University of Colorado
Aerospace Engineering Sciences
ASEN 4018
Conceptual Design Document

Baffling Buffs

September 26, 2016

1 Information

1.1 Project Customer

NAME: Scott Taylor
ADDRESS:
Surrey Satellite Technology US, LLC
345 Inverness Dr. Suite #100
Englewood, CO 80112
PHONE: (720) 545-0868
EMAIL: staylor@sst-us.com

1.2 Team Members

Anthony Anglin Anthony.Anglin@colorado.edu (720) 224-5820	**Emmett Bailey** emmett.bailey@colorado.edu (970) 485-3379
Aspen Coates asco1092@colorado.edu (719) 459-1702	**Lindsay Goldworm** ligo3313@colorado.edu (303) 641-5092
Steven Hays hays.steven.m@gmail.com (303) 519-3775	**Elizabeth Luke** elizabeth.luke@colorado.edu (719) 930-0394
Zachary McConnel zamc5798@colorado.edu (303) 668-1704	**Nicholaus Monahan** niro7522@colorado.edu (619) 321-7465
Mary Scites (Allison) maal2274@colorado.edu (719) 640-3535	**Sierra Williams** siwi6002@colorado.edu (720) 251-1838

Contents

2 Project Description[1]

2.1 Project Overview

Stray light from the Sun and Earth poses problems for star trackers on satellites. Star trackers need to see dim light from stars in order to determine the attitude of a spacecraft. The Sun has a magnitude of 26.72, while the next closest and brightest star, Sirrus has a magnitude of 1.46. Because of the large difference in brightness of the stars, the light from the sun must be blocked in order for the star tracker to view the stars, thus a star tracker baffle is required.

Baffles are used with star trackers in order to block stray light, which enables the star tracker to see the dim stars more easily. The baffles that are currently used on spacecraft are relatively large and heavy structures. While the need to attenuate light for star trackers still exists, this is a problem for small spacecraft because of their relative size. Small satellites require a baffle that is smaller and weighs less than any that are currently being used.

The Baffling Buffs project will create a small lightweight deployable star tracker baffle to be used on small satellites. The baffle shall be deployable once the satellite is in orbit, shall weigh less than 300 grams and shall fit inside a 125x125x50 mm volume prior to deployment. When deployed, the baffle shall have a 30 degree light exclusion angle. Testing shall be done on the baffle to simulate the stray light environment the baffle will encounter in orbit to ensure the light exclusion angle of 30 degrees has been achieved. To ensure that our objectives our clear, our tiers of success can be seen in Table 1 below.

Table 1: Tiers of Success for Project Requirements

	Tier 1	**Tier 2**
Deploy Baffle	Manual Deployment	Electronic Deployment with Wired Connection
Baffle Light Exclusion	40 ° Light Exclusion Angle	30 ° Light Exclusion Angle
Baffle Mass	<500 g	<300 g
Stowed Baffle Volume	Constrained by: 175 mm width 175 mm length 50 mm height	Constrained by: 125 mm width 125 mm length 50 mm height

The success of this project depends on the ability to remotely deploy the baffle via an electronic process such that it creates a 30 degree half-angle light source exclusion zone, as measured from the boresight of the optical sensor. In simpler terms, this angle is shown in Figure 1 and is defined as the angle between the light source (in this case the sun) and the star tracker camera's normal axis, where a zero degree light exclusion angle is defined when the light source is located directly over the sensor. Success also includes creating a test methodology and instrumentation suite to confirm that the baffle meets these requirements and to perform these tests accordingly.

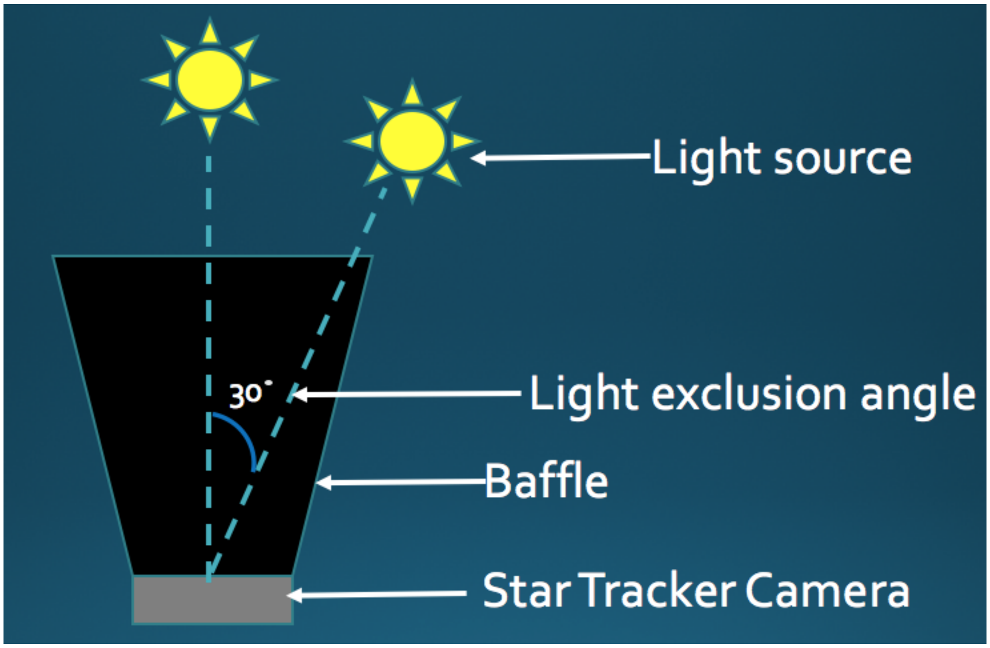


Figure 1: Light Exclusion Angle

2.2 CONOPS

The CONOPS diagram shown in Figure 2 shows how the baffle designed in this project will fit into a mission for a small satellite. The small satellite will be deployed with the baffle stowed. Once the star tracker is needed the baffle will deploy. The light that reaches the star tracker will allow the satellite to find star patterns and use that to determine its attitude. The scope of this project only includes those mission elements included in the light blue oval. This project will focus on the deployment of the baffle and the resulting light attenuation.

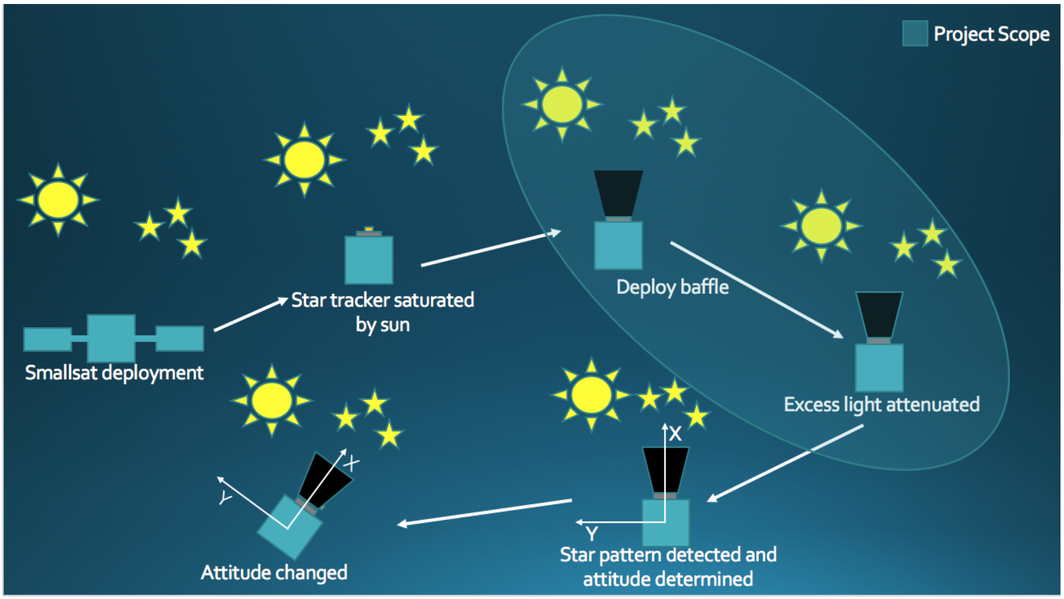


Figure 2: Mission CONOPS Diagram

In order to confirm that the project meets requirements, testing will be done to determine the light exclusion angle of the designed baffle. This testing will be conducted in a dark room with a light sensor in the baffle as shown in Figure 3. Once the baffle is deployed, light will be shined down the baffle at the maximum exposure angle. The incident angle of the light will then be increased to determine how well the baffle design attenuates stray light.

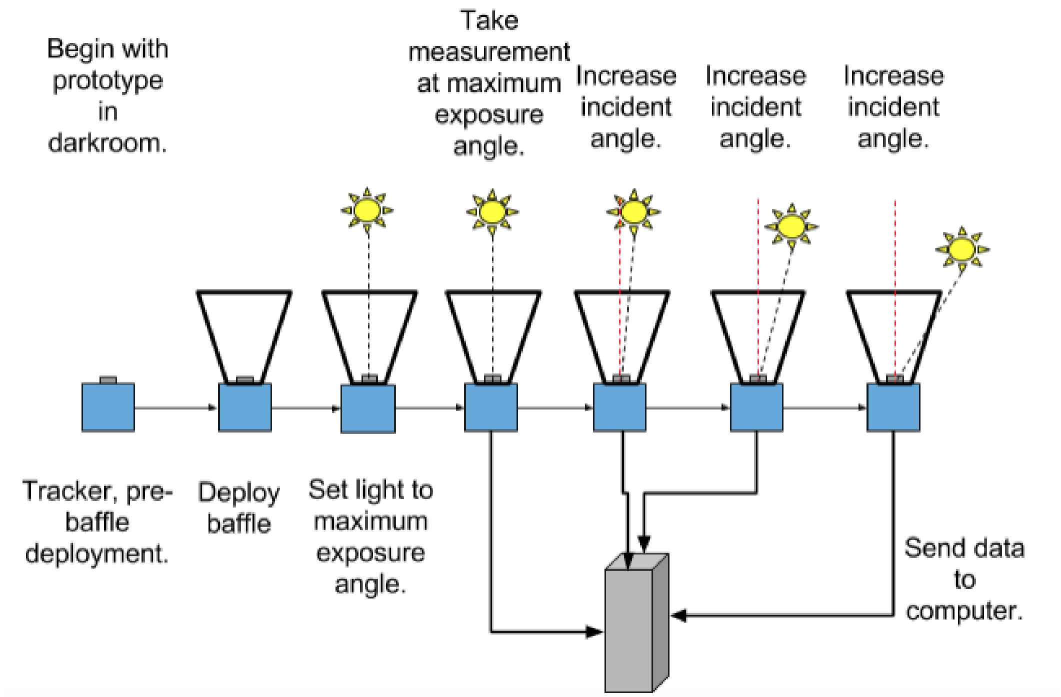


Figure 3: Operational Testing CONOPS

2.3 Functional Block Diagram

The functional block diagram, depicted in Figure 4, details the system interactions necessary to test and verify the baffle prototype. A central processing unit will send a one-time deployment command to the mechanism that will deploy the baffle. Light from an external source will be attenuated by the baffle and sent to the optical sensor. The resulting optical data will be sent to a DAQ module for processing and then sent back to the central processing unit to command an attitude adjustment, if required. The star tracker unit will be powered by the satellite's available on board power supply, which is limited to 28 DC Volts.

