Corrosion Test Stand
Army – Corp 1

U.S. ARMY AVIATION AND MISSILE COMMAND

Group Members
Vance Beatty
Rob Goodwin
Jake Mattox
Scott Mayo
Alan Peters
Jackson Wilson

April 13, 2009
Final Report
Dr. Beale – Comprehensive Design Two – MECH 4250 – Spring 2009

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Executive Summary

With the mission of building a portable, corrosion resistant rack to hold fifty 3”x5”x1/8” or one hundred 3”x1/2”x1/8” metal coupons at a 45 degree angle, our group designed a rack that holds fifty-six coupons at a 45 degree angle. All the given requirements were met or exceeded. The previous concept has evolved into a more compact and simpler design where all the coupons are facing the same direction. All main components of the assembly are made from 6061aluminum, and all fasteners are 18-8 stainless steel. The coupon retainers will be made from PTFE. Engineering analyses was performed and no major displacement or stresses were found in the components of the assembly. From the calculations, the bolts and all necessary parts will not fail. A maintenance plan was developed that covers the entire lifespan of the test stand. The corrosion rack was machined and assembled in less than 2 months. There was only one revision done to the stand due to a part dimension discrepancy. The total cost of the test rack is $2,937.01. The rack was tested for structural integrity, and the parts were tested in a salt chamber to ensure that the material would not undergo sever degradation. Safe operating instructions were created to ensure simple and fast assembly and disassembly of the stand.

Introduction

a. Problem Statement:

Our sponsor, the U.S. Army, requires a new corrosion test stand. Our mission is to build a portable, corrosion resistant rack to hold fifty 3”x5”x1/8” or one hundred 3”x1/2”x1/8” metal coupons at a 45 degree angle. This test stand will be deployed in the field and used to test and analyze the effects of corrosion on specific metals and coatings.

b. Engineering Requirements for Corrosion Rack:

- Light Weight
  - Let the material control the weight
  - Must weigh less than seventy lbs without coupons
    - This will allow one person to carry it
    - Keep shipping costs down
  - Must fit into back of pickup of truck
- Easily assembled/disassembled
  - No special tools required for assembly
  - Maximum two people required to assembly/disassemble
  - Standard U.S. tools
  - Field assembly, maybe battery powered tools
  - Must take less than 1 hour to assembly/dissemble
  - Attach to:
    - Ground
    - Post
    - Hand-railing
    - Existing structure
    - Stay away from concrete
- Coupon insulated from rack
  - Electrically insulated to prevent galvanic corrosion
  - Withstand desert, marine, industrial environments
    - Nylon, PET, Teflon
- Coupon must be at a forty-five degree angle
- Rack must be corrosion resistant
  - Resistance against:
    - Sunshine
      - UV ray
    - Temperature
      - -35 to 60 °C
    - Humidity
      - < 95%, rain resistant
    - Salt/marine

                - Salt or chloride exposure
            - Industrial atmosphere
                - H_2S (hydrogen sulfide)
    - Maintenance:
        - One year maintenance free
        - 3.5 year maintenance schedule
        - Seven year life expectancy
- Hold fifty coupons
    - Max size (3” x 5” x 1/8”)
    - Make it adjustable for any 3”x1/8” coupon
- Exposed to three different environments
        - Cape Canaveral
            - 74 mph wind
            - Marine
        - CTC Arizona
            - Desert, rural
        - Test stand E (At Redstone Arsenal)
            - Industrial
            - Will be exposed to exhaust from rockets (H_2S)
    - Acknowledge wind speed and other elements
- Cost less than three thousand dollars per unit

Concept Review

At the midterm presentation the "tent" concept was chosen. From that point many changes have occurred due to the need to meet certain engineering requirements and the manufacturability of the test stand.

The original concept had coupons on two sides, both at a 45 degree angle from the ground. After speaking with the sponsor, it was determined that all coupons must face the same direction in order for uniform testing of the coupons. To meet this new requirement the concept was altered so that all the coupons would be held on one angled side. To accommodate the extra coupons, the stand's length was increased by eight inches and the height was increased by ten inches. Please refer to Figures 1 and 2.

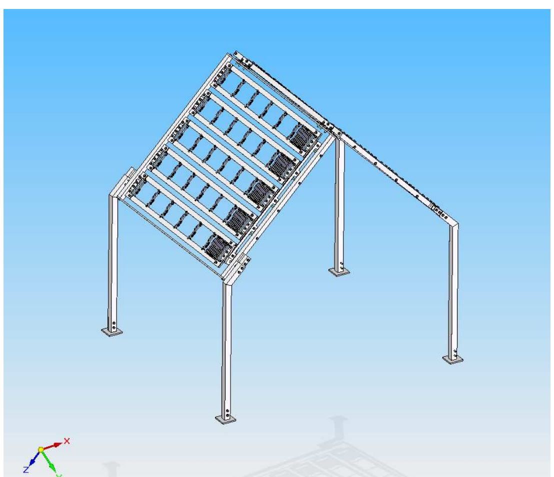


Figure 1: Old Concept

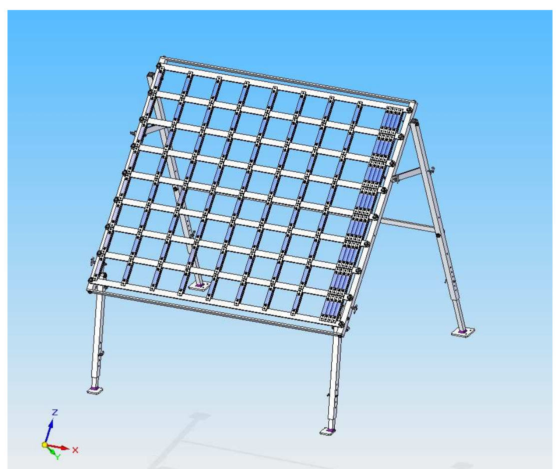


Figure 2: New Design

The next major change to the concept was the removal of the "Venetian blind" style of movement of the coupons. This was removed due to binding, corrosion, stability, and manufacturability concerns. The final concept holds the coupons at a stationary 45 degree angle which satisfies the requirement.

Once the rotation of the individual coupon racks was no longer a feature, the concept was able to be simplified. This simplification was done by extending the cross bars that the coupon retainers were mounted on. The longer cross bars were then bolted to the frame. The elimination of the rotating aspect also eliminated the need for each row of coupon retainers to be held by two cross bars. Now the top cross bar of one row serves as the bottom of the next row. These changes eliminated many unnecessary parts and will drastically reduce the weight and time required to manufacture. Please refer to Figures 3 and 4.

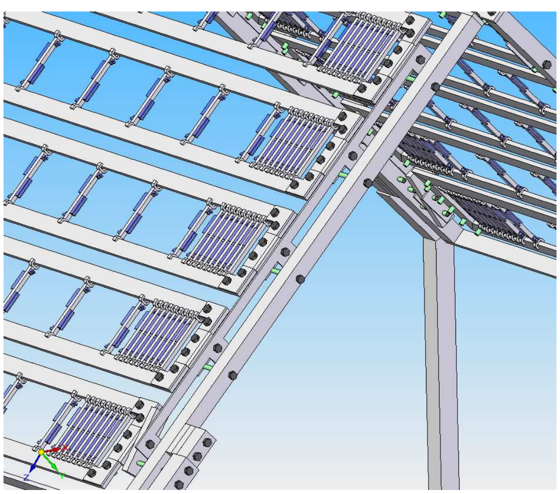


Figure 3: Old Concept

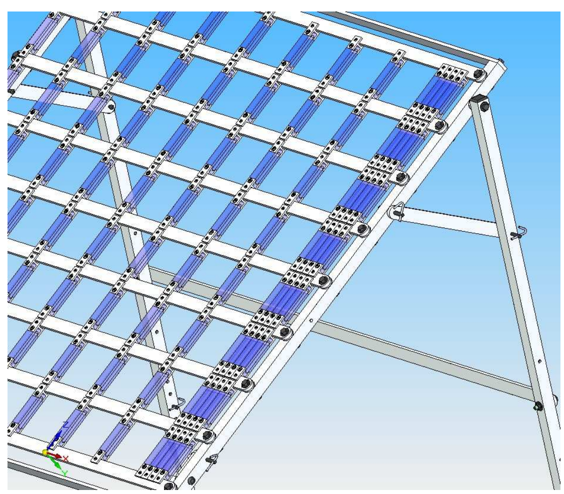


Figure 4: New Design

The original concept had four removable legs that when assembled stood at a 90 degree angle from the ground. The legs on the final concept do not need to be removed for transportation. Each leg is able to be folded into the main frame structure and then pinned to the frame to prevent unwanted movement. When unfolded, the legs will be pinned at a 75 degree angle from the ground for added stability.

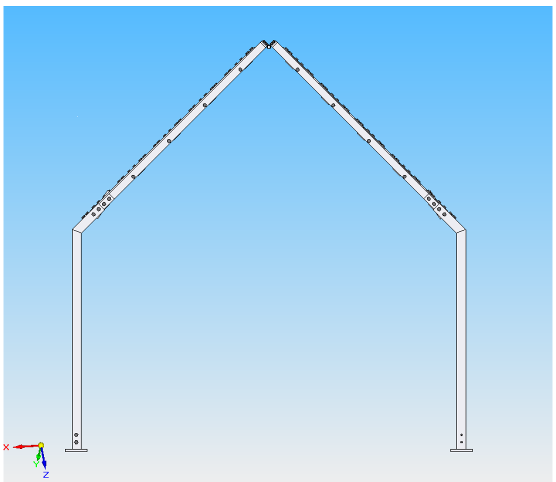


Figure 5: Old Concept

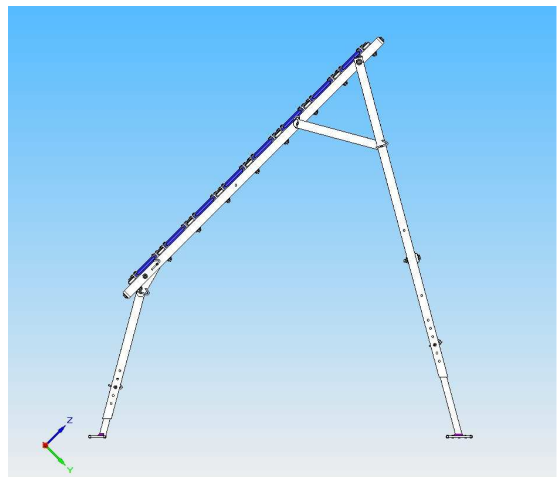


Figure 6: New Design

In order to allow the coupons to be completely insulated from any metal and for manufacturability concerns, the coupon retainers were altered. Previously, the coupon retainer consisted of an aluminum shaft on which channeled PTFE pieces were mounted to hold the coupons. The final retainer mechanism consists of a solid piece of PTFE that channels are machined out of in order to hold the coupons. The solid piece of PTFE is then held to the cross bars by an aluminum H-bar. The retainer will be bolted to the H-bar and the H-bar will then be held onto the cross bar through the use of set screws. Please refer to Figures 7 and 8.

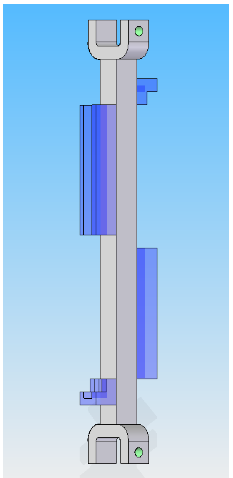


Figure 7: Old Concept

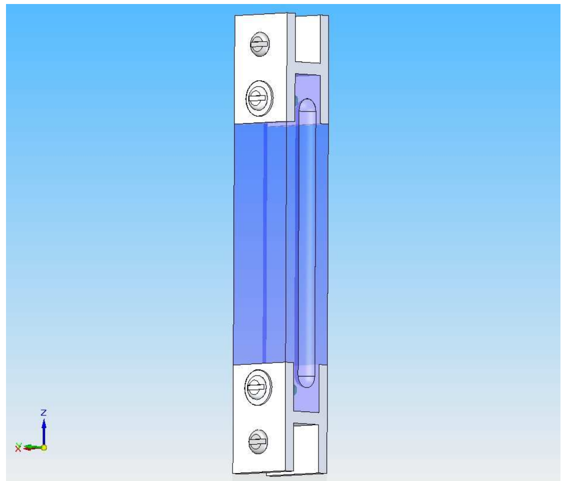


Figure 8: New Design

Product Presentation

a. Material Selection:

When selecting which materials should be used, there are several key factors that must be considered. Of these are environmental corrosion, galvanic corrosion, strength, and the materials weight. The failure of one of these topics will greatly affect each of the other topics being examined, which in return could result if product failure.

