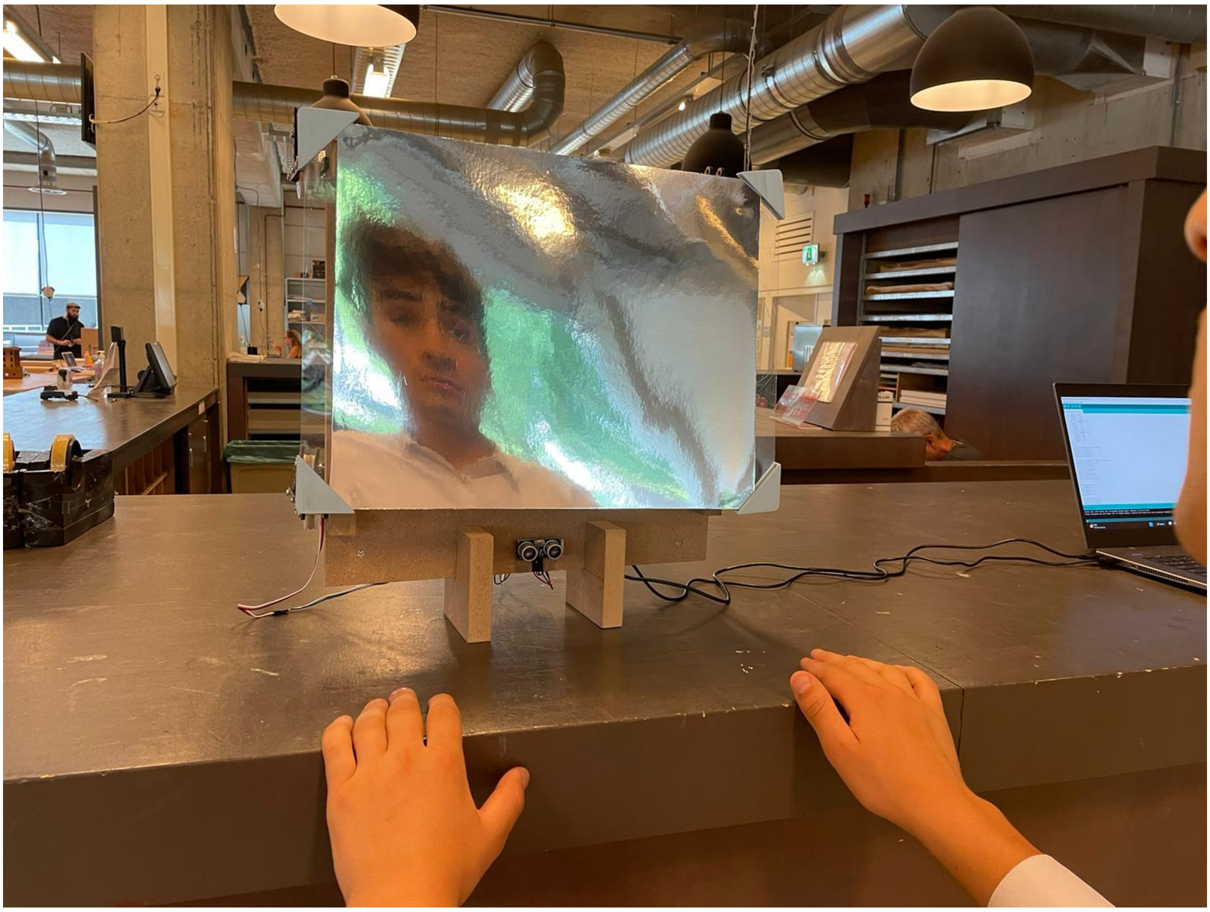

FINAL REPORT

DBB114 (2022-4) - Creative mechanical design, engineering and manufacturing (Advanced)

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Date:

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INTRODUCTION

Assignment description

For the course 'Creative mechanical design, engineering and manufacturing', the task was given to design, engineer, realise and demonstrate a device which can show at least one emotion. The emotion(s) should be on/off switchable. Furthermore, the machine should be realised using (mainly) rapid prototyping manufacturing techniques.

Content

This report discusses the design and design process of a laughing mirror that can change its shape whenever a user walks in front of it. It elaborates on all of the relevant applied mechanical principles, exact kinematic constraint design techniques, finite element analysis, engineering and manufacturing methods. Moreover, the design process, final design and evaluation on design choices will be incorporated.

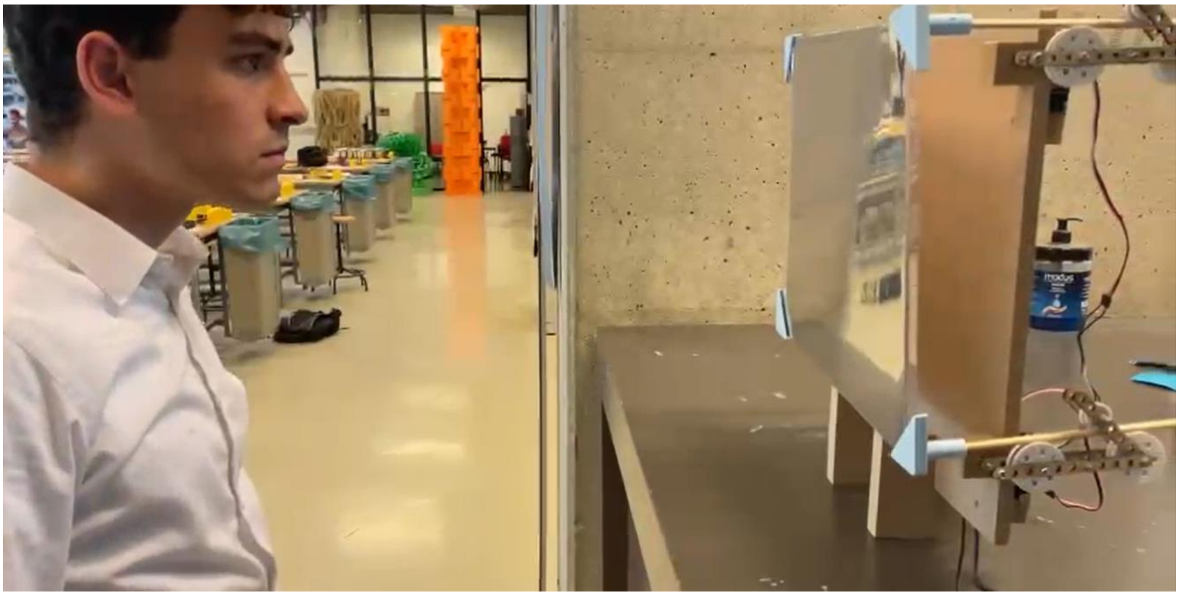


Figure 1. User interacting with laughing mirror that is mechanically controlled to change shape

Design goal

The goal of designing this laughing mirror is to design something interesting applying the acquired knowledge of this elective and forming it into something that would spark the interest of anybody interacting with the design. We chose to design a laughing mirror because of its qualities to instantly change somebody's emotions positively by looking at their reflection. The design challenge is to figure out how to mechanically adjust a bendable, reflecting surface using all the earlier acquired knowledge on mechanics.

BACKGROUND

In this section, all relevant physics and mechanics for our design will be elaborated. This includes exact kinematic constraint, grooved wheels, friction wheels, material flexibility, torque and displacement and finite element analysis. The main source for information for the mechanical backdrop for this project has been the wiki that has been provided by the course (see references: *Delbressine, 2023*).

Exact constraint

Our product has a certain purpose. This means that the design, mechanics and materials all together make sure this purpose and sub-goals are reached. To limit the different elements in their behaviour, exact constraint is needed to direct a part in the needed displacement or movement. A particle can have 6 degrees of freedom, 3 in movement, and 3 rotational. Let us assume we want the object to only move back and forth in de x-axis. Then we need to control the other 5 degrees of freedom. With force-closure, like nodes and attachments, the unneeded types of freedom are controlled.

Wheel grooves bigger than stick diameter

When you throw a basketball down into a valley from a mountain, the ball comes to a stop in the valley between two mountains. This is because of the gravity and the size difference of the valley and the ball. The mechanism of the mirror uses the same physics in a slightly different size. The grooves on the wheels are bigger than the radius of the stick. That way the stick is always centred in the direction of movement.

Friction wheels

Friction often sounds like something holding you back from movement as it feels like touching the throttle and brake paddle at the same time. However, friction could also be used to prevent your tires from slipping on the asphalts. The friction created by the rough elastic bands creates enough traction on the stick to move it whilst the wheel is rotating.

Material flexibility

To create effects of reflection you need curvatures for hollow or bulbous surfaces. The surface needs some allowance of compression and stretch, the bendability. The hardness of a material decides whether it is easy of difficult to bend. With reflection on a smooth surface, the projection is one-to-one with reality. When the surface is curved, the projection is also curved, bended and deformed. This gives a illusion of reality, which is in most cases very much to laugh about.

The wheel is turned using torque force from the servo. Although the stick and mirror a lightweight, we need quite some torque to replace the rotational force with linear displacement.

Finite element analysis

Finite element analysis is the use of simulation software to accurately predict how materials and objects will react under different forces and loads. It can be used to determine whether a material or design is suitable. FEA helps to justify the viability of design decisions and material selections. A factor of safety can also be determined to decide the safety for human interaction. A high factor of safety is required for products that have heavy human interaction.

Factor of safety Calculation:

$$FOS = \frac{maximum\ strength}{design\ load}$$

Using equitation 1 it is possible to use the data from an FEA analysis to calculate a factor of safety. The FEA analysis will be conducted using Solid worksSolidWorks and will measure the stress and strain, deflection, and the factor of safety of the chosen designs and materials.

DESIGN (& DEMO VIDEO)

After sketching out several iterations of the mirror on paper, attempting to figure out how we could create the effect of a laughing mirror. The choice was made to make use of servo motors. The servo motors that were used in the design are the S3003, for which a datasheet is provided in the appendix. The major challenge of our design was figuring out how to transform a rotational motion into a translational motion. Doing so, we would be able to move the corners of the mirror, to ultimately be able to bend the plexiglass which the mirror is made of.

After multiple sketches, discussions with each other, and Q&A's directed to the teacher, the decision was made to work with (friction) wheels and exact constraint. For a more detailed explanation about these separate elements we refer to the background section and mechanics section. In figure 2, that shows the side view of the design, this is illustrated. The mechanism would allow us to keep stick's motion restricted to move merely on one axis, namely the axis perpendicular to the mirror.

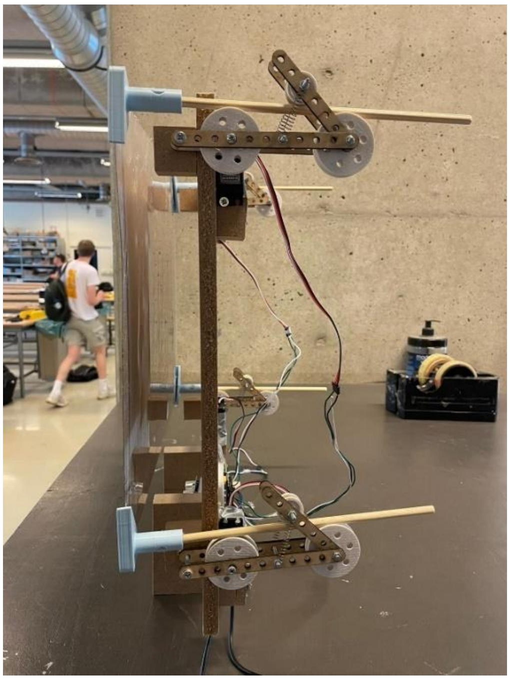


Figure 2. Side view of the design with wheels attached to servo, allowing for translational motion of four corner pieces of the mirror

After assembling everything together, hooking up the previously elaborated on 'exact-constraint friction wheels construction' to the MDF back-plate, the mirror could be attached to the rest of the construction. The 3D-printed corner pieces (which we will elaborate on in the manufacturing section), are designed in such a way that the sticks can fit right inside of them. The dimensions of the mirror are a fraction larger than the distance between the placement of the respective corner pieces, making the mirror stuck into its place. Again, we refer to figure 2, in this side view you can see how the corner pieces are attached to the mirror.

After putting the mirror into place, the effect of the bending of the mirror and the resulting reflection were evaluated. Although the displacement of the sticks was restricted to a narrow 6 centimetres, the effect of distortion was quite noticeable. As you can see from the visual in figures 3 and 4 on the next page, there is a significant difference when the mirror is bended vs when it is not bended. The mirror itself is made of two parts. Firstly, the flexible "mirricard" foil that can be purchased at the counter in the Vertigo workplace. Secondly, a piece of plexiglass, attached to the back, allowing for the right stiffness and flexibility balance for the mirror. Read the materials section to find out more.

Figure 3. Front view of when the mirror is straight. The reflection is straight as well.

Figure 4. Front view of when the mirror is bend. The reflection is noticeably distorted.

To wrap up the design section, let us elaborate on the parts allowing for interactivity. As stated earlier, the mirror is equipped with a distance sensor (HC-SR04) and four servo's (S3003) (both datasheets provided in the appendix). These are connected to a breadboard with *Teensy 3.1*, *and YwRobot PrMB mini 1* power supply to make sure that all of the four servo's get the required 5 volts. Of all of the aforementioned different electronics, only the distance sensor can be spotted in figures 3 and 4. The rest of the electronics are placed on the back (figure 5). All of the code is provided in the appendix as well.

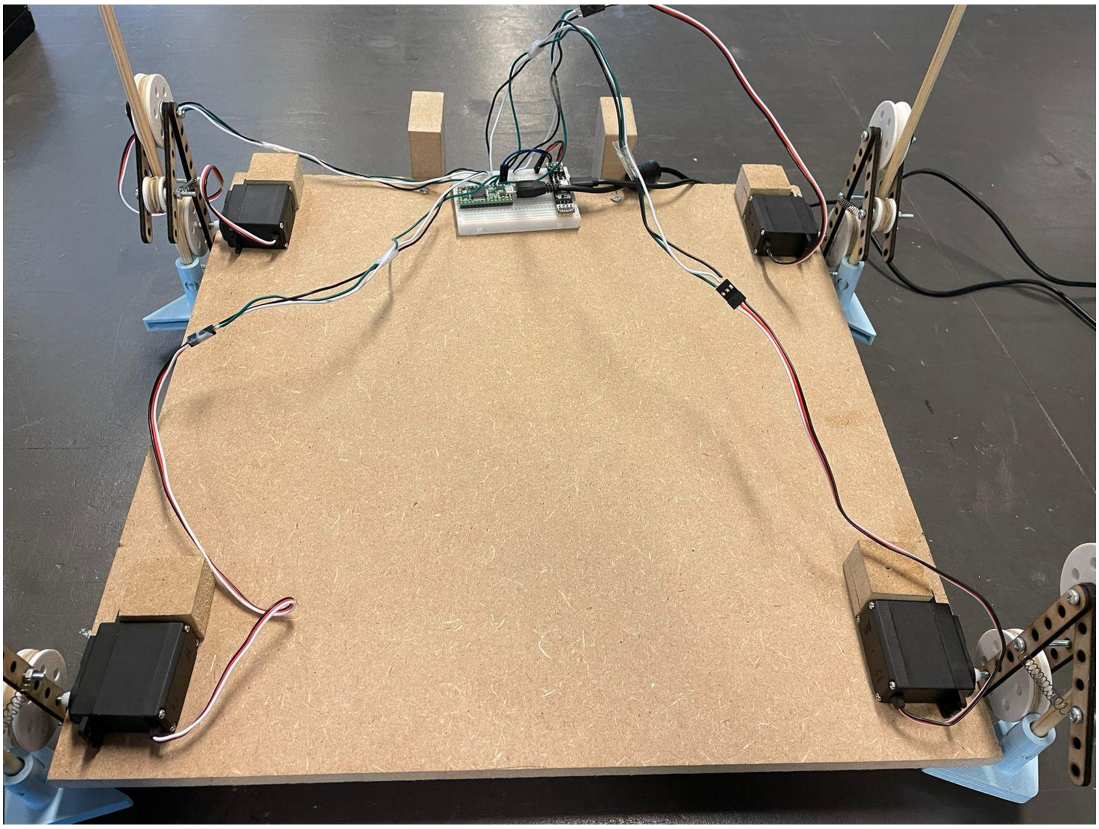


Figure 5. Back side of the mirror's MDF backboard. Servo's attached to the four corners, wires attached to breadboard with Teensy microcontroller and power supply, both attached to laptop. Then four female jumper wires to the front to connect the distance sensor to the microcontroller.

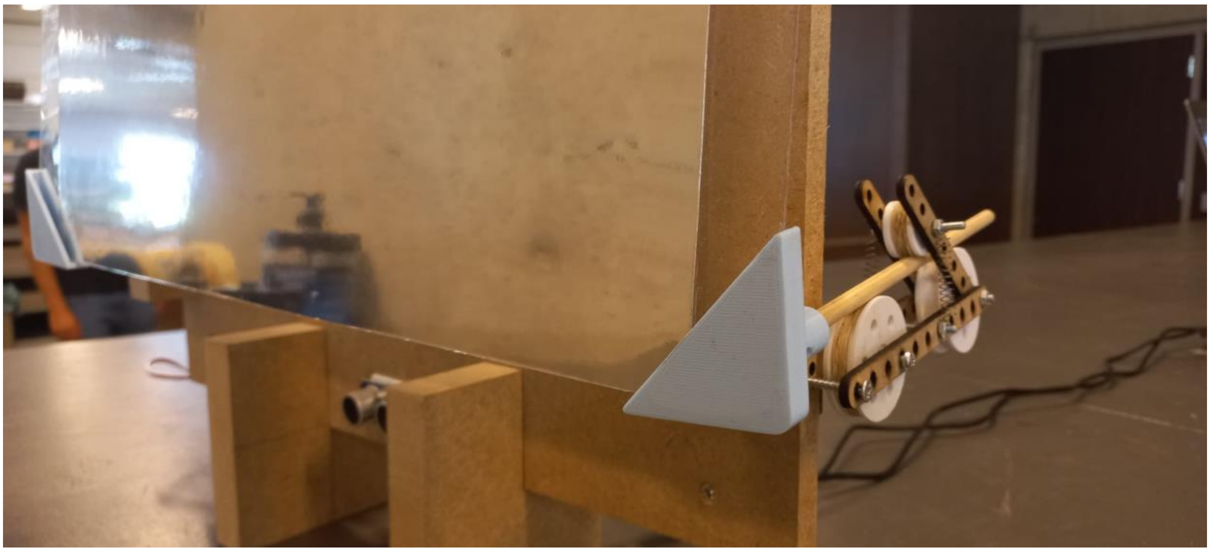


Figure 6. Front view of one of the corners of the mirror, with the corner piece and the mechanical components visible.

Now that all of the separate elements of the design are discussed, lets elaborate on the aesthetics and interactivity of the design. As stated earlier, the product is able to 'flick an emotion on or off' by changing the configurations of the four servo's randomly, causing the mirror to bend differently. For the "facial expression" of the person to change, the top of the mirror is placed at the height of the face of the person (see figures 1, 3 and 4). The mirror only starts to bend itself when the user is standing in between 10 and 100 centimetres from the distance sensor. This way, the face of the user is always warped sufficiently and the user is not standing too close. In terms of aesthetics, the choice was made to keep the mechanical parts more or less exposed (figure 6). This way, the user can be even more amazed by the way they can interact with the device since they can see the parts move. For a more elaborate explanation on the manufacturing processes, please view the manufacturing section.

Ultimately, with all of these previously described parts working together, the effect of the mirror sparked the interest from the people around us in the Vertigo workplace. To see the interaction for yourself, please take a look at the demo-video. This is the link to the demo video:

https://youtu.be/55TZmOotlTw

MECHANICS

This section discusses how the previously elaborated concepts (in the background section) are applied on our design.

Exact constraint

The stick slides back and forth as the back wheel is being turned. The stick is rounded which means it can rotate in its longitudinal direction. However, all other 5 degrees of freedom are regulated due to the friction on the wheels and the force from the upper wheel. That wheel is pushed on the stick with a spring force. This spring is connected from the axis of the wheel to the fixed part of the outer structure.

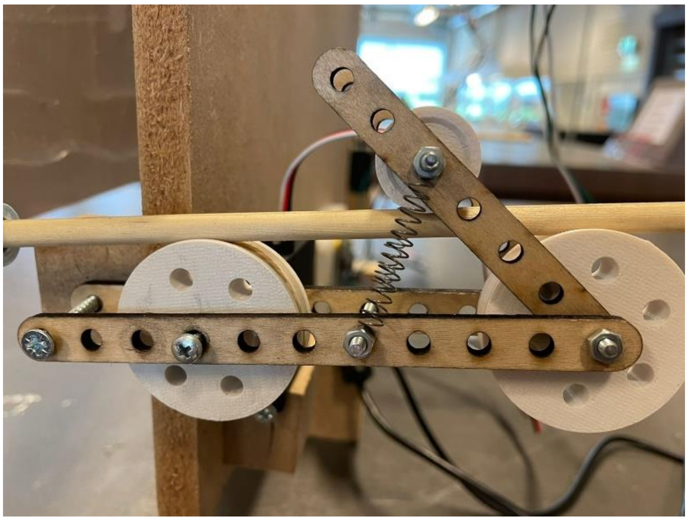


Figure 7. Exact constraint mechanism, making sure the position of the stick is always determined

Wheel grooves bigger than stick diameter

The three wheels on each corner mechanism have a groove on the outside which fits the round stick sliding over. This groove is slightly wider than the stick. This is to make to stick balance to the middle of the groove because of the roundness of both objects.

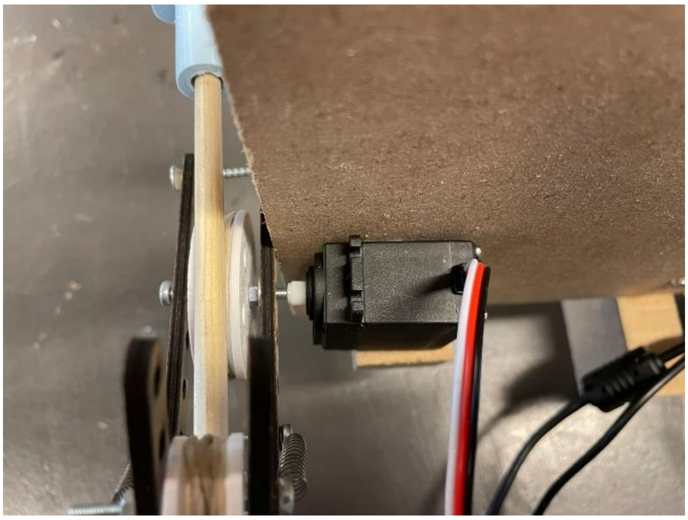


Figure 8. Diameter of stick being smaller than wheel grooves to keep the stick into place

Friction wheels

The wheels are 3D printed. This material is really smooth and slippery. To make the stick slide over the wheels without slip, a friction on the wheel is needed. Elastic bands are wrapped around the outside of the wheels to therefore have a better grip on the wooden stick.

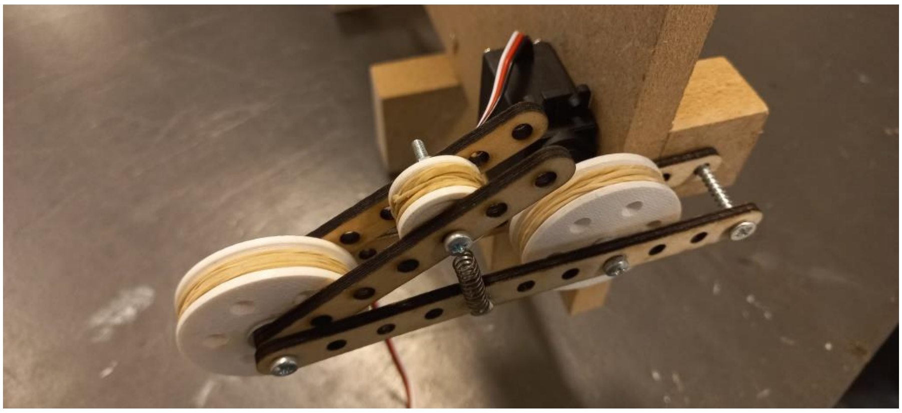


Figure 9. Elastic rubber bands around the wheels to prevent the stick from slipping, but allow for a better translational motion.

Material flexibility

Almost all mirrors are made out of glass because of the very smooth surface. This surface comes with one of the hardest materials on earth. This hardness of glass makes it difficult to bend and curve for our effect. Therefore, a reflective sheet of paper is sticked onto a sheet of plastic. This combination is lightweight, flexible and reflective. As seen in Figure X, there is a great visual effect even with the slightest curvature.

Figure 10. Flexibility of the mirror foil with plexiglass on the back.

Torque and displacement

The 5V Servo motor generates enough torque (3.2 kg.cm) to rotate the wheel and therefore the stick. The ratio on the rotation of the servo and the wheel is 1:1. The radius of the wheel is 0.03 m. This means that the maximum displacement of the stick is:

Finite element analysis

Drive wheel

A static analysis was used on the Drive Wheel, as the design uses this component to propel the mirrors edge forward or backwards and the wheel would be connected to the servo. This component has a certain amount of torque running through it and in turn propels the mechanism and rod forward and backwards.

For the Drive Wheel we selected ABS plastic as the material selected for our FEA test which has the properties of chemical and abrasion resistance, dimensional stability, surface hardness and rigidity. This material is easy to 3D print with and has a solid body in this component.

