lunalight™

Bringing light to the expanding world.

California Polytechnic State University, San Luis Obispo
By: Gabriela M. Igel, Daniel J. Patrick, and Kimberley M. Smith

June 7, 2013

Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Table of Contents

List of Figures

Executive Summary

The LunaLight, a solar rechargeable light and cell phone charger, addresses the lack of access to electricity faced by 1.4 billion of the world's population (International Finance Corporation). The LunaTech team has developed a product that is bright, simple, compact, versatile and competitive with existing products. Through a partnership with the non-profit organization One Million Lights, LunaTech has improved a previous team's design to address user feedback, concerns of durability, and manufacturability.

The LunaLight design includes a 5 component plastic housing held together by 4 screws, a surface mounted PCB, a lithium-ion (Li-Ion) battery, one high-brightness LED, a solar panel, and a buckled strap. The plastic housing is compact and can be worn comfortably across the front of the body. LunaTech designed the product to meet a set of engineering specifications based on both user and distributor needs and to provide the unique benefit of hands-free use. With the final design complete, LunaTech has laid out the current design and plans for design verification and production in the following report.

To produce initial prototypes, LunaTech utilized the 3D printers operated by the Materials Engineering and Mechanical Engineering departments at Cal Poly as well as the reflow lab operated by the Industrial and Manufacturing Engineering department. The team completed the first fully assembled prototype including a 3D printed ABS housing and an assembled PCB. This prototype was tested for functionality.

Once the LunaLight design was verified, LunaTech produced four fully assembled housing components using plastic casting with the goal of completing 25 units by the end of Spring Quarter. To complete the product LunaTech ordered 25 fully assembled PCBs and sets of external components. Students have assembled these units to be sold and distributed through One Million Lights, Living Goods, and the Dominican Sisters of Oakford. After gathering feedback from these customers during the summer,the LunaLight will be market-proven and may move into mass production. Before shipping these models to the customers, several tests were performed including ergonomic, charging, battery life, and brightness tests. Please find a detailed description of the final design, production plans, and design verification plans in the following pages.

CHAPTER 1:

INTRODUCTION

1.1 The Need

According to the International Finance Corporation 1.4 billion people in the world live without access to electricity. Many rural households rely on kerosene lighting to perform household tasks, allow their children to study, retrieve water or use the toilet after dark. Indoor use of kerosene creates pollution, causes respiratory illness, and can lead to burn injuries and destruction of household property. Further, purchasing kerosene is a significant monthly expense, averaging approximately $8/month in Kenya (International Finance Corporation). Finally, these families with limited access to electricity often use cell phones but have to walk up to several miles to the nearest cell phone charging station to pay to charge their devices (Raftery).

The LunaLight is designed to serve this off-grid market in developing countries. LunaTech, the 2012-2013 senior project team, aims to develop and produce a solar rechargeable light and cell phone charger that is bright, multi-functional, durable, and manufacturable on a large scale. Through One Million Lights and potential partners such as Living Goods, a micro-franchising company, and other organizations, LunaTech will distribute the LunaLight to communities that lack sufficient access to their nation's power grid. Initially designed by a previous Cal Poly San Luis Obispo senior project team, the LunaLight traveled to Africa as 5 prototypes that were distributed by One Million Lights in the spring of 2012. These LunaLight prototypes were well-received by the Maasai community of southern Kenya.

1.2 The Product and Team

This year's LunaTech team has improved on the existing design taking into account consumer feedback, product sustainability, and market viability. The overall goal is to lower production costs through material and component selection while increasing production volume. The design modifications focus on the electrical efficiency, heat sink for the LED, manufacturability of the plastic housing, and water resistance of this housing. The manufacturing and assembly processes were designed and prepared for full-scale production. The team has secured funding through grants and competitions for production of 25 units by the end of June 2013.

Further, the LunaTech team collaborated with a senior project team in the Orfalea College of Business to develop a comprehensive and robust business plan for the sourcing, assembly, distribution and sale of the LunaLight. The team has identified the core value propositions and most viable customer segments for the LunaLight and analyzed the unit economics and cost breakdown of the product. The customer segments that are served will determine how the LunaLight is assembled and distributed. Options include selling fully assembled products to organizations for distribution or selling sets of components to groups for independent assembly and distribution.

The current business model will be tested with the sale and distribution of the first 25 units by determining whether the targeted customer segments are truly willing and equipped to

distribute the LunaLight and narrowing down the appropriate price point. The business plan must take into account the end goal of LunaTech: lasting benefit to the target communities through access to clean lighting and cell phone power as well as accessible business and employment opportunities for locals.

After the team re-designed the LunaLight and established a preliminary business model, they were able to complete the final design, test the prototypes, and secure commitments to purchase and distribute the first production run of the LunaLight. The team, listed in Table I, has accomplished these tasks over the past nine months.

Table I: LunaTech Team Members

Name	Role
Gabby Igel	Industrial Engineering Student
Daniel Patrick	Mechanical Engineering Student
Kimberley Smith	Materials Engineering Student
Jessica Bell	Entrepreneurship Student
Jennifer Kerr	Entrepreneurship Student
Mike Deagen	Project Advisor
Dr. Richard Savage	Engineering Faculty Advisor
Dr. Jonathan York	Entrepreneurship Faculty Advisor
Additional Contributors	
Arsh Gill	Electrical Engineering Student
Dawei Zhang	Electrical Engineering Student
Laura Chao	One Million Lights Project Manager
Philip Streeter	Materials Engineering Student
Princepal Buttar	Electrical Engineering Student

1.3 Project Management

The main objective of the project manager is to create and adhere to a project schedule and manage any updates due to actual events that occurred. This project schedule was created in the beginning of Fall Quarter 2012 and maintained throughout the year (see Gantt Chart in Appendix G and Production Schedule in Appendix H). The entire team was able to track the progress of the project in the form of weekly updates to the project advisors and bi-weekly updates to the originally established project sponsor (which later became solely a customer). Weekly updates summarized the goals and completed tasks for the week and established goals for the following week. They also tracked how many hours each students worked on the project with specific tasks associated with them (summarized in Appendix G). This allowed for the team to take stock every week of the project goals and accomplishments and set a clear directive for the next week. The updates also facilitated

realistic inventories of quarter progress every few months.

Funding was also a major project concern throughout the year. Though the major pivot point of switching from injection molding to plastic casting drastically decreased production required costs with an estimated budget of $7,000 for all PCB, production, website, research and development, material, and testing needs. The LunaTech team worked tirelessly throughout the year to raise these funds to make the project possible. A full list of accomplishments can be found in Table II summarizing how LunaTech earned $7,850 this year.

Table II: LunaTech Accomplishments

Accomplishment	Amount	Date
CP Connect Interdisciplinary Grant	$2,500	September 2012
Center for Innovation and Entrepreneurship Elevator Pitch Competition: 3rd place and Audience Choice Award	$750	October 2012
SDSU LeanModel Business Competition: 2nd Place and Elevator Pitch Finalist	$4,000	March 2013
IME Student Fee Committee	$500	April 2013
Innovation Quest Finalist	$100	May 2013
Total	**$7,850**	**June 2013**

CHAPTER 2:
BACKGROUND

The need for clean, safe lighting in communities not connected to the electrical grid has been evidenced by the success of companies such as d.light, established in 2007, and organizations such as One Million Lights, founded in 2008. Households seeking a viable and inexpensive alternative to kerosene have begun to turn to solar-rechargeable options. These consumers see products such as the LunaLight and d.light as a high quality option for long-lasting and sustainable lighting. Further, these products allow the user to charge cell phones at home rather than walking to the nearest charging station. Of the 1.4 billion people living without access to electrical infrastructure, one of three people own a personal mobile phone (GSMA), and these cell phones are used not only for communication but also for mobile banking and other vital services.

Both the need and desire for solar lighting and charging are established, and the design of the LunaLight has received support both from One Million Lights and from the pilot users in Kenya. One Million Lights distributed five prototypes to Kenyan users in March of 2012. The positive and negative feedback from this pilot has been used to improve upon the previous design.

2.1 Competitors

To ensure that the LunaLight is competitive with other products on the market, existing products have been analyzed and compared to the LunaLight as shown in Table III. While many solar lighting products are available, most lack cell phone charging capability. This charging capability puts the LunaLight in a smaller group of products valued more highly by off-grid consumers as in-home cell phone charging is strongly desired. The unique value propositions of the LunaLight are its brightness, hands-free ability, and durability. The current design is twice as bright as the main competing product, d.light. Other products do not offer the option of hands-free use, which is vital when using the light while completing outdoor work, walking or biking.

Table III: Comparison of LunaLight to competitors

	LunaLight	d.light S250	Coleman Black Solar LED
Hours of light	6	4	4
Hands free carrying	Yes	No	No
Hanging ability	Yes	Yes	Yes
Price	$45	$45	$50

2.2 Objectives

Development of the LunaLight was focused on benefiting target communities by increasing the availability of renewable energy for clean lighting and mobile phone charging, as is the mission of One Million Lights. LunaTech strives to create a business plan that incorporates local assembly and distribution to provide business opportunities in economically sparse

regions of the world. The product, the production methods, and the business practices must be of high quality and be ethically based to accomplish these goals.

2.3 Applicable Standards

The World Bank and International Finance Corporation established a joint program called Lighting Global as well as a closely related program called Lighting Africa. In January 2013, Lighting Global published a set of quality assurance standards for off-grid lighting products called *Lighting Global: Quality Assurance Protocols 3.1*. Lighting Global can certify submitted lighting products. This standard applies to the LunaLight product.

CHAPTER 3:

DESIGN DEVELOPMENT

3.1 Design Requirements

Evaluation of end-user and distributor needs shaped the design requirements for the LunaLight. Discussion with One Million Lights and research of users in developing countries refined the design criteria.

The end-user needs include concerns of value of the product, practicality, and preference. In order to perceive the product as a valuable item, the user requires that the device fully charges within 8 hours of daylight or less and the charge lasts at least 6 hours of lighting or one full charge of a cell phone. Practical concerns require that the LunaLight is lightweight, compact, can be used hands free and can be comfortably held with 4 fingers. The hands-free option can be made more multi-functional if the light can also hang or be strapped to a bike as well as sit upright on a flat surface. In order to make the initial investment of purchasing a LunaLight worthwhile, the product must last a minimum of 5 years. Requirements dictated by preference are that the design is religion neutral, visually appealing, and provides an appealing hue of light.

The distributor requires a competitive and practical product to assemble and distribute. To compete with other products and alternatives, the LunaLight must: have a market price of $45 or less, emit light comparable to kerosene lanterns, and charge many cell phone types, primarily Nokia and Motorola models. Simple assembly of the components requiring minimal tooling and skills are crucial to practical assembly and distribution. All design requirements were incorporated in a comprehensive list of engineering specifications on which the product testing was based (Appendix E).

Development of the LunaLight consists of printed circuit board (PCB) design, design of the housing, and material selection of the housing components. The PCB and housing were redesigned based on prior LunaLight prototypes.
Literature research, user feedback and evaluation of past prototypes led to areas of focus for the redesign:

- Electrical efficiency
- Circuit components durability
- Heat dissipation of the LED
- Manufacturability of the housing
- Water resistance of the housing

With the final design selected, the team will create a complete prototype and test for compliance to the product specifications. This design verification will determine whether the design is ready for production.

3.2 Preliminary Research

Preliminary research included interviews to gain feedback from customers who have used the prototypes in Kenya, those working in developing communities, and other businesses

who have experience in the lighting industry. LunaTech conducted these interviews to seek an understanding of what products are already on the market and how well they address user needs. This provided insight into extant designs, what customers desired from a similar product, and if there are potential investors. The following individuals or groups were interviewed:

- One Million Lights: Laura Chao and Barrett Raftery (sponsor, potential distributor)
- The Dominican Sisters of Oakford located in South Africa (potential distributor)
- KIVA (lending organization)
- Living Goods (micro-franchise)
- d.light (competitor)
- Barefoot Power (competitor)
- Dr. Lee McFarland (human factors professor, Cal Poly)
- Laura MacCarley (volunteer with Engineering World Health in Tanzania)
- Martin Koch (Industrial and Manufacturing Engineering professor, Cal Poly)

Insight from these interviews has culminated in both a preliminary business plan and design modifications of the housing. Understanding the competition prepares LunaTech to produce a market-ready product that has an advantage with longer battery life and brighter light than the main competitor. Through conversations with those who either live in or frequently work with developing countries, the team understands the price is the most important factor to a successful product. By driving the cost down, the LunaLight will be able to reach more individuals who live on very little income. Great design at an affordable price is crucial, but finding buyers is equally important. Working with One Million Lights and contacting Living Goods has made them into potential customers. Both organizations have expressed a high level of interest in purchasing a portion of the first batch of lights. Successful interviews with said companies have given LunaTech good reason to pursue more interested customers in this market.

Barrett Raftery of One Million Lights provided feedback on the prototypes that traveled to Kenya. As a One Million Lights volunteer, he delivered the lights to the Maasai community of southern Kenya. He explained how the local market works and how the d.light is purchased through financing. The most important user need is low price: “The price is the determining factor on the feasibility of selling this as a product to developing countries. Look at financing. Look at perspective.” (Raftery). He suggested a $20 price per unit. The users liked the shape, size, and brightness, so these features will endure through the redesign. Barrett stressed the utility of the LunaLight’s cell phone charging capability. Cellphone charging became the primary function of the product, with lighting as a secondary function. This function must be emphasized when pitching to investors, as it differentiates the LunaLight from many competitors. Meeting the needs of users will make or break a design. Barrett indicated two of the lights broke within the first week of use and the others eventually had battery capacity issues. The longevity of the LED, battery and PCB are

crucial to successful, long-lasting product.

Laura MacCarley, a Cal Poly Electrical Engineering student who had spent a summer in East Africa volunteering with Engineering World Health, provided useful insight into the resilience of the local people. She shared her experience at local markets in rural communities in Tanzania. Some electronic components are available, mostly from broken devices and not in any standardized way. There are talented tinkerers who are intuitive and resourceful enough to repair electronics. Keeping the design simple and providing a long-lasting lithium ion battery should allow the LunaLight to function for multiple years and be repaired by semi-skilled locals if necessary.

The information gleaned from interviews guided the design process and provided useful commentary for pitching the business model. The existence of a market, the competitiveness of the product, and the potential buyers allow the team to push forward with the development of the LunaLight. The interviewees have provided valuable insight has guided business research and design before the product is ready to be manufactured on a larger scale. This information provided a good foundation for the User Feedback Survey that can be found in Appendix G. With an excellent foundation in function, the LunaLight must now achieve a lower price.

3.3 Printed Circuit Board

The PCB charges a lithium ion (Li-Ion) battery inside the housing with power from a solar panel. The Li-Ion battery powers an LED controlled by a manual rocker switch and a USB cell phone charger. Development of the design began with a basic level 0 block diagram shown in Figure 1. This level 0 block diagram groups all components of the LunaLight into one unit. The inputs and outputs of system are laid out in Table IV.

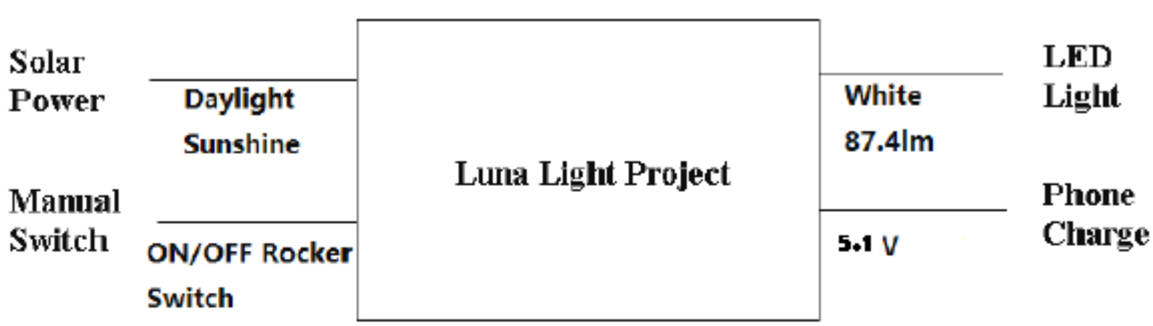


Figure 1: Level 0 block diagram of electronic system for LunaLight

Table IV: Identification of inputs, outputs and functionality of LunaLight electronics

Module	LunaLight Block Diagram
Inputs	Sun light, ON/OFF rocker switch
Outputs	White, 93.9lm LED Light, 5.1V DC voltage USB charger
Functionality	Convert solar power into 3.2V DC voltage to charge the internal battery, provide output voltage to charge cell phone at 5.1V DC, operate LED with 93.9 lm output to be controlled by manual rocker switch

Expanding to a level 1 block diagram includes the basic functional units of the electronic system of the LunaLight. The level 1 block diagram shown in Figure 2 includes the solar panel, battery, LED driver, and voltage boost. The inputs and outputs of each unit are listed in Table V.

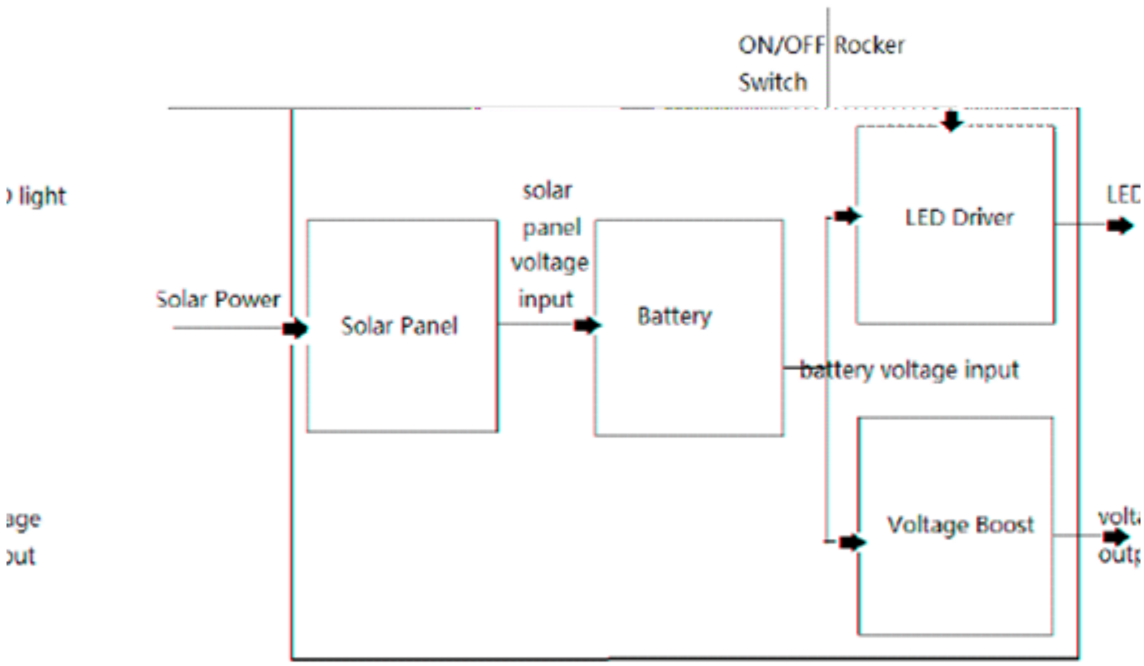


Figure 2: Level 1 block diagram of electronic system for LunaLight

Table V: Identification of inputs, outputs and functionality of modules on PCB

Module	Inputs	Outputs	Functionality
Solar panel	Sunlight	3 - 4.5V DC power	Convert solar power into 3 - 4.5V DC power. Maximum efficiency at 4.2V while charging the battery
Battery	3 - 4.2V DC power	3 - 4.2V DC power	Convert solar power into 3 - 4.2V DC power to activate LED driver and voltage boost
LED driver	3 - 3.8V DC power, rocker switch ON/OFF control	93.9 lm white LED light, 300 mA high brightness setting, 180 mA low brightness setting	Drive LED with constant current with Vin from battery
Cell phone charger	3 - 4.2V DC power	5.1V DC power	Convert input voltage from 3 - 4.2V to 5.1V DC

The electronic circuit function diagram contains three parts: battery management circuitry, LED drive and cell phone charger. First, the DC voltage input from the solar panel charges via the battery management circuitry efficiently and safely. Second, the LED driver takes the DC voltage pulse input from the battery and charges the inductor parallel with the LED. Next, the inductor will charge the LED with a constant current, which greatly reduces power consumption and enhances the life cycle of the LED. Typically an LED driver drives a series of LEDs. However, here the design uses a Single Ended Primary Inductance Converter (SEPIC) circuit specific to single LED driving. Finally, a voltage boost circuit takes the DC voltage input from the battery and outputs an international standard 5.1V for USB cell phone charging. See Appendix B for the detailed circuitry diagram. This circuit design allows the LunaLight to convert solar energy into stored battery power, which can power a bright LED light and a universal USB cell phone charger.

3.4 Housing

In January 2013, the LunaLight team wisely changed the housing direction away from injection molding and towards the cheaper alternative, plastic casting. The goal of this change was to verify the housing design before diving into the high risks of injection molding. Plastic casting allowed the team to cast a small volume of LunaLights on campus and relatively cheaply. This let the team control the production process and learn valuable

manufacturing techniques. There are a few differences when designing for plastic casting as opposed to injection molding. The list below highlights a few of the major design changes to the housing as we move from injection molding to plastic casting.

