HPVCP

Final Testing Documentation

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2020

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1 Introduction

The HPVCP project is a design project that aims to improve the existing human vehicle propulsion system. The purpose of this is to make full use of the power provided by the human operator and use the leg muscles to generate the greatest energy from the human body, thereby moving forward more efficiently. The goal of the later development of the project is to design a vehicle that can store additional energy,the mi reclaimed from so that it can be used when additional power is needed. So far, the team has redesigned the systems, created the electrical systems and integrated components to collect data and display metrics, as well as improved the customer and engineering requirements.

At the beginning of the semester, the propulsion system was still under design as a stand-alone drive. Dr. Perry Wood, the team client, proposed that the team redesign the obsolete vehicle to make it a new usable vehicle. In the original design, manpower was input through pedals as well as a hand crank, and transferred to wheels. During the summer term, the team designed the vehicle to input power through cycling and rowing. The flywheel would also be used to store a large amount of lost energy, so as to achieve the purpose of reducing input from the rider. In the subsequent design, no direct input from the operator would be required. The propulsion system would be retrofitted to the existing vehicle, as suggested, and needed repairs would be added.

In the new design, we added several brackets and shafts to support our clutch and flywheel. We have carefully designed the specific dimensions and related data of the clutch and flywheel to ensure that they can be installed on the vehicle without engineering problems and engineering damage. The team specifically measured the dimensions of the original HPV and redrew the CAD. The team also used solidworks to draw CAD of the flywheel and clutch. This helps us provide assistance in actual assembly and testing. The circuit components and Ardurino were used for energy measurement and data collection, and the team members also used Solidworks for FEA testing of critical components.

2 Customer Requirements (CRs)

Our customer requirements were originally created with Dr. Trevas however, he has since left NAU. Changes between the customer requirements from Summer 2021 to this semester are primarily due to the change of our customer and scope of project. The most significant requirement change is from maximum and efficient use of multiple muscle groups, to only inputting energy by pedaling. Originally this entailed the creation of a row bar along with pedaling to increase energy created from the body. We have also refined our requirements with the help of our current client. Our customer requirements, ranked by importance, are as follows:

1. Store Energy to be Used Later ------------------------------------- **High**
2. Achieve Max Usable Energy Storage ----------------------------- **High**
3. Display Bike Speed --- **High**
4. Display Flywheel Speed/Energy Stored in Flywheel ----------- **High**
5. Display Efficiency --- **Mid**
6. Low Budget --- **Mid**
7. Safe to Operate --- **Low**

The main objectives are to use and store energy safely and efficiently, while also displaying informative metrics to the user. The purpose of storing energy is to set this HPV apart from all the others in the past, one of the goals given by our original client, and the defining characteristic. Our new client, Perry Wood, liked the idea of an energy storage/recovery system on an HPV, as he is excited to maintain NAU being an innovator in the HPV competitions. For this purpose, Energy storage became the main focus moving forward. Achieving max energy storage and displaying flywheel energy storage and speed go hand in hand, as the display metrics will allow us to test our energy storage efficiency. Energy storage capabilities were an original client requirement, but since our client has changed, our priority for attaining max energy storage has increased. As such, the team planned to spend much effort on calculating and refining our energy storage capabilities. and verifying with testing.

Most HPVs do not have a displayed speed, since it is not a very important part of the design. For our design however, this is very important, as it dictates when it is appropriate to engage the energy recovery system. Displaying speed, energy, and efficiency metrics are a high priority due to it's multipurpose use. Calculating and displaying these metrics will not only allow us to test our requirements in an efficient manner but will also allow the user to most efficiently use our HPV. This is an important part of setting our HPV apart from all the others.

Lastly, safety and budget have the lowest priorities. The budget priority is low as it has already been calculated. Planned purchases and costs do not predict any budget issues, currently the team is well under half of the budget. Safety is also a low priority as the HPV will not be in use for a long period of time, as well as the fact that the frame has already been built by a previous HPV team, who we can assume took high measures of safety into account in their design. Furthermore, due to unforeseen constrictions, the original mounting system had to be discarded, and the new one was made in a matter of 3 days to be functional, however is not safe for testing. So far the team has not come across any safety concerns with the existing vehicle, except for a broken steering, which we plan to fix in the event that testing is possible. The greatest addition to safety measures for our vehicle is the planned addition of a flywheel cover, and possibly a roll cage if the client requests one.

3 Engineering Requirements (ERs)

An important part of any engineering project is the Engineering Requirements. Without these, there is no goal to design for. Our project started with a very unclear set of requirements, since the scope and final product were a little unclear as well. With the start of the new semester, and the change in client, our scope and requirements became much more clear. Almost all of the following ERs have been updated or added since last semester.

3.1 ER #1: Optimal Energy Storage

3.1.1 ER #1: Optimal Energy Storage - Target = 600 J

The most important requirement for this propulsion system as it now stands is energy storage. Originally it was planned to have two forms of propulsion on the vehicle, as well as an energy storage system. When the scope changed to retrofitting the design to an existing HPV, this was no longer feasible. In order to keep most of the original design, the team and client decided that a purely energy storage based HPV would be the best choice. The target that was set was based on a rough estimate of the maximum kinetic energy that can be stored in the movement of the HPV. The weight of the HPV is still unknown, but was estimated to be roughly 25 kg prior to including the propulsion system, which is an additional 20kg, with a max speed designated in ER #3. The total kinetic energy of the vehicle is roughly

2 kJ. If a flywheel can store roughly half of that energy, it can return 15%t of the energy to the vehicle when needed.

3.1.2 ER #1: Optimal Energy Storage - Tolerance = ± 60 J

The tolerance for this engineering requirement is approximately 10% of the total system kinetic energy. Since the difference in weight between the flywheel and the vehicle is vast, there is not much room for error in the energy storage system if it is to be effective.Thus the tolerance is a maximum of 10% of the total system energy. This was a metric decided on by the team, and their vision of how this vehicle is to function.

3.2 ER #2: Regenerative Braking Efficiency

3.2.1 ER #2: Regenerative Braking Efficiency - Target = 15% Efficient

Efficiency has always been an important metric to this project. Since last semester however it has been brought to the attention of the team that the original efficiency of 10% was not reasonable if the energy storage system was going to be worth the investment of time put into it. Thus the goal now is to have the efficiency at 15%. This means that the energy taken out of the flywheel is roughly 15% of the energy that was put into the flywheel. This can also be considered from a velocity standpoint. If the storage system brings the vehicle to a stop, it should be able to start the vehicle giving it roughly half of its original velocity. This requirement has to do with not only the flywheel, but also the quality of the friction plate and the amount of pressure applied to it. The team will need to run many tests in order to achieve this target efficiency.

3.2.2 ER #2: Regenerative Braking Efficiency - Tolerance = ± 2.5%

This tolerance is very high, allowing the team to work with many different layouts. Ideally the system efficiency would land within 5% of the target, and that is what we will aim for. In order to do this we plan to try out multiple gear ratios with sprockets in order to reach the maximum storage and efficiency.

3.3 ER #3: Max Speed

3.3.1 ER #3: Max Speed - Target = 20 mph

The max speed of the vehicle is an important factor in calculating the total energy consumption and storage. This ER goes along with the CR of displaying the speed, as well as keeping the rider safe. The speed of the HPV determines the total system kinetic energy, which directly translates to the total energy that can be stored. In order to ensure that the energy storage can be efficient, but that the rider is safe while operating the vehicle, the max speed has been set to 20 mph. Note that this is not the top speed of the vehicle, but rather the speed at which the display will issue a warning to slow down. Anything past this speed is a good opportunity to engage the clutch, adding more energy into the flywheel.

