Final Project

Mechanical Design Simulation Analysis

Group 1

Adrian Diaz

Zion Lewis

Lael Saint Fleur

EML 3036: Simulation Software for Mechanical Engineers

Instructor: Dr. Wei-Yu Bao

Session: U01, Tuesdays, Thursdays 5-6:15 pm

Fall 2025

Table of Contents: List of Tables:

TEAM INTRODUCTION

Adrian Diaz: Mechanical engineering student heavily interested in aerospace applications, particularly manufacturing, testing, and quality engineering. Born and raised in the United States, some of my hobbies include going to the gym, sports like basketball, mma, boxing, and learning new skills.

ZION LEWIS: I am a Mechanical Engineer driven by a strong passion for the transportation industry, with particular interest in aerospace systems, automation technologies, and rail transportation. I enjoy tackling complex engineering challenges that push the boundaries of efficiency, safety, and innovation.

LAEL SAINT FLEUR: I am interested in System Integration & Testing Validation and understanding how individual components combine to form complex mechanical systems. My hobbies are playing basketball and reading books.

INTRODUCTION

The purpose of this project is to apply mechanical design and simulation principles using SolidWorks Simulation to analyze key components of a simplified internal combustion engine and evaluate the aerodynamic behavior of an airfoil. Working as a team, we created or used a simplified engine assembly consisting of five core parts: the piston, piston pin, connecting rod, crankshaft, and engine block. These components represent critical elements of engine operation, and analyzing their structural behavior allows us to better understand real-world mechanical loads and design considerations.

For each component, we performed the required mechanical simulation studies, including compression, bending, shear, torsion, and buckling analyses depending on the part's function and expected loading. Our goal was to obtain detailed engineering results such as maximum stress, strain, deformation, factor of safety, load factor, and critical buckling values when applicable. Each simulation includes clearly defined boundary conditions, applied loads, and references that justify the assumptions made in our models.

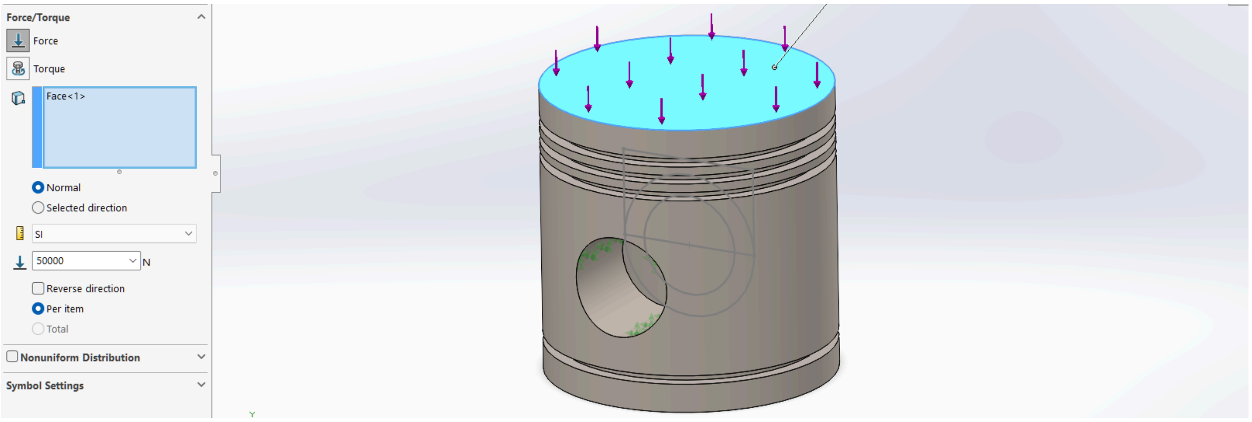
As part of the project requirements, we also conducted a design study on one selected static case to investigate how varying a dimension or material property influences the part's performance. This helped us identify an optimal design configuration based on stress reduction, improved stiffness, or increased safety.

For the optional advanced simulation, we chose to perform an **external fluid flow study over an airfoil**. This analysis allowed us to compute aerodynamic forces such as lift and drag while visualizing airflow behavior around the geometry. By examining the resulting velocity distribution, pressure contours, and force data, we evaluated how the airfoil performs under specified flow conditions.

This project integrates multiple aspects of engineering design including CAD modeling, structural analysis, design optimization, and CFD, and helps us develop practical skills in simulation-driven decision making. Through this work, we aim to strengthen our understanding of fundamental mechanical and aerospace engineering concepts while gaining hands-on experience using SolidWorks Simulation for real-world applications.

