Spring 2020

EV Mirror Project

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Abstract

An ongoing project for the Electric Vehicle Club is to build a fully working Electric Vehicle that can be used for any of the Electrathon America races across the country. Like most cars, the vehicle would need safety equipment that would allow the driver of the vehicle to drive the course both safely and efficiently. The event has specific requirements for the safety equipment that require the driver to be able to see behind them or when another driver is approaching from behind. Therefore, this project objective was to design and manufacture a set of mirrors that satisfy this requirement. The device is made from ABS Plastic, 18-8 (304) Stainless Steel Screws, and acrylic mirrors. These materials were chosen for the project due to the lightweight of the materials and corrosion resistance. This allows there to be minimal weight increase for the entire vehicle. The design of the project was chosen based of thorough calculations of forces on the mirror with a safety factor of 2. The device will be tested using visual assessments. The project result is expected to allow for the driver to see up to 200 feet behind the vehicle while maintaining a drag coefficient of .4.

Keywords: Drag Coefficient, Electric Vehicle, ABS Plastic

Introduction

Description

The goal of this project is to design and develop rearview side mirrors for the ongoing electric vehicle (E.V.) project. The E.V. project is an ongoing project to create a pure electric vehicle that will have to drive for one hour and go as far as possible in that one hour. In order to qualify for the Electrathon the vehicle must have a variety of safety and motor functions that a regular car would have. The mirrors are one of the vital components in order to qualify for this race. The mirrors have to be aerodynamic and be able to be mounted to the outer body of the vehicle. The use of the mirrors is to enable the driver to see behind them while operating the vehicle.

Motivation

The mirror project was motivated by the need of the E.V. needing mirrors in order to qualify for the race. Most vehicles need mirrors in order to see properly behind the vehicle. The mirrors are one of the main safety components while operating the vehicle.

Function Statements

The main purpose of the device will allow the driver to see objects or other vehicles behind the vehicle as well as not impeding the frontal view of vision.

Project Requirements

Thus, the mirrors will need to have the following requirements:

- Each side mirror must weigh less than 1 lb.
- Mirrors can be rotated 15 degrees in either the left or right direction
- The mirrors must be able to withstand speeds up to 65 mph while mounted to the vehicle
- Must comply with Electrathon America Guidelines for mirrors.
- Must have a drag coefficient of .3 or less
- Meets Washington State Automotive Mirror Regulations
- Able to see at least 200 ft behind the vehicle
- Must be able to attach to existing structure of the EV
- Must have the ability to add electrical components to the mirror for future use

Success Criteria

The success of the project will be based primarily on passing the requirements for the Electrathon. It will also be determined by meeting the requirements that have been set forth. One of successes of the project will be set on if there is a working prototype by the end of project time frame.

Scope of Effort

The mirror project will focus mainly on the design of the entire mirror structure. The design of the mirror structure will be to optimize the mirror by using material that is light weight but still strong enough to withstand the speeds and stresses of the outside wind and air.

Benchmark

There have been many new ways to look at mirrors and how they should perform in order to reduce less drag and be light. Many of them are on concept cars that ever make it to the road. One of these examples that will help for the project is the Hyundai i-flow concept mirror. It has a balance of aerodynamic ability while also looking sleek, so it molds to the car.

Success of Project

One of the successes of the project will be determined by if the mirrors survive the competition, if the EV makes it to the competition. Another success of the project will be determined if the mirrors are able to be mounted to the body of the car without damaging the integrity of the body. Success for the project will also be determined if it meets all of the requirements set previously.

Design and Analysis

Approach

One of the design solutions for this project in order to keep the part light a still functional is to use a combination of materials in order to create the strongest and lightest mirror. The proposed idea for the project would be to make the main component that holds the mirrors out of plastic and then create a carbon fiber overlay in order to add strength to the plastic against other forces. In order to create a sturdy foundation for the plastic and carbon fiber mirror, the proposed solution would to be use an aluminum alloy for the support beam. By using a plastic and carbon fiber and aluminum, entire mirror weight should be under 1 lb. The strength of the aluminum will be strong enough to handle the shear forces from the air speeds. The overlay will need to be relatively thin and since it will be thin, the adhesive will be neglected from the total weight. As for the mirrored surface, a small convex mirror will be added to the left side mirror to add a wider view for behind the vehicle. This means there will be two different designs for the mirrors on each side of the vehicle.

Design Process

During the design process of the project the needs for the design changed. Due to time constraints and the process of printing parts took longer than expected, the carbon fiber parts were scrapped as well as the aluminum support arm. The support arm was determined to become carbon fiber but was later turned to ABS just for testing purposes. The main outcome of the design portion of the project came down to time and how much time was actually needed to make parts. In the future, more time would attribute to creating proper molds so that those could be used to make carbon fiber parts.

Design Description

The mirror design is designed to fulfill the weight limit. The weight limit of less than a pound was taken into consideration when developing a supplementary design. The beginning stages of the design began with an ABS plastic inner mirror design that will hold the actual mirror in place. The reason for this choice is not only because it’s light but also because with the 3D printer mirror holder and what will help the mirror be rotated could potentially be implanted into the design of the holder without needing to mount anything within the holder which would add extra weight to the entire mirror.

Benchmark

Some benchmarks that would need to be met for the duration of this project are to complete the full design of the project, finish manufacturing parts for the project, put project together based off assembly drawings, and testing the final design of the project.

The first benchmark will need to be done by the 2nd week of January. This will ensure that the project will finish on time and parts will be able to be manufactured correctly and in a timely process. This benchmark is crucial for the entire project to finish on time. If this isn't done by the time the second week comes along, this will greatly affect when parts can and will be printed.

The second benchmark for this project is the next crucial step because without the finished parts, the assembly can't be finished. This task will be done from weeks 2 – 8 of the manufacturing stages of the project. The time for this project will need to include any failed parts when printing. Many parts will have trouble printing due to the ABS not being the most cooperative material. The material itself has certain specifications it needs in order to print right.

Putting the project together is important because it allows for testing to take place. The project will need to have all screws and parts in place because this will ensure that the project doesn't fall apart due to outside forces other than what is being tested. This step will need to be done by the last week of the winter quarter so testing can begin at the start of spring quarter.

The last step is testing. All requirements will be tested for to ensure the project meets all requirements. Testing is an important role for this project because it will allow for better designs for the mirrors to be made in the future. The EV project is an ongoing project for the department and this part will be vital in successfully being able to compete in the Electrathon America event.

Performance Predictions

Some of the performance predictions for this product are that due to the lightness and strength of the Carbon Fiber the mirror assembly will stay under the desired weight limit. The strength of the materials will add stability to the overall design and will not ruin the integrity of the existing body of the EV. The project will also meet all requirements because each requirement has been thought through and have been analyzed beforehand. The mirrors will allow the driver to see further behind them and will meet the requirement of at least 8 in^2 of mirror space.

Description of Analyses

The analyses located in this proposal will describe shear forces in the support beam and the screws. They will also cover all the forces acting upon the parts. Two of the analyses will help determine which materials will be used in order to complete the project as well. These analyses will ensure the success of this project.

Scope of Testing and Evaluation

One aspect that will need to be tested for is the drag coefficient. In order to make sure that the mirror is aerodynamic, simulated tests will have to be done on the mirrors to check for this. Another test that will have to be done is testing the supporting beam to make sure it can handle the shear forces from the wind without the weight of the mirror. It will then have to be tested again with the weight of the mirror added to it. To test for the 15 degree of movement, this can just visually test to make sure it is able to rotate for the driver to be able to get the best view possible for behind the vehicle. The best way to test for this is to know who the driver will be and find the best line of sight for the driver in order to comply with the safety guidelines of the competition.

Analysis

Force Caused by Wind Velocity

One of the main things to consider when creating mirrors for a vehicle is how the wind will affect the mirror once they are in place. For the first part of this analysis, the force that is resulted by the wind velocity was calculated in order to determine how much force would act on the supporting beam of the mirror. This analysis can be found in Appendix A, in figure A.1. To start the analysis, the assumption was made that the wind velocity would be equal to how fast the vehicle was going. The wind speed that was used was 65 mph. This speed was used from the one of the design requirements stated in the introduction. To calculate the force, the 65 mph was converted to meters per second. This came out to be 29 m/s. The force was then calculated by using the air density at sea level, which is 1.229 kg/m^3. The air density at sea level was used because the air density at the Bonneville Salt Flats and in Ellensburg would be slightly less than at sea level. This would ensure that the maximum force would be calculated. The force at 65 mph was 1034 N. To find the tolerance of 15% for the force, the force was calculated at both 60 mph and 70 mph. This was done because although the vehicle may not go this fast, the vehicle will have varying speeds and therefore different forces acting on it. The forces found at 60 was 884 N and the force at 70 was 1203 N.

Shear Force on Supporting Rod

In order to determine the material selection for the supporting rod is a good fit for the needs of the project, the shear stress had to be calculated in both the short side of the rod as well as the long side. These analyses can be found in A.2 and A.8. The resulting shear stresses in the short side and long side were, 2446 psi and 214 psi respectively. This means the choice for the carbon fiber support arm would be a good choice. The carbo fiber support arm is able to handle stresses well over the shear stresses that were calculated. To solve for the shear stress in both scenarios, the area of which the shear stress would affect was calculated. In the short side an area of .1104 in^2 was calculated. In the long side, the area was 1.2566 in^2. The carbon fiber would not need to be very thick considering the strength that carbon fiber has. The shear force of 270 lbs. was used in order to calculate the shear force. The reason for this is because the main force acting on the mirrors will be the wind force.

Ideal mirror edge

The ideal length the mirror sits from the existing body of the EV is one aspect of the project that is important. Where the mirrors are place will either help the drive see better or worse. One of the requirements listed above is to be able to see up 200 feet behind the vehicle at all times. This isn’t a safety requirement for the Electrathon, but it is a safety requirement for Washington State Roads safety which the mirrors are also supposed to comply with. The calculations for this analysis showed that that the position of the mirrors should be 6.5 inches from the bottom base of the support beam, or the body of the EV, in the vertical direction. The edge of the mirror encasement should be about 2.5 inches from the body in the horizontal direction. According, to this data this should equate to the optimal rear side vision that the vehicle needs. These calculations can be found in appendix A.3. The degree angle of the mirrors should also be 68.8 degrees. This angle will provide the mirror with the correct view we’ll also limiting the amount of pressure to the bolts that attach the mirrors.

Drag Force

One of the other requirements required for the project is the mirrors must have a drag coefficient of .3 or less to ensure the overall aerodynamics of the EV remain intact. To maintain this stage coefficient the dimensions of the upper encasement of the mirror will need to be able to with stand certain drag pressures and forces. The drag force that is calculated helped decide which materials were the proper materials to use. The resulting material was a carbon fiber outer encasement with an ABS inner encasement. The resulting drag force for the project was 485 N. The material selection will allow for the mirrors to be made of carbon fiber due to its strong yield strength and its overall ability to protect the glass mirrors within. Drag force on the mirrors played an important part in the design process because if the force was too great then the mirrors would fail and rip off the EV body. These calculations are recorded in A.4 in the appendices.

Mass of the Rod

The importance of this analysis is was to determine if the weight of the rod would be too much for the overall weight. It was done to ensure that the requirement of 1 lb. or less was satisfied. This was done by taking the density of the aluminum alloy in question and multiplying it by the volume. The density of the aluminum allow was .0975 lb./in cubes. This resulted in a total weight of 9.77 gram or .02144 lbs. The total volume of the rod was .2614 in cubes. This means that the overall weight of the mirror would stay below the necessary requirement for the mirror. Later models were done on the rod to make it lighter by switching to carbon fiber. This analysis can be found in Appendix A.5

Loading in all 3-axis

This analysis was to determine the loading on the supporting rod in all 3 axial directions. This was done to check the loading so the material chosen would be able to support the loads that it would have to support. Although not a requirement for the project, this is important to the overall scope be user it ensures the rod won't break under loading. The results for the x direction loading was .675 lbs. This is x component of the shear force acting on the rod. It also includes the force that will most likely be holding the mirror to the rod. The components in the y direction was -83.52 lbs. This is the required force that the rod will be pushing pack on the mirror in order to keep it from breaking. This force is reasonable because the maximum supporting weight that was needed to support the mirror was .51 lbs. The results in the z direction was the 242 lbs. This force is also reasonable because the force that the mirror must withstand is 270 lbs. worth of shear force the resulting z direction force is under this 270 lb. limit, meaning the rod would be able to withstand the wind force acting on it. This analysis is in Appendix A.6.

Deflection of Supporting Beam

The deflection of the supporting beam was calculated in order to determine if the mounted mirror would be too heavy for the rod. This isn't a major concern because the material being used is carbon fiber and it is a pretty strong material. But knowing the deflection of the rod will help determine if the rod will need to be thicker. If it deflects too much, then it will bend out of place and will need to be replaced. If it is too rigid, then if a force hits it the rod could break due to it being too brittle. The force that was used was the angular downward force of the mirror. The downward force was approximately .5 lbs. and resulting in an angular force of .62 lbs. The moment of inertia of the rod was .0012566 in^4. The deflection was then calculated, and it resulted in a 2.492×10^{-6} inches. This deflection is so minor that it wouldn't be noticeable in any instance. This means the rod will be sufficient in holding up the mirror. This analysis can be found in A.11.

Shear Stress on Screws

The shear stress on the screws was done in order to determine if the chosen screws would suffice in holding up the entire assembly. 1/4 – 20 screws were chosen for this particular analysis. The area of the screw was calculated to be around .4 in^2. The area was then used the shear stress equation. The resulting shear stress was 685.55 psi. Since there will be 4 screws holding the mirror in place on the EV, the shear stress of the wind will not affect the integrity of the mirror or the screws. The screws chosen have a tensile strength of around 75000 psi. The shear stress is minuscule compared to the tensile strength of the screws. This analysis can be found in the A.12.

Changes to Analyses

Changes that were made for the project analyses were for the support arm. Since the support is a vital component to the overall project, when the part was changed from carbon fiber to ABS it was re-evaluated to make sure the design would still fit the needs of the project. Even though the material is substantially weaker than the carbon fiber, upon further analysis of the ABS, the stress levels should not go over the stress limits for the ABS as well.

Methods and Construction

Methods

This project will require for multiple materials to be tested in order to fully understand which ones will be best to make the mirror work the proper way and under the requirements stated. Materials that should be tested would be ABS, carbon fiber, and aluminum. These materials are the proposed ideas for this project because they are the lightest materials. These light materials should keep the total weight of each mirror under a pound each. The best way to test the materials would be to apply similar loads to them on small specimens. This will give the best estimated result of how they will act in the environment they are intended for. Another way that the project could be tested is by doing air drag tests on the design of the project to confirm it conforms to the drag coefficient requirement.

Support Arm

One of the main problems when making the support arm for the project is making sure the main long arm of the support doesn't distort in any major way. Also, one of the issues that has come into play when creating the part is the ABS hasn't been cooperative and has delayed the ability to print the 3D core for the part. The solution that has been considered is to use PLA instead since the printer is having a much easier time printing it, however one issue with this solution is the PLA isn't as strong and rigid as ABS. This could create problems when printing and laying the carbon fiber. If the core cracks before the carbon fiber is laid, a new core will need to be printed. This will take more of the budget as well as take more time to create the part.

Mirror Holder (Left and Right)

The mirror holder thus far has been the hardest part to manufacture. Since the mirror holder is taking much longer than expected to get right the first time, modifications had to be done for the part to come out the way it should. In the second attempt for the mirror holder, the printing didn't print out the swivel ball holder, so another part had to be made in order to fix this issue. This tiny part was designed to only fit in the exact spot that the piece was initially going to go. Due to the integrity of the plastic and where the placement of this piece needs to be, this piece will have to be as close as possible to the original desired area. Another issue that this created was that since the little piece was originally attached to the mirror holder, the glue will have to be strong enough to support the weight of the mirror component and the tiny mirror ball mount. Also, a fillet has been added to this part on the original mirror holder and mount. Without this fillet there will be added stress to the component. Since printing the second mirror holder, modifications were made to the drawing and part so the mount inside will be printed the next time the mirror holder is printed. One side of the EV mirror will have the inner mount printed while the other will not. This is being done because of time.

Mirror Swivel Ball

After some consideration and creating a new drawing, the solution for holding the mirror in place will be a swivel ball that will rotate left and right. This will satisfy the requirement of the 15-degree rotation. The main issue for this part is that it is small and will need to be strong enough to hold up the mirror surface itself. The mirror itself will be relatively light due to the weight requirement. This component will be 3D printed and then glued to the back of the mirror surface with a strong epoxy. This should allow the mirror to be moveable and light without destroying the integrity of the main mirror assembly. This part will be made of ABS. The multimodal center on campus will be utilized in this situation because of the access they have to ABS and the ability to print in ABS. Like described above, even though the ABS is stronger, the reliability of the part will need to be checked just in case part does not print out right the first time. Time will be allotted for this. Due to the small size of the part, extra care will be taken care of the part when transporting it from building to building.

The mirror ball swivel had some difficulties printing the first time around because the part was hollow which was not previously known at the time. This caused the design to be changed so that the rod was slightly thicker. This change will ensure a better strength value and less stress on the swivel mount.

Support Plate

This part was made from ABS plastic. The part was more rigid than initially thought and will need to be slimmed down a little bit so the part will be able to bend when being attached the actual EV. The part will also be enlarged a so that the part will is coving more area which will help create a broader area for the stress to be applied to. Due to the mirror having to be attached to the EV, there will be some modifications that will need to be made to act as a place holder for the material that will be between the mirror support rod and the mirror support plate.

Construction

Description

The main construction of the project will be connecting all the parts for the mirrors into one piece for the vehicle. Once the materials have been fitted together, they will need to be attached to the vehicle securely. Having this secure fit will enable the mirrors to properly work how they are intended to. The construction of the actual mirrors will use bonding adhesive to fuse the carbon fiber overlay with the ABS shell. The main supporting rod for the mirrors will at this time be connected using screws, this will create a tighter fit for the support beam to attach to the mirrors. The mirrors are design so that screws will be able to but in through the bottom without ruining the integrity of the mirror.

Manufacturing Issues

One of the manufacturing issues that has recently come up is how the long arm of the supporting beam will be attached to the body of the vehicle. Due to the curvatures of the body, molding the beam to the body would require extra machining or heating of the both the support plate on the inside of the body and the main connecting plate on the rod. Due to the already small size of the supporting beam it would be difficult to change the geometry of the supporting plate as well as the connecting plate.

Another issue with the design is due to how the beam is shaped that is supporting the actual mirror, the aluminum that is being used can't be easily molded in the way that it would need to be molded. If the rod would stay in the shape as initially proposed, either the supporting beam material would have to be changed, which could potentially add weight to the total weight of the entire mirror structure, or the rod would have to be molded and welded together in that particular orientation.