Pictures of the FEA analysis:

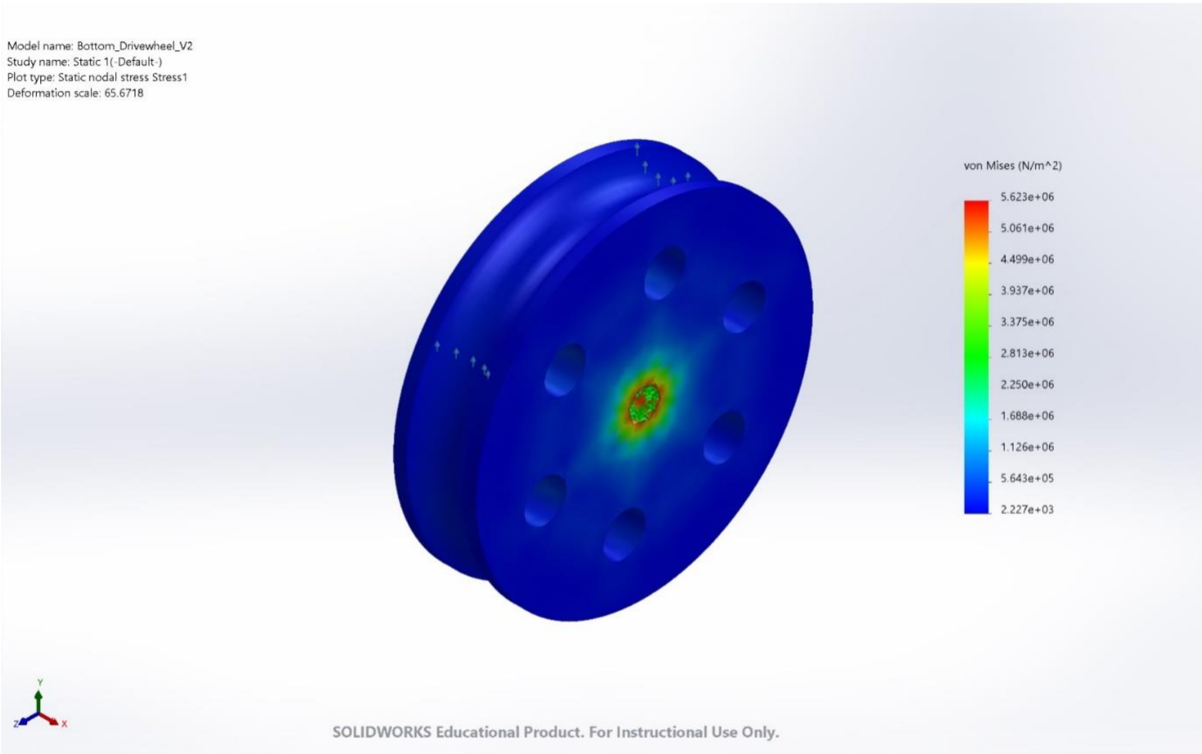


Figure 11. Stress analysis

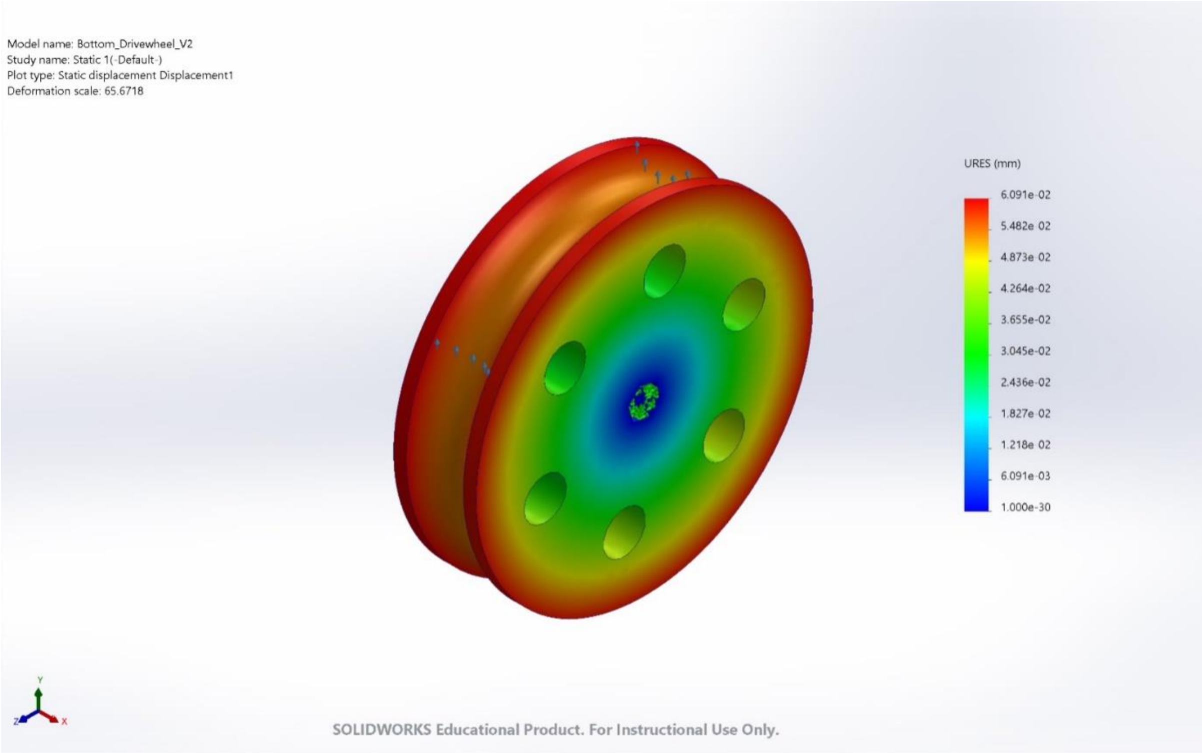


Figure 12. Displacement analysis

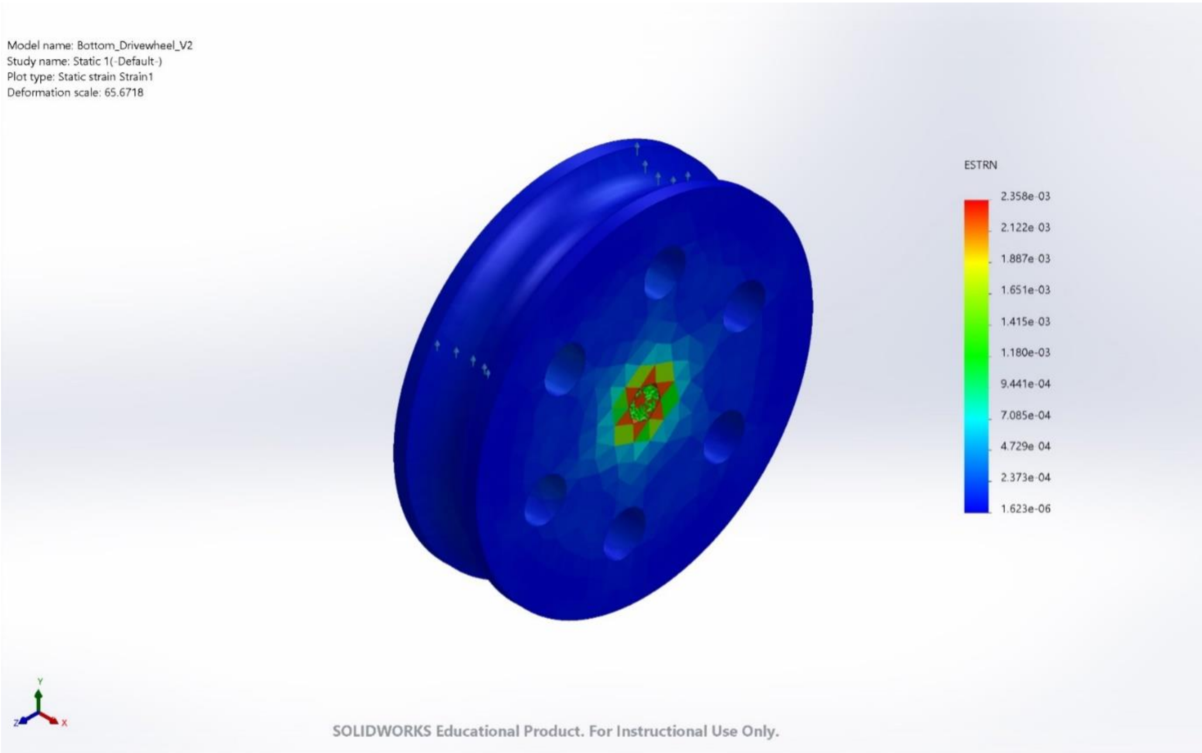


Figure 13.

From this analysis, it is evident that the design and material are suitable for the prototype. The maximum stress on the wheel is 5.623e+06/m^2 and the maximum strain is 2.358e-03 meaning that the stress and strain is minute. From these material results it can be shown that the material is fit for the needs of the design.

The maximum deflection is 6.091e-02mm this again a minute movement and therefore doesn't affect the mechanics of the design and overall product.

The factor of safety can be calculated to be 12,553. This is within the operating range of the design used and is suitable for human interaction.

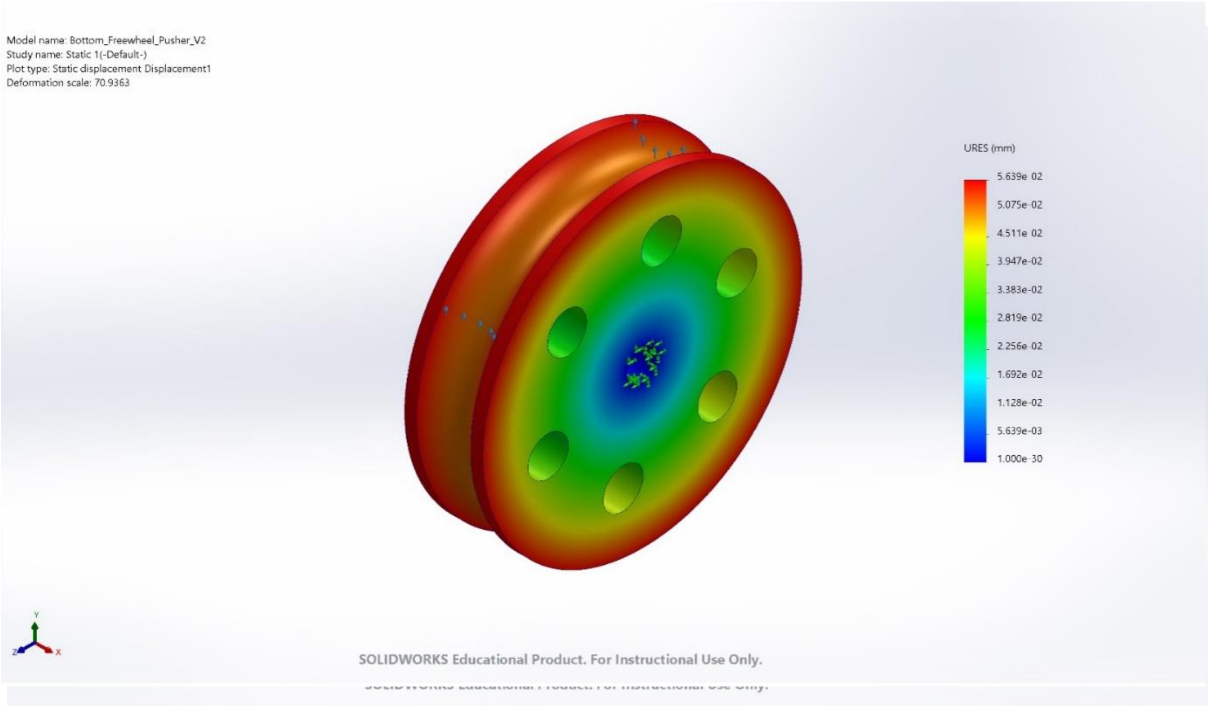
From the FEA analysis performed on the drive wheel of the bendable mirror design, it can be determined that the material ABS plastic is suitable for this component of the design as it does not strain or stress enough to affect the mechanical integrity of the design nor the safety of the user.

Bottom free wheel

A static analysis was used on the bottom free wheel, has the design has this wheel moving with the Drive wheel to propel the rod. This wheel is free and is not connected to a servo, instead it assists the Drive wheel to guide the rod forward and backwards in a straight line. This wheel has 1 Nm of torque running through it applied to the middle axis and 1 value of force applied to the middle as well.

The material selected is ABS plastic due to its rigidity, firmness, chemical and abrasion resistance, and dimensional stability. This material was also chosen due to the ability to readily 3D print the component with it.

Pictures of the FEA analysis:



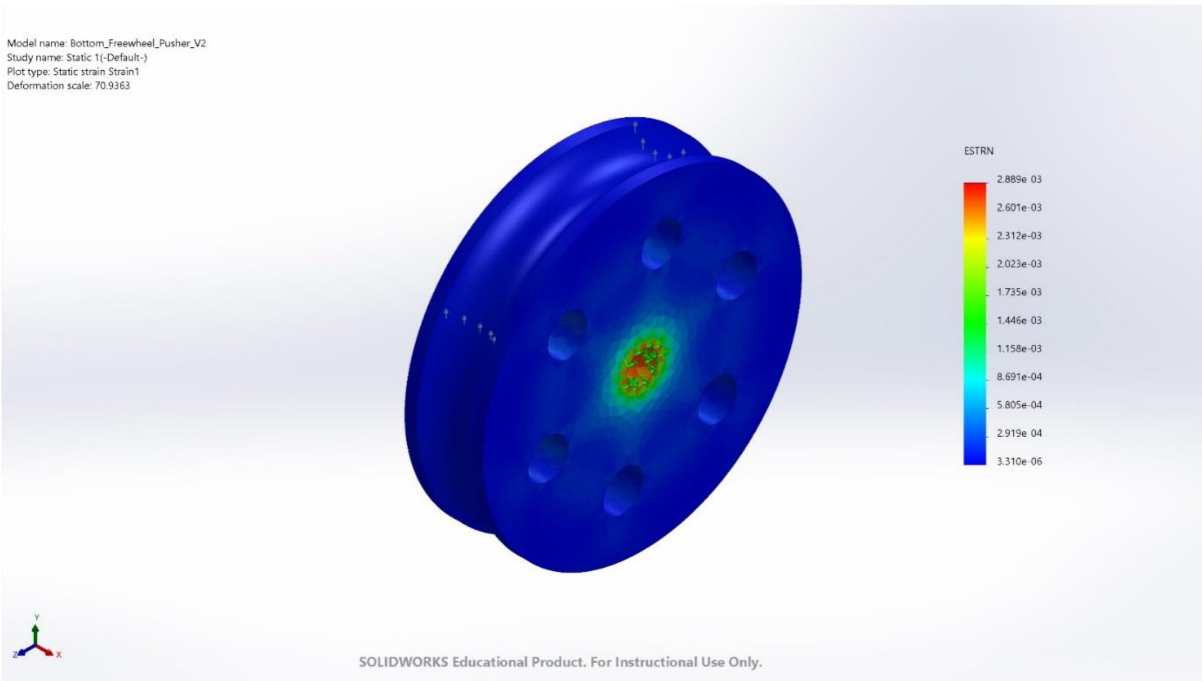


Figure 15. strain analysis

From this analysis it is shown that the design of the bottom free wheel is suitable for the prototype. The maximum stress is 7.025e+06N/m^2 and the maximum strain is 2.889e-03 which shows that the two figures are well within the range the prototype can handle. The calculated maximum deflection of the wheel is 5.639e-02mm which is less deflection than the drive wheel, therefore this wheel would not affect the integrity of the design.

The factor of safety has been calculated to be 10246. This is well within the applicable safety range needed for this prototype therefore meets the requirements of this design.

From this FEA analysis on the bottom free wheel, it is shown that it will be able to bare any strain, stress or deflection applied to it. Its maximum range of all the above values show that the wheel is suitable for the application in this design and the factor of safety indicates it is safe for human interaction.

Top free wheel

A static analysis was used on the Drive Wheel, as the design uses this component to propel the mirrors edge forward or backwards and the wheel would be connected to the servo. This component has a certain amount of torque running through it and in turn propels the mechanism and rod forward and backwards.

A static analysis was used on the Top free wheel, the design component uses this wheel along with springs (downward force) to enable the rod to create traction with the wheels below and thus keeping it in place. This component has 1N of force down to mimic the force created by the spring.
The material chosen for this wheel is ABS plastic which has properties as previously mentioned in the discussion above. This is suited to the design as it can be 3D printed like the wheels above.

Pictures of the FEA analysis:

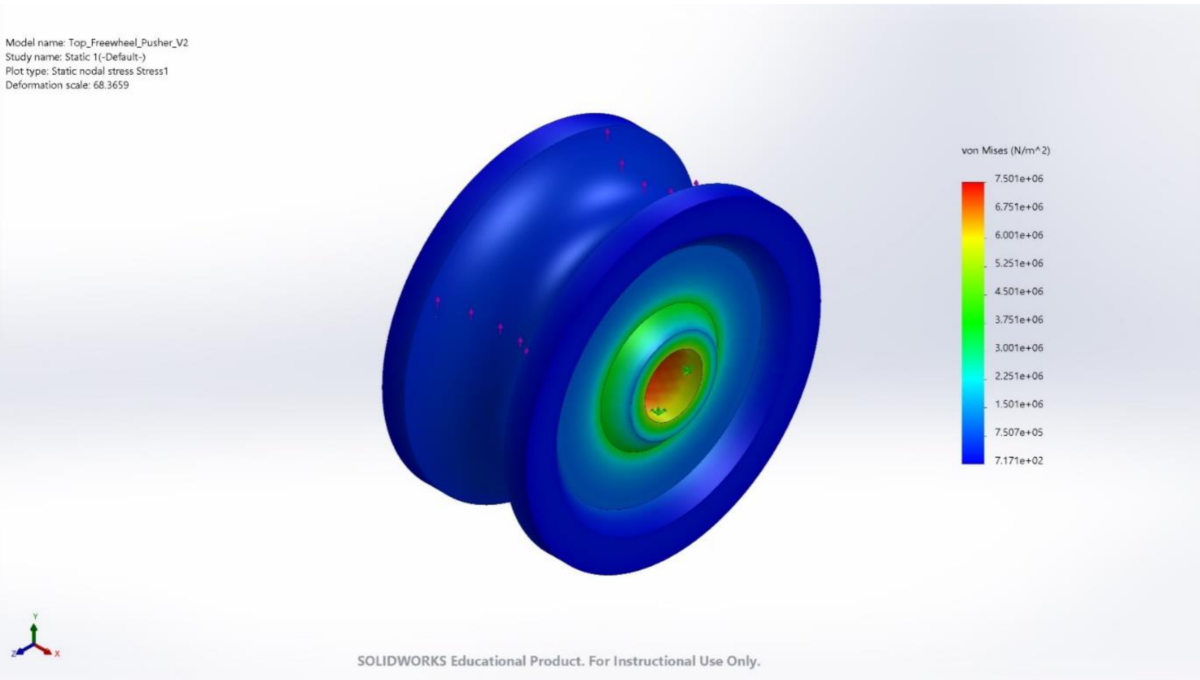


Figure 16. stress analysis

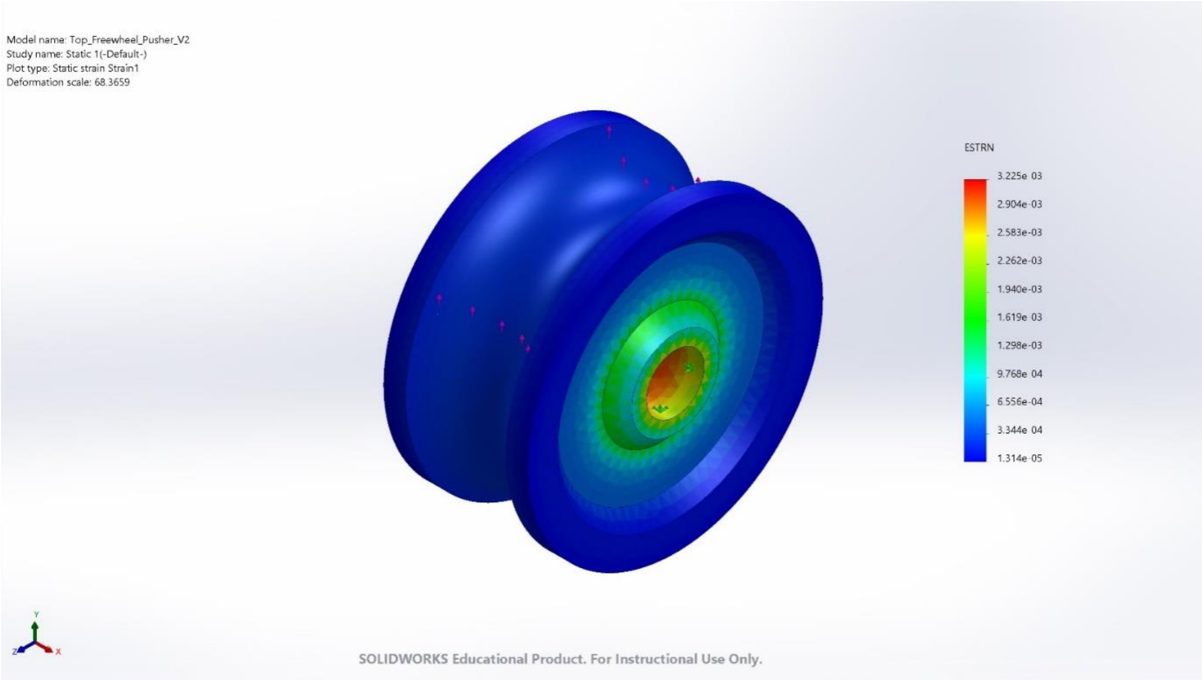


Figure 17. deflection analysis

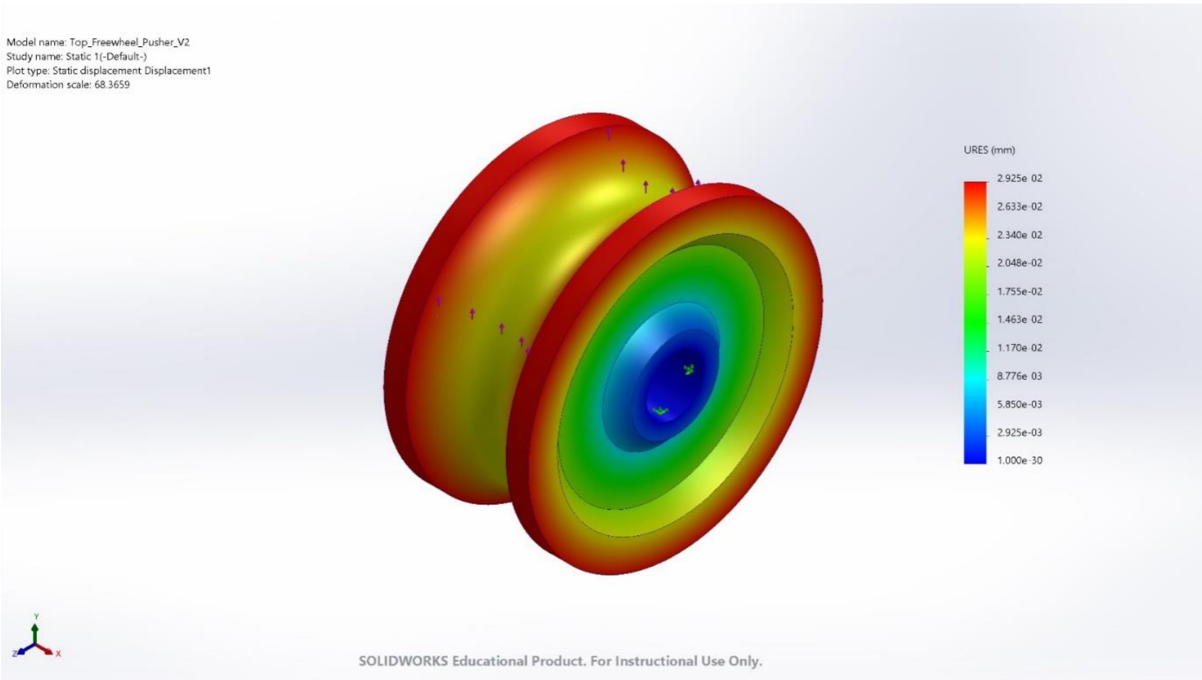


Figure 18. strain analysis

This analysis shows that the specifications of the wheel meet the requirements of the design. The maximum stress of the wheel is 7.501e+06N/m^2 and the maximum strain is 3.225e-03 which indicates the potential strain and stresses are low for the amount the material can possibly bare. The maximum deflection calculated is 2.925e-02mm which is significantly less than the deflection in the other wheels in the design most likely due to the size of wheel.

The factor of safety has been calculated to be 9178 which is well over the necessary factor of safety needed for this component of the design, making it suitable for the prototype and safe for human interaction.

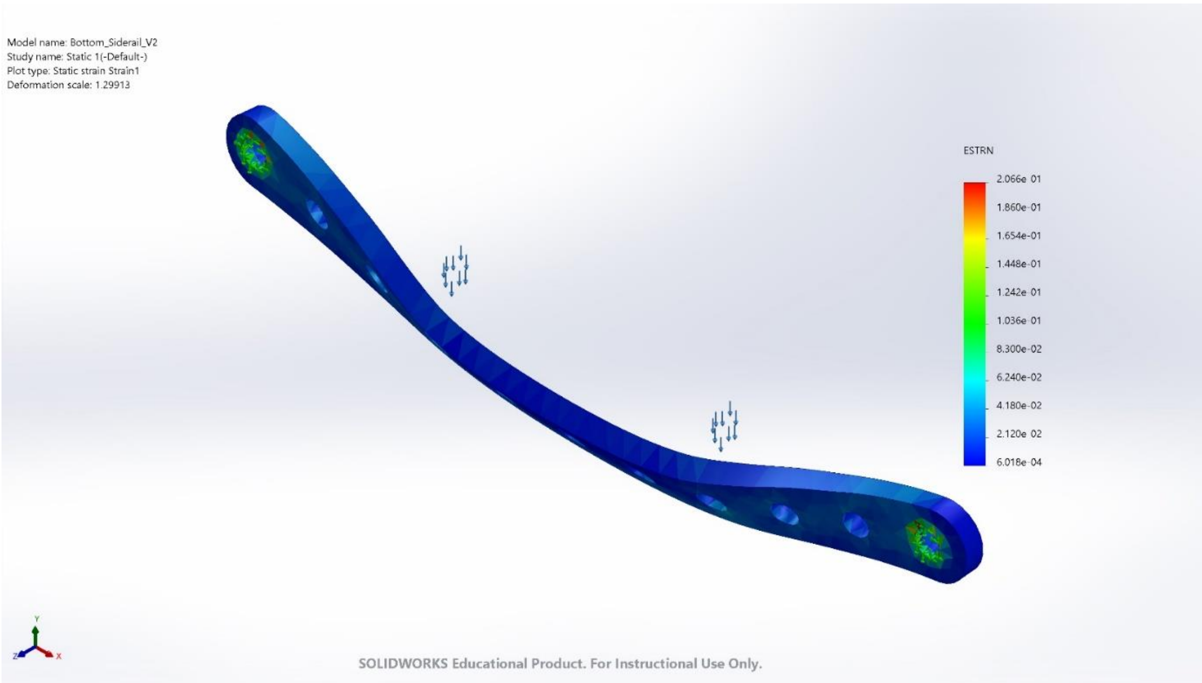
From this FEA analysis on the top free wheel, it is shown that the maximum strain or stress that the wheel will bear is a minimal number and therefore with not inhibit the functionality of this design. As shown above the factor of safety is well above the needed requirement for it to be safe for human interaction.

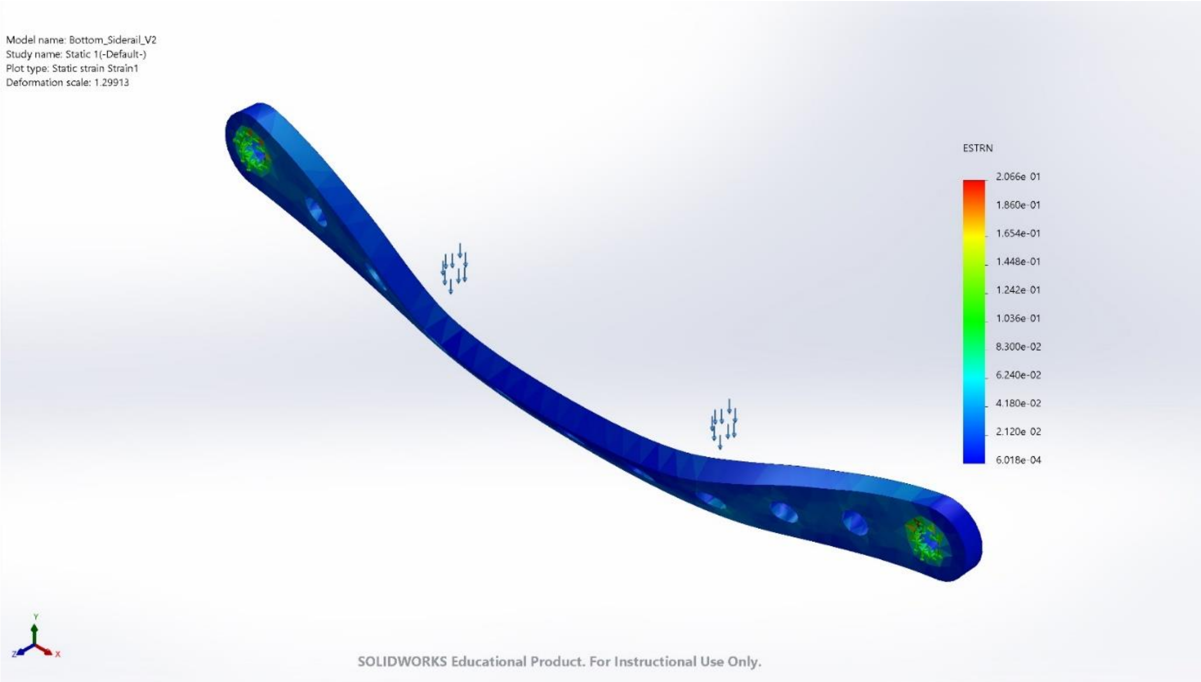
Bottom side rail:

For the bottom beam of the pusher, a static analysis was performed. The analysis consists of two fixed points on either end of the beam. These represent mounting locations to the rest of the mirror structure. Two loads are placed on the beam in the negative y direction. These represent the force of both the drive wheel and rolling wheel that are attached to this beam. Finally, a load is placed in the middle of the beam in the positive y direction which represents the pulling force from the spring that is used to hold the design together.