SIMULATION SETTINGS FOR EACH STUDIED CASE

Piston



Face<1>

● Normal
○ Selected direction

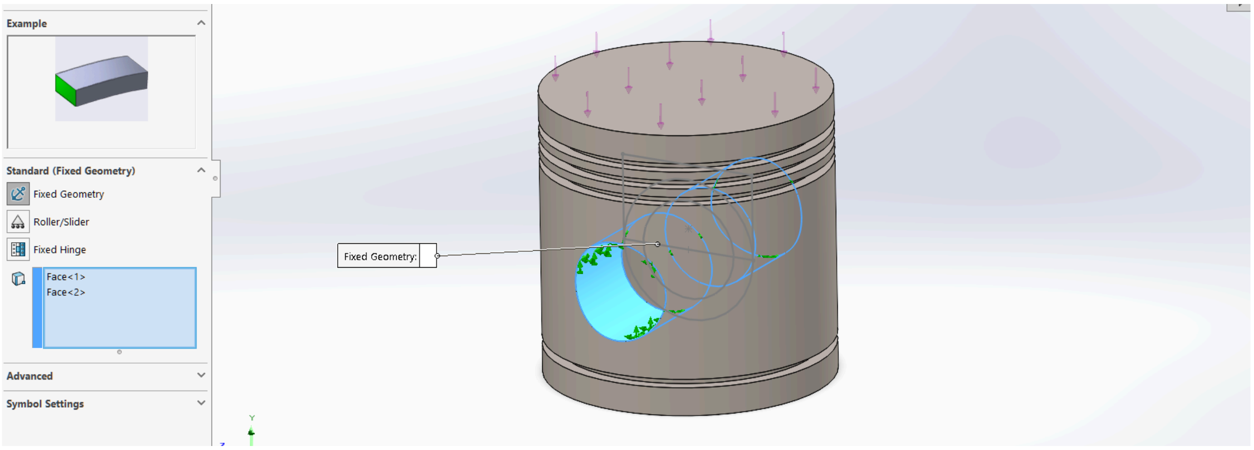
SI

50000 N

☐ Reverse direction
● Per item
○ Total

☐ Nonuniform Distribution

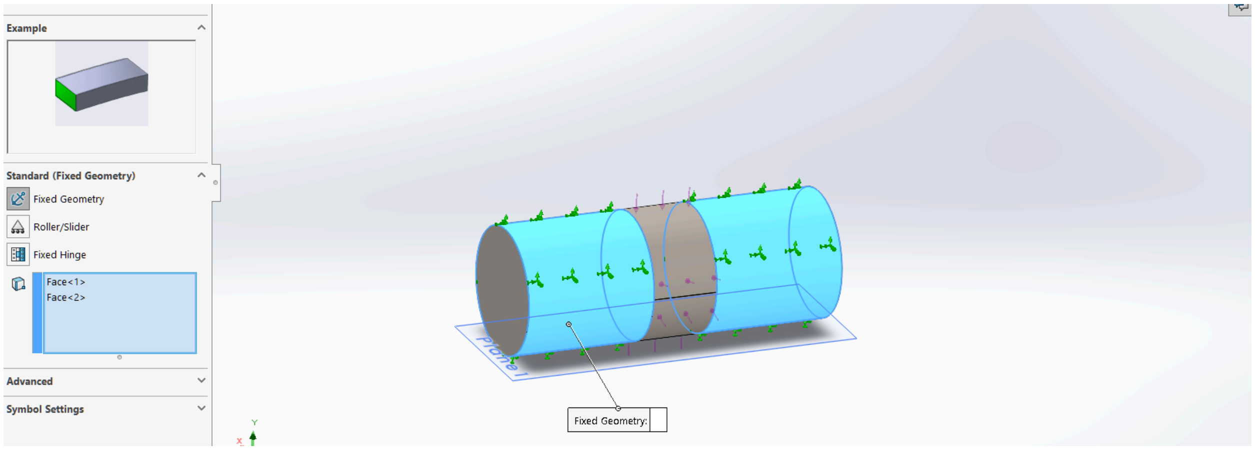
-50kN of force applied to the Top Face



Face<1>
Face<2>

-Fixed at both holes on both ends

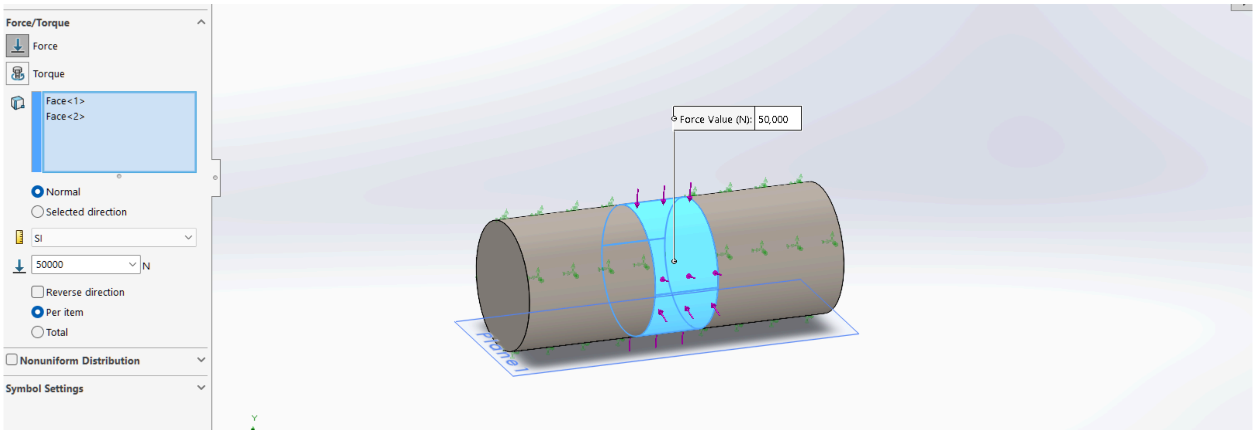
Piston Pin:



Face<1>
Face<2>

Fixed Geometry:

-Split the ends of the pin from the middle
-Fixed ends of Piston Pin



Face<1>
Face<2>

● Normal
○ Selected direction

SI

50000 N

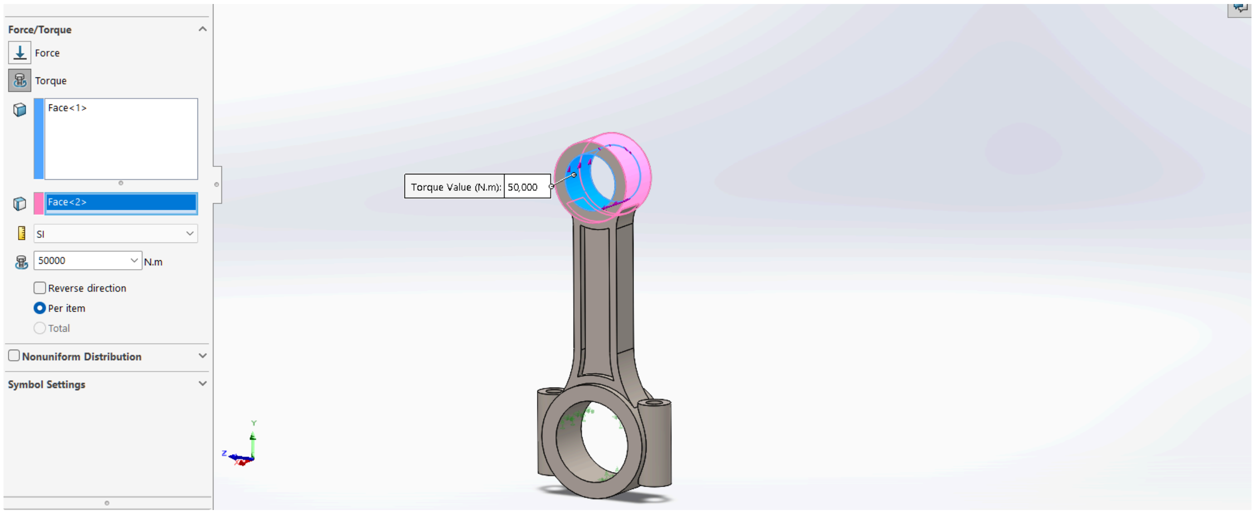
☐ Reverse direction
● Per item
○ Total

☐ Nonuniform Distribution

Force Value (N): 50,000

-Applied 50kN in the middle of the piston pin

Connecting Rod (Vertical):



Face<1>

Face<2>

SI

50000 N.m

☐ Reverse direction

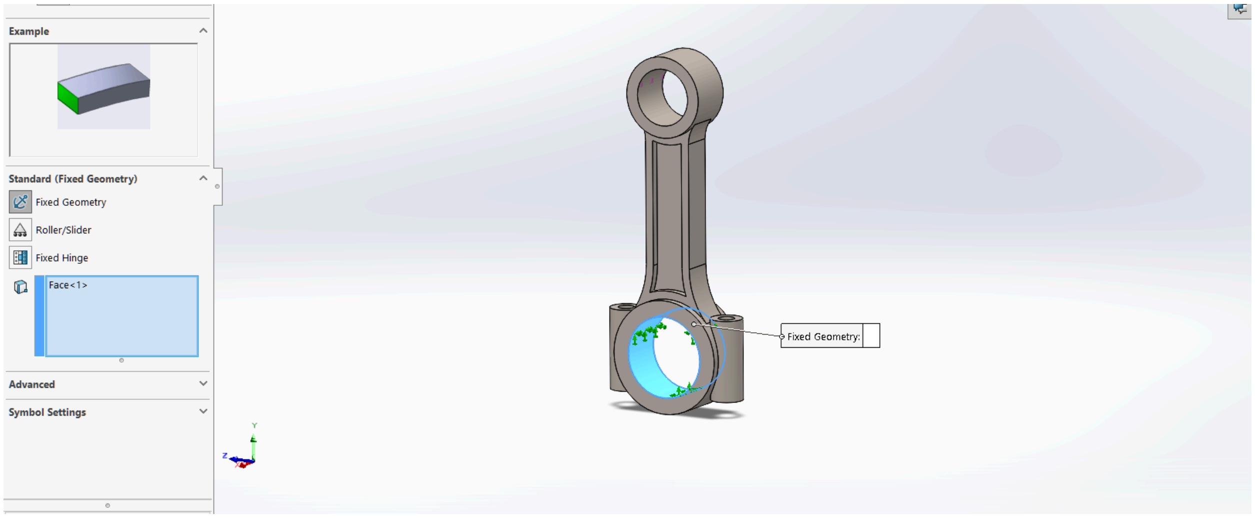
● Per item

○ Total

☐ Nonuniform Distribution

Torque Value (N.m): 50,000

(Torque)