3.3.2 ER #3: Max Speed - Tolerance = ± 5 mph

This tolerance was not a specific calculated one, but more of a safety measure taken to ensure that the rider can keep control of the vehicle. This tolerance, as well as the target speed, are merely rough guesses based on typical bicycle speeds since the current HPV being retrofitted is not yet operational. The ± 5 mph tolerance allows the rider to operate at a slightly faster speed if needed. The max speed should not fall below 15 mph however, or the regenerative braking system will not be as efficient as planned.

3.4 ER #4: Display Flywheel Metrics and Speed

3.4.1 ER #4: Display Metrics - Target = Correctly Displayed

One of the customer requirements is that the rider be able to see the speed, energy and efficiency metrics. This leads to a very simple engineering requirement with a yes/no or on/off metric. If the flywheel energy, total kinetic energy, HPV speed, and regenerative braking efficiency are all displayed correctly then this requirement has been met. If not, more testing is required to ensure that it is met. Though the ER is simple, this is an important step for ensuring that the vehicle can be operated at maximum efficiency. Without the screen displaying these metrics, and notifying the rider when their speed is too fast, or the difference in energy is sufficient to engage the clutch, there is no way of knowing the speed of the vehicle or optimizing the energy storage feature.

3.4.2 ER #4: Display Metrics - Tolerance = None

Since this ER has a very simple on/off target, there is no tolerance required. As stated before, if the screen displays all the metrics correctly the ER has been met. There will be a significant amount of tests run to ensure that all sensors are reading correctly, and that they are transferring data correctly to the LCD screen.

3.5 ER #5: Develop Threshold of Usable Energy

3.5.1 ER #5: Usable Energy Threshold - Target = 300 J

As part of the displayed metrics, the team would like to show the vehicle operator when it would be beneficial to engage the clutch, changing it from stored to kinetic energy. The value of 500 J is meant to be the difference between the stored energy and the total kinetic energy. If the difference is 500 J or more, it will be useful to use it to add energy to the vehicle. The 500 J value was chosen specifically because it is half of the desired target energy storage, and a quarter of the total possible system kinetic energy. Keep in mind that any amount of energy added to the system is helpful, but if it is to make any difference to the speed of the heavy system it needs to be near this value.

3.5.2 ER #5: Usable Energy Threshold - Tolerance = 50 J

This tolerance is again only 10% of the target value for the ER. That is because energy, and tracking energy and differences in energy is so important to this project. If the difference in energy is more than 10% off of what is being displayed, then the driver will not be able to get a useful amount of energy out of the system.

3.6 ER #6: Budget Limit

3.6.1 ER #6: Cost under $1,500 - Target = $1,250

This engineering requirement is very self explanatory. The maximum we are able to spend is $1500, so we have set ourselves a target of $1,250. Though this number may seem high for a project strictly focused on propulsion, it allows for a lot of “wiggle room” to choose the best parts for our system. The team’s plan is to spend less than this.

3.6.2 ER #3: Cost under $1,500 - Tolerance = ± $250

By setting a $250 tolerance, the team had to lower their maximum target value to be $1,250 since the goal is to not go over $1500. A tolerance of $250 also allows for any parts that break in the assembly and testing phases of this project.

4 Test Results

This section will specifically analyze how several tests meet engineering requirements. The test will be divided into three specific parts, the finite element analysis of SolidWorks, the hardware analysis of specific circuit components, and the analysis of energy storage and efficiency.

4.1 Finite Element Analysis (FEA)

Figure 1 below shows part of the finite element analysis of the designed shaft. The material used is 1020 Steel, and its Yield Strength is 3.5E8 Pa. This shows that for this shaft, when the pressure caused by the force and torque it receives is less than its Yield Strength, this shaft is absolutely safe. During the test, we used more force and torque than can be caused under actual conditions. More comprehensive and detailed results will be shown in the appendix A.

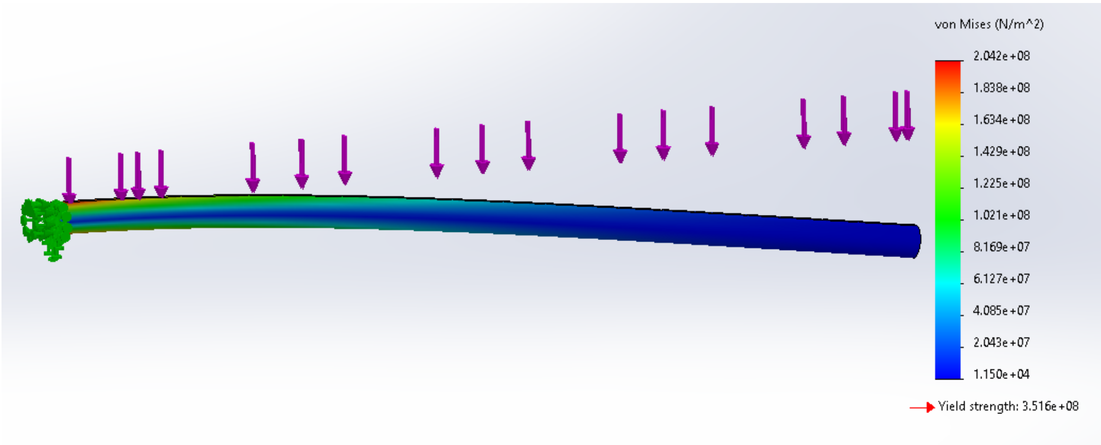


Figure 1: FEA of shaft

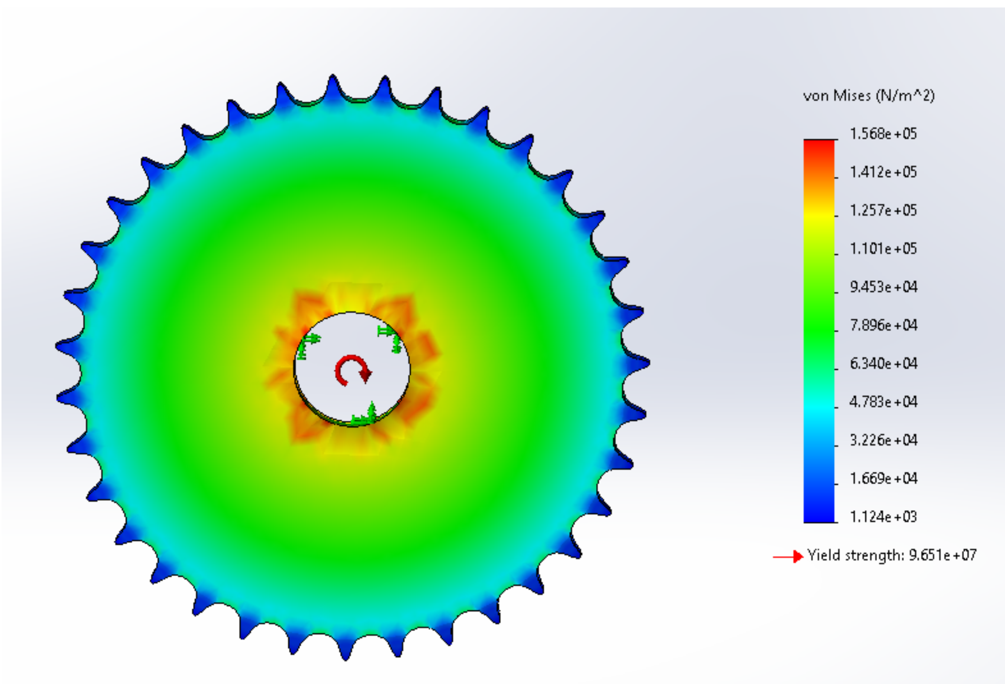


Figure 2: FEA of sprocket

Figure 2 and Figure 3 are not the designed connection part, but the specific component analysis. We use the actual size and materials to perform finite element analysis on the purchased sprocket and flywheel. This test mainly includes stress, strain and displacement tests, and will test whether these two components may cause damage in actual use. According to the data on the figure, it can be seen that the sprocket and flywheel we purchased can fully meet our design requirements.