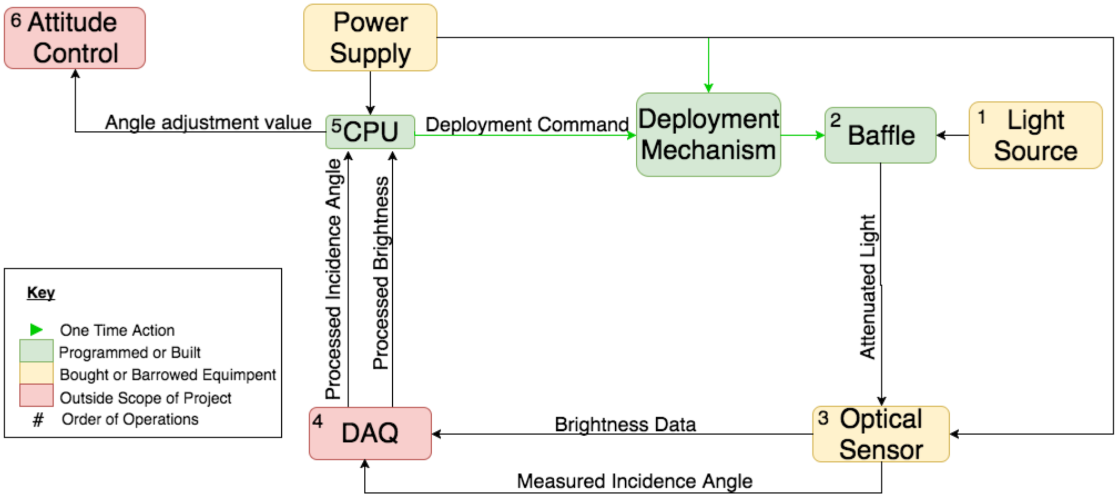


Figure 4: Functional Block Diagram

2.4 Functional Requirements

FR1 The baffle shall be deployable.
FR2 The stowed baffle shall fit within the given volume constraint.
FR3 The baffle mass shall adhere to the given mass constraint.

FR4 Testing shall be done to determine the light exclusion angle of the baffle.

3 Design Requirements

The acronym ”V & V” stands for verification and validation.

FR1 The baffle shall be deployable.
DR 1.1 The baffle shall deploy via an electronic method.
DR 1.1.1 The baffle shall deploy via an electronic impulse of 28 Volts.
Source: Customer requirement. An on-orbit baffle will require an electronic interface with the satellite in order to power the deployment mechanism. Also, the satellite can only supply 28 V to the baffle deployment as defined by the customer.
V & V: Test. The baffle will need to transition from a stowed position to a fully deployed position via a controlled electronic signal of the given voltage.

FR2 The baffle shall fit within the given volume constraints.
DR 2.1 When stowed, the baffle shall fit within a 125 x 125 x 50 mm volume (defined as width by length by height).
Source: Customer requirement. Width and length are based on an accepted baffle aperture size. Height is the variable most desired to be minimized in order to reduce the package size of the delivered satellite payload.
V & V: Inspection and measurement. The stowed baffle will need to be manufactured and confirmed to fit within the given volume requirement.

FR3 The baffle shall adhere to the given mass constraints.
DR 3.1 The total baffle mass shall be less than 300 g.
Source: Customer requirement. The fully constructed baffle will be lighter than other existing baffles manufactured by Surrey Satellite Technology. Lighter components leads to an overall cheaper launch cost. Also, due to the growing popularity of small satellites, lighter, deployable baffles are a growing need due to launch constraints.
V & V: Measurement. The fully constructed baffle will be weighed to ensure it adheres to the mass requirements.

FR4 Testing shall be done to determine the light exclusion angle of the baffle.
DR 4.1 The light exclusion angle shall be 30 degrees, as measured from the boresight of the optical sensor as shown above in Figure 1.
Source: Customer requirement. This matches acceptable light attenuation performance of baffles currently used in the space industry.
V & V: Test. The baffle will be placed in a dark room with a light source to simulate the presence of sunlight. The baffle must be able to shield the stray light beyond a 30° exclusion angle, allowing the sensor to identify distant stars. The exact methodology of angle measurement is still under consideration.

4 Key Design Options Considered

4.1 General Shape

4.1.1 Cone

Surrey Satellite Technology’s star trackers, currently on the market, specified to a 30 degree sun exclusion angle, all utilize cone shaped baffles[2]. This is not unique to Surrey, however, a paper published in the Proceedings of The 4S Symposium: Small Satellites, Systems and Services also shows a cone shaped baffle design[4]. The paper ”Miniaturised star tracker (AA-STR) ready to fly” depicts a cross sectional schematic view of a cone shaped baffle, similar to Figure 5[3]. These baffles consist of a smaller diameter cone at the sensor head and a larger diameter cone at the end of the baffle (pointing away from the spacecraft). The baffles are not a perfect cone, they are tiered in a cone like shape which can be seen in Figure 5.

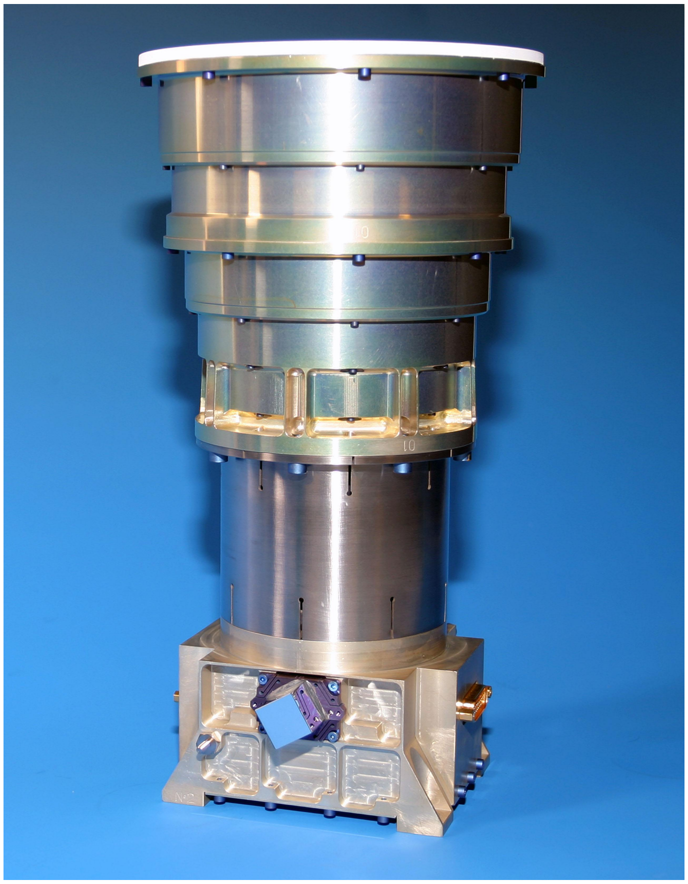


Figure 5: Rigel-L star tracker from Surrey Satellite Technology[2]

Table 2: Pros and Cons for Cone Baffle Shape

Pros	Cons
• Proven heritage, used on startrackers currently in space	• Complicated manufacturing
• Geometry reduces mass	

4.1.2 Cylinder

Strict cylindrical baffle shapes are severely lacking in proven heritage. After extensive research, the closest thing to a cylindrical star tracker baffle that was discovered was from a star tracker design back in 1993 for the Clementine mission and is shown below in Figure 6. It was a fixed, tiered baffle with concentric cylinders[5]. Simple trigonometric analysis (as seen in the Trade Study section of this report) shows that a cylinder with the same exact same radius and height of a cone would contain more mass. It is likely that this is what deterred baffle designers from considering strict cylinders since reducing mass for space applications is a key element in space design.

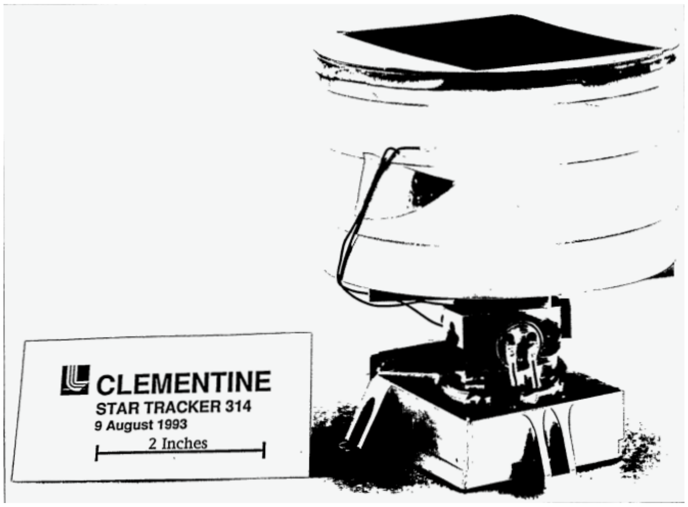


Figure 6: Clementine Star Tracker Camera[5]

Table 3: Pros and Cons for Cylindrical Baffle Shape

Pros	Cons
• Simple geometry	• No proven heritage
	• More mass than conic shape for same geometric constraints

4.1.3 Parabolic

Parabolic shapes are typically used for lighting purposes, satellite dishes, and telescopes. They are used when light needs to be gathered at a focal point. Documented research was hard to find as to why this shape is not utilized for baffles. One source documented a manufactured shape that was created by compounded parabolic shapes, but the end result was still conical[6]. One possible reason why this shape is not used in baffle design is because cones and vanes for a baffle typical do not focus light but instead reflect the light away from the star tracker sensor or absorb it. A parabola, on the other hand, would focus light which may create optical noise that the star tracker sensor could detect.

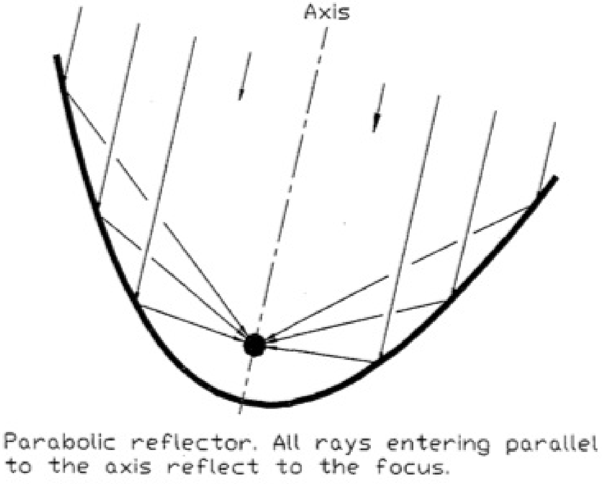


Figure 7: Parabolic Reflector w/ light centered on focal point[7]

Table 4: Pros and Cons for Parabolic Baffle Shape

Pros	Cons
• Ability to redirect light	• Very little to no prior research about design
	• Highly difficult to manufacture correctly
	• Redirected light is focused on a single point

4.2 Manufacturing Method

4.2.1 Telescoping

This design is based on the centuries-old design used for spy glasses. This design makes use of multiple rigid shapes nested inside each other that, when stretched, will overlap and create a longer structure. This has been done with several different base shapes, but is most often done with cylinders. When the structure is stowed, the height is dependent on how large the sections are. This makes it so that a long piece can be stowed into a much smaller volume using many nesting shapes. Though this method has not been used directly for baffles, it has been used for space antennae, whose size measures upwards of 0.9 m in diameter[8]. The length of a telescoping design is limited by the amount of overlap that is required, as well as the desired thickness of the structure[9].