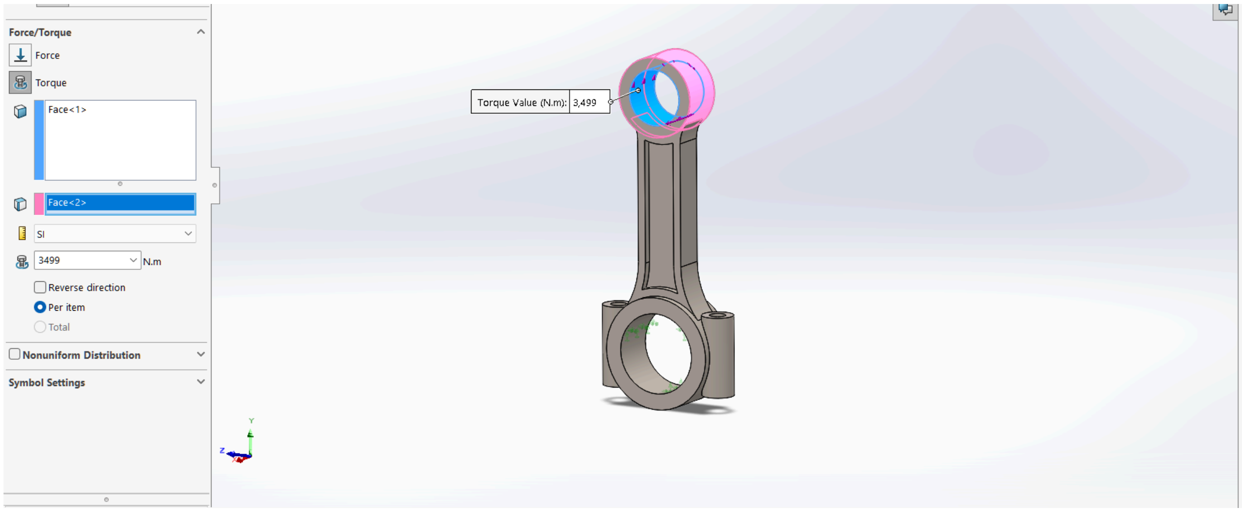
Face<1>

Fixed Geometry:

(Fixed End)

-Fixed in the bottom hole and the Torque is applied to the top hole

Connecting Rod (Max Angle):



Force/Torque

Force

Torque

Face<1>

Face<2>

SI

3499 N.m

☐ Reverse direction

● Per item

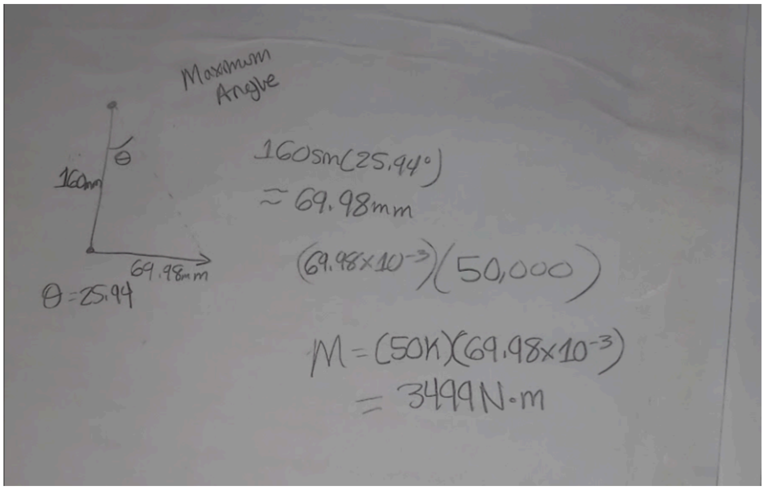
○ Total

☐ Nonuniform Distribution

Symbol Settings

Torque Value (N.m): 3,499

- Maximum Moment of 3499N*m applied on the top hole



160sin(25.94°)

≃ 69.98mm

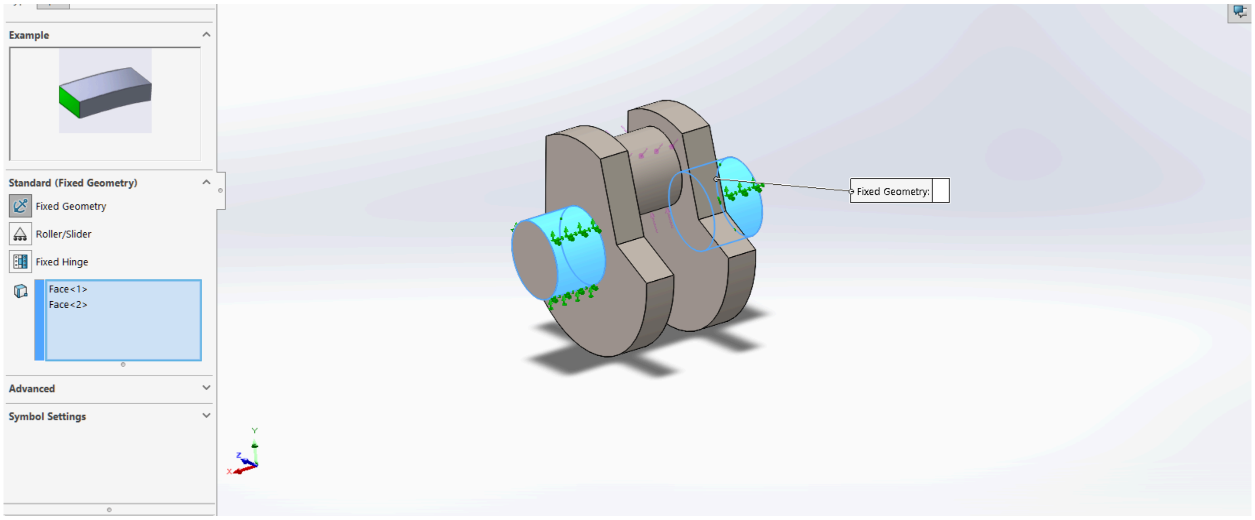
(69.98×10^{-3})(50,000)

M = (50K)(69.98×10^{-3})

= 3499N·m

-Max angle of 25.94 degrees determine by measuring from the center of hole to center hole and getting that angle

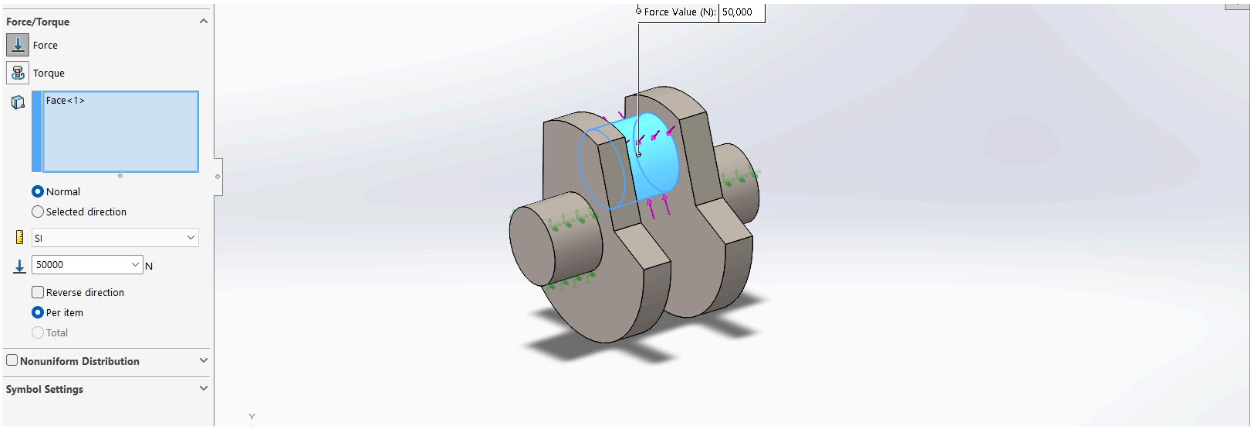
Crankshaft:



Face<1>
Face<2>

Fixed Geometry:

-Both rods fixed at both

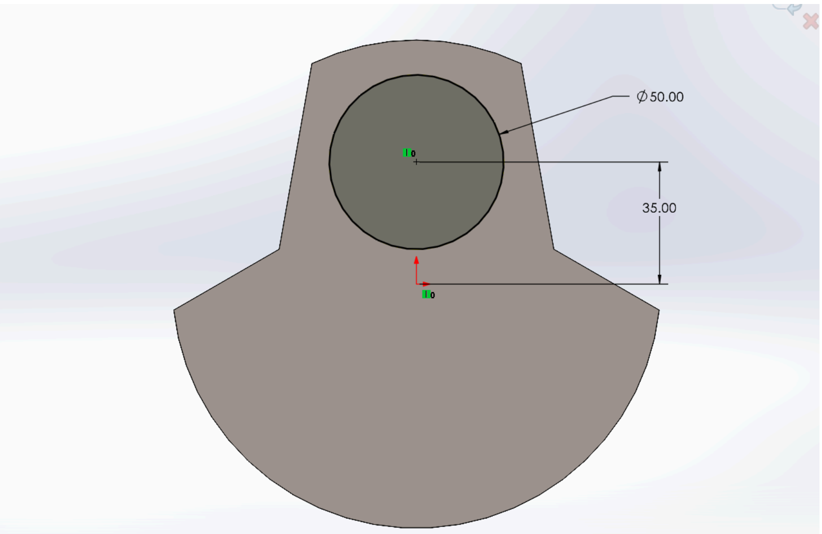


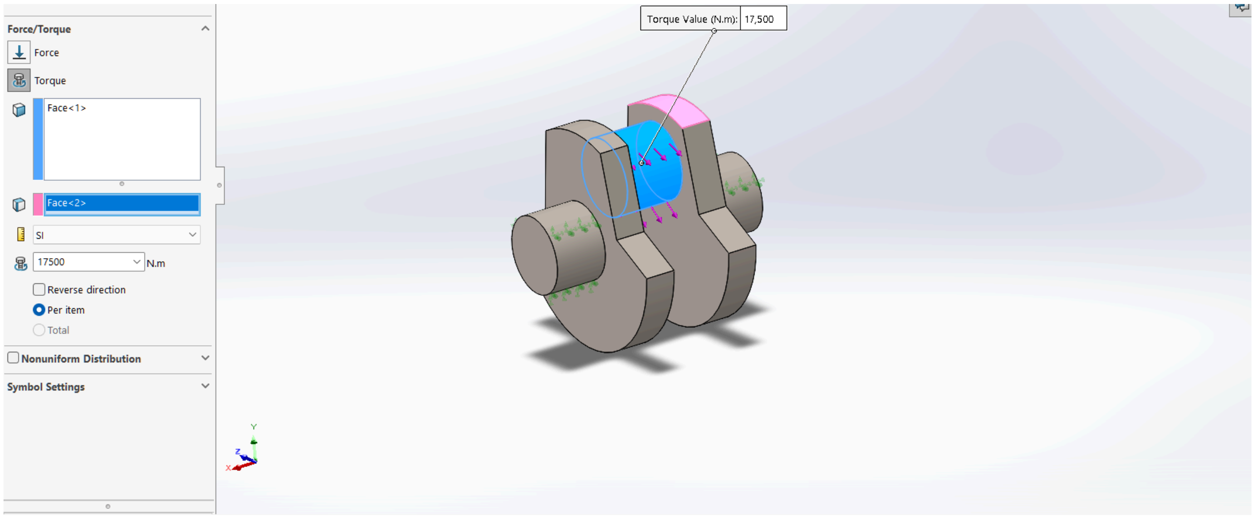
Face<1>

● Normal
○ Selected direction
SI
50000 N
☐ Reverse direction
● Per item
○ Total
☐ Nonuniform Distribution

Force Value (N): 50,000

-Force of 50kN applied in the middle of the crankshaft (Torque)





Force/Torque

Force

Torque

Face<1>

Face<2>

SI

17500 N.m

☐ Reverse direction

● Per item

○ Total

☐ Nonuniform Distribution

Symbol Settings

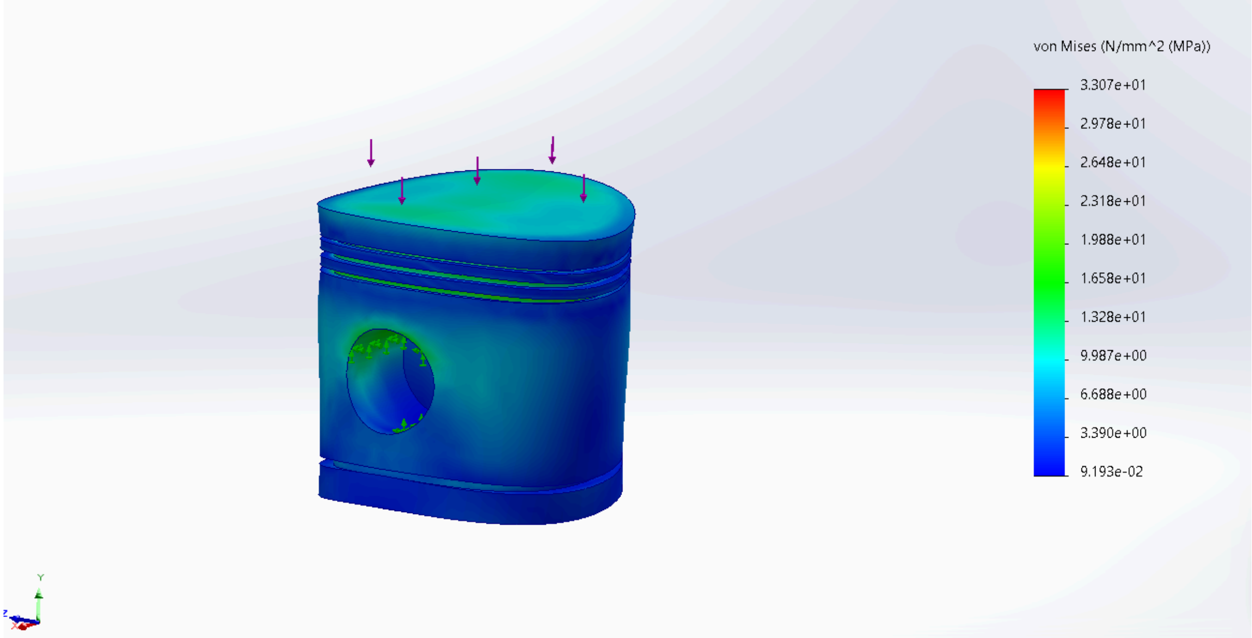
Torque Value (N.m): 17,500

-Take 50kN force times the distance from the axis of rotation which is 0.35m to create torque (M=F*d)

RESULTS & DISCUSSIONS

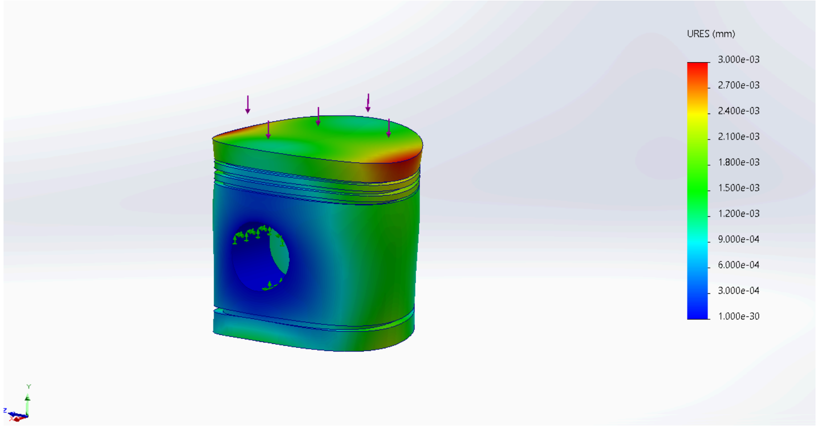
Piston

Stress



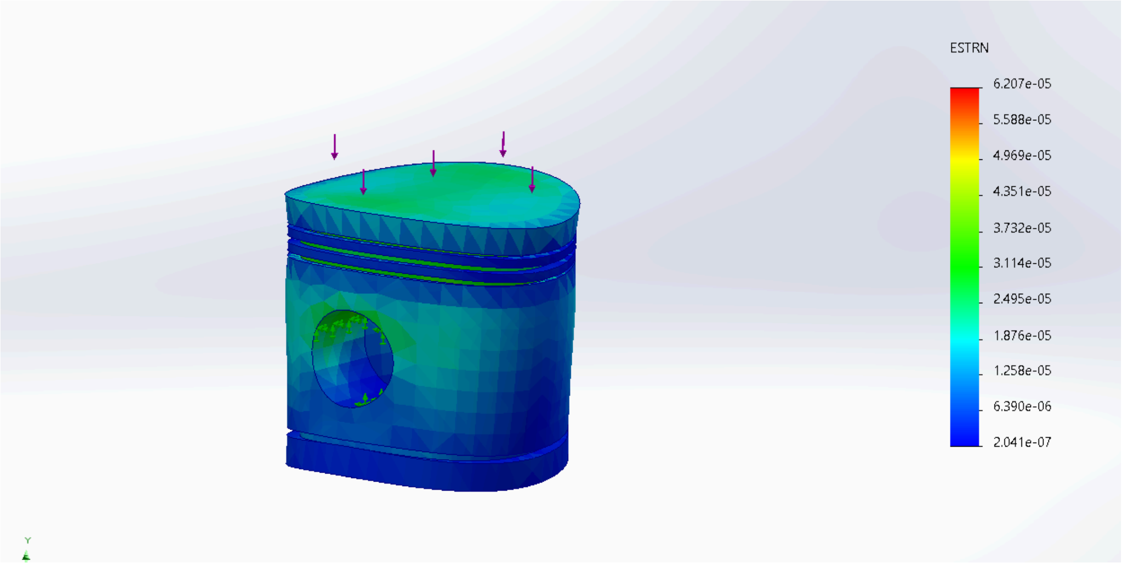
The stress distribution shows the highest von Mises stress located near the crown and pin boss area, where the applied combustion load is concentrated. The peak stress remains well below the material yield strength, indicating that the piston can safely withstand the applied loading conditions.

