Team 4B – Test Fixture for Flight Components (Willy)

Final Report

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DISCLAIMER

EXECUTIVE SUMMARY

The team was tasked with the responsibility of either redesigning or creating an original concept of a universal test fixture capable of testing a variety of missile flight components, such as radomes and leading edges, while withstanding simultaneous thermal and mechanical loading. The project's mentor and client, Chuck Vallance, is a former Raytheon employee with expertise in missile testing and its procedure. Chuck has conveyed to the team that current missile component test fixtures require a large time allocation for set up and take down of this testing environment, in addition to a significant number of workers to complete these tasks. The outcome of this project is to design a test fixture that addresses these inefficiencies while satisfying all other customer and engineering requirements.

Once customer and engineering requirements were decided upon, the team started brainstorming designs and benchmarking based on the functional and black box model. Although many of the test fixtures that were benchmarked are not of the same nature as the test fixture, they all provided valuable information. The benchmarking process helped the team determine what should be included in the fixture’s final design and what should be left out.

Originally, the team was only able to design for mechanical and thermal loading as the primary subsystems, but as the calculations became more thorough, the team was able to create a complete test fixture. A decision matrix was used and evaluated to determine the full fixture designs.

The first system level design iteration was only suited for radomes, but incorporated a square, universal mounting plate fit for radomes up to three feet (ft.) in diameter. The fitted plate, which connects to the radome attachment ring, is fastened to the fixture with 24 individual screws that line the perimeter of the fitted plate. The radome mounting plate combined unit is fixed and held in place for testing on either side by symmetrical, “A” shaped side components, which are firmly mounted to the floor. To induce the thermal loading required to achieve the necessary temperatures and heat fluxes of actual missile flight, the team will surround the radome with six to eight radiant, quartz heat lamps. Finally, to apply the prescribed mechanical load to the radome, the team has designed an attachment to the end of a hydraulic ram that will cradle the radome as it pushes it into an upwards compression.

After consulting Chuck about the design, he provided the team with insight into which aspects of the test fixture design were plausible, and which components were unrealistic. Although presently the design is heavy and is largely dimensioned, it is robust, has a limited number of parts, and is simple to assemble, transport, and store. The first iteration of heat flux, mechanical loading, beam, and bolt calculations helped inform the final design for the semester, and with each subsequent iteration, the specifications of the design will become more detailed, as will the bill of materials.

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1 BACKGROUND

1.1 Introduction

The team has been presented with the task of creating a universal test fixture for missile flight components such as radomes and leading edges in high-temperature and high-pressure flight conditions. The final design must have a quick assembly and take down time, with minimal time delay between each step in the process. The team's client and sponsor, Chuck Vallance, is a former Raytheon employee who has requested the team to make changes to the current testing environment either by improving upon the currently existing design or by a redesign using an original concept to increase the efficiency of the testing process. This project is significant because as missile and flight technology continue to improve and advance, the equipment used to test these designs must also do so. Large quantities of money are invested into missiles and aircrafts. Testing these vehicles is one of the most essential steps to assuring that failure during an actual flight does not occur, which typically leads to huge financial loss. By designing a functional and technologically competent test fixture that can improve upon and more accurately apply and measure the modes of loading, the findings of the final design could potentially have applications in the flight industry.

1.2 Project Description

The following is the project description verbatim from the client.

> "Outer mold line flight components, such as missile and aircraft radomes and wing leading edges often operate in extremely harsh environments. Small practical radomes can be 6 inches in diameter and 18 inches in length. A large radomes can be 4 feet in diameter and 8 feet long. Wing leading edges can vary as dramatically. Successful design efforts for these hardware components include testing to validate the design. Common environments to which the hardware is subjected to include internal and external pressure, high heat fluxes, and pressure induced flight loads. Specialized test rigs to perform the testing are standard. The output of this project will be a set of design specifications for a test fixture which can be deployed in standard laboratories (may be outside) and capable of testing a wide variety of radomes and leading-edge shapes and sizes as well as producing a wide variety of testing environments (pressures, loads, fluxes). Some fabrication and testing of scaled models of the test fixture will benefit this project to prove it is viable but is not required."

1.3 Original System

The original system is a missile radome and leading-edge test fixture. The fixture simulates supersonic flight conditions and applies mechanical and thermal loading in different orientations. The following sections will describe the original fixture in further detail.

1.3.1 Original System Structure

The team's mentor, Chuck Vallance, had provided a representation of what a missile flight component test fixtures might look like; this was also the basis of the benchmarking process. Testing occurs in a large room where all equipment can fit in a 24 ft. by 24 ft. space. The loading area is typically built on a steel platform with holes drilled every six inches as to form a grid where things can be screwed down into the floor. The loading structure is a three ft. tall mechanism made of steel I-beams with a strap attachment. To reproduce a thermal load that a missile component would experience during flight, several quartz heat lamps are placed in multiple, specific locations around the component. Sensors, such as thermocouples and calorimeters, are placed along the surface of the radome as well as inside to measure temperature. Force transducers and load cells are used to measure mechanical loads. Linear variable differential transformers (LVDTs) collect deflection data. Figure 1 shows the provided schematic of the original test fixture.

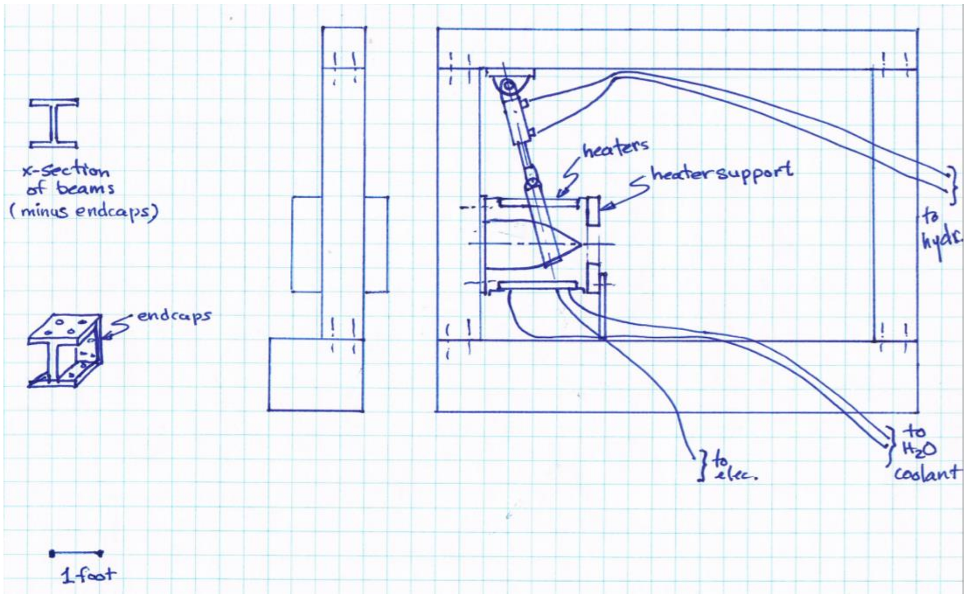


Figure 1: Original System Schematic

1.3.2 Original System Operation

When the fixture is powered, it begins simulating flight conditions. The strap is designed to cradle the flight component that is subjected to testing and replicate a pulling mechanical load. The quartz lamps are used to achieve a heat flux that is as equally distributed as possible. The quartz lamps include a water-cooling system. Separate from the test fixture is a control room that receives signals from the sensors and displays data from the testing room as well as prescribes loading and temperature profiles to the mechanical and thermal equipment.

1.3.3 Original System Performance

The team was unable to visit the original test fixture. The client had also refrained from giving specific performance parameters for the current fixture because he wanted the team to figure them out. Within the first semester, the team was only able to observe fixtures and data collected from a select few designs that are available to the public, many of which concern a different aspect of flight testing than that of which the team was striving to address.

1.3.4 Original System Deficiencies

Although the original system was functional, there were three main areas of concern for the fixture. As it stands, it takes hours or even days to set up and take down the assembly, meaning there is a large time and labor investment. With this, it also required a lot of man power to assemble and tear down. Lastly, it was unable to support testing for a variety of different radome sizes and orientations, making its capabilities and diversity limited.

2 REQUIREMENTS

The following section details the customer and engineering requirements for the test fixture. It also includes testing procedures to ensure that the fixture fulfills the requirements and a house of quality to evaluate how each requirement relates to another.

2.1 Customer Requirements (CRs)

After meeting with the client, customer requirements were established. The purpose of the customer requirements was to narrow the scope of the project and translate what the client wanted into qualitative design requirements. The customer requirements are related to the functionality of the test fixture, as well as safety, durability, and ease of use. Table 1 shows the customer needs that must be fulfilled for the test fixture, as well as their corresponding weights. The requirements that were weighted the highest were those that the client emphasized were of greater importance, such as simulating flight conditions, minimal labor, and ability to test a variety of missile parts. Safety was also rated highly as it is essential to any functional design.

Table 1: Customer Requirements

Qualitative Customer Requirements	Weight (1-10)
Simulate supersonic and hypersonic flight conditions	9
Ability to test a variety of missile parts	7
Applies varying mechanical loads	7
Applies varying heat loads	7
Applies loads in different orientations	5
Minimal labor required for set up and changing out parts	9
Measures loads, strain, temperature, and heat flux	7
Transmits measurements to the command center	5
Portable	9
Compact Storage	3
Safe	9

2.2 Engineering Requirements (ERs)

Engineering requirements were decided based on customer requirements. The team identified how each customer need could be translated into an engineering requirement that can be quantitatively measured. Table 2 shows the engineering requirements as well as their target values. The target values were rough estimates based on information provided by the client. The team does not have target values for the resistance and voltage requirements because it was stated that the sensors and loads needed to be driven from another location, but the exact numbers were not necessary.

Table 2: Engineering Requirements and Target Values

Engineering Requirement	Target Value
Transports quickly from storage	1 hr.
Assembles quickly	2 hrs.
Mounts to a standard bolt pattern	6 in.
Applies and withstands extreme loads	$4.9*10^5$ in-lb.
Applies and withstands heat flux	50 W/cm^2
Ability to test parts up to 3 feet diameter	3 ft.
Safety Factor	4
Sensors read out to a different location	ohm
Load driven from an alternate location	Volt
Small storage space	100 ft^3

Two engineering requirements have changed due to the completion of new analyses. Previously, the team was planning on using 75 W/cm^2 as the heat flux for the testing environment. After modifying the heat flux calculations, only 50 W/cm^2 will be applied, as it is still a conservative number, but is more accurate to the actual flight conditions. The other engineering requirement that changed was magnitude of the mechanical load. It was initially set at 100,000 inch – pounds (in-lb.), which was an estimated value. Once the compressible flow calculations were completed, the maximum moment was changed to 49,000 in-lb.

2.3 Testing Procedures (TPs)

Testing is essential to the success of the team's design because it confirms what has been found in theory to what would occur in real life. Although this project is mostly analytical, it is essential to come up with tests that can ensure the functionality of the test fixture. It is also important to be able to fulfill all the necessary engineering requirements however, it should be noted that nearly all testing for this project will be using simulations and calculations, and there will always be some uncertainty with theoretical modeling. The following sections will detail future and hypothetical test scenarios.

2.3.1 Quick Transportation Test

A quick transportation test will be completed to confirm that the fixture can be moved quickly from storage to the testing environment. For the hypothetical full-scale fixture, the transportation time could be tested by estimating the distance the fixture will have to travel, and timing how long it takes using any timer. This test would require a forklift as well as manpower to transport the full-size fixture. In this project’s case, a simulation could be used in SolidWorks or hand calculations could be done to estimate the time it takes to pack and unpack pallets and distance travelled to approximate the time. To ensure that the SolidWorks transportation test meets the 1-hour target value, the team will have to allot a time that is slightly more than what would be expected for both loading and unloading the fixture. Because the team is unable to build a full-scale test fixture, there is no way to ensure that a physical test fixture will meet the target time, other than using estimated values.

2.3.2 Quick Assembly Test

To ensure that the design can be quickly assembled, a simulation will be completed in SolidWorks of the full assembly. Every part of the fixture can be modeled, and the rate of assembly can be slowed in the simulation to more closely match the speed at which workers could realistically assemble a fixture, which will allow the simulation to be measured in real time. Completing several runs of this simulation at varying rates of assembly and averaging the times may yield a rough estimate of the manpower required to complete the assembly within the two-hour target value. An alternative way the assembly time can be tested is to construct a scale model and time how long it takes to put together by hand. Then, scale model analysis would be completed to see how much time it would take for the full-scale design. With this assembly test, the team will need to contact the client to discuss how long each specific part takes to assemble, as there are some very particular ways some specific parts need to be installed. This would perhaps be a less accurate estimation of time, as the magnitude of the full-scale weight or adjusting the rate of assembly to account for varying degrees manpower cannot be considered. The prototype would be 3D printed using on campus resources. Aside from that, the only materials required are glue to hold the pieces together, a timer, and a person to assemble the fixture.

2.3.3 Standard Bolt Test

To test that the bolts fit the standard six-inch (in.) bolt pattern of the floor, one hole can be drilled into a similar steel that would be utilized in the theoretical full-scale assembly. Then, the bolts in question could be fitted to see if they matched the hole size and dimensions. For the purpose of this project, the bolt part file will be downloaded from its vendor and matched to holes that will be modeled in SolidWorks. From both tests, it will be clear whether the bolts will match with the bolt pattern correctly in the simulation as well as an actual model.

2.3.4 Extreme Loading Test

The mechanical loading test can be completed hypothetically by attaching a force gauge to the mechanism applying the load. This device can be found online at many retailers. The force meter will accurately ensure that the target force of 7,500 pounds (lbs.) is being applied to a specific sized flight component to induce the desired moment of 10^5 in-lb. A simulation can be modelled in ANSYS to see what stresses are applied to the radome. The simulation is useful for this project, but only testing the mechanism in real life will ensure that the necessary force is applied. The most accurate way to test if the hypothetical fixture itself and the components can withstand the loads applied without failing, is to assure that the factor of safety calculations are correct and that the factors of safety that are used are liberal.

2.3.5 Extreme Temperature Test

In order to test how much heat flux would be applied to the radome, ANSYS will again be utilized. The approximate target heat flux of 75 W/cm^2 will be applied using the software, then a temperature profile will be plotted as a result of the applied heat flux. The software will also supply a heat flux contour plot. This test will help ensure that the heat flux is being applied in the correct place and at the correct value. The software will also be able to give values for heat flux for many kinds of missile parts. If extreme heat fluxes were to be tested in real life, the temperatures at different points around the radome could be taken using thermocouples and given the heat transfer coefficient conductive heat flux could be calculated. This would be a way to ensure the design was applying the correct amount of loading.

2.3.6 Part Size Test

The ability of the fixture to handle different sizes of radomes can be quickly tested. The maximum diameter radome that will be tested is three ft., therefore the mounting plate can be tested by modeling a radome of that size in SolidWorks. This is a simple way to test the interface. One way to ensure the plate is large enough is to measure it using a tape measure. The mounting plate should also have a few extra inches on each side to ensure that it is large enough. Another analysis that should be considered after the test is completed, is to ensure that the bolt holes on the plate are in the correct orientation to accept all types and orientations of parts.

2.3.7 Safety Factor Test

Safety factors will be tested and calculated based on the results of the other tests, to assure that the fixture will not fail at any point in the test. Every part of the fixture must have a minimum safety factor of four, and that will be ensured by hand calculations as well as computer software. ANSYS can be used to determine stresses and strains as a result of the mechanical loading, and factor of safety will be calculated from there. ANSYS can also be used similarly for heat transfer applications, as mentioned in section 2.3.5.

2.3.8 Sensor Test

One way to test that the sensors are working correctly is to perform calibrations for each sensor. Once calibrations are complete, the fixture can be run to see if the values received are within reason. If this test is completed multiple times, it should ensure that all the sensors are connected correctly and are reading out reasonable values. It also ensures that the data is being transmitted to the intended location.

2.3.9 Power Test

The power output of the fixture can be tested using a voltage and current reading. A voltmeter and ammeter will be used to collect data for the power calculation. Power estimations can also be used by contacting the vendor of the parts to obtain their power estimations.

2.3.10 Storage Test

A storage test can be completed by measuring the dimensions of the fixture when it is collapsed to confirm it is under a volume of 100 ft^3. A similar process can be completed using SolidWorks and the modelled parts.

2.4 House of Quality (HoQ)

Once customer and engineering requirements were determined, the team created a House of Quality to relate them to each other, as well as ranked currently existing designs. The House of Quality helped the team prioritize design requirements by calculating the relative and absolute technical importance. The team gave each customer need a value (on a 1-9 scale) based on how important it was to the client. Next, the team determined how much each engineering requirement might influence each customer need. These values were then used to determine absolute and relative technical importance. Each engineering requirement was evaluated for how it related to other engineering requirements as well. As a result of the House of Quality (Appendix A), applying both mechanical and thermal loads will be prioritized because they are ranked highest in relative technical importance. Quick assembly, transportation, and testing parts up to three ft. are ranked second, third, and fourth respectively. These requirements will be important, although slightly less so than those ranked above. One item to note is that the team does not currently have voltage or resistance target values for outputting the signals however, second semester those calculations will be completed. Not only did the House of Quality help the team prioritize technical requirements, it also provided benchmark information for existing test fixtures. Four existing fixtures were benchmarked, so that the team could identify the strengths and weaknesses of the designs. Benchmarking helped the team discern which elements of other fixtures should be incorporated into the current design and which should be discarded.

3 EXISTING DESIGNS

This section of the report contains a compilation of all the aspects of research that have been completed for the capstone design project. Starting with a description of how the team chose to conduct research and select designs for the benchmarking analysis, each subsequent section will explore existing designs that are similar as a full system to the original system. Following the broad overview of each system, the team will provide an elaborate break down of the systems in the form of a functional decomposition and black box model. Sequentially, each existing design will be broken down into a variety of sub-system components and elaborate on their relevance to the engineering requirements and in the design project.

3.1 Design Research

For the team to gain a more comprehensive understanding of the current state of flight component test fixtures, it was necessary to conduct research on presently existing designs. Due to facility restrictions, on-site observations are not a viable research option. Instead, information on existing systems was attained through web-based research, as it proved to be the most extensive and efficient method of research. Through recommendations and guidance from the client in addition to academic resources, the team was able to gather a small, but enough assortment of scholarly articles and studies.

After selecting three designs from the team's research with similar processes as the current design, each design was benchmarked, as seen in the QFD, located in Appendix A. Selected benchmarking designs were scored in the right-most column of the QFD based upon how well each benchmark met each customer need. As a result of detailed research, the team was able to acquire a thorough enough understanding of the functionality and capabilities of each design to give each the most reasonable score in comparison to the existing design. The benchmarking process compared three existing designs that serve a different purpose than the team's test fixture, but each of them included some type of approach that either applied a mechanical or thermal load, or a testing environment that could be considered when synthesizing design concepts.

3.2 System Level

Due to the nature of this project as well as company confidentiality, existing test fixture designs are not readily available for public access. Because of this dilemma, the system level designs detailed in the following three sections will not serve the same purpose as the system the team is expected to replace. The design research for currently existing designs that exemplify components, testing procedures, or features that are similar or can be related to the project objective. With limited system level options, the three existing designs in this section were reviewed by the team and selected as the systems that most accurately aim to include and execute the same tests and requirements as the original design.

3.2.1 Existing Design #1: Gulfstream Aerospace Test Fixture

The first design that the team benchmarked was the Gulfstream test fixture. The team used videos of the testing environment to gather the information needed to benchmark this design [2]. The Gulfstream Aerospace test fixture is suitable for only testing wings and leading edges. The inner side of the wing, which would be attached to the body of the aircraft, is held in place by a fastening mechanism while the opposing side, the point of the wing farthest away from the body, is subjected to a load in order to test how the moment impacts the point closest to the body. The load is applied by a strong pully mechanism, lifting the wing up, causing the wing to bend into an upwards, curved shape until fracture or the conclusion of the test. Many wires and sensors are attached to the wing and the equipment to convey information and data to the control room. Due to the restrictions on the content that Gulfstream Aerospace can release about their testing environment, an educated assumption was made that thermal load testing must occur in a separate environment that achieves all requirements needed for a successful and accurate thermal load test. Referring to the QFD (Appendix A), the Gulfstream test fixture scored excellent for the following customer needs:

- Applies varying loads
- Measures load, strain, temperature, and heat flux
- Measurements and data collection outside the bay
- Safe for operators

These ratings were justified because this design meets all the basic requirements needed for the types of loading that will be analyzed and could safely execute the desired test while keeping the operators and analysts in the control room safe. Although it met these basic requirements needed for any loading test, it was still missing quite a few major elements requested by the client and scored poorly in all other categories. This benchmark was not precisely the type of design that is being considered, but it provided some valuable information that helped the team identify areas in the designs that missed the target set by the client.

3.2.2 Existing Design #2: *Pyroceram* Radome Thermal Testing

The second system level design that the team analyzed and benchmarked was an experiment that sought to determine the thermal environment that would induce failure due to compressive stress for the *Pyroceram* missile radome [3]. This experiment involved two major relevant testing analyses to determine if the radome design was suitable for harsh thermal stresses under Mach four flight conditions. The first component of this study consisted of conducting a thermal analysis computer simulation, using an IBM 7094 computer program. The radome trajectory and geometry selected for the simulation were chosen such that the results would yield the highest rate of heat input as well as its corresponding tensile stress induced by the thermal load. The data collected from this theoretical test was then used to influence the conclusion and verify the speculated results by means of a full-scale wind-tunnel test. In order to induce tensile stress due to thermal loading, the wind-tunnel was set to the desired Mach number, and then radome was placed into the airstream for a pre-determined amount of time. The same test was conducted multiple times to assure measurements for pressure, temperature, and tensile stress were consistent with each trial. The only variable that was adjusted for each test was the radome's initial temperature, to observe the varying effects of temperature on tensile stress. The experimental data was recorded to compare its accuracy to the theoretical predictions.

As seen in the benchmarking columns of the QFD (Appendix A), the *Pyroceram* thermal loading test scored well in the subsequent areas:

- Simulate supersonic and hypersonic flight conditions
- Applies varying heat loads and fluxes
- Measures load, strain, temperature, and heat flux
- Safe for operators

Although this experiment was dissimilar to this project, as it was primarily focused on the radomes and evaluating their structural adequacy, this analysis conducted a thermal test in a manner that the team would ideally wish to utilize in this project. By using a different means to achieve the same goal, despite the contrasting focus, this study can be related to this project by comparing the similar flight conditions and the anticipated results of this project. This test gave insight into what an efficient and successful thermal testing process would consist of, had the team been given the opportunity to continue further with the project.

3.2.3 Existing Design #3: NASA Aerostructures Test Wing (ATW)

The final existing design the team researched was the piezoelectric actuator structural excitation test, used to induce instability identical to flutter during flight turbulence, in the NASA ATW [4]. Light-weight aircraft wings lack structural stiffness, which can cause complications during flight. Piezoelectric devices are used to both measure and generate motion to more accurately predict the onset of flutter in real flight scenarios. This experiment used the piezoelectric actuators to test their ability to invoke the first-bending and first-torsion modes on the ATW for both the ground and in-flight tests.

The impact vibration ground test was performed by first striking the ATW with a large mass, stimulating the piezoelectric sensors to convert the movement into electrical signal response data. Accelerometers placed at the outer edge of the ATW were also used to collect time response data at specific locations along the wing. Conversely, an electrical signal is sent to the piezoelectric actuators via various frequencies and voltages to prompt vibrations, which are applied to the ATW. The wingtip accelerometers were used once again to record the actuator data at each of the voltages. The other phase of the actuator testing consists of measuring the turbulence excitation and wing response at multiple, stabilized test points over a 30 second interval. After the stabilization period, the piezoelectric actuators were signaled to generate motion over the wing for 60 seconds while the accelerometers gather the response data, as before.

