Payload Separation System

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Progress Report

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 re-design 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.

1.6 Final Design

The final design consists of a rocket ring, a payload ring, 4 cylindrical keys, 4 solenoids, and three 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. Later in the semester there is a possibility that the base plates on the RR will be altered into a pinwheel pattern to mount the solenoids more symmetrically and therefore distribute the weight more evenly.

Table 1**:** Material Selection

Design Components	**Quantity**	**Material**
Payload Ring (PR)	1	7075 Aluminum
Rocket Ring (RR)	1	7075 Aluminum
Cylindrical Key	4	304 Stainless Steel
Solenoid	4	n/a
Metallic Mesh Kickoff Springs	3	AISI 304 Stainless Steel

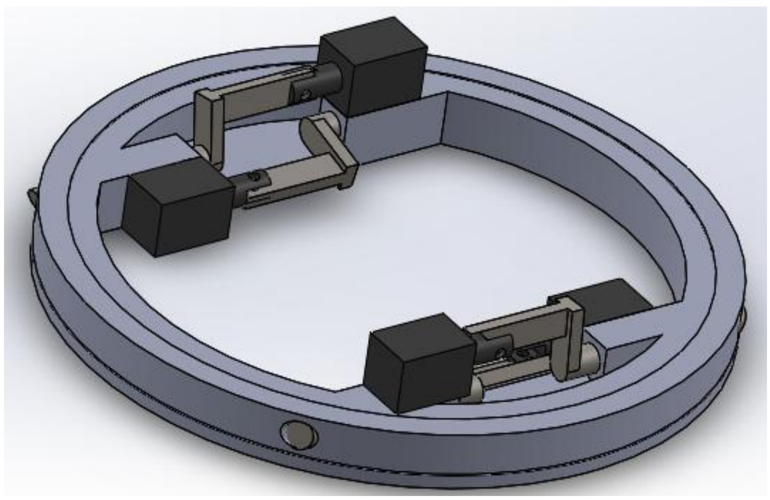

Figure 1: Isometric view fully engaged

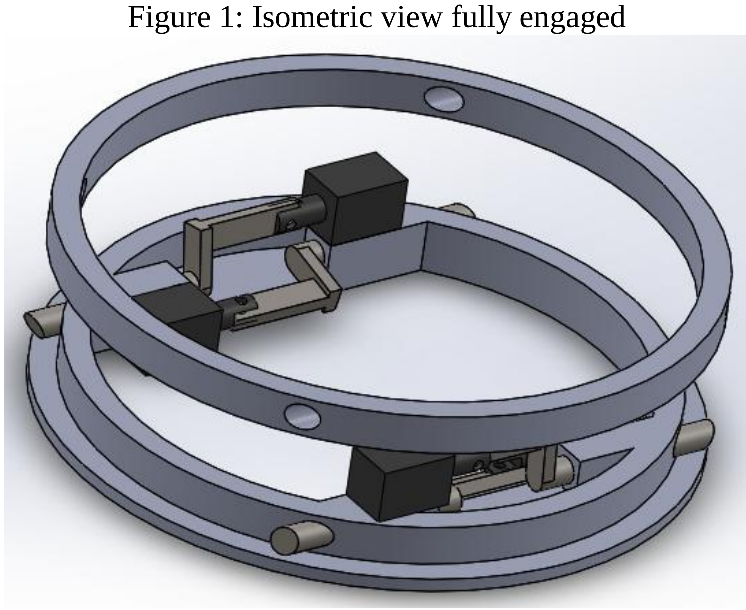

Figure 2: Isometric view after separation

Chapter 2. Manufacturing

2.1 Overall Manufacturing Process

Manufacturing of the prototype P.S.S. will require a CNC end mill, a bandsaw, and a drill press for removing the excess aluminum from the payload and rocket rings. The same equipment will be used to manufacture both rings. Stainless steel cylindrical keys will be purchased and the bandsaw will be used to cut an angle with respect to the dimensions of the payload ring. Male ends will be welded to the keys to mount to the solenoids. The solenoids will be mounted to the key housings and pins will connect the plunger of the solenoid to the male end of the key. Recesses will be milled into the lip of the RR for the springs to be mounted. There is a possibility that neodymium magnets will be used instead of metallic mesh kick off springs, and if used the magnets will be countersunk into the lip of the RR. Further exploration of the magnets can be read in chapter 3 of this report. 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/Magnets (+mounting)	Kate