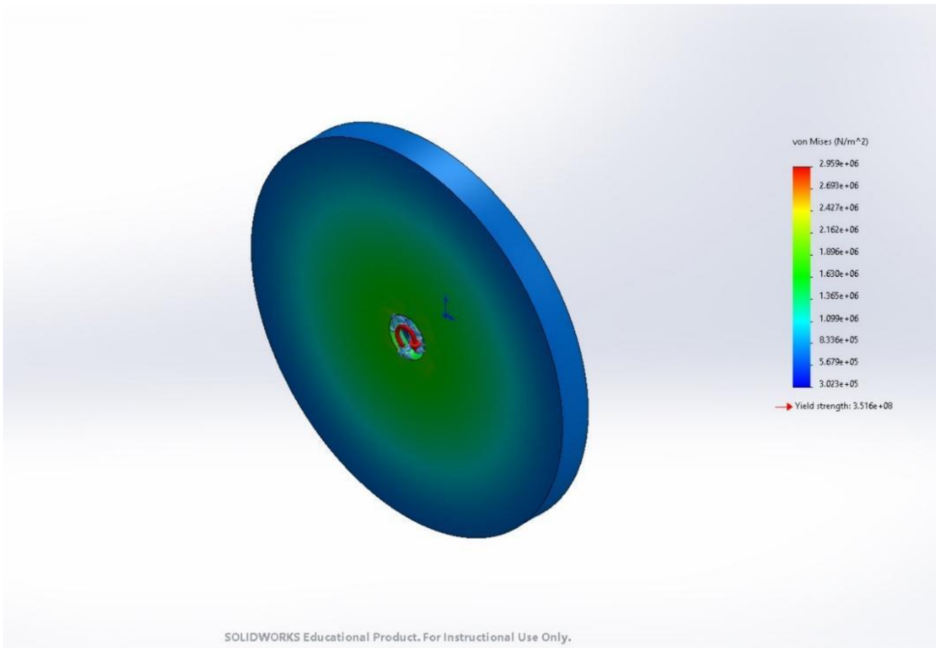


Figure 3: FEA of flywheel

4.2 Energy Storage & Efficiency Test

In order to ensure that the design meets engineering requirements 1 & 2, testing is required for energy storage and efficiency. This is done by the following procedures:

1. Measure vehicle speed
    a. Electrical sensors will measure speed
        i. This must be done after sensors are calibrated and tested
    b. Double check speed through a phone app
    c. Record data
2. Engage clutch to transfer power to flywheel from vehicle
    a. Measure the amount of time of engagement
        i. This is only important to be able to measure clutch wear
3. Measure flywheel angular velocity - this will allow the team to know how much energy is being stored in the flywheel. The goal is 600 J.
    a. Electrical sensors will measure angular velocity
    b. Double Check with tachometer
4. Re-measure vehicle speed as in step one
5. Bring vehicle to a stop

6. Engage clutch to transfer power from flywheel to vehicle as in step 2
7. Measure vehicle speed as in step one
8. Repeat steps 1-7 at different speeds
    a. Increments of roughly 5 mph up to the max speed

These procedures have not yet been carried out, but as soon as the vehicle is ready for testing, they will be. The theoretical check for this is using a design tool created by the team to calculate the total energy throughout the vehicle.

Table 1: Energy Storage Design Tool

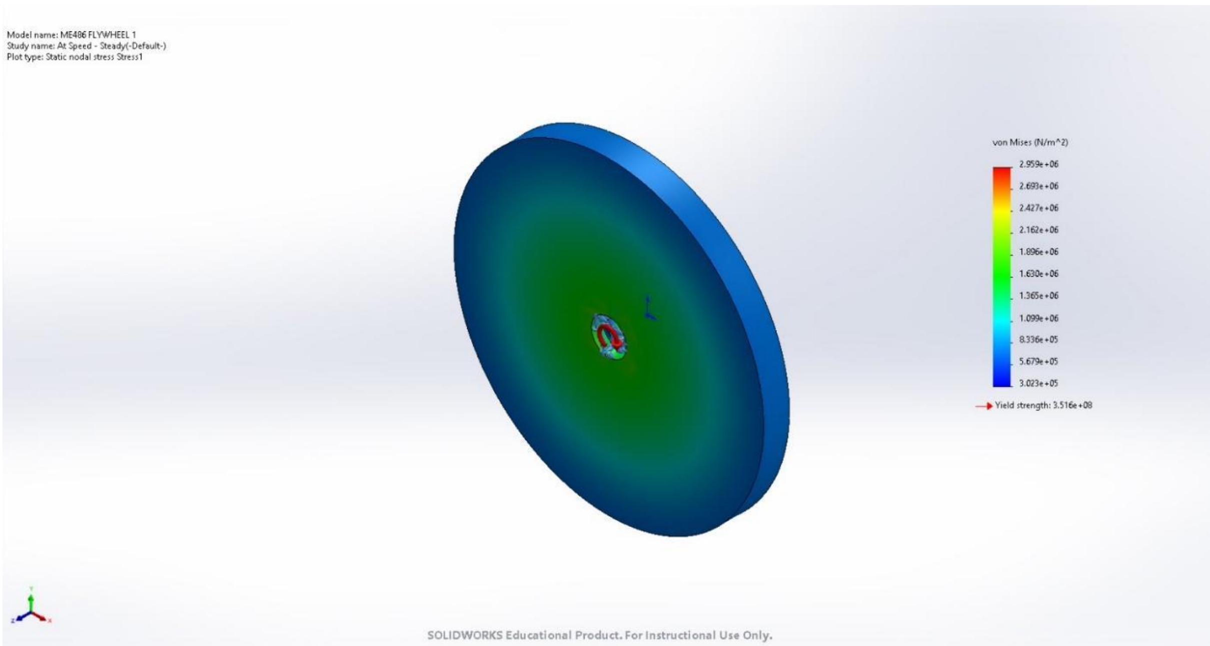
Material			Steel	Bike Mass	m_b	kg	35
Angular Velocity	w	rad/s	136.28	Bike Speed	v	m/s	9.00
Density	p	kg/m^3	8000	Wheel Diameter	D_b	m	0.6604
Inner Diameter	d	m	0.0127	Angular Velocity	w_b	rad/s	27.26
Outer Diameter	D	m	0.254				
Thickness	th	m	0.0254	Bike KE	E_b	Nm (J)	2835.0
Flywheel Mass	m_f	kg	10.27				
Inertial constant	k	-	0.5	Input Values			**Final Speed**
				Stagnant Values			**% Efficient - 13.57%**
Moment of inertia	I	kg*m^2	0.083	Calculated Values			3.31 m/s
Flywheel KE	E_f	Nm (J)	769.2				7.42 mph

Based on the calculations from the degn tool displayed in table 1, the vehicle will be able to store roughly 750 J of energy with a rough estimate of 13.5% efficiency. These will be verified by real life tests as soon as the vehicle is ready for testing. It is anticipated that values will be slightly lower than these values due to losses in friction which were unable to be taken into consideration in the design tool.

