Payload Separation System

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Midpoint Review
Document

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Chapter 1. Introduction

1.1 Background

Launch vehicles that place payloads into orbit require mechanisms to release the payload into orbit. The payloads are typically fragile and are composed of various optical components that can be harmed when transported. Due to this problem, companies have designed various payload separation systems that have become too expensive and complicated. Mary Rogers, the Electronic Packaging and Actuators Manager from Orbital Sciences Corporation, has requested for a new design of the payload separation system. This new design of the system must be reduced in cost, impart minimal shock to the payload, and be less complicated by reducing the number of parts. The team will design, analyze, and build a sub-scale model of the payload separation system for testing for ME 476 Capstone Senior Design by May of 2014.

1.2 Problem Statement

Orbital Sciences Corporation, located in Phoenix Arizona, is interested in designing a Payload Separation System (PSS) that is lighter, less expensive, less complicated, and imparts minimal vibrational shock levels onto the payload. The primary interest of this senior design project is to deliver a payload into polar orbit around the Earth. Generally, the design is a ring that must be strong enough to secure a payload to the front of the Pegasus space launch vehicle, separate on command, and release the payload into orbit. The goal is to improve the current payload separation system today while making sure the design is simple so that it can be manufactured at Orbital.

1.3 Introduction

Current payload separation systems are generally composed of some cylindrical ring that is mounted on the tip of a launch vehicle just before the payload. The ring needs to be able to withstand the weight of the payload, and the forces and properties at Mach speeds when launched into orbit. Some of the forces that need to be considered are extreme temperatures, accelerations, vibrations, and various other material stresses caused by the environment. The purpose of this report is to document any progress performed since the final proposal on December 13, 2013. As well, the manufacturing process of the sub-scale model and possible future testing ideas will be included in this report. The overall project will eventually entail trade studies, design, analysis, and a half scaled model for testing. Some payloads that might be used in industry today include: satellites, telecommunication systems, optical systems, and experimental projects. These payloads can be delicate due to the nature of the mechanisms they carry. The payload and the launch vehicle are extremely expensive, although by reducing the number of parts the cost will be reduced as well.

1.4 Needs Identification

The client Mary Rodgers contacted Northern Arizona University with a need for a payload separation system. Currently the payload separation systems are too expensive and do not account for the shock due to vibrations of the separation, causing damage to the payloads. The need of this project is to redesign a payload separation system that is less expensive, and imparts as little shock to the payload as possible.

1.5 Project Goal

Orbital Sciences Corporation is interested in a payload separation system that is lighter, less expensive, less complicated, and imparts minimal shock to the payload. The goal is to improve the system so that it can break apart consistently on command with little impact to the payload. Mary Rogers has also requested that the new design be able to be machined in-house by Orbital Sciences, so to eliminate sub-contracting.

Chapter 2. Final design

2.1 Final Design

The final design consists of a rocket ring (RR), a payload ring (PR), 4 cylindrical keys, 4 solenoids, and approximately 4 metallic mesh kick-off springs. All design components, including the quantity and material selection, can be seen in table 1. See figure 1 for an engaged isometric view of the final design and figure 2 for an isometric view after separation in SolidWorks. The diameter of the sub-scaled payload ring is 12 inches. A pinwheel pattern was implemented to mount the solenoids symmetrically and therefore distribute the weight more evenly between the quadrants. This will eliminate the issue with orienting the solenoids in abstract angles to allow a proper release. With the pinwheel design, the rocket ring is now divided into four equal quadrants that will evenly distribute the load compared with the original asymmetrical layout.

Table 1: Quantity of components and material selection

Design Components	**Quantity**	**Material**
Payload Ring (PR)	1	7075 Aluminum
Rocket Ring (RR)	1	7075 Aluminum
Cylindrical Key	4	Steel
Solenoid	4	n/a
Metallic Mesh Kickoff Springs	4	304 Stainless Steel

