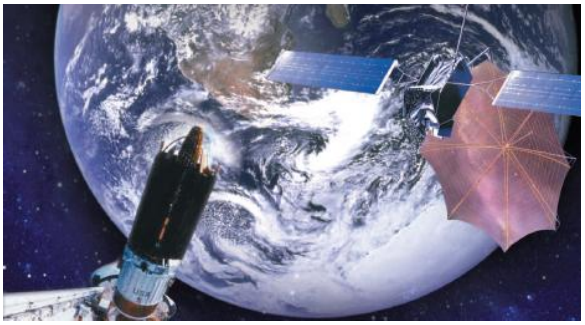
Panel Interlocking Mechanism for Solid Reflector

Senior Design Final Report – April 2012

By
Ashley Saunders, Cory Slingsby, Thomas Patten
Department of Mechanical Engineering



Project Sponsor
Mr. Gustavo Toledo, Mechanical Engineer
Harris Corporation

Department of Mechanical Engineering
FAMU-FSU College of Engineering
2525 Pottsdamer St, Tallahassee, FL 32310

ii. List of Figures

ii. List of Tables

Section I – Abstract

The report details development of a panel Interlocking Mechanism (IM) for a tangentially deploying solid reflector. The project’s goal and scope were thoroughly assessed to ensure preservation of the customer’s voice. Many concepts for the IM were considered before down selecting. The concept was then incorporated with the material and functional objectives to develop a final design. Raw materials were procured, and the components fabricated. The panels were assembled and integrated with the sister team’s hub mechanism. Together, the two assemblies form a complete, operational, physical model of a tangentially deploying solid reflector with interlocking panels. The record concludes with the team’s reflections on the process and recommendation for future endeavors.

Section II – Introduction

Project Overview/Introduction

This document details the scope of the contract between Mr. Gustavo Toledo (“the sponsor”) and FAMU-FSU Senior Design Team 6 (Solid Panel Interlocking Mechanism, “Panel Team”) for the production of a prototype high surface accuracy tangential deployable reflector dish for interstellar antennae applications. Devices of this nature are used to send and receive K_u band EMF transmissions, and require an aperture (Diameter of dish) of 4-10m. Special considerations must be further made for a space based application to accommodate restrictions on weight and volume, and to ensure function with zero maintenance.

Figures 1 and 2 below show a concept generation provided by the sponsor to help explain the aim of the project. The second figure illustrates the technology currently in use, generally known as a radial rib reflector. This technology consists of an elastic fabric type material that is stretched across a rigid frame. Such an approach offers excellent stowed volume, minimal weight, and reliable operation which explain why the method is the current standard. However, as one can imagine, the fabric skin “kinks” as it passes over each rib such that the reflector surface does not perfectly follow the ideal parabolic shape. This deviation, known as the Surface Accuracy, is expressed as a tolerance with units of length. Low surface accuracy results in lower efficiency and increased signal degradation as compared with reflectors of the same aperture that possess higher surface accuracy. High surface accuracy is achieved more easily with a solid reflector.

Solid reflectors have some rigid material that is cast, molded, rolled or otherwise shaped to match the chosen ideal parabolic shape. The use of this solid material makes extremely high surface accuracies possible, but they generally require a rigid framework to support the mass of the dish. In space applications however, mass is an issue for different reasons than for ground based applications, and adequate structural support can be achieved with minimal bracing. Figure 1 shows the general aim of the project; to produce a tangentially deployable solid reflector. The concept consists of multiple panels which are initially stacked. These panels rotate about a central point, translating in plane, thus achieving tangential deployment.

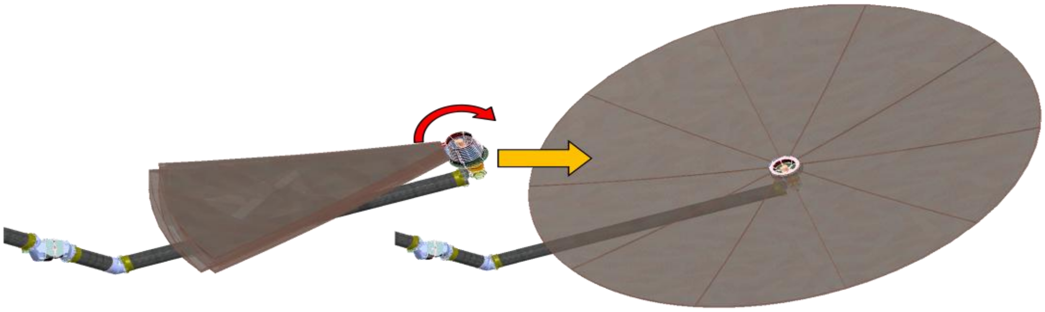


Figure 1: Concept illustration for a solid, paneled, tangentially deployable reflector, courtesy of Harris Corp

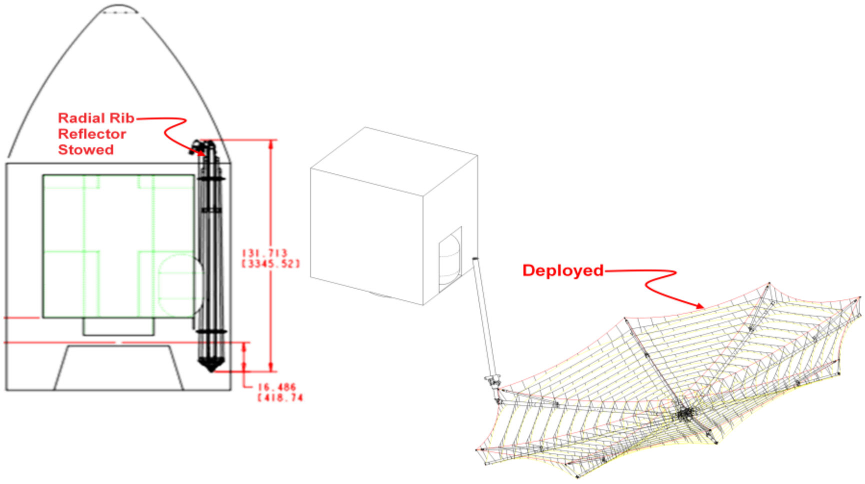


Figure 2: Schematic illustration of a Radial Rib Reflector in stowed and deployed state, courtesy of Harris Corp.

The tangentially deployable solid reflector concept consists of two sub systems:

> ***Hub Mechanism:*** This system drives and synchronizes the deployment of the panels. *See Team 5 for more detail.*
>
> ***Panel Interlocking Mechanism:*** This system controls the manner in which each panel connects to its adjacent panels. This is the focus of this and all subsequent documents prepared by Team 6 (Panel Interlocking Mechanism).

The resulting function of these subsystems will be that the paneled reflector can be stored in a volume comparable to that of reflectors of a radial rib design. The reflector must then be cable of autonomously deploying. This deployment must include alignment and locking of the individual panels; interstellar applications will not allow for post deployment positioning of the panels, such that a misaligned panel would render the dish inoperable. The final deployed reflector must be capable of exhibiting higher surface accuracy and performance than comparable radial rib designs.

The following figure, located below, gives visual representation to Harris Corporation's needs as well as where, within Harris' needs, the solid panel interlocking mechanism team's needs fall.

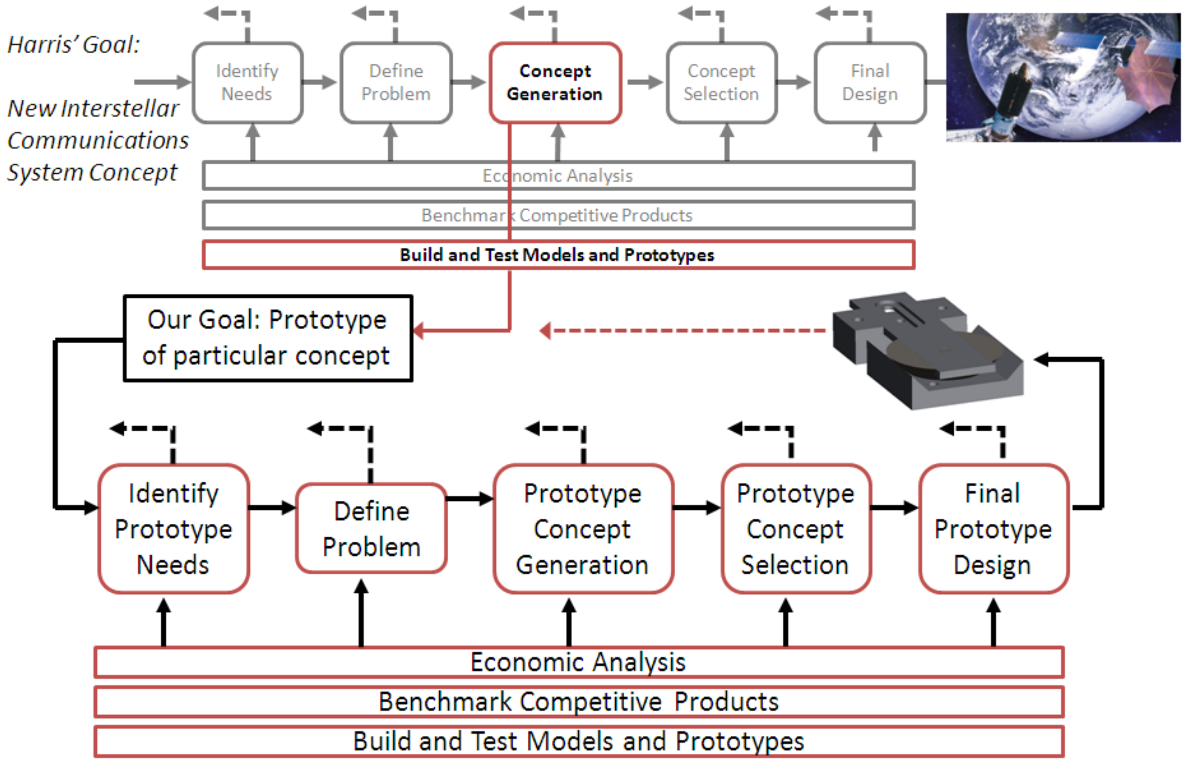


Figure 3. Flow Diagram of project process.

Section II – Introduction

As can be seen, Harris Corporation has a need for a solid reflector which acts as an alternative to radial rib reflectors. The motivation behind the solid reflector is its improved surface accuracy when compared to the alternatives currently being used. Within this need falls the need of the panel interlocking mechanism. As can be seen in the figure above, within Harris Corporation's concept generation comes the need particular to the interlocking panel team. The particular need here is to develop a successfully working prototype which demonstrates the functionality of the interlocking panel mechanism. The prototype acts as a stepping stone in the bigger picture of Harris Corporation's goal. Though the prototype does not have to be capable of functioning in a space environment, since space application is an objective to Harris Corporation's need, the latching mechanism concept demonstrated within the prototype is designed with intentions for use in space.

Section II – Introduction

Needs Assessment and Needs Statement

Table 1. Interpretation of Customer Needs

Currently Uses: Radial Rib Mesh Reflector		
Question/Prompt	Customer Statement	Interpreted Need
Typical Uses of commercial reflector	The reflectors Harris develops are for interstellar communications applications	The reflector will operate in space and survive launch into orbit. The reflector has correct aperture
	The reflector will send receive Ka and Ku band frequencies	and surface accuracy for Ka and Ku band signal transmission
	The technology could be adapted for ground applications	The reflector can operate in 1g
Likes – Current commercial System	Radial Rib reflectors collapse to a very small volume	Reflector has a small stowed volume
	They are light weight	Reflector is light
	They deploy autonomously	Reflector deploys autonomously
Dislikes – Current commercial System	The mesh has low surface accuracy	Reflector has high surface accuracy
	It’s difficult to deploy and align ribs precisely	Reflector deploys and aligns easily
Suggested Improvements	A solid material would be better	Reflector surface is a rigid material
Prototype	The prototype should demonstrate the dual motion	Prototype reflector utilizes radial-translational deployment
	The prototype should consist of several solid panels	Prototype consists of a series of panels
	Panels should lock together	Panels interlock during deployment
	The prototype should look like a reflector	The deployed reflector exhibits parabolic shape
	Prototype should be smaller than an actual reflector	Prototype is a scaled model of commercial reflector
	I need to be able to deploy the reflector without touching it	The prototype deploys autonomously
	I need to be able to reset/ stow the prototype for repeat demonstrations	Prototype is resettable

Problem Description

Goal Statement

The goal of this project is to create a working prototype of the interlocking panels to demonstrate its functionality.

List of Objectives

Table 2. Objectives and Criteria

Objectives	Criteria
Autonomous Deployment	Interlocks without assistance
Panels interlock	Engagement proximity Engagement Force Separation failure No play (Gapping)
IM Concept capable of Working in space	Temperature range Weight, volume Does not require gravity Reliability
Transportable	Scaled model Weight/durability
Looks like a dish	Parabolic shape Solid/rigid material Panels that form Continuous surface
Reuse materials	Utilize panels donated by sponsor Price/Cost
Effective Demonstration	Panels interlock Panels stay interlocked Physical model Resettable Simplicity
Fit in panel	Volume

Testing Environment

These metrics represent critical performance characteristics that the interlocking concept must be capable of achieving to be considered a viable option for full scale production. However, these are just the team's estimation of the most interesting characteristics that can be investigated with a scale model. Also, minimum values that would determine viability have not been established with the client. Therefore, it is the intention of the team that testing result not in a definite affirmation of viability of a concept. Instead, testing is intended to provide reference, and merely reflect the performance characteristics of this prototype. This is consistent with the scope and needs assessment that established the type of prototype to be constructed.

- **Engagement Proximity** The minimum distance the panels must travel before the interlocking mechanism can engage.
    - Test: Translate two panels toward each other until interlocking occurs, record distance before interlocking.
- **Engagement Force** The force required to engage the interlocking mechanism once the panels are within the minimum *engagement proximity*.
    - Test: Move panel into deployed position by applying force. Record force required as interlocking occurs.
- **Separation Failure** The force required to separate the panel-panel seams once the interlocking mechanisms have engaged.
    - Test: Select direction(s) that are most likely to be experienced in operation, and that are most likely to result in separation. Apply force of increasing magnitude in these directions until interlocked panels separate and record the minimum force required for separation.
- **Stability** Resistance to flexure or rigidness, and vibration damping.
    - Test: Compare flex vs force for interlocked and separated panels
- **Force applied by interlocking mechanism once engaged** Interlocking mechanism should have an applied active force while engaged to satisfy the no play/gapping criteria and allow the system to remain stable.
    - Test: same as 3, but failure occurs when gapping or misalignment occurs.

List of constraints

The primary constraint within this design is the budget set forth at the commencement of the project. The expenses towards the panel interlocking mechanism cannot exceed the amount of $2,500 provided by Harris Corporation. Aside from the budget, there is a constraint on the interlocking panel design in that it must successfully work with the hub team's design in order to create a working prototype of the entire system to demonstrate its functionality. Though the two designs must work together, the specific aspects to the design of each are not constrained.

Functional Diagram

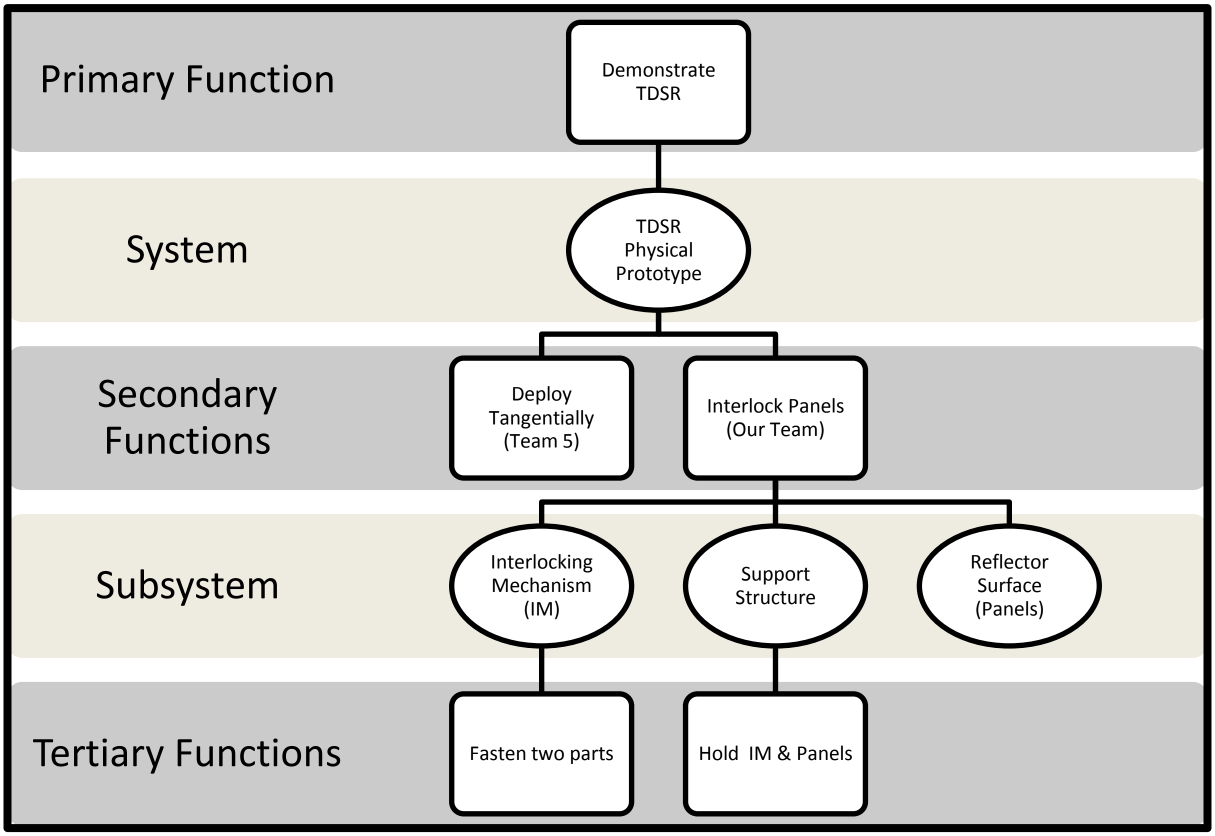
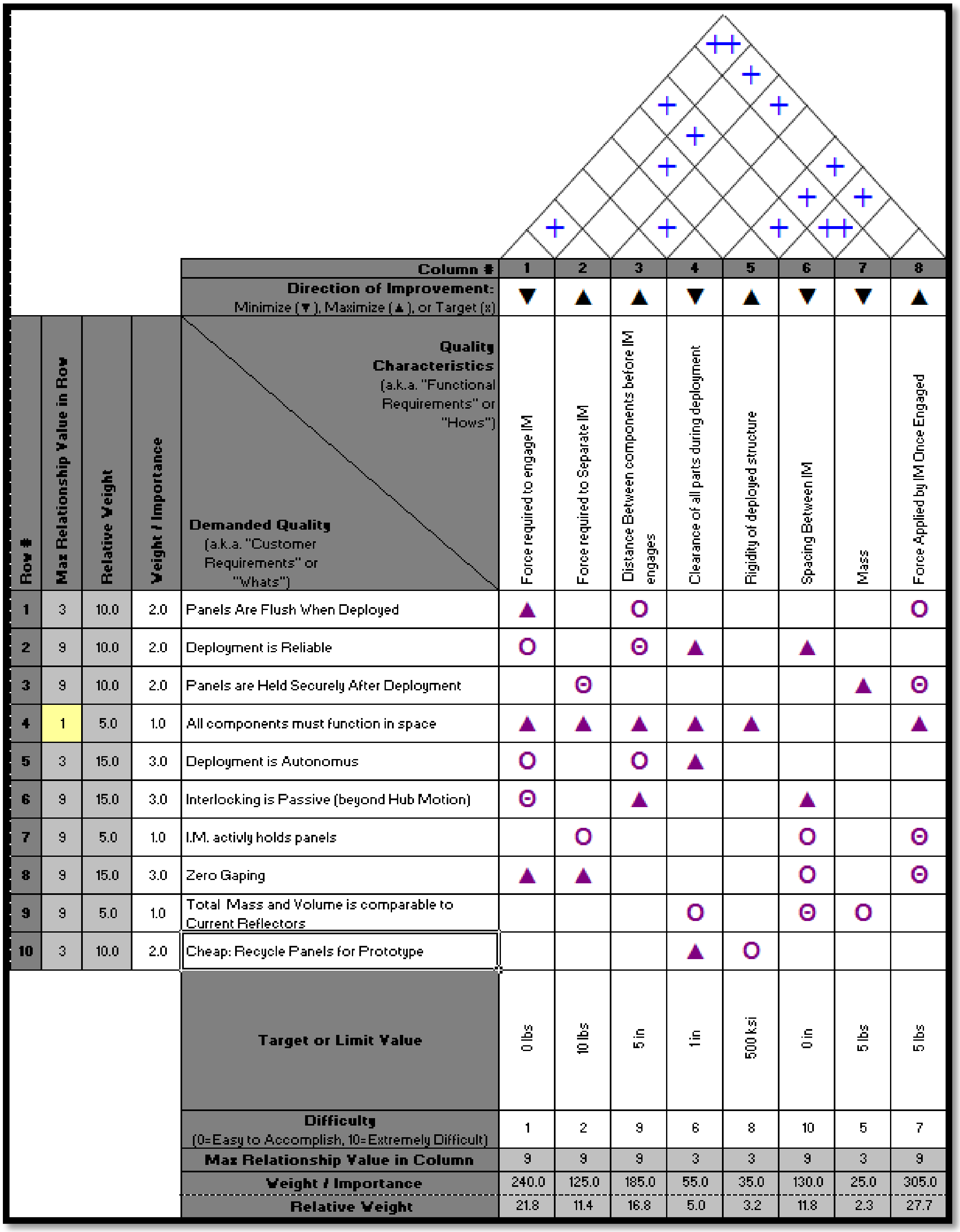


