototypes and final fabricated model. The majority of this will take place between August 2022 and December 2022, from weeks 17-32 of the project timeline. The documents reviewed include specifications on CubeSat dimensions, testing procedures and guidelines, as well as the environmental conditions device will experience on the spacecraft before it is deployed.

1. PAYLOAD SPECIFICATION FOR 3U, 6U AND 12U [6]

This document outlines specifications on the dimensions and design criteria for payload designers. This document will aid in providing a semi-realistic demo model for testing the prototype device and final device. Additionally, it provides details on mass properties and locations of hardware, components, and cutouts (such as holes/slots) that may be seen on a CubeSat. The contents of this document will allow the team to design this mock CubeSat to closely model the relationship the HDRM will have with a real satellite.

2. GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) For GSFC Flight Programs and Projects [7]

Although extensive testing and certification for space travel is not in the scope of this 32-week project, basic testing will be required to verify feasibility and room for future improvements on this device. This may include structural/mechanical, electromagnetic, thermal and containment considerations. By reviewing this document, the team will be able to conduct basic testing of these requirements and provide insight and adequate reason guaranteeing that future improvements will allow our design to meet these environmental verification standards.

### 3.1.3 Maia Warren

Maia's roles include communication between the HDRM team and the GA-EMS team, and budgeting all expenses for travel, manufacturing, repairs, testing and parts. The budget was made early in the first semester simultaneously with designing the HDRM so the parts would be listed out, but the majority of the budget will not be used until the second semester after travel is paid for and parts are ordered during testing.

1. Previous Capstone Team [8]

One of the sources we have been checking with quite frequently is the previous GA-EMS Mechanical Engineering CubeSat capstone team [8]. The website they created allowed our team to double check the expenses on their Bill of Materials for travel and plan out how much we need to budget since we will be going on the same trip. Although much research was done through airlines and hotels on our own, their list was beneficial to determine when we needed to begin making purchases to match the same budget they successfully used. We have also been able to use the dimensions from the CAD models they included on their website so we can base the size of our HDRM from the CubeSat they built.

2. Online Source [9]

A YouTube video called "Hold-Down and Release Mechanisms for Non-Pyrotechnic for Release of Satellites and Appendages" [9]. This video broke down the basic functions of HDRMs and the most common methods of building them. It included animations showing the process from hold to release of each design, so we understood the stages. The main type of HDRM the video explained was non-pyrotechnic methods which helped the team a lot because of a customer requirement being no explosive methods. The video also showed multiple sizes so we could get dimension ideas for what we might aim for to fit into the CubeSat.

3. Meeting with the GA-EMS team [10]

Our team meets with the GA-EMS team weekly to go over progress and answer any questions either team might have. The GA-EMS team consists of five engineers with different roles, so they are equipped to help in any area [10]. During these weekly meetings, the engineers have provided useful information for our team such as engineering requirements, customer needs, engineering documents with testing information, dimensions, deadlines, etc. The team has so far ensured that we are kept on schedule and are meeting requirements that combine Dr. Pete's with their own.

4. McMaster-Carr [11]

Another source the team has used is McMaster-Carr.com which is a website that has every part we might need, along with information on prebuilt HDRMs as well [11]. While we began to order parts from amazon solely for testing purposes, we used McMaster-Carr to see what products we might need when building the final device that will be presented and how much we should budget for each individual part. The website sells parts more specific to engineering, some of which may only be used for the final product, and some that with be beneficial for testing.

5. Journal Article [12]

This article was used to learn more about how to use shape memory alloys and why they are beneficial in HDRMs [12]. It explained the difference between using materials like Nitinol and Frangibolt and how they are used in specific devices. This article helped to narrow down the materials we wanted to use and allowed us to decide on Nitinol, which we have now ordered and begun testing with. It also gave us ideas of how shape memory alloys have been used in the past and how we can improve upon the existing designs.

## *3.2 Benchmarking*

The benchmarking process for this project has been conducted through internet research and discussions with the representative team of engineers from GA-EMS. Specific areas of focus during this process include non-pyrotechnic designs and resettable designs, as those are design criteria defined by the client. Additional areas of focus during this process are common shapes and sizes for similar devices. After identifying some products to benchmark, the subsystems are benchmarked to compare functions, allowing a thorough analysis and break-down of these products.

### 3.2.1 System Level Benchmarking

#### *3.2.1.1 Existing Design #1: First Move HDRM*

The first existing design that the team found during the benchmarking phase was the First Move HDRM (figure 2). This student designed HDRM worked “flawlessly” during ground testing [13]. It successfully deployed in orbit as well. This design meets a few of our engineering requirements such as no pyrotechnics, low outgassing, and no space debris. However, one requirement the First Move HDRM does not meet is the that the device is not resettable. For the device to release it must melt a dynemma string and can only be reused by replacing this string. This is the designs biggest flaw, and it is the team's most important engineering requirement. The team can take inspiration from this design and what it did successfully, while improving the reset ability of the mechanism.

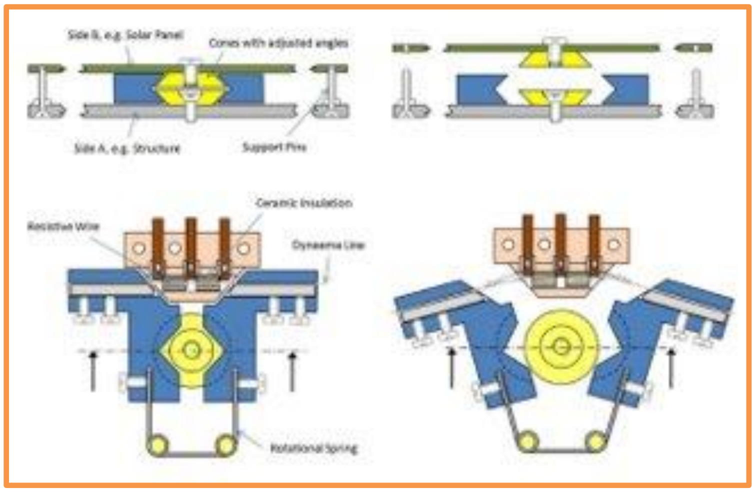


Figure 2: First Move HDRM

### 3.2.1.2 *Existing Design #2: EBAD TiNi Pin Puller*

The next design is the EBAD TiNi Pin Puller (figure 3). This is the model that General Atomics previously used and meets all the team’s engineering requirements. The TiNi Pin Puller is a fitting example of an HDRM that the team eventually plans to build. The device works by retracting a pin which release the CubeSat panels. It can be reset using an additional device, see figure 4. While this device does have a method for resetting, the team would like to improve this by eliminating the second device and can self-reset. This function can be seen in the next existing design.