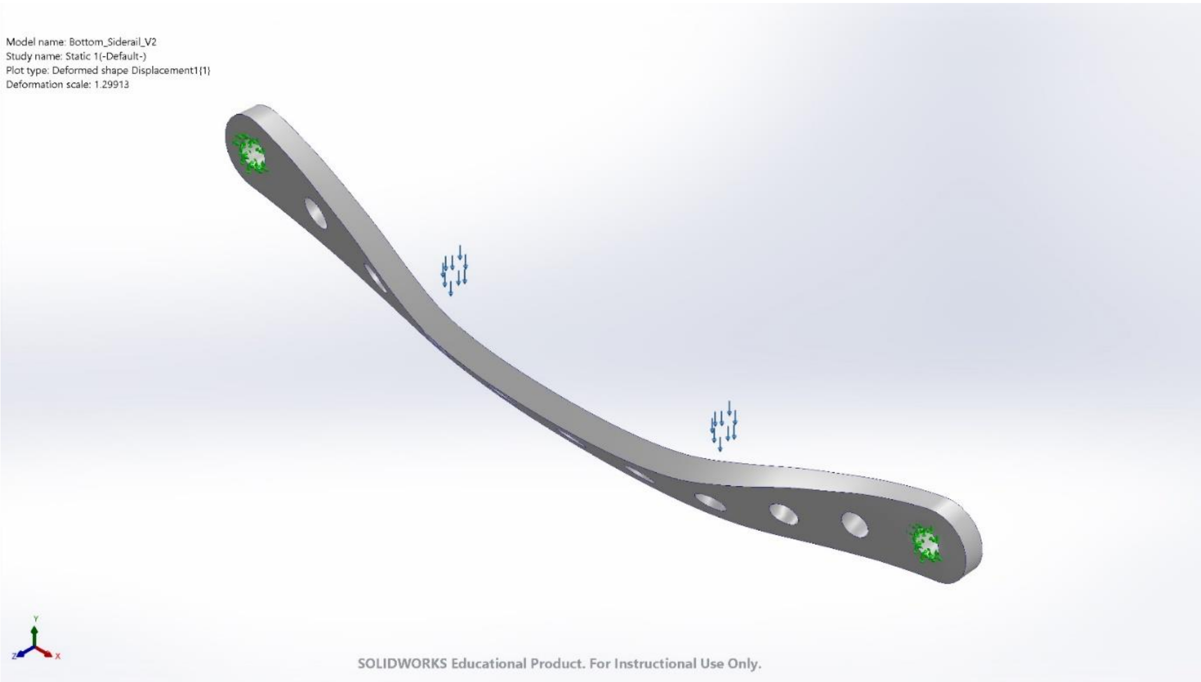
The material was set to pine plywood which has a tensile stress of 27.6Mpa and a shear strength of 1.72Mpa

Stress and strain pictures:





Deformation/deflection pictures:



From the analysis, it is evident that the design and material are suitable for the product. The maximum stress on the beam is 3.690e+06N/m^2 and the maximum strain is 2.066e-01. From the material data we can determine that this is within the specifications needed for the design of the mirror pushing rod.

From the analysis it is determined that the maximum deflection is 1.064e+01mm. This is negligible as it will not affect the performance of the overall product.

The factor of safety is calculated to be x. This is within the standard operating range that is suitable for a product that has human interaction involved.

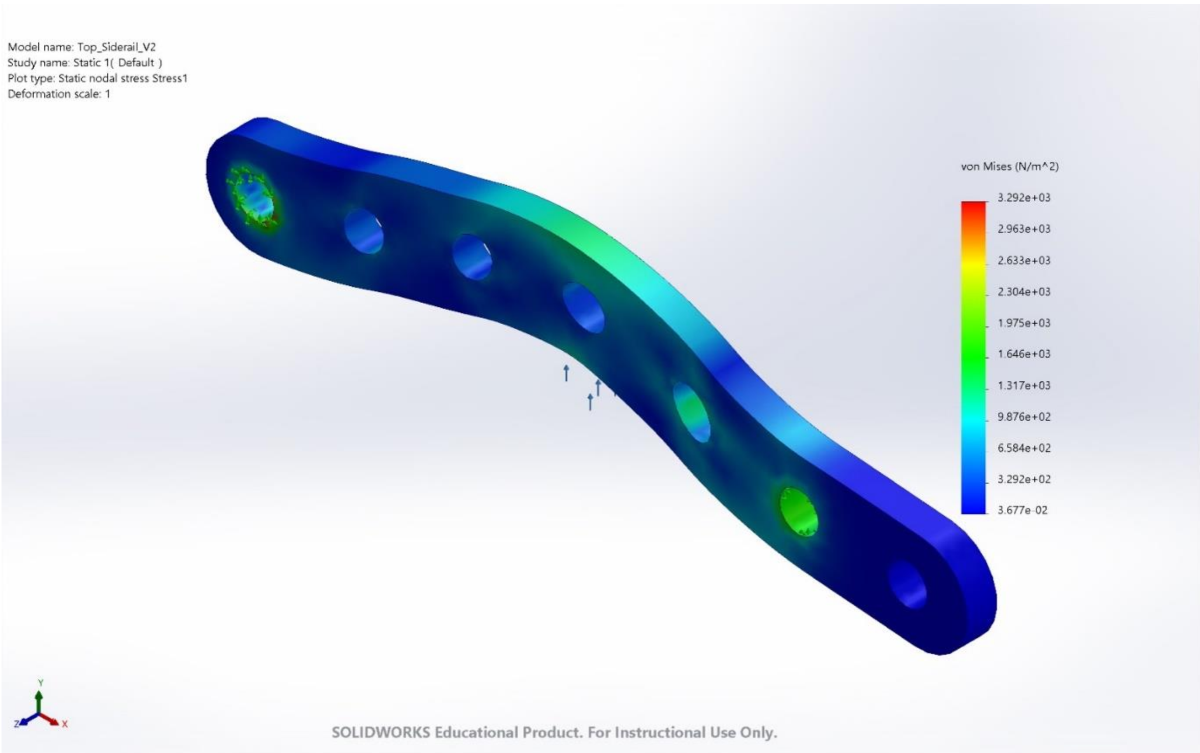
From the FEA analysis performed on the lower beam of the pusher design, it can be determined that the 3mm thick pine plywood is a suitable material to be used for the project as it does not deflect enough to affect the function of the device, and its stress and strain properties allow for it to be used safely with human interaction.

Top side rail:

For the bottom beam of the pusher, a static analysis was performed. The analysis consists of two fixed points on either end of the beam. These represent mounting locations to the rest of the mirror structure. Two loads are placed on the beam in the negative y direction. These represent the force of both the drive wheel and rolling wheel that are attached to this beam. Finally, a load is placed in the middle of the beam in the positive y direction which represents the pulling force from the spring that is used to hold the design together.

The Top side rail of the pully system there was a static analysis was performed. The analysis consists of two fixed point restraints on either end of the beam. The points represent the points at which the beam is connected to the bottom beams and to the springs on the top side. One small load is placed in the negative y direction to mimic the top wheel. Finally, a load is placed in negative y direction as well at the end of beam to represent the spring pulling the beam down.
The material selected for this beam was 3mm plywood which has a tensile stress of 27.6Mpa and a shear strength of 1.72Mpa.

Pictures of the FEA analysis:



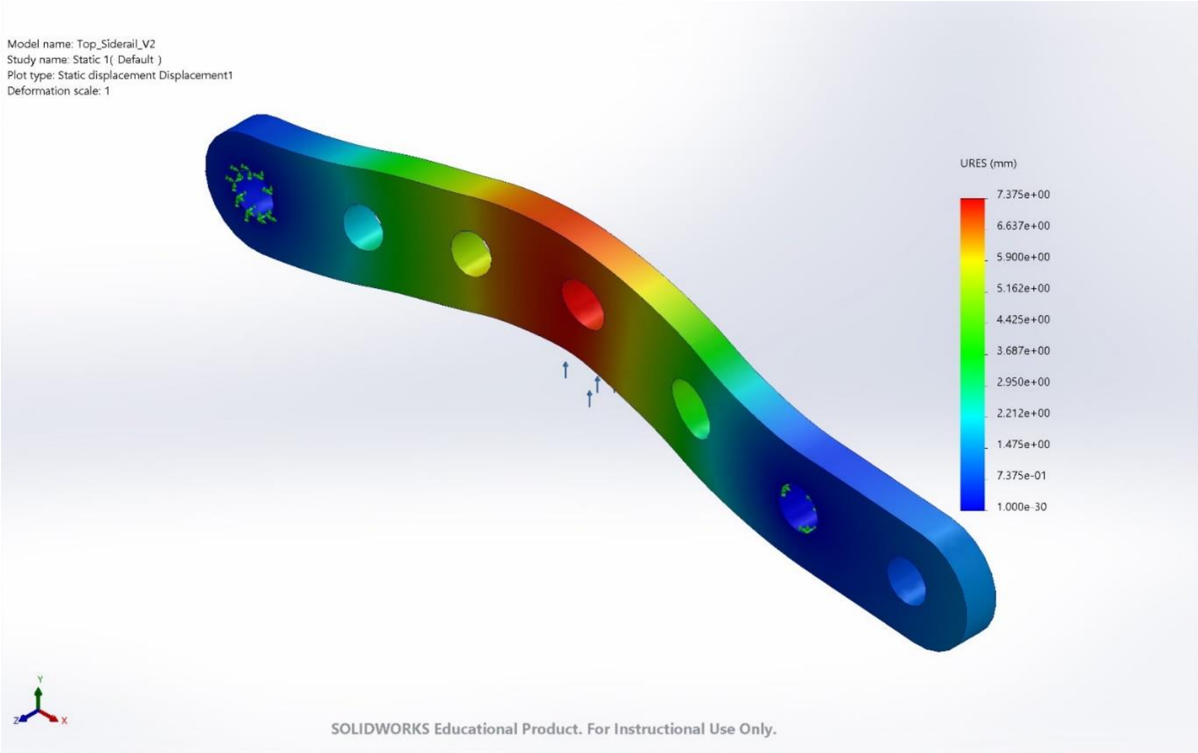


Figure 13. strain analysis

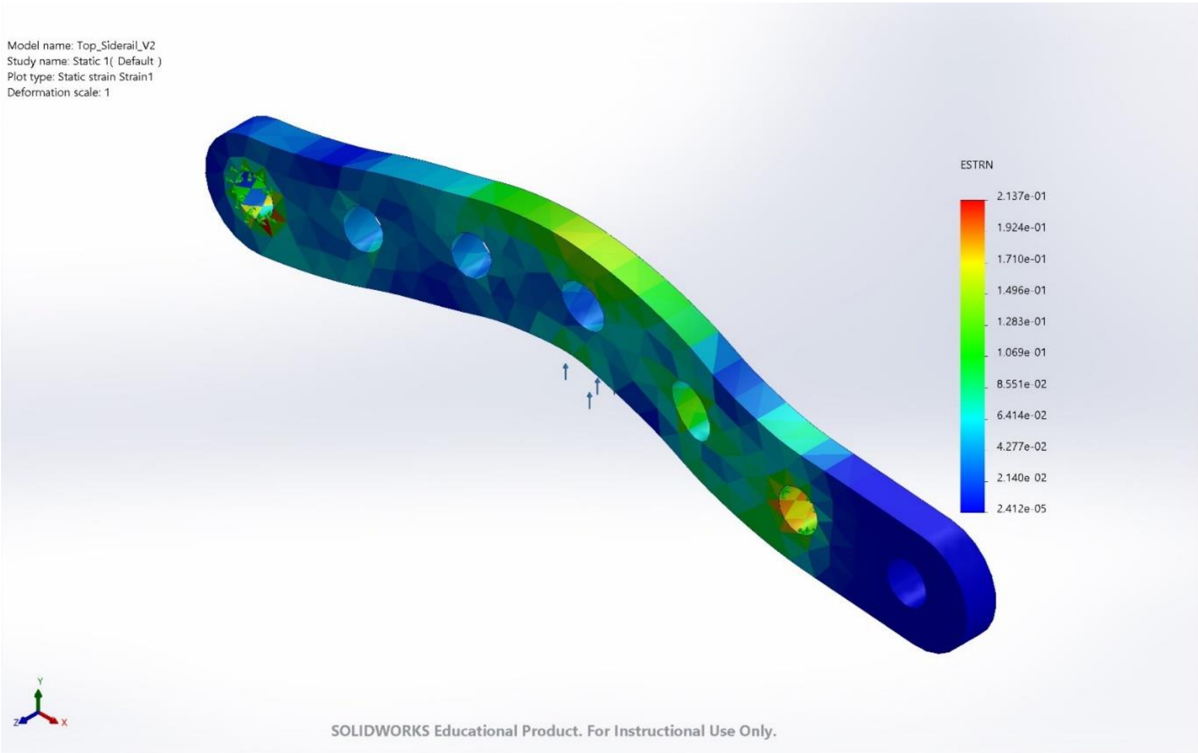


Figure 14. deflection analysis

From this FEA analysis, it is clearly shown that this beam is suitable for this design. For the maximum stress on the beam, it was calculated to be 3.292e+03N/m^2 and the maximum strain is 2.137e-01 on the

beam. These two figures indicate that these values are within the range needed for the overall design of the mirror. The maximum deflection of the beam is 7.375e+00mm.
The factor of safety is 145.06. This is within the range of a normal operating range that is suitable for a product that has human involvement.

From the FEA analysis conducted on the Top side rail, it is concluded that the 3mm plywood is a suitable material for this component as it does not deflect enough for the purpose of component in the design.

MATERIALS

After several considerations and design discussions, the selection of chosen materials that would best serve the realization of the concept was created. An in-depth description of the chosen materials, along with their uses and properties can be seen below.

Plywood

Plywood was used to construct parts that had a relatively simple shape but were sturdy enough to provide a structural framework. In the case of our concept that would be the wooden 'pillars' to support the wheels.

We have chosen plywood to serve as a structural framework because of several properties. Firstly, plywood is available in multiple thicknesses and sizes. It is available in almost all hardware stores, as well as on campus, making it readily accessible for prototyping purposes. Next, Plywood is known for its strength and durability. It provides pretty good structural integrity, allowing prototypes to withstand assembly processes. The layered construction of plywood reduces the risk of warping, ensuring stability during manufacturing. Plywood can also be easily cut or drilled using common woodworking techniques. In this case a laser cutter was used to get the exact shape and size of the needed parts without much effort. This allows for quick modifications or adjustments to the design as needed. Finally, compared to materials like metals or solid wood, plywood is relatively lightweight. This makes it easier to handle and assemble prototypes. This was particularly useful in our concept, as the plywood parts were partly suspended in the air.

MDF (Medium-Density Fibreboard)

MDF was utilized for the creation of the backboard of the prototype, as well as plateaus for the servomotors to be attached to. MDF is manufactured by using wood fibres in combination with resin, which is compressed using high pressure. This results in a dense consistent material. This makes MDF reliable for prototyping purposes. Just like plywood, MDF can be easily cut, shaped and drilled using woodworking tools. Furthermore, MDF has very low moisture absorption, which results in a material that is unlikely to be affected due to expansion, contraction, or warping compared to solid wood. This stability ensures that the prototype's dimensions remain consistent over time.

Lastly, MDF is more affordable than solid wood. This made sure that large parts of the concept could be manufactured without many worries or constraints.

PLA (Polylactic Acid)

PLA was used to create the mirror corner pieces of our concept, since these parts have a complex shape and need to be scaled precisely to make our concept fully work mechanically. This meant 3D printing was the most logical option regarding time and cost.

PLA is used in 3D printing due to its great printability. It can be extruded at low temperatures, reducing the risk of warping or deformation during printing. This makes PLA a popular choice for prototyping. 3D printing was used for our concept because it is one of the fastest and easiest ways to create parts that contain complex shapes. Instead of other 3D printable materials like ABS or nylon, PLA is more affordable while still providing a high enough quality for prototypes.

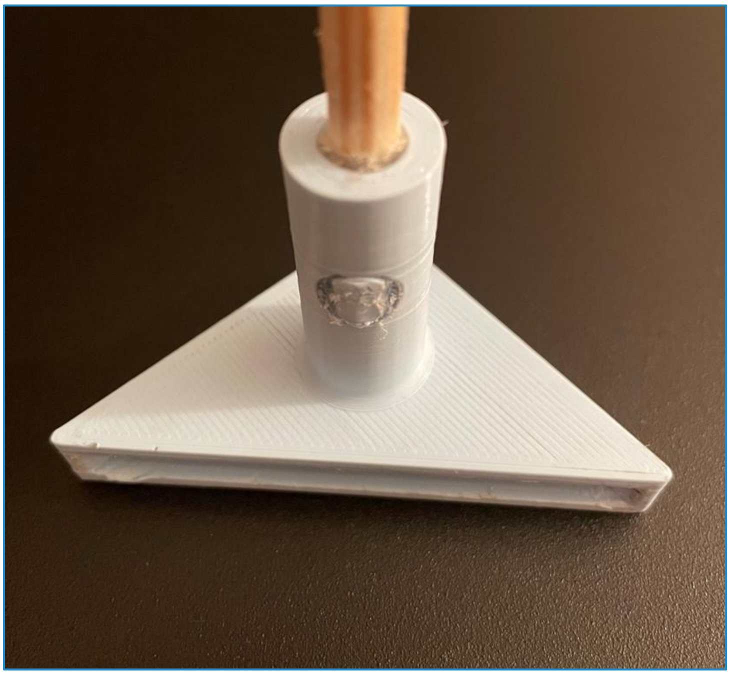


Figure 15. Corner piece made of PLA

ABS (Acrylonitrile Butadiene Styrene)

In addition to using PLA for the corner pieces, ABS was used for the printing of the wheels. This choice was made because the wheels were under a greater mechanical stress than the corner pieces, which means that the wheels needed a durable material. ABS is known for its strength and durability, which made it the logical material option for the wheels.

Perspex with mirricard

To construct the mirror itself, a combination of Perspex and mirricard was used. The Perspex sheet allowed for a sturdy surface that could still be manipulated by linear force to create a bent surface. The mirricard allowed for a surface in which the user can see itself.

MANUFACTURING

Manufacturing the different components for this mirror we used a variety of methods such as laser cutting, 3D printing and workshop tools such as the bandsaw and hot glue gun. All these different manufacturing techniques allowed us to explore and create a diversified prototype, with applications that are easily repeatable.

Laser cutting is a technology that uses a laser to burn materials precisely, resulting in either a cut or marked edge or shape. This method is typically used for a variety of industrial manufacturing applications.

3D printing is a technology that uses a variety of materials to precisely print out a model of an object or prototype. The model is often modelled in solid works or other commonly used CAD software and then ‘sliced’ before printing the model. Most common material used for 3D printing is PLA or ABS plastic.

Figure 16. Construction of mechanism

At the beginning of the manufacturing process, we began by constructing the mechanisms that enable the mirror to move. These pieces were made up of ABS plastic wheels, with three different specifications. These wheels were padded out with rubber bands to allow for more grip onto the rod as it moved between them. 4 beams made from plywood; two that run along the bottom of the mechanism holding the big wheels in place and two smaller beams that lead to a smaller guidance wheel and two springs creating resistance on the rod. All these parts are assembled with M3 nuts and bolts to secure each wheel and spring in place. Once the moving parts formed a structure for the rod to sit in, the rod was then fed through the wheels and sat between the bottom two wheels and top small having a small amount of force applied to it through the springs, in both y directions so it would have grip. Once the overall mechanism was assembled, we screwed the driver wheel into the servos using the M3 bolt that ran through the wheel as they fit perfectly within the servo’s attachment.

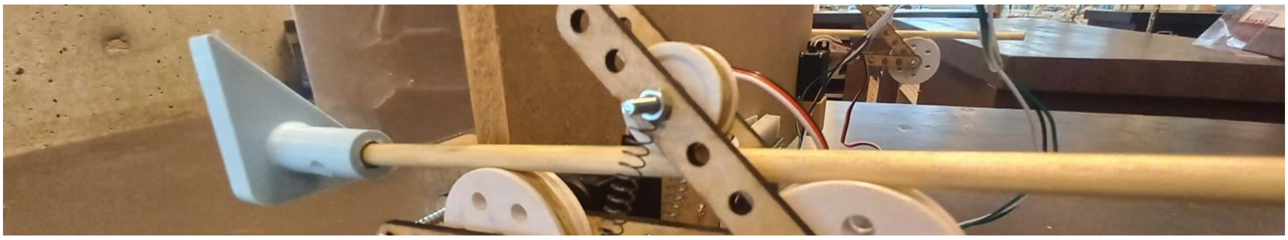


Figure 17. PLA corner piece attached to plywood rod

Once the main moving apparatus was constructed, the corner pieces made from PLA were then attached to the end of the rod. This was constructed using a hot glue gun, injecting the glue into the hollow cylinder of the corner pieces and then the plywood rods were then placed inside to set.

To construct the mirror two materials and one adhesive was used. The mirror made from mirricard was applied to a thin plexiglass these two materials were merged using spray on adhesive. This was to avoid any abrasions affecting the underside of the mirror therefore distorting the mirror more.

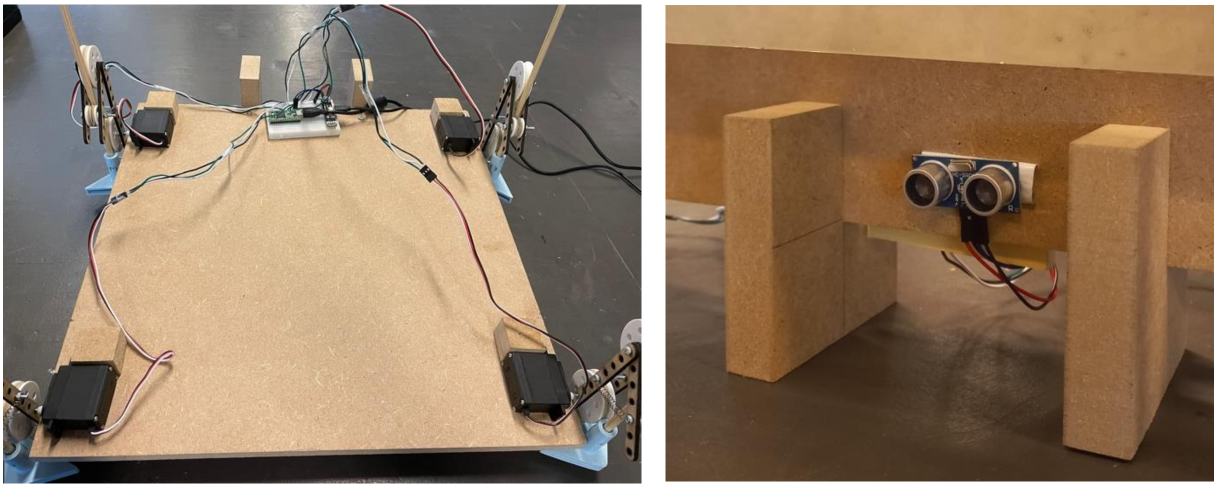


Figure 18. application of servos onto backboard and sensor onto backboard

To place the servos and attached mechanisms onto the backboard eight small blocks were cut to size using the bandsaw to fit onto the front and back of the backboard, they were measured to allow enough space for the servos to sit at each corner of the backboard. This allowed the design to have the largest mirror space possible. The movement sensor is then positioned at the base of the board, so it can detect movement in front of the mirror.

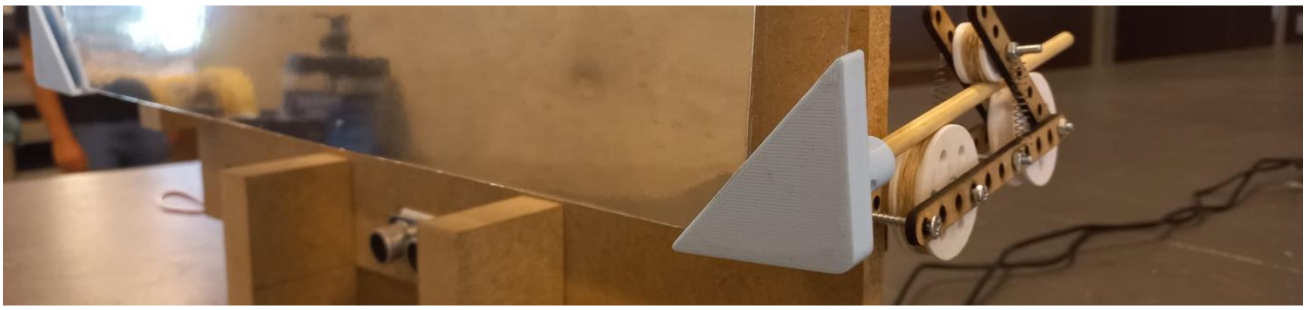


Figure 19. mirror placed into corner piece

After assembling every component together, the flexible mirror is then placed in the corner holds to complete the construction.

CONCLUSION

In conclusion, the design and manufacturing process of the laughing mirror showcases a creative and innovative approach to achieve a captivating and emotive interactive experience. By operating servo motors, friction wheels, and exact constraints, these mechanisms successfully transformed rotational movement into translational movement, permitting the bending of the plexiglass mirror. Through careful iteration and collaboration, the challenge of how to integrate mechanical processes required for this design was achieved.

The use of the mirror's bending effect exposed an evident distortion in the reflection, demonstrating the effectiveness of the chosen materials and construction techniques. The combination of the bendable "mirricard" and the semi flexible plexiglass backing proved to be a suitable balance of stiffness and flexibility.

The incorporation of the movement and distance sensor and servo motors adds an engaging element to the mirror. By randomly changing the program of the servo's configurations, the mirror can create and distort the face to create various facial expressions, enriching user interaction and amusement. The addition of the one-meter-long range for activation ensures optimal face distortion while maintaining a safe distance for the user.

Visually, the decision to expose the mechanical mechanisms adds to the overall appeal and wonder about the mirror. Allowing users to witness the movement of the mechanisms increases their amazement and appreciation for the design.

Overall, the design of the laughing mirror effectively combines mechanical ingenuity, interactivity, and aesthetic appeal. The mirror achieves its proposed purpose of delivering an entertaining and visually captivating experience for users.

DISCUSSION

As suspected, there were a few bottlenecks during the manufacturing phase of our concept. Firstly, the ABS that was used for the wheels didn't afford the proper friction that was needed to move the wooden rod. As time was limited, the decision was made to add rubber bands to add friction to the wheels. For future iterations, either a different material with more friction could be used, such as silicone, or the outside of the wheels could be covered in a material with rubber like properties. Another bottleneck was the fact that the rotation from the servo motors did not transfer to the wheels fully. This is because screws connected to bolts had to be used as the axis for the wheels to spin around due to time constraint. This resulted in the screws loosening when the servo turned clockwise. This could be fixed by designing and manufacturing a hexagon rod with a part that can be attached to the servo and change the centre hole of the wheel to a hexagon as well. This will make sure the wheel always rotates at the same rate as the servo motor.