Figure 4. Functional Diagram

The two Harris teams are working together to demonstrate the concept of a Tangentially Deploying Solid Reflector (TDSR). This is the primary function of the project. In order to accomplish this, a physical system of the TDSR is needed, and so a prototype must be developed. The prototype must possess two secondary functions: the ability to deploy tangentially and the ability to interlock its panels. The tangential deployment of the system is the focus of the hub team. The focus of the panel team is this second function of ensuring that the panels interlock to remain in their fully deployed configurations. Focusing solely on interlocking function, there are three subsystems to the overall system which pertain to the interlocking of the panels: the interlocking mechanism, the support structure and the reflector surface. These three subsystems possess their own tertiary functions within the overall system. For example, the latching mechanism is used to fasten and hold two parts together while the support structure provides a surface on which to mount the latching mechanism. Lastly, the panels provide the visual representation of a dish in which the support structures themselves can be mounted. In understanding the functions of the overall system, the individual components which pertain to the interlocking of the panels, can be analyzed. In further deciphering the subsystems making up the interlocking panels, their functions, and components, each aspect of design can be determined to provide a means of accomplishing the objectives previously set forth while succeeding in the development of a working prototype of the interlocking panels.

Quality Function Deployment (and HOQ)



	1	2	3	4	5	6	7	8
1		+				+		++
2					+	+		+
3				+				+
4								
5						+	+	+
6							++	+
7								
8								

				Column #	1	2	3	4	5	6	7	8
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	▼	▲	▼	▼	▲
Row #	**Max Relationship Value in Row**	**Relative Weight**	**Weight / Importance**	**Quality Characteristics** (a.k.a. "Functional Requirements" or "Hows") **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Force required to engage IM	Force required to Separate IM	Distance Between components before IM engages	Clearance of all parts during deployment	Rigidity of deployed structure	Spacing Between IM	Mass	Force Applied by IM Once Engaged
1	3	10.0	2.0	Panels Are Flush When Deployed	▲		○					○
2	9	10.0	2.0	Deployment is Reliable	○		⊝	▲		▲		
3	9	10.0	2.0	Panels are Held Securely After Deployment		⊝					▲	⊝
4	1	5.0	1.0	All components must function in space	▲	▲	▲	▲	▲			▲
5	3	15.0	3.0	Deployment is Autonomus	○		○	▲				
6	9	15.0	3.0	Interlocking is Passive (beyond Hub Motion)	⊝		▲			▲		
7	9	5.0	1.0	I.M. activly holds panels		○				○		⊝
8	9	15.0	3.0	Zero Gaping	▲	▲				○		⊝
9	9	5.0	1.0	Total Mass and Volume is comparable to Current Reflectors				○		⊝	○	
10	3	10.0	2.0	Cheap: Recycle Panels for Prototype				▲	○			
				Target or Limit Value	0 lbs	10 lbs	5 in	1 in	500 ksi	0 in	5 lbs	5 lbs
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	1	2	9	6	8	10	5	7
				Max Relationship Value in Column	9	9	9	3	3	9	3	9
				Weight / Importance	240.0	125.0	185.0	55.0	35.0	130.0	25.0	305.0
				Relative Weight	21.8	11.4	16.8	5.0	3.2	11.8	2.3	27.7

Figure 5. House of Quality

The figure above shows our quality function chart (QFC). As you can see at the very top of the QFC, the force required to engage our latching mechanism and the force applied by the latching mechanism are the top two engineering specifications. These qualities are located in the first and last columns at the top under “Quality Characteristics”. It is important to notice that relative weight, located along the bottom of the QFC, establishes both of these forces. However, the largest impact on the engineering specifications is the requirement that all components work in space, as you can see in the fourth row down under “Demanded Qualities.”

An important aspect that the QFC helped us to notice is that most of the engineering specifications are inversely related. For example, we can’t make our panels more lightweight without making them weaker and, similarly, we can’t make them more lightweight without reducing their stiffness. While our objectives are to minimize the mass of the panels while increasing the strength and stiffness of them, we will constantly have to reassess our limiting values in order to best satisfy all areas.

Project Plan

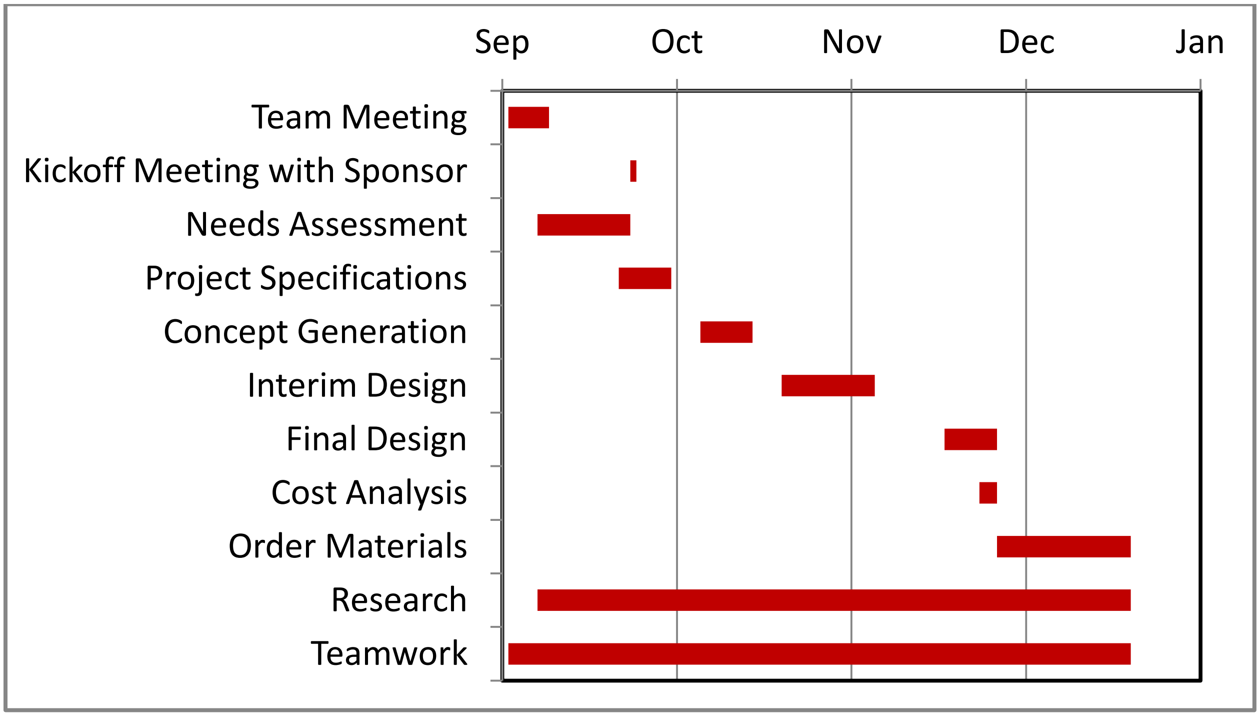


Figure 6. Fall Schedule

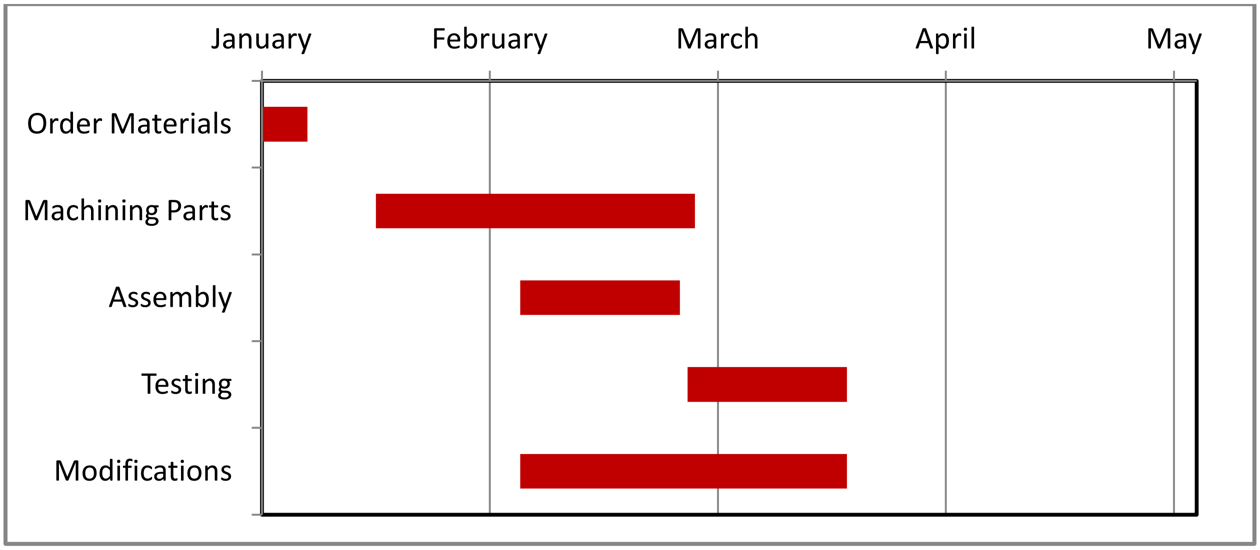


Figure 7. Spring Schedule

The project plan was organized by using Gantt charts to ensure tasks were completed on time. By following a project plan the goal of the project was able to be completed.

Section III – Concept Generation & Selection

Concept Generation

In formulating various design concepts, the requirements and constraints of the Interlocking Mechanism (IM) concept were considered as though it would be implemented in space. As the device transitions from its fully stowed to its fully deployed state, the requirements and limitations of each panel transition from state to state as well. In order to best design a means of fully satisfying the needs of our design, all states of our mechanism and their corresponding expectations and restraints must be considered.

State Function Analysis

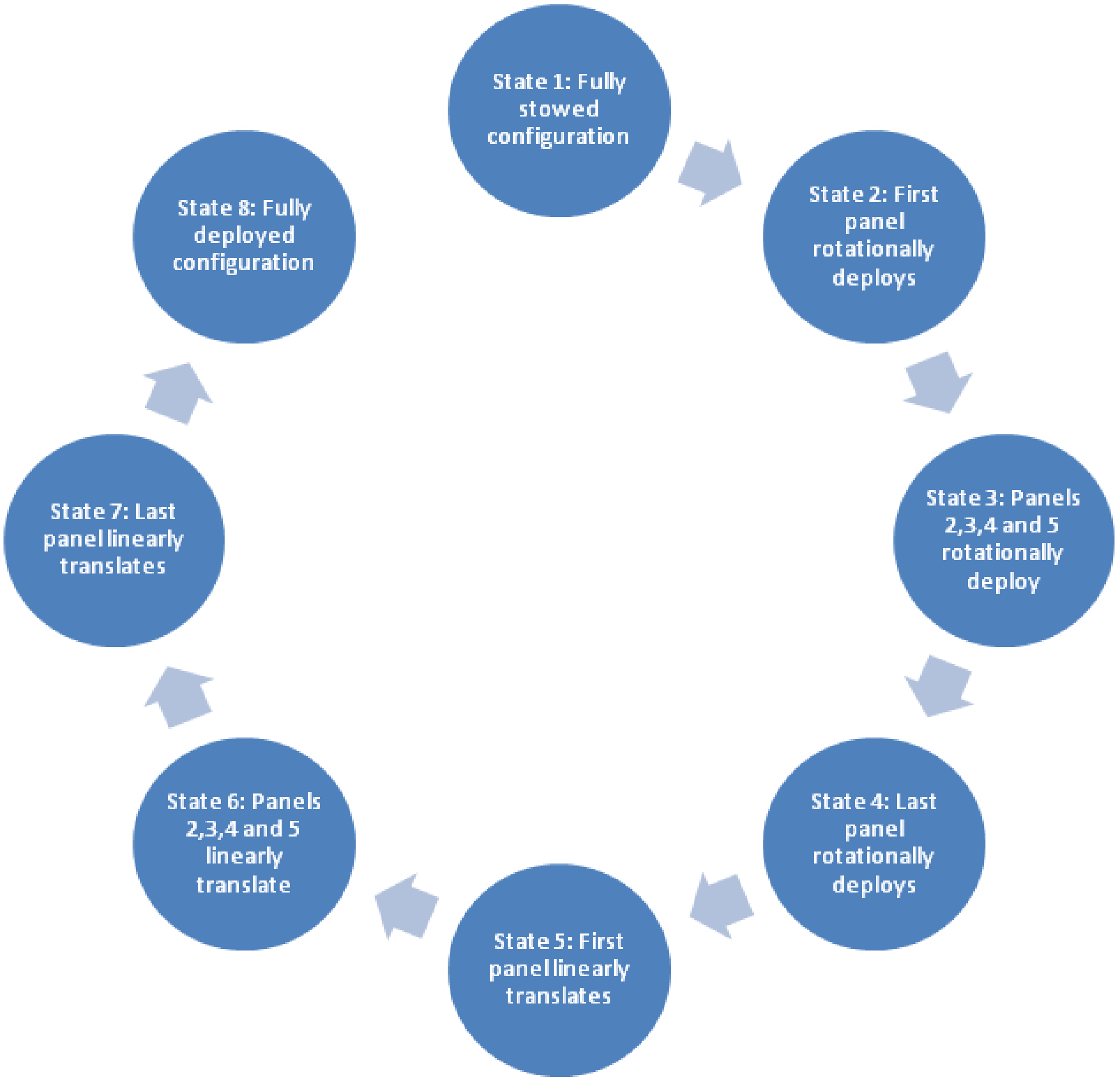


Figure 8. shows the 8 states of deployment that our design must satisfy

A visual representation of the 8 different states the system passes through is outlined in the figure above. As the requirements of a panel change based on their status in deployment, the state changes as well. Panels that undergo the same requirements at that point in deployment are categorized into the same state. The breakdown and conditions of each state is as follows:

State 1: All components must remain stowed during launch and into orbit

State 2: The first panel deploys
    This panel will not be preceded by any other panels
    Latching mechanism (LM) must not catch leading edge
    LM must not catch during deployment
    LM must not catch on trailing edge
    Panel will be followed by second panel

State 3: Panels 2, 3, 4, and 5 deploy one after the other
    These panels will be preceded by the another panel
    LM must not catch leading edge
    LM must not catch during deployment
    LM must not catch on trailing edge
    These panels will be followed by another panel

State 4: The last panel deploys
    This panel will be preceded by panel 5
    LM must not catch leading edge
    LM must not catch during deployment
    LM must not catch on trailing edge
    This panel will not be followed by any other panels
    Once state 4 is over, all 6 panels are in their intended radial positions

State 5: The first panel linearly translates

First panel to reach its fully deployed configuration

This panel comes down with no panels on either side initially

State 6: Panels 2,3,4 and 5 linearly translate

Each of these panels comes down adjacent to the preceding panel

As panels come down, LM should engage with preceding panel

Each of these panels, once in their final linear position, will have a panel coming down on the edge opposite the preceding panel

As following panels come down, LM should engage with the following panel

State 7: The last panel linearly translates

This panel will be coming down with two fully deployed panels on either side

This panel will not be followed by any other panels

State 8: Fully deployed configuration

All components remain flush and secure with their two adjacent panels

In being conscious of the 8 states the system goes through and their correspondingly changing requirements, we know all that is expected of each individual panel and at what point in sequence it is expected. In doing so, we can now formulate the best design to transition the system from state 1 successfully through all 8 states and ultimately devise the best design to achieve the overall goal in autonomously taking these panels from a fully stowed to a fully deployed configuration.

Concept Descriptions

A detailed discussion of the top concepts considered is presented here. The concepts are grouped into the categories: Mechanical, Magnetic, Cable, and Other. Finally, a brief discussion of omitted concepts is proffered.

Mechanical Concepts

The goal of the mechanical concepts is to use rigid mechanical components to very securely hold the panels in place. The mechanical latch is an extremely mature technology. However, the design challenges facing this method are many. Space is limited everywhere: at the site of engagement, in and around the hub, and on either side of the panels. The no-gapping criteria all but necessitates an active retaining force be applied post engagement. Finally, the ability of a panel to push back a latch strike is likely very limited at best. The following concepts represent the team's consensus of potential designs that may be able to accommodate these challenges.

Mechanical Concept 1: Plate Design

This concept is very simple and easy to install. A stiff plate is installed beneath each panel and the adjacent panel will rest on the plate once the panels are collapsed. The simplicity of this design is important because it can be applied with other designs if needed. The design on its own will not be secure enough.