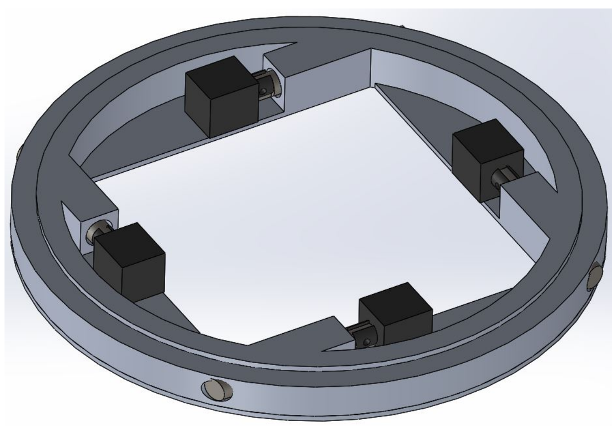

Figure 1: Isometric view of PSS fully engaged

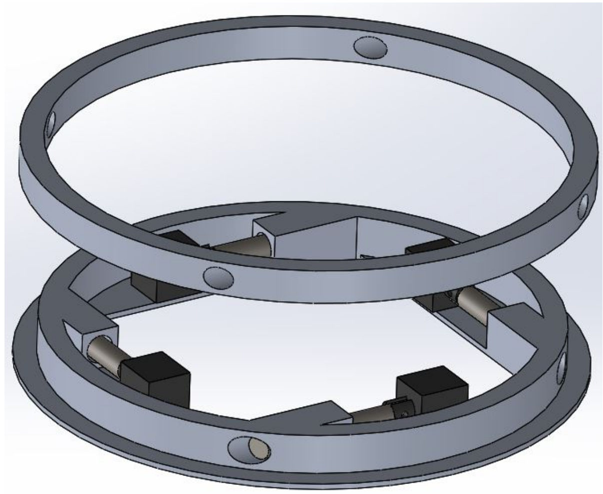

Figure 2: Isometric view of PSS after separation

2.2 Back up Plan

To increase reliability, the back-up plan consists of a small, suspended ring that has four members fixed tangent to the ring at 12:00, 3:00, 6:00, and 9:00 o-clock. The four members are connected and fastened to the same location where the solenoid’s plunger is pinned with the keys. See figure 3 for a schematic of the back-up plan. If a solenoid doesn’t retract a key entirely, the other solenoids will have disengaged and therefore rotating the inner ring that will then pull out the key that did not retract. Although, after testing the PSS and confirming that the system is reliable enough, the back-up plan will not be necessary and will not be implemented. Its purpose is to provide additional security so that the keys will disengage simultaneously without fail.

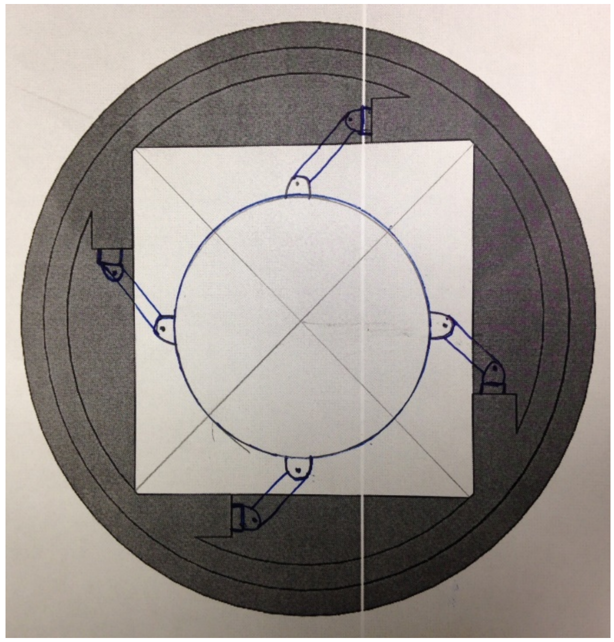

Figure 3: Back up plan schematic

Chapter 3. Manufacturing

3.1 Overall Manufacturing Process

Manufacturing of the prototype PSS has required a CNC end mill, a band saw, a drill press, and a lathe for removing the excess aluminum from the payload and rocket rings. First a wax mold was made the same 12” x 12” x 1” size square as the aluminum pieces to test the feasibility of the machine shop at building our system. The wax showed how well our G-code worked in the HAAS, and allowed us to model how we will lathe the sides off of the system. After the wax had been cut, the RR inner features were all milled out by the HAAS in under 2 hours 30 minutes. The RR square edges, not reachable by the HAAS, were lathed off to make the whole system circular. The keyholes will be drilled out using the drill press once the PR is finished, so that the holes will line up correctly for the keys. A stainless steel rod has been purchased for the cylindrical keys, and the band saw and end mill were used to cut out four equally sized keys with square tabs on one end to fit into the solenoids and payload ring. Research continues on the stiffness and damping of the springs with the manufacture, once the deformation limits of the springs are known the springs will be purchased and integrated into our system. Each team member has been assigned a component of the design to be responsible for and can be reviewed in table 2 below.