This testing method strives to achieve a completely different set of objectives than this project, and therefore, there were a limited number of engineering requirements this analysis could meet. Although this existing design served a different purpose than the intended test fixture, there were still a few concepts and design considerations used in this testing environment that could have potential applications in this design and testing procedure. For this test to improve upon current flutter measurements and predictions, wing excitation was essential for gathering the proper data needed to validate the structural dynamics of an aircraft. In a way, this test was analogous to the team's test fixture in that the design must apply the correct thermal and mechanical loads to the flight components during the testing phase to assure that those components do not fail during an actual flight. The piezoelectric actuator is a small and simple, yet versatile device that was able to quickly drive and sense various loads with precision, when used in conjunction with the accelerometers. These components of the excitation test conform to the requirements of applying loads (although to a significantly lesser degree), sensing input, and transmitting data.

3.3 Functional Decomposition

The project had some complex processes, and it was necessary to break it down into pieces. This section contains a black box model to show the inputs and outputs of the fixture: the types of material that go into and out of the system, the types of energies that the fixture will be using, and the type of signals that go into and out of the system. The next step was constructing a functional model, which explain the functional roles of each input and output.

3.3.1 Black Box Model

The purpose of the black box model (Figure 2) was to show the input and the output of the design. There are three types of inputs: materials, energy, and signals. The material inputs for the design were the fixture and the missile parts that will be connected to the fixture. In terms of energies, there is hydraulic energy, heat energy, electricity, and human energy. In terms of signals, there is a load signals input. The outputs of this design were the fixture and the missile part. The only output energy was the human energy in order to break down the fixture. The signal output will be the sensor signals that will be connected to the control center. This model helped the team know what kind of input flows were required to transform them into desired output flow.

Figure 2: Black Box Model

3.3.2 Functional Model

The functional model (Figure 3) was made based on the black box. The purpose of a functional model was to break down the design into smaller systems and functions that were associated with each input and output. The inputs and outputs are materials, energy, and signals. The functional model shows the process each input goes through. The reason why a functional model is helpful is because each piece is a function that needs to be solved and put to help the next function, one by one to reach the purpose of the design. There will be four imports: the control center, fixture, missile part, and sensors. Each import will be assembled by human energy. The control center will send signals to apply both mechanical and thermal loading. The sensors that will be used are strain gages for the mechanical loading and thermocouples for the thermal loading. Both types of sensors are connected to the missile part. The output will be signal of voltage transfer back to the control center where all the data will be measured and calculated. Then using human energy, the fixture will be taken down.

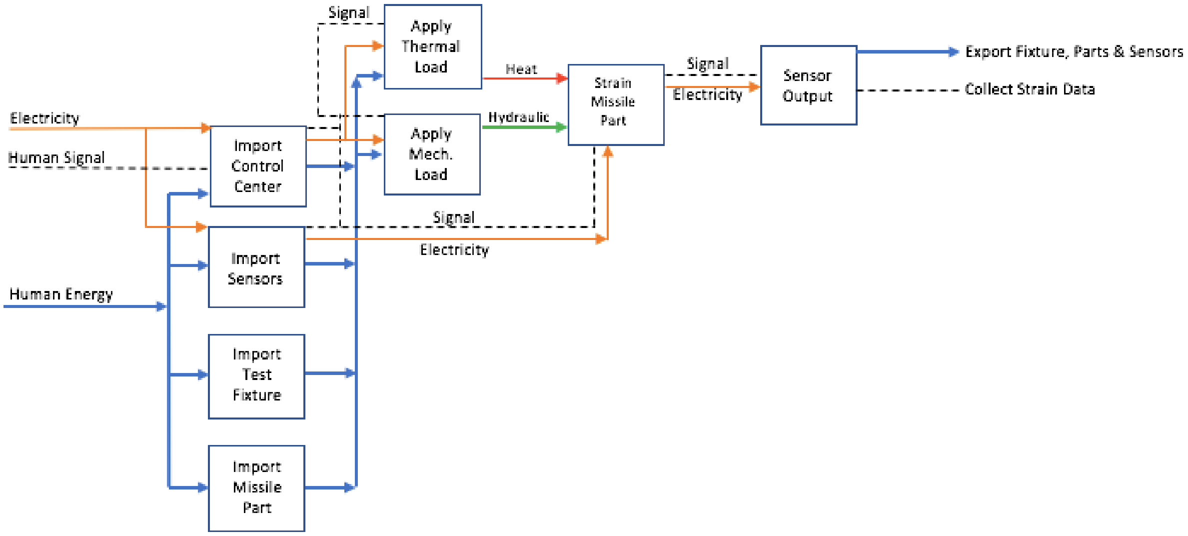


Figure 3: Functional Model

3.4 Subsystem Level

This section contains three subsystem levels that will be helpful for the design in order to ensure the design produces accurate results for supersonic conditions and can be assembled quickly. The three subsystem levels are thermal loading, mechanical loading, and the best beam to use. For each subsystem, the team did research of existing designs that would help creating the best design possible for the fixture.

3.4.1 Subsystem #1: Thermal load

One of the requirements of the fixture was to test a missile part at a high temperature and to create an environment as similar as possible to the flight conditions of hypersonic missiles. Hypersonic missiles endure very high temperatures which can cause damage to the fixture. As a result of this, it was necessary to research existing designs that apply these kinds of temperatures and find out the benefits and disadvantages of each.

3.4.1.1 Existing Design #1: Pyroceram Radome Thermal Testing

This design was designed to apply the temperatures that occur at Mach number four. To get the thermal loading analysis, they used IBM 7094 computer program [3]. This program can handle three dimensional geometric configurations of heat transfer for radiation, convection, and conduction. This was helpful for the team's design because the output analysis was like what was required of this project.

3.4.1.2 Existing Design #2: Combined Loads Test Fixture

Their design was to test aerospace vehicle panels under simultaneous structural and thermal loading. The density of quartz lamps is high. The goal was to reach the necessary higher heat flux, for the flight conditions. A fence is important to shield the less massive material from the high heat. This design utilized heat lamps in the same way the new design will [5]. One advantage this design had was that it minimized the heat loss. The heat shield also made it safer.

3.4.1.2 Existing Design #3: A Test Fixture for Measuring High-Temperature Hypersonic-Engine Seal Performance

In this design, NASA is measuring a hypersonic engine seal at a high temperature. High density Watt heaters are strapped on the sides, top, and bottom of the test rig. The heaters that they have been using are 35 kW. The fixture's temperature reached 1500 °F in five hours [6]. This was helpful because the team's design has the same purpose: to apply a high thermal loading and test it. Also, it gave the team some idea of how long it will take to complete the testing. The test will most likely only be a few minutes long.

3.4.2 Subsystem #2: Mechanical Load

One of the major requirements that the fixture needs is the ability to apply a mechanical load that meets with hypersonic flight conditions. For this design, mechanical loading will be applied to the missile part using hydraulic energy. Because of the high temperatures, the material is important as well as the performance.

3.4.2.1 Existing Design #1: Gulfstream Aerospace Test Fixture

The first existing design applies the mechanical load by a hydraulic ram that is connected to a beam above the wing that is being tested. Two straps are connected on the end of the wing in order to pull it up and six hydraulic rams push up in six different locations. These loads create a huge amount of moment on the wing and that is the purpose of the test [2]. This is helpful because their goal is to create a high moment to see if the wing can withstand it. In this project, the team will apply a moment to the missile part, which will be a similar process.

3.4.2.2 Existing Design #2: Combined Loads Test Fixture

In this design NASA is applying mechanical loading to a vehicle panel. The panel is 48-by-48-in. The load applied is from 30,000 lbf to 50,000 lbf. Hydraulics are used in order to add pressure from two sides on ten different areas [5]. The is important for the design because it introduces the idea of using more than one ram. Also applying the pressure from more than one side could make the results more accurate.

3.4.2.3 Existing Design #3: NASA's Armstrong Flight Research Center

For this design, they use weight as pressure force, which means they are using gravity to apply pressure.

Using this type of pressure is less expensive than using hydraulics [7]. On the other hand, using weight requires more room for the weight. This way is also not as safe as the hydraulics, because hypersonic missiles accumulate huge amounts of pressure. This design introduces another way of applying the moment to the missile part.

3.4.3 Subsystem #3: Beams

The beams are essential for the structure of the fixture. The hydraulic ram will create a high stress area where it attaches to the beam. A large moment will be applied to the plate that holds the radome. According to OSHA standards, the factor of safety needs to be four or more, which means the beams need to have high moment of inertia. When the moments of inertia of the beams are high, the stresses on the beam will be lower. As a result, the mechanical load will be more directly applied to the missile part, instead of the beam deflecting.

3.4.3.1 Existing Design #1: Gulfstream Aerospace Test Fixture

The beams that Gulfstream use are rectangular beams. While I-beams have a higher moment of inertia, rectangular beams are better at withstanding high stresses at bolt connections. Also, regarding the shear stress that the bolts are holding [2], this information could be helpful if the shear calculations are higher than expected. The team could use rectangular beams in that case.

3.4.3.2 Existing Design #2: HDT Global

This company has designed a beam that has unique properties by creating a highly oriented fiber layer. The structure is flexible, and the angles of its fiber will increase the beam's strength under pressure loads [8]. This design is helpful because one of the goals of this project is to make it fast to assemble, using fiber rather than steel will make the beam lighter and quicker to assemble.

3.4.3.3 Existing Design #3: Hybrid Composite Beams

This beam is designed to endure high mechanical loading. At the same time, it is light. They use this kind of beam for bridges. They use a concrete arch, a low-density foam core, and a fiber plastic shell [9]. The purpose of their design is different than the purpose of this project, but it is still applicable. Using a fiberglass beam, which is a lightweight, strong material, will help the design.

4 DESIGNS CONSIDERED

For this design project, there are three parameters that must be evaluated. The first two are the means by which mechanical loading and thermal loading must be determined. Each has a unique set of engineering requirements and there are many options for how these loads could be applied. The third parameter that must be analyzed is the overall orientation and geometry of the test fixture. The test fixture will affix the components and allow the loads to be applied. This section will review the designs considered and the impact of each of the designs.

4.1 Thermal Loading

The thermal loading which simulates the extreme temperatures of supersonic flight must be replicated at the same time as the mechanical loading. A successful design is one that will have an even distribution of heat flux and still allow for the mechanical loading mechanism to operate. The next four designs are attempts at solving these problems.

4.1.1 Design #1: Oven

The first thermal loading concept is simply an oven. In this concept, the entire test fixture is loaded into an oven and the mechanical load is applied. The primary benefit to this system is that it is very simple, and it avoids using complex and expensive heating mechanisms. Unfortunately, the drawbacks are extensive. First, every single component in the test fixture would have to withstand temperatures nearing the melting point of steel. This will drive up the cost of virtually every component on the structure, negating any savings. Another drawback is the oven would now have to heat a large volume and would result in a long heat up time.

4.1.2 Design #2: Heat Coils

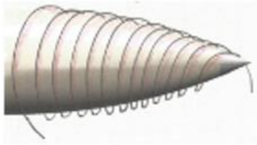


Figure 4: Heat Coils Design

In this design, a coil system containing electrical current is wrapped around our flight component. As high currents travel through the coils, heat is expelled, and the flight component is heated. One nice feature of this design is that the amount of heat delivered can be accurately controlled. The coils can also be wrapped around a variety of parts making it universal. Another benefit to this design is that the heat is evenly distributed on the test component. The drawback of this design is that it blocks the part from being able to receive the mechanical load.

4.1.3 Design #3: Fixture

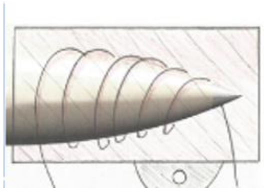


Figure 5: Fixture Design

The thermal loading mechanism we are calling the fixture utilizes the same concept as the heat coils with one addition. The entire heat coil mechanism is encased in metal allowing the mechanical load to be applied. The inner surface of the fixture is perfectly matched to interface with the aerospace component to be tested. This is the major drawback of this design. Every single part that would be tested requires a unique fixture, eliminating the customers universal requirement.

4.1.4 Design #4: Fluid

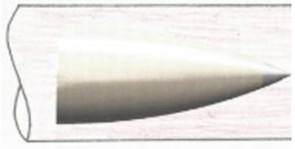


Figure 6: Fluid Design

The application of thermal loading through a dense fluid is another way mechanical and thermal loading can be applied simultaneously. The component to be tested would be inserted into the fluid stream at some non-orthogonal angle, creating a moment on the part. The hot fluid would then heat the part. There are several issues with this design, the first being that the extreme temperatures would cause many oils to combust. Secondly, the part may become damaged from being in contact with the fluid. Finally, there could be a health or safety risk if the oil were to spill.

4.2 Mechanical Loading

As flight vehicles turn while traveling at high velocities, there are lateral pressure loads applied to various components. In addition to pressure loads, the vehicles experience lateral acceleration while turning. This acceleration causes forces which must also be replicated in testing. The following two designs apply the mechanical loading to flight components.

4.2.1 Design #5: Rings

Figure 7: Ring Design

The application of mechanical loading using concentric rings will allow for a more even distribution of loading. The rings would have to be custom-made for each component leading to the same issues as the fixture. One advantage to the ring design is that they could potentially be used on a variety of radome sizes, the only differences being that they would just be situated at different distances from the base.

4.2.2 Design #6: Cradle

Figure 8: Cradle Design

The cradle is designed to evenly distribute the mechanical load on test parts and is also more universal than the rings. The major disadvantage is that the curvature is generalized so it will not distribute loads as evenly as the rings however, the overall cost will be lower as multiple fixtures will not have to be manufactured.

4.3 Test Fixture

The test fixture is the overall assembly which holds and stabilizes the flight component and delivers the mechanical and thermal loading to it. The design of the fixture will have a significant impact on assembly times, storage volume, and ease of use. The fixture will also dictate the size and shape of components that can be tested. Most importantly, the fixture will determine the overall safety and success of the tests to be performed.

4.3.1 Design #7: Rail

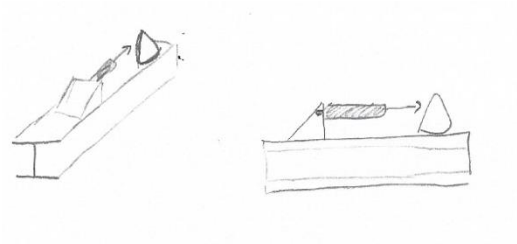


Figure 9: Rail Design

The rail test fixture is a one-piece test fixture designed for simple setup and operation. The fixture is composed of a single I-beam with the hydraulic ram and part interface permanently affixed. This test fixture would transport easily and could be stored in pieces. There are a few disadvantages to this design, which is that there is a small range of parts that can be tested; large components will simply not fit on the I-beam.

4.3.2 Design #8: Turntable

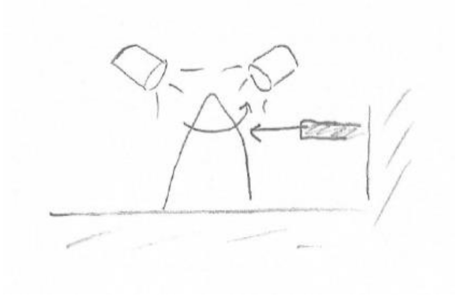


Figure 10: Turntable Design

The turn table fixture is unique in that it rotates as mechanical and thermal loading is being applied. Under normal test conditions, a part must be fully tested and then rotated 90 degrees and re-tested. This fixture would save time as the parts would not have to be disconnected in between tests. In theory, the part could be rotated during the test to create a sinusoidal load, effectively testing fatigue. This fixture also offers the benefit of even heat distribution.

4.3.3 Design #9: Upright

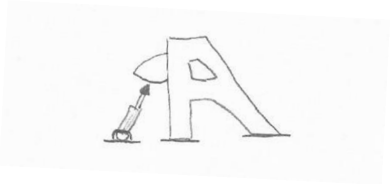


Figure 11: Upright Design

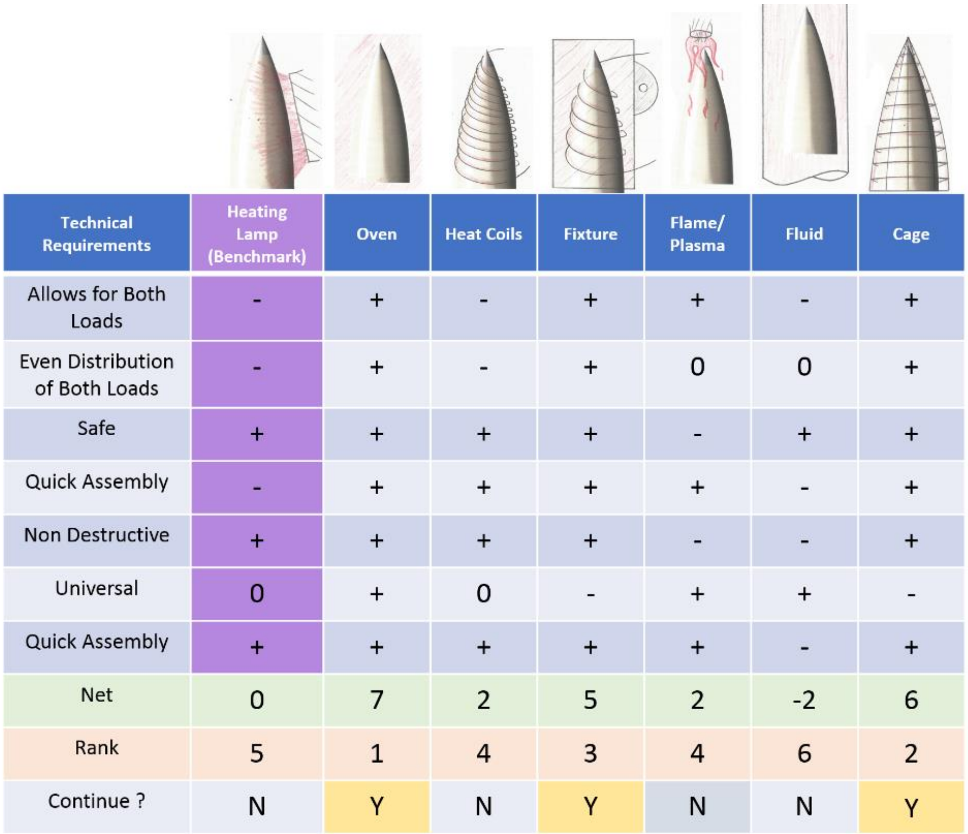
The upright is a multi-sectional test fixture which is designed to handle a wide variety of components. The mechanical load is applied from the floor minimizing deflection of the fixture. The fixture is versatile and perhaps could be adapted for other tests.

5 DESIGN SELECTED – First Semester

The following section describes the process that the team used to select a design. First, a Pugh chart and decision matrix helped the team decide on which designs to pursue. Next, the team completed engineering calculations to validate that the designs could fulfill the necessary requirements.

5.1 Rationale for Design Selection

In the first iteration of the design process, the team focused on two subsystems: mechanical and thermal loading, as they were the most important parts of the design. As a result of the Pugh charts in Figures 12 and 13, the team decided to continue with the designs that most easily incorporate simultaneous mechanical and thermal loading. This design was the fixture design, which fulfills all the customer needs except universality. The fixture design was safe, nondestructive, and could be quickly assembled because it was one single piece however, after meeting with the client and continuing with the iterative calculation process, this fixture is not being considered anymore. The problem with the fixture is that inductance coils were going to be used, which detracts from the universality of the fixture. Inductance coils can only be used for metal radomes and do not work with all materials. This is an issue because radomes are made of many different materials, even quartz.



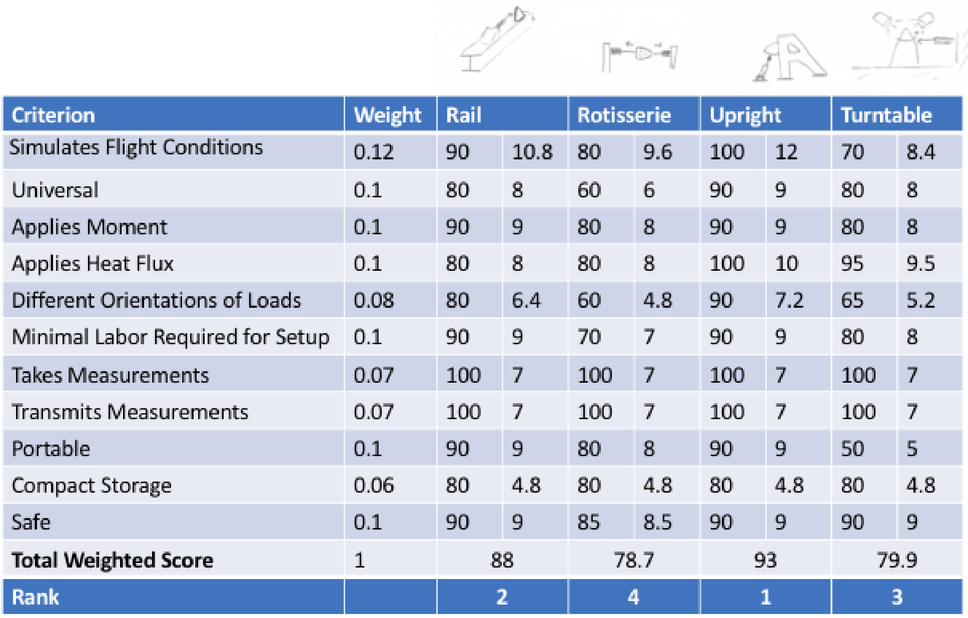
Technical Requirements	Heating Lamp (Benchmark)	Oven	Heat Coils	Fixture	Flame/ Plasma	Fluid	Cage
Allows for Both Loads	-	+	-	+	+	-	+
Even Distribution of Both Loads	-	+	-	+	0	0	+
Safe	+	+	+	+	-	+	+
Quick Assembly	-	+	+	+	+	-	+
Non Destructive	+	+	+	+	-	-	+
Universal	0	+	0	-	+	+	-
Quick Assembly	+	+	+	+	+	-	+
Net	0	7	2	5	2	-2	6
Rank	5	1	4	3	4	6	2
Continue ?	N	Y	N	Y	N	N	Y

Figure 12: Thermal Loading Pugh Chart

Technical Requirements	Strap (Benchmark)	Block	Cradle	Fixture	Rings	Fluid
Allows for Both Loads	-	-	-	+	-	0
Even Distribution of Both Loads	-	-	-	+	-	+
Safe	+	+	+	+	+	+
Quick Assembly	+	+	+	+	+	-
Non Destructive	+	0	+	+	+	-
Universal	+	+	-	-	-	+
Quick Assembly	+	+	+	+	+	-
Net	3	2	1	6	1	0
Rank	2	3	4	1	4	5
Continue ?	N	N	N	Y	N	N

Figure 13: Mechanical Loading Pugh Chart

Instead of using the fixture design, the team is going to move forward with the cradle design and heating lamps for the time being. The heating element may be changed, but lamps are being used for now because that is a standard practice for the client's company. Next, a decision matrix for the designs of the entire fixture was created (Figure 14). The team decided it was necessary to get a picture of the entire fixture. Each design encompasses all three subsystems mentioned in Section 3. The cradle design has been modified so that there will be multiple sizes of cradle for the different radomes. There will not be a cradle for every single radome, but enough that it can accommodate any part.



Criterion	Weight	Rail		Rotisserie		Upright		Turntable	
Simulates Flight Conditions	0.12	90	10.8	80	9.6	100	12	70	8.4
Universal	0.1	80	8	60	6	90	9	80	8
Applies Moment	0.1	90	9	80	8	90	9	80	8
Applies Heat Flux	0.1	80	8	80	8	100	10	95	9.5
Different Orientations of Loads	0.08	80	6.4	60	4.8	90	7.2	65	5.2
Minimal Labor Required for Setup	0.1	90	9	70	7	90	9	80	8
Takes Measurements	0.07	100	7	100	7	100	7	100	7
Transmits Measurements	0.07	100	7	100	7	100	7	100	7
Portable	0.1	90	9	80	8	90	9	50	5
Compact Storage	0.06	80	4.8	80	4.8	80	4.8	80	4.8
Safe	0.1	90	9	85	8.5	90	9	90	9
Total Weighted Score	1	88		78.7		93		79.9	
Rank		2		4		1		3	

Figure 14: Full Fixture Decision Matrix

As a result of the decision matrix, the upright fixture is being pursued. It fulfills nearly every design requirement as is the most robust of the four. It was also selected because of its high scores in simulating flight conditions, minimal labor for setup, and universality. The client has emphasized the importance of these requirements, so they were considered most. The rail design also scored relatively high due to its simple and effective design. However, the rail design cannot be used for large radomes as they will not fit on the I-beam. Both the rotisserie and turntable design could not apply loading in different orientations, so they were not selected. The rotisserie design also scored lower in universality. Therefore, the upright fixture is the best design to fulfill all requirements and apply the mechanical and thermal loading simultaneously.