Displacement



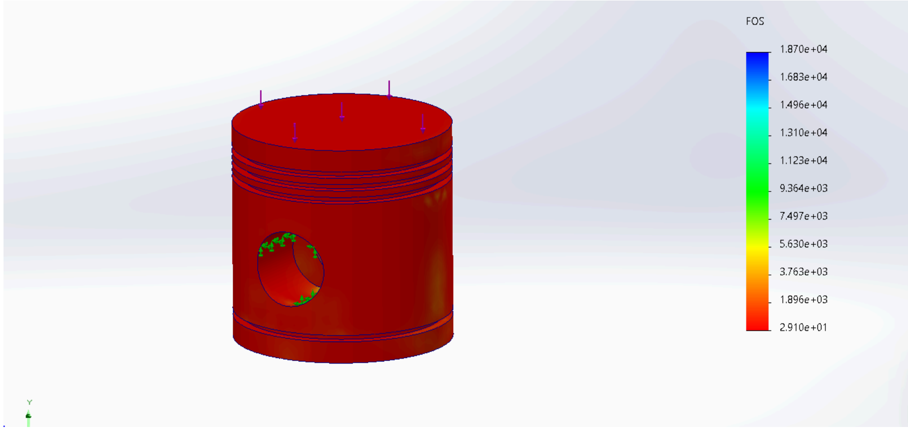
The piston experiences very small overall displacement, with the maximum occurring at the top surface where the compressive load is applied. The deflection is minimal relative to the piston dimensions, showing that the structure maintains its shape under loading and behaves as a stiff component.

Strain



Strain values follow the same pattern as the stress distribution, with the largest strain occurring near the loaded crown and around the pin boss. The strain levels are low, indicating that the piston stays in the elastic region and does not approach plastic deformation.

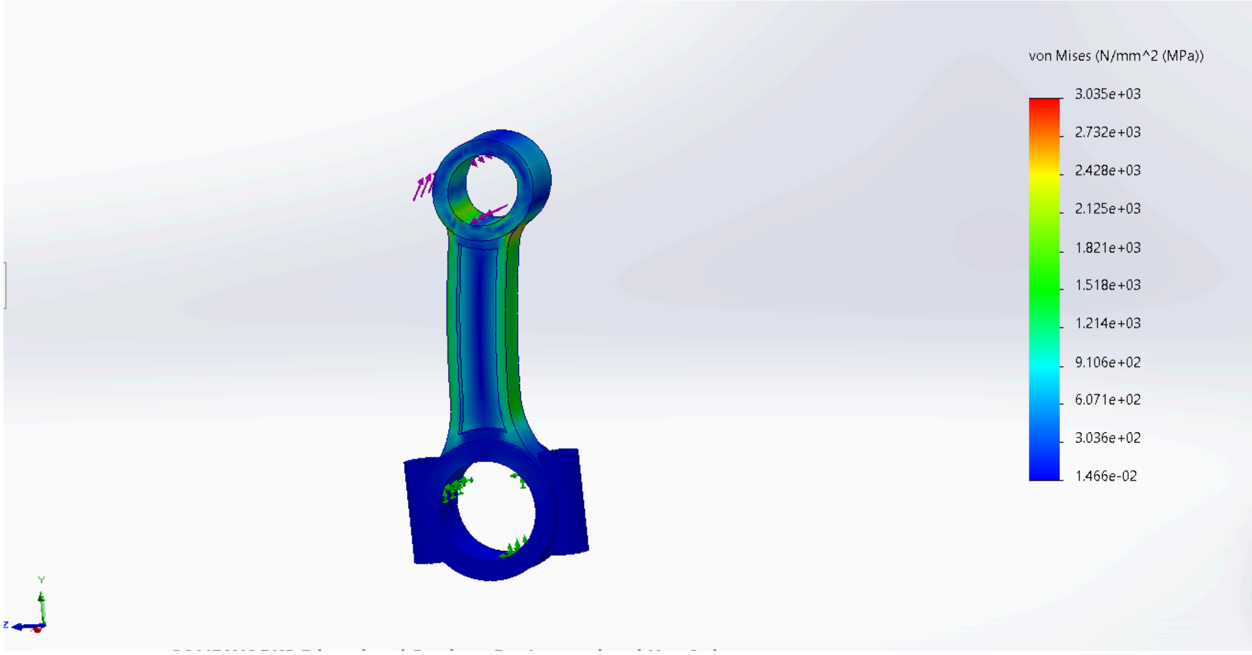
FOS



The computed factor of safety is above 1 across the entire piston, confirming that the design can safely carry the applied load. Critical regions show a lower FOS but still remain within acceptable limits, suggesting the piston is structurally adequate for the simulated operating conditions.

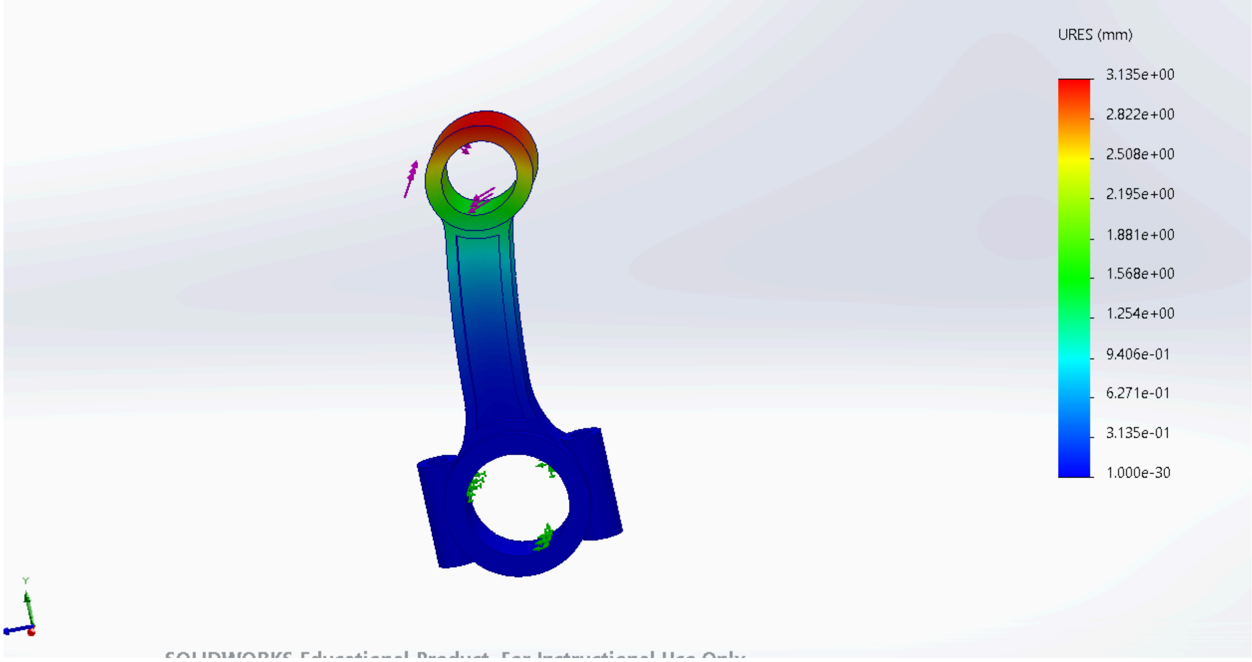
Connecting Rod (Max Angle Case)