Appendix

Appendix A: FEA of flywheel

Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.023e+05N/m^2	2.959e+06N/m^{2+}



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.884e-06	9.495e-06

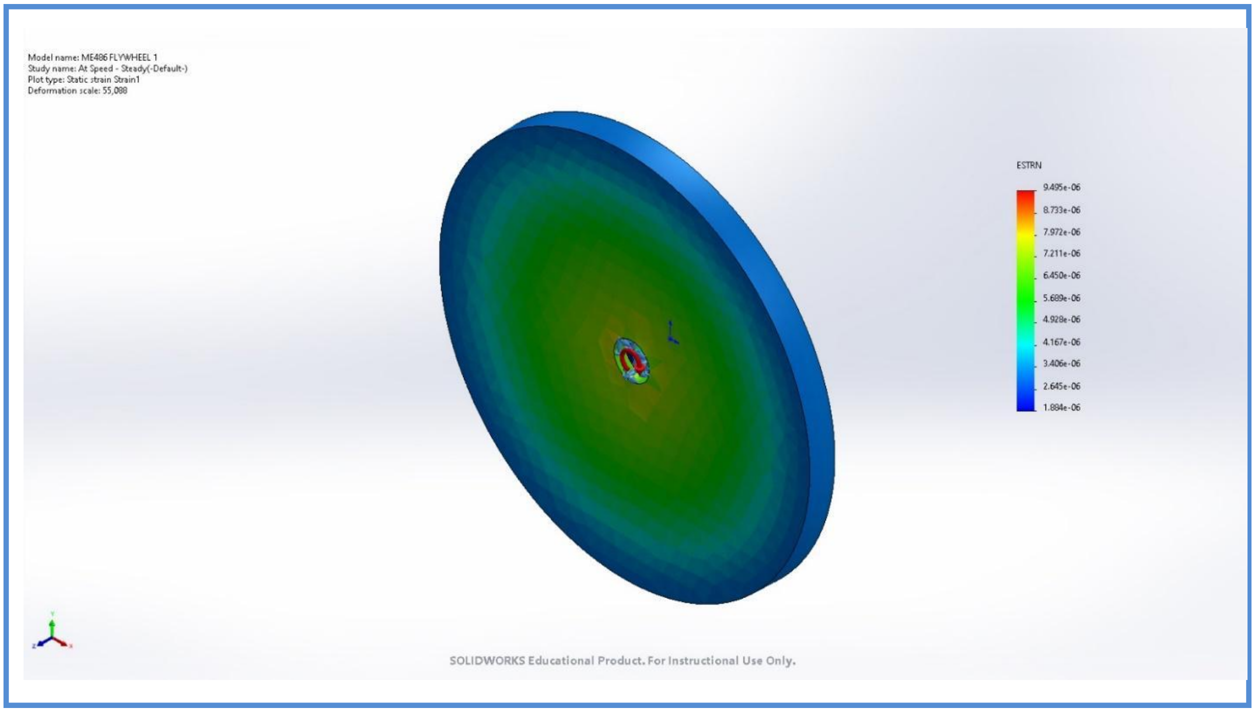
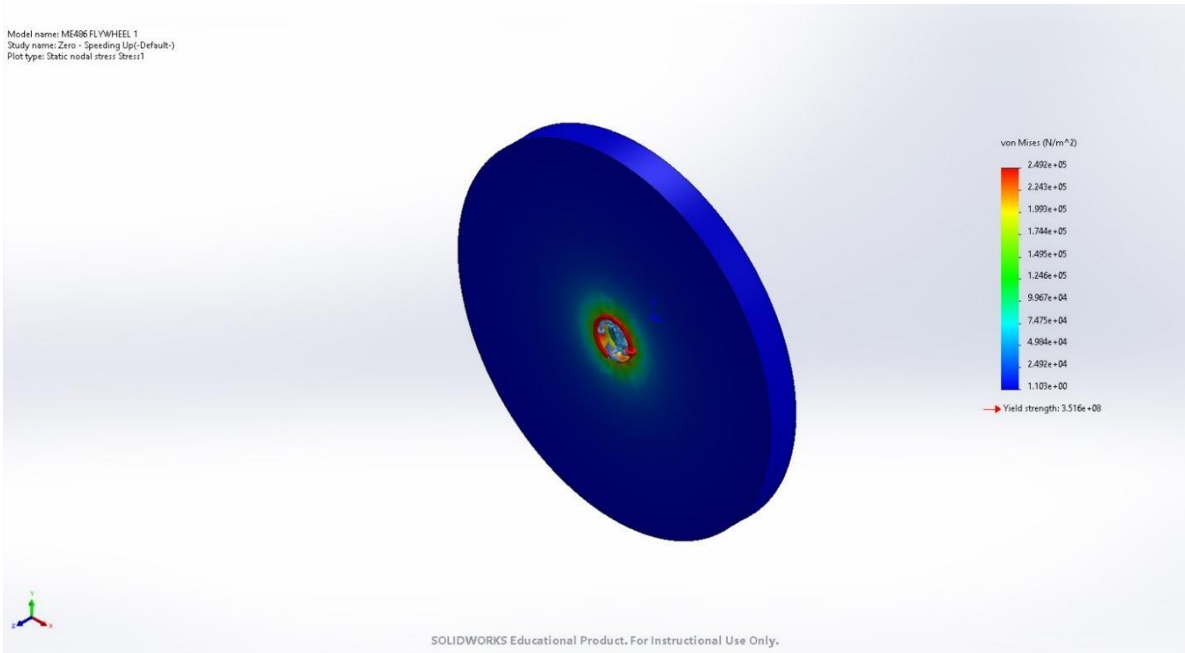


Figure A1: Stress and Strain under Condition 1

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.103e+00N/m^2	2.492e+05N/m^2



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.845e-10	9.011e-07

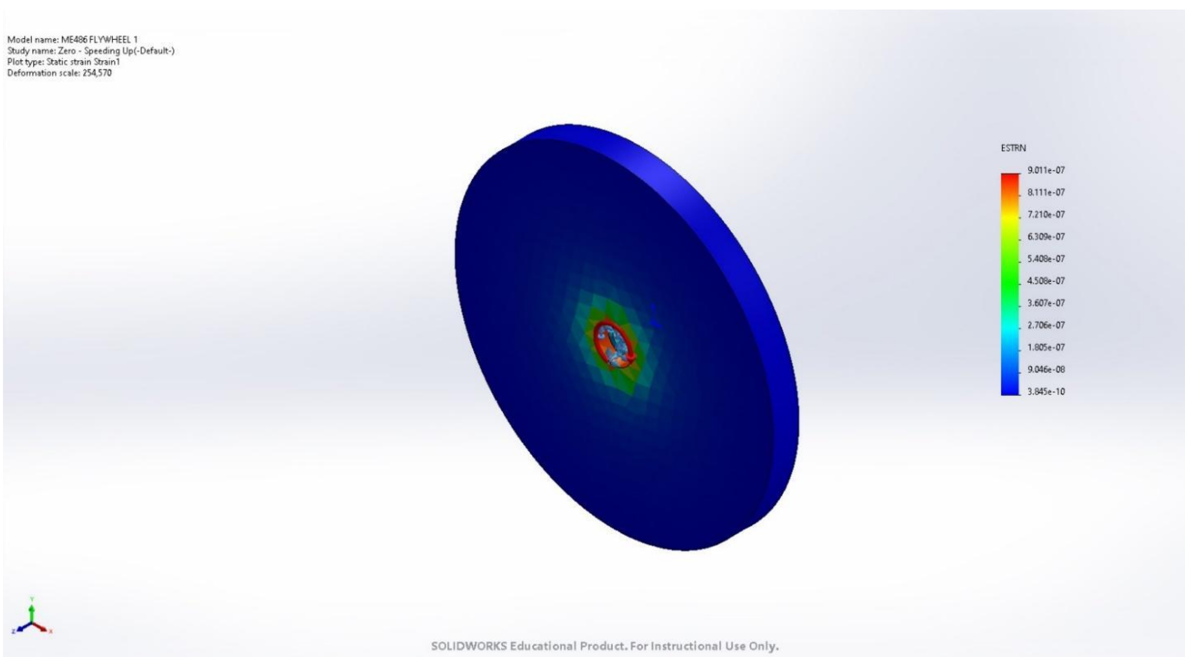
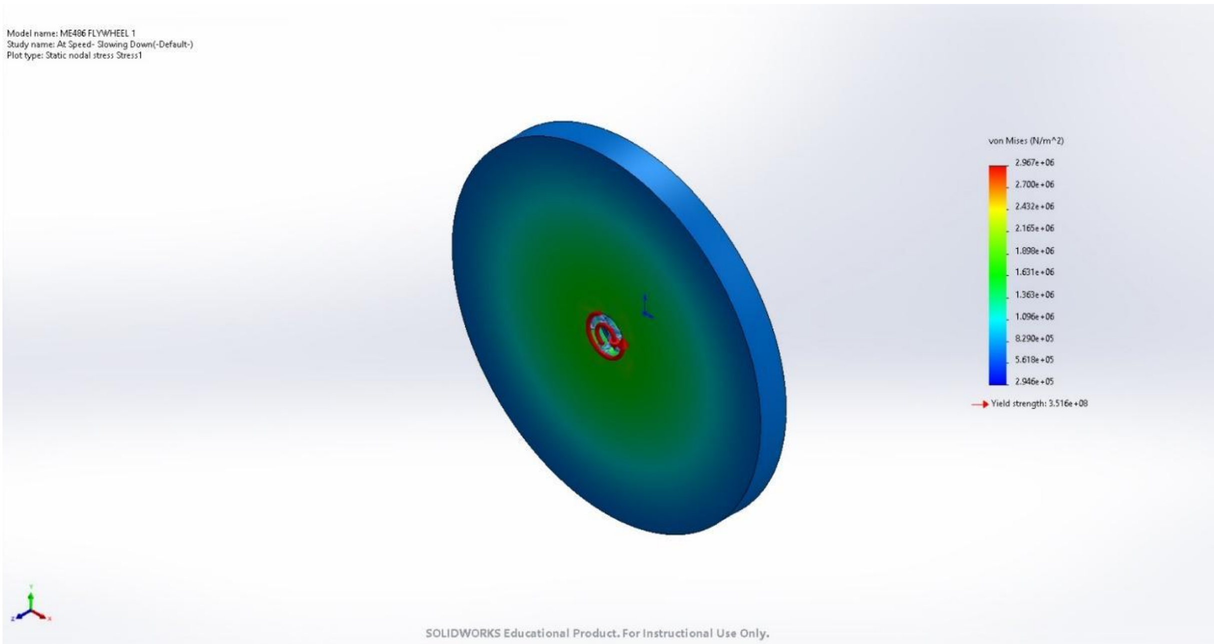