-

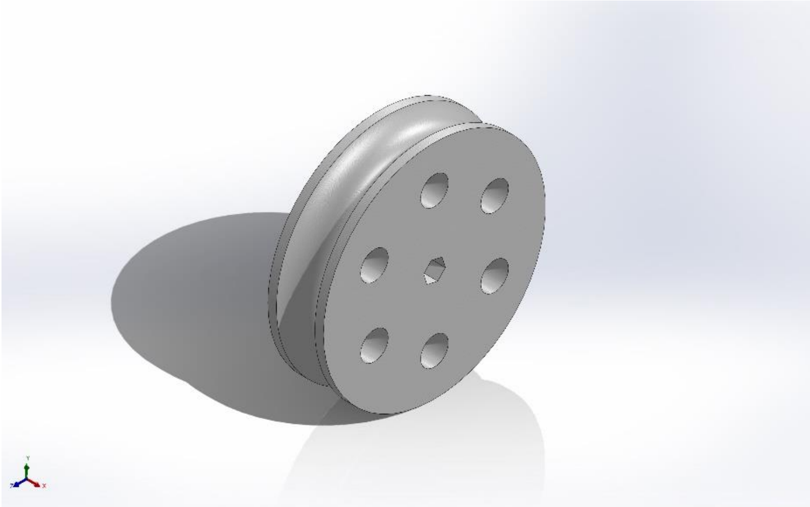
REFERENCES

Delbressine, F. L. M. (2023). *Mechanical Design, Engineering and Manufacturing*. Notion. https://nine-pegasus-b36.notion.site/Mechanical-Design-Engineering-and-Manufacturing-66a3909b8e18438cad5d6e44e3f0eab8

APPENDIX

A) CAD designs and finite element analyses

Driver wheel FEA analysis:



Simulation of Bottom_Drivewheel_V2

Date: Monday, 19 June 2023
Designer: Solidworks
Study name: Static 1
Analysis type: Static

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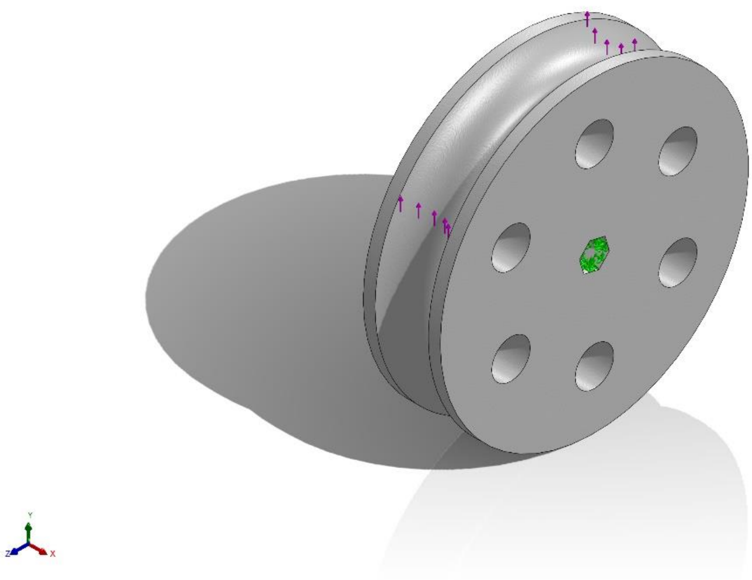
Description

No Data

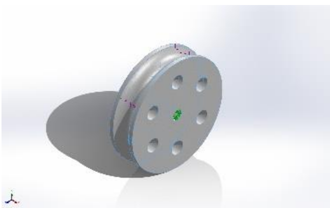
Assumptions

Model Information



Model name: Bottom_Drivewheel_V2
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
CirPattern1 	Solid Body	Mass:0.0103021 kg Volume:1.01001e-05 m^3 Density:1,020 kg/m^3 Weight:0.100961 N	C:\Users\Griffin\Documen Georgie\CAD\Emotions Mirror\Bottom_Drivewhee 2.SLDPRT Jun 16 15:50:51 2023

Study Properties

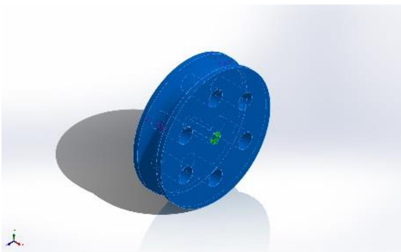
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off

Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Griffin\Documents\Georgie\CAD\Emotions Mirror)

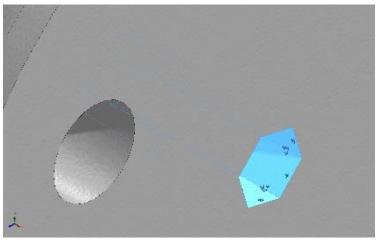
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

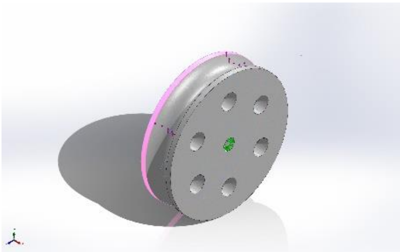
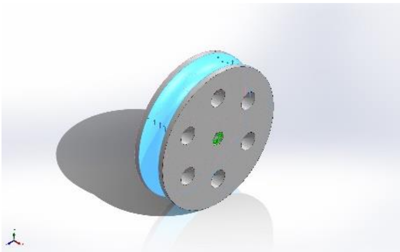
Model Reference	Properties	Components
	Name: **ABS** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Tensile strength: **3e+07 N/m^2** Elastic modulus: **2e+09 N/m^2** Poisson's ratio: **0.394** Mass density: **1,020 kg/m^3** Shear modulus: **3.189e+08 N/m^2**	**SolidBody 1(CirPattern1)(Bottom_Dri heel_V2)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 edge(s), 6 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	-2.98023e-08	-0.999448	-0.00160291	0.99945
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Torque-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1 N.m
Force-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply force **Values:** 1, ---, --- N

Connector Definitions
No Data

Interaction Information
No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh

Jacobian points for High quality mesh	16 Points
Maximum element size	2.16243 mm
Minimum element size	0.720802 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	16116
Total Elements	10152
Maximum Aspect Ratio	4.907
% of elements with Aspect Ratio < 3	99.3
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	GRIFFINXPS

Sensor Details
No Data

Resultant Forces
Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-2.98023e-08	-0.999448	-0.00160291	0.99945

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-3.08028e-08	-5.72857e-06	-6.19553e-05	6.22196e-05

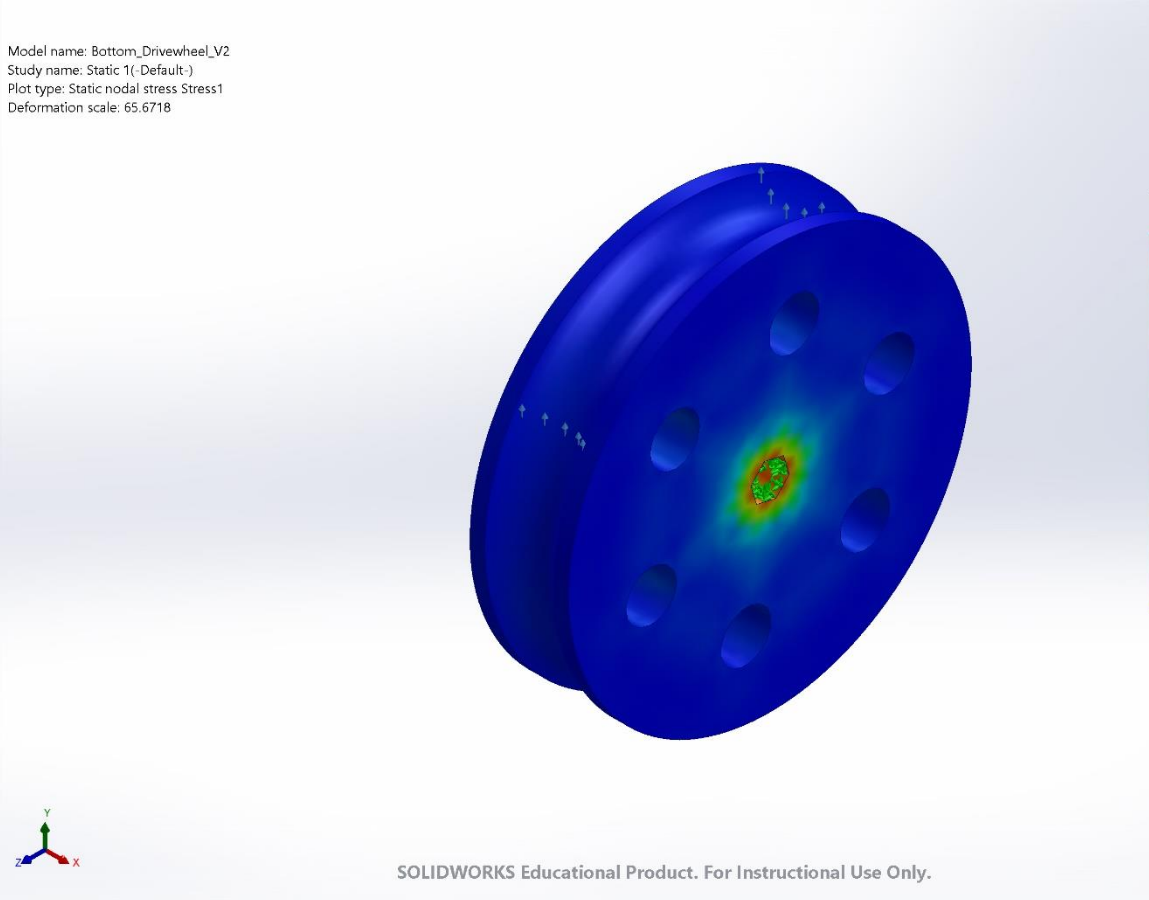
Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Beams
No Data

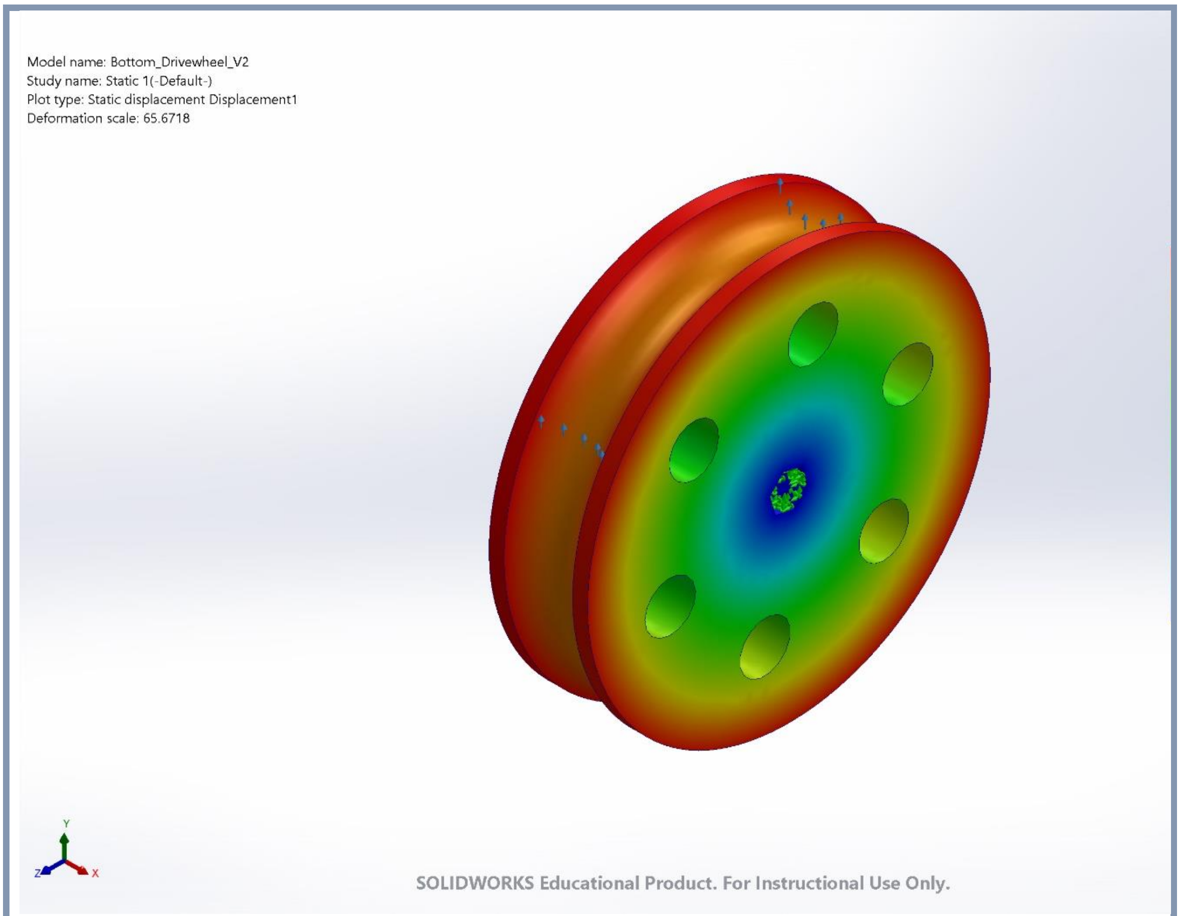
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	2.227e+03N/m^2 Node: 13520	5.623e+06N/m^2 Node: 13726



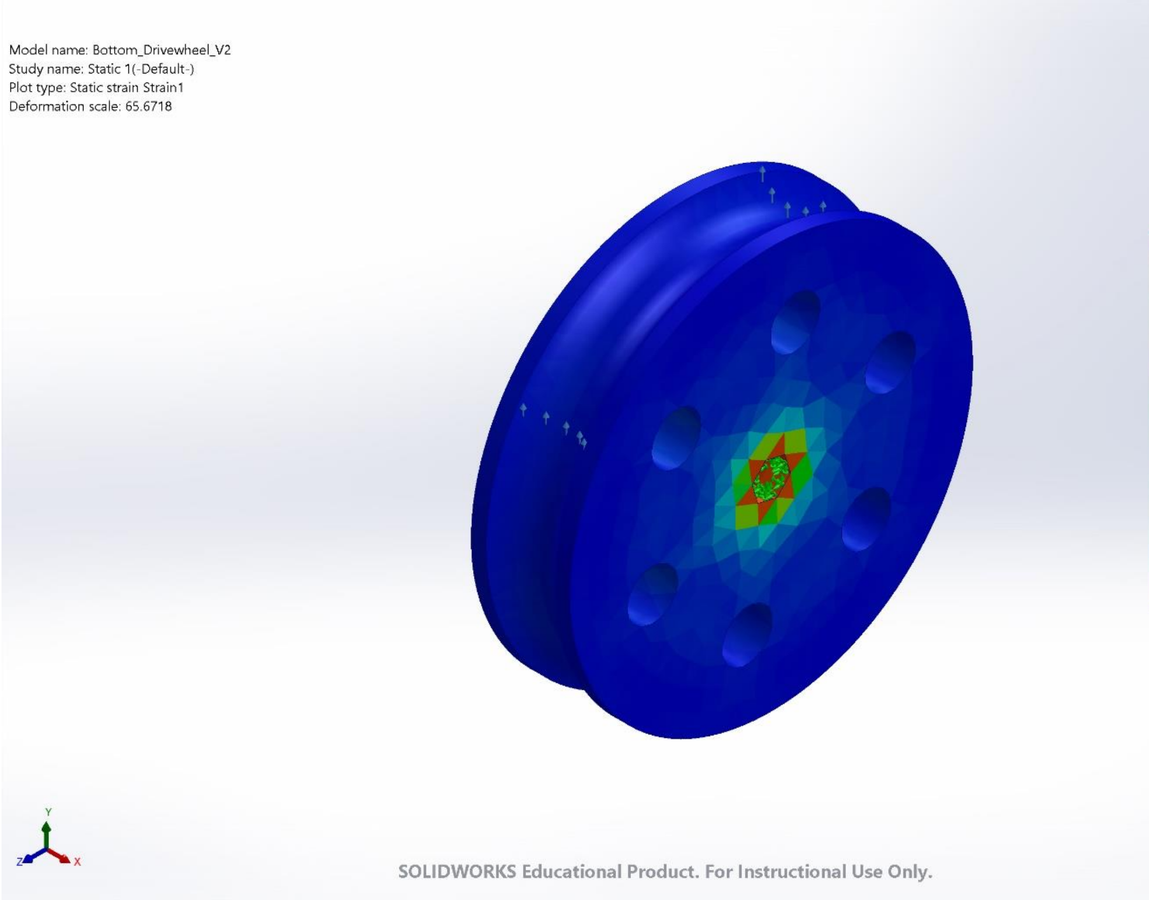
Bottom_Drivewheel_V2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 21	6.091e-02mm Node: 4



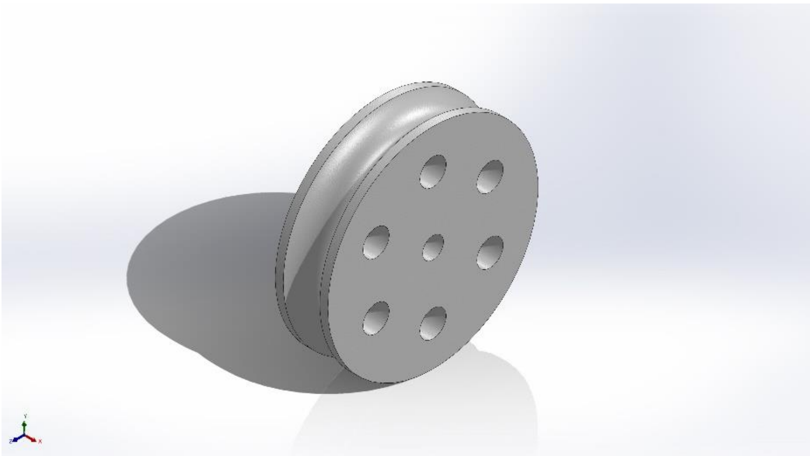
Bottom_Drivewheel_V2-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.623e-06 Element: 4397	2.358e-03 Element: 8098



Bottom_Drivewheel_V2-Static 1-Strain-Strain1

Free bottom wheel FEA analysis:



Simulation of Bottom_Freewheel_Pusher_V2

Date: Monday, 19 June 2023
Designer: Solidworks
Study name: Static 1
Analysis type: Static

Description
No Data

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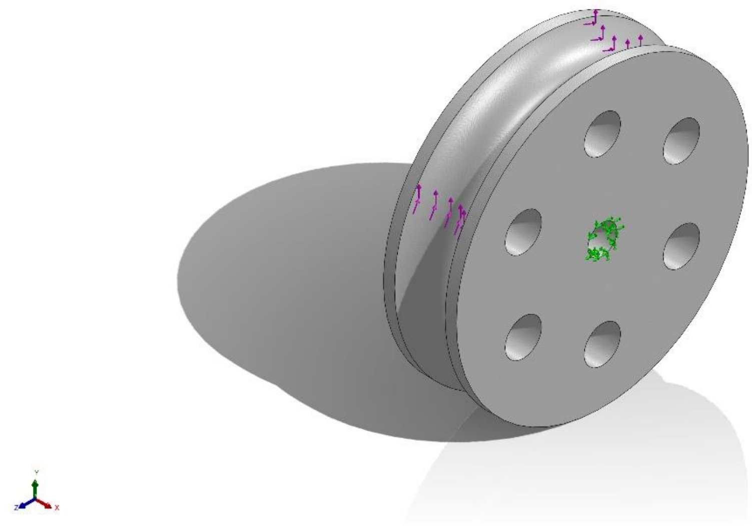
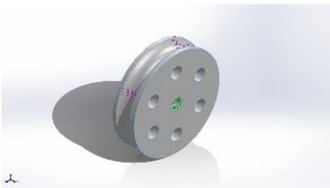
Assumptions

Model Information



Model name: Bottom_Freewheel_Pusher_V2
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
CirPattern1 	Solid Body	Mass:0.0102799 kg Volume:1.00784e-05 m^3 Density:1,020 kg/m^3 Weight:0.100743 N	C:\Users\Griffin\Documen Georgie\CAD\Emotions Mirror\Bottom_Freewhee usher_V2.SLDPRT Jun 16 15:51:34 2023

Study Properties

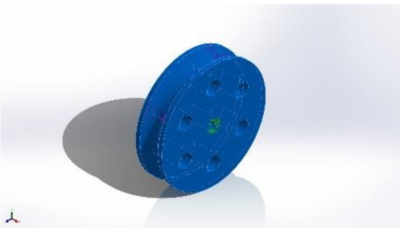
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off

Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Griffin\Documents\Georgie\CAD\Emotions Mirror)

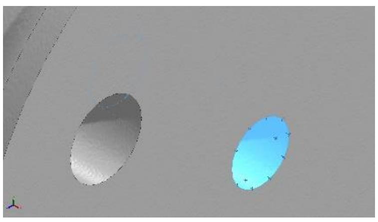
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

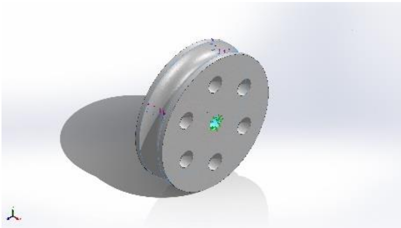
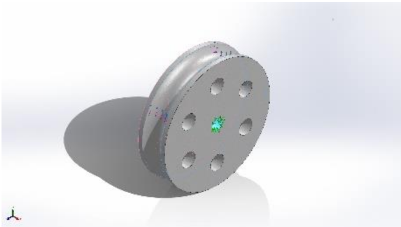
Model Reference	Properties		Components
	Name: Model type: Default failure criterion: Tensile strength: Elastic modulus: Poisson's ratio: Mass density: Shear modulus:	**ABS** **Linear Elastic Isotropic** **Unknown** **3e+07 N/m^2** **2e+09 N/m^2** **0.394** **1,020 kg/m^3** **3.189e+08 N/m^2**	**SolidBody 1(CirPattern1)(Bottom_Fre eel_Pusher_V2)**
Curve Data:N/A			

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details	
Fixed-1		**Entities:** **Type:**	**2 edge(s), 1 face(s)** **Fixed Geometry**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-0.000953282	-1.00022	-0.00129056	1.00023
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Torque-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1 N.m
Force-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply force **Values:** 1, ---, --- N

Connector Definitions
No Data

Interaction Information
No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	1.16147 mm
Minimum element size	0.387153 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	85119

Total Elements	57548
Maximum Aspect Ratio	3.5848
% of elements with Aspect Ratio < 3	100
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:03
Computer name:	GRIFFINXPS

Sensor Details
No Data

Resultant Forces
Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.000953282	-1.00022	-0.00129056	1.00023

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00431014	-0.00075084	-0.0033685	0.00552158

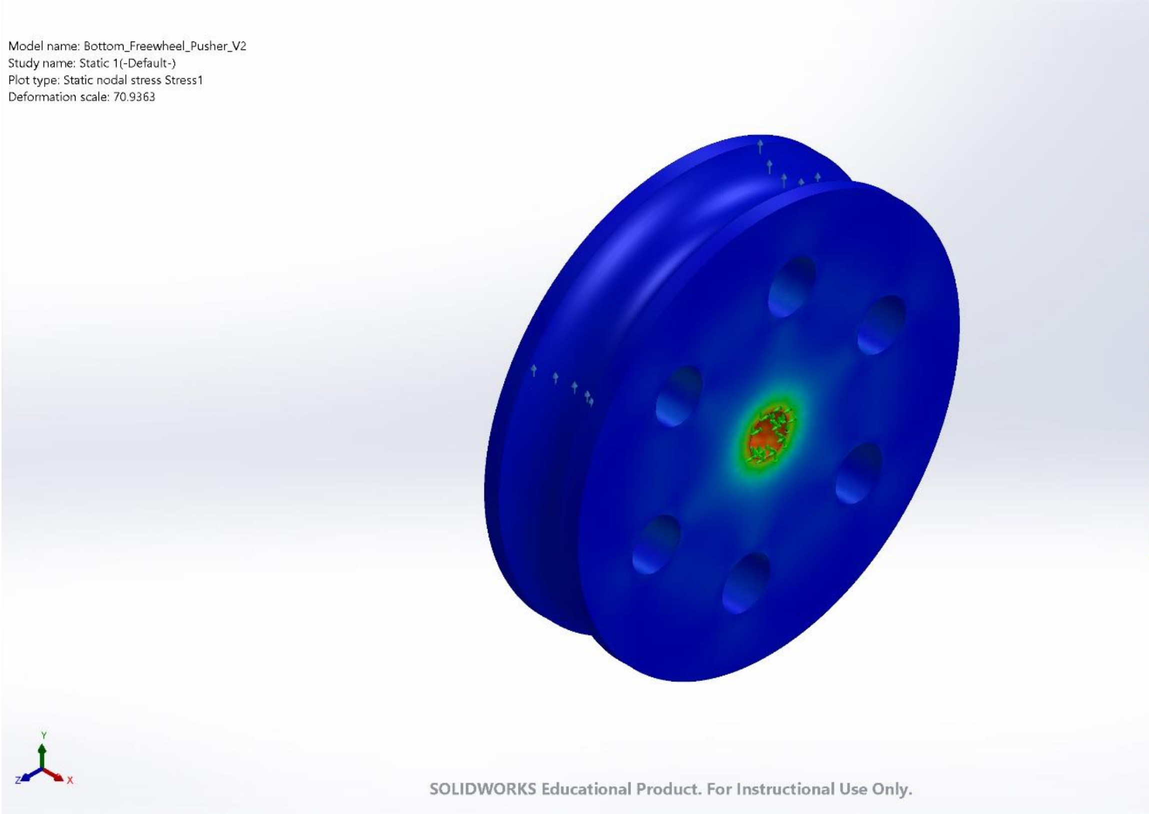
Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Beams
No Data

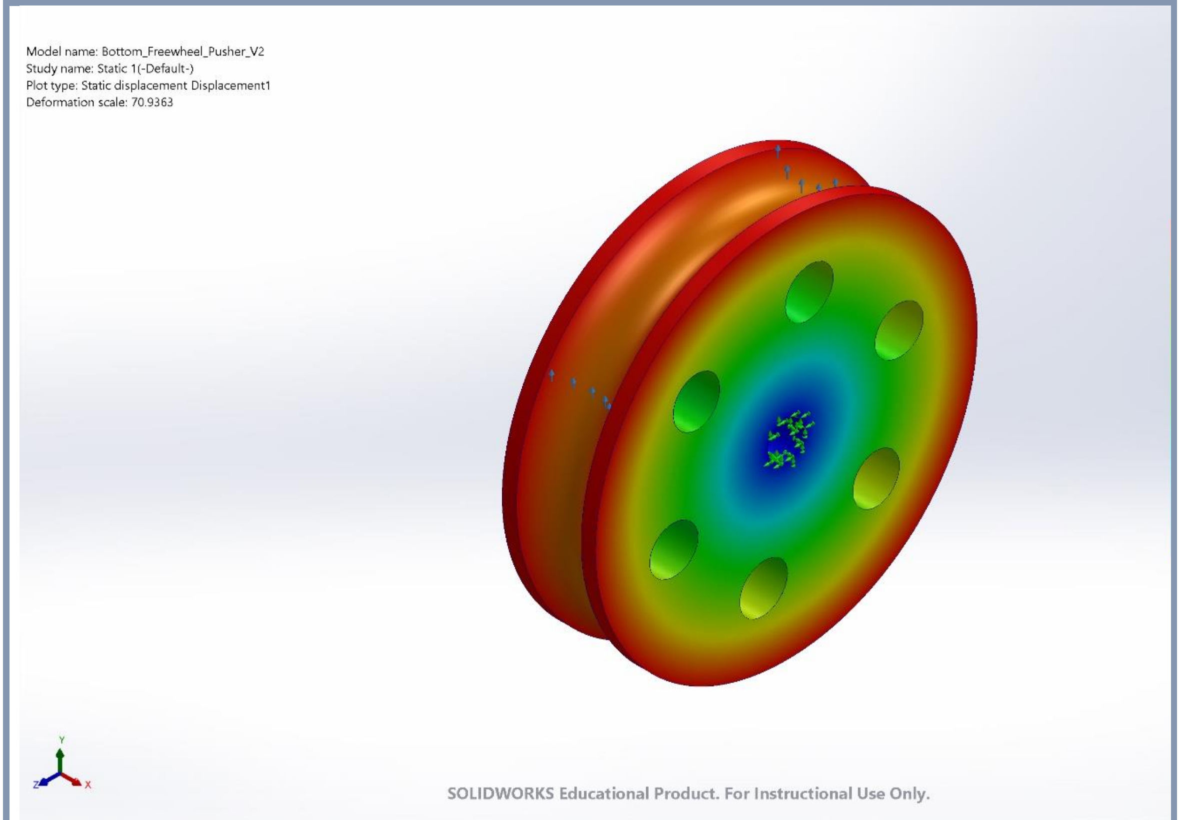
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	2.207e+03N/m^2 Node: 66848	7.025e+06N/m^2 Node: 28583



