Separation Connector

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Design Proposal

Ball Bearing Detent Design

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1. Problem Statement

The goal of this project is to design and prototype a relatively easy to manufacture, inexpensive, and perfectly reliable separation connector.

1.1 Introduction

Orbital Sciences Corporation is an engineering design company that contracts in space vehicles and missile defense systems. Our sponsor from Orbital Sciences Corporation is Mary Rogers. She is the current electronics packaging and actuator manager. She has requested, on behalf of Orbital Sciences Corporation, that our capstone group aid in redesigning their current separation connector. The separation connector is the device that allows the launch vehicle to de-mate from to the device being deployed. It is a mechanical device that detaches the communication wires of the launch vehicle and the deployed device. Ideally, this new separation connector will be easy to manufacture, lightweight, and more effective than its predecessor.

Figure 1: Current separator connector

1.2 Background Research

Mary Rogers supplied a series of resources for us including the Glenair and Amphenol catalogs, several news articles about failures due to separation connectors, as well as a sample of a separation connector. The Glenair and Amphenol catalogs have a collection of different separation connectors. This allowed us to use some of the different ideas combined with the constraints given to us by our client to design a unique separation connector for our project. The news articles provided an insight of how important the separation connector is during the stage separation and launching of a rocket. Lastly, the sample of the separation connector allowed us to gather important dimensions about the original device that we may need when designing our new separation connector.

1.3 Needs Identification

Mary Rogers approached us with this project in hopes of improving the current separation connector. She had some specific requests on what her company was looking for. Some of her requests included:

- The device being able to withstand military specification testing
    - including but not limited to thermal, shock, and vacuum tests
- The device should not de-mate prematurely
- The device should separate with a reasonable amount of force
    - For static separation, reasonable is defined as 10-30 lbf
- During dynamic de-mate, the device must be able to withstand a force of 200lbf
- The leash must be able to withstand a pulling force of 300lbf
- The device must be reliable enough to mate and de-mate a minimum of 50 times without failure or damage
- The male end of the connector is to remain unchanged
- Must be able to be easy to manufacture

From these needs, we concluded that the customer needs a separation connecter that is easy to manufacture, perfectly reliable, and can statically de-mate under smaller loads than are currently available.

1.4 Project Goal

It is essential that the new separation connector mates and de-mates at least 50 times with no signs of damage or failure. Thus, the goal of the project is to design an improved separation connector that will separate cleanly 100% of the time. Static de-mate, for this new separation connector, will be achieved when a force of 10-30 lbf is applied to it and it will be able to withstand a force of 200lbf during dynamic de-mate. Lastly, the entire design will be easy to manufacture so that it can be machined in-house by Orbital Sciences Corporation's machine shop.

1.5 Objectives

Our objectives are to create an inexpensive, more reliable, separation connector that is easy to manufacture. We want the price to be less than $400, which is the average price of a single separator connector. For reliability, we want the new separator connector to meet the client's requirement of passing 50 tests without failure or damage. Lastly, the new design needs to be easier to manufacture. Our client currently purchases all of their separator connectors from other companies. However, they would like to manufacture them in their own machine shop. See below for the table of objectives.

Table 1: Table of objectives

Objectives	**Basis**	**Units**
Inexpensive	Material cost	$
Ease of manufacturing	Time to manufacture	$/hr.
Reliability	Percent of failure	%
Robust design	Pull angle	°
Size no greater than 125% of original	Total size	in.

1.6 Constraints

This section includes the specifications to which our design must abide by. These constraints were given by our client to ensure the separation connector meets Orbital Sciences Corporation's rigorous standards. Below is a list of the required specifications:

- Bayonet grooves must match military specifications
- Must de-mate statically with a force ranging from 10-30 lbf
- Must be able to withstand a minimum pulling force of 200 lbf during dynamic de-mate
- Leash must be able to withstand a minimum pulling force of 300lbf
- Must be able to statically mate/de-mate a minimum of 50 times without failure
- Must withstand a temperature gradient of -34°C – 71°C with no damage to the material
- Must withstand a static acceleration of 15 G-Force
- Must not fail during a drop test
    - From a height of 3 feet dropped onto a concrete floor
- Must pass a "rattle test"
    - The object is shaken by hand, or in a vibration machine, and must not rattle or de-mate
- Must not exceed an increase in size of 25 % greater than the original (~1.43" inner diameter for male end)
- Must not exceed an increase in size of 25 % greater than the original (~1.42" outer diameter for female end)

1.7 Functional Diagram

This section contains our functional diagram. The functional diagram relates the customer's requirements to equivalent engineering requirements. It also helps choose which requirement of the project is most important. The most important engineering requirements, according to our functional diagram, are cost and having a high yield strength material. However, the most important customer requirement is reliability (chosen by the customer).

		Engineering Requirements					
		Yield Strength	Manufacturability	Safety Factor	Weight	Cost	Low out-gas in vacuum
Customer Requirements	Materials	x	x		x	x	x
	Contact Size				x	x	
	Resist Damaging	x		x			
	Inexpensive					x	
	Reliability	x		x			
	Easy to manufacture		x				
	Robust design				x		x
	Units	psi	$/hr		lb	$	
				1.5			
	Engineering Targets						

Figure 2: Functional Diagram

1.8 Criteria Tree

The objectives of the project was given to the team by the client and are redefined as engineering criteria by the team as shown in table 2 and figure 3. The criteria tree, figure 3, separates the newly transformed objectives into an easy to read diagram of the criteria.

Table 2: Objective and Equivalent Criteria

Objective	Criteria
Inexpensive	Cost
Ease of manufacturing	Manufacturability
Reliability	Failure rate
Robust design	Pull angle
Size no greater than 125% of original	Total size

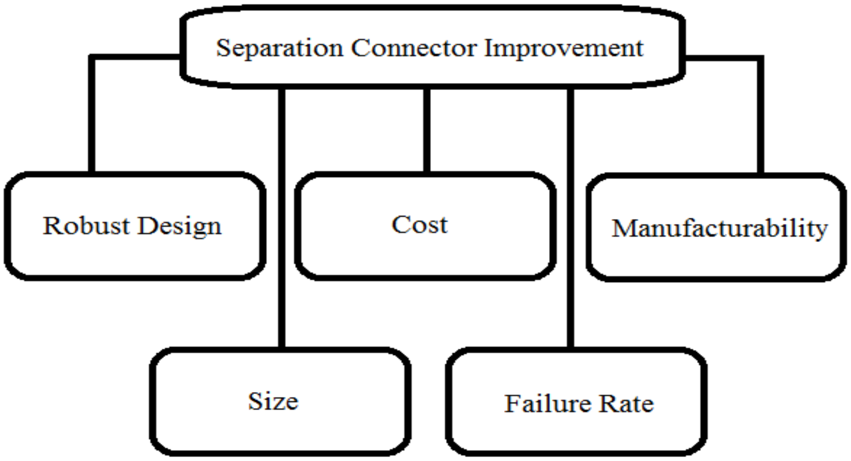

Figure 3: Criteria Tree

1.9 Quality Function Deployment (House of Quality)

This section contains our house of quality diagram. This diagram relates our engineering requirements to each other. The relationship between any two engineering requirements is positive if they are directly proportional, negative if they are inversely proportional, or no relationship if they do not affect each other.