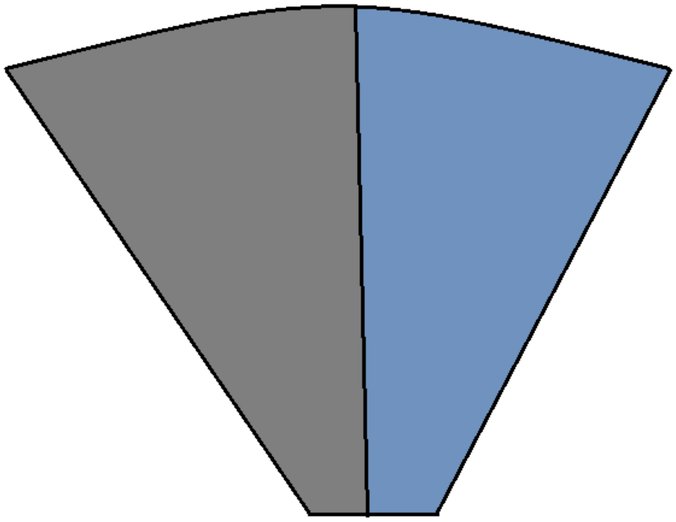


Figure 9. Top view of two panels

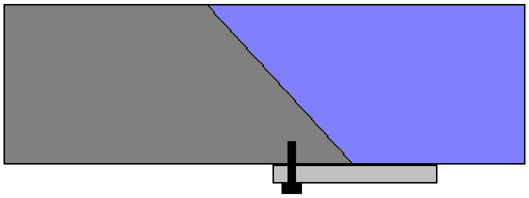


Figure 10. Cross section, side view of two panels

Mechanical Concept 2: Cup and Cone Design:

This design concept is a simple cup and cone. Each panel will have a cup on one side and a cone on the other. When the panels come together, the cups and cones will mesh together just like a jigsaw puzzle. This will help lock the panels together and keep them from shifting around after the panels collapse. This design concept will be able to be utilized with other designs as well.

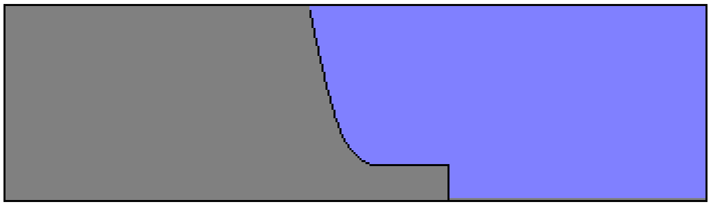


Figure 11 Cross section, side view of two panels using the cup and cone design

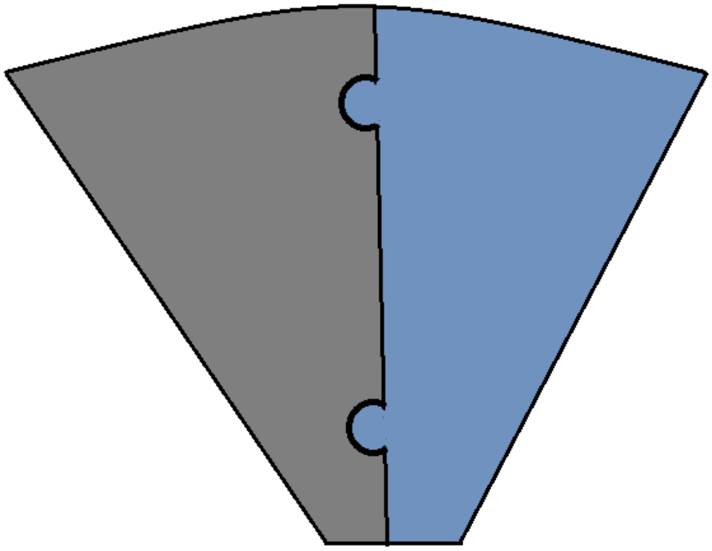


Figure 12.Top view of two panels using cup and cone design

Mechanical Concept 3: Double Spring Design

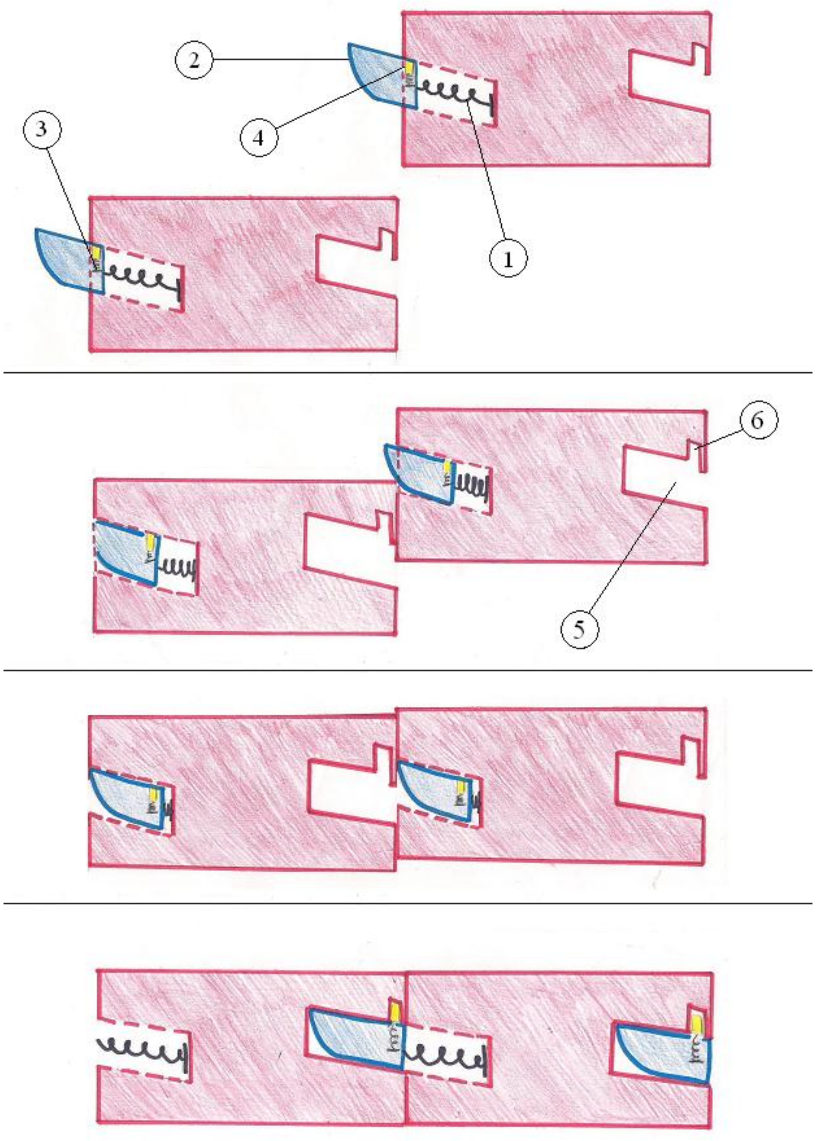


Figure 13. Shows a visual representation of the stages during latching for the double spring design

This design (shown in figure 13 to the right) implements the use of two springs as the means to the latching between panels. There is one large spring (1) contained within the cross section of each panel. This spring is connected to a piece of material (2) that is designed with a curved bottom and a flat top. Within this material is a smaller spring (3) connected to a smaller piece of material (4) that is rectangular in shape. The smaller spring (3) is initially fully compressed while the larger (1) remains uncompressed in its stowed position. Once the panels have completed their path of rotational motion, they will move downward to find a final, level position. As two panels come together at a time, one side of the lower stationary panel will essentially be pushing along the curved bottom of the piece of material (2) which is exposed on the opposing side of the moving panel. This will force the larger spring (1) to compress and the exposed material (2) to submerge within the panel's cross section. The material (2) will continue to be pushed until the larger spring (1) reaches its fully compressed state. This mechanism is designed so that once the surfaces of the two panels are flush, the large compressed spring (1) and material (2)will meet an opening (5) and no longer have a force to maintain its compressed state. It must then be released, and the material (2) will be moved into the opening of the opposite panel beside it (5). As it is inserted, the smaller spring (3) is designed with the same intentions as the larger, only releasing in an upward direction. There is a small slot (6) within the larger opening (5) on the side of the panel that will hold the smaller piece of material (4) once the smaller spring (3) is released. The larger spring assembly is used to restrict vertical motion, while the smaller spring assembly restricts horizontal motion, thus providing a final, flush position between panels.

The benefit to this design is its security. Once the panels have reached their fully deployed positions, the interlocking provided by the spring assemblies will lock and hold them together. However, this design is non reversible. Additionally, with numerous moving parts the chances of failure are increased due to the complexity of design. The material selection would also be limited to those stiff enough to support the force of the large spring against the thin panel wall without failing.

Mechanical Concept 4: Ring and Latch Design

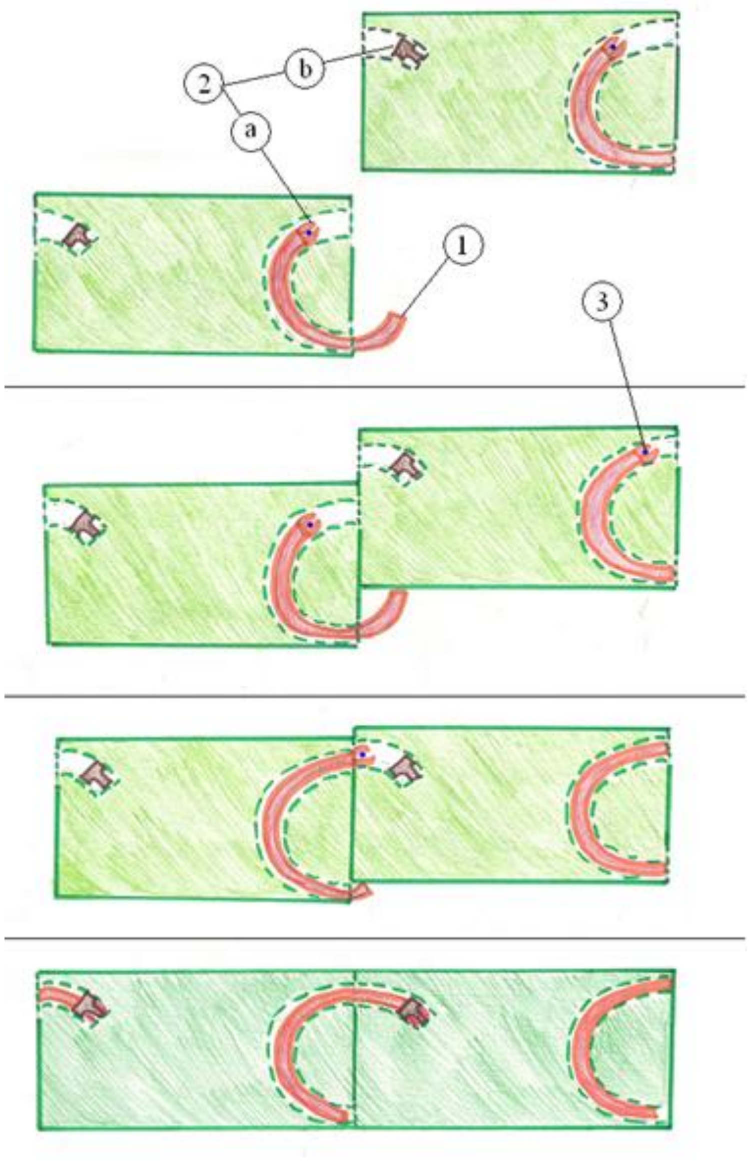


Figure 14. The ring and latch design in different stages during the latching of the mechanism.

This design (shown in figure 14 to the right) incorporates a ring (1) and a latch assembly (2ab) to hold the panels together. Within the cross section of each panel is a ring (1) that is partially exposed on one side. After panels are rotationally flush, they begin to move downwards. Due to their offset vertical position relative to one another, the process of aligning panels happens as the panels meet and latch together one at a time, with a brief period of time in between connections. In focusing on two panels at a time, it can be modeled as one panel moving downwards towards a lower, stationary panel. At this point the panels are rotationally flush, and as they come together the moving panel will come in contact with the semi-exposed ring (1) contained within the other panel. The downward force of the moving panel will, in turn, cause the ring (1) to rotate within the other panel. As rotation continues, the ring will circle back around to an opening in the first moving panel. The moving panel is essentially pushing the ring (1) through the other panel and back into itself. This panel must exert enough force to both move the ring (1) and then engage the latching mechanism (2ab). The latching mechanism consists of two parts. The first half (2a) is located on the upper end of the ring (1). It consists of two pieces of material that are held together using an uncompressed spring (3). The second half of the latching mechanism (2b) rests inside the opposite end of the panel. It is designed with intentions of the first half of the mechanism (2a) to fit, but only when the spring (3) is under compression. Thus, the panels must be exerting enough force on the ring (1) to rotate it and, in turn, produce enough force so when both ends of the latching mechanism (2ab) come together, the spring (3) on the first half (2a) will compress and slide through the second half (2b). The second half (2b) is also designed so that when the first half (2a) reaches a certain point, there is no longer any compression on the spring (3) and it can return to its uncompressed state, remaining locked in place.

The benefit to this design is its security. Once the two pieces of the latching mechanism (2ab) have interlocked, there are no forces acting inside of the panels to recompress the spring (3) and release it from its fastened state. However, this design is not reversible and the dependency on the force of the panels to rotate the ring (1) increases the chance of failure. Also, the force that is being exerted on the ring (1) is dependent on the angle of contact between the panel and the ring (1). This angle is constantly changing due to the rotation of the ring and is, in turn, changing the force the panel is exerting. This fluctuation increases the chance of snag which increases the chance of failure.

Magnetic Concepts

Permanent, rare earth magnets offer the unique capacity to engage and apply an active retaining force with no moving parts. While they have not been proven for use in interstellar applications, the technology seems strikingly well suited for the application.

Magnet Concept: Magnet Design

This design uses magnets to lock the panels together. The magnets are a cheap way to unite the panels once deployed without having any worries of mechanical failure. When reversing the operation to bring the panels back to a stowed position, the force of the magnets will have to be overcome by the hub. As a result, the magnets cannot be too powerful for the reversible prototype.

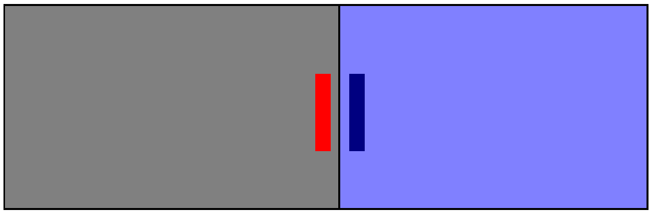


Figure 15. Cross section, side view of two panels using magnets

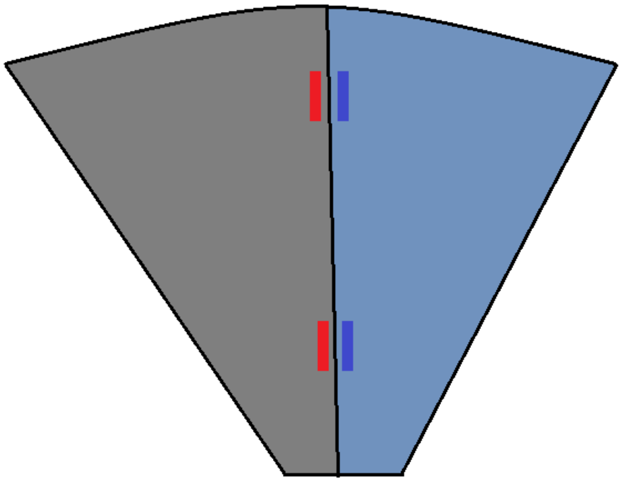


Figure 16. Top view of two panels using magnets

Cable Concepts

An obvious concern of employing cables for support, electrical current, or any other reason, is that the cables are likely to get caught, snag, or otherwise impede deployment. Tension must be carefully controlled by a motor and spool or other mechanism, as over or under tensioning would likely result in failure. Never the less, the potential for a single spooling unit to apply tension across a many areas of the reflector is a feat not closely matched by any other method. The following concepts are a selection of characteristic cable implementations.

Cable concept 1: Guyline

Tensioned guylines are used to restrict movement of a structure beyond a certain point. They are commonly employed to increase the effective base of a collapsible or portable structure while only nominally increasing the stowed footprint.

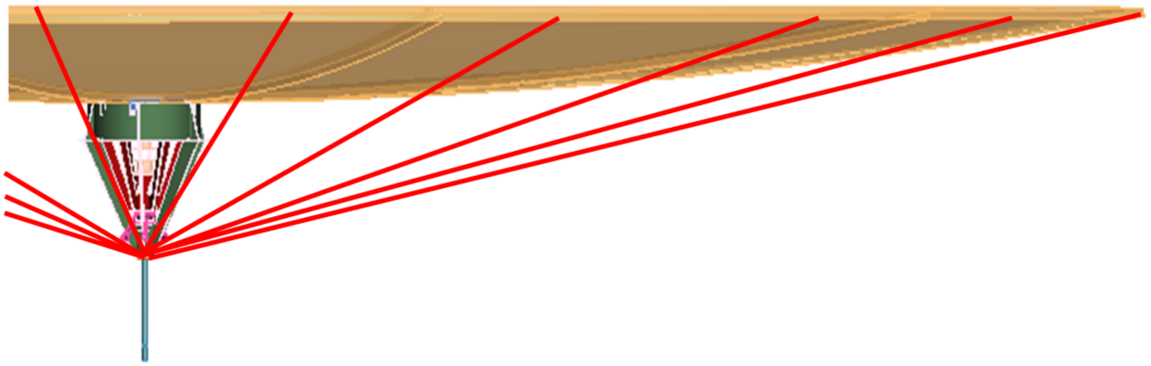


Figure 17. Guyline Cable Concept

The figure illustrates a side view of a potential guyline implementation. The guyline cables (red) run between the hub assembly and the outer edges of each panel. This concept will require slack cable to accommodate the stowed position of the reflector, necessitating some means of tensioning the cables either during or after deployment. A tensioner of some kind will be necessary for all cable implementations. The tensioner may feasibly be incorporated into the hub assembly, which would increase the functionality of the hub motor. Compared to alternate cable implementations, this guyline concept requires less cable, meaning less potential for cable snag. Guylines may be particularly well suited for applications where the reflector is expected to experience high forces, such as would result from a wind gust.

Cable Concept 2: Shoelace

The shoelace concept consists of slots along the edges of each panel (dark red). A cable (red) passes through a slot on one panel and then through a corresponding slot on the mating edge of the adjacent panel. The cable continues in this fashion, passing back and forth from panel to panel through mating slots along the length of a panel-panel seam. The concept could be implemented with a single cable that skips to the next seam after running the length of the panels, or multiple cables could be employed, one per seam.

The image shows two stages of deployment with a shoelace interlocking cable. The right-most panel-panel seam is in the deployed configuration, while the zigzag of cable to the left illustrates the path of the cable during deployment.

The unique quality of such an interlocking mechanism is that in addition to securing the panels in their deployed configuration, the shoelace cable can be tensioned during deployment to assist with deployment and ensure appropriate positioning. As the cable is tensioned, the mating slots on adjacent panels will be pulled together. This differs from a buckle mechanism for instance, where the hub assembly alone must bring the panels into alignment such that the mating features of the buckle meet precisely. The buckle clasp were to miss, they mechanism would not engage and the reflector would not be considered to have successfully deployed. Such a cable implementation could be advantageous for implementations where alignment is complicated by the panels sagging out of place as by gravity.

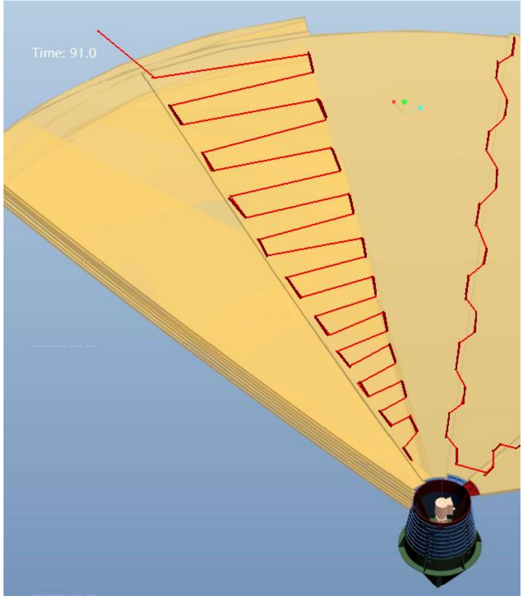


Figure 18. Shoelace Cable Concept

Cable Concept 3: Ring Tensioner

The final cable concept is an adaptation of the shoelace. Here, a cable makes a single pass around the deployed reflector. Much of the benefits of the shoelace are achieved while drastically reducing the total length of cable required to achieve a stowed position.