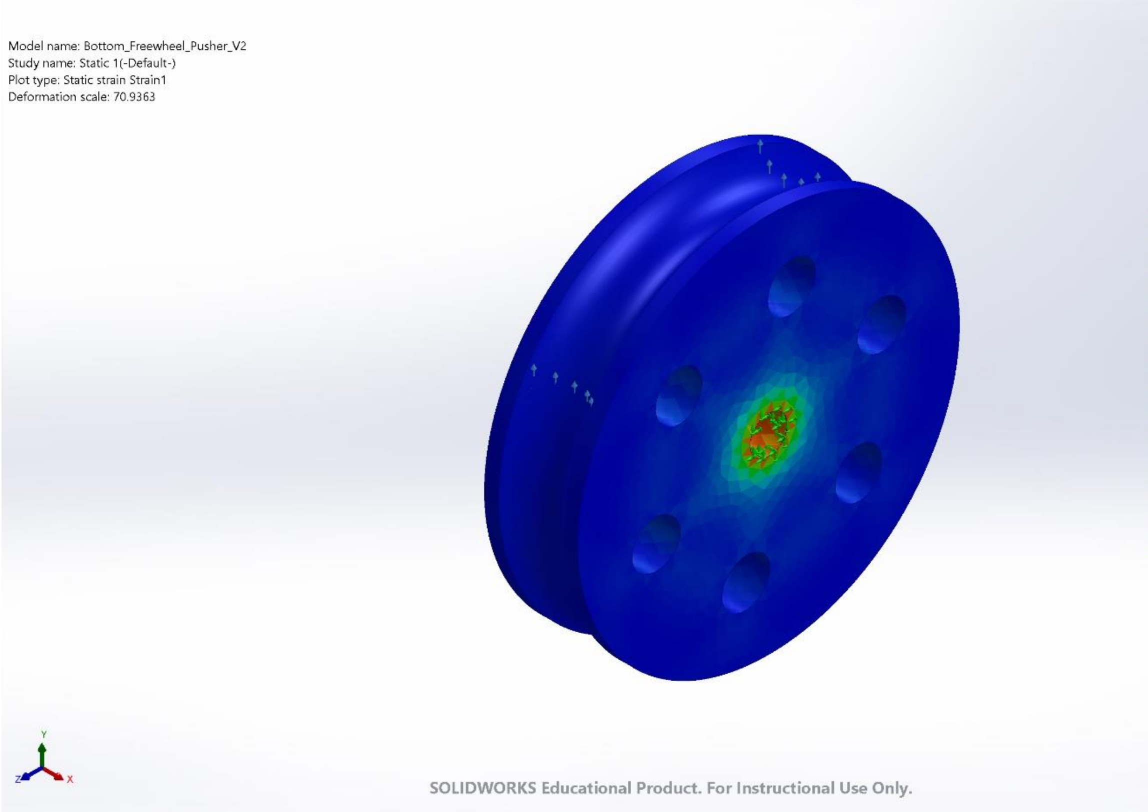
Bottom_Freewheel_Pusher_V2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 21	5.639e-02mm Node: 1



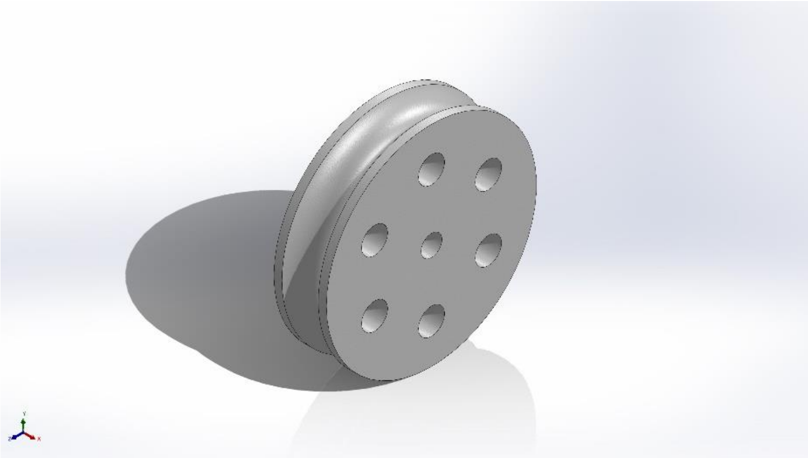
Bottom_Freewheel_Pusher_V2-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.310e-06 Element: 20532	2.889e-03 Element: 23615



Bottom_Freewheel_Pusher_V2-Static 1-Strain-Strain1

Conclusion



Simulation of Bottom_Freewheel_Pusl r_V2

Date: Monday, 19 June 2023
Designer: Solidworks
Study name: Static 1
Analysis type: Static

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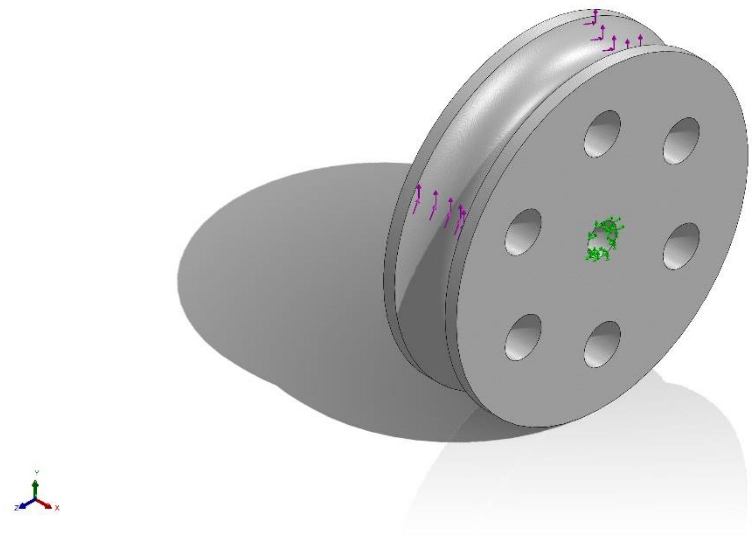
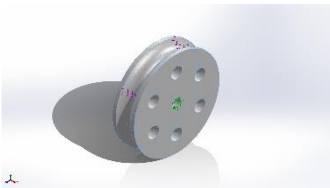
Description
No Data

Assumptions

Model Information



Model name: Bottom_Freewheel_Pusher_V2
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
CirPattern1 	Solid Body	Mass:0.0102799 kg Volume:1.00784e-05 m^3 Density:1,020 kg/m^3 Weight:0.100743 N	C:\Users\Griffin\Documen Georgie\CAD\Emotions Mirror\Bottom_Freewheel usher_V2.SLDPRT Jun 16 15:51:34 2023

Study Properties

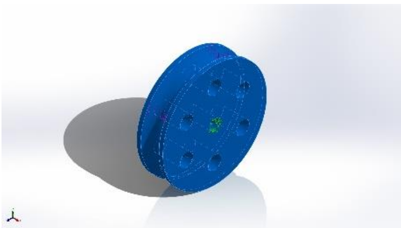
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off

Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Griffin\Documents\Georgie\CAD\Emotions Mirror)

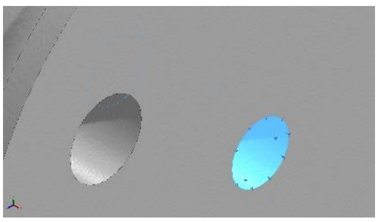
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

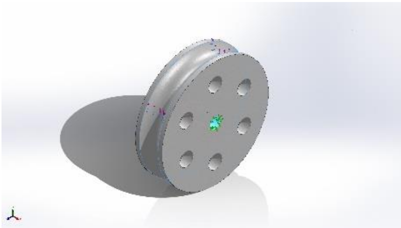
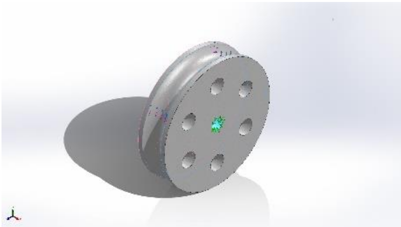
Material Properties

Model Reference	Properties	Components
	Name: **ABS** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Tensile strength: **3e+07 N/m^2** Elastic modulus: **2e+09 N/m^2** Poisson's ratio: **0.394** Mass density: **1,020 kg/m^3** Shear modulus: **3.189e+08 N/m^2**	**SolidBody 1(CirPattern1)(Bottom_Fre eel_Pusher_V2)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **2 edge(s), 1 face(s)** **Type:** **Fixed Geometry**

Resultant Forces				
Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**-0.000953282**	**-1.00022**	**-0.00129056**	**1.00023**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Torque-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1 N.m
Force-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply force **Values:** 1, ---, --- N

Connector Definitions
No Data

Interaction Information
No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	1.16147 mm
Minimum element size	0.387153 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	85119

Total Elements	57548
Maximum Aspect Ratio	3.5848
% of elements with Aspect Ratio < 3	100
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:03
Computer name:	GRIFFINXPS

Sensor Details
No Data

Resultant Forces
Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.000953282	-1.00022	-0.00129056	1.00023

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00431014	-0.00075084	-0.0033685	0.00552158

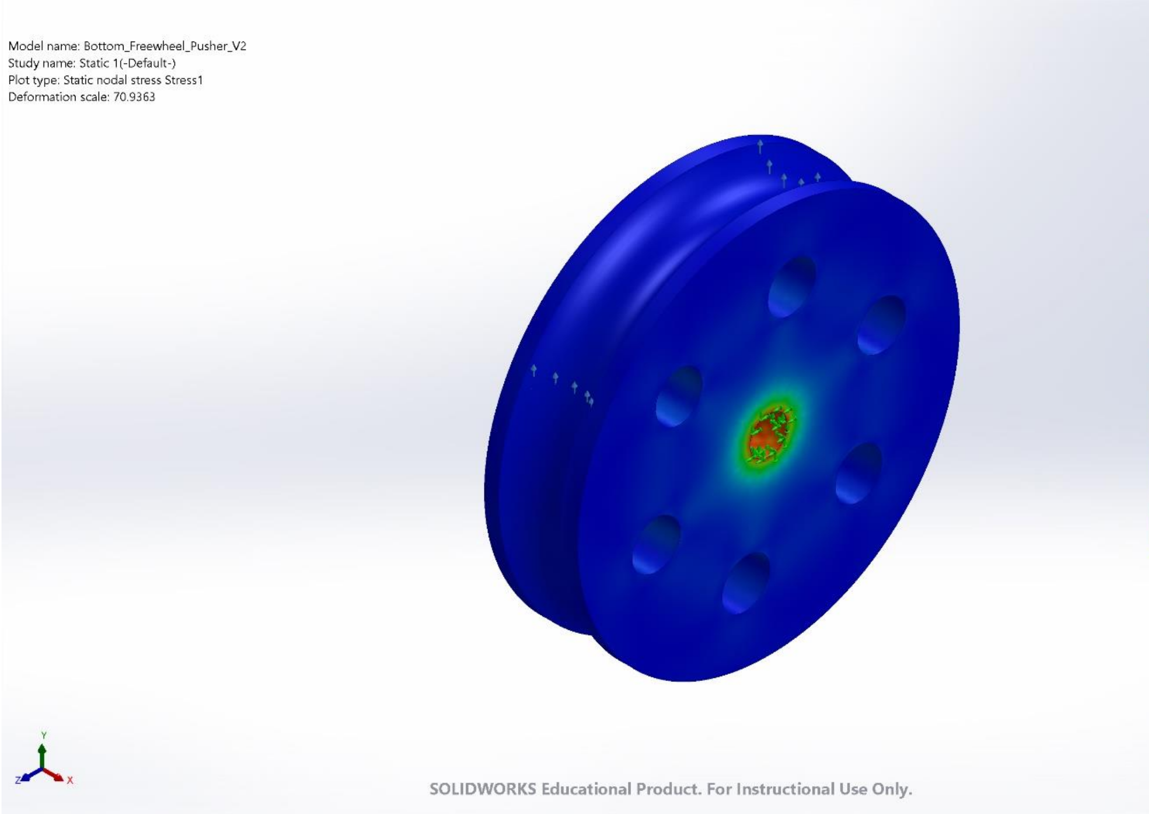
Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Beams
No Data

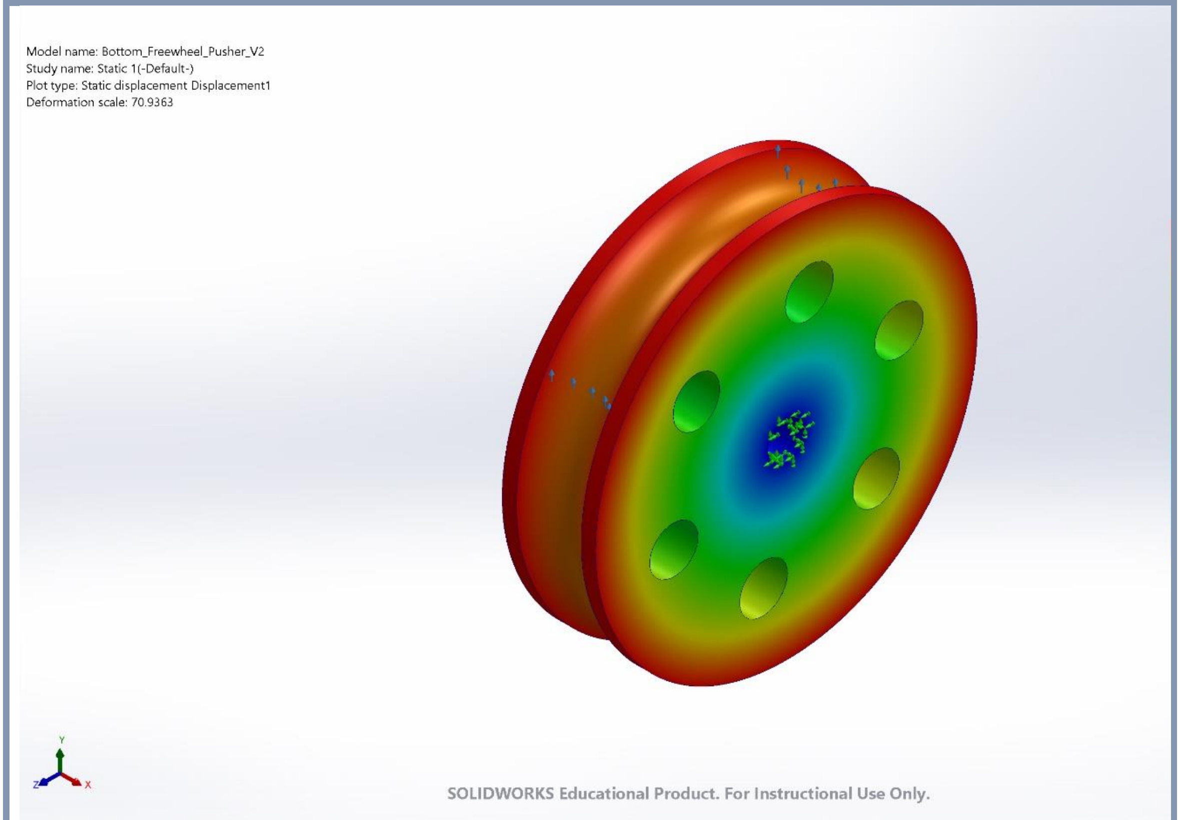
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	2.207e+03N/m^2 Node: 66848	7.025e+06N/m^2 Node: 28583



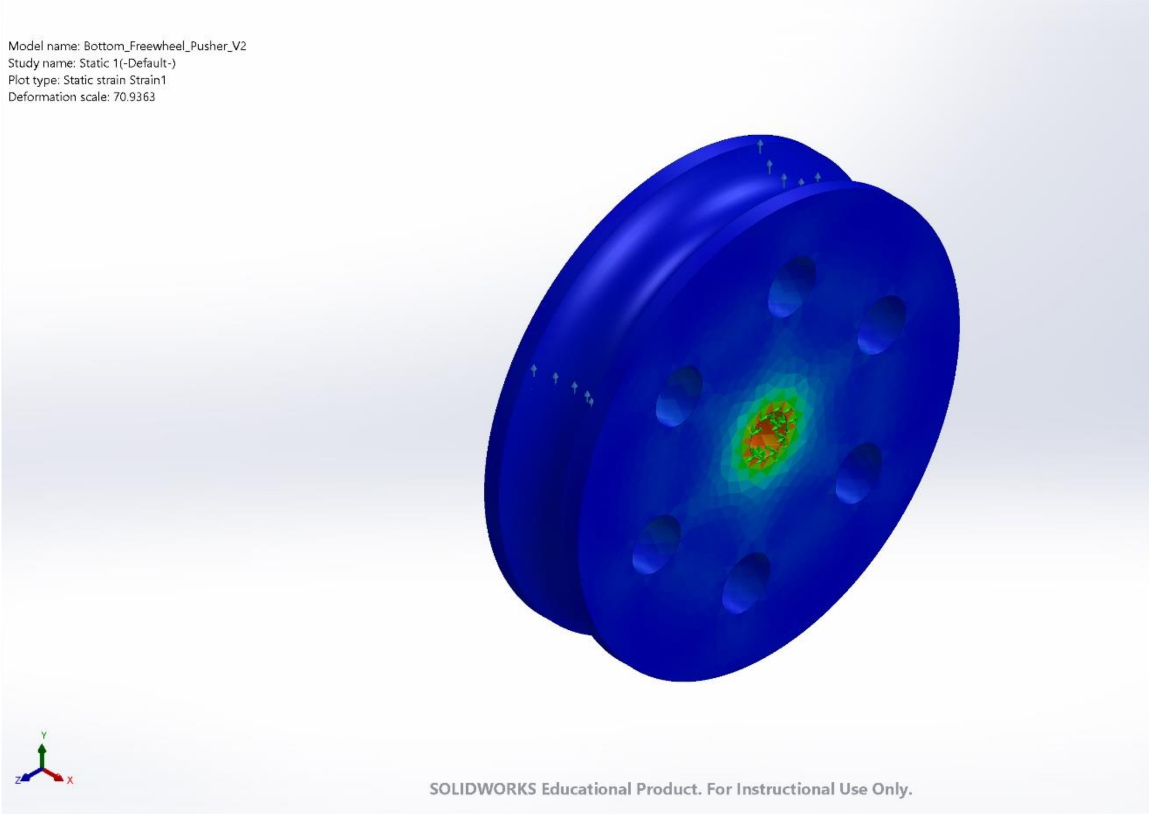
Bottom_Freewheel_Pusher_V2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 21	5.639e-02mm Node: 1



Bottom_Freewheel_Pusher_V2-Static 1-Displacement-Displacement1

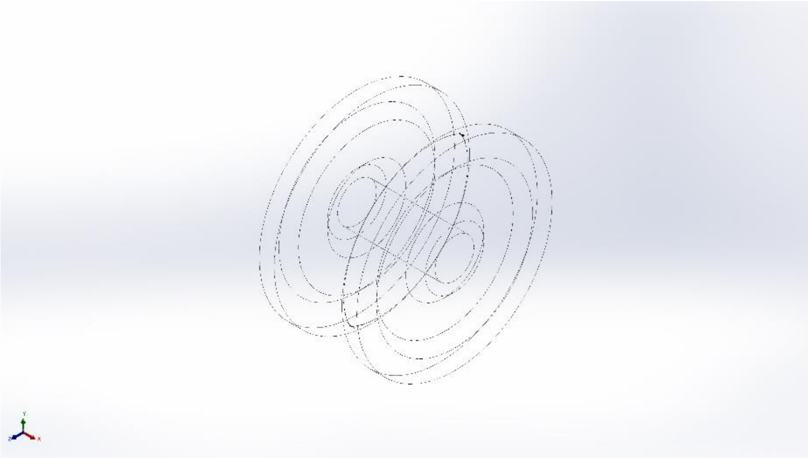
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.310e-06 Element: 20532	2.889e-03 Element: 23615



Bottom_Freewheel_Pusher_V2-Static 1-Strain-Strain1

Conclusion

Free top wheel FEA analysis:



Simulation of Top_Freewheel_Pusher_2

Date: Monday, 19 June 2023
Designer: Solidworks
Study name: Static 1
Analysis type: Static

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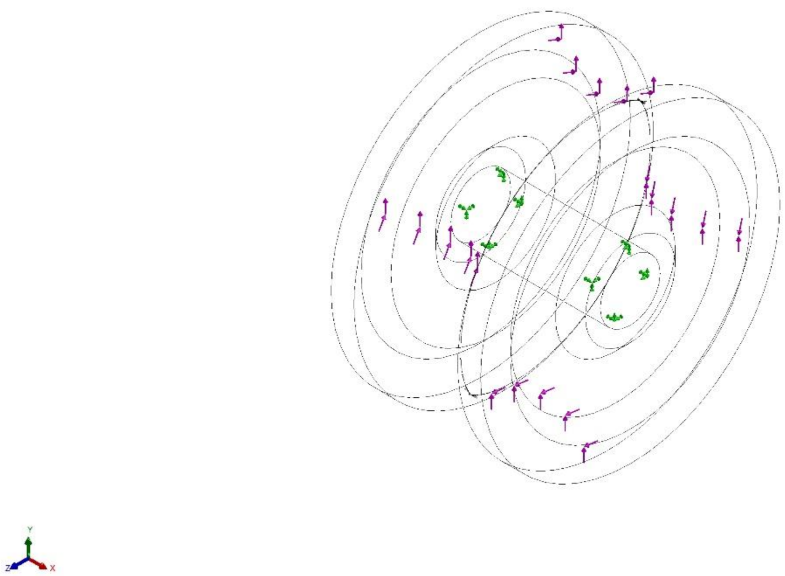
Description
No Data

Assumptions

Model Information



Model name: Top_Freewheel_Pusher_V2
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Chamfer3 	Solid Body	Mass:0.00220987 kg Volume:2.16654e-06 m^3 Density:1,020 kg/m^3 Weight:0.0216568 N	C:\Users\Griffin\Documen Georgie\CAD\Emotions Mirror\Top_Freewheel_Pu r_V2.SLDPRT Jun 16 15:52:31 2023

Study Properties

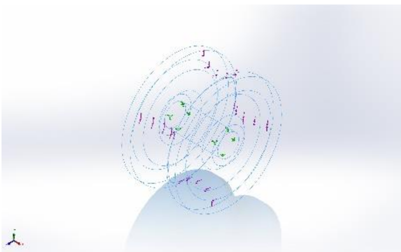
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off

Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Griffin\Documents\Georgie\CAD\Emotions Mirror)

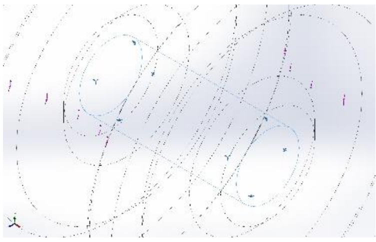
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

Model Reference	Properties	Components
	Name: **ABS** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Tensile strength: **3e+07 N/m^2** Elastic modulus: **2e+09 N/m^2** Poisson's ratio: **0.394** Mass density: **1,020 kg/m^3** Shear modulus: **3.189e+08 N/m^2**	**SolidBody 1(Chamfer3)(Top_Freewhe usher_V2)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**0.00182584**	**-1.00538**	**-0.00262611**	**1.00539**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply force **Values:** 1, ---, --- N
Torque-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1 N.m

Connector Definitions

No Data

Interaction Information

No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh

Jacobian points for High quality mesh	16 Points
Maximum element size	0.647264 mm
Minimum element size	0.647264 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	91210
Total Elements	62400
Maximum Aspect Ratio	4.3583
% of elements with Aspect Ratio < 3	99.9
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	GRIFFINXPS

Sensor Details
No Data

Resultant Forces
Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00182584	-1.00538	-0.00262611	1.00539

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.0052986	-0.0030084	-0.0117525	0.013238

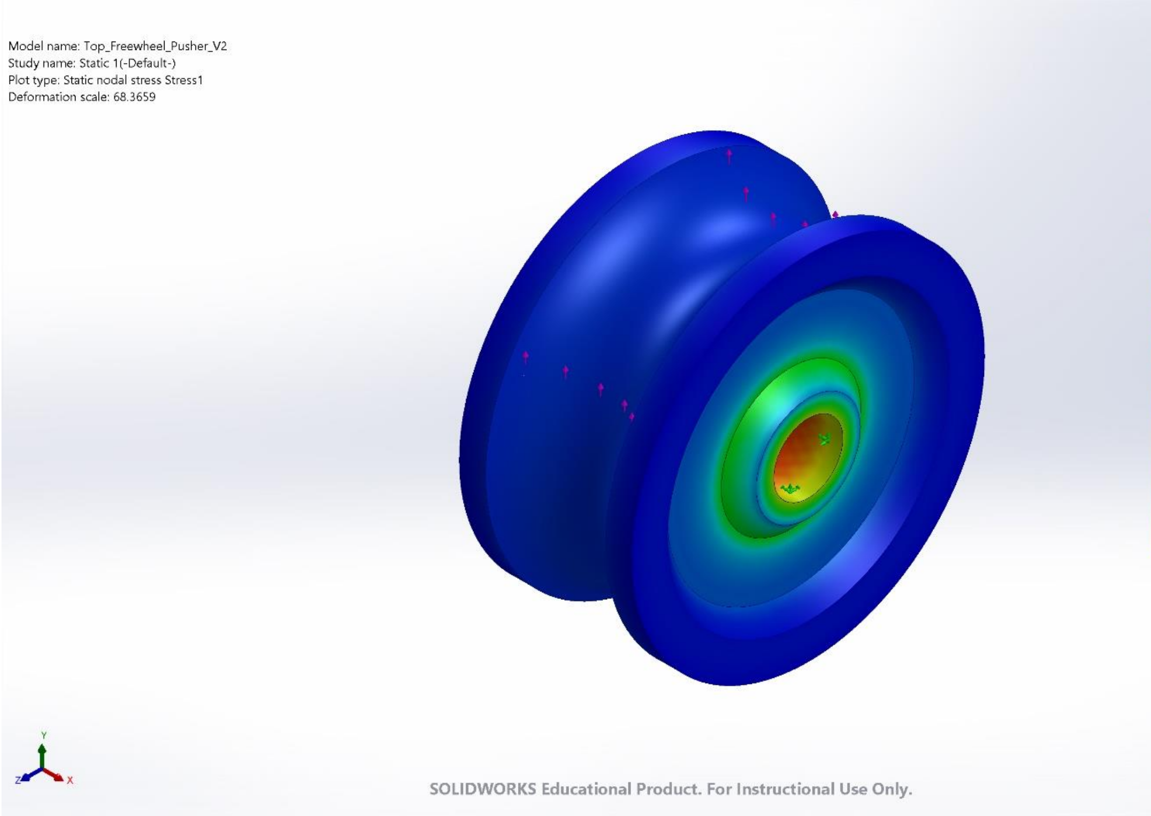
Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Beams
No Data

