Payload Separation System

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Final Proposal

Document

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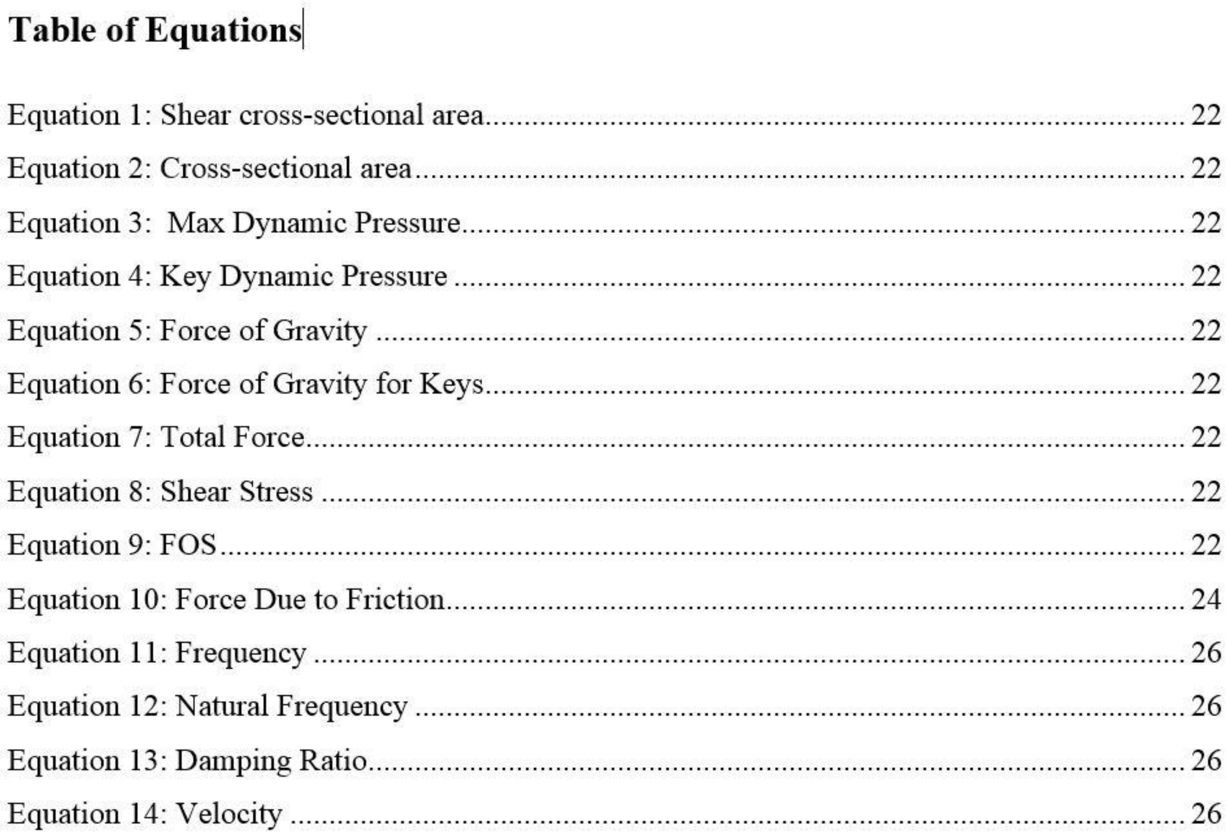

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Chapter 1. Introduction

1.0 Abstract

A Payload Separation System (PSS) is the component of a rocket that controls when and how the payload will separate into a low Earth orbit. This device is the only thing that is placed in between the rocket from the payload. Therefore, the (PSS) is required to lock in the payload until separation is sequenced while minimizing destructive levels of vibration due to shock. 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 vibration 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. Costs can be as high as $500,000 for a reliable system that includes over 1,000 parts from third party manufactures. In this proposal, a design that is within a budget of $1,000 is analyzed. The redesigned (PSS) will minimize shock with a metallic mesh kick off spring. The small disk made of interwoven steel fibers will act as a dampened spring to minimize shock during flight while reliably executing the separation sequence. The (PSS) will use four keys controlled using solenoids that will withstand the rigors of launch and be contracted to release the payload. To overcome the low pulling power of the solenoids; Teflon surfaces will be applied to the keys in the payload ring's channel to reduce friction compared with aluminum on aluminum contact. These keys will withstand the maximum dynamic force achieved shortly after belly launch from an airplane. By using an aluminum unibody construction, the rings will be lightweight, strong, and inexpensive to produce. All reductions in cost to this component will benefit Orbital Science's total launch cost, and bringing humanity closer to the final frontier of outer space exploration and technology.

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 explain the analysis process that was performed on the final design. The keys were determined to be the weakest part of the final design and will be the main focus of this analysis. An analysis will also be performed on the thrusters used to separate the payload from the launch vehicle once orbit is reached. The overall project will eventually entail trade studies, design, analysis, and possible sub-scale models and 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 State Of The Art Research

There are various different types of payload separation systems that are currently being used for space flight missions. Costs can get as high as $500,000 for a reliable system that includes over 1,000 parts such as the Marmon Clamp PSS that SAAB manufactures. Orbital Sciences Corporation, over a billion dollar company, specializes in manufacturing and launching satellites into space. They are also very well known for developing missile defense launch systems, and for this reason alone much of their work becomes unobtainable by the general public. This is where the Pegasus User's Guide becomes a valuable source pertaining to this project. This user guide includes all of the dimensions needed for the Pegasus rocket as well as important charts and tables that include key information that was later used for the analysis of the PSS.

1.5 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 re-design a payload separation system that is less expensive, and imparts as little shock to the payload as possible.

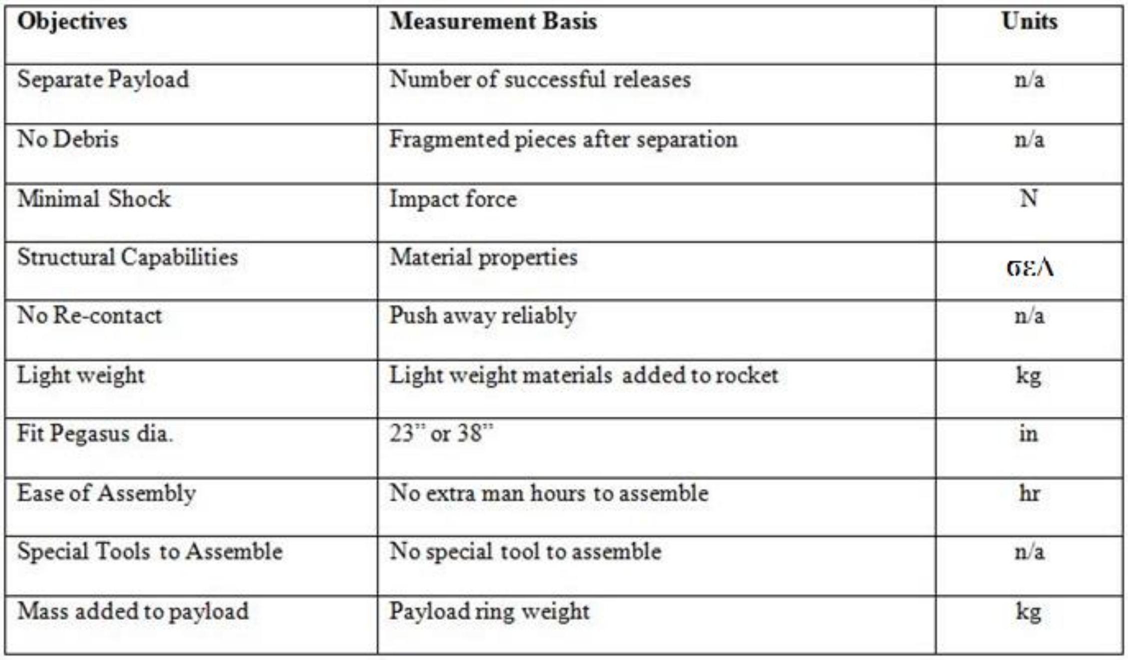
1.6 Project Goal

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.

1.7 Objectives

The objectives are quantifiable expectations of performance. See Table 1 for information regarding measurement basis and units for each objective. Following the table is a brief description of what each objective means.

Table 1: List of Objectives



Objectives	Measurement Basis	Units
Separate Payload	Number of successful releases	n/a
No Debris	Fragmented pieces after separation	n/a
Minimal Shock	Impact force	N
Structural Capabilities	Material properties	σεΛ
No Re-contact	Push away reliably	n/a
Light weight	Light weight materials added to rocket	kg
Fit Pegasus dia.	23" or 38"	in
Ease of Assembly	No extra man hours to assemble	hr
Special Tools to Assemble	No special tool to assemble	n/a
Mass added to payload	Payload ring weight	kg

The payload separation system must:

1. Separate the payload - The main goal is to separate the payload at a predetermined altitude.
2. Have no debris – So to eliminate space trash and debris falling back into Earth's atmosphere.
3. Impart minimal or no shock – The payloads can be fragile and the shock can cause damage.
4. Meet appropriate structural capabilities - Material properties built as per the specifications will meet the loading and force factors involved when in transit
5. Have no re-contact - This will occur after the rocket has been separated from the payload. The payload cannot make contact with the delivery vehicle after separation.
6. Be light-weight – The payload separation system needs to be as light weight as possible to decrease the overall weight and possibly allow for the launch vehicle to carry a heavier payload.
7. Fit Pegasus dimensional constraints - We are designing our system to fit the Pegasus rocket, therefore, it will need to meet Pegasus specifications.