5.2 Design Description

Based on the outcomes of the decision matrix and Pugh chart, and after having a discussion with the client, we decided to move forward with the upright test fixture. In this section we will discuss in further detail the fixture itself and the analyses used to determine the features of the fixture.

5.2.1 Design Description

The test fixture is composed of just four major components. There are two uprights which compose the major structure, a universal plate and the hydraulic ram. The entire structure is assembled using various threaded fasteners. The uprights can be lifted with forklift straps and the plate has a lift hook for easy transport. The uprights as well as the universal plate can be stacked in small space reducing the overall storage required. The hydraulic ram is a commercially available part however, the base plate and cradle will need to be manufactured. The following figure illustrates the critical components of the assembly and shows an AMRAAM radome. Figure 15 shows the orientation of the full design.

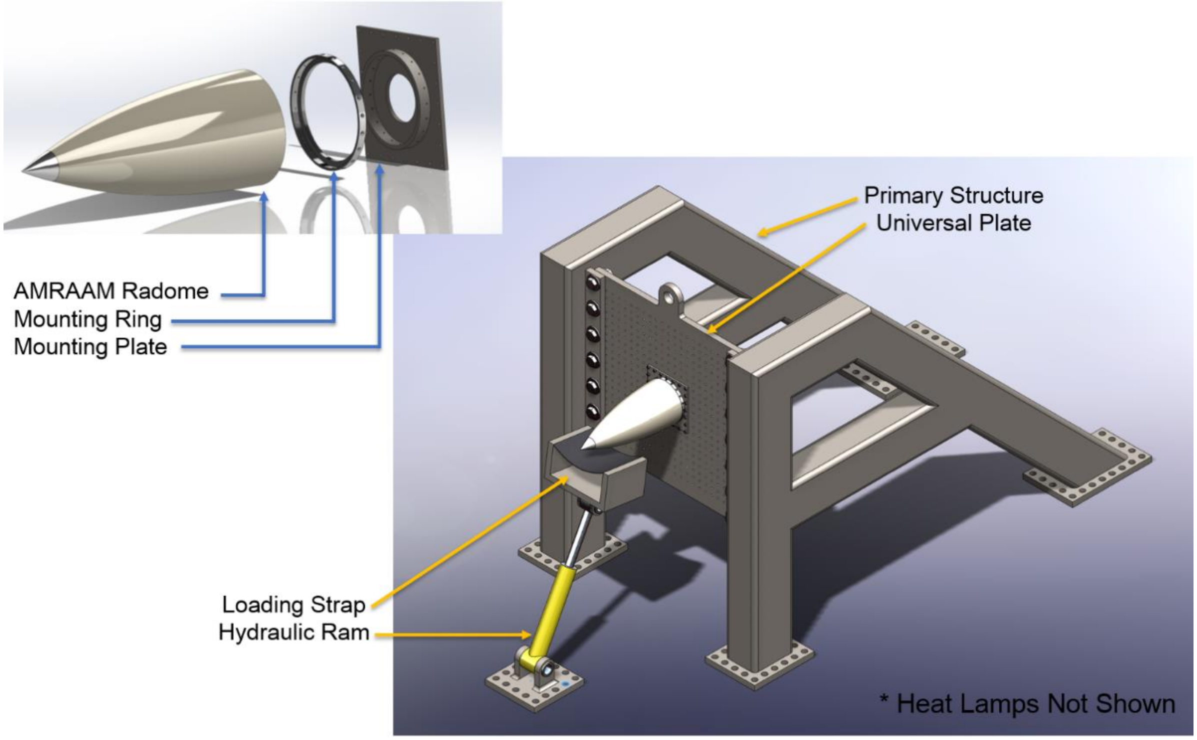


Figure 15: Proposed Test Fixture

The primary component in the fixture is the uprights. The uprights are constructed from six-in by eight-in box beams with a 3/8-in. wall. The tubes are to be cut and welded into the configuration shown. Base plates made from one-in. plate steel will be used to bolt the fixture to the floor of the testing bay. The upright also has a lip with mounting holes for the plate to be bolted to. The two uprights are virtually identical, the only difference being the side that the mounting lip is welded to. Figure 16 illustrates the left-hand side upright in closer detail.

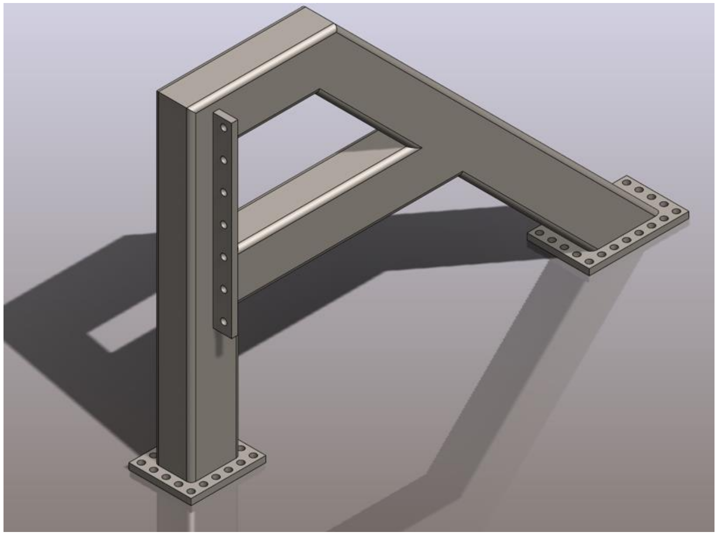


Figure 16: Left Upright

The main plate or universal plate is designed to allow a wide variety of aerospace components to be bolted to the fixture. This interface is what allows a wide range of parts to be tested. This plate is 30 in by 30 in which is just large enough to test a Tomahawk radome. The plate has one-in diameter holes to connect to the uprights, and a three-in diameter center hole to allow sensor cables to be passed through. Figure 17 highlights the universal plate design.

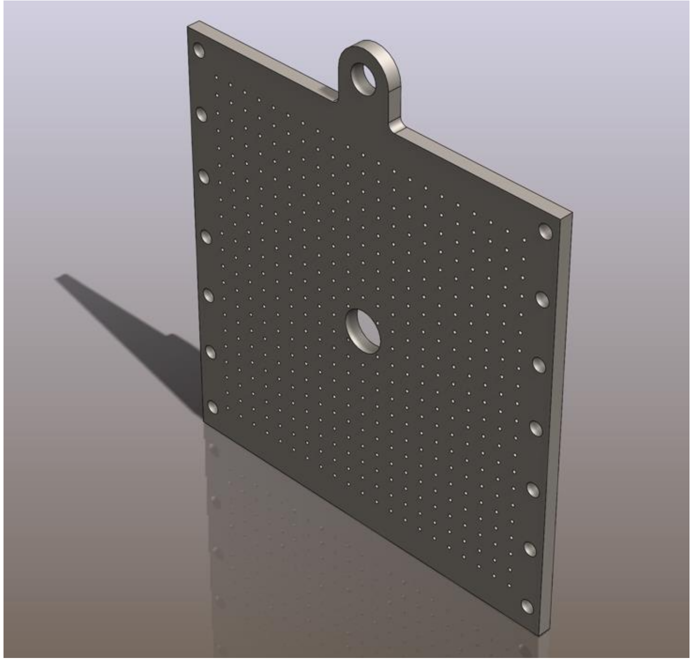


Figure 17: Universal Plate

Each of the components in this assembly will have to be analyzed to ensure they can withstand the mechanical and thermal loading which will be applied. The following sections provide a brief overview of these analyses. Several of the analyses in the following sections were calculated before deciding upon this fixture, and because of that, the beam calculations were performed on an I-beam instead of a box beam. It is important to note that these the heat flux calculations and mechanical loading calculations were performed for an AMRAAM missile and analyzing different missiles would result in unique loads.

5.2.2 Thermal Loading Calculations

The amount of heat flux applied to the missile components was a critical part of this project's analysis. Calculations were completed to determine how much heat flux should be applied to the specific radome used in this example. Two calculations were completed: heat flux at the tip of the nose cone and heat flux along the running length of the radome. MATLAB was utilized to compute determine these heat fluxes. Figure 18 shows the flow chart for the script used.

Figure 18: Code Flow Chart

First, density and air properties were calculated using the altitude and velocity information. These properties include: reference temperature, dynamic viscosity, specific heat capacity, adiabatic wall temperature, Prandtl number, Reynolds number, and thermal conductivity. Next heat flux was calculated using those properties, as well as Nusselt number and heat transfer coefficient. When the original analysis was completed, the team planning on applying 200 W/cm^2 using heating coils. However, after discussing these results with the client and searching for materials, the team determined that this heat flux is too large, and we decided to move forward with a heat flux of approximately 75 W/cm^2 [1]. This number will be more accurate because it is the heat flux located about three to six inches along the radome. The initial estimate was calculated at the tip of the nose cone, which receives a much larger flux than the body of the radome and is of less interest. Heating lamps were chosen for this project because heating coils may not be able to apply the same flux. Therefore, the team will be utilizing about six to eight lower wattage quartz lamps.

5.2.3 Mechanical Loading Calculations

The calculations for the flight conditions on the AMRAAM radome were broken down into two sections. The loading due to supersonic flight and the loading due to hard banking. The first load is caused by the vehicle traveling at Mach four. At these speeds, immense pressure is applied to the nose of the vehicle. The second load comes from the vehicle banking at 40 G's. In order to determine these loads, several properties needed to be determined including mass, distance to the center of gravity and other geometric properties of the missile radome. SolidWorks was utilized to determine these geometric and mass properties for our analysis.

In order to determine the loading due to stagnation pressure at Mach four, we utilized the isentropic flow equation:

$$P_s = \left(\frac{P_{0,2}}{P_1}\right) P1$$

The ratio of $\frac{P_{0,1}}{P_1}$ can be found in Appendix B of Fundamentals of Aerodynamics [10]. For our example, at Mach 4, $\frac{P_{0,2}}{P_1}$ is equal to 21.07. By using atmospheric pressures, we were able to determine the forces for various altitudes and for various angles of attack. The results are summarized in the following table.

Table 3 - Force due to Mach 4 Flight

AOA	X-sectional Area [in^2]	Altitude [ft]	Atmospheric Pressure [$\frac{lb}{ft^2}$]	Stagnation Pressure [$\frac{lb}{ft^2}$]	Force [lbf]
0°	**38.48**	**52,000**	**232.8**	**4,905**	**1,311**
5°	**38.59**	**52,000**	**232.8**	**4,905**	**1,314**
10°	**38.93**	**52,000**	**232.8**	**4,905**	**1,326**
0°	**38.48**	**20,000**	**973.3**	**20,507**	**5,480**
5°	**38.59**	**20,000**	**973.3**	**20,507**	**5,496**
10°	**38.93**	**20,000**	**973.3**	**20,507**	**5,544**
10°	**38.93**	**0**	**2116.2**	**44,584**	**12,053**

For determining the loading due to 40G turns, we simply used:

$$F = ma \tag{1}$$

$$F = 5.91[lb] * 40 * \mathbf{32.2}\ [\tfrac{ft}{s^2}]$$

$$\underline{\mathbf{F=7{,}612\ [lbf]}}$$

The final calculation in Table 3 shows the vehicle traveling at Mach 4 at sea level. While this speed is most likely unattainable at this altitude, the longitudinal force is 12,000 pounds. The lateral force due to a 40G turn was calculated to be 7,600 pounds. Fortunately for the vehicle, the maximum longitudinal and lateral forces will not happen simultaneously. These calculations can now be used to determine the loading on the individual components of the test fixture. These loading conditions can be multiplied by an appropriate factor of safety and each flight component can be tested. The size and dimensions of the test fixture will also be determined from these calculations.

5.2.4 Bolt Calculations

The bolt loading analytical calculations investigated the structural integrity of the threaded fasteners that connect the mounting plate to the universal plate of the test fixture. The ¼"-20 X 1 ¾" UNC SAE grade 8, steel hex head screw was the selected fastener for the first iteration of these bolt calculations. A total of 24 bolts with a preload of 5.5 kips was used to estimate the tensile load, the yielding and joint factors of safety. As requested by the client, all aspects of our design must meet a factor of safety of four or greater. Using the plate thickness, nut length, and washer thickness, the tensile load per bolt, yielding factor of safety, and joint factor of safety came out to a value of 0.417 kip, 0.683, and 16.83, respectively. Although the joint factor of safety significantly exceeds requirements, the yielding factor of safety noticeably misses the mark. Upon further inspection, when the preload is reduced to approximately three kip, the factor of safety requirements are met. This is important because it informs us that the current state of the test fixture will be unable to support the required maximum load without failure. To account for this and assure the fixture will be able to achieve a factor of safety of 4 while enduring expected maximum loading, specific variables of the fasteners and universal mounting plate will need to be modified in the 2nd iteration of our calculations.

5.2.5 Beam Calculations

The purpose of this beam calculation is to determine the correct specification for the I-beam required for this test fixture The I-beam was initially chosen because they typically have large moment of inertia compared to other beams. The assumptions are that the load should be 100,000 N, and that the material is steel, considering steel has high yielding stress which is 1,000 MPa [11] The stress of the I-beam should not exceed 250 MPa and the length of the I-beam that is connected to the hydraulic ram is 0.9 m. After finding the stress calculation, the best result was 233.233 MPa, which will make the factor of safety 4.3. The cross-sectional area should be 917 mm^2. If the cross-sectional area of the I-beam were to increase, the factor of safety will also increase. The mass of the 0.9 m beam will be 9 kg if the steel is exposed to an environment of 20 °C [12].

5.2.6 Proof of Concept Prototype

Figure 19 shows the proof of concept prototype. It was created to serve as a visual aid of the design. Prototyping will be continued with the purpose of quick assembly testing.

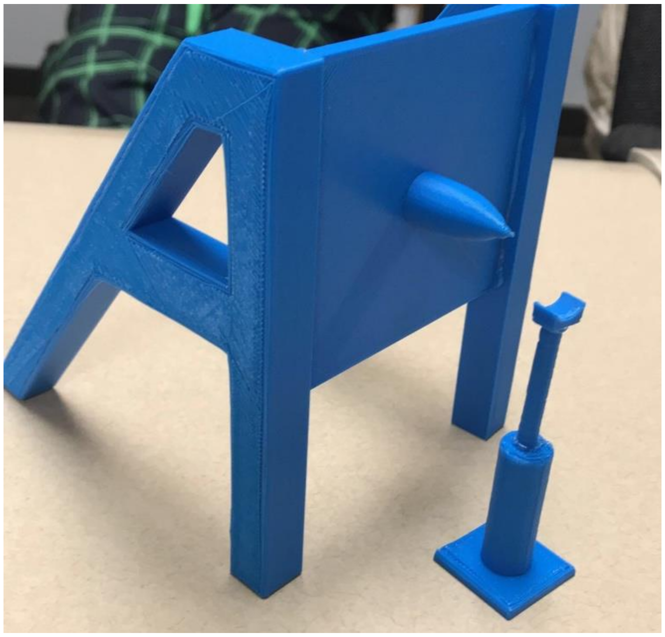


Figure 19: Initial Prototype

6 PROPOSED DESIGN – First Semester

The following section details the plan for implementing and furthering the design. It also includes the resources that will be required for implementation and the bill of materials for the design. The schedule and budget for the upcoming semester will be detailed in this section. The SolidWorks models of the assembled design and parts will also be shown.

6.1 Description of Implementation Plan

The first step in implementing the design is to produce more detailed specifications using the current drawings. Parts of the design have not been validated mathematically, so that will be a future requirement. Bolt calculations for the radome mounting plate need to be readdressed in order to produce finite specifications. These calculations may also reveal design flaws or weaknesses that will need to be addressed. After all the parts have been validated and design changes have been made, a second iteration of 3D printed prototyping will be completed. This prototype will be used to test the assembly time of the entire test fixture. Next, load and power estimations will be completed for the whole fixture. The team will also decide what will be used to power the fixture. After the power calculations are completed, a third iteration of calculations will be completed if necessary. Because this project is iterative in nature, the design will likely change before the end of the semester. Several rounds of calculations and prototyping may be the result of this project.

6.2 Resources Needed

The bill of materials for the proposed design can be found in Appendix B. This details all the necessary components to construct a full-scale fixture. It includes the part description, unit cost, total cost, and a link to where the item cam be purchased. It is important to note the bill of materials does not include any labor costs that may be required to build the full-size test fixture. Other resources that will be required for implementation will be computer software. ANSYS and SolidWorks will be utilized to simulate and model the test fixture. Another resource that will be needed for prototyping is a 3D printer. In addition, the team will need various textbooks and online resources to continue to refine the test fixture design.

6.3 Implementation, Scheduling, and Budget

Table 4 shows the scheduling for the implementation procedure as described in 6.1. The dates are tentative and will be revised as the semester progresses. The scheduling may also have to be accelerated based on capstone requirements.

Table 4: Schedule

Task	Estimated Completion Date
Produce Specifications	September 10th, 2018
2nd Iteration Bolt Calculations	September 24th, 2018
2nd Iteration of Prototyping	October 15th, 2018
Quick Assembly Testing	October 22nd, 2018
FEA Temperature Profile Modeling	October 22nd, 2018
Load and Power Estimates	November 5th, 2018
3rd Iteration of Calculations	November 26th, 2018
3rd Iteration of Prototyping	December 5th, 2018

As this is an analytical project, all the team's expenses came from 3D printing. The overall budget of this project is approximately $800 which was supplied by the university. However, the team intends to use less than $200 on 3D printing for prototyping purposes. At this point in time 3D printing is the only expense, however another potential area of cost is analytical software. Currently only $12.50 has been spent on 3D printing for the proof of concept prototype. The MakerLab on campus will be used to print the prototype.

6.4 Design Model

The following image (Figure 20) shows an isometric view of the entire test fixture assembly. The figure shows the side legs of the test fixture and the universal mounting plate. A radome can also be seen connected to the square adaptor plate. The universal plate has many bolt holes so that a wide variety of parts can be easily attached to the fixture. Figure 12 also shows the hydraulic ram and cradle, which will be used to apply the bending moment about the adapting plate. The heat lamps are not shown but will be set up in a ring around the missile radome.

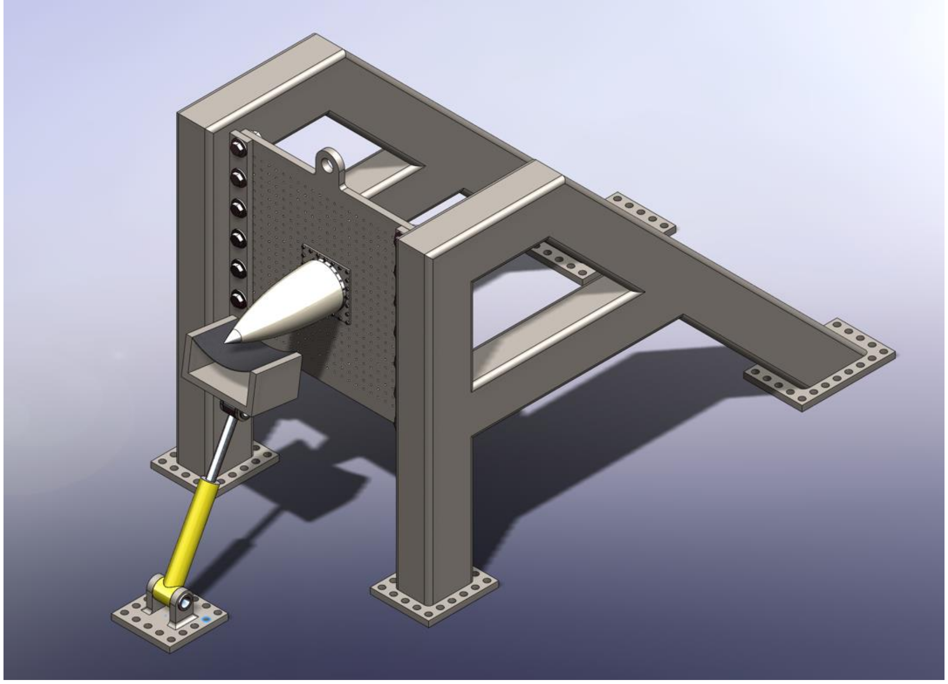


Figure 20: Assembly View of Test Fixture

Figure 21 shows an up-close view of the radome and adaptor plate in an exploded view. There is a ring that attaches the missile to the adaptor plate. The bolts that will hold the assembly together are not shown.

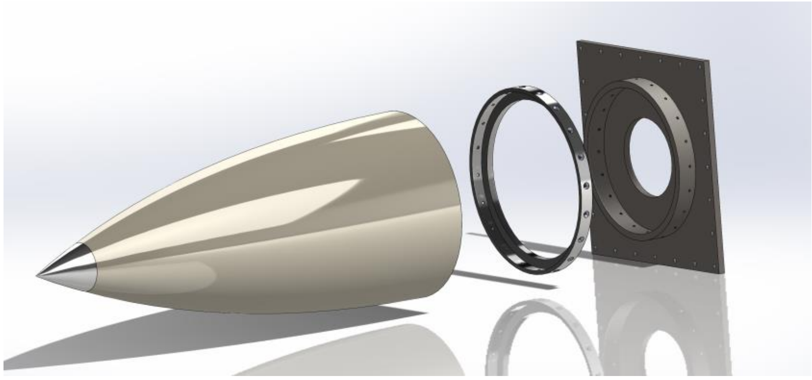


Figure 21: Exploded View of the Radome Connection Assembly

Further modeling details and drawings part of the test fixture can be found in Appendix C.

7 IMPLEMENTATION – Second Semester

Designing the test fixture is entirely analytical, therefore no physical implementation or manufacturing will be completed. In place of manufacturing, the team is using analyses to validate that the design is viable. The following section details the analyses that have been completed this semester. These analyses are used to justify each design choice. Design changes as a result of each analysis will be discussed as well.

7.1 Scheduling

In order to validate the design, the team continued the necessary analyses, including second iterations of thermal loading, mechanical loading, beam, and bolt calculations. Figure 22 shows the schedule for implementing our design and completing the necessary analyses.