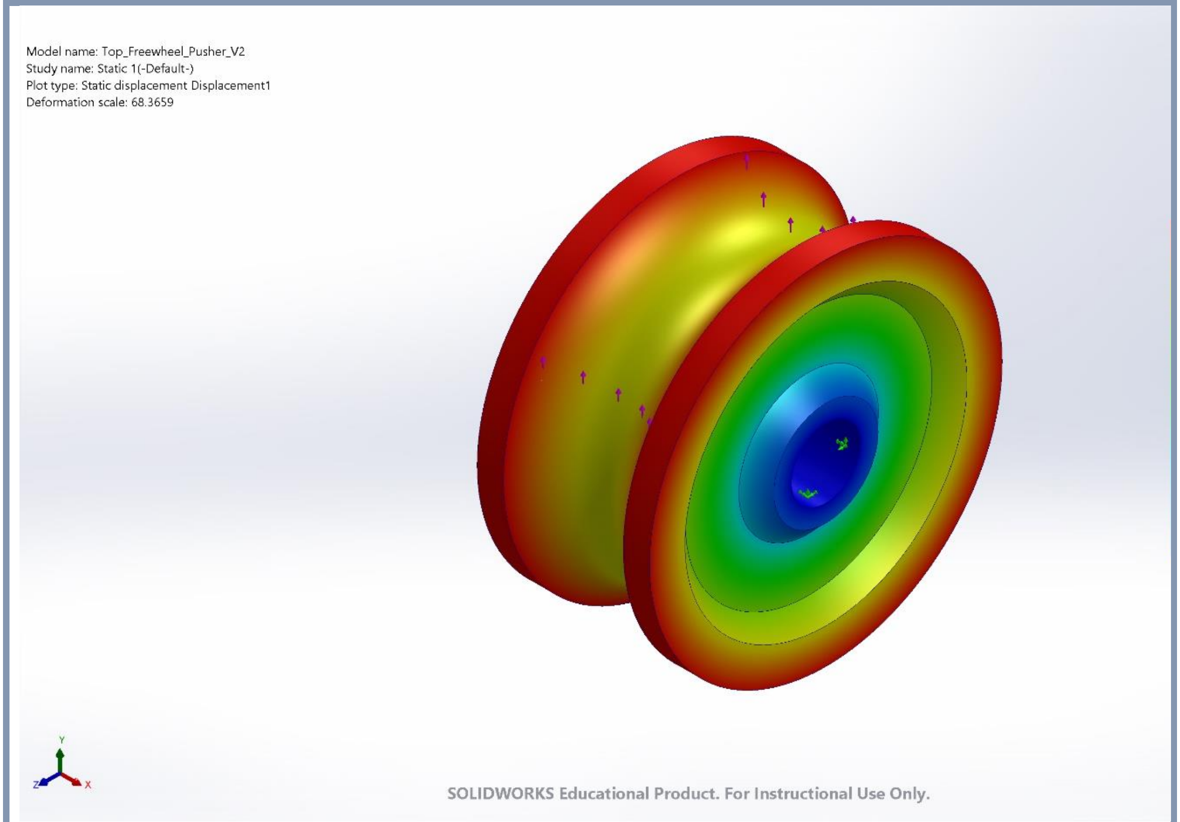
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.171e+02N/m^2 Node: 3	7.501e+06N/m^2 Node: 2991



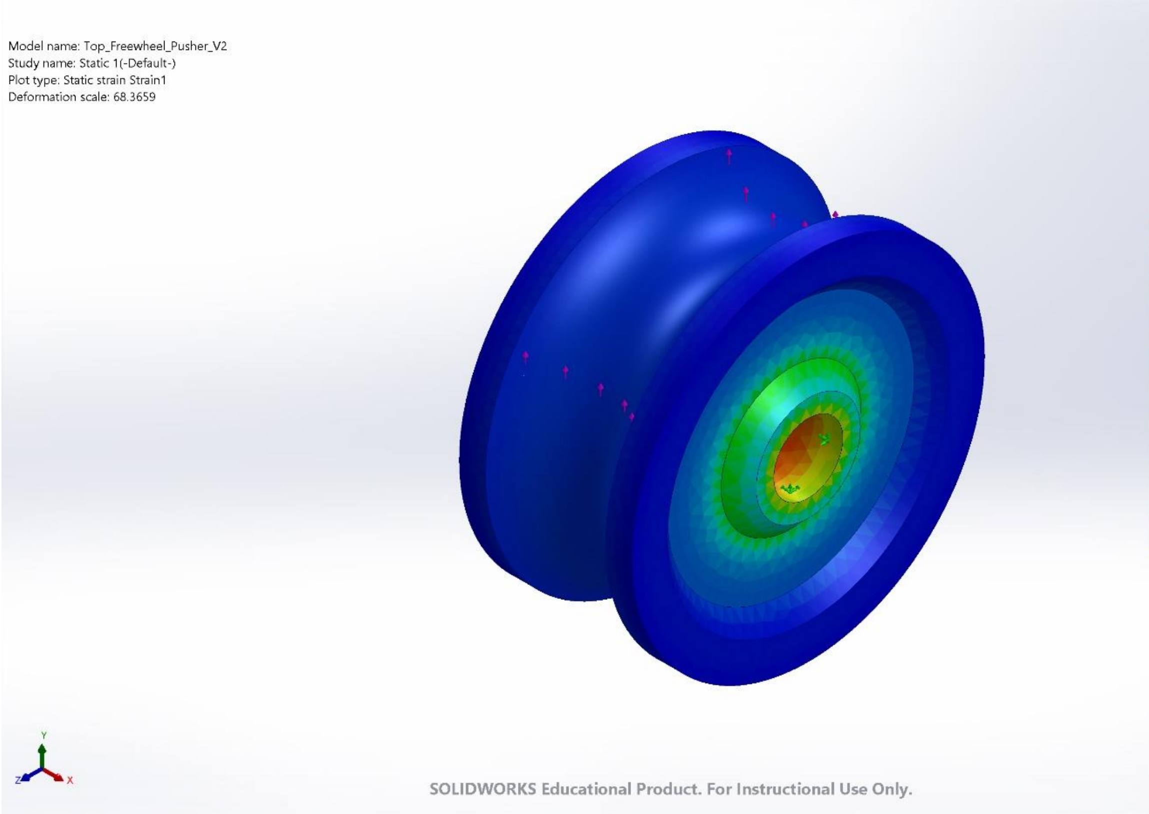
Top_Freewheel_Pusher_V2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 9	2.925e-02mm Node: 1006



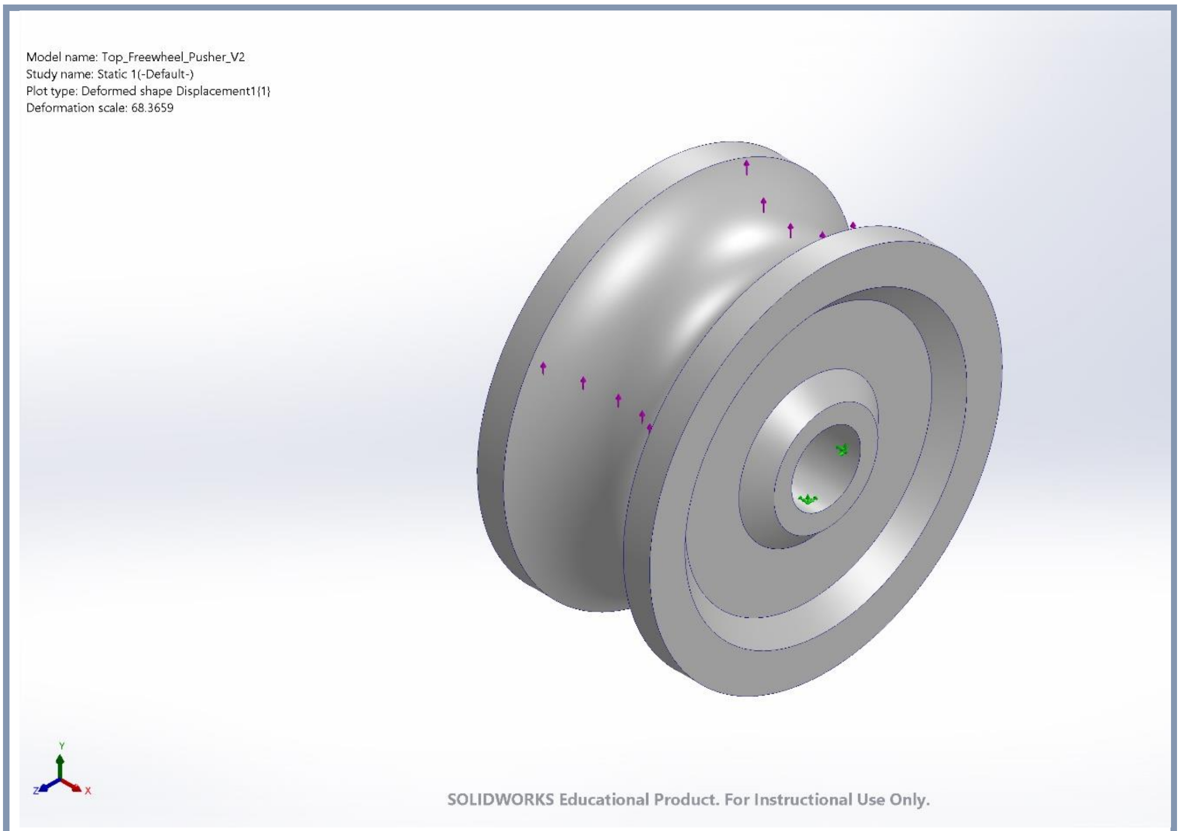
Top_Freewheel_Pusher_V2-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.314e-05 Element: 27384	3.225e-03 Element: 21817



Top_Freewheel_Pusher_V2-Static 1-Strain-Strain1

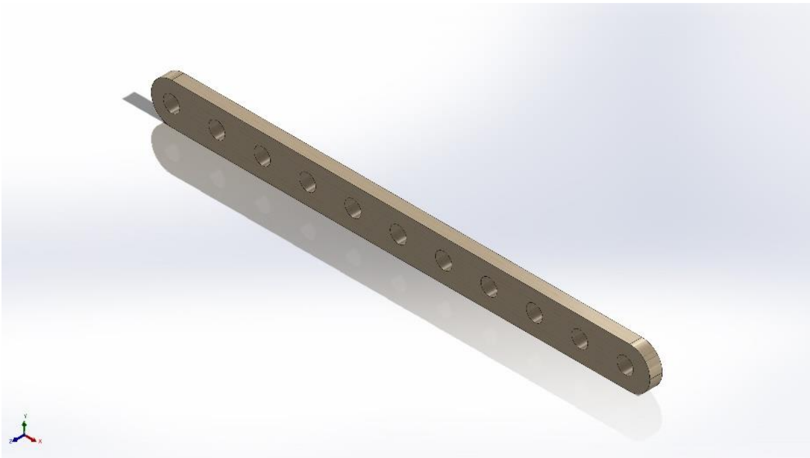
Name	Type
Displacement1{1}	Deformed shape



Top_Freewheel_Pusher_V2-Static 1-Displacement-Displacement1{1}

Conclusion

Bottom side rail FEA analysis:



Simulation of Bottom_Siderail_V2

Date: Monday, 19 June 2023
Designer: Solidworks
Study name: Static 1
Analysis type: Static

Description

No Data

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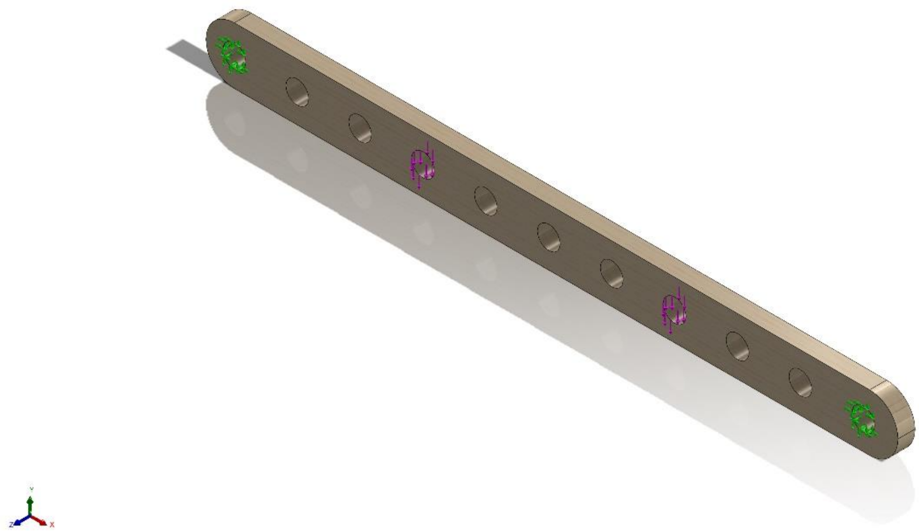
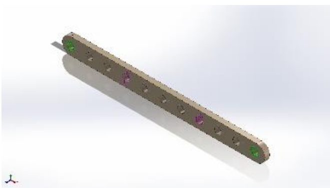
Assumptions

Model Information



Model name: Bottom_Siderail_V2
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1 	Solid Body	Mass:0.0010816 kg Volume:3.18119e-06 m^3 Density:340 kg/m^3 Weight:0.0105997 N	C:\Users\Griffin\Documen Georgie\CAD\Emotions Mirror\Bottom_Siderail_V: LDPRT Jun 16 16:29:14 2023

Study Properties

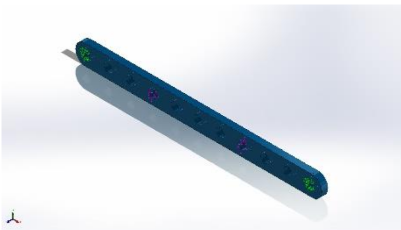
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off

Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	On
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Griffin\Documents\Georgie\CAD\Emotions Mirror)

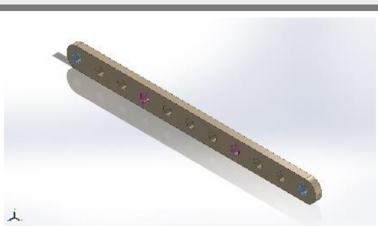
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

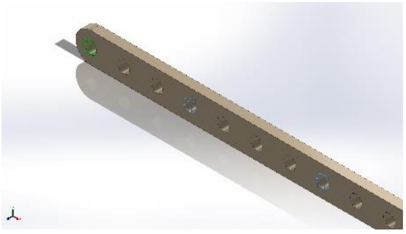
Model Reference	Properties	Components
	Name: **Pine** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Elastic modulus: **7e+06 N/m^2** Poisson's ratio: **0.3** Mass density: **340 kg/m^3**	**SolidBody 1(Boss-Extrude1)(Bottom_Siderail**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **2 edge(s)** **Type:** **Fixed Geometry**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**0.000137284**	**1.99895**	**0.000272021**	**1.99895**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-1		**Entities:** 2 edge(s) **Reference:** Edge< 1 > **Type:** Apply force **Values:** ---, ---, 1 N

Connector Definitions
No Data

Interaction Information
No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	2.94268 mm
Minimum element size	1.14029 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	5632
Total Elements	2881
Maximum Aspect Ratio	123.13
% of elements with Aspect Ratio < 3	94.9
Percentage of elements with Aspect Ratio > 10	0.278
Percentage of distorted elements	0

Time to complete mesh(hh;mm;ss):	00:00:01
Computer name:	GRIFFINXPS

Sensor Details
No Data

Resultant Forces
Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.000137284	1.99895	0.000272021	1.99895

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0	0	0	0

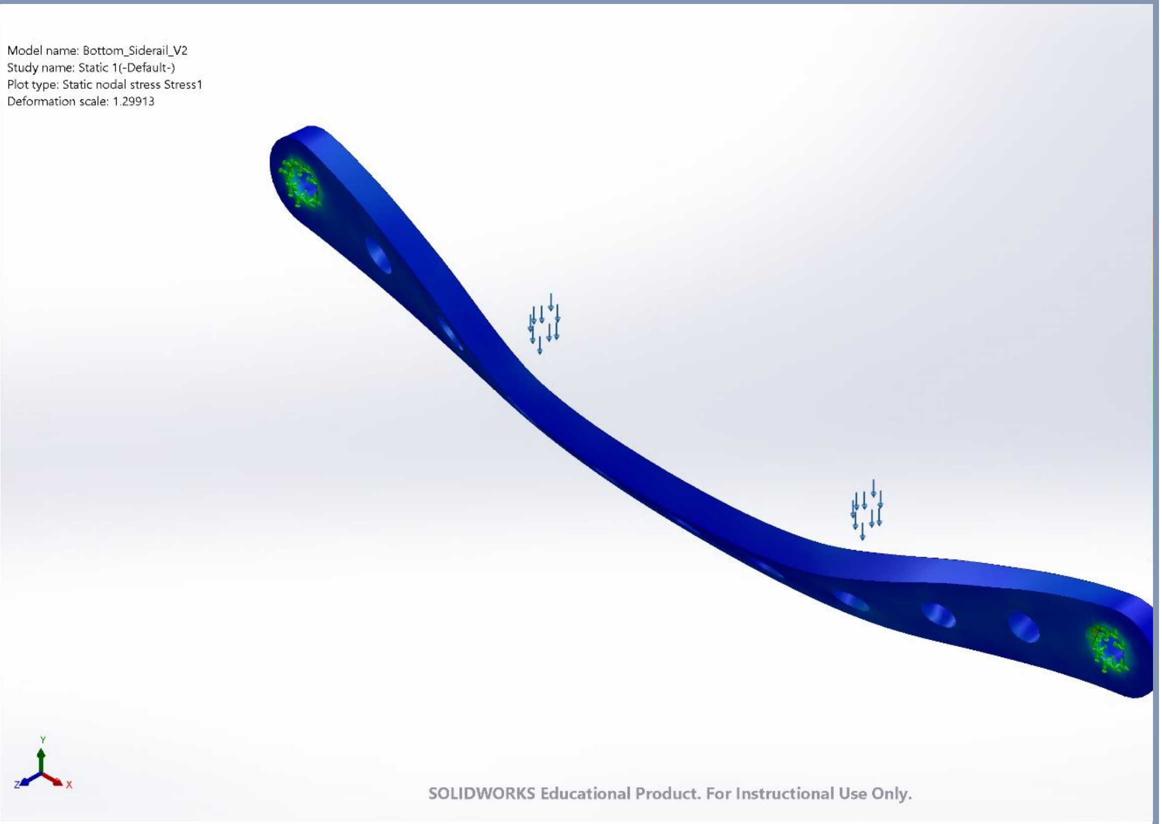
Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Beams
No Data

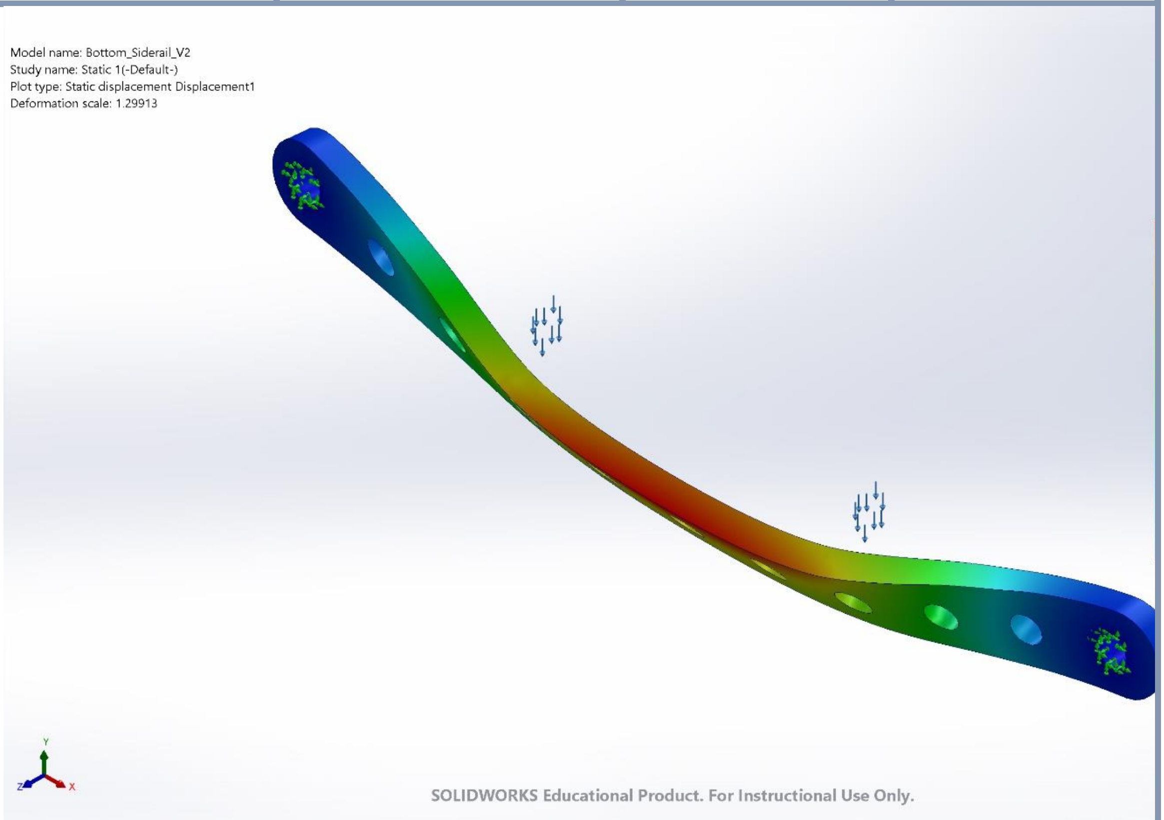
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.151e+03N/m^2 Node: 2380	3.690e+06N/m^2 Node: 3714



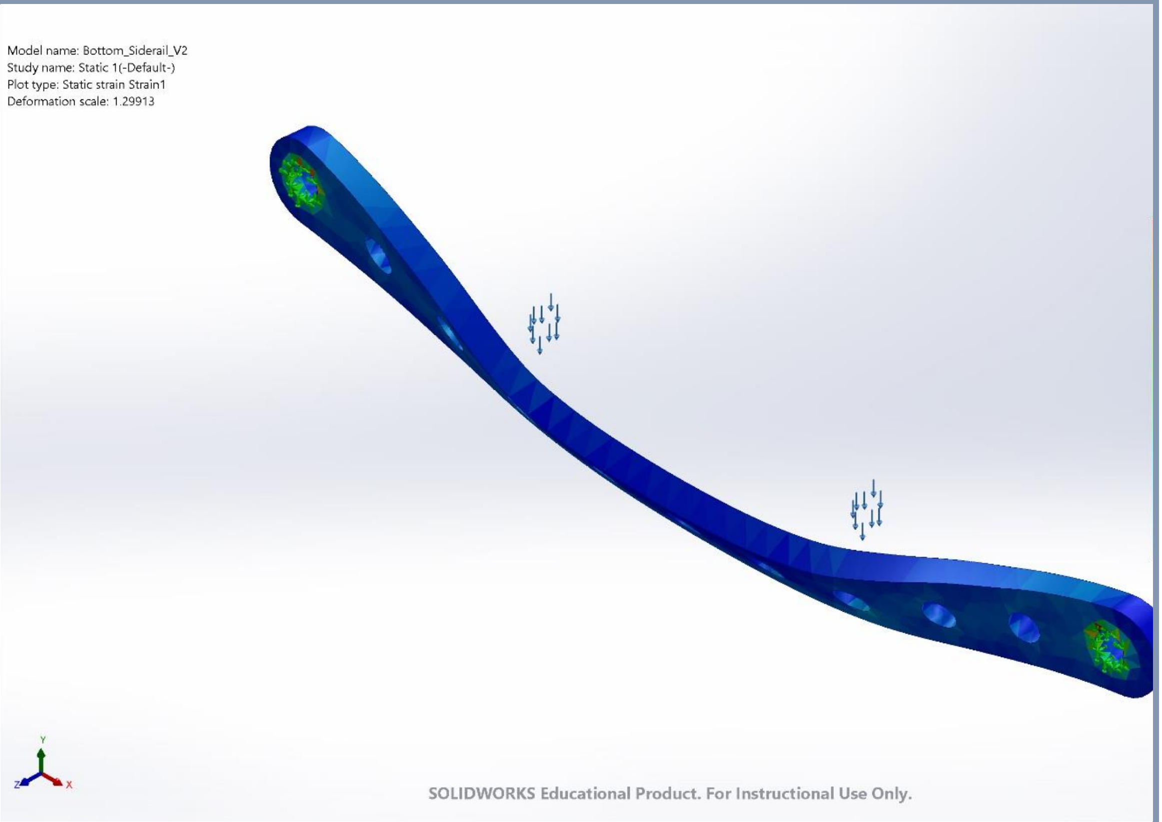
Bottom_Siderail_V2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 9	1.064e+01mm Node: 3991



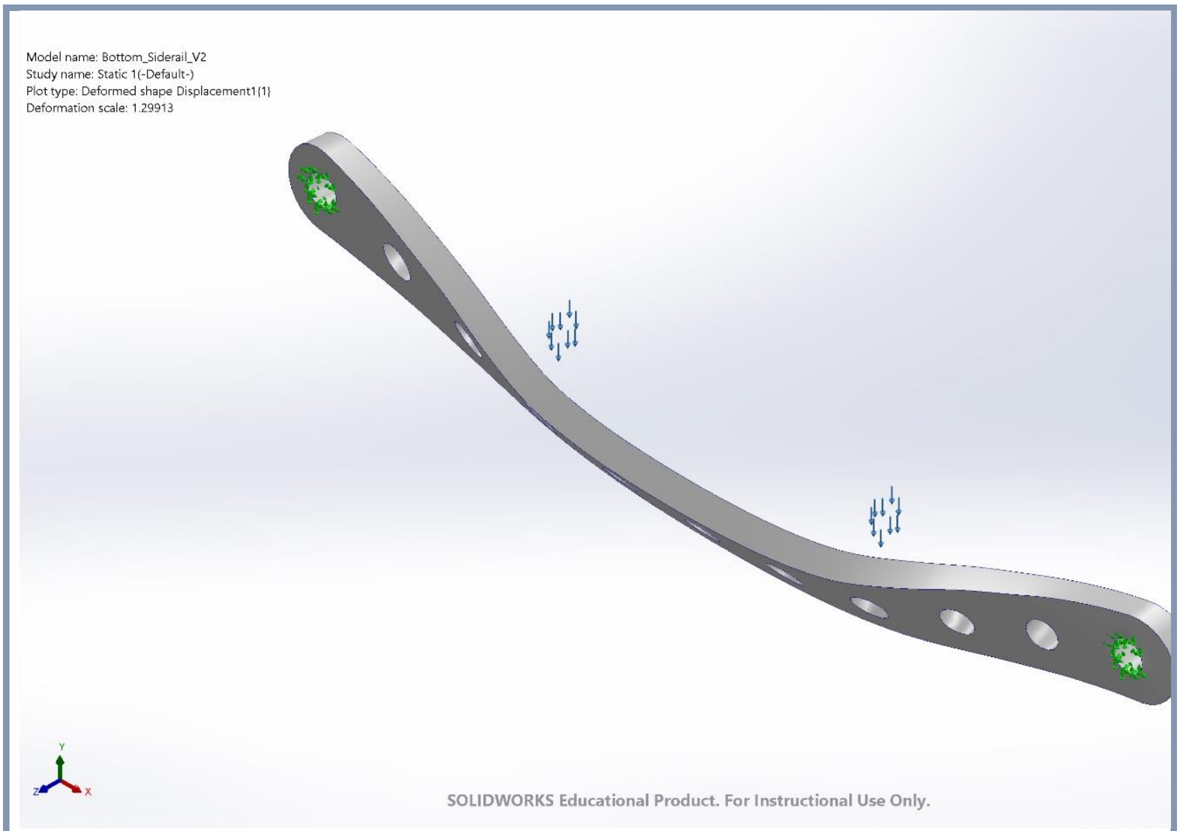
Bottom_Siderail_V2-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	6.018e-04 Element: 126	2.066e-01 Element: 773