8. Be easy to assemble - This objective branched out from simplicity. Although this was not one of the major requirements made by our client, it would still be a benefit to reach this objective.
9. Special Tools to Assemble - This objective branched out from simplicity as well. It is not one of the major areas we need to focus on.
10. Mass Added to System and Payload - There are certain weight restrictions that our overall system can be as well as weight that will remain on the payload after separation.

1.8 Requirements

After meeting with the client, Mary Rogers, the team was able to narrow a vast list of requirements to the following. Mary made this defined list based on what she feels most needs attention.

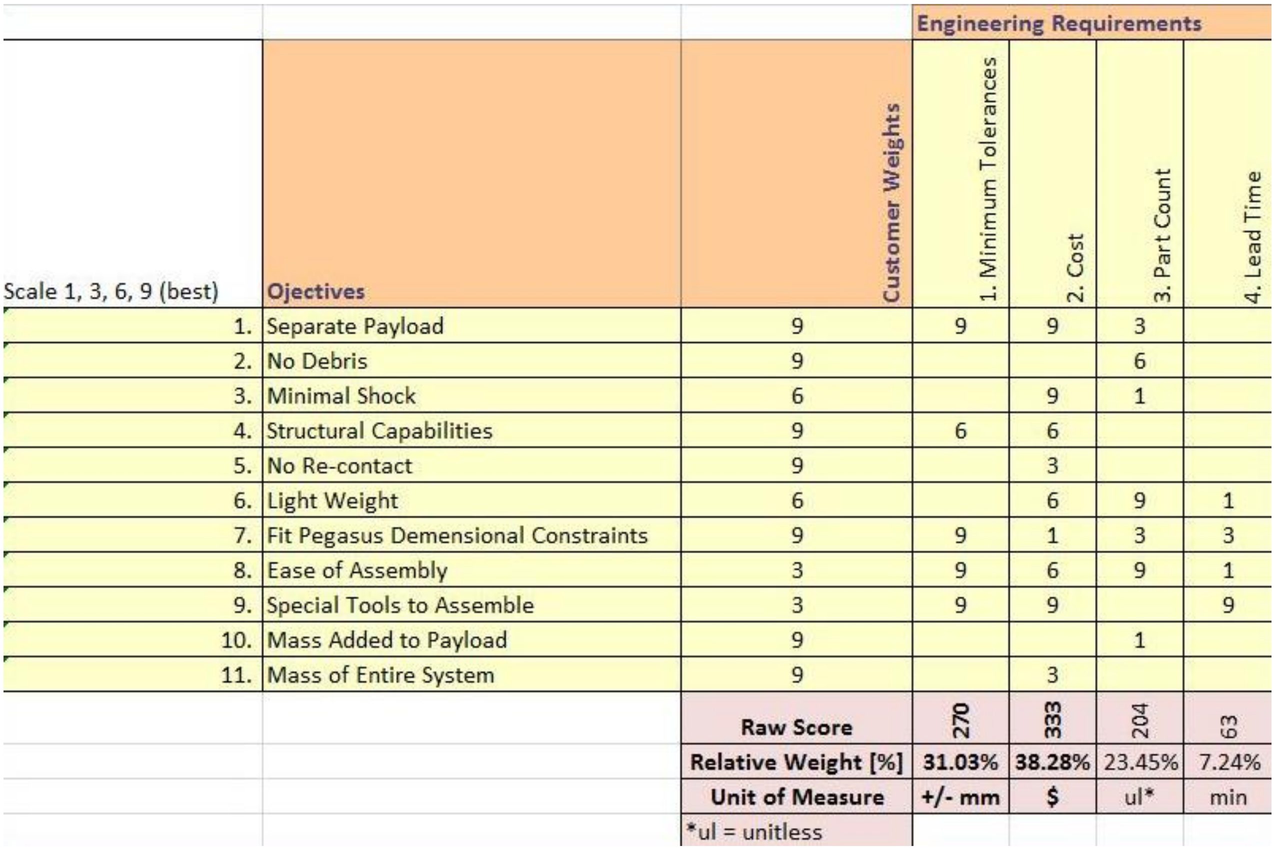
1. Minimum tolerances – The system must be extremely reliable because of the cost of the system. There cannot be any mistakes or failures during separation, therefore tolerances are small.
2. Cost - Current payload separation systems can cost upwards of $500,000 per unit. For a non-recoverable system this is enormous. The complexity of modern PSS systems lends itself to these high costs. To solve this the solution is most easily defined as simplicity.
3. Part count **-** Current payload separation systems are complex beyond what is humanly recognizable. Reducing the gross number of components will help to simplify, lessen in weight, increase reliability, and lower cost overall.
4. Lead time – The time taken to receive purchased materials prior to manufacturing.

1.9 Constraints

There are several key constraints that we as a team will need to consider based on the needs specified by our client, Mary Rogers. Below are listed material constraints that need to be considered. The material needs to withstand compressible air at supersonic speeds, when Mach number is greater than 1. This ties into the velocity that the launch vehicle needs to endure. At its highest speed, the system reaches 24,550 ft/s. In order for the design to fit the specifications of the rocket sizes, it will need a bolt circle diameter that is between 23” or 38”. Furthermore, the material needs to withstand a height of 400 nautical miles. At 400 nautical miles microgravity starts its process that will last around 6 min, and can possibly affect the surface tensions of the materials. Furthermore, the payload separation system material will need to survive temperatures which can reach upwards of 3000°F. Other major constraints include a less expensive mechanism, and a low profile so the launch vehicle can hold more of the payload and less of the mechanism. The weight of the payload is also significant because the max load it can withstand would be 485 kg. In addition, we have to design a device that can hold more than 126kg. This system will also need to endure vibrational stresses and a lateral frequency of 20 Hz. Since our client was looking for a lower cost design, the simplicity and manufacturability of the design will be considered a constraint as well.

1.10 Quality Function Deployment

The Quality Function Deployment, or QFD, can be found in Figure 1. The purpose of a QFD is to find what is most important to the client and relate it to the requirements to identify which requirement will need the most attention further along in the design process. To further explore what objectives are most important to the client, the team set up a conference call with Mary Rogers as well as a meeting and weighted each objective using a scale of 1 to 9, 9 being most important. The objectives in the rows on the left of the QFD were then scaled by the team in relation to its importance to the four requirement columns. As a result, each column was multiplied by the customer weight and then summated in the bottom rows labeled raw score.
The goal is to design a system that can withstand small scale tolerances to increase the reliability of the overall payload separation system while keeping the cost low. Due to limited building time plus the complexity of the project, it is necessary to make sure that the time spent ordering parts and materials is minimized. All of the objectives and requirements can be seen in the QFD columns and rows.



			Engineering Requirements			
Scale 1, 3, 6, 9 (best)	Ojectives	Customer Weights	1. Minimum Tolerances	2. Cost	3. Part Count	4. Lead Time
1.	Separate Payload	9	9	9	3	
2.	No Debris	9			6	
3.	Minimal Shock	6		9	1	
4.	Structural Capabilities	9	6	6		
5.	No Re-contact	9		3		
6.	Light Weight	6		6	9	1
7.	Fit Pegasus Demensional Constraints	9	9	1	3	3
8.	Ease of Assembly	3	9	6	9	1
9.	Special Tools to Assemble	3	9	9		9
10.	Mass Added to Payload	9			1	
11.	Mass of Entire System	9		3		
		Raw Score	270	333	204	63
		Relative Weight [%]	31.03%	38.28%	23.45%	7.24%
		Unit of Measure	+/- mm	$	ul*	min
		*ul = unitless				

Figure 1: QFD

1.11 Working Environment

When leaving Earth's atmosphere and traveling at Mach speeds, a variety of properties change as explained in the constraints section of this report. Due to such extreme velocities and temperatures, the materials tend to be manipulated on a molecular level that can cause failures in the system. Orbit Sciences is interested in reaching heights as high as 35, 785 km, or also known as geocentric orbit. Geocentric orbit is the most common height that satellites orbit around Earth as shown in Figure 1 as the dotted black line on the outer surface. To further explain the environment of the launching process see Figure 2. First the launch vehicle, in this case the Pegasus, is belly launched from an airplane at around 39,000 feet above sea level. After the first stage ignition and burnout, the second stage begins at 229,900 feet. The payload separation system must undergo a third stage and finally separates the payload at a height of 400 nmi. The system must be designed to withstand all of these environmental conditions.

Chapter 2. Concept Generation and Selection

2.1 Five Initial Design Concepts

The concept generation selection process involved developing five initial design concepts. Each concept is illustrated below with a brief description including advantages and disadvantages of the design.