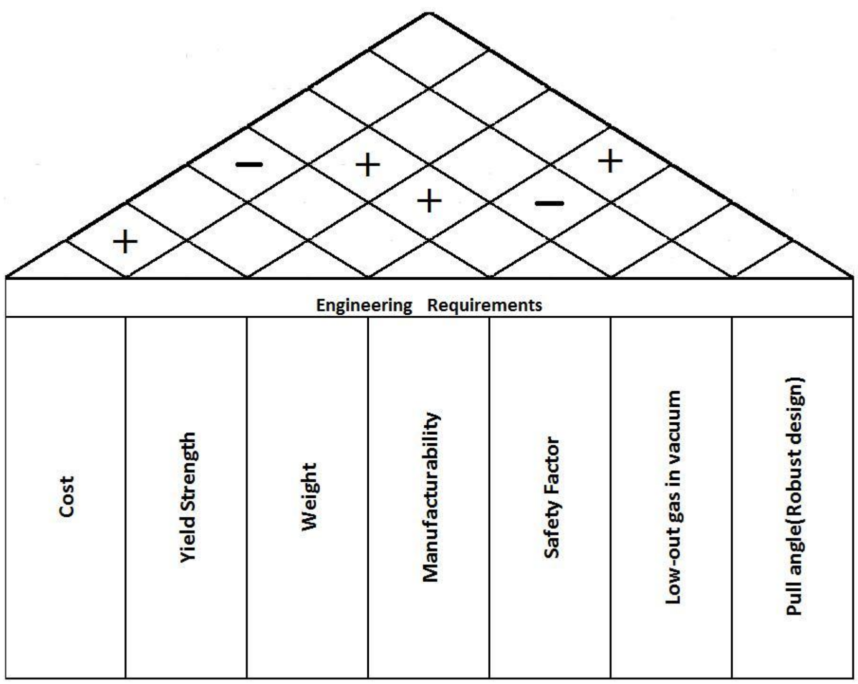

Figure 4: House of Quality

2. Concept Generation

We started our concept generation phase by brainstorming design ideas that we thought had the potential to solve the problem. Throughout the brainstorming sessions, we generated one hundred different ideas that could solve the problem. Although some of the ideas were not feasible, it allowed us to become more creative in the ways we approached the problem. Our team was able to eliminate the impractical ideas and narrow it down to four concepts that we believe best solved the problem presented by our client.

2.1 Ball Bearing Design

This design utilizes six evenly spaced bearings on the female end of the connector. The bearings are implanted into the female piece with springs directly behind them. The springs allow the bearings to retract so that the male end of the connector can mate/de-mate with the female end of the connector easily. There is also a coupling piece in the middle that mates the female to the male end. On one side, there is a helical track cut on the inside that allows the male end to screw in one-third of a turn, per request of the customer. On the opposite end, there is a groove cut into it to allow the ball bearings to expand and hold onto the coupling. The groove will be big enough to allow the ball bearings to slide into it but small enough to allow them to be pulled out. Figure 5 below shows a CAD drawing of the conceptual “Ball Bearing” design. A modified version of this design became our final design choice.

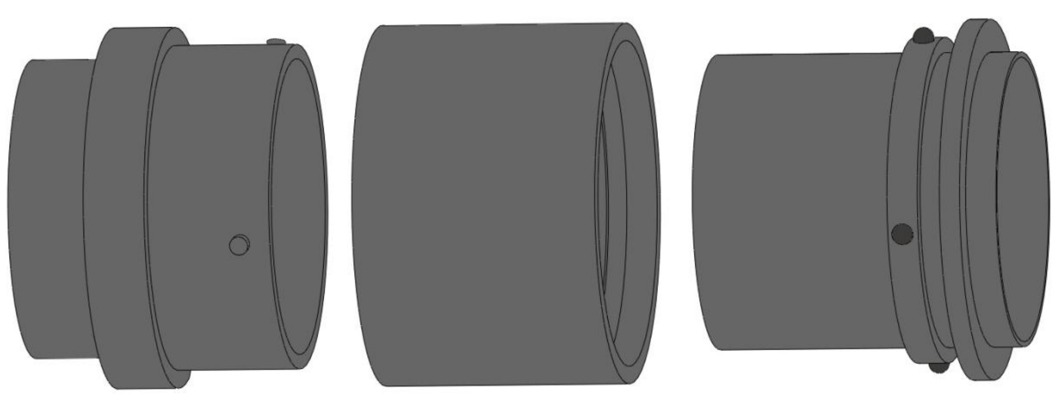

Figure 5: Ball Bearing Design Concept

2.2 Spring-Button Design

This design is inspired by a door's handle. When you push a door handle down the locking mechanism retracts. This is how our design is supposed to work. There are two buttons at the top of the male end that control to locking mechanisms at the bottom of the piece. The female end will be a shell with a groove cut into it that will receive the locking mechanism. The locking mechanism will be spring-loaded and will compress when the buttons are pressed and release when the buttons are released. Figure 6 below shows a CAD drawing of the conceptual "Spring-Button" design. This design was eliminated because of the constraint that restricted changing the male end in any way.

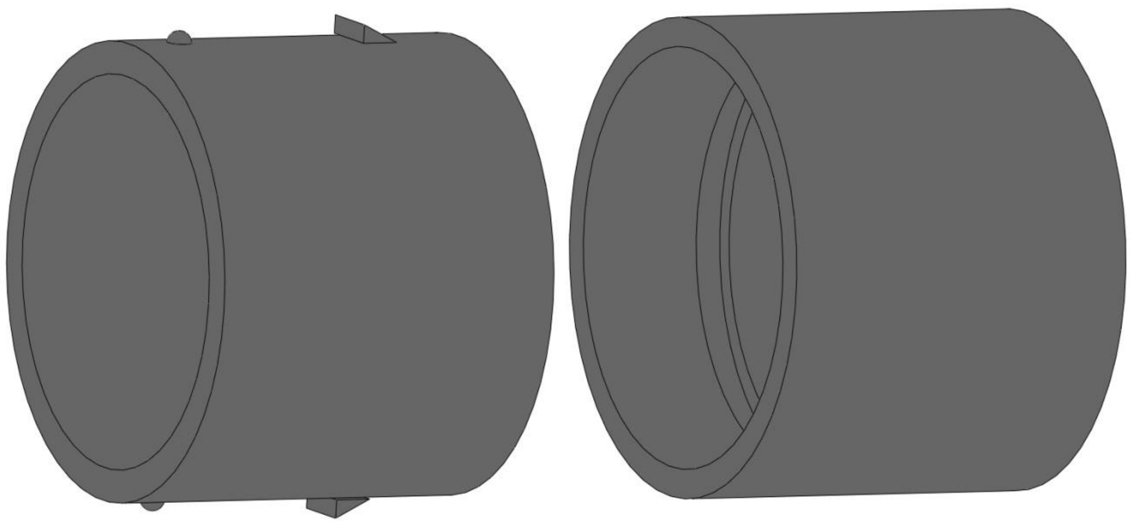

Figure 6: Spring-Button Design Concept

2.3 Spring-Hammer Design

The spring hammer design uses a spring loaded “hammer” or cylindrical ring locked on the inside of the outermost collar. When the release cord is pulled, the outermost collar is pulled down which unlocks the guided springs. This forces the cylindrical hammer ring to strike the mated surfaces and causes the two ends of the connector to de-mate. To reset the connector, simply twist the male and female connectors together. The overall idea is to de-mate using the stored force provided from the springs’ potential energy. Figure 7 below shows a CAD drawing of the conceptual “Spring Hammer” design. This design was eliminated because the rocket would provide all of the force necessary to pull the connector apart making the extra force provided by the “hammer” unnecessary.

Figure 7: Spring Hammer Design Concept

2.4 Lever-Action Design

During the mating process, the three levers are exposed on outside of the connector. Once the wires are mated, the levers are placed flush with the collar, which locks the two ends together. One pull cord is connected to each lever and then connected to each other to form a single lanyard. When the lanyard is pulled, the three levers will be pulled down into the unlock position and the connector will de-mate. Figure 8 below shows a CAD drawing of the conceptual “Lever-Action” design. This design was eliminated because it required too many small pieces and would have been difficult to manufacture.

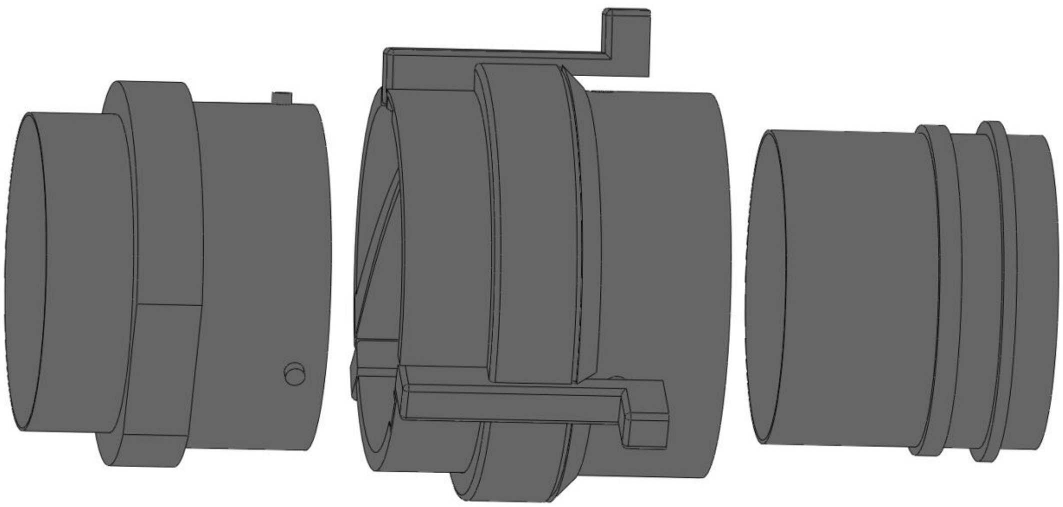

Figure 8: Lever-Action Design Concept

3. Concept Selection

The tables below show the data that we calculated in order to decide on a design. By using a multiple criteria table, a pairwise comparison, and a decision matrix, we concluded that the “Spring-Hammer” design was the best decision. However, this decision was not the final design. We presented our evidence and arguments to Mary Rogers and allowed her to make the final decision on which design she thought was best suited for her needs. After talking to Mary Rogers, we found that the “spring-hammer” design was too complex and hard to manufacture. We found that she preferred the ball bearing design because it was a simplistic and unique solution in comparison to all of our other designs.