Figure 8: Example of Telescoping Deployment[10]

Table 5: Pros and Cons for Telescoping Deployment Method

Pros	Cons
• Allows for a variety of baffle shapes	• Mainly used in slender structures
• Easily stowable to various heights	• Heavier due to more material required for overlapping
• Has been used many times in space deployment applications	

4.2.2 'Vegetable Steamer'

The general concept of this design will be based on a typical household item, the vegetable steamer. Most vegetable steamers are made of stainless steel or plastic. They consist of a circular base with square shaped leaves which are attached at their bottom to the base by a hinge. The leaves typically have some curvature to them and are attached in such a way that they are flush with one another. Vegetable steamers have two positions: their stored position and their operational position. When they are being stored, the leaves are retracted so that there is a minimal opening to the inside of the steamer. When the steamer is deployed, it forms a parabolic disc shape where the opening to the steamer is larger. The stowed and deployed states are shown in Figure 9 below.

Figure 9: Stowed and Deployed Steamer Positions[11]

This design was considered because the shape of the steamer is similar to the shape of a baffle and has a deployment aspect to it. One of the advantages of this design is that it is fairly simple and could provide inspiration for the deployment manufacturing of our baffle. Another advantage to this design is the simplicity of manufacturing since the leaves are assumed to all be of the same size and shape, thus simplifying the manufacturing process.

One of the disadvantages of this design would be making it optically adequate. Most baffles have vanes to shield stray light within the baffle, and putting vanes on the leaves could prove to be very difficult because the amount of surface area of each leaf touching each other varies between the deployed and stowed state. Another disadvantage is that there is no literature on how to design a vegetable steamer, so it would have to be reverse engineered. This would mean the baffle design would have more risk, as the team would not have the details needed. Also, cost could be an issue depending on the type of material chosen and how easily that material can be manipulated.

Table 6: Pros and Cons for Vegetable Steamer Manufacturing Method

Pros	**Cons**
• Simple design	• Optical challenge
• Simplistic component manufacturing	• No previous literature
	• Potential design/manufacturing costs

4.2.3 Smooth Sides

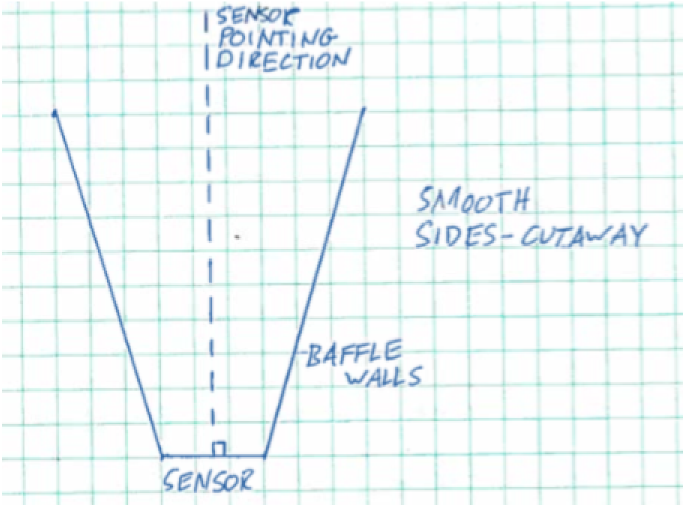


Figure 10: 'Smooth Sides' Manufacturing Method

Smooth Sides pertains to a method of articulation that uses a single piece of foldable material. In this case 'foldable material' is a flexible material (for example the thin film used for solar sails) that depends on the deployment mechanism for both its deployment, as well as its rigidity. Thus, the shape of the baffle will be confined to either a conical or cylindrical shape. This confinement exists because the deployable baffle cannot assume more than one complex overall shape because it is limited by its flexible nature. Thus, the final shape of the deployable baffle is not concrete when using a flexible material. Likewise, using a light, flexible material makes the baffle more fragile overall. Thin metallic films are very prone to puncture when not protected adequately. However, such an articulation method benefits from being relatively simple to manufacture. Ideally, such a design is composed of very few pieces. Also, an entire baffle composed of a single piece of light foil is very low in mass, falling well within the mass constraints of this project. This is illustrated in Table 7.

Table 7: Pros and Cons for Smooth Sided Manufacturing Method

Pros	Cons
• Simple to manufacture	• Cannot assume ideal shape
• Lower mass required	• Very fragile

4.2.4 Hinged Clamp

The hinged clamp consists of two halves that are connected by a hinged joint at the base. In its stowed configuration, the two halves are resting flat in the storage compartment. Once the deployment mechanism is activated, the two halves of the baffle rise up and clamp together. This baffle type is loosely based on the release of stowed solar arrays used on a Saudi Arabian cube-sat, developed by the Arab Satellite Communication Organization. In that particular case, the deployment mechanism consisted of torsion springs that were released from a displaced state and deployed the arrays by folding out large sections using the springs' potential energy[12].

The simplicity of this design allows for minimal mass due to the lack of elaborate, heavy deployment mechanisms and complex fasteners. However, the sun exclusion angle could be limited due to the fact that the hinged clamped baffle does not change size. Its maximum deployed height is constrained by its maximum stowed width. Sun exclusion could also be threatened due to light penetrating the interfacing sections of the clamped halves. Also, in the case of the torsion spring release method, there is no resistive force to the spring snap, resulting in a somewhat uncontrolled deployment. A more simplistic, everyday application that illustrates this baffle type is a P-Clamp, which can be seen in Figure 11.

Figure 11: A P-Clamp provides simple illustration of the hinged clamp baffle design[13]

Table 8: Pros and Cons for Hinged Clamp Manufacturing Method

Pros	Cons
• Simple to manufacture	• Deployed height is a function of stowed width
• Low mass requirement	• Possibility of violent deployment
	• Possible light penetration at clamp interface

4.3 Deployment

4.3.1 Spring

Spring based deployment would involve the use of an initially compressed spring that occupies the lining of the material. Consequently, the material selection would be limited to soft, flexible fabric because it would be very difficult to confine the spring to a rigid material. Locking would be relatively easy with a simple clamp to hold the spring in its compressed state. The clamp would be released and the baffle structure would pop up immediately. However, the rigid protrusions from the spring on the interior of the baffle could potentially deflect light to an undesirable location.

Figure 12: Metal Spring Structure[14]

Table 9: Pros and Cons for Spring Based Deployment Method

Pros	**Cons**
• Easy to lock in place	• Interior ridges
• Low volume requirement	• Limits material selection

4.3.2 Electrostatic Deployment

Electrostatic deployment relies on electrostatic discharge for correct operation. For space applications, electrostatically inflated membrane structures (EIMS) are used. These structures consist of ultra-thin, highly-flexible, tightly packed material that consists of a conducting film[16]. When deployment is desired, the conductive film is charged which causes repulsive forces to inflate the membrane structure. The expansion is limited by a rib structure within the material[16]. This concept can be seen in Figure 13.

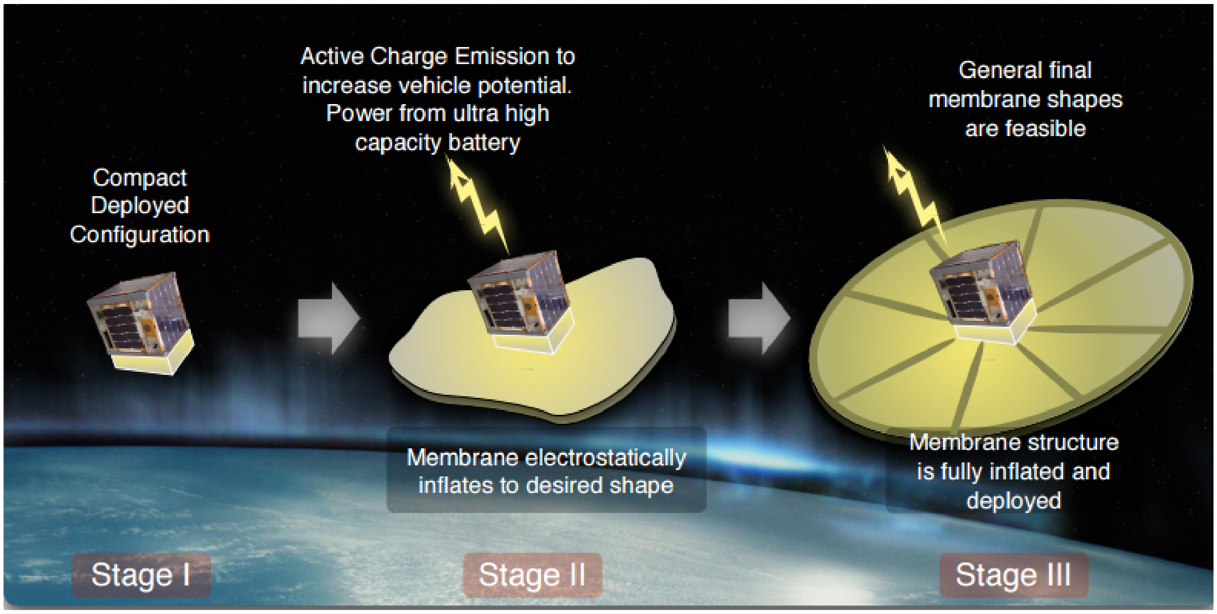


Figure 13: Electrostatically Inflated Membrane Structure[15]

An advantage of this design is that the structural components for these structures need not be stiff. This allows for a significantly smaller stowed and deployed volume which directly relates to one of our main design requirements. There are also no moving or sliding mechanical parts in these structures which would simplify the manufacturing process[16].

A disadvantage of this design is that electrostatic discharging could cause problems with other instruments on the spacecraft. Another issue is that the power required for these structures is in the kilo-volt range and this project only has 28 volts at its disposal. A method to keep this structure deployed is a continuous charge emission which may not be practical considering the limited power source. Some of these structures implement an ultra high capacity battery, however this may add considerable mass and cost to the baffle design. Considerable assistance would be required if this option is chosen, which will require time and money.

Table 10: Pros and Cons for Electrostatic Deployment Method

Pros	**Cons**
• Structure need not be rigid	• Potential interference with other spacecraft instruments
• No moving mechanical parts	• Power requirements
	• Sustaining deployment with constant power
	• Assistance required due to lack of experience
	• Cost

4.3.3 Pneumatic Deployment

Pneumatic deployment would involve storing a highly pressurized gas, such as carbon dioxide, on the small satellite for inflating the material to form the baffle structure. This method of deployment places automatic restrictions on the types of material as it would be confined to flexible, collapsible material such as nylon or fabric, similar to that of an airbag. Balloon deployment is advantageous with regard to mass and volume because it would only require the use of a small, pressurized cylinder to hold the gas before releasing the valve and allowing the gas to occupy the material and form the appropriate shape. This would be relatively easy to manufacture, as there are few moving parts involved. However, pressurized gases can be prone to unintended explosions, which would fatally endanger the entire expedition, at least within the confines of Earth's atmosphere. Otherwise, the balloon is a relatively simple, yet unreliable method of deployment.