Stress



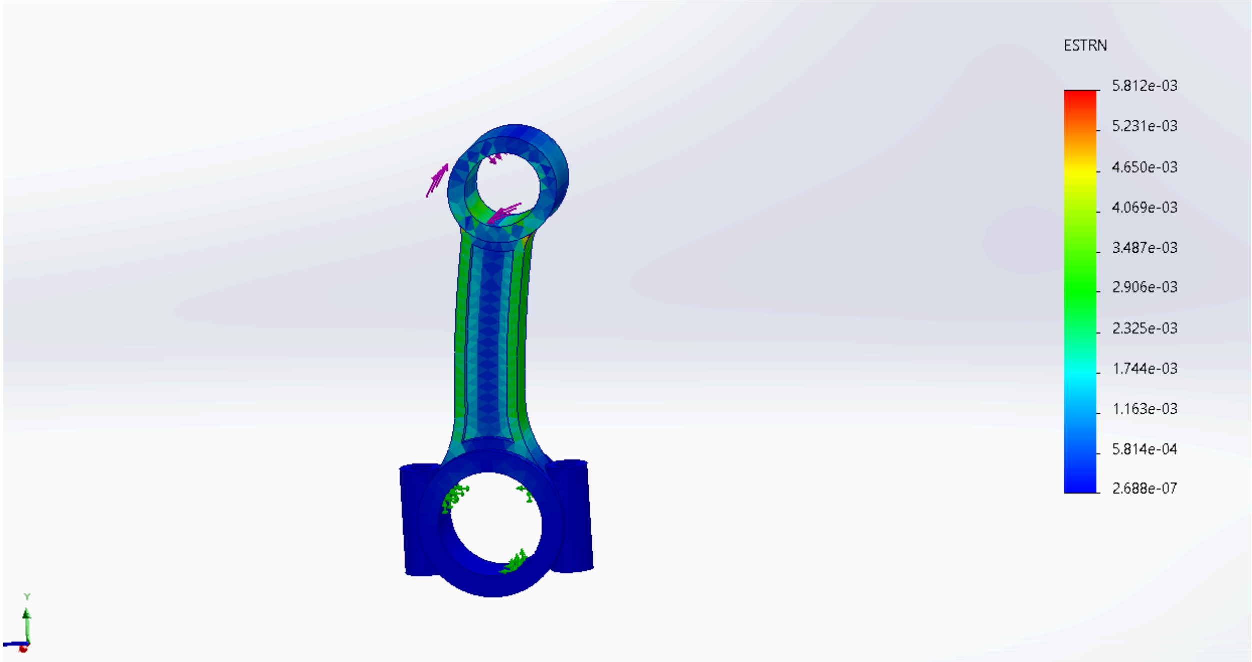
The highest stresses appear around the small-end and big-end fillet regions, where bending and load transfer are most severe at maximum crank angle. Although the mid-section carries the load primarily in compression, the ends experience localized peak stresses. These values remain below the material yield limit, indicating safe operation under this loading condition.

Displacement



Displacement is concentrated toward the ends of the connecting rod, with the maximum occurring near the small end where the applied load is angled. Overall deformation remains small, meaning the component maintains structural stiffness even in the most critical loading orientation.

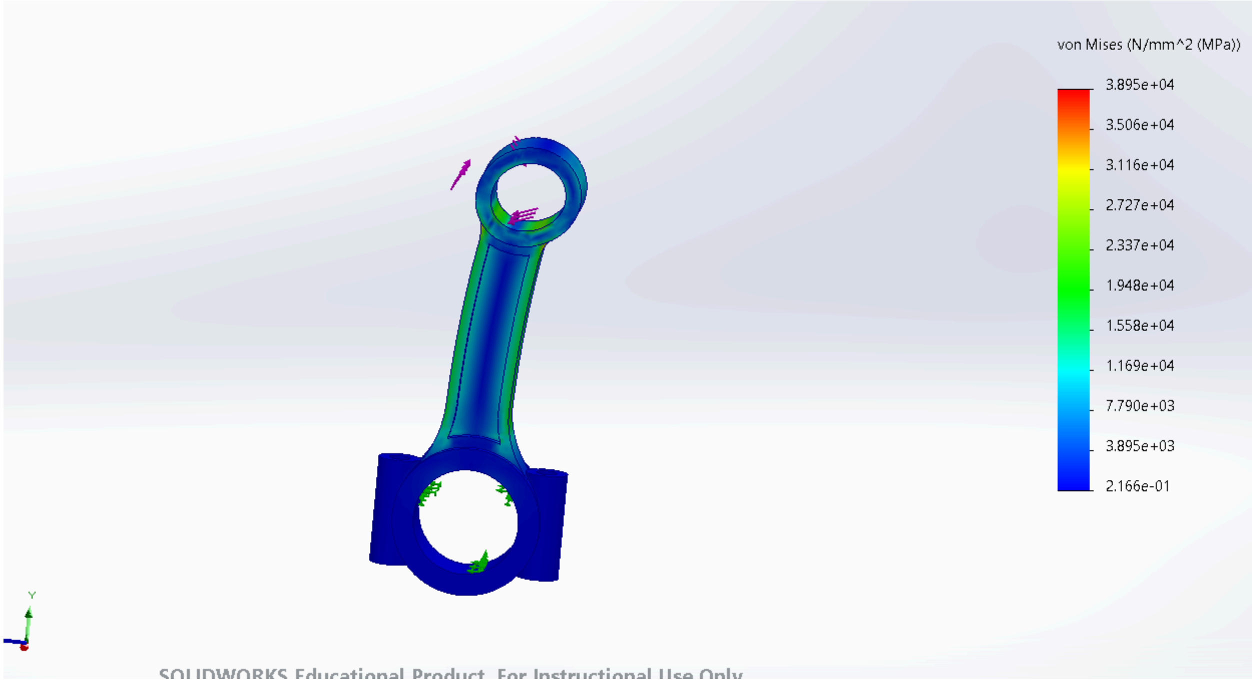
Strain



Strain follows the same pattern as stress, with the highest strain values located around the small-end hole and big-end fillets. The strain levels remain within the elastic range, showing that the rod does not approach permanent deformation in this case.

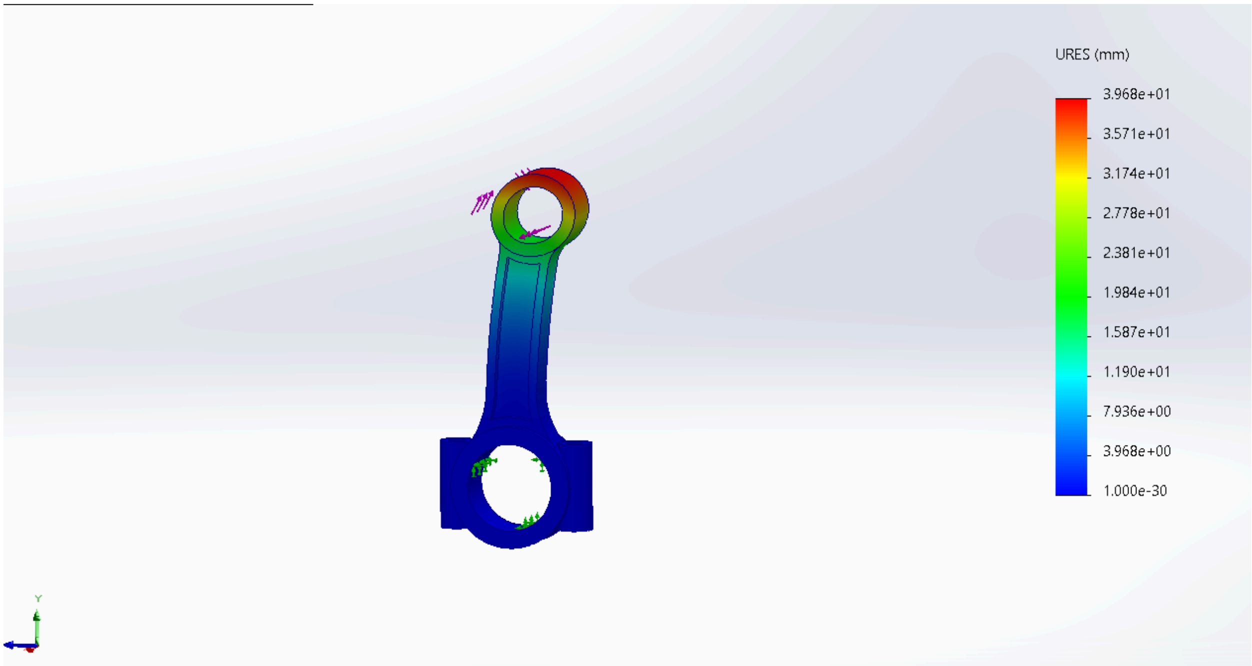
Connecting Rod (Normal)