Finished Product

The working device at the end of the construction was temporarily glued together so that the parts could be in the proper place when the screws were put in. The screws that were initially bought were too big to fit in the holes of the support arm because the holes didn't print out to the correct tolerance that was set for them. This resulted in the screw cracking a piece of the support arm. The plan for the final construction was to get smaller bolts and nuts so that the nut would fit perfectly in the slot that was provided. This cost more money for the project but in the end, it would help the final design for testing purposes. Another issue that resulted from parts not being perfectly printed was that the inner connector rod and the ball mount connector part didn't fit. This resulted in the part cracking. This would need to be fixed in the future, so the mirror is able to perform its proper functions.

Drawing Tree

The drawing tree for this project can be found in Appendix I of this document.

Testing Method

Introduction

One of the main components that will need to be tested is how strong the ABS and carbon fiber will work together. Due to their different properties the strength of the materials will go slightly up when fused together. The next thing that will need to be tested is how well the support beam works when acted upon in the different directions. A test will need to be done to simulate the shear force acting on the beam when driving upward of 60 mph. If the mirror is unable to support the shear force acting on it the beam itself will need to be changed. The downward force or weight of the actual mirror will also influence how the beam will function. Although the main mirror component is less than a pound, how the beam reacts in the vertical direction when this small load is applied will also need to be tested. Another test will need to be done to make sure the design of the mirror meets the requirement of the drag coefficient. The last part of the project that will need to be tested is if the actual mirrors are able to rotate inside the mirror holder. The requirement of 15-degree rotation in either direction will need to be tested in order to ensure the driver of the EV is able to adjust the mirrors, so they are able to see clearly behind them.

Method and Approach

Every one of these tasks will need to be tested in one way or another. For a few of them it will be a very simple test that will take less than 10 minutes to accomplish. The first item that will be tested is the combined stress that the ABS and Carbon Fiber are able to with stand when the force of the wind is applied to it. Due to the wind force being a fluctuant force a direct and precise answer will be hard to determine. From calculations the mirror itself will need to be able to handle up to 1200 N worth of force or in pounds, 270. The best way to test the outcome would be to test it using the Instron because it is able to determine what force the composite of the plastic and carbon fiber will break at. This will give a better understanding of when the composite will.

The next component that will be tested will be how well the support beam is going to act under the compression due to the main mirror component weight as well as the shear force that are acting on it due to the wind. The main concern will be the connecting points where the support connects to the mirror and the body of the EV. This can be tested by also using the Instron by using the compressive function to compress the material in a downward direction. The shear component can be tested by just using a weighted system and applying weights to the material to see if it is able to withstand 270 lbs. The main issue with testing this will be finding a way to apply the 270 lbs. to the rod. According to the calculations found in Appendix A.2, a rod being .375 inches in diameter will be able to support this load. Using a safety factor of about 2, the rod diameter was increased to 0.80 inches. This will ensure that the rod doesn't break when the wind force is acting upon it.

The third test that will take place is putting a scale model of the mirror in a small wind tunnel in order to determine if the coefficient of drag is below .3. The wind tunnel has its constraints, and this will be considered as the necessary speed in order to test for this will have to be 140 mph. Unfortunately, the wind tunnel may not be able to reach speeds of this magnitude and therefore any tests will only give minor results to what is needed. These constraints will be recorded when the testing has occurred.

Finally, the last test that will take place is making sure the mirrors are able to rotate in order to offer a clear line of sight behind the driver. The constraint was 15 degrees. Therefore, in order to test for this, the mirror once constructed will be pushed from both the right and left side and where the mirror stops rotating the degree at which it stops will be recorded. Due to the way the inner mirror core is hollowed out, this should not be a problem. The hard part of testing this will be to make the part doesn't rotate further than what is needed.

Test Procedure

For all these tests to take place on time, each part will need to be manufactured in order of importance. Before the mirror has been made, a scale model of the mirror will need to be made in order to test for the drag coefficient. The next step would be to test the support rod since this will be the primary component that holds everything together. If the support beam fails everything else for the project will not work for the project. After the support beam has been tested, the mirror structure, meaning the encasement for the mirror will need to be tested. Since the encasement for the mirror will holding the actual mirror in it, this will need to be tested next to ensure the safety of the actual mirror. The last thing that will be tested will be the rotating of the mirror since this requirement can't take place until the entire mirror has been completed and put together.

Due to time constraints during the manufacturing stage, some of the tests will be different in some way or entirely different. One difference will be the strength test. Since there is no longer carbon fiber surrounding the parts, the parts won't be as strong as previously predicted. New analysis was done to make sure the ABS can withstand the amount of force that will be applied to it while in motion. Another test that will be slightly different is the wind tunnel testing. There wasn't enough time to make a smaller model, so the full-sized mirror will be used for this test.

The wind tunnel test for drag coefficient may not be as successful because the mirror holder itself has small defects that will cause some problems with the flow. Also, since the mirror holder will no longer be encased in carbon fiber, the design and surface finish won't be as smooth as previously hoped.

FEA analysis of the mirror holder will also be done to see how well the calculated, prediction, and tested values differ from one another. This should give better clarity and what is truly needed to make sure the mirrors work in the proper way and survive any and all texting that will be done to them.

Deliverables

The testing will determine if the deflections and forces were accurately and precisely done. By testing each requirement, the mirrors will meet the purpose for which they are designed. By measuring the wind flow around the mirror, it will determine if the mirrors will add to the drag coefficient of the vehicle or help minimize it. Testing the degree of motion in the mirrors will help determine if the driver will be able to adjust them as needed in order to see better behind. Since no driver has been recruited yet, this degree testing is important so any driver that is chosen can adjust the mirrors.

Testing Issues

With any major project, there will be issues that will arise that either were unforeseen or known about. The first major issue with testing of the project came with the unexpected closure of the school and its buildings. This created unforeseen problems with the testing. The test that would be done to test the requirement of drag coefficient was unable to be performed at this time due to the labs not being open. However, many of the other tests that needed to be done using school resources were able to be done without them. It required some intuitive thinking on what can be done to best accomplish the tests of the requirements.

Another testing issue that came up is that some of the testing damaged the integrity of the mirror that was being tested. This showed that some items will either need to be redesigned or remade. However, there was a lack of computer programs to redesign the parts needed. Luckily, there were some spares made that would allow for the project to continue to be tested. These parts were utilized to accomplish the tasks that remained.

The parts that were damaged, were the inner mirror mount when it was being tested for rotation and the support arm in transfer from testing sites. The support arm has a spare, so the spare was used for testing in other areas of the project. Since the inner mount could not be redesigned, it was temporarily glued back together. This will be discussed later in the discussion section on why it was glued back together, as well as how it affected testing after.

Budget

Suppliers

The suppliers for this project will be McMaster Carr for all the materials needed to assemble the project together. This includes screws, bolts, and washers. These types of items are better bought in bulk and all the parts, there will be more than what is needed. Due to the cheapness of the products, this isn't going to cause many problems with the overall budget. The suppliers for the resin and sandpaper will be Amazon. Many of the products needed can be bought at Amazon for a lower price than found on other websites. The ABS black filament will also be bought from Amazon. The last item of value is the carbon fiber that is needed for the supporting rod and outer encasement for the mirror structure, this will be bought from FibreGlast. They offer deals on carbon fiber rolls that are relatively cheap. The part list for this project can be found in Appendix C. The overall cost of the parts and materials for the project is $318.73 (this includes all taxes). Just in case there are overtures in the project, a 10% safety budget is also included in the budget. This leaves a final budget for the parts at around $351. The breakdown of the budget can be found in Appendix D.

Estimated Labor Costs

Due to the assembly and manufacturing taking place at the school, the cost of outsourcing is minimal and many of the parts can be manufactured by the team members of the project. The estimated cost for labor is around $690. This is assuming it will take around 60 hours to complete the assembly and manufacturing of the parts. This does not include any of the testing time for the parts. This estimated cost leaves the total of the project to be around $1041. The cost of labor was determined on an hourly basis of $11.50/hr.

Labor

The labor for this project includes all the manufacturing of the parts as well as the assembly of the parts. The assembly for the project will take less time than the manufacturing of parts. The manufacturing of the parts will take approximately 80% of the total time required to complete the labor side of the project. This is only an estimate and does not include any time needed to replace parts if the first try fails.

Funding

The funding for most of the project will come from the school. If needed some of the cost will be from out of pocket especially for materials that less costly such as the screws, nuts, and washers. If possible, getting the mirror aspect of the chrome mirrored surface will be donated, however the mirrored surface isn’t too expensive to just buy.

Testing Costs

This project required additional costs outside of what was planned. Due to some funds not being used during the manufacturing process, this did not affect the budget in any way. During the testing process the mirror surface had to be fixed. The mirror acrylic stickers that were bought during the manufacturing stage had to be rebought so the mirror surface could be replaced and fixed. The stickers themselves were not expensive and only added an additional 15 dollars to the overall cost of the project.

The ending cost for the entire project was 196 dollars. This means only 55% of the total budget was spent. The main reasons why cost was so far under what was predicted was because carbon fiber was not bought for the project. If the project were to be redone and tested, carbon fiber would be needed which would result in the costs being increased. The costs were kept low due to parts only being made of ABS plastic and light and relatively cheap materials. In the future this shows that the cost of mirrors could be kept lower if better materials are chosen that were longer lasting.

Scheduling

Specific Tasks

Some tasks that will that will need to accomplish in the design process will be the overall assembly of the project. The final assembly of the project will determine if the project is a feasible and if it is capable of finishing on time. For this task to be accomplished, all parts will need to be made in SolidWorks. The parts must fit together in the way they are intended to. The final assembly will need to have all mates defined, as well as include any notes that must be considered during the manufacturing stage of the project. The manufacturing stage main task that needs to be accomplished, is the actual manufacturing of parts or ordering or parts such as screws, washers, and nuts. This task will need to be accomplished in order to finish the actual assembly of the project. Without the needed parts the project cannot move on into the testing phase of the project. The final task that will need to accomplished is attaching the mirrors to the body of the EV. This task will be accomplished by assembling the project and testing all functions of the mirror before attaching.

Task Dates

- Final Assembly: November 23rd, 2019
  Creating the assembly and parts for the assembly in SolidWorks, will take approximately 6.5 hours to create the necessary parts for the assembly. The assembly itself will take approximately 2.3 hours to create. The resulting drawings from these drawing and assembly will take around 8.75 hours. The total time for the assembly will be 17.55 hours.
- Manufacturing Task: March 1st, 2020
  The manufacturing time will be approximately 50 hours to create the parts and let the resin for the carbon fiber to harden to the surfaces. The actual assembly of the parts will take around 2.5 hours to complete. This includes any minor mishaps that could occur in the process of making the assembly. This equates to 52.5 hours.
- Attaching the Mirrors: May 3rd, 2020
  The attaching of the mirrors will take around 1 hour. However, the testing of the parts before attaching them will take around 20.75 hours because multiple items will need to be tested and many of the testing will take longer because of the speeds of the machines, as well as the final calculations needing to be done in order to see if the testing resulting in satisfying results. This total time for this task is 21.75 hours. The final hours for these three tasks are around 91.8 hours.

The total time required to finish this project will be around 140 hours because of the work that must be put into the report and the testing. It will also require multiple changes throughout the process in order to complete tasks. The resulting hours is only an estimate of what the project time could be.

Scheduling Updates

The schedule had to be updated multiple times to accommodate for parts needing to be remade. The mirror holder and the support arm had to be reprinted multiple times for the project to be finished on time. Some updates that were made was changing any carbon fiber parts into ABS parts so that the project can be put together. This resulted in analyses needing to be changed so that the parts would still be able to handle the forces of the original design.

Manufacturing Processes

The scheduling for this project has changed over time. It was originally thought that the manufacturing process would only require around 50 hours of work. However, as the project progressed through the manufacturing stage, the amount of time needed to print certain parts took longer than expected. For instance, the main mirror holder took 13 hours each time to print, instead of the 8 hours that was originally planned for. This is in part because the speed of the 3-D printer was not known before the schedule was made. Due to the time, the smaller part for the entire assembly were printed at a different location to maximize the time needed. The Multimodal Education Center was utilized in this scenario. The total time after week 6 of the manufacturing process was 30 hours for printing parts. Due to the printing in two separate locations, it has allowed for the process to go by quicker. The smaller parts only take about 1 hour to print.

Another issue that has affected time on this project is reprinting parts. Since changes will need to be constantly made in order to create the best part possible for the project, parts were reprinted up to 3 times. In one specific instance, the mirror holders for the project were printed and then redesigned to be slightly larger but will a thinner material thickness to minimize cost. However, the second time this part was printed, the part did not come out in the proper format which meant that the part had to be reprinted once more. To minimize time, only one new mirror was printed and a smaller part that can be glued into the other was made to speed up the process.

The main inner mirror mount was the easiest to fix which didn't take add much extra time to the manufacturing portion of the project.

Testing Problems

With any project, there were some testing delays. The first one came at the beginning of the testing process because testing didn't begin until a week later than originally scheduled. This resulted in more tests needing to be done closer together and in a smaller time frame than originally thought. This pushed most of the testing report data until later in the testing process and closer to the beginning of when SOURCE documents had to be completed. Even though there was no access to Hogue Technology Building, tests were still able to be completed in a timely manner. But due to circumstances, not all tests were completed. This would've taken more time to complete the testing, so in a way it was upside to the project because it allowed the tests that could be done to be done correctly and efficiently.

For the project there was travel involved for certain tests. When initially making the testing plan, this was not included in the final time. This took extra time to test the project, and all its components. This extra travel time made things harder for the project because tests had to be completed a certain time in order to get the project done on time. The time of day for the tests became an important factor in the project. Other testing delays and when tests could be completed, the testing of the project remained on schedule and just had to be adjusted to be condensed in a smaller testing time frame.

The Gantt Chart for this project is in Appendix E.

Project Management

Human Resources

Many of the human resources that will be used for this project will be Matt, Dr. Johnson, Prof. Pringle, Dr. Choi, and fellow classmates. Matt will be a valuable resource because he will be able to order materials that are needed for the project as well will be good to talk to when deciding if the design will work well or not. Dr. Johnson will be used when it comes to the composite materials since he has knowledgeable in this area. Professor Pringle will be used it comes to determining if the aspects of the design are feasible in the manner of which it needs to be done. Dr. Choi will help when it comes to the fluid dynamics of the project such as drag force since he is an expert in this area. Classmates will be used to bounce ideas off of and if they have any ideas for the project.

Physical Resources

The machines required to complete this project will be drills for holes that will need to be drilled as well as screwing together parts, a 3D printer will need to be used as well to print the inner encasement of the mirror, and a some sort of glass cutter will be needed as well in order to cut the glass mirror into the shape that is needed.

Soft Resources

Software that be utilized for this project will be the internet for looking up products that are both affordable and useful for the project, SolidWorks for making parts and assemblies and analyzing the parts to see if they will work in the way they are supposed to work, and lastly Microsoft products such as PowerPoint, Word, and Excel. The Microsoft products will be used to make reports and to document any changes that occur in the design process.

Financial Resources

The main financial resource that was used for this lab was leftover grant money used for financial aid. This was the main source because the grant money is used to further educational needs. This project fell under that guideline and would be no extra cost on others for the project.

Discussion

Design Evolution

Mirror Holders

The mirror holders for the project were designed to have a spot where an attachment could be used to connect the actual mirror to the holder. The mirror holder itself was also going to have a carbon fiber outer layer to protect and make it stronger than the plastic on its own.

After the first attempt of printing the part, it was taken note that the mirror holder would unlikely need a carbon fiber outer layer. This is due in large part because the mirror holder was sturdy on its own. So, the carbon fiber outer layer was discarded because it would eliminate overall cost and create a lighter mirror in the end. The last revelation that came from printing out the part was that the walls of the mirror holder could be thinned out. This would allow for the printing time to be decreased as well creating some flexibility in the part. This could be a safety factor added to the mirror holder, so the part doesn't create any sharp corners if it does get destroyed.

Some issues that will need to be fixed before the next printing are the main connecting sphere slot and the screw plate area. The first issue that was derived from the print involved the ball joint in the mirror holder to connect the mirror to. This will be redesigned because it was easily destroyed with a little pressure and it will require some pressure to get it attached and secured. Another issue that helped evolve the project, is the main area where the screws would be put in was too thin. If a screw was screwed into this area the screw would tear through the plastic area. This would ruin the integrity of the part and the connection between the main connecting rod the mirror holder.

Inner Mirror mount

This part is a new part that was designed for the purpose of connecting the mirror to the mirror holder. The is small and doesn't need to be all that strong as it will only be supporting the mirror surface which will be made of acrylic. Its main function is to only hold the mirror in place. However, upon evaluation of the inner mirror mount the center rod holding the plastic ball bearing was easily cracked in half. This was due in large part that the print was hollow. Knowing that the part would be hollow. A re-design will take place of the mirror holder will take place. New options will be considered if this part cannot be fixed in a timely manner.

Another issue that is now known is that the 3D printer will make a base platform and then begin making the part. This is important to note because it will need to be cut off carefully to ensure the part doesn't break. As well making sure it fits in the space of the mirror holder. The extra layer on the bottom would push out the mirror from the safety of holder. This could potentially damage the mirror. If the mirror was made of glass this would be a bigger issue.

Support Arm

The support arms for the mirrors were originally meant to be carbon fiber due to its lightweight properties and strength. This had to be changed in later iterations because the time it would take to cure the carbon fiber was going to be too long. The printing of the ABS plastic support arm was tougher than originally thought. Due to the mirror being "thicker" on the bases of the support arm, the printer had a tough time getting the arm to print. So, the final support arm will only be ABS plastic. This will still be suitable for the testing section of the projects process. The only downside to the arm being plastic is the arm won't have the same strength as the carbon fiber, so this will need to be adjusted for during testing.

The main issue that arose from printing the support arm is that the arm kept lifting from the platform. This made it so the printing could not continue, and it had to be restarted 5 different times for it to print. The last attempt acetone was used about an hour into printing to get the support arm to stick and to stay on the surface. The arm was able to be finished and matched up perfectly with the mirror holder. The only issue that needed to be solved was detaching the mirror from the face of the support beam that had been printed.

Support Plate

The support plates were by far the easiest item to print out. This is in large part because it's such a simple shape. The support plate was printed once before the design was slightly changed to make it thinner and more elastic than the first print put. There were no noticeable deficiencies in the design. However, the thickness of the plate lacked bendability, this resulted in a design change to make it slightly thinner than the first print out.

The second print out of the support plate had its difficulties but after 2 attempts, the support plate was able to be finished. The time needed to print these parts was shorter in comparison to other parts, in large part because they did not need to be reprinted later.