Table 2: Team member responsibilities

Components to be Manufactured	Team Members
Payload Ring (PR)	Jason, Alen, Ben
Rocket Ring (RR)	Kate, Mark, Matt
Keys	Jason, Alen, Ben
Solenoid (+mounting)	Mark, Matt
Springs (+mounting)	Kate

3.2 Rocket Ring

The rocket ring is the most complicated piece to manufacture, shown figure 4. First off, G-code for the PR and RR was generated using CAMWorks in conjunction with SolidWorks. Using the G-code, the rocket ring will be milled using the CNC Haas in the machine shop. Before milling the 7075-aluminum, the team will run the code for practice on a polymer plate with the same 12"x12"x1" dimensions as the aluminum plate. The polymer plate was milled correctly, and only small modifications were made to the G-Code prior to cutting the aluminum. The CAMWorks generated code spiraled out from the inside of the aluminum to generate the interior of the RR. This approach though effective is time consuming and does not utilize the material efficiently. To save an 8"x8" aluminum plate from the center of the RR the G-code was modified to remove the spirals, only cutting one large square first. Once the interior is cut and removed the code cuts the base plates into the aluminum and defines the key housings. Once finished the CNC milling has produced the inner diameter and all inner features, minus the keyholes. The exterior diameter will be turned on a lathe.

The square plate will first have the corners removed, creating a rounded square, earlier to turn on a lathe. Once on a lathe the RR lip was produced, and the RR walls. The RR was turned down to have an ID 4/1000" smaller than that of the PR, needed to minimize friction between the two surfaces. This is a rough estimation, but on Earth conditions where thermal expansion can be mostly neglected it will provide enough tolerance between the surfaces. Should this design be accepted by Orbital, further thermal expansion and contraction calculations need to be addressed. Finally the keyholes will be drilled, using a hand mill. To ensure a perfect mate between the keyholes in the RR and the PR, they two rings will be mated together and drilled simultaneously. The rings will either be spot welded, or clamped to ensure they do not shift during the cutting process.

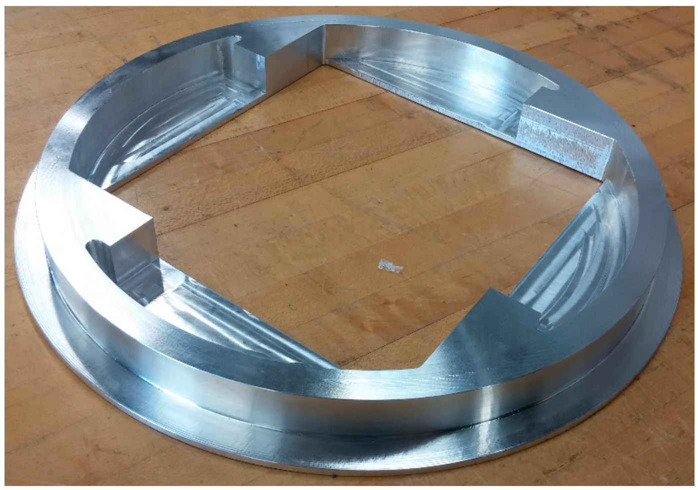

Figure 4: Rocket ring

3.3 Payload Ring

The payload ring will be cut with a similar process. First, a special bolt clamp will be attached to the mill to keep the outer edge of the block secure. Next, a hole the size of the inner diameter will be drilled into the side of the block. This hole within the square block will be used to secure the metal piece to the lathe. The attachment of the lathe works such that a special clamp connected to the chuck will hold the block securely by the inside diameter. The lathe will then turn and carve out the outer diameter of the payload ring. Then, an end mill will be used to drill four holes for the keys while a vise secures the payload ring and the rocket ring. Depending on the payload, adaptor holes will need to be tapped and threaded to allow bolts to secure the payload from the top. To hang the system with springs for possible future testing, D shaped adaptors will be milled or attached to the outer diameter. See figure 5 for a SolidWorks view of the payload ring.