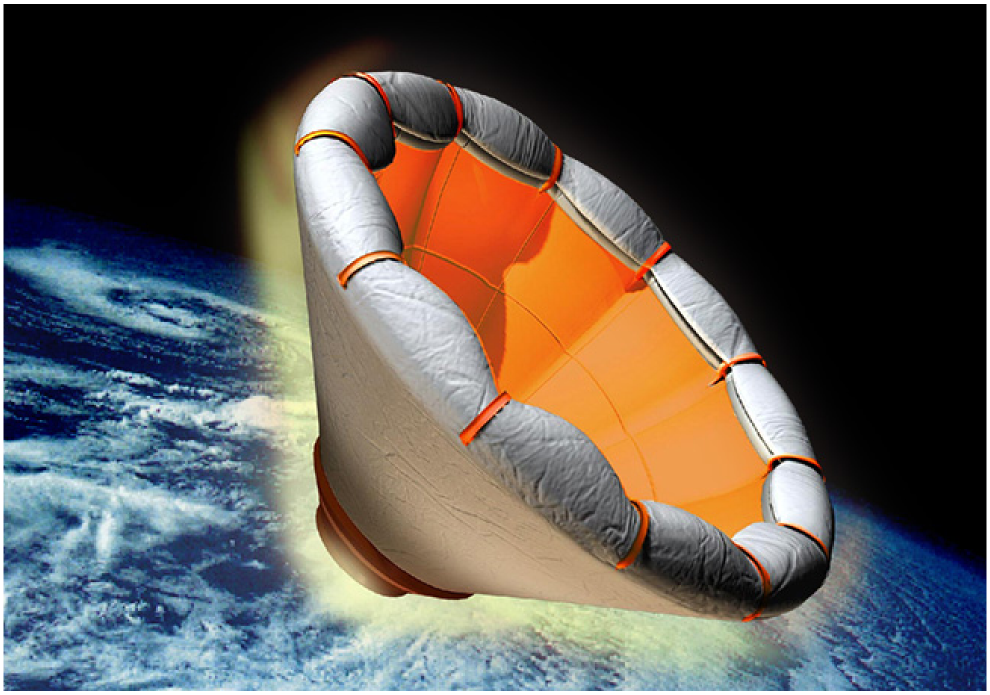


Figure 14: Example of a Pneumatic Structure[17]

Table 11: Pros and Cons for Pneumatic Deployment Method

Pros	Cons
- Simple to manufacture	- Restricts material selection
- Low mass and volume	- Possibility of explosion

4.3.4 Magnets

Magnetic deployment includes both permanent magnets and electromagnets. For this reason the two categories will be split below with their own descriptions as well as tables of pros and cons.

Permanent magnets come in a variety of shapes, sizes and metals. They have been used for hundreds of years going back to the first compasses and are depended upon in electronic devices everywhere today.[18] Although they are widely used, they are not without their weaknesses, such as possible loss of magnetic strength when poles are stored near similar polarities, which is relevant to this project as they may be stored in this fashion[19].

Table 12: Pros and Cons for Permanent Magnetic Deployment Method

Pros	Cons
- Relatively cheap	- Potential loss of polarity under certain stresses
- Low mass and volume	- Can interfere with electronic equipment
	- Lock down mechanism will add manufacturing complexity
	- Fragile; may shatter resulting in outward ejection

To elaborate and explain some of the pros and cons, the proposed set up for these permanent magnets would have them stored with similar poles facing each other. This way when the baffle is released from the lock-down position the magnetic force between them would naturally cause them to separate outward and deploy the baffle. With other deployment mechanisms utilizing electrostatic materials or electromagnets, the baffle must be forced out with power from a source like a battery. While using permanent magnets in the way described above would be more like setting a spring, with electric power only needed to release the down-locking mechanism. This down-locking mechanism is considered a con giving it's added complexity. All deployment methods will have some storing mechanism, however ones used for permanent magnets or springs will require a more robust design due to their nature[20].

Figure 15: Permanent ring magnets[21]

Similar to permanent magnets, electromagnets are used widely in a variety of devices, with the obvious advantage of being able to turn them on and off as desired. Most of the time the two forms of magnets are used together in electric motors as discussed in the section below.

Table 13: Pros and Cons for Electromagnetic Deployment Method

Pros	**Cons**
• Dependable	• Can be heavy
• Given power specs. when purchased	• Power requirements may consist of constant voltage
• May not require lock down mechanism	• If broken would likely require full replacement
	• Can be fragile

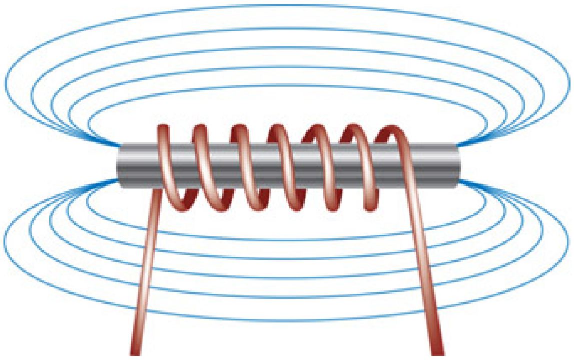


Figure 16: Diagram of simple electromagnet[22]

4.3.5 Motors and Servos

This section discusses the deployment methods involving powered motors and electric servos. Items such as extending arms and scissor lifts can be powered by these devices and can be either electrically or pneumatically driven. All of these devices would likely be purchased over built, as they are typically available and can be relatively cheap. These devices are used widely in many applications, including satellite delpoyable systems[23].

Table 14: Pros and Cons for Servo & Motor Based Deployment Method

Pros	Cons
• Detailed specs. from manufacturer	• Can be expensive
• Dependable if used properly	• Difficult to fix if broken, likely need full replacement

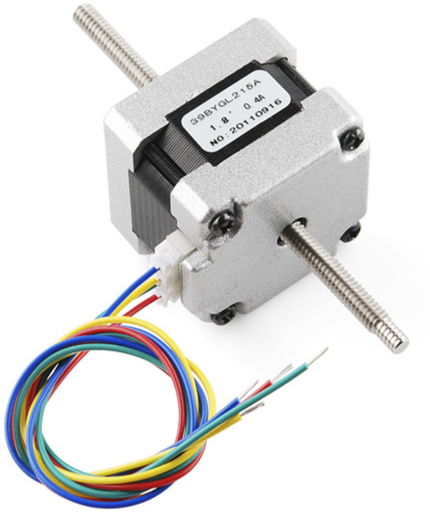


Figure 17: Linear Stepper Motor Available from Sparkfun[24]

4.4 Stray Light Attenuation

4.4.1 Vanes

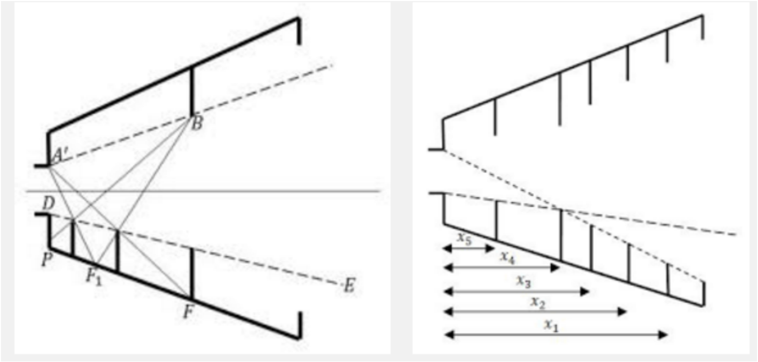


Figure 18: Light rays nteracting with vanes[25]

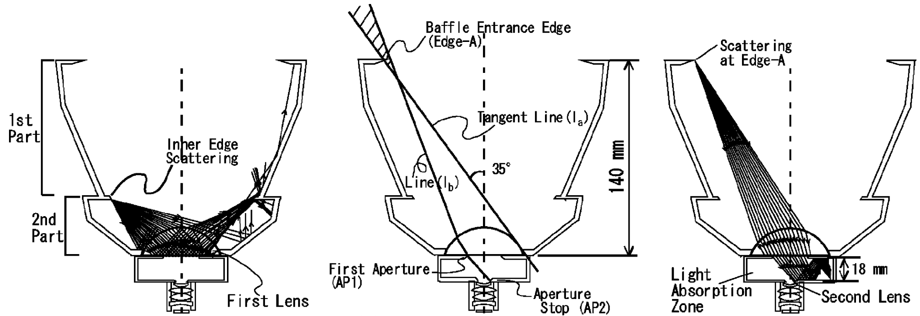
Vanes are a method of eliminating the stray light that enters the star tracker baffle. Vanes are placed on the inside walls of the baffle in geometrically determined locations that block light from hitting the sensor. If light does enter the baffle, the vanes become new area where stray light can reflect off of and thus will not affect the sensor. In order to minimize the reflective problem, the side of each vane must be filed down to a knife edge which may be hard to manufacture properly[26].

Table 15: Pros and Cons for Vanes as a Light Attenuation Method

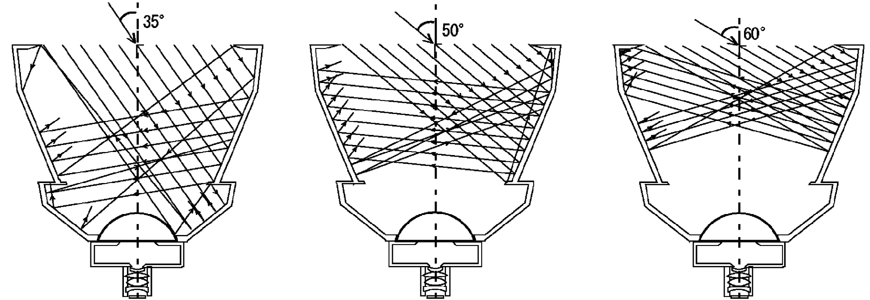
Pros	Cons
• Effective at blocking incoming stray light	• Hard to manufacture
• Common in industry	• Not 100% effective at attenuating light within baffle

4.4.2 Lenses & Mirrors

Lenses are optical devices that focus or disperse beams of light. While lenses are typically used with the star tracker, there has been prior use of additional lenses (including mirrors) inside baffles. Mirrors serve as a means to purposefully reflect stray light from ambient sources away from the star tracker. Lenses have been used to focus light from a specific star pattern to the star tracker for maximum recognition. They have also been used to refract unwanted light away from the star tracker[27]. Examples of special lenses on the baffle include the near-hemispherical lens seen in Figure 19.



(a) Application of TIR (b) Decision of Baffle Length (c) Light Absorption Zone



(d) 35° sun (e) 50° sun (f) 60° sun

Figure 19: Hemispherical Lens Inside Star Tracker Baffle[27]

One of the advantages of using lenses on a star tracker baffle includes the ability to redirect light. This is an advantage because lenses could potentially shorten the height and diameter of the baffle ultimately reducing mass and stored volume. Another advantage to using several different lenses for the purpose of the project is that more lenses would allow for light to be refracted in more ways, however this could add complexity. In this application the lenses would serve as a high-incidence angle filter, only allowing low-incidence light rays from faraway stars to be detected.