- Thicker walls and ribs
- Increased draft angles (3 degrees)
- Eliminated sharp and thin features

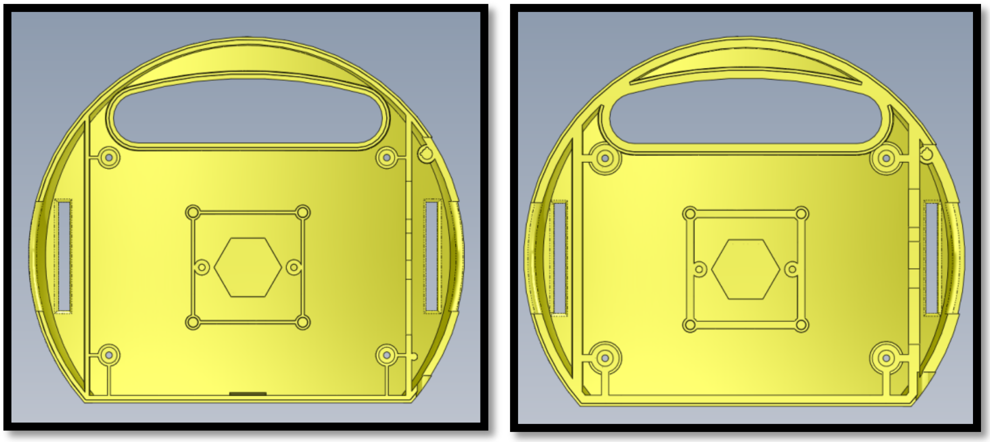


Figure 3: Comparison of parts designed for injection molding (left) compared to parts designed for plastic casting (right). Notice the thicker features on the plastic casting part.

The SolidWorks model was refined for plastic casting but the original parts designed for injection molding will also be saved for future reference when injection molding is feasible.

The most recent design changes were justified by designing for manufacturability, aesthetics, ergonomics, and repairability. In order to increase manufacturability, the housing design uses less material and is simple to assemble because of the use of only one screw size. The use of screws also allows the user to take the housing apart and perform repairs if necessary. The aesthetics of the design were improved by incorporating the golden ratio for the diffuser shape. The ergonomics were considered when the user is holding the light as well as when they are using it hands free. This was accomplished via a thicker grip for the handle to fit varying hand types as well as a shallower curved back so that the sides don't dig into the user’s body when strapped on as seen in Figure 4 below.

Figure 4: Demonstration of hands-free operation and why ergonomics was an important part of the design considerations

The improved housing design provides increased water and dust resistance. A port cover protects the opening that provides access to the barrel jack, USB port and switch. The port cover has been improved from the first 3D print and is now wider to accommodate a larger finger and will snap closed.

The strap of the previous design ran vertically along the back of the housing. The strap looped through the handle of the LunaLight, interfering with the user's hand while carrying the light. Rotating the strap inlets from the top and bottom to the sides allows the strap to run horizontally across the back of the housing as shown in Figure 5 below. The strap enters behind the port cover and exits in the same location on the opposite side of the rear of the housing. Rotating the curvature of the housing to match the orientation of the strap maintains the ergonomic shape of the LunaLight when the user is wearing it.

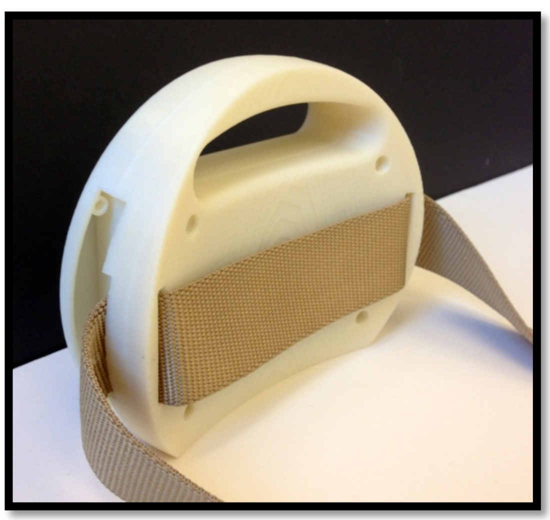


Figure 5: Rear of housing, showing port hole and strap inlets

The final design protects the PCB from impact if the LunaLight is dropped onto front housing and/or diffuser. The diffuser rests on the reflector, which rests on the PCB alignment posts, which protrude from the back of the housing. Any force on the diffuser will transfer through the reflector to the back of the housing rather than to the PCB. This system reduces the likelihood of breaking the printed circuit board or any delicate electrical components. Figure 6 shows the configuration of these four components.

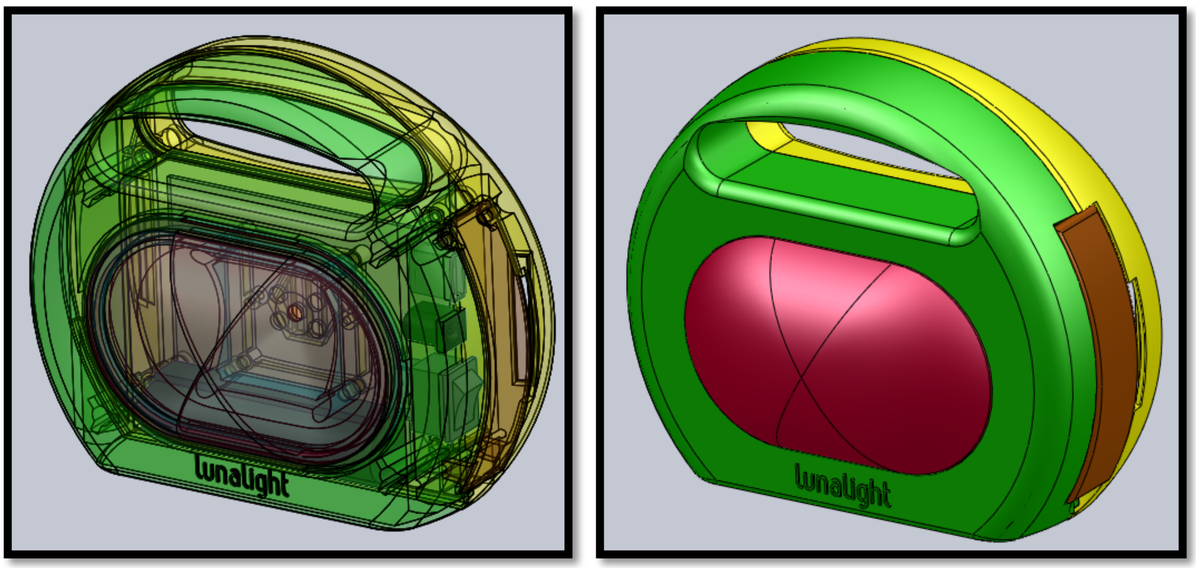


Figure 6: Transparent housing assembly of the LunaLight (left) as well as the external view (right)

With the help of Dr. Richard Savage, LunaTech utilized the on-campus 3D printers to create a physical prototype of the refined design. Figure 7 (below) shows the prototype of the back housing interacting with the PCB.

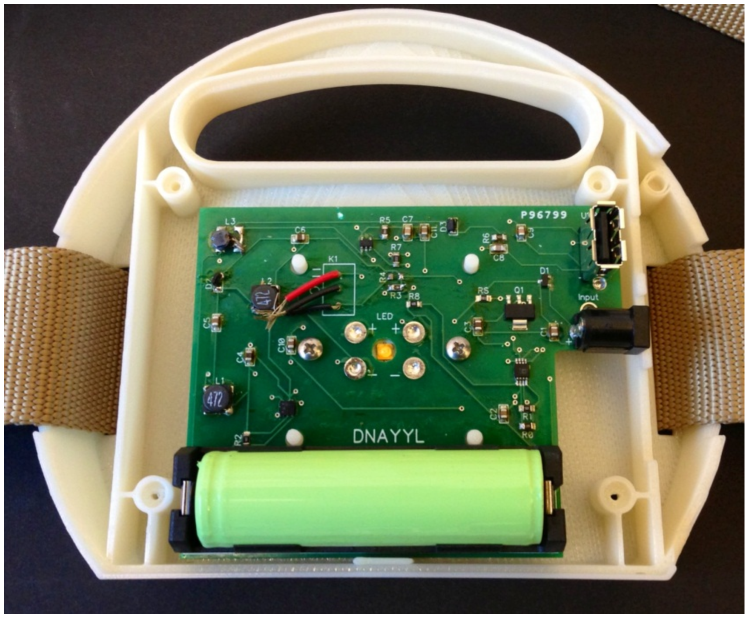


Figure 7: PCB installed into the 3D printed back part to check the fit. Port holes do not align with the ports therefore small refinements are still necessary.

In addition to the practical and aesthetic changes to the housing, a heat sink has been added to dissipate heat from the LED. The previous iteration of the LunaLight had no heat sink for the LED, which led to the two prototypes to fail with minimal use. The LED will be mounted onto an aluminum starboard to dissipate waste heat. Mounting the aluminum starboard directly to the back of the housing will maximize heat loss to the environment. Minimizing the wall thickness of the housing and adding ribs for increased surface area where the heat sink is mounted should increase heat transfer out of the housing. Multiple interfaces (LED to aluminum to plastic) reduce the heat transfer rate, but by using a thermal epoxy between the surfaces we hope to achieve good thermal contact to allow sufficient heat transfer.

$$\dot{q} = \frac{kA(T_{Hot} - T_{Cold})}{L}$$

Based on the conduction equation above, and the increased surface area from the ribs (over 2.5 times the heat transfer area compared to a flat surface), the heat transfer from the LED to the surrounding air should be significantly increased.

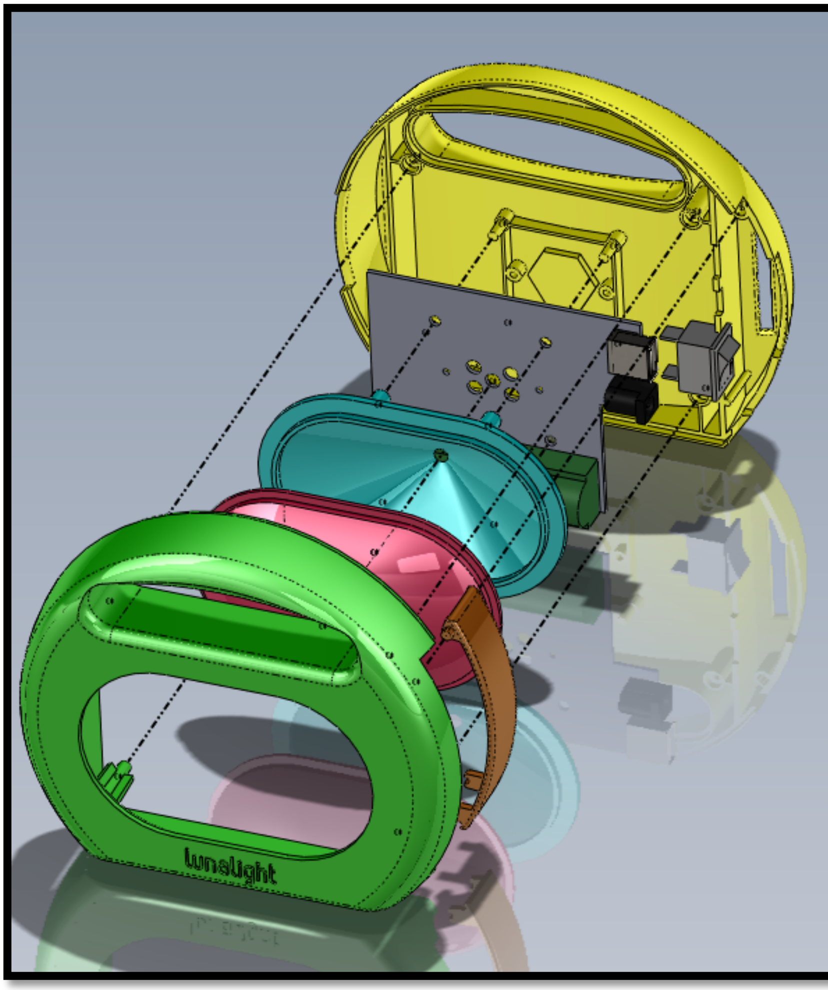


Figure 8: Exploded view of LunaLight assembly

3.5 Materials Selection

Because production of the LunaLight housing will take place in two phases, plastic casting and injection molding, the team performed materials selection for each phase separately. The selection for injection molded materials was based primarily on moldability, cost and durability or impact resistance. Information provided by the injection molding company Protomold as well as the Cambridge Engineering Selector (CES) informed the final decisions shown in Table V. The full selection matrices for each component can be found in Appendix C. The molds used for injection molding can be aluminum or steel. Aluminum is preferred for smaller quantity products such as the LunaLight because the cost to machine aluminum is lower although aluminum molds do not last as many cycles as steel molds.

In contrast, the materials for plastic casting were largely constrained by cure time as the resin must flow completely into all features of the molds before hardening. As the plastic casting materials come with a set additive package, they were also chosen for resistance to

environmental degradation. Finally, the molds for plastic casting must be formed in a silicone rubber material. Of the available silicone rubbers, a firm rubber that can hold features was chosen. The team discussed these considerations with a representative from Smooth-On, the material supplier, and chose the materials shown in Table VI.

Table VI: Materials chosen for production of LunaLight housing

Component	Injection Molding Material	Plastic Casting Material
Front and back halves	ABS	Smooth-Cast Urethane 305
Reflector	ABS	Smooth-On Urethane 305
Diffuser	Polycarbonate	Smooth-On Crystal Clear 202
Mold	Aluminum	Smooth-On Silicone Mold Star 30

3.6 Proof of Concept

The two initial functioning PCBs were assembled during the first week of May. These first working prototypes exhibited 3 functioning light settings: high, low and off. They also showed functioning solar charging capability and the correct voltage across the USB contacts.

The PCBs with the barrel jack, USB port, rocker switch, battery holder, battery, and starboard with mounted LED fit into the 3D printed prototype of the LunaLight housing. The team exhibited this first working prototype at the Night of Green and Gold event held by Cal Poly to showcase student projects and organizations to university donors and administration.

The team has since assembled four prototypes using plastic cast housing components and PCBs manufactured and assembled by Advanced Circuits.

3.7 Milestones and Obstacles

DESIGN

Housing: The housing design has transformed throughout the course of the year. The first milestone was seeing our first 3D printed model. The 3D printed model was too small and too thin to be a feasible product so a redesign was in order. The completed the injection moldable design was completed in December but shortly thereafter the team decided to pursue plastic casting as an intermediate step. Another redesign was in order to incorporate thicker walls and larger features for ease of plastic casting. During this time the overall shape of the housing was maintained but small improvements were incorporated. The handle was rounded and enlarged to incorporate all hand sizes. The port cover proved to be

a tough part to design so that it was moldable without a sliding cam. In order to plastic cast it, the cover was made symmetrical about its' centerline. Also, a lip was added to and it was redesigned so that it would snap closed to the housing.

The last major obstacle regarding the housing design was the mold design. The parts that had a simple shape did not pose any problems, but the Front and Back both have complex geometries and jagged parting lines which made it difficult to mold in SolidWorks. It was difficult to get a parting surface because the parting line was on multiple planes. Using the 'manual' parting surface mode in SolidWorks, the molds were finally completed and sent out for G-coding. Once the molds were machined we found that the jagged parting surface did not provide a perfect seal when pouring the liquid plastic into the mold and we would get incomplete parts. We corrected this issue by applying clay to the opening to help the liquid from leaking out of the mold.

PCB: Several improvements were made to the printed circuit board during this year's rendition of the LunaLight. Two brightness settings were added using a combination of two resistors (labeled R3 and R4 on the PCB, high and low brightness, respectively) and a rocker switch. The circuitry is much more efficient, almost completely charging in 6 hours (see Chapter 6: Design Verification for test results) using a 1.5 Watt solar panel, compared to 10 hours and 2 Watts for last year's model.

Completing the PCB design was particularly difficult for LunaTech due to lack of electrical engineering expertise in the core group of engineering students. There were three Electrical Engineering students that worked on the LunaLight as side projects, but were unable to commit to the senior project for the entire year because they did not receive adequate academic credit for the course. This was a major challenge throughout the year that set the PCB design and production behind a quarter.

PRODUCTION

Quantity Produced: In the beginning of the 2012-2013 Academic Year, LunaTech agreed on producing 100 units by June 2013. Unfortunately due to design and production delays, coupled with inadequate funding for injection molding, the team decided that 25 units was most appropriate using the resources available.

Silicone does not cure when exposed to soft wax: The LunaTech team quickly learned the silicone does not cure if it has any contact with soft wax or wax residue. Therefore clay replaced the wax for any sort of sealing purposes.

Plastic Casting: Based on monetary and material constraints the LunaTech team decided to move forward with a small batch of plastic casted parts rather than pursuing injection molding. Plastic casting allows for much smaller production runs, temporary molds that allow for design changes, and more affordable molds. Injection molding requires more

permanent molds that last for 10,000 to 100,000 parts per mold that are much more appropriate for large scale production. While the labor costs associated with plastic casting is typically very high, making injection molding more economical in the long run, the LunaTech student team manufactured the parts for no wages. The main purpose of the first rendition of the LunaLight was to confirm the design and allow for any design changes in a small scale, which made plastic casting the most appropriate form of manufacturing for the LunaLight during this academic year.

Based on this production pivot, the design of the housing was altered based on the consultation with Martin Koch, an IME professor well versed in the area of manufacturing and casting. The walls of the LunaLight were revised to be thicker to allow for better material flow when casted. Most small features were modified, as well, to become thicker, as intricate features do not fill as well and are prone to bubble. This leads to an unsatisfactory finish and possibly an incomplete part.

Pressure Chamber: After several iterations of plastic casting the diffuser, it was found that allowing the part to cure under pressure resulted in the best surface finish and the most complete part. First, the production team poured the mixed Crystal Clear liquid was poured into the mold without the use of a vacuum or pressure chamber and allowed the part to cure. The result was unsatisfactory with more than one hundred bubbles approximately 1 millimeter in diameter and large gaps (1 to 3 centimeters) in the rim of the diffuser. Next the vacuum chamber was utilized in attempt to abate this obstacle. The two parts were combines, stirred, and then placed in the vacuum chamber for 1 minute to remove the bubbles initially. Then the mixture was poured into the mold that was set inside the vacuum chamber. The part was left inside the vacuum chamber for 9 minutes, which is approximately how long it took for all the bubbles to be removed from the part. Once the vacuum chamber was turned off, all of the bubbles that were extracted re-entered the mold, creating even more bubbles than the first iteration (see image below). At this point in production, the pressure pot was in working condition. After the first use of the pressure pot, the parts came out perfectly. Eventually we chose to stack two diffuser molds into the pressure chamber to more efficiently utilize the mechanism.

Figure 9: Diffuser Lens Cured in Vacuum chamber

Heating the Diffuser: After the initial iterations of plastic casting the diffuser, LunaTech discovered that the material was still flimsy, even after curing overnight in the pressure chamber. As per the Crystal Clear data sheet, all diffusers were baked at 70°Celsius for 4 to 6 hours in the IME Foundry oven on designated silicone molds to retain the shape of the diffuser.

Incomplete Fill: When pouring the parts outside of the pressure pot, a common problem was an incomplete fill of the mold. This problem was associated with leakage from the side of the molds or when removing the funnel. By adding weights to the top of the molds after pouring and before completely curing, this problem was minimized but not all together rectified. Pressure was added to the sides of the gate to reduce the spillage from the funnel removal. When possible, the funnel remained inside the gate during the entire cure process completely eliminating any spillage associated with the funnel.

Post-Cure Clean Up: For the diffuser, when removing the extra material associated with the risers and gates, several parts were scrapped due to cracking. When the material was cut off using wire cutters or cutting shears the lens would crack resulting in an unacceptable part. After the first few occurrences the team mandated that all excess material on the diffuser be removed with the sanding belt or the dremel tool. This solution solved the problem for all future diffusers.

3.8 Lessons Learned

Do not solely rely on non-dedicated external partners to complete critical tasks.

For the majority of this year's project, the team has been behind the planned schedule. This is partly due to optimistic scheduling on the team's part, but can be mostly attributed to relying too heavily on outside resources to complete major critical tasks in the design and production plan. As mentioned above in Obstacles, the three Electrical Engineering students working on the LunaLight project were doing so solely on a voluntary basis. While they all performed exceptionally well to the highly demanding project, the fact was that they were busy students with their own coursework that took precedence over this side project. Relying too heavily on their expertise first set the project back in January when the planned design verification was expected to be complete. Unfortunately it was not and bled into Spring Quarter--when the fully assembled PCBs were expected to be ordered and received.

Production is another major aspect of this project that was delayed because of heavy reliance on external partners. The team worked very closely with Martin Koch, a lecturer that manages the IME Foundry, because of his extensive work with the 2011-2012 LunaLight team, and CNC and casting expertise. He has been an invaluable resource for the LunaLight team, lending machining expertise, advice, extensive time, materials and valuable real estate in the Foundry for storage and casting the parts. Again, the team relied too much on a very busy resource for an extremely pivotal part of the project. The team relied solely on Martin for the machining of the wax mold frames until May, but due to Martin's large load of responsibilities, he did not have the time to create the tool paths for the final three components, the front, back and port covers.