Figure 3: Tini Pin Puller

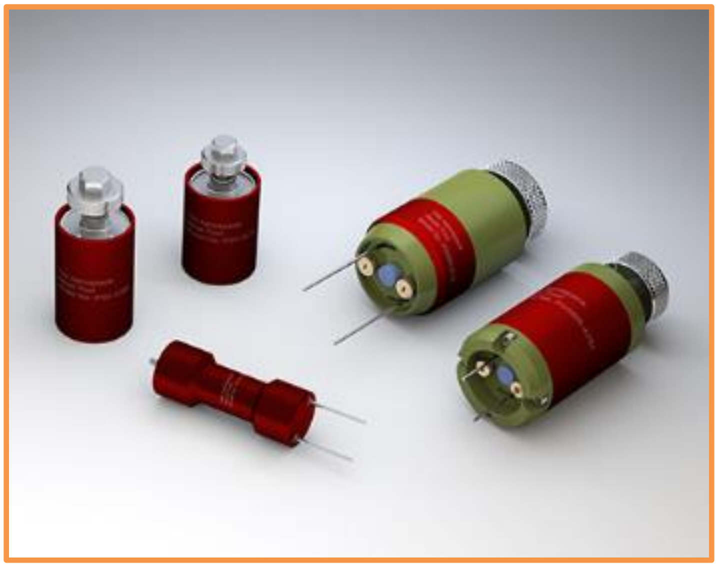


Figure 4: Tini Pin Puller Reset Device

#### 3.2.1.3 *Existing Design #3: React HDRM*

The REACT HDRM (figure 5) is a resettable non pyrotechnic device that utilizes a shape memory alloy actuator. This device perfectly meets all of the engineering requirements and has the best reset mechanism. The SMA material is the key component that allows for such a great device.

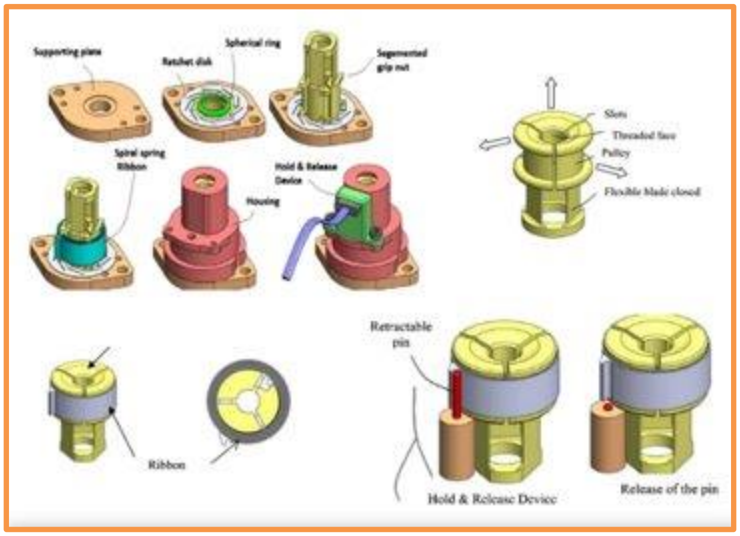


Figure 5: React HDRM

### 3.2.2 Subsystem Level Benchmarking

#### 3.2.2.1 *Subsystem #1: Hold Type*

The first subsystem is hold type, which is responsible for holding the CubeSat in the folded position. The hold type is an important subsystem of an HDRM as the device must be able to support enough weight.

##### 3.2.2.1.1 Existing Design #1: First Move HDRM

The First Move HDRM is held together by a dyneema string. A dyneema string is a strong durable material that can support the required weight.

##### 3.2.2.1.2 Existing Design #2: EBAD TiNi Pin-Puller

Design 2 uses a pin to hold together the CubeSat panels. A weight can be hooked around the pin, the panels to stay in place. This is a popular and reliable method for HDRMs.

##### 3.2.2.1.3 Existing Design #3: React HDRM

The React HDRM uses the pin pusher method. A pin is attached to the HDRM and to the CubeSat, holding the two together. This is another effective method that is commonly used.

#### *3.2.2.2 Subsystem #2: Release Type*

Once the satellite has been launched into orbit, the HDRM must be able to release the panels. Without a functional release mechanism, the satellite would not be functional, meaning this is an important subsystem.

##### 3.2.2.2.1 Existing Design #1: First Move HDRM

First Move's release mechanism involves melting the dyneema string that holds everything together. Once the string has been melted it opens the contraption, see figure 2.

##### 3.2.2.2.2 Existing Design #2: EBAD TiNi Pin-Puller

The Pin-Puller releases the payload by pulling in the pin that is supporting the weight. Once the pin is pulled in the panels will spring out due to the hinges that are attached to them.

##### 3.2.2.2.3 Existing Design #3: React HDRM

The React HDRM does the opposite of the pin-puller. Rather than pulling in the pin it pushes out the pin attached to the satellite. This will allow the panels to open freely.

#### *3.2.2.3 Subsystem #3: Reset Mechanism*

The reset mechanism is key to saving time, money, and assessing the reliability of the device. It allows for the device to be tested repeatedly and get an understanding of how reliable the device is.

##### 3.2.2.3.1 Existing Design #1: First Move HDRM

This design's biggest weakness is its reset mechanism. The First Move HDRM can be used again after soldering a new dyneema wire. This current method is not reliable since putting together new parts creates a new untested device, making it difficult to determine how reliable the device is.

##### 3.2.2.3.2 Existing Design #2: EBAD TiNi Pin-Puller

The Pin-Puller uses a secondary device to reset the HDRM, see figure 4. By inserting the device into the HDRM, one can quickly reset the pin position and allow it to run again.

#### 3.2.2.3.3 Existing Design #3: React HDRM

React HDRM uses an SMA actuator to automatically reset the device. Since SMA's shape can be manipulated using temperature, this allows for many innovative solutions to making the device resettable.

## *3.3 Functional Decomposition*

### 3.3.1 Black Box Model

This black box model, shown in figure 6, summarizes the inputs, functions, and outputs of the device. The process begins by securing the load (in this case, a panel), then energy is supplied upon receiving a command signal. The device releases the panel, which is moved to its operational location, and a confirmation of release is sent to the operator. When put simply, the device holds a load, and then when energy is supplied, it releases the load.