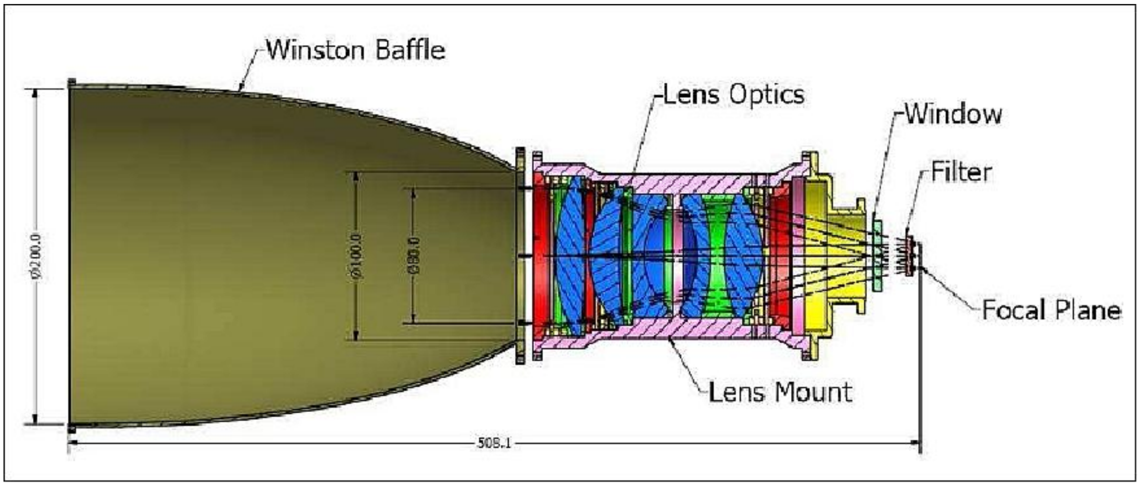


Figure 20: Lenses Used Within a Baffle[28]

A disadvantage is the fact that deploying lenses or mirrors will be exceedingly difficult because using lenses means a very small factor of error for manufacturing for the light beams to behave exactly as desired.

Table 16: Pros and Cons for Lenses & Mirrors Light Attenuation Method

Pros	Cons
• Ability to redirect light	• Deployability issues
• Shortens height and width of baffle	• More difficult to manufacture correctly
• High-incidence angle filter	• Increased complexity
• Multiple lenses can be used	

4.4.3 Coating

Light absorbing coatings can be used on surfaces to osmose stray light and have already been used in star tracker applications on satellites. In the baffle application, the coating minimized the internal light reflection in the baffle because of the high absorptivity of the coating. Coated foils that adhere to the surface of a material can also be considered as well as coatings that have a spray on capability. According to Berlin Space Technology, the use of a light absorbing coating in star tracker baffles will enable smaller, lighter baffles to offer the same high performance as their larger counterparts[29].

An advantages of using a coating is that it will increase the stray light attenuation without adding a significant amount of mass, and can be inexpensive. These materials are also easy to work with so applying it to the baffle would be simple[30].

Some disadvantages of using a coating are that certain coatings can have a significant cost. A coating can also change the thickness of the baffle which could present problems for the stowed state of the baffle in addition to the optics. An additional disadvantage is that an adhesive application of a coating would present problems with the deployability of the baffle. Adhesive applications are similar to stickers so having it applied to a deployable baffle could damage the coating.

Table 17: Pros and Cons for a Coating as a Light Attenuation Method

Pros	Cons
• Increases stray light attenuation	• Changes thickness of baffle
• Low mass	• Adhesive applications
• High-incidence angle filter	• Increased complexity
• Easy to work with	

4.5 Sensors

4.5.1 Luminosity Sensors

Luminosity sensors are advanced digital light sensors that can detect a wide range of light in different situations. Luminosity sensors, in their simplest form, can measure visible light while more complex luminosity sensors can also measure both infrared and other spectrum of light. Just as the human eye detects light by sending electrical pulses to the brain, luminosity sensors send electrical impulses to the an output, like a LED light or a meter to measure the intensity of the light[31]. An example is shown below in Figure 21

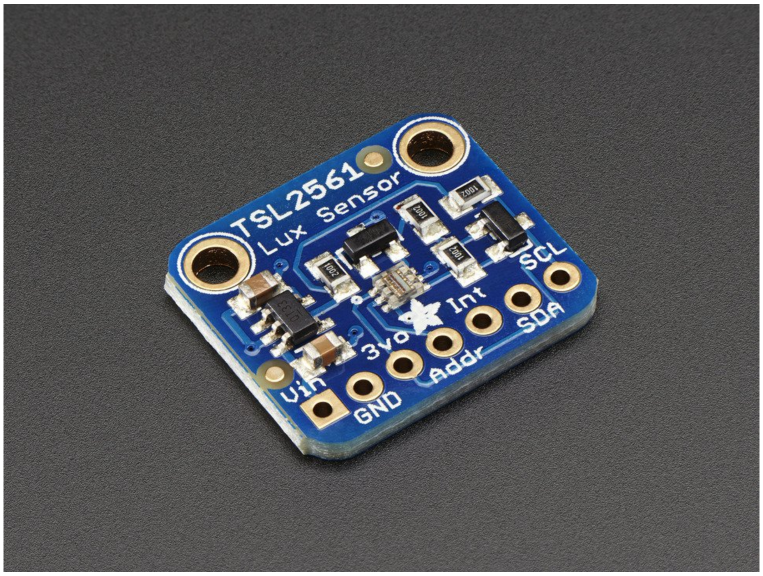


Figure 21: Adafruit TSL2561 Digital Luminosity/Lux/Light Sensor[32]

Advantages of the luminosity sensor would be it's small size, light weight, and capability to detect multiple ranges of light for a low cost. The luminosity sensor fulfills the basic needs of the light exclusion test but does not have the capability to determine the attitude of the satellite though star recognition. The sensitivity to light wavelegths for this sensor can be seen in Figure 22.

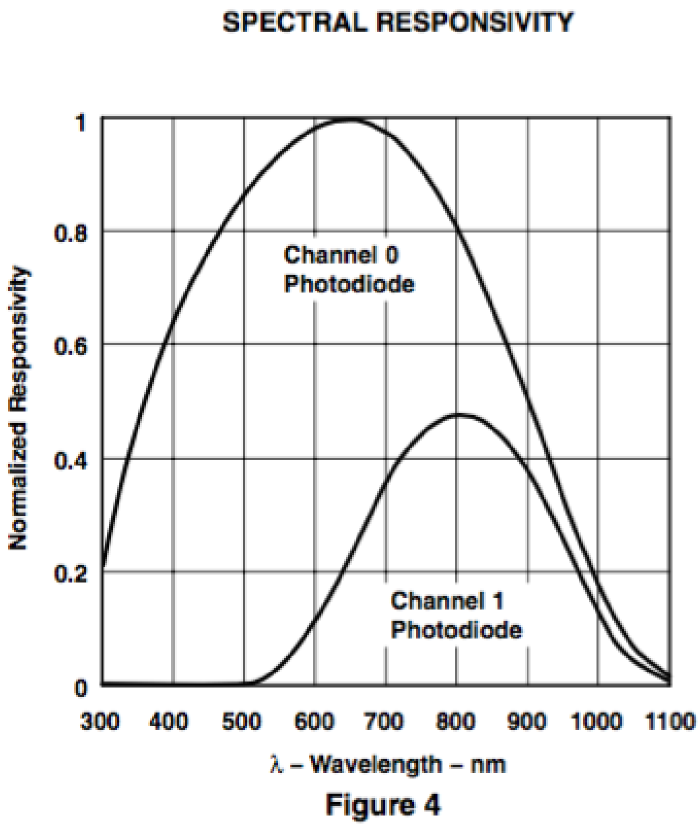


Figure 22: Percent Responsivity of an Adafruit Luminosity Detector[32]

Table 18: Pros and Cons for a Luminosity Sensor

Pros	Cons
• Small size	• Limited capability (cannot compare measured light to star catalog, as a star tracker would)
• Lightweight	
• Detects light across broad range of light spectrum	
• Low cost	

4.5.2 Cameras

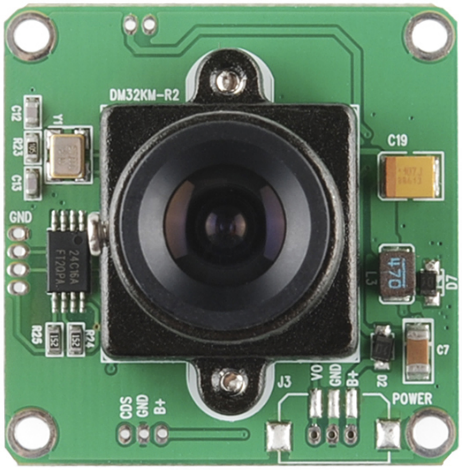


Figure 23: Sparkfun CMOS Camera Module[33]

Cameras are an optical recording device that allow for visual images to be captured and processed. Traditional star trackers use a space grade camera as an optical sensor in order to capture images of stars that can be processed to determine the attitude of the satellite[2]. Purchasing a camera as the optical sensor for the team's baffle design would allow for basic light exclusion tests to be done as well as star tracking simulations. Most cameras have a CCD (charged coupled device) or a CMOS (complementary metal-oxide-semiconductor) as their optical sensor[34]; the camera shown in Figure 23 uses a CMOS optical sensor which has the wavelength sensitivities shown below.

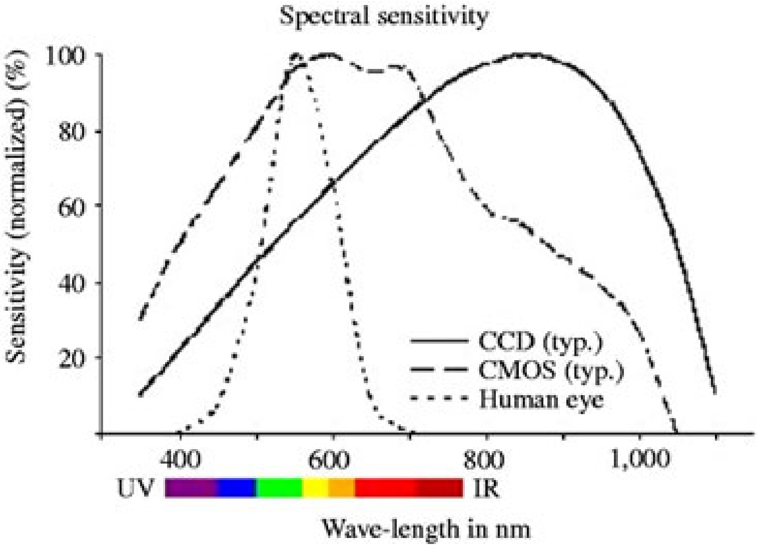


Figure 24: CMOS wavelength sensitivities[35]

Table 19: Pros and Cons for an RGB Camera Sensor

Pros	Cons
• Allows for on orbit environment simulations	• Expensive
• Industry standard	Gathers more data than required

4.5.3 Photoresistor

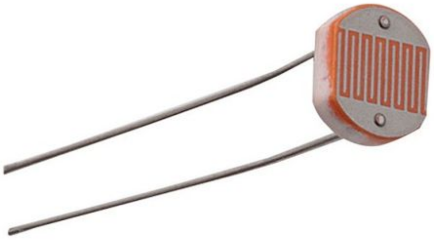


Figure 25: Example photoresistor[36].