By the end of the quarter, the team was in desperate need to complete the final parts, but had also not gained the programming knowledge to create the molds in MasterCam, assign the proper tooling, and program the CNC to cut the front and back of the housing. So, the team called in a favor to Trevor Johnson, a recent graduate and lab tech at Mustang '60. He was able to program and cut all of the housing molds within two weeks! Unfortunately, busy schedules arise and the team currently does not have the mold for the port cover (though it is "scheduled" to be cut and complete by the end of the quarter).

Adequate resources are a key ingredient to a successful project with scheduling as a definitive factor in completing a task. In the situations mentioned above, the tasks were all outside the core group of student's knowledge and expertise.

Define a realistic scope.

The LunaTech team had many problems this year associated with scope creep and overly optimistic goals set from the very beginning. Though all students and professors involved in the project were highly ambitious it is very important to take stock in the beginning of the project for what is realistically feasible to complete for a student project. Understanding and

defining the scope in more definitive and rigid terms in the beginning of the year would have prepared the team better for the year ahead and create a practical plan accordingly.

Plastic casting is much more challenging than originally anticipated.

Again the LunaTech team was overly optimistic with the ease of completing 25 complete parts with plastic casting. There is a great deal of variability associated with plastic casting, specifically when using silicone. Not each mold creates a perfect part similar to the rapid prototyped parts. The silicone can sag which leads to inconsistency in wall thickness and most often, material leakage. Material leaking out of the sides of the mold wasted precious material and often led to incomplete pours and rejected parts. Plastic casting is also extremely time consuming. If a part is poured correctly and is generally acceptable, all of the gates, risers, and other excess material must be sanded off. This process was not the most reliable either, often leading to removing too much material which means that the part most likely would not fit together with the other parts. The team does not recommend any future iterations using plastic casting. It served its purpose this year, but the learning curve is rather steep and the results are not satisfactory.

CHAPTER 4: DESCRIPTION OF THE FINAL DESIGN

4.1 Design Overview

LunaTech sought to improve the LunaLight by integrating feedback from the customers into design changes. Problems with the prototypes identified by users in Kenya and relayed by One Million Lights necessitated modifying the electronics and layout of the design. Current improvements include a port cover for weatherproofing and strap relocation as discussed in the design development section. The first redesigned prototype was 3D printed to allow LunaTech to evaluate the design modifications. This prototype is shown next to the prior design in Figure 10.

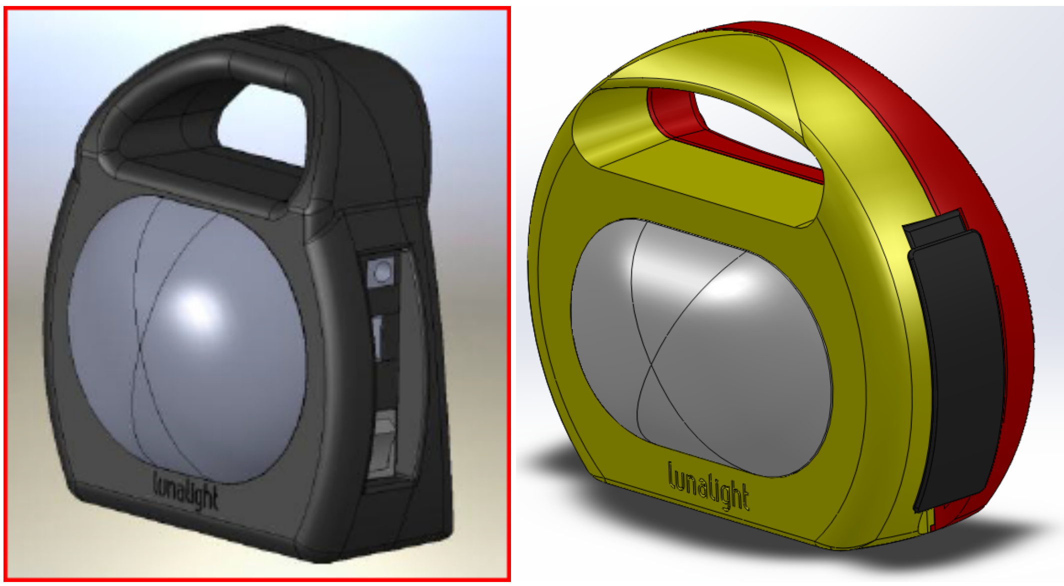


Figure 10: Prior LunaLight design on the left, first physical prototype of the redesigned LunaLight on the right.

Handling the prototype led the team to modify the handle to allow the hand of an adult male to fit. A locking mechanism to keep the port cover closed will ensure the cover actually protects the ports and switch. Enlarging the handle on the SolidWorks housing model resulted in the latest housing design, as shown in Figure 11.

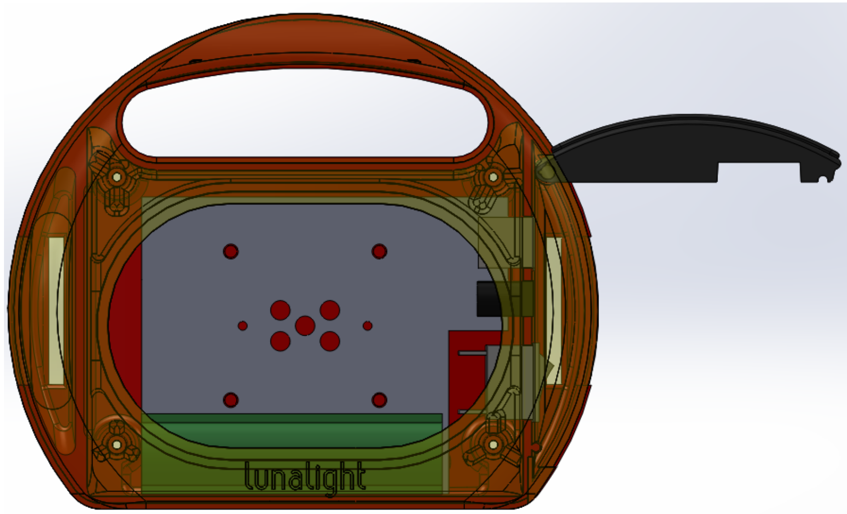


Figure 11: Front view of the housing showing the diffuser and larger handle.

Dimensioned drawings of each part of the housing are shown in Appendix B. They reflect the enlarged handle as well as the snap-on mechanism for the port cover.

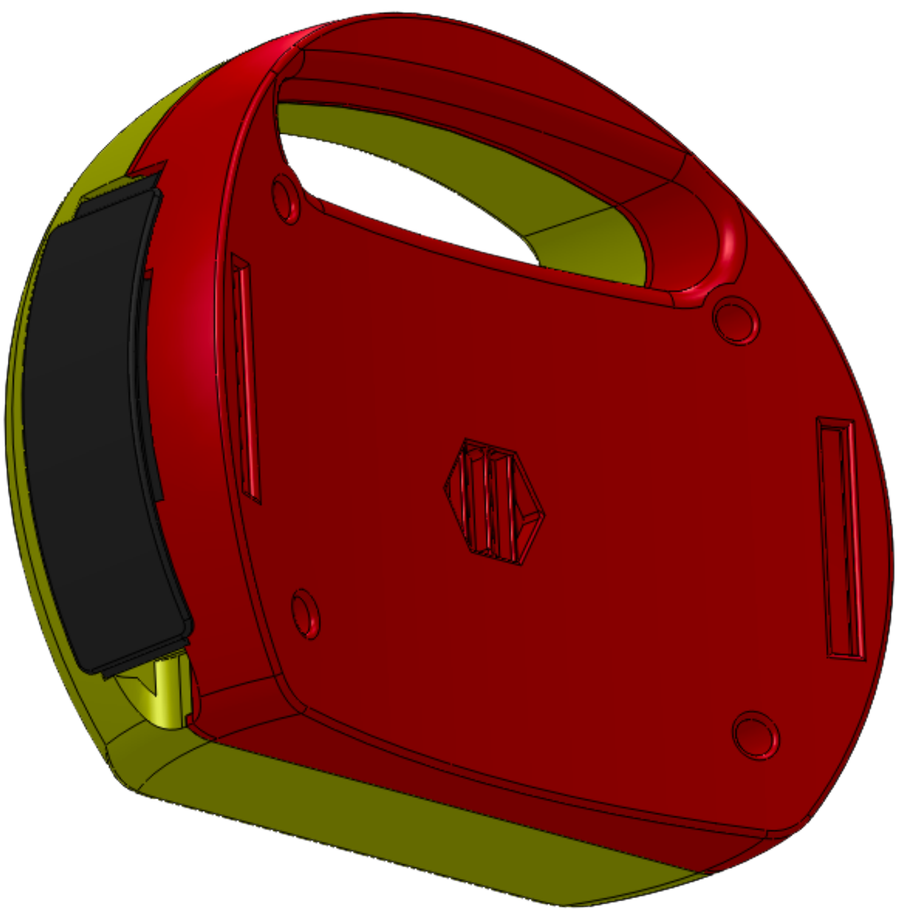


Figure 12: Back of Housing

4.2 Detailed Design Description

The newest design has improved water and dust resistance, better strap placement, smoother external shape, and higher impact resistance for the PCB. A port cover protects the sensitive internal electronic components from the environment. A lip between the front and back of the housing provides a physical seal that prevents contaminants from entering the LunaLight. Rotating the strap inlets to the sides allows the strap to run horizontally across the back of the housing, getting the strap out of the handle. Rotating the curvature of the housing to match the orientation of the strap maintains the ergonomic shape of the LunaLight.

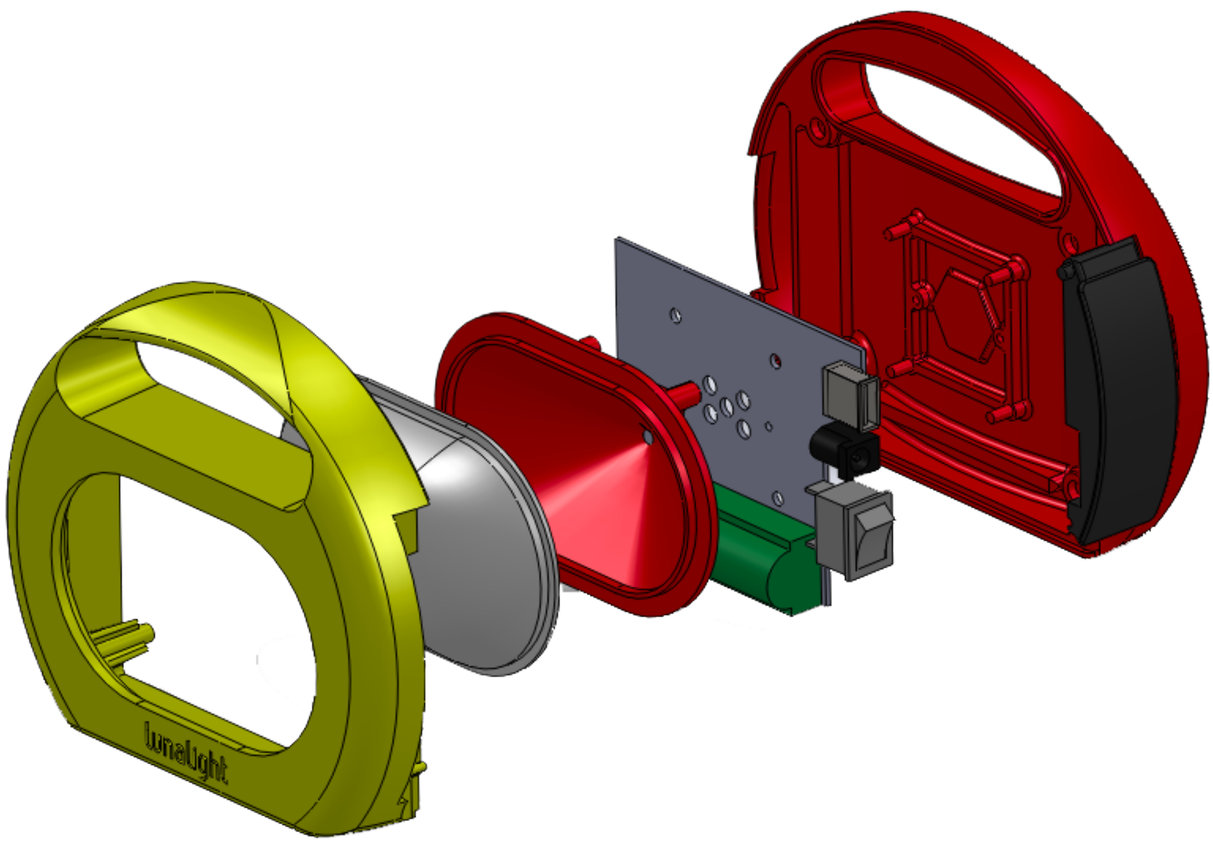


Figure 13: Exploded view of LunaLight

The current SolidWorks models integrate features recommended by Protomold to improve injection moldability. Further correspondence with Protomold will lead to adjustment of these parameters. Improvements in progress include faster battery charging, a battery with more charge cycles and a heat sink for the LED.

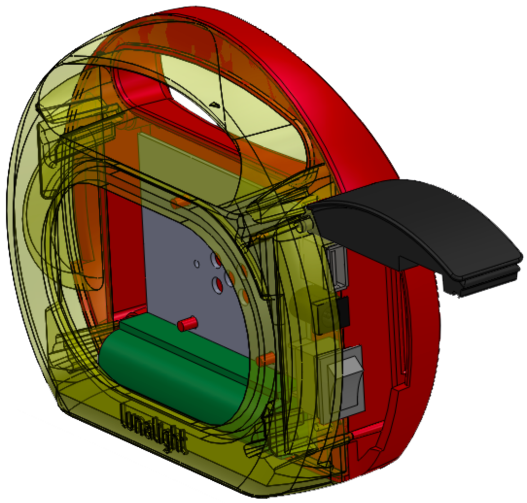


Figure 14: CAD drawing with PCB and Battery

The LunaLight housing design has become more compact and ergonomic than previous designs but can still be improved. Based on customer feedback that we receive, certain problem areas can be targeted and improved.

4.3 Analysis and Modeling Results

Analysis is important to predict the performance of the LunaLight during usage. The electronic circuit has been analyzed to predict the number of hours the product will produce light as well as how many 'average' cell phones it can charge on a full battery. These values are based on the efficiency of the circuit as well as the total battery capacity. See the product testing section to see how these theoretical values held up on the actual product.

The heat sink performance has been theoretically calculated (see Appendix G) but still needs to be tested in the field to verify the mathematical model. The model shows that there is sufficient heat transfer from the LED to the environment by both conduction and convection to maintain the ideal operating LED temperature of 150 ^{o}C. One extra source of heat that was not included in the analysis is the heat generated by the battery. The battery also makes contact with the back of the housing so some of the heat will be conducted to the environment but it will no doubt increase the internal temperature of the housing, especially during extended periods of charging. The field test will ensure the LED does not experience thermal degradation due to extreme internal temperatures with repeated use over extended periods of time.

4.4 Cost Breakdown

The final cost of low volume production was largely driven by the cost of the PCB production and assembly, the plastic casting materials, and the solar panel. In small quantities, the team was unable to secure low prices, and the total cost per unit totaled $147.05.

At high volumes, the significant contributors to the variable cost are the solar panel, Li-Ion battery, housing and PCB. Products manufactured at high volumes would use injection molding to produce the housing.

Although injection molding has a low per-unit cost when the cost of molds is amortized over the units produced by a single set of molds, the high initial cost is impractical for low quantities of production. Table VII shows the cost of the components required to assemble a single LunaLight, and Table VIII compares the tooling costs of injection molding and plastic casting. Note that labor costs are not included in these cost estimates as plastic casting labor, while intensive, was performed free by the student team and two additional volunteer.

Table VII: Total cost of each set of LunaLight components at quantities of 25, 10,000, and 1,000,000

Item	Cost per Unit (Qty 25)	Cost per Unit (Qty 10,000)	Cost per Unit (Qty 1,000,000)
External components	$37.86	$16.77	$8.39
Solar panel	$18.46	$7.00	$3.50
Li-Ion battery	$6.98	$5.99	$3.00
Plastic housing			
Injection molded	$13.74	$9.77	$4.89
Plastic cast	$18.75	$18.75	$9.38
PCB	$65.00	$8.36	$4.18
Total			
Injection molded	$142.04	$47.89	$23.95
Plastic cast	$147.05	$56.87	$28.44

Table VIII: Comparison of initial tooling costs to mold plastic housing

	Injection Molding	Plastic Casting
Cost of molds	$23,000	$516
Units produced per mold	50,000 (Estimated)	25
Cost per unit	$0.46	$8.60

4.6 Manufacturing Drawings

After all of the parts were designed in SolidWorks and verified via 3D printing, the next step in order to manufacture the parts was to design a mold for each part. This included identifying a parting line, creating shutoff surfaces where holes exist, as well as specifying the depth of each mold half. This mold design could then be used to create G-code which communicates a tool path to the CNC machine so the molds could be cut. With the help of Martin Koch and Trevor Johnson we were able to translate the SolidWorks mold files into physical wax blocks that we then used to make our silicone molds. A sample of the SolidWorks mold file can be seen in Figure 15 below. All of the part drawings used for manufacturing are included in Appendix B.

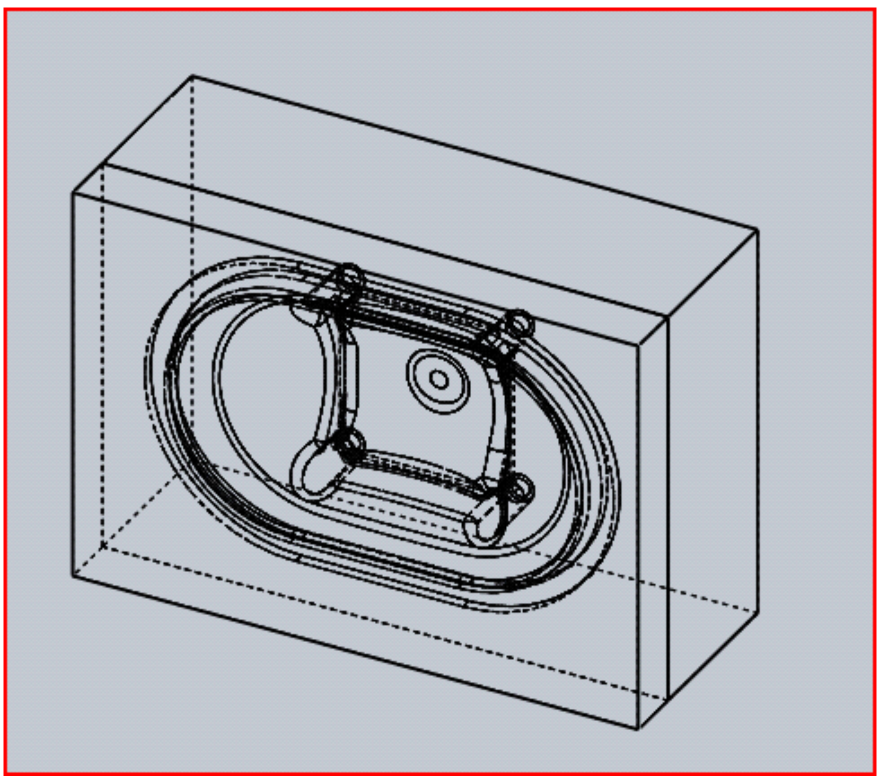


Figure 15: CAD drawing of wax mold for reflector

4.7 Safety Considerations

The LunaLight poses few safety risks as it is meant to be appropriate for use by all ages. The safety risks that do exist include choking caused by the strap, pinching of the skin in the strap's buckle, and cutting of the skin on sharp edges that could be exposed if the plastic housing is cracked. The choking risk is minimal as the strap is wide and would distribute any pressure over its 1.5 inch width. While pinching the skin in the buckle is likely, this would not cause a serious injury. Cutting the skin on a broken plastic component could cause bleeding, but it is not likely to cause a serious injury either.

The electronic components pose little to no safety risk. While the chips and LED generate heat, the heat is not sufficient to cause burning of the skin. The voltage of the battery and across the components are not high enough to cause electrocution.

4.8 Maintenance and Repair

The LunaLight was designed to be repairable. The housing can be opened by unscrewing four screws from the back of the housing. Opening the housing provides access the the PCB which contains all electrical components. The circuitry is simple enough that a self-trained cell phone or electronic repair technician should be able to identify any problems. Unfortunately, the plastic cast housings experience stripping of the screw holes when the screws are inserted and removed multiple times. This limits the number of times a unit can be opened and closed. This should be resolved by injection molding components as the ABS material is less brittle than the polyurethane.

Likely failures of the LunaLight that would require repair include an incapacitated battery, dislodged component such as the battery holder or starboard, broken component, and burnt out chip or burnt out LED. The battery is an 18650 Li-Ion battery with PCB protection. This is a standard size that can be purchased in any country and is therefore replaceable. A dislodged component can be re-attached with a soldering iron. While a soldering iron is not a household item, cell phone and electronic repair shops even in rural areas are likely to have one. A broken component such as a broken battery holder could be replaced if the component can be purchased. The availability of these components may be limited in rural areas of the developing world where the LunaLight would be sold. A burnt out chip or LED would be the most difficult problem to solve. It is likely that these would render the unit irreparable due to lack of access to replacement parts and the difficulty of removing and mounting new surface mount components to the PCB.