Figure 6: Black Box Model

### 3.3.2 Functional Model

The functional model for an HDRM system is relatively simple; what makes it such a complex device is maximizing reliability and making it safe for space travel. Figure 7 outlines the flow of functions that the device performs to complete its task. Notice the model contains a loop; this is because the HDRM we are designing can be used again if the mechanism is reset manually and the panel is placed back into its stowed position.0

This model aids the team by providing a visual representation of how what the device must do. Often this model is overly complex, depending on the device it is representing. The simplicity of this model, however, allows the team to easily understand the function flow of the device.

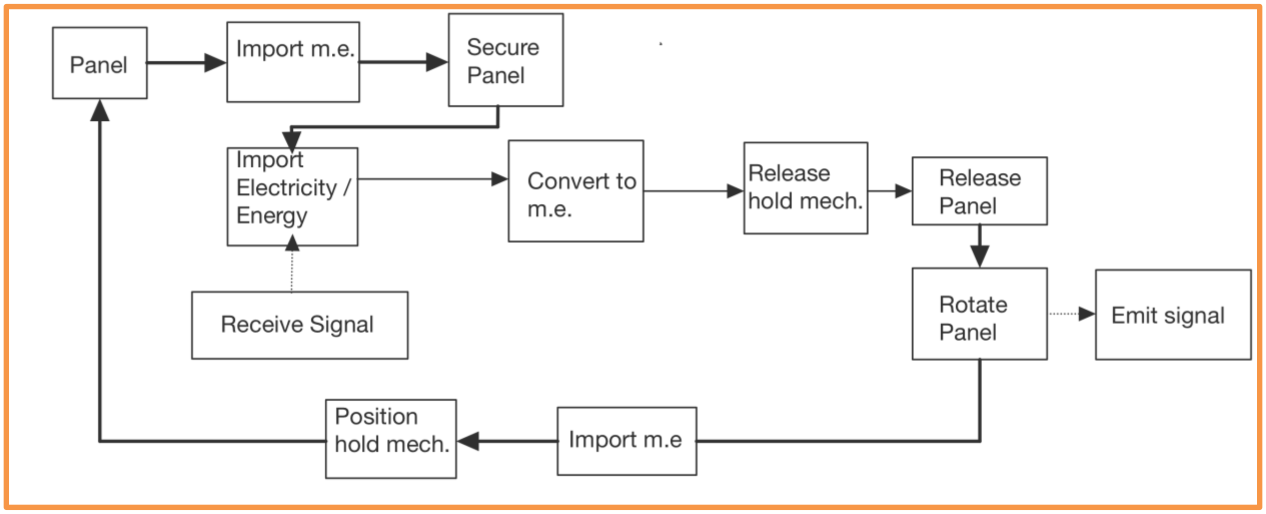
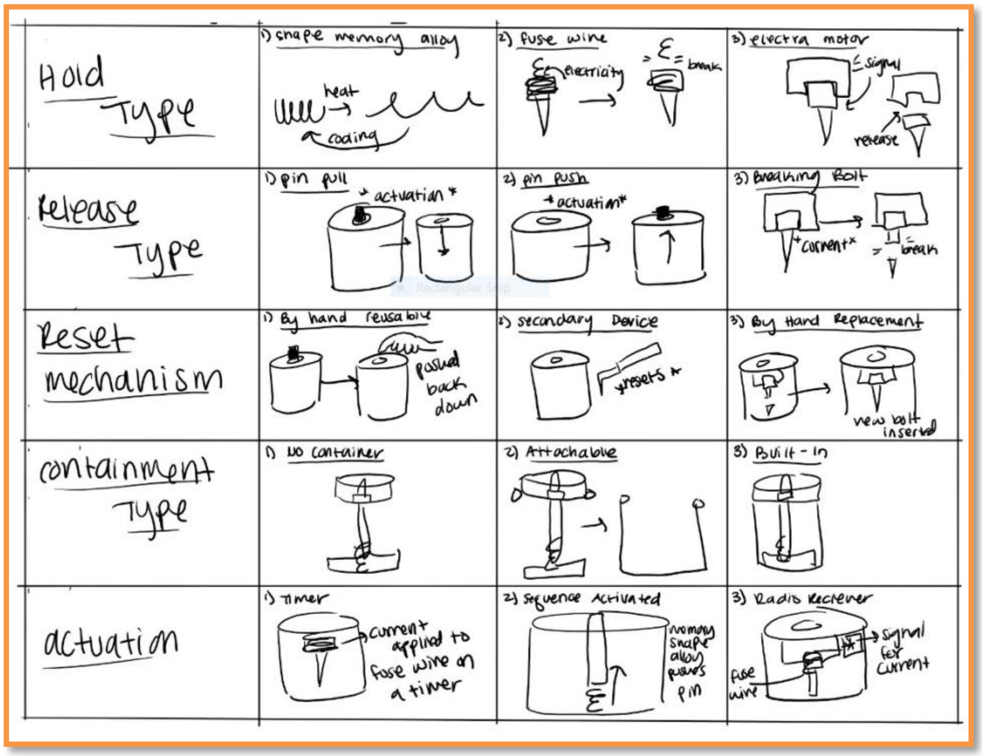


Figure 7: Functional Model

# 4 CONCEPT GENERATION

Upon understanding of current state-of-the-art mechanisms and designs, each of the three team members brainstormed and sketched a potential HDRM design. Then, these ideas were analyzed as a group, from which the sub-functions were defined, and design concepts generated. The team then generated multiple feasible design alternatives for each sub-function in a morphological matrix. This matrix can be seen in figure 8. Six different full-system concepts were generated, and then evaluated using the methods in section 5. The top three concepts are sketched and shown in section 4.1.



| | | | |
|---|---|---|---|
| Hold Type | 1) shape memory alloy | 2) fuse wire | 3) electra motor |
| Release Type | 1) pin pull | 2) pin push | 3) Breaking Bolt |
| Reset mechanism | 1) By hand reusable | 2) secondary Device | 3) By Hand Replacement |
| containment Type | 1) No container | 2) Attachable | 3) Built-In |
| actuation | 1) Timer | 2) Sequence Activated | 3) Radio Reciever |

Figure 8: Morphological Matrix

## 4.1 *Full System Concepts*

### 4.1.1 Full System Design #1: Pin Releaser

The following design is a pin-pusher (releaser) design. The illustration in figure 9 shows a cross-section of this concept. The lock parts drawn in green are biased closed, as seen in the left side. A wedge above it is forced down with the expansion of a spring, pushing the lock parts aside and allowing the pin to freely exit the container. The spring is made on nitinol shape memory alloy, to allow it to be actuated using heat generated by electrical current and reset without replacing parts.