3.1 Multiple Criteria Table

The function of this criteria table is to make the decision matrix impartial by placing values on the criteria. These values range from one (inadequate) to nine (perfect). They are used in the decision matrix to rank the designs based on the given criteria. The values are gathered from research and are ranked according to what we consider an inadequate or perfect design. For example, the average cost of a separation connector is $400 and we would like it to be $200 or less. Therefore, the $400 separation connector receives a ranking of 1, or inadequate, and the $200 separation connector receives a ranking of 9, or perfect.

Table 3: Multiple Criteria Table

Performance Level	Value	Cost ($)	Manufactura-bility (hrs.)	Damage Resistant (in.)	Reliability (%)	Weight (lb.)	Pull Angle (°)	Size (in.)
Perfect	9	200	<4	0.01	100	>1.50	>25.0	>2.0
	8	<225	>5	>.02	>99.75	>1.75	>22.5	>2.1
Excellent	7	<250	>6	>.03	>99.50	>2.00	>20.0	>2.2
	6	<275	>7	>.04	>99.25	>2.25	>17.5	>2.3
Good	5	<300	>8	>.05	>99.00	>2.50	>15.0	>2.4
	4	<325	>9	>.06	>98.75	>2.75	>12.5	>2.5
Fair	3	<350	>10	>.07	>98.50	>3.00	>10.0	>2.6
	2	<375	>11	>.08	>98.25	>3.25	>7.50	>2.7
Inadequate	1	>400	>12	>.09	>98.00	<3.50	<5.00	>2.8

3.2 Pairwise Comparison Table

The pairwise comparison table allows us to assign higher importance to certain criterion, defined as the normalized weight. The normalized weights are determined through a comparison of any two criteria. Each criterion is given a rating of "1" meaning more important or a "0" meaning less important. For example, the arrows on the chart are pointing at a "0", which is relating cost to size. Since cost is less important than size, it receives a zero. If the table has an "X", it is a criteria being related to itself and needs no rating. The values are totaled horizontally and placed in the "Total" column. Then each of the "Total" values is divided by the sum of the "Total" column to get the normalized weights.

Table 4: Pairwise Comparison Table

	Cost	Size	Weight	Manufacturability	Reliability	Pull Angle	Damage Resistant	Total	Normalized weights
Cost	**X** →	↓ 0	0	0	0	1	0	1	0.047
Size	1	**X**	0	0	0	1	0	2	0.095
Weight	1	1	**X**	0	0	1	0	3	0.142
Manufactu-rability	1	1	1	**X**	0	0	1	4	0.190
Reliability	1	1	1	1	**X**	1	1	6	0.285
Pull Angle	0	0	0	1	0	**X**	1	2	0.095
Damage Resistant	1	1	1	0	0	0	**X**	3	0.142

3.3 Un-weighted Decision Matrix

The un-weighted decision matrix assigns rankings to each design idea. Each design is given raw scores based on how well we thought it met each criterion. The raw scores are then converted into values based on the multiple criteria scale above in table 3. The design with the highest total score is rated as the best design on an un-weighted scale. The weighted decision matrix below will help choose the best design based on the customer's highest priorities.

Table 5: Un-weighted Decision Matrix

		Spring Hammer Design		Ball-Bearing Design		Lever-Action Release Design		Spring Button Design	
Criteria	Units	Raw Score	Value on Scale	Raw Score	Value on Scale	Raw Score	Value on Scale	Raw Score	Value on Scale
Cost	$	300	5	275	6	325	4	300	5
Manufacturability	hrs.	6.00	7	5.00	8	8.00	5	7.00	6
Damage Resistant	in.	0.04	6	0.02	8	0.04	6	0.02	8
Reliability	%	99.7	8	98.7	4	99.2	6	99.2	6
Weight	lb.	2.25	6	2.00	7	2.25	6	1.75	8
Pull Angle	°	15.0	5	12.5	4	15.0	5	15.0	5
Size	in.	2.40	5	2.20	7	2.50	4	2.30	6
Total			42		44		36		44

3.4 Weighted Decision Matrix

This weighted decision matrix multiplies the values obtained from the un-weighted decision matrix by the normalized weight of the corresponding criteria. Taking the sum of the new weighted values yields the weighted total of each design. The design with the highest total value is the best design choice; in this case, our recommendation would be the "Spring-Hammer" design.

Table 6: Weighted Decision Matrix

		Spring Hammer Design		Ball-Bearing Design		Lever-Action Release Design		Spring Button Design	
Criteria	Weights	Value on Scale	Raw Score	Value on Scale	Raw Score	Value on Scale	Raw Score	Value on Scale	Raw Score
Cost	0.047	5	0.238	6	0.285	4	0.190	5	0.238
Manufactur-ability	0.190	7	1.333	8	1.523	5	0.952	6	1.142
Damage Resistant	0.142	6	0.857	8	1.142	6	0.857	8	1.142
Reliability	0.285	8	2.285	4	1.142	6	1.714	6	1.714
Weight	0.142	6	0.857	7	1.000	6	0.857	8	1.142
Pull Angle	0.095	5	0.476	4	0.380	5	0.476	5	0.476
Size	0.095	5	0.476	7	0.666	4	0.380	6	0.571
Total			6.523		6.142		5.428		6.428

3.5 Final Design Choice

Although the concept selection process and calculations pointed towards the "spring-hammer" design, our client decided that the ball bearing design is the best solution to the problem. The "spring-hammer" design required too many small pieces, which decreases its reliability and makes it more difficult to manufacture. The ball bearing design required far fewer parts, which increased its reliability and made it the best choice overall.

4. Engineering Analysis

This section will elaborate on the material, cost, static, and dynamic analysis of our final design that we plan to prototype. The analysis was performed on the newest modification of the ball bearing design that we named the "Ball Bearing Detent" design. The final design is explained in-depth below in section 5.

4.1 Assumptions in Analysis

We have not finalized the dimensions for our designs; therefore, the calculated values for our analysis are all approximates. Additional assumptions for the analysis of the designs include:

1. Material used is Aluminum 6061 alloy
2. Horizontal de-mate (no pull angle)
3. No friction while de-mate occurs
4. Perfect reliability
5. Dimensions of the device are correct

4.2 Material Analysis

The materials we chose were the aluminum 6061 T6, steel ball bearings, and high-carbon steel springs (music wire). Although the properties of 7075 aluminum are better than 6061 aluminum, we chose aluminum 6061 T6 for the male end, female end, and the coupling because it is the most workable of all our choices and met all of our requirements. Both the steel ball bearings and high-carbon steel springs were chosen from catalogs online because they met the calculated values needed. Lastly, we will use a 3-D printer, which prints with ABS plastic, to make plastic prototypes of our design.

Aluminum 6061 has ultimate tensile strength of at least 40,000 psi and yield strength of at least 35,000psi. Its thickness can vary from of 0.250 inches or less and has elongation of 8% or more. The fatigue limit of aluminum 6061 T6 under cyclic load is 14,000 psi for 500,000,000 completely reversed cycles using a standard RR Moore test machine. Based on this data and material properties, aluminum 6061 T6 is the best material for our separation connector.