A photoresistor is a simple resistor in which the internal resistance decreases with an increase in incident light. As such, this type of sensor is capable of measuring the light exclusion metric of the deployable baffle only–it is incapable of simulating the tracking of stars or determining an incidence angle. A photoresistor benefits from being very aforadable as well as being widely available by any electronic component retailer. However, a photoresistor is relatively inaccurate when compared to a star tracker, or even to a camera. It can only detect incident light acting on the sensor in the form of a decreased resistance. Just as well, a photoresistor has no pre-existing interface between the sensor and the data acquisition system. Such an interface would have to be built by the team, increasing the complexity involved with using a photoresistor. These pros and cons are organized in Table 20. The sensitivity of the photoresistor to light wavelengths can be seen in Figure 26.

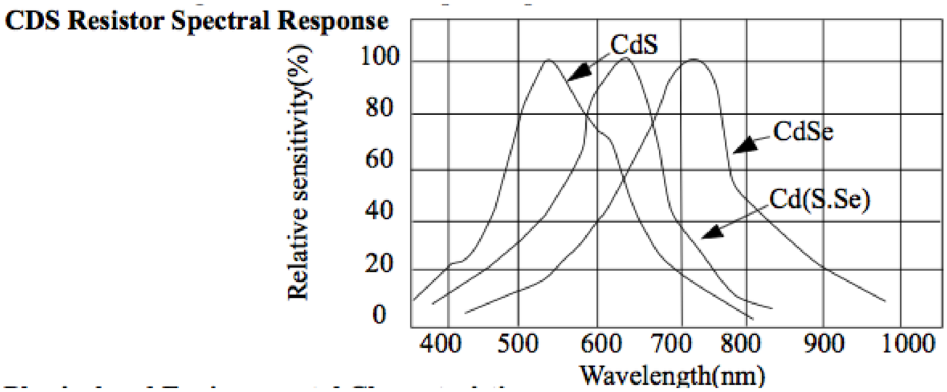


Figure 26: Percent Responsivity of three types of photoresistors[36].

Table 20: Pros and Cons for a Photoresistor Sensor

Pros	Cons
• Very affordable	• Low relative accuracy
• Widely available	• No pre-existing interface

5 Trade Study Process and Results

5.1 Common Metrics

Trade studies conducted in this project all share some common metrics. These are defined in Table 21. Other metrics are redefined for each key design element, which are introduced individually.

Table 21: General Metrics used across all trade studies.

	5	4	3	2	1
Simplicity of Design	No outside resources required	Little faculty help	Heavy faculty help	Custom ordered	Tech doesn't exist
TRL	TRL 8-9	TRL 6-7	TRL 4-5	TRL 2-3	TRL 1
Receiving Time	2 days	1 Week	2 weeks	1 month	>1 month
Stored Volume	<smallest volume tier	= smallest volume tier	= largest volume tier	>largest volume tier	Too much volume
Mass	<smallest mass tier	= smallest mass tier	= largest mass tier	>largest mass tier	Too much mass

5.1.1 Metric Definitions

1. **Simplicity of design**: In general, how easy will it be for Baffling Buffs to develop a novel take on a well-proven space technology? This metric is geared toward ranking the challenge of designing a particular facet of the deployable baffle and how confident the team is that the design can be made and implemented.

2. **TRL**: This is Technology Readiness Level as accepted by the general science community. It is not, however, the TRL of a star tracker baffle. Instead, this refers to how experimental a considered technology is in general. For example, this compares how developed telescoping shells are compared to two shells that would clamp together. In other words, to what extent would the Baffling Buffs have to invent a new technology? This differs from Simplicity of Design in that Simplicity of Design grades the design on its complexity whereas TRL rates the design on how experimental or widespread the technology is, simple or not.

3. **Receiving Time**: How long will it take to receive a component once it's been ordered? Likewise, how long will the development of the project have to wait on the reception of a key element?

4. **Reliability** A metric that gauges the survivability of the baffle is required so that it is weighed in the decision making process. This metric rates how many times the baffle will get to be used before its structure has been compromised such that it can no longer maintain the desired light exclusion angle. For example, a spring may be slightly bent during a test so that it does not extend the baffle to the length required for a 30° light exclusion angle. At this point, the baffle would be in need of repair.

5. **Stored Volume**: This is simply a gauge as to how well Baffling Buffs predicts candidates for some key design elements will fit into the tiers of success defined earlier. Since there are no prototypes yet developed, this is still a rough prediction.

6. **Mass**: Like 'Stored Volume,' this metric gauges how well Baffling Buffs predicts candidates will fall within the tiers of success defined for mass.

5.2 Baffle Shape

5.2.1 Baffle Shape Metrics

The metric unique to this trade study is outlined in Table 22. Affordability is unique in this trade study in that it is a relative scale based on the surface area of the three key design options considered. It is assumed that the cost of the material required to manufacture a baffle increases linearly with material needed.

Consider both a cone and a cylinder with key parameters held constant. This is illustrated in Figure 27.

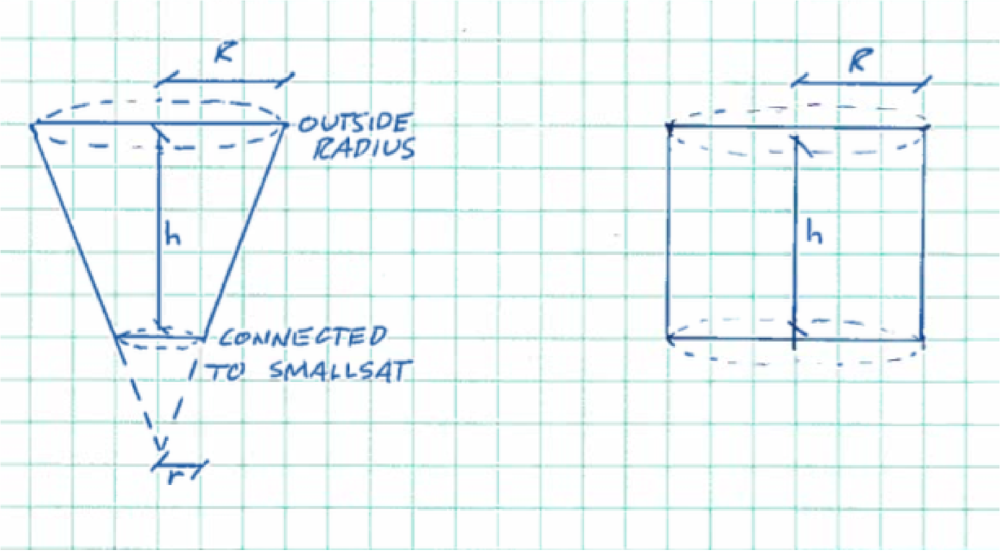


Figure 27: Cone and cylinder being compared in the surface area comparison study.

The cone and the cylinder represent two of the key design options for the general shape of the baffle. In this case, the parameters held constant are the height, h, and the outside radius, R. Both are held constant because both parameters determine the attenuation of the baffle much more so than the other geometric parameters (only remaining for the cone, the radius at the sensor for example). The mathematical study is conducted for both the cone and the cylinder using the defining equations in eq. (1) and the test parameters defined in eq. (2). Note that these test parameters are only meant to find a trend in surface area of a conical baffle shape versus a cylindrical baffle shape. They are not the final dimensions to be used for Baffling Buffs' deployable baffle. Also note that the parabolic dish is not compared in this model. It is assumed that the parabolic dish uses less material than a cylinder and more than a cone, leading to the ranking in Table 23.

$$SA_{cone} = \pi(Rd - rl), \quad SA_{cylinder} = 2\pi Rh \tag{1}$$

$$h = 10cm, \quad R = 4cm, \quad r = 3cm \tag{2}$$

Such test parameters produce the results

$$SA_{cone} = 149.41cm^2, \quad SA_{cylinder} = 251.3cm^2$$

This trend leads to the affordability outlined in table 23.

Table 22: Relative affordabilty between general baffle shapes

	5	4	3	2	1
Relative Affordability	Requires most material	-	-	-	Requires least material

5.2.2 Baffle Shape Weighting

Weighting was assigned to each section depending on the importance of the section. For this trade study, TRL was given a weight of 0.5 because that would require the most design hours to complete. For the same reason, simplicity of design was given a weight of 0.3 because it does not require as many hours to develop as designing a newly shaped baffle. Affordability was given a weight of 0.2 because it does not require design or manufacturing hours but does limit the project due to the budget restriction.

5.2.3 Baffle Shape Trade Studies

Table 23: Trade Study for baffle shape

	Weight	Cone	Cylinder	Parabolic Dish
TRL	0.5	5	5	1
Affordability	0.2	5	1	3
Simplicity of Design	0.3	5	4	2
Total	1	5	3.9	1.7

5.3 Manufactured Shape

Manufactured Shape pertains to the method with which the deployable baffle will articulate. Another way to think about 'Manufactured Shape' is 'articulation method.' For example, one method of articulation is a telescoping baffle which consists of concentric shells that will extend outward from the small satellite, as described in the key design options section.

5.3.1 Manufactured Shape Metrics

Metrics unique to Manufactured Shape are affordability, reliability, and heritage. Affordability in this case is the same as in the previous key design option, though cannot be proven prior to the selection of a manufactured shape. In this case, affordability also takes into account the financial and time costs of developing complex or simple articulation methods, next to how much material would cost in relation to each other. Reliability, a metric that gauges the survivability of the baffle, is required so that it is weighed in the decision making process. This metric rates how many times the baffle will get to be used before its structure has been compromised such that it can no longer maintain the desired light exclusion angle. For example, a spring may be slightly bent during a test so that it does not extend the baffle to the length required for a 30° light exclusion angle. At this point, the baffle would be in need of repair. Also introduced in these metrics is 'heritage.' 'Heritage' is a relative consideration of what shapes are already used for baffles that do not deploy. In the case of Baffling Buffs' deployable baffle, some of the shapes already used in the industry take on the same final form as the manufactured shapes considered in this trade study. For example, no baffles in industry currently deploy telescopically, but do in fact take on a multistage form that a telescoping baffle would replicate. In other words, 'heritage' describes a predicted performance of a deployable baffle based on current non deployable baffle designs. These metrics are described in Table 24.

Table 24: Unique metrics to the manufactured shape

	5	4	3	2	1
Affordability	Most affordable				Least Affordable
Heritage	Most similar to current technology		Somewhat approximates current technology		Least similar to current technology
Reliability	Survives all tests	Only needs repairs	One spare needed	2 spares needed	>2 spares needed

5.3.2 Manufactured Shape Weighting

Weighting was assigned to each section depending on the importance of the section. For this trade study, simplicity of design and stored volume were both given a weight of 0.3 because they will likely require the most design hours to complete. Heritage was given a weight of 0.2 because basing the baffle shape off of shapes commonly used will be a significant time saver. Affordability and Reliability were both given a weight of 0.1 because they do not have as much impact on required design hours but still play a role in the manufacturing shape.

5.3.3 Manufactured Shape Trade Study

Table 25: Trade Study for manufactured shape

	Weight	Telescoping	Veggie Steamer	Hinged Clamp	Straight Side
Simplicity of Design	0.3	4	1	2	5
Affordability	0.1	4	2	3	5
Stored Volume	0.3	5	4	2	5
Reliability	0.1	4	3	3	2
Heritage	0.2	5	1	1	4
Total	1	4.5	2.2	2	4.5

5.4 Stray Light Attenuation

Stray light emission is a measure of what structures or techniques will most effectively reflect or absorb light noise from within a baffle of any shape chosen in the trade studies above.