Concept 1 is an interlocking design that is made up of a top and bottom ring. The bottom ring is actuated by a driving gear which will pull the arms inward, releasing the payload from the rocket. At this point, springs on the outside of the ring will push the payload away causing no re-contact. See Figure 2 for a simple sketch of the design. The main advantage of this interlocking design is simplicity. The disadvantage to this design is the shock impact, this is because the payload will have an instant release.

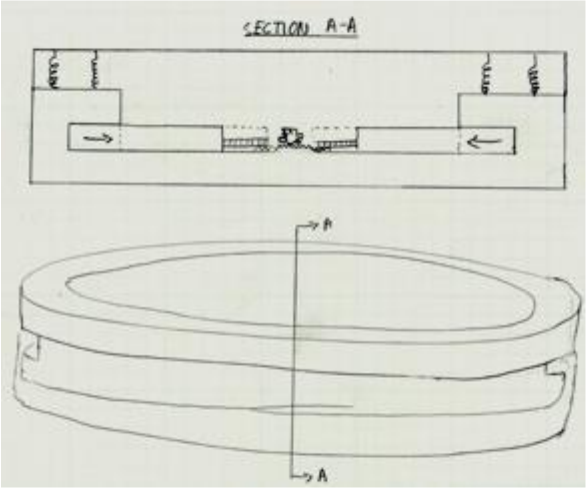


Figure 2: Concept 1 Interlock Design

Concept 2 is a spring loaded gear system that is locked in place similar to a blender locked into the base rotor. A large gear with four teeth will rotate to a position. The gear is powered by a programmed servo motor. Once the big gear reaches the designated angle, the payload adaptor will be pushed away by kick off springs mounted underneath the four teeth. The four teeth will rotate into voids where they will not obstruct the kick off springs and ultimately cause the separation. See Figure 3 for a sketch of the design.

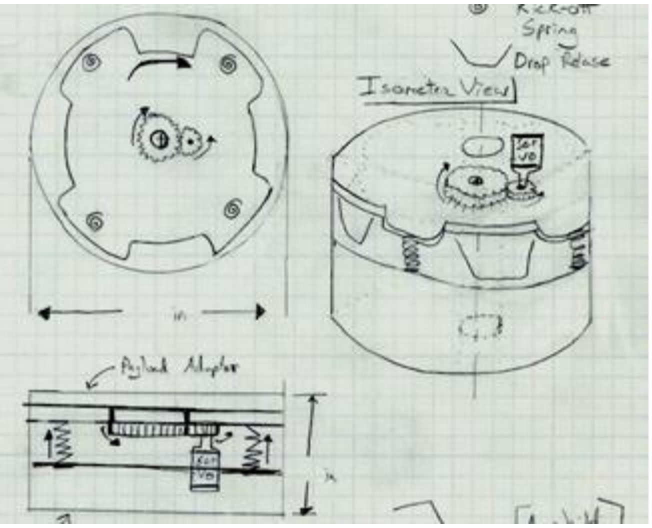


Figure 3: Concept 2 Blender

Concept 3 is a worm screw powered by a programmed servo motor that will unthread a double sided bolt. This double sided bolt will be threaded into both female ends of the launch vehicle adaptor as well as the payload adaptor. Once separation process is initiated, the bolt will be rotated until it's free of the payload. Once free, the payload will then be pushed away by kick off springs. See Figure 4 for a sketch of the worm design.

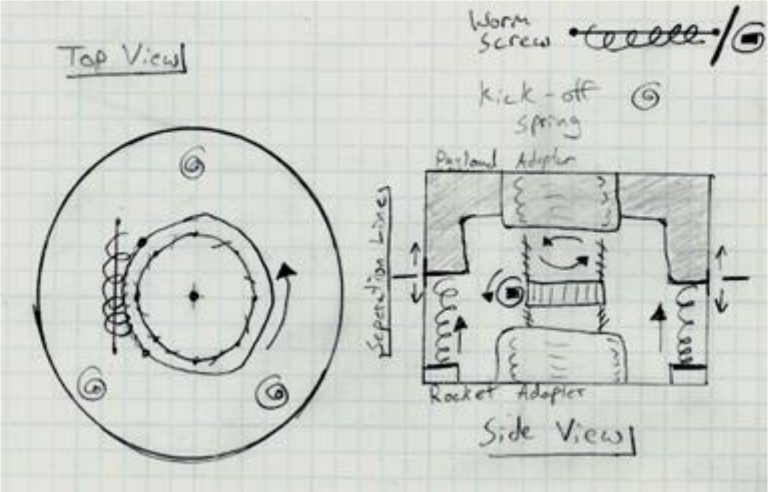


Figure 4: Concept 3 Worm

Concept 4 uses a servo motor to turn a centered shaft. The shaft will have three spokes equally spaced apart with hinges. Similar to a bike rim, the spokes will travel along slots on the perimeter until the plate has rotated enough for the kick off springs to pop up through the holes.

Once the springs are free from the plate, the payload adaptor separates from the launch vehicle. See Figure 5 for a sketch of the tangent spoke design.

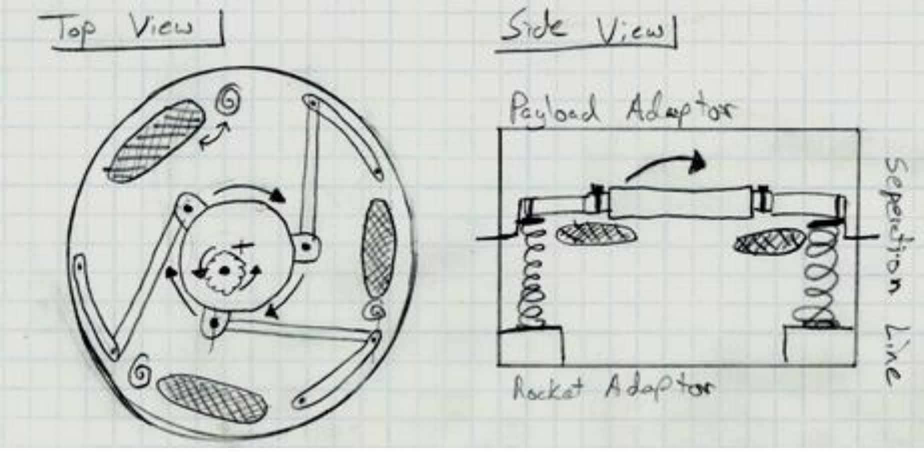


Figure 5: Concept 4 Tangent Spoke

Concept 5 was inspired by a BNC connector that is most commonly used in lab. The simple design is made of two cylinders, a male and female end that connects via two pins. The male cylinder is connected to the payload while the female cylinder rotates inside the launch vehicle similar to a large bearing. Once a motor rotates the female end, the cylinders disconnect, and a floor that is preloaded with springs pushes away the payload to avoid re-contact. The advantage of this design is the simplicity and minimal number of parts. Although simple, the cylinders are heavy and can cause weight problems further along in the design process. See Figure 6 for a sketch of the BNC design idea.