Testing the Design

Testing Issues

Some of the issues in the testing process were more logistical than with the actual project itself. Many of the plans for the original testing plan had to be changed because of the ongoing changes in how school was being conducted. One of the changes that had to be made was how the support arm would be tested in the different directions. It was easier enough to check for the support in the y direction of mirror. This test was for the top loading. If the support didn't break under the weight of the mirror holder, it was determined a success. Another logistical change was where the project would be tested. Many of the tests were conducted at home or at parks in the area. Two major tests that had to be changed were the aerodynamic test and the side loading test.

The last issue there was that occurred during some of the tests was some of the parts didn't survive the initial testing. So, the other mirror components needed to be used in order to complete the testing. However, in future testing of the design, this should be kept in mind just in case parts do break that weren't intended to break.

Final Testing Info

During the process of testing, there were some issues. Either parts broke when they were not intended to break, or logistically tests could not take place due to the resources that were available. The biggest testing problems were not from breaking of parts but because tests couldn't happen. To keep others safe during the testing session, the wind tunnel needed for tests was not available. This means in the future this test will need to be done to get definitive account of the whole testing process and what can and needs to be improved. The other test that was unable to be performed was the side loading because the requirement was 200 lbs. but without access to a machine or 200 lbs. worth of weight the mirror was unable to be tested.

However, even with all the issues in testing, the greatest successes for the project came from top loading and the deflection tests. The top loading was not tested to failure, but it was tested to over the required limit of 2.5 lbs. and was still under the maximum deflection that was deemed acceptable. This means that the support arm will be able to support the mirror holder for a while before needing to be replaced and fixed. The project as whole needs work and improvements before it can be added to the electric vehicle, but the project provides a great steppingstone in the right direction. It allows for further growth to take place. The tests provided improvement areas in the support arm and in the mirror itself. The tests helped conclude that the even though ABS plastic is a great lightweight material, another material will need to be used in order to make this project more successful. In the future a recommended material of Carbon Fiber should be used because it improves strength without sacrificing weight.

Overall

This project had some difficulties when it came to creating and manufacturing parts. This resulted in overtures in time that was not originally allotted for the project. This made it so certain aspects of the project had to be changed in order to finish on time. The support for instance had to change from carbon fiber to ABS because there was just not enough time to create cores for the mirror as well create the carbon fiber parts. Another part that required changing was the mirror holder. This part was extremely difficult because it had to be printed twice which resulting in 24 hours' worth of printing time. It would've taken more time but since time was short adjustments were made to fix the mistakes listed above. All changes that were made were to ensure the project could be tested at the end of the manufacturing stage.

Conclusion

The purpose of this project is to create mirrors that will enable a driver to see behind them while in motion. The mirrors will follow a set of requirements that have been predetermined by the designer and their mentors. The design of this product will be completed by following the tasks that have been set forth. The tasks of assemblies, manufacturing parts, and testing will allow for the project to finish on time. Important analyses to keep in mind when the project is being fulfilled is the materials that were chosen, the shear stresses on all the parts, as well as how the minor parts will be affected by the forces of nature and assembling them together. These analyses will contribute to the final product because they will help determine ahead of time if the project is viable and can be done using the tools that are provided by the school, outside resources, and by mentors and people who intend to help finish the product on time. This project will be successful because tasks have been set with hard deadlines, resources have been outlined, and the design requirements of the project are capable of being completed and are not unreasonable.

For this project to be successful the mirrors must meet the aerodynamic factor, the weight limit, as well as the mirror component of seeing 200 ft behind the vehicle. These three requirements will be important because they cover the most important aspects of the design of the project. The main purpose of the mirror is to be able to see behind a vehicle. If this isn't met, then the projects main purpose will be useless. The aerodynamic factor is important because it allows for the drag coefficient to go unchanged for the entire vehicle. This will become important when the race takes place later. The weight limit is also important because if too much weight is added to the vehicle, it will make the vehicle heavier which will slow the vehicle down even further. These three requirements will be the most tested during the testing section of this project.

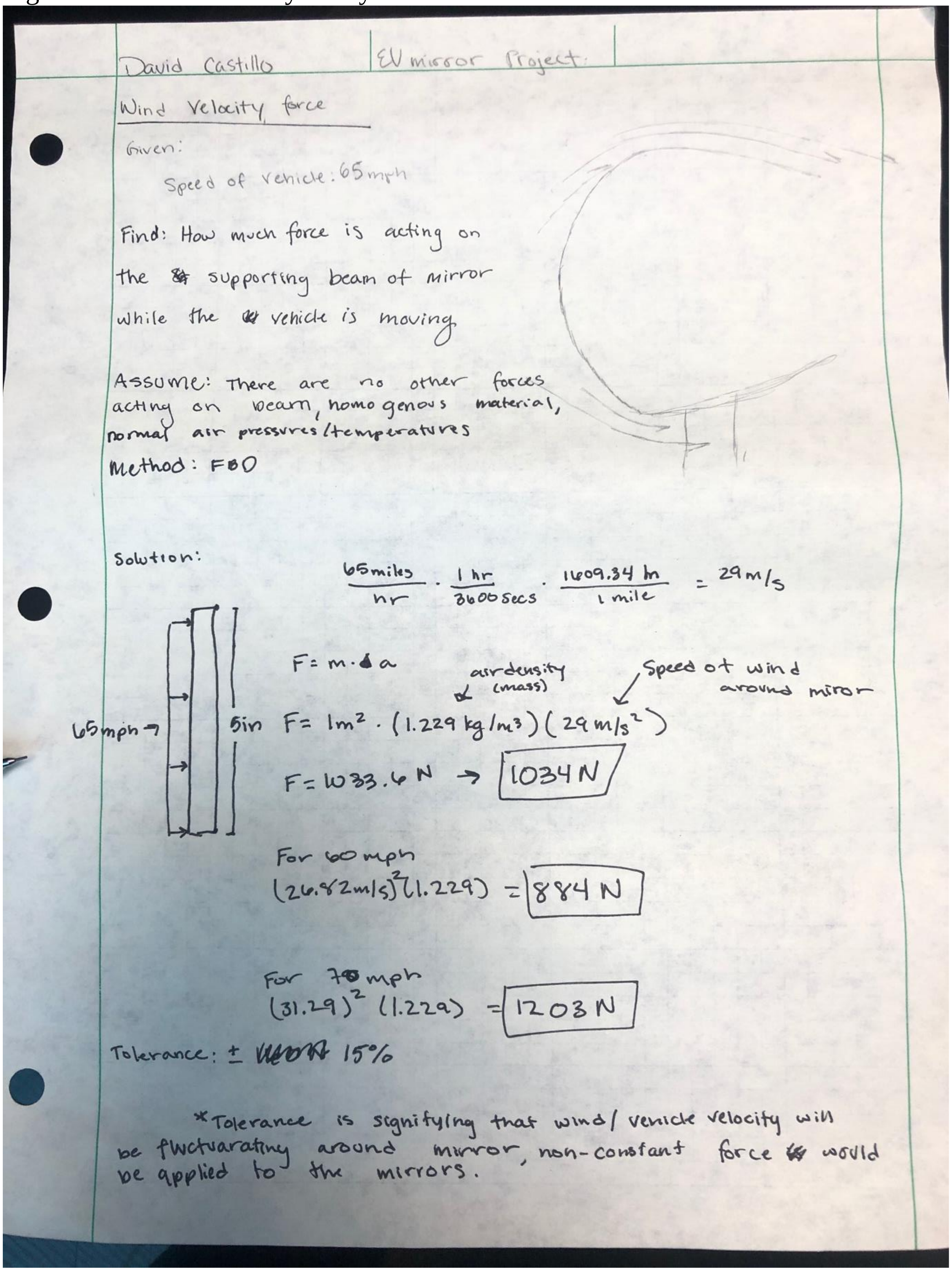
The project was finished on time. There were plenty of difficulties and things that will need to change in the future to make the project even more successful than it was during this time around. The results of the project showed that although the mirrors were a great steppingstone in the right direction for the mirrors and the electric vehicle, things will need to be improved before the project can be considered a complete success. Some things that would need to be improved are the materials for the mirrors and the reflective surface. As mentioned above the reflectivity of the mirrors was the most important aspect for this project. Even though the acrylic stickers were cheap and at the time seemed like a good alternative to actual mirrors, the result of the mirror was less than desired. It didn't reflect enough and if the mirror was even slightly distorted the image became unclear and made it difficult to see anything except blurry shapes. Unfortunately, the aerodynamic factor was not able to be tested because the wind tunnel was not able to be accessed. Without this test the mirrors could not be fully tested so this left out one of the major requirements. The last requirement that was important was the weight of the mirrors. This requirement was set because the mirrors needed to under 1 lb so they don't affect the speed of the vehicle. The mirror weight for one mirror came out to be .81 lbs. which is well under the weight requirement. This means out of the 3 requirements, only one was successful.

To improve the design of the mirrors, the mirrors will have to be made of stronger of material. Either that or the mirror support arms will need to be thicker so they can handle more weight and are better suited for the environment they will be in. The one other thing that can be fixed is the material for the mirrors. The material should be stronger and thicker than the stickers and will need to be able to handle the force of rotating the mirrors.

This project was successful in many ways and unsuccessful in others, but the goal of the project remained intact. The mirrors were finished on time and they did attach to the existing structure of the EV. They will just need to be improved.

Appendix A - Analyses

Figure A.1: Wind Velocity Analysis



David Castillo | EV mirror Project

Wind Velocity force

Given:

Speed of vehicle: 65 mph

Find: How much force is acting on the supporting beam of mirror while the vehicle is moving

Assume: There are no other forces acting on beam, homogenous material, normal air pressures/temperatures

Method: FBD

Solution:

$$\frac{65 \text{ miles}}{\text{hr}} \cdot \frac{1 \text{ hr}}{3600 \text{ secs}} \cdot \frac{1609.34 \text{ m}}{1 \text{ mile}} = 29 \text{ m/s}$$

65 mph → 5 in

$F = m \cdot a$

air density (mass)

Speed of wind around miror

$F = 1 m^2 \cdot (1.229 \text{ kg/m}^3)(29 \text{ m/s}^2)$

$F = 1033.6$ N → **1034 N**

For 60 mph

$(26.82 \text{ m/s})^2 (1.229) =$ **884 N**

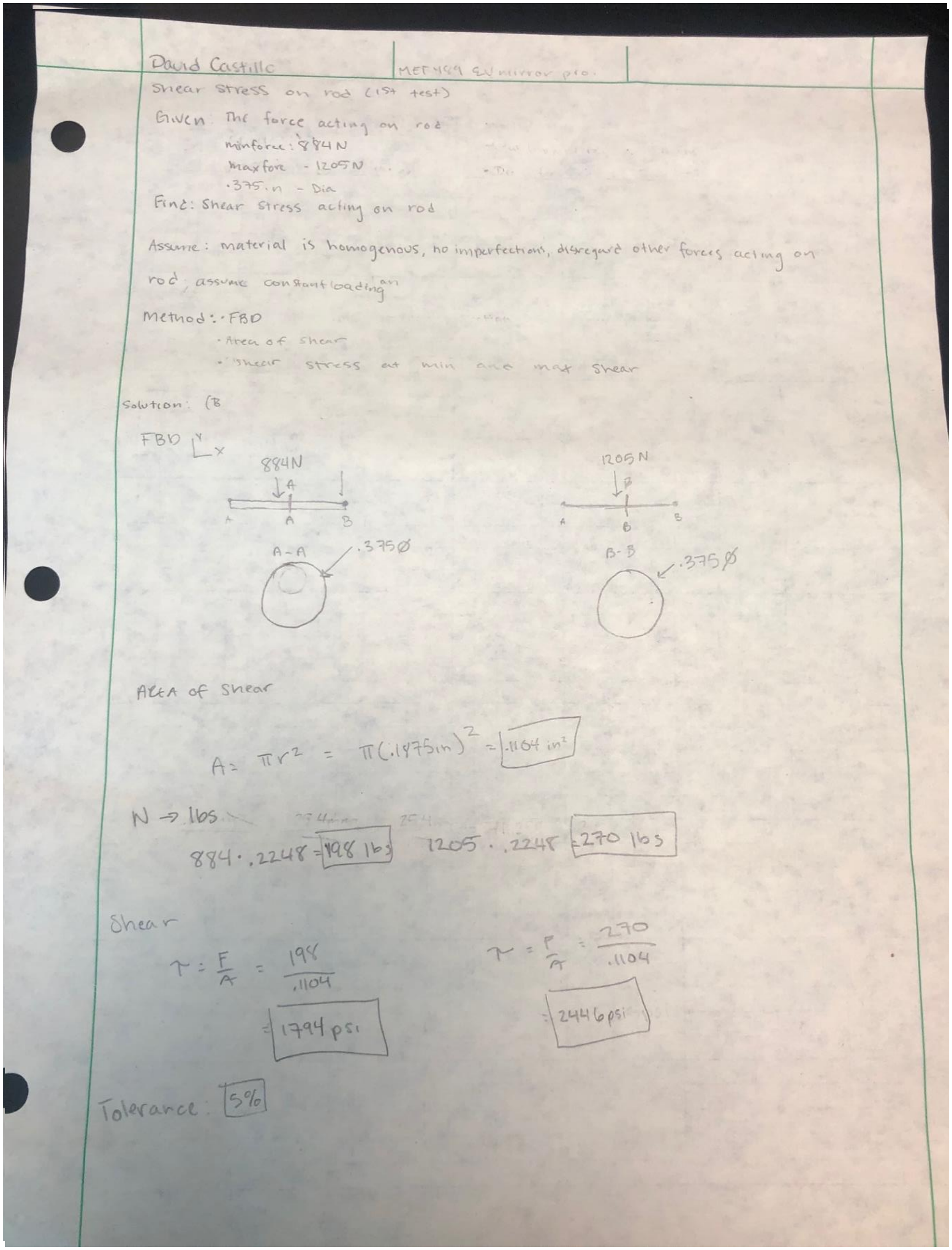
For 70 mph

$(31.29)^2 (1.229) =$ **1203 N**

Tolerance: ± 15%

*Tolerance is signifying that wind/vehicle velocity will be fluctuarating around mirror, non-constant force would be applied to the mirrors.

Figure A.2: Shear Stress on Supporting Rod (Short side)



David Castillo | MET 489 SW mirror pro.

Shear stress on rod (1st test)

Given: The force acting on rod

minforce: 884 N

max force - 1205 N

.375 in - Dia

Find: Shear stress acting on rod

Assume: material is homogenous, no imperfections, disregard other forces acting on rod, assume constant loading

Method: · FBD

· Area of shear

· shear stress at min and max shear

Solution: (B

FBD

Area of shear

$A = \pi r^2 = \pi (.1875 in)^2 = .1104 in^2$

N → lbs

$884 \cdot .2248 = 198 lbs$ $\quad 1205 \cdot .2248 = 270 lbs$

Shear

$\tau = \frac{F}{A} = \frac{198}{.1104} = 1794 psi$ $\quad \tau = \frac{F}{A} = \frac{270}{.1104} = 2446 psi$