The top right of the image shows a 90% deployed panel-panel seam. Mating rings from adjacent panels are nearly aligned, awaiting only the horizontal hub motion that will bring the panels into a single contiguous plane. Along the left edge of the image are the radial edges of two panels with the ring tensioner cable in the "zigzagged" or stowed position; notice that the cable must run approximately 2x the length of the radial edge to correctly pass through the rings.

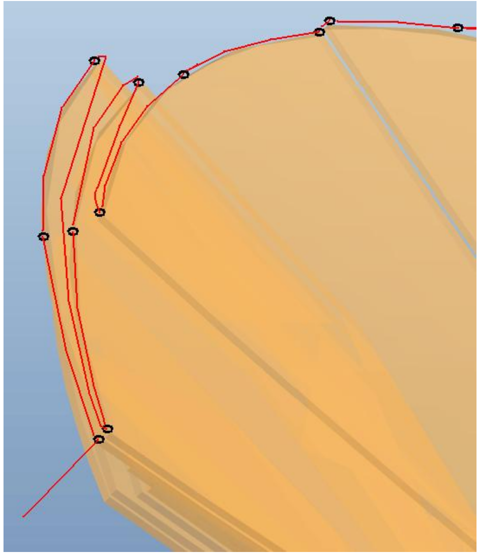


Figure 19. Ring Tensioner Cable Concept

A variation of this concept would be to mount the rings along the back surface of the panels. Doing so could mitigate risk of the cable catching on the corners of the panels, as well as reducing the total length of required cable.

Other Concepts

This section contains concepts not directly applicable to the categories previously established.

Other Concept 1: Solenoid Design

This concept utilizes the common plunger solenoid. By sending an electrical current into a solenoid, the plunger deploys into the adjacent panel where a hole is located. The plunger will secure the two panels together. Using solenoids will require that the mechanism has a source of power, which can be a drawback compared to other designs that do not require power. However, the strength of the connection may be more important than the inconvenience of needing power.

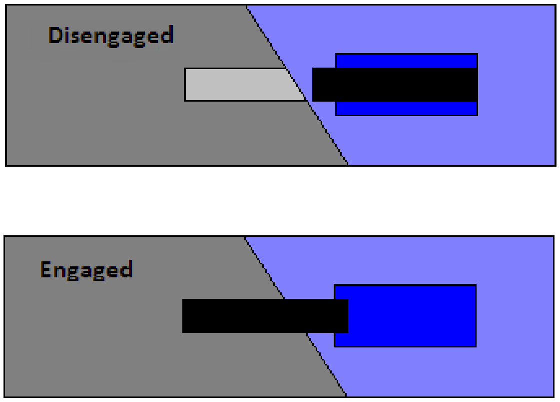


Figure 20. Cross section, side view of two panels using solenoid design

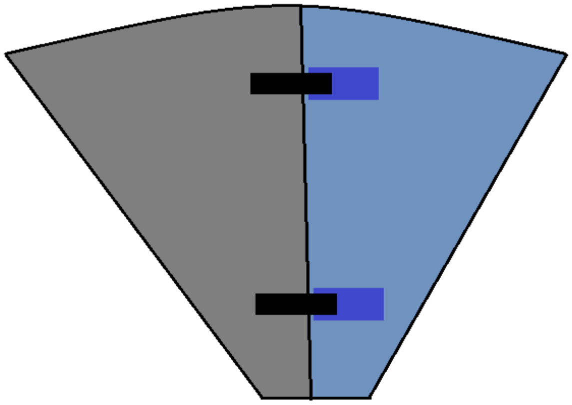


Figure 21. Top view of two panels using solenoid design.

Other Concept 2: Magnet and Pin Design

This design utilizes a pin (1) and three magnets. One magnet (2) is located within the neck of the pin (1) while two others (3) act as a latch. This magnetic latch (3) is connected onto the base of the panels by hinges (4), essentially acting as a door. For each panel, the pin (1) rests at the base of one side of the panel, while the magnetic latch (3) is located at the base on the opposite side of the adjacent panel. As one panel moves downwards, its pin (1) and the latch (3) on the stationary panel beside it are designed to come into contact with one another. The pin (1) will use the force exerted by the moving panel to overcome the restriction of the latch (3). As the panel continues to move down, the latch (3) will continue to open until it surpasses a maximum point and the latch doors (3) are no longer in contact with the pin (1). At this point, the latch (3) will return to its initial position, only now all three magnets (2 and 3) are aligned and the pin (1) of one panel is contained within the magnetic latch (3) on the opposite adjacent panel.

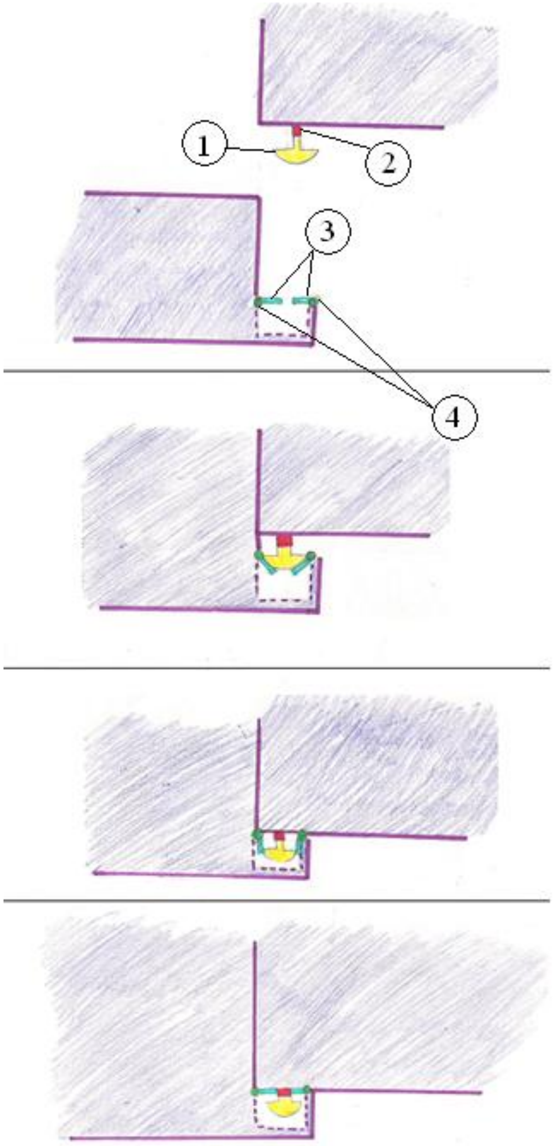


Figure 22. Magnet and pin design at different stages during latching.

This design is beneficial in that it is reversible. However, the design also uses the panel's downward movement as a latching force, as opposed to solely using the motor to connect the panels. This adds extra stress to the panels and increases risk of failure.

This particular design can be altered in both the contour of the panels as well as the latching mechanism. For example, instead of using magnets a non magnetic mini touch latch (seen in figure 12 on the right) could be used to replace the pin (1) and magnets (2 and 3).

Comments – Omitted Concepts

Of all the concepts generated, some novel ideas were simply deemed unfeasible for this stage of development. In future efforts, these concepts may be worth reconsidering.

Actively Engaging Mechanical Latch

The security and strength of connection is unparalleled by mechanical latches. With this design approach, the force required to engage such a latch is supplied by an external source. This source might take the form of individual motors at each latching site, or a gearing system that couples multiple latches. Development of this concept was discontinued due to the volume/space requirements, and the intricacy which resulted in a drastic increase in failure modes.

Spring/Roller Assisted Cam Latch

This concept incorporated a standard spring/roller with a "C" shaped cam unit. A deploying panel would push the bottom of the C-cam down as the panel collapsed vertically. Once the spring/roller past a particular contour on the cam, the spring force would be applied in such a way as to force the top of the C-cam over on to the deploying panel. In this manner, an interlocking device is achieved that is passively engaging, actively retaining, and mechanically latching, all without requiring external power to augment the force supplied by the panel motion. It was decided that the force a panel would be able to apply to engage the cam would likely be insufficient, and that the space required for the cam's rotation could not be accommodated by the panel spacing.

Concept Selection

In order to evaluate concepts, a selection criterion is necessary. Since one of the main needs of this system is to autonomously deploy in space, reliability is very important. System failure is a waste of money and resources. Another important factor to consider is the security of the panel to panel connection. The panels are meant to be for a solid reflector, any gapping or separation of the panels is a design failure. Other important attributes the concepts will screen include: reversibility, complexity, and price. Detailed descriptions of each selection criterion are found in section 2.3.2.

The best method of evaluating each concept is to develop a trade matrix based on the selection criteria. A weighted ranking system is used to determine the importance of the criteria and a score is given to the concept based on its ability to satisfy that criteria. The total score for each concept is summed up to give a total that can be used to compare designs against each other. A trade matrix for each design can be found in section 2.3.3.

Selection Criteria

Alignment Criteria

(1) **Engagement Proximity** This is the minimum distance the panels must travel before the interlocking mechanism can engage.

(2) **Engagement Force**

This is the force required to engage the interlocking mechanism once the panels are within the minimum *engagement proximity*. A negative force represents attraction, such as would be experienced with a magnetic based mechanism.

Structural Criteria

(3) **Separation Failure**

This defines the force required to separate the panel-panel seams once the interlocking mechanisms have engaged.

(4) **Stability**

Resistance to flexure after deployment, such as would be caused by acceleration of the assembly. Hypothetical sources include gravity for ground applications, and post deployment repositioning of a satellite for space applications. Stability also encompasses dynamic stability and vibration dampening.

Implementation Criteria

(5) **Reversibility**

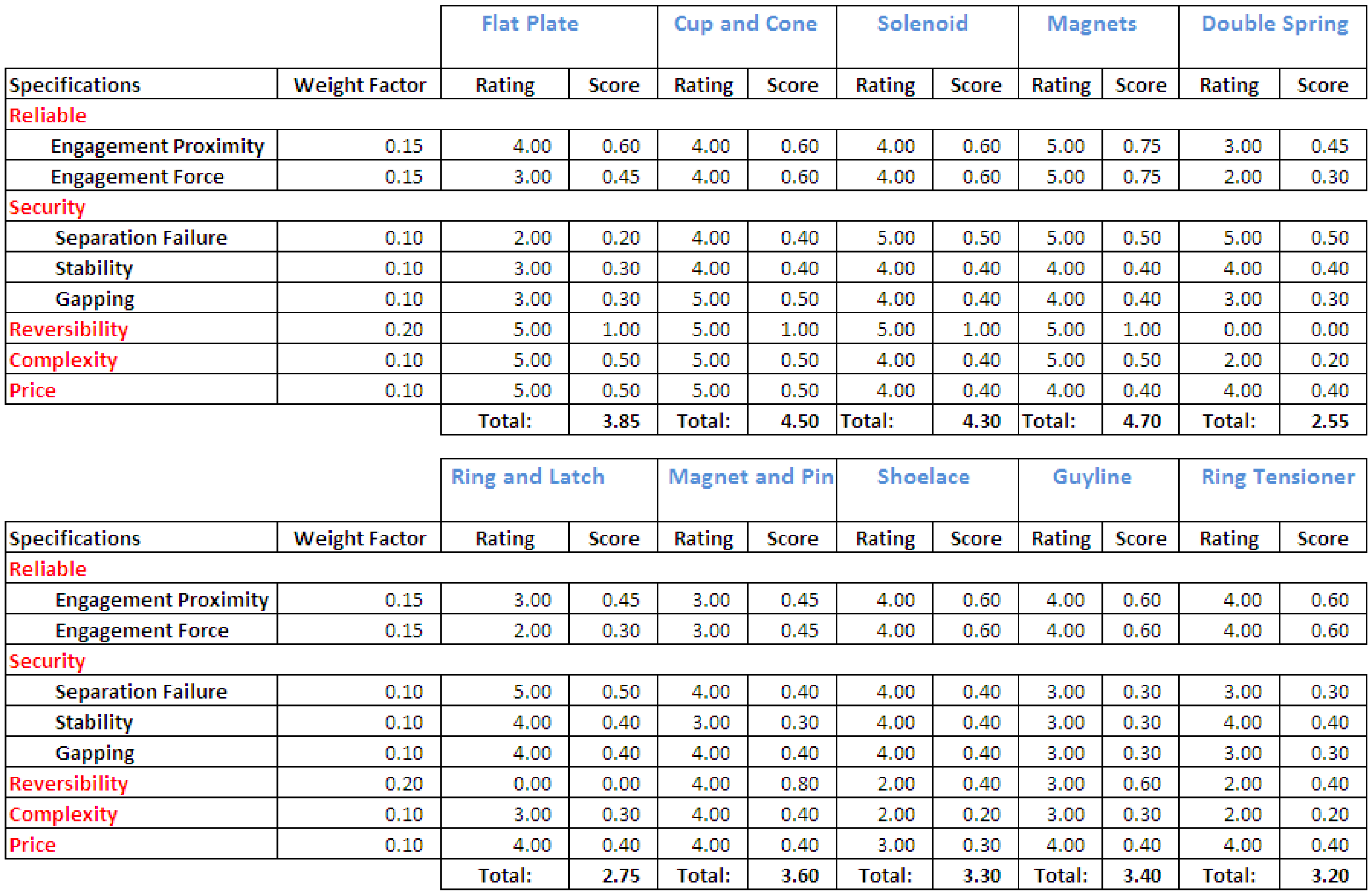
The ability of the reflector to collapse into the stowed position after deployment. An autonomously reversible reflector would be ideal for many ground applications, but is outside of the project scope where the primary consideration is for spaced based applications. Demonstration of the prototype, however, will require assisted separation of the panels, and the final design must take this into consideration.

(6) **Complexity**

Intricate designs will incur increased costs for production, and increase potential sources of failure. The simplest possible solution that satisfies the all criteria should be favored.

Trade Matrix

Table 3. Trade Matrix



		Flat Plate		Cup and Cone		Solenoid		Magnets		Double Spring	
Specifications	Weight Factor	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Reliable											
Engagement Proximity	0.15	4.00	0.60	4.00	0.60	4.00	0.60	5.00	0.75	3.00	0.45
Engagement Force	0.15	3.00	0.45	4.00	0.60	4.00	0.60	5.00	0.75	2.00	0.30
Security											
Separation Failure	0.10	2.00	0.20	4.00	0.40	5.00	0.50	5.00	0.50	5.00	0.50
Stability	0.10	3.00	0.30	4.00	0.40	4.00	0.40	4.00	0.40	4.00	0.40
Gapping	0.10	3.00	0.30	5.00	0.50	4.00	0.40	4.00	0.40	3.00	0.30
Reversibility	0.20	5.00	1.00	5.00	1.00	5.00	1.00	5.00	1.00	0.00	0.00
Complexity	0.10	5.00	0.50	5.00	0.50	4.00	0.40	5.00	0.50	2.00	0.20
Price	0.10	5.00	0.50	5.00	0.50	4.00	0.40	4.00	0.40	4.00	0.40
		Total:	3.85	Total:	4.50	Total:	4.30	Total:	4.70	Total:	2.55

		Ring and Latch		Magnet and Pin		Shoelace		Guyline		Ring Tensioner	
Specifications	Weight Factor	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Reliable											
Engagement Proximity	0.15	3.00	0.45	3.00	0.45	4.00	0.60	4.00	0.60	4.00	0.60
Engagement Force	0.15	2.00	0.30	3.00	0.45	4.00	0.60	4.00	0.60	4.00	0.60
Security											
Separation Failure	0.10	5.00	0.50	4.00	0.40	4.00	0.40	3.00	0.30	3.00	0.30
Stability	0.10	4.00	0.40	3.00	0.30	4.00	0.40	3.00	0.30	4.00	0.40
Gapping	0.10	4.00	0.40	4.00	0.40	4.00	0.40	3.00	0.30	3.00	0.30
Reversibility	0.20	0.00	0.00	4.00	0.80	2.00	0.40	3.00	0.60	2.00	0.40
Complexity	0.10	3.00	0.30	4.00	0.40	2.00	0.20	3.00	0.30	2.00	0.20
Price	0.10	4.00	0.40	4.00	0.40	3.00	0.30	4.00	0.40	4.00	0.40
		Total:	2.75	Total:	3.60	Total:	3.30	Total:	3.40	Total:	3.20

Concept Selection Conclusion

By using a trade matrix, it is apparent that the top three design concepts are solenoids, cup and cone, and magnets. In order to optimize the strengths of the designs, it was decided to combine a coupling mechanism (cup and cone) with magnets for increased security. Solenoids were not chosen for a final design due to the requirement of power which would complicate the design of the panels and lead to a risk of failure during deployment.

A cup and cone coupling mechanism allows the panels to deploy in the correct position. The addition of magnets will secure the panels in their positions once deployed and maximize security of the panel to panel connection. The combination of these two concepts has a very low chance of failing since all parts are passive and can be used for indefinite cycles of operation.

As a team, our task is to develop a working prototype to meet our sponsor’s needs. The use of our coupling mechanism with magnets will allow us to test with many different magnets and give our sponsor feedback about the feasibility of possible use of magnets in space. In addition, the prototype will be highly modifiable, so any changes or additions to the design will be possible.