Task	Person Assigned	Start Date	Completion Date	27-Aug	3-Sep	10-Sep	17-Sep	24-Sep	1-Oct	8-Oct	15-Oct	22-Oct	29-Oct	5-Nov	12-Nov	19-Nov	26-Nov	3-Dec	10-Dec
Final Proposal Report Rewrite	All	27-Aug	29-Aug	■															
Individual Post Mortem	All	27-Aug	31-Aug	■															
Website Check 1	Aziz	10-Sep	14-Sep		■	■													
Progress Presentation	All	7-Sep	17-Sep		■	■	■												
Hardware Review 1	All	20-Sep	3-Oct				■	■	■										
Individual Analysis II																			
-Bolt Calculations	Shanna	20-Sep	12-Oct				■	■	■	■									
-Box Beam Calculations	Aziz	20-Sep	12-Oct				■	■	■	■									
-Compressible Flow Calculations	Israel	20-Sep	12-Oct				■	■	■	■									
-Quartz Lamp Calculations	Lexie	20-Sep	12-Oct				■	■	■	■									
Hardware Review 1 Summary	All	3-Oct	5-Oct						■										
Peer Evaluation 1	All	5-Oct	7-Oct						■										
Midpoint Report	All	8-Oct	19-Oct							■	■								
Midpoint Presentation/HR2	All	13-Oct	29-Oct							■	■	■							
Power and Water Requirements	Aziz	13-Oct	29-Oct							■	■	■							
Plate Stress Analysis	Lexie	13-Oct	29-Oct							■	■	■							
Bolt Thermal Expansion	Shanna	13-Oct	29-Oct							■	■	■							
Assembly Time Study	Israel	13-Oct	29-Oct							■	■	■							
Hardware Review 2 Summary	All	24-Oct	2-Nov									■							
Peer Evaluation 2	All	26-Oct	4-Nov									■							
Website Check 2	Aziz	28-Oct	9-Nov									■	■						
Draft of Poster	All	26-Oct	9-Nov									■	■						
Draft of Operation Manual	All	26-Oct	9-Nov									■	■						
Final Product Testing Proof	All	26-Oct	12-Nov									■	■	■	■				
Final Presentation	All	12-Nov	26-Nov												■	■	■		
Final Poster	All	12-Nov	26-Nov												■	■	■		
Final Operation Manual	All	12-Nov	30-Nov												■	■	■		
Final Report	All	20-Nov	7-Dec													■	■	■	
Final CAD and BOM	Israel	26-Nov	5-Dec														■	■	
Website Check 3	Aziz	7-Dec	10-Dec															■	■
Peer Evaluation 3	All	10-Dec	12-Dec																■

Figure 22: Gantt Chart

For the most part the team stayed on schedule throughout the second semester. However, as the semester progressed, more analyses that needed to be completed arose and the team had to adjust for those. For example, while doing the heat flux analyses, it made sense to also look at the temperature distributions, which was an additional analysis. Also, some of the analyses required even more iterations than expected. For example, the team ended up completing three iterations of the beam, bolt, and heat flux calculations.

7.2 Manufacturing

7.2.1 Proof of Concept Prototype

The prototype of the project was made at the end of the first semester to show the audience what the fixture looks like. It was used to show that the fixture was the right scale and identify any errors that could only be seen on a physical model. The prototype was modelled in SolidWorks and printed with a 3D printer. An AMRAAM radome is shown on the prototype. The heat lamps are not included in this prototype. The prototype (Figure 23), is four pieces: the two A-Frames, the plate with radome attached, and the hydraulic ram. The radome and ram are not exactly to scale.

Figure 23: Fixture Prototype

Furthermore, the team did not continue to prototype because an online time study proved to be more effective and accurate.

7.2.2 Hypothetical Manufacturing

Although the team was not tasked with manufacturing the fixture in real life, it is necessary to make sure the fixture could be manufactured. The material of the frame beam and the universal plate are steel because it has a good tensile and yield strength. For the A-Frame, a box beam is welded by another beam that has the same size in 45° [15]. For a single A-Frame there are two ends that will be connected to the ground. Each end contains six threaded holes for 5/8” bolts on each side of the A-Frame there are seven threaded holes for the same size of bolts to connect it to the universal plate. The hydraulic ram is welded to a steel plate with the same geometry as the frame leg, and it is threaded in six holes as well to make the ram stable while applying mechanical force on the missile part.

For the universal plate, a hole would be cut in the middle of it allowing the sensors wires to go behind the plate to the connection panel that is attached to one of the A-Frames. Also, seven threaded holes are made on each side of the universal plate for 5/8-in bolts allowing the plate to be connected to both frames. 21 x 21 holes are made on the plate for two reasons. The first reason is to be able to attach the mounting plate, and to attach the heat lamps to them as well. Using this number of holes allows us to test for different sizes of missile part with one plate.

The only part in the fixture that is not universal is the mounting plate, this is custom designed by the type of missile that is tested [16]. Also, each heat lamp would be welded on the right-side with a threaded rod, as shown in Figure 24. The threaded rods will go through the holes on the universal plate.

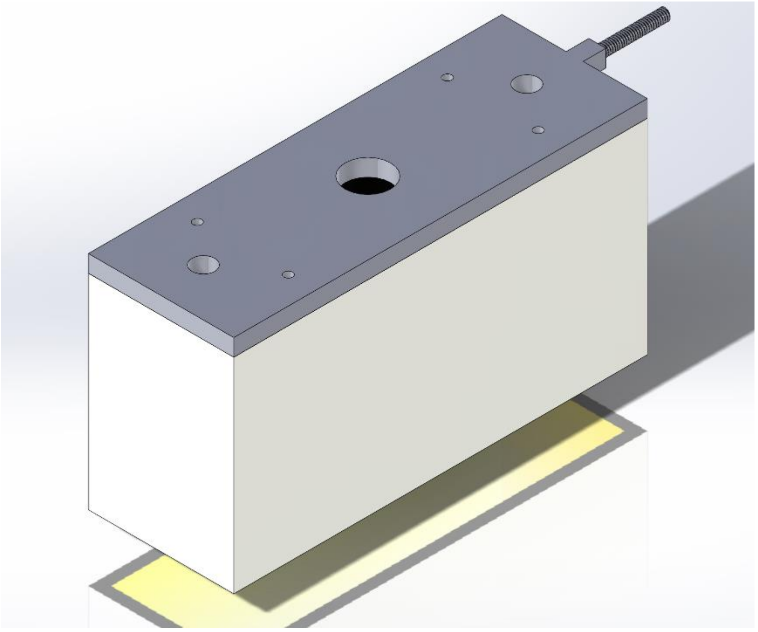


Figure 24: Heat Lamp with Threaded Rod

7.3 Analyses

7.3.1 Temperature Distribution Analyses

One analysis that was performed was the temperature distribution analysis. This analysis was completed in order to influence how the quartz lamps will be placed around the radome and to ensure there is temperature data for future calculations. It is important that there is not a high temperature differential surrounding the radome. The heat flux analysis that was discussed earlier was necessary for the temperature distribution. For this reason, MATLAB was used, and new code was added to the previous program. Finite-differencing was utilized and the radome was vertically cut into 20 slices. First, heat flux due to aero heating was found for each slice. Then the height, radius, surface area, contact area, and volume were found for each slice. After that the heat flux into and out of each slice was computed. This included fluxes due to convection, conduction, radiation, and aero heating. Figure 25 shows the resistive network that was used to sum the fluxes.

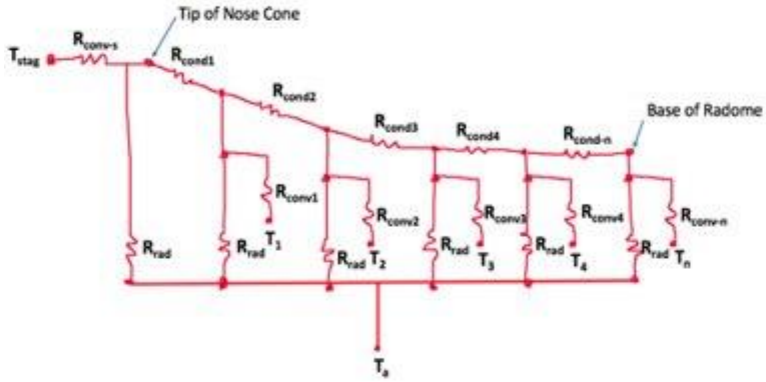


Figure 25: Resistive Network

Once the fluxes were found, temperatures were computed using the mass, surface area, time of flight, heat transfer coefficient, and specific heat capacity of each section of the radome. Figure 26 shows the flow chart of the code.

Figure 26: Temperature Distribution Flow Chart

Figure 27 shows the resulting temperatures of each section of nose cone. This model is of AIM-120D AMRAAM, because the team is using this radome as a baseline. The temperatures only vary from about 125°C to 160°C at the base of the radome.

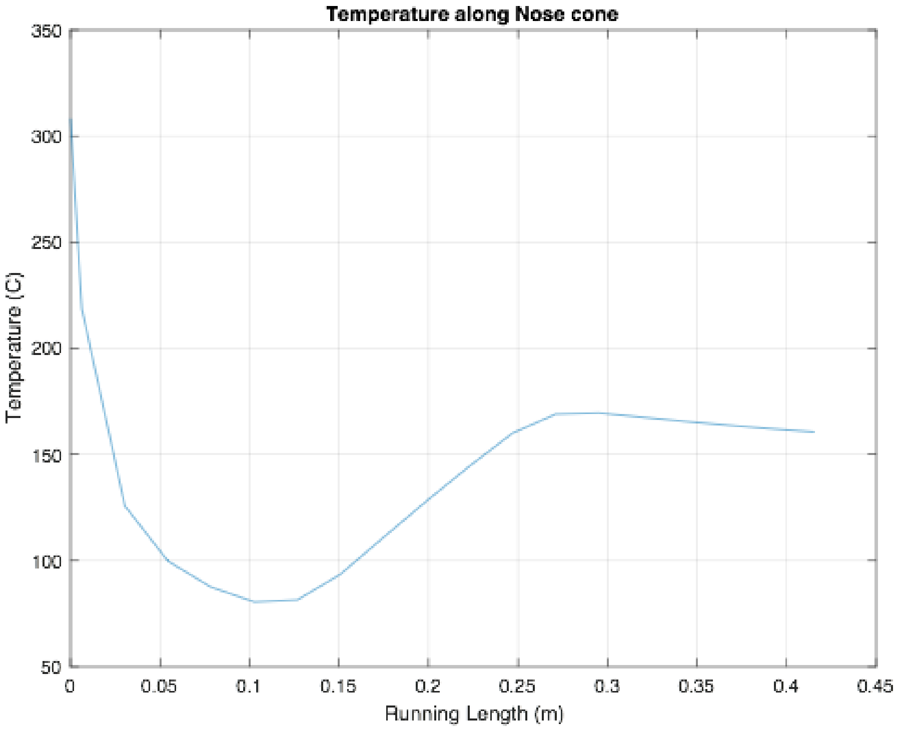


Figure 27: Temperature Results

7.3.2 Heat Flux Distribution Analysis

After the temperature distribution calculations were completed, the heat flux distribution was modelled using the ray tracing method. Figure 28 shows the schematic used for this method.

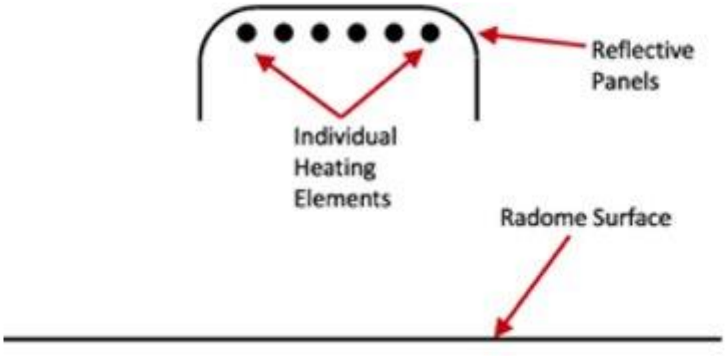


Figure 28: Quartz Lamp Schematic

Figure 29 shows the six heating elements in each lamp and the rays that extend from each. The surface of the radome was split into 20 sections, and the number of rays in each was added up. This data was plotted and curve-fitted as seen in Figure 30.

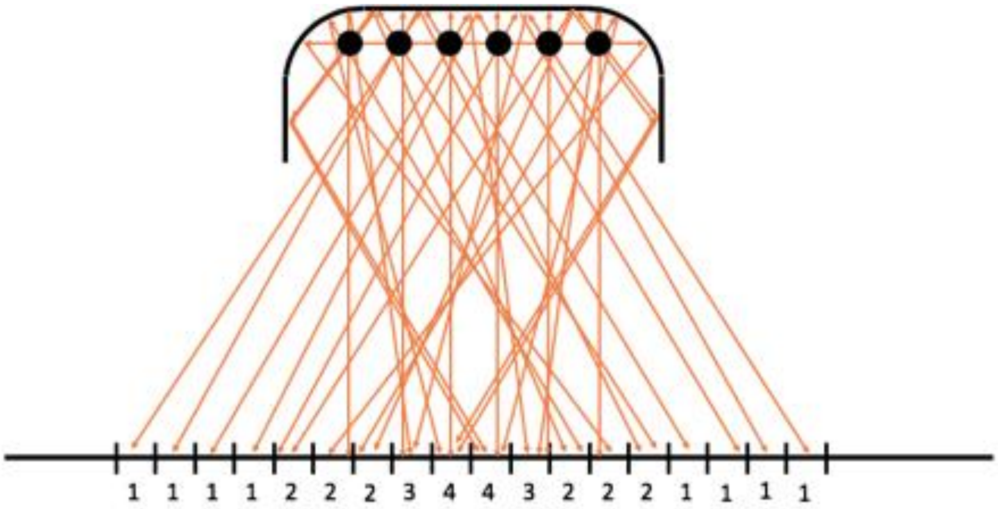


Figure 29: Ray Tracing for Heat Flux Distribution

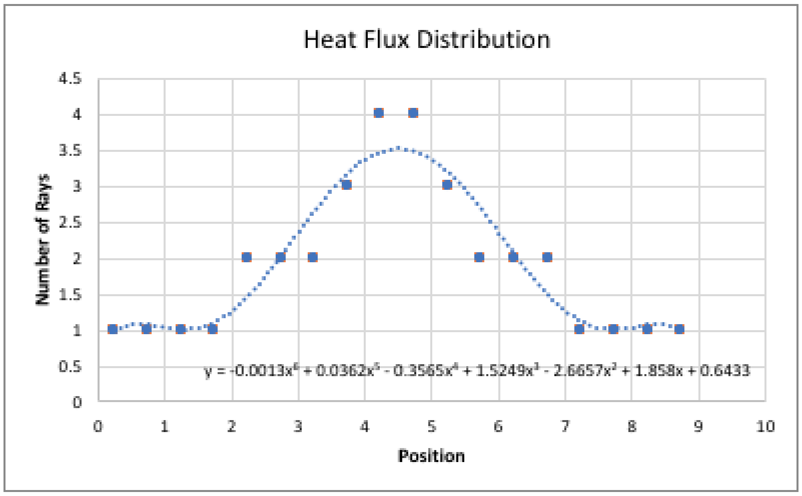


Figure 30: Heat Flux Distribution Plot

Both analyses show that in order to have an even heat flux and temperature distribution, the lamps must be nearly touching each other, and should be 1 to 2 inches away from the radome. This is because the rays do not extend out very much past the position of the lamp, which is extends from Position 2 to 7. The team wants to heat each section to with 50 W/cm^2 ± 10%. This spacing will ensure that the radome is evenly heated and is in the same temperature range.

7.3.3 Second Iteration Heat Flux Distribution – lexie

Because the first iteration of the heat flux distribution only showed the behavior qualitatively, further analysis needed to be completed to determine any quantitative heat flux values. The curve fit in the first iteration did not fit as well as necessary, so the data was fit again to better match the data. Figure 31 shows the data with the curve fit.

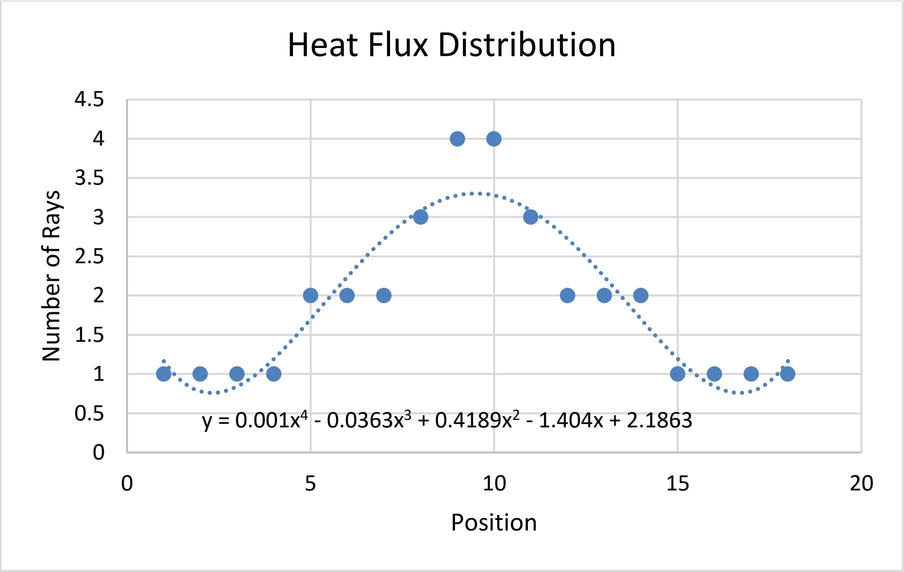


Figure 31: Qualitative Heat Flux Distribution

Figure 32 shows the quantitative heat flux distribution. This was found using the above curve fit and the given value of 50 W/cm^2. The lamps span from about Position 4 to 15. The peak at Position 18 is due to errors in the curve fit.

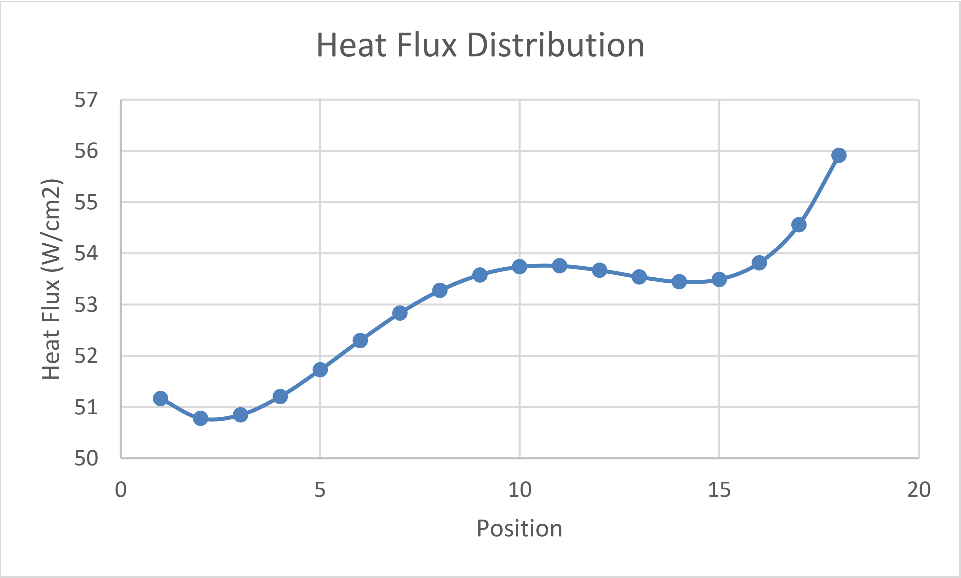


Figure 32: Quantitative Heat Flux

7.3.4 Second Iteration Compressible Flow

The second analysis performed was the mechanical loading analysis. The loading is generated from two different modes. High speed flight and extreme G banking. The first load is caused by the vehicle traveling at Mach 4. At these speeds, immense forces are applied to the nose of the vehicle. The second load comes from the vehicle banking at 40 G's. Determining these loads is crucial in the design and testing of AMRAAM radomes. The lateral loading of the radome was completed last semester so this section will focus on compressible flow due to traveling at Mach 4.

The longitudinal loading the vehicle experiences is primarily composed of drag due to traveling at Mach 4. This drag force will be calculated utilizing isentropic compressible flow models. More specifically, oblique shock waves and the resultant drag forces will create a moment if the vehicle changes its angle of attack.

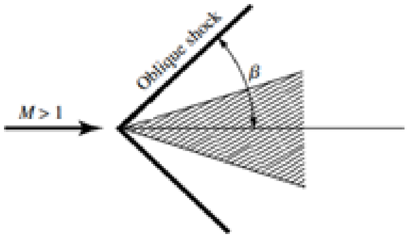


Figure 33: Oblique Shock Wave on Conical Section

The first step in the analysis is to determine the angle of the oblique shock wave which is designated β (see Figure 33). The shock wave angle can be determined utilizing figures within the Fundamentals of Aerodynamics text book. Figure 9.9 on page 613 illustrates the shock wave angle as a function of the conical section half angle and the speed of flight (see Figure 34**)**. For this example, the half angle of the cone is 26° and the Mach number is 4. The output of this chart is the angle of the oblique shock wave β. For this example, β is 40°.

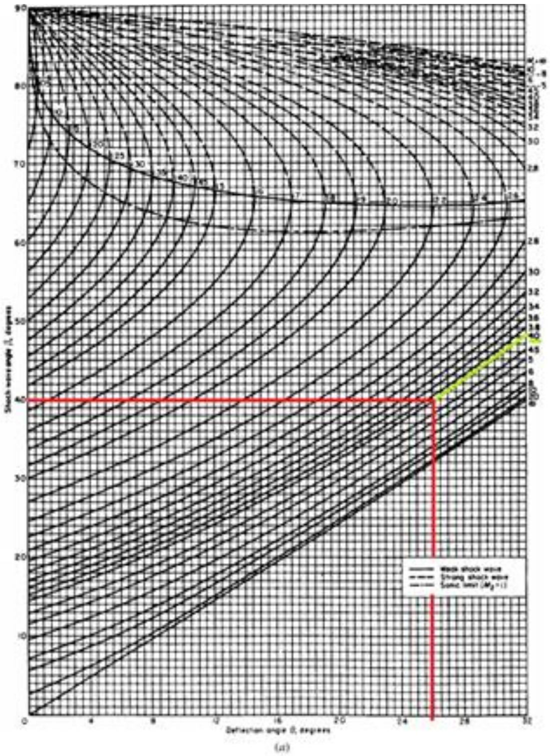
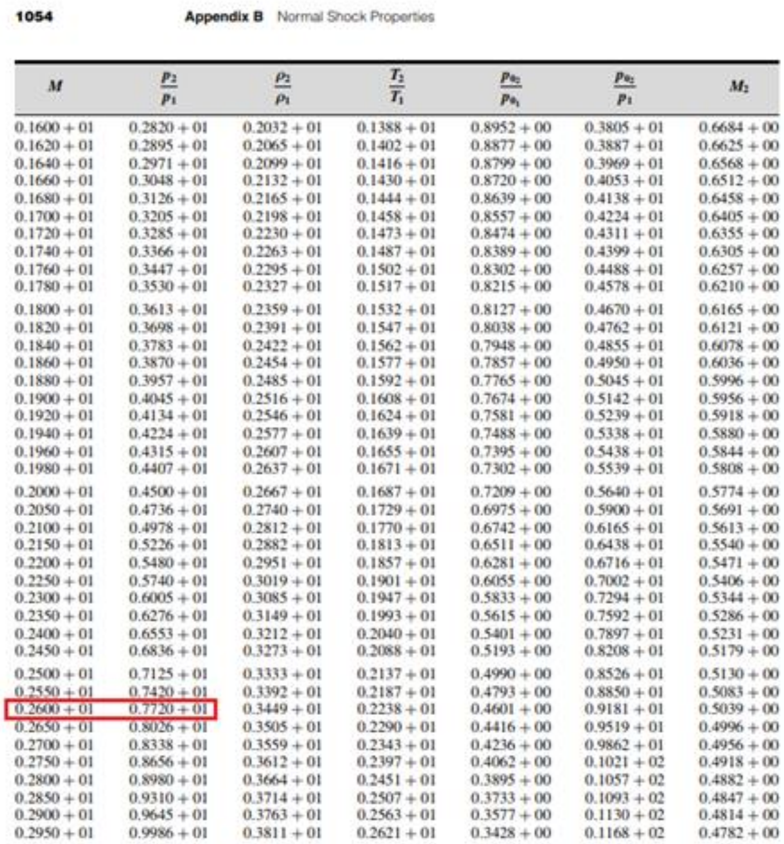


Figure 9.9 Oblique shock properties: $\gamma = 1.4$. The θ-β-M diagram. (*Source: NACA Report 1135, Ames Research Staff, "Equations, Tables and Charts for Compressible Flow," 1953.*)

Figure 34: Figure 9.9 from Fundamentals of Aerodynamics [10]

The next step in the analysis is to determine the pressure difference after the shock wave. Appendix B of Fundamentals of Aerodynamics text book will be utilized for this result. Having determined that the air speed after the shock wave is Mach 2.6, Appendix B then tells us that the ratio of pressure before and after the shock wave will be 7.72.