Table 7: Material Analysis

Length (L=1 in.)	Aluminum alloys				Stainless steel	
Force (P = 300 lbf)	6061-T6		7075-T6		AISI Type 304	
Area (in^2)	σ (psi)	ε	σ (psi)	ε	σ (psi)	ε
0.1	3.00E+03	2.88E-04	3.00E+03	3.00E-04	3.00E+03	1.07E-04
0.2	1.50E+03	1.44E-04	1.50E+03	1.50E-04	1.50E+03	5.36E-05
0.3	1.00E+03	9.62E-05	1.00E+03	1.00E-04	1.00E+03	3.57E-05
0.4	7.50E+02	7.21E-05	7.50E+02	7.50E-05	7.50E+02	2.68E-05
0.5	6.00E+02	5.77E-05	6.00E+02	6.00E-05	6.00E+02	2.14E-05
0.6	5.00E+02	4.81E-05	5.00E+02	5.00E-05	5.00E+02	1.79E-05
0.7	4.29E+02	4.12E-05	4.29E+02	4.29E-05	4.29E+02	1.53E-05
0.8	3.75E+02	3.61E-05	3.75E+02	3.75E-05	3.75E+02	1.34E-05
0.9	3.33E+02	3.21E-05	3.33E+02	3.33E-05	3.33E+02	1.19E-05
1	3.00E+02	2.88E-05	3.00E+02	3.00E-05	3.00E+02	1.07E-05
1.1	2.73E+02	2.62E-05	2.73E+02	2.73E-05	2.73E+02	9.74E-06
1.2	2.50E+02	2.40E-05	2.50E+02	2.50E-05	2.50E+02	8.93E-06
1.3	2.31E+02	2.22E-05	2.31E+02	2.31E-05	2.31E+02	8.24E-06
1.4	2.14E+02	2.06E-05	2.14E+02	2.14E-05	2.14E+02	7.65E-06
1.5	2.00E+02	1.92E-05	2.00E+02	2.00E-05	2.00E+02	7.14E-06
1.6	1.88E+02	1.80E-05	1.88E+02	1.88E-05	1.88E+02	6.70E-06
1.7	1.76E+02	1.70E-05	1.76E+02	1.76E-05	1.76E+02	6.30E-06
1.8	1.67E+02	1.60E-05	1.67E+02	1.67E-05	1.67E+02	5.95E-06
1.9	1.58E+02	1.52E-05	1.58E+02	1.58E-05	1.58E+02	5.64E-06
2	1.50E+02	1.44E-05	1.50E+02	1.50E-05	1.50E+02	5.36E-06

Table 8: Material Properties

	Stainless steel	Aluminum 6061	Aluminum 7075	Abs Plastic
Tensile Yield Strength (ksi)	31.2	40	73	61
Fatigue Strength (ksi)	35	14	23	11
Brinell Hardness	123	95	150	X
Modulus of Elasticity(ksi)	28000	10000	10400	310

4.3 Stress Analysis

This section contains the stress analysis of ball bearing retention ring, the female end, and the coupling. In the following stress analysis screenshots, blue areas have the least amount of stress and red has the most amount of stress. Each of the analysis below was done with SolidWorks with a force of 200 lbf.

Ball Bearing Retention Ring Stress Analysis:

- Fixtures are where the set screws hold it to the internal female end
- The stress is pulled up and away because it would create more stress than retention ring would actually have.
- As seen in the legend to the right of the picture, the yield strength of the material is 55,148,500.0 [N/m^2] and the max stress found in the piece is 53,617,888.0 [N/m^2]
- Aluminum 6061 T6 has an acceptable yield strength to withstand the max load

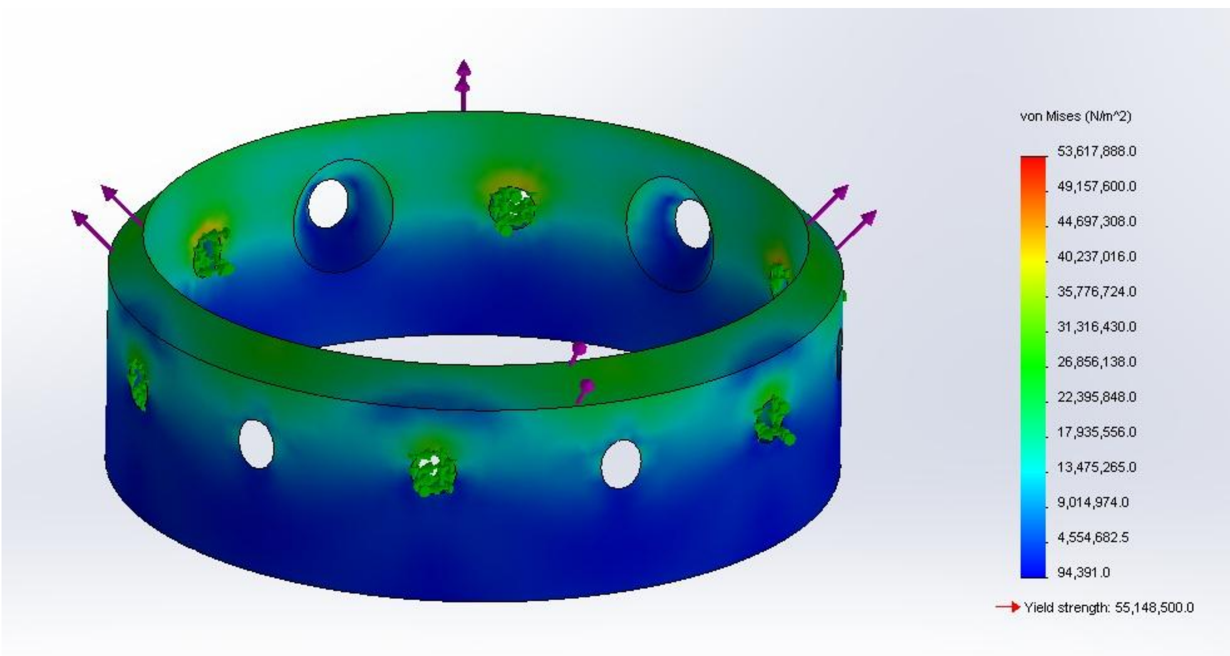

Figure 9: Ball Bearing Retention Ring Stress Analysis

Internal Female End Stress Analysis:

- The fixtures are the green arrows on the base of the chamfered piece to represent where the ball retention ring would be holding the female end.
- The red ring on the bottom represents the stress concentrator do the sharp corner this can be reduced with the use of a fillet however the stress at the concentrator is only 16,175,465.0 [N/m^2] whereas the yield strength is 55,148,500.0 [N/m^2]
- Aluminum 6061 T6 is an acceptable material to be used in this part.

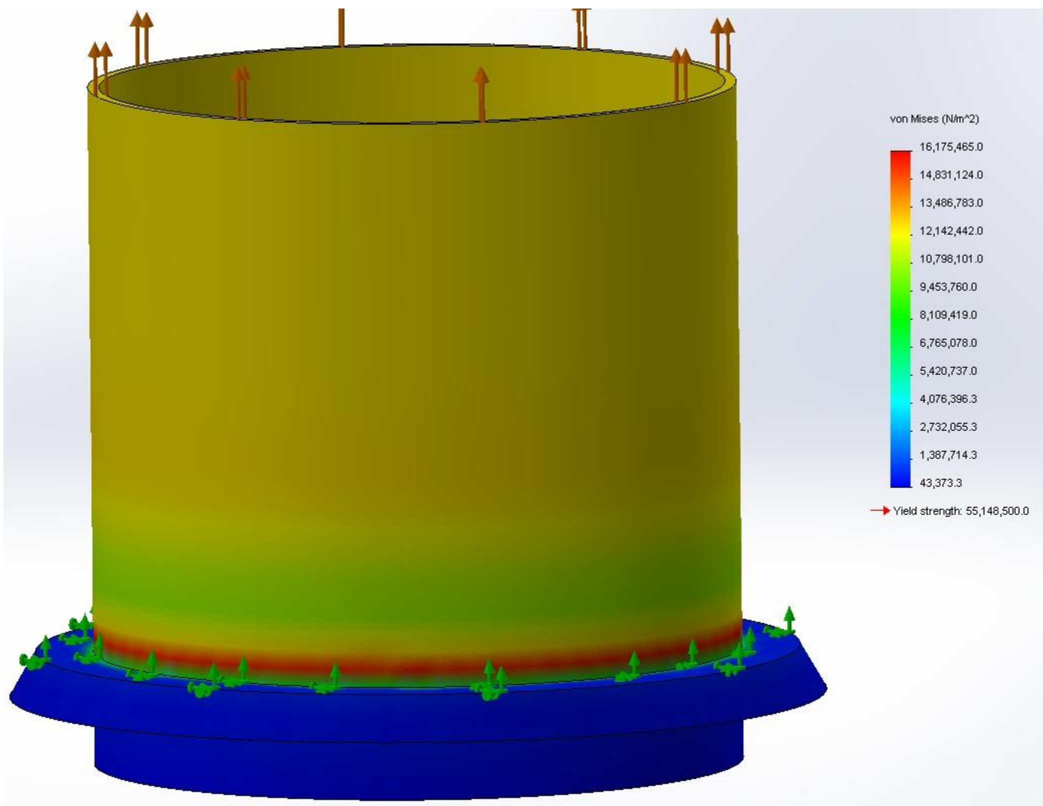

Figure 10: Female End Stress Analysis

Outer Collar Stress Analysis:

- The fixtures are where the male end bayonet pins will be in place during the stress event
- The force is acting down on the grove inside the part
- There are no significant stresses in the grove at the bottom but the stresses in the bayonet grove are significantly higher
- Aluminum 6061 T6 is an acceptable material for this piece because the yield strength is again 55,148,500.0 [N/m^2] and the stress found at its highest is 49,658,064.0 [N/m^2]

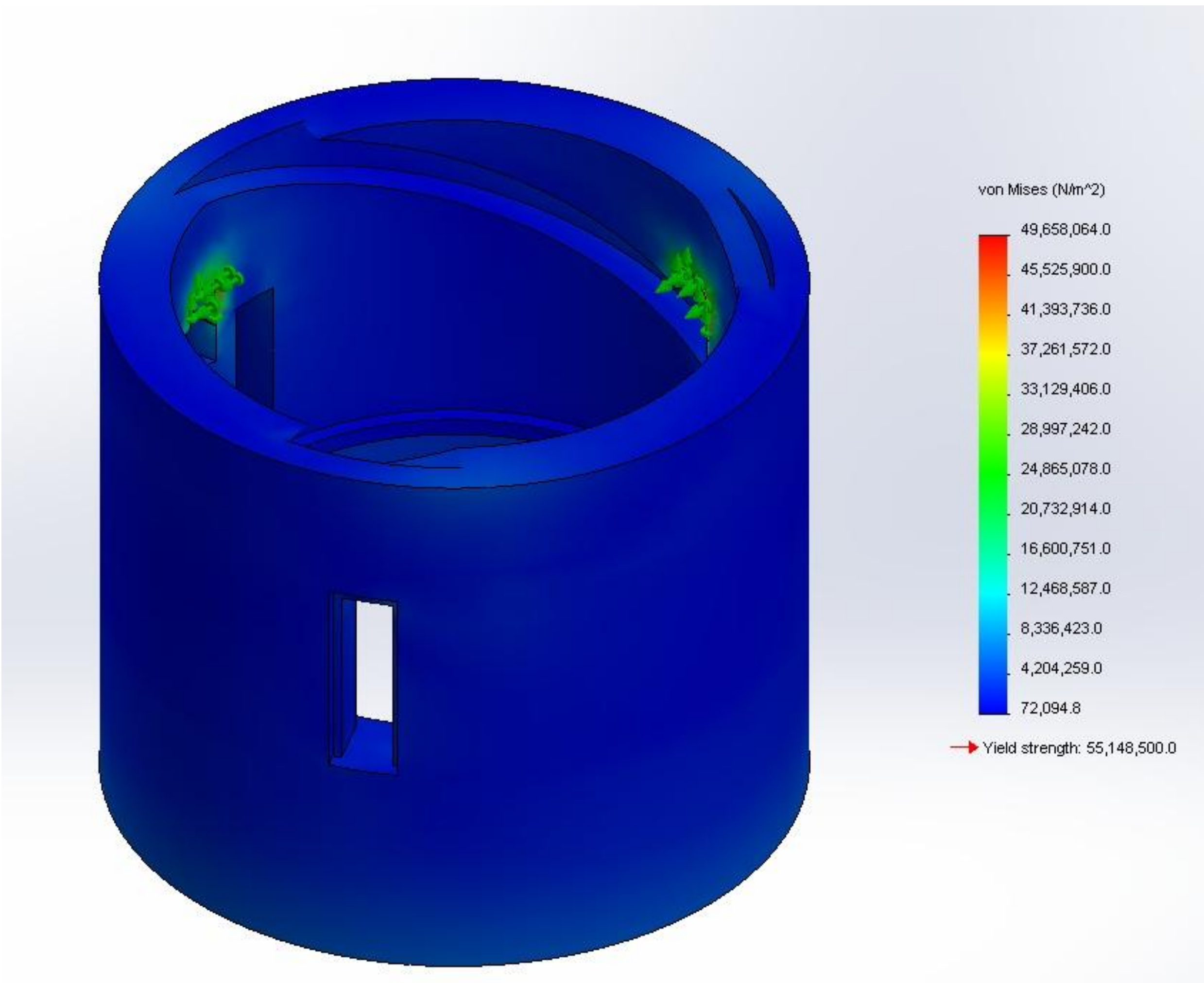

Figure 11: Coupling Stress Analysis

5. Final Design – Ball Bearing Detent

The "Ball Bearing Detent" design is our final design that we will prototype. This design has undergone extensive modifications in order to meet the requirements and constraints given. The new design consists of five part major pieces: a male end, a female end, a coupling connector, a pressure plate, and the ball bearing retention ring. The minor pieces include: a wide spring for the pressure plate, six ball bearings, and six smaller springs that rest behind the ball bearings.

This design will de-mate statically when a force of approximately 30lbf is applied to both ends in opposite directions. This condition is also true for dynamic de-mating as the separation connector will be located inside of a rocket and will not experience too many forces. However, the device has potential to experience higher pull forces during flight as opposed to being on the ground. These higher forces are the forces experienced when, for example, a rocket has separating stages. When the stages separate, one end will continue its flight causing a high pull force on all of the internal components. To account for these high pull forces, we have designed our separation connector to be able to withstand forces of up to 200 lbf. This ensures the parts used in separation connector will not shear or catastrophically fail due to instant "shock" forces that may happen during flight.

5.1 Final Design Description

This design utilizes the original male end and a modified female end. Both ends connect to each other by being inserted into a third piece, the coupling. The male end inserts into the coupling by twisting it clockwise one-third of a turn, which allows the bayonet pins to follow a track on the inside of the coupling. When it reaches the end of the track, the pressure plate inside of the coupling applies an opposing force that forces the bayonet pins into a groove and mates the male end to the coupling. To mate the female end, simply push the female end into the coupling. When the female end is pushed into the coupling, the ball bearings will retract allowing it to enter the coupling. When the ball bearings reach the inner groove cut into the coupling, the ball bearings will expand and mate the female end to the coupling.

In order to de-mate the device there must be a pulling force on both ends of the connecter. The ball bearings on the female end will retract when approximately 30lbf of force is applied to them. This allows the female end to detach both statically and dynamically. For static de-mate of the male end, the male end must be pushed down and twisted counter-clockwise one-third of a turn simultaneously. The male end will not de-mate during dynamic conditions. Instead, the female end will be removed and the coupling will stay with the male end.

5.2 Major Pieces

- Male end
    - Due to the customer's constraint, we were unable to change this part. Therefore, this part remained the same as the original design.
- Female End
    - This piece is a simplistic shell that holds all of the communication wires. It has an extrusion on the bottom half with holes tapped in it to hold the springs that apply force to the ball bearings. It will contain the springs and ball bearings when the ball bearing retention ring is put on.
- Coupling
    - This piece is a coupling that has grooves cut into both ends to accept both the male and the female ends. The end that accepts the male end has a helical groove that allows the male end to rotate one-third of a turn (as per military specifications). The end that accepts the female end has a circular (180°) groove cut into it to accept the ball bearings. When the ball bearings are pushed into the coupling, they compress. The ball bearings will expand when they hit this groove causing it to mate with the coupling.
- Pressure Plate
    - This piece in its simplest form is a ring. The ring is has three holes in it that will be threaded to hold 1/10" screws. The ring is placed on top of the wide spring and both are placed inside the male side of the coupling. The screws act as pins and travel along a slit cut into the coupling to keep the plate from rotating. The main purpose of this piece is to compress when

the male end is inserted and expand when the male end reaches the end of the track; thus, holding the male end in place.