**Pros**

- Reliable locking
- Resettable
- Potential to be a heavy design

**Cons**

- Mechanically complicated – difficult to manufacture
- Takes up significant "vertical" space (along axis of pin)
- Needs to be contained due to the pin being fully released

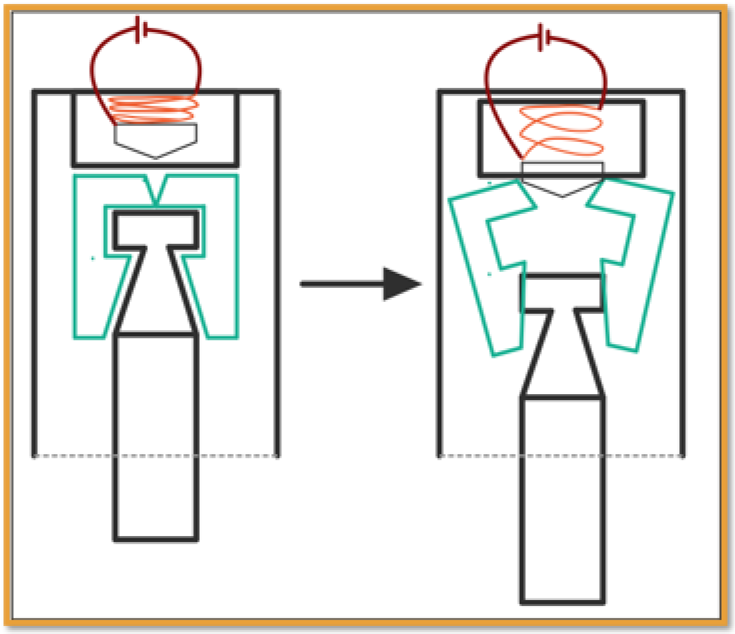


Figure 9: Pin Releaser

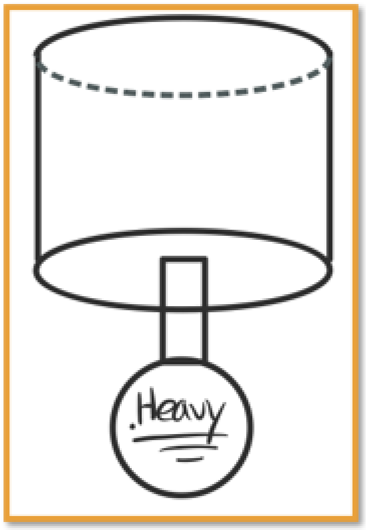


Figure 10: Pin Releaser Pay Load View

### 4.1.2 Full System Design #2: SMA Actuator

This design uses existing principles of shape memory alloy springs to result in a mechanism that resembles a linear actuator. Figure 11 illustrates this mechanism. There exists two springs, separated by a divider which is connected to the output pin. The leftmost spring is a regular spring to bias the output pin to the right (relative). The rightmost spring is made of shape memory alloy, which when heated up with electrical current, overcomes the bias spring and drives the output pin into the mechanism.

**Pros**

- Simple mechanism
- Can be made relatively small
- Easily resettable

**Cons**

- No locking mechanism – free moving
- Temperature change much be quick and consistent
- Difficult to ensure the current is reliable enough to actuate while in orbit

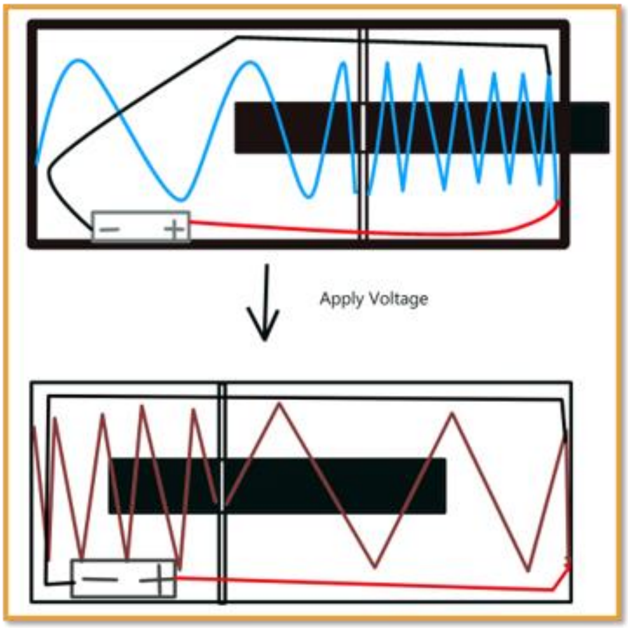


Figure 11: SMA Actuator

### 4.1.3 Full System Design #3: Locking SMA Actuator

This design functions by pulling the output pin inwards to the mechanism. A bias spring (top) under compression pushes the output pin inwards, stopped by a lock. A release mechanism on the lower portion of the design is engaged to disengage the lock via SMA. Once the lock is released, the compressed bias spring extends, pulling the output pin into the mechanism. This can be seen in figure 12, showing a top view on the left and a cross section side view on the right.

**Pros**

- Locking
- Easily resettable

- Solar panel lock(s) may be easily attached to the center output pin

**Cons**

- The bottom spring must be stronger than the weight of the above mechanism
- Temperature change must be consistent
- The locks must move fluidly

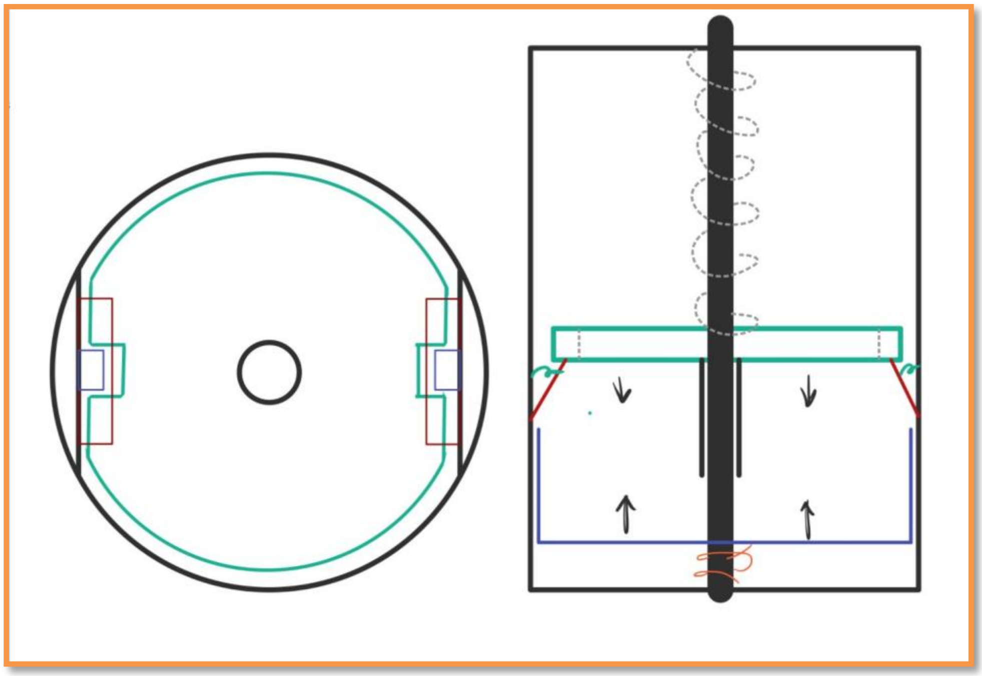


Figure 12: Locking SMA Actuator

## *4.2 Subsystem Concepts*

The following includes the subsystem design concepts for the project.