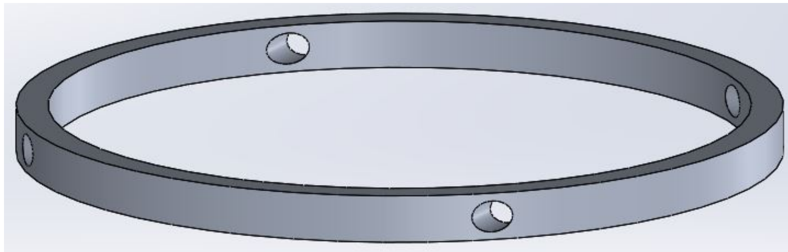

Figure 5: Payload ring

3.4 Keys

The four keys were cut from a 0.49” x 3’ steel stock into eight equal 4” pieces. The steel stock was purchased from Ace Hardware in Flagstaff, AZ. One end of each piece was cut at an angle to be flush with the payload ring and the other end was milled to fit the solenoid “C” shaped plunger. Then a small hole was drilled within the tab to connect the plunger to the key. The PR will be secured to the rocket when the keys are engaged and inserted into the holes of the payload ring. An analysis was performed on the keys to make sure the keys at this size would not fail due to shear stress caused by the maximum dynamic pressure, among other high stress points of the journey. See Chapter 4: Engineering Analysis Alterations for specifics on the alterations to the analysis. See figure 6 and 7 for a SolidWorks view of one key and the relation of the four keys to the solenoids in the final design.

Figure 6 Machined Key

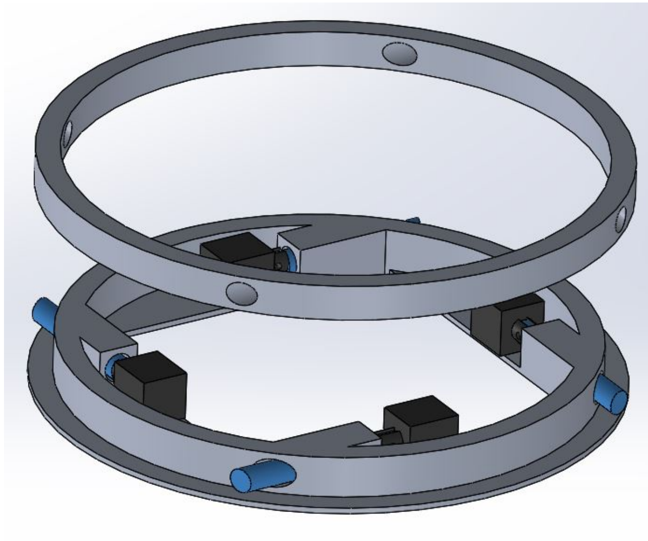

Figure 7 Keys in the Keyholes

3.5 Solenoid

Four solenoids were purchased from Element14, a material supply company. Unfortunately once received it was made clear they would not work, with dimensions not allowing for placement on the baseplates. New solenoids have since been ordered and meet the size constraints. The solenoids serve to provide the actuation for the keys. When signaled, each solenoid will actuate, pulling each key into their respective housing simultaneously by .5 inch. Once the keys reach their final resting position the kick off springs will engage. See Figure 8 for a photograph of the solenoid.

