Automated Mirror Cover for Telescope Application

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Design Analysis

Document

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Introduction

The NPOI (Navy Precision Optical Interferometer) located at the top of Anderson Mesa in Flagstaff Arizona, is a United States Naval Observatory (USNO). This facility uses a series of expensive aluminum coated mirrors to reflect starlight down vacuum tubes, where the starlight is then captured by sensors. The data is then analyzed by astronomers to produce a high resolution image of stars.

The capstone's contact and client, James Clark, has been working at the NPOI since 1990. James Clark has become concerned about the potential safety risks associated with removing the mirror caps. The mirrors aluminum coating is only a few molecules thick, so the mirrors need to be covered when not in use or the coating can be damaged by moisture or debris. Currently the mirrors are protected by a Lexan cover with a nitrogen purge. The Lexan protects the mirrors from debris and the nitrogen purge maintains 10 psi of pressure that prevents moisture from condensing on the mirror. This requires NPOI employees to crawl into each siderostat housing, remove the mirror cap, and crawl out either late at night or before dawn with no lights, this process can be very dangerous particularly in winter and is a major safety concern with the addition of 2 new taller telescopes.

The aluminum mirrors are re-coated once every three years. In order to lengthen the time between coatings, the mirrors are cleaned only three to four times in three years. This practice ensures that no unnecessary contact with the mirror is made that can damage the coating. A protective dome surrounds the siderostat and when the facility is not is use, the dome closes. Within the dome, there is a climate controlled environment which protects the mirror from harsh weather and debris. Once the dome is closed, moisture begins to condense on the mirrors surface, if left alone, frost may form, significantly reducing the useable life of the mirror. In order to counteract this process, the Lexan cover was built which creates a nitrogen blanket on the mirror's surface.

Problem Statement

The NPOI needs an automated mirror cover that can operate without interfering with current equipment while maintaining a nitrogen purge.

Design Considerations

The goal of this project is to produce a motor operated cover for the facilitys' siderostats. Once installed, they will require no manual intervention from the observers that open and close them, and should require little maintenance by the engineering staff at NPOI. Due to the extreme sensitivity of the equipment upon which these covers will be mounted, there are several key constraints that must be met.

Wind is an issue at the facility, which is located at Anderson Mesa, near Flagstaff. The siderostats are precision instruments that use small movements to track celestial objects while the Earth is rotating. Anything that is mounted on them cannot interfere with this task. Due to the high wind speeds that are possible, a low profile cover is required. It has been requested by the sponsor that no fabric folds be exposed to the wind, as this type of system may act as a sail, disrupting observation. This constraint has proven to be a more prominent consideration than was previously anticipated. Any previously considered design that employs the use of hinges or pivots was reexamined. If any of the moving components do not have an extremely tight tolerance, allowing essentially zero unanticipated movement, then they would have to be replaced by higher quality components.

The clearance within the siderostat housing is minimal. The cover must be able to open and close while the dome is closed, allowing maintenance to be performed at any time. During the team's most recent visit to the facility, we were able to disconnect the drive motors from one of the siderostats and move it through its entire range of motion. What we found was that the clearance that had previously been estimated was not to be realized in a functioning siderostat. The critical clearances that must be accommodated are the clearance between the bottom of the mirror cell and the base as well at the clearance between the top of the mirror cell and the dome when it is closed. The top and bottom clearances are measured to be 10 inches and 4 inches respectively. This has had several impacts upon our design possibilities. It is not feasible to have a cover which remains in one piece when being opened or closed. Figure 1 illustrates the clearance issues with one of our previous designs. The figure shows a one piece cover in an open position. The solid blue line represents the 10 inch clearance that must be met by our design, which the fully extended cover is well above. The dotted line represents the clearance that the design could reach if it were reengineered to fold in half while opening. This possibility is also not viable as it is still several inches too tall.

Another design which was previously discussed was also analyzed based on these newly recognized clearances. The four bar design uses linkages with a linear actuator to move to equally sized semicircles above and below the mirror cell. The top clearance is not an issue with this design, however the space under the mirror cell is. The cover requires just over 6 inches to move into its fully opened position. The option of having two covers with different sizes was considered. It was concluded that a larger top cover would not solve a problem, but rather it would create another. A larger piece would create a larger cross section to be influenced by the wind and would affect the balance of the siderostat.