Stress



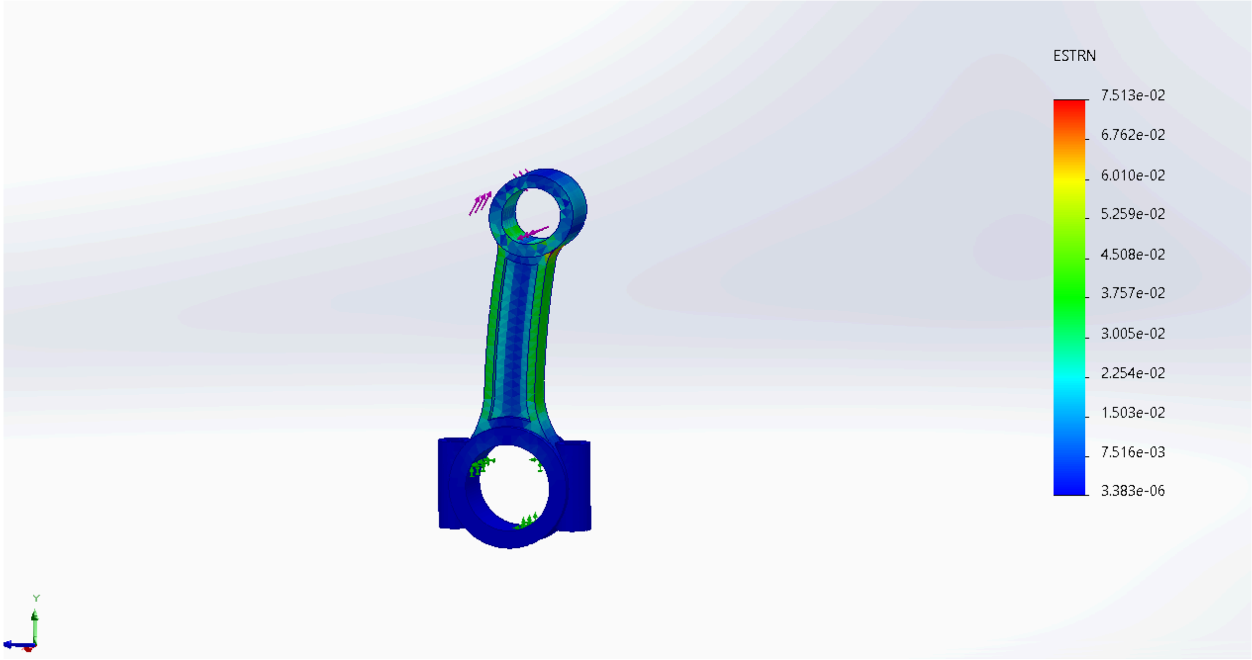
Under the normal loading case, the highest stresses occur around the fillets near the small end and big end, where the geometry forces load concentration. The stress levels are significantly lower than in the max-angle case, indicating that the rod experiences primarily axial compression with minimal bending in this condition.

Displacement



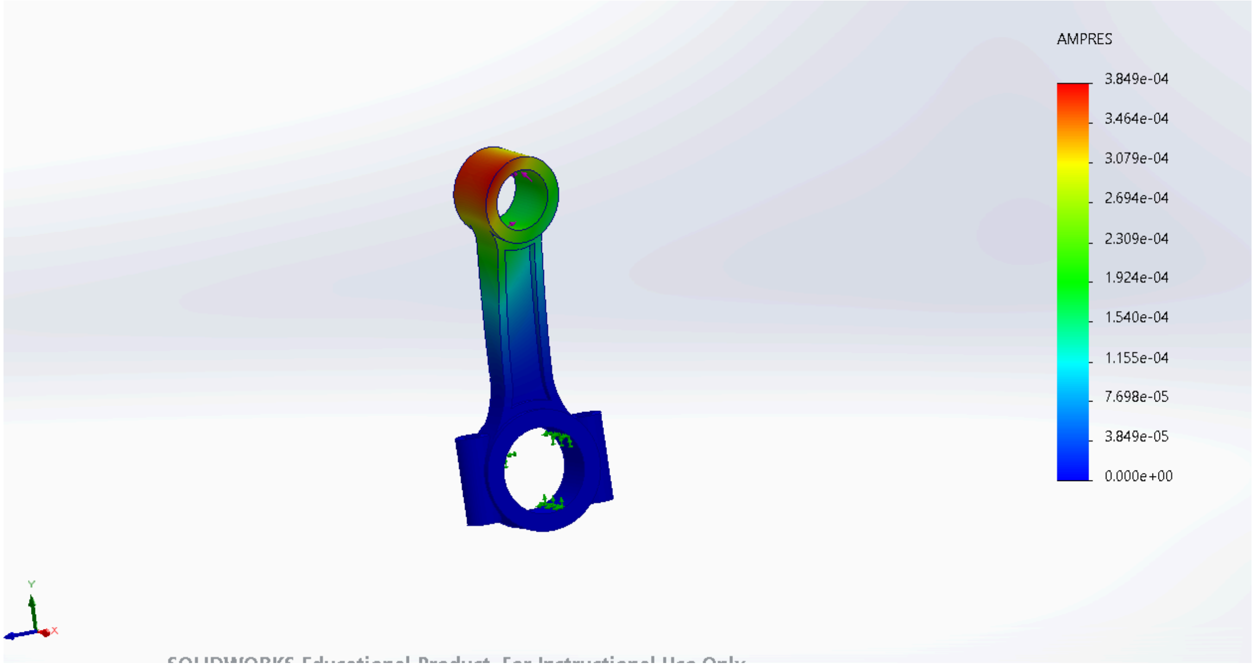
Displacement is minimal and mainly located toward the small end, following the direction of the applied load. The overall deformation is small relative to the rod length, confirming that the connecting rod remains stiff under normal axial loading.

Strain



Strain distribution mirrors the stress pattern, with the largest strain values appearing near the fillet regions. The strain remains within the elastic range, showing that the material is not approaching any permanent deformation under normal conditions.