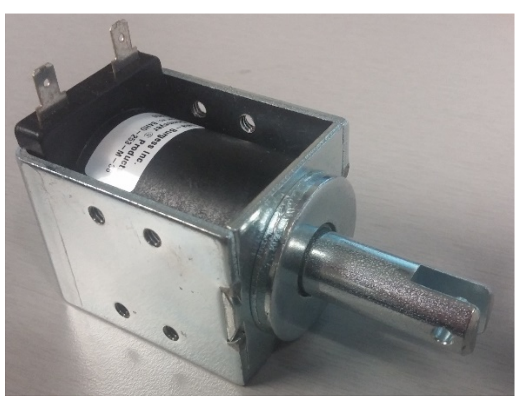

Figure 8 Large Solenoid

3.6 Kick off Springs

Kinetic Structures Company has offered to donate their mesh springs to the team to help with the project. Kinetic is working with the team to design the ideal spring for the prototype. As of now, we have samples in three sizes that we will test in the mechanics of materials lab, Room 117, for deflection and spring coefficients. The springs due to their variable mesh nature will not yield exact deflections. After speaking with Dr. Tuchsherer, a setup in the lab using load cells and a hydraulic jack, the team can calculate the springs' specifications such as deflection and spring constant. Testing for dampening may be solved by pulling on the spring and measuring the time it takes to return to original position. A small slow motion camera can be used to watch frame by frame for a time interval.

The metallic mesh kick off springs made out of AISI 304 stainless steel will expand to accelerate the payload away from the rocket. Because the spring is made of tiny coils of aluminum, this causes an internal damper and thus releases slower than a preloaded spring. An analysis was performed on the mesh kick off springs, and can be seen in chapter 3 of this report. The analysis confirmed that the kick off springs will successfully separate the payload from the rocket under constant acceleration. Figure 9 is an enlarged photo of the metallic mesh spring.

Figure 9 Kick-Off Spring

Chapter 4. Engineering Analysis Alterations

4.1 Analysis Alterations

After communicating with our new clients, Matthew Johns and Steven Hengl, the assumptions that the team was making in prior analyses were corrected. The max dynamic pressure is no longer a concern because the fairing at stage two ignition was designed to protect the system from such forces.

The only forces on the system are the largest g's that the PSS is experiencing when acceleration is the largest, and the 1.5 g's the payload experiences in the lateral direction. See figure 10 for a drawing of the 1.5 g's applied in the lateral direction at the center of gravity of the payload. The highest acceleration was calculated between the second stage ignition and second stage burnout. The total g's the PSS would experience in the longitudinal direction would then be acceleration of 134.5 ft/s^2 divided by gravity at an altitude of 471,900 ft, giving 4.178 axial g force. The force per key, 313.3lbs, was calculated by multiplying the axial g force by the weight of the payload ring and then dividing by the four keys. Using the diagram in figure 10, the force due to the moment of the 1.5 g's in the lateral direction resulted in 1125lbs. By adding the forces and diving by the cross sectional area of the keys, the shear force amounted to 7325.4 lbf/in-s^2. The shear yield of steel is 42,456 lbf/in-s^2, therefore the factor of safety is 5.796. This ensures that the keys will not fail due to the lateral and longitudinal g forces that the PSS will experience at the highest acceleration.

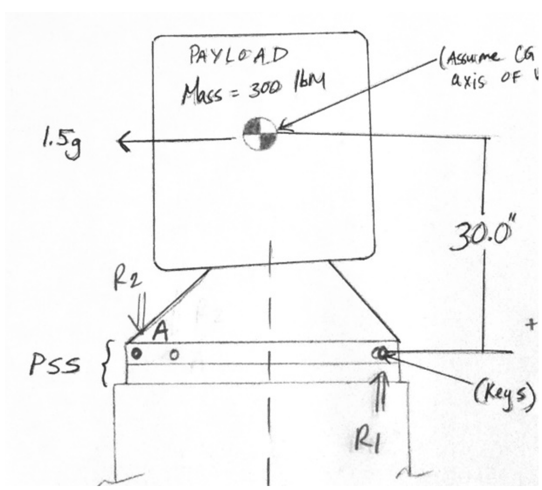

Figure 10 Lateral Forces

Tear out and bearing stress of the payload ring when lateral and longitudinal g's are applied was also of main concern. Although the tear out of the payload ring came to 11064.1 lbf/in-s^2 and bearing stress is 4639.8 lbf/in-s^2. The PR will not fail due to tear out or bearing stress.

Chapter 5. Testing

5.1 Key and PR Failure Test

The universal testing machine (UTM) in the mechanics and materials lab will be used to test failure of keys, PR, and RR. Unfortunately the UTM does not allow for dynamic loading, and will only load at a static rate two options arise, the estimation that 50% of that of dynamic loading can be used to find the dynamic loading failure, or Charpie impact testing on the keys. This is a simple approach to test the dynamic loading failure of the keys, but does not test the RR or PR.