Tolerance: 5%

Figure A.3: Ideal Length from Mirror Edge to Car Edge

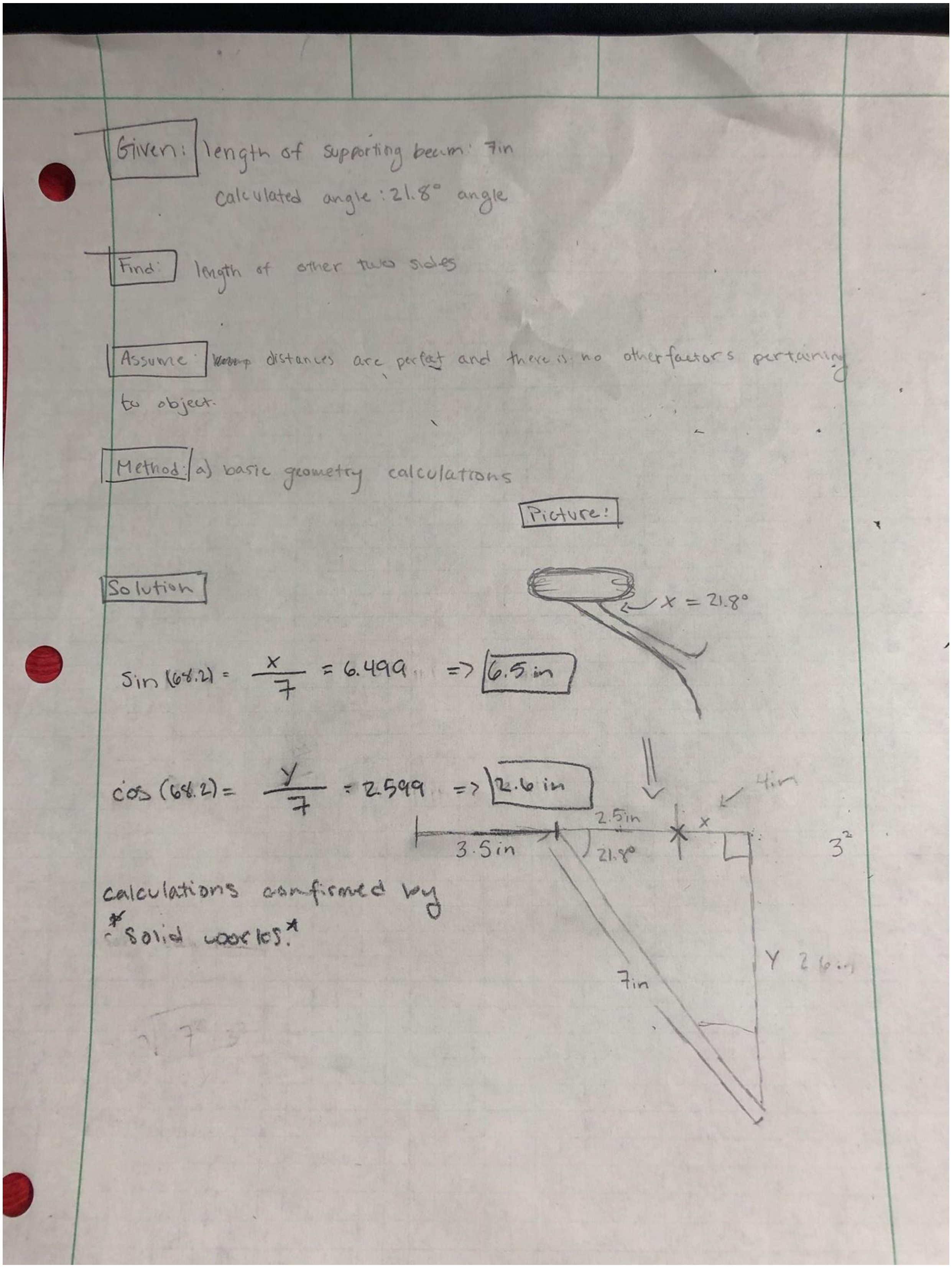
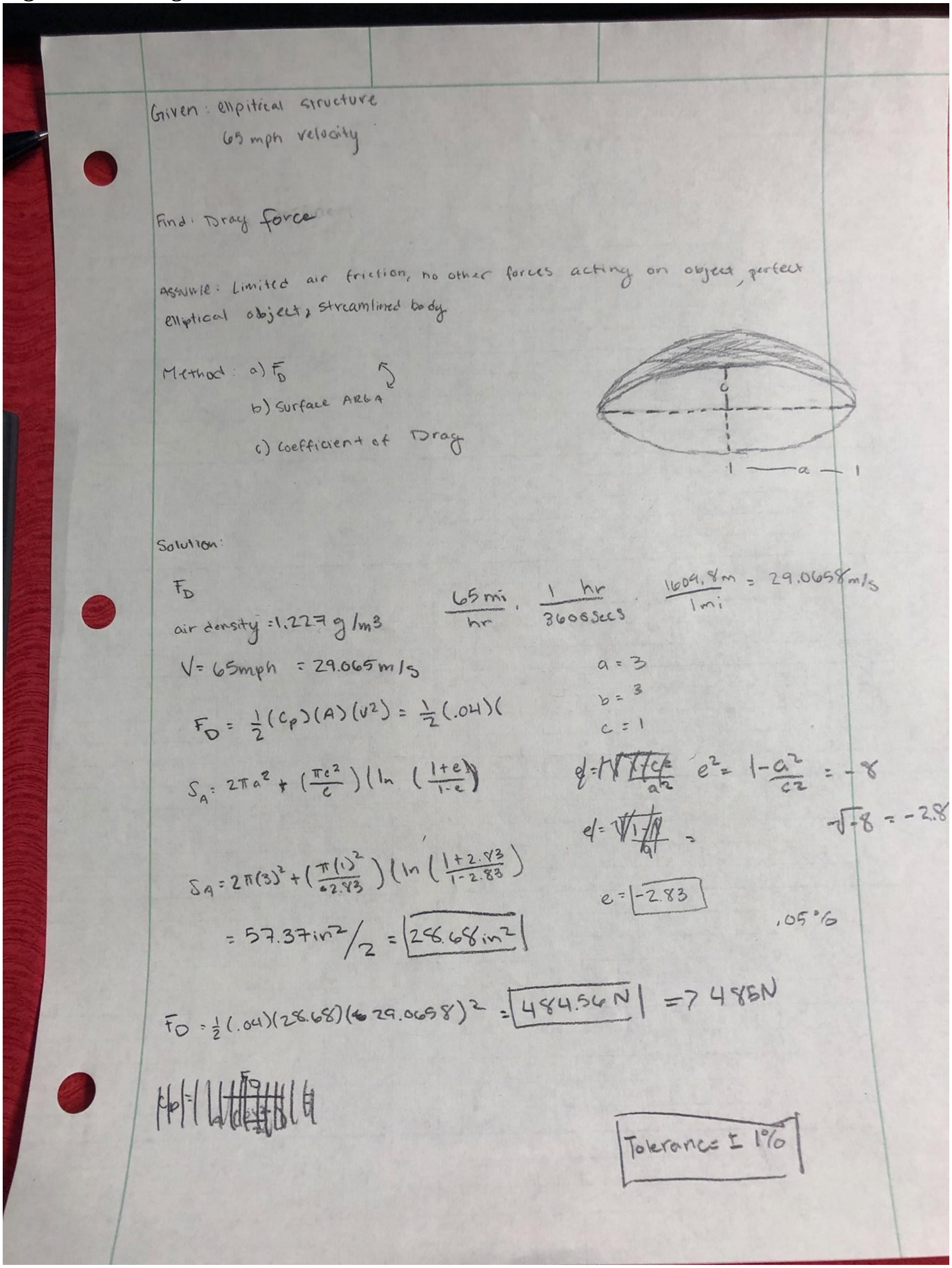


Figure A.4: Drag Force on Mirror Holder



Given: ellipitical structure
65 mph velocity

Find: Drag force

Assume: Limited air friction, no other forces acting on object, perfect elliptical object, streamlined body

Method: a) F_D
b) Surface Area
c) Coefficient of Drag

c
a

Solution:

F_D

air density = 1.227 g/m3

$\frac{65\ mi}{hr} \cdot \frac{1\ hr}{3600\ secs} \cdot \frac{1609.8\ m}{1\ mi} = 29.0658\ m/s$

V = 65mph = 29.065 m/s

a = 3
b = 3
c = 1

$F_D = \frac{1}{2}(C_D)(A)(v^2) = \frac{1}{2}(.04)($

$S_A = 2\pi a^2 + \left(\frac{\pi c^2}{e}\right)\left(\ln\left(\frac{1+e}{1-e}\right)\right)$

$e^2 = 1 - \frac{a^2}{c^2} = -8$

$\sqrt{-8} = -2.8$

$S_A = 2\pi(3)^2 + \left(\frac{\pi(1)^2}{-2.83}\right)\left(\ln\left(\frac{1+2.83}{1-2.83}\right)\right)$

$= 57.37\ in^2 / 2 = 28.68\ in^2$

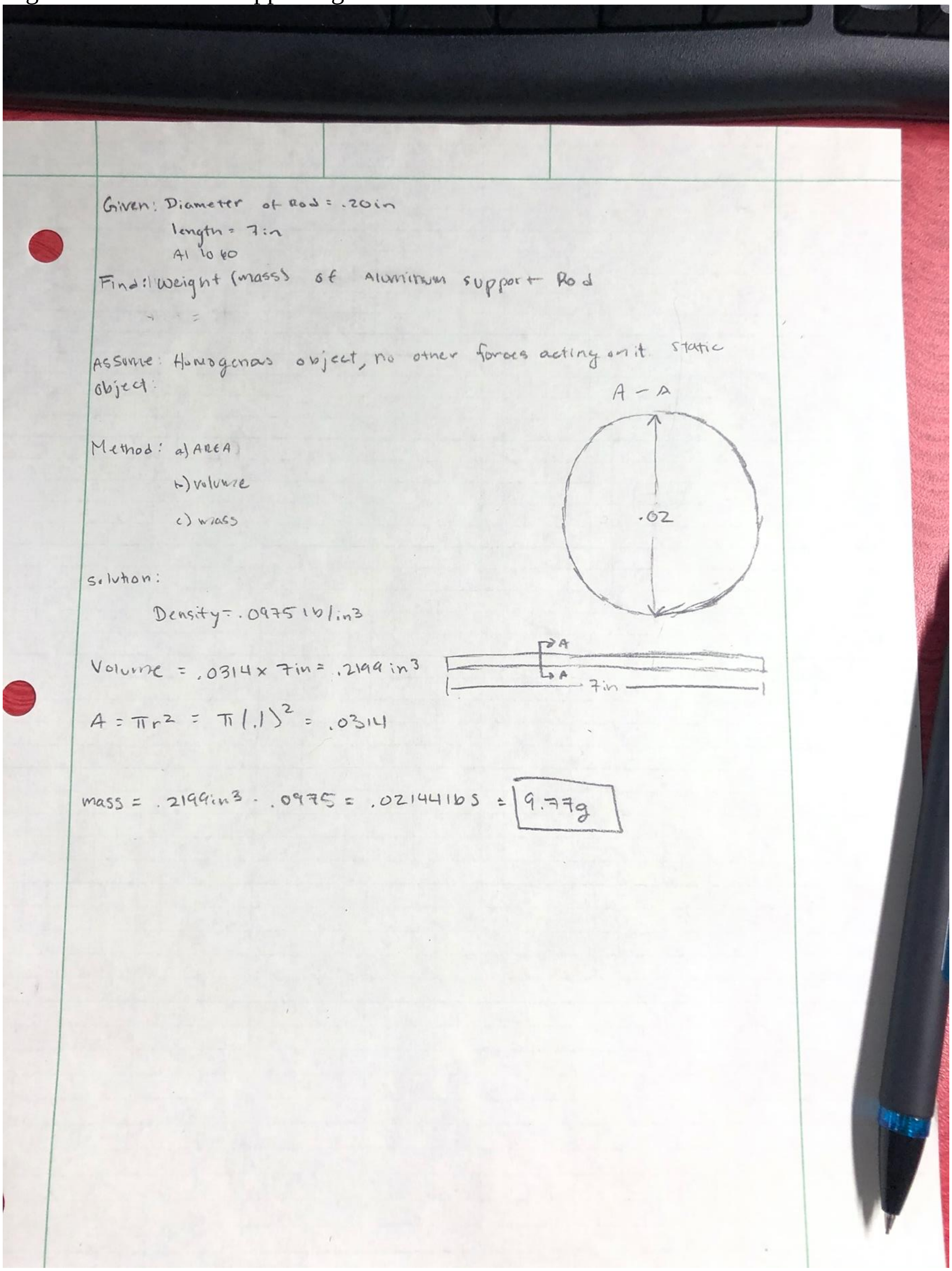
e = -2.83

.05%

$F_D = \frac{1}{2}(.04)(28.68)(29.0658)^2 = 484.56\ N \Rightarrow 485N$

Tolerance ± 1%

Figure A.5: Mass of Supporting Beam


Given: Diameter of Rod = .20in
length = 7in
Al 6061
Find: weight (mass) of Aluminum support Rod

Assume: Homogenous object, no other forces acting on it static object.

Method: a) AREA
b) volume
c) mass

Solution:

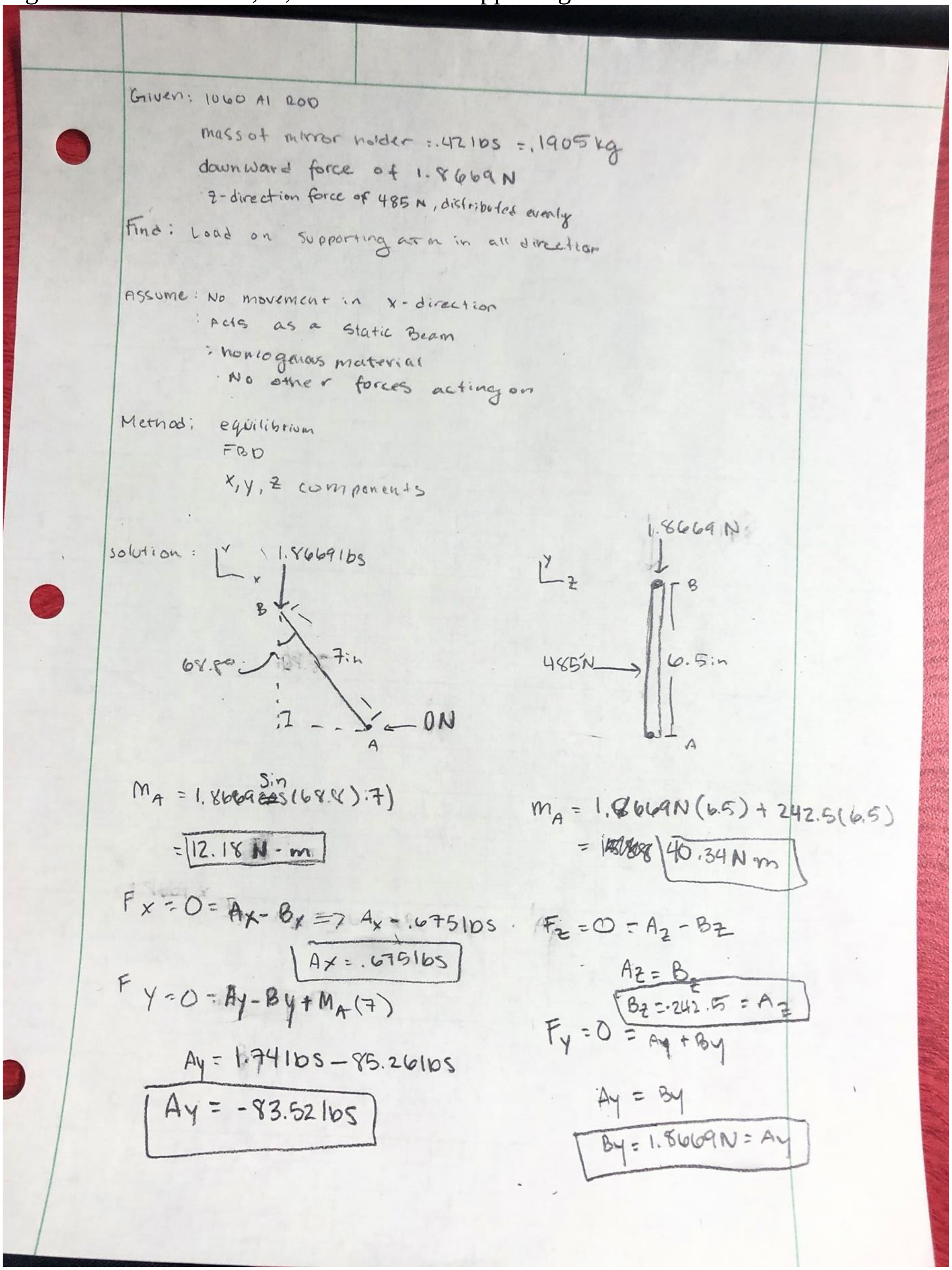
Density = .0975 lb/in3

Volume = .0314 x 7in = .2199 in3

A = πr2 = π(.1)2 = .0314

mass = .2199in3 · .0975 = .02144lbs = 9.77g

Figure A.6: Loads in X, Y, Z direction of Supporting Beam


Given: 1060 Al ROD

mass of mirror holder = .42 lbs = .1905 kg

downward force of 1.8669 N

z-direction force of 485 N, distributed evenly

Find: Load on Supporting arm in all direction

Assume: No movement in x-direction

: Acts as a Static Beam

: homogenous material

: No other forces acting on

Method: equilibrium

FBD

x, y, z components

$M_A = 1.8669 \sin(68.8)\cdot 7)$

$= 12.18\ N\cdot m$

$F_x = 0 = A_x - B_x \Rightarrow A_x = .675\ lbs$

$A_x = .675\ lbs$

$F_y = 0 = A_y - B_y + M_A(7)$

$A_y = 1.74\ lbs - 85.26\ lbs$

$A_y = -83.52\ lbs$

$M_A = 1.8669N(6.5) + 242.5(6.5)$

$= 40.34\ N\cdot m$

$F_z = 0 = A_z - B_z$

$A_z = B_z$

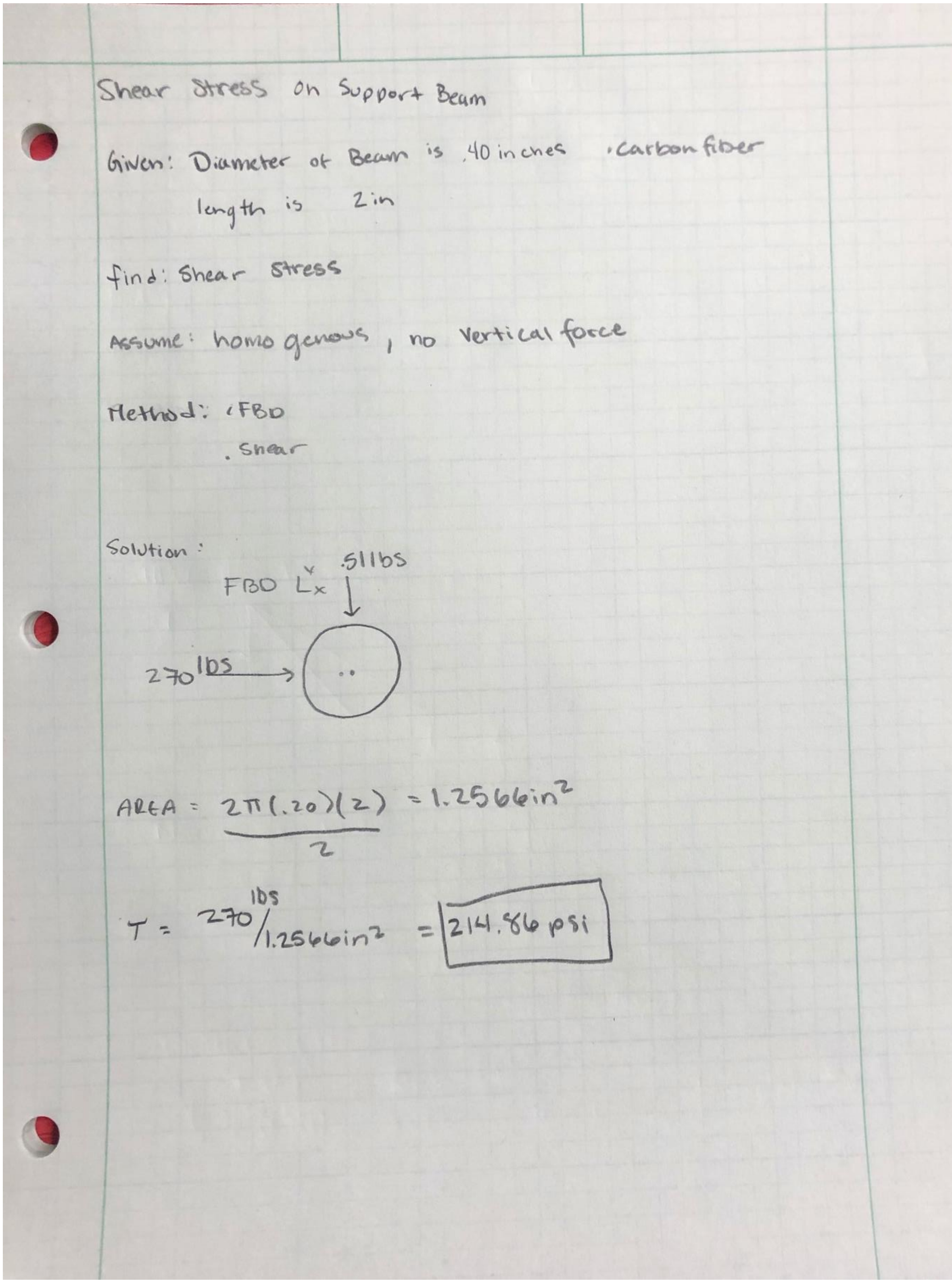
$B_z = -242.5 = A_z$

$F_y = 0 = A_y + B_y$

$A_y = B_y$

$B_y = 1.8669N = A_y$

Figure A.7: Maximum Allowable Shear Stress on Supporting Beam (Long Side)



Shear Stress on Support Beam

Given: Diameter of Beam is .40 inches
· Carbon fiber
length is 2in

find: Shear Stress

Assume: homogenous, no vertical force

Method: · FBD
· Shear

Solution:

$$AREA = \frac{2\pi(.20)(2)}{2} = 1.2566 in^2$$

$$T = 270 lbs / 1.2566 in^2 = \boxed{214.86 psi}$$

Figure A.8: Decision Matrix for Supporting Beam

Material Choice for Supporting Beam									
		Score: 0 to 3 (best)							
Criterion	**Weight**	**3**	ABS		Carbon Fiber		Aluminum		
	1 to 3 (must)	Best Possible	1	Score x Wt	2	Score x Wt	2	Score x Wt	
Design	3	9	3	9	3	9	1	3	
Cost	3	9	2	6	1	3	1	3	
Molding Abilty	2	6	3	6	2	4	1	2	
Obtaining Material	1	3	2	2	1	1	3	3	
Size	1	3	1	1	3	3	2	2	
Testing Capabilty	2	6	3	6	2	4	1	2	
Total	12	36		30		24		15	
NORMALIZE THE DATA (muliply by fraction, N)			2.8	83.3		66.7		41.7	Percent
								63.9	Average
								21.0	Std Dev.
Decide if Bias is Good or Bad		Good Bias:	Standard Deviation is two or more digits				Good? Then you're done.		
		Poor Bias:	Standard Deviation is one or less digits				Poor? Then change something!!!		
			You can change the criteria, weighting, or the projects themselves…						
	Weighting/Scoring Scale								
		1	Worst (too many hours, too little technical content, too big, too costly etc.)						
		2	Median Values, or Unsure of actual value						
		3	Best (Low Cost, Very Feasible, High industrial involement)						
	Criterion								
		Design	How easilty will it to be to design the rod in SolidWorks						
		Cost	How much it will it cost to get the materials						
		Mold. Ability	How easily can the material be molded to fit the current struture						
		Obt. Mat.	Is the material easily obtained						
		Size	How much material will need to be used in order to accomplish the support beam						
		Test. Cap.	How easily can the material be tested with current capabilites of school facilities						

According to decision matrix the best material to use for the supporting beam would be ABS and aluminum although cheap and easily accessible would be the worst choice for the beam. Even though the ABS would be the best option for the supporting beam, the strength of the actual material would require for more material to be used in order to support the weight of the mirror at the desired angle, as well as, the shear stress caused by the wind. To accomplish the task at hand, the best option would be Carbon Fiber due to its strength, sizing requirements, and molding capabilities. It is not directly in the middle of the materials chosen to examine, but it leans toward the ABS side which means it will closely match to the same criterion as the ABS. It will be more expensive, but less material will need to be used and it fits the needs of the project.