Another major consideration is the method for mounting the design to the cast aluminum mirror cell. The cover must be able to open and close while in any position, this eliminated the possibility of mounting the cover to the base or any other position with close proximity to the mirror. The cover must move as part of the mirror. This constraint further emphasized the need for a compact design which would allow for the full range of motion of the equipment. The client reiterated the extreme precision of the siderostats, requesting that whatever final design is decided upon should be non-intrusive while mounting. It would be possible to drill into the cast aluminum cell but not preferred. This requires the design and implementation of a mounting band or other device, allowing for relatively easy installation and removal while maintenance is performed on the mirror itself.

Figure 1

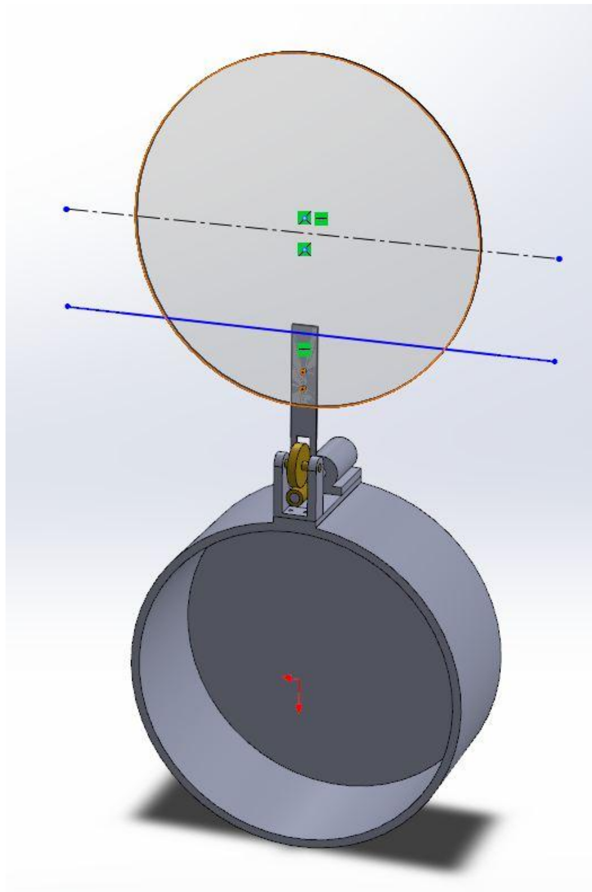
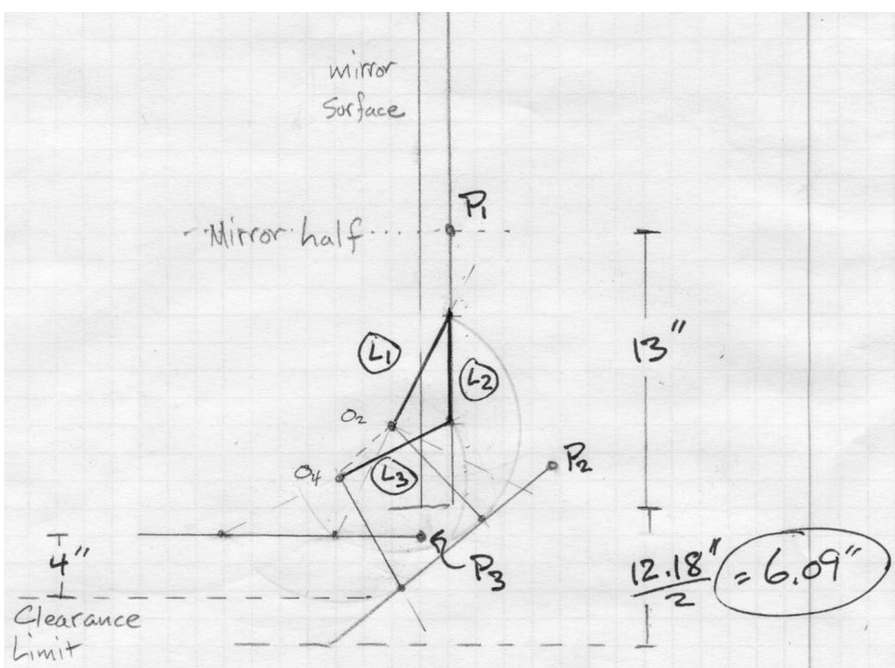


Figure 2



Material Constraints

Materials selection has been somewhat simplified for our project based on the client's requirements. Whatever is mounted to the mirror cell must have the same rate of thermal expansion as what it is mounted upon. The only viable mounting location for out cover is the mirror cell which is made of cast aluminum. Due to the expense of acquiring this material, we will be using 6061-T6 aluminum for any parts that will be directly mounted to the mirror cell. This type of aluminum should have a thermal expansion close to the cast aluminum while being available at a reasonable cost.