1054 **Appendix B** Normal Shock Properties

M	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{0_2}}{p_{0_1}}$	$\frac{p_{0_2}}{p_1}$	M_2
0.1600 + 01	0.2820 + 01	0.2032 + 01	0.1388 + 01	0.8952 + 00	0.3805 + 01	0.6684 + 00
0.1620 + 01	0.2895 + 01	0.2065 + 01	0.1402 + 01	0.8877 + 00	0.3887 + 01	0.6625 + 00
0.1640 + 01	0.2971 + 01	0.2099 + 01	0.1416 + 01	0.8799 + 00	0.3969 + 01	0.6568 + 00
0.1660 + 01	0.3048 + 01	0.2132 + 01	0.1430 + 01	0.8720 + 00	0.4053 + 01	0.6512 + 00
0.1680 + 01	0.3126 + 01	0.2165 + 01	0.1444 + 01	0.8639 + 00	0.4138 + 01	0.6458 + 00
0.1700 + 01	0.3205 + 01	0.2198 + 01	0.1458 + 01	0.8557 + 00	0.4224 + 01	0.6405 + 00
0.1720 + 01	0.3285 + 01	0.2230 + 01	0.1473 + 01	0.8474 + 00	0.4311 + 01	0.6355 + 00
0.1740 + 01	0.3366 + 01	0.2263 + 01	0.1487 + 01	0.8389 + 00	0.4399 + 01	0.6305 + 00
0.1760 + 01	0.3447 + 01	0.2295 + 01	0.1502 + 01	0.8302 + 00	0.4488 + 01	0.6257 + 00
0.1780 + 01	0.3530 + 01	0.2327 + 01	0.1517 + 01	0.8215 + 00	0.4578 + 01	0.6210 + 00
0.1800 + 01	0.3613 + 01	0.2359 + 01	0.1532 + 01	0.8127 + 00	0.4670 + 01	0.6165 + 00
0.1820 + 01	0.3698 + 01	0.2391 + 01	0.1547 + 01	0.8038 + 00	0.4762 + 01	0.6121 + 00
0.1840 + 01	0.3783 + 01	0.2422 + 01	0.1562 + 01	0.7948 + 00	0.4855 + 01	0.6078 + 00
0.1860 + 01	0.3870 + 01	0.2454 + 01	0.1577 + 01	0.7857 + 00	0.4950 + 01	0.6036 + 00
0.1880 + 01	0.3957 + 01	0.2485 + 01	0.1592 + 01	0.7765 + 00	0.5045 + 01	0.5996 + 00
0.1900 + 01	0.4045 + 01	0.2516 + 01	0.1608 + 01	0.7674 + 00	0.5142 + 01	0.5956 + 00
0.1920 + 01	0.4134 + 01	0.2546 + 01	0.1624 + 01	0.7581 + 00	0.5239 + 01	0.5918 + 00
0.1940 + 01	0.4224 + 01	0.2577 + 01	0.1639 + 01	0.7488 + 00	0.5338 + 01	0.5880 + 00
0.1960 + 01	0.4315 + 01	0.2607 + 01	0.1655 + 01	0.7395 + 00	0.5438 + 01	0.5844 + 00
0.1980 + 01	0.4407 + 01	0.2637 + 01	0.1671 + 01	0.7302 + 00	0.5539 + 01	0.5808 + 00
0.2000 + 01	0.4500 + 01	0.2667 + 01	0.1687 + 01	0.7209 + 00	0.5640 + 01	0.5774 + 00
0.2050 + 01	0.4736 + 01	0.2740 + 01	0.1729 + 01	0.6975 + 00	0.5900 + 01	0.5691 + 00
0.2100 + 01	0.4978 + 01	0.2812 + 01	0.1770 + 01	0.6742 + 00	0.6165 + 01	0.5613 + 00
0.2150 + 01	0.5226 + 01	0.2882 + 01	0.1813 + 01	0.6511 + 00	0.6438 + 01	0.5540 + 00
0.2200 + 01	0.5480 + 01	0.2951 + 01	0.1857 + 01	0.6281 + 00	0.6716 + 01	0.5471 + 00
0.2250 + 01	0.5740 + 01	0.3019 + 01	0.1901 + 01	0.6055 + 00	0.7002 + 01	0.5406 + 00
0.2300 + 01	0.6005 + 01	0.3085 + 01	0.1947 + 01	0.5833 + 00	0.7294 + 01	0.5344 + 00
0.2350 + 01	0.6276 + 01	0.3149 + 01	0.1993 + 01	0.5615 + 00	0.7592 + 01	0.5286 + 00
0.2400 + 01	0.6553 + 01	0.3212 + 01	0.2040 + 01	0.5401 + 00	0.7897 + 01	0.5231 + 00
0.2450 + 01	0.6836 + 01	0.3273 + 01	0.2088 + 01	0.5193 + 00	0.8208 + 01	0.5179 + 00
0.2500 + 01	0.7125 + 01	0.3333 + 01	0.2137 + 01	0.4990 + 00	0.8526 + 01	0.5130 + 00
0.2550 + 01	0.7420 + 01	0.3392 + 01	0.2187 + 01	0.4793 + 00	0.8850 + 01	0.5083 + 00
0.2600 + 01	0.7720 + 01	0.3449 + 01	0.2238 + 01	0.4601 + 00	0.9181 + 01	0.5039 + 00
0.2650 + 01	0.8026 + 01	0.3505 + 01	0.2290 + 01	0.4416 + 00	0.9519 + 01	0.4996 + 00
0.2700 + 01	0.8338 + 01	0.3559 + 01	0.2343 + 01	0.4236 + 00	0.9862 + 01	0.4956 + 00
0.2750 + 01	0.8656 + 01	0.3612 + 01	0.2397 + 01	0.4062 + 00	0.1021 + 02	0.4918 + 00
0.2800 + 01	0.8980 + 01	0.3664 + 01	0.2451 + 01	0.3895 + 00	0.1057 + 02	0.4882 + 00
0.2850 + 01	0.9310 + 01	0.3714 + 01	0.2507 + 01	0.3733 + 00	0.1093 + 02	0.4847 + 00
0.2900 + 01	0.9645 + 01	0.3763 + 01	0.2563 + 01	0.3577 + 00	0.1130 + 02	0.4814 + 00
0.2950 + 01	0.9986 + 01	0.3811 + 01	0.2621 + 01	0.3428 + 00	0.1168 + 02	0.4782 + 00

Figure 35: Appendix B from Fundamentals of Aerodynamics [10]

Now that the pressure post shock wave is known, all of the information required to calculate the coefficient of drag is available. The equation for the coefficient of drag is:

$$Cd = \frac{4\tan(\theta)}{\gamma {M_1}^2}(\frac{p_2}{p_1} - 1)$$

$$Cd = \frac{4\tan(26°)}{(1.4)4^2}(7.72 - 1)$$

$$\underline{Cd = .585}$$

Where γ is the ratio of specific heat for air. This coefficient of drag can now be used to determine the force of drag that the AMRAAM radome experiences along with the moment being applied to the base. The force of drag is found using:

$$Fd = \frac{Cd\rho V^2 A}{2}$$

$$Fd = \frac{.585(.0317\left[\frac{\text{lbf}}{\text{ft}^3}\right])(4051\left[\frac{ft}{s}\right])^2.267[ft^2]}{2}$$

$$\underline{\text{Fd=40,627[lbf]}}$$

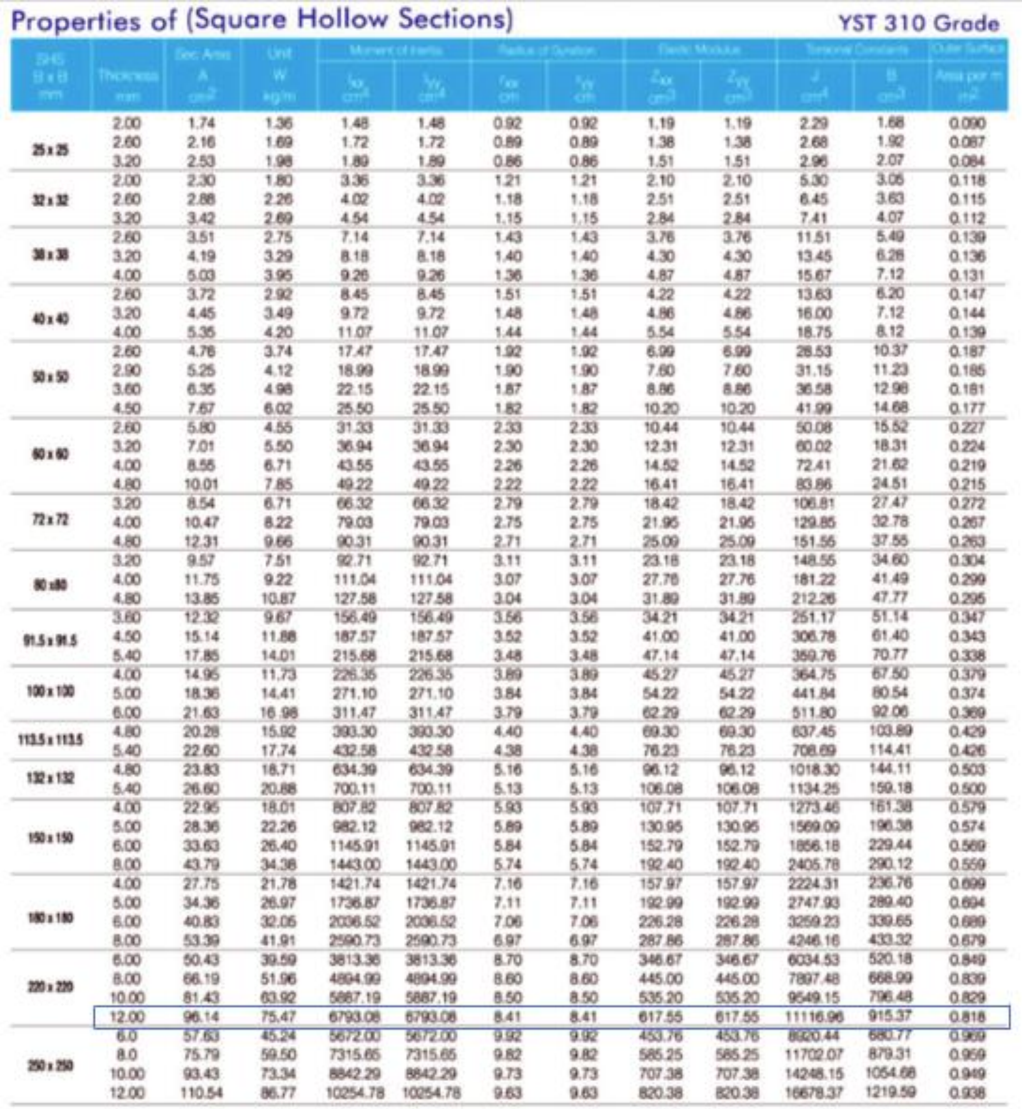
After calculating the lateral and longitudinal forces on the radome, it becomes clear that there are enormous forces being applied to the quartz. The final calculation from equation 6 shows the vehicle traveling at Mach 4 and with a 10° angle of attack will produce a moment of 45,503 in-lb. The lateral force due to a 40G turn was calculated to be 7,612 lbs creating a moment of 49,098 in-lb. Fortunately for the vehicle, the maximum longitudinal and lateral forces will not happen simultaneously. These calculations can now be used to determine the requirements of the test fixture. Ultimately, it was shown that the moments from 40G turns and full speed maneuvers produce similar moments. The value of 49,000 in-lb will be used in further calculation of our test fixture to determine the size and dimensions of the structure.

SUMMARY OF RESULTS

Maximum Force Due to 40G Turn ………………………………….…..……7,612 [lbf]
Maximum Drag Force Due to Mach 4 Velocity ……………….…………40,627 [lbf]
Maximum Moment Due to Turn ………….………….…………..….…49,098 [in-lb]
Maximum Moment Due to Velocity …………………..………………..…19,404 [in-lb]

7.3.5 Second Iteration Beams

This analysis is about getting the right size of the beams, using the maximum force applied on an AMRAAM radome. Based on the geometry of the fixture and the maximum force that would be applied to a missile part, allowing ten inches between the base on the part and the hydraulic ram. The force should be split in half and the calculation would be for one of the uprights. The reaction forces have also been calculated all over a single A-Frame beams in order to get the maximum moment in order to get the maximum stress on the upright. The material is YST 310 steel, which has a high yield strength and the factor of safety of four. Next, considering the moment of inertia for a square hollow section will get us the dimensions of the cross section needed. After that, using the density of steel and the dimensions of the beam gave us the weight of a single upright which is 331 kg. Figure 31 shows the table that was used to choose the beam size.



Properties of (Square Hollow Sections)

YST 310 Grade

SHS B x B mm	Thickness mm	Sec Area A cm²	Unit W kg/m	Moment of Inertia		Radius of Gyration		Elastic Modulus		Torsional Constants		Outer Surface
				I_{xx} cm⁴	I_{yy} cm⁴	r_{xx} cm	r_{yy} cm	Z_{xx} cm³	Z_{yy} cm³	J cm⁴	B cm³	Area per m m²
25 x 25	2.00	1.74	1.36	1.48	1.48	0.92	0.92	1.19	1.19	2.29	1.68	0.090
	2.60	2.16	1.69	1.72	1.72	0.89	0.89	1.38	1.38	2.68	1.92	0.087
	3.20	2.53	1.98	1.89	1.89	0.86	0.86	1.51	1.51	2.96	2.07	0.084
32 x 32	2.00	2.30	1.80	3.36	3.36	1.21	1.21	2.10	2.10	5.30	3.05	0.118
	2.60	2.88	2.26	4.02	4.02	1.18	1.18	2.51	2.51	6.45	3.63	0.115
	3.20	3.42	2.69	4.54	4.54	1.15	1.15	2.84	2.84	7.41	4.07	0.112
38 x 38	2.60	3.51	2.75	7.14	7.14	1.43	1.43	3.76	3.76	11.51	5.49	0.139
	3.20	4.19	3.29	8.18	8.18	1.40	1.40	4.30	4.30	13.45	6.28	0.136
	4.00	5.03	3.95	9.26	9.26	1.36	1.36	4.87	4.87	15.67	7.12	0.131
40 x 40	2.60	3.72	2.92	8.45	8.45	1.51	1.51	4.22	4.22	13.63	6.20	0.147
	3.20	4.45	3.49	9.72	9.72	1.48	1.48	4.86	4.86	16.00	7.12	0.144
	4.00	5.35	4.20	11.07	11.07	1.44	1.44	5.54	5.54	18.75	8.12	0.139
50 x 50	2.60	4.76	3.74	17.47	17.47	1.92	1.92	6.99	6.99	28.53	10.37	0.187
	2.90	5.25	4.12	18.99	18.99	1.90	1.90	7.60	7.60	31.15	11.23	0.185
	3.60	6.35	4.98	22.15	22.15	1.87	1.87	8.86	8.86	36.58	12.98	0.181
	4.50	7.67	6.02	25.50	25.50	1.82	1.82	10.20	10.20	41.99	14.68	0.177
60 x 60	2.60	5.80	4.55	31.33	31.33	2.33	2.33	10.44	10.44	50.08	15.52	0.227
	3.20	7.01	5.50	36.94	36.94	2.30	2.30	12.31	12.31	60.02	18.31	0.224
	4.00	8.55	6.71	43.55	43.55	2.26	2.26	14.52	14.52	72.41	21.62	0.219
	4.80	10.01	7.85	49.22	49.22	2.22	2.22	16.41	16.41	83.86	24.51	0.215
72 x 72	3.20	8.54	6.71	66.32	66.32	2.79	2.79	18.42	18.42	106.81	27.47	0.272
	4.00	10.47	8.22	79.03	79.03	2.75	2.75	21.95	21.95	129.85	32.78	0.267
	4.80	12.31	9.66	90.31	90.31	2.71	2.71	25.09	25.09	151.56	37.55	0.263
80 x 80	3.20	9.57	7.51	92.71	92.71	3.11	3.11	23.18	23.18	148.55	34.60	0.304
	4.00	11.75	9.22	111.04	111.04	3.07	3.07	27.76	27.76	181.22	41.49	0.299
	4.80	13.85	10.87	127.58	127.58	3.04	3.04	31.89	31.89	212.26	47.77	0.295
91.5 x 91.5	3.60	12.32	9.67	156.49	156.49	3.56	3.56	34.21	34.21	251.17	51.14	0.347
	4.50	15.14	11.88	187.57	187.57	3.52	3.52	41.00	41.00	306.78	61.40	0.343
	5.40	17.85	14.01	215.68	215.68	3.48	3.48	47.14	47.14	359.76	70.77	0.338
100 x 100	4.00	14.95	11.73	226.35	226.35	3.89	3.89	45.27	45.27	364.75	67.50	0.379
	5.00	18.36	14.41	271.10	271.10	3.84	3.84	54.22	54.22	441.84	80.54	0.374
	6.00	21.63	16.98	311.47	311.47	3.79	3.79	62.29	62.29	511.80	92.06	0.369
113.5 x 113.5	4.80	20.28	15.92	393.30	393.30	4.40	4.40	69.30	69.30	637.45	103.89	0.429
	5.40	22.60	17.74	432.58	432.58	4.38	4.38	76.23	76.23	708.69	114.41	0.426
132 x 132	4.80	23.83	18.71	634.39	634.39	5.16	5.16	96.12	96.12	1018.30	144.11	0.503
	5.40	26.60	20.88	700.11	700.11	5.13	5.13	106.08	106.08	1134.25	159.18	0.500
150 x 150	4.00	22.95	18.01	807.82	807.82	5.93	5.93	107.71	107.71	1273.46	161.38	0.579
	5.00	28.36	22.26	982.12	982.12	5.89	5.89	130.95	130.95	1569.09	196.38	0.574
	6.00	33.63	26.40	1145.91	1145.91	5.84	5.84	152.79	152.79	1856.18	229.44	0.569
	8.00	43.79	34.38	1443.00	1443.00	5.74	5.74	192.40	192.40	2405.78	290.12	0.559
180 x 180	4.00	27.75	21.78	1421.74	1421.74	7.16	7.16	157.97	157.97	2224.31	236.76	0.699
	5.00	34.36	26.97	1736.87	1736.87	7.11	7.11	192.99	192.99	2747.93	289.40	0.694
	6.00	40.83	32.05	2036.52	2036.52	7.06	7.06	226.28	226.28	3259.23	339.65	0.689
	8.00	53.39	41.91	2590.73	2590.73	6.97	6.97	287.86	287.86	4246.16	433.32	0.679
220 x 220	6.00	50.43	39.59	3813.36	3813.36	8.70	8.70	346.67	346.67	6034.53	520.18	0.849
	8.00	66.19	51.96	4894.99	4894.99	8.60	8.60	445.00	445.00	7897.48	668.99	0.839
	10.00	81.43	63.92	5887.19	5887.19	8.50	8.50	535.20	535.20	9549.15	796.48	0.829
	12.00	96.14	75.47	6793.08	6793.08	8.41	8.41	617.55	617.55	11116.96	915.37	0.818
250 x 250	6.0	57.63	45.24	5672.00	5672.00	9.92	9.92	453.76	453.76	8920.44	680.77	0.969
	8.0	75.79	59.50	7315.65	7315.65	9.82	9.82	585.25	585.25	11702.07	879.31	0.959
	10.00	93.43	73.34	8842.29	8842.29	9.73	9.73	707.38	707.38	14248.15	1054.68	0.949
	12.00	110.54	86.77	10254.78	10254.78	9.63	9.63	820.38	820.38	16678.37	1219.59	0.938

Figure 36: Properties of square hollow section [14]

7.3.6 Second Iteration Floor Bolts

The second iteration of the bolt analysis focuses primarily on the fasteners that hold each of the four legs into the ground, keeping the entire fixture in place under any loading condition applied. Although the only directly applied force from the hydraulic is applied onto the radome, each of the legs of the test fixture receives a reaction force. These reaction forces, based upon the applied force on the radome, will determine whether the entire fixture will be able to withstand the load on the radome. Firstly, there are a few variables that the team has either calculated or were specifically given by the client; these specifications will remain unchanged as all other variables are determined. The client has stated that the bolts used in securing the fixture to the floor must be 5/8-in diameter bolts with 18 threads per inch. The fixture must be able to handle and apply conditions to a variety of radome lengths and diameter sizes. For the sake of consistency across all fixture analysis the team has decided to use a radome 17 in. in length and 7 in. in diameter. The final parameter was the moment about half the radome's diameter, located at the connection point between the radome and the AMRAAM mounting ring, M_c. The moment created was 49,098 in-lbf, which was established from the aforementioned compressible flow calculations. For the purpose of this analysis and in the manner the calculation program operates, the value of the force applied on the radome, F_a, and its distance from the connection point, L_{AC}, are arbitrary values and can be adjusted at any time; the only constraint is that L_{AC} must be greater than 6 in. due to the extension length of the heat lamps from the mounting plate. Given M_c, L_{AC} was selected to be 8 in., meaning F_a is 3,608.62 lbf applied on the radome.

Approaching the design from a side profile as seen in the figure called *Upright*, to solve for the reaction forces at the front leg, named point B, and the back leg, named point D, the moment about point D must be calculated to find $F_{D.}$ To find these moments, it's important to also know the various distances between each of the points where either a moment occurs, or a force is applied. Finally, finding the reaction forces requires the sum of the forces at equilibrium in the Y direction to solve for the reaction forces F_a, F_B, F_C. It is to be noted that the force at point B puts the bolts in tension, while the force at point D puts the bolts in compression. This however, should not affect the test results of the bolt integrity. The results are as follows, summarized in Table 5.

Table 5: Summarized Floor Bolt Force Results and Distances

Point Type / Name	**Point Location**	**Force at Point Location [lbf]**
Point A	Applied force on radome	3068.62
Point B	Center of base of front leg	4196.11
Point C	Given moment at mounting ring	---
Point D	Center of base of back leg	1127.49
Relevant Distances	**Distance Value [in]**	
Length AB	8.25	
Length AC	8	
Length AD	74.25	
Length BD	66	
Length BC	0.25	
Length CD	66.25	

7.3.7 Quartz Lamp Requirements

Quartz lamps required three major items to work: water, air, and power. Each heater operates at 6 kW with a voltage of 240 V. Testing an AMRAAM radome for example takes eight heaters touching side by side. The power control system is model 915 [17], and it is wired to the junction box. Control current or voltage from 0 to 97% with 0.1% resolution, which is highly accurate. Water and air are required to cool the lamps after testing. The cooling process takes three to four minutes to be safe to touch. All the inlet tubes would be connected to each other from one heater to the other and the same with the outlet water, allowing to use only one water pump for the system. Using two tanks of forty gallons capacity, the water flow rate is 10 gallons per minute and the temperature of the water is room temperature. For the compressed air, cooling air flow is 4 SCFM at 3 PSI with a regenerative blower for each heater of 20 CFM at 6.2 PSI. Table 6 shows the amount of energy required for each test time for different numbers of lamps.

Table 6: Amount of Energy Required for Lamps

Test time	8 Lamps (kwh)	10 Lamps (kwh)	12 Lamps (kwh)
30 seconds	0.4	0.45	0.5
45 seconds	0.6	0.675	0.75
1 minute	0.8	0.9	1
2 minutes	1.6	1.8	2
3 minutes	2.4	2.7	3

7.4 Design Changes

7.4.1 Quartz Lamps

One way that the test fixture design has changed is the way the quartz lamps will be arranged and what model will be used. Previously, the team did not have a design for an apparatus to hold the lamps. Now, the lamps will each be attached to a bracket that inserts into a hole in the universal plate. This design was chosen because it fits easily with the current design and can cater to the size of the radome; lamps can be added or removed. Model 5209 with 5 in. of lighted length are the chosen lamps because they can provide the right heat flux and fit best with the design [13]. The team is using shorter lamps because the base of the radome is the most important section, and the rest of the radome does not need to be heated. Having shorter lamps also allows more room to apply the mechanical loading using the ram. Due to the above heat flux and temperature analyses, the lamps will be nearly touching and will be 1 to 2 in. from the radome. The spacing of the lamps is influenced by the analyses detailed in Section 7.1.1.