Figure A.9: Decision Matrix for Material Selection of Mirror Structure

Material Choice for Mirror Structure									
		Score: 0 to 3 (best)							
Criterion	**Weight**	**3**	ABS		Carbon Fiber		Aluminum		
	1 to 3 (must)	Best Possible	1	Score x Wt	2	Score x Wt	2	Score x Wt	
Design	2	6	3	6	3	6	1	2	
Cost	3	9	2	6	1	3	1	3	
Molding Abilty	3	9	3	9	2	6	1	3	
Obtaining Material	2	6	2	4	1	2	3	6	
Size	2	6	1	2	3	6	2	4	
Testing Capabilty	1	3	3	3	2	2	1	1	
Weight	3	9	3	9	2	6	1	3	
Total	16	48		39		31		22	
NORMALIZE THE DATA (muliply by fraction, N)			2.1	81.3		64.6		45.8	Percent
								63.9	Average
								17.7	Std Dev.

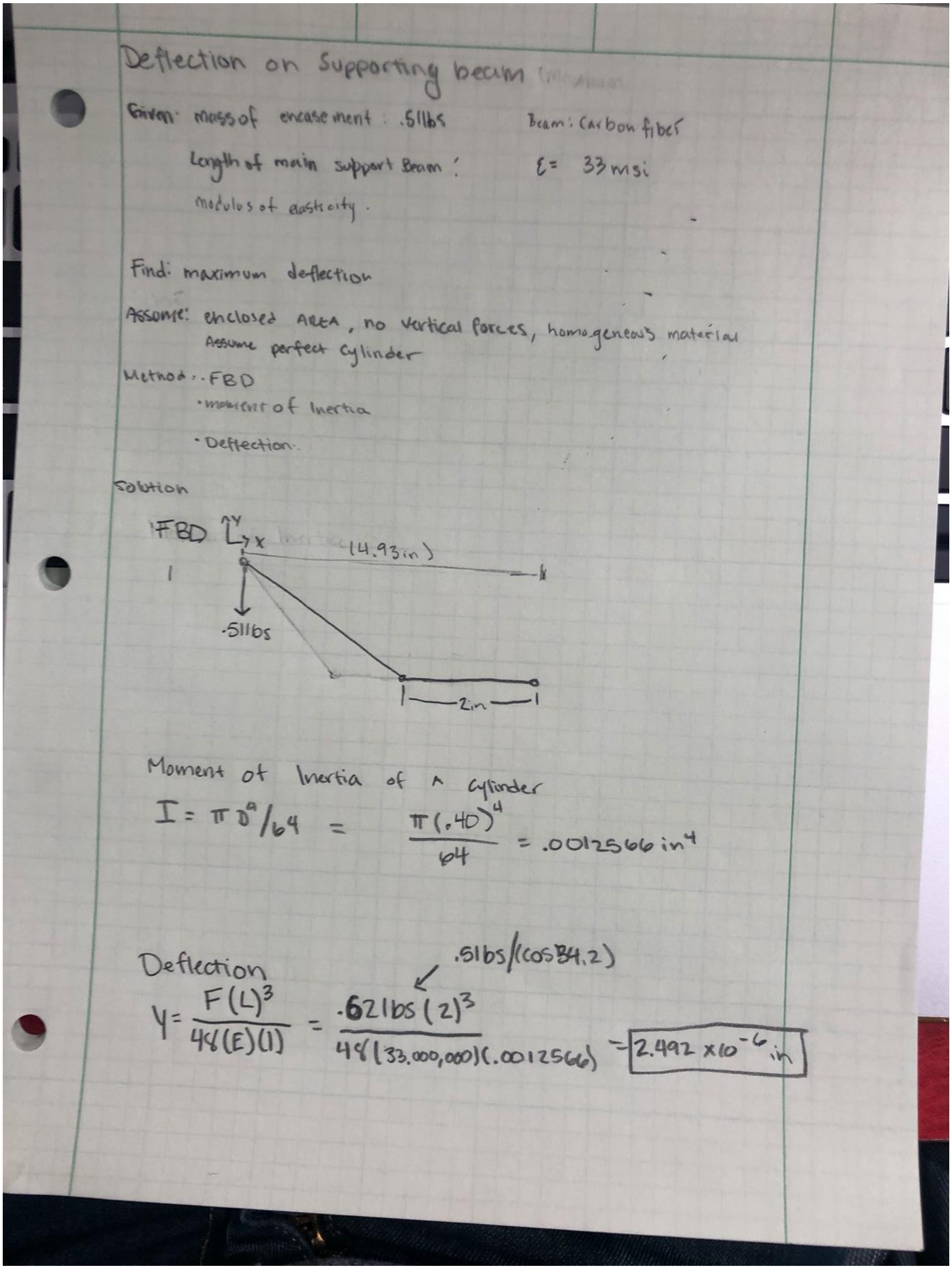
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then you're done.
	Poor Bias:	Standard Deviation is one or less digits	Poor? Then change something!!!
		You can change the criteria, weighting, or the projects themselves…	

Weighting/Scoring Scale	
1	Worst (too many hours, too little technical content, too big, too costly etc.)
2	Median Values, or Unsure of actual value
3	Best (Low Cost, Very Feasible, High industrial involement)

Criterion	
Design	How easilty will it to be to design the rod in SolidWorks
Cost	How much it will it cost to get the materials
Mold. Ability	How easily can the material be molded to fit the current struture
Obt. Mat.	Is the material easily obtained
Size	How much material will need to be used in order to accomplish the support beam
Test. Cap.	How easily can the material be tested with current capabilites of school facilities
Weight	How light is the material

This decision matrix was to help determine which material would be best for the actual mirror encasement. The decision matrix shows that ABS would be the best option for the project. However, due to its strength being low, it was determined the best course of action would be to use an ABS inner encasement and a carbon fiber shell surrounding it. This will allow for extra strength in the mirror enclosure. It would also keep the mirror relatively light since a requirement for the project is to keep the weight of each mirror under 1 lb. This will be easily done because of the strength and the lightness of the product.

Figure A.10: Deflection of Supporting Beam



Deflection on Supporting beam

Given: mass of encasement: .51lbs

Beam: Carbon fiber

Length of main support Beam:

E = 33 msi

modulus of elasticity.

Find: maximum deflection

Assume: enclosed Area, no vertical forces, homogeneous material

Assume perfect cylinder

Method: · FBD

· moment of Inertia

· Deflection.

Solution

Moment of Inertia of a cylinder

$$I = \pi D^4/64 = \frac{\pi(.40)^4}{64} = .0012566\ in^4$$

Deflection

.51lbs/(cos 34.2)

$$y = \frac{F(L)^3}{48(E)(I)} = \frac{.62lbs(2)^3}{48(33{,}000{,}000)(.0012566)} = 2.492\times10^{-6}\ in$$

Figure A.11: Shear Stress on Screws

Calculating shear stress for a screw

Given: Depth of hole (through): .20 + .35 + .125 = .675 inches

material of objects - carbon fiber

wind force: 1200N @ 70mph → 270 lbs ≈

find: Determine if chosen screws are strong enough off of shear stress on screw

Assume: No other forces acting on it, enclosed environment, use safety factor 1.5

Method: ∟ FBD

Shear stress

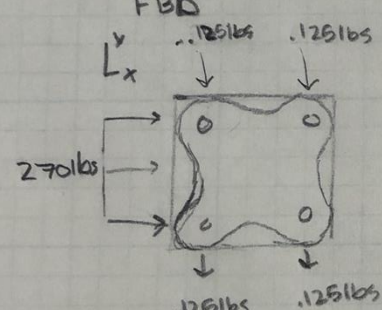
screw size / Dimension

Solution

Screw depth = .675 · 1.5 = .9375

15/16 → 1 in

FBD



only one side will be getting full force of wind

Shear Stress

AREA: 2πrh/2

T = shearing force / AREA

$$\frac{2\pi r h}{2} = \frac{2\pi .125 (1)}{2}$$

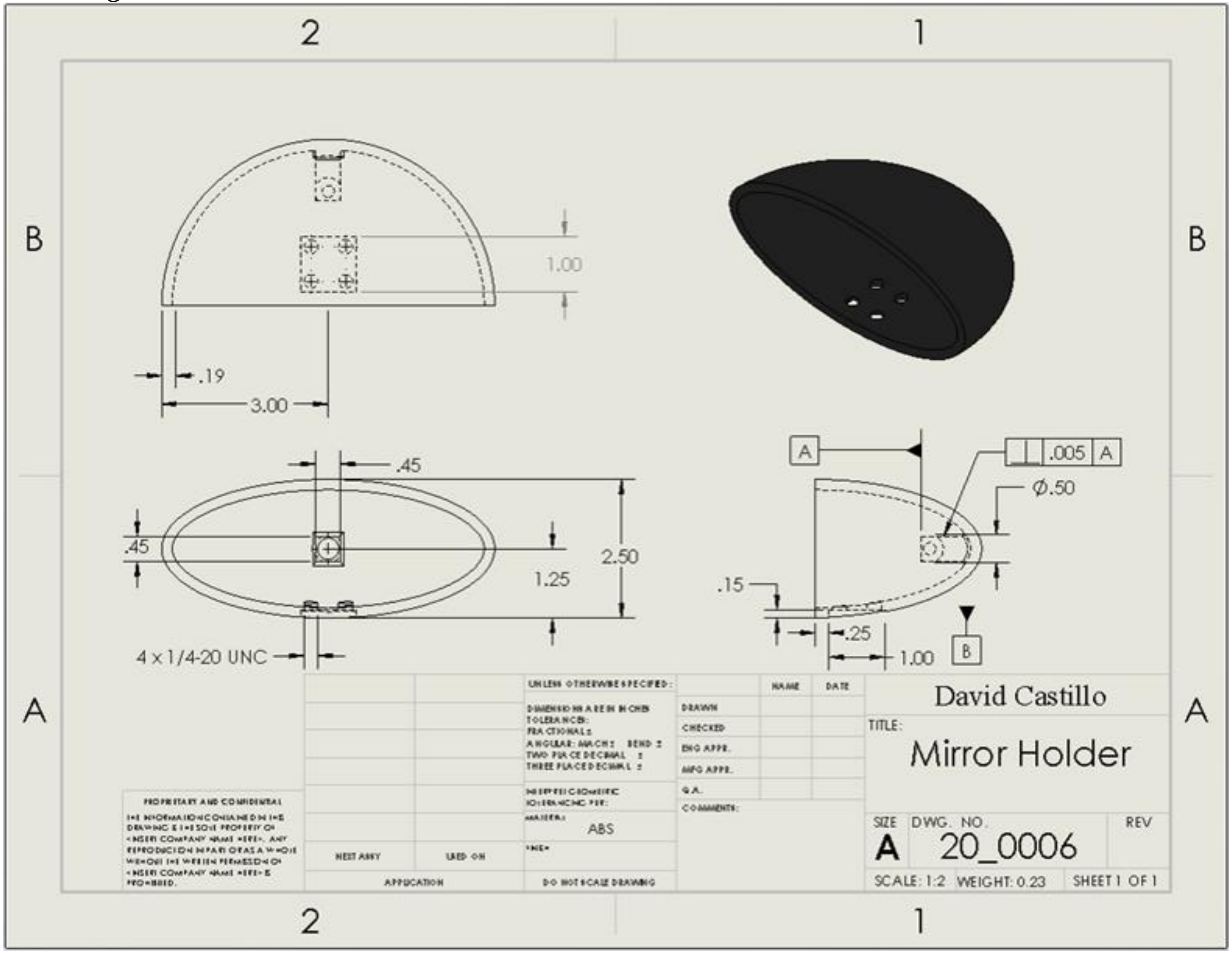
$$270\text{lbs} / .3926 = \boxed{687.55 \text{ psi}}$$

= .3926 in³

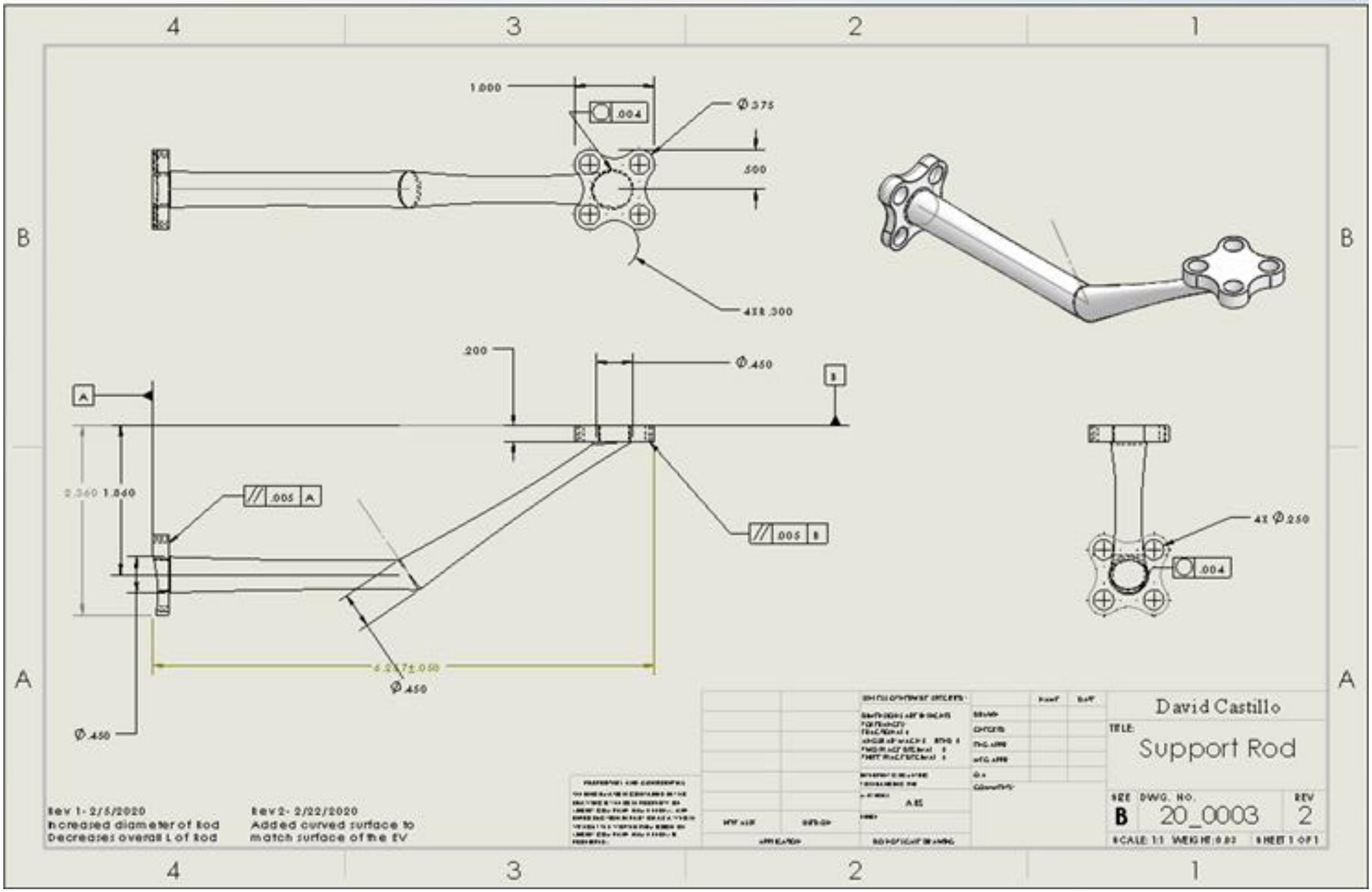
Due to the 688 psi shear stress, the screw chosen for the project will suffice because the shear stress will be shared by 4 screws