Environmental corrosion plays a significant role in the life of the product. If environmental corrosion begins to occur, the materials strength is impaired which could lead to fatigue failure. As described in the initial requirements, the material must be UV resistant, withstand a temperature range of -35 to 60°C, resistant to rain, resistant to salt or chloride exposure, and resistant to H_2S (Hydrogen Sulfide). An additional factor to consider when selecting materials was the possibility of galvanic corrosion occurring between different types of materials.

The materials strength and weight are also key elements that must be considered when selecting which materials should be used. It was initial decided that the completed assembly, without test coupons, must weigh no more than 70 pounds. Also, when loaded with coupons, the completed assembly must be able to withstand winds up to 74 mph. With this being said, the materials selected must be light weight while at the same time be relatively strong.

After taking all of these key factors into account, it was first decided to use 18-8 stainless Steel for all of the hardware used to assemble the product due to its excellent corrosion resistance. It was decided to use 18-8 stainless steel hardware instead of 316 stainless steel hardware in order to minimize the number of different materials that will be in contact once the product is assembled, and also since the clevis pins were only offered in 18-8 Stainless Steel from our supplier. After researching the galvanic corrosion of various combinations of materials with 18-8 Stainless Steel, it was determined that 6061 Aluminum would be our best choice for the structural members of our product. The 6061 Aluminum Alloy has exceeds our requirements for corrosion resistance, strength, and weight, as well as having a fair machinability aspect. In addition to using 6061 Aluminum as the structural material, it was also decided that the aluminum will be anodized with chromate coating to help reduce the rate of environmental corrosion.

The final decision to be made was the selection of a material to isolate the test coupon from metallic surfaces. In addition to the previously listed requirements, this material must also be an electronic insulator. It was determined that there are numerous types of materials that would fulfill our desires such as UNICAR (Polycarbonate), ULTEM (Polyethermide), VHMW (Polyethylene), and PTFE (Polytetrafluoroethylene) or most commonly known by the DuPont brand name Teflon. Upon further research and consulting with several material engineering professors at Auburn University, it was determined that PTFE, or Teflon, would be the best material for our application. PTFE experiences little to no corrosion due to environmental exposure, as well as salt or chloride exposure. This material was also chosen due to the fact that PTFE experience no galvanic corrosion with metallic materials. This will be a great asset to our product as that the test coupons will not adhere to the PTFE coupon retainer bar when corrosion of the test coupon occurs.

b. Requirement fulfillment:

- Requirements:
  - Light weight
  - Easily assembled/disassembled
  - Coupon insulated from rack
  - Coupon must be at a forty-five degree angle
  - Rack must be corrosion resistant
  - Hold fifty coupons
  - Exposed to three different environments
  - Cost less than three thousand dollars

The final design must not weigh more than 100 pounds completely loaded with coupons. This weight requirement is in effect to allow easy transportation of the structure by one person, if necessary. Also, low weight translates to low shipping costs. The design incorporates 56 coupons, 6 more than the minimum 50 coupon requirement, weighing roughly 30 pounds total. Therefore, the design structure itself cannot exceed 70 pounds. This requirement was accomplished by choosing lightweight materials, such as aluminum 6061, and eliminating unnecessary parts and fasteners. Using these criteria throughout the evolution of the project, we were able to successfully design a structure that meets all of the requirements with a maximum weight of 70 pounds, fully loaded with 56 3 in. by 5 in. steel coupons.

The final design must be easily assembled and disassembled. Also, the structure must be able to fit in the back of a standard pickup truck for ease of transportation. These requirements were achieved by designing the corrosion rack to be completely assembled before it is shipped out to the field. No special tools or skills are required to assemble the structure in the field, and a two-person team could easily set up the corrosion rack. All that is required during the set-up process is to remove pins and replace them in different locations to lock the structure in place. All welding and soldering will be completed before the product is shipped. The entire setup process can be completed in less than ten minutes, which is considerably less than the one hour requirement. Finally, holes have been designed into the feet of the corrosion rack to allow the structure to attach to various surfaces such as undeveloped earth, posts, or existing structures.

The coupons must be insulated from the rack. Also, the rack must be corrosion resistant within the three specified environments and held at a 45 degree angle to obtain optimum corrosion test results. The coupons themselves are only in contact with a housing of polytetrafluoroethylene (PTFE), which does not exhibit any behavior in the form of galvanic corrosion. Therefore, they are completely insulated from the corrosion rack, which is mainly composed of aluminum. To prevent galvanic corrosion, the number of dissimilar metal contact points was limited to fasteners only. For example, all structural members are composed of the same material to nullify galvanic corrosion. However, the fasteners were chosen to be stainless steel which would be in contact with the aluminum members. Fortunately, it was discovered that the galvanic corrosion between stainless steel and aluminum would be negligible for the purposes of this project. To further aid in the resistance of corrosion, the entire structure will be anodized with a chromate coating. The material selection process revealed that this combination of materials and coatings was optimal for corrosion resistance due to galvanic corrosion, UV rays, humidity, marine atmospheres and industrial atmospheres. Also, the materials were selected because of their favorable resistance to extreme temperature between -35 °C and 60 °C. These are the types of environments that were determined to be involved at the following three locations: Cape Canaveral, CTC Arizona, and Test Stand E at Redstone Arsenal. Further, the design is required to withstand the winds of a category 1 hurricane (74 mph winds at the Cape Canaveral location). Extensive FEA work was completed to ensure that the structure will be able to withstand the extreme loads that would accompany winds of such magnitude. Next, the design is intended to have a seven-year life expectancy. It will be one-year maintenance free with a 3.5 year planned maintenance overhaul. Finally, the rack is fixed at a 45 degree angle to meet the corresponding requirement.

Lastly, the entire structure will cost $2,937.01. This includes the cost of all materials and the anodizing of the parts. The costs also include the purchasing of machine tools such as drill bits and taps. The cost for tooling is estimated to be around $1,097.77. This cost is under the $3,000.00 maximum requirement and proves to be a cost-effective design.

c. Method of Use:

The test stand was designed in order to allow two people to carry and set up on location. The legs fold into and are pinned to the frame. One at the location, each leg can be unpinned from the frame, folded out, and pinned into position to erect the stand. Each leg is adjustable, so that the test stand can be set up on uneven ground. Once erected, attaching the coupons is achieved through the use of adjustable coupon retainers and set screws. Each coupon will be inserted one at a time, and the coupon retainers will be adjusted to hold the coupon securely and then locked in place with set screws located at the top and bottom. In order to allow the removal of one coupon without being required to remove an entire row, you can slide an extra coupon retainer over to allow a break in the chain and therefore individual removal.

d. Design Considerations:

-Environmental

The chromate the coating used to anodize the aluminum is environmentally safe. The material used to insulate the coupons, PTFE, is a non-toxic, FDA approved material which will not have any harmful environmental effects. In operation, the test stand has no potentially harmful emissions.

-Sustainability

The test stand is designed for a useful life of seven years. In order to achieve this life we had to take into account many different factors during the design phase. The maintenance plan for this unit is one year maintenance free with a three and a half year maintenance schedule. At the scheduled maintenance time, the unit will be visually inspected, with a focus on the PTFE coupon retainers. After inspection, the unit will be repaired as needed. Examples of repairs which may be needed include but are not limited to: tightening or replacement of bolts, pins, nuts, washers, set screws and PTFE coupon retainers. In order to reduce corrosion and wear on the unit the test stand was designed with minimal parts. The frame consists of aluminum 6061 or 6063, which will be coated with a chromate coating in order to prevent any corrosion. Stainless steel bolts are used because of the similarity of the metals which reduces the amount of galvanic corrosion between the dissimilar metals.

-Manufacturability

All aluminum parts will be ordered to length. Once received bolts holes will be drilled and rounds will be added if needed. The PTFE coupon holders will be manufactured from a solid piece of PTFE. The coupon holders will be cut to length and then will be machined to the specified dimensions. Welds are only needed for the attachment of the feet. This ensures that the outsourcing of the weld job will not interfere with any other manufacturing processes. All manufacturing processes and assembly excluding welding and anodizing will be completed at Auburn University in the Design and Manufacturing Laboratory and Mechanical Engineering Project Room.

-Ethical

Failure of the test stand will not result in loss of human life or significant loss of property. To the best of our knowledge no one objects to the eradication of corrosion.

-Health and Safety

The test stand is designed with safety in mind. Any potentially dangerous corners or sharp edges are rounded to prevent injury. The stand is light which will prevent personnel injury during set up and tear down. All materials and coatings are non-toxic and safe for individual use.

-Social and Political

The test stand will aid in both social and political aspects. The stand will be used to determine better corrosion coatings for use by the Department of Defense, specifically the U.S. Army Aviation and Missile Command. Corrosion losses cost the U.S. government billions of dollars per year, and the development of a better corrosion test stand will aid in lowering this expense. As the motto of the U.S. Army Aviation and Missile Command's corrosion prevention division states, "When corrosion wins, the mission fails."

Engineering Analysis

a. FBD

The use of engineering analysis will ensure that the structure will not fail under the designed load. The analysis will include both hand and computer calculations where they can be compared for accuracy. The components of the design are attached using bolts. All the loads on the assembly will have to flow through the bolts. Therefore, the calculations of the forces need to be determined for each part of the assembly.

The analysis begins at the coupon and the weights and forces will trickle down the entire assembly. The coupons are held up by the PTFE coupon retainers. Since the coupons are at a forty-five degree angle, they will rest on the PTFE coupon retainers. The H-brackets hold the PTFE pieces to the coupon rail (1x.25x48.5in bar). There will be a total of nine loaded PTFE coupon retainers on the coupon rack bar. In order to engineer for the worst case scenario, all the members will be assumed to be a cantilever. A cantilever is a beam that is supported at one side. This will also allow for statically determinate solutions in the analysis. The side bars (1x1x48.5in) will hold the eight coupon rails in place. The front and rear legs will hold the two side bars in place. To account for the worst case scenario, all of the components of the analysis will undergo a cantilever setup where the entire load is on one side of the part. This will create a two component reaction and its corresponding moment.

Once the hand calculations are complete, a list of forces on each of the members of the assembly can be found. Please refer to Appendix C in the Final Report from Senior Design I for the hand calculations. A summary of the component forces can be found in Table 1. The bolt calculations can be calculated from the forces in the members. A calculation of the maximum shear and tensile stress in the bolts will be completed and analyzed to ensure that the bolts will not fail under a normal condition. A summary of the shear stress on the bolts can be found in Table 2, and a summary of the tensile stresses in the bolts can be found in Table 3.