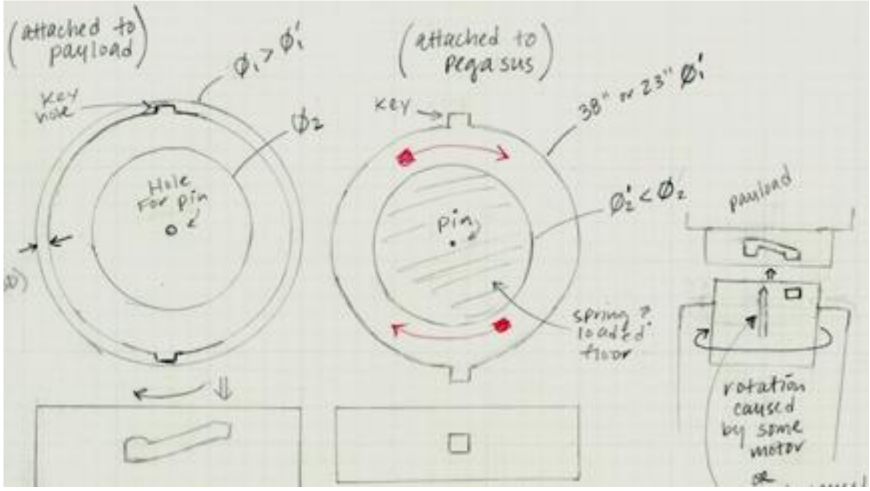
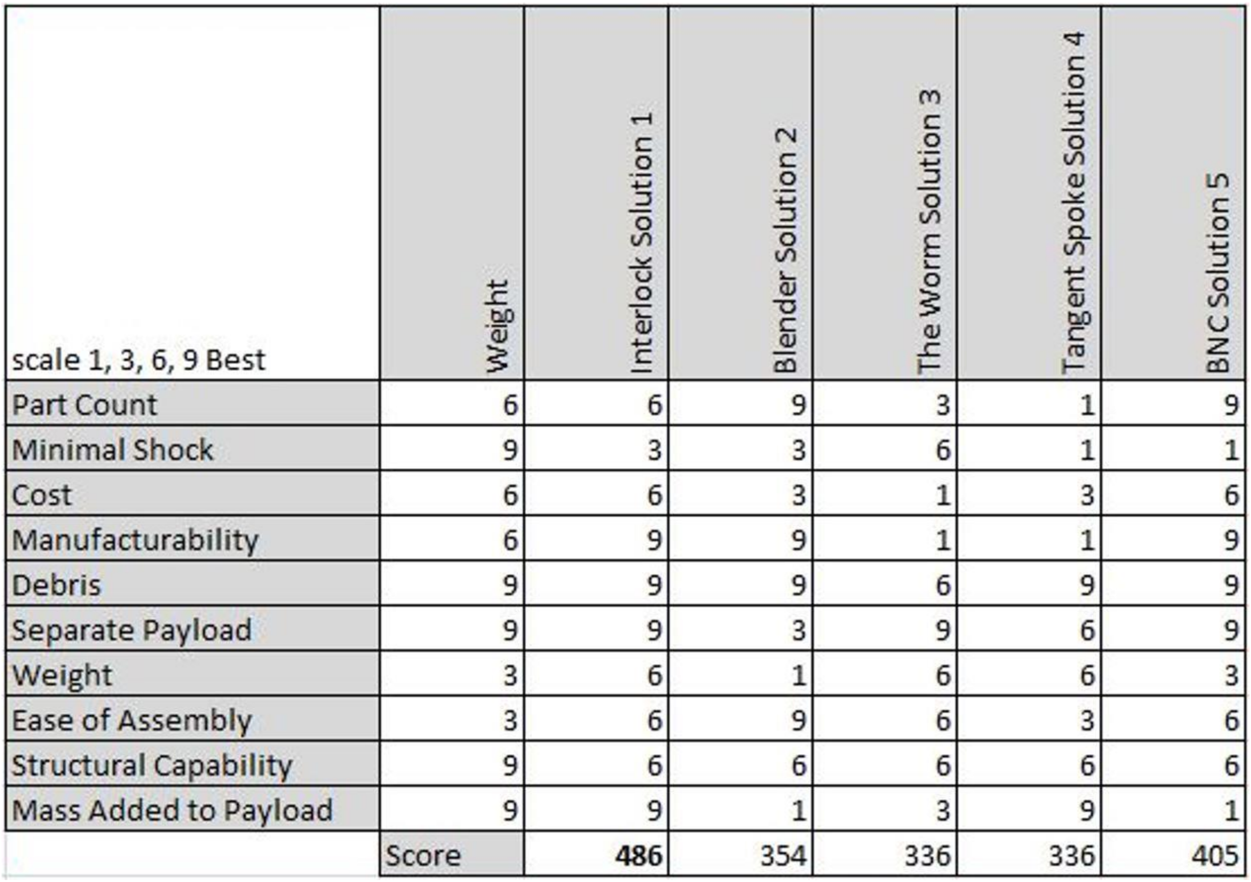


Figure 6: Concept 5 BNC Connector

2.2 Decision matrix

The decision matrix helped to narrow down the best design concept. See Figure 7 for the decision matrix. A multiplier of 1, 3, 6, and 9 were used to weigh the design criteria listed in the rows. The columns are a list of the 5 initial design concepts. The team weighed the criterion based on what the client thought was most important, 9 being the best. Minimal shock, debris, separate payload, structural capability, and mass added to the payload all received 9's for most important design criterion. It is essential that the payload separation system deliver the payload into orbit with minimal shock. Therefore there must be zero failures in the structural design and cause zero debris so to minimize space trash or re-contact with the payload. Part count, cost, and manufacturability received a 6, deemed second most important design criterion. The number of parts needed is related to the cost and ease of manufacturability. With less parts, Orbital Sciences Corporation can manufacture the payload separation system on site, saving money overall. Weight and ease of assembly were weighted with least importance because Orbital is willing to sacrifice some weight and time for a reliable system. After each solution was compared and weighted by the designs ability to satisfy the criterion, each column was summed and the Interlock solution 1 had the highest score. The matrix shows that design concept 1 would best fit the client's needs and design requirements. The interlock was chosen as an outline for the final design.



scale 1, 3, 6, 9 Best	Weight	Interlock Solution 1	Blender Solution 2	The Worm Solution 3	Tangent Spoke Solution 4	BNC Solution 5
Part Count	6	6	9	3	1	9
Minimal Shock	9	3	3	6	1	1
Cost	6	6	3	1	3	6
Manufacturability	6	9	9	1	1	9
Debris	9	9	9	6	9	9
Separate Payload	9	9	3	9	6	9
Weight	3	6	1	6	6	3
Ease of Assembly	3	6	9	6	3	6
Structural Capability	9	6	6	6	6	6
Mass Added to Payload	9	9	1	3	9	1
	Score	**486**	354	336	336	405

Figure 7: Design Matrix

2.3 Final Design

The final design consists of a rocket ring, a payload ring, 4 keys, 4 solenoids, and 6 metallic mesh kick off springs. All design components, including the quantity and material selection, can be seen in Table 2. See Figure 8 for an isometric view of the final design in SolidWorks. The diameter of the payload ring is 23 inches.

Table 2: Material Selection

Design Components	**Quantity**	**Material**
Payload Ring (PR)	1	7075 Aluminum
Rocket Ring (RR)	1	7075 Aluminum
Key	4	7075 Aluminum
Solenoid	4	n/a
Metallic Mesh Kickoff Springs	6	AISI 304 Stainless Steel

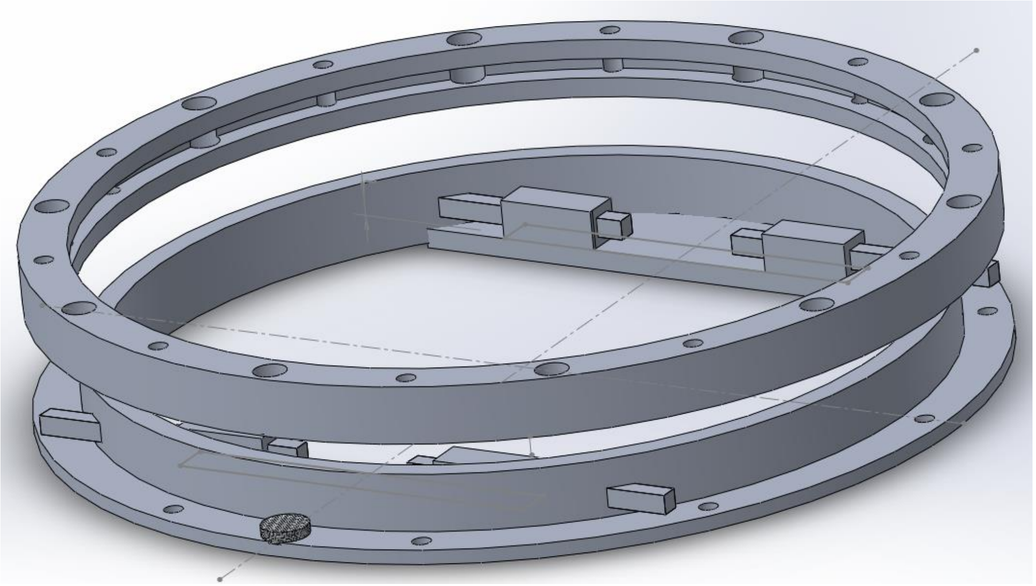


Figure 8: Isometric View

The payload ring is attached to and will remain with the payload after separation. On the inner surface of the payload ring is a 1 centimeter deep channel where the keys are later inserted during the loading process. The payload ring will be machined from a solid plate of 7075 aluminum. Holes will be drilled in a symmetric pattern around the ring for both attachment to the payload and reduction in mass. The estimated payload ring weight will be 5.29 lbs. This is a weight reduction from the current payload separation system whose payload ring weights approximately 6 lb. See Figure 9 for a SolidWorks view of the payload ring in relation to the final design.

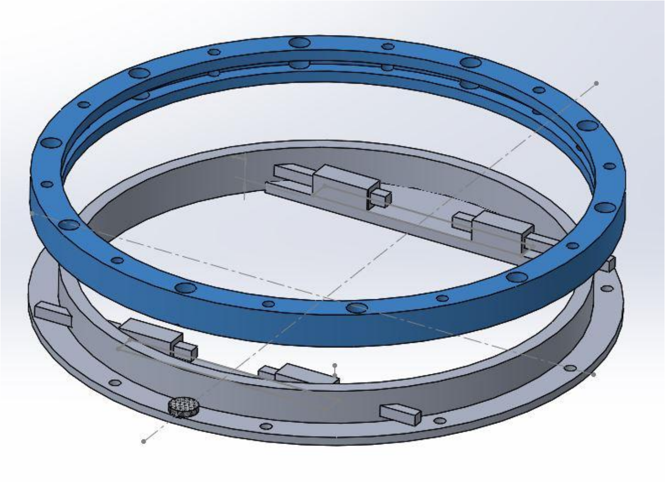


Figure 9: Payload Ring

The rocket ring is attached to the rocket or Pegasus launch vehicle and will disintegrate with the third stage rocket debris. The rocket ring will have two mounting plates on the inside of the ring, one for each side. These mounting plates will have housings for the keys to be recessed into once the releasing process is initiated. The rocket ring, including the base plates and key housing, will be machined from a single plate of 7075 aluminum. Recesses on the perimeter of the ring lip will hold the mesh kick off springs in place. The RR will weigh 7.29 lbs. See Figure 10 for a view of the rocket ring in relation to the overall final design.