Section IV – Final Design – Interlocking Mechanism Prototype

4.1 Detail Description

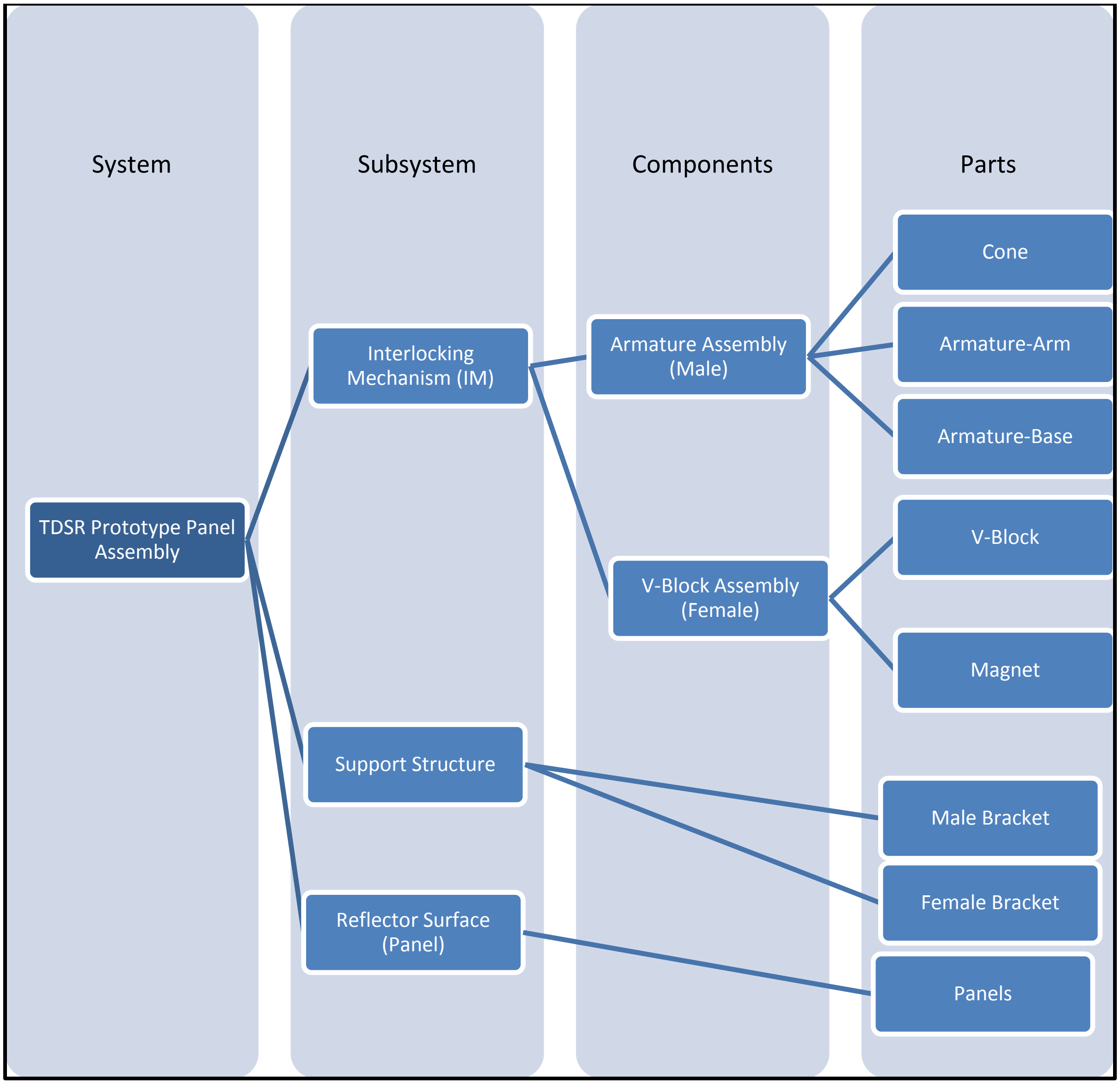


Figure 23. Flow Chart Breakdown of Final Design

Design of the TDSR prototype was divided into a Panel Assembly, for which we are responsible, and a Hub Assembly. The two teams cooperatively designed the interface for the two systems. Our functional analysis of the TDSR Prototype Panel Assembly reveals three subsystems:

- **Interlocking Mechanism (IM):** project goal;
- **Support Structure:** mounting surface for IM and support for Reflector Body;
- **Reflector Body**: looks like a satellite dish.

The remainder of this section covers the components and their corresponding parts which make up the subsystems pertaining to the panels of the TDSR. Methods employed to develop these designs as well as changes and modifications made to simply fabrication and assembly will be discussed as well.

4.2 Discussion of Components

As can be seen in the previous figure, there are three subsystems within the overall system that pertain to the interlocking panels of a TDSR: the interlocking mechanism itself, the support structure for the interlocking mechanism, and the reflector surface to which the support structure is mounted. In assuring that the components to these subsystems provide the necessary means to satisfy the objectives previously mentioned, the goal of developing a successful working prototype for the interlocking panels of a TDSR will be met. In order to accomplish such, the specifications to each individual part making up these components were carefully determined.

One of the subsystems to the TDSR is the interlocking mechanism used between each set of adjacent panels to maintain them in their final deployed state. One of the previously mentioned objectives was to choose a latching mechanism that interlocks the panels of the prototype and holds them in their final configuration. The latching mechanism chosen for this design was chosen for its ability to satisfy this objective. Each interlocking mechanism has one male and one female assembly. A male assembly on the edge of one panel in conjunction with a female assembly located on the edge of the panel adjacent to the first is what forms the interlocking mechanism. Male assemblies are positioned on the edges of the panels that come down next to an adjacent panel already in its final deployed state. Since the last panel to reach its fully deployed state will be coming down next to two panels, one on each side, it has two male assemblies. Each male assembly is made up of three parts: a cone, an armature base and an armature arm.

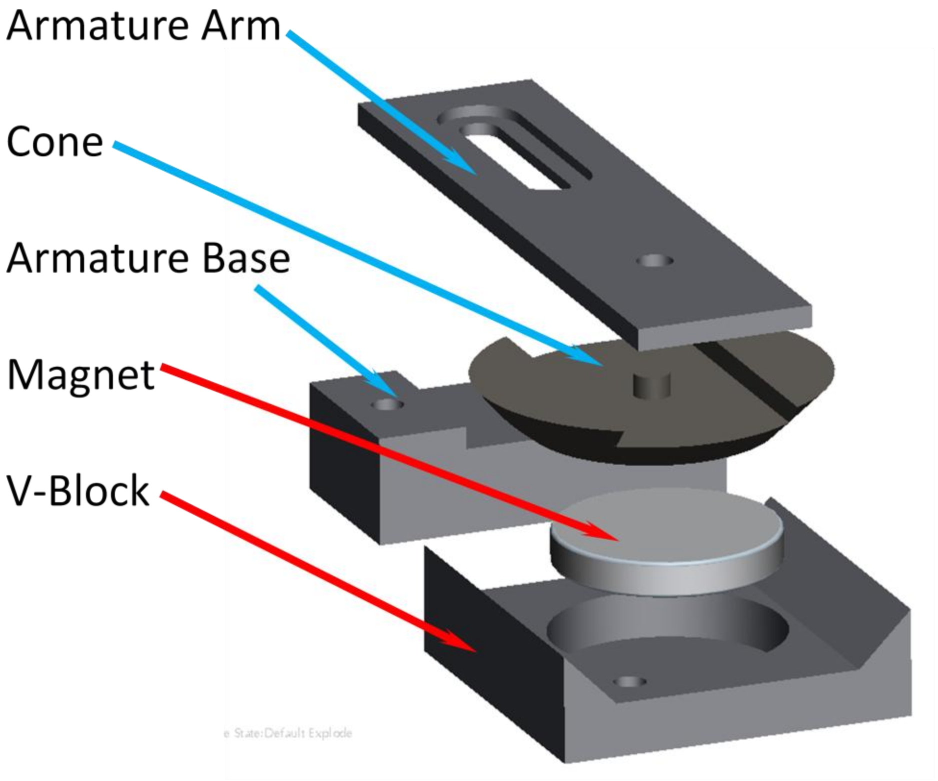


Figure 24. The female (red) assembly and the male (blue) assembly as the IM subsystem.

Cone:

The latching mechanism uses cones as a part of the male component in conjunction with magnets on the female component to create the force required to hold adjacent panels together. Cones were chosen to be machined from 1117 low-carbon steel for its ferrous properties. As can be seen in figure 24 located in the appendix, some material has been removed from the top of the cone, leaving a small amount of material cylindrical in shape with a diameter of 0.10 inches in the center of the cone. This remaining material is press fit into the hole of the armature arm which can be seen in figure 24. Once the cone has been press fit into the armature arm, the top surface of the cone and armature arm form a flush assembled surface. This conserves the space between the panels and further satisfies the objective of having the latching mechanism fit within the panel. The cone possesses a flat bottom surface so that there is no interference between cup and cone surfaces once the panels have reached their deployed configurations and the latching components are in contact with one another. The rounding of the cone goes along with the design of the cup (which utilizes a 45 degree angle) to ensure that the cone is appropriately guided into its intended location.

Armature Base:

The armature base, along with the remaining parts discussed in this section, is machined from aluminum 6061. With mechanical properties sufficient enough to provide an effective demonstration and not potentially interfere with the magnets, aluminum 6061 was most logical and cost effective choice. Each armature base incorporates three holes as can be seen in figure 25 (engineering drawings located in the appendix). The two outer holes are the holes that will be used to connect the armature base to the armature bracket. The third hole located in the center of the armature base is used to connect the armature arm to the armature base. As maximizing the amount of space between panels is essential in this design, material has been removed from the height of the armature base around the central hole to better fit the armature arm when they are assembled.

Armature Arm:

Resting within of the armature base is the armature arm. It, too, is machined from aluminum 6061. As can be seen in figure 24, there is one hole and one slot incorporated into its design. The hole is used to connect and hold the cone to the armature arm. The slot is incorporated into the design to allow for the adjustment of the armature arm within the armature base. By having this slot, it allows for 0.25 inch of adjustment. Having potential to adjust the component which is holding the cone allows for modification in the placement of the cone in relation to the cup. This better assures that the panels reach their intended, deployed locations.

The second component making up the interlocking mechanism is the female assembly. Female assemblies are located on the edges of the panels that are free once in their deployed configuration and do not yet have an adjacent panel. Similarly to how the last panel to deploy comes down on two panels already in their final states, when the first panel reaches its final state, both edges of the panel are free; the first panel initially has no adjacent panels. For that reason, the first panel to deploy has two female assemblies. Each female assembly is made up of a v-block and a magnet.

V-block:

V-blocks act as the cups incorporated into this design. They are also machined from aluminum 6061. As can be seen in figure 24, there are two smaller holes located at opposite corners of the v-block. These holes are used to connect the v-block to the v-block bracket. A larger hole is incorporated into the body of the v-block. This hole, machined from the top surface, is used to house the magnet. Material has been removed from the top of the v-block at an angle of 135 degrees. This is so that as the cone is coming down onto the v-block, it is coming down onto a surface which has an angle of 45 degrees. 45 degrees was chosen because a value any less than this would risk being too flat to guide the cone into its intended location. A value any larger than this risks restricting the location to which the cone must end in order to be guided to its intended location.

Magnet:

Neodymium magnets of grade N42 were chosen to incorporate into the female assembly of the latching mechanism. These magnets are 5/8” in diameter and 1/10” thick, fitting into the v-block almost perfectly. A picture of one of the magnets used in the final prototype can be seen in figure 25 below.

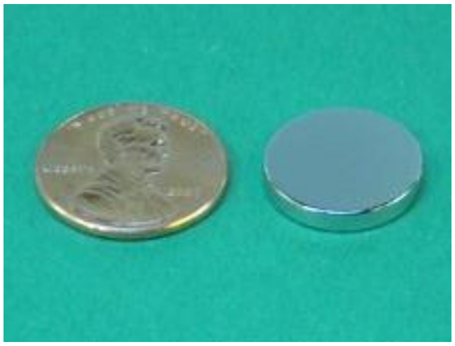


Figure 25. Magnet

Bare metals in space can be coated with a transparent Teflon material, which increases the materials emissivity and maintains its already relatively low absorptivity. In doing so, the exposed temperature of the metals remains in the range of -129 to 120 degrees Celsius. Neodymium SH, UH, EH and possibly H type magnets would all be good candidates to send into space. However, due to the increased price and reduced availability of these types of magnets, a neodymium magnet of grade N42 was chosen for the prototype. On earth, the maximum temperature limitation isn’t a factor. In knowing that there are magnets available that are composed of the same material but have a different grade and therefore a higher temperature range to survive in space conditions, a neodymium magnet of grade N42 will suffice for the purpose of the prototype.

The next subsystem relevant to the interlocking panels of the TDSR is the support structure. Making up the support structure for each panel are two different types of brackets. The type of bracket used on a panel is dependent on whether it is supporting a male or a female assembly of the interlocking mechanism. Male assemblies are supported by the armature bracket while female assemblies are supported by the v-block bracket. Both of these brackets were designed with volume in mind. In maintaining the thickness of these brackets, the objective of ensuring them to fit within the panel can be satisfied. Specific details to each of these brackets are mentioned below.

Figure 26. The support structure subsystem with detail of armature bracket (left) and v-block bracket (right).

Armature Bracket:

One of the two types of brackets incorporated into the support system is the armature bracket which can be seen in figure 27. It is made of aluminum 6061. Eleven sets of holes are located along the length of the bracket. Each set of holes is a potential location for the armature base and, as a result, the cone. There is one hole with a larger diameter than the rest located on one side of the bracket. This is the hole that is used to mount the bracket to the hub. As can be seen in figure 27, a small amount of material has been removed from this same side of the bracket. This is to ensure that when all twelve brackets are assembled on the hub they do not overlap or interfere with one another. The brackets were rolled to match the curve of panels provided by Harris Corporation to continue fulfilling the objective of looking like a dish.

V-block Bracket:

Just as the cone assembly rests on a bracket, the v-block (cup) rests on a bracket as well. Referred to as the v-block bracket, this part of the support structure is also machined from aluminum 6061. As can be seen in figure 27, eleven sets of slots are incorporated into the length of the bracket. These eleven slots match up to the eleven holes in the armature bracket as can be seen in figure 27. Slots are used in this bracket design to allow for the adjustment of the v-block for up to 0.25 inch in both the positive and negative “Y” direction for a potential adjustment of 0.5 inch in the positioning of the v-block. There is a hole located at one end of the bracket which is used to mount the bracket to the hub. Additionally, from this same side a piece of material has been removed at an angle of 30 degrees. Just as was done with the armature bracket, this is to ensure that when the brackets are all assembled onto the hub they do not interfere with one another. Furthermore, just like the armature brackets the v-block brackets are also curved to match the curve of the panels incorporated into the system.

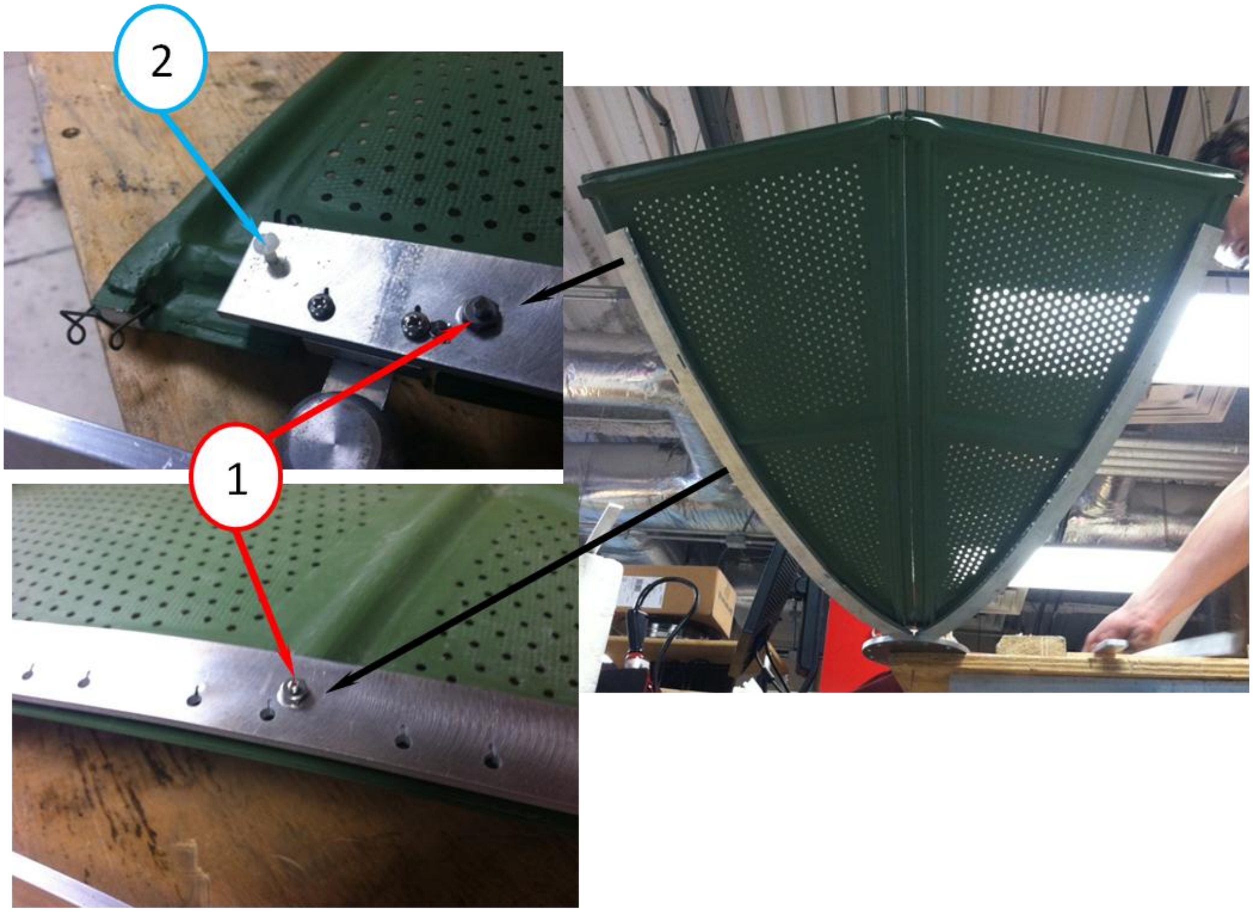


Figure 27. Detail of support bracket attachment to panel (1) and the plastic screw which prevents snagging (2).

The third and final subsystem is the reflector surface. Harris Corporation provided arbitrary panels for use in the final prototype at the beginning of this project. Three of these panels can be seen assembled in figure 29 below.

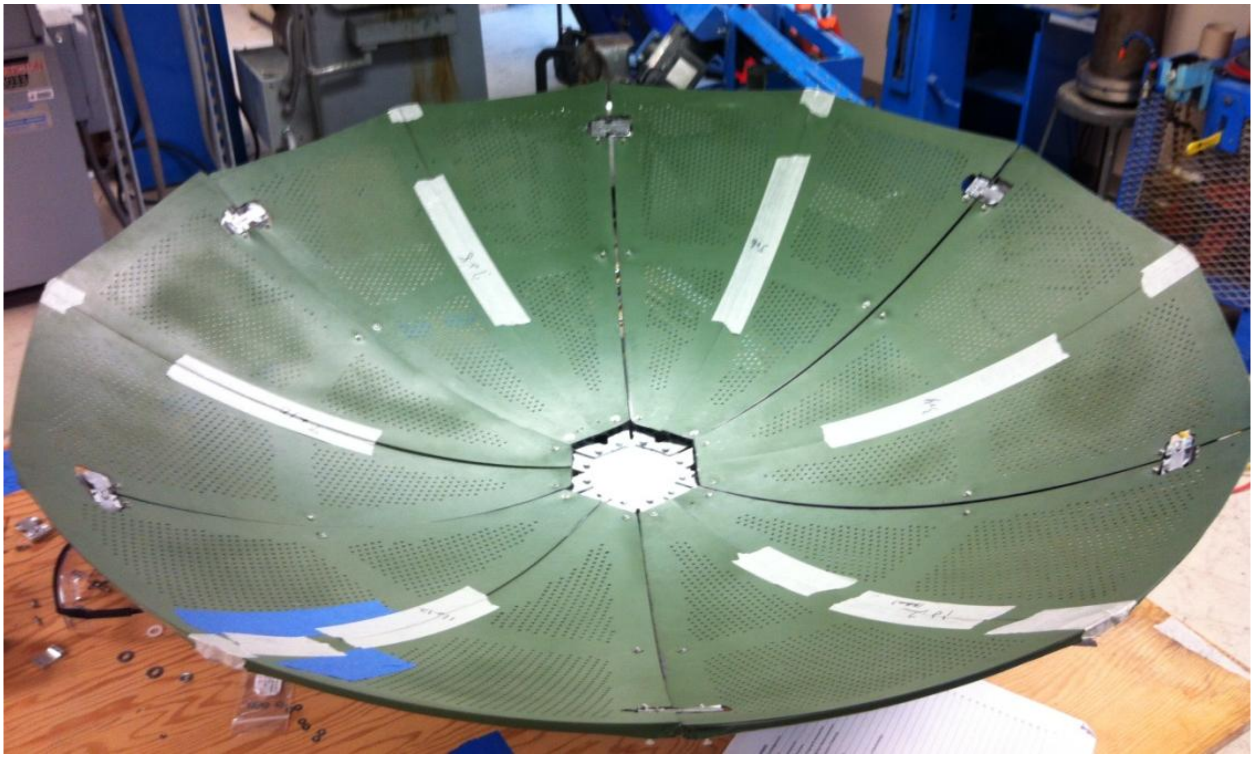


Figure 28. A solid, continuous surface that resembles an actual dish.