The only grease that is allowed near the mirror is high specific weight grease because if the grease evaporates then the vapor can get on the mirror and jeopardize the mirrors resolution. This option is out of the project budget because this grease cost approximately $600 per ounce.

If plastic is used, it must be able to withstand small to moderate amounts of ultraviolet radiation without ceasing to function. The plastic must not be hydroscopic, such as nylon. It will be exposed to moisture and a hydroscopic material will swell and could cease to function properly.

Environmental Concerns

The high wind is a concern for this project, as has been previously discussed. Other environmental concerns include the extreme temperatures of the region and the exposure to sunlight. The team's design must be able to function properly in temperatures ranging from -20 Fahrenheit to 100 Fahrenheit. When the facility is not in use, the siderostats will be protected from sunlight by the protective dome. However, there are situations in which the dome will be open during the day. This will expose the mirror cover to ozone and ultraviolet radiation.

Blinds Concept

Description

This concept was suggested to our team as a possible design solution by our client. The design is fundamentally a pair of rollers located at the top and bottom of the mirror, connected by a rope or belt to roll up and unroll a sheet of flexible material. The flexible material, while unrolled, would serve as an adequate barrier to the outside elements and provide and envelope for nitrogen to be continuously purged into, so that the environment directly in contact with the mirror surface can be controlled. While this design has many positive aspects; including low cost, ease of fabrication, material sourcing convenience and minimum machining, our group feels that the design also has negative aspects to be considered.

Design Drawbacks

- Wind
  - One major concern with any blinder type concept is that while in the open or closed position, the design would have fabric on either side of the siderostat. Fabric is susceptible to wind and could oscillate and vibrate with the wind, causing distortion of the mirror, which is unacceptable.
  - The tensioning ropes or belts that would be used to open and close the blind cover would always be exposed to the elements, potentially leading to further vibrations during operation of the mirror.
- Nitrogen Purge will be difficult to mount due to the rolling aspect of the cover.
- Concern over the lifespan of the curtain material in the cold environment, unrolling during the coldest part of the day (dawn).
- Mounting locations on the siderostat frame will be complicated.
- Clearance, specifically below the siderostat will be an issue. The triangular shape of the base will interfere with any roller below the mirror.

Iris Lens

Description

After concluding many of our initial concepts would not comply with the design constraints, our team began searching for alternative ways of covering a surface. While researching theatre spotlights, it came to our group’s attention that the device used to focus a spotlight on an actor could be reversed in its application to close off light from the opposite side. During our groups research into the mechanics of a theatre iris diaphragm, it was found that this type of device effectively had only three components; a lower frame ring that was fixed, an upper frame ring that rotated relative to the lower, and a series of interior leaflets. The movement of the interior leaflets is determined by the relative rotation of the two frame rings. This design solved many of the issues that our group was encountering with previous design concepts, including material concerns, mount location considerations as well as simplicity of design and fabrication. The Iris design has the smallest cross section of all designs that have been considered. The small area occupied by the iris will reduce the wind's ability to move the siderostat during observation.

Although there are many individual parts, they consist of only three major parts which are repeated. This will allow replacement and repair of the iris to be simple and easy compared to other designs. The iris is one piece when removed from the siderostat, further increasing the ease of installation and removal when maintenance is required. This will also reduce the risk of damaging the mirror during installation and removal.

Material Selection

For the movable leaflets of the iris design, a polymer is the most likely design choice considering polymer plastics are generally light weight, affordable and easy to manufacture. Listed in the table below are several engineering properties of thermoplastics that could be considered. The third column of this table is density, the fourth column is the modulus of elasticity, the fifth column is the break normal strength, and the sixth column is the elongation at break. Preferably, a material would be selected based on a low density and high shear strength. However, with the information available it is safe to assume that a high break normal strength is a result of a close pack polymer, which has a high shear strength. Therefore an ideal material has a low density and a high break strength.