### 4.2.1 Subsystem #1: Hold Type

The hold type designs that were created have been used in previous HDRMs and our team is now attempting to improve upon them to create a new holding design. The hold type is the first of two positions the HDRM reaches.

#### *4.2.1.1 Design #1: Shape Memory Alloy*

Our team has considered using a shape memory alloy as the hold type for our HDRM because of its ability to be first molded and then change its shape by conducting a change in temperature. The temperature change has to be consistent and reliable, but it is ultimately a simple holding method due to how easily the shape memory alloy can be manipulated.

#### *4.2.1.2 Design #2: Fuse Wire*

The fuse wire has also been considered for the innovative design because it is a reliable holding type that can be manipulated around any part by simply wrapping and without any temperature change needed. Once the device is actuated, a current will be applied to break the fuse wire and cause a release. The fuse wire is easily resettable by hand but relies on a consistent current and produces waste from the broken wire.

#### *4.2.1.3 Design #3: Electra Motor*

The electronic motor will hold all parts of the HDRM into place and only release once a signal has allowed it to. This method uses electricity to complete its task, so it is not reliant on position, but the design options are limited since it will require an external signal to release the solar panels.

### 4.2.2 Subsystem #2: Release Type

The release type designs that were created have been used in previous HDRMs and our team is now attempting to improve upon them to create a new releasing design. The release allows the HDRM to reach its second and final position.

#### *4.2.2.1 Design #1: Pin Pull*

The pin pull release method works by holding a pin in place and allowing it to be pulled into the device during actuation and move the HDRM into its new position. The pin pull method is reliable since it works from device movement and gravity, but it requires a smooth track for all parts of the device to function properly through multiple tests without ware.

#### *4.2.2.2 Design #2: Pin Push*

The pin push release method works by holding a pin in place and pushing it towards to outside of the device during actuation. This step also allows the HDRM to move into its new position. The pin push method also relies on a smooth, ware resistant track and makes the device easily resettable.

#### *4.2.2.3 Design #3: Breaking Bolt*

The breaking bolt release method works by holding a pin in place and applying a current to break the bolt, creating room for the HDRM to move into the second position. The breaking bolt method is reliable since it works from pressure and gravity, but it requires a containment device to catch the broken pin and is entirely dependent on current.

### 4.2.3 Subsystem #3: Reset Mechanism

The reset mechanism designs that were created have been used in previous HDRMs and our team is now attempting to improve upon them to create a new resetting design. Resetting is important while testing because the device must prove to be durable enough for multiple uses.

#### *4.2.3.1 Design #1: By Hand Reusable*

The by hand reusable rest mechanism is the most efficient and cost-effective method because it does not require any replacement of parts or extra devices to aid the reset while performing multiple tests. The difficult part of using this method is creating a simple enough design that does not require any new parts or cause ware during testing.

#### *4.2.3.2 Design #2: Secondary Device*

A secondary device could cause expenses to rise and require more time during testing, however it could simplify the HDRM design by removing parts that are meant for a reset from within the device itself. There would be a second device to design and test and may create more room for error.

#### *4.2.3.3 Design #3: By Hand Replacing*

By hand replacement is simpler than using another device and will be easier to manipulate the new parts around the remaining ones. This method will allow for waste of products since the team can remove the waste after each test, but this may also increase the price of the HDRM since more parts are required per test.

### 4.2.4 Subsystem #4: Containment Type

The containment type designs that were created have been used in previous HDRMs and our team is now attempting to improve upon them to create a new containment design. Containment is important if the design breaks or releases parts.

#### *4.2.4.1 Design #1: No Container*

The price and the weight of the HDRM design, without including a container, will be lower due to less material being attached; however, it limits the design options because there can be no waste or breaking parts since there will be nothing to catch them and keep them from turning into space debris.

#### *4.2.4.2 Design #2: Attachable*

The attachable container provides a way to catch any waste from broken or released products and allows for an easy removal of the waste when detached. There is also a higher risk of error since the design is built to be removed and could be weaker when withstanding space conditions.

#### *4.2.4.3 Design #3: Built-In*

Built in containment will be the simplest design for the HDRM because it will provide freedom for all design ideas that include breaking or released parts. It will also be sturdier than the detachable containment but will make it difficult to remove the waste when resetting.

### 4.2.5 Subsystem #5: Actuation

The actuation designs that were created have been used in previous HDRMs and our team is now attempting to improve upon them to create a new actuating design. Actuation is the most crucial step for the device because it determines if the HDRM can perform its tasks.

#### *4.2.5.1 Design #1: Timer*

An internal timer can limit error during actuation because the device will not have to wait for an outside signal and there are fewer steps that need to be completed to begin its tasks. The timer must be tested until deemed reliable and it must allow actuation to occur in the right amount of time to allow the HDRM to unfold perfectly.

#### *4.2.5.2 Design #2: Sequence Activated*

There is more room for error when using a sequence activated method because if a step in the sequence malfunctions the actuation could never occur, rendering the HDRM useless and wasting the parts and funding. The benefit of using the sequence method is that the actuation happens internally and does not rely on outside signals.

#### *4.2.5.3 Design #3: Radio Receiver*

The radio receiver could be a trustworthy form of actuation because if there is no error the HDRM can be told exactly when to unfold by humans remotely, removing device error. The risk of using an outside signal is that the connection could break upon sending the part through the detumble stage and turbulence could disturb the housing of the radio receiver.

# 5 DESIGNS SELECTED – First Semester

The following section will focus on the three designs that received the highest weight from the Pugh Chart, resulting in the final designs that the team will move forward with when looking towards prototyping and testing. This section will show a breakdown of components used to weigh the designs and will then explain why the components received their specific weighting.