Figure A2: Stress and Strain under Condition 2

Name	Type	Min	Max
Stress1	VON: von Mises Stress	2.946e+05N/m^2	2.967e+06N/m^2



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.843e-06	9.522e-06

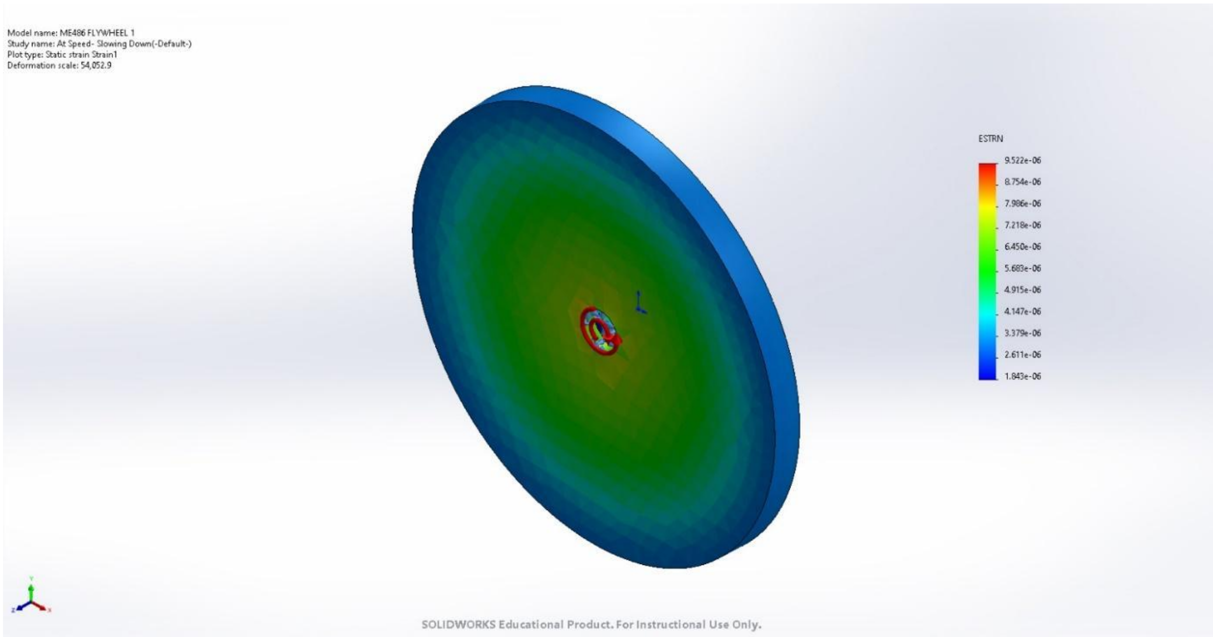
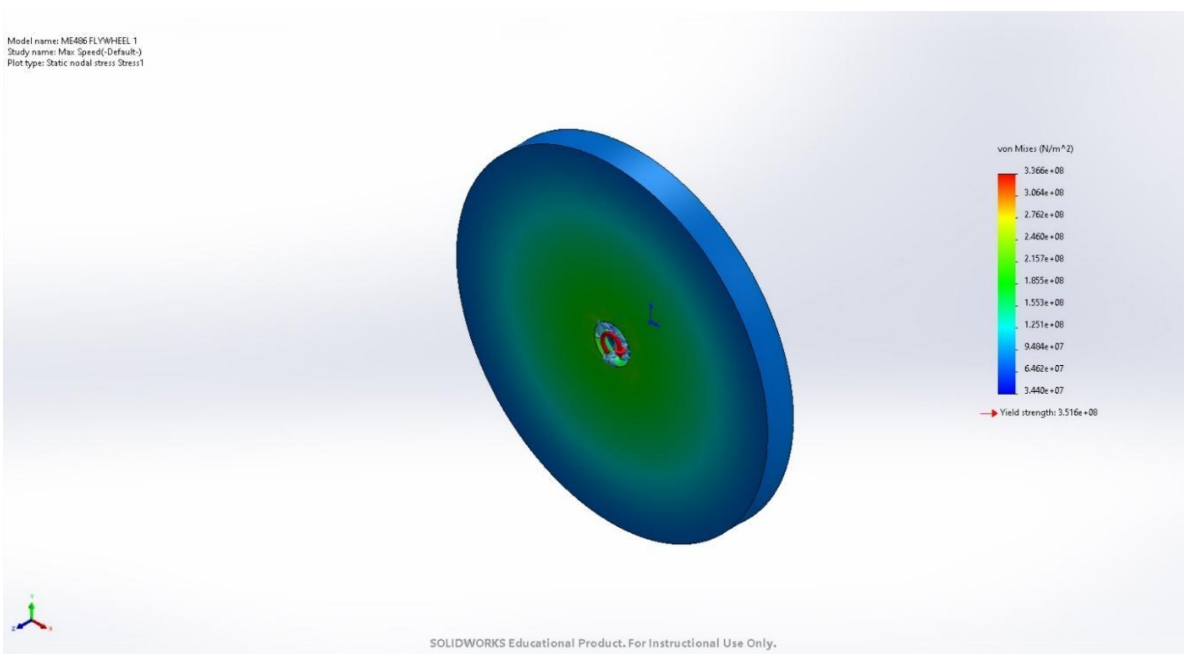


Figure A3: Stress and Strain under Condition 3

Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.440e+07N/m^2	3.366e+08N/m^2