Table 1: Component forces of parts in assembly

Part Name	Force	Units	Comments
Coupon			
F1	0.177	lb	F=Force
F2	0.177	lb	
PTFE			
F3x	0	lb	
F3z	0.62	lb	
M3	0.658	in lb	M=Moment
PTFE Assembly			
F4x	0	lb	
F4z	0.62	lb	
M4	0.878	in lb	
Coupon Rail			1x.25x48.5in
F5x	0	lb	
F5z	3.38	lb	
M5	4.2	in lb	
Side Bar			1x1x42in
F9x Rear	0	lb	
F9z Rear	34.42	lb	
M9	548.8	in lb	
Rear Leg			
F10x	165.73	lb	
F10z	80.5	lb	
F11	171.6	lb	No bolt Load
Inner Rear Leg			
F12x	0	lb	
F12z	36.45	lb	
M12	969	in lb	
Front Leg			
F13x	162.9	lb	
F13z	78.813	lb	
F14	168.6	lb	No bolt Load
Inner Front Leg			
F15x	0	lb	
F15z	35.4	lb	
M15	738.6	in lb	

~~Part Name~~	~~Force~~	~~Units~~	~~Comments~~
~~**Coupon**~~	-	-	-
~~F1~~	~~0.177~~	~~lb~~	~~F=Force~~
~~F2~~	~~0.177~~	~~lb~~	-
~~**PTFE**~~	-	-	-
~~F3x~~	~~0~~	~~lb~~	-
~~F3z~~	~~0.62~~	~~lb~~	-
~~M3~~	~~0.658~~	~~in lb~~	~~M=Moment~~
~~**PTFE Assembly**~~	-	-	-
~~F4x~~	~~0~~	~~lb~~	-
~~F4z~~	~~0.62~~	~~lb~~	-

~~M4~~	~~0.878~~	~~in-lb~~	~~-~~
~~**Coupon Rail**~~	~~-~~	~~-~~	~~1x.25x48.5in~~
~~F5x~~	~~0~~	~~lb~~	~~-~~
~~F5z~~	~~3.38~~	~~lb~~	~~-~~
~~M5~~	~~4.2~~	~~in-lb~~	~~-~~
~~**Side Bar**~~	~~-~~	~~-~~	~~1x1x42in~~
~~F9x Rear~~	~~0~~	~~lb~~	~~-~~
~~F9z Rear~~	~~34.42~~	~~lb~~	~~-~~
~~M9~~	~~548.8~~	~~in-lb~~	~~-~~
~~**Rear Leg**~~	~~-~~	~~-~~	~~-~~
~~F10x~~	~~165.73~~	~~lb~~	~~-~~
~~F10z~~	~~80.5~~	~~lb~~	~~-~~
~~F11~~	~~171.6~~	~~lb~~	~~No bolt Load~~
~~**Inner Rear Leg**~~	~~-~~	~~-~~	~~-~~
~~F12x~~	~~0~~	~~lb~~	~~-~~
~~F12z~~	~~36.45~~	~~lb~~	~~-~~
~~M12~~	~~969~~	~~in-lb~~	~~-~~
~~**Front Leg**~~	~~-~~	~~-~~	~~-~~
~~F13x~~	~~162.9~~	~~lb~~	~~-~~
~~F13z~~	~~78.813~~	~~lb~~	~~-~~
~~F14~~	~~168.6~~	~~lb~~	~~No bolt Load~~
~~**Inner Front Leg**~~	~~-~~	~~-~~	~~-~~
~~F15x~~	~~0~~	~~lb~~	~~-~~
~~F15z~~	~~35.4~~	~~lb~~	~~-~~
~~M15~~	~~738.6~~	~~in-lb~~	~~-~~

Table 2: Shear forces on bolts under normal load

Part Name	Bolt Load	Total Force	Shear Stress	units	Factor of Safety
PTFE	F3	0.62	25.99580713	psi	1616
PTFE Assembly	F4	0.62	25.99580713	psi	1616
Coupon Rail	F5	3.38	141.7190776	psi	296
Side Bar	F9	34.42	1443.186583	psi	29
Rear Leg	F10	184.2462561	3862.60495	psi	11
Front Leg	F13	180.9638057	3793.790476	psi	11

Table 3: Tensile forces on bolts under normal load

Part Name	Bolt Load	Total Force	Shear Stress	units	Factor of Safety
PTFE	F3	0.62	77.98742138	psi	898
PTFE Assembly	F4	0.62	77.98742138	psi	898
Coupon Rail	F5	3.38	425.1572327	psi	165
Side Bar	F9	34.42	4329.559748	psi	16
Rear Leg	F10	184.2462561	23175.6297	psi	3
Front Leg	F13	180.9638057	22762.74286	psi	3

From the tables, all the bolts will not shear under the normal load. This is encouraging, and it ensures that the assembly will not fail from shearing in the bolts.

b. FEA

The use of finite element analysis will be used to analyze the behavior of the parts of the assembly. The forces have already been calculated and can be input into the computer. The parts of the assembly have been created in Solid Edge where they can be transferred to Algor (FEA software). The loads can be applied to the parts and the resulting displacement and stresses can be found. From the computer calculations, there will be minimal displacement in the members under normal load. Please refer to Figures 9-16 for a summary of the results of the FEA software. Under the normal loads, the assembly will not be under any significant displacement or stresses. The maximum displacement was in the rear leg and was .5 inches. In figure 12, analytical calculations were performed to find the displacement of the coupon rail. Comparing the graph with the FEA, the results are very similar which validates the FEA results.