2.2 Rocket Ring

The rocket ring is the most complicated piece to manufacture. 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 Tormac 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. If the G-code is correct the rocket ring will begin as a solid plate of 7075 aluminum 12”x12”x1”. The process will drill the outer diameter for the lip first, then find the center of the plate to drill out the concentric center including the base plates and key housings. Secondly, four holes 0.5” inch in diameter will be drilled for the key housings. Then, small recessed holes for the springs will be drilled into the lip to specifications. See figure 3 for a view of the rocket ring in relation to the overall final design.

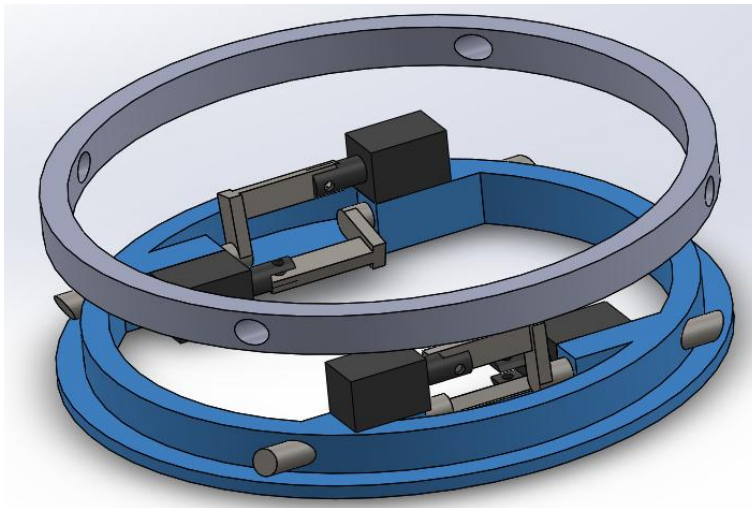

Figure 3: Rocket Ring in relation to the final design

2.3 Payload Ring

The payload ring will be cut with a similar process. First, the square plate of 7075 aluminum will be cut along the inside diameter using the using G-code with the CNC end mill. Then, an end mill will be used to drill four holes for the keys to secure the payload to the RR. Finally, the outer diameter will be cut away using the end mill to produce a payload ring of aluminum. 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 4 for a SolidWorks view of the payload ring.

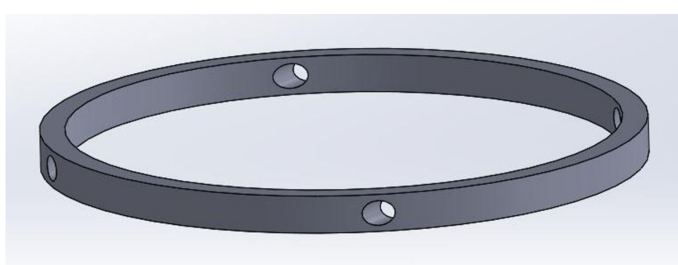

Figure 4: Payload Ring

2.4 Keys

The four keys are cut from a 0.5" diameter 7075 aluminum rod that is initially 2ft long stock. One end will be cut at an angle and the other end will be welded to a male end that will connect the key to the solenoid with a pin. 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 would not fail due to shear stress caused by the maximum dynamic pressure. See chapter three for alterations to the analysis. See figure 5 and 6 for a SolidWorks view of one key and the relation of the four keys to the solenoids in the final design.