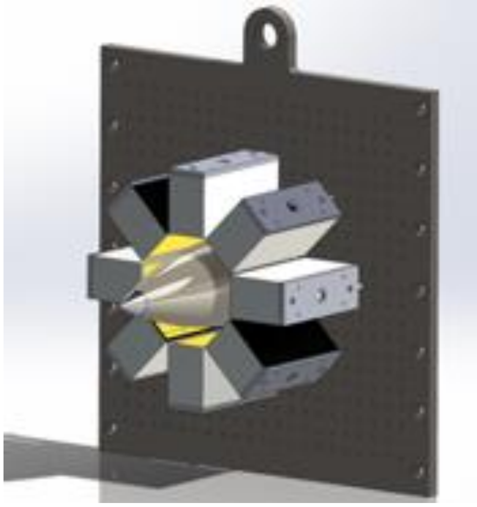


Figure 37: Heat Lamps Attached to Plate

7.4.2 Beams

The recent calculation of beams has changed the dimensions of the cross section of the beam, before we just assumed the dimensions without knowing the amount of stress on the system. But at this moment considering the stresses on the beam, it should be 220 mm x 220 mm, with thickness of 12 mm. Also, the material is YST 310 steel which has the highest yield strength among the other types of steel. These conclusions are a result of the second iteration of the beam calculations.

7.4.3 Floor and AMRAAM Mounting Plate

From the second iteration analysis and the team's most recent meeting with the client, we have found that one of the best ways that we can improve our design to lower assembly and disassembly time is to use the same exact specifications for every bolt utilized in our design. In our case, this means we much change and adjust the bolt selection, number of bolts, and bolt distribution that currently exists for the AMRAAM mounting plate and have them match those of the floor bolts. This would involve recalculating the factors of safety given the new bolt specifications and determining if the fasteners between the AMRAAM mounting plate and universal mounting plate would still hold. The results of this analysis have led to the decision that all fixture bolts will be steel, 5/8"-18 UNF, SAE grade 5 (Q&T), and have a fastener length of approximately 1.96 inches or greater. The fixture is significantly over built, and with the given load, the AMRAAM mounting plate is still well within the required load and joint factors of safety, and the number of bolts can be reduced from 24 to 8. Regarding the floor bolts, again, the load, joint, and fatigue factors of safety are well over what is expected of the design, and therefore the number of bolts in the front leg can be reduced from 18 to 6 and the number of bolts in the back leg can be reduced from 22 to 8 bolts and still be well over the required factors of safety.

7.4.4 Control Panel

A control panel was added to the test fixture. This control panel is intended to aide in the wiring of sensors, heat lamps, and the hydraulic ram. The back of the control panel has terminal blocks which allows wires to be quickly connected. The front of the control panel has pin out connectors which can be connected to a netDAQ or computer. Having a method to organize wiring will greatly reduce setup times as well as errors. As a safety feature, a master kill switch was also added so the entire machine can be quickly turned off in the event of an emergency. Figure 38 shows the control panel.

Figure 38: Control Panel

7.4.5 Final Design

The final design after changes were applied can be seen in Figure 39.

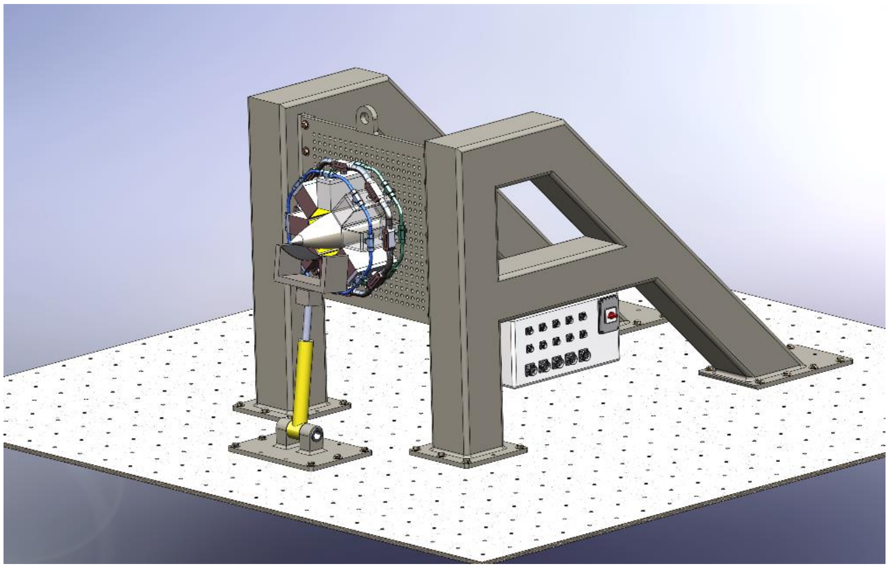


Figure 39: Final Design Isometric View

Figure 40 shows a close-up view of the lamps with the air, power, and water lines.

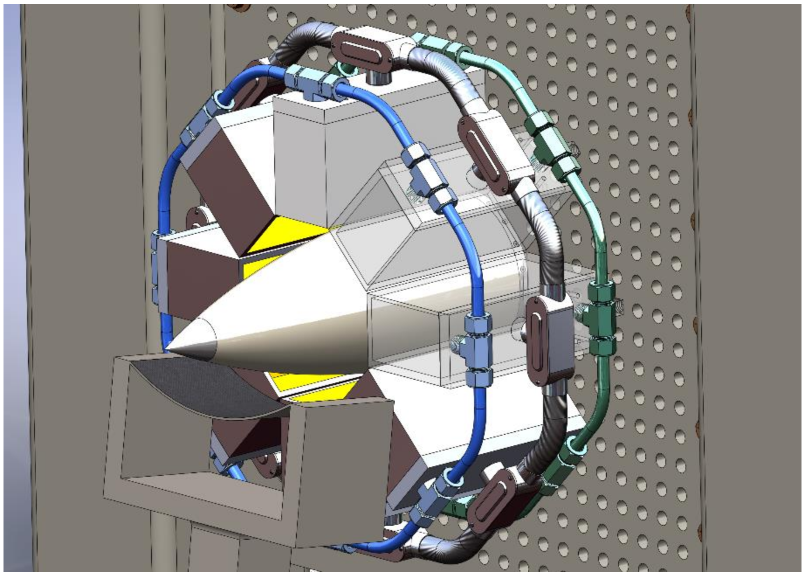


Figure 40: Close-Up of Radome and Lamps

8 Testing

8.1 Introduction

The following sections detail the testing that was performed in order to validate that the system fulfills all the target values for each engineering requirement. In cases that the system does not hit the requirement, explanations and justified redesigns are proposed. All testing was performed analytically. Table 6 shows what each target value is. A more detailed section on why the customer and engineering requirements were chosen is Section 2.

Table 7: Engineering Requirements

Engineering Requirement	Target Value
Transports quickly from storage	1 hr.
Assembles quickly	2 hrs.
Mounts to a standard bolt pattern	6 in.
Applies and withstands extreme loads	$4.9*10^5$ in-lb.
Applies and withstands heat flux	50 W/cm^2
Ability to test parts up to 3 feet diameter	3 ft
Safety Factor	4
Sensors read out to a different location	ohm
Load driven from an alternate location	Volt
Small storage space	100 ft^3

8.2 Assembles Quickly (Time Study)

The target assembly time for the test fixture was one day total. Utilizing two employees and air wrenches the assembly time was able to be kept under nine hours. As mentioned in section 8.2, the setup time for the basic structure is approximately one hour, which is under the initial engineering requirement of 2 hours. The total set up time for the AMRAAM radome testing was just under nine hours. Most of the setup time consists of connecting the sensors and plumbing. The sensor and plumbing layout will change when testing various aerospace components. Table 7 shows the details of the time study.

Table 8: Time Study

Item #	Description	Quantity	Time (min)	Total (min)
1	Forklift A-Frame into position	2	7	14
2	Forklift Universal Plate into position	1	7	7
3	Torque Fixture Bolts w/ Nuts	12	0.75	9
4	Torque Fixture Bolts w/o Nuts	24	0.5	12
5	Attach Radome Mounting Plate to Universal Plate	1	10	10
6	Attach Radome to Mounting Plate	1	15	15
7	Connect Thermocouples to Radome	150	2	300
8	Connect Strain Gauges to Radome	25	2	50
9	Forklift Hydraulic Ram into Position	1	7	7
10	Connect Load Cell and Warm Up	1	7	7
11	Connect Heat Lamps to Universal Plate	8	5	40
12	Connect Air/Water Lines to Heat Lamps	18	2.5	45
13	Connect Master Sensor and Power Cables to Fixture	8	1	8
	Total Set Up Time		524 Min	8.7 Hours

8.3 Transports Quickly from Storage

The target value for the transport of the test fixture to its destination was one hour. However, this engineering requirement is somewhat ambiguous because the team did not have one specific situation in mind. The transportation distance and time will greatly vary given the situation. In the time study, the total time it takes to forklift each part into place is 28 minutes, which is under the target value. In this example case, the transportation time fulfills the engineering requirement.

8.4 Mounts to Standard Bolt Pattern

One of the engineering requirements was that the fixture needed to bolt to a 6 in. square bolt pattern. Figure 41 shows the base of one of the A-Frame. The bolts fit into the necessary pattern.

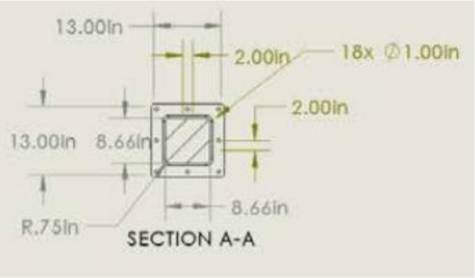


Figure 41: A-Frame Base

8.5 Applies and Withstands Extreme Loads (Plate Stress)

8.5.1 Plate Stress First Iteration

In order to make sure that the plate would not fail, ANSYS Workbench was used. The target loading was 4.9 x 10^5 in-lb. The analysis was also used to see if the plate could be made any thinner. First, the temperatures on the plate were analyzed, then the stresses were. The stress depends on the thermal boundary conditions, so both analyses were necessary. The first iteration of the plate stress did not account for the thermal loading, but this was fixed in the second iteration. The universal plate was cut into four pieces. There is not true quarter-symmetry, because of the top piece. The top piece was not load bearing, so it was not considered. This was in order to utilize all available nodes and elements. For the thermal analysis, the edges where the cuts were, were perfectly insulated. A lower heat flux of 5 W/cm^2 was applied as it produced temperatures that were closer in range to the values that the previous heat flux analysis produced. The results of the analysis can be found in Figure 42.

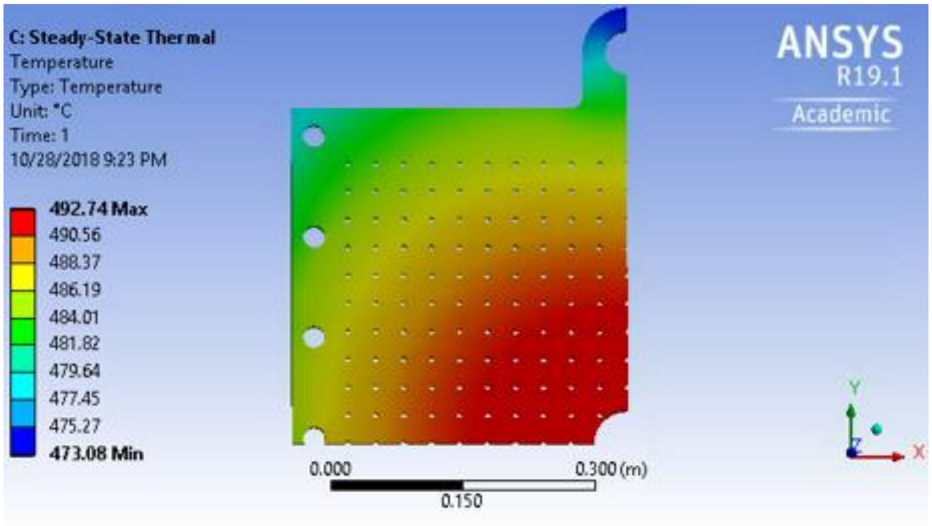


Figure 42: Thermal Results

For the structural analysis, where each cut was, a roller boundary condition was applied. A moment of 50,000 in.-lb. was applied to the plate. The bolt holes on the far left were fixed as they will be bolted to the fixture. The results of this analysis are shown in Figure 43.

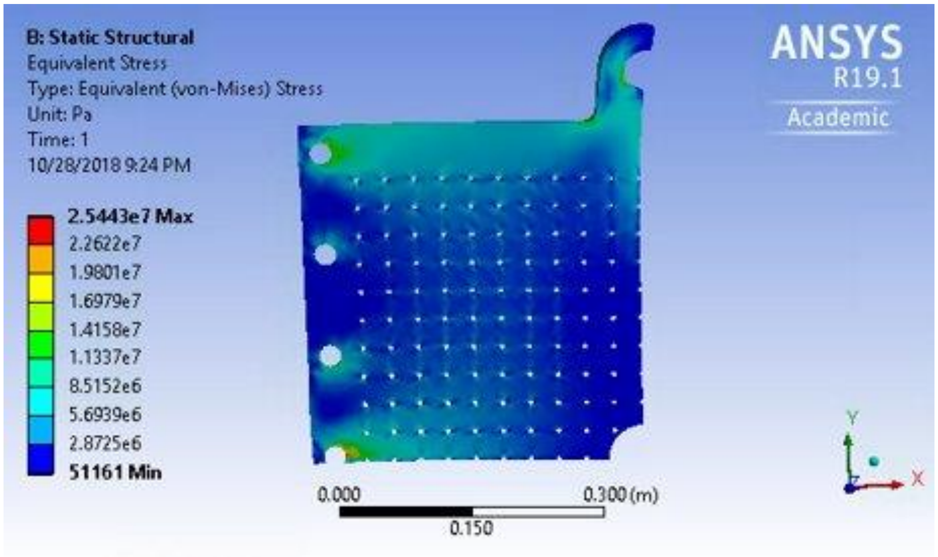


Figure 43: Structural Results

8.5.2 Plate Stress Second Iteration

After the first plate stress iteration, multiple errors were found that needed to be fixed. This second model also had a 0.75 in. thickness compared to a 1 in. thickness. First, the heat analysis was modelled again, still using quarter symmetry. This time, however, the radome and adaptor plate were also modelled. These parts were necessary to include in order to get the right heat transfer results. In the last model, only the plate itself was modelled, which is not an accurate representation, and ignores modes of heat transfer. For this analysis, the cuts boundaries were perfectly insulated. Conduction was applied between all bodies that were touching. Radiation was also applied so that the surfaces radiated to each other. Lastly, all surfaces open to the air were allowed to convect. A heat flux of 10 W/cm^2 was applied to the radome. This value was applied because it was an average value and produced similar temperatures to what was expected. Applying a 50 W/cm^2 heat flux to this model produced temperatures of 15,000°C, which is a much too conservative model. Figure 44 shows the results of the entire model.

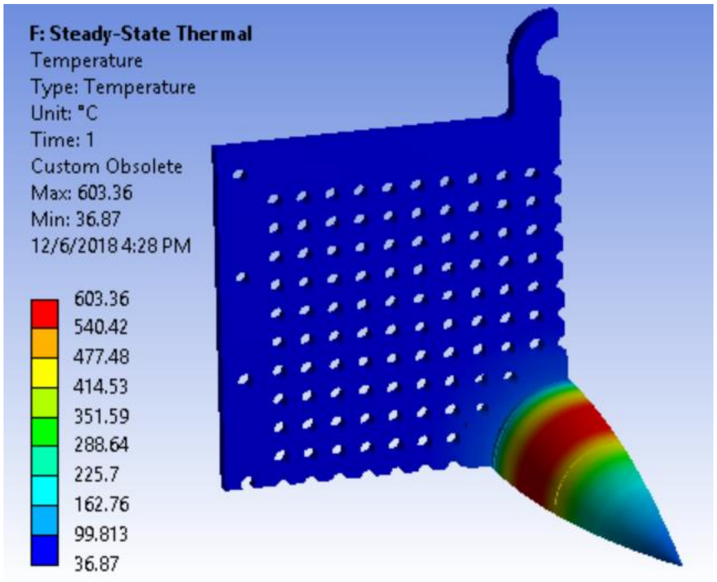


Figure 44: Thermal Results

Figure 45 shows the temperature results on just the plate.

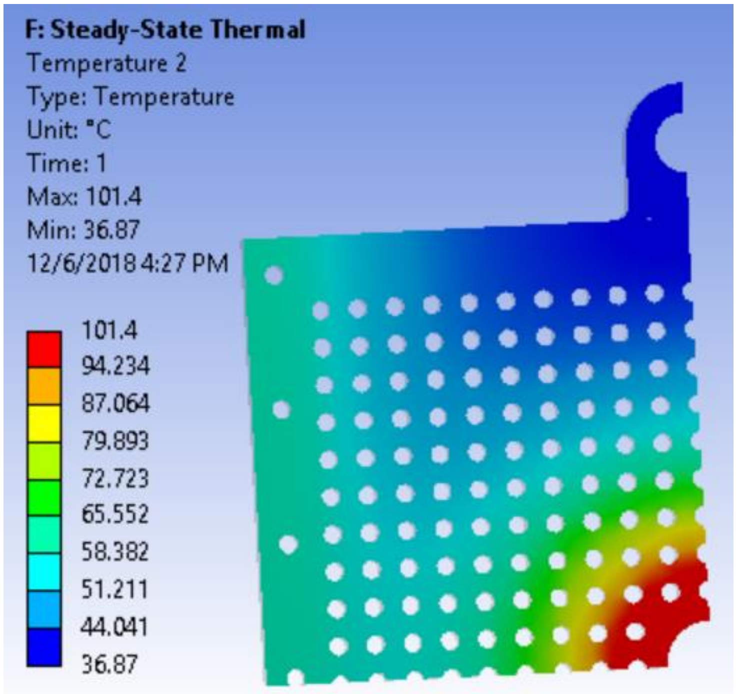


Figure 45: Thermal Plate Results

After the thermal analysis was completed, the solution to that model was imported to a new structural model. This model was set up the same as the first iteration but used the thermal results as well. As seen in Figure 46, most sections of the plate are well below the yield strength of steel, however, some higher stresses occur due to the shape of the adaptor plate, which will change with each radome. Therefore, the plate fulfills the engineering requirement of handling large amounts of mechanical loading.

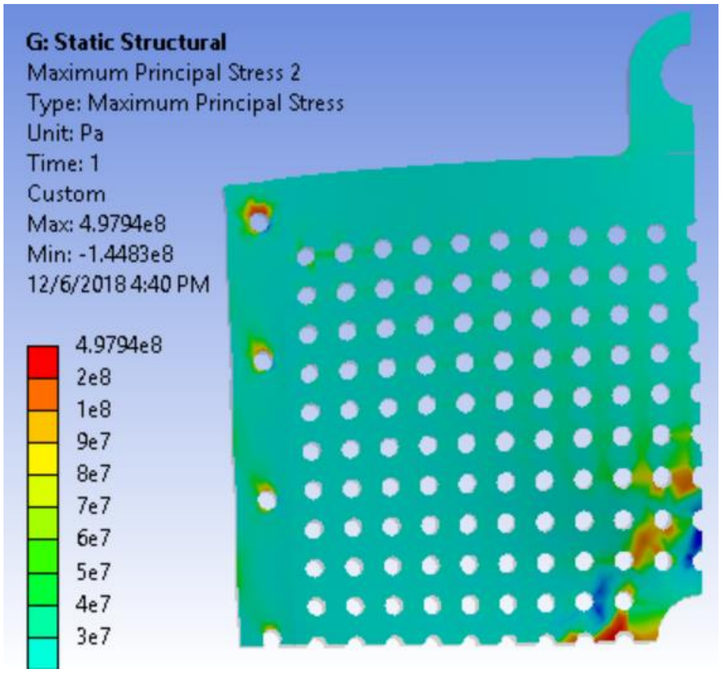


Figure 46: Plate Principal Stress Results

8.6 Applies and Withstands Heat Flux

In order to validate that the test applies a correct amount of heat flux, the code that was used to determine the correct heat flux for flight conditions was modified to apply a constant heat flux, which is representative of the test environment. Figure 47 shows the temperatures in flight, and Figure 48 shows the temperatures during the test. The lamps apply a heat flux of 50 W/cm^2 to the aft half of the radome, which is the area of concern. The goal of the plots was to show that the temperatures in test meet or exceed the temperatures in flight.

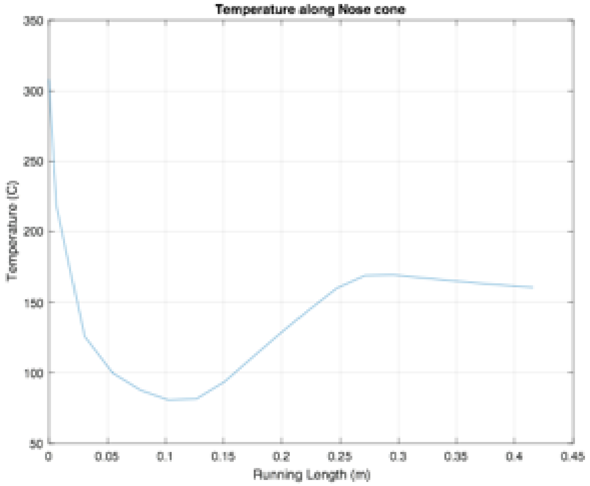


Figure 47: Temperatures in Flight

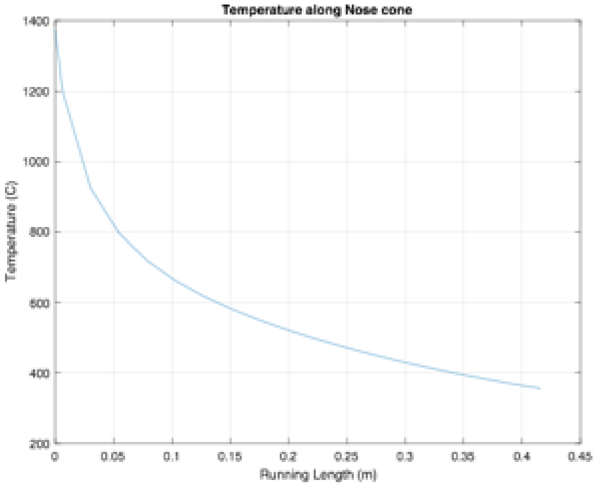


Figure 48: Temperatures in Test

8.7 Ability to Test Parts of All Sizes

One of the other engineering requirements is the ability to test parts of sizes up to a three ft. diameter. The team chose a universal plate with many holes to fulfill this need. Figure 49 shows the dimensions of the universal plate. The plate is 30 in. wide, which does not quite meet the three-foot diameter requirement. However, the radome adaptor ring could be modified so that a very large missile could still be tested. In the case that a large radome could not be tested in this way, the plate would need to be made 6 in. wider and taller to fit a three ft. radome.