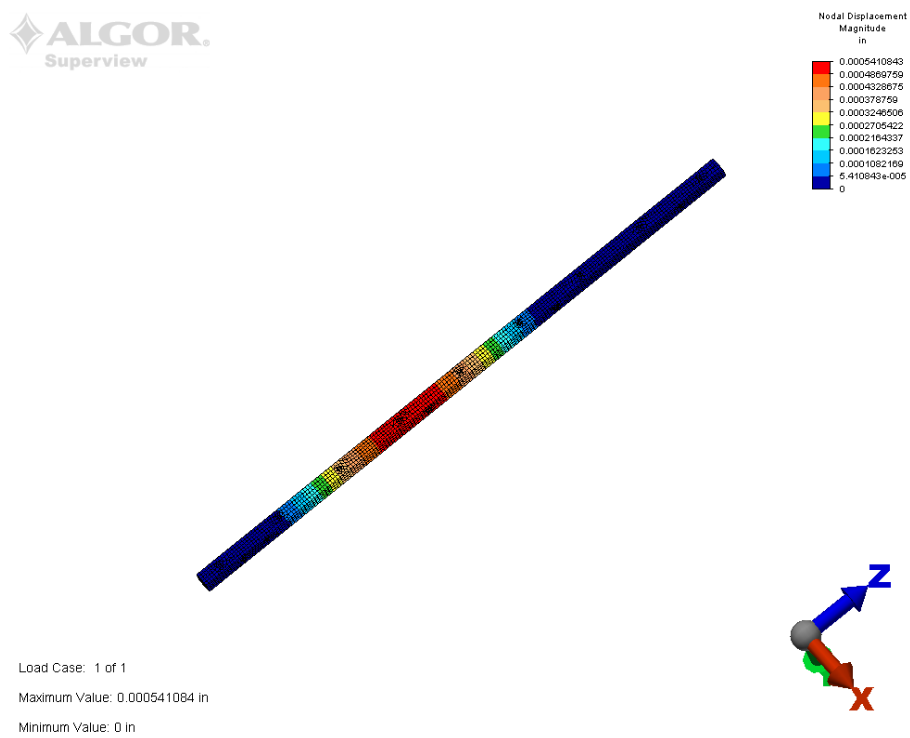


Figure 9: Displacement of side bar (1x1x42in) under normal load

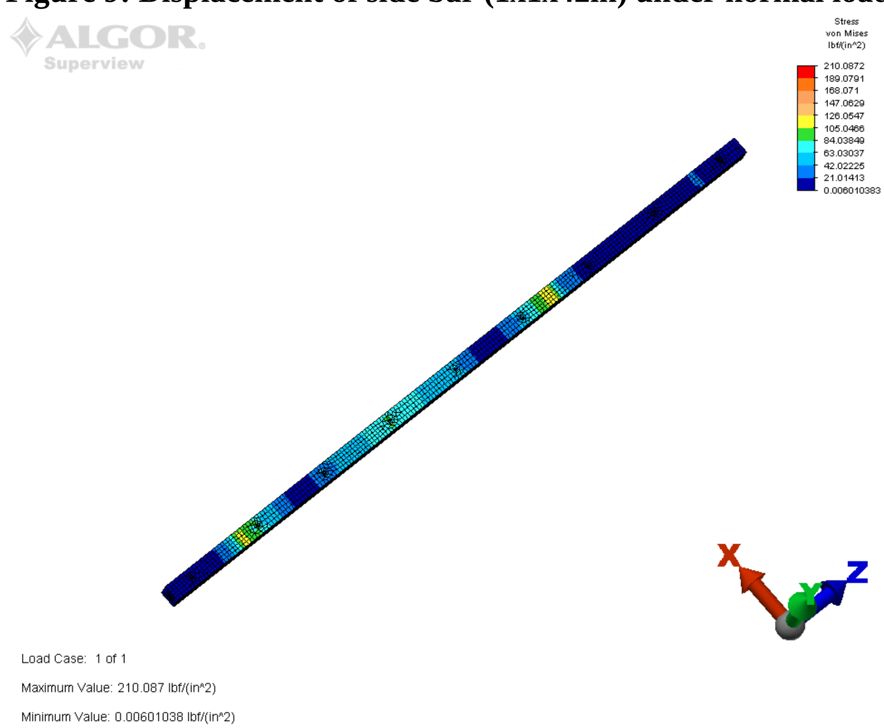


Figure 10: Stress of side bar under normal load

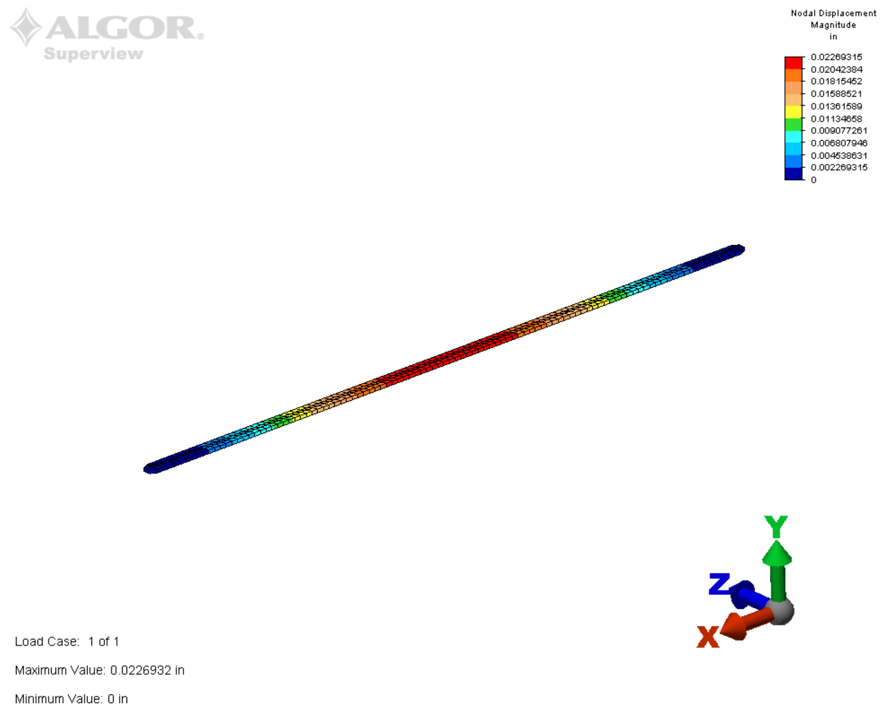


Figure 11: Displacement of coupon rail under normal load

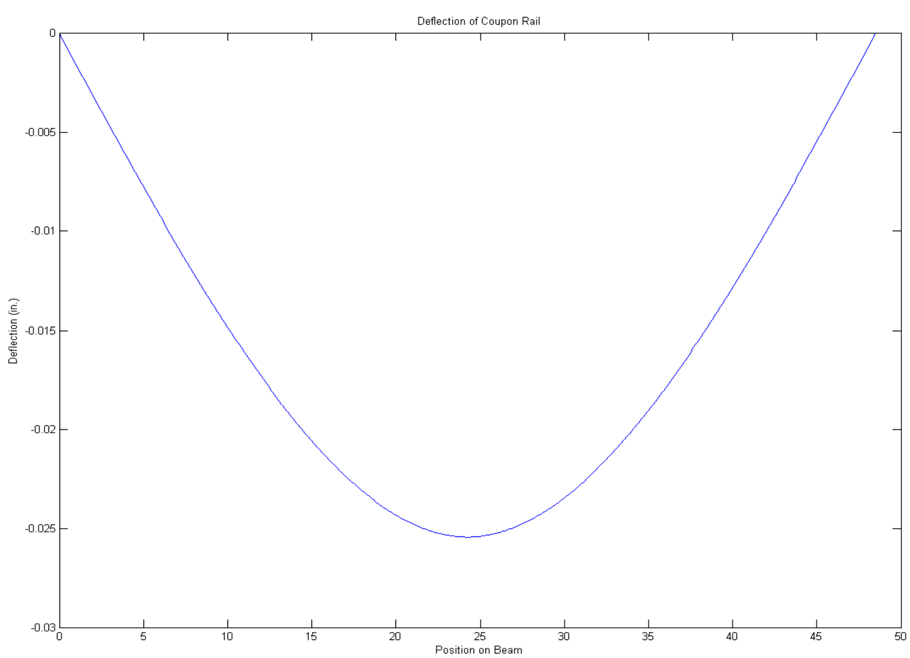


Figure 12: Analytical results for displacement of coupon rail under normal load

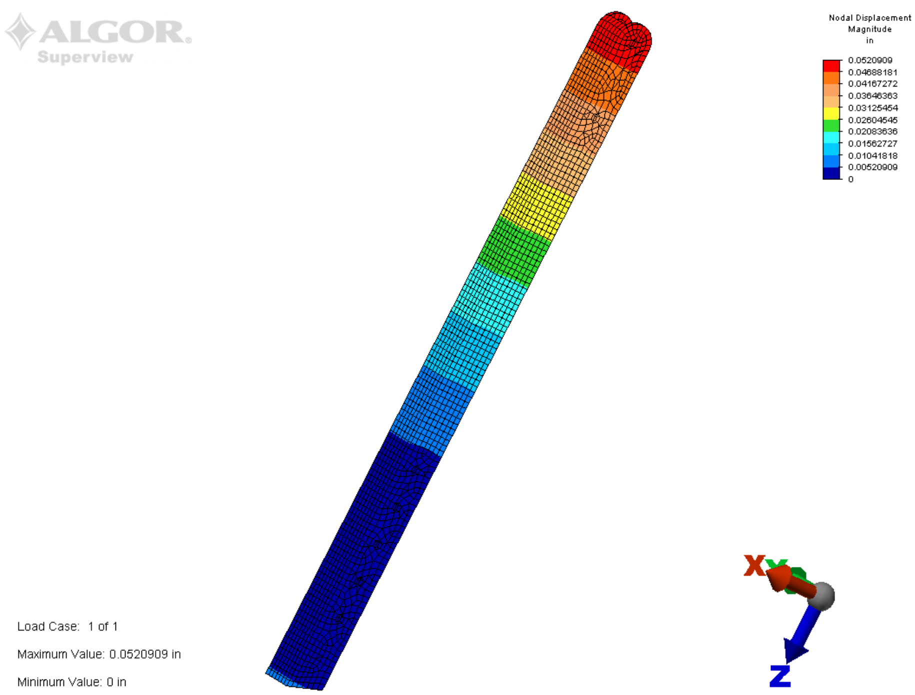


Figure 13: Displacement of front leg under normal load

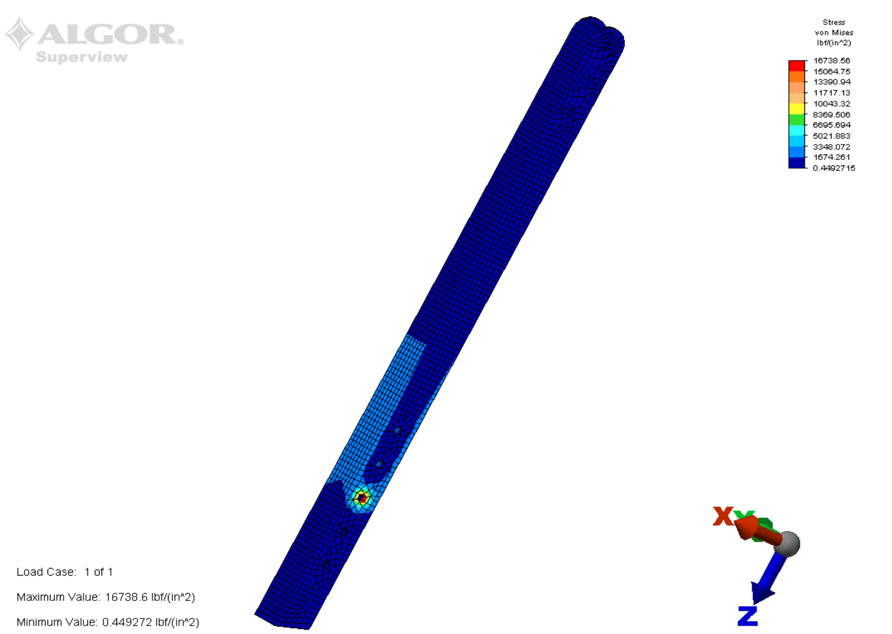


Figure 14: Stress of front leg under normal load

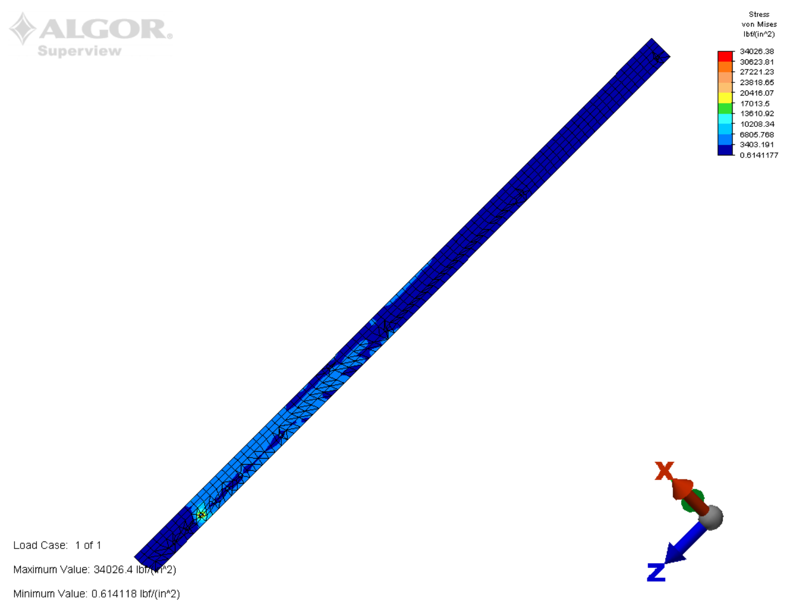


Figure 15: Stress of rear leg under normal load

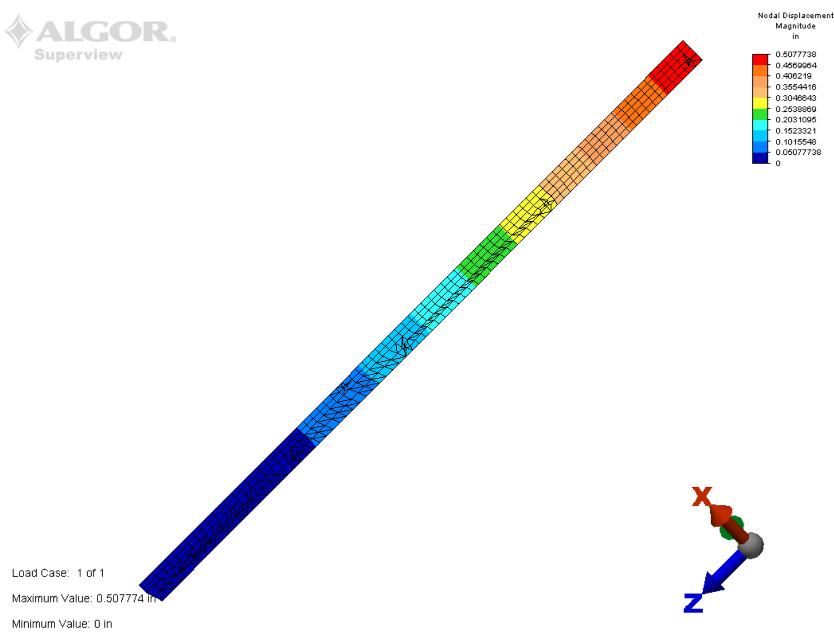


Figure 16: Displacement of rear leg under normal load

c. Wind Load Analysis

One of the requirements of the design is that the assembly can withstand a 75 mph wind load. Please review Appendix D from the Final Report from Senior Design I. for a more clear understanding of the engineering analysis that went into the wind calculation. Simple fluid calculations reveal that the force on each coupon will be around 42 lbs. This sums into 1,176 lbs of wind on the entire assembly. Using the same methods in the previous section, the component forces in each part can be found. A summary of the component forces can be found in Table 4. The bolt calculations can be calculated from the forces in the members. A calculation of the maximum shear and tensile stress in the bolts will be completed and analyzed to ensure that the bolts will not fail under the worst case scenario. A summary of the shear stress on the bolts can be found in Table 5, and a summary of the tensile stresses in the bolts can be found in Table 6.

Table 4: Component forces of parts in assembly given worst case scenario

Coupon			
F1	15	lb	F=Force
F2	15	lb	
PTFE			
F3x	0	lb	
F3z	42.54	lb	
M3	58.8	in lb	M=Moment
PTFE Assembly			
F4x	0	lb	
F4z	42.54	lb	
M4	60.2	in lb	
Coupon Rack Bar			1x.25x48.5in
F5x	0	lb	
F5z	192	lb	
M5	287.8	in lb	
Side Bar			1x1x42in
F9x Rear	588.15	lb	
F9z Rear	414	lb	
F9x Front	1002	lb	
F9z Front	803	lb	
Rear Leg			
F10x	479.2	lb	
F10z	701.7	lb	
F11	1105	lb	No bolt Load
Front Leg			
F13x	207.13	lb	
F13z	590	lb	
F14	823.18	lb	No bolt Load

Table 5: Shear forces on bolts given worst case scenario

Part Name	Bolt Load	Total Force	Shear Stress	units	Factor of Safety
PTFE	F3	42.54	1,783.65	psi	24
PTFE Assembly	F4	42.54	1,783.65	psi	24
Coupon Rail	F5	192	8,050.31	psi	5
Side Bar Rear	F9 Rear	719.247122	30,157.11	psi	1
Side Bar Front	F9 Front	1300	54,507.34	psi	1
Rear Leg	F10	849.71497	17,813.73	psi	2
Front Leg	F13	625.302196	13,109.06	psi	3

Table 6: Tensile forces on bolts given worst case scenario

Part Name	Bolt Load	Total Force	Tensile Stress	units	Factor of Safety
PTFE	F3	42.54	5,350.94	psi	13
PTFE Assembly	F4	42.54	5,350.94	psi	13
Coupon Rail	F5	192	24,150.94	psi	3
Side Bar Rear	F9 Rear	719.247122	45,235.67	psi	2
Side Bar Front	F9 Front	1300	81,761.01	psi	1
Rear Leg	F10	849.71497	53,441.19	psi	1
Front Leg	F13	625.302197	39,327.18	psi	2

The bolts will not fail under a wind load at 75 mph. This means that almost 1,200 lbs can be applied to the entire assembly, and the bolts will not fail.

FEA was also performed with the new forces on each of the members of the assembly. Please review Figures 17- 30 for all the FEA results. The results of the FEA show that there will be now permanent yielding in the parts of the assembly. The rear leg analysis was supported in two places to prevent permanent yielding. This can be done since the actual leg will be supported by a brace between the leg and the side bar. The greatest displacement was found in the front leg at a distance of 0.8 inches.