Bottom_Siderail_V2-Static 1-Strain-Strain1

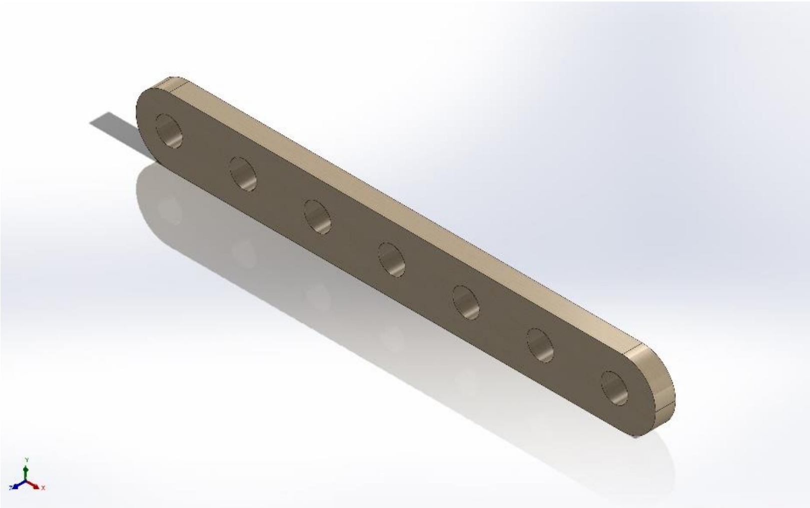
Name	Type
Displacement1{1}	Deformed shape



Bottom_Siderail_V2-Static 1-Displacement-Displacement1{1}

Conclusion

Top side rail FEA analysis:



Simulation of Top_Siderail_V2

Date: Monday, 19 June 2023
Designer: Solidworks
Study name: Static 1
Analysis type: Static

Description

No Data

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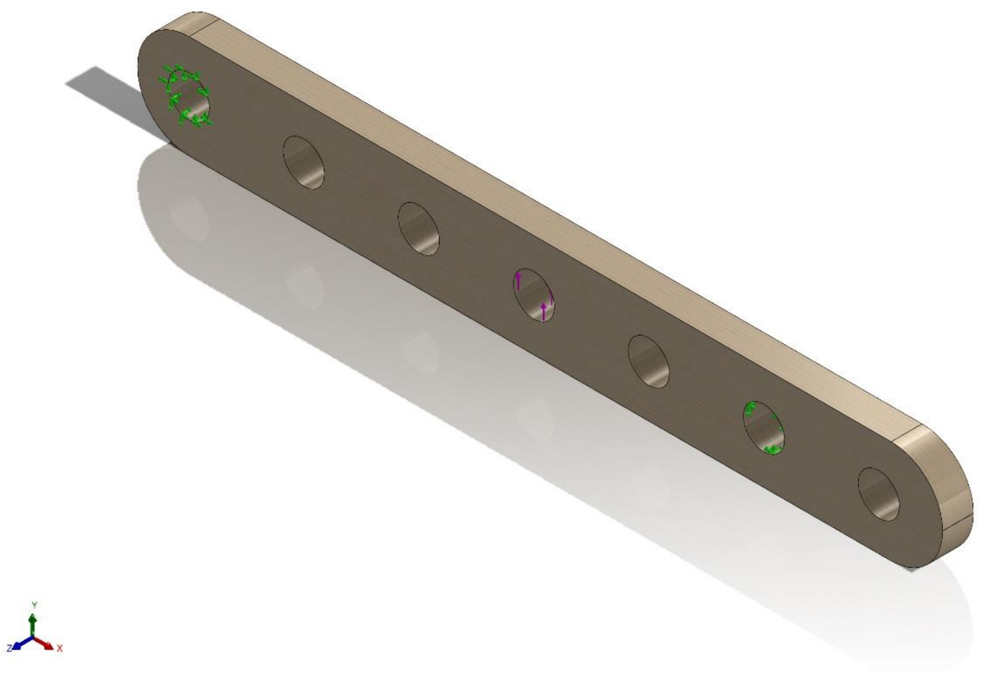
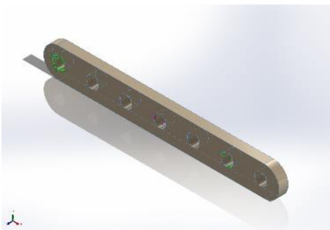
Assumptions

Model Information



Model name: Top_Siderail_V2
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1 	Solid Body	Mass:0.000684074 kg Volume:2.01198e-06 m^3 Density:340 kg/m^3 Weight:0.00670393 N	C:\Users\Griffin\Documen Georgie\CAD\Emotions Mirror\Top_Siderail_V2.SL RT Jun 16 16:31:43 2023

Study Properties

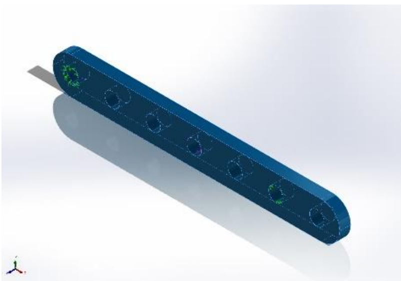
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads

Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	On
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Griffin\Documents\Georgie\CAD\Emotions Mirror)

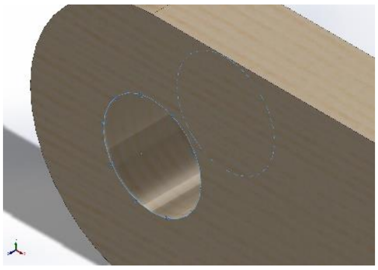
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

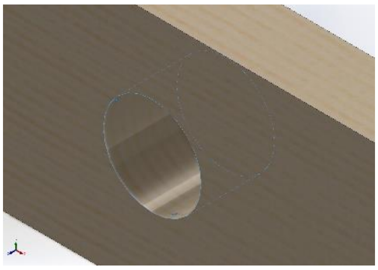
Model Reference	Properties	Components
	Name: **Pine** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Elastic modulus: **7,000 N/m^2** Poisson's ratio: **0.3** Mass density: **340 kg/m^3**	**SolidBody 1(Boss-Extrude1)(Top_Siderail_V2)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 2 edge(s) **Type:** Fixed Geometry

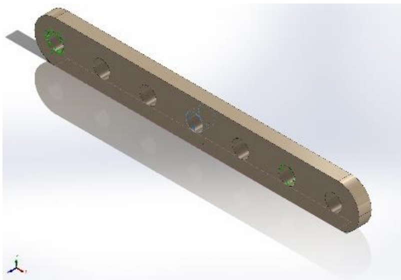
Resultant Forces

Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**-0.00408541**	**-0.00343116**	**1.87785e-07**	**0.00533511**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Fixture name	Fixture Image	Fixture Details
Fixed-2		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**0.00408589**	**-0.00656814**	**-1.58811e-07**	**0.0077353**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply force **Values:** ---, ---, 0.01 N

Connector Definitions
No Data

Interaction Information
No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	2.52597 mm
Minimum element size	1.48401 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	3666
Total Elements	1892
Maximum Aspect Ratio	126.28
% of elements with Aspect Ratio < 3	93.8
Percentage of elements with Aspect Ratio > 10	0.423
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:01
Computer name:	GRIFFINXPS

Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	4.7675e-07	-0.0099993	2.89328e-08	0.0099993

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0	0	0	0

Free body moments

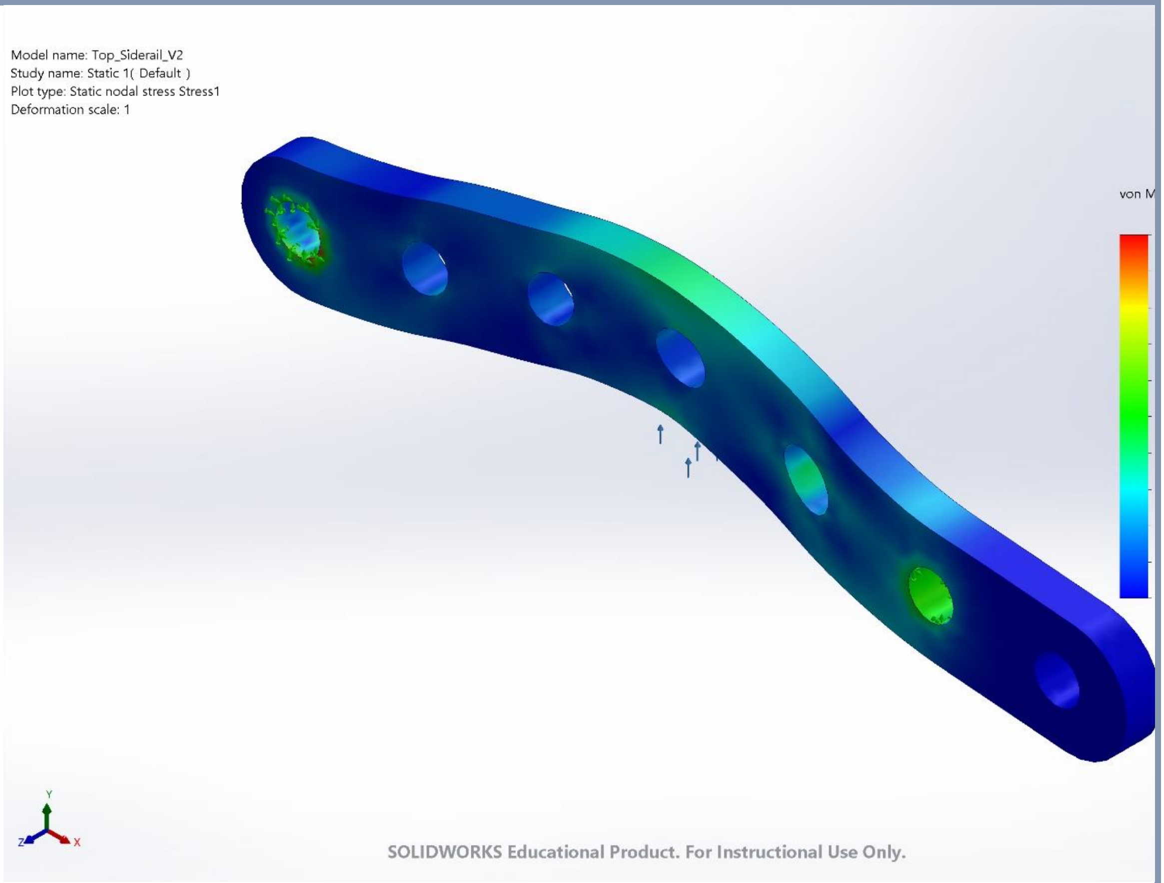
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Beams

No Data

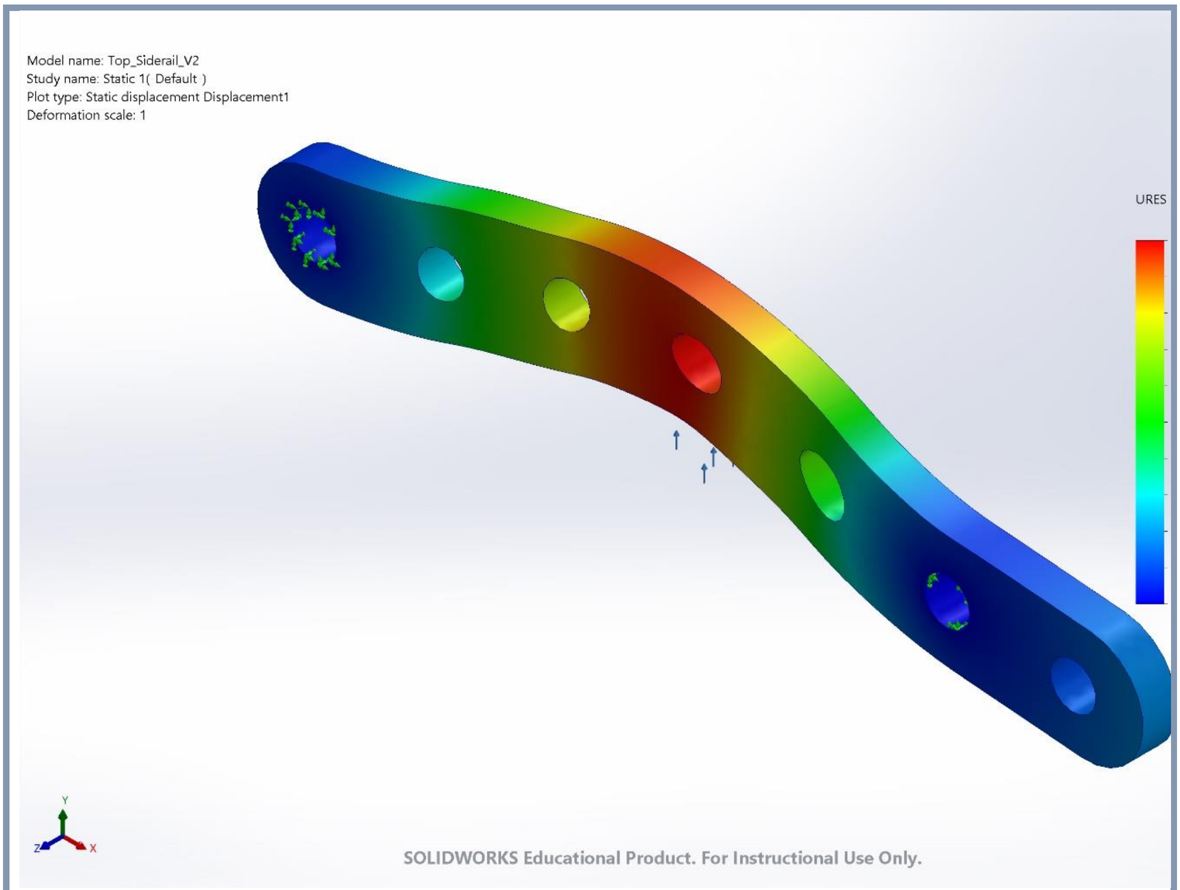
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.677e-02N/m^2 Node: 2036	3.292e+03N/m^2 Node: 3535



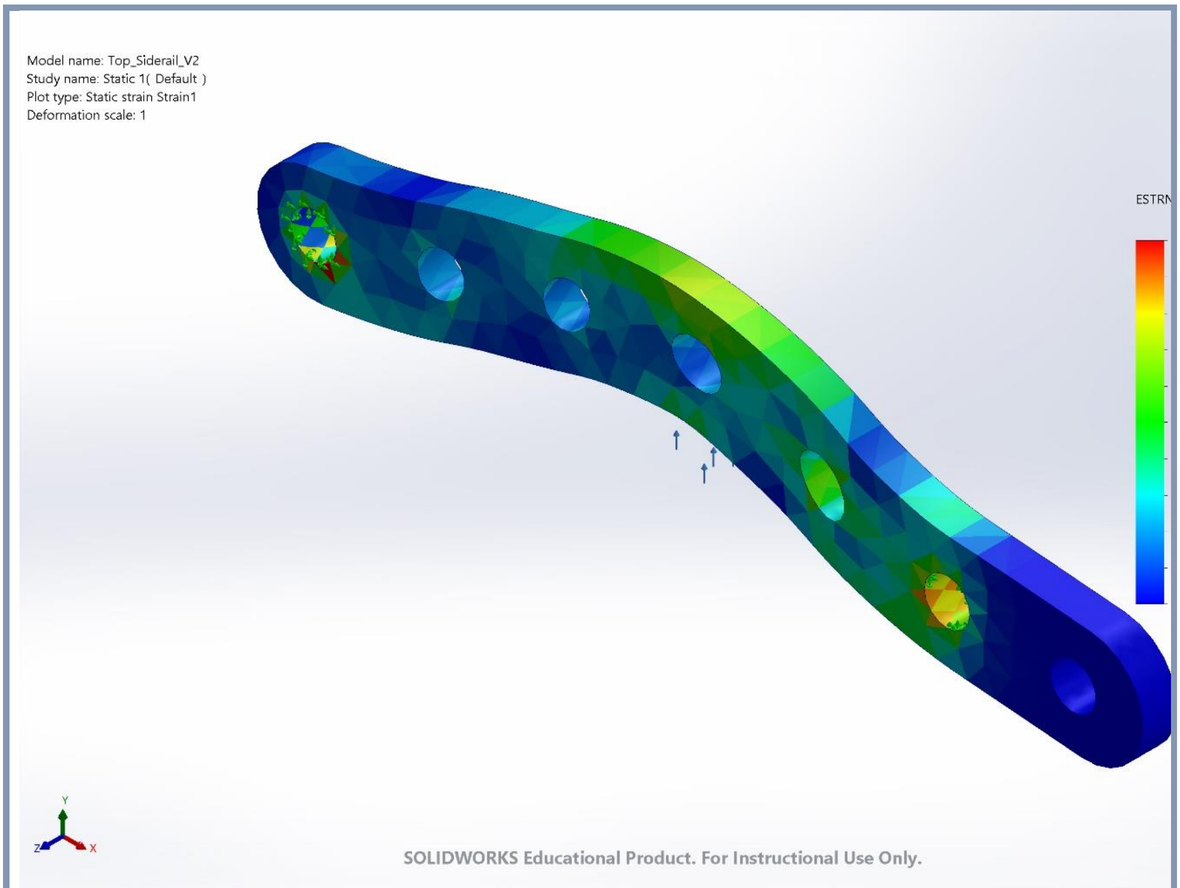
Top_Siderail_V2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 9	7.375e+00mm Node: 132



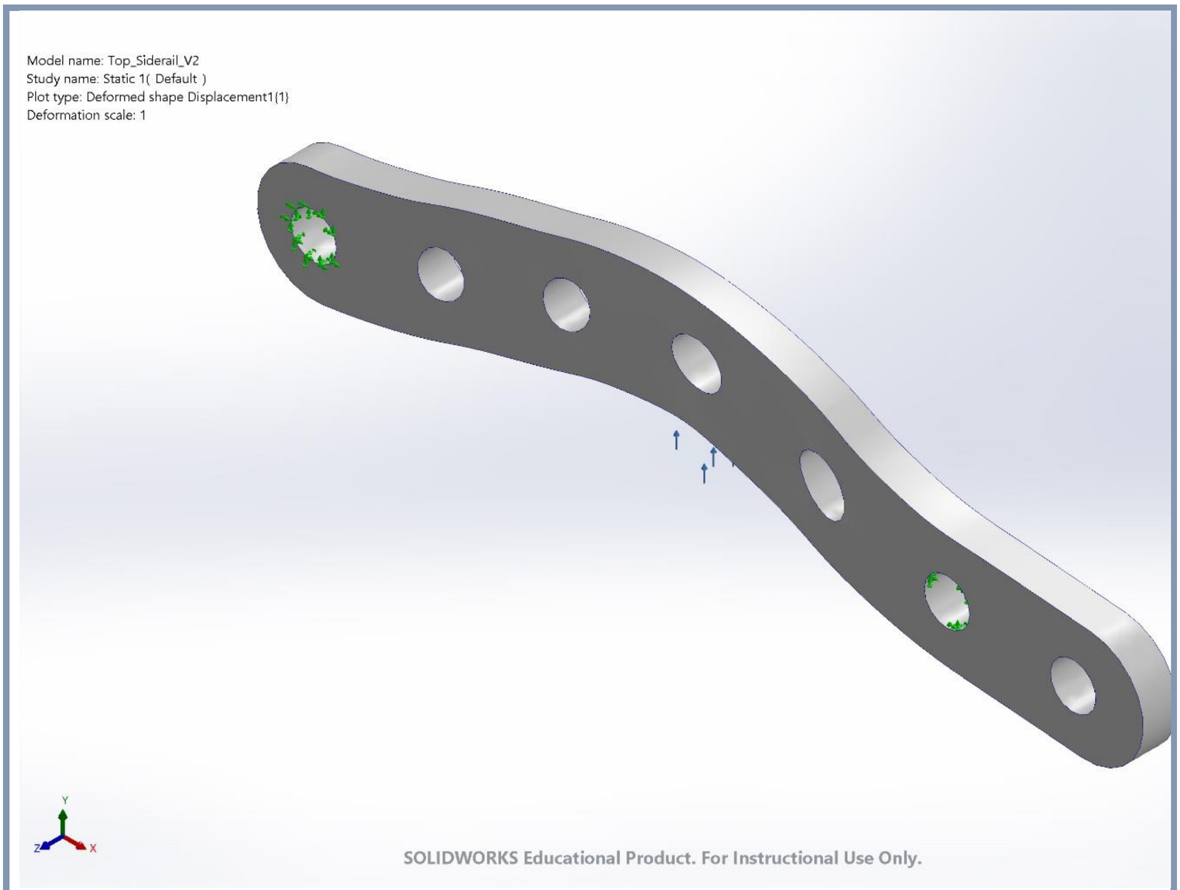
Top_Siderail_V2-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.412e-05 Element: 379	2.137e-01 Element: 1515



Top_Siderail_V2-Static 1-Strain-Strain1

Name	Type
Displacement1{1}	Deformed shape



Top_Siderail_V2-Static 1-Displacement-Displacement1{1}

Conclusion

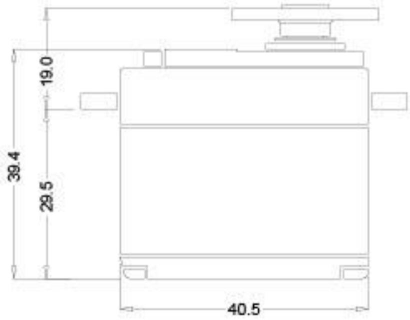
B) Datasheet servo

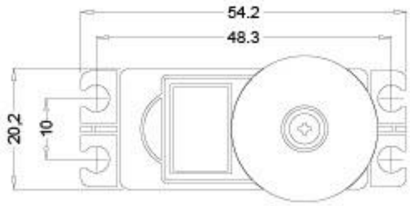
luxorparts®
Dedication to innovation! Servo Solutions

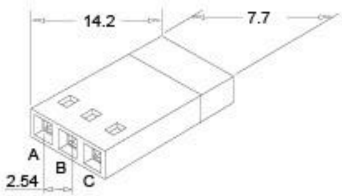
S3003 Standard Servo

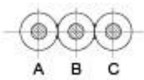
Servo motor for Arduino and Raspberry-Pi robotics projects.
Typical use: Model aircraft, cars and robots.
Rotates forward or backwards to a given position.
Bidirectional rotation - pulse duration determines the direction.

Item no: 87902 single pack, 90721 pack of 4 pcs.
Model no: S3003
Weight: 38g.
Rotation Angle: 180°
Torque: 3,2 kg/cm (31 Ncm) (at 4,8 V).
Torque: 4,1 kg/cm (40 Ncm) (at 6 V).
Speed: 0,23 sec/60° (at 4,8 V).
Speed: 0,19 sec/60° (at 6 V).
Linear response to PWM for easy ramping.
Operating voltage: 4,8-6 V.
Operating temperature: -10 to 50 °C.
Current idle: 7.2mA at 4.8 V, 8 mA at 6 V.
Current max: < 1000 mA.
Cable length: 290 mm.
Connector type: JR / Futaba
Breadboard friendly connector 2,54 mm pitch.
Connector wire gauge: 28 AWG.
Control system: PWM (Pulse Width Modulation)
Pulse Frequency / Duty cycle: 50 Hz / 20 ms square wave
Direction w/ Increasing PWM Signal: Counter Clockwise



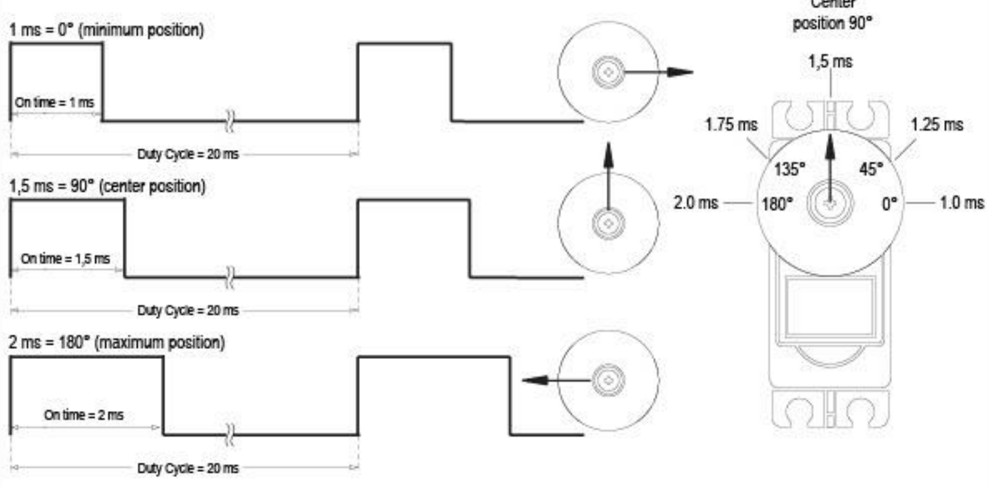






A - Black (-)
B - Red (+)
C - White (signal)

180° servo PWM signal timings



www.luxorparts.com
Box 50435, Malmö, Sweden
Update: Nov 30, 2017

Specification subject to change
Dimensions are in millimeters

C) Datasheet sensor

Ultrasonic Ranging Module HC - SR04

Product features:

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:
(1) Using IO trigger for at least 10us high level signal,
(2) The Module automatically sends eight 40 kHz and detect whether there is a pulse signal back.
(3) IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning.
Test distance = (high level time×velocity of sound (340M/S) / 2,

Wire connecting direct as following:

- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

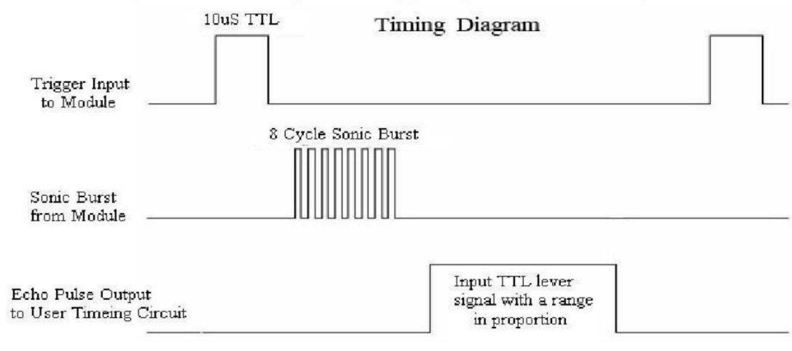
Electric Parameter

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Vcc Trig Echo GND

Timing diagram

The Timing diagram is shown below. You only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion .You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: uS / 58 = centimeters or uS / 148 =inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.