Because the LunaLight housing is custom designed and manufactured, cracked and broken parts are not replaceable. However, these plastic components could be glued or taped back together. In the event that the entire housing is rendered unusable, the PCB could be placed in an alternate container and could still be used. One example that has been observed in other products is the use of a plastic 2 liter soda bottle as a housing or container for the light.

CHAPTER 5:
PRODUCT REALIZATION

5.1 Manufacturing Processes

The production of the LunaLight takes place in three stages: initial prototypes, first 25 units, and mass production. External components have been sourced from reliable, low-cost suppliers most of whom can be used at all three stages of production. The primary suppliers are Mouser Electronics, Jameco, and Strapworks. Suppliers that were used for the first 25 units only include Smooth-On, All-Batteries and RadioShack. The PCB and plastic housing however, must have adjusted production methods depending on the volume of production.

For initial prototypes of the PCB, the team applied each surface mount component by hand and used a reflow oven to connect the components. This method avoids the high set-up costs of outsourcing this assembly to another company, but it is severely time intensive. The custom boards themselves were ordered from Advanced Circuits. The LunaTech team then applied solder paste to each contact point on the PCB and sent the PCB through the reflow oven to melt the solder into place. Flux paste was then applied to the contacts to prevent oxidation of the solder, and each resistor, capacitor, inductor, diode and chip were hand placed. The PCB entered the reflow oven again to attach the components to the solder and contacts. To ensure that all connections were successful, the team tested connectivity of each electrical path and each component using a multimeter. The process took approximately 5 hours for each PCB. This time commitment will be impractical when producing multiple PCBs, however it was necessary to use this method to identify problems with the PCB before committing the funds for more efficient production.

Because LunaTech could not afford to spend this much time on each PCB when producing 25 units, the PCBs outsourced to be almost completely assembled. The boards were cut and assembled by Advanced Circuits with automated capabilities to pick and place components onto the board. This automated manufacturing process will drive down the cost as production volume increases. For the first 25 units the final components including the LED, starboard, switch, and ports were hand soldered. This will not be the case if LunaLight moves into mass production.

Similar to the PCB, the production of the housing will evolve with increased volume. The initial housing prototypes were rapid prototyped using the 3D printers operated by the Materials Engineering and Mechanical Engineering departments at Cal Poly. Three-dimensional printing requires no custom tooling and can be printed directly from the CAD files of the housing components. However, the material cost and time consumption are high. Three-dimensional printing is only practical for initial prototypes to verify that the designed components fit together and perform as desired.

The next phase in housing production was to produce the first 25 units. These units were plastic cast using only equipment available within the Cal Poly campus. Plastic casting involves creating positive molds of each part by cutting wax with the CNC machine, see

figure 16. Martin Koch and Trevor Johnson programmed the tool paths for each of the five LunaLight parts in MasterCam and then cut the wax using the IME Foundry machines (Martin's notes can be found in Appendix H). The molds were then smoothed out using a combination of GooGone, soft tissue, and an air compressor. The silicone (MoldsStar30) is extremely sensitive, imprinting even a fingerprint! Once the wax mold was cleaned, mold release was sprayed over the mold to allow for easy removal later (Figure 18). Alignment pins were inserted in the molds where they had been programmed in MasterCam. The two parts of the silicone could then be combined and poured over the wax mold, creating a negative of the part (Figure 18).

Figure 16: CNC cutting wax mold

Figure 17: Spray Mold Release

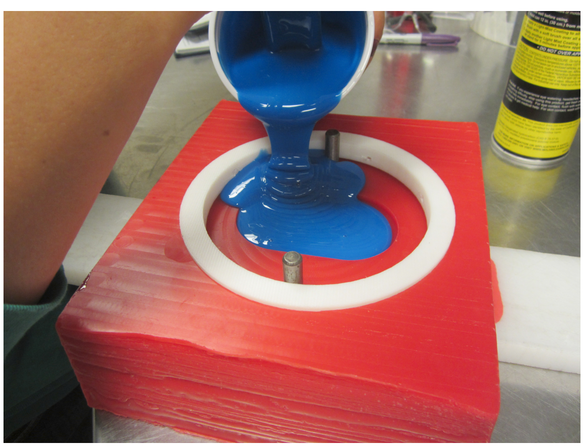


Figure 18: Pouring silicone

Figure 19: Weights on casted parts

For the front housing, back housing, diffuser, and port cover, the CNC milling machine operated by the Industrial and Manufacturing department cut these wax positive of the top and bottom of each part. This allowed for smooth surface finish for the inside and the

outside of the parts. The reflector molds were created slightly different, though. Silicone rubber was then poured over the wax to make a mold of the top of the part. To make the back bottom mold of the part, the 3D printed part was inserted into the top half of silicone mold, mold release was sprayed over the entire part, a barrier around the edge was created and sealed with wax (see 3.7 Milestones and Obstacles for issues that arose with this), then the silicone rubber was poured. This creates a front and back half the silicone molds for each housing part.

These silicone molds were then used to form the final urethane parts. The two halves of the silicone molds were placed together, and the liquid urethane resin was poured into the mold. The diffuser cured in a pressure chamber to eliminate bubbles and thin areas. Once the parts solidified, the molds were removed from the pressure chamber and pried off of the part. Each set of molds will produce 25 units using this method.

The initial 25 units are scheduled to be complete by the end of Spring Quarter 2013. Ten will be sold to One Million Lights, one to the Dominican Sisters of Oakford, one to LivingGoods, and a few to Engineers Without Borders, and distributed to utilized internationally. Feedback will be collected and then the third iteration of the LunaLight will begin based on the field-testing results.

5.2 Distinctions Between Prototypes and Final Design

Due to the manufacturing processes used, the initial prototypes, first 25 units and mass produced units will have distinct differences in the plastic housings.

The initial prototypes were 3D printed iterations of the design that will be used for injection molding during mass production. The penultimate 3D printed housing is the same dimensions as the injection molding design. However the layered 3D printed ABS creates a rough surface finish and brittle components. Injection molded components would be smooth and less brittle as the ABS would include different additives, and there would be no layers that provide crack initiation points.

The first 25 units produced by plastic casting have significant design differences from the 3D printing and injection molding design. Plastic casting involves pouring a liquid thermoset into a mold using only gravity to feed the material into the mold. Thin walls and features do not fill fully, and the design was modified to replace these features with thick sections. Even with these design changes, many of the features did not fill consistently during production and lead to a high defect and scrap rate. Further, the silicone molds were flexible and did not hold the exact dimensions of the components. This led to components that did not fit together perfectly. Finally, the silicone mold halves did not create a perfect seal at the parting line, and cured components had significant flashing that had to be cut and dremelled off. The plastic cast parts have both aesthetic and functional defects that would not be present in injection molded parts.

The PCB production method for the 25 units and mass produced units are the same. In both cases, the manufacture and assembly are outsourced to a company that specializes in PCB production. However, the circuitry design requires modification to resolve the USB charging function before mass production. Currently, the current at the USB port is a maximum of 300 mA, but most devices require 500 mA to charge.

5.3 Design Recommendations

Although the LunaLight team made significant advancements to the product, design issues remain. The following housing issues are due to the dimensional inaccuracy of plastic casting due to the flexible silicone molds and poor mold filling. However, they should be noted and considered.

- Interference between port hole walls and USB port, barrel jack and rocker switch
- Interference between housing front screw posts and housing back screw holes
- Lack of contact between housing front screw posts and housing back screw holes when posts do not fill completely
- Interference between housing front groove and housing back lip around edge of part
- Incomplete fill of housing front, back
- Interference between hollow reflector posts and battery holder
- Ridges along edges of housing front and back

Additional housing problems may persist in the injection molding design and should be remedied.

- Screw holes stripped after repeated screwing and unscrewing, limiting the number of times the unit can be opened and closed
- Insufficient impact resistance causing failure during the drop test

The following problems were observed with the PCB and must be resolved before mass production.

- Insufficient current in the USB port
    - USB charged devices require 500 mA
    - The USB driver limits the current at 300 mA
    - The board's ability to charge 2.5 cell phone batteries could not be tested due to this problem
- Poor contact between the starboard and PCB
    - Solder melted into the holes in the PCB on the contact points of the starboard provide inconsistent contact
    - Approximately 50% do not make electrical contact after the first round of soldering and required further soldering
    - Those that did connect may fall off when handled

    - Visual inspection cannot reveal whether or not contact is sound
- U2 and U3 generate large amounts of heat on some boards
- Buzzing noise observed in some boards when switch is off indicating some leakage of power causing a vibration
- Holes for battery holder pegs too small
    - Half of peg on each side had to be removed before battery holder could be inserted and soldered

5.4 Future Production

The LunaLight can move into mass production using the injection molding design of the plastic housing components and pending resolution of the USB charging problem. The recommended injection molding supplier is Protomold (www.protomold.com) as this company specializes in lower volumes and new products. Protomold provides counseling and assistance in preparing for the injection molding process. Advanced Circuits (www.4pcb.com) has proved to be reliable for PCB production and assembly. When the most recent housing design was submitted for a quote, the parts did not require any changes (ie. the parts were moldable) but the Protomold software identified some areas that can be improved. The future housing design should attempt to satisfy all of their recommendations to eliminate thick or thin sections and eliminate sliding cams. Working with a representative from protomold to increase the moldability of the parts would be advantageous to the company and help make superior parts at the lowest cost. Advanced Circuits gives educational discounts and has proved to be reliable for PCB production and assembly so we would recommend continuing to use them as the circuit board provider.

CHAPTER 6:

DESIGN VERIFICATION

6.1 Testing Summary

It is important that LunaLight customers around the world receive a quality product that will last for many years and provide a reliable alternative to kerosene. The team performed a series of tests to validate the product claims. The following table describes specific tests that the team conducted to verify the specifications. Appendix E contains further detail about these tests.

Table IX: Test Summary

Spec. #	Spec. Category	Test Category	Requirement	Tolerance	Risk	Compliance	Test Description	Qty Tested	Result	Qty Pass	Qty Fail	Notes
1	Geometry	Physical	Maximum size of 15 cm x 15 cm x 8 cm	Max	L	I	Inspect/measure	4	All Pass	4	0	H: 13 cm, W: 14.5 cm, D: 5.5 cm
2	Forces: Body of unit	Physical	Withstand drop from a minimum height of a 2.5 m	Min	M	T, A	Drop unit, inspect for damage; FEA	4	Failure when dropped upright, lens down, back down. Minimal damage when dropped handle down.	0	4	Only one repetition of drops from upright, lens down, back down because of damage to unit.
3	Forces: Latch	N/A	Locking mechanism requires less than 45 N of input for user to open.	Max	M	T, A	No longer relevant. No longer using snap closed design.	N/A	N/A	N/A	N/A	
4	Battery Charge Time	Physical	Charges within 8 hours of daylight	Max	H	T, A	Place solar panel in sunlight, connect to unit. Measure voltage of battery at intervals to determine time to charge.	10	Near complete charge at 6 hours	9	1	One unit did not charge at all.
5	Material: Housing	Physical	UV resistant plastic housing	Pass/Fail	L	T, A	UV chamber unavailable. Reference plastic supplier's specifications.	N/A	"Castings can be displayed outdoors after priming and painting. Unpainted castings will yellow over time - more quickly when exposed to ultra-violet light." from Smooth Cast 305 technical bulletin.	N/A	N/A	Mass produced units would be made with an ABS which includes a UV stabilizing additive.

Spec. #	Spec. Category	Test Category	Requirement	Tolerance	Risk	Compliance	Test Description	Qty Tested	Result	Qty Pass	Qty Fail	Notes
6	Material: Lense	Physical	Transparent diffuser lens	Pass/Fail	L	T, A	Visual inspection	14	All transparent	14	0	
7	Signals	Physical	3 light settings (high, low, off)	Pass/Fail	M	I	Visual inspection	24	15 out of 24 function on all three settings	15	9	9 PCBs do not light up on any setting. Likely due to poor LED contact.
8	Safety	Physical	No sharp edges/pinch points	Pass/Fail	L	I	Visual, tactile inspection	4	2 pass, 2 fail due to protruding edges	2	2	Edges not sharp enough to cut but noticeable.
9	Safety	Physical	Not flammable	Pass/Fail	L	A	Hold near open flame	1	1 pass	1	0	Material is not flammable
10	Safety/Reliability	Physical	LED does not overheat	Pass/Fail	M	T	Measure LED temperature by applying thermocouple to starboard during light usage after steady state is reached. Max junction temp: 150 ° C (CREE XPE data sheet)	2	Pass: Steady state temp of 64.4 °C, 37.3 °C	2	0	Assumed that due to high thermal conductivity of aluminum starboard, starboard contact point where temperature was measured was the same temperature as the junction.
11	Ergonomics: Handle	Ergonomic	Large enough for 4 fingers	Min	M	I	Test with range of hand sizes	3	Pass	3	o	
12	Weight	Physical	2 pounds	Max	L	I	Weigh assembled design	4	Pass	4	0	All 0.9 lb or below
13	Portable: Hands free	Ergonomic	Ability to use light hands free	Pass/Fail	L	I,T,S	Trial: Ensure ordered straps are functional	3	Pass	3	0	
14	Portable: Hand-held	Ergonomic	Ability to carry light by handle	Pass/Fail	L	I	Trial: Ensure sure handles are functional	3	Pass	3	0	
15	Usability: Stand Alone	Ergonomic	Ability of light to stand upright on a surface	Pass/Fail	M	I	Trial: Set on table, make sure weight of strap does not pull unit off table, base of unit is flat	3	Pass	3	0	
16	Usability: Hanging	Ergonomic	Ability to hang from a wall or ceiling	Pass/Fail	L	I	Trial: Hang on hook, nail	3	Pass	3	0	

Spec. #	Spec. Category	Test Category	Requirement	Tolerance	Risk	Compliance	Test Description	Qty Tested	Result	Qty Pass	Qty Fail	Notes
17	Production	Analytical	Housing is easily constructed by injection molding	Pass/Fail	M	A, S	Upload into Protomold simulator	0	Pass	N/A	N/A	Design can be injection molded.
18	Operation	Analytical	Last 5 years	Min	M	A	Calculate projected lifespan	0	Not completed	N/A	N/A	Due to lack of expertise of current team, calculations could not be completed.
19	Maintenance	Analytical	Replace the Li-Ion battery every 2 years or after 350 cycles	Min	M	A	Data sheet	0	Product spec: Minimum life of 500 cycles	N/A	N/A	
20	Cost	Analytical	Maximum consumer price of$45	Max	H	A	Calculations	0	Pass: See Variable cost table	N/A	N/A	Consumer price of $45 feasible at high volumes
21	Brightness	Physical	100 lux at distance of 60 cm	Min	M	S,T	Use 1mx1m chart, lux meter	3	All units pass	3	0	Surface charts of light output over 1 m^2 in appendix.
22	Comfort	Ergonomic	Must be comfortable to wear for more than 1 hr	Pass/Fail	L	T	Have users report any discomfort	3	Pass	3	0	
23	Brightness (qual.)	Ergonomic	Must light up a room sufficient enough to work in	Pass/Fail	M	T	Have users do homework, read using only LunaLight, report amount of strain on eyes	1	Pass	1	0	
24	Brightness (qual.)	Ergonomic	Must light up a path while walking	Pass/Fail	L	T	Have users hike a path of at least 1 mile using LunaLight only (little to no light pollution, moon), provide feedback	3	Pass	3	0	

Spec. #	Spec. Category	Test Category	Requirement	Tolerance	Risk	Compliance	Test Description	Qty Tested	Result	Qty Pass	Qty Fail	Notes
25	Brightness (qual.)	Ergonomic	Must be bright enough to work under outdoors (small booth/vendor, working with livestock, etc.)	Pass/Fail	L	T	Have users perform outdoor work (run farmer's market booth) using LunaLight only, provide feedback	3	Pass	3	0	
26	Environmental resistance	Physical	Must not degrade under typical exposure to heat and humidity	Pass/Fail	M	T	Environmental chamber if available.	0	N/A	N/A	N/A	Environmental chamber not available when units completed
27	USB Charging	USB Charging	5.1 V, 500 mA	Pass/Fail	M	T, A	Measure voltage, current of USB, charge cell phone	2	Fail	1	9	No boards successfully charge cell phone
28	Battery Capacity: Light	Battery Capacity: Light	Provides 6 hours of light on high brightness	Min	M	T	Turn on lights on high setting and record when each turns off	10	Fail	1	9	8 lights lasted 4 hours. One did not turn on. One lasted 8 hours.

6.2 Discussion of Key Tests

DROP TEST (SPEC. 2)

The drop test involved dropping the LunaLight from four different orientations from a distance of 2.5 m onto a concrete surface. The orientations were upright (Figure 20), lens down (Figure 21), back down (Figure 22), and handle down (Figure 23).

The upright orientation caused 2 of the screws to fail, allowing the housing to open. The battery holder came off of the PCB despite being soldered in place, and the plastic at the positive end of the holder broke off, rendering it unusable. Two of the PCB alignment posts broke, and the epoxy holding the starboard to the back of housing became detached from the housing. Despite this damage, the unit still functioned when it was re-assembled and the battery holder was replaced.

The lens down drop caused the soldered connection between the starboard and PCB to fail. Once this was re-soldered, the unit functioned again.

The back down drop caused the unit to not light up when turned on initially. However, the unit functioned again after several minutes without any repairs.

The handle down drop scratched the diffuser but did not cause any other damage. The drop was repeated, and no damage occurred for a second time.

Figure 20: **Drop Test Upright**

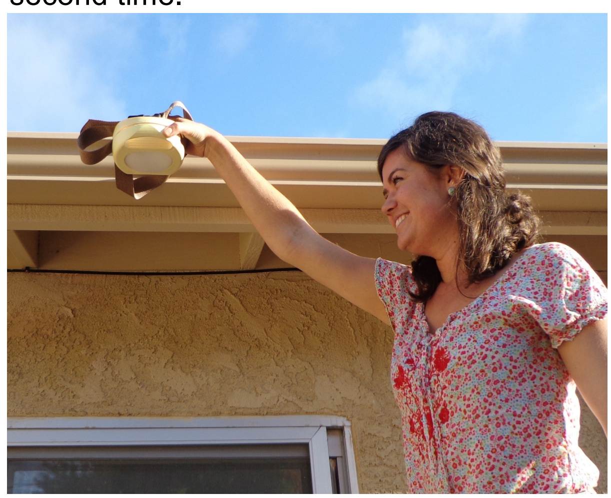


Figure 21: **Drop Test lens Down**

Figure 22: Drop Test Back Down

Figure 23: Drop Test Handle Down

BATTERY CHARGE TIME (SPEC. 4)

The charge time was tested by plugging 10 solar panels into 10 PCBs and setting them in the sun (Figures 24 and 25). The voltage of the battery was then measured after 6 and 8 hours. After 6 hours all batteries were near the battery's maximum voltage. One unit did not charge at all.

Figure 24: Ten solar panels charge LunaLight battery in CP Connect Room

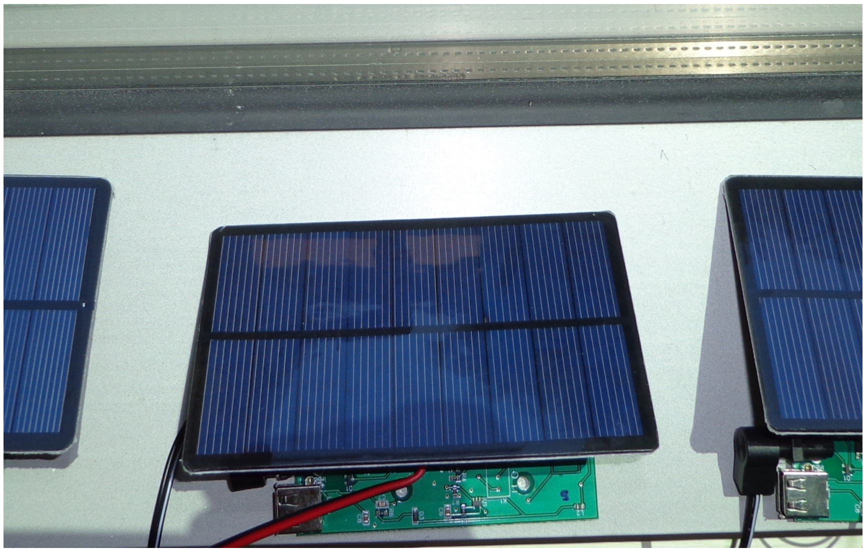


Figure 25: Solar panel charging battery

LED THERMAL MANAGEMENT (SPEC. 10)

Two LEDs were turned on the high brightness setting, and the temperature of the starboard was measured approximately every minute until the units reached steady state. While the two LEDs varied significantly in temperature, both were well below the maximum junction temperature of the LED of 150 $^{\circ}$C. The boards reached 64.4 $^{\circ}$C and 37.3 $^{\circ}$C. The difference in temperature is likely due to the level of contact of the epoxied starboard to the housing back.

This test assumes that the thermal conductivity of the starboard is sufficient that the junction temperature of the LED and the temperature of the starboard are the same.

