Quick Change Electrical Connection

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Final Report

Document

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Contents

1.0 Introduction

Quick change nose assemblies are used for various applications in today's world. Such designs are currently used for things such as Formula1 and Indy race cars. Yet these designs are purely mechanical connections that simply connect the nose to the desired structure and have no electrical components. In this project, our team wants to bridge this gap and create a design that will allow for electronics to be connected as well. This connection would allow our client to mechanically attach a nose assembly to the body of a structure without having to worry if the electrical components are attached correctly, because our design should insure that this happens. This connection should be able to withstand the operating conditions of the structure and provide proper electrical performance through its entire use.

This report will discuss the progress of the project at the midpoint of the semester. It will discuss the design changes, next steps, and the testing apparatus the team has designed for the project. In addition, it will discuss the steps the team is taking to machine a prototype.

1.1 Background Research

Our client for the Quick Change Electrical Connection (QCEC) is Raytheon Missile Systems. Raytheon is the world leader in design, development and production of missile systems. The company was started over 90 years ago, originally producing household items. During World War II, Raytheon came up an electron tube that could detect enemy aircraft and ships. Raytheon also made the computer that allowed Apollo 11 to be the first successful moon landing. Since then, Raytheon has expanded out into missile production which allowed them to create a branch just for defense contracting, Raytheon Missile Systems.

1.2 Needs Identification

The current electrical connection design for the missile system by Raytheon does not allow for a simple and effective connection between the nose and body of the missile. As the design stands, the electrical connection must be manually connected, which both is inefficient and does not assure that the connection is properly made. This also requires two individuals to work together on the assembly – one to connect the electrical connection while the other holds the nose until the connection is made.

1.3 Project Goal and Scope of Project

Raytheon desires an assembly of the missile nose to the body with only one individual and assurance that the electrical connection is secure between the two components. To do so, the connection must be self-aligning, endure numerous environmental factors without failing, and must not disconnect during use or otherwise compromise the functioning of the missile. The design of the connection is limited solely to a given volume on the bottom inner area of the nose and body of the missile and not the physical connection of the two components of the missile.

1.4 Objectives

The objectives of the QCEC project that the team is trying to accomplish are to make the connection and its zone as cheap as possible, to make the connection last as long as possible before failing, to make the connection easily replaceable or repaired, and to make sure the area is within the approved dimensions. The point of making the connector and its zone inexpensive is to make sure that when it is mass-produced that it doesn't end up costing Raytheon a lot of money. Although the long life may not be as big of a concern since missiles are not reused, they are mass-produced and do tend to sit around for a while beforehand. Making sure the part is easy to replace if it cannot be repaired is also necessary so that a small amount of time is used up changing out the nose cone if needed. The objectives along with their basis of measurement and units used in these measurements can be found below in table 1.

Table 1: Objectives

Objective	Basis of Measurement	Units
Inexpensive	Cost of producing 200 per year	$
Long Life	Time before failure	Years
Field Replaceable	Time taken to replace	Minutes
Easily Repaired	Distance part is deformed	Inches
Size	Area we have to work with	Inches

1.5 Constraints

Raytheon has a specific set of criteria for the Quick Change Electrical Connection to meet in order to function properly. The constraints include operation at:

- A temperature range of -34 to 51 °C
- Sand particle size between 47.7 and 645 micrometers at a concentration of .684 gram/m^3 at a velocity of 25mph
- Dust less than 96 micrometers in size at a concentration of 6.84 ± 3 grams/m^3 at a velocity of 25mph
- Water and ice at 0.7 inches per hour at a velocity of 556 feet per second and with an average droplet size of .045 inches with no failure during icing conditions
- Corrosion resistance to a salt solution with a 3% atmospheric salt solution
- Transportation loads of 19 G's of force
- Bomb rack ejection shock of 32 G's of force
- No material reaction in the presence of JP-10 jet fuel in both its vapor and liquid forms

Physical constraints are also a major factor given by Raytheon. The volume that the connection can be within is 1" by 2.5" by 1.25", which is shared between the nose and body of the missile. Additionally, the connection must make the mating tolerance in order to ensure the connection is made successfully without any doubt and does not affect the physical connection of the two components. The components must have a warranty of 15 years and a service life of 20 years. The overall cost should not exceed $250, be field replaceable, and take into account support issues that ensure damage to hardware can easily be repaired.

2.0 Original Design

This design was proposed to Raytheon in December 2012 and approved by them for manufacturing in the spring semester of 2013. The concept was chosen over other initial ideas using concept selection and engineering analysis.

2.1 Description

The solid guided design as previously stated is a self-aligning mechanism that allows the electrical connector to mate within the specified tolerance. This allows for any misalignment between the nose and body to still create a good bond between the two electrical pieces by allowing the male connector to be automatically aligned into the female connector, ensuring the electrical connections would mate. A gasket along flat, vertical faces of the connectors allows for a tight seal to block any foreign matter including water, dust, and salt, ensuring the electrical connectors will not be compromised. This is shown in figure 1 below.

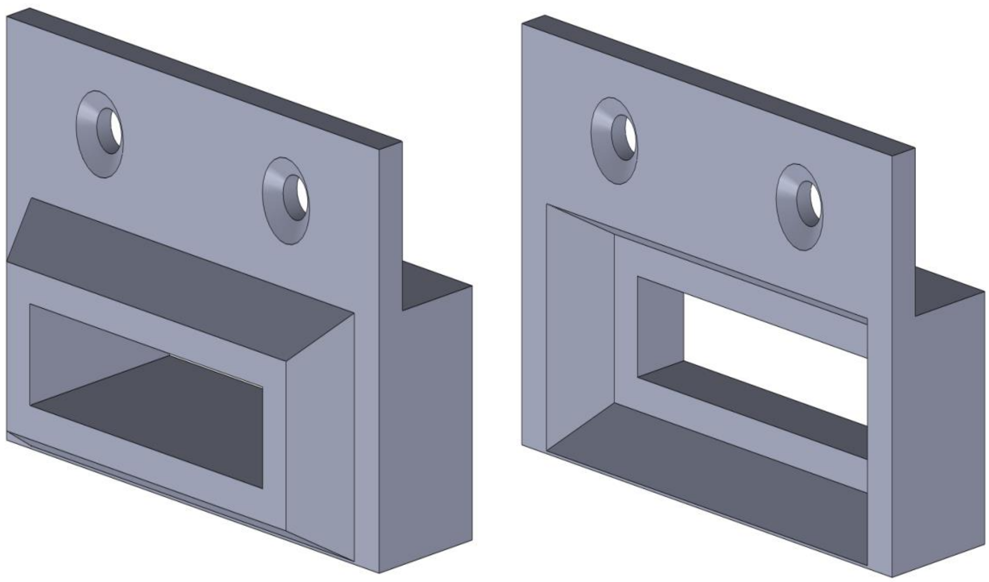

Figure 1 – CAD rendering of the proposed design

2.2 Dimensions

The dimensions for this design fit within the designated space in the body and nose of the missile, with some overlap onto an aluminum plate above this area. Overlapping onto the plate allows for this design to be securely mounted to both the nose and body without compromising frame or body parts of the missile. Figure 2 below shows the overall dimensions of the components for the nose and body connectors.

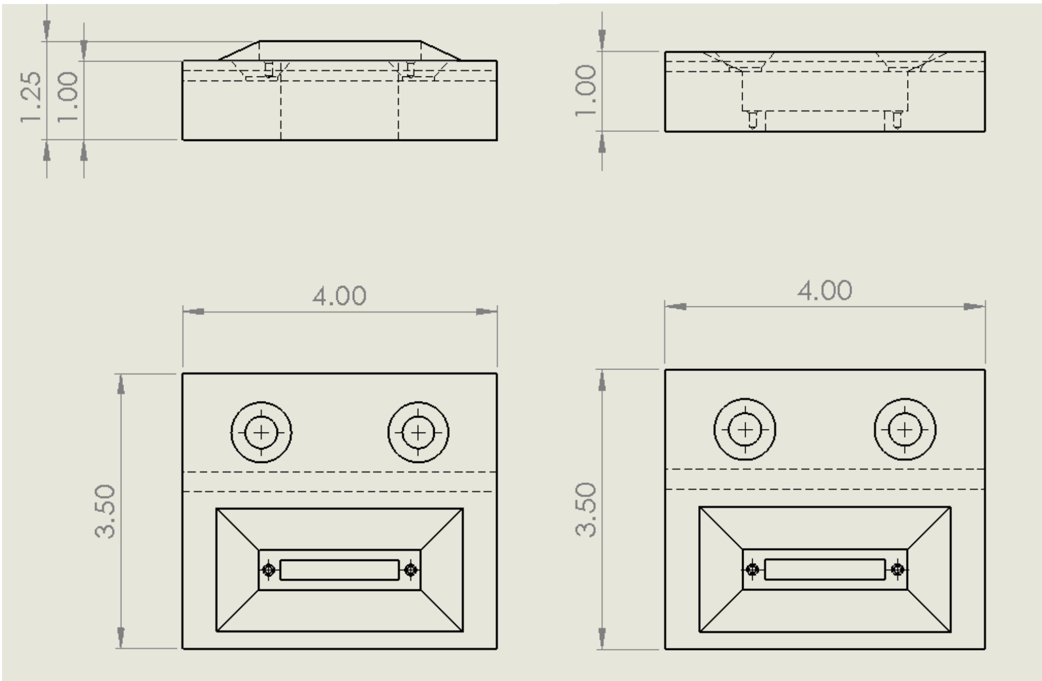

Figure 2 – Drawings of the proposed design body (left) and nose (right) components

Mounting the connectors to the frame of the missile, figure 3 shows the missile body cross-section and the location of mounting for the connector.

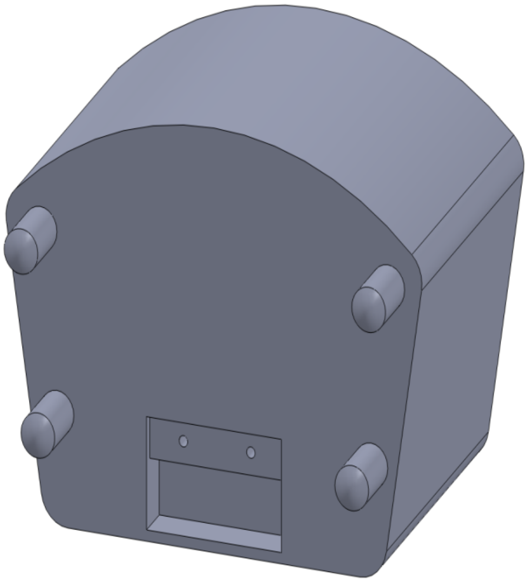

Figure 3 – Location of mounting of the connector to the missile body

2.3 Material Selection

The focus for evaluating the materials used in our concepts will be the specified operating conditions that were previously discussed. These are the most important because if the developed design cannot meet all of the given criteria, then it will be considered to have failed. Based upon the different conditions that the design must operate under, the team has comprised a list of material properties that will allow for the final design to withstand these conditions. This list of properties includes:

- Have a low thermal conductivity
- Be corrosion/rust resistant
- High ductility
- High hardness
- High tensile strength

Given the component's need to withstand corrosive environments through salt and jet fuel, strong forces when ejecting, and high temperatures in its operating conditions, the team chose to use Stainless Steel. Specifically, the team chose AISI 303 Stainless Steel due to its relative ease of machining and greater availability of the material. A contributing reason for choosing this material included the assumption that most of the shock from the ejection would be taken by the outside shell of the missile and not the connector, putting corrosion as a higher priority. This material is annealed, making it stronger and less brittle, has a high resistance to corrosion and rusting due to the fundamental properties of stainless steel, and has a high melting point, meeting all of the major requirements for the material used on the design. Table 2 gives exact specifications of AISI 303 Stainless Steel, indicating the high strength and melting temperature of this material.

Table 2: Properties for AISI 303 Stainless Steel

Property	Value
Modulus of Elasticity	27.6 Mpsi
Yield Strength	35 kpsi
Ultimate tensile Strength	87.3 kpsi
Melting Point	1400˚C

2.4 Cost Analysis

The cost analysis for our original design is split up into two sections, what it would cost our team to prototype the design and our predicted cost for manufacturing at Raytheon. These are the estimated cost for our design prior to our design changes.

Table 3: Cost of Prototyping

Category	Units	Cost
Material	$	$250
Manufacturing	Free (Machine Shop)	
Electrical Connector	$2 per unit	$2
Totals		**$252**

The estimated cost for Raytheon was calculated below, in table 4, for one unit.

Table 4: Estimated Cost Analysis

Category	Units	Cost
Material	$	$250
Manufacturing	Man Hours	4 hours ~ $80
Production Cost	Man Hours	2 hours ~ $40
Electrical Connector	Glenair Unit Price	$20
Totals		**$390**

This shows the estimated unit cost is over the desired cost as specified per Raytheon's request. Due to the increased costs of machining, both our costs and the costs to Raytheon will be changed. In the following sections of the report it will show the revisions to our design so it can meet the design requirements from Raytheon.

3.0 Design Revisions

At the start of the spring semester, the team was dedicated to the proposed design outlined in section 2.0 above. However, upon submitting the design to the NAU Machine Shop, problems arose that were not expected by the team nor the Shop staff until the design was analyzed further. The most prominent problem with the design was the difficulty the Shop would have cutting the material at the specified slants, as shown in Figure 1 above. The material, itself, became an issue due to the great difficulty in cutting stainless steel using the available equipment at the NAU Machine Shop. It was advised by the Shop staff to redesign the connector to have no slants, if possible, and to investigate another material that would be more easily machined.

Outside of the problems noted by the Shop, further analysis done internally by the team pointed to problems with the location of the electrical connectors, over-designing the part, and limitations with its field replaceability. In this design, the electrical connectors stuck out from the stainless housing, forcing the weaker electrical connectors to be used to guide the connection together rather than the robust metal housing as was intended. Additionally, the slant put on the nose side of the connection was unnecessary, as it contributed to problem of using the electrical connector to guide the connection together. Lastly, to increase the field replaceability required by Raytheon for this connection, an orifice was added to the back of both connectors for easier access to the electrical connections, making it easier to mount the pre-installed wiring on the missile to this connection. All of these issues lead to a complete overhaul of the design used for the connection.

4.0 Final Design

The final design uses the previous nose and body pieces but they were updated to insure field replaceability and improved manufacturability. The nose section of the design in figure 4 has and extruded square area that will make contact with the elliptical indent on the body side of the design in figure 5. 4-40 screw holes were added to design to insure that the electrical connectors could be easily replaced. Also to increase field replaceability orifices were added to the back of the designs so the electrical connector could be removed. Our design has two areas that enhance the field replaceability in the tapped holes that will connect to the tin plate, the 4-40 screws that allow the electrical connector to be replaced. The two pieces of our design work like the previous design but have many improvements to the functionality. In the final design the elliptical indent ensures proper connection while protecting the connector from the preload forces. Our final design is shown below in figures 4, 5, and 6.

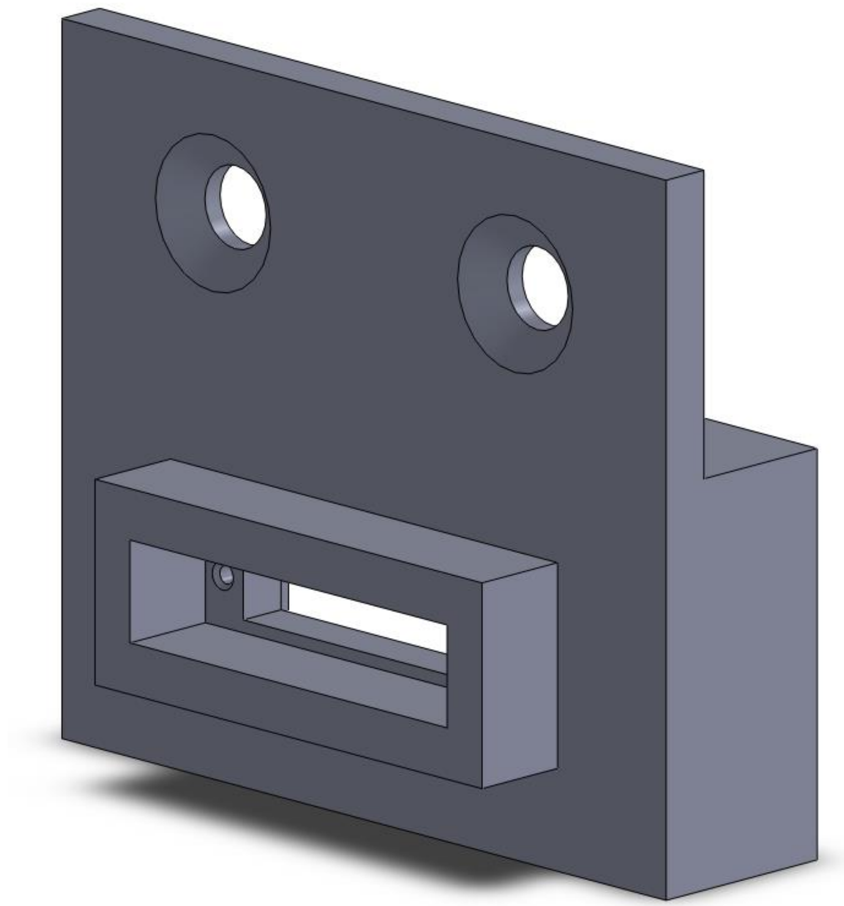

Figure 4 – Nose Side of Design

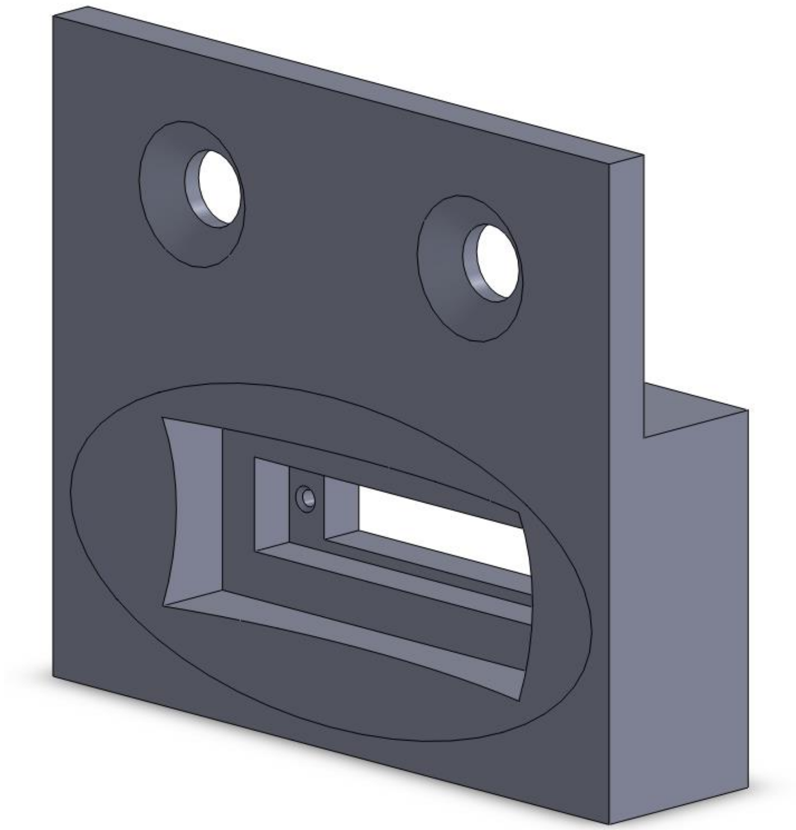

Figure 5 – Body Side of Design

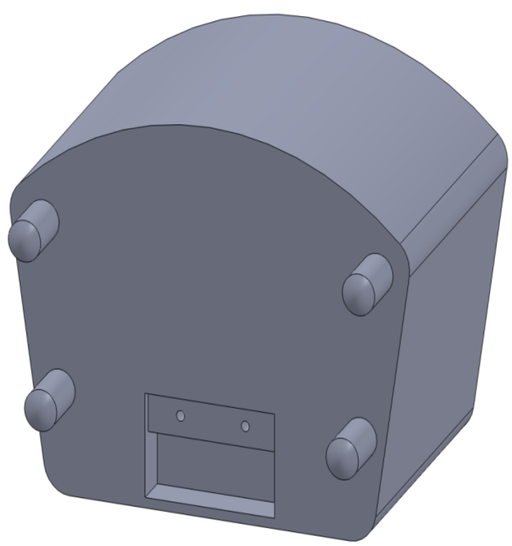

Figure 6 – Mounting Location

4.1 Dimensions

The dimensions that pertain to the designs stated above are in the following drawings. These dimensions are for the electrical connector that was used for the prototype.

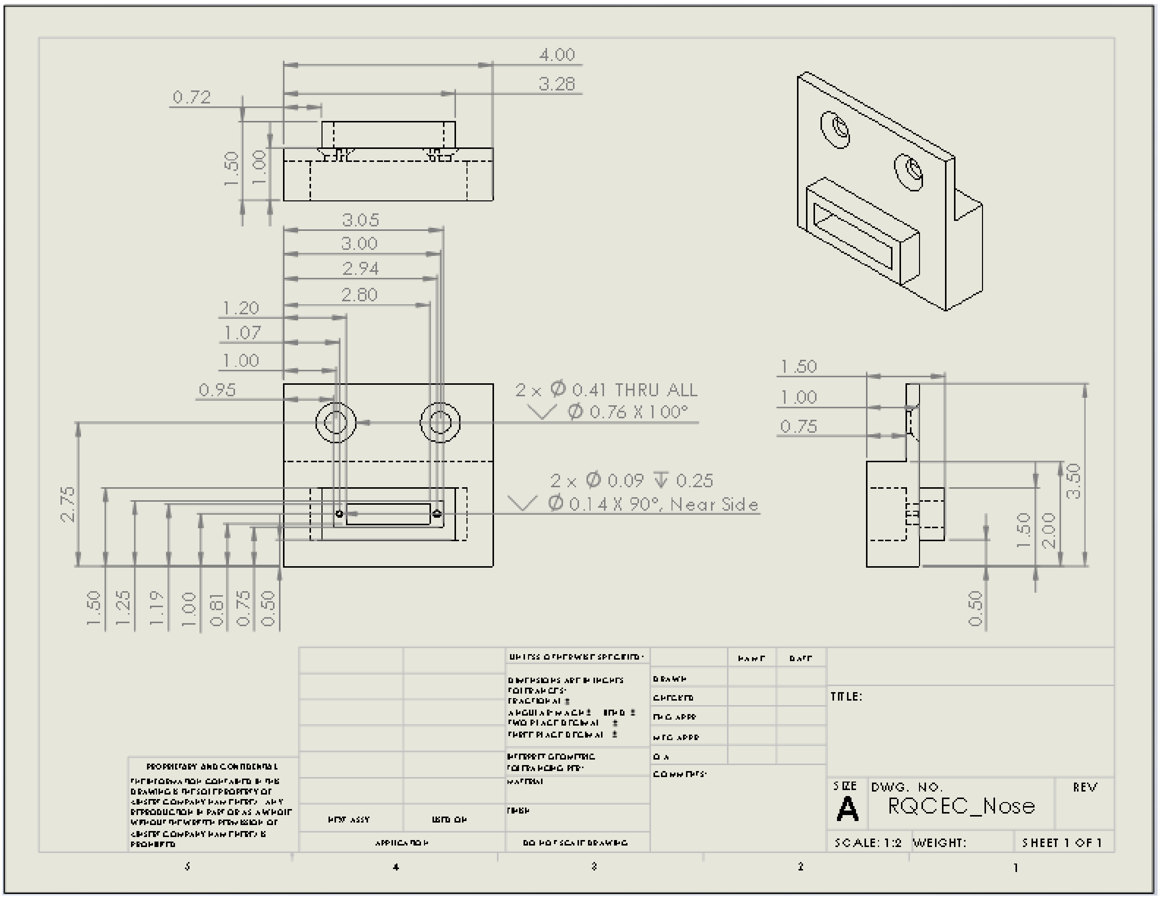

Figure 7 – Dimensions for Nose Side of the Design

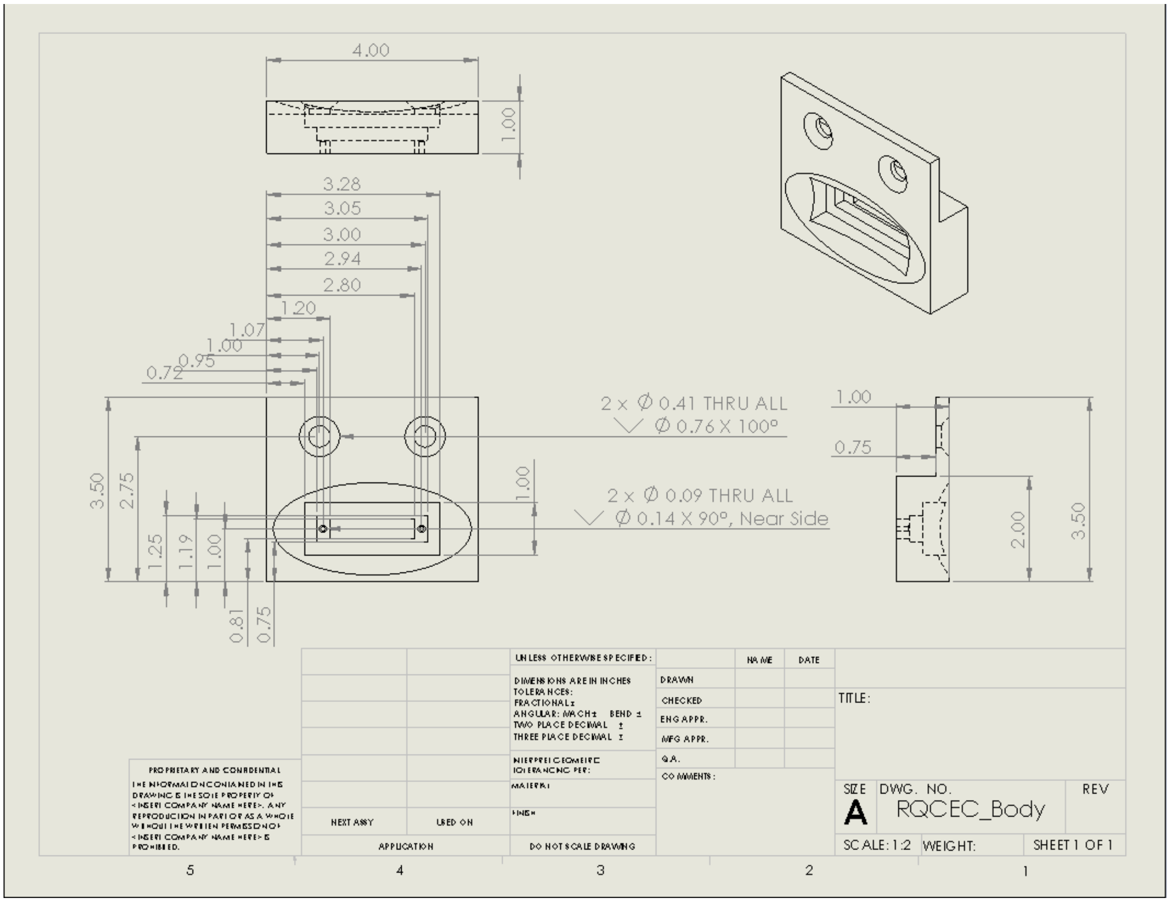

Figure 8 – Dimensions for Body Side of the Design

5.0 New Material

The first task that the team will be focused on was solving the issues with the machining of our prototype. This was accomplished by continuing discussions with both Raytheon and the faculty at the Northern Arizona University machine shop. The material that was decided on was 6061 Aluminum. The reason for changing the material, as discussed above, was due to the improved manufacturability and it cuts the cost of the final design. The material properties of the Aluminum are comparable to the stainless steel with the additional features of lower cost. The pertinent properties of 6061 Aluminum are listed in table 5 below.

Table 5: Aluminum Material Properties

Property	6061 Aluminum
Hardness	95
Ultimate Tensile Strength	310 MPa
Modulus of Elasticity	68.9 GPa
Thermal Expansion at 250˚C	25.2 µm/m-C˚

6.0 Cost Analysis

The current cost analysis of our part is shown in table 6 below.

Table 6: Cost Analysis for Final Design

Category	Units	Cost
Material	$	$50
Manufacturing	Man Hours	2 hours ~ $100
Electrical Connector	Glenair Unit Price	$20
Totals	**1**	**$170**
	500	**$85,000**

This table shows that the price with Aluminum 6061 as the new material is within the specified budget, per Raytheon's request. This was done by decreasing the time to machine and lowering the cost for the material. These numbers were calculated for the worst case scenario.

7.0 Machining

Due to the changes in our original design, it was decided amongst the team, professor, and the NAU machine shop to create a rapid-prototype model of our new design. This allowed the team to have a physical copy of the design while also being able to make it from less expensive, plastic, material. Doing so made it easier for the team to make design changes and also to discuss these changes amongst the team as well as with our professor and those working at the machine shop. After the team was satisfied with the design changes and outcome of two plastic prototype models, the decision was made to create our final prototype from the 6061 Aluminum that was previously discussed.

This aluminum proved much easier to machine than what was anticipated for the original material choice of AISI 303 Stainless Steel. The nose side portion of the design was machined first. An end mill was used to create the extrusion as well as the space where the electrical connectors will be placed. Then a simple drill was used to create the holes for the fasteners to connect it to the nose of the missile. The body side of the design proved to be slightly more difficult and more time consuming to machine. The drill was again used to create the holes for fasteners and the end mill used to create the drop through for the electrical connector. Then CNC code had to be written for the elliptical indent. This code was written by workers at the machine shop in conjunction with several conversations with the team to ensure that the final product would meet the team's expectations. The final machined design for both the nose and body side portions can be seen below in figure 9.

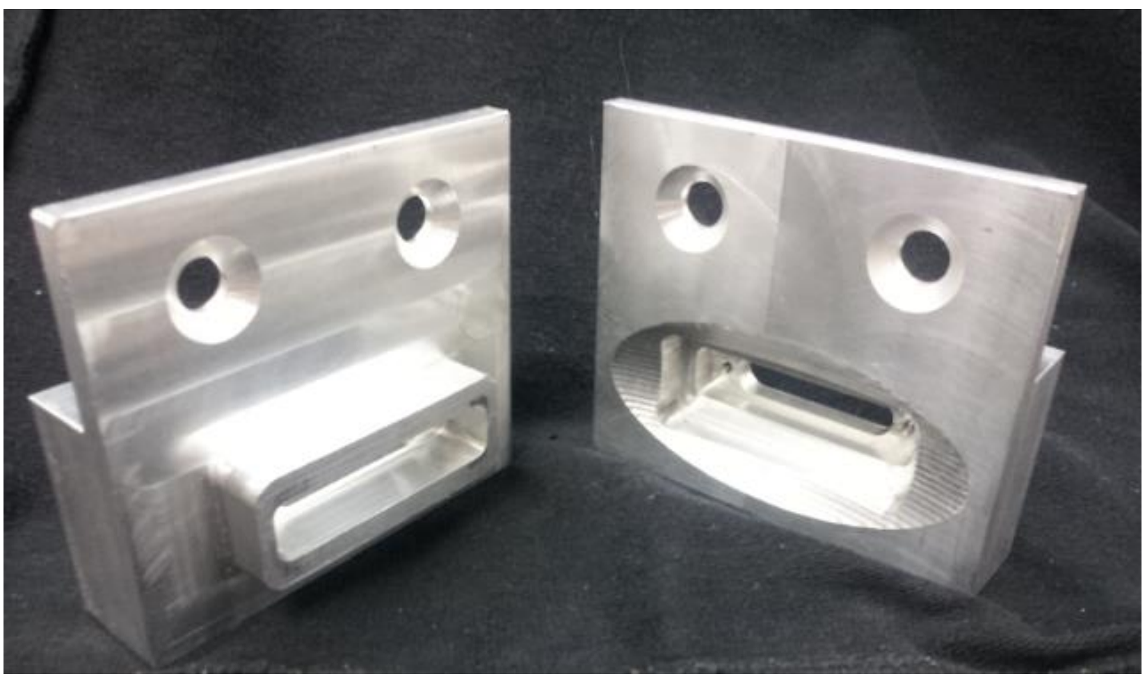

Figure 9 – Final Machined Design

This final product is what the team expected to receive and it should fulfill all of the requirements given by our client. With this final product there are a few changes that could be made if our client choses to do so in the future without having to make any major changes to the product that our team has produced with this design. Now with the final design in hand, the team was able to test it to ensure that it completed all necessary tasks and held up to the standards that the team is able to test it against.

8.0 Testing

The electrical connection was tested using multiple methods. The primary objective was to insure that alignment occurred relatively easily despite any initial offset within 0.114" radially. Testing also had to insure, that not only was the connection made with alignment issues, but also that the connection was valid and all 32 pins were connected. Further testing also insured that these conditions were met under various environmental effects such as water, ice, and debris in the air. Lastly, the loads experienced during the bomb ejection applied a 50 g shock to the electrical connection, in order to insure this did not deform or damage the part a FEA analysis was performed to find the highest stresses experienced by the part.

8.1 Radial Alignment

The radial alignment was tested through trial and error. This was done through a series of test placing the two sides at a misalignment within the tolerance. After being misaligned a normal force was applied until the parts either aligned properly or failed to align. This test was performed roughly 100 times using different offsets in both the x and y direction. The results placed the alignment to occur accurately 93% of the time, and only failed when the force was not directly normal to the surface and caused the piece to rotate and jam sideways into the other piece. This failure was determined to not be allowed because the current alignment system does not allow for any rotation and we can assume it will not happen during the alignment of our part.

8.2 Electrical Connection

The accuracy of the electrical connection was confirmed through an electrical circuit that contained a 0-9 numerical LED display, and a blue led light. The electrical circuit would light up the blue LED if no electrical connection was made after alignment, and would illuminate the numerical display depending on how many pins made a connection after alignment.

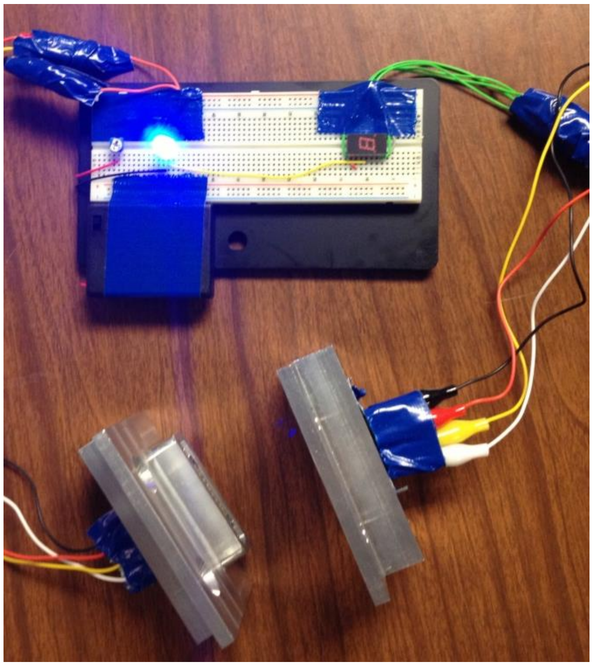

Figure 10 – Blue light showing for no connection

For this setup, an 8 being displayed on the numerical display signified that a perfect electrical connection was made and no pins were broken or misaligned.

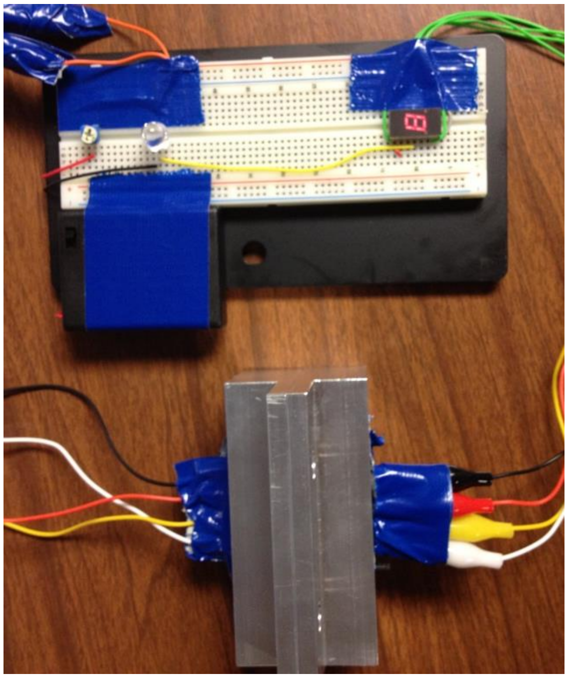

Figure 11 – Connection made, numerical display shows eight

This process was tested in the same way as the radial alignment and has not provided a result other than 8. As a result, it was concluded that the electrical connection had little to no error and can be expected to perform above expectations.

8.3 Environmental Factors

In order to test the effects of the environment on the connector multiple test were performed. First, the connector is housed inside an airtight housing as a result water and icing effects are expected to be minimal if they occur. However, the connection was sprinkled with water and ice in order to check for corrosion or if any serious effects occur under minimal exposure to water. Furthermore, dust and sand was sprayed over the connection to see if any damage occurred. The overall conclusion was that the aluminum effectively protected the internal connection from any external factors with little wear or corrosion on the housing.

8.4 Finite Element Analysis

The finite element analysis utilized a 500 N to 5000 N force applied in every direction around the pivot point where the device connects to the missile. This was done by creating a very fine mesh for the part in solid works and applying the force normal to a surface. This resulted in a range of pressures that were significantly below the yield strength of aluminum. The expected value to be experienced by the part is a 500 N shock and resulted in a minimal stress with a minimum factor of safety of 9.5. This was further extended to analyze a 5000 N force where the factor of safety resulted in about 1 and certain parts were close to failure. The results of the FEA analysis proved that aluminum would be more than capable of withstanding all the force applied during missile flight and deployment. The resulting FEA simulations are in the following figures.

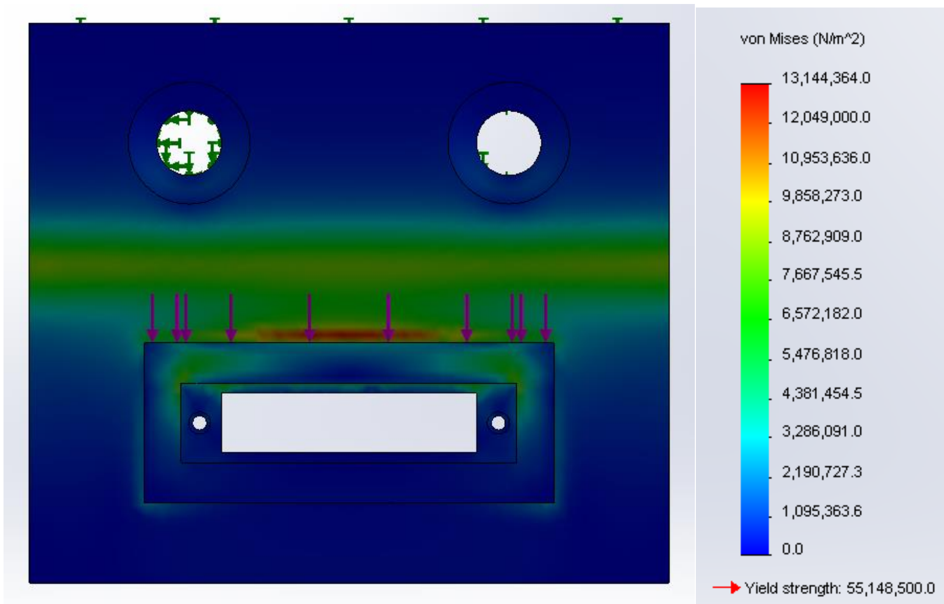

Figure 12 – FEA Simulation for Nose Side

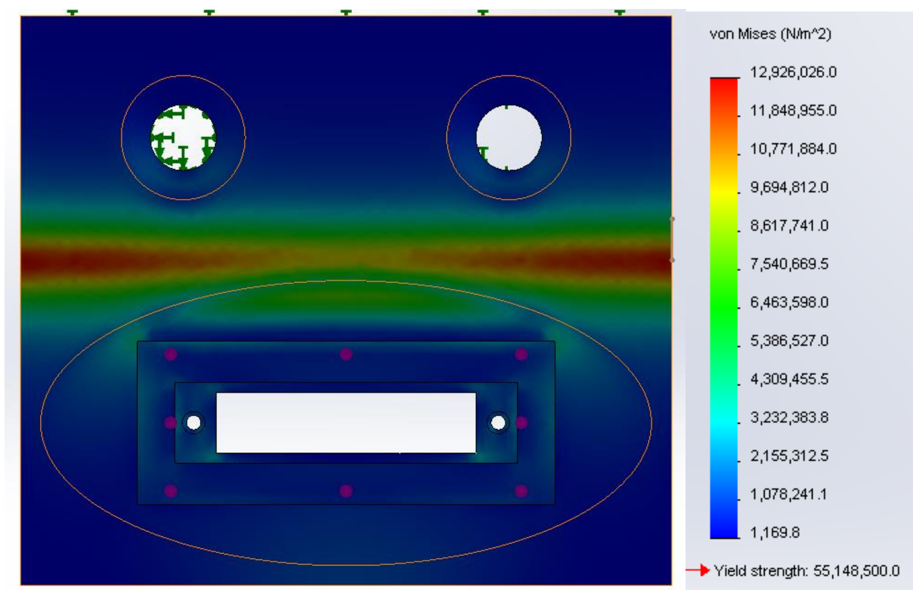

Figure 13 – FEA Simulation for Body Side

9.0 What We Learned

Each individual in our group learned various things throughout this project as different obstacles presented themselves. Though as a team, there were four major learning outcomes that developed from this project. The first was a full application of the engineering design process.

Due to the length of the project, there were many different designs created and analyzed by the team before finally coming to a final design. The team was constantly learning about different things involved in the design that required changes to be made. Though the general design of our project stayed the same, there were small nuances that changed on a weekly basis. This was a direct result of our second learning outcome; communication in a long project is a key component to success. The team overcame several difficulties when it came to communication. This especially happened very early on during the project. Once the communication between the team, our client, and all of our teammates became more fluid, so did the progression and success of our project. When communication was an issue, so was time management. If communication broke down, the team was then pressed for time to complete our next goal. As the project progressed the team learned how to use the time that was given in a much better manner. This was done by being more proactive in our communication and also learning how to use the resources that our team had in a more efficient manner. Not only does this include talking to our client, professor, or those who work at the machine shop but also our own teammates. There were different phases of the project in which each team member excelled at a different task. Recognizing this and allowing team members to work on those aspects of the project, truly accelerated the overall progress and success of the project. While the overall goal of this project may have been very specific, the members of Team 9 learned more than they could have ever imagined by working together on this project.

10.0 Conclusion

In conclusion, the final design that the team created and had machined was successful. While this design has not been fully tested, examined, or used by our client there are a few markers that allowed our team to believe that it is a successful design. The largest indicator of success is that it is able to correct any misalignment that it reasonably might encounter. Another big goal that was accomplished with the final design is that it can be easily replaced in its field of use. After testing and performing basic finite element analysis on the design, the team is confident that the design will be able to last the expected lifetime that was requested by our client. Our final check for success with our design is that our design meets all of our client's requirements, while also exceeding them in some areas of our design. These successes within the design combined with all of the things that were learned, our team feels that this project has been an overall success.

11.0 References

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[3]. Larimore S, Bliss S, Morzinski M, and Concilio A, 2012, "2012-2013 University Design Project: Quick Change Electrical Connect Project Package," Revision A, Raytheon Missile Systems.Raytheon official website. Web. 3 December