In choosing to use these panels, two objectives are fulfilled. First, it reuses material which is cost effective when considering the materials needed to be purchased in order to construct the final prototype. Second, these provided panels are parabolic, rigid, and form a continuous surface when fully deployed. In choosing to use them the objective of developing a prototype that replicates a dish is accomplished.

Panels:

Initially, twelve panels were provided by Harris Corporation to use in the assembly of the system. In order to reduce the amount of rings required by the hub team, these twelve panels were connected by tape in sets of two to provide six new panels which are used by the final system. The panels are green and are believed to be made of a type of fiberglass, though the origin of the panels is unknown. They possess a curve which is also unknown, though it is known that the radius of curvature is not constant and changes as the length of the panel changes.

The outer ends of the panels had hook latches while the inner ends of the panels incorporated a ring to hold the panels around the originally provided hub. This originally provided hub was not used in the final design of the system, and the hooks as well as the rings located on both ends of the panels were removed to incorporate the new components of design. A picture showing the panels before and after the removal of the rings can be seen in figure 30 below.

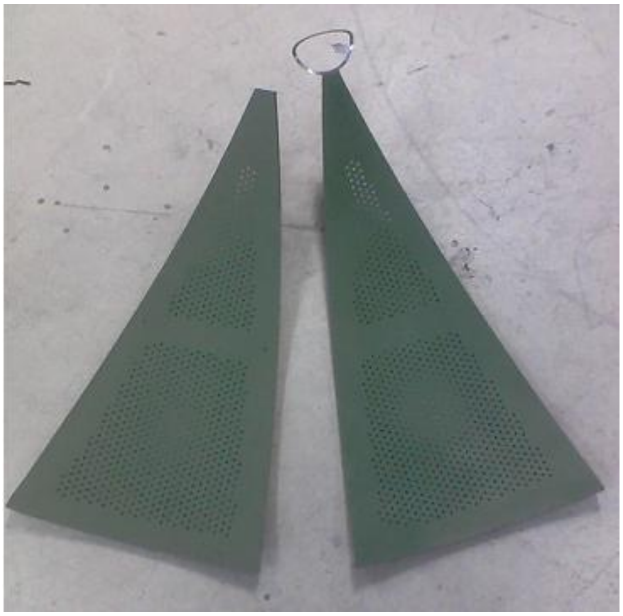


Figure 29. a panel with ring (right) and then the panel after ring was removed (left)

These panels are used to provide visual representation of a solid reflector deployment system. Additionally, they reinforce the stiffness of the overall system and provide a base to mount the supporting structure to.

Mount Plate:

Though not incorporated into the final system, a mount plate was used in order to assist in the testing and modifications of the final system. A drawing of the mount plate can be seen in the appendix. It, too, is machined from aluminum 6061. There are twelve holes located in the plate 30 degrees relative to one another. This plate is an exact match up to the hub when it is in its deployed configuration. Once the panels were fully assembled, mounting the panels to this plate allowed the final deployed configuration to be seen without having the actual hub. In seeing the panels in their fully deployed configuration, modifications to the curve of the brackets as well as any other aspects of design could be made.

Stress Analysis

The prototype proposed is not intended to be loaded beyond the weight of materials and forces applied in handling during assembly, operation and transportation. The team has identified the connection between the support brackets and the hub as the most likely component to fail due to yielding. High stresses are expected to result in this region as a result of the relatively great length of the panels compared to the area used for the hub connection. Therefore, yielding would be expected to occur as a result of a bending moment.

The following is a description of the analysis performed. First, one curved support bracket in modeled as a cantilever beam. The weight of the panel, any hardware, and any forces applied to the area of the panel are represented in the free body diagram by a single point load, P. The load is applied in the direction of maximum reaction moment. The reaction moment and shear force are calculated. Next the stress due to shear and bending at point “A” are calculated. The principal stresses at this point are derived. Finally, the Von Mises yield criterion is utilized to determine approximate yield strength. This value is then checked against a finite element model.

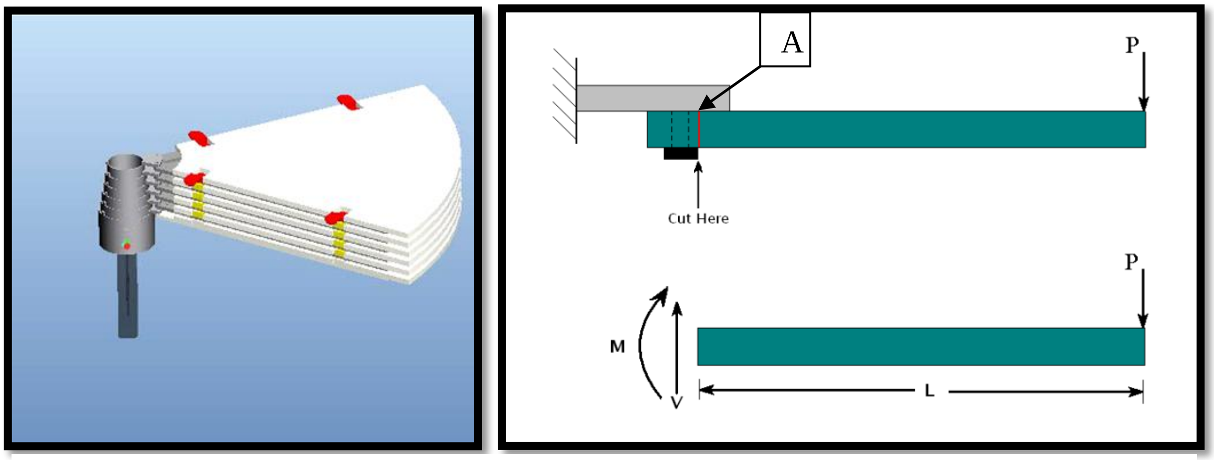


Figure 30. Shows (left) the stowed panel assembly and (right) the modeling of one of these panels as a cantilevered beam

Applied Load: P

Reactions: M, V

Dimensions: L, A=WxH

The shear stress is given by:

The stress due to bending is given by:

Where:

Such that:

The Principal Stresses are given by:

The Von Mises or strain energy density yield criterion is expressed in terms of the principal stresses by:

$$\sigma_v = \sqrt{\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 + 3\tau_{12}^2}$$

Therefore, the material will yield if $\sigma_v > \sigma_o$, or if the Von Mises stress surpasses the material yield strength in tension.

Substituting approximate dimensions and solving, the Von Mises stress found to be (The mathcad used for this calc is included in appendix ii):

σ_o=11.5 ksi for, L=24in, H=0.25in, W=1in, P=5lb

A finite element analysis (FEA) also predicts stresses on the order of 10-20ksi in this region. The FEA also predicts stress concentrations.

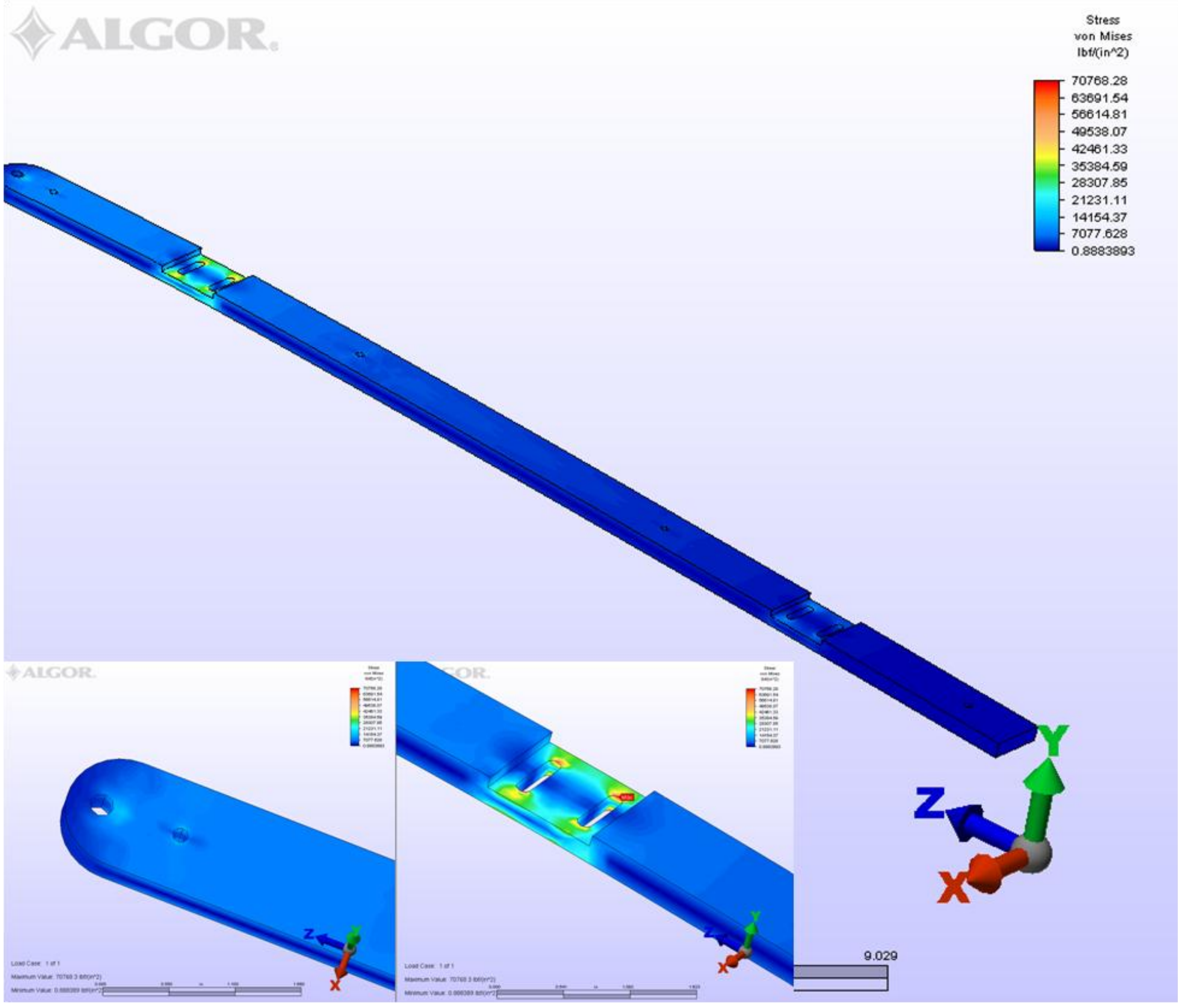


Figure 31. Stress prediction in a finite element analysis of one of the brackets.

4.5 Design Manufacturing and Assembly

Simpler designs are more appealing for many reasons. Ease of assembly and machining as well as a reduced risk of failure are some of the reasons that more basic design ideas are more desirable. Modifications to this design were made along the way to account for this.

The final design for this latching mechanism had always incorporated brackets in order to hold the cup and cone configurations. However, initially, there were five versions of brackets. These brackets were different from one another depending on whether or not they held a cone or a v-block as well as in their spacing of available locations to hold these components. The spacing on varying brackets was different in order to provide a staggered position for the v-blocks and cones so that, when stacked, they did not interfere with one another. As assembly continued, the numerous versions of brackets began to get confusing and a simplified version was desired. Thus, modifications to the brackets took place and the number of versions of brackets was reduced from five to two. The initial bracket designs only incorporated two potential locations for cone and v-block connections. By designing new brackets with eleven sets of slots and holes as opposed to two, the number of potential locations for the cone and v-block increased. Additionally, this still allows for the staggering of the connections, if needed, while letting all the v-blocks to use the same v-block bracket design and all of the cones use the same armature bracket design.

The new bracket design increased the ease of assembly. Additionally, this design also increased the ease of machining. While the earlier brackets had been machined from a mill, the new brackets, with their simpler setup, could be machined using a water jet. As opposed to having to have someone individually make each bracket for all five versions, a long strip of material could now instead be put into the water jet and all of the brackets for each version could be made quicker, easier, and all at once.

Furthermore, adjustments were also made to the final design to reduce the risk of failure of the system. Maximizing the space between panels and ensuring that they do not catch or snag during deployment is of utmost importance when it comes to this design. The brackets that were initially used in the design were 0.25 inches thick. With the hub only allowing 0.75 inch of thickness from panel to panel, the brackets taking up one third of this space seemed worrisome.

Thus, when the bracket design was changed from five versions to two, the thickness of the brackets used was also reduced from 0.25 inch to 0.125 inch. As a result, the amount of available space between panels increased and, in using thinner brackets, the method of bending them to the panel's curve was simplified.

A second modification done to reduce the risk of failure was in the design of the v-block. With a hole extruded from the top surface to house the magnet, the initial design of the v-block had the magnets connected to the v-block by means of an epoxy. This posed a couple of potential risks. One being the failure in this connection should the magnetic forces exerted between the cone and magnet being too strong. An occurrence such as this would result in the failure of the system. Second, the neodymium magnets used are very brittle. If a magnet were to come loose and collide with something else, the risk of shattering the magnet and harming those around the system could occur. Thus, instead of using an epoxy to hold the magnet within the v-block a set screw was introduced into the v-block to better hold the magnet in its intended location.

Results

The overall goal at hand is to create a working prototype for a solid reflector deployment mechanism. With this prototype we aim to demonstrate the mechanical ability of our latching mechanism to engage during deployment and securely hold our six panels in a final, flush configuration for a prolonged period of time. Once the prototype has been assembled, analysis on the mechanism will take place. From this analysis we aim to:

- Find the minimal load for separation of the panels
- Evaluate the ability of our panels to self align using our kinematic coupling design
- Evaluate and experiment the hold of our chosen magnets
- Evaluate the forces exerted by the panels during deployment

Types of Tests

Testing will begin towards the end of January and continue through February.

Proposed tests

- Finding the minimal load for separation of the panels:
  - Determine the direction of loading and minimum load magnitude required to separate panels
  - Apply a various range of loads (approximately 1 to 5 lbf) to the end of the panels to experiment with their yield strength
- Evaluate the ability of our panels to self align:
  - The slots in the brackets of our design allow for alterations to the positioning of the v-blocks and cones
    - Strain panels into misaligned configurations. Determine maximum misalignment direction and magnitude where panels do not realign
- Evaluate and experiment the hold of our chosen magnets
  - Do the magnets securely hold the panels in their intended final positions?
    - Is there any gapping?
  - Approximately how much force needs to be applied in order to separate the panels

As experimentation and analysis take place, alterations and modifications to the original design of the latching mechanism may be necessary.

Strengths and Weaknesses of Design

Design Strengths:

- Passive
    - No power required for panels to interlock
- Simple
    - No moving parts to fail
- Reliable
    - Panels will not fail to interlock due to design
- Secure
    - Once interlocked, panels remain locked due to magnetic forces
- Modifiable for prototype testing
    - Design can be updated or changed if prototype fails

Design weaknesses:

- No mechanical latch
    - Panels can be forced apart by high external forces acting upon panels
- Unexplored use of magnets in space
    - Operation time indefinite
    - No documentation of magnet use in space

Recommendations for Future Efforts

- Allow more tolerance
    - Ease of adjustment
    - More modifiable
- Make parts completely interchangeable
    - Completely customizable prototype
    - All parts can be relocated if needed
- Incorporate panel and brackets in one part
    - Eliminates need for two separate parts
    - Ease of assembly
- More spacing between panels for testing purposes
    - Allows more space for testing
    - Ease of interchangeability
- Different geometries for kinematic coupling
    - Test different geometries' effectiveness
- Test different magnets

    - Sizes and strengths
- Method of bending brackets
    - Have machined with the proper curve
- Multiple mounting plates to test panels without hub mechanism
    - Plate for deployed configuration
    - Plate for stowed configuration

- Troubles ran into during construction
    - Bending brackets to fit panels
        - Arbitrary curve difficult to replicate
        - Methods attempted:
            - Press
            - Hammer
            - Bending to mold and clamping
            - Roller
    - Attaching panels to brackets
        - Misalignments have very small tolerance for full deployment
        - Methods attempted:
            - Measuring distance along panels using tape
            - Put panels in deployed position and guide drill holes
        - Some panel overlapping

Section V – Engineering Economics

The following table shows the details of the complete funds spent towards the interlocking panels latching mechanism.

Table 4. Total money spent for prototype.

Vendor	Item Description	Qty	Unit Price	Total Cost
McMaster Carr	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/2” x 1” x 3’)	2	17.23	34.46
	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/8” x 1” x 6’)	6	9.97	59.82
	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/4” x 1” x 6’)	5	16.02	80.10
	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/16” x 1/2” x 6’)	1	2.04	2.04
	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/4” x 8” x 1’)	1	16.63	16.63
	Machine able 1117 Low-Carbon Steel Rods (1” diameter x 1’)	4	10.35	41.40
	Wrap Around Safety Glasses	1	7.31	7.31
K&J Magnetics, Inc.	Grade N42-Nickel Plated Magnets (5/8” diameter x 1/10” thick)	12	1.40	16.80
	Grade N42-Nickel Plated Magnets (5/8” diameter x 1/8” thick)	12	1.64	19.68
	Grade N52-Nickel Plated Magnets (5/8” diameter x 1/8” thick)	12	2.08	24.96
			Total:	**303.20**

The items in table 3 above were used in the construction, assembly and testing of the latching mechanism prototype. Materials seen here include extra materials that were ordered to machine additional latching mechanism components as request of the customer. The final assembled prototype consists of six panels, six support systems and six latching mechanisms. Table 4 below shows the details of the funds spent solely on the materials used in the final prototype.

Table 5. Budget used for only the parts actually being used

Vendor	Item Description	Quantity	Unit Price	Total Cost
McMaster Carr	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/2" x 1" x 3')	1	17.73	17.73
	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/8" x 1" x 6')	4	9.97	39.88
	Multipurpose Aluminum Alloy 6061 Rectangular Bars (1/16" x 1/2" x 6')	1	2.04	2.04
	Machine able 1117 Low-Carbon Steel Rods (1" diameter x 1')	2	10.35	20.70
K&J Magnetics, Inc.	Grade N42-Nickel Plated Magnets (5/8" diameter x 1/10" thick)	6	1.40	8.40
			Total:	**88.75**

Harris Corporation provided a $2,500 budget towards the necessary expenses required to create a working prototype of the interlocking panels to further demonstrate its functionality. Of this $2,500, a grand total of $303.20 was needed to complete the designing, testing, construction and necessary modifications to the prototype. The panels used in the prototype were donated by Harris Corporation and the hardware used in the connection of the components was also provided. Machining was done at the FSU/FAMU College of Engineering and was free of charge. Disregarding excess materials ordered for modification and testing purposes, the final prototype is comprised of $88.75 worth of purchased materials. The amount of money spent is modest compared to the allotted amount of spending because the main goal was to show proof of concept by creating a working prototype for these interlocking panels. The physical prototype is not intended for use in space, however, the design concept within the prototype is applicable in space. There are available resources (for example, panel material) capable of functioning in space, however they are found at a much higher cost. For the purpose of demonstrating the mechanical properties of the system as well as staying within the allowed budget, cheaper materials still capable of demonstrating the functionality of the prototype were chosen as opposed to more expensive materials. Although the more costly materials may have the ability to work in space, they deliver no additional benefits to the effectiveness of the prototype in the demonstration of deployment.

Section VI – Results and Discussion

Three variations of magnets were purchased in order for testing. All magnet types are neodymium. Two of them are a grade N42, differing only in their thickness, while the third magnet is a little stronger with a grade N52. Once the panel interlocking prototype was developed, two tests were done on the magnet. These tests were used to get a better understanding of the degree of the separation force required and the engagement proximity for each magnet type.