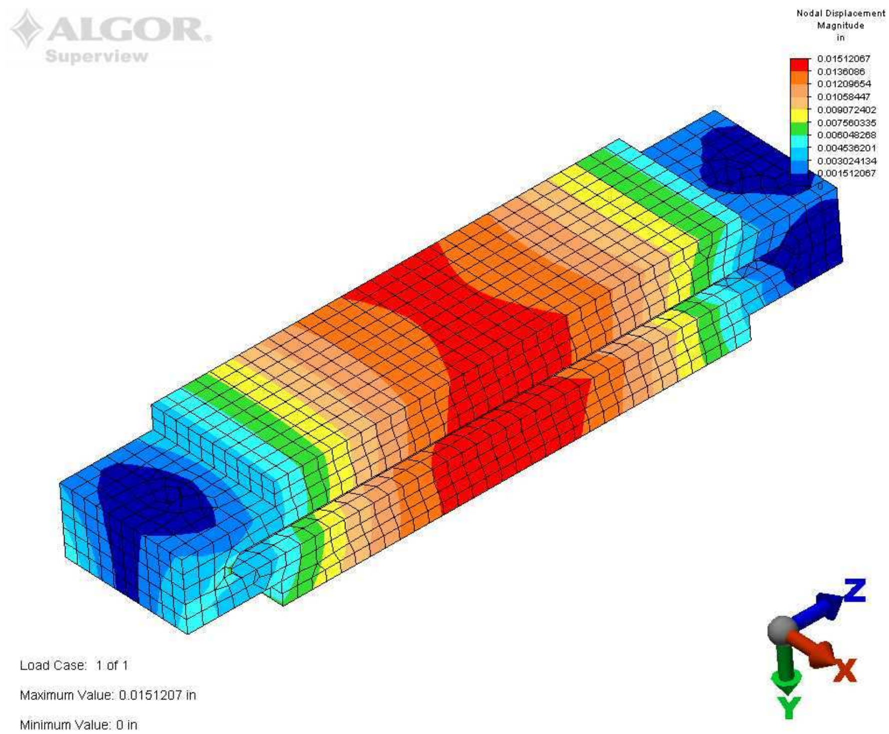


Figure 17: Displacement of PTFE given worst case scenario

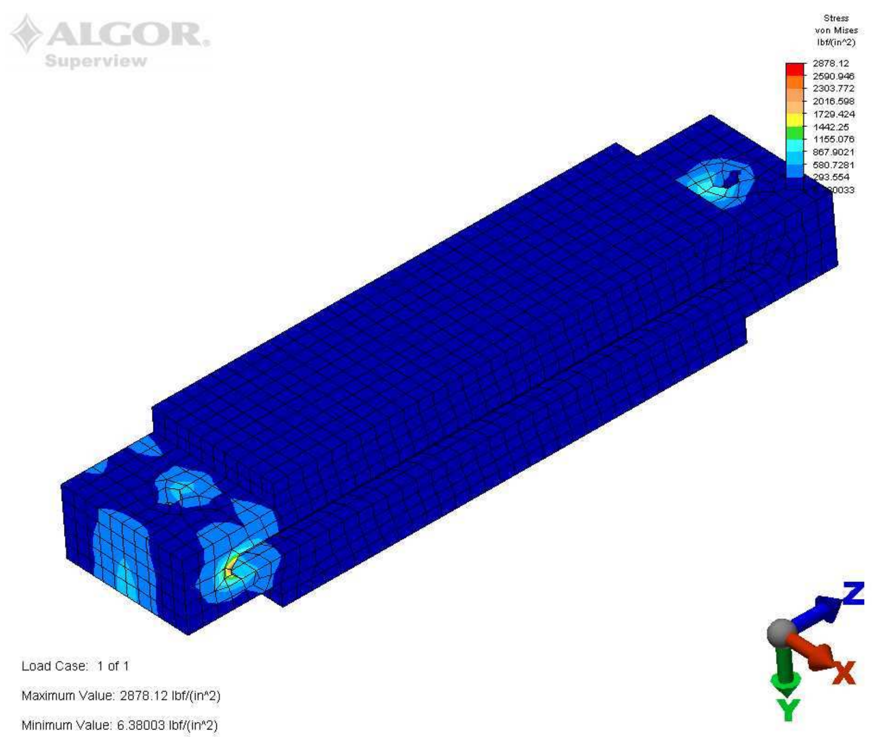


Figure 18: Stress of PTFE given worst case scenario

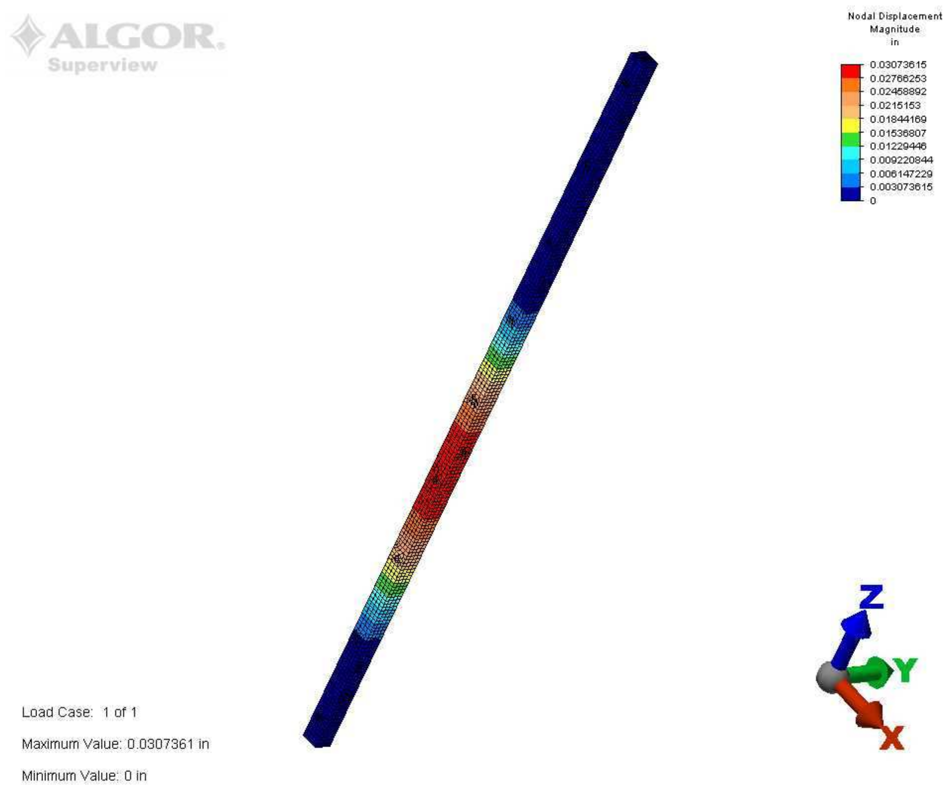


Figure 19: Displacement of side bar given worst case scenario

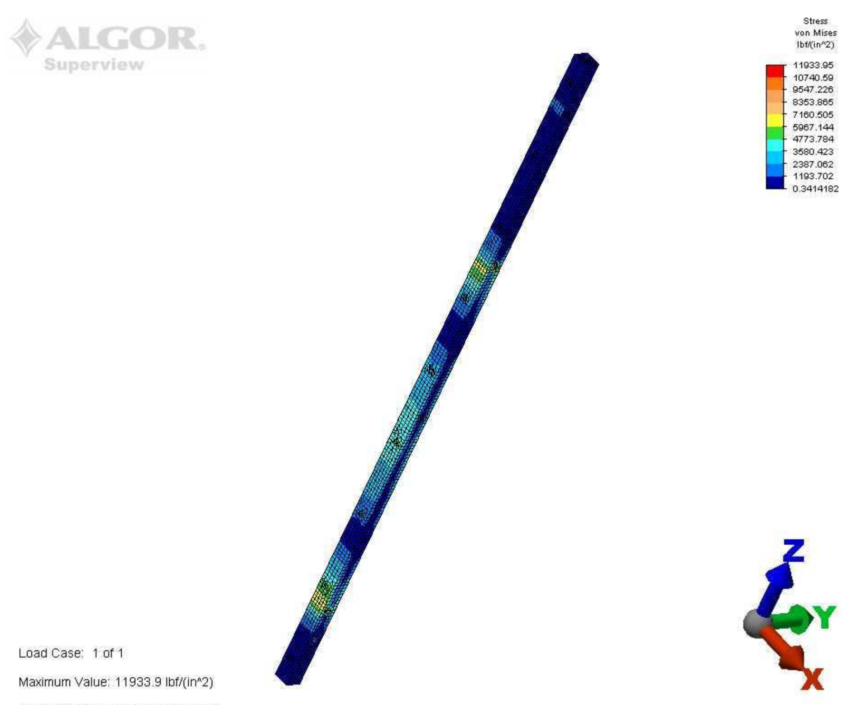


Figure 20: Stress of side bar given worst case scenario

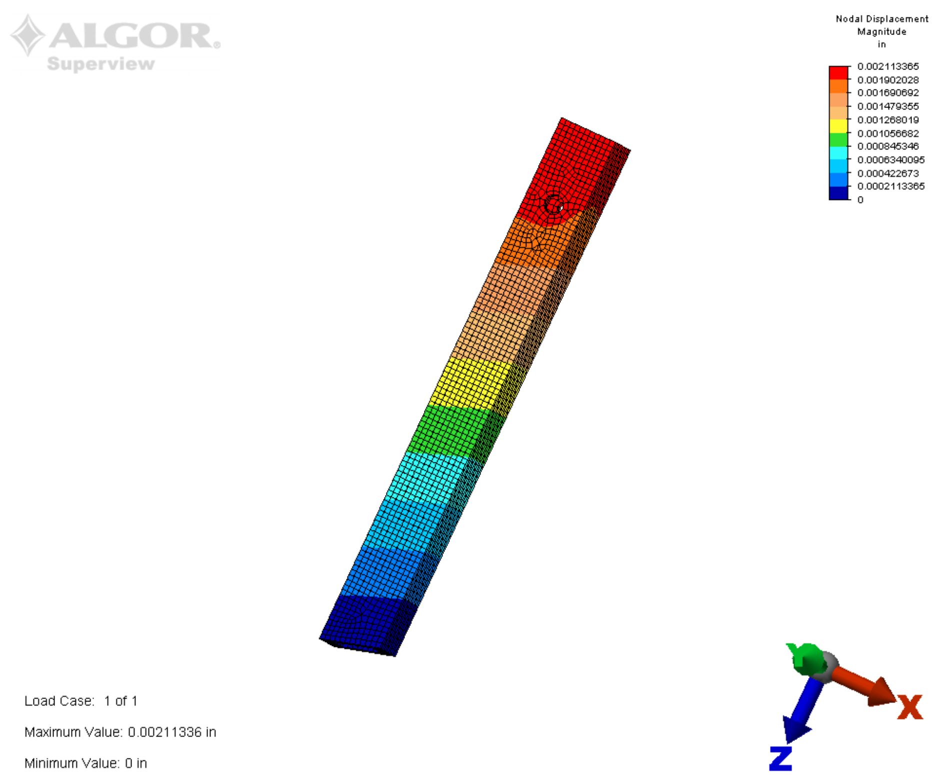


Figure 21: Displacement of front leg insert given worst case scenario

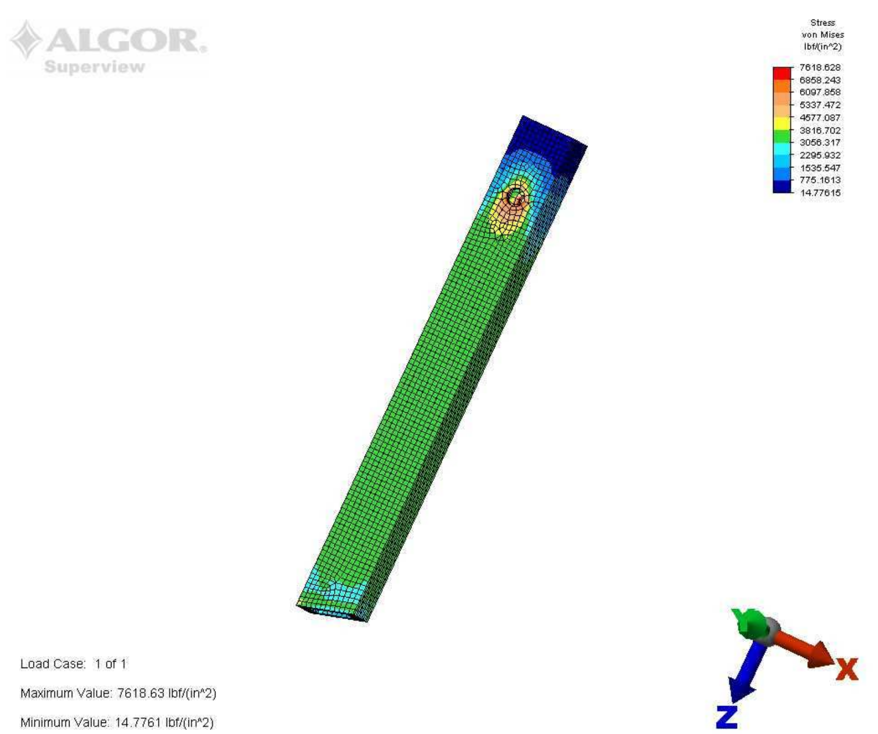


Figure 22: Stress of front leg insert given worst case scenario

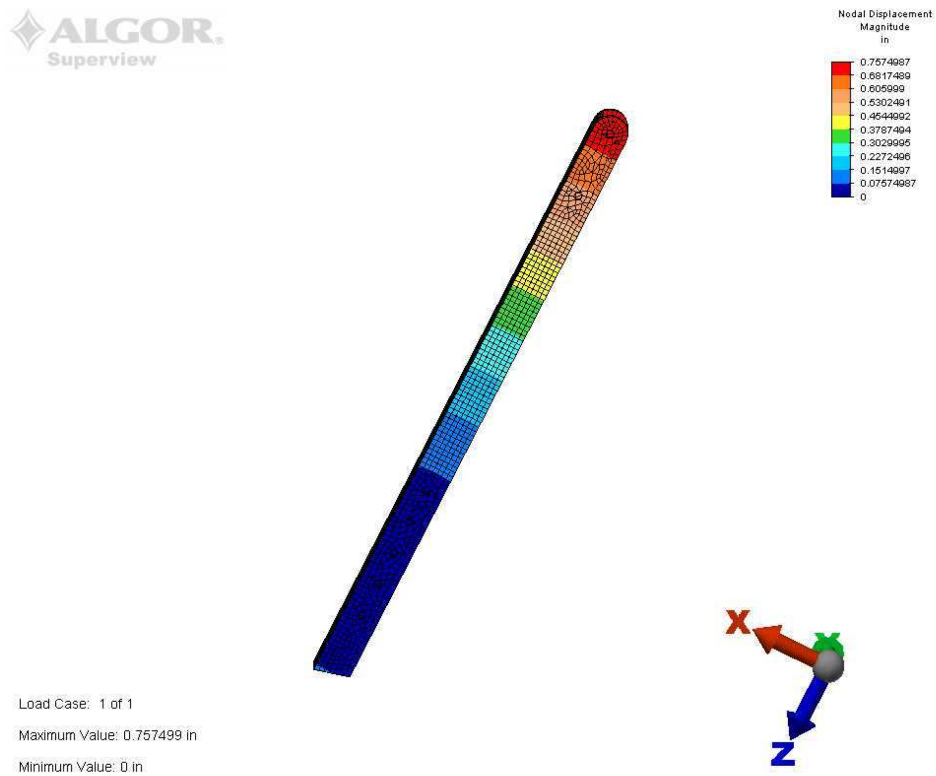


Figure 23: Displacement of front leg given worst case scenario

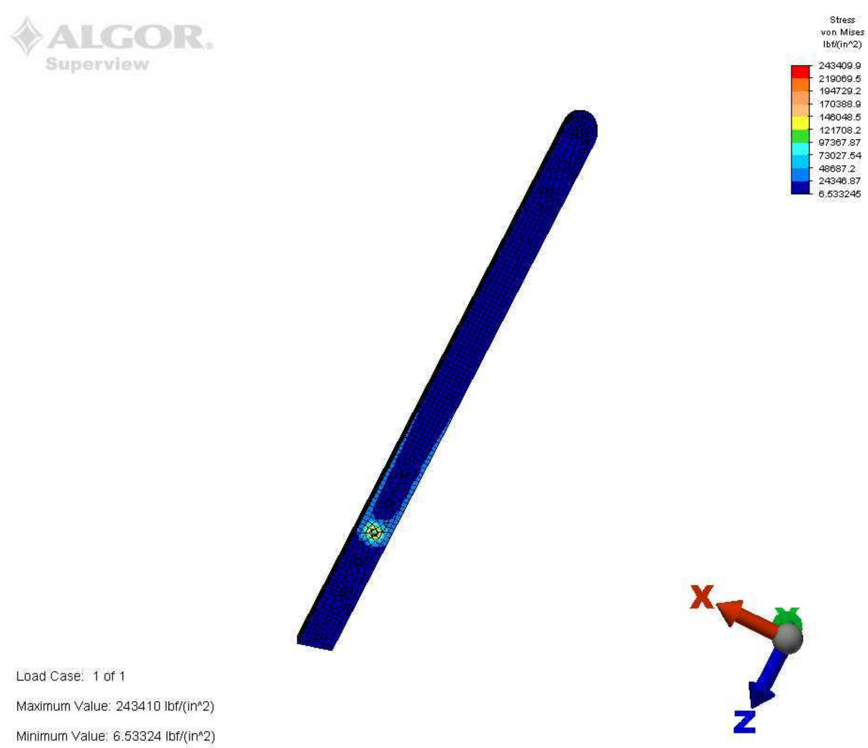


Figure 24: Stress of front leg given worst case scenario

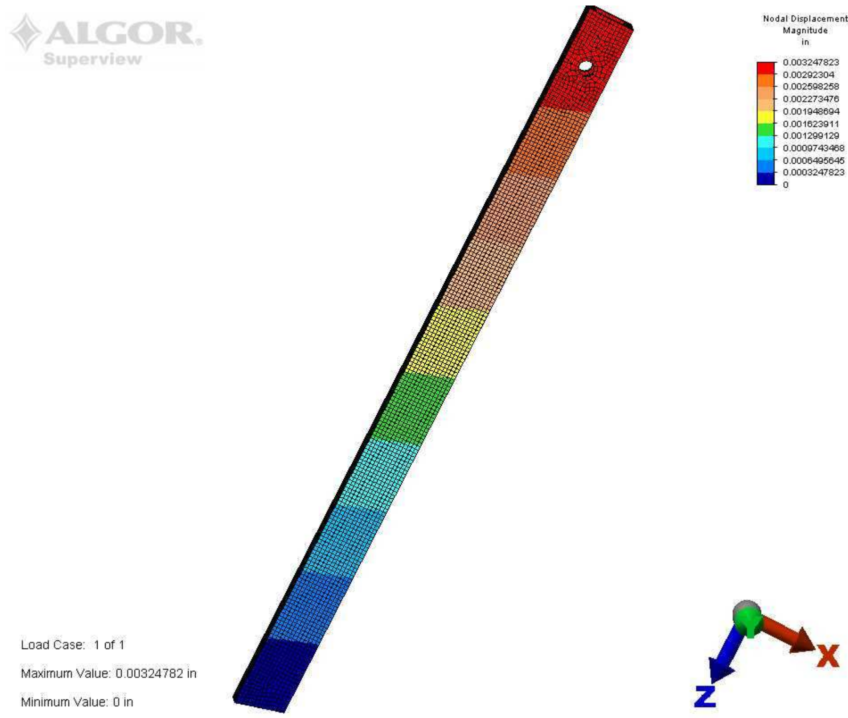


Figure 25: Displacement of rear leg insert given worst case scenario

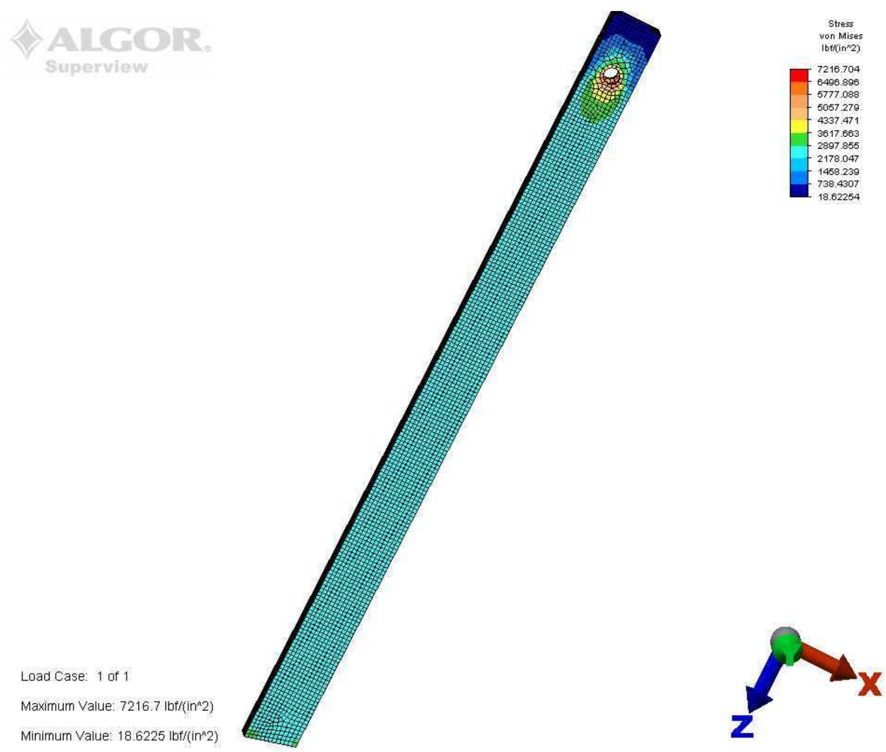


Figure 26: Stress of rear leg insert given worst case scenario

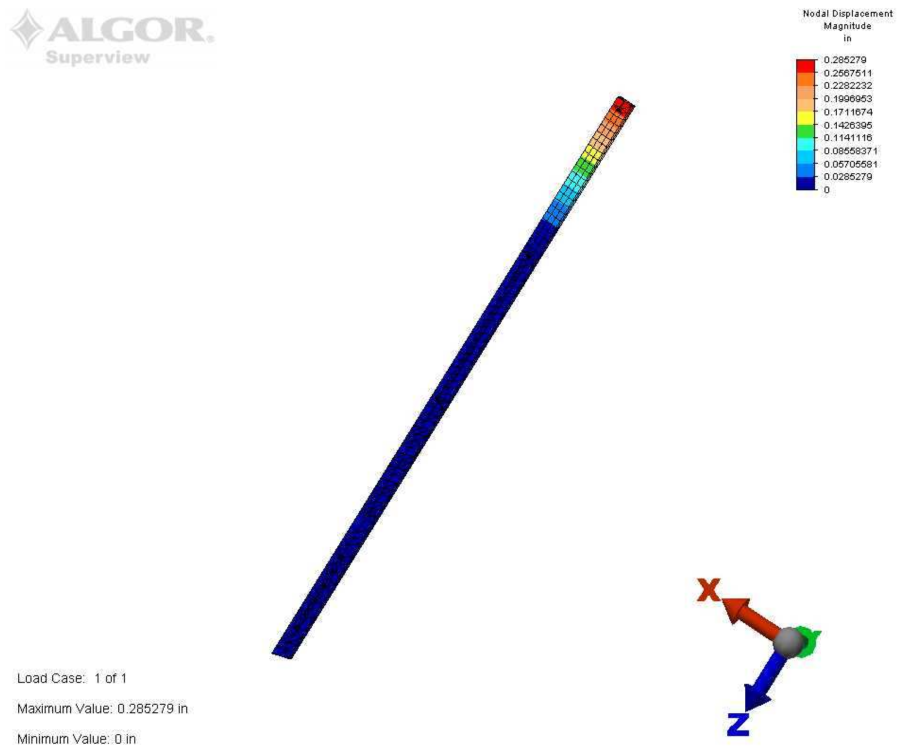


Figure 27: Displacement of rear leg given worst case scenario

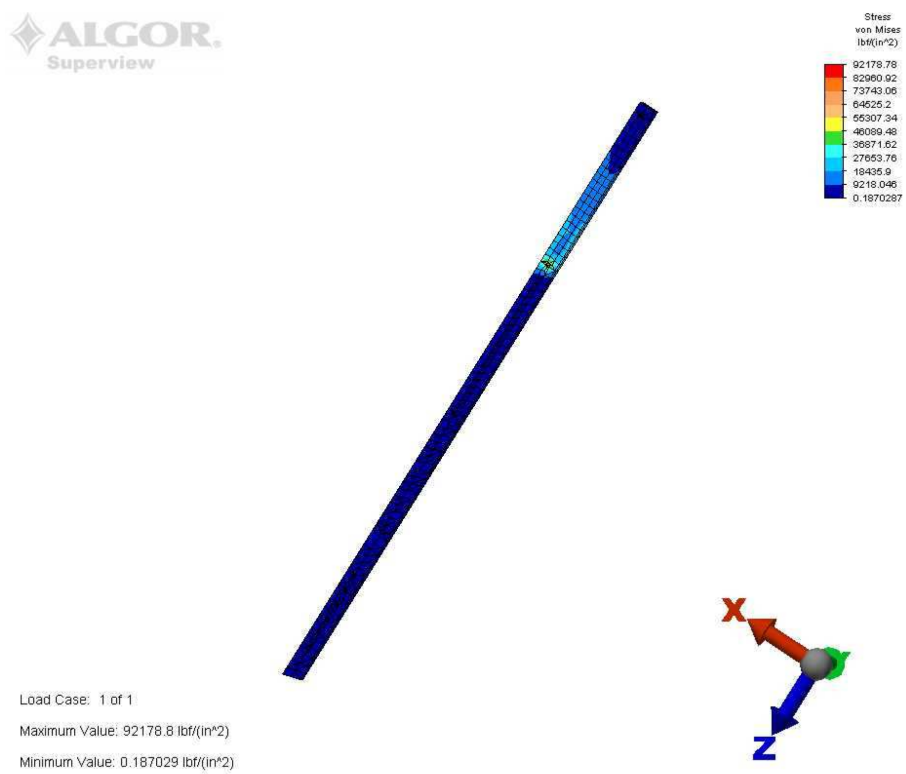


Figure 28: Stress of rear leg given worst case scenario

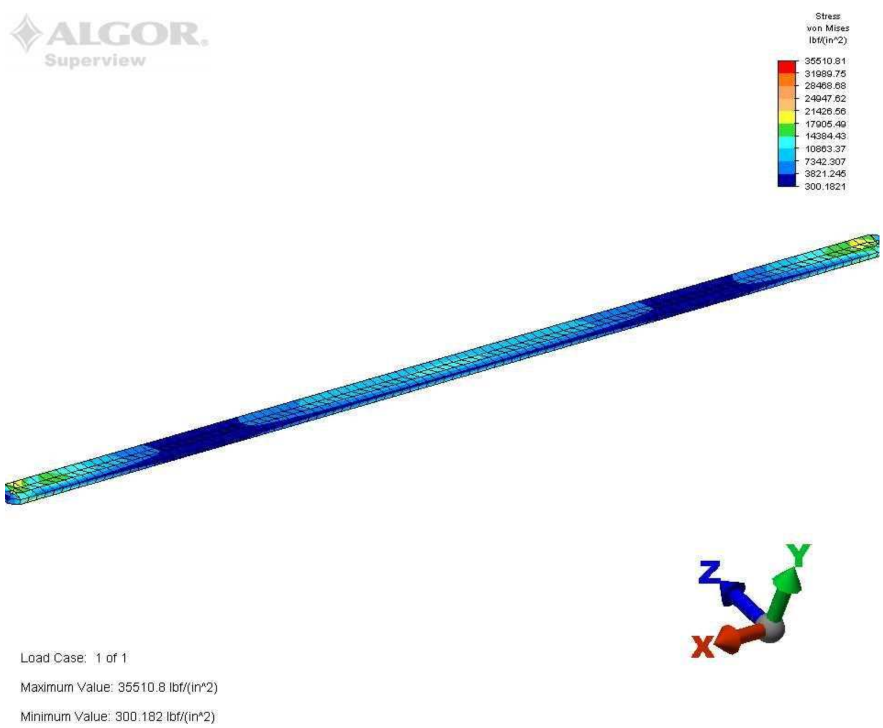


Figure 29: Displacement of side bar given worst case scenario

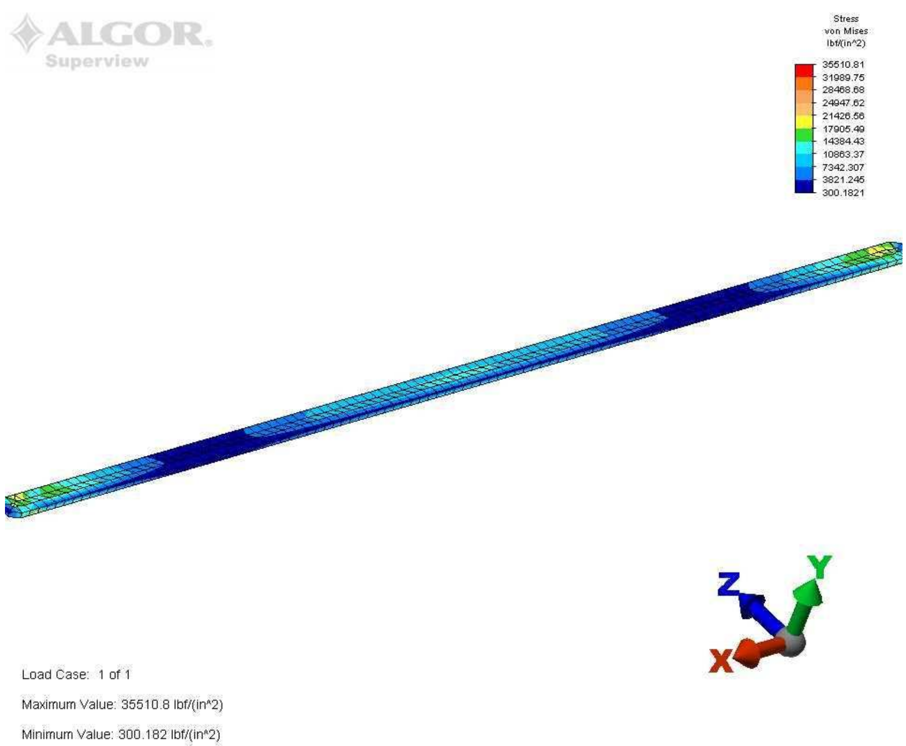


Figure 30: Stress of side bar given worst case scenario

Economic Analysis

The budget given to our group was $3000 to complete this project. The total cost of all our ordered materials and parts is approximately $2.037.01 (see Appendix B). Once receiving our materials, our group will do our own machining and part fabrication using the DML lab, cutting much of the labor cost of the project. We do, however, expect to outsource the task of completing three small welds to an external machine shop. This is also a minor cost which will easily be covered by our budget. Another cost is that of anodizing the aluminum. This is a cost that is undetermined at this time, but will not affect our group's ability to stay within the budget. Please refer to Figure 31 for a breakdown of the costs. The total cost of the corrosion test stand will be $2,937.01. Appendix B breaks down the costs of the materials and the tooling costs. The purchasing receipts from the project can be found in Appendix D.