That said, Charpie testing will be used on the keys, and an estimation will be used on the PR and RR. The two materials will be stressed to failure then the team will deduce a dynamic loading limit.

The physical design of the RR does not allow for a compression test for failure, though since the PR is symmetric about the Z-axis, a tension test will serve the same. The two rings will be pulled under tension until either the keys shear, or tear out is achieved on the PR.

5.2 Separation and Reliability Test

The team has decided to use a pulley system complete with two separate 300lb masses, shown in figure 11. One mass will be attached to the PR directly with the other attached via a system of pulleys and cable to the PR. This system will emulate a neutral buoyant scenario, in that any outside force will generate some movement. This system will give results toward spring effectiveness. Using high-speed film, data will show the acceleration at separation, and ensure a low unloading factor.

This data can be used to make changes to the spring design. The hope is that a damped factor is high enough and the mesh springs alone will provide both the kickoff force and damping.

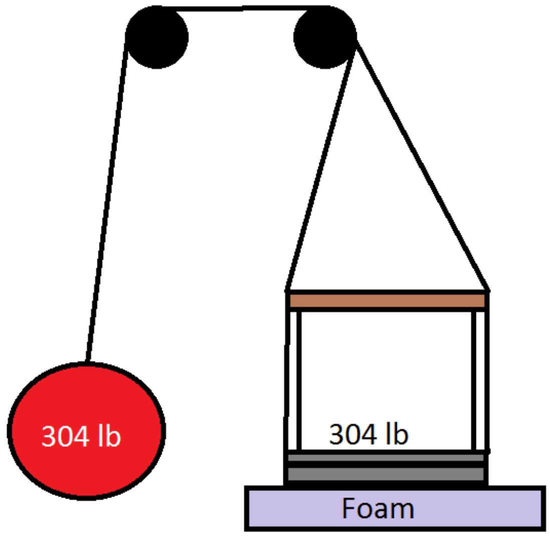

Figure 11 Separation Test

5.3 Spring Testing

The springs will be tested for the application load at which they plastically deform, desired deflection, unloading rate or damping coefficient, and spring stiffness. Harry Artenian, the president of Kinetic Structures, is willing to accommodate for all specifications. To test the sample springs Harry had provided, see figure 12 for the apparatus. The springs will sit on a plate to evenly distribute the load onto the loading cell. Then the load cell will sit on a larger rectangular plate so to distribute the weight evenly from the hydraulic rams. There are potentiometers on either side of the rams to measure the deflection of the springs. The entire apparatus will be sitting inside of the UTM (universal testing machine), so that it will have a fixed ceiling and floor. A DAQ will be wired to the loading cell and potentiometers to acquire the appropriate data.

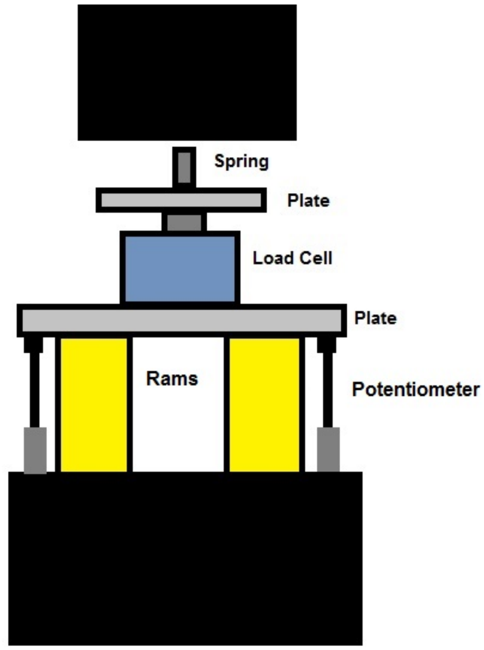

Figure 12 Spring Testing with UTM

Chapter 6. Cost Analysis

6.1 Bill of Materials

The bill of materials has changed drastically since the final proposal. Earle M. Jorgensen (EMJ) generously donated a 28” x 48” x 1’’ plate of 7075-aluminum to our team which reduced the previous $837.76 bill to a current approximation of $286.40. Furthermore, four solenoids were purchased at unit cost of $39.10. The bill of materials will also increase once spring cost, batteries, and other misc. components are decided upon to purchase. See table 3 for the current bill of materials.