5.4.1 Stray Light Attenuation Metrics

Unique to this trade study is a measure of Attenuation. It is a prediction of how well internal structures or methods will block stray light from the sensor once light has entered the baffle rather than how well light is strictly kept outside of the baffle. Also continued in this trade study is the measure of affordability. Also like the previous trade study, there is a consideration of cost for both development as well as manufacturing. Likewise, introduced in this trade study is the metric of 'ease of manufacturing,' which is in place of 'simplicity of design.' The levels of this metric appear in Table 26. In essence, this metric considers what may be purchased off the shelf or what must be developed and manufactured specially for the use of Baffling Buffs' deployable baffle. This is considered in place of 'simplicity of design' because no new reflection methods are being developed; rather, existing methods are weighed against each other to determine the best technology to incorporate in Baffling Buffs' baseline design. Existing technology is already proven and does not need to be reinvented. These metrics are described in Table 26.

Table 26: Light Attenuation Metrics

	5	4	3	2	1
Affordability	Most affordable				Least Affordable
Ease of Manufacturing	COTS (Commerical-Off-The-Shelf) product, no modification needed	COTS product, 1-2 hrs post processing, or made in house with no post manufacturing	COTS product, 2-5 hrs post processing, made in house with <2hr post manufacturing, custom ordered with no post manufacturing	COTS product, 5-10 hrs post processing, made in houes with 2-5hr post manufacturing, Custom ordered with <1hr post manufacturing	COTS product, >10 hrs post processing, made in houes with >5hrs post manufacturing, Custom ordered with >1hr post manufacturing
Attenuation	30 degree exclusion	40 degree exclusion	30 degree, semi transparent	40 degree, semi transparent	Unacceptable attenuation

5.4.2 Stray Light Attenuation Weighting

Weighting was assigned to each section depending on the importance of the section. For this trade study, attenuation and TRL were given a weight of 0.2 because these are likely to require the most hours to complete. Ease of Manufacturing and Availability were given a weight of 0.15 because they will require time to complete but likely not as much time as the attenuation and TRL require. Mass, stored volume, and receiving time were each given a weight of 0.1 because these are likely to require the least amount of time to complete because they are not a major design metric but rather a flow down from the higher ranked metrics.

5.4.3 Stray Light Attenuation Trade Study

Table 27: Trade Study for Stray light admittance

	Weight	Vanes	Lense	Coating
Mass	0.1	3	2	4
Stored Volume	0.1	3	2	5
Ease of Manufacturing	0.15	3	3	5
Receiving Time	0.1	3	2	5
Attenuation	0.2	4	2	4
TRL	0.2	5	3	4
Availability	0.15	5	2	4
Total	1	3.9	2.05	4.35

5.5 Deployment Method

Deployment method describes the technology used to deploy Baffling Buffs' baffle. The metrics considered here are exclusively the deployment technology, thus keeping separate any other considerations that may overlap. In other words, the mass of the deployment method is weighed without consideration to mass of the baffle, for example. So the mass metric in this section, like the previous design options in which mass is considered, is of the deployment method only.

5.5.1 Deployment Method Metrics

The metrics considered unique in this trade study are affordability and ease of manufacturing. Both are used here are seen in previous trade studies, as outlined in Table 26. Introduced to this section is the metric for 'impulse powered.' This is a 5 or 0 score for whether or not the deployment method requires constant power to maintain the baffle's rigidity. A score of 5 means that the requirement for impulse power is met and is further considered while a 0 means that the method does not meet the impulse requirement.

5.5.2 Deployment Method Weighting

Weighting was assigned to each section depending on the importance of the section. For this trade study, ease of manufacturing and impulse powered were given a weight of 0.3 because they will likely require the most amount of design time to complete because they are the main restrictions for this section. Mass was given a weight of 0.2 because it is one of the functional requirements for this project and could greatly limit the deployment method options. TRL and Affordability were given a weight of 0.1. TRL of the deployment will not require many development hours, whether it were already available or needed to be made, due to the simplicity of the mechanism. There is little impact of affordability on the project due to the deployment method being a relatively inexpensive part of the project.

5.5.3 Deployment Method Trade Study

Table 28: Trade Study For Deployment Method

	Weight	Spring	Balloon	Motor	Magnets	Electrostatic
TRL	0.1	5	3	5	2	3
Ease of Manufacturing	0.3	4	3	4	3	3
Affordability	0.1	5	3	3	4	2
Impulse Powered	0.3	5	5	5	5	0
Mass	0.2	4	4	2	3	5
Total	1	4.5	3.8	3.9	3.6	2.4

5.6 Sensor Selection

This is the trade study in which the earliest components of the testing suite are considered. It is assumed here that the primary driver behind developing a successful testbed for a deployable baffle is the light sensor. Every other decision in the process of developing a successful testbed will be designed from the top down.

5.6.1 Sensor Selection Metrics

The 'affordability', 'sensitivity to intensity' and 'data handling' metrics are unique in this trade study for the sensors considered. In this trade study, a direct dollar value sets the ranking. Unlike affordability in the previous sections, this technology is not only already developed, but is also within a narrow range of options for which the Baffling Buffs may make a selection. When exclusively considering price, the less expensive the sensor, the better. Also, the upper and lower ends are driven by the prices of the extremes in the options available. A camera that may be used for collecting light flux data is about \$40.00 while a simple photoresistor is commonly no more than \$1.00. Table 29 describes the price ranking. The metric for 'sensitivity to intensity' is a comparison of percent responsivity a light sensor has to incident light. It was seen in Figures 26, 24 and 22 that a photoresistor is 90% sensitive to visible light from $525nm - 575nm$, the camera from $530nm - 710nm$ while the luminosity detector is 90% sensitive to $550nm - 750nm$, a larger range. Visible light consists of wavelengths $400nm - 700nm$ with an average wavelength of $550nm$. According to these graphs, a luminosity detector is more sensitive to a wider range of wavelengths, leading to a higher score for sensitivity when considered in its trade study. Likewise, the highest score in the trade study is 90% responsivity to the most light, and so on. 'Data handling' is a measure of how easy it is to transform a signal detected by the sensor to raw flux data. A higher score pertains to COTS products that both take in a signal and transform it to some type of data that may be used to reach a conclusion about the effectiveness of the baffle. Likewise, a lower score pertains to a sensor that may emit a resulting signal in proportion to light flux experienced, but it is up to Baffling Buffs to design and manufacture a useful interface.

Table 29: Metric ranking for the light sensors.

	5	4	3	2	1
Affordability	\$0-\$1	\$1-\$5	\$5-\$20	\$20-\$40	>\$40.00
Sensitivity to Intensity	90% responsivity	80% responsivity	70% responsivity	50% responsivity	Sensor either reads incident light or doesn't
Data Handling	All-inclusive suite	Easy micro controller integration	Needs extra peripheries	Requires unique interface	No apparent interface

5.6.2 Sensor Selection Weighting

Weighting was assigned to each section depending on the importance of the section. The sensitivity to intensity was given the highest weighting because if the sensor is not as sensitive to the intensity of light reaching it, it will not preform as well for testing. Receiving time was given the weight of 0.2 because if this sensor cannot be received in a reasonable amount of time it becomes harder to integrate into the system and any sensor issues have the possibility of causing major time delay in the project. The affordability was given the weight of 0.25 because this project does have a limited budget and as such the cost of the sensor could greatly impact the choice of sensors. Data handling was given a weight of 0.1 because, although important to the project, this metric does not require a great amount of hours whether the data were considered simple or more difficult to transition from the testing to analysis phase.

5.6.3 Sensor Selection Trade Study

Table 30: Trade Study for Sensor Selection

	Weight	Camera	Photoresistor	Luminosity Sensor
Data Handling	0.1	5	2	4
Affordability	0.25	2	5	3
Sensitivity of Intensity	0.45	3	2	4
Receiving Time	0.2	5	5	5
Total	1	3.35	3.35	3.95

6 Selection of Baseline Design

6.1 Baffle Shape

According to the trade study in Table 23, a conical baffle is the preferred general shape. This was a test measuring how relatively simple the design is, how affordable it is, and what the TRL is. In this case, TRL is considered with respect to the intended use. Conical baffles are widely used across industry for star trackers while cylindrical baffles are normally used for telescopes. However, nowhere was it found that parabolic dishes could be used for light attenuation. Thus, parabolic dishes were disregarded with a score of 1 while cylinders came up as an alternative to cones. Likewise, using the mathematical study when considering affordability, cones will always take less surface area than cylinders when the outside radius and height are held equal, making a conical baffle less costly in mass.

6.2 Manufactured Method

Telescoping and straight sided articulation methods are preferred. Straight sided is the simplest, can be made out of a single sheet of flexible material, and is predicted to be the easiest to design and manufacture. Likewise, the telescoping articulation method is more complex because it involves the design and development of rigid, concentric shells. However, once a baseline cross section of a shell is designed, it is much simpler to adjust its dimensions depending on where it is on the length of the baffle. In comparison, veggie steamer and hinged clamp articulation methods involve rigid shells that are not only concentric, but must also bend around the baffle, making their designs quite complex.

In terms of affordability, both the straight sided and telescoping articulation methods may be built in house. The telescoping method may even be additively manufactured (disregarding the effects of out-gassing on 3D printed material because making the baffle space-grade is beyond the scope of this project). The veggie steamer may also be built in house, but requires many hinges and tight seals between the joints. Likewise, the hinged clamp encounters the same drawbacks, but simply requires fewer hinges and seals.

It is predicted that the telescoping method and the straight sided method can both fit within the smallest volume level of success, thus the tie between the two. Through careful design and packing, the veggie steamer may even come close. Nonetheless, it is predicted to at least meet the smallest volume level of success if not just barely overshoot it. However, the hinged clamp works by folding the two halves of the baffle down alongside the face of the small satellite, its stowed length or width equal to twice the height of the baffle. This was predicted to fit or barely overshoot even the largest volume tier.

The telescoping method is both made of rigid material and has only separations rather than moving parts. It does however involve several interfaces between shells, thus making those pieces vulnerable to failure. Both the veggie steamer and hinged clamp involve rotating hinges that are vulnerable to breakage. Straight sided scored the lowest because it is the only candidate that uses a flexible material, which is softer and more prone to folding and puncture. Again, a ’breakage’ or failure is considered in need of repair if the shape no longer meets the light exclusion requirement. A folded baffle may be used in testing and be folded so that it cannot extend all the way. This is considered a failure in need of repair, quick or otherwise.

Heritage of a telescoping baffle is well proven. There are no deployable baffles that telescope, but almost all star tracker baffles are multistage, which approximate the final shape of a telescoping deployable baffle. Thus, the telescoping method scored the highest. Neither veggie steamer nor hinged clamp are used for many deployable space structures. They are, however, used in technology that exists more widely on the ground (the veggie steamer is a widely used culinary device). Thus, they both scored a 3 because it was predicted that the technology could be adapted to the space environment. Finally, straight sided is considered as any technology that deploys in space using a single, flexible material. However, since star trackers are rarely ever totally straight sided and have never been made of flexible material, straight sided did not get a full score for heritage.

6.3 Stray Light Attenuation

According to the trade study results in Table 27, a light absorbent coating was the preferred method for stray light attenuation, followed by vanes. In terms of mass and volume, light absorbent coating gets nearly a full score. It is relatively light and takes up little volume because it is more like a paint or a second layer of coating material rather than extra hardware. Vanes scored second in both categories because they do take up more mass and volume than coating due to being added hardware to the baffle structure. In contrast, lenses scored low on both mass and volume because they would be quite large and massive compared to the baffle.