Appendix B - Drawings

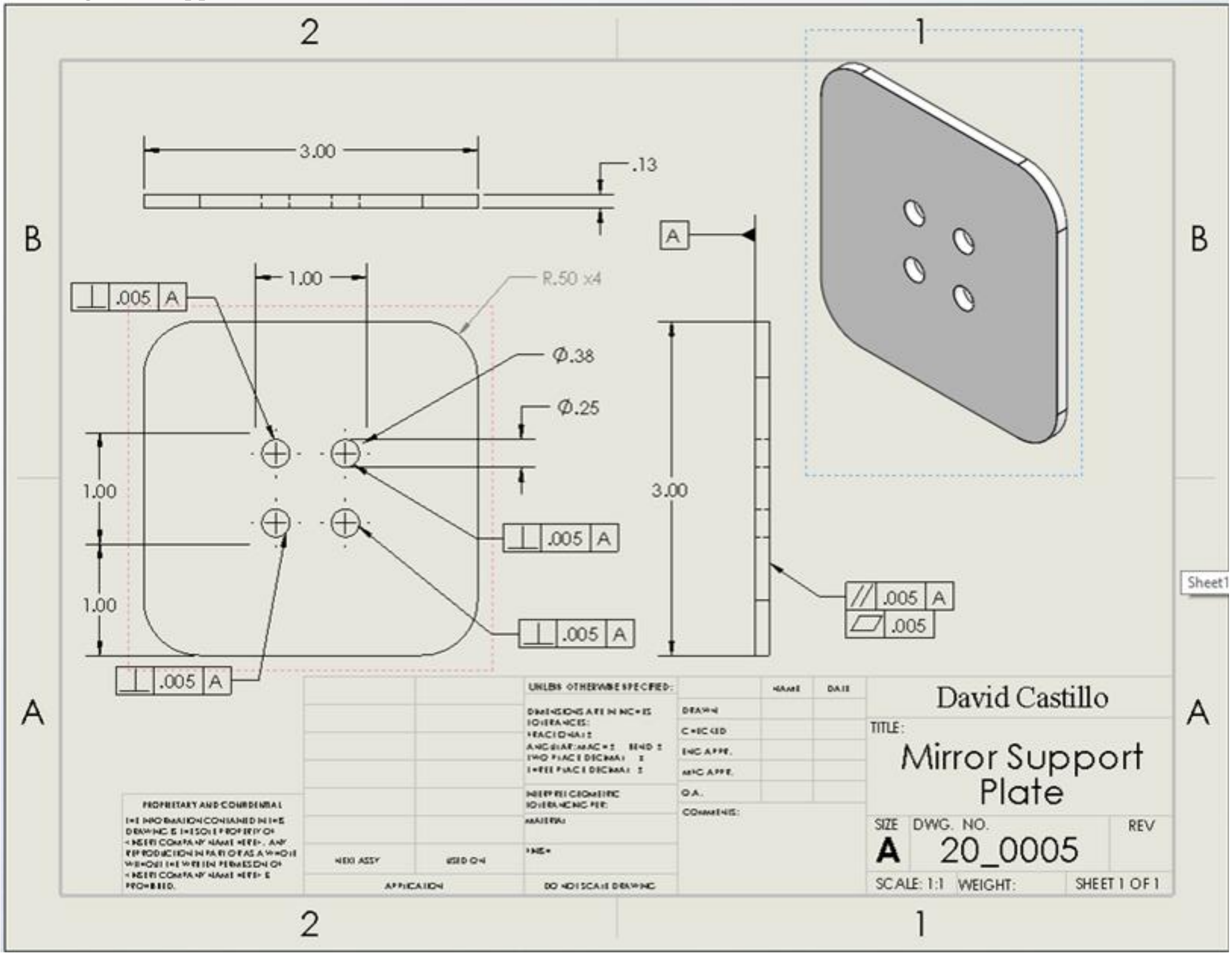
Drawing B.1: Mirror Holder



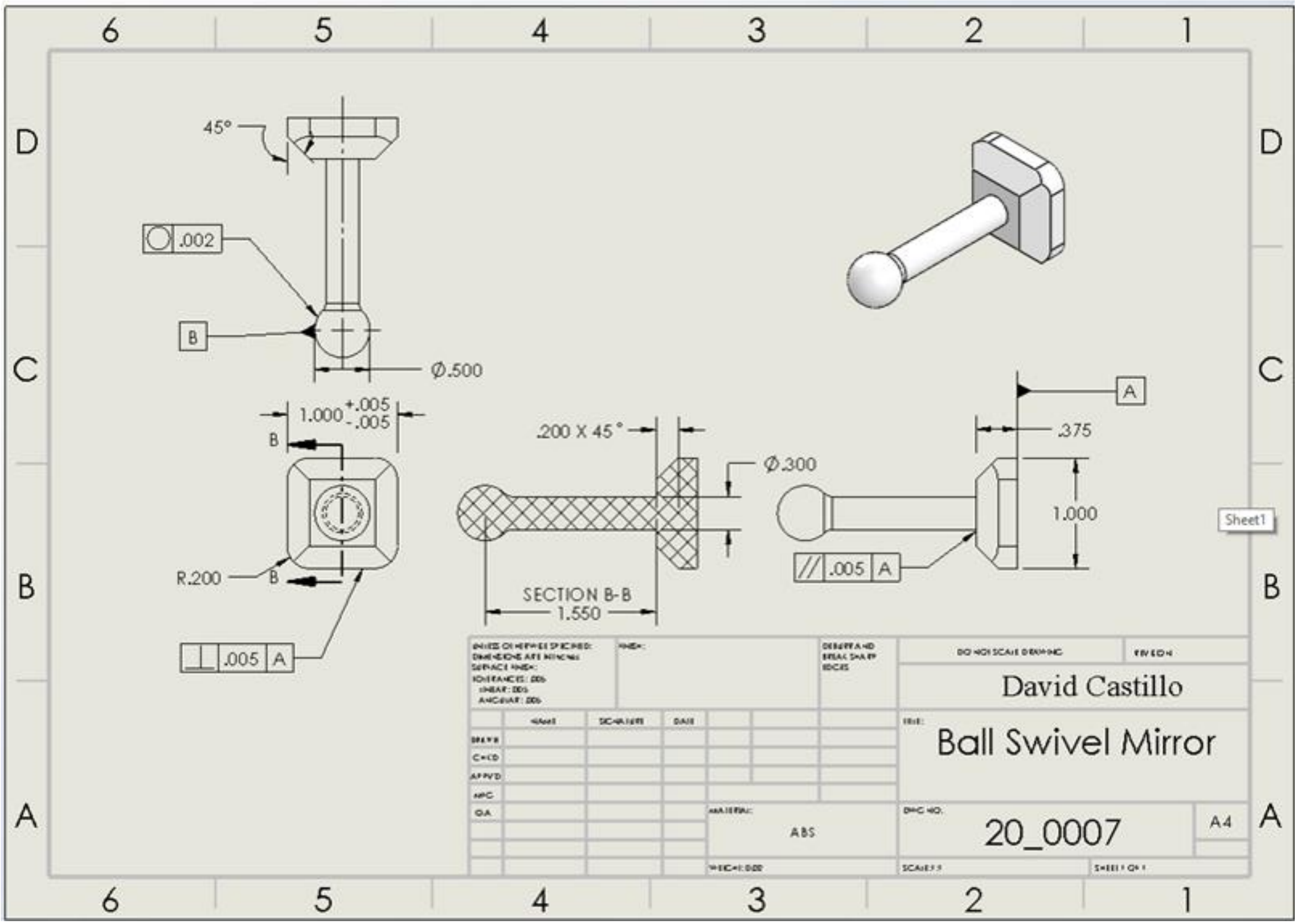
Drawing B.2: Support Arm



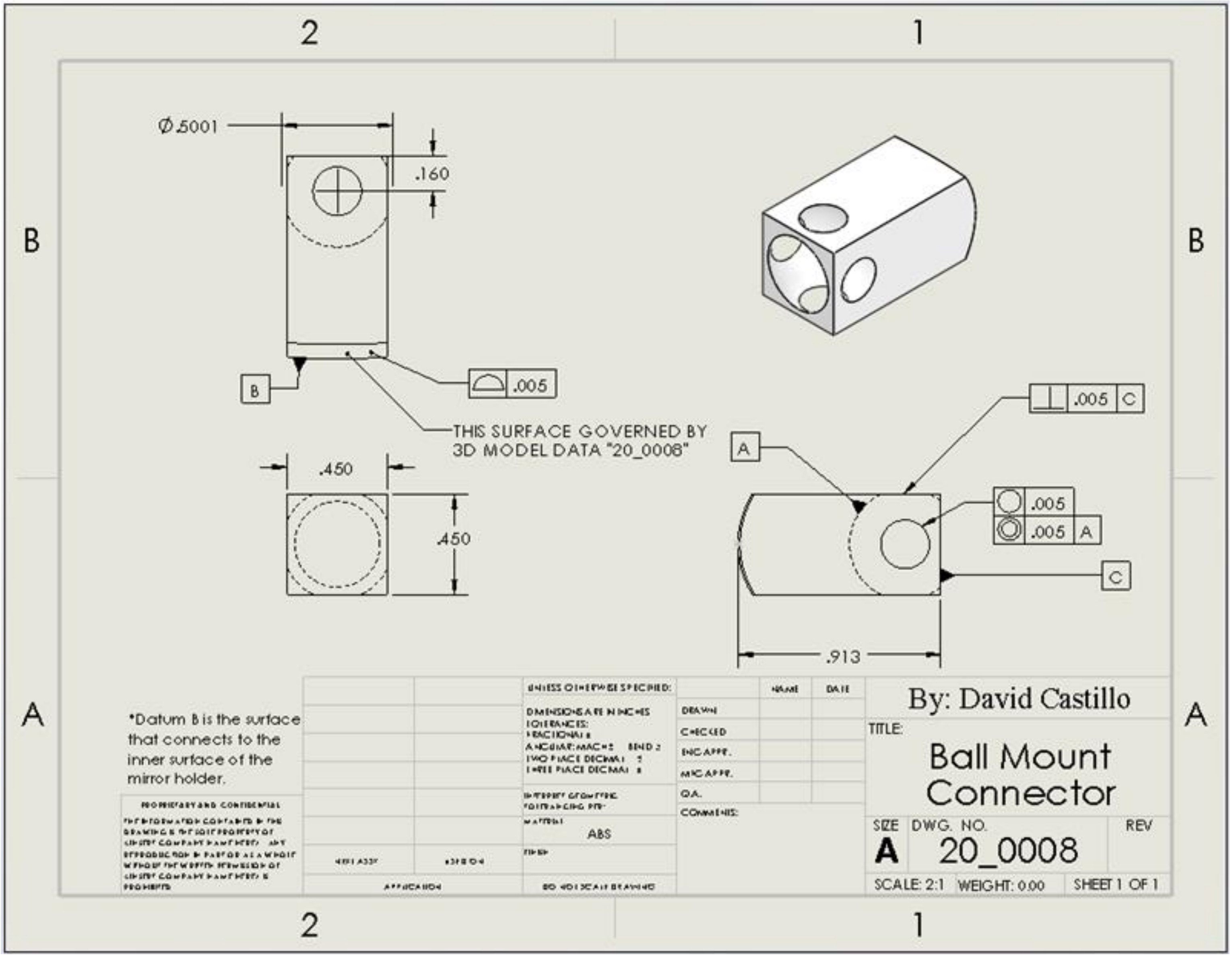
Drawing B.3: Support Plate



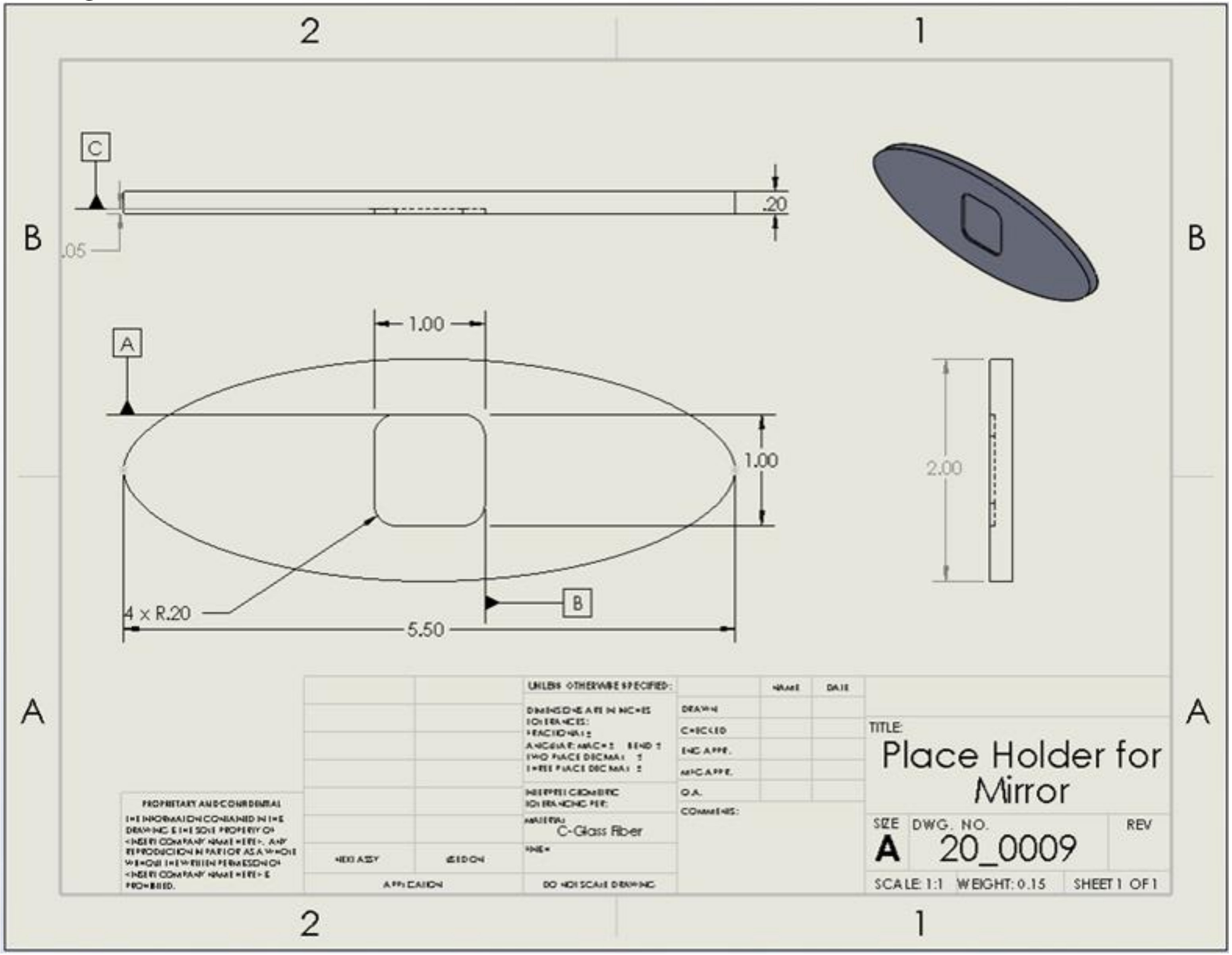
Drawing B.4: Inner Mirror Mount



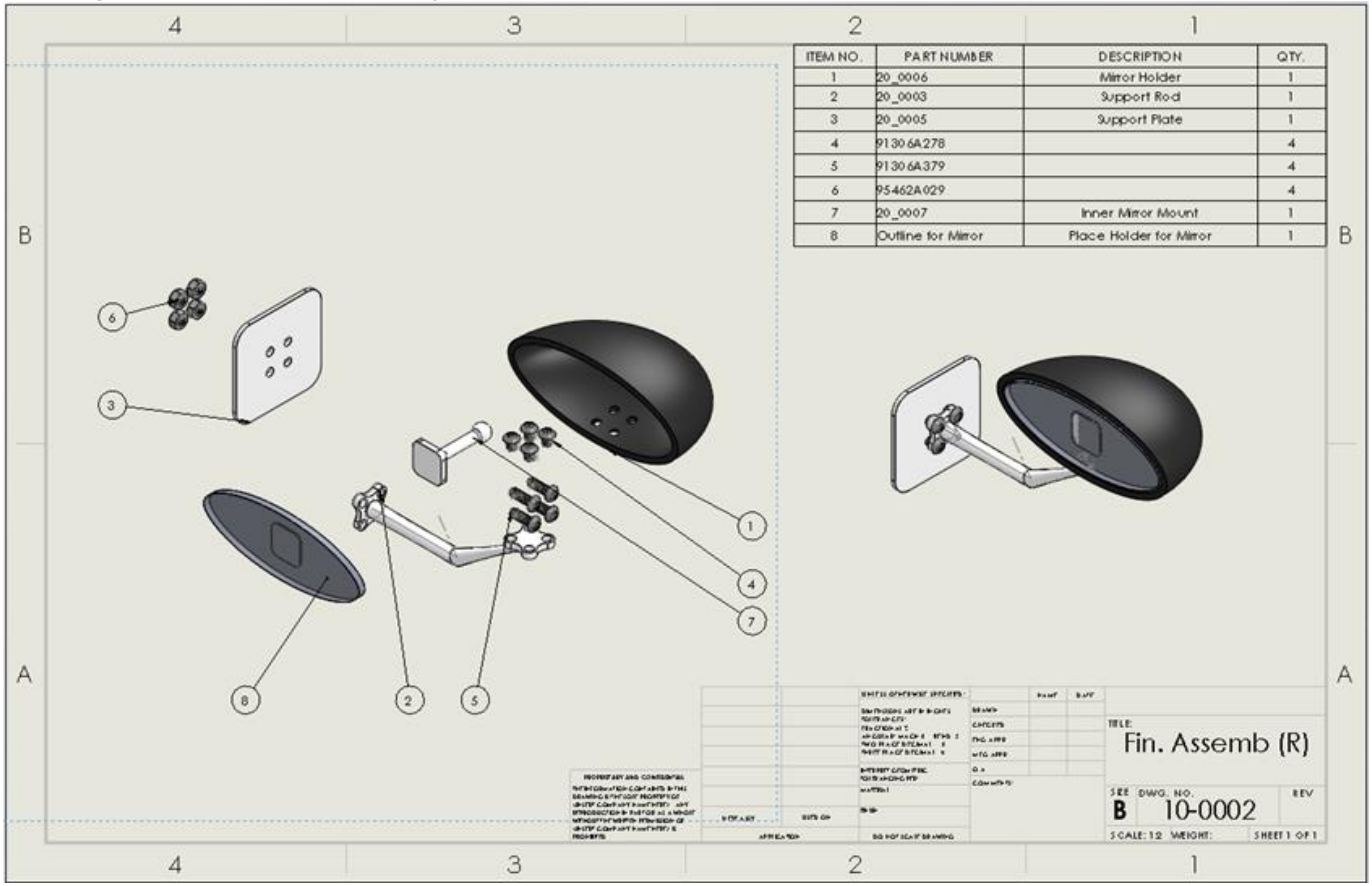
Drawing B.5: Ball Mount Connector



Drawing B.6: Mirror Place Holder



Drawing B.7: Final Mirror Assembly



Appendix C – Part List

Part	Material - ID	Brand	Qty
Mirror Holder	ABS		
Supporting Beam	ABS		
Acrylic Mirrored Surface	Chrome Mirror		4 sheets
Inner Support Plate	ABS		.5 yd
Screw Inserts	Steel	Amazon	12 pcs.
Screws	Steel	Amazon	20 pcs.