The separation force required was defined as the amount of force necessary to disengage the latching mechanism once it has already been engaged. Testing was accomplished by attaching a weight to the bottom of the v-block assembly while the magnet within the v-block was engaged with the cone in the armature assembly. The weight attached was gradually increased until the latching mechanism disengaged. Once disengaged, the amount of weight required was measured and converted to Newtons. The same procedure was applied to all three magnets.

The engagement proximity was defined as the minimum amount of space between the top of the magnet and the base of the cone before the latching mechanism engaged. During testing, two panels were used. One panel remained stationary while the second panel was slowly moved towards the first in the same manner the hub would move the panels. A ruler was fixed at the top of the magnet and once the latching mechanism began to engage the distance between the magnet and cone was recorded. This procedure was repeated ten times and the average of the ten measurements was recorded for each magnet. Due to the small increments of measurement and the grey area in decided when the latching mechanism really began engaging, the recordings were termed the “approximate engagement proximity.”

Table 6. Summary of Results

Magnet Type	**Separation Force Required (N)**	**Approximate Engagement Proximity (mm)**
1/10" thick N42	7.8	6
1/8" thick N42	15.7	7
1/8" thick N52	26.5	7

Results for the two tests conducted were recorded and can be seen in the table above. As shown, the separation force required increased as the size of the magnet increased. Similarly, when the grade of the magnet increased the force required to separate the mechanism increased, too. When it came to the approximated engagement proximity, minor differences were noted. It appears that the engagement proximity is dependent on magnet size rather than strength, as the magnets with the same grades experienced different proximities while the magnets with the same size experienced the same engagement proximity distances. The acquired data here gives a reference as to the degree of separation force and engagement proximity as generally seen by these types of magnets to get a better understanding of their use and application for this design.

Section VII – Environment, Health and Safety

Due to the scale and nature of this project, there is minimal risk of any kind. However, with any design, risk assessment is still necessary. With this design there are two main concerns in the use of magnets:

Risk of pinching
Risk of chipping

Both of these risks increase as the size of the magnets being used increases. Due to the small dimensions of our magnets, neither of these risks pose too great of a threat, however it is still important to be aware of these potential concerns.

In the case that someone’s finger or skin is pinched, a brass wedge should be inserted in between the magnets to remove the pressure and withdraw the hand or skin from the vicinity. Simply attempting to pull a member out from between the magnets (or in our case, the magnet and cone) will increase the force being exerted on it while simultaneously decreasing the area over which the pinching is occurring. This, overall, increases the added pressure on the hand or skin and is best relieved by simply using a wedge before attempting to release the member.

Chipping is a second risk when using magnets. Different magnet types have different material properties and some are more prone to chipping than others. Being fully aware of the type of magnet and its material properties is important with this design. Although with our design the magnets should not be exhibiting any high mechanical loads, if deemed necessary protective eyewear may be used.

Section VIII – Conclusion

The interlocking mechanism designed by the panel interlocking team was successful in showing the functionality of a tangential deploying solid reflector as requested by Harris Corporation. A working prototype that demonstrates the panel interlocking mechanism concept was constructed. Specifically, this mechanism utilizes a kinematic coupling system to ensure that the panels be guided to their intended location after deployment. The final prototype resembled a dish, was comprised of recycled panels, fit within these provided panels, and the latching mechanism design incorporated into it is capable of functioning in space. Thus, the main goal of producing this working prototype was achieved while satisfying the objectives previously set forth at the beginning of this project and staying within the constraints of the budget. The only other constraint in the design of the latching mechanism was its intention for use along with the hub, and had to be designed to function with it as an assembly. The latching mechanism and the hub mechanism prototype, designed by the hub team, were assembled to create a fully functioning prototype of the entire system. This final prototype successfully demonstrated the capabilities of the overall system by utilizing first rotational and then linear motion to transfer solid panels from stacked to deployed position without snagging or catching. Criteria for the magnets intended for use was tested and general information regarding the separation forces and engagement proximity particular to these magnets was found. This information along with the prototype can be passed on to Harris Corporation to further assist them in their need to create a solid tangential deploying reflector for intended use in space.

Section IX – Acknowledgements

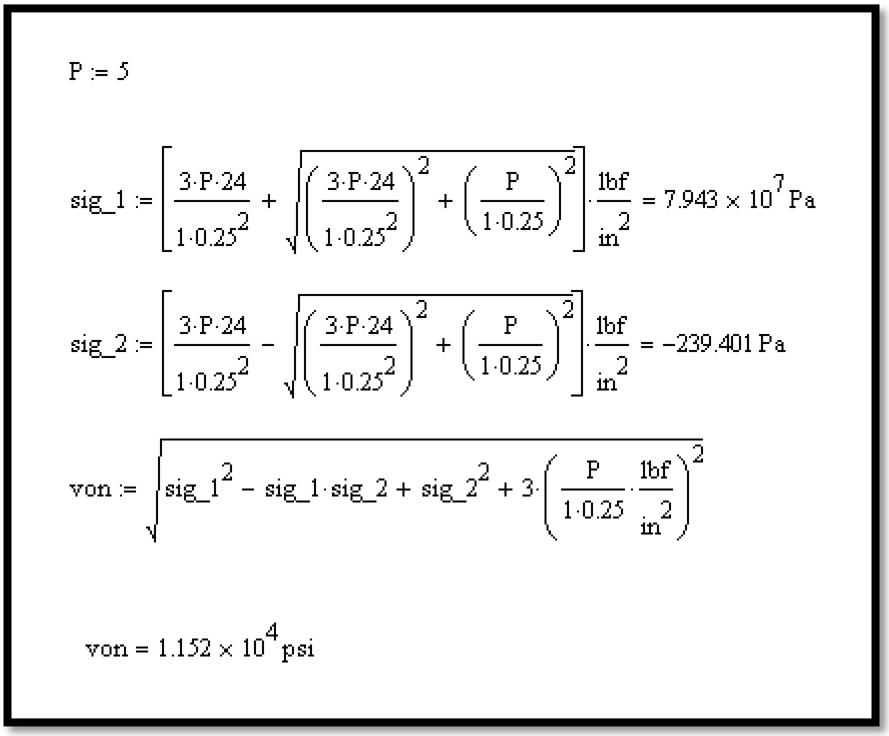
Mr. Gustavo Toledo, Harris Co. – Project Sponsor

Dr. Dalban-Canassy, Dr. Kosaraju, Dr. Shih – Faculty Advising

Bill Starch, ASC Machine Shop

FSU Machine Shop

Section X – Appendix



$$P := 5$$

$$\mathrm{sig\_1} := \left[\frac{3\cdot P\cdot 24}{1\cdot 0.25^2} + \sqrt{\left(\frac{3\cdot P\cdot 24}{1\cdot 0.25^2}\right)^2 + \left(\frac{P}{1\cdot 0.25}\right)^2}\,\right]\cdot\frac{\mathrm{lbf}}{\mathrm{in}^2} = 7.943\times 10^7\,\mathrm{Pa}$$

$$\mathrm{sig\_2} := \left[\frac{3\cdot P\cdot 24}{1\cdot 0.25^2} - \sqrt{\left(\frac{3\cdot P\cdot 24}{1\cdot 0.25^2}\right)^2 + \left(\frac{P}{1\cdot 0.25}\right)^2}\,\right]\cdot\frac{\mathrm{lbf}}{\mathrm{in}^2} = -239.401\,\mathrm{Pa}$$

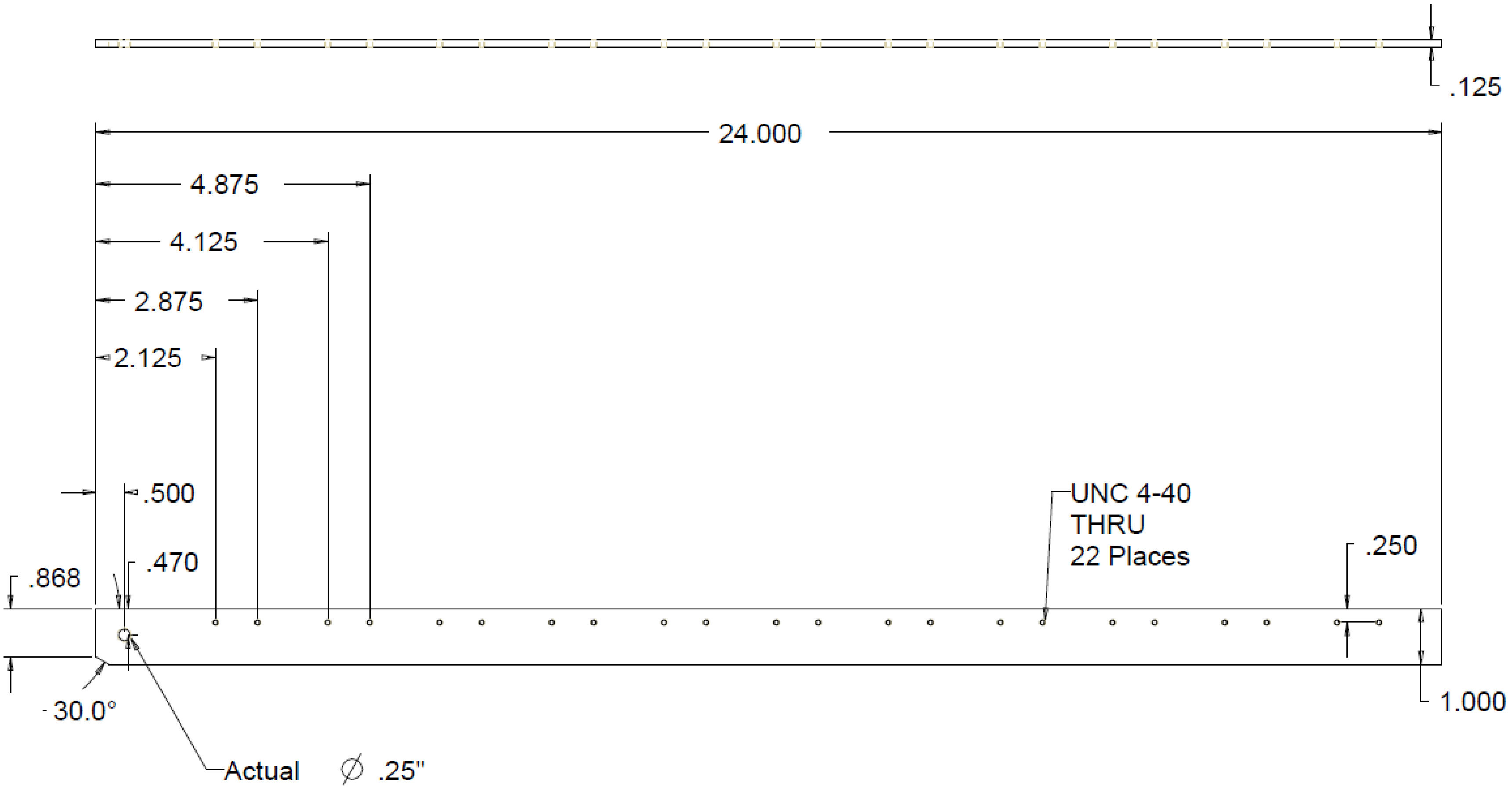
$$\mathrm{von} := \sqrt{\mathrm{sig\_1}^2 - \mathrm{sig\_1}\cdot\mathrm{sig\_2} + \mathrm{sig\_2}^2 + 3\cdot\left(\frac{P}{1\cdot 0.25}\cdot\frac{\mathrm{lbf}}{\mathrm{in}^2}\right)^2}$$

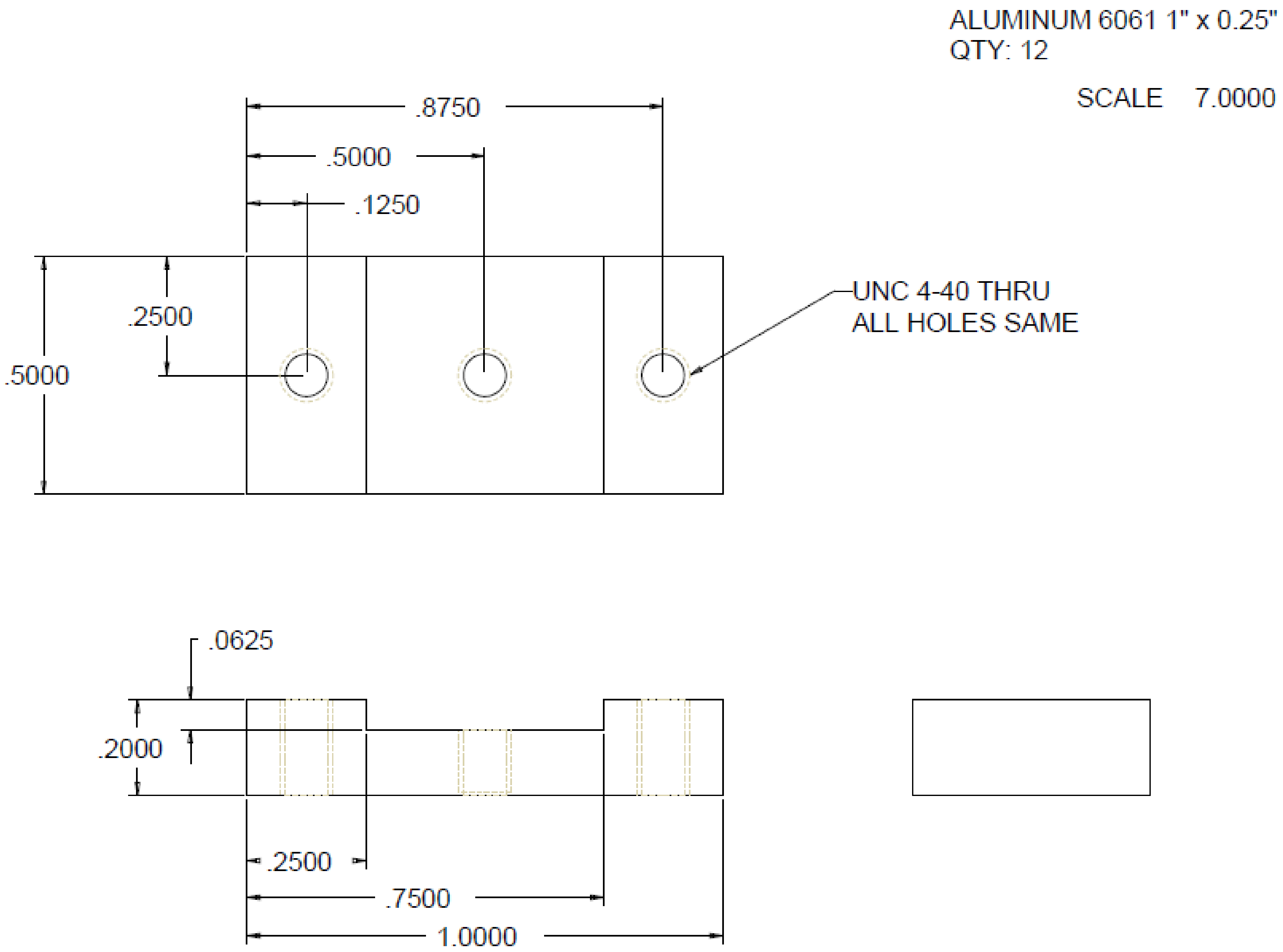
$$\mathrm{von} = 1.152\times 10^4\,\mathrm{psi}$$

Figure 32. Stress analysis verification.

Section XI – Engineering Drawings

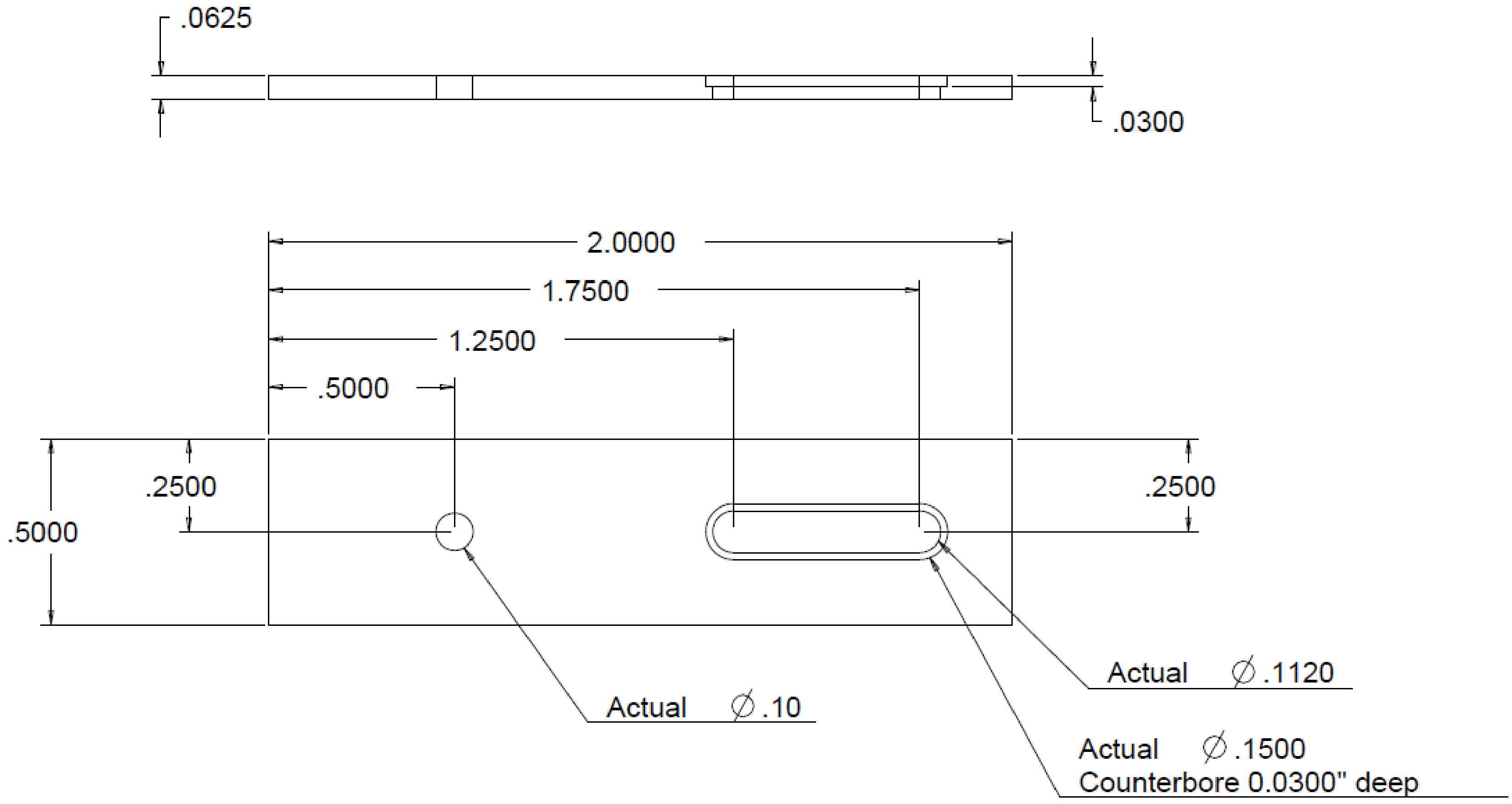
ALL DIMENSIONS IN INCHES
MATERIAL: ALUMINUM 6061
PART: ARMATURE BRACKET 1/8 INCH
QTY: 6
SCALE 0.800