Corrosion Test Stand Costs	
Materials	$ 939.24
Anodizing	$ 900.00
Machine Tools	$1,097.77
Total	$2,937.01

Figure 31: Corrosion Test Stand Costs

Maintenance Plan

Once anodized, the aluminum becomes very corrosion resistant and should not need further maintenance for the desired life span of the test stand, 7 years. The test stand is designed for a one year maintenance free period, with an inspection scheduled at the midpoint of life. At the scheduled inspection time, the unit will be visually inspected, with a focus on the PTFE coupon retainers. After inspection, the unit will be repaired as needed. Examples of repairs which may be needed include but are not limited to: tightening or replacement of bolts, pins, nuts, washers, set screws and PTFE coupon retainers.

Test Report

-Test Plan

Once the test stand has been assembled, immediate testing will be conducted. The test stand will be introduced into an accelerated corrosive environment to test the anodizing of the aluminum parts. The test stand will also be tested for structural integrity. The method of use will be tested by two students setting up and taking down the test stand under a designated time constraint with minimal tools. Additional testing will be performed as we continue to complete the design process.

-Test Results

After manufacturing all the parts of the corrosion rack, our most important test was to determine the corrosive resistance of the aluminum to see if it needed to be coated. We sent three pieces of aluminum with different surface finishes to our sponsor at the Redstone Arsenal, who placed them into a salt spray machine. This test revealed to us how our parts would hold up against a salty environment such as a coastline. The results after 100 hours in the salt spray machine are shown below in Figure 32:

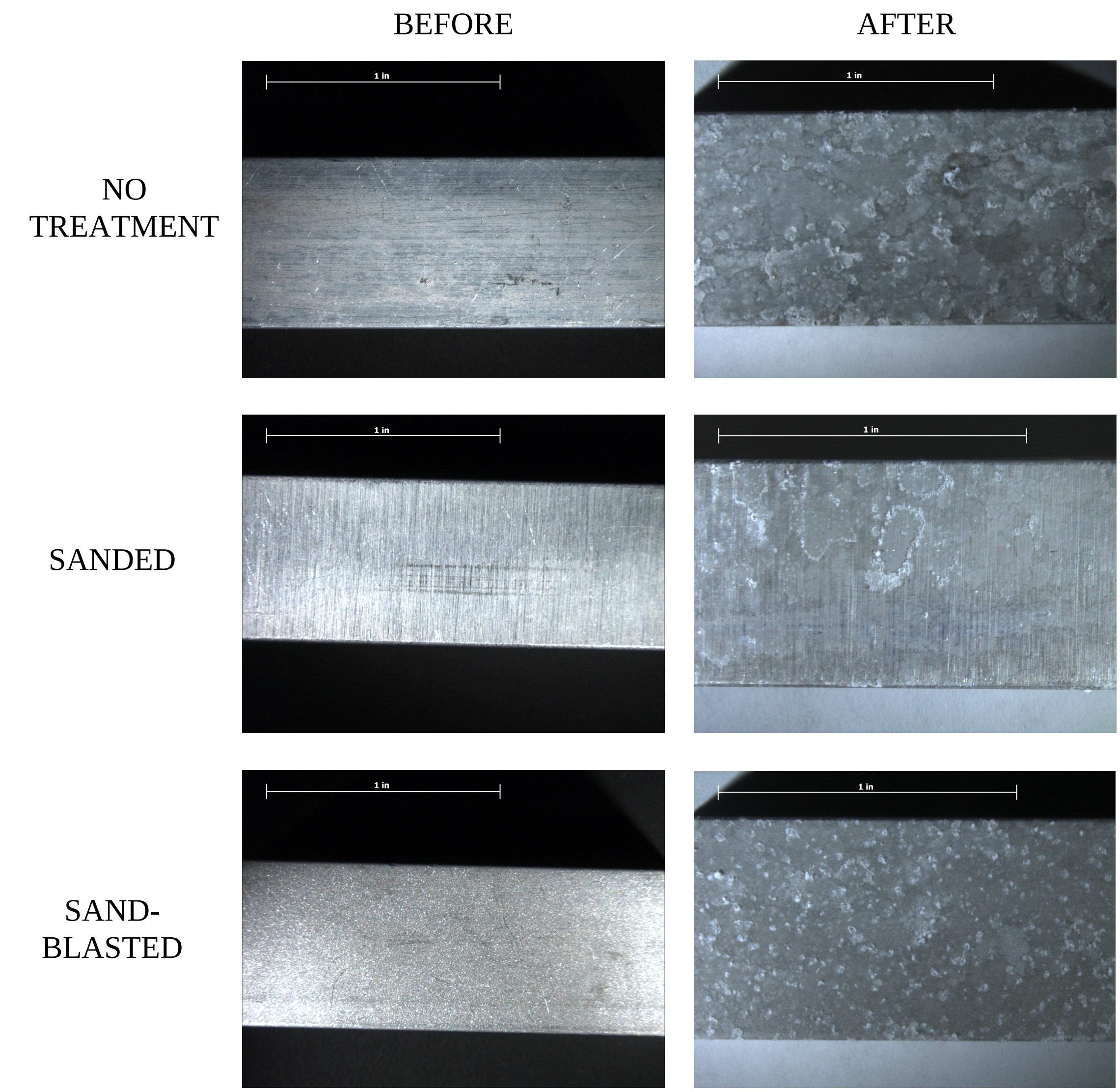


Figure 32: Salt Chamber Results