Attention:

- The module is not suggested to connect directly to electric, if connected electric, the GND terminal should be connected the module first, otherwise, it will affect the normal work of the module.
- When tested objects, the range of area is not less than 0.5 square meters and the plane requests as smooth as possible, otherwise ,it will affect the results of measuring.

www.Elecfreaks.com

D) Code for servo's

```
#include <Servo.h>


// Define the servo objects

Servo servo1;

Servo servo2;

Servo servo3;

Servo servo4;


// Pin assignments for the servos

int servo1Pin = 2;

int servo2Pin = 3;

int servo3Pin = 4;

int servo4Pin = 5;


// Pin assignments for the distance sensor

int triggerPin = 0;

int echoPin = 1;


// Variables for distance measurement

long duration;

int distance;


void setup() {

  // Attach servos to their respective pins

  servo1.attach(servo1Pin);

  servo2.attach(servo2Pin);

  servo3.attach(servo3Pin);
```

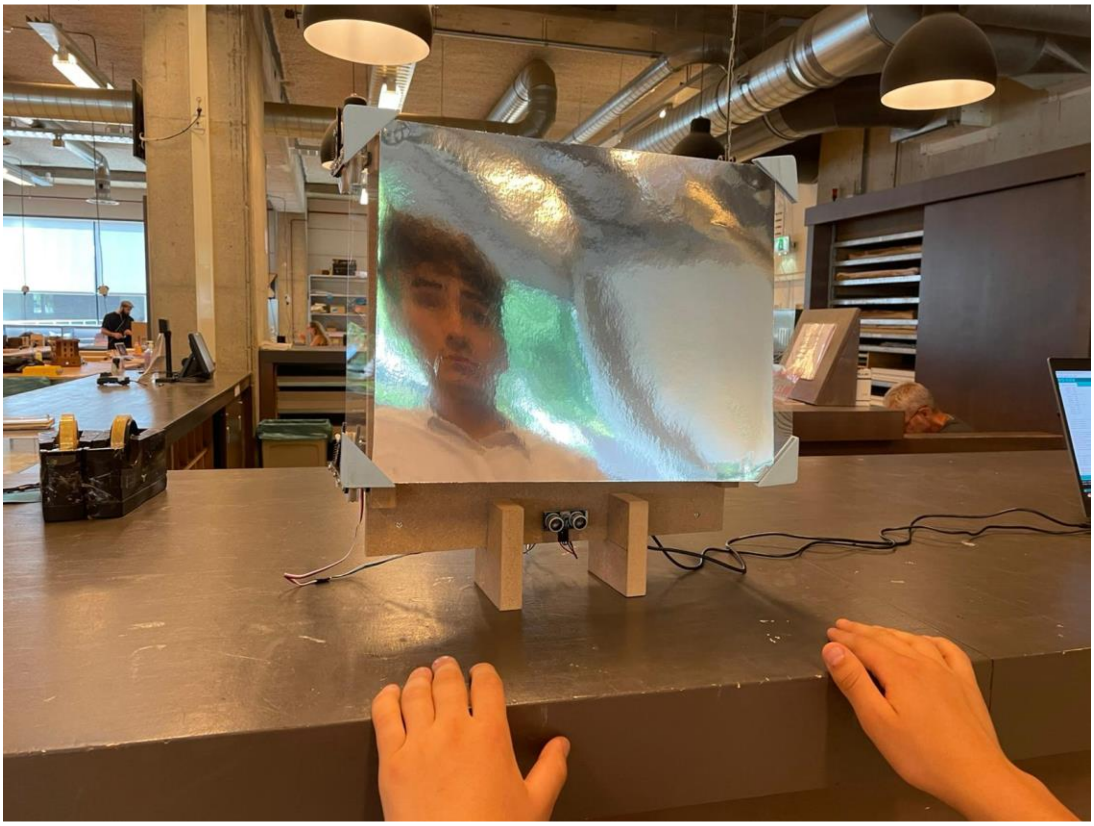
```
  servo4.attach(servo4Pin);

  // Set up the distance sensor pins
  pinMode(triggerPin, OUTPUT);
  pinMode(echoPin, INPUT);

  // Initialize serial communication
  Serial.begin(9600);
}

void loop() {
  // Measure the distance
  distance = measureDistance();

  // Check if the user is one meter away
  if (distance >= 10 && distance <= 100) {
    // Set random angles for the servos
    setRandomAngles(random(1, 4));
    delay(10000); // Wait for 20 seconds before resetting the servos
  } else {
    resetAngles();
  }
}

int measureDistance() {
  // Clear the trigger pin
  digitalWrite(triggerPin, LOW);
  delayMicroseconds(2);
```

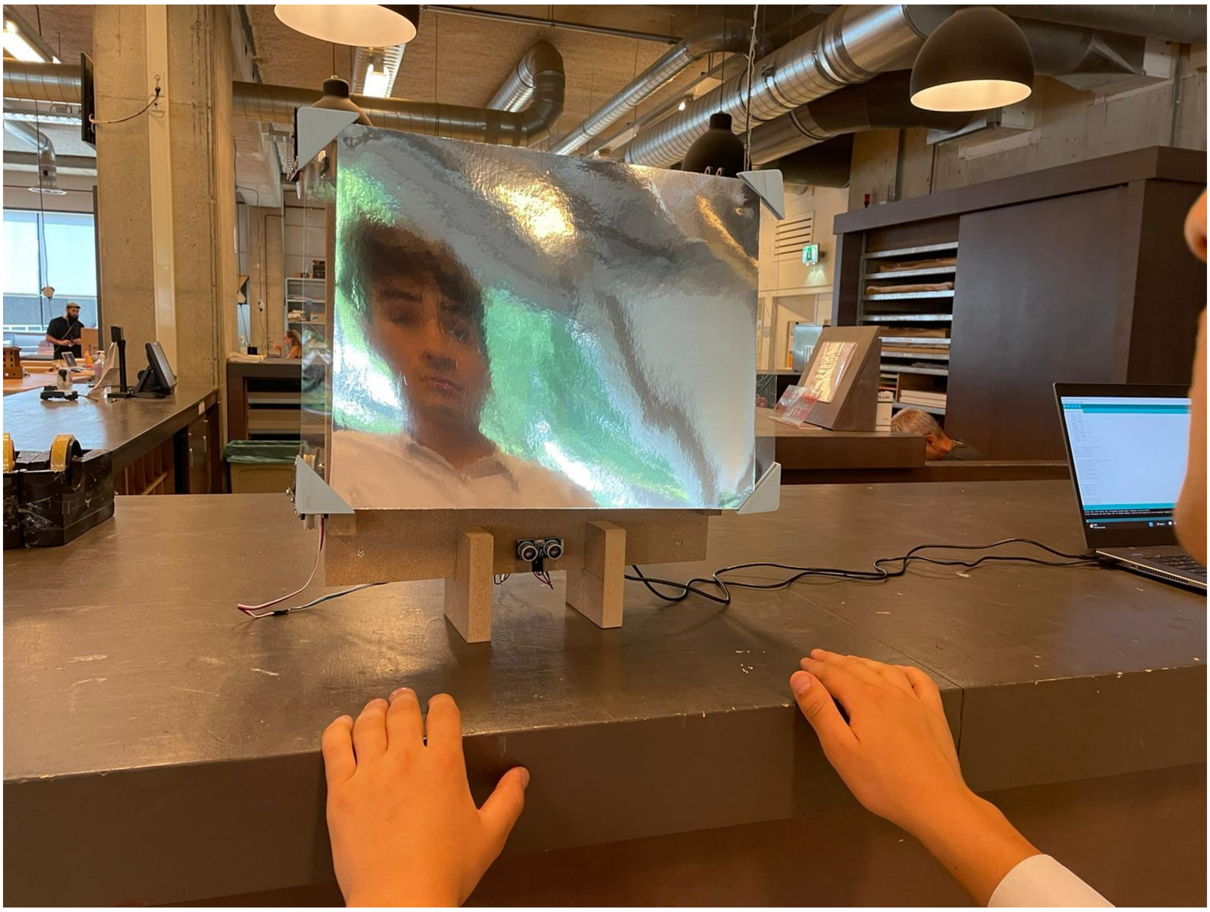
```
  // Send a pulse to the trigger pin
  digitalWrite(triggerPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(triggerPin, LOW);

  // Measure the duration of the echo pulse
  duration = pulseIn(echoPin, HIGH);

  // Calculate the distance in centimeters
  int distance = duration * 0.034 / 2;

  // Print the distance to the serial monitor
  Serial.print("Distance: ");
  Serial.println(distance);

  return distance;
}

void setRandomAngles(int modeNr) {
  int angle1, angle2, angle3, angle4;

  if (modeNr == 1) {
    angle1 = 180;
    angle2 = 0;
    angle3 = 0;
    angle4 = 180;
  } else if (modeNr == 2) {
```

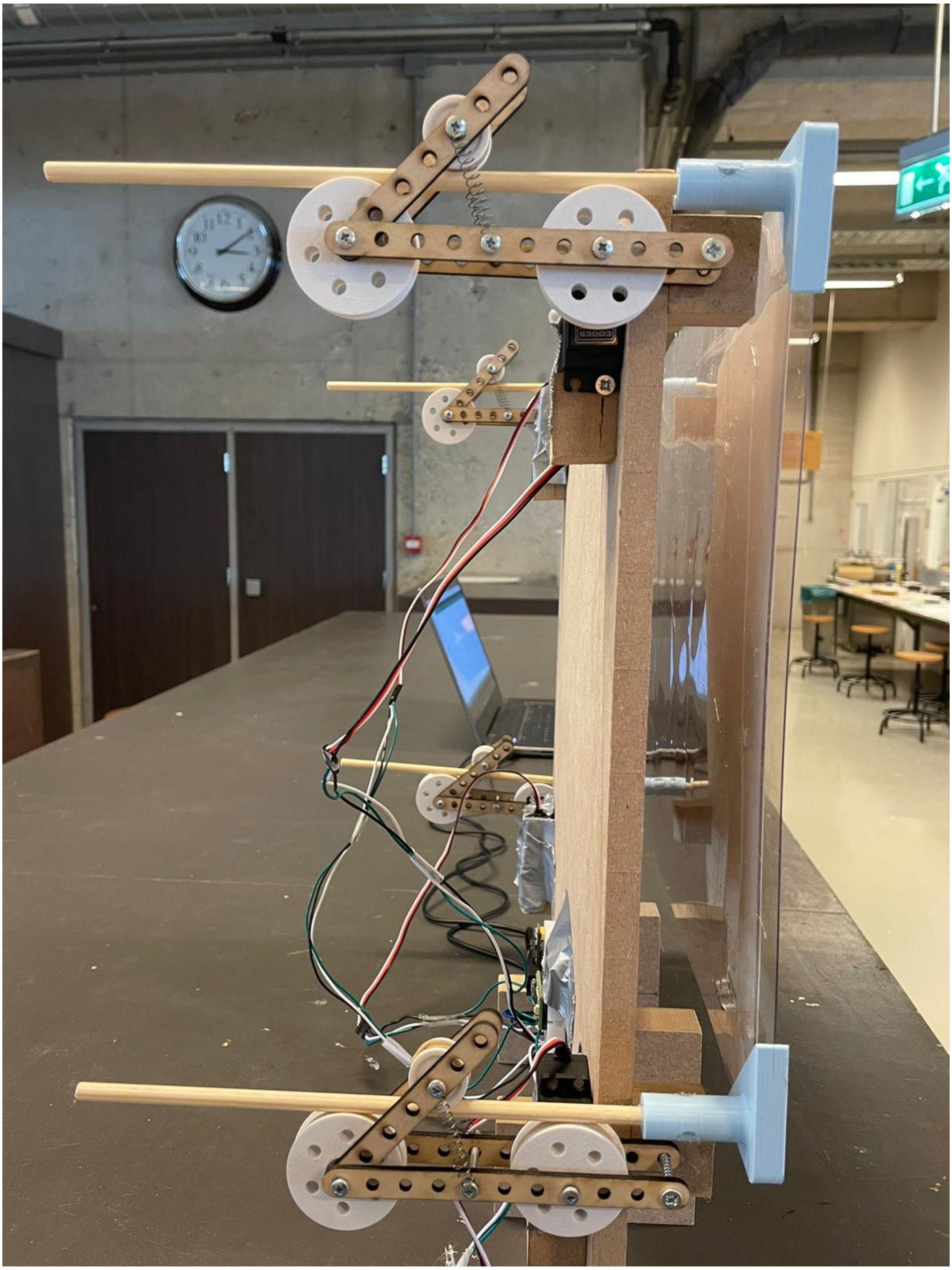
```
    angle1 = 0;
    angle2 = 180;
    angle3 = 0;
    angle4 = 180;
} else if (modeNr == 3){
    angle1 = 0;
    angle2 = 0;
    angle3 = 180;
    angle4 = 180;
} else if (modeNr == 4) {
    angle1 = 180;
    angle2 = 180;
    angle3 = 0;
    angle4 = 0;
}

// Set the angles for the servos
servo1.write(angle1);
servo2.write(angle2);
servo3.write(angle3);
servo4.write(angle4);

// Print the angles to the serial monitor
Serial.print(" Angles: ");
Serial.print(angle1);
Serial.print(", ");
Serial.print(angle2);
Serial.print(", ");
```

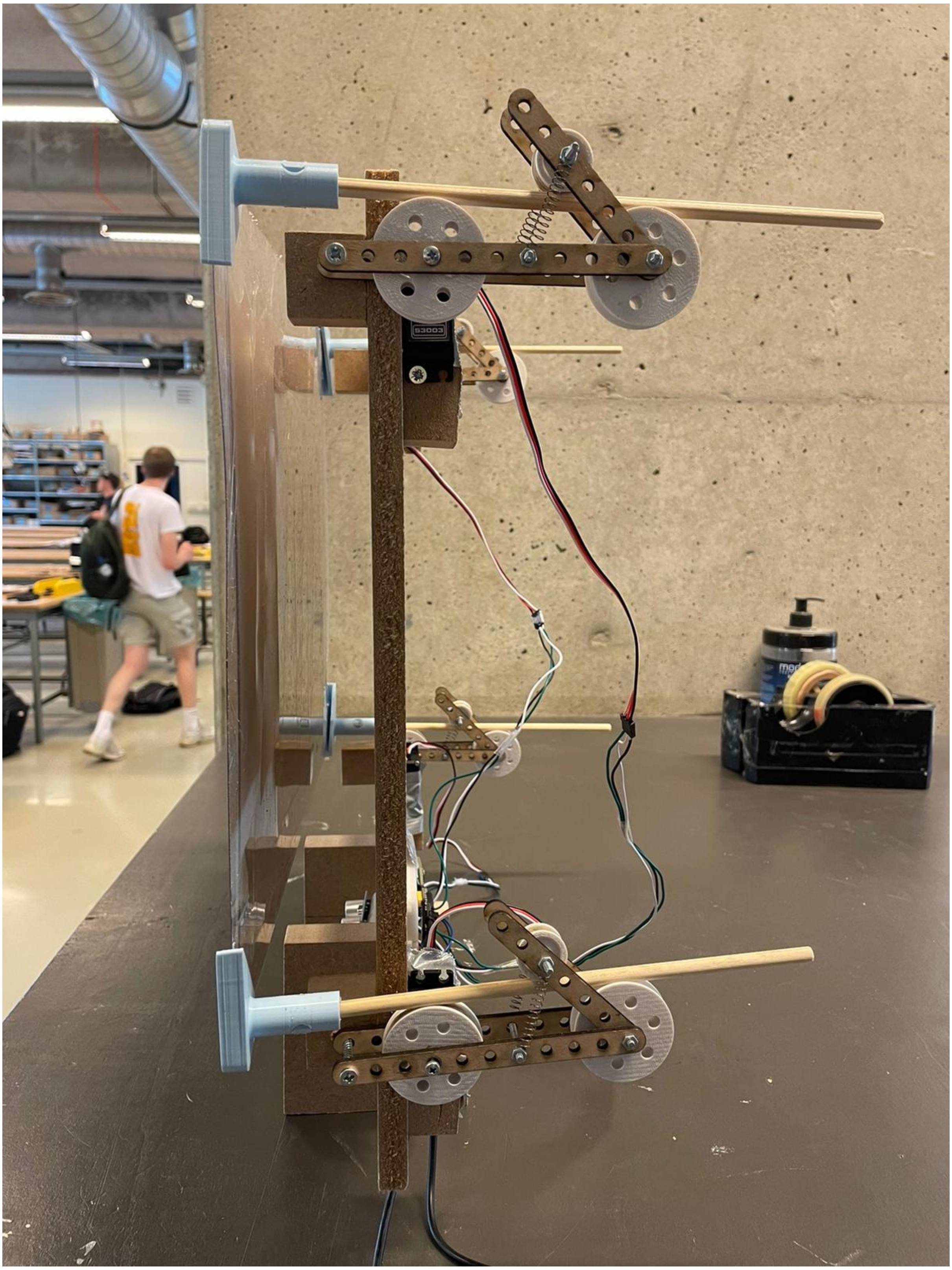
```
  Serial.print(angle3);
  Serial.print(", ");
  Serial.println(angle4);
}

void resetAngles() {
  int angle1 = 90;
  int angle2 = 90;
  int angle3 = 90;
  int angle4 = 90;

  servo1.write(angle1);
  servo2.write(angle2);
  servo3.write(angle3);
  servo4.write(angle4);

    // Print the angles to the serial monitor
  Serial.print(" Angles: ");
  Serial.print(angle1);
  Serial.print(", ");
  Serial.print(angle2);
  Serial.print(", ");
  Serial.print(angle3);
  Serial.print(", ");
  Serial.println(angle4);
}
```

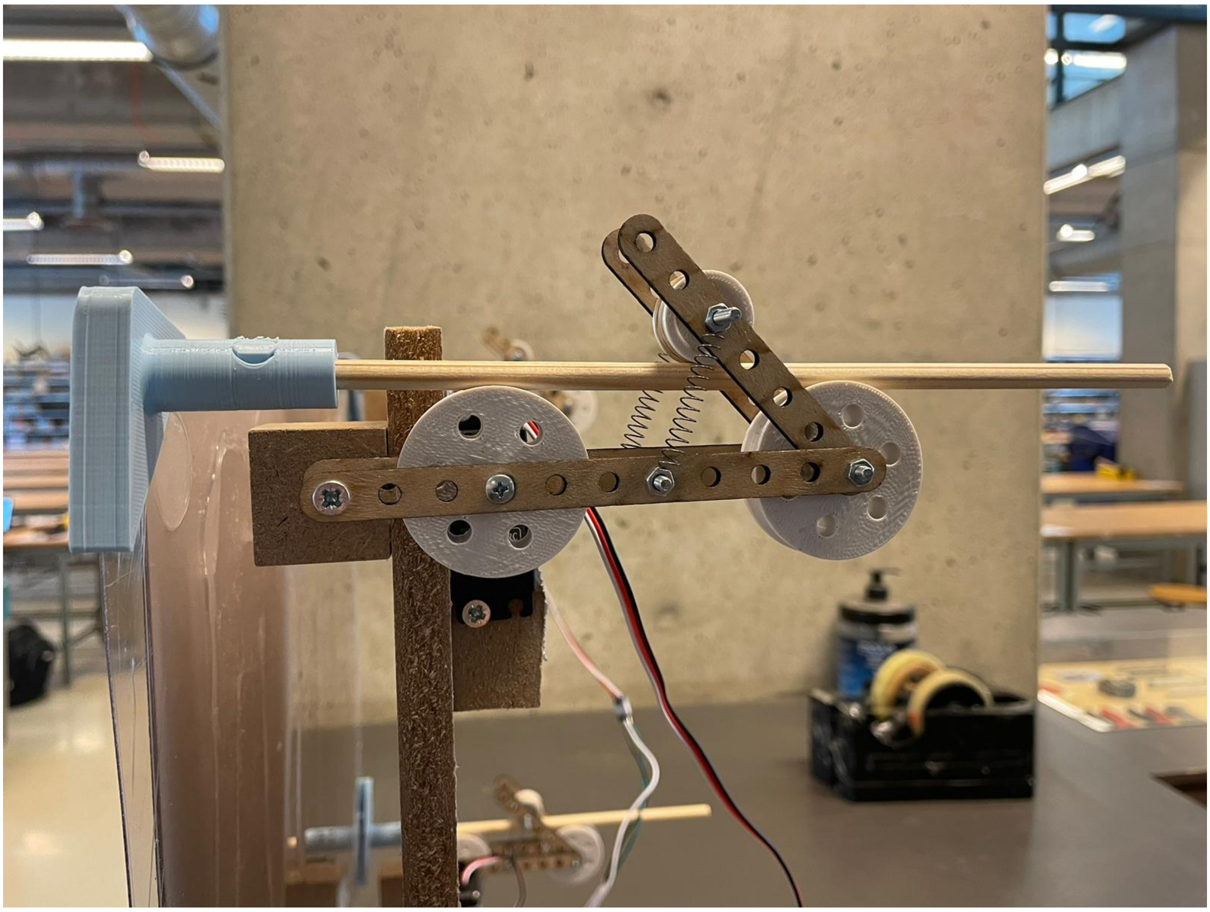
E) Additional visuals

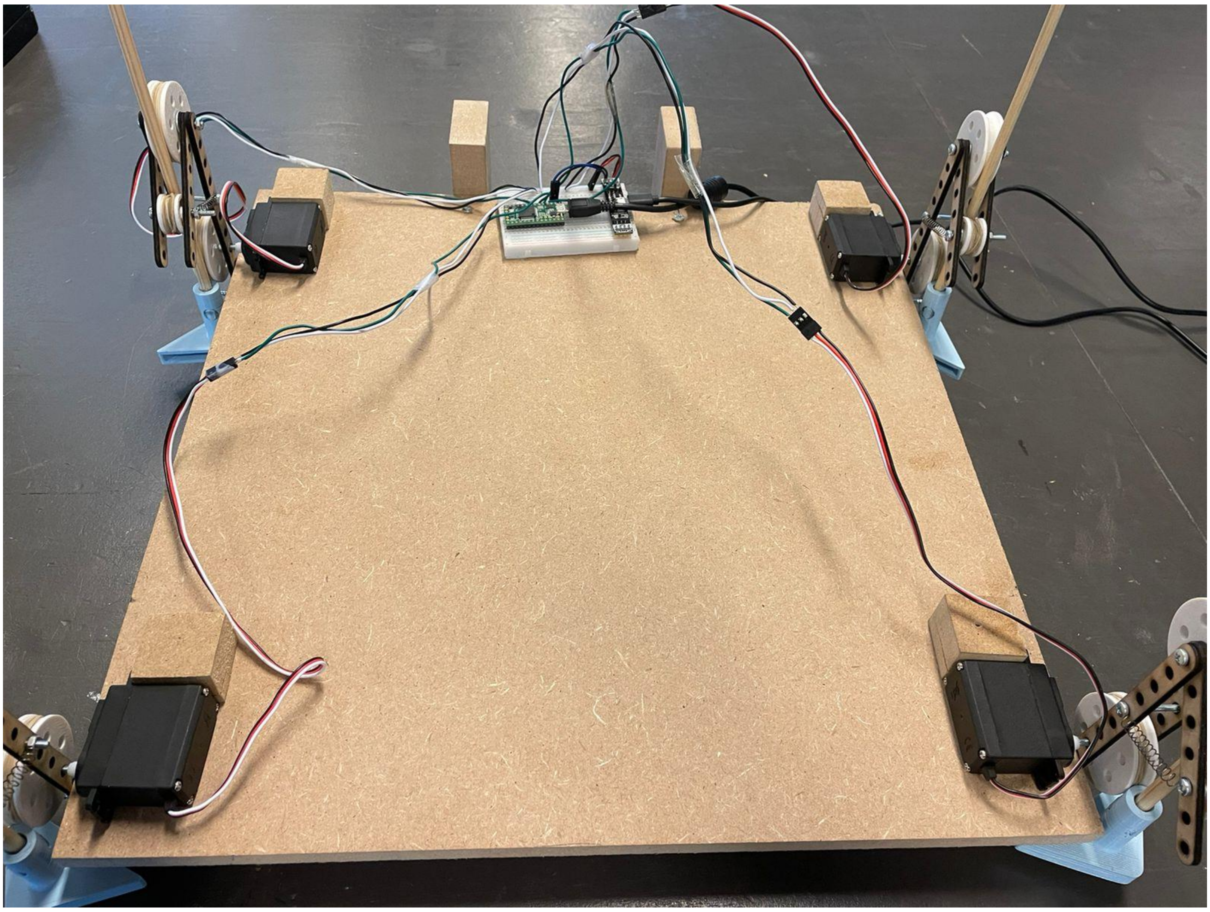


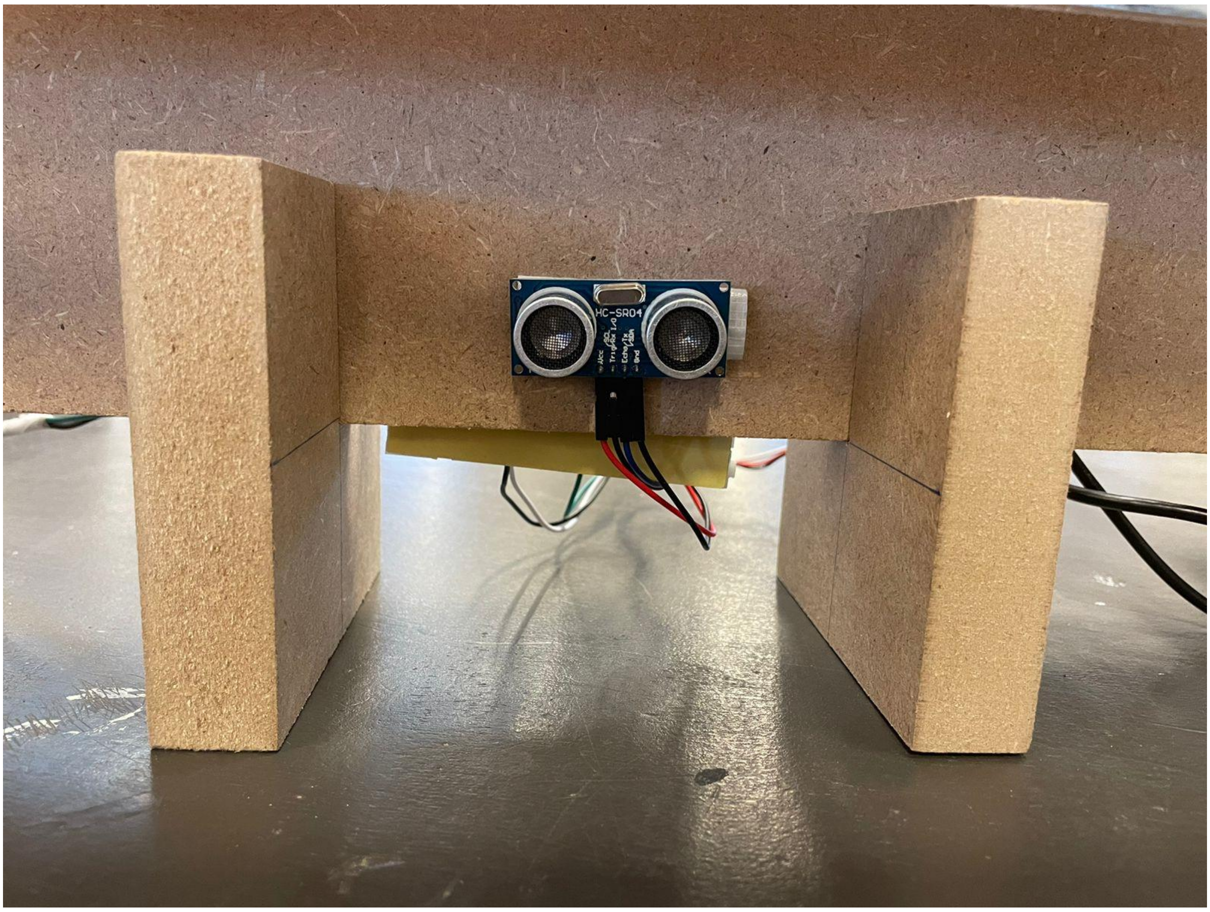



S3003


S3003






HC-SR04