Table 1-Mecanical Properties of thermoplastics

Polymer	Grade	ρ/(g/cm^3)	E/(GPa)	σ_b/(MPa)	ε_b/(%)
PE LD, LDPE Polyethylene, low density		0.915-0.93	0.14-0.3	7-17	200-900
PE LD, LDPE Polyethylene, high density		0.94-0.97	0.7-1.4	20-40	100-1000
PP Polypropylene	Homopolymer	0.90-0.91	1.1-2.0	30-40	100-600
PP Polypropylene	-40% glass fiber filled	1.22-1.23	6.8-72	60-110	1.5-4
PP	Copolymer	0.89-0.905	0.9-1.2	28-40	200-500
PVC	Flexible (FPVC, plasticized)	1.16-1.70	0.05-0.15	6-25	150-400
PS Polystyrene		1.04-1.05	2.4-3.2	30-60	1-4
SB Styrene-butadiene	Rubber-modified PS, High impact PS, HIPS	0.98-1.10	1.5-2.5	15-40	15-60
ABS Acrylonitrile-butadiene-styrene	Medium IS	1.03-1.06	2-2.8	30-50	15-30
ABS Acrylonitrile-butadiene-styrene	High IS	1.01-1.04	1.6-2.5	30-40	5-70
SAN Styrene-acrylonitrile		1.07-1.09	3.4-3.7	55-75	2-5
Acrylate-styrene-acrylonitrile		1.05-1.07	2.2-2.4	30-50	20-40

Solid Works

Below are several drawings of the major components of the Iris.