Appendix D: Budget

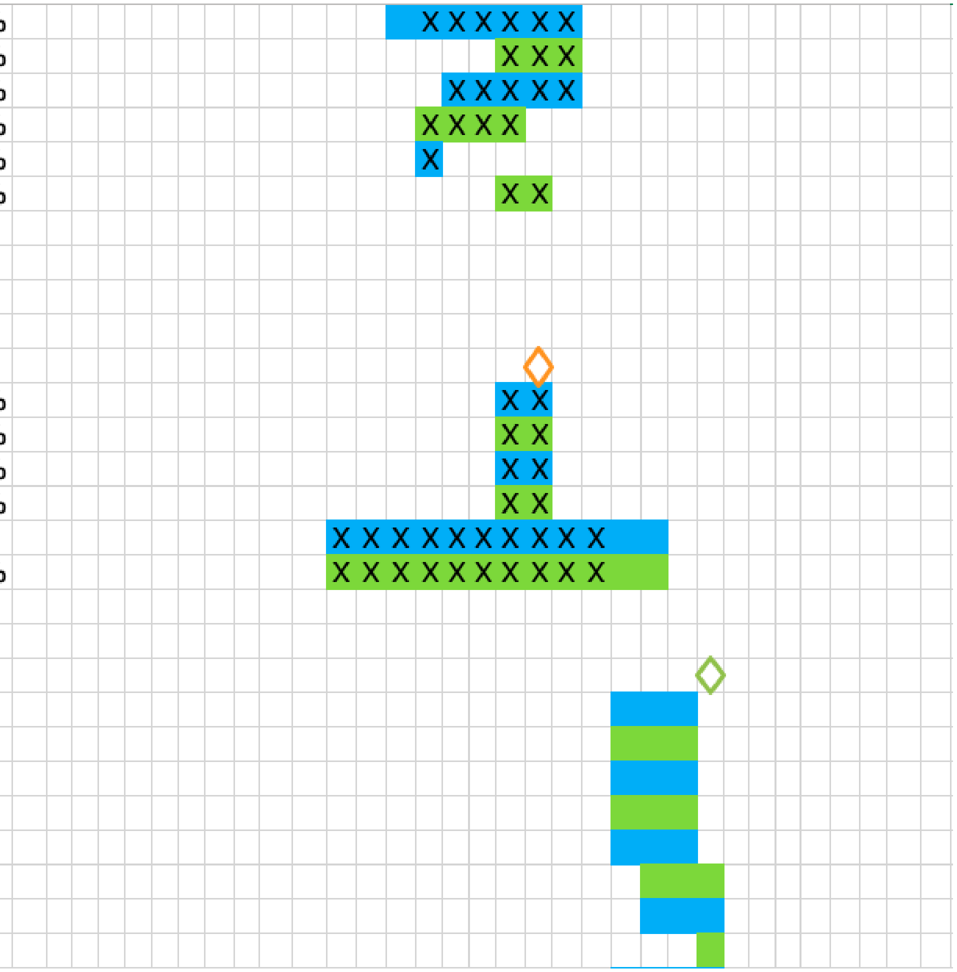
EV Mirror Project Budget												
Part	Dwg Part No.	Material	Supplier	Quanitity	Unt. of Meas.	Cost	Actual	Subtotal	w/Tax			
Outer Mirror Encasement	20_0002	Carbon Fiber		2	yd	56.65	$0.00	$113.30	$124.40			
Mirror Holder	20_0001	ABS	Amazon	1	kg	20	$30.00	$20.00	$21.96			
Support Beam	20_0003	ABS		1	kg	20	$0.00	$20.00	$21.96			
Bonding Material (CF Filament)	N/A	Resin	Amazon	1	bottle	40	$0.00	$40.00	$43.92			
Bonding Screws (.75 inches)	N/A	Steel	Amazon	1	pack	$15.49	$15.00	$15.49	$17.01			
Bonding Bolts	N/A	Zinc-Steel	Amazon	1	pack	$7.77	$15.00	$7.77	$8.53			
Bonding Washers	N/A	Steel	Amazon	1	pack	$8.25	$0.00	$8.25	$9.06			
Fine Sand Paper	N/A		Amazon	1	pack	10	$10.00	$10.00	$10.98			
Bonding Screws (1.5 inches)	N/A		Amazon	2	pack	$9.41	$15.00	$18.82	$20.66			
Support Plate		ABS		1	kg	$20.00	$5.00	$20.00	$21.96			
Inner Mirror Mount		ABS		1	kg	$20.00	$4.00	$20.00	$21.96			
						Total	$94.00	$293.63	**$322.41**	**$354.65**	Safety Budget	
Note: .75 inch screws only come in packs of 50												
Note: Bolts and washers for screws only come in packs of 100												

Appendix E: Gantt Chart

PROJECT TITLE: EV Mirror Project															
Principal Investigator.: David Castillo															
		Duration													
TASK:	Description	Est.	Actual	%Comp.	S	Oct.	Nov.	Dec	Jan.	Feb.	Mar.	Apr.	May	Jun.
ID		(hrs)	(hrs)											
1	Proposal*					X X X X		◇						
1a	Outline	2	2	100%		X X X X	X							
1b	Intro	1	2	100%		X X X	X X X							
1c	Methods	3	6	100%		X X	X X							
1d	Analysis	12	14	100%		X X X X	X X X X	X						
1e	Discussion	3	4	100%			X X X X	X						
1f	Parts and Budget	4	2	100%		X	X X X X	X						
1g	Drawings	12	8	100%	X	X X X X	X X X X	X						
1h	Schedule	2	3	100%			X X X X	X						
1i	Summary & Appx	2	3	100%			X X	X						
	subtotal:	41	44											
2	Analyses								◇					
2a	Wind Velocity Force	1	1.5	100%	X									
2b	Shear Stress on SA (Short)	1	1.3	100%	X									
2c	Ideal SA Length	1	2	100%	X	X								
2d	DragForce On Mirror Holder	1	1	100%	X	X								
2e	Mass of Support Arm	0.5	0.4	100%		X X								
2f	Load X, Y, Z SA	1	1.2	100%		X X								
2g	Max Allow Shear SA	1	1.1	100%		X	X							
2h	DecMatSupportArm	1	2	100%		X	X X							
2i	DeCMatMirrStructure	1	2	100%			X X X							
2j	Defelection Support Arm	1	1	100%			X X X							

2k	Shear Stress Screws	0.5	0.5	100%	X X
2l		0	0	100%	
	subtotal:	10	14		
3	Documentation				
3a	Mirror Holder (L)	1	3	100%	X X X X X X
3b	Support Plate	0.5	0.75	100%	X X X
3c	Support Arm	2	4	100%	X X X X X
3d	Mirror Holder (R)	1	1.6	100%	X X X X
3e	Inner Mirror Mount	0.5	1	100%	X X X X
3f	Connecting mount (int)	1	1	100%	X
3g	Mirror Surface Plate	1	0.95	100%	X X X X X
3h		0	0		
3i		0	0		
3j		0	0		
3k		0	0		
3l		0	0		
3m		0	0		
	subtotal:	7	12.3		
4	Proposal Mods				
4a	N/A	0	0		
4b	N/A	0	0		
4c	N/A	0	0		
	subtotal:	0	0		
7	Part Construction				
7a	Buy Screws and Nuts	0.2	0.5	100%	X

7b	Print Mirror Holder	24	36	100%
7c	Print Arm Support	8	10	100%
7d	Print Support Plate	6	12	100%
7e	Print Mirror Swivel	2	3	100%
7f	Buy Mirror Stickers	0.2	0.5	100%
7g	Print out inner mount	1	1	100%
	subtotal:	41	63	
9	Device Construct			
9a	Subassemb (R MH)	1	1	100%
9b	Subassemb (L MH)	1	1	100%
9c	Assembly (L)	0.8	1.5	100%
9d	Assembly (R)	0.8	1.5	100%
9e	Take Dev Pictures	0	0	
9f	Update Website	30	20	100%
	subtotal:	34	25	
10	Device Evaluation			
10a	Test for Drag Co	2	0	
10b	Test for Side loading (SA)	1	0	
10c	Test for Top Loading (SA)	1	0	
10d	Reflection Distance	0.5	0	
10e	Mirror Rotation	0.5	0	
10f	Write Testing Analysis	10	0	
10g	Make Poster Design	2	0	
10h	Print Poster	0.5	0	



10i	Update Testing Report	10	0	
10h	Update Website	15	0	
	subtotal:	43	0	
11	<u>495 Deliverables</u>			
11a	Get Report Guide	0	0	
11b	Make Rep Outline	0	0	
11c	Write Report	0	0	
11d	Make Slide Outline	0	0	
11e	Create Presentation	0	0	
11f	Make CD Deliv. List	0	0	
11e	Write 495 CD parts	0	0	
11f	Update Website	0	0	
11g	Project CD*	0	0	
	subtotal:	0	0	
	Total Est. Hours=	175	158	=Total Actual Hrs
Labor$	0	0		
Note:	Deliverables*			
	Draft Proposal			
	Analyses Mod			
	Document Mods			
	Final Proposal			
	Part Construction			
	Device Construct			
	Device Evaluation			
	495 Deliverables			

Appendix F: Expertise and Resources

People

- Dr. Johnson
- Prof. Pringle
- Dr. Choi
- Jose Reyna
- David Castillo
- Matt
- Ted Bramble
- Other Classmates

Special Needs

- Space to make the mirrors
- Space to assemble the mirrors to EV
- Access to the EV existing body
- Files to current EV project

The people for this project were all important for the process of this project. For the manufacturing section of this project the roles of the contributors became more important. Prof Pringle was very helpful in this project because he printed all the parts for the project. Bramble was also a great help to this project because he helped with making sure the drawings were up to speed with current standards for industry. Dr Choi and Dr Johnson helped with various questions throughout the quarter about materials and the report in general.

Appendix G: Testing Report

Top Loading Test

Introduction

The main purpose of this test was to determine if the support arm could support the weight of the mirror holder. The mirror holder itself is only .47 lbs. But with an ideal mirror, the entire weight of the mirror would be around .7 lbs. The ideal weight it can support is 2.5 lbs. Even though the mirror itself needs to be less than 1 lb, the support it can hold will ensure the support will not fail over time with the mirror holder on top of it. The test is labeled as a success if it reached the 2.5 lbs. without breaking.

Method and Approach

The test itself is easy to accomplish. The test only needs the mirrors, weight up to 2.5 lbs. and the data sheets for the test. To accomplish the actual test the mirrors needed a stable place to be set so the weight could be attached without causing any unwanted damage to the support arm. To ensure nothing affected the outcome of the test, everything that was not needed was moved out of the vicinity.

Testing Procedure

Summary:

The goal of this test was to test for the top loading requirement. The top loading requirement for this project is 2.5 lbs. Even though the top loading would not be this high in any circumstance, this ensures that the mirror holder would only cause the absolute minimal stress on the support. The nature of this test is simple. The test only requires the support arm, mirror holder, 1 lb weight, and a 2.5 lb weight. The test will consist of going through all 3 "weights" and informing whether it breaks or not. For further, information, deflection will be gathered as well as in later tests.

Time to Complete: Approximately 1 hour
- Set-up Time: 5 minutes
- Testing Time: 30 minutes
- Analysis Time: 25 minutes

Time of Day: N/A

Place: Home

Resources Needed:
- Data Table
- Support Arms
- Access to a Computer
- Weights up to 2.5 pounds
- Mirror Holders

Procedure:
1. To begin the test, the user would test the support arm under its own weight.
2. If there was not noticeable change of sagging than the mirror holder would be attached.

3. Once the mirror holder had been attached another a visible test would be done
4. After this the mirror holder was detached and a 1 lb weight was attached.
5. After this the 2.5 lb weight was attached to the support arm.
6. Do the steps 2 more times on the support arm.

Risk and Safety

The main risk in this test is accidently dropping a weight and it lands on a body part. To ensure that this doesn't happen always use two hand when moving the weights. Even though the weights are small, they could potentially do more damage than wanted. Another safety issue that could come up is if the support arm does break, it could splinter or have sharp ends. So always use caution when parts break. Use gloves and safety glasses always to ensure no cuts or abrasions appear and that eyes are fully protected.

Deliverables

The goal for the support arm was to support the 2.5 lb weight without breaking. The results of the test concluded that the support arm did survive the weight. The calculated value for the support arm was that it would be able to support the 2.5 lb weight and deflect 7.87x10-4 inches. So according to calculations the support arm should have easily support the weight of the mirror holder and any extra weight. Even though the test was successful, there are some aspects that could be changed to improve the design of the mirror. First the support could be designed so it was thicker so it would allow for more weight to be supported. Also, instead of just supporting the very center of the of the mirror holder, the support could follow the curvature of the mirror holder so there would be more supporting area which would increase the amount of weight that could be supported.

Mirror Rotation Test

Introduction

The main goal of this test was to determine if the mirrors could rotate as originally intended. The requirement that was being tested was mirror rotation. The requirement was at least 15 degrees in rotation. There was no maximum set for this test.

Method and Approach

The method taken for this test was just to use simple means to accomplish the test. Only a paper and pencil were needed for this test. The mirror was rotated on the x-z plane. A line would have been made on the paper where the mirror stopped rotating. The hardest was finding a stable surface to test the mirror because of the curvature of the mirror holder. Since it can't be mounted now, other means were used to stabilize it. The mirror was held between two heavier books, so the support arm was sitting in between the books while the mirror holder rested on top of the books.

Testing Procedure

Summary:

The goal of this test is to determine the maximum degree angle that the mirrors can turn without breaking or interference. This will test the requirement of the mirror rotation. The minimum standard is 15 degrees in either direction. This requirement will allow the driver to adjust the mirrors before the vehicle begins to move. Since not all drivers are the same size, the degree rotation allows for the these adjust to be made. The success of the test will be determined by if it reaches 15 degrees. If it surpasses the mark, it will be still be labeled as a success. The test will take place indoors since adjusting mirrors does not need a specific environment.

Time to Complete: Approximately 45 minutes

- Set-up Time: 10 minutes
- Test Time: 15 minutes
- Analysis Time: 20 minutes

Time of Day: N/A

Place: Indoors with good lighting

Resources needed:

- Pencils
- Paper
- The Mirrors
- Data Tables
- Access to a Computer
- Protractor

Procedure:

1. Set up the mirror so it is to see how far the mirror rotates
2. Make markings on the paper that have degree markings of 0º, 5º, 10º, 15º, and 20º
3. Do this on both sides of the paper.
4. This will allow for the mirror to be tested all at once.
5. Slide a small piece of paper underneath the mirror surface.

6. The mirror will have clearance between the mirror surface and the mirror holder.
7. Rotate the mirror in increments of 5 degrees.
8. After each increment, mark it down that it rotated that far.
9. Once the mirror is unable to rotate, stop the test.
10. If the mirror stops between an increment, create a mark for the stop point.
11. After the mark has been made on both sides, create a line to the mark from the center point.
12. Use the protractor to measure the stop angle of the mirror surface.

Risk and Safety:

The main risk for this lab is possibly pinch points from moving the mirror back and forth. To avoid any pinching, rotate the mirror slowly and by pushing on the mirror sides as close to the center as possible.

Deliverables

The results of the test ended up being less than desired. It was unable to rotate due to the rigidity of the mirror holder connecting rod. The calculated value was supposed to be 15 degrees. It was designed to be on ball so the mirror could freely rotate around the mirror holder. Success was to be measured on the success of the mirror being able to rotate 15 degrees in either direction. So, the results of the test are a failure. However, this test did inform of the inadequacies of the design. Even though in theory the ball mount should've worked, this means another method should be utilized in the future. One way the design can be improved is using a built-in swivel through the bottom of the mirror holder. This would also allow for the mirror to only be moved in the right and left directions. Another way this could be improved is put the mirror holder on a swivel, so the entire mirror moves. There would have to be a locking mechanism so it wouldn't move due to air pressure. In conclusion, the device fails to meet this requirement but there are ways it can be improved.

Reflection Distance Test

Introduction

The purpose of this test is to determine the max distance at which the mirrors can reflect a clear and visible image. For the intents of the test, the test will go up until neither a clear nor visible image is seen. The mandated Washington State law for vehicles is that they have a minimum reflection distance of 200 feet to be considered street legal. However, for the Electrathon, only being able to see behind the vehicle is important from what the rulebook implies. The 200 feet will be the benchmark that the mirrors are able to achieve. The success of the test will be determined by the mirrors being able to reflect up to 200 feet.

Method and Approach

The way this test would take place is in a wide-open area such as a field or empty parking lot. Since the mirrors will be attached to a vehicle, being outside to test them is the best way to get the most accurate data because it will include any weather variables that could affect the way the mirror is used and how effective they work. The tester would then either mount the mirror to a mounting area or place a cone or object in the rearview of the mirror space and walk forward with the mirror until the test is complete. The main goal of the test is just to get a maximum distance. If done in a parking lot, the vehicle used to get to the place of the test could be used. If done in a field, a cone is probably the better option.

Testing Procedure

Summary:

The goal for this test is to determine the maximum reflection distance of the mirrors. This test is to help test for the requirement of 200 ft reflection distance. This distance was chosen based of Washington state safety designs for vehicles. The mirror will be tested for distances of 50, 100, 150, and 200 ft. The goal is to determine the maximum distance, if the mirrors are unable to meet the 200 ft requirement then the test will then be done in 10 ft increments from the last distance that it was successful at. The test is simple as the response for each distance will be a yes or no for the distance. The test will take place outside because the mirrors will be used outside and attached to a vehicle.

Time to Complete: Approximately 2 hours

- Travel Time: 15 minutes
- Setup Time: 15 minutes
- Test Time: 1 hour
- Analysis Time: 30 minutes

Time of Day: Mid-Morning, outside

Place: Park or Parking Lot (Rotary Park)

Resources Needed:

- The mirrors
- Measuring tape
- Camera for documenting distances and images
- Microsoft Word
- Computer

- Data Tables
- Cone
- Means of Travel

Procedure

1. Setup the mirror so that the mirror is at one edge of the Field so that the mirror can see behind it.
2. Set up cone 50 ft behind the vehicle
3. In the table below mark down if the cone is visible in the mirror and how clear it is (clear, visible but fuzzy, not clear).
4. Repeat steps 2-3 for distances 100, 150, 200 ft. If at any point the image is no longer clear, start measuring from the last visible image at 10 ft increments. Ex: if the image is no longer clear at 200 ft, go back to 150 ft and measure from 160 ft then 170 ft, and so on until the image is no longer clear.
5. Add additional notes on whether things that could have affected the image. (i.e. weather, people, nature etc.)
6. Answer discussion questions at the end of the testing report

Risk and Safety

Some Risk involved with this test is having to get to the park. Since it involves travel, making sure to get there safely is important. Other than this there is no real worry when it comes to testing this part. All the data for this is visual based with no loading being applied to the device. Therefore, no real risk is involved with this test. However, to practice proper safety precautions, safety glasses should be used while testing.