Our team determined that the results from our test showed it would be beneficial to anodize all the parts to achieve increased corrosive resistance. This anodizing would defend the rack from corrosion for approximately 24 years.

After assembling the corrosion rack, it was necessary to test the structural integrity of the rack. We initially tested the rack by placing 160 lbs on the stand. There was no deformation from this load. Two people then placed all their weight on the stand to increase the load on the stand. Once again, there was no deformation or instability in the stand. This equaled a combined weight of 560 pounds on the corrosion rack, which showed no visible deformation throughout the test. Finally, four concrete bags were placed on the stand and four people placed their weight on the stand and there was no deformation. This combined to a total of 1120 lbs of force on the corrosion stand. It was concluded after this structural test that the stand will easily withstand normal loads and loads during a hurricane. Please refer to Figures 33 and 34.

Figure 33: Structural Integrity Testing of Corrosion Stand using Concrete Bags

Figure 34: Structural Integrity Testing of Corrosion Stand using Concrete Bags and Personnel

We also tested the holding strength of the coupon holders. We placed three metal coupons in adjoining slots in the top row. Once the holders were tightened down in place, we placed forces in numerous directions at key locations of the metal coupons. This testing with forces that are greater than that which will occur in the environment ensured us that the coupon holding elements will perform as designed.

Our team then tested the ease of use multiple times. We folded the rack in and out three times, as well as extending each of the legs, to test the user-friendliness of our product. Each time, the pins were easily removed and replaced, as well as the legs easily folded.

During our testing phase, our team also weighed the rack to ensure it was within the required specifications. The weight of the rack is around 59.2 pounds which is under the limit of 70 pounds. The final dimensions of the rack were also compared to the drawings. All dimensions for the corrosion test stand completely agree with the design specifications.