Figure 3 – Top Plate

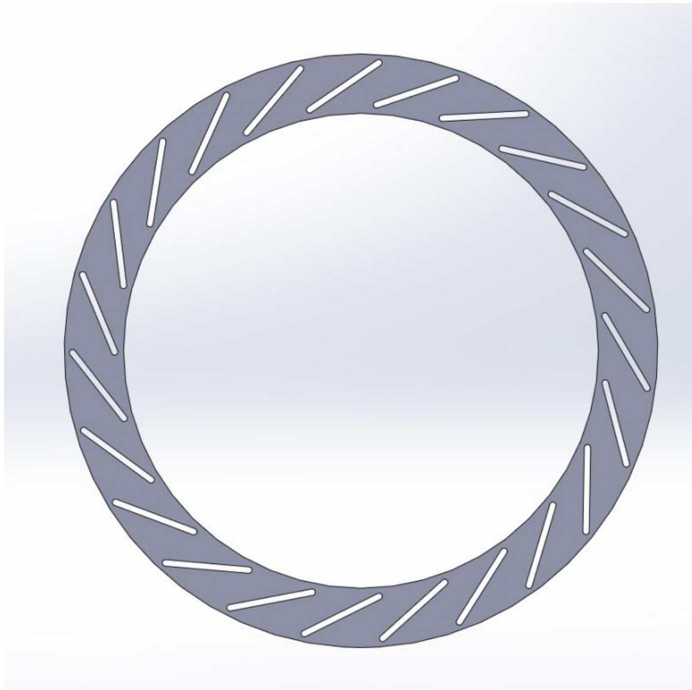


Figure 4 - Base Plate

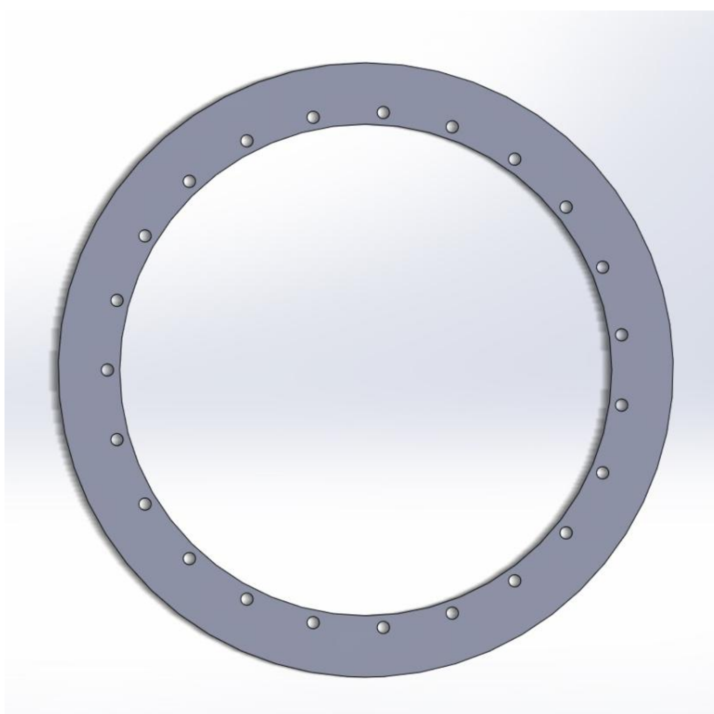


Figure 5 - Blade

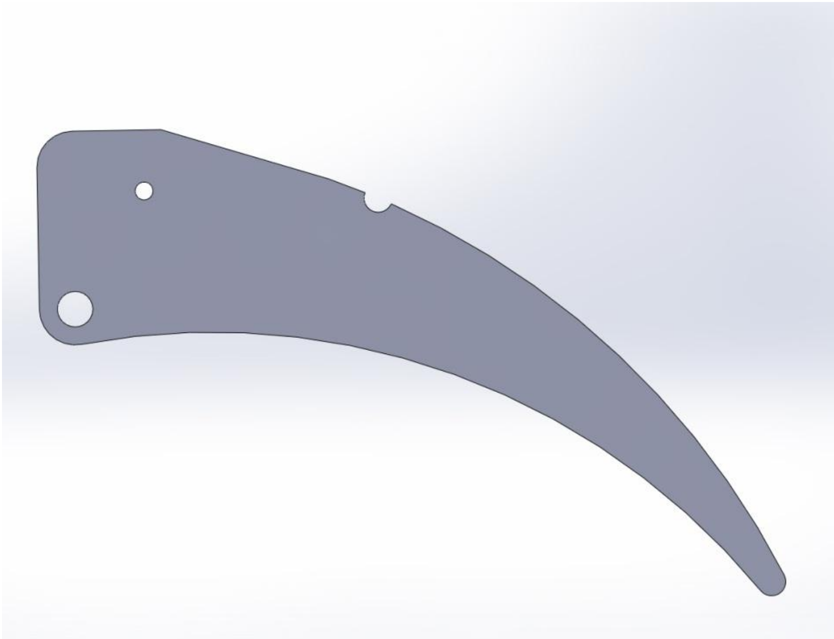
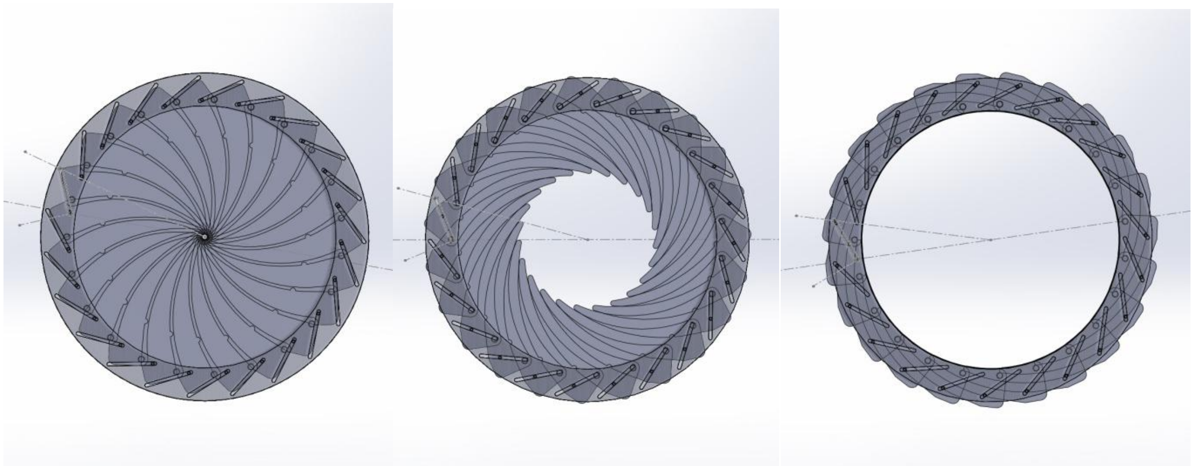


Figure 6 – Assembly Moving from Closed to Open



Cost Analysis

A budget of 500 dollars was acquired for design and construction of the mirror cover. In order for the iris diaphragm mirror cover to be a viable option the material and specialized labor costs must be within budget.