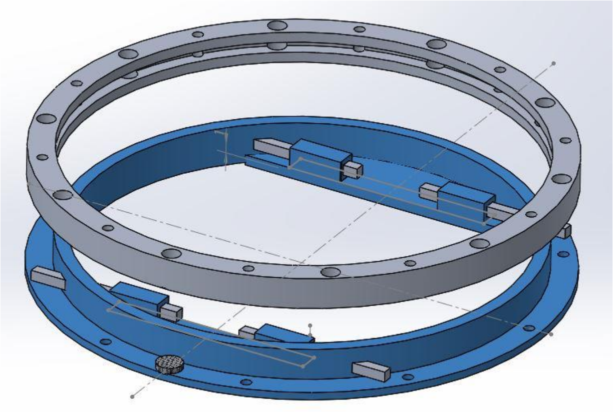


Figure 10: Rocket Ring

The four keys are cut from a 3/8 square inch 7075 aluminum rod and are approximately 10 cm long. Each key will weigh approximately 0.09 lbs. The PR will be secured to the rocket when the keys are engaged and inserted into the inner channel of the payload ring. An analysis was performed on the keys to make sure the keys would not fail due to shear stress caused by the maximum dynamic pressure. See Figure 11 and 12 for a SolidWorks view of one key and the relation of the four keys to the final design.

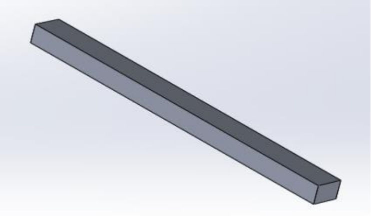


Figure 11: Keys

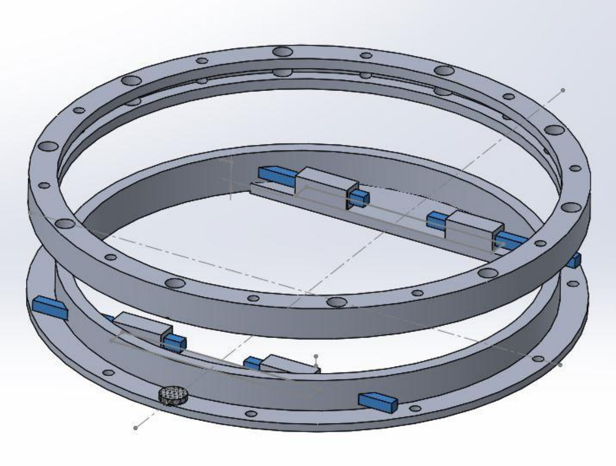


Figure 12: Keys to Final Design

Four solenoids will be purchased and fastened onto the base plates and keys. When signaled, each solenoid will actuate, pulling each key into their respective housing simultaneously by 1 cm. Once the keys reach their final resting position the kick off springs will engage. See Figure 13 for a photograph of the solenoid and Figure 14 for an isometric view of the final design with the base plates highlighted to represent where the solenoids will be fastened.

Figure 13: Solenoid

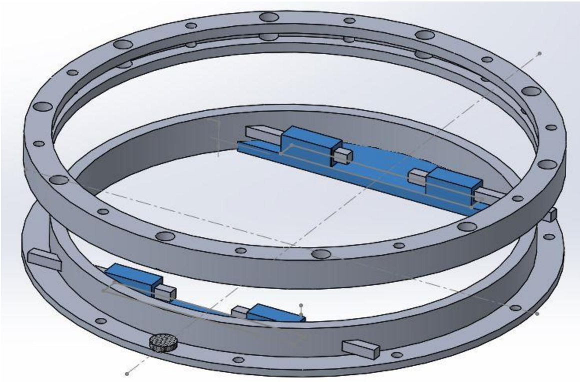


Figure 14: Base Plate

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 the analysis section of this report. The analysis confirms that the kick off springs will successfully separate the payload from the rocket under constant acceleration. See Figure 15 for the springs in relation to the final design. Figure 16 is an enlarged photo of the metallic mesh spring.

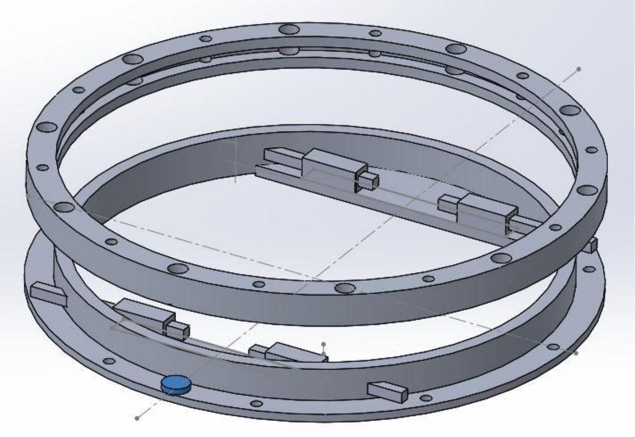


Figure 15: Springs

Figure 16: Metallic Mesh Spring [10]

See appendix A for various views of the final design.

Chapter 3. Engineering Analysis

3.1 Analysis Dimensions

Preliminary dimensions used for analysis (See appendix A for dimensional drawings):

***Subject to change*

Rocket Ring (RR)

- RR OD = 58.42 cm
- RR ID = 53.42 cm
- RR wall thickness = 2.5 cm
- RR contact height = 7.5 cm

Payload Ring (PR)

- PR OD = 58.44 cm
- PR ID = 56.44 cm
- PR lip thickness = 1.0 cm
- PR wall thickness = 1.25 cm
- PR height = 3.0 cm

Key

- Width = 1.0 cm
- Height = 1.0 cm
- Length = 10 cm
- Key contact surface length = 1.0 cm

Key Housing

- Width = 1.5 cm
- Height = 1.5 cm
- Length = 7.0 cm

3.2 Shear Force on Keys

Key calculations, based on 1cm X 1cm:

Variables:		**Units:**
A_{s-c}	Key contact surface area	m^2
A_c	Cross sectional area of key	m^2

q_{max}	Maximum dynamic pressure	Pa
q_{key}	Dynamic pressure on each key	Pa
P	Pressure	Pa
ρ	Density	kg/m^3
F_g	Force due to gravity	N
$F_{g\text{-}key}$	Force due to gravity on key	N
F_t	Total force acting on keys	N
W	Weight of payload	kg
I	Key moment of inertia	m^4
t	Key thickness	m
V	Velocity	m/s
g_{local}	Local gravitational constant	m/s^2
τ_{max}	Maximum allowable shear	Pa
F.S.	Factor of safety	N/A
a	Acceleration	m/s^2
$M_{payload}$	Mass of payload	kg
$\dot{m}$	Mass flow rate of CO_2 leaving tank	kg/s
T	Thrust	N
m_t	Mass of total system	kg
m_{CO_2}	Mass of CO_2 in tank	kg
t	Time	s

Equations:

$$A_{s-c} = lw \tag{1}$$

$$A_c = wh \tag{2}$$

$$q_{max} = \frac{1}{2}\rho V^2 \tag{3}$$

$$q_{key} = \frac{q_{max}}{4\ keys} \tag{4}$$

$$F_g = Wg \tag{5}$$

$$F_{g-key} = \frac{F_g}{4\ keys} \tag{6}$$

$$F_t = q_{key}A_{s-c} + M_{payload}a \tag{7}$$

$$\tau = \frac{3F_t}{2A_c} \tag{8}$$

$$F.S. = \frac{\tau}{\tau_{max}} \tag{9}$$

Solved Values:

τ = 59342121.54 Pa

F.S. = 5.58

The shear force is the dominate force that will cause the keys to fail from the time the Pegasus launch vehicle begins ignition stage 1 to the final stage of payload separation. During analysis and visualization, the keys ended up being the failure point without any question. The keys are by far the most exposed piece to the PSS and the forces upon lift off or stage 1 will be the only force that would have the strength to break the keys and cause a catastrophic failure throughout the whole system. The shear force that would cause the keys to fail is calculated by summing the force of the payload due to gravity acting on the key and the force due to the max dynamic pressure caused by the first stage of ignition. To illustrate, forces caused by the max dynamic pressure were calculated by multiplying q_{key} by $A_{s\text{-}c}$. The $A_{s\text{-}c}$, key contact surface area, was calculated using simple geometry and came to be 0.000134 m^2. See Figure 17 for the angles and dimensions that were found to calculate an accurate surface area. The values of each variable can be seen in Table 3.