Testing: Checklist for How We Met Requirements

1. The deliverable must weigh less than 70 lbs.
    - The weight of the deliverable is approximately 59.2 lbs.
2. A standard truck must be able to transport the deliverable.
    - The dimensions of the deliverable are 51” x 52”.
3. The deliverable must be easily assembled and disassembled.
    - No special tools are required for assembly. Two people can easily assemble or disassemble the deliverable using standard tools in less than 10 minutes. Coupon assembly can be completed by two people in less than 30 minutes.
4. The deliverable must be able to attach to various structures and surfaces.
    - The deliverable has built-in feet that have been welded to the rest of the assembly. These feet have holes that allow for the deliverable to be staked into the ground or bolted to posts. Also, the deliverable was designed to have extra holes in the legs so that it can be attached to existing structures.
5. The deliverable must support coupons that are insulated from the rest of the rack.
    - The design incorporates Teflon into the assembly to ensure that any coupons installed on the rack are completely insulated from other materials. Specifically, Polytetrafluoroethylene (PTFE), or Teflon, was chosen as the insulating material for its high corrosion and elemental resistance.
6. The deliverable must support coupons at a 45° angle.
    - The deliverable, when placed on flat terrain, will naturally hold all installed coupons at the specified angle. If there is a case where no flat ground can be located for assembly, the deliverable’s legs are individually adjustable in length to ensure that the coupons are held at the specified angle.
7. The deliverable must hold at least 50 standard coupons.
    - The deliverable is designed to hold a maximum of 56 coupons that are 3” by 5”.

8. The deliverable must be corrosion resistant.

    - The materials chosen for the deliverable were selected to accommodate multiple extreme environments, including the three specific environments at Cape Canaveral, CTC Arizona, and Redstone Arsenal. Also, the Teflon parts insulate the coupons from the rest of the structure.

9. The deliverable must be able to withstand 70 mph winds.

    - FEA analysis revealed that the deliverable would withstand 70 mph winds.

10. The deliverable must cost less than three thousand dollars.

    - Total Cost: $2,937.01

Revisions

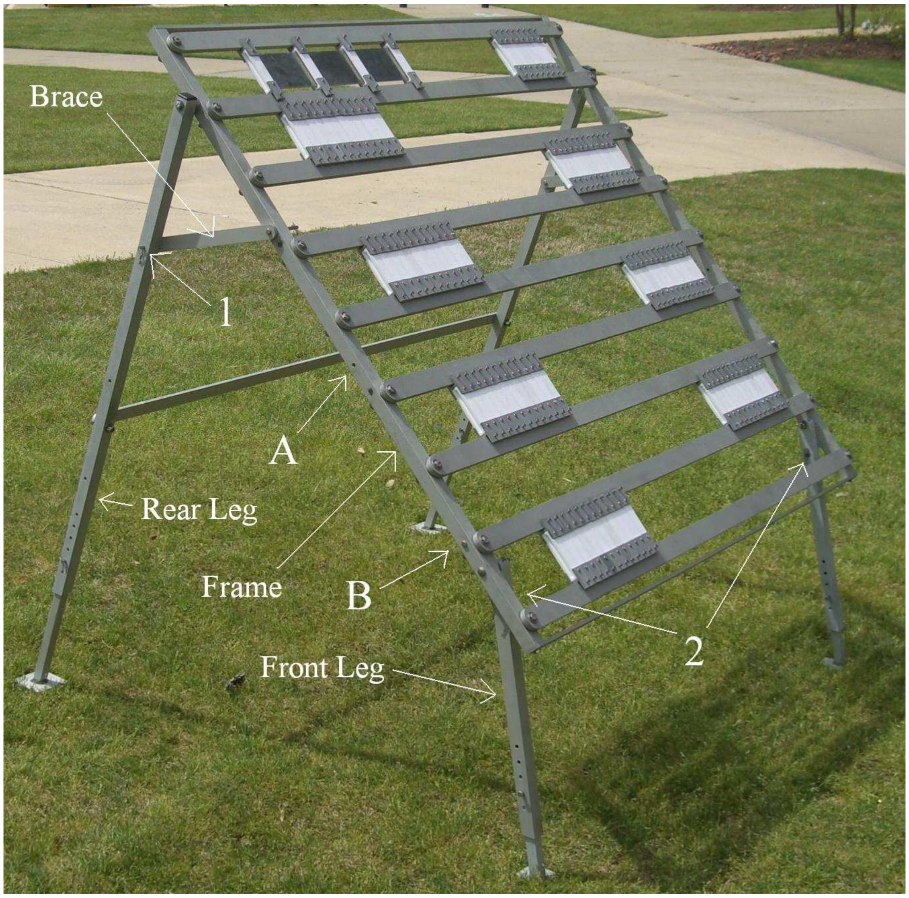
During the manufacturing process, the H-bar received were not the size that we had dimensioned. The H-bar was assumed to have an inside dimension of 3/8', but the H-bar we received was actually ½". We searched for 3/8" H-bars, but found that we could locate any vendors with our desired product. We then made the necessary adjustments to the corrosion rack to accommodate the larger H-bars. The changes included purchasing larger crossbars. The thicknesses of the crossbars were increased from ¼" to 3/8" and the width was increased to 1-1/2". This adjustment actually increased the stability of the corrosion test stand substantially. Please refer to Figures 35 and 36 for pictures of the completed test stand.

Figure 35: Completed Corrosion Test Stand

Figure 36: Completed Corrosion Test Stand Compacted

Instruction Manual

Detailed Instructions



Holes 1,A, and B have corresponding holes on the opposite side of the test stand.

Set-up Instructions (from folded configuration using two people):

Tools Needed: one 7/16" wrench, one ½" wrench
Optional tools: rubber mallet (for inserting/removing of pins)

1. With one individual on each side of the stand, place the stand vertically on the ground with the black plastic inserts of the rear legs facing up.
2. Remove the three inch pins from both A holes, set pins aside.
3. With the pins removed the rear legs and the braces will be free to rotate. Rotate the legs back and position the brace so that a bolt may be inserted through the brace and leg at hole 1. Tighten bolt.
4. Reinsert the three inch pins into the A holes in the frame.
5. Remove the three inch pins at each hole B in order to free the front legs. Once free, reinsert the three inch pins so that it goes through both the frame and bracket.
6. Now with the front legs free, position each leg in order to lock the legs in place with a bolt going through each hole 2. Tighten bolt.

Installation and Positioning of coupons:

Tools Needed: flat-head screwdriver

1. To install coupons, first loosen the setscrews of one PTFE assembly and slide along the crossbars to the far edge of the frame.
2. Once positioned, tighten the setscrews with a screwdriver to lock in place.
3. Now, insert a coupon into the groove of the now securely positioned PTFE assembly. While holding the coupon in place, slide the next PTFE assembly so that the coupon is held in place between the two PTFE assemblies. Tighten the second PTFE assemblies' setscrews.
4. Repeat until the desired number of coupons is held.

Variations:

In order to facilitate in removal of the coupons, a break in the chain of coupons may be inserted merely by placing two PTFE assemblies next to each other without a coupon in between. This will allow for removal of some of the interior coupons without having to remove many others.

Adjusting Stand Height:

Tools Needed: None
Optional Tools: Rubber Mallet

1. Remove the pin in each front leg.
2. Lengthen or shorten the front legs by sliding the lower part of the leg up or down inside of the upper portion of the leg.
3. Once at the desired location, reinsert each pin into the front legs.
4. Perform steps 1-3, on the back legs to achieve desired height.
5. Ensure all feet are flat on the ground.

Tear-down Instructions

Tools Needed: one 7/16" wrench, one ½" wrench
Optional tools: rubber mallet (for inserting/removing of pins)

1. Remove the bolt going through each 2 hole. (Store bolts for later use.)
2. Remove the three inch pin in each B hole.
3. Rotate each front leg in order to lock them in place, along the frame, with the three inch pins going through each B hole.
4. Place the bottom of the frame on the ground.
5. Remove the bolt in each 1 hole. (Store bolts for later use.)
6. Remove the three inch pin from each A hole.
7. Position the brace and the rear leg along the frame and lock in place with the three inch pin at each A hole.
8. Stand is now secured and ready for transport or storage.

Conclusion

The final design incorporates all favorable aspects of every previously developed concept. The design underwent several evolutionary changes throughout the design process to make sure that all factors were taken into account and that all the requirements specified by the sponsor were met. This design does, in fact, meet all of the project requirements and provides a cost-effective and portable product that can be used long-term in the field. Extensive computer aided design work and finite element analysis work was completed to ensure that the structure would not only meet but exceed the design requirements and withstand the extreme environments in which its integrity will be tested. Upon approval of the design by the sponsor, the manufacturing of the design will begin immediately starting with the ordering of stock parts. Finally, we believe that the design will be an excellent improvement compared to previous designs and will be a valuable asset for the United States Army and its initiative towards the prevention of corrosion problems.

It is concluded that the project is a success. The final design was selected from a trade study of concepts based on its ability to meet the project requirements. Detailed analysis and redesign was necessary throughout the design process to provide the best deliverable within the given time and cost constraints. Extensive hand calculations, as well as FEA simulations, were completed to ensure that the final deliverable would meet the project requirements. Manufacturing began in January and was completed early March. The corrosion test rack was anodized in March as per the corrosion resistance requirements. Next, the test rack was assembled to make sure that no conflicts existed and so that testing could be performed. Testing revealed that the corrosion test rack met all of the project requirements. Therefore, the project is complete and the assembly is ready for delivery to the U. S. Army Aviation and Missile Command. Please refer to Figure 37 for a picture of the Corp_1 members.

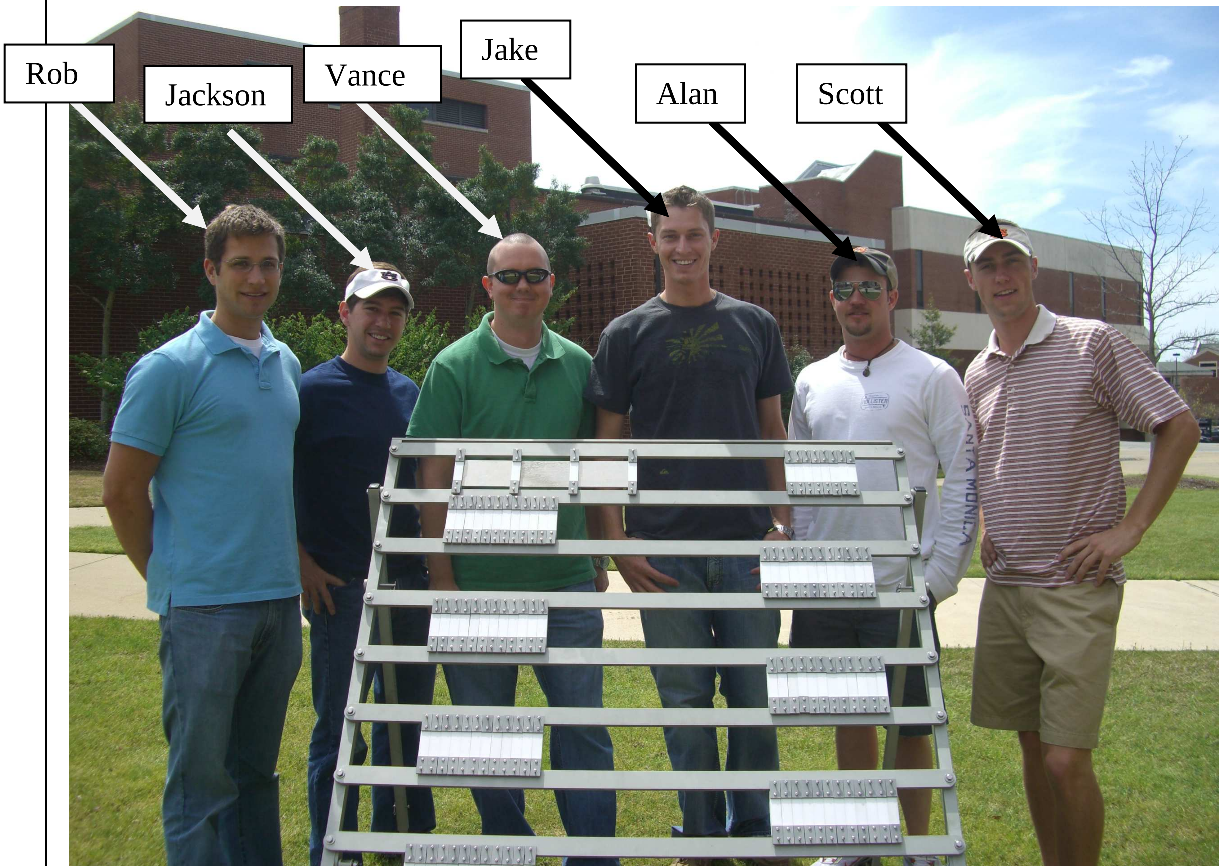


Figure 37: Corp_1 Members and Corrosion Test Stand

References

1. http://www.mcmastercar.com

2. http://www.speedymetals.com