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.143e-04	1.080e-03

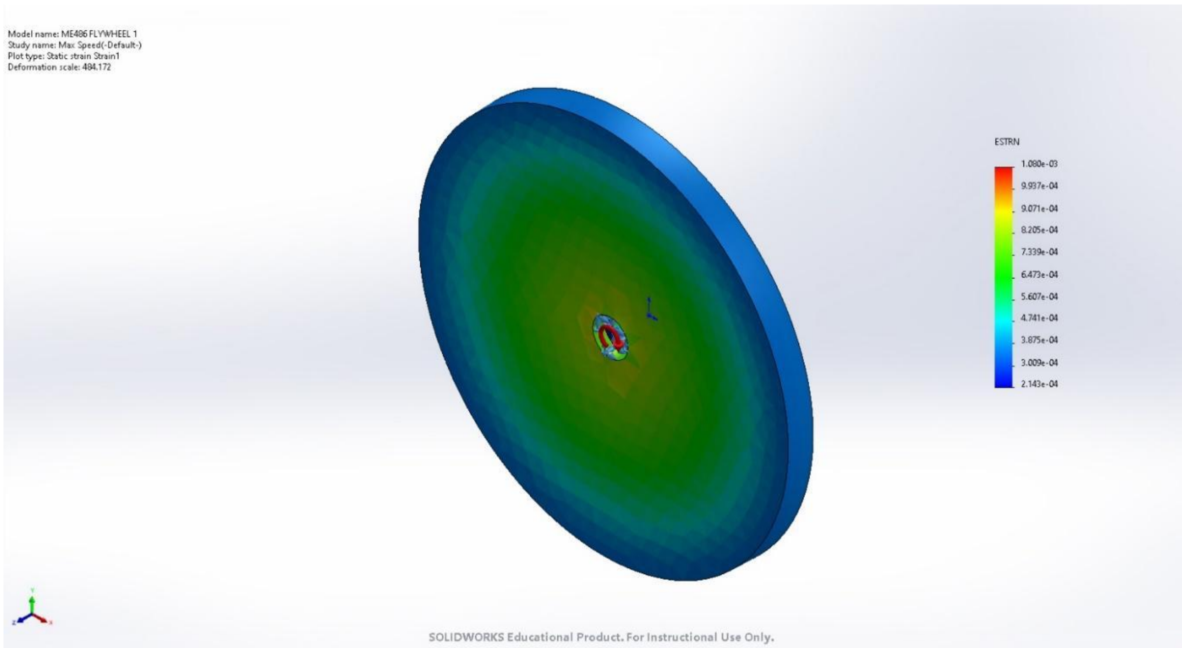
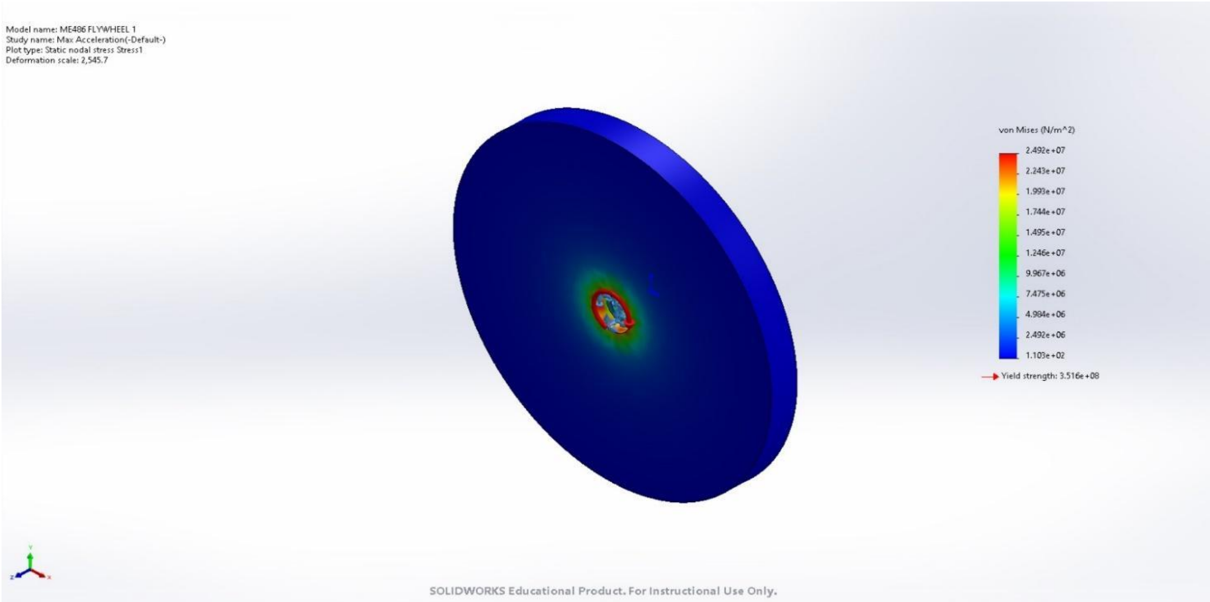
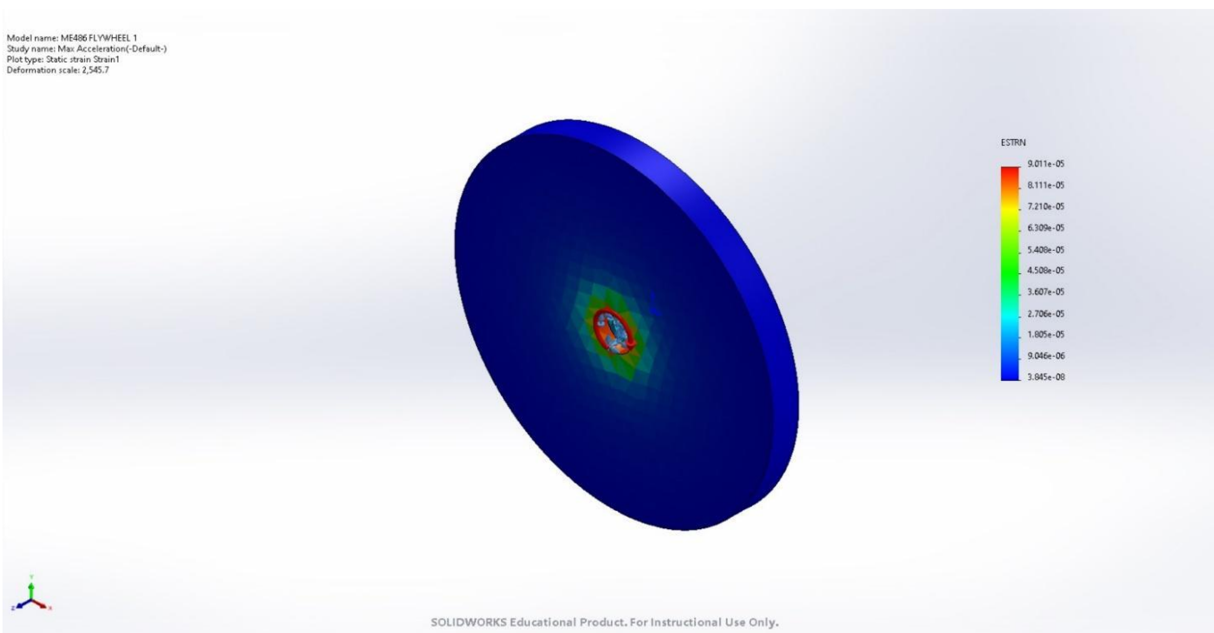


Figure A4: Stress and Strain under Condition 4

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.103e+02N/m^2	2.492e+07N/m^2