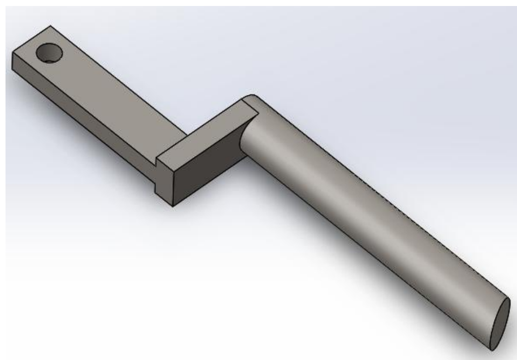

Figure 5: Keys

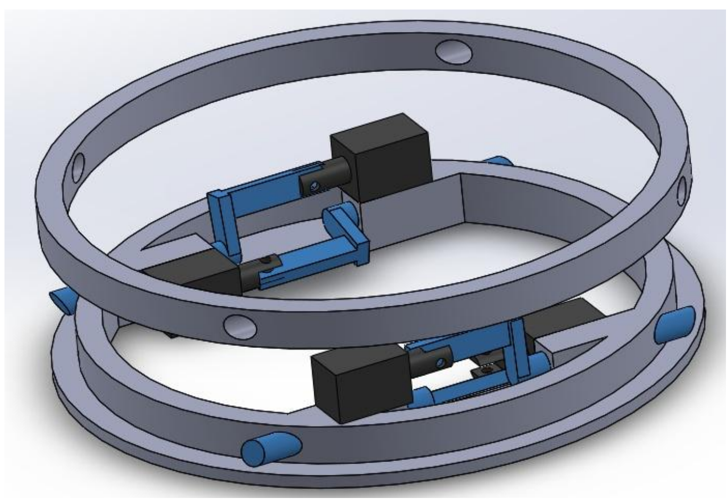

Figure 6: Keys to Final Design

2.5 Solenoid

Four solenoids will be purchased and fastened onto the key housings and keys themselves. When signaled, each solenoid will actuate, pulling each key into their respective housing simultaneously by 1 inch. Once the keys reach their final resting position the kick off springs will engage. See Figure 7 for a photograph of the solenoid and Figure 8 for an isometric view of the final design with the solenoids highlighted to show where they would be fastened.

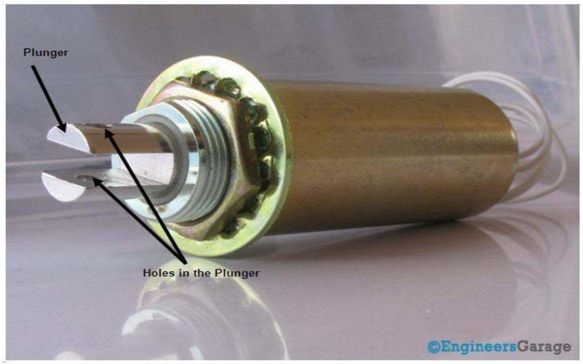

Figure 7: Solenoid

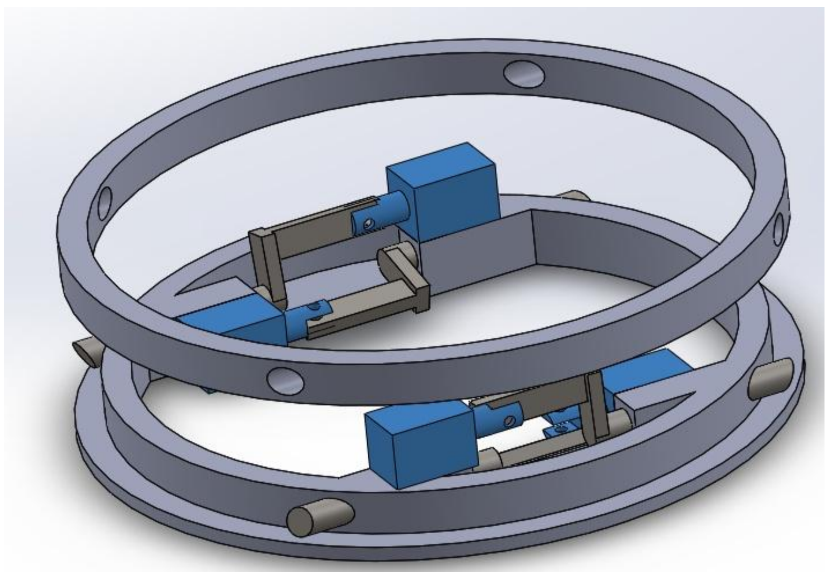

Figure 8: Solenoid with respect to the final design

2.6 Metallic Mesh Kick off Springs

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 alteration to the 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.