Similarly, coating is deemed to be the easiest to manufacture. It is simply an extra layer to add to the inside of the baffle. For the example of light absorbent paint, 'manufacturing' is simply an application of the paint. Likewise, vanes must be built specific to this particular project. Thus, they scored lower than coating. However, vanes are relatively simple because they involve no moving parts and may even be 3D printed, scoring higher than lenses. Lenses scored the lowest on ease of manufacturing because they would require a very specific shape that must be custom ordered and cannot be built or manufactured in house.

Affordability of the light emission methods varies with the mass and volume costs. Coating may be purchased online in the final form that it will be used inside the baffle. Thus, the only financial cost with the coating is its procurement. Vanes scored second because they will cost the raw material, but will also cost time and effort in their individual development in house. However, the possibility of being 3D printed keeps their score as the second option. Finally, mentioned previously, lenses must be custom ordered uniquely to the design of this baffle, making them much more costly.

Attenuation is a measure of how effective each method of light exclusion reflects light away from the inside of the baffle. Vanes and light absorbent coating are quite effective and have been proven in existing technology. However, lenses have more commonly been used to focus light to a specific point rather than scatter or reflect it. The use of lenses in a baffle tends to be the inverse of their intended use, giving them a low score in this study.

TRL for vanes is the highest score because of how widespread vanes are in baffles of many types. Likewise, light absorbent coating also scored high for the same reason. However, it did not score the highest score because it is not used exclusively as a light emission technique; it is always used in conjunction with vanes but never alone. Likewise, lenses have rarely ever been used as a light emission technique, making their use 'experimental.'

Finally, vanes can be 3D printed, making its availability score the highest. Coating cannot be procured in house, it must be ordered online or purchased. But it can be purchased locally or ordered from a great number of sources online. Lenses cannot be ordered as COTS products because they must be custom ordered according to the specific dimensions of the baffle. Thus, they cannot be procured quickly.

6.4 Deployment Method

According to the trade study shown in Table 28, a spring is the preferred deployment method. The TRL for this deployment method is high because different types of springs and spring systems have been used in space to deploy systems. The ease of manufacturing of a spring is relatively high because it can be bought in most cases with minimal post processing work on the product. If the piece cannot be bought it can be manufactured in house out of spring steel with no post processing. The affordability is high for a spring because springs are relatively inexpensive to buy from many places, as is spring steel. In order for the spring to deploy it would only need one time power, giving it the highest score in terms of impulse powered. The spring was given a relatively high score for mass because it will be relatively light weight, but may be heavier than other options due to the materials that work well for springs and the possible size of the spring.

6.5 Sensor Selection

When all of the sensors were compared in a trade study, the lumonisity sensor came out as the best option for sensors. The data handling score for the luminosity sensor was relatively high because while it can not connect directly to a computer, it does connect directly into a microcontroler and can easily connect from there. It came in lower in affordability because it comes in around \$10. The sensitivity of the luminosity sensor is relatively high, and give an 80% responsitivity. The score for receiving time is high because many companies carry these sensors and they can be obtained in very little time.

References

[1] ”Project Definition Document.” ASEN 4018 (2016): n. pag. Web. 26 Sept. 2016.

[2] ”Rigel-L Star Tracker,” Surrey Satellite Technology Limited, [https://www.sstl.co.uk/Products/Subsystems/Actuators-Sensors/Sensors/Rigel-L-Star-Tracker. Accessed on 20 Sep 2016.]

[3] Boldrini, F., D. Procopio, S. P. Airy, and L. Giulicchi. ”SAO/NASA ADS: ADS Home Page.” SAO/NASA ADS: ADS. N.p., Nov. 2004. Web. 27 Sept. 2016.

[4] ”Miniaturised star tracker (AA-STR) ready to fly” Proceedings of The 4S Symposium: Small Satellites, Systems and Services (ESA SP-571). 20 - 24 September 2004, La Rochelle, France. Editor: B. Warmbein. Published on CDROM., id.46.1 [http://articles.adsabs.harvard.edu//full/2004ESASP.571E..46B/0000046.003.html. Accessed on 24 Sep 2016.]

[5] Kordas, J., Lewis, I., Wilson, B., Nielson, D., Park, H., Priest, R., Hills, R., Shannon, M., Ledebuhr, A., Pleasance, L., ”Star Tracker Stellar Compass for the Clementine Mission,” Lawrence Livermore National Laboratory, [http://www.osti.gov/scitech/servlets/purl/86977-ULkJcR/webviewable/. Accessed on 18 Sep 2016.]

[6] Yang, Choel Sun, Ki Chang Soo, Geon Kim Hee, Myeong Kim Sang, and Sang Lee Yong. Jig for Winston Cone Baffle Machining. Korea Basic Science Institute, assignee. Patent US 20130255461 A1. 28 Dec. 2010. Print. ¡http://www.google.ch/patents/US20130255461?hl=de¿.

[7] [http://images4.wikia.nocookie.net/__cb20080728030646/solarcooking/images/f/fd/Parabolic_diagram_1.jpg. Last Accessed on 23 Sep 2016.]

[8] Guest, Simon David, ”Deployable Sturctures: Concepts and Analysis”, University of Cambridge, http://www2.eng.cam.ac.uk/ sdg/preprint/SDG%20dissertation.pdf

[9] Tibert, Gunnar, ”Deployable Tensegrity Structures for Space Applications”, Royal Institute of Technology Department of Mechanics http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.731.9984rep=rep1type=pdf

[10] Stanley London Premium Quality 13-inch Brass Spyglass Telescope, http://www.stanleylondon.com/tele13prem.htm

[11] Homemaker, Happy, ”Sunsella Stainless Steel Vegetable Steamer”, Happy Homemaker, [https://sanyadalove.wordpress.com/2014/09/16/sunsella-stainless-steel-vegetable-steamer/]

[12] Baig, Hamza, ”Integrated Design of Solar Panels Deployment Mechanism For a Three Unit Cubesat”, Arab Satellite Communication Organization, 2012

[13] ”P-Clamps,” Amphenol PCD, [http://www.amphenolpcd.com/products/system-attachments/p-clamps. Accessed 20 Sep 2016.]

[14] ”Able Spring Manufacturers.” Compression Springs in Chennai, Tamil Nadu, India. N.p., n.d. Web. 27 Sept. 2016.

[15] Schaub, Dr. H, Stiles, L. A., Maute, K. K., Moorer, D. F., ”Electrostatic Inflation of Membrane Space Structures”, AAS/AIAA Astrodynamics Specialists Conference, [http://hanspeterschaub.info/Papers/Stiles2010.pdf]

[16] Schaub, Dr. H., ”Electrostatically Inflated Membrane Structures”, University of Colorado, Boulder, [http://hanspeterschaub.info/research-EIMS.html]

[17] [http://space.tekever.com/images/tech$_{s}tructures.jpg$]

[18] Jezek, Geno. ”How Magnets Work - History of Magnets.” History of Magnets. Custom-magnets.com, 2015. Web. 19 Sept. 2016. ¡http://www.howmagnetswork.com/history.html¿.

[19] Harza, Sid. ”Will Forcing Two Magnets Together along Repeling Poles Weaken the Magnets after a While?” Quora. Quora, 17 Feb. 2016. Web. 19 Sept. 2016. ¡https://www.quora.com/Will-forcing-two-magnets-together-along-repeling-poles-weaken-the-magnets-after-a-while¿.

[20] Jezek, Geno. ”How Magnets Work - Industrial Uses.” Industrial Uses of Magnets. Custom-magnets.com, 2015. Web. 20 Sept. 2016. ¡http://www.howmagnetswork.com/uses.html¿.

[21] Ring Magnets. Digital image. SuperMagnetMan. N.p., n.d. Web. 22 Sept. 2016. ¡https://supermagnetman.com/products/r1005c-n45h?variant=11410332547gclid=CKjhhr6BpM8CFQySaQodxj8MpA¿.

[22] Electromagnet3. Digital image. HowStuffWorks. Science Channel, n.d. Web. 20 Sept. 2016. ¡http://science.howstuffworks.com/electromagnet3.htm¿.

[23] Denton, Tom. Automobile Electrical and Electronic Systems: Automotive Technology: Vehicle Maintenance and Repair. New York: Routledge, 2012. Print(Google scholar).

[24] Stepper Motor - 29 Oz.in. Digital image. SparkFun, n.d. Web. 22 Sept. 2016. ¡https://www.sparkfun.com/products/10848¿.

[25] Marciniak, M., Enright, J., Sinclair, D., Dzamba, T., ”Microsatellite Star Tracker Baffles: Validation and Testing,” AIAA/USU, [http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2930context=smallsat. Accessed on 19 Sep 2016.]

[26] Marciniak, M. ” On the Testing and Validation of Stray Light Attenuation for Microsatellite Star Tracker Baffles.” Ryerson University Department of Aerospace Engineering, 2012 [http://digital.library.ryerson.ca/islandora/object/RULA%3A3384. Accessed on 19 Sep 2016.]

[27] Hama, Kazumori. Kawano, Hiroyuki. Nakamura, Shuji. Miyatake, Katsumasa. Shimoji, Haruhiko. Yoshikawa, Shoji. ”Solar-light shielding using a near-hemispherical lens for a star sesnor”, Spie. Digitial Library, [http://dx.doi.org/10.1117/1.2402101. Last accessed on 26 Sep 2016].

[28] Kramer, Herbert J. ”STSat-3 - EoPortal Directory - Satellite Missions.” STSat-3 - EoPortal Directory - Satellite Missions. Eo, n.d. Web. 26 Sept. 2016.

[29] ”World’s blackest coating material makes its debut in space”, Surrey Nano Systems, [https://www.surreynanosystems.com/media/news/*Vantablack%20used%20in%20satellite%20star%20trackers. 16 May 2016. Web. 26 Sept. 2016].

[30] ”Light Absorbing Black-Out Material”, Edmund Optics, [http://www.edmundoptics.com/lab-production/general-tools/light-absorbing-black-out-material/1502/. Web. 26 Sept. 2016].

[31] Standards, By Educational. ”How Does a Light Sensor Work? - Lesson.” Www.teachengineering.org. Teach Engineering, 30 Apr. 2016. Web. 26 Sept. 2016.

[32] 20, Taos059N March. TSL2560, TSL2561 LIGHT-TO-DIGITAL CONVERTER (n.d.): n. pag. Web. 26 Sept. 2016.

[33] ”CMOS Camera Module – 728x488,” sparkfun, [https://www.sparkfun.com/products/11745, Accessed on 20 Sep 2016.]

[34] Lange, Robert. ”3D time-of-flight distance measurement with custom solid-state image sensors in CMOS/CCD-technology.” Diss., Department of Electrical Engineering and Computer Science, University of Siegen, 2000 Sep 8 [http://home.arcor.de/koerner.jena/3D_Time_Of_Flight_Distance_Measurement_With_Custom_Solid_State_Image_Sensors_In_CMOS-CCDTechnology.pdf. Accessed on 24 Sep 2016.]

[35] ”Lighting for Machine Vision,” Global Innovative Technology Co., Ltd., [http://www.gitthailand.com/Lighting_for_Machine_Vision.php. Accessed on 23 Sep 2016.]

[36] Wu, Hsiu-Wen. ”CDS Photo Resistor Datasheet.” N.p., n.d. Web. 26 Sept. 2016.