Material	Quantity	Unit Cost
Carbon Steel Key 0.5" dia x 3’ long	1	$15.00
7075 Aluminium plate 28" x 48" x 1"	1	Donated
Solenoid	4	$39.10
K & M Work Order	N/A	$65.00

Nuts/ Bolts/ Misc.	TBD	$50.00
Total Cost		**$286.40**

Table 3: Bill of Materials

Chapter 7. Conclusions

7.1 Project Planning

The manufacturing phase for the PSS is almost finalized. The rocket ring, which is more difficult to manufacture is nearly completed, leaving the team having to only worry about manufacturing the key holes, recesses, and the payload ring. Since these areas are fairly simple, the team can forward our attention to the testing phase. The Gantt chart, which can be seen in appendix A.1, provides a nice layout of the plan that is put in place for the rest of this semester. Over the next few weeks, the team will concentrate on the three separate tests; the key and payload ring failure test, separation and reliability test, and the spring testing as well. As can be seen in the Gantt chart, the last day for testing is set to be March 28th. This deadline was made because Steven Hengl and Matthew Johns, the team's contacts from Orbital Sciences, are set to meet with the team on March 28th to aid with the testing. They will aid in the testing phase, but the team will aim to conclude the testing before the meeting. The time allotted for each testing phase is set to just under a week before the team analyzes and further explore those results until the testing will validate that the PSS will separate the payload with minimal shock while also being extremely reliable.

7.2 Conclusion

The final design underwent minor changes over the last few weeks, which mainly include the solenoids being in a different orientation. Updated analysis of this system also took place due to the modified design which showed that the system will not fail due to the factor of safety being over 5. Since the final design and the analysis was completed, manufacturing of the PSS began and is now in its final stages. With this nearly completed as well, we can focus our attention to testing our system. The first test that will take place is the testing of the springs to determine the damping coefficient as well as the spring constant that is needed for the best results of separation. This test will be the priority due to the fact that the springs still need to be purchased. The four solenoids also still need to be purchased due to the company in which we purchased them from sent us solenoids which were bigger than anticipated. Once all the parts come in and the testing phase starts, our team will also have to determine the need of a backup system. If the PSS shows the ability to constantly separate without any malfunctions, then the backup system can be discarded. The other two tests, which include the key and payload ring failure test, as well as the pulley system testing, will be performed in the upcoming future as well. This will entail the next phase of this project to ensure that we have designed a reliable and effective payload separation system.

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Appendix

A.1 Spring 2014 Gantt Chart

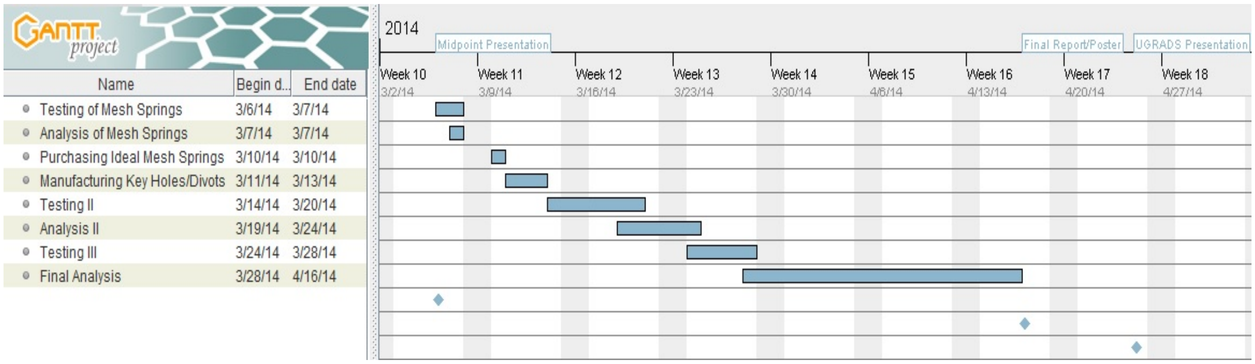

Figure 13 Gantt Chart