ERGONOMICS (SPEC. 11, 13-16, 22-25)

Three volunteer test users spent an evening using the LunaLight (Figure 26) and provided feedback to the team on the function and ergonomics of the product. Their activities included hiking, observing graffiti in the Poly Canyon Architecture Graveyard, and climbing a structure. The feedback received from the post-hike survey confirmed the team's belief that the light is comfortable and usable at night. The full responses to the survey can be found in Appendix E.

Figure 26: Human subjects wearing LunaLight for night hike

BRIGHTNESS (SPEC. 21)

In order to ensure that the LunaLight provides 100 lux at 60 cm directly in front of the diffuser and to observe the distribution of light, the team tested the light output using a lux meter and a 1 m by 1 m grid. The LunaLight was placed 60 cm from the zero point of the grid. The lux meter was used to measure the illuminance at this point. The illuminance at each point at 10 cm intervals was then taken for 50 cm in the positive and negative x- and y- directions. This yielded a surface chart showing the illuminance over the 1 m by 1 m area. The three units tested provided 162, 116, and 114 lux at the center point, averaging 131 lux. The surface charts for these tests can be found in Appendix X.

USB CHARGING (SPEC. 27)

To charge a cell phone, the USB should provide 5.1 volts and 500 mA. The 9 boards tested all yielded between 5.0 and 6.3 V. However, the maximum current was 300 mA. This is insufficient to charge a cell phone. It is possible that components in the USB driving circuitry can be changed to correct this.

BATTERY CAPACITY: LIGHT (SPEC. 28)

The duration of light on a fully charged battery was tested by turning on 10 lights on the high brightness setting (Figure 27). The duration that each lasted before turning off was recorded along with the initial brightness. The brightness remained constant until the last several minutes before each light went out. 7 of the lights lasted 4 hours, one lasted 8 hours, one lasted 2 hours, and one did not turn on. The required light duration was 6 hours, meaning the product failed this test.

Figure 27: Ten LunaLight undergo battery capacity testing

CHAPTER 7:
BUSINESS DEVELOPMENT

The Business Model Canvas was developed in depth in partnership with Jessica Bell and Jennifer Kerr, Business Entrepreneurship students with the guidance of Dr. Jonathan York. This model has guided both the business and engineering decisions, giving the project a clear goal to work towards. Each of the nine sections of the Business Model Canvas (BMC) have been highly developed and thoroughly researched by both the engineering and business students. Figure 28 below shows the simplified BMC that truly focuses on the important aspects of the business model.

<table>
<tr>
<td rowspan="2">Key Partners
•Local governments
•Investors
•Strategic Distributors</td>
<td>Key Activities
•Contract assembly
•Sourcing
•Distributor selection</td>
<td rowspan="2">Value Proposition
•Bright
•Hands free
•Cell phone charger</td>
<td>Customer Relationships
•Frequent communication
•After sales service</td>
<td rowspan="2">Customer Segments
•Non-profits
•Micro-franchising organizations</td>
</tr>
<tr>
<td>Key Resources
•Distributor connections
•Supplies
•Trademark, patent</td>
<td>Channels
•Non-profit distribution
•Micro-franchise
•Online sales</td>
</tr>
<tr>
<td colspan="2">Cost Structure
•Materials and production
•Assembly costs
•Import taxes
•Shipping costs</td>
<td colspan="3">Revenue Streams
•Micro-financing
•Bulk sales
•While labels</td>
</tr>
</table>

Figure 28: Business Model Canvas

The business development has added great value to the project, allowing for LunaLight to gain traction in the Cal Poly Entrepreneurship community.

Mission: To brighten lives and empower communities through quality design and social responsibility.

Promotional Material

Website

Address: www.lunalight.org
Host: www.wix.com

Logo

Font: Zag Regular
Colors: luna RGB: 236 | 158 | 39
light RGB: 251 | 226 | 55

CHAPTER 8:

ACKNOWLDEGEMENTS & REFERENCES

Acknowledgements
The LunaLight Team would like to thank all those involved in making this project a success:

Dr. Richard Savage, Senior Project Engineering Advisor
Dr. Jonathan York, Business Entrepreneurship Advisor
Mike Deagen, LunaLight Advisor

Anna Sidana, One Million Lights CEO
Arsh Gill, Electrical Engineering Student
Barrett Raftery, One Million Lights Representative
Brooke Wheeler, SmoothOn Representative
Bryce Norton, MATLAB Expert
Caitlyn Cook, MATE Student and Production Volunteer
Cal Poly Center for Innovation and Entrepreneurship
Cal Poly Entrepreneurs
Cal Poly Industrial and Manufacturing Engineering Department
Cal Poly Industrial and Manufacturing Engineering Department Student Fee Committee
Cal Poly Innovation Quest
Cal Poly Materials Engineering Department
Cal Poly Mechanical Engineering Department
Cal Poly Mustang ‘60 Lab
Dawei Zhang, Electrical Engineering Student
Dr. Art MacCarley, Senior Project Instructor
Dr. Jane Lehr, Senior Project Lecturer
Dr. James Widmann, Senior Project Instructor
Dr. Lily Laiho, Senior Project Instructor
Jennifer Kerr, Business Entrepreneurship Student
Jessica Bell, Business Entrepreneurship Student
Laura Chao, One Million Lights Program Manager
Luke Thornley, MATE Student and Production Volunteer
Martin Koch, Foundry Manager and Programmer
Philip Streeter, Materials Engineering Student
Princepal Buttar, Electrical Engineering Student
ProtoMold Injection Molding
San Diego State University LeanModel
Trevor Johnson, Programmer

References

ASTM Standard D1435, 2005, “Standard Practice for Outdoor Weathering of Plastics,” ASTM International, West Conshohocken, PA, 2010, DOI: 10.1520/D1435-05, www.astm.org.

ASTM Standard D3045, 2010, “Standard Practice for Heat Aging of Plastics Without Load,” ASTM International, West Conshohocken, PA, 2010, DOI: 10.1520/D3045-92R10, www.astm.org.

ASTM Standard D4364, 2005, “Standard Practice for Performing Outdoor Accelerated Weathering Tests of Plastics Using Concentrated Sunlight,” ASTM International, West Conshohocken, PA, 2010, DOI: 10.1520/D4364-05, www.astm.org.

CES EduPack 2011. Vers. 2011. Cambridge, UK: Granta, 2011. Computer software.
GSMA. *Bi-Annual Report November 2010*. GSMA, International Finance Corporation, 23 Nov. 2010. Web.

International Finance Corporation, and The World Bank. *Lighting Africa Market Assessment Results: Quantitative Assessment - Kenya*. Lighting Africa, 2008. PPT.

International Finance Corporation, and The World Bank. *Lighting Global: Quality Assurance Protocols 3.1*. Lighting Global, 2013. PPT.

Raftery, Barrett. Personal Interview. 25 Oct. 2012.

"Resin Guide for Injection Molded Parts." Resin Guide for Injection Molded Parts | Plastic, Acetal, Nylon, Polycarbonate & Acrylic. Proto Labs, Inc. Web. 03 Nov. 2012. <http://www.protomold.com/DesignGuidelines_ResinGuide.aspx>.

The World Bank. “Energy- The Facts.” *Energy*. Web. 14 Nov. 2012.

Appendix

Appendix A: Housing Shape Decision Matrix

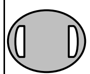
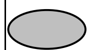
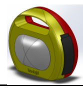
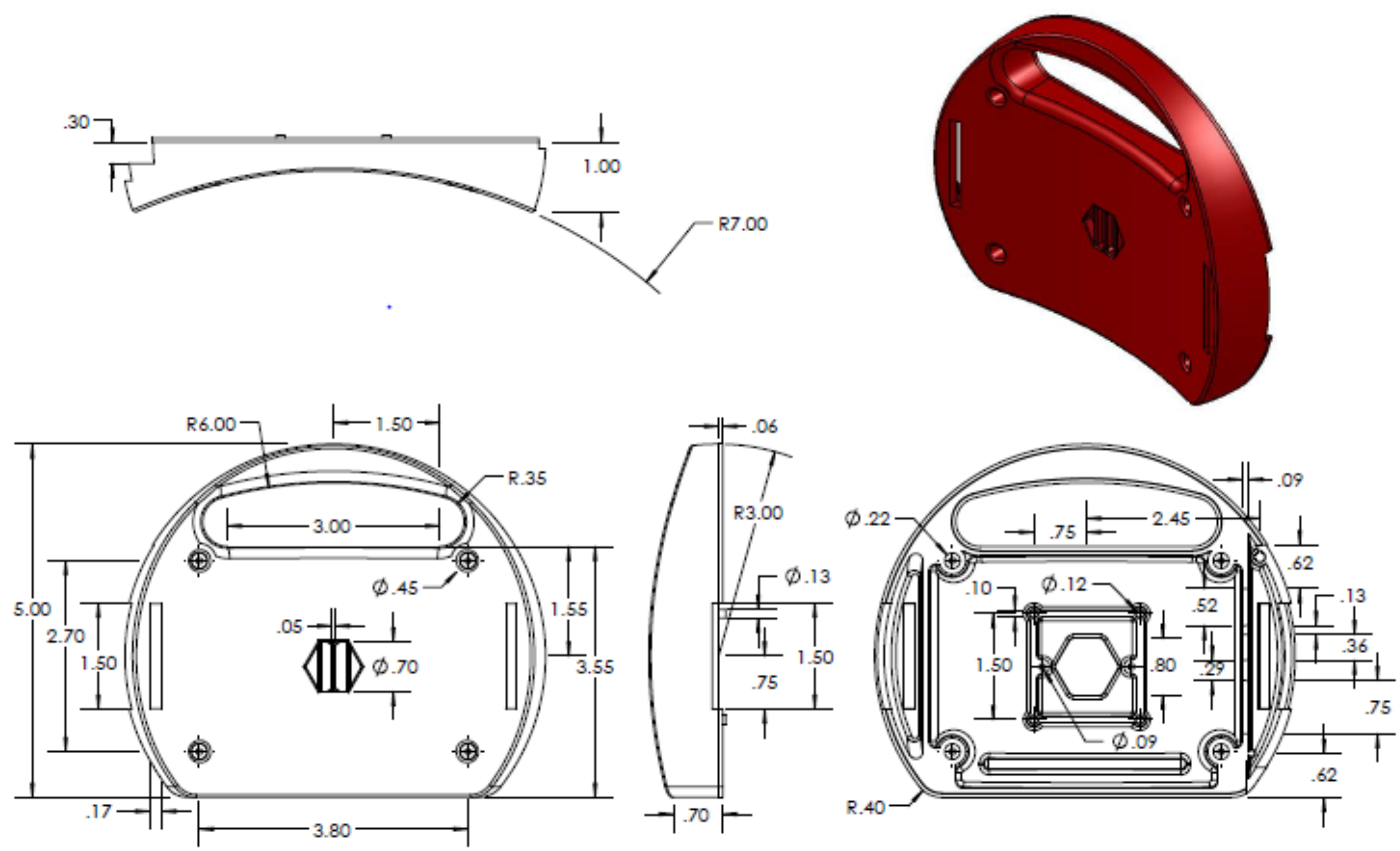
										
	Orb	*Half Moon*	*Double Handle*	*Box*	*Egg*	***Rounded Crescent***	*Flash Light*	*Lantern*	*Headlamp*	*Spring '12 Prototype*
Ability to use hands-free	0	0	0	-1	0	**0**	-1	-1	1	0
Culturally neutral	0	0	0	0	-1	**0**	0	0	-1	0
Durable (Withstand drop from 2.5m)	-1	0	0	0	0	**0**	0	0	0	0
Water resistant	1	0	0	0	1	**0**	0	-1	0	0
Comact (Less than 15cm x 15cm x 8 cm)	-1	-1	0	0	0	**0**	0	-1	1	0
Lightweight	0	0	0	0	0	**0**	0	-1	1	0
Handle fits 4 fingers, range of hand sizes	-1	0	0	0	0	**1**	-1	-1	-1	0
UV resistant	0	0	0	0	0	**0**	0	0	0	0
No sharp edges	0	0	0	-1	0	**0**	0	0	0	0
Stands upright	-1	-1	0	1	-1	**1**	-1	1	-1	0
Can be hung	0	0	0	0	0	**0**	-1	-1	0	0
Can be made by injection molding	0	0	0	-1	0	**0**	0	0	0	0
Better than standard	**1**	**0**	**0**	**1**	**1**	**2**	**0**	**1**	**3**	0
Worse than standard	**4**	**2**	**0**	**3**	**2**	**0**	**4**	**6**	**3**	0
Same as standard	**7**	**10**	**12**	**8**	**10**	**10**	**8**	**5**	**6**	12

TABLE XI: MORPHOLOGICAL CHART

Function	Means						
Produce light	LED	Incandescent	Fluorescent	Glow			
Hands free	Shoulder strap	Necklace	Head lamp	Velcro	Bike mount		

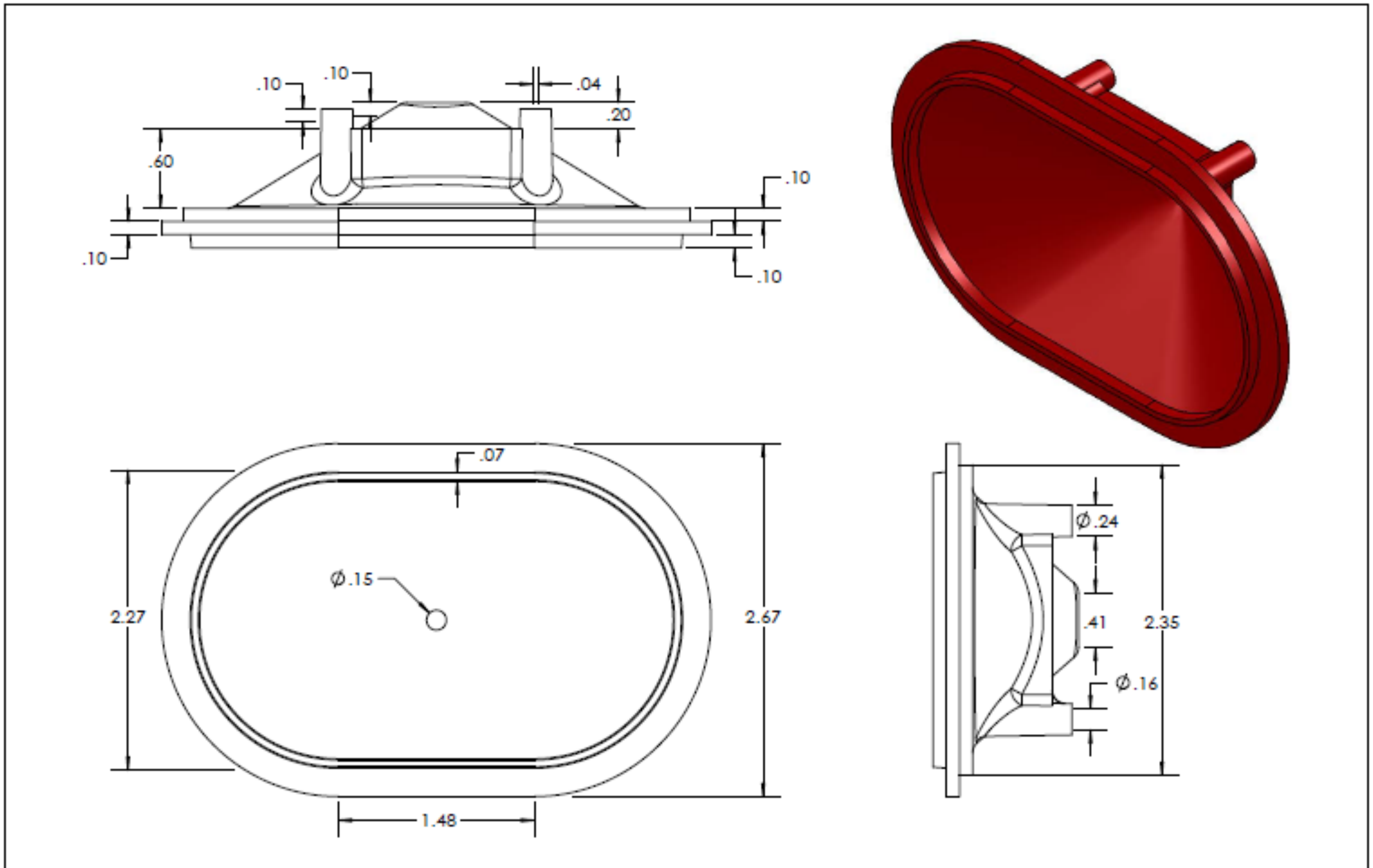
Holding	Integrated plastic handle	Cloth strap	Wrist strap	Hand strap			
Hanging/self standing	Hook	Tripod	Suction	Velcro	Flat	Necklace	Strap
Cellphone charging	USB port on light	Direct from solar panel	Phone specific plug	Wireless			
Color temperature	Incandescent	Tailored LED					
Light focus	Diffusor	Mirror	Lens	Multiple LEDs	Lamp	Flashlight	
Battery charging	Solar panel	Kinetic/shaking	Crank	Bike generator	Plug into socket	Separate charging unit	
GPS	Integrated	Sextant	Compass				
Sparker	Piezoelectric	Capacitor					
Internal storage	Cavity	Compartment					
Light dispersion	Spherical	½ sphere	Beam				
Educational	Calculator	Reading light					

Appendix B: Final Drawings



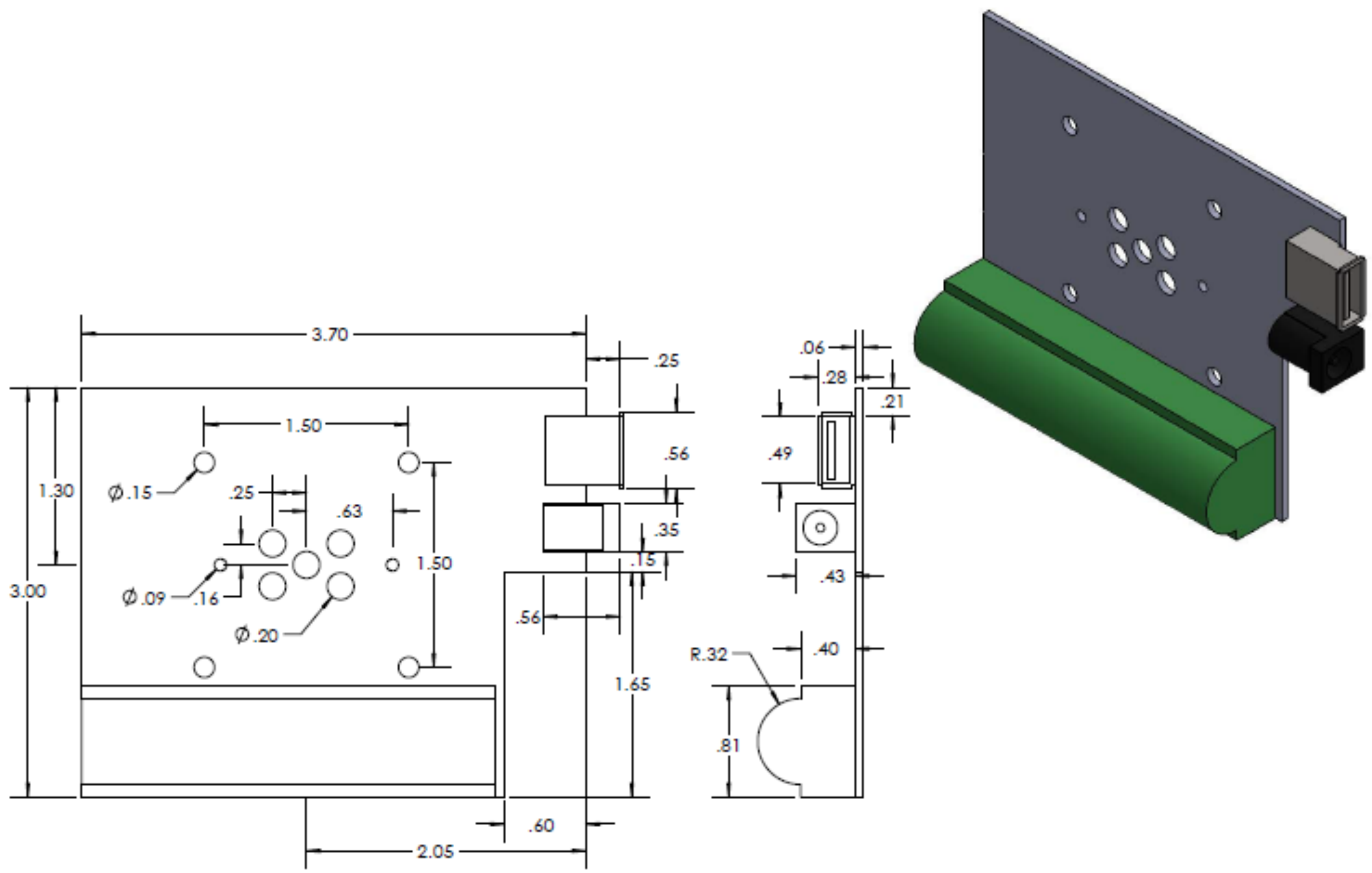
ME470 Spring 2013 lunalight™	SCALE: 1:2	PART: BACK
	UNITS: INCHES	DATE: JUNE 7, 2013
	TOLERANCE: ±0.005 INCHES	MATERIAL: POLYURETHANE
	DWG #: 1	DRAWN BY: D PATRICK