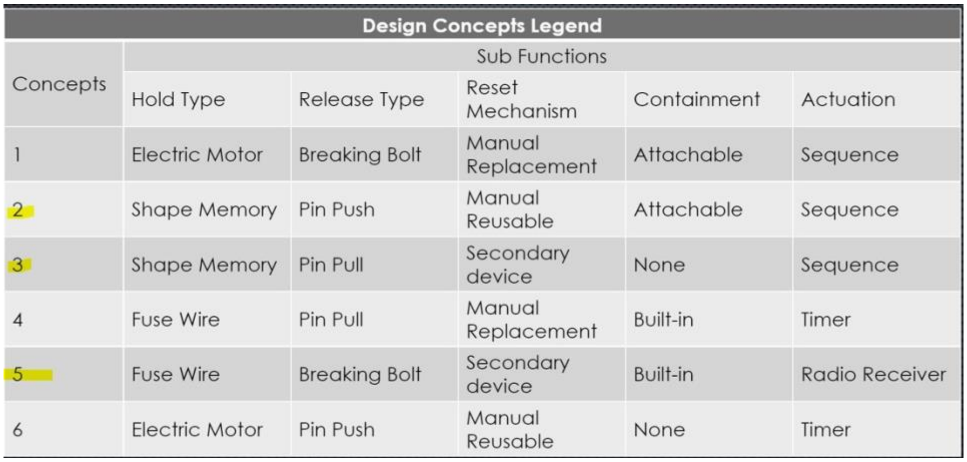
## 5.1 *Technical Selection Criteria*

The team has decided to use a list of ten different criteria in the Decision Matrix and five technical requirements on the Pugh Chart that we feel represents the customer and engineering requirements given to our team by GA-EMS and added into the HoQ. The top three designs were determined using the morphological matrix and will now be weighed against all ten criteria to find the design that best satisfies the technical requirements and criteria.

## 5.2 *Rationale for Design Selection*

Shown below is the decision legend (table 2) and the decision matrix (table 4) where the performance is estimated by weight for each of the three designs. After the weight was determined, our team decided that Design 2 and Design 3 would be the best designs to proceed with due to how close their scores were. These designs will continue to be drawn into CAD models to help decide which one will be prototyped. At the moment Design 3 received the highest score and will be the first to be tested, leaving Design 2 as a backup.

Table 2: Design Legend

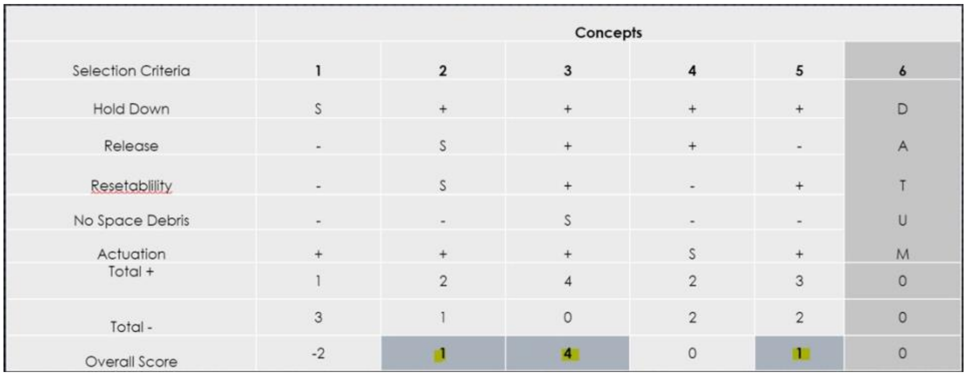


**Design Concepts Legend**

| Concepts | Sub Functions | | | | |
|---|---|---|---|---|---|
| | Hold Type | Release Type | Reset Mechanism | Containment | Actuation |
| 1 | Electric Motor | Breaking Bolt | Manual Replacement | Attachable | Sequence |
| 2 | Shape Memory | Pin Push | Manual Reusable | Attachable | Sequence |
| 3 | Shape Memory | Pin Pull | Secondary device | None | Sequence |
| 4 | Fuse Wire | Pin Pull | Manual Replacement | Built-in | Timer |
| 5 | Fuse Wire | Breaking Bolt | Secondary device | Built-in | Radio Receiver |
| 6 | Electric Motor | Pin Push | Manual Reusable | None | Timer |

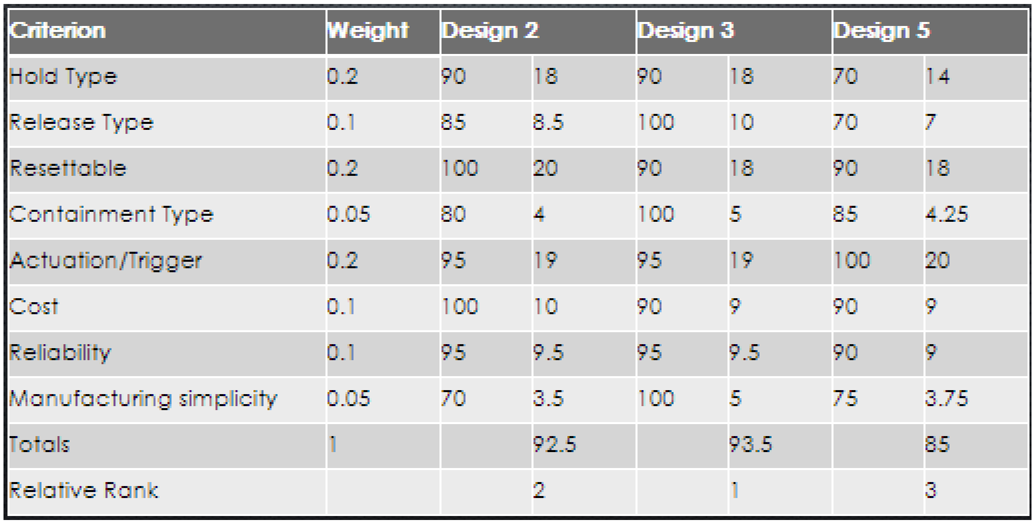
Table 3 is the Pugh Chart which was used to weigh the original five designs against the datum, or a functional existing design. The numbers and “-/+” symbols predicted correspond to whether the devices are weighted better or worse than the datum, and if the design received a “0” the design was deemed equal to the datum. The results from the Pugh Chart tell the team that Design 1 is predicted to perform worse, Design 4 will perform equally, and Design 2,3,4 will perform better than the datum. The results also show that Design 3 has by far the highest weight and is predicted to be the leading design. F