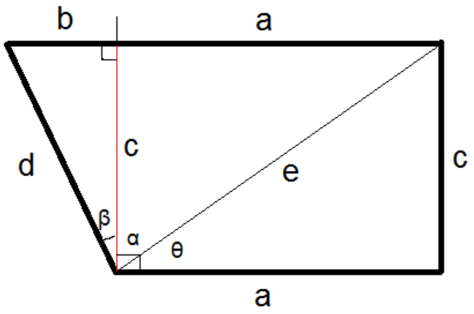


Figure 17: Angles on Key, Geometry of calculated contact surface area of key on payload ring

Table 3: Values of each Variable

a [m]	**b [m]**	**c [m] (thickness)**
0.0075	0.0119	0.01
d [m] (diagonal length)	**e [m] (diagonal)**	**f [m] (width)**
0.0156	0.0125	0.0156
θ [Degrees]	**β [Degrees]**	**α [Degrees]**
53.13	50.13	36.87

The forces due to gravity and weight of the payload are calculated by multiplying the mass of the payload by the acceleration where the max dynamic pressure was calculated. See variables and equations for clarification of definitions. Using equation 7 and 8, the shear force due to these two forces resulted in a value of 5.93 x 10^7 Pa. 7075 Aluminum has been tested to shear at 3.31 x 10^8 Pa, therefore concluding with a factor of safety of 5.58. This confirms that the keys will not fail due to shear force given that the keys are made out of 7075 Aluminum. The design is safe and reliable.

3.3 Solenoid Analysis

The final derivation of the design has moved from servos to solenoids for key retraction force. Solenoids consist of a magnetic solid placed within an electrical field. When a current is applied to the field, the magnetic solid will move to the opposite end of the field. Solenoids are very common industrial components as they are highly reliable by nature. Solenoids utilize one moving part by design, whereas servos are more complex and prone to failure. Solenoids are also advantageous over servos as they are actuated by a simple on/off or in this case engaged/disengaged state. Solenoids are high speed, reaching their full stroke much quicker than a servo will. The keys will now be preloaded by the metallic mesh kickoff springs, developing friction between the keys and the corresponding key channel on the PR. For a clean separation, with minimal torque developing on the keys a solenoid will provide the actuation needed, at the high speed desired.

The solenoids chosen had to meet the summation of two force criteria.

1. The weight of the keys
2. The frictional force at the key and PR channel interface

The weight of one key is small, only 1.48 oz. The force due to friction is the larger challenge. The frictional constant μ for polished aluminum surfaces is μ=0.4. The kickoff springs develop 3000N of normal force on the keys at the PR interface.

Force due to friction:

$$F_f = F_n \mu \tag{10}$$

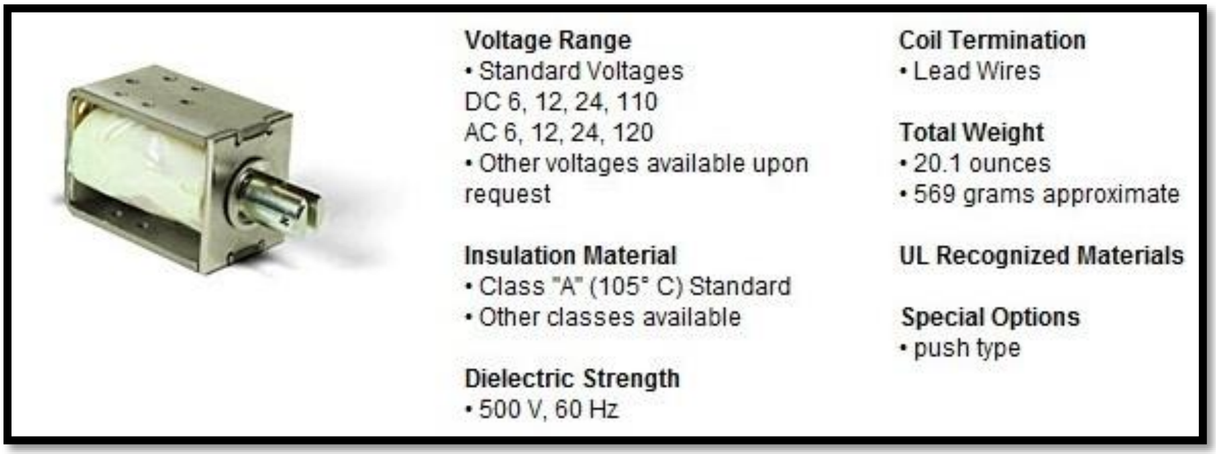
Where:

F_f = Frictional force, [N]

F_n = Normal force, [N]

μ = Coefficient of friction

Using the above equation, the frictional force between the aluminum surfaces is F_f=1200N. This is very large, too large in fact for any reasonably sized solenoids. To accommodate the limits of solenoids the team has decided to coat the aluminum contact surfaces with Teflon. Teflon has a very low friction coefficient of only 0.04, making the F_f=120N. The new frictional force is well within the operational limits of many off-the-shelf aerospace quality solenoids. This said, the team has selected Magnet-Schults of America D-frame 612 solenoid [9]. This solenoid has the force required to overcome the static friction of the Teflon-Teflon surface. Once static friction is overcome, the kinetic friction is less and will be tolerated by the 612 solenoid. This solenoid has a stroke range of 0.25 to 1.0 within the needed 1cm (0.39in). See Figure 18 below for a photo of the 612 solenoid and its given information.



Voltage Range
- Standard Voltages
DC 6, 12, 24, 110
AC 6, 12, 24, 120
- Other voltages available upon request

Insulation Material
- Class "A" (105° C) Standard
- Other classes available

Dielectric Strength
- 500 V, 60 Hz

Coil Termination
- Lead Wires

Total Weight
- 20.1 ounces
- 569 grams approximate

UL Recognized Materials

Special Options
- push type

Figure 18: 612 Solenoid Specifications

3.4 Metallic Mesh Kickoff Springs Analysis

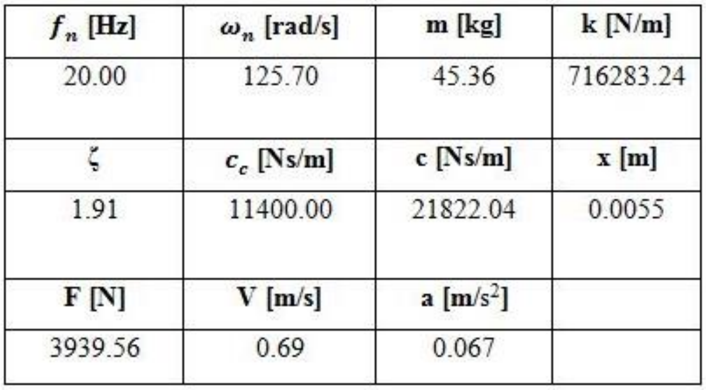
Our final proposal for the kickoff mechanism has been switched to metallic mesh kickoff springs. The team was previously investigating the use of impinging jets on a target surface with compressed air. While the jets do allow for a controlled kickoff method, they are not reliable and will have a higher failure potential. A conventional coil spring has a much more reliable kickoff method. Conventional coil springs however are not effectively damped (disregard internal damping characteristics of material) and have a very fast unloading rate. This is not desired, as minimal shock to payload was one of the top criteria for the PSS. Metallic mesh springs were found to be the best choice. Metallic mesh utilizes dry friction Coulomb damping as the thousands of fibers in the mesh create friction with each other. As the material deforms within its plastic range, the fibers slow the return stroke of the spring, effectively damping the system. Analytically it was very difficult to estimate the damping qualities of the mesh but estimation for the acceleration is given below. It was found that mesh springs do not have the high damping constant of a viscous damped system, but they do limit the unload speed of the payload, thus limiting the shock on the system.

The worst case scenario was analyzed for the springs, a 600lb payload. Under these circumstances the mesh springs chosen will have to be used in parallel. Each spring has a maximum force of 500N and with the max force due to gravity on the payload at 2640N, 6 springs will have to be used, generating 3000N of normal force when combined.

Under the above circumstances the springs will generate an acceleration of the payload of 0.067 m/s^2. This acceleration is roughly 1/10 the current acceleration by kickoff springs, and hence 1/10 the overall force assumed by the payload.