Appendix B: Final Drawings



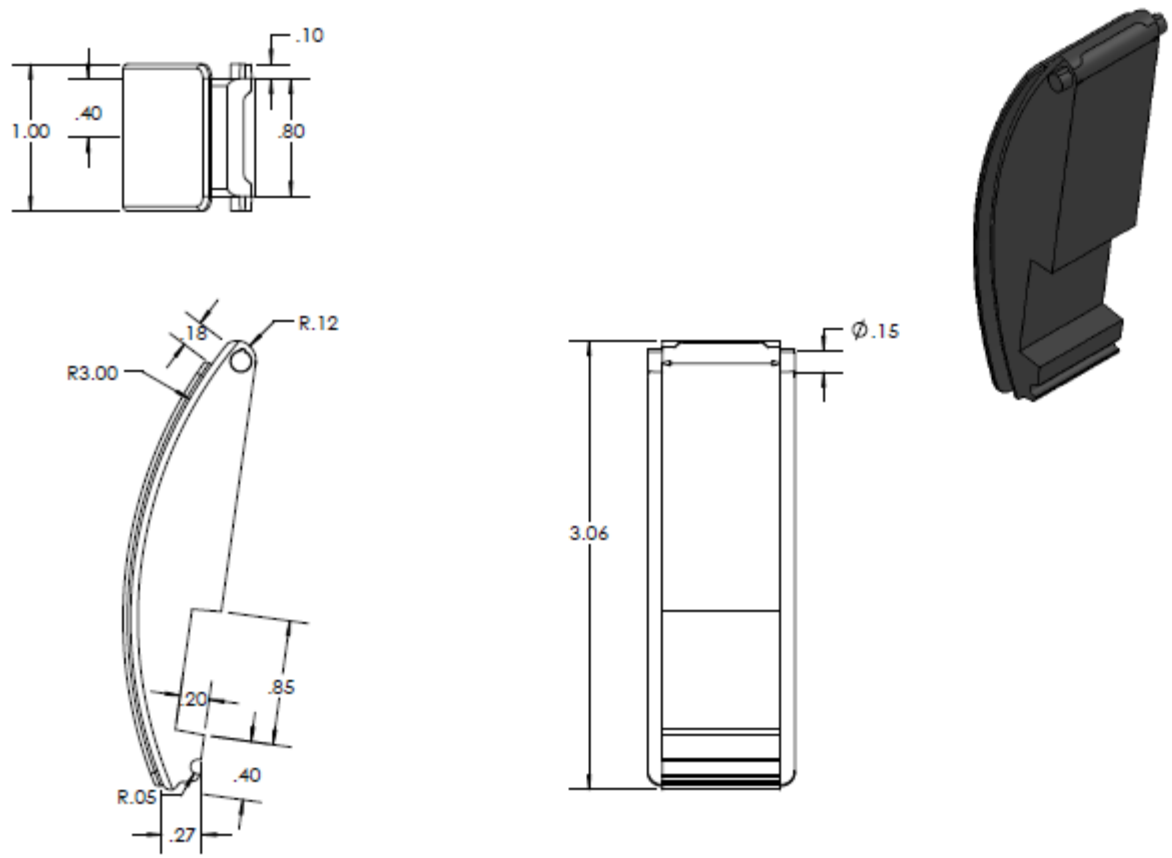
ME470 Spring 2013	SCALE: 1:1	PART: REFLECTOR
	UNITS: INCHES	DATE: JUNE 7, 2013
	TOLERANCE: ±0.005 INCHES	MATERIAL: POLYURETHANE
	DWG #: 2	DRAWN BY: D PATRICK

Appendix B: Final Drawings



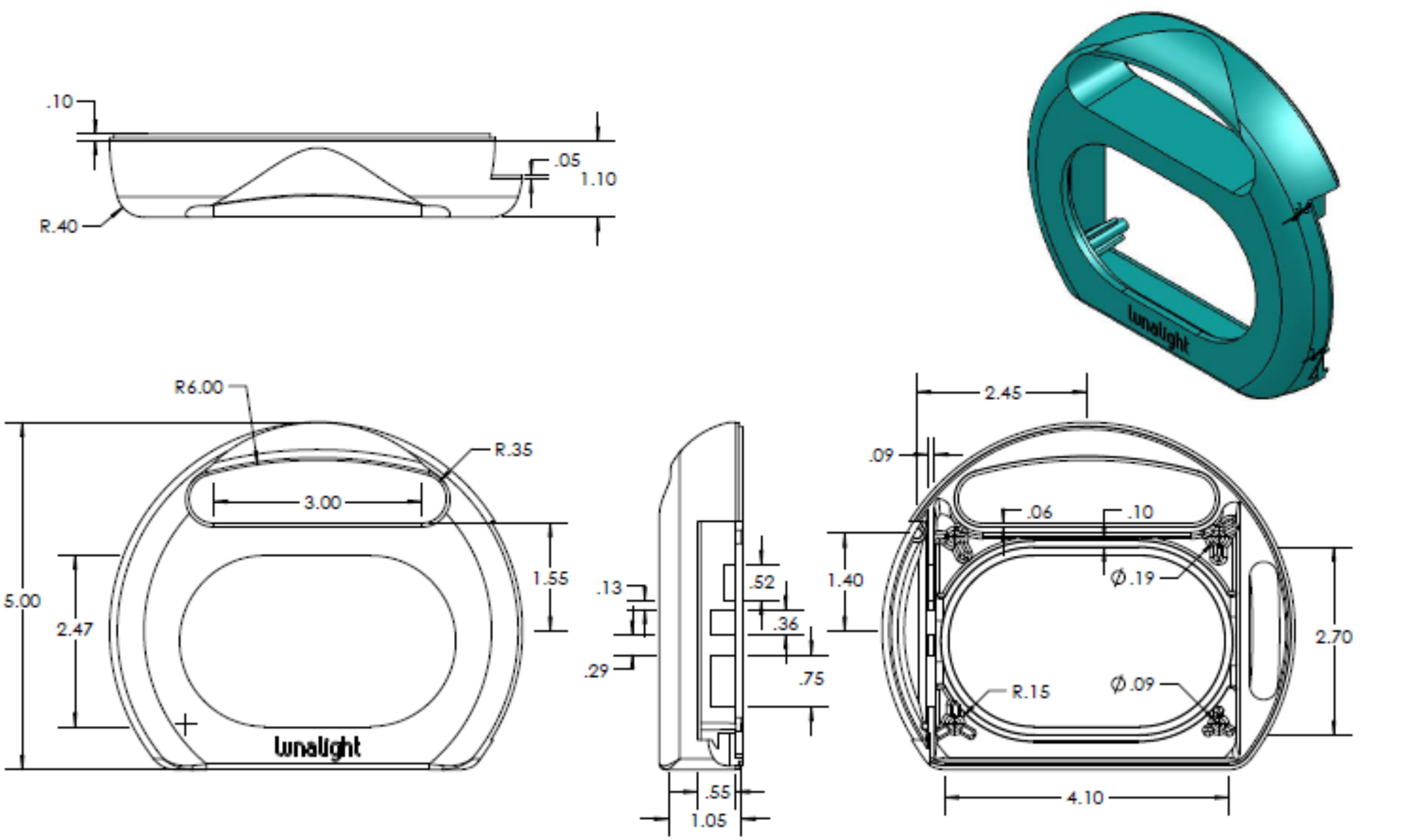
ME470 Spring 2013	SCALE: 1:1	PART: PCB ASSEMBLY
lunalight™	UNITS: INCHES	DATE: JUNE 7, 2013
	TOLERANCE: ±0.005 INCHES	MATERIAL: VARIES
	DWG #: 3	DRAWN BY: D PATRICK

Appendix B: Final Drawings



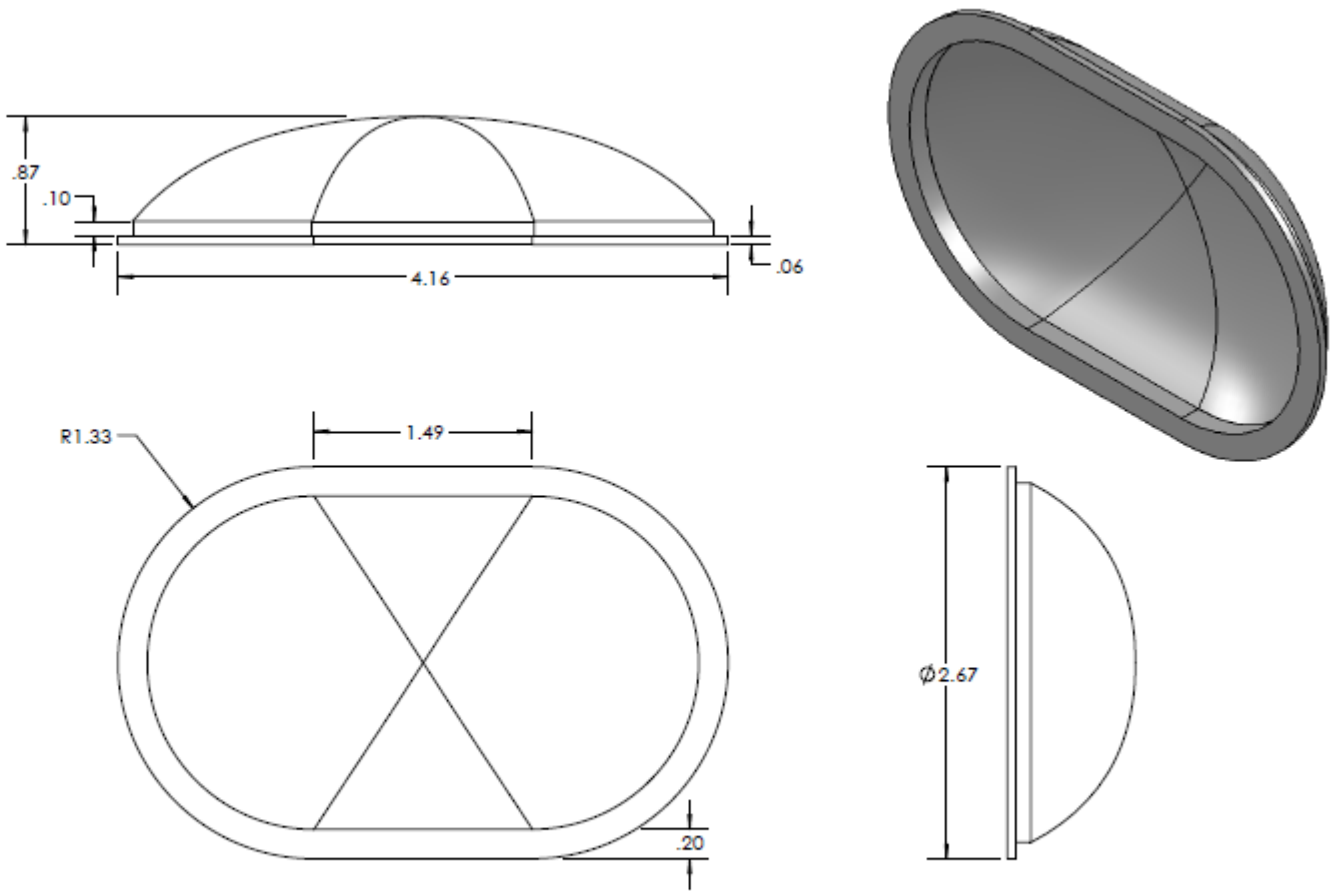
ME470 Spring 2013	SCALE: 1:1	PART: PORT COVER
lunalight™	UNITS: INCHES	DATE: JUNE 7, 2013
	TOLERANCE: ±0.005 INCHES	MATERIAL: SILICONE
	DWG #: 4	DRAWN BY: D PATRICK

Appendix B: Final Drawings



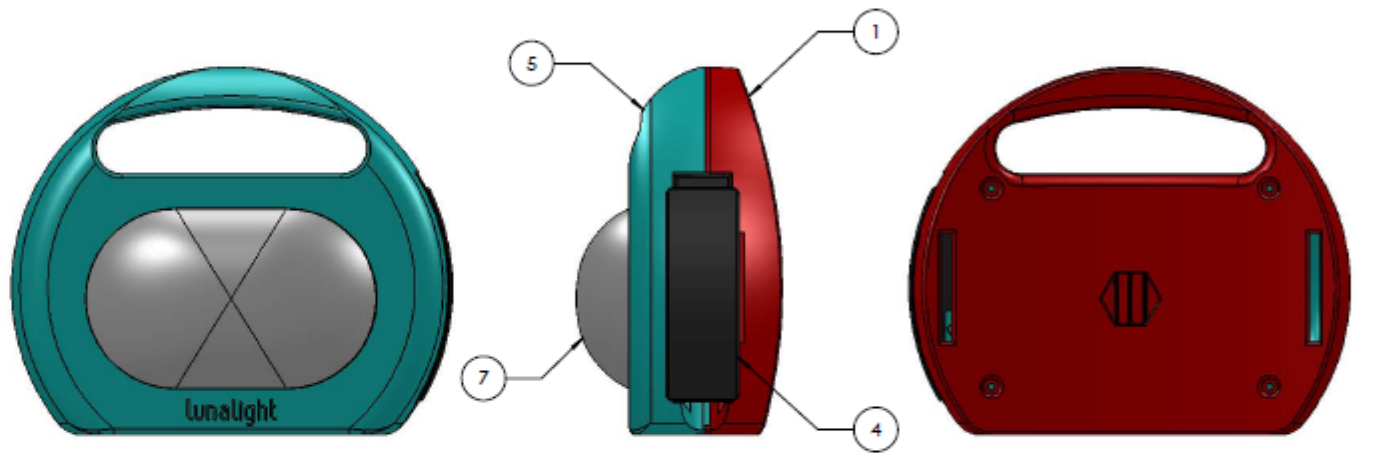
ME470 Spring 2013	SCALE: 1:2	PART: FRONT
lunalight™	UNITS: INCHES	DATE: JUNE 7, 2013
	TOLERANCE: ±0.005 INCHES	MATERIAL: POLYURETHANE
	DWG #: 5	DRAWN BY: D PATRICK

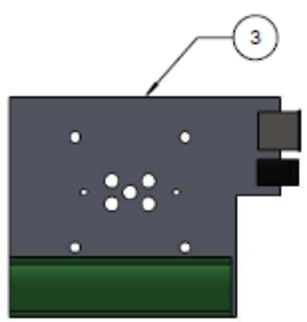
Appendix B: Final Drawings



ME470 Spring 2013	SCALE: 1:1	PART: DIFFUSER
lunalight™	UNITS: INCHES	DATE: JUNE 7, 2013
	TOLERANCE: ±0.005 INCHES	MATERIAL: POLYURETHANE
	DWG #: 7	DRAWN BY: D PATRICK

Appendix B: Final Drawings





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BACK	BACK OF HOUSING WITH HEAT SINK	1
2	REFLECTOR	REFLECTS LIGHT THROUGH DIFFUSER	1
3	PCB ASSEMBLY	ELECTRONIC COMPONENTS	1
4	PORT COVER	HINGED SIDE COVER	1
5	FRONT	FRONT OF HOUSING	1
6	ROCKER SWITCH	ON/OFF SWITCH	1
7	DIFFUSER	CLEAR LENS THAT SPREADS LIGHT	1

ME470 Spring 2013

lunalight™

SCALE: 1:2	PART: BILL OF MATERIALS
UNITS: INCHES	DATE: JUNE 7, 2013
TOLERANCE: ±0.005 INCHES	MATERIAL: VARIES
DWG #: 8	DRAWN BY: D PATRICK

Appendix C: Bill of Materials

Item No.	Description	Supplier's Description	Manufacturer's Model No.	Supplier	Supplier Website	Qty (per unit)	Cost (USD per unit)	Total Cost (USD)
1	1.5 W, 4.5 V Solar Panel	RadioShack® 1.5W Solar Panel 4.5V	P1545	RadioShack	www.radioshack.com	1	$17.09	$17.09
2	High Power Neutral White LED	High Power LEDs - White XLAMP XPE LED WT	XPEWHT-L1-R250-00BE6	Mouser Electronics Inc.	www.mouser.com	1	$2.44	$2.44
3	Starboard	Thermal Substrates - MCPCB ind Star CREE XP-E	951-804090	Mouser Electronics Inc.	www.mouser.com	1	$0.91	$0.91
4	Li-Ion Battery	Tenergy PCB Protected Li-Ion 18650 Cylindrical 3.7V 2200 mAh rechargeable batteries	30004	All-Battery.com	www.All-Battery.com	1	$5.63	$5.63
5	USB Cell Phone Adapter	10in1 USB CAR CHARGER ADAPTER 4 SAMSUNG HTC iPhone iPod	N/A	Doorbusters Direct	www.amazon.com	1	$2.89	$2.89
6	Strap	Side Release Buckle Straps w/ 1-1/2" Lightweight Polypropylene	SRBS112L	StrapWorks	www.strapworks.com	1	$2.90	$2.90
7	Solar Panel Plug	DC Power Connectors DC POWER 2.5mm	171-3216-EX	Mouser	www.mouser.com	1	$0.88	$0.88
8	Electrical Cord	Electrical Cord, 100 ft	Jameco 100280	Jameco	www.jameco.com	10 Ft	$2.39	$2.39
9	Housing Screws	#4 x 3/8 in. Zinc-Plated Steel Flat-Head Phillips Sheet Metal Screws (16-Pack)	26441	Home Depot	www.homedepot.com	6	$0.44	$2.66
10	Smooth-Cast 305	Smooth-Cast 305 - Gallon Unit	N/A	Reynolds Advanced Materials	www.reynoldsam.com	4 gallons total	$343.40	$5.28
11	Crystal Clear	Crystal Clear 202 - Gallon Unit	N/A	Reynolds Advanced Materials	www.reynoldsam.com	1 gallon total	$177.06	$2.72
12	Mold Star 30	Mold Star 30 - Gallon Unit	N/A	Reynolds Advanced Materials	www.reynoldsam.com	3 gallons total	$518.82	$7.98
13	Rocker Switch	Switch Rocker ON OFF ON Single Pole, Double Throw Quick Connect Rocker 16A 250VAC	R13-66D-02	Jameco Electronics	www.jameco.com	1	$0.89	$0.89
14	Barrel Jack	DC Power Connectors DC POWER JACK 2.5MM PIN TYPE 002	ADC-002-2	Mouser Electronics Inc.	www.mouser.com	1	$0.24	$0.24
15	USB Port	Connector USB Female 4 Position Solder Right Angle Thru-Hole 4 Terminal 1 Port Tube	USB-A-S-RA, 2096181	Jameco Electronics	www.jameco.com	1	$0.45	$0.45
16	Battery Holder	Battery Holders, Snaps & Contacts PCB PLSTIC BATT HLDR THM 1 CELL	1043	Mouser Electronics Inc.	www.mouser.com	1	$2.35	$2.35
17	PCB	Standard Spec Board	N/A	Advanced Circuits	www.4pcb.com	1	$13.95	$13.95
18	PCB Asssembly	5-Day Labor	N/A	One-Stop-Assembly through Advanced Circuits	www.4pcb.com	1	$23.78	$23.78

Appendix C: Bill of Materials

Item No.	Description	Supplier's Description	Manufacturer's Model No.	Supplier	Supplier Website	Qty (per unit)	Cost (USD per unit)	Total Cost (USD)
19	D3	Schottky Diodes & Rectifiers 0.5A 20V	MBR0520LT3G	Mouser Electronics Inc.	www.mouser.com	1		
20	D1	Schottky Diodes & Rectifiers 1.0A 40V	BAT1000-7-F	Mouser Electronics Inc.	www.mouser.com	1		
21	Q1	Transistors Bipolar - BJT PNP Medium Power	FZT549TA	Mouser Electronics Inc.	www.mouser.com	1		
22	U1	DC/DC Switching Regulators SIMPLE SWITCHER 20V out,1.4A SU Vltg Reg	LMR62014XMF/NOPB	Mouser Electronics Inc.	www.mouser.com	1		
23	U2	LED Lighting Drivers	LM3410YMF/NOPB	Mouser Electronics Inc.	www.mouser.com	1		
24	C6, C8	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 16V 4.7uF X7R Boardflex Automotive	CGA4J3X7R1C475K/SOFT	Mouser Electronics Inc.	www.mouser.com	2		
25	C3, C4	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 10uF 16volts X5R 10%	CGA4J1X5R1C106K	Mouser Electronics Inc.	www.mouser.com	2		
26	C2	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 250V 0.1uF X7T Boardflex Sensitive	C2012X7T2E104K/SOFT	Mouser Electronics Inc.	www.mouser.com	1		
27	C7	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 680pF 25volts X7R 5%	VJ0805Y681JXXCW1BC	Mouser Electronics Inc.	www.mouser.com	1		
28	C1, C5	Multilayer Ceramic Capacitors MLCC - SMD/SMT 2.2uF 16V X7R 10%	CC0805KKX7R7BB225	Mouser Electronics Inc.	www.mouser.com	2	$21.70	$21.70
29	RS	Current Sense Resistors - SMD 0.3ohm 1%	CRL0805-FW-R300ELF	Mouser Electronics Inc.	www.mouser.com	1		
30	R7	Thick Film Resistors - SMD 1K 1%	CR0805-FX-1001ELF	Mouser Electronics Inc.	www.mouser.com	1		
31	R6	Thick Film Resistors - SMD 1/8watt 3.09Kohms 1% 100ppm	CRCW08053K09FKEA	Mouser Electronics Inc.	www.mouser.com	1		
32	R5	Thick Film Resistors - SMD 1/8watt 1Mohms 1% 100ppm	CRCW08051M00FKEA	Mouser Electronics Inc.	www.mouser.com	1		
33	R4	Thick Film Resistors - SMD 0.25W 10ohm 1% 200ppm	SG73P2ATTD10R0F	Mouser Electronics Inc.	www.mouser.com	1		
34	R3	Current Sense Resistors - SMD 0.825ohms 1% 100 PPM	SR732ATTER825F	Mouser Electronics Inc.	www.mouser.com	1		
35	R2	Thick Film Resistors - SMD 1/8watt 100Kohms 1% 100ppm	CRCW0805100KFKEA	Mouser Electronics Inc.	www.mouser.com	1		
36	R0, R1	Thick Film Resistors - SMD 0805 1.0Mohms 0.25W 1% Tol	ERJ-P06F1004V	Mouser Electronics Inc.	www.mouser.com	2		
37	L1, L2	Fixed Inductors SHIELD 500mA 10uH	MLZ2012N100L	Mouser Electronics Inc.	www.mouser.com	2		
38	U3	IC CHARGER LI-ION 4.2V 8MSOP	ADP2291ARMZ-R7	Digi-Key Corporation	www.digikeycom	1		
							Total	**$138.83**

Smooth-Cast 305

Smooth-Cast® 300 Series

Bright White, Ultra Low Viscosity Liquid Plastics

SMOOTH-ON
www.smooth-on.com

PRODUCT OVERVIEW

The Smooth-Cast® 300 Series of liquid plastics are ultra-low viscosity casting resins that yield castings that are bright white and virtually bubble free. Vacuum degassing is not necessary. They offer the convenience of a 1A:1B by volume or 100A:90B by weight mix ratio. The differences between them are pot life and demold time.