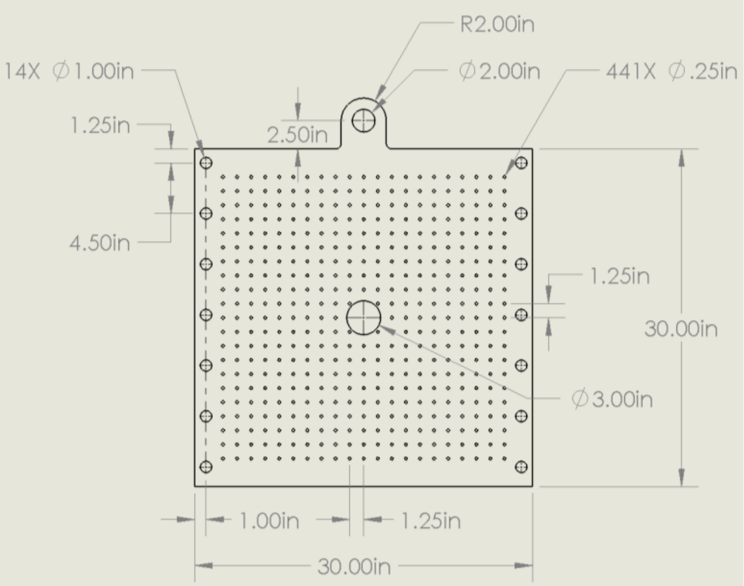


Figure 49: Universal Plate Dimensions

8.8 Safety Factor

For safety factor, all factories and companies are required to follow OSHA standards, according to OSHA the factor of safety must be four or more. When mechanical loading applies the maximum force on the missile part, the factor of safety of the weakest point at the A-Frame would be 4.23 and the rest of the beam would be higher considering the moment will be less on these points. On the universal plate, while applying force, some nodes exposed to high stress, the maximum stress can a node take is 200 MPa, which will make the factor of safety 1.25 on the maximum point. Increasing the cross-section area would reduce the maximum stress, but there is no need to cause the rest of the nodes would have factor of safety between five and nine. Also, the deformation would not happen even on the max stress node which would make it safe to use. The load factor of safety of the adapter plate is 10.37. For the A-Frame leg the maximum stress has a load factor of safety of 7.7. Therefore, the fixture will be safe to use at the maximum force applied by the hydraulic ram once the fixture gets assembled.

8.9 Sensors

While there was no specific target value for the sensors, the team incorporated them into the design. The sensors would be attached inside the missile part then the part would be attached to the universal plate. All the wires will go through the plate to the circular connectors and terminal blocks on one of the A-Frames, and that would be connected to a computer to show the data of the test. The sensors that would be used in the test are thermocouples, strain gauges, and linear variable displacement transducers. The concern was how many sensors it would take to make the data accurate and to cover the entire part. Fifty to a hundred stain gauges and thermocouples would be distributed inside the part depending on the size of the missile part.

8.10 Load Driven from Alternate Location

The fixture has three parts that need to transfer from storage to the test location using forklift, two A-Frames and the universal plate. The forklift can carry 5,500 lbs. as a maximum weight, each A-Frame has 730 lbs., and the universal plate is about 116 lbs., so the forklift that will transfer the fixture has no problem with the weight. But, the lane between the storage to the test location must be at least 90 inches width, the A-Frame has 75 inches in width, allowing at least seven inches on both sides.

8.11 Small Storage Space

To make the fixture accessible and convenient for the user, the fixture design must be easily stored and fit within a space consisting of a volume of 100 ft^3. Although this test cannot be physically performed, the test fixture was designed in such a way that it can be quickly and easily disassembled, and its major components stacked and stored flat. Given that the dimensions of each individual part of the fixture is known, when disassembled, the team can confidently estimate that the design will comfortably fit within the required storage volume.

8.12 Thermal Expansion in the Bolts

A matter mentioned in a formal team meeting by the client regarding structural soundness during extreme loading, was bolt reliability under high temperature and heat fluxes. Communicated by Chuck, it became a concern that the fasteners used in the design were more likely to fail due to high thermal loading, with additional mechanical loading, than large applications of mechanical loading alone. Discovered in the mounting plate bolt calculations from section 5.2.4, under mechanical loading exclusively, the fasteners will hold, and the system will not fail. The aim of the bolt thermal expansion test calculation was to identify the stress the bolts will experience due to the applied thermal load, and then determine the amount of deflection that will occur under these conditions. Minor deflection is expected in such an environment, but this test is to assure that bolt deflection is minimal and will have no noticeable effects on radome testing. Based on the previously calculated heat fluxes, applied temperature properties, and minimal time exposure to this environment, it is fair to assume that any thermal applications that will encounter the floor bolts or the bolts that connect the universal mounting plate to the rest of the fixture will be so insignificant that their affects are negligible. The bolts that will experience the greatest deflection during a test and therefore will require testing analysis are the adapter plate bolts, which are located closest to the heat source. The calculated results from this test predicted a thermal loading stress 43.8 KSI. The notable output of this analysis revealed that each bolt would only deflect .00363 inches. Confirming this result with the client proved that the effects of deflection due to thermal loading are so insignificant that it will not compromise any sector of the fixture, signifying that the current bolt arrangement is satisfactory.

9 CONCLUSIONS

The design of this test fixture at both the system and subsystem level is a complicated task which required many iterations of design and analysis. The storage, transport, and construction of the test fixture defined the performance at the system level. The means in which the thermal and mechanical loading is applied, as well as the measurement data defined the performance of the sub functions. The team completed beam, bolt, thermal loading, mechanical loading, plate stress, quartz lamp calculations, and power requirements, which helped influence the design decision and validate that the fixture could be manufactured. The team chose the upright fixture because of its unique and robust design.

Throughout the project, there were some contributors to project success and opportunities for improvements.

9.1 Contributions to Project Success

As stated in the team charter, the team's goals were to successfully fulfill all the client's needs, complete every part of the design process, and strive to receive an A in the class. The team has done our best to make our client happy and produce a validated system. The team was successful in producing calculations that support each design choice that was made. The team also has successfully completed all the capstone course deliverables.

Ground rules and coping strategies were also discussed in last semester's team charter. The team agreed to follow rubrics for deliverables, finish capstone and client deliverables on time, and satisfy the client's needs. The team charter also discussed tactics for conflict. The team agreed to prioritize communication and be respectful of all ideas. Communication was especially important this semester as many tasks were analytical and were difficult to work together as a team on. These ground rules were followed, and coping strategies were utilized when necessary. Conflict was addressed immediately, and all parties involved worked to resolve it. The team did not allow problems to fester too much. One other rule was that everyone would attend as many meetings as possible. The team stayed in communication so that meetings were scheduled during times that worked for everyone. Overall, attendance was usually pretty good, and team members let the others know in advance if they could not make a meeting. The team also kept meeting minutes of all team and client meetings, which helped when people missed meetings.

Another contributor to project success was that everyone on the team had different strengths, and we assigned work based on those skills. For example, some team members were good at technical writing, so they took the lead on writing and editing team papers. Others were good at computer modelling and took the lead on the CAD work. However, the team still worked collaboratively on almost all deliverables, and made sure if there were questions or confusion that they were remedied. Having more than one person's input produced the best results. The team also made sure to distribute the work evenly. There were some disparities in workload mid-semester, but that has been fixed in the last month of the semester.

The team also stayed organized by coming up with a schedule and adhering to it. The schedule had a breakdown for each class deliverable and when each analysis should be done. Knowing when both technical and capstone deliverables were due was essential to managing time wisely. The schedule helped the team prioritize tasks and keep the client happy. For the same purpose, weekly emails were sent out, detailing what was due over the next couple weeks and what everyone should be working on as a team and individually. This helped the team see what they should work on immediately as well as what they should work on next.

As far as went well technically, some strategies that were used were starting analyses early and seeking help from our client and professors. Because of the amount of iterations this project required, it was essential that time was managed effectively, and tasks were started as early as possible. Talking to the client and asking question helped guide the team's analyses and design process. The client was very knowledgeable and offered many suggestions for analytical techniques as well as what assumptions the team should make and what changes could be made to improve the design.

Some other positive aspects of the team's performance were the amount of analyses that were completed using a variety of techniques. The team completed bolt analyses to determine the sizes and number of bolts required for different aspects of the design, bolt thermal analysis to see if the high temperatures would cause them to fail, and beam stress analysis to optimize the shape of the beams used. The team also learned how to do complex compressible flow calculations and heat flux calculations. Many different techniques were used for these analyses, such as: Excel, MATLAB, ANSYS, and hand calculations. The team successfully completed all the analyses required for the project.

Some additional technical lessons learned were about the behavior of missiles and general knowledge of the aerospace industry. The team learned about what loading missiles experience in flight, where the high temperatures are, what missile parts are made of, as well as many others. Our client also shared his knowledge of the aerospace industry that the team would not have exposed to otherwise.

9.2 Opportunities for Improvement

Although the team considered this project as an overall success, given the information known now concluding the project, there are opportunities for project improvement and structure. Throughout the project's entirety, the team remained on schedule to meet requirements and the design was able to fulfill its purpose. Due to the analytical and hypothetical nature of the project, nearly all major issues were transparent, noticed promptly, and their solutions were uncomplicated. Although the finished design was notable, completion did not prove easy. With every collaborative project, comes minor complications that delay project development. A few of the small-scale barriers were individual team member schedule conflicts, distance and schedule conflict between the team and the client, and initially, understanding what was expected of the final deliverable.

Scheduling conflicts were one of predictable, yet unavoidable hinderances to the team's productivity. Prioritizing multiple, weekly, team meetings imposed that each team member accommodate each other on occasion. Although coordinating frequent team meetings amongst busy and dissimilar schedules was not a simple operation, all team members were cooperative, willing, and flexible, allowing for straightforward planning. The more complicated aspect of scheduling involved arranging semi-regular, in-person conferences with the client, Chuck. Although continual efforts were made throughout the year to integrate a considerable number of in-person meetings, schedules and availability seldomly aligned. Chuck is based out of Tucson and would periodically pay brief visits to Flagstaff. These visits usually consisted of a narrow time frame of availability and days of availability seemed to infrequently coordinate with the team's presence in Flagstaff. These unfortunate circumstances led to intermittent communication, where the primary mode of contact was through email, as he was also difficult to reach via phone call. Conversations conducted through email were far less productive and detailed than both in-person and teleconference meetings. Although communication through email was simple, required less coordination, and was more convenient for the client, engaging in more persistent requests to establish a regular teleconference schedule would have been beneficial and worthwhile by limiting breaches in communication and understanding.

When presented with the task description and expected outcomes, the open-endedness of the project initially caused confusion. For confidentiality and security reasons, there were no images, videos, articles, or readily available information regarding missile test fixtures and testing environments, making the purpose difficult to understand and the finished product complicated to visualize. Fully understanding the client's aspirations for this project was mandatory for a successful project and client satisfaction, meaning that total comprehension of the device and its functionality as well as complete awareness of fixture requirements would be the first and most significant challenge of this project. This fundamental challenge delayed the progression of the design process but spending the initial weeks of the project consistently meeting with the client for further clarification and more explicit fixture illustrations, configuring a reasonable, organized, and achievable method of approach, and arranging individual project obligations proved to mitigate related issues following the foundation of these operations and procedures.

Being that the project is primarily analytical, most of the team's greatest challenges were due to the hypothetical nature of this project. From the project's beginning, the team was not given the opportunity to view or access the testing environment or visually inspect, analyze, or observe the current state and functionality of the test fixture. Without even any access to exact fixture specifications or performance data, the team was missing some significant information and considerably lacked resources. This was also true of all similarly purposed testing equipment and devices, which hindered conceptual understanding and visualization of part testing and turned existing and comparable design research into an unnecessarily laborious task. With Chuck being the only and most reliable source of missile test fixture information, it was imperative to assure that all questions were thoroughly answered and that all other detailed or desired information was noted in full.

Even though the fixture's functionality and plausibility were verified by an extensive series of calculations, it would have been ideal to have a physically existing test fixture concluding the project. Due to time, resource, and financial limitations, it would not be realistic for a group of four people to forge a functional and safe missile test fixture. Had the team been granted the opportunity to manufacture the final test fixture design, the team would have more substantial testing proof that the design was safe, practical, and able to meet all engineering requirements as stated.

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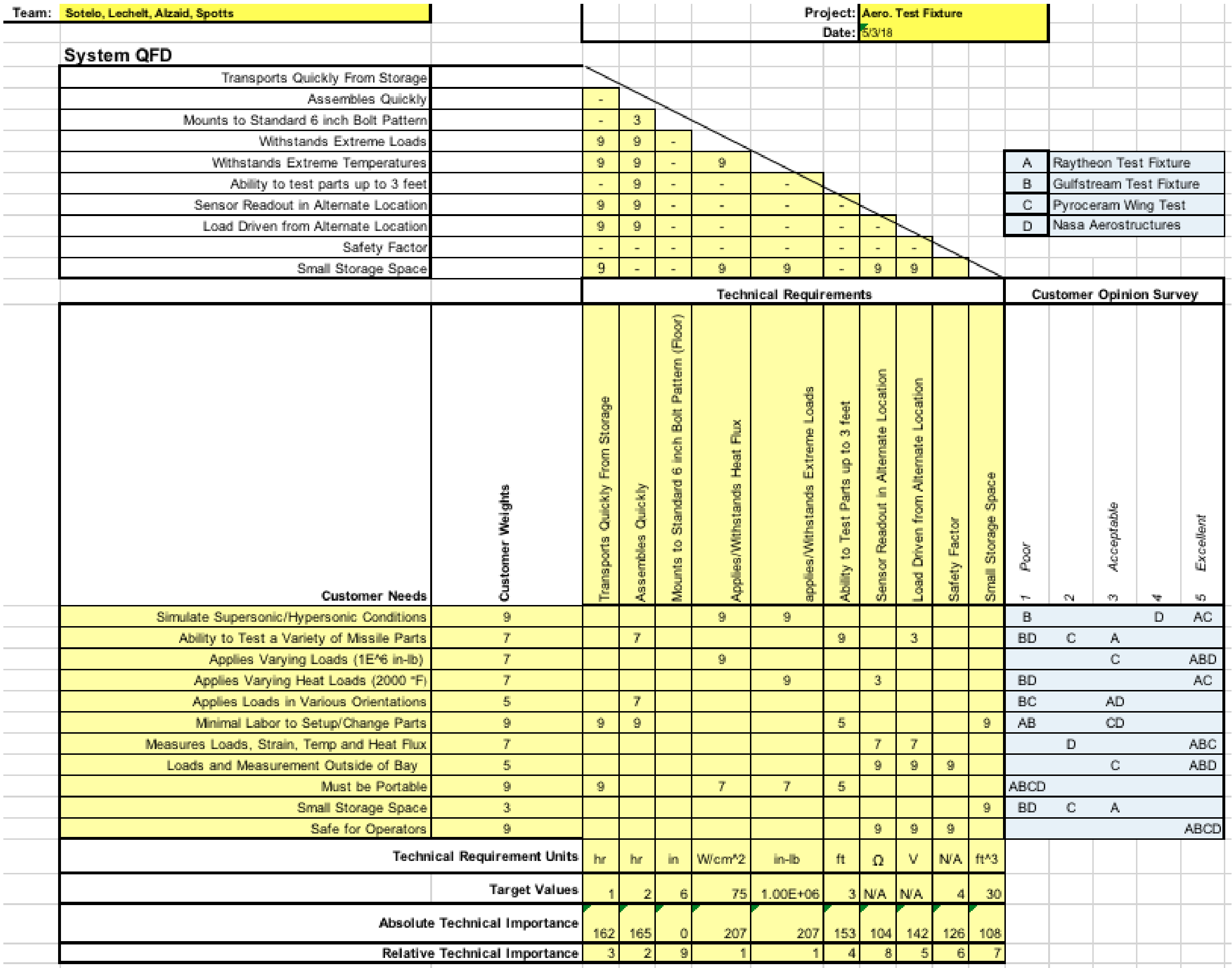
11 APPENDICES

11.1 Appendix A: House of Quality



Team: Sotelo, Lechelt, Alzaid, Spotts

Project: Aero. Test Fixture
Date: 5/3/18

System QFD

Transports Quickly From Storage									
Assembles Quickly	-								
Mounts to Standard 6 inch Bolt Pattern	-	3							
Withstands Extreme Loads	9	9	-						
Withstands Extreme Temperatures	9	9	-	9					
Ability to test parts up to 3 feet	-	9	-	-	-				
Sensor Readout in Alternate Location	9	9	-	-	-	-			
Load Driven from Alternate Location	9	9	-	-	-	-	-		
Safety Factor	-	-	-	-	-	-	-	-	
Small Storage Space	9	-	-	9	9	-	9	9	

A	Raytheon Test Fixture
B	Gulfstream Test Fixture
C	Pyroceram Wing Test
D	Nasa Aerostructures

		Technical Requirements										Customer Opinion Survey				
Customer Needs	Customer Weights	Transports Quickly From Storage	Assembles Quickly	Mounts to Standard 6 inch Bolt Pattern (Floor)	Applies/Withstands Heat Flux	applies/Withstands Extreme Loads	Ability to Test Parts up to 3 feet	Sensor Readout in Alternate Location	Load Driven from Alternate Location	Safety Factor	Small Storage Space	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
Simulate Supersonic/Hypersonic Conditions	9				9	9						B			D	AC
Ability to Test a Variety of Missile Parts	7		7				9		3			BD	C	A		
Applies Varying Loads (1E^6 in-lb)	7				9									C		ABD
Applies Varying Heat Loads (2000 °F)	7					9		3				BD				AC
Applies Loads in Various Orientations	5		7									BC		AD		
Minimal Labor to Setup/Change Parts	9	9	9				5				9	AB		CD		
Measures Loads, Strain, Temp and Heat Flux	7							7	7				D			ABC
Loads and Measurement Outside of Bay	5							9	9	9				C		ABD
Must be Portable	9	9			7	7	5					ABCD				
Small Storage Space	3										9	BD	C	A		
Safe for Operators	9							9	9	9						ABCD
Technical Requirement Units		hr	hr	in	W/cm^2	in-lb	ft	Ω	V	N/A	ft^3					
Target Values		1	2	6	75	1.00E+06	3	N/A	N/A	4	30					
Absolute Technical Importance		162	165	0	207	207	153	104	142	126	108					
Relative Technical Importance		3	2	9	1	1	4	8	5	6	7					

11.2 Appendix B: Bill of Materials

#	Item	Unit Cost	Units	Total	Supplier
1	5/8-11 X1½" HH	$1.16	45	$52.20	https://www.mcmaster.com/standard-hex-head-screws
2	5/58" Washer	$0.73	45	$32.90	https://www.mcmaster.com/90107a035
3	5/8" Nut	$0.30	24	$7.29	https://www.mcmaster.com/95462a533
4	Signal/Power Connector, 37Poles	$53.93	4	$215.72	https://www.mcmaster.com/8903t74
5	Signal/Power Connector, 7 Poles	$15.95	4	$63.80	https://www.mcmaster.com/8903t36

6	12 Circuit Terminal Block	$26.40	15	$396.00	https://www.mcmaster.com/terminals
7	8x6x3/16" A550 Box Tube	$42.30	25	$1057.50	https://www.metalsdepot.com/steel-products/steel-rectangle-tube
8	Quartz Heat Lamps	$679.00	10	$6790.00	http://www.infratechheatersusa.com/lighting/
9	Hydraulic Ram	$655.12	1	$655.12	http://www.tooldiscounter.com/
	Total			**$9270.41**	