Metallic mesh spring calculations:

Table 4: Kickoff Spring Calculations



f_n [Hz]	ω_n [rad/s]	m [kg]	k [N/m]
20.00	125.70	45.36	716283.24
ζ	**c_c [Ns/m]**	**c [Ns/m]**	**x [m]**
1.91	11400.00	21822.04	0.0055
F [N]	**V [m/s]**	**a [m/s^2]**	
3939.56	0.69	0.067	

$$f_n = 2\pi\omega_n \tag{11}$$

$$\omega_n = \sqrt{\frac{k}{m}} \tag{12}$$

$$\zeta = \frac{c}{2\sqrt{km}} \tag{13}$$

$$V = \sqrt{\frac{kx^2}{m}} \tag{14}$$

Where:

f_n= Natural frequency, [Hz]

ω_n= Natural frequency, [rad/s]

k = Spring stiffness, [N/m]

m = Mass of total system, [kg]

ζ = Damping ratio

c = Damping coefficient, [Ns/m]

V = Separation velocity, [m/s]

a = Separation acceleration, [m/s^2]

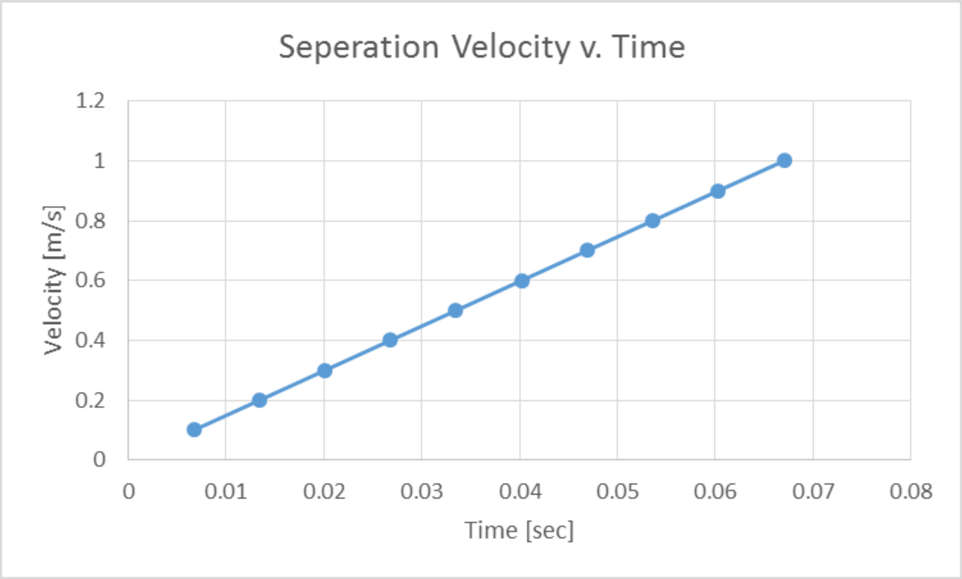


Figure 19: Separation Velocity vs. Time

Chapter 4. Cost Analysis

4.1 Bill of Materials

Table 5: Bill of Materials

Material	**Quantity**	**Unit Cost**
7075 Aluminum Key 3/8" x 3/8" x 24"	1	$2.52
7075 Aluminium plate 24" x 48" x 1"	1	$654.24
Solenoid	4	$32.75
Nuts/ Bolts/ Misc.	TBD	$50.00
Total Cost		**$837.76**

4.2 Man Power Costs

Table 6: Man Power Cost

Team Members	**Pay ($/hr)**	**Rocket Ring Fabrication (hr)**	**Payload Ring Fabrication (hr)**	**Key Fabrication (hr)**	**Assembly (hr)**	
Matthew Mylan	20	10	10	2		
Mark Majkrzak	20	10	10		1	

Kate Prentice	20	10	10			
Alen Younan	20			4	1	
Ben Dirgo	20			4	2	
Jason McCall	20	10	10			
	Total Cost ($)	800	800	200	80	**1880**

4.3 Manufacturing Costs

One of the goals of this design is to be more cost effective compared to current systems being used today. We believe that this design will save the client money while not sacrificing reliability. Assuming that the client will manufacture in house, there will be an initial investment to train employees, and, if necessary, buy new equipment for building it. We estimate that the initial investment can range from $25,000 - $150,000 based on the client’s needs. Such as if Orbital does not have the basic shop equipment needed for manufacture.

The cost of materials (shown in detail in Figure XYZ: BOM) are estimated to be between $1,000 and $1,500. This includes the raw aluminum that will be machined in house to our specifications, the required electronics and gears for making the keys that actuate, and miscellaneous nuts bolts and other materials that may be needed. The reason for a large range for parts is because the price in aluminum varies by supplier.

The Pegasus rocket has had 42 launches in the 22 years it has been in service [5], we don’t expect that number to change in the years to come. That comes out to roughly 1.5 launches a year. If Orbital Sciences makes roughly 25% profit on the Pegasus out of the $11 million Orbital charges for a flight they make $2.75 million. Finally, assuming they spread out that cost among the subsystems in the vehicle, an initial investment of $25,000 plus the cost of materials at $1,500 would be paid back after the first flight, in 1 year. All these assumptions would of course change the final result of when the payback point if even one was off by a significant amount.

Chapter 5. Conclusions

5.1 Project Planning

The Fall 2013 Gantt chart was one way for the team to keep on track with all the necessary tasks and deadlines. The chart was useful when the team needed to reference deadlines. Although due to frequent schedule changes, the chart became a hassle to change regularly. All in all, the Gantt chart was constantly changed and as a result became a timeline that was constructed as deadlines passed rather than a timeline to follow. The final Gantt chart that the team concluded with is located in appendix B.1.

In addition, it was requested that a Gantt chart be constructed for next semester, Spring 2014. This Gantt chart was made upon assumptions regarding the manufacturing of the product itself. Everything from ordering the parts to assembly is shown in the chart. The image of the Spring 2014 Gantt chart is shown in appendix B.2.

The Spring 2014 Gantt chart shows how the team will complete the manufacturing, assembly, and testing by April 25, 2014. The manufacturing process will include milling the payload ring and the rocket ring out of one solid part of aluminum. Testing is also included in the upcoming semester although is currently being negotiated. Overall, the final product and presentation to Orbital Sciences will be finalized in the last week of April.

5.2 Conclusion

In conclusion, the problem description was generated for the Payload Separation System Project. This problem description is that Orbital Sciences Corporation, located in Phoenix Arizona, is interested in designing a PSS that is lighter, less expensive, less complicated, and imparts minimal shock level into the payload. In addition, the concept generation process was one of the most important steps the solution. The five concepts that were generated were the Interlock, Blender, Worm, Tangent Spoke, and BNC design. The final design was an iteration off of the Interlock design given the fact that the design matrix showed it as the best design in multiple categories. Furthermore the engineering analysis was the most tedious part of the entire final design process. The analysis involved the mesh kick off springs, the keys and the solenoid. Based on many mathematical equations and much time, it was confirmed that each piece of the system analyzed would work without breaking or fracturing in any way. Finally what was done to complete the process was the cost analysis. The two costs analyses that were completed were the Manpower Cost and the Part Cost. The Manpower Cost ended up adding to about $1880 which would be from $20/hr per person. In addition, the Part Cost that was generated added up to $837.76, which is under our $1000 budget given by Orbital Sciences. All in all, everything with the design ended up how it should as in the analysis was successful and the parts needed came under budget.