These resins readily accept fillers (such as URE-FIL® 3 from Smooth-On) and can be colored with SO-Strong® or Ignite® color tints (Smooth-Cast® 325 series accepts pigments better than the Smooth Cast® 300 series). Fully cured castings are tough, durable, machinable and paintable. They resist moisture and mild solvents. Applications for Smooth-Cast® 300 Series Liquid Plastics include reproducing small to medium size sculptures, making prototype models, special effect props and decorative jewelry.

Those interested in making roto cast pieces should refer to the Smooth-Cast® 65D technical bulletin.

TECHNICAL OVERVIEW

	Pot Life @ 73°F / 23°C (ASTM D-2471)	Cure Time ** @ 73°F / 23°C	Tensile Strength (ASTM D-638)	Tensile Modulus (ASTM D-638)	Elongation at Break % (ASTM D-638)	Flexural Strength (ASTM D-790)	Flexural Modulus (ASTM D-790)	Compressive Strength (ASTM D-695)	Compressive Modulus (ASTM D-695)	Shrinkage in./in. (ASTM D-2566)
Smooth-Cast® 300Q	30 Sec.	4 - 5 Min.	3,000 psi	139,500 psi	5%	4,510 psi	128,000 psi	4,000 psi	45,800 psi	0.01
Smooth-Cast® 300	3 Min.	10 Min.	3,000 psi	139,500 psi	5%	4,510 psi	128,000 psi	4,000 psi	45,800 psi	0.01
Smooth-Cast® 305	7 Min.	30 Min.	3,000 psi	134,000 psi	7.50%	4,000 psi	118,000 psi	3,800 psi	44,900 psi	0.0065
Smooth-Cast® 310	15-20 Min.	3 - 4 Hours	3,000 psi	134,000 psi	7.50%	4,000 psi	118,000 psi	3,800 psi	44,900 psi	0.0065

Mix Ratio; 1A:1B by volume or 100A:90B by weight	Color; White
Mixed Viscosity, cps; 80 (ASTM D-2393)	Shore D Hardness; 70 (ASTM D-2240)
Specific Gravity, g/cc; 1.05 (ASTM D-1475)	Heat Deflection Temp; 120°F/50°C (ASTM D-648)
Specific Volume, cu. in./lb.; 26.4 (ASTM D-1475)	

*All values measured after 7 days at 73°F/23°C
** Depending on Mass

PROCESSING RECOMMENDATIONS

PREPARATION... ***Safety*** Materials should be stored and used in a warm environment (73° F / 23° C). These products have a limited shelf life and should be used as soon as possible. All liquid urethanes are moisture sensitive and will absorb atmospheric moisture. Mixing tools and containers should be clean and made of metal, glass or plastic. Mixing should be done in a well-ventilated area. Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk. Because no two applications are quite the same, a small test application to determine suitability for your project is recommended if performance of this material is in question.

Applying A Release Agent - A release agent is necessary to facilitate demolding when casting into or over most surfaces. Use a release agent made specifically for mold making (Universal® Mold Release or Mann's Ease Release® 200 available from Smooth-On or your Smooth-On distributor). A liberal coat of release agent should be applied onto all surfaces that will contact the plastic.

~IMPORTANT: To ensure thorough coverage, apply release and brush with a soft brush over all surfaces. Follow with a light mist coating and let the release agent dry for 30 minutes. Smooth-On silicone rubber molds usually do not require a release agent unless casting silicone into the mold. Applying a release agent will prolong the life of the mold.

Smooth-Cast 305

IMPORTANT: Shelf life of product is reduced after opening. Remaining product should be used as soon as possible. Immediately replacing the lids on both containers after dispensing product will help prolong the shelf life of the unused product. XTEND-IT® Dry Gas Blanket (available from Smooth-On) will significantly prolong the shelf life of unused liquid urethane products.

Safety First!

The material safety data sheet (MSDS) for this or any Smooth-On product should be read before using and is available on request. All Smooth-On products are safe to use if directions are read and followed carefully. ***Keep Out of Reach Of Children.***

Smooth-Cast® 300 PART A
WARNING: IRRITANT TO EYES, SKIN & MUCOUS MEMBRANES. Contains Methylene Diphenyl Isocyanate. Do not get in eyes, mucous membranes or on skin. Do not take internally. Do not breathe fumes. Use only with adequate ventilation. Wear chemical-resistant gloves and eye protection when using this product.
First Aid: In case of eye contact, flush thoroughly with water for 15 minutes and get immediate medical attention. In case of skin contact, wash thoroughly with soap and water. If irritation persists, get medical attention. If swallowed, do not induce vomiting. Drink 1-2 glasses of water and get immediate medical attention. If vapors are inhaled or if breathing becomes difficult, remove person to fresh air. If symptoms persist, get medical attention. **Keep Out Of Reach Of Children.**

Smooth-Cast® 300 PART B:
CAUTION: In case of eye contact, flush with water for 15 minutes. If irritation persists, get medical attention. For skin contact, wash with soap and water. **Keep Out Of Reach Of Children.**

CAUTION: HOT! When combined, parts A & B generate heat in excess of 212°F (100°C) which could cause burns to the skin. Let cured plastic cool before handling. **Keep Out Of Reach Of Children.**

IMPORTANT - The information contained in this bulletin is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained from the use thereof, or that any such use will not infringe upon a patent. User shall determine the suitability of the product for the intended application and assume all risk and liability whatsoever in connection therewith.

MEASURING & MIXING...

Liquid urethanes are moisture sensitive and will absorb atmospheric moisture. Mixing tools and containers should be clean and made of metal, glass or plastic. Materials should be stored and used in a warm environment (73°F/23°C).

Stir or shake both Part A & Part B thoroughly before dispensing. After dispensing equal amounts of Parts A and B into mixing container (100A:90B by weight) and mix thoroughly. Stir deliberately making sure that you scrape the sides and bottom of the mixing container several times. Be careful not to splash low viscosity material out of the container.

POURING, CURING & PERFORMANCE...

Pouring - Pour your mixture in a single spot at the lowest point of the containment field and let the mixture seek its level. This will help minimize air entrapment.

For Best Results . . . Best results are obtained using a pressure casting technique. After pouring the mixed compound, the entire casting assembly (mold, dam structure, etc.) is placed in a pressure chamber and subjected to 60 PSI (4.2 kg/cm^2) air pressure for the full cure time of the material.

Curing - Warning: Fumes, which may be visible as this product starts to "gel" and cure, will dissipate with adequate ventilation. Only use this product with room size ventilation and do not inhale/breathe fumes. Castings will be extremely hot immediately following cure and may burn the skin. Let cool to room temperature before handling. Smooth-Cast® 300 will cure in 7 - 10 minutes (Smooth-Cast® 305 in 30 – 40 minutes and Smooth-Cast® 310 in 2 - 4 hours) depending on mass and mold configuration.

Post Cure - Castings will reach "full cure" faster and achieve maximum physical properties if post cured. Allow material to cure for recommended Cure Time at room temperature followed by 4 - 6 hours at 150°F/65°C. Allow casting to come to room temperature before handling.

Performance - Cured castings are rigid and durable. They resist moisture, moderate heat, solvents, dilute acids and can be machined, primed/painted or bonded to other surfaces (any release agent must be removed). If machining cured material, wear dust mask or other apparatus to prevent inhalation of residual particles. Castings can be displayed outdoors after priming and painting. Unpainted castings will yellow over time - more quickly when exposed to ultra-violet light.

Because no two applications are quite the same, a small test application to determine suitability is recommended if performance of this material is in question.

Call Us Anytime With Questions About Your Application.
Toll-free: **(800) 762-0744** Fax: **(610) 252-6200**

The new www.smooth-on.com is loaded with information about mold making, casting and more.

092412 - JR

Appendix D: Material Data Sheets

Crystal Clear 202

Crystal Clear® Series

Clear Urethane Casting Resins

SMOOTH-ON
www.smooth-on.com

PRODUCT OVERVIEW

Crystal Clear® 200, 202, 204 and 206 are water white clear and made specifically for applications that require clarity. These rigid urethane casting resins differ only in working and demold times. Low viscosity ensures easy mixing and pouring. **Crystal Clear®** resins cure at room temperature* with negligible shrinkage. Cured castings are UV Resistant and are not brittle. Vibrant colors and color effects are achieved by adding pigment dispersions. Applications include encapsulation, making prototype models, lenses, sculpture reproductions, decorative cast pieces, jewelry, prototype models, special effects and props. **Crystal Clear® 220 and 221** are harder, heat cured products that offer advantages over these room temp. cure products. A separate tech bulletin is available for CC220 and CC221 at www.smooth-on.com.

CAUTION: NOT FOR HOME USE. THIS PRODUCT IS FOR INDUSTRIAL USE ONLY. Proper ventilation, A NIOSH Approved Respirator and Protective Clothing (gloves and long sleeves) are required to minimize the risk of inhalation and dermal sensitization. If breathing is affected or a dermal rash develops, immediately cease using this product and seek medical attention. Read MSDS before using.

TECHNICAL OVERVIEW

	Pot Life @ 73° F / 23°C (ASTM D-2471)	Cure Time ** @ 73° F / 23°C	Tensile Strength (ASTM D-638)	Tensile Modulus (ASTM D-638)	Elongation at Break % (ASTM D-638)	Flexural Strength (ASTM D-790)	Flexural Modulus (ASTM D-790)	Compressive Strength (ASTM D-695)	Compressive Modulus (ASTM D-695)	Shrinkage in./in. (ASTM D-2566)
Crystal Clear® 200	20 Min.	16 Hours	2,500 psi	73,200 psi	10%	10,650 psi*	200,000 psi	6,385 psi*	40,000 psi	0.001
Crystal Clear® 202	9 Min.	90 Min.	3,500 psi	86,240 psi	10%	5,390 psi	183,200 psi	4,200 psi	44,000 psi	0.0125
Crystal Clear® 204	2 Hours	48 Hours	3,500 psi	86,240 psi	10%	5,390 psi	183,200 psi	4,200 psi	44,000 psi	0.002
Crystal Clear® 206	7 Hours	5 Days	2,500 psi	73,200 psi	10%	10,650 psi*	200,000 psi	6,385 psi*	40,000 psi	0.002

Mix Ratio; 100A:90B by weight

Mixed Viscosity, cps; 600 (ASTM D-2393)

Specific Gravity, g/cc; 1.036 (ASTM D-1475)

Specific Volume, cu. in./lb.; 26.7 (ASTM D-1475)

Color; Clear

Shore D Hardness; 80 (ASTM D-2240)

Heat Deflection Temp; 120°F/50°C (ASTM D-648)

REFRACTIVE INDEXES

Crystal Clear 200: 1.49962 at 20°C; 1.49894 at 25°C

Crystal Clear 202: 1.49888 at 20°C; 1.49893 at 25°C

Crystal Clear 204: 1.49888 at 20°C; 1.49830 at 25°C

Crystal Clear 206: 1.49962 at 20°C; 1.49894 at 25°C

ELECTRICAL PROPERTIES

Dielectric Strength; 260 Volts/MIL (ASTM D-149)

Dielectric Constant; 3.36 @77°/25°C at 100 Hz (ASTM D-150)

Dielectric Constant; 3.34 @77°/25°C at 1 kHz (ASTM D-150)

Dissipation Factor; 0.00 @77°/25°C at 100 Hz (ASTM D-150)

Dissipation Factor; 0.01 @77°/25°C at 1 kHz (ASTM D-150)

Vol. Resistivity; 1.4 x 1015 @77°/25°C ohm-cm (ASTM D-257)

*Values measured after material has been post cured as directed by product technical bulletin ** Depending on Mass

PROCESSING RECOMMENDATIONS

PREPARATION... ***Safety*** Store and use at room temperature (73°F/23°C). These products have a limited shelf life and should be used as soon as possible. Environmental humidity should be as low as possible. Good room size ventilation is essential. Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk. Wearing a NIOSH approved respirator will minimize inhalation of residual fumes.

Selecting A Mold Rubber - Pour into a urethane rubber mold (Vytaflex urethane – release agent required), tin cured silicone mold (Mold Max® silicone) or Mold Star® platinum cured silicone. Do not use other rubber mold products.

If using Mold Max silicone; to prevent cure inhibition, post-cure newly silicone mold for 8 hours at 60° C / 150° F and let cool prior to casting resin. If you are unsure about surface compatibility, a small scale trial casting should be made.

For Best Results Before Pouring Crystal Clear® Into Mold: Pre-heat rubber mold at 212°F / 100°C for 4 hours. This will minimize chances of fish-eyeing, suck back, corner rounding, large bubbles, etc. in finished casting.

Appendix D: Material Data Sheets

Crystal Clear 202

IMPORTANT: Shelf life of product is reduced after opening. Remaining product should be used as soon as possible. Immediately replacing the lids on both containers after dispensing product will help prolong the shelf life of the unused product. XTEND-IT® Dry Gas Blanket (available from Smooth-On) will significantly prolong the shelf life of unused liquid urethane products.

Safety First!

The Material Safety Data Sheet (MSDS) for this or any Smooth-On product should be read prior to use and is available upon request from Smooth-On. All Smooth-On products are safe to use if directions are read and followed carefully.

Be careful.

Part A is a modified aliphatic diisocyanate. Vapors, which can be significant if heated or sprayed, cause lung damage and sensitization. Use only with adequate ventilation. Contact with skin and eyes may cause severe irritation. Flush eyes with water for 15 minutes and seek immediate medical attention. Remove from skin with waterless hand cleaner followed by soap and water Refer to MSDS.

Part B is irritating to the eyes and skin. Avoid prolonged or repeated skin contact. Remove from skin with soap and water. If contaminated, flush eyes with water for 15 minutes and seek immediate medical attention. Use only with adequate ventilation.

Important: The information contained in this bulletin is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained from the use thereof, or that any such use will not infringe upon a patent. User shall determine the suitability of the product for the intended application and assume all risk and liability whatsoever in connection therewith.

MEASURING & MIXING...

Liquid urethanes are moisture sensitive and will absorb atmospheric moisture. Mixing tools and containers should be clean and made of metal or plastic. Materials should be stored and used in a warm environment (73°F/23°C).

Measuring - Materials should be stored and used at room temperature (73°F / 23°C). The proper mixing ratio is 100A: 90B by weight. You must use an accurate scale (gram scale or triple beam balance scale) to weigh these components properly Dispense the required amount of Part A into a mixing container. Weigh out the appropriate amount of Part B and combine with Part A.

Mixing - Mix SLOWLY, but thoroughly, for at least 90 seconds making sure that you scrape the sides and bottom of your container several times. If coloring or filling Crystal Clear® product, add filler or pigment dispersion to Part B and mix thoroughly before adding Part A.

Bubbles in the finished casting will be greatly reduced by vacuum degassing prior to pouring. Subject mixture to 29 h.i.g. mercury in a suitable vacuum chamber for until mixture rises, breaks and falls. Allow for 3 to 4 times volume expansion in mixing container.

POURING, CURING & PERFORMANCE...

Pouring - If casting Crystal Clear® into a rubber mold, pour mixture in a single spot at the lowest point of the mold. If encapsulating an object, do not pour the mixture directly over the object. Let the mixture seek its level. A uniform flow will help minimize entrapped air.

For Best Results: Bubble elimination is best achieved by pressure casting. After pouring the mixed compound, the entire casting assembly (mold, dam structure, etc.) is placed in a pressure chamber and subjected to 60 PSI (4.2 kg/cm2) air pressure for at least two hours prior to heat curing.

Post Curing - Castings will achieve maximum physical properties, better heat and UV resistance if Crystal Clear® is post cured. Post curing is recommended if castings are thin or of low mass concentration. Castings should be post cured in a mold or support structure. Post Cure Schedule: Allow the material to cure for 6–8 hours at room temperature followed by 6 hours at 150°F–160°F (65°C–72°C). Allow casting or part to cool to room temperature before demolding.

Materials should be stored and used in a warm environment (73°F / 23°C). Castings will reach ultimate physical properties at room temperature in 5–7 days. Castings removed from mold before recommended cure may exhibit a tacky surface that can be eliminated by exposing casting to 150°F / 65°C for 6 hours.

Casting Thickness & Cure Time - The cure time and ultimate shrinkage of all Crystal Clear® products will vary depending on mass concentration, thickness of the casting, mold configuration, etc. For example, a 200 gram mass of CC 200 will cure faster if left to cure in a conical vessel (cup) versus a casting dispersed as a thin sheet measuring 3 centimeters square by 1 mm thick. This is due to the heat generated by the concentration of material in the cup versus heat that is dissipated from the sheet casting. Castings will resist yellowing when exposed to UV, but may darken over time.

- **Crystal Clear® 200** is intended for a casting thickness ranging from ½" to 3" at a casting weight maximum of 16 lbs. (7.25 kgs.) Castings greater than 3" should be layer cast.
- **Crystal Clear® 202** is intended for casting in thin sections. Developed for casting thicknesses of no more than ½".
- **Crystal Clear® 204** can be cast in thicknesses up to 6" at a casting weight maximum of 35 lbs. (15.88 kgs.).
- **Crystal Clear® 206** is for castings greater than 6".

Because no two applications are quite the same, a small test application to determine suitability for your project is recommended if performance of this material is in question.

Call Us Anytime With Questions About Your Application

Toll-free: **(800) 381-1733** Fax: **(610) 252-6200**

The new www.smooth-on.com is loaded with information about mold making, casting and more. 051513-JR

Mold Star 30

Mold Star® 15, 16 and 30

1A:1B Mix By Volume Platinum Silicone Rubbers

SMOOTH-ON

www.smooth-on.com

PRODUCT OVERVIEW

Mold Star® rubbers are easy to use platinum silicones which are mixed 1A:1B by volume (no weighing scale necessary). Mold Star® silicones feature relatively low viscosities and vacuum degassing is not required for most applications. The pot life of Mold Star® 15 SLOW is 50 minutes and cure time is 4 hours at room temperature. Mold Star® 16 FAST is a faster material with a 6 minute pot life and 30 minute cure time. Mold Star® 30 is a harder material, with a 30A Shore hardness

Mold Star® silicones cure to soft, strong rubbers which are tear resistant and exhibit very low long term shrinkage. Molds made with Mold Star® will last a long time in your mold library and are good for casting wax, gypsum, resins, concrete and other materials. Cured Mold Star® rubber is heat resistant up to 450°F (232°C) and is suitable for casting low-temperature melt metal alloys. ***Note: Mold Star® rubbers are not intended for brush-on moldmaking.***

Note: This product *will not* cure against surfaces containing sulfur, even when sealed.

TECHNICAL OVERVIEW

	Mixed Viscosity (ASTM D-2393)	Specific Gravity (g/cc) (ASTM D-1475)	Specific Volume (cu in./lb) (ASTM D-1475)	Pot Life (ASTM D-2471)	Cure Time	Shore A Hardness (ASTM D-2240)	Tensile Strength (ASTM D-412)	100% Modulus (ASTM D-412)	Elongation at Break % (ASTM D-412)	Die B Tear Strength (ASTM D-624)	Color
Mold Star® 15 SLOW	12,500 cps	1.18	23.5	50 min.	4 hours	15A	400 psi	55 psi	440%	88 pli	Green
Mold Star® 16 FAST	12,500 cps	1.18	23.5	6 min.	30 min.	16A	400 psi	55 psi	440%	88 pli	Blue-Green
Mold Star® 30	12,500 cps	1.12	24.7	45 min.	6 hours	30A	420 psi	96 psi	339%	88 pli	Blue

Mix Ratio: 1A:1B by volume

Shrinkage *(in./in.) (ASTM D-2566)*: < .001 in./in.