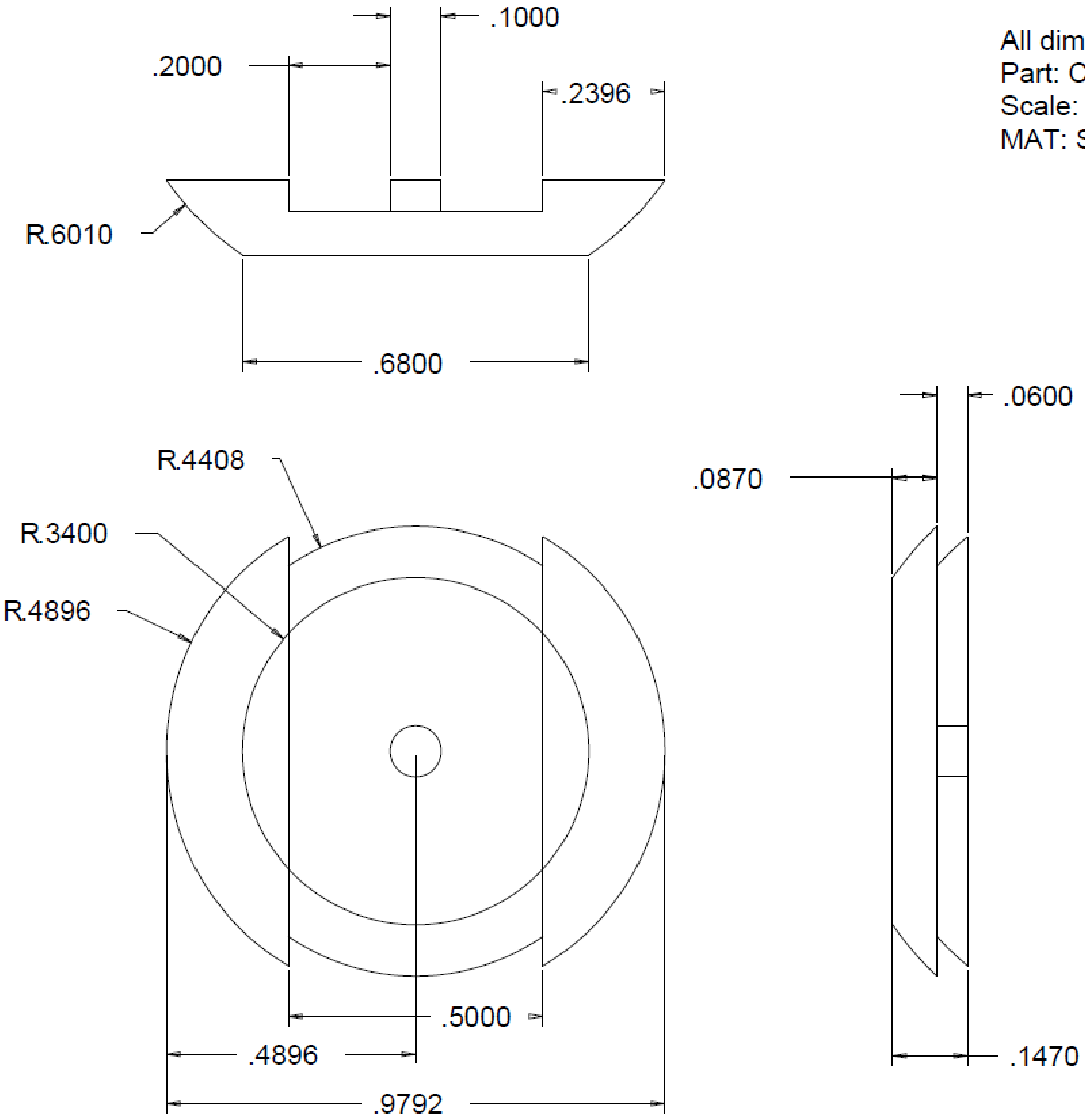

ALUMINUM 6061 1" x 0.25"
QTY: 12
SCALE 7.0000
.8750
.5000
.1250
.2500
.5000
UNC 4-40 THRU
ALL HOLES SAME
.0625
.2000
.2500
.7500
1.0000

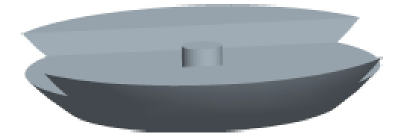
MAT: Aluminum 6061
Dimensions: 1" x 0.5" x 1/16"
QTY: 12

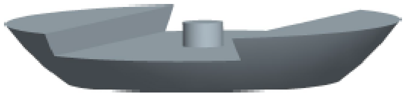
SCALE 5.0000

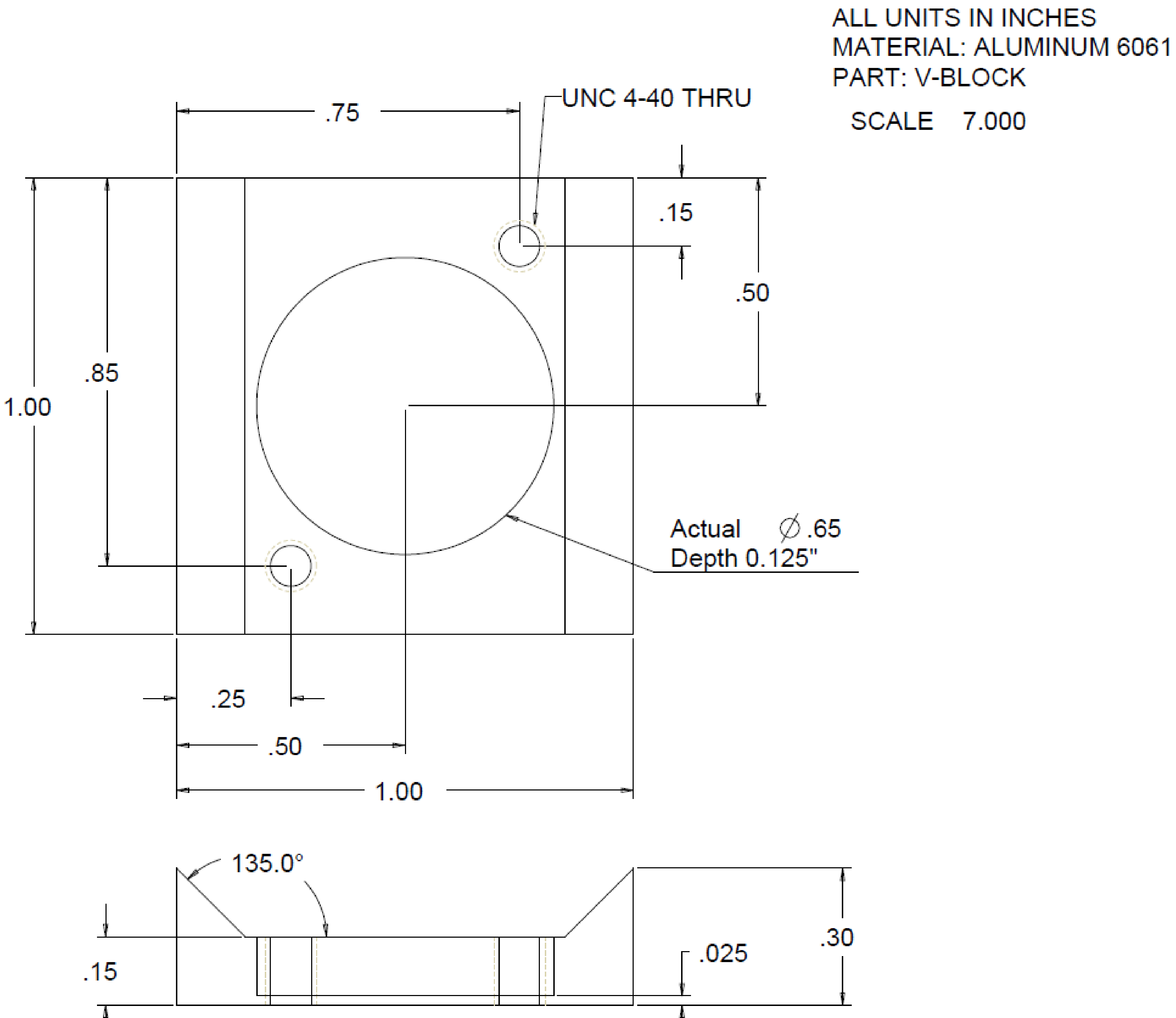


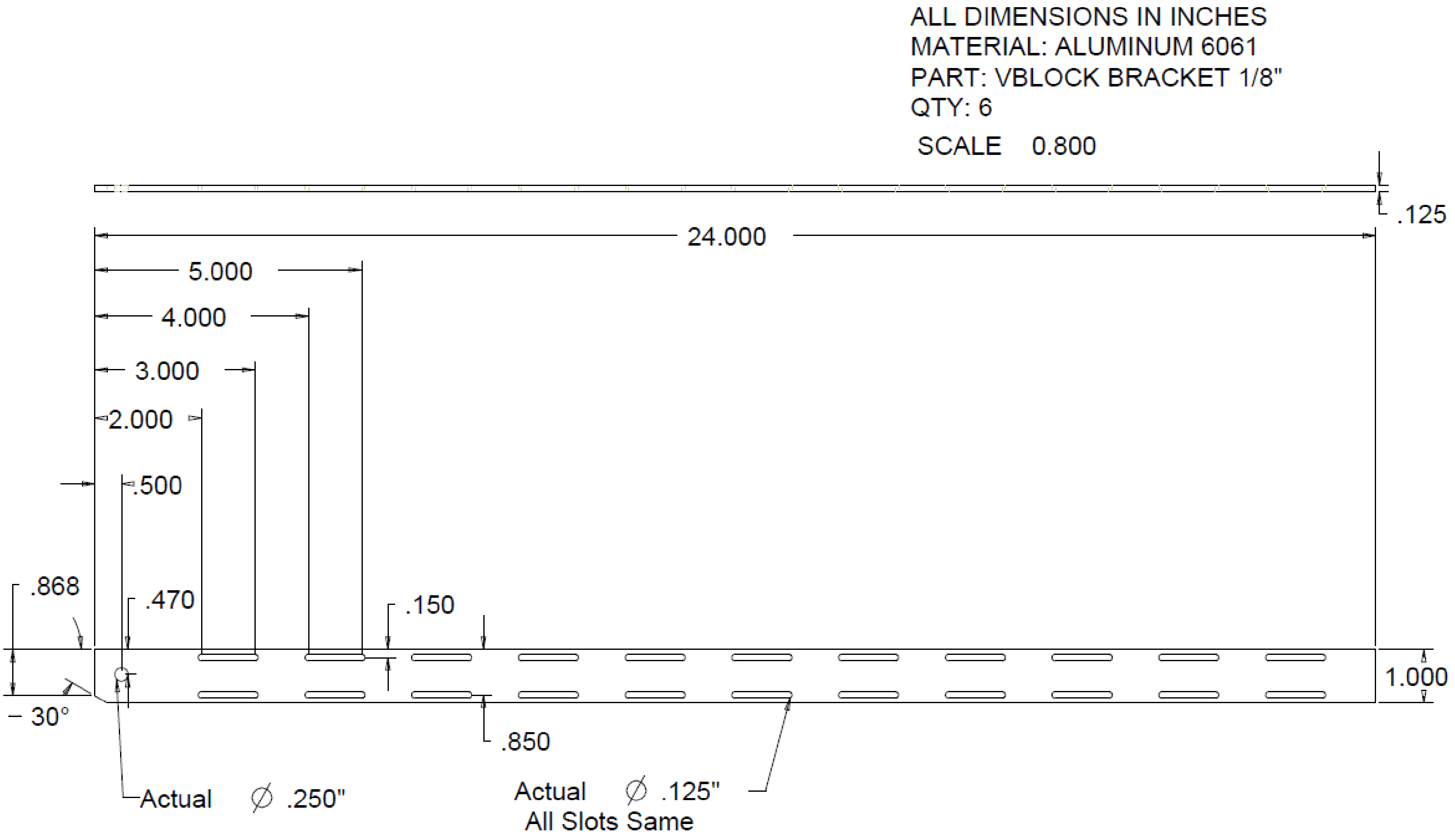
All dimensions in inches
Part: Cone
Scale: 7
MAT: STEEL A36

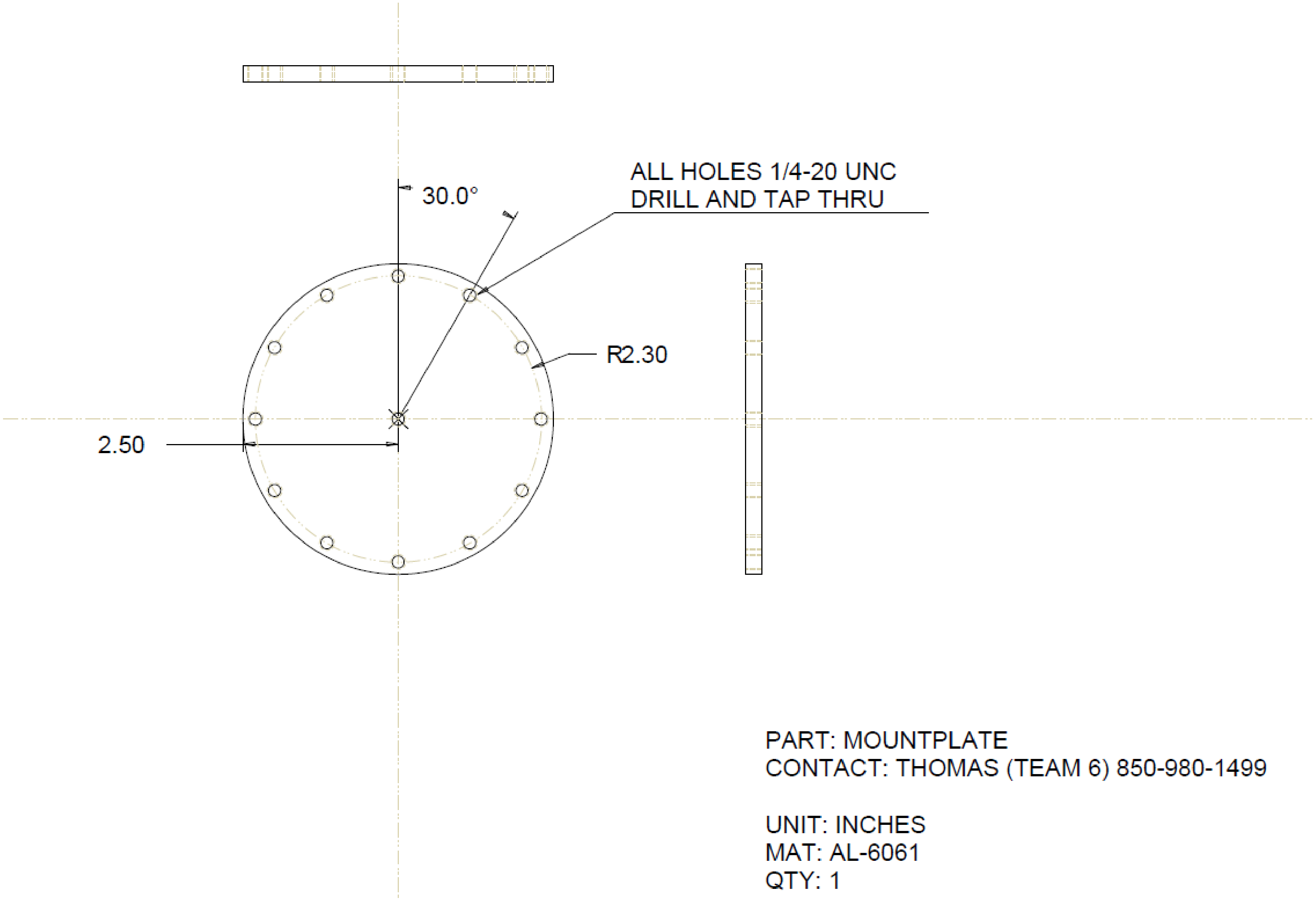



SCALE 5.000


SCALE 5.000


ALL UNITS IN INCHES
MATERIAL: ALUMINUM 6061
PART: V-BLOCK
SCALE 7.000
UNC 4-40 THRU
.75
.15
.50
.85
1.00
Actual ∅.65
Depth 0.125"
.25
.50
1.00
135.0°
.15
.025
.30


ALL DIMENSIONS IN INCHES
MATERIAL: ALUMINUM 6061
PART: VBLOCK BRACKET 1/8"
QTY: 6
SCALE 0.800
.125
24.000
5.000
4.000
3.000
2.000
.500
.868
.470
.150
1.000
30°
.850
Actual ∅ .250"
Actual ∅ .125"
All Slots Same



PART: MOUNTPLATE
CONTACT: THOMAS (TEAM 6) 850-980-1499

UNIT: INCHES
MAT: AL-6061
QTY: 1

Section XII – References

Ashby, M. F. *Materials Selection in Mechanical Design*. Third ed. Amsterdam: Butterworth-Heinemann, 2005. Print.

Ashby, M. F. *Materials Selection in Mechanical Design*. Fourth ed. Burlington, MA: Butterworth-Heinemann, 2011. Print.

Design of Accurate and Repeatable Kinematic Couplings. Martin L. Culpepper, Alexander Slocum and Peter Baile. Precision Engineering Journal.

Design of Low Cost Kinematic Couplings Using Formed Balls and Grooves in Sheet Metal Parts. Martin L. Culpepper, Alexander Slocum and Peter Baile. Precision Engineering Journal.

Lewis, W. P., and A. E. Samuel. *Fundamentals of Engineering Design*. New York: Prentice Hall, 1989. Print.

Dym, Clive L., and Patrick Little. *Engineering Design: A Project-based Introduction*. New York: John Wiley, 2000. Print.

Smith, Karl A. *Project Management and Teamwork*. Boston, MA: McGraw-Hill, 2000. Print.

Ulrich, Karl T., and Steven D. Eppinger. *Product Design and Development*. Boston: Irwin/McGraw-Hill, 2000. Print.

Material Sources

http://www.mcmaster.com

http://www.kjmagnetics.com/

http://www.mceproducts.com/

http://www.rare-earth-magnets.com/Permanent-Magnet-Selection-and-Design-Handbook.pdf

http://www.precisionballs.com/index.html

http://www.magnet4less.com/

Section XIII – Biographical Sketch

Thomas Patten is an undergraduate mechanical engineering student studying at Florida State University. With an emphasis on mechanics and materials, his intern experience is in the processing and characterization of the High Temperature Superconductor (HTS) Bi-2212. Outside of class, Thomas has conducted humanitarian efforts in Peru with the student group Engineers Without Borders. As member of the Rock Climbing Club at FSU, he guides climbing trips throughout the Southeast. He was also a member of Screech, the trumpet section of the distinguished Florida State University Marching Band. Thomas intends to pursue a career in R&D in the outdoor industry.

Cory Slingsby is studying at Florida State University for his B.S. degree in mechanical engineering. He has an emphasis in materials and is in his last semester of his undergraduate career. During school, Cory worked at the Florida State University machine shop, participated in intramural sports, is a member of ASME, and frequently on the President’s list and Dean’s list for his academic performance. He is currently working part time for a family business and preparing for graduation. After graduation he will be available for employment.

Ashley Saunders is an undergraduate student acquiring her bachelor’s degree in mechanical engineering at Florida State University. With an initial major of mathematics education, her enjoyment in the study of math and physics geared her towards an interest in engineering. She has been a member of the American Society of Mechanical Engineers for almost two years and has worked part time in the service industry while simultaneously taking classes the past five years. She holds a particular interest in sales engineering and has never let go of the idea of teaching high school or college level calculus classes.