Table 3: Pugh Chart



| | Concepts | | | | | |
|---|---|---|---|---|---|---|
| Selection Criteria | 1 | 2 | 3 | 4 | 5 | 6 |
| Hold Down | S | + | + | + | + | D |
| Release | - | S | + | + | - | A |
| Resetablility | - | S | + | - | + | T |
| No Space Debris | - | - | S | - | - | U |
| Actuation | + | + | + | S | + | M |
| Total + | 1 | 2 | 4 | 2 | 3 | 0 |
| Total - | 3 | 1 | 0 | 2 | 2 | 0 |
| Overall Score | -2 | 1 | 4 | 0 | 1 | 0 |

Table 4: Decision Matrix



| Criterion | Weight | Design 2 | | Design 3 | | Design 5 | |
|---|---|---|---|---|---|---|---|
| Hold Type | 0.2 | 90 | 18 | 90 | 18 | 70 | 14 |
| Release Type | 0.1 | 85 | 8.5 | 100 | 10 | 70 | 7 |
| Resettable | 0.2 | 100 | 20 | 90 | 18 | 90 | 18 |
| Containment Type | 0.05 | 80 | 4 | 100 | 5 | 85 | 4.25 |
| Actuation/Trigger | 0.2 | 95 | 19 | 95 | 19 | 100 | 20 |
| Cost | 0.1 | 100 | 10 | 90 | 9 | 90 | 9 |
| Reliability | 0.1 | 95 | 9.5 | 95 | 9.5 | 90 | 9 |
| Manufacturing simplicity | 0.05 | 70 | 3.5 | 100 | 5 | 75 | 3.75 |
| Totals | 1 | | 92.5 | | 93.5 | | 85 |
| Relative Rank | | | 2 | | 1 | | 3 |

After careful evaluation of all the designs, design 3 was the highest ranked design. A CAD model is shown below in figure 13. The team generated this CAD model using simple shapes that are convenient for 3D modeling. The goal for this initial model is to be able to assemble it with ease and show proof of concept with the SMA springs. This CAD model will be 3D printed to create the first prototype.

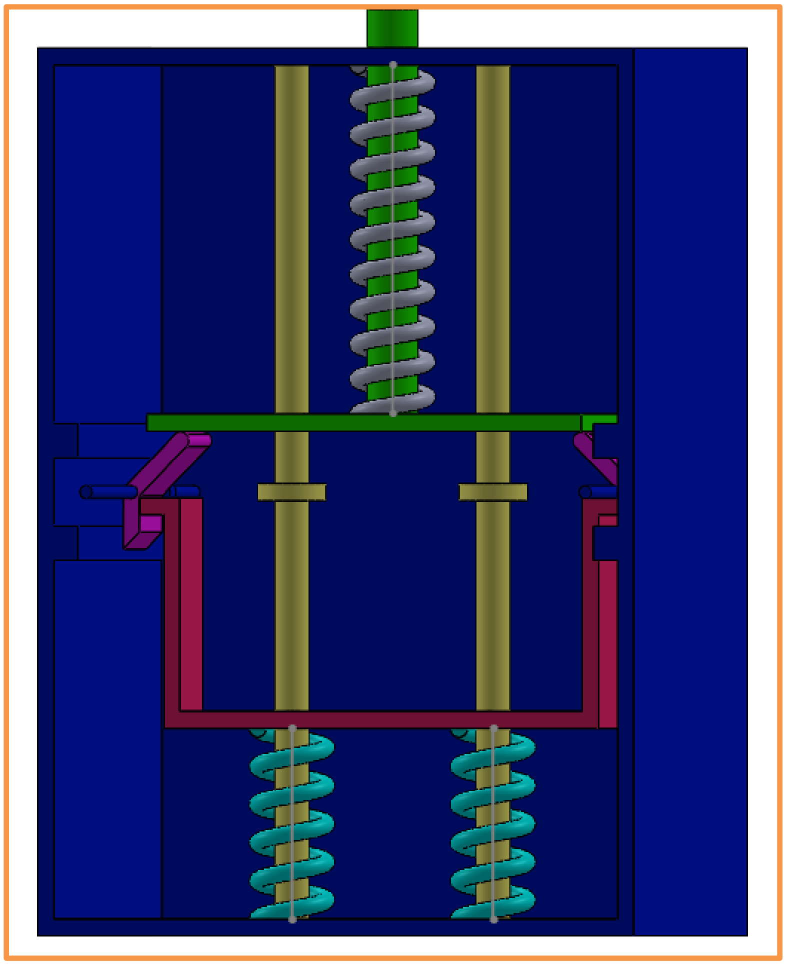


Figure 13: Design 3 CAD

# 6 SCHEDULE

The following section provides a brief update on the team's progress in the context of the scheduled timeline. Currently, the team is on week 10 out of 16 for semester 1. The goal by week 16 is to have a finalized design and CAD with an animation visual aid. Leading up to that, analyses on feasibility and system requirements will be conducted, CAD will be completed and additional research into manufacturing the final design will be conducted. Moving into next semester, where an additional 16 weeks are allotted, Prototyping, and manufacturing a final design will lead to a final demonstration in the ending weeks. A simplified schedule for weeks 1-16 is shown in table 5. The Gantt chart for weeks 10-16 can be seen in appendix A**.**

Table 5: Schedule for Weeks 1 to 16

| Legend | Current Week | Next Week |
|---|---|---|

| Week | Week Start | Agenda / Due | Date Due | Description |
|---|---|---|---|---|
| 1 | 10-Jan | | | concept generation |
| 2 | 17-Jan | | | |
| 3 | 24-Jan | | | |
| 4 | 31-Jan | Presentation 1 | 3-Feb | |
| 5 | 7-Feb | | | |
| 6 | 14-Feb | | | |
| 7 | 21-Feb | Presentation 2 | 22-Feb | Concept gen/ starting selection |
| 8 | 28-Feb | | | Concept selection / PDR |
| 9 | 7-Mar | Website Check | 11-Mar | |
| — | 14-Mar | PDR Memo | 20-Mar | |
| 10 | 21-Mar | | | |
| 11 | 28-Mar | Presentation 3 | 31-Mar | Presenting PDR |
| 12 | 4-Apr | Analytics Memo | TBD | CDR/CAD/Prototype |
| 13 | 11-Apr | | | |
| 14 | 18-Apr | CDR Memo | 8-Apr | |
| Final (15) | 25-Apr | Prototype demo | 29-Apr | CDR / Cad w/ animations/ possibly prototype |
| 16 | 2-May | Website check 2 | 6-May | Finalize website for sem |

# 7 BUDGET

The total budget of the report for both semesters will be $5,000 provided by GA-EMS. The budget has been split into two categories: travel and device manufacturing. Our team has calculated a manufacturing total of $92.46 (shown in appendix B) but have allotted $150 towards the category for shipping and tax. The team also planned for a testing budget of $100 and a repairs budget of $100 so we have room for errors. The other half of the budget breakdown goes to travel, which can also be seen below with a total of $3,000. The grand total that has been calculated so far comes to $3,350, leaving a cushion of $1,650.