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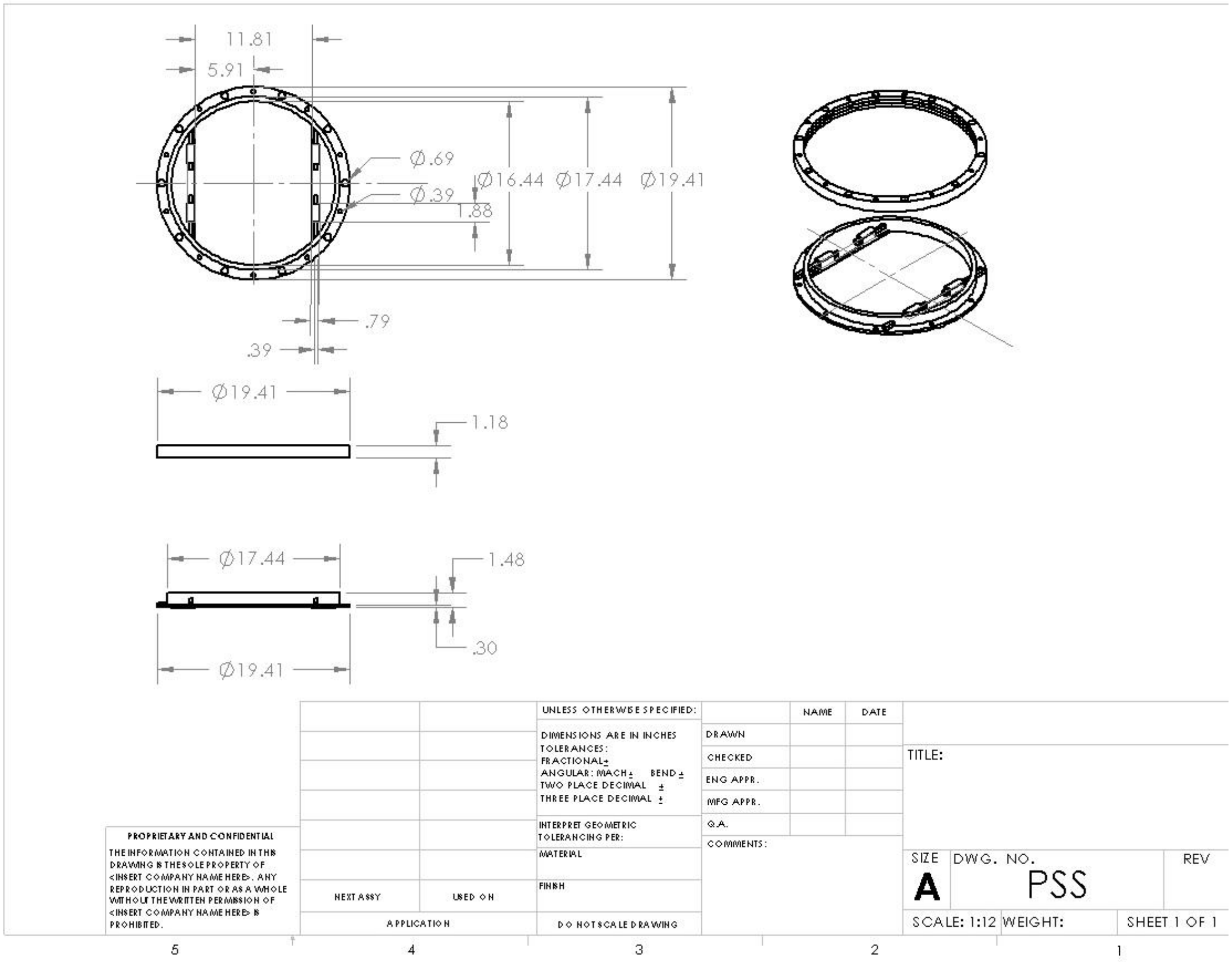
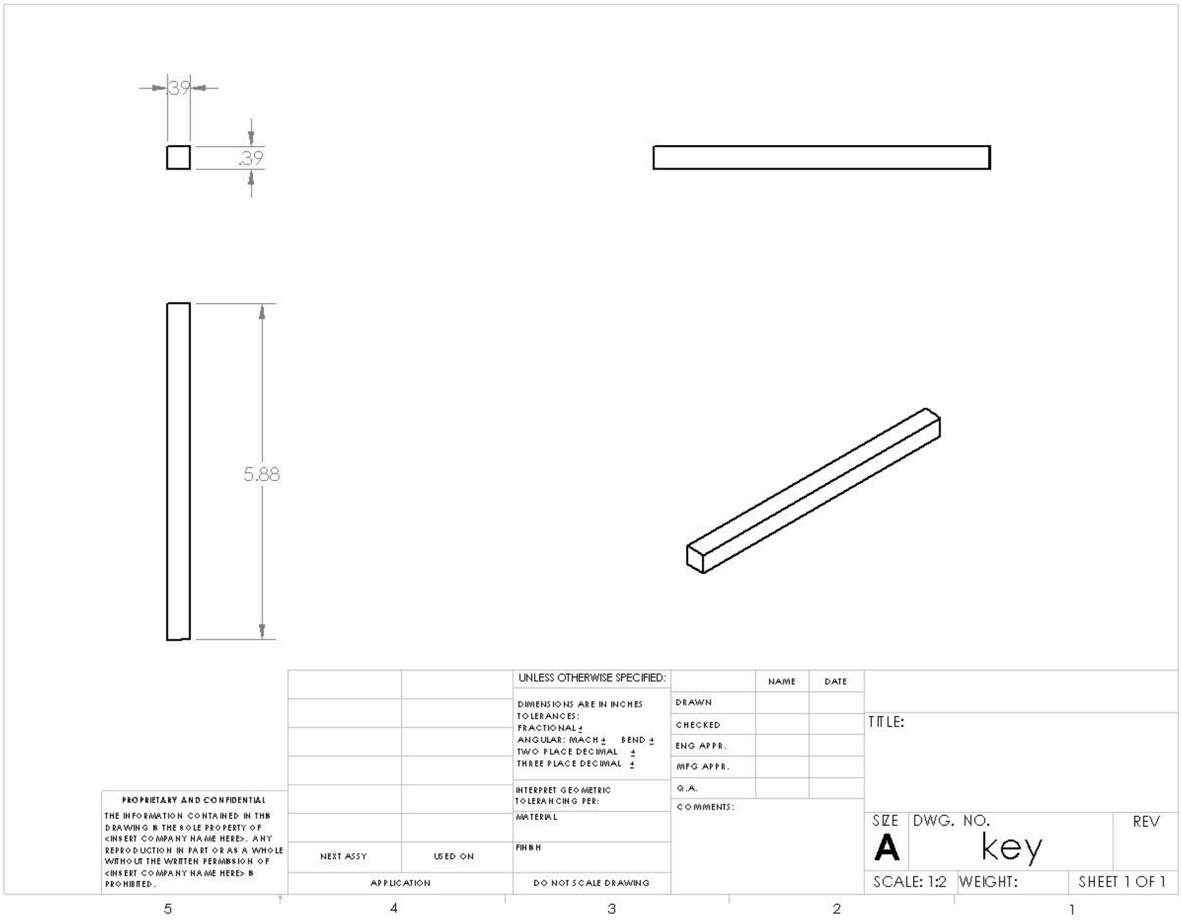
Appendix

A.1 Dimensional Drawing



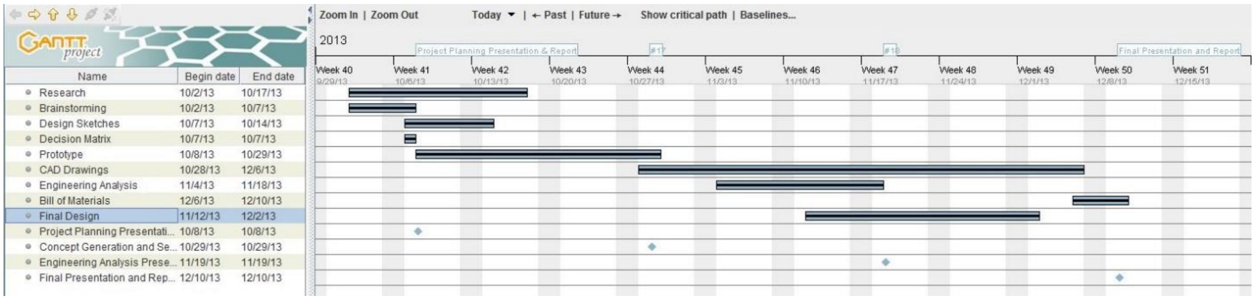
*Note: 1:12 scale

A.2 Key Dimensional Drawing



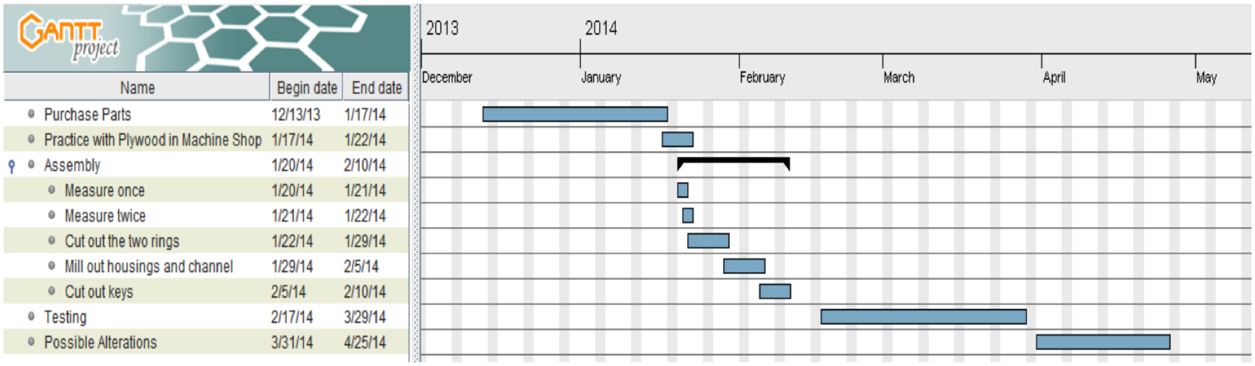
*Note: 1:12 scale

B.1 Fall 2013 Gantt Chart



Name	Begin date	End date
Research	10/2/13	10/17/13
Brainstorming	10/2/13	10/7/13
Design Sketches	10/7/13	10/14/13
Decision Matrix	10/7/13	10/7/13
Prototype	10/8/13	10/29/13
CAD Drawings	10/28/13	12/6/13
Engineering Analysis	11/4/13	11/18/13
Bill of Materials	12/6/13	12/10/13
Final Design	11/12/13	12/2/13
Project Planning Presentati...	10/8/13	10/8/13
Concept Generation and Se...	10/29/13	10/29/13
Engineering Analysis Prese...	11/19/13	11/19/13
Final Presentation and Rep...	12/10/13	12/10/13

B.2 Spring 2013 Gantt Chart



Name	Begin date	End date
Purchase Parts	12/13/13	1/17/14
Practice with Plywood in Machine Shop	1/17/14	1/22/14
Assembly	1/20/14	2/10/14
Measure once	1/20/14	1/21/14
Measure twice	1/21/14	1/22/14
Cut out the two rings	1/22/14	1/29/14
Mill out housings and channel	1/29/14	2/5/14
Cut out keys	2/5/14	2/10/14
Testing	2/17/14	3/29/14
Possible Alterations	3/31/14	4/25/14