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.845e-08	9.011e-05



ME486 FLYWHEEL 1-Max Acceleration-Strain-Strain1

Figure A5: Stress and Strain under Condition 5

Appendix B: FEA of the inner shaft

Table B.1: Material Properties of the inner shaft

Material Properties

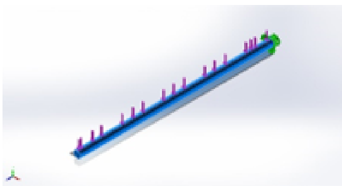
Model Reference	Properties		Components
	Name: Model type: Default failure criterion: Yield strength: Tensile strength: Elastic modulus: Poisson's ratio: Mass density: Shear modulus: Thermal expansion coefficient:	AISI 1020 Linear Elastic Isotropic Max von Mises Stress 3.51571e+08 N/m^2 4.20507e+08 N/m^2 2e+11 N/m^2 0.29 7,900 kg/m^3 7.7e+10 N/m^2 1.5e-05 /Kelvin	SolidBody 1(Boss-Extrude1)(ME486C inner shaft 1)
Curve Data:N/A			

Table B.2: Resultant Forces of the inner shaft

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.0247879	200.015	-0.0538635	200.015

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	-0.345837	0.0100467	0.104384	0.361386

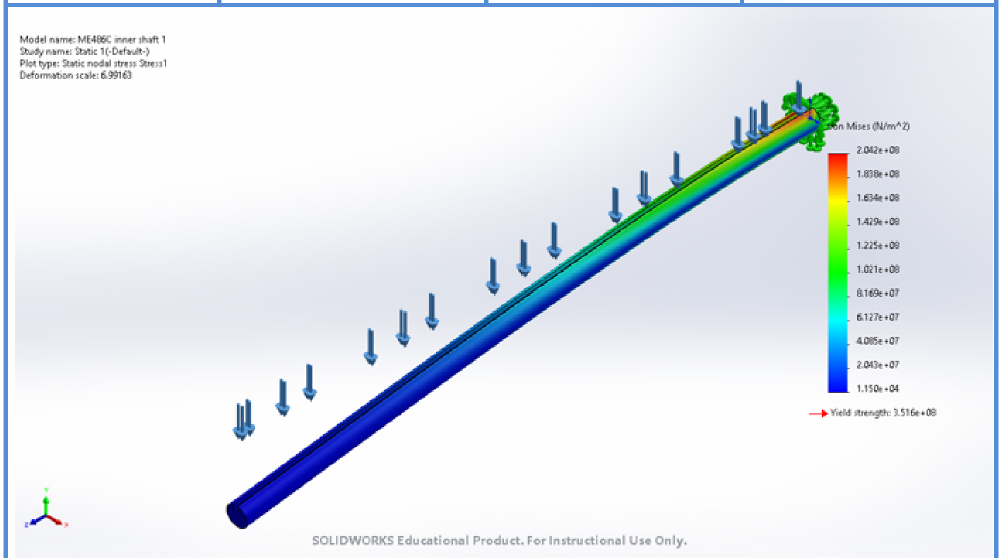
Free body moments

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

Table B.3: Stress of inner shaft

Study Results

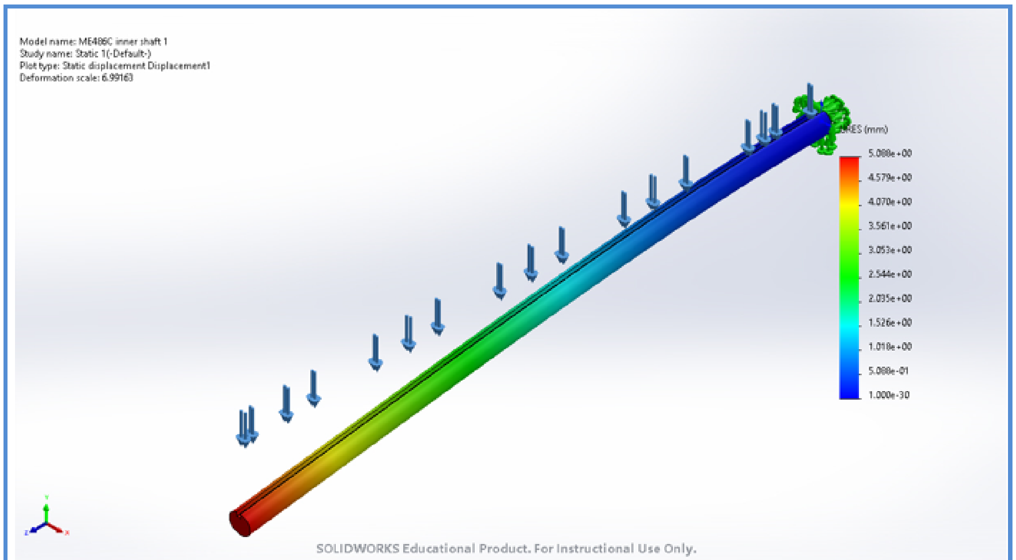
Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.150e+04N/m^2 Node: 7455	2.042e+08N/m^2 Node: 525



ME486C inner shaft 1-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 107	5.088e+00mm Node: 516

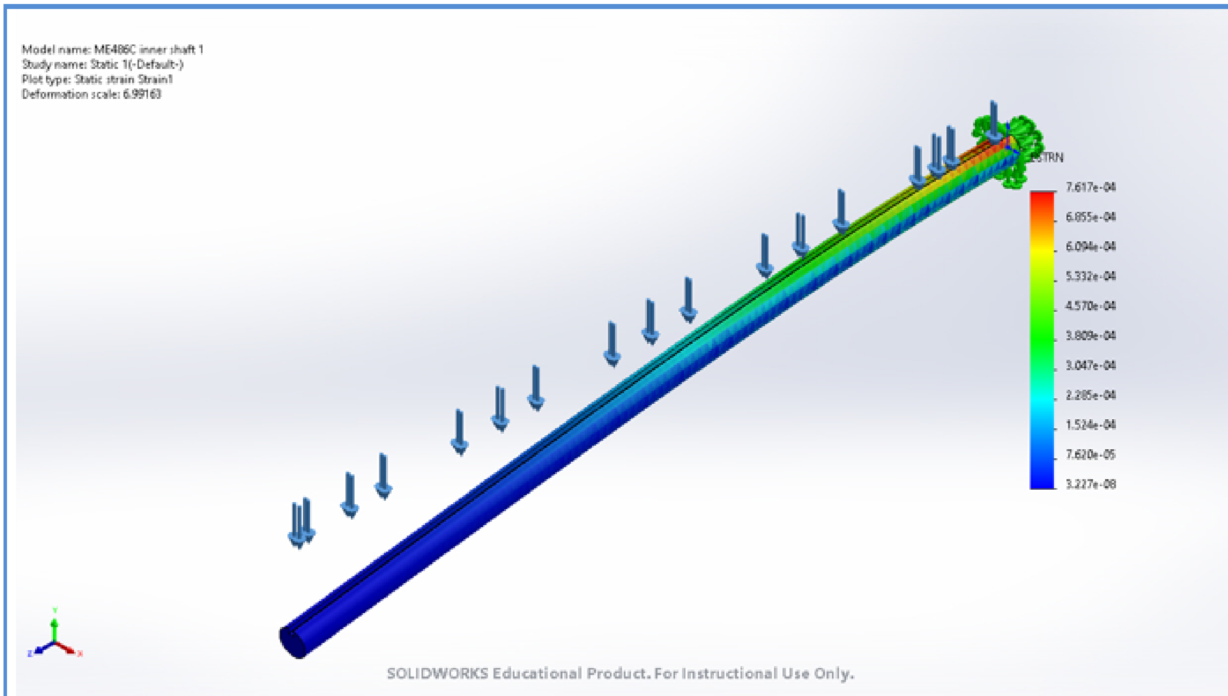
Table B.4: Displacement of the inner shaft



ME486C inner shaft 1-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.227e-08 Element: 3540	7.617e-04 Element: 8032