This is where the budget currently stands, and the team is happy with the leftover funds so that we can afford mistakes and updates. We anticipate expenses to change as we start testing and learn more about the device.

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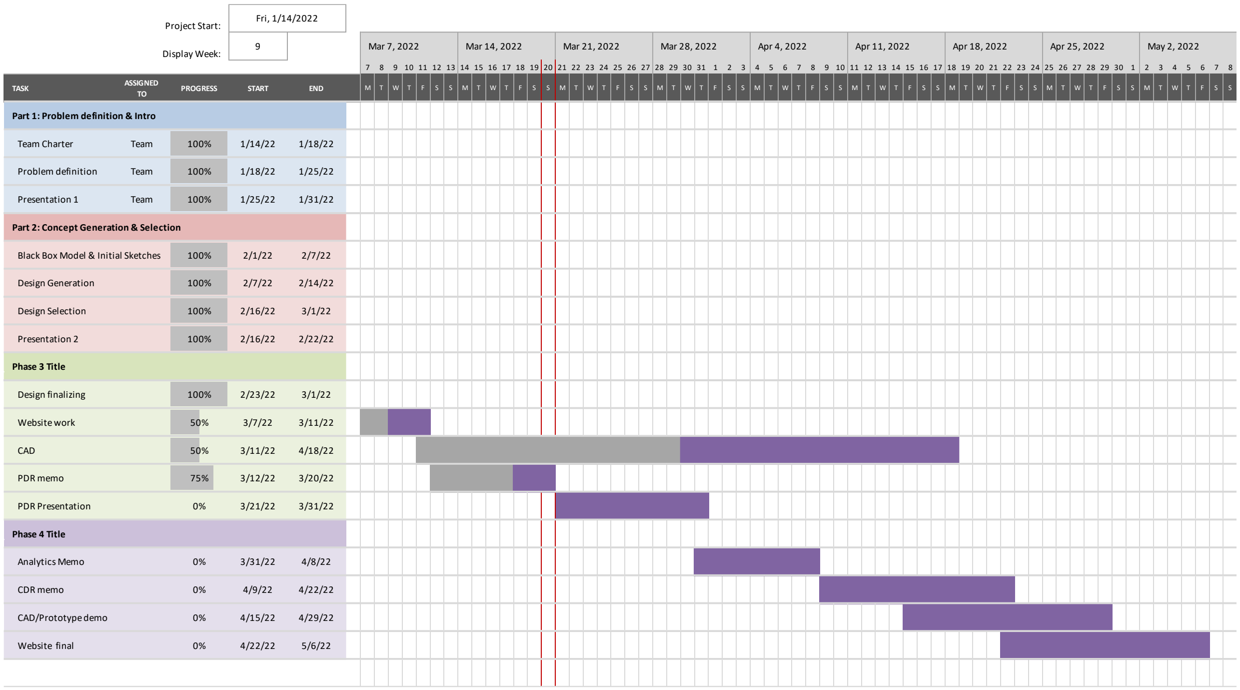
# 9 APPENDICES

## 9.1 *Appendix A: Gantt Chart*



Project Start: Fri, 1/14/2022

Display Week: 9

| TASK | ASSIGNED TO | PROGRESS | START | END |
|---|---|---|---|---|
| **Part 1: Problem definition & Intro** | | | | |
| Team Charter | Team | 100% | 1/14/22 | 1/18/22 |
| Problem definition | Team | 100% | 1/18/22 | 1/25/22 |
| Presentation 1 | Team | 100% | 1/25/22 | 1/31/22 |
| **Part 2: Concept Generation & Selection** | | | | |
| Black Box Model & Initial Sketches | | 100% | 2/1/22 | 2/7/22 |
| Design Generation | | 100% | 2/7/22 | 2/14/22 |
| Design Selection | | 100% | 2/16/22 | 3/1/22 |
| Presentation 2 | | 100% | 2/16/22 | 2/22/22 |
| **Phase 3 Title** | | | | |
| Design finalizing | | 100% | 2/23/22 | 3/1/22 |
| Website work | | 50% | 3/7/22 | 3/11/22 |
| CAD | | 50% | 3/11/22 | 4/18/22 |
| PDR memo | | 75% | 3/12/22 | 3/20/22 |
| PDR Presentation | | 0% | 3/21/22 | 3/31/22 |
| **Phase 4 Title** | | | | |
| Analytics Memo | | 0% | 3/31/22 | 4/8/22 |
| CDR memo | | 0% | 4/9/22 | 4/22/22 |
| CAD/Prototype demo | | 0% | 4/15/22 | 4/29/22 |
| Website final | | 0% | 4/22/22 | 5/6/22 |

## *9.2 Appendix B: Budget Breakdown*

| **Budget Breakdown** | | |
|---|---|---|
| Device Manufacturing Budget: | Travel Budget: | **Leftover:** |
| $350 | $3,000 | **$1,650** |
| **Total =** | **$3,350** | |

| **Travel Budget** | | | |
|---|---|---|---|
| **Description:** | **Price ($):** | **Quantity:** | **Source:** |
| Gas (To and from Phoenix) | $50 | 1 | Gas Station |
| Parking (Airport) | $14 | 5 | Airport Lot |
| Flight (Round Trip) | $580 | 3 | American Airlines |
| Uber (Airport – Hotel) | $70 | 2 | Uber |
| Hotel (Two Rooms) | $200 | 4 | Average online |
| Uber (To and from GA) | $200 | N/A | Uber |
| **Total Cost =** | **$3,000** | | |

| **Device Manufacturing Budget** | | | |
|---|---|---|---|
| **Part Description:** | **Part Price ($):** | **Quantity:** | **Source:** |
| Aluminum Bolt | $1.50 | 2 | Amazon |
| Gate Latch | $6.88 | 4 | Amazon |
| Nitinol Wire (2.4 mm) | $9.96 | 2 | Amazon |
| Aluminum Block | $36.99 | 1 | Amazon |
| Screw | $2.25 | 4 | Amazon |
| Spring | $3.99 | 1 | Amazon |
| Nuts | $0.50 | 4 | Amazon |
| **Total Cost =** | **$92.46** | **($150 allotted to account for tax/shipping)** | |
| **Manufacturing Total: $150** | **Testing Total: $100** | **Repairs Total: $100** | **Final Total: $350** |