Discussion

1. How did the testing progress through each step?

The testing progressed smoothly through the process. There was some wind while doing the test which made it hard to see out of the mirror at times because dust would accumulate to the surface. However, a quick dust off solved this issue.

2. Were there any challenges that made it hard to complete the test?

The main challenge for the test was the mounting of the mirror, since the mirror couldn't be mounted to anything, the mirror was moved the distance required while the cone was stationary. The benefit of this was that it made sure the car was always in view no matter where the mirror was at.

3. Did anything unexpected happen during testing?

Nothing unexpected happened during testing. Other than the weather not being completely ideal, the test was able to get done in a timely manner.

4. What can be done to improve the device?

The one thing that can be improved on the device is the actual material. Real glass is not ideal because of the weight, but if there was a plastic mirror that could be used and cut to shape without causing any problems to the mirror, this would be ideal. It would not only create a better mirror, but it would be more stable overall and create a harder surface that was less likely to get damaged by the elements.

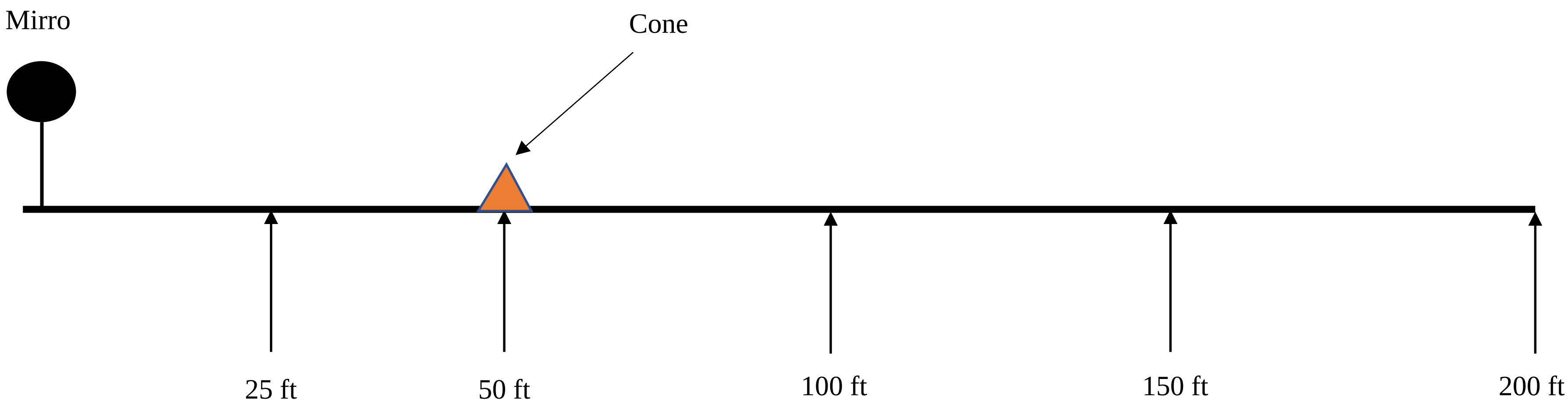
5. What was the maximum distance that was achieved?

The maximum distance that was reached by the mirrors themselves was only 160 feet. This was unfortunate because the minimum distance required by state law is 200 feet. Which was the intended goal for the test and what the requirement was.

6. What can be done to improve the testing in the future?

The one main thing that could be improved for the test in the future is to make a mounting platform that would mimic the height of the electric vehicle. This would create a more stable platform for the mirrors. It would also allow for multiple things to be tested in one complete test. It would allow for the mirror to be tested for a cockpit view. This would be needed because that's the main purpose of the mirrors and it would be easier to move a mounting station than an entire vehicle.

Simple diagram for set – up



Other Requirements Tested

Weight

The weight requirement didn't require a test, all that needed to be done was to weigh the total weight of the mirrors with all the components. If the total weight was underneath the 1 lb limit the requirement was considered to be successful. The predicted weight of the mirrors was .9 lbs. However, the total weight of the mirrors was approximately .81 lbs. The main reason for this was that the since the mirrors were made from the ABS plastic, the printing process is not perfect, and the parts were designed to be solid and they were hollow after printing. This made the mirrors lighter.

Mirror surface area

The mirror surface area requirement was also just a quick calculation and if the mirror holder printed out correctly, the surface area of the mirror would not change from the design. To calculate the area of the mirror, surface the equation for the surface area of an ellipse was used. The equation was A x B x π. The "A" component is half the width of the ellipse and the "B" component is half the height of ellipse. The final surface area of a single mirror was 17.1 in2. This puts the final total for both mirrors to be 34.2 in2. The requirement for the project was 8 in2.

Appendix G1 Procedure Checklist

Required Items

- ☐ The Completed Mirrors
- ☐ Blank Data Sheets
- ☐ Video Capturing Device
- ☐ Measuring Tape
- ☐ Means of Transportation
- ☐ Green Sheets for Calculations
- ☐ Material data sheets on ABS Plastic

Items to Complete

- ☐ Printing of the Support arms
- ☐ Printing of the Mirror Holders
- ☐ A complete assembly of the Mirrors
- ☐ Analysis of the parts being tested.
- ☐ All connecting parts ordered for the Mirrors
- ☐ All parts have been manufactured.
- ☐ Test procedures written up for all tests that require it.

Appendix G2: Data Forms

Table for Top Loading Test:

Weight	Did it Break?	Predicted Deflection	Actual Deflection
Support Arm (0 lb)			
Mirror Holder (.47 lb)			
1 lb weight			
2.5 lb weight			

Table for Rotation Test:

Angle of Rotation	Did it make to the Angle? (Yes/No)
0º	
5º	
10º	
15º	
20º	

Reflection Distance Test Table:

Distance (in ft)	Image Clarity	Additional Notes

Appendix G3 Raw Data

Table for Test:

Weight	Did it Break?	Predicted Deflection	Actual Deflection
Support Arm (0 lb)	No	0 inches	N/A
Mirror Holder (.47 lb)	No	.00015 inches	N/A
1 lb weight	No	.00032 inches	N/A
2.5 lb weight	No	.00079 inches	N/A

*The actual deflection of mirror was hard to determine with exactness.

Table for Rotation Test:

Angle of Rotation	Did it make to the Angle? (Yes/No)
0º	Yes
5º	No
10º	No
15º	No
20º	No

Reflection Distance Test

Distance (in ft)	Image Clarity	Additional Notes
50 feet	Clear and Visible	The weather was clear with no cloud cover.
100 feet	Clear and Visible	The same conditions apply as the above conditions. There was some wind, so there was dust accumulation on the mirrors.
150 feet	Not Clear but Visible	The same conditions apply as the above conditions. There was some wind, so there was dust accumulation on the mirrors.
200 feet	Not Clear or Visible	The same conditions apply as the above conditions. There was some wind, so there was dust accumulation on the mirrors. The car was unable to see clearly and or visibly, for this reason it fails at this distance.
160 feet	Not Clear but Visible	The same conditions apply as the above conditions. There was some wind, so there was dust accumulation on the mirrors. The car is visible, but the image is not clear.
170 feet	Not Clear or Visible	The same conditions apply as the above conditions. There was some wind, so there was dust accumulation on the mirrors. At this distance the image becomes to foggy to consider to be visible.

Appendix G4 Evaluation Sheet

Equations needed for tests:

Moment of Inertia

$$\frac{\pi D^4}{64}$$

Deflection

$$\delta = \frac{PL^3}{48EI}$$

Calculating Deflection (example Table):

Load (P)	Length of Arm (L)	Mod of Elasticity (E)	Moment of Inertia (I)

This table can be used to calculate organize and then help calculate the data. This table could be used to calculate the theoretical deflection which then could be used to compare with actual deflection.

Appendix: G5 Gantt Chart w/ Test day Details

Top Loading Test Day

- Date of Test: April 15, 2020

This test was done in the morning when more there was more time to do it. Since this test didn't require any specific place and time needs, weather wasn't an issue, and neither was getting to a location. The test took place around 9 am and was completed by 10 am. The test itself only took about 30 minutes to complete because the test only had to be done 3 different times and the test was not heavily focused on numerical values. It wasn't until later that deflection was added to the data sheet to have a better comprehensive test. The unfortunate part of the test is due to the small nature of the weights, the deflection for 3 of the weights were either not existence or too small to measure. The only deflection that could be seen was in the 2.5 lb weight. This is reflected in the data table above.

Reflection Distance Test Day

- Date of Test: April 17, 2020

The test was done midmorning around 10 am. This test took about 2 hours to complete. This included the driving to time to get to the park. However, it does not include the time required to get back from the park. Most of the analysis was done at the park. So, the drive back was not included on the total time for the test. Since the test was to be done outside, the optimal weather conditions were chosen so the mirror stickers would not get damaged from any sort of weather. The morning was sunny and there weren't many people at the park yet. This was great because it meant the test could be done in the parking lot instead of the field. This allowed for a bigger object to be used for the mirror. There was some slight wind, but this wasn't a problem, there was dust/dirt accumulation on the mirrors, but it didn't cause too big of an issue for the overall of the test. The test was completed by noon.

Mirror Rotation Test Day

- Date of Test: April 19, 2020

The test took place in the afternoon rather than in the morning. It was the weekend so there was less going on. This allowed for time to be focused on the test and no other things. The test itself was not so great. After several tries to move the mirror in its degree of motions, the main connecting rod snapped in half. This resulted in a failure of the test. The cause for this may be that the part was not printed out perfectly, but without access to the files and the right technology to run the programs, the part could not be redesigned. However, it did lead to possible solutions for the mirrors.

Appendix H: Resume

DAVID CASTILLO

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OBJECTIVE

To be able to create a better world that we live in and to provide for my family.

SKILLS

I am adept at learning new things quickly. Once I have learned something new I will soon after be able to do things both quickly and efficiently. I am also always willing to always learn new trades or skills in order to help others. Can navigate both SolidWorks and AutoCad with efficiency and accuracy

EXPERIENCE

LOOMIS ARMOR US
October 28th, 2018 - present
Check in/out routes, Count money inventory, Balance Liability, Pack money to various locations. I was trusted to have alarm codes and vault codes to the building.
Certified as an Armed Vault Guard

FRED MEYER
July 2017 – November 2017
My main job was just stocking the shelves at night and keeping inventory of what we had. Make sure all items were not expired and were easily accessible to customers

EDUCATION

BS MECHANICAL ENGINEERING TECHNOLOGY/ JUNE '20
Central Washington University
Certified: Basic SolidWorks
Dean's List – Winter '18, Spring 18'

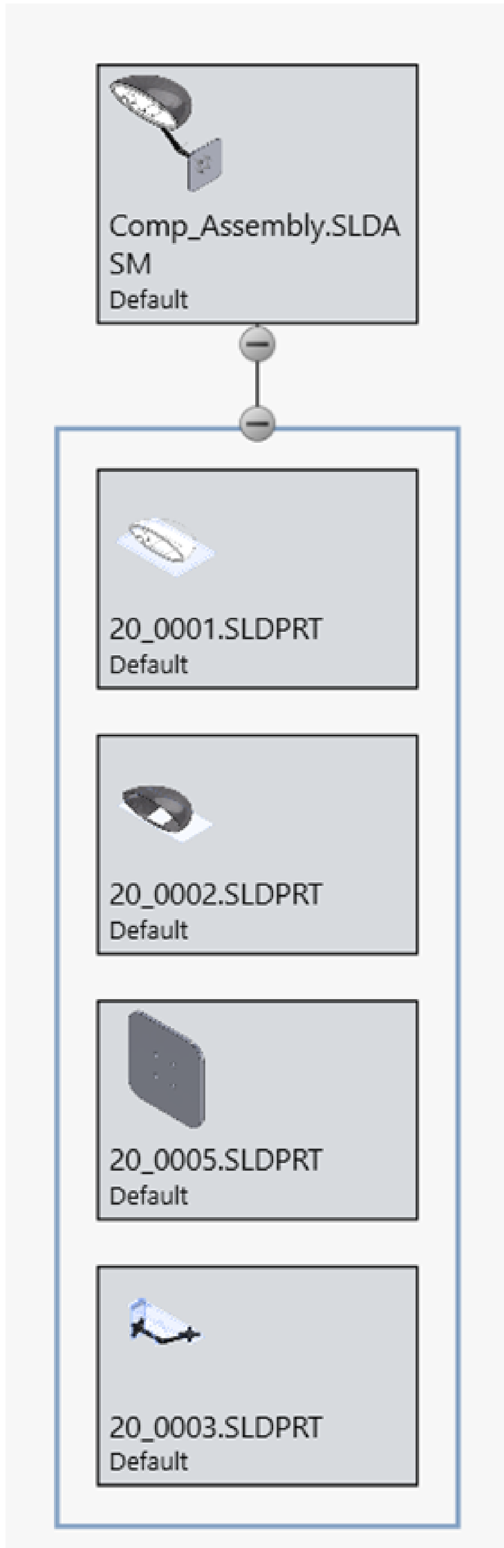
HIGH SCHOOL DIPLOMA JUNE '14
Lake Stevens SR. High School
Scholar Award in Technology and Engineering Courses '13
Scholar Athlete – '12, '14
Graduated top 5% of class

VOLUNTEER EXPERIENCE OR LEADERSHIP

High School
Team Captain – 2013 Cross Country Team
Volunteered as a coach for Middle School through all 4 years

Central Washington University
VP of EV Club

Appendix I: Drawing Tree



Appendix J: Job Hazard Analysis

JOB HAZARD ANALYSIS
{EV Mirror}

Prepared by David Castillo	Reviewed by: Approved by:

Location of Task:	Central Washington University – Machine Lab (Hogue), Materials Lab (Hogue)
Required Equipment / Training for Task:	Drill Press, how to handle carbon fiber, abs, and adhesive, hole press, understanding of safety policy in Hogue Labs, training involved with 3D – Printing, ANSI and OSHA approved eye and hand protection
Reference Materials as appropriate:	MSDS Sheets for Resin, Hazards and Manual Involved with 3D – Printer, Material Properties for Carbon Fiber and ABS/PLA UC Berkley JSA for 3D - Printing

Personal Protective Equipment (PPE) Required
(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)

Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☐	☒	☐	☐

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

PICTURES	TASK DESCRIPTION	HAZARDS	CONTROLS
	Hand Drill	**Pinching** **Cuts and abrasions** **Burns**	**Proper Training and PPE** **Keep hands away from tooth bit to avoid cuts and pinching.** **Avoid wearing long sleeve clothing to avoid clothing being stuck in drill** **Keep hands away from drill bit in case of excess heat from drilling. Wear gloves when necessary.**
	Adhering Carbon Fiber to ABS plastic	**Accidental Spills of Adhesive product** **Resin getting into eyes while applying** **There could be noxious films while using the resin**	**Wear Safety Glasses and Gloves** **Wash hands thoroughly after using glue** **Do not touch Eyes when using material** **Use resin in a well-ventilated room with safety standards in place to ensure safety**

			of others
	Attaching Mirror to Vehicle	**Pinch point Accidental dropping of mirror**	**Wear Gloves if glass has been broken, wear safety glasses in case of accidental glass breakage. Avoid spacing between mirror edge and mirror holder edge**
	3D-Printing Operations Heat Hazards	**During operation, the extruder can reach temperatures of 518°F**	**Do not touch the metal extruder tip of the printer when the 3D printer is turned on. Wear ANSI-approved eyewear & gloves when working with the 3D-printer.**
	3D-Printing Operations Chemical Hazards	**During operation the melted filament (both ABS & PLA) will produce toxic fumes (styrene & volatile organic carbon).**	**Operate the 3D printer in a well-ventilated room or in a hood.**
	3D – Printing Operations Mechanical Hazards	**During operation, the 3D-printer's gantries and belts pose pinch hazards to the user.**	**Do not touch the 3D-printer while the extruder head is in motion.**
	Using scissors to cut Carbon Fiber to Shape	**Pinch Point Cuts and abrasions**	**Keep fingers in proper holes to avoid pinching of fingers Use proper handling of scissors and what they are intended for by keeping fingers only on the handle Cut away from the body to avoid accidentals cuts to person**
	Assess work area; is it clear of obstructions and slip/trip hazards?	**Slip, Trip or Fall**	**Remove any obstructions or trip hazards. Maintain a dry floor.**
	Assess path to emergency eye wash station; is the path clear and free of obstructions?	**Not immediately able to access emergency eyewash station if needed**	**Remove any obstructions and maintain clear pathway**
	Select and don personal protective equipment	**Exposure of corrosive solution to eyes or skin.**	**Use of PPE is required and mandatory**
	Select items/parts needing dissolve support removed and place in appropriate soak basket	**Loss of parts within solution tank**	**Use appropriate basket**
	Slowly raise lid of solution tank and allow condensate to drain back into the solution tank	**Possible corrosive solution spilled outside of solution tank.**	**Place lid in secondary containment container**
	Slowly lower soak basket into solution tank making sure not to splash solution	**Exposure of corrosive solution to eyes or skin.**	**Work in a slow and deliberate manner**

	Make sure basket is submerged and sitting level on the bottom of tank	**Possible corrosive solution from being splashed on operator**	**Work in a slow and deliberate manner**
	Replace solution tank lid	**Possible accidental exposure of corrosive solution**	**No not operate without lid in place**
	Set timer on solution tank control	**Solution tank not dissolving support material properly**	**Verify timer is set and operating**
	Do not allow observers within splash area during time while parts are put into or being removed from dissolve tank	**Possible exposure of corrosive solution to eyes or skin.**	**Maintain a three-foot perimeter anytime the tank lid is removed**
	Maintain tank water levels within the manufacturer's specifications	**Possible exposure of corrosive solution to eyes or skin.**	**Don personal protective equipment, remove solution tank lid, and replace/remove water as necessary**
	Draining solution from tanks as necessary	**Possible corrosive solution spilled outside of solution tank or exposure of corrosive solution to eyes or skin.**	**Don personal protective equipment, remove drain plug from tank, attach hose to drain, and drain liquid into designated 5 gallon containers. Constantly monitor disposal container, DO NOT overfill (more than 4 gallons)**
	Mixing and adding new solution to tanks	**Possible corrosive solution spilled outside of solution tank or exposure of corrosive solution to eyes or skin.**	**Don personal protective equipment SPECIAL NOTE: ALWAYS! ADD concentrate (P400-SC) to water, NEVER add water to concentrate!**