Buckling



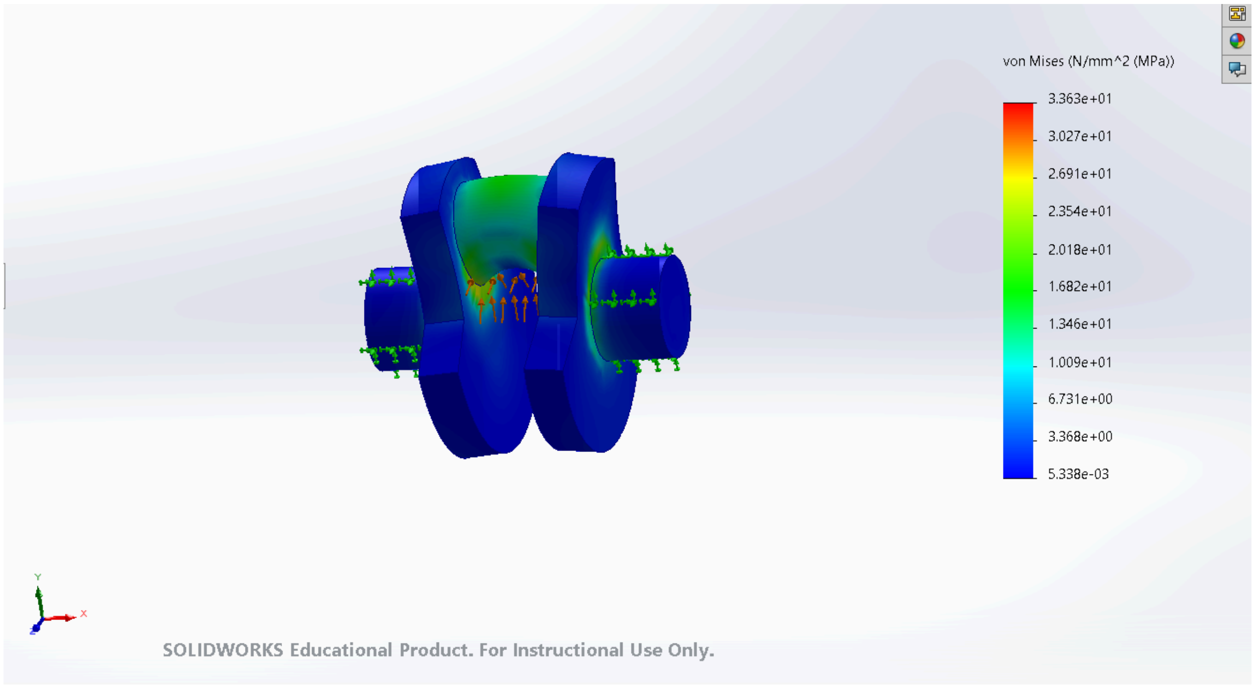
The buckling mode shows lateral deflection concentrated at the slender mid-span of the shank. This out-of-plane displacement in the first mode is significantly larger than the elastic displacement from the static load, indicating susceptibility to flexural instability rather than large elastic Bending.

FOS

The calculated factor of safety for the connecting rod in the engine assembly is 0.019, indicating that the applied operating loads exceed the allowable capacity by a large margin. This extremely low FoS shows that the component would experience failure well before reaching normal service conditions. Rather than maintaining structural integrity, the connecting rod is operating at less than 2% of the strength required for safe performance, attempts were made to increase the FOS but finding a higher safety rate proved difficult.

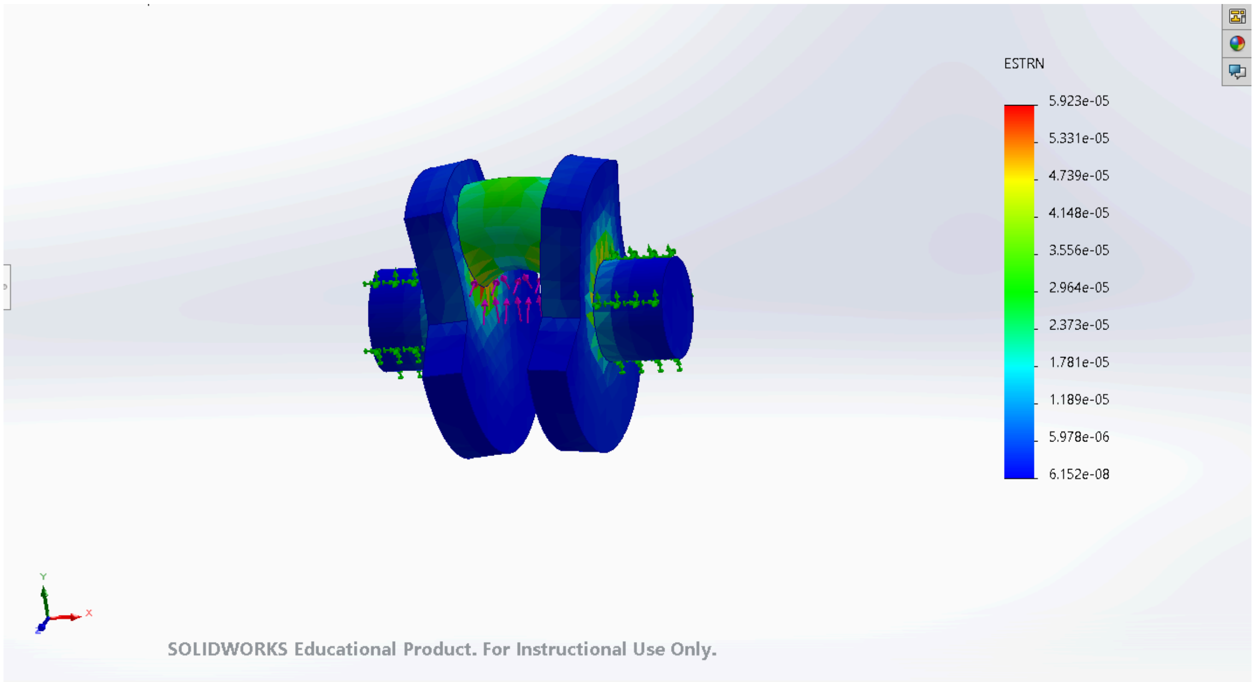
Crankshaft (Vertical)

Stress



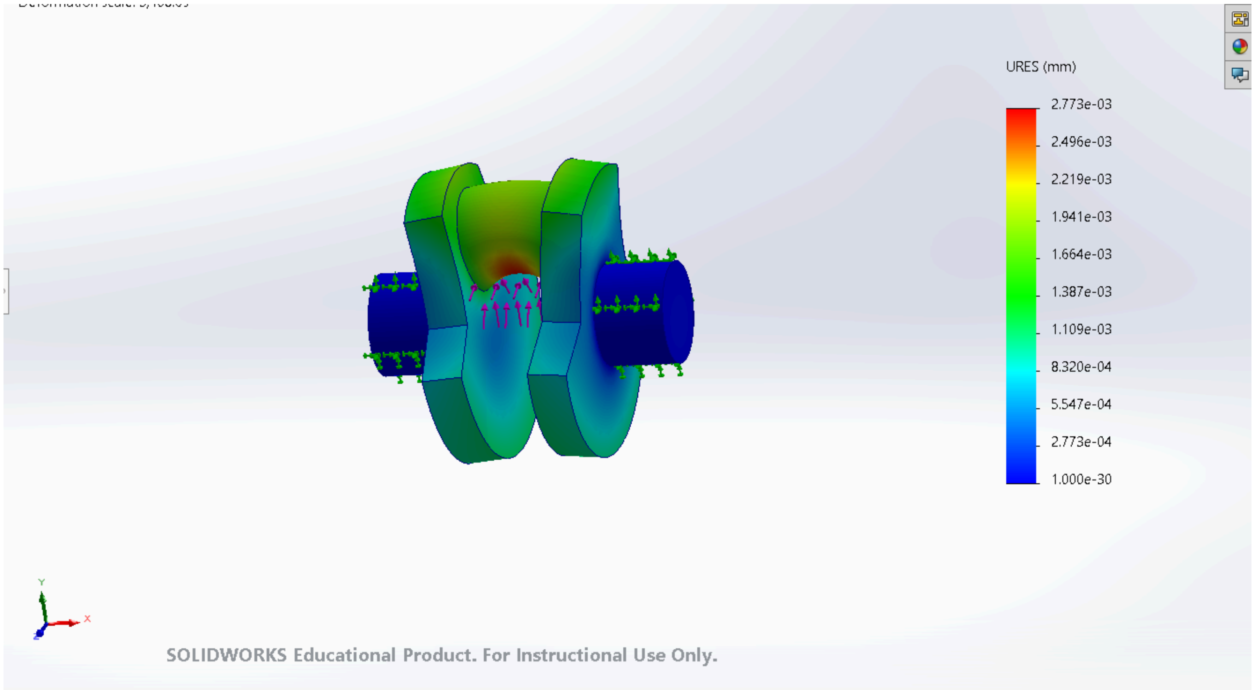
The von Mises stress is highest around the crankshaft fillet areas where the crank web meets the shaft, which is expected due to geometric stress concentration. Even at these locations, the maximum stress remains relatively low, showing that the vertical loading does not significantly challenge the structural capacity of the crankshaft.

Strain