The team has explored the possibility of building a test fixture. This would be a replica of the aluminum siderostat that the mirror cover will mount to. This will allow the team to test its designs without the possibility of damaging the precision equipment at NPOI. A list containing the cost of materials for the test fixture is shown in Table 1.

Table 1- Scale model mirror housing, materials and cost

1/2" Ply wood 4'x8'	$18.95
4 inch x 2ft ABS pipe	$10.95
1lb 1-1/4" wood screws	$6.47
2" x 4" x 8', quantity 3	$9.15
Total Cost	**$45.52**

The iris diaphragm concept requires several different materials. The base plate and top ring must be made of aluminum to match the thermal expansion of the mirror cell. Table 2 shows typical prices for materials that will be required for the prototype.

Table 2 – Iris diaphragm material costs

1/8" x 4'x 4'Aluminum Plate	Base and face plates	$150
1/2 "x 2'Aluminum bar stock	Mounting pins	$1.20
1/8 "x 2' Aluminum bar stock	Mounting pins	$3.10
060" x 24" x 96" Black ABS	Iris leafs	$29.93
	Total Cost	**$184.23**

Specialized labor to machine the base plate, faceplate, and iris leafs is estimates to take 3 hours at 40$/hr. The total cost for specialized labor is estimated to be $120 to machine all major parts of our design. In order to omit this cost these items can be machined by our team. As Table 2 illustrates, the materials for the Iris should be well within budget, leaving room for machining costs or higher quality materials to be purchased. In addition, different sources may be located, allowing the team to purchase more appropriately sized sheets of material, further reducing the cost of production.

Conclusion

After visiting the NPOI facility and speaking with our client, the team began working in a new direction, eliminating the previous concepts. Due to the environmental conditions, the newly discovered clearance issues, and the imposed budget, an entirely new design was created and discussed with the client. The Iris Diaphragm is believed to be the best design for this project based on its simplicity, reliability and cost of construction. The Iris will be composed of two rings, a lower and upper, both made of high quality aluminum. The rings will be durable in the environment as well as a suitable match for the cast aluminum mirror cell in terms of thermal expansion. The leaves of the Iris will be made of a low friction, non-hydroscopic, thermoplastic. All parts of the Iris will be produced by the team, reducing the manufacturing costs.

Project Plan Gantt Chart

The project Gantt chart had to be modified in the last revision.

Task Name	Duration	Start	Finish
Project Assesment and Identification	**8 days?**	**Thu 9/27/12**	**Tue 10/9/12**
Design and Testing	**24 days**	**Sat 10/13/12**	**Thu 11/15/12**
Concept Generation	1 day	Sat 10/13/12	Mon 10/15/12
Concept Selection	3 days	Fri 10/19/12	Tue 10/23/12
Presentation: Concept Generation	0 days	Tue 10/23/12	Tue 10/23/12
Report: Concept Generation	0 days	Fri 10/26/12	Fri 10/26/12
Visit NPOI/Jim Clark - Accurate measurements for Siderostat Model	1 day	Tue 10/30/12	Tue 10/30/12
Test Proposed Concepts	14 days	Mon 10/29/12	Thu 11/15/12
Prototype Analysis	**23 days**	**Tue 10/30/12**	**Fri 11/30/12**
Solid Works model	3 days	Fri 11/2/12	Tue 11/6/12
Materials Selection	3 days	Tue 10/30/12	Thu 11/1/12
Presentation: Engineering Analysis	0 days	Tue 11/6/12	Tue 11/6/12
Report: Engineering Analysis	0 days	Fri 11/9/12	Fri 11/9/12
Redesign of Analyzed components	5 days	Fri 11/2/12	Thu 11/8/12
Concept Finalization	8 days	Fri 11/9/12	Tue 11/20/12
Presentation: Final Design	0 days	Tue 11/27/12	Tue 11/27/12
Report: Final Design	0 days	Fri 11/30/12	Fri 11/30/12