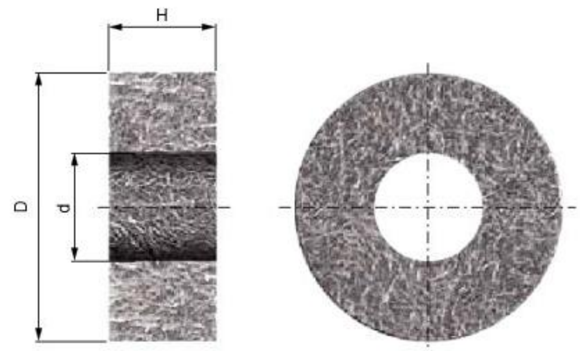

Figure 9: Metallic Mesh Spring [10]

Chapter 3. Engineering Analysis Alterations

3.1 Solenoids

In choosing the solenoids there were a variety of factors and requirements that needed to be met. Solenoid requirements:

- Overall size < 1"x1"x2"
- Stroke >= 1"
- DC Power (Battery operated)
- Force >= 14N
- Mounting compatibility

Meeting the above criteria will ensure that the solenoids will serve their purpose of retracting the keys into the housings. The largest obstacle was finding keys with enough force to overcome the force of friction (Ff) from internal qualities of the steel keys and the aluminum housing. Appropriate solenoids were found with a force of 15N.

3.2 Metallic Mesh Kickoff Springs

Metallic mesh kickoff springs have very clear advantages with respect to this project over conventional coil springs. Mesh springs are comprised of thousands of weaved SS fibers. When the material is deformed the fibers will contact each other and the similar metals will have dry friction at the contact surfaces. This Coulomb friction will slow the rebound of the spring, thus limiting the unloading factor to the payload. The internal qualities of mesh springs have shown twice the damping factor of coil springs.

Another advantage of the mesh spring comes in harmonic reduction. Metallic mesh springs are developed as harmonic reducers, often used on large pieces of machinery. On the PSS the mesh will serve a similar purpose and limit any potential harmonic that may arise during flight, further preventing damage to the payload.

3.3 Key Analysis Alterations

The keys are one of the most important, if not the most important part of this whole project. Because of this fact, there needs to be a 100% chance that these will work. To do this, the keys were modified from a square shape key to what is now a cylindrical key. This makes the manufacturing process easier, and if nothing else it makes it stronger. After analysis was done using the new cylindrical keys, it turns out that the cylinders had a better factor of safety. In addition, the keys were changed from an aluminum material to a steel material. This was done because the friction coefficient from steel on aluminum is much lower than it would be with aluminum on aluminum. With the friction coefficient lower, it means that the keys will last longer and it requires a lower powered solenoid to move the keys from engaged to disengaged. Furthermore, the keys will also have a 45 degree cut on the end that enters the PR to make them more flush with the payload ring without causing too much of a nuisance.

Chapter 4. Testing

4.1 Testing Solutions

The testing of the P.S.S. poses some technical challenges due to the fact that we have Earth's gravity to compensate for. The team has a few ideas to try and off set gravity as much as possible in order to receive accurate results. There are two scenarios that need to be tested for, max dynamic force and extremely low gravitational field as experienced in low Earth orbit.

The max dynamic pressure is what the P.S.S. needs to withstand. This can be achieved by applying a 300 pound weight. This should not be an issue.

The zero gravity stage of the rocket where the separation will occur can be difficult to achieve. One idea is to leave three tabs on each ring to attach wires or springs, thereby creating an artificial neutral buoyancy. Once the P.S.S. is neutrally buoyant, the solenoids can then be triggered to release the payload ring from the rocket ring and check for separation shock. The tabs can then be removed in the machine shop. Another idea is to drop the system from a height and while in free fall, the payload will experience relative weightlessness for the separation to commence. This experiment will have other factors such as air resistance that will need to be accounted for. The last but not least idea for neutral buoyancy is to create a medium for the ring to sit in such as heavily salted water or pudding. The problem with this idea is the solenoids may malfunction in such a medium.

The team is keeping an open mind about this aspect of the project for now. As of now the tabs and springs to replicate a neutrally buoyant medium are the front runner.