- Ball Bearing Retention Ring
    - This piece is the outer ring that holds the ball bearings in place on the female end. It has six chamfered holes that allow the ball bearings to extrude out from the surface. The smaller holes are for setscrews. The setscrews will secure the ring onto the female end and ensure that the ball bearings do not fall out.

5.3 Minor Pieces

- Wide Spring
    - This spring is for the pressure plate. It will have a wide inner diameter that will fit inside of the coupling on the male end. The spring will contract when the plate applies pressure to it and expand when the male end reaches the end of its track; thus, holding the male en in place. This piece will be purchased from a catalog
- Ball Bearings
    - There are six steel ball bearings. Each ball bearing will have a diameter of .1”. They will be purchased from a catalog. The ball bearing will be held to the female end with help from the ball bearing retention ring. Behind each ball bearing, there will be a small spring to allow the ball bearing to retract into the female end when a force is applied to it. The ball bearings expand when the force is no longer being applied. For example, in our design the ball bearing retracts when the female end is forced into the coupling and expands when it reaches the inner groove of the coupling; causing them to be mate.
- Ball Bearing Springs
    - There are six small springs. These springs sit behind the ball bearings on the female end. They allow the ball bearings to expand and contract when forces are applied and removed from them.

5.4 Detailed CAD Drawings

This section contains the three-dimensional computer aided design (CAD) drawings of our final design. Figure 12, below, is the cross-sectional view of our Ball Bearing Detent design. The male end and outer coupling are transparent to show the details of the inside of the design. See Appendix B for dimensions of individual pieces.

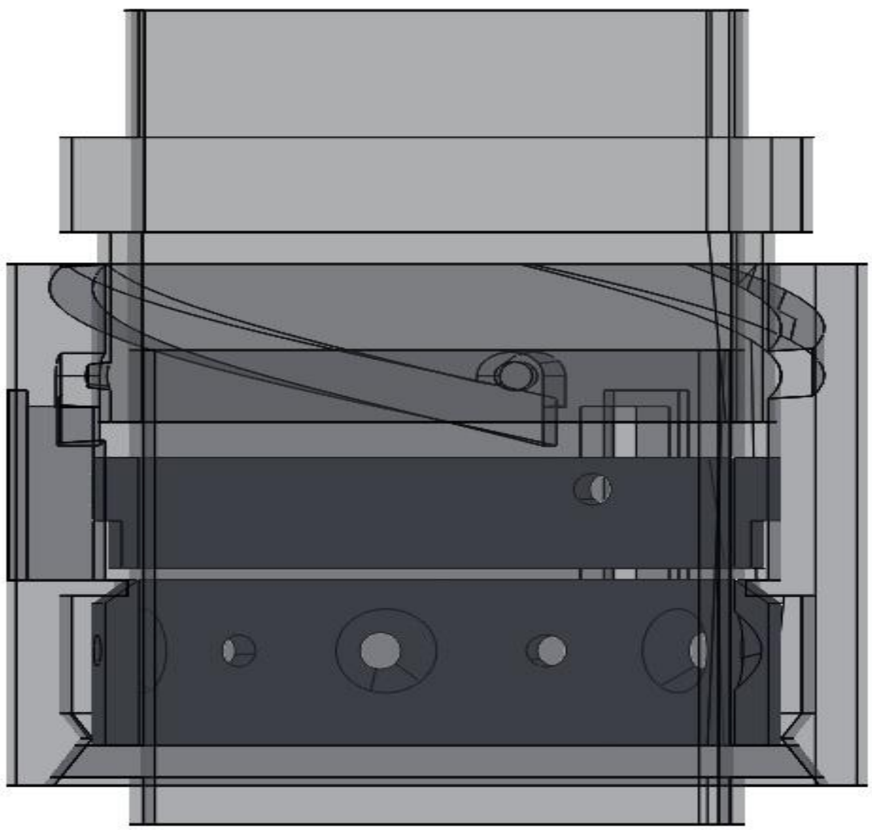

Figure 12: Ball Bearing Detent: Cross-sectional View

Figure 13, below, is the exploded view of our assembly. This view shows each individual part in the order they are assembled. From left to right we have: the male end, pressure plate, coupling, ball bearing retention ring, and the female end.

Figure 13: Ball Bearing Detent: Exploded View

6. Future Tasks

Beginning next semester, Spring 2013, our team will start prototyping our finalized design. The prototype will help in finalizing our dimensions and help in working out any problems with our design. Below, is a list of plans we plan to complete by the end of the next semester to ensure that our design exceeds our customer's expectations.

1. Make a model using 3D printing
    - Use the FDM 3D printer or LOM 3D printer to make initial prototypes
2. Determine the correct dimensions for final design
    - Search the industry and engineering websites for materials
3. Recreate the new connector in SoildWorks
    - Using the new finalized dimensions
    - Update stress and dynamic analysis
4. Buy the materials to make a metal prototype
    - Buy material from industry and engineering websites
5. Build the connector
    - Use the CAMworks to get the G-code or write the code by hand
    - Machine the prototype in the machine shop on NAU campus
    - Use the CNC machine milling to rapid prototype our design out of metal
6. Test the connector
    - Vibration test
    - Torsion test
    - Tension test

7. Project Plan

This section contains our updated Gantt chart. The Gantt chart shows the deadlines we need to meet as well as deliverables that have already been completed. This schedule is tentative and is subject to change. See figure 14 below for updated Gantt chart. (Updated 12/06/2012)

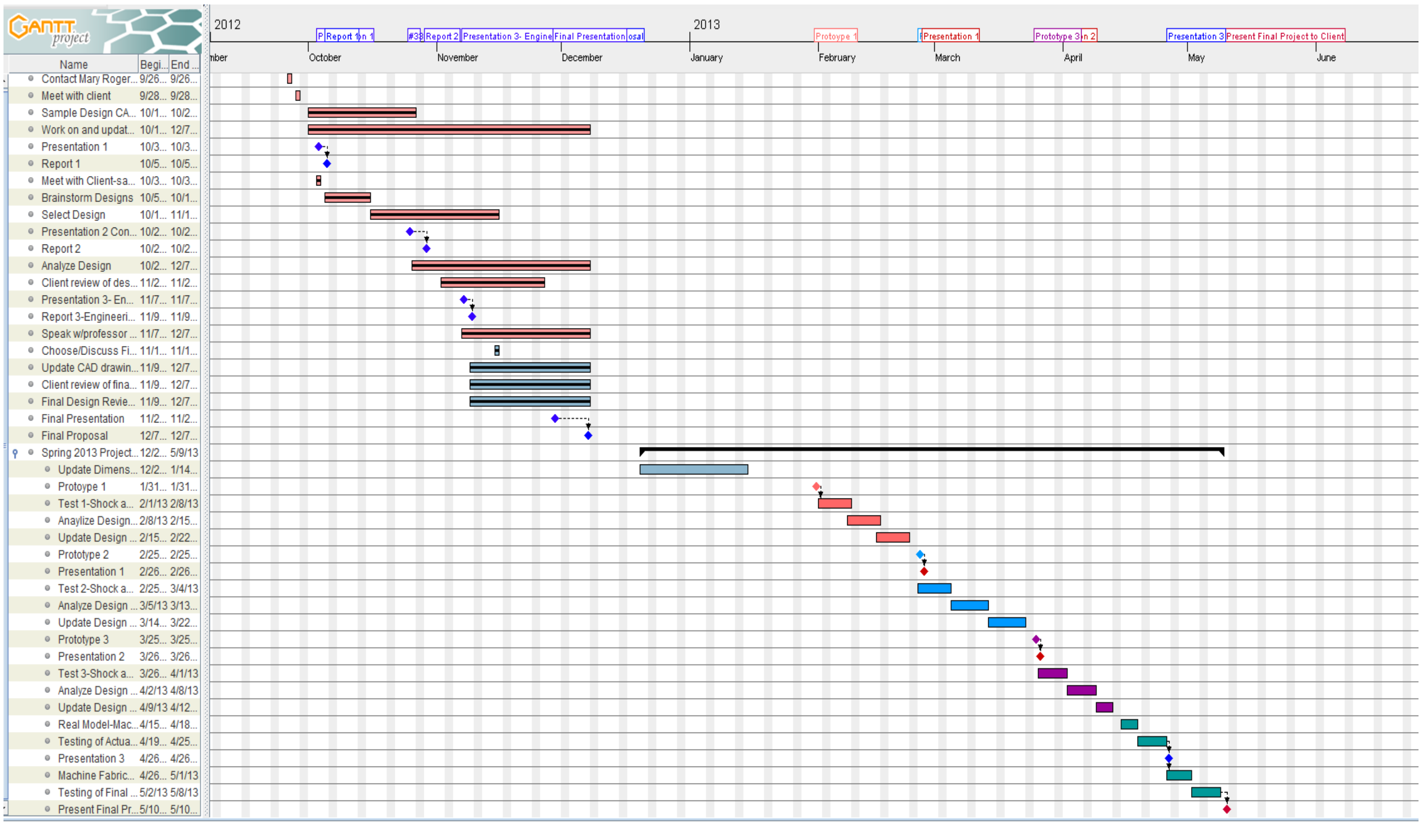

Figure 14: Updated Gantt Chart

8. Conclusion

The goal of this project is to design and prototype a relatively easy to manufacture, inexpensive, and perfectly reliable separation connector. The ball bearing detent design machined with 6061 T6 aluminum is the best solution to this problem. This design is easy to manufacture, inexpensive in comparison to the original design, and will be perfectly reliable. If permission is granted, we will begin prototyping and produce an effective separation connector that exceeds all of the customer's needs.