Useful Temperature Range: -65°F to 450°F (-53°C to 232°C)

*All values measured after 7 days at 73°F/23°C

PROCESSING RECOMMENDATIONS

PREPARATION... Safety - Use in a properly ventilated area ("room size" ventilation). Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk. Wear vinyl gloves only. Latex gloves will inhibit the cure of the rubber. Store and use material at room temperature (73°F/23°C). Warmer temperatures will drastically reduce working time and cure time. Storing material at warmer temperatures will also reduce the usable shelf life of unused material. These products have a limited shelf life and should be used as soon as possible.

Cure Inhibition - Addition cured silicone rubber may be inhibited by certain contaminants in or on the pattern to be molded resulting in tackiness at the pattern interface or a total lack of cure throughout the mold. Latex, sulfur clays, certain wood surfaces, newly cast polyester, epoxy or urethane rubber my cause inhibition. If compatibility between the rubber and the surface is a concern, a small-scale test is recommended. Apply a small amount of rubber onto a non-critical area of the pattern. Inhibition has occurred if the rubber is gummy or uncured after the recommended cure time has passed. To prevent inhibition, one or more coatings of a clear acrylic lacquer applied to the model surface is usually effective. Allow any sealer to thoroughly dry before applying rubber.

Even with a sealer, Mold Star® silicones *will not* cure against surfaces containing sulfur. If you are not sure if your clay contains sulfur, do a small compatibility test before using for an important project.

Applying A Release Agent - Although not usually necessary, a release agent will make demolding easier when casting into most surfaces. Ease Release® 200 is a proven release agent for releasing silicone from silicone or other surfaces. Mann Ease Release® products are available from Smooth-On or your Smooth-On distributor. Because no two applications are quite the same, a small test application to determine suitability for your project is recommended if performance of this material is in question.

Appendix D: Material Data Sheets

Mold Star 30

Safety First!

The Material Safety Data Sheet (MSDS) for this or any Smooth-On product should be read prior to use and is available upon request from Smooth-On. All Smooth-On products are safe to use if directions are read and followed carefully.

Keep Out of Reach of Children

BE CAREFUL - Avoid contact with eyes. Silicone polymers are generally non-irritating to the eyes however a slight transient irritation is possible. Flush eyes with water for 15 minutes and seek medical attention. Remove from skin with waterless hand cleaner followed by soap and water. Children should not use this product without adult supervision.

IMPORTANT - The information contained in this bulletin is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained from the use thereof, or that any such use will not infringe upon a patent. User shall determine the suitability of the product for the intended application and assume all risk and liability whatsoever in connection therewith.

MEASURING & MIXING...

Measuring & Mixing - Before you begin, pre-mix Part A and Part B separately. After dispensing required amounts of Parts A and B into mixing container (1A:1B by volume), mix thoroughly making sure that you scrape the sides and bottom of the mixing container several times. The rubber should be a uniform green color with no streaks.

Optional... Vacuum Degassing - Although not necessary, vacuum degassing helps eliminate any entrapped air in pourable silicone rubber. After mixing parts A and B, vacuum material for 2-3 minutes at 29 inches of mercury, making sure that you leave enough room in container for product expansion.

POURING, CURING & PERFORMANCE...

Pouring - For best results, pour your mixture in a single spot at the lowest point of the containment field. Let the rubber seek its own level. A uniform flow will help minimize entrapped air. If using as a mold material, the liquid rubber should level off at least 1/2" (1.3 cm) over the highest point of the model surface.

Curing - Allow **Mold Star® 15 SLOW** silicone rubber to cure for **4 hours** at room temperature (73°F/23°C) before demolding. **Mold Star® 16 FAST** silicone rubber can be demolded after **30 minutes** at room temperature (73°F/23°C). **Mold Star® 30** must be allowed to cure for **6 hours** at room temperature (73°F/23°C) before demolding.

Heat Curing - Time to demold can be reduced by applying mild heat. **Example:** After pouring **Mold Star® 16** rubber at room temperature, place the mold in a hot box or industrial oven at 140°F (60°C). This will reduce the time to demold of a 1/2" (1.3 cm) thick section to about 10 minutes. **Note:** Time will vary depending on mold thickness.

Adding an appropriate amount of **Plat-Cat®** cure accelerator will also reduce demold time (See **Plat-Cat®** technical bulletin available at www.smooth-on.com for details). The pot life and cure times can be extended using **Slo-Jo®** cure retarder (see **Slo-Jo®** technical bulletin available at www.smooth-on.com for details). Do not cure rubber where temperature is less than 65°F/18°C.

Mold Performance & Storage - The physical life of the mold depends on how you use it (materials cast, frequency, etc.). Casting abrasive materials such as concrete can quickly erode mold detail, while casting non-abrasive materials (wax) will not affect mold detail. Before storing, the mold should be cleaned with a soap solution and wiped fully dry. Two part (or more) molds should be assembled. Molds should be stored on a level surface in a cool, dry environment.

SMOOTH-ON

Call Us Anytime With Questions About Your Application.

Toll-free: **(800) 762-0744** Fax: **(610) 252-6200**

The new **www.smooth-on.com** is loaded with information about mold making, casting and more.

062612 - JR

Appendix E: Test Results

Drop Test (Spec. 2)

Upright Drop

Unit tested: A

Observations:

- No cracks to housing
- Screws came undone
- Battery holder dislodged and broken, must be replaced
- Two PCB alignment posts broke off
- Epoxy holding starboard to housing came off of housing
- Once battery holder replaced, unit still functions

Lense Down Drop

Unit tested: B

Observations:

- No cracks to housing
- Screws in tact
- Unit does not light up
- Soldered contacts between starboard and PCB broke
- Battery came out of holder
- Once battery replaced and starboard re-soldered, unit still functions

Back Down Drop

Unit tested: C

Observations:

- No cracks to housing
- Screws in tact
- Does not light up
- No repairs were made, and unit was not opened or adjusted, but unit began to function again

Handle Down Drop

Unit tested: D

Observations:

- Diffuser scratched
- No further damage
- Test repeated with no further damage

Appendix E: Test Results

Battery Charge Time (Spec. 4)

	0 hr	6 hr	8 hr (Previous 2 hr after dusk)	10 hr (Left plugged in over night, final 2 hr in sunlight)
PCB #	Battery Voltage	Battery Voltage	Battery Voltage	Battery Voltage
1	0 V	3.72	3.72	3.74
2	0 V	3.74	3.74	3.75
5	0 V	4.03	4.03	4.04
7	0 V	0	0	0
13	0 V	4.04	4.04	4.05
15	0V	3.67	3.54	0
16	0 V	3.87	3.87	3.84
17	0 V	4.03	4.04	4.05
19	0 V	3.68	3.56	0
23	0 V	3.72	3.73	3.75

LED Heating (Spec. 10)

	T (^{0}C)																			
PCB #	0 min	0.5 min	1.5 min	2 min	3.25 min	4.75 min	5.5 min	6.5 min	8 min	9 min	10 min	11 min	12 min	13 min	14 min	15 min	16.5 min	20.5 min	23 min	24 min
4	21.1	32.2	34.4	45.1	52	44.4	54.7	55.4	57.5	59.9	59.9	62.5	54	61	63	64.4	61.6	49.9	53.3	64.4
24	21.1	24	28.2	32	32	33.5	34	35.4	34.2	36.2	36	36	35.3	36	36.6	35.6	37.3	34.4	33.8	37.1

Weight (Spec. 12)

Unit	Weight (lb)
A	0.87
B	0.89
C	0.9
D	0.88

Appendix E: Test Results

Brightness (Spec. 21)

Illuminance at 60 cm:

PCB 18: 116 lux

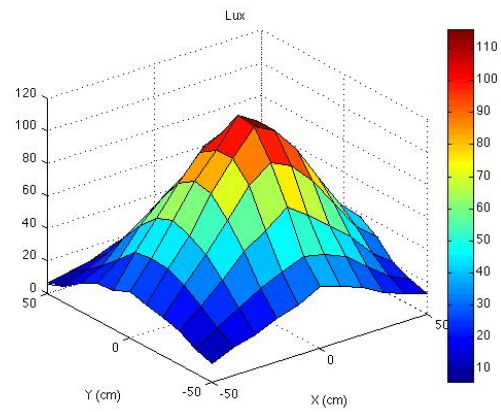
PCB 24: 162 lux

PCB 25: 114 lux

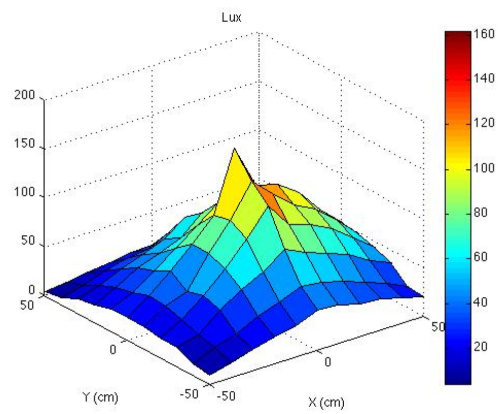
Average: 131 lux

Surface Charts of Illuminance:

PCB 18:

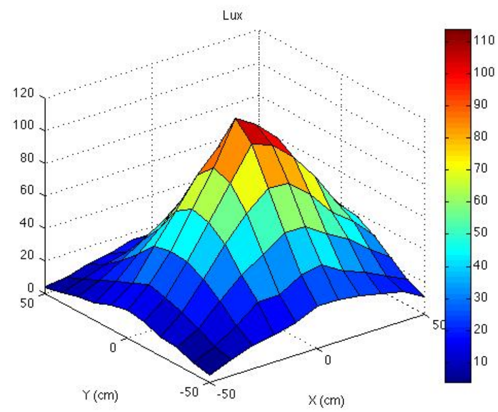


PCB 24:

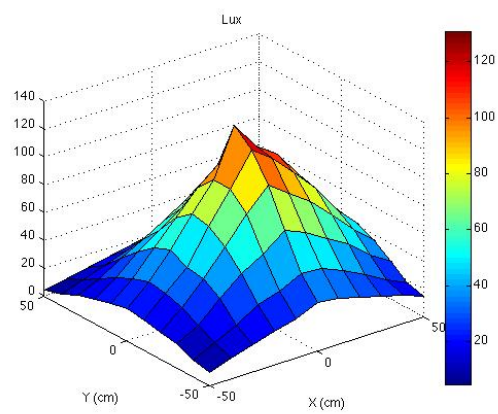


Brightness (Spec. 21)

PCB 25:



Average:



Appendix E: Test Results

USB Charging (Spec. 27)

PCB #	**Voltage Accross USB (V)**	**Max Current (mA)**
8	6.33	
9	6	
10	6.25	
11	5.03	
12	6.08	
20	6.18	
21	6.19	
22	6.28	
25	6.19	
EE testing PCB A	N/A	300
EE testing PCB B	N/A	300

Hours of Light (Spec. 28)

PCB #	Initial Illuminance (lux)	Hours Lasted
1	163	4
2	166	4
3	166	4
5	185	4
6	222	4
9	0	0
11	181	4
12	122	8
13	185	4
14	219	4

Survey #	I am participating in the LunaLight survey on a voluntary basis.	Please rate the LunaLight in the following categories. [Brightenss]	Please rate the LunaLight in the following categories. [Durability]	Please rate the LunaLight in the following categories. [Ease of Use]	Please rate the LunaLight in the following categories. [Comfort]	In which situation did you use the LunaLight?
1	I agree.	4	4	5	4	Outdoors: Hands-free around your waist, Outdoors: Hands-free around your hips, Outdoors: Hold by the handle
2	I agree.	4	5	5	4	Outdoors: Hands-free across your shoulder
3	I agree.	3	3	3	3	Outdoors: Hands-free around your waist, Outdoors: Hands-free around your hips
Average		3.7	4.0	4.3	3.7	

Survey #	If you used the LunaLight hands-free, on a scale from 1-5 how COMFORTABLE did you find the LunaLight?	If you used the LunaLight by holding it by the handle, on a scale from 1-5 how COMFORTABLE did you find the LunaLight?	On a scale from 1-5 how EFFECTIVE WAS THE BRIGHTNESS of your LunaLight?	On a scale from 1-5 how EFFECTIVE WAS THE BRIGHTNESS of your LunaLight in completing a task?	Please add any additional feedback below.
1	4	5	4	4	
2	4		5	4	Good at lighting things up that are relatively close to you. But doesn't light things up that are far away so well. I liked the color options, mine was mint. Better than a headlamp for hiking because it had a larger scope of light.
3	5		5	5	
Average	4.3	5.0	4.7	4.3	

Appendix F: Production Planning

	Total	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Fall quarter	400											
Kim*	70	7	7	7	7	7	7	7	7	7	7	
Danny*	70	7	7	7	7	7	7	7	7	7	7	
Gabby*	70	7	7	7	7	7	7	7	7	7	7	
Dawei*	70	7	7	7	7	7	7	7	7	7	7	
Jessica	60	6	6	6	6	6	6	6	6	6	6	
Jenny	60	6	6	6	6	6	6	6	6	6	6	
Winter	427											
Kim	76.75	7	6	9.5	6	6	4.5	5	7	7	15.75	3
Danny	80	8	8	8	8	8	8	8	8	8	8	
Gabby	84.25	6	8	12	11	6	3	2	3	2	23.25	8
Dawei*	66	6	6	6	6	6	6	6	6	6	6	6
Jessica	60	6	6	6	6	6	6	6	6	6	6	
Jenny	60	6	6	6	6	6	6	6	6	6	6	
Spring	415											
Kim	128.5	7	9	8	10	8.5	15	12	12	17	30	10
Danny	114	7	3	7	10	10	13	12	12	15	25	10
Gabby	116.5	7.5	10	5	10	10	15	12	12	12	23	10
Arsh	28	1	2	4	3	3	3	3	3	3	3	
Prince	28	1	2	4	3	3	3	3	3	3	3	
*Approximations												
Total	**1242**											

Appendix F: Production Planning

PRODUCTION SCHEDULE

Week	6	7						8					
Part		Mon	Tues	Wed	Thur	Fri	Total	Mon	Tues	Wed	Thur	Fri	Total
Diffuser	4		2	1	2	2	7		2	1	2	2	7
Reflector	6		2	2	2	2	8		2	2	2	2	8
Front	0				3	2	5		2	2	2	3	9
Back	0				3	2	5		2	2	2	3	9
Port	0					4	4		4	4	4	4	16
Total	10	0	4	3	10	12	29	0	12	11	12	14	49

Week	9						10						Total
Part	Mon	Tues	Wed	Thur	Fri	Total	Mon	Tues	Wed	Thur	Fri	Total	
Diffuser		2	1	2		5		2	2	2	1	7	30
Reflector		2	2	2		6		2				2	30
Front		2	2	2		6		3	3	3	2	11	31
Back		2	2	2		6		3	3	3	2	11	31
Port		4	4	4		12						0	32
Total	0	12	11	12	0	35	0	10	8	8	5	31	154

Appendix G: Design Calculations

Dimensional Tolerances

Daniel Patrick | LumaLight | 12/4/12

Tolerances

Clearance Fits:

$\phi + t$ $\phi - t$

Tolerance from protomold = ± 0.003" (probably more expensive)

For our purposes ± .005" or 0.01" clearance

Screw Holes

ϕ Nominal Diameter = 0.21"

Back mounting Hole = 0.21" + .01" = 0.22"

Front mounting Boss = 0.21 - .01 = 0.20"

(.02" clearance)

Alignment Posts to reflector

ϕ Nominal Diameter = 0.14"

Reflector Hole = 0.14" + .01" or 0.15"

Alignment Post = 0.14 - .01" or 0.13"

(.02" clearance)

Port Cover

ϕ Nominal Diameter = 0.14"

Front/Back Hole = 0.14" + .01" or 0.15"

Port cover Post = 0.14" - .01" or 0.13"

(.02" clearance)

PCB Dimensions

Rocker switch: .53" × .35"   Grow

USB ↓.2"   .33 ↓ .06 .51   .16

Charging → .03" ↓ .35"   .35

Appendix G: Design Calculations

Heat Transfer

David Patrick | LunaLight | Heat Sink

Known: Conduction through a plane wall
Heat Transfer surface area (Starboard) = $3.14 \times 10^{-4}\ m^2$ ($r = .02\ m$)
Wall thickness (L) = 0.05 in or 0.00127 m
Thermal conductivity of plastic: $k = 0.17\ W/m{\cdot}K$
LED operation Temperature: $T_1 = 85°C$

Find: Heat transfer through wall ($\dot{Q}$)

Assume: Ambient Temperature (T_2) = 25°C

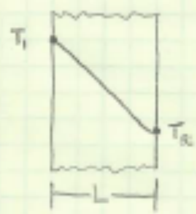
Solution

$$\dot{Q} = \frac{-kA(T_2 - T_1)}{L}$$

$$= \frac{-(0.17\ W/m{\cdot}K)(3.14 \times 10^{-4}\ m^2)(298K - 358K)}{0.00127\ m}$$

$$\boxed{\dot{Q} = 2.52\ W}$$

Schematic



Known: Free convection to environment from back of housing
Convection coefficient of air (h) = $10\ W/m^2K$
Thermal conductivity of plastic (k) = $0.17\ W/mK$
Surface area = $0.011110\ m^2$

Find: Heat Transfer $\dot{Q}$

Assume: Wall Temperature (T_w) = 55°C
Ambient Temperature (T_∞) = 25°C

Solution

$$\dot{Q} = hA(T_w - T_\infty)$$

$$= (10\ W/m^2K)(0.011110\ m^2)(328K - 298K)$$

$$\boxed{\dot{Q} = 3.333\ W}$$

∴ sufficient heat transfer

Appendix H: Budget

Income			
Description	**Amount**	**Date**	**Person**
CPConnect	$2,500.00	Spring 2012	Mike
Elevator Pitch	$750.00	Oct. 2012	Danny
LeanModel Pitch	$4,000.00	Mar. 2013	Gabby, Kim, Jessica
IME Student Fees	$500.00	Apr. 2013	Gabby
iQ Finalists	$100.00	May 2013	Danny
TOTAL	**$7,850.00**		

Expenditures				
Description	**Amount**	**Date**	**Person**	**Category**
Components	$48.00	11/2012	Dawei	PCB
Domain Name	$24.85	10/2012	Danny	Website
Monthly Website Fee	$9.90	10/2012	Danny	Website
d.light	$44.95	11/28/2012	Gabby	R&D/Competitors
Nokero	$13.95	11/28/2012	Gabby	R&D/Competitors
5' Strap (for prototype)	$5.44	12/17/2012	Kim	Components
External Components (Barrel jack X4, plug X1, USB port X4)	$27.14	12/20/2012	Kim	Components
External Components (Rocker switch X4)	$12.38	12/20/2012	Kim	Components
External Components (Plug X3, Battery Holder X3, LED X4, Starboard X4)	$43.45	12/28/2012	Kim	Components
PC Boards	$149.92	Jan	Mike	PCB
PCB Components	$250.00	Jan	Dawei	PCB
Solar Panels	$80.00	Jan	Dawei	Components
Santa Barbara Hotel	$78.00	Jan	Gabby	Printing/Promotional Material
Plastic Materials	$1,218.76	Apr	MATE	Cast
Second PC Boards	$200.00	Mar	Mike	PCB
Second PCB components	$104.18	Apr	Kim	PCB
SD Dinner	$112.00	3/11/2013	Kim	Buffer
SD gas/travel (Jessica)	$100.00	3/12/2013		Buffer

Expenditures				
Description	**Amount**	**Date**	**Person**	**Category**
Income Tax (LeanModel)	$800.00	N/A		Buffer
Production Supplies from Home Depot	$13.99	4/24/2013	Gabby	Cast
Production Supplies from Dollar Tree	$17.44	4/24/2013	Gabby	Cast
Gas from SDSU	$70.89	3/15/2013	Gabby	Printing/Promotional Material
BMC Print	$43.20	5/2/2013	Gabby	Printing/Promotional Material
Celebratory Drinks	$32.50	3/17/2013	Gabby	Buffer
PC Boards	$488.25	5/14/2013	Dr. Savage	PCB
PCB Assembly	$594.60	5/14/2013	Dr. Savage	PCB
PCB Surface Mount Components	$542.50	5/14/2013	Dr. Savage	PCB
PCB Through Hole + External Comopents from Mouser	$238.54	5/16/2013	Kim	PCB
PCB Through Hole + External Comopents from Jameco	$73.73	5/17/2013	Kim	PCB
Batteries	$174.59	5/17/2013	Kim	Components
USB Adapters	$72.25	5/19/2013	Kim	Components
Solar Panels	$461.45	5/24/2013	Kim	Components
Straps	$75.93	5/28/2013	Kim	Components
Screws, epoxy, electrical tape	$24.45	6/4/2013	Kim	Components
Frame, easle	$38.00	5/30/2013	Gabby	Printing/Promotional Material
TOTAL	**$6,285.23**			
	Total remaining funds	**$1564.77**		