Chapter 5. Cost Analysis

5.1 Bill of Materials

The bill of materials has changed drastically since the final proposal. Ruger, so generously, donated a 2’ x 4’ x 1’’ plate of 7075 aluminum to our team which reduced the previous $837.76 bill to a current approximation of $190.00. The bill of materials will increase once spring cost, batteries, and other misc components are decided upon to purchase. See table 3 for the current bill of materials.

Table 3: Bill of Materials

Material	**Quantity**	**Unit Cost**
Stainless Steel Key 0.5" dia x 2’ long	1	$9.00
7075 Aluminium plate 24" x 48" x 1"	1	Donated
Solenoid	4	$32.75
Nuts/ Bolts/ Misc.	TBD	$50.00
Total Cost		**$190.00**

5.2 Manpower Cost

Two columns were added to the previous manpower cost table: Spring assembly, solenoid assembly. Team members have responsibilities as was shown in table 2. Therefore the hours have changed and in some cases have increased. See table 4 for the manpower cost.

Table 4: Manpower Cost

Team Members	**Pay ($/hr)**	**Rocket Ring Fabrication (hr)**	**Payload Ring Fabrication (hr)**	**Key Fabrication (hr)**	**Spring Assembly (hr)**	**Solenoid Assembly (hr)**	**Assembly (hr)**	**Total Hours**
Matthew Mylan	20	10	4	2		3	1	20
Mark Majkrzak	20	10	4		2	3	1	20
Kate Prentice	20	10	4		2	3	1	20
Alen Younan	20		10	2	3		1	16
Ben Dirgo	20		10		3		2	15
Jason McCall	20		10	2	3		2	17
	Total Cost ($)							**$2,160**

5.3 Manufacturing Cost

The manufacturing cost is extremely important when it comes to building the device. See table 5 for the manufacturing cost. The Machine Shop located on campus has all of the tools to get the job done. It seems that the process does have some roadblocks seeing that the scale chosen does have a twelve inch diameter. Recently the group learned that the CNC Mill can only hold up to an eight inch diameter if it wants to be kept in one piece. Otherwise, the system will have to be separated into parts and glued together in the end. It has been decided that the final piece needs to be one part. This way it would make it stronger and more reliable to use in space. This was Orbital's most important need and it needs to stay that way. All in all, the system needs to be as simple as possible, so that manufacturing costs would go down and the total hours of man work should also go down. The more simple the process is, the better the result.

Table 5: Manufacturing Cost

	Pay ($/hr)	Man Power (hr)	Part Cost ($)	Manufacturing Cost ($)
RR	20	30	donated	600
PR	20	42	donated	840
Keys	20	6	9	129
Solenoids	20	9	32.75	212.75
			Total ($)	**1781.75**

Chapter 6. Conclusions

6.1 Project Planning

Our plan for this semester is to start building as fast as we can. The sooner the system is built, the more time the team will have for testing and design alterations. The team has made a Gantt chart as seen in appendix A.1, to help plan out what needs to get done and in what order. The three things that need to get finished is building the PSS, testing it for failure and complete separation, and a final analysis of the design. With the available aluminum, the team is able to start the building phase. More than enough time was given to build the PSS, because there is enough material to build two PSS's and if need be the team could manufacture a second one. After building, testing begins immediately. Post initial testing, data will be analyzed and further explored through results and discussion repetitions. This pattern will repeat until testing validates that the PSS will separate the payload with minimal shock and be extremely reliable. Final presentations will conclude on May 2, 2014.

6.2 Conclusion

At this point we are finalizing our design before we start our build and testing phase. This is the final phases of the project before the final presentation. We have made some key changes to the designs that mostly have to do with making a subscale model for ease of manufacturing reasons. Changes include the position of the keys and their solenoids, and the selection of dampened springs or a pair of opposing magnets. Once those changes have been made and we finish building the sub-scale model of the PSS we will begin testing. We have many different ideas for how to test this system; suspending the system in two parts and simulating the zero-g that it will experience in space, underwater testing of the system, and taking the system to high enough an altitude to bring it to terminal velocity. Thanks to the generosity of Ruger, the budget for the project can now be spent on other items without worrying about the aluminum which was the most expensive piece. The next phase of the project is to finalize the design based on the analysis in this report and to begin building the subscale model based on those designs.

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Appendix

A.1 Spring 2014 Gantt Chart