Table B.5: Strain of inner shaft



ME486C inner shaft 1-Static 1-Strain-Strain1

Appendix C: FEA of sprocket

Table C.1: Material Properties of the sprocket

Material Properties

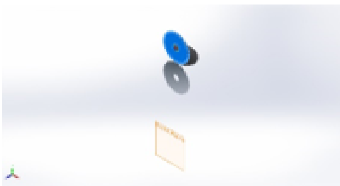
Model Reference	Properties	Components
	**Name:** 2014 Alloy **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 9.65098e+07 N/m^2 **Tensile strength:** 1.65445e+08 N/m^2 **Elastic modulus:** 7.3e+10 N/m^2 **Poisson's ratio:** 0.33 **Mass density:** 2,800 kg/m^3 **Shear modulus:** 2.8e+10 N/m^2 **Thermal expansion coefficient:** 2.3e-05 /Kelvin	SolidBody 1(Cut-Extrude2)(ME486 sprocket 1)
Curve Data:N/A		

Table C.2: Resultant Forces of the sprocket

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00466174	0.00423688	-1.93715e-07	0.00629944

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	-0.0329967	-0.00746796	-1.93715e-07	0.0338312

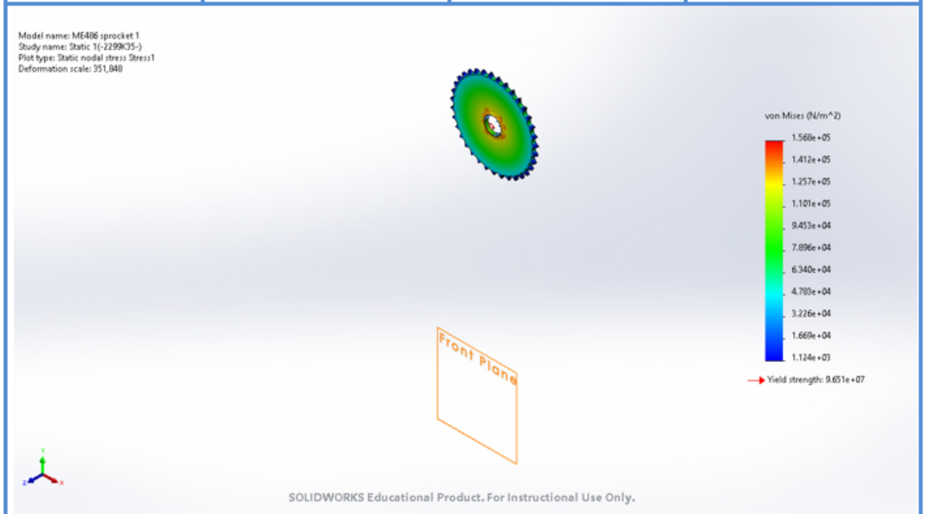
Free body moments

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

Table C.3: Stress of the sprocket

Study Results

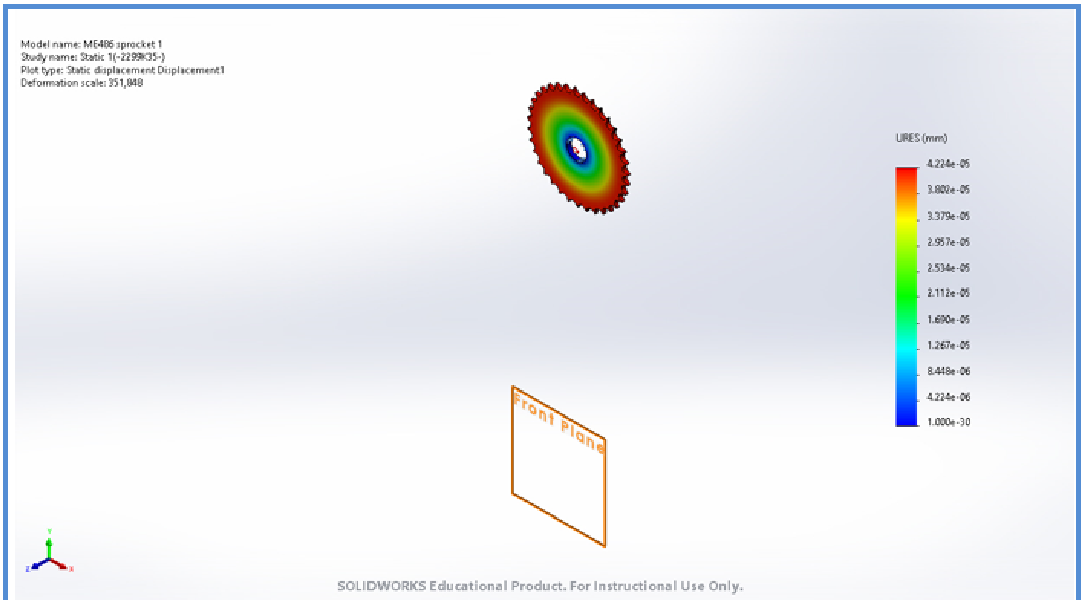
Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.124e+03N/m^2 Node: 9610	1.568e+05N/m^2 Node: 14219



ME486 sprocket 1-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 1	4.224e-05mm Node: 9956

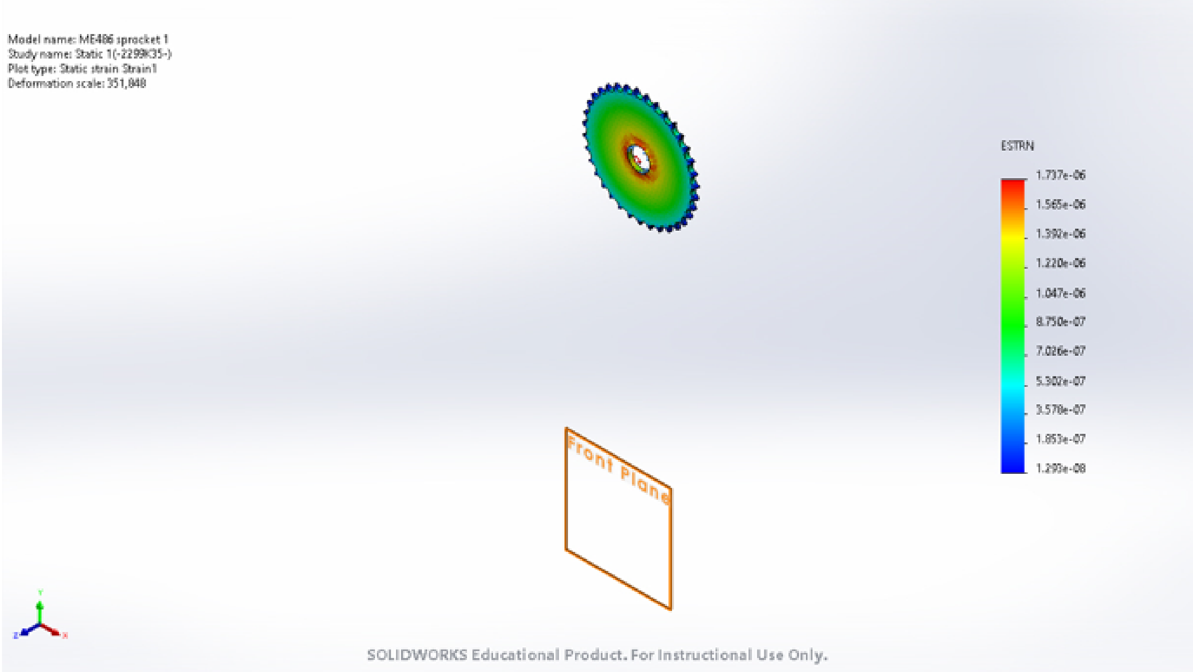
Table C.4: Displacement of the sprocket



ME486 sprocket 1-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.293e-08 Element: 4267	1.737e-06 Element: 9895

Table C.5: Strain of the sprocket



ME486 sprocket 1-Static 1-Strain-Strain1