9. References

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Appendix A

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Appendix B

This appendix contains the drawings made from our SolidWorks CAD models.

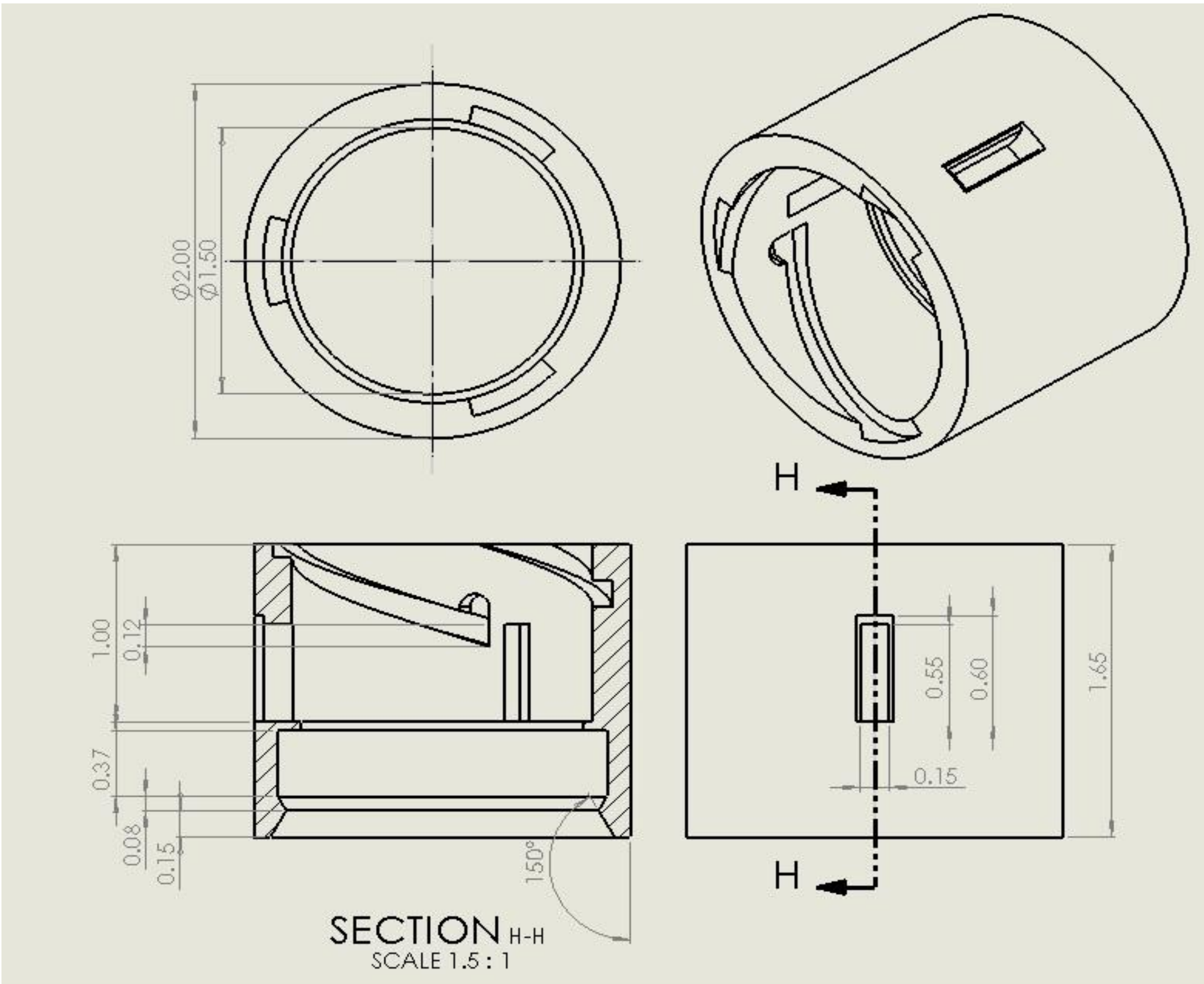

Figure 15: Coupling Dimensions

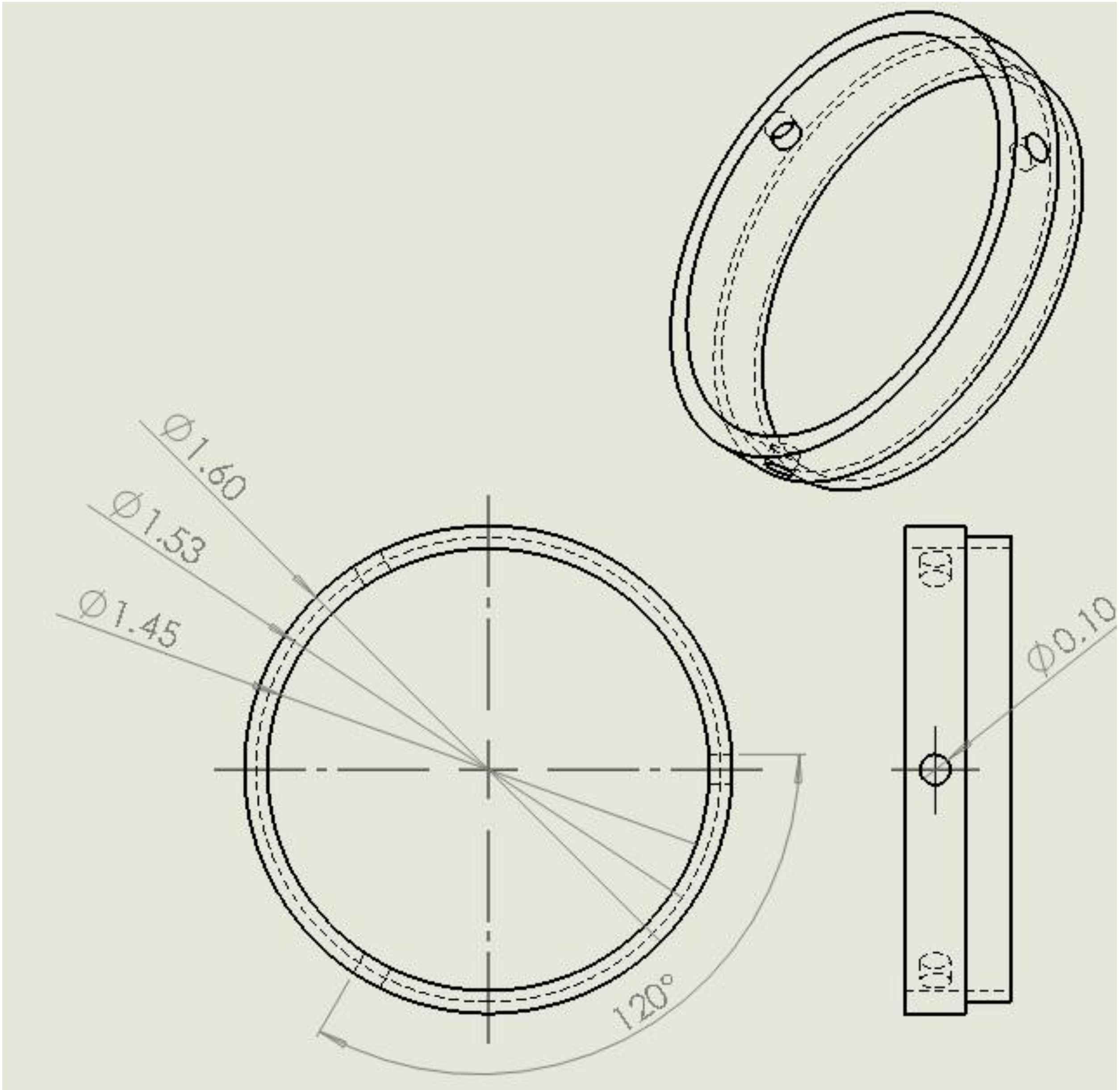

Figure 16: Pressure Plate Dimensions

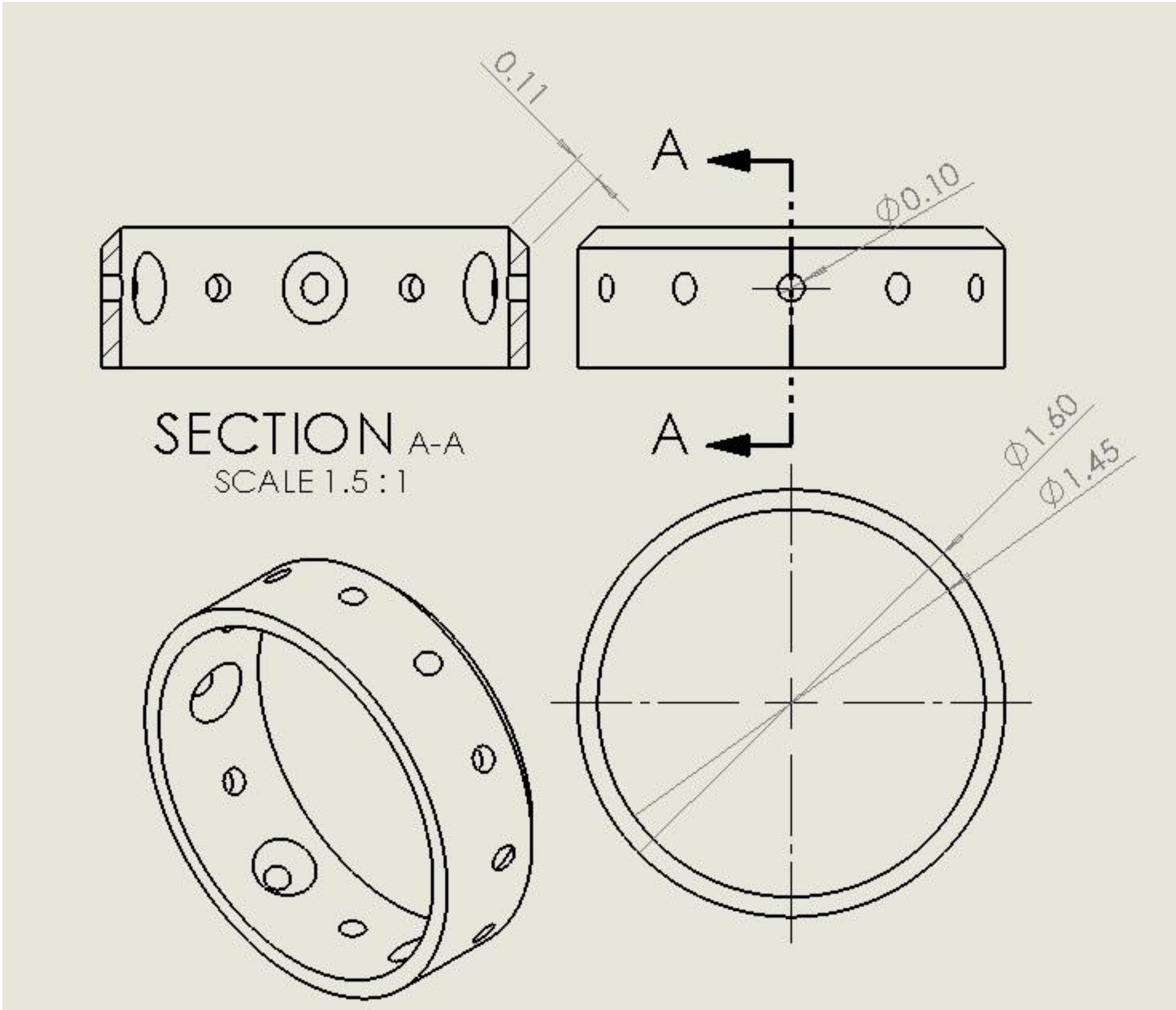

Figure 17: Ball Bearing Retention Ring Dimensions

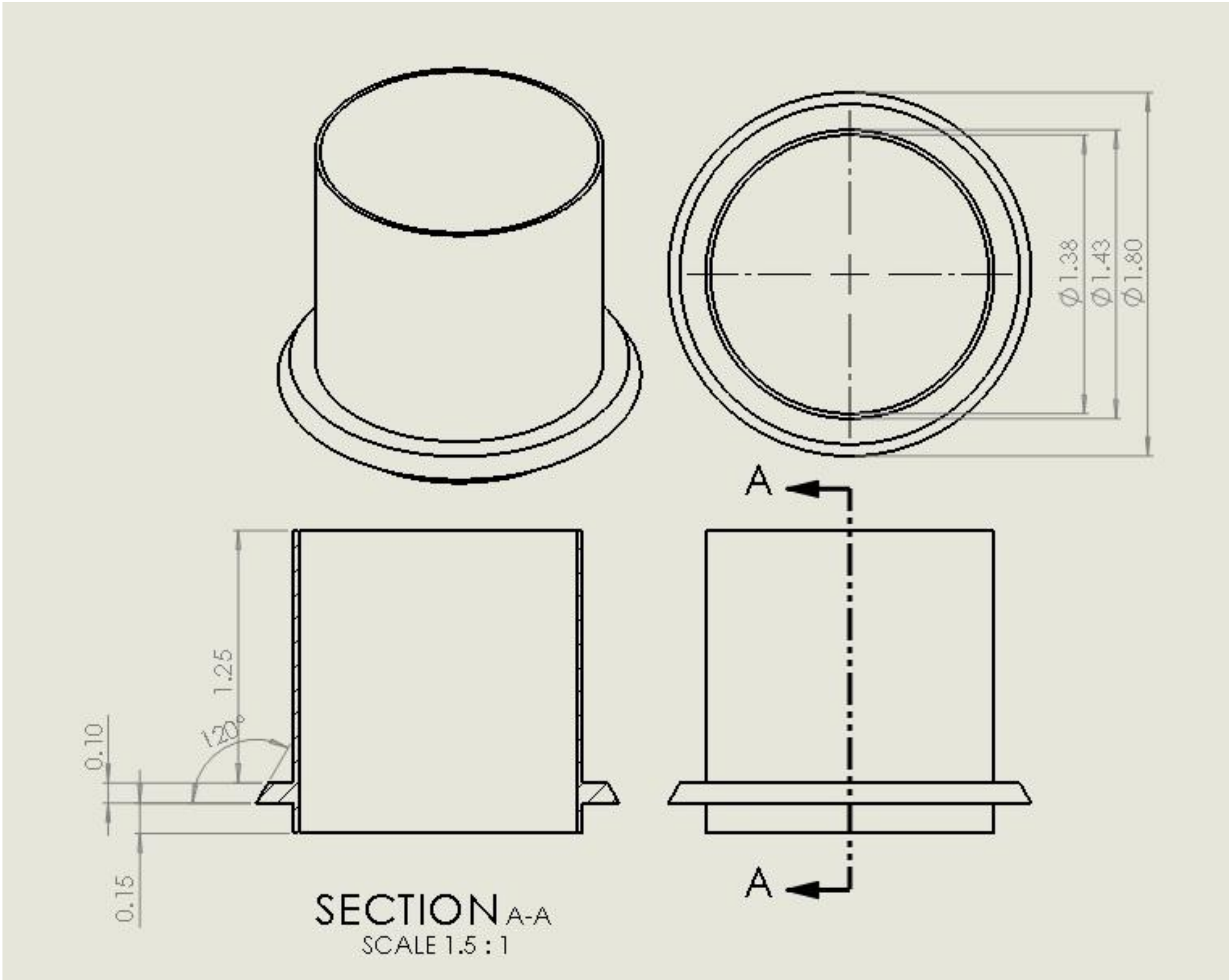

Figure 18: Female End Dimensions