11.3 Appendix C: CAD Models

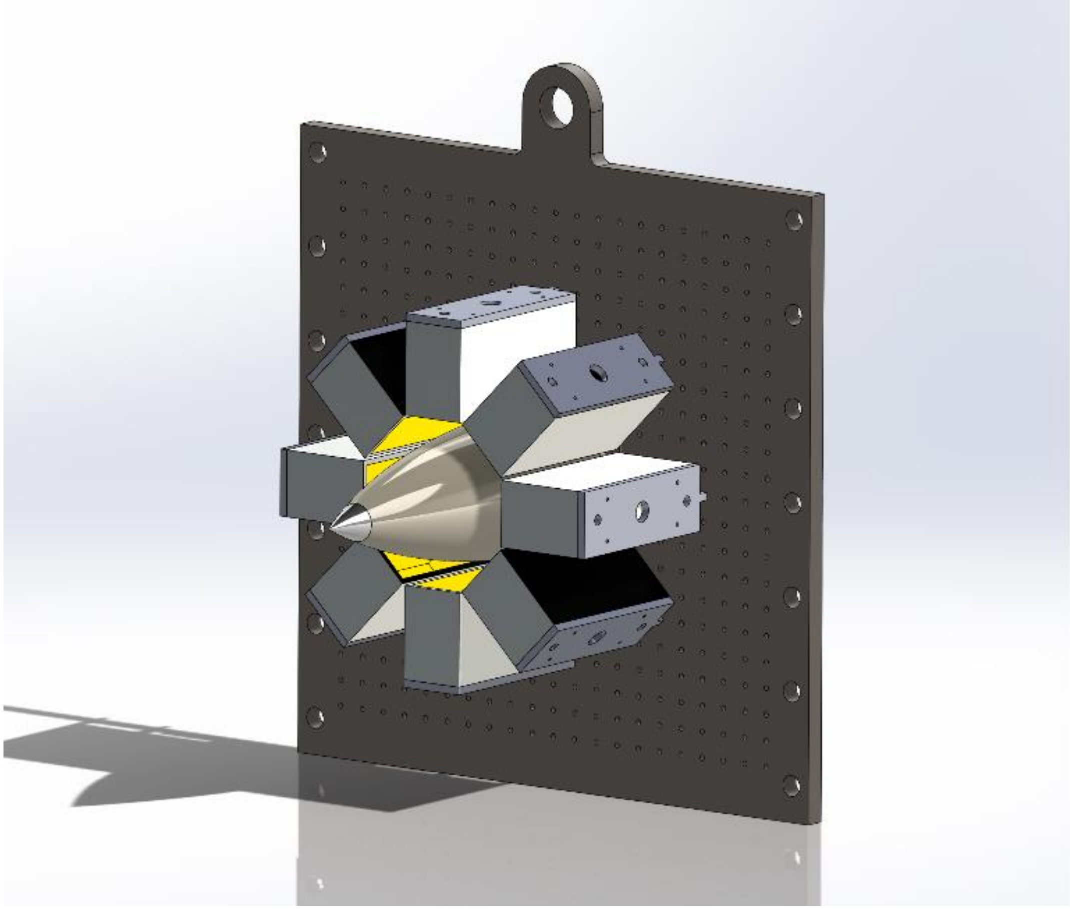


Figure 50: Radome with Lamps

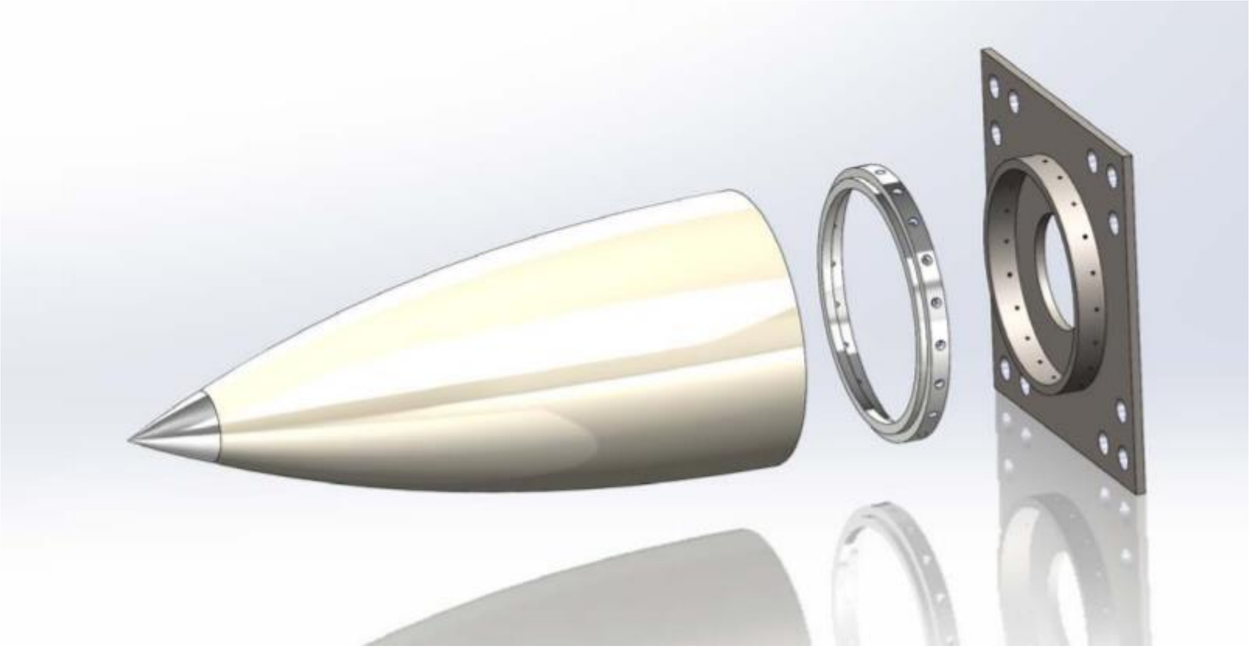


Figure 51: Radome Connector Subassembly

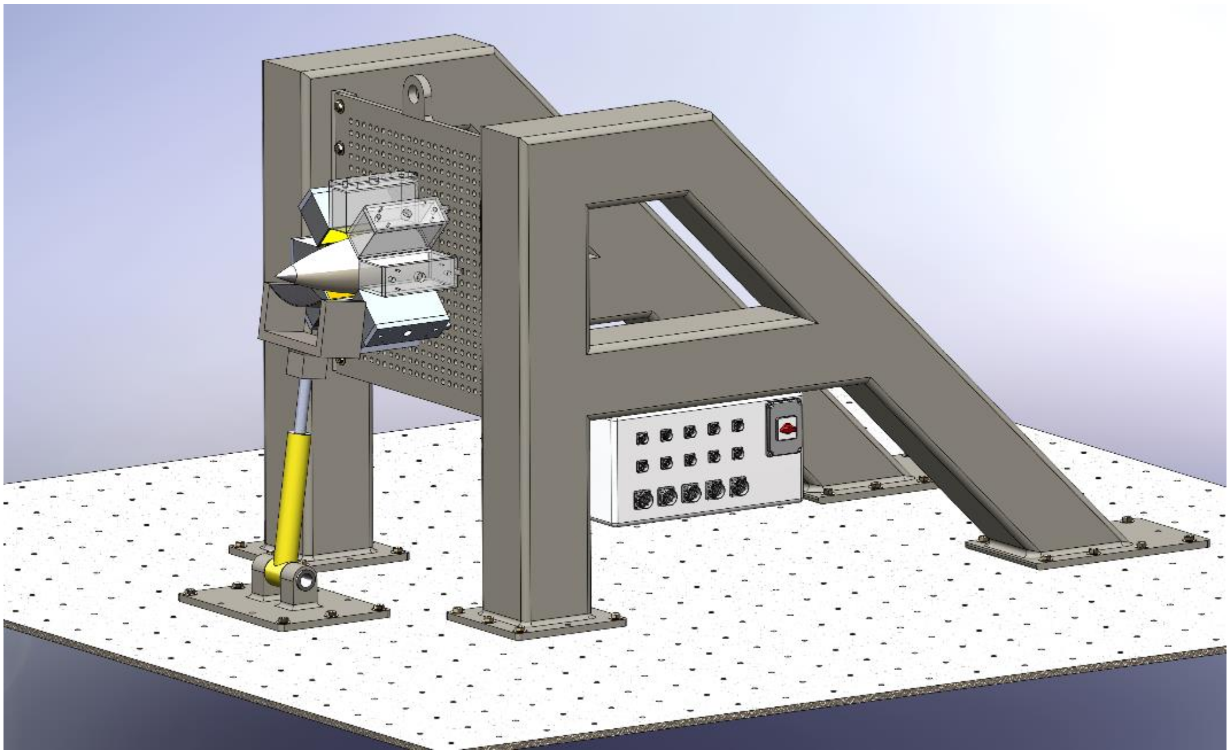


Figure 52: Final Design without Air, Water, and Power Supplies

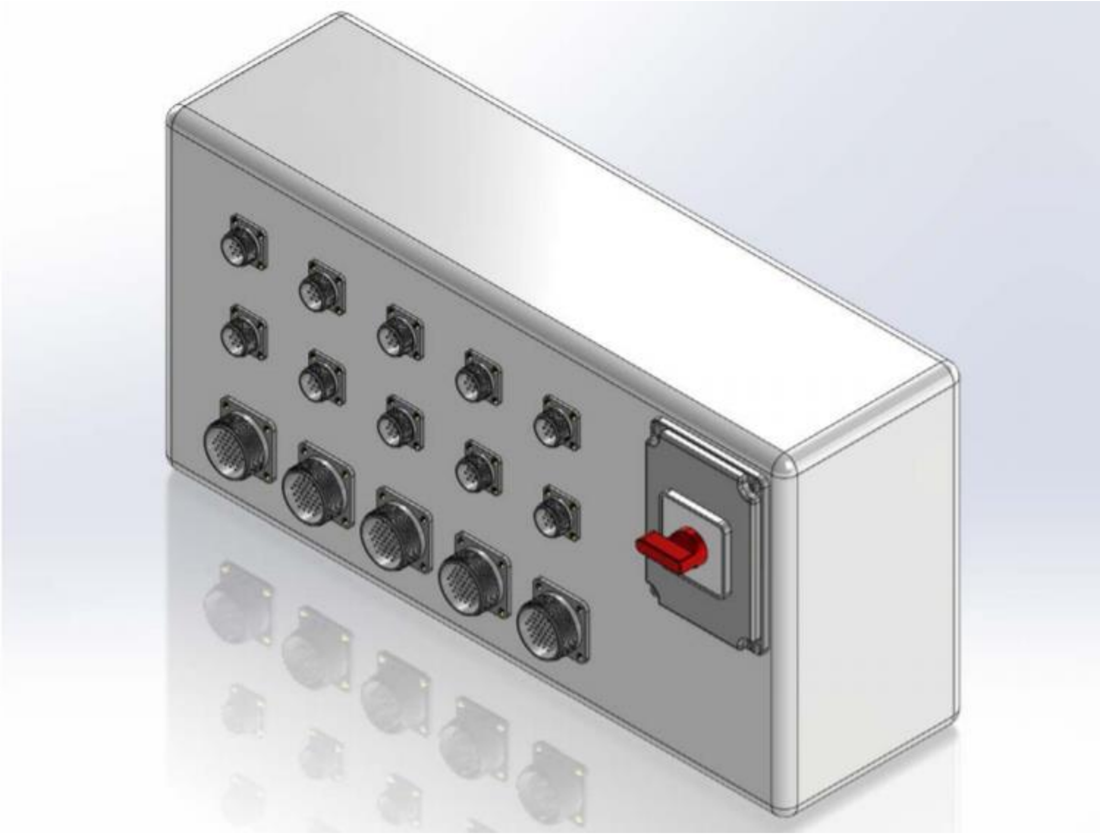


Figure 53: Control Panel 1

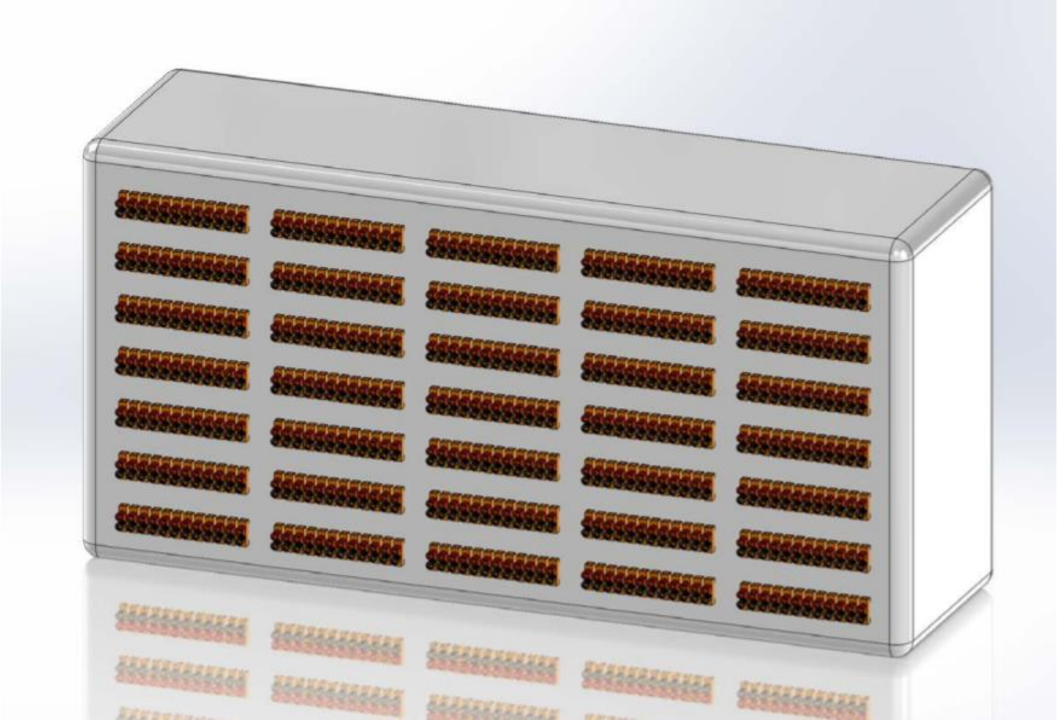


Figure 54: Control Panel 2

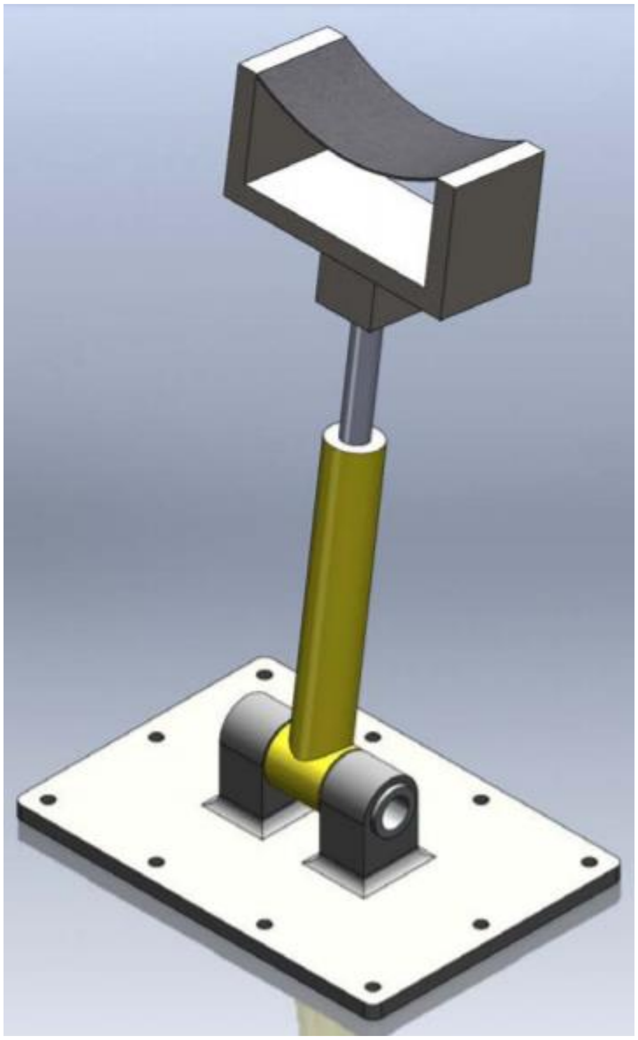


Figure 55: Hydraulic Ram

Figure 56: Mounting Ring

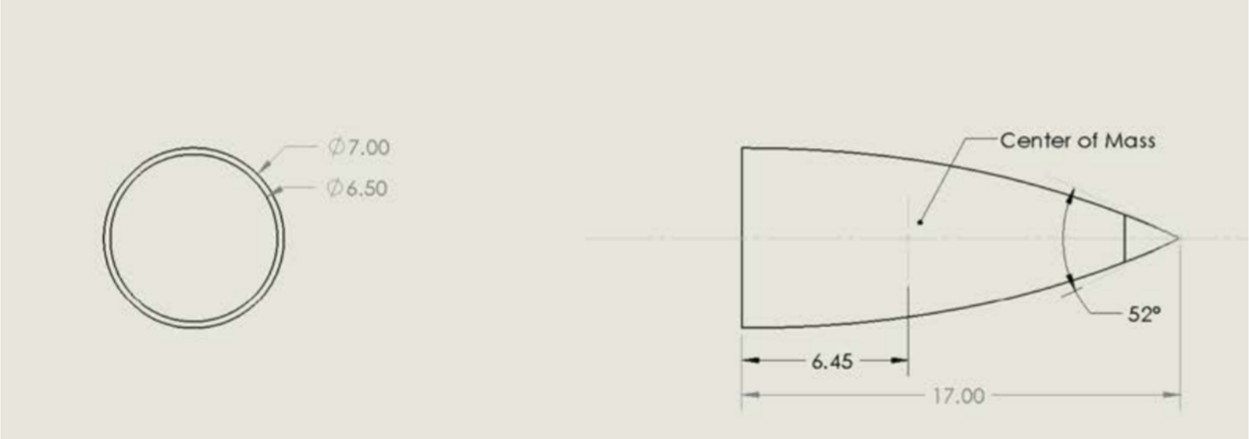


Figure 57: Radome Dimensions

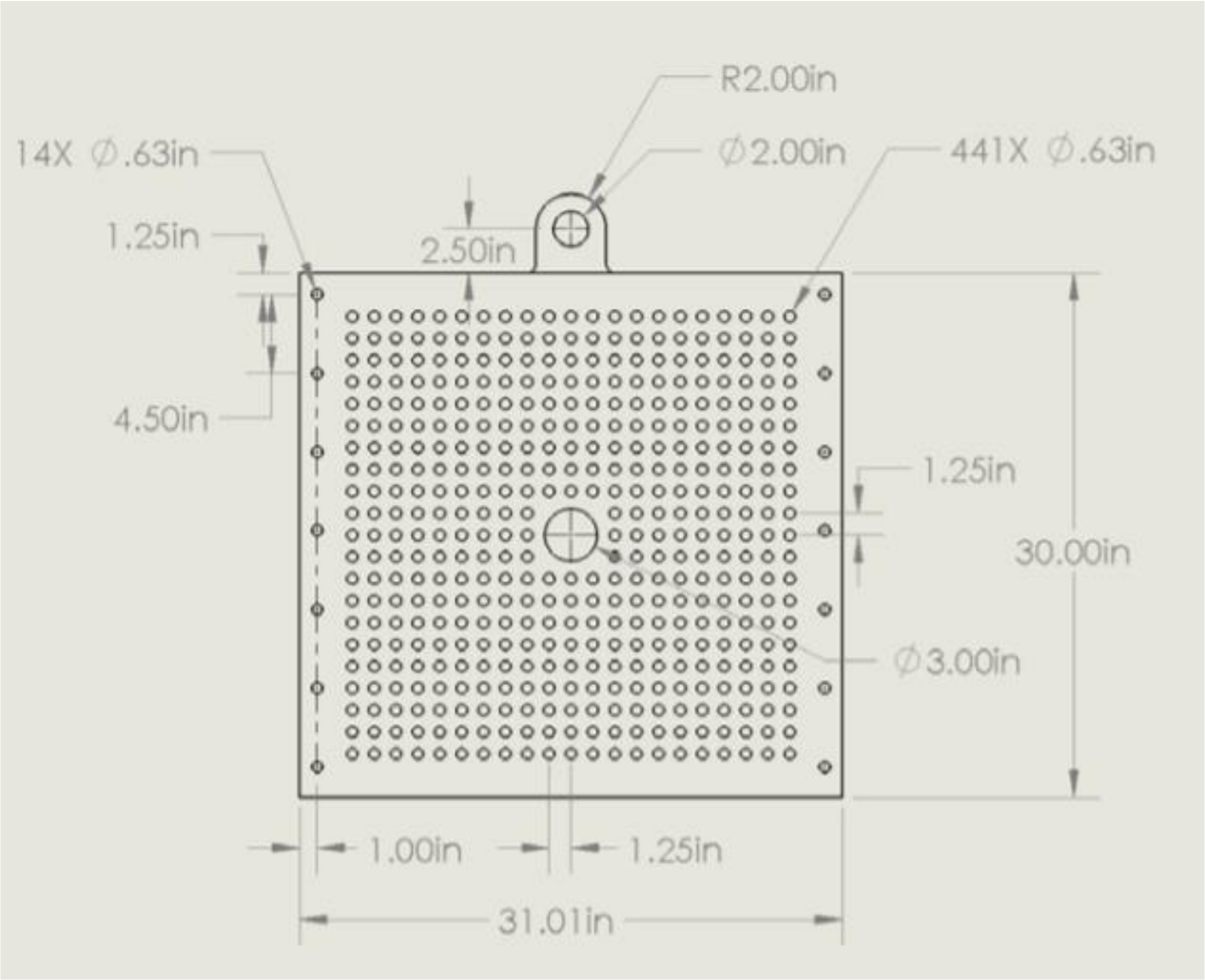


Figure 58: Universal Plate Dimensions

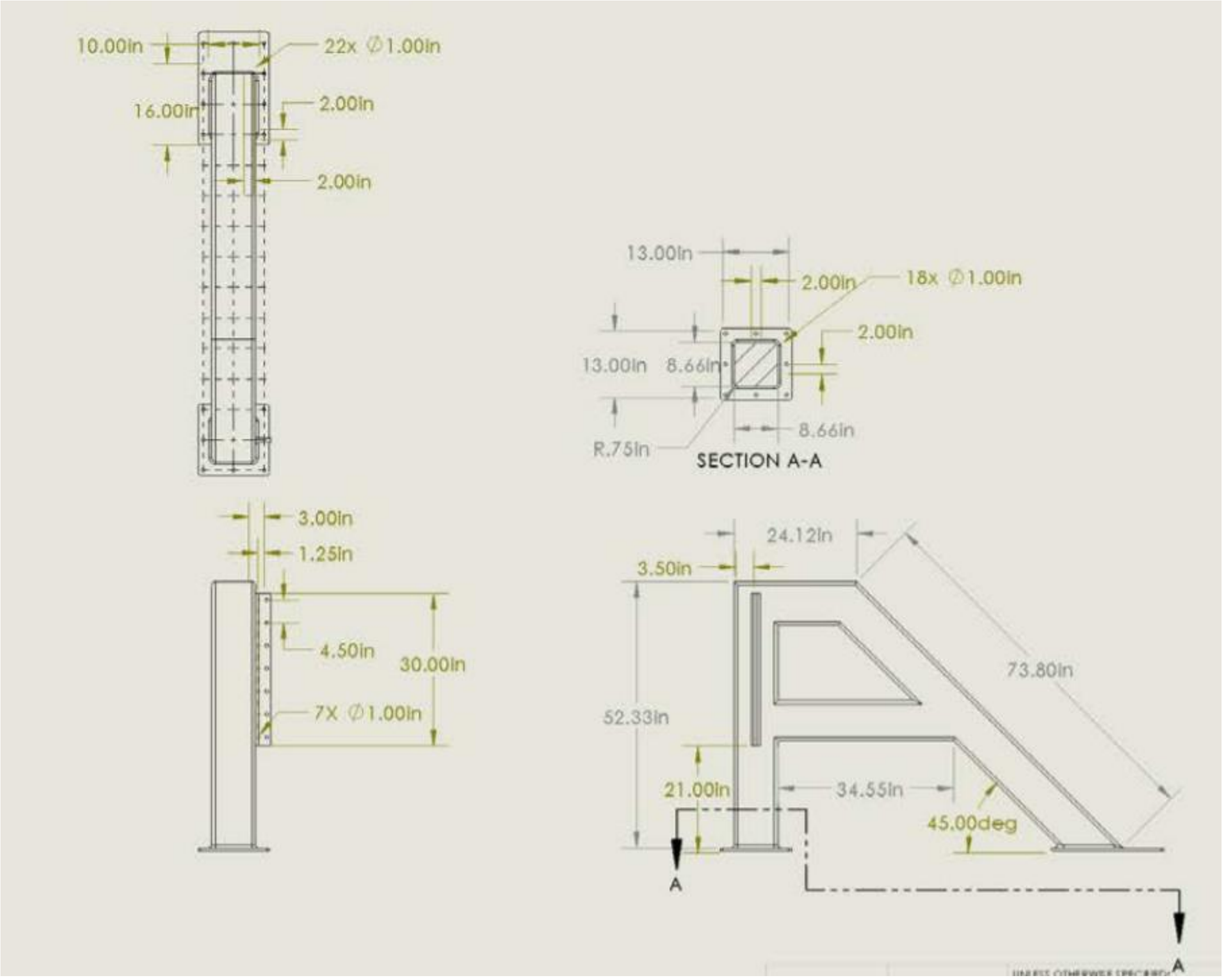


Figure 59: Left Upright Dimensions

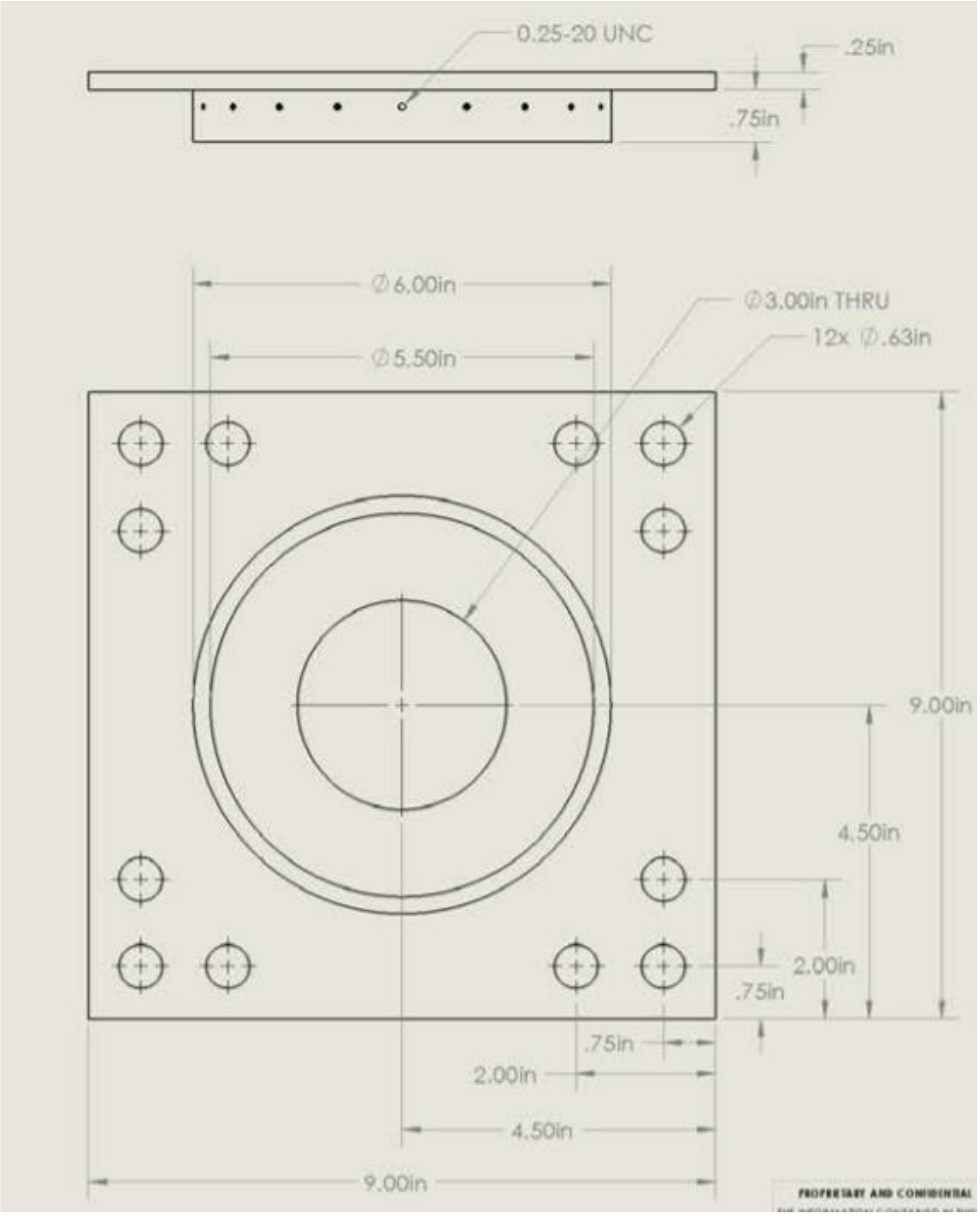


Figure 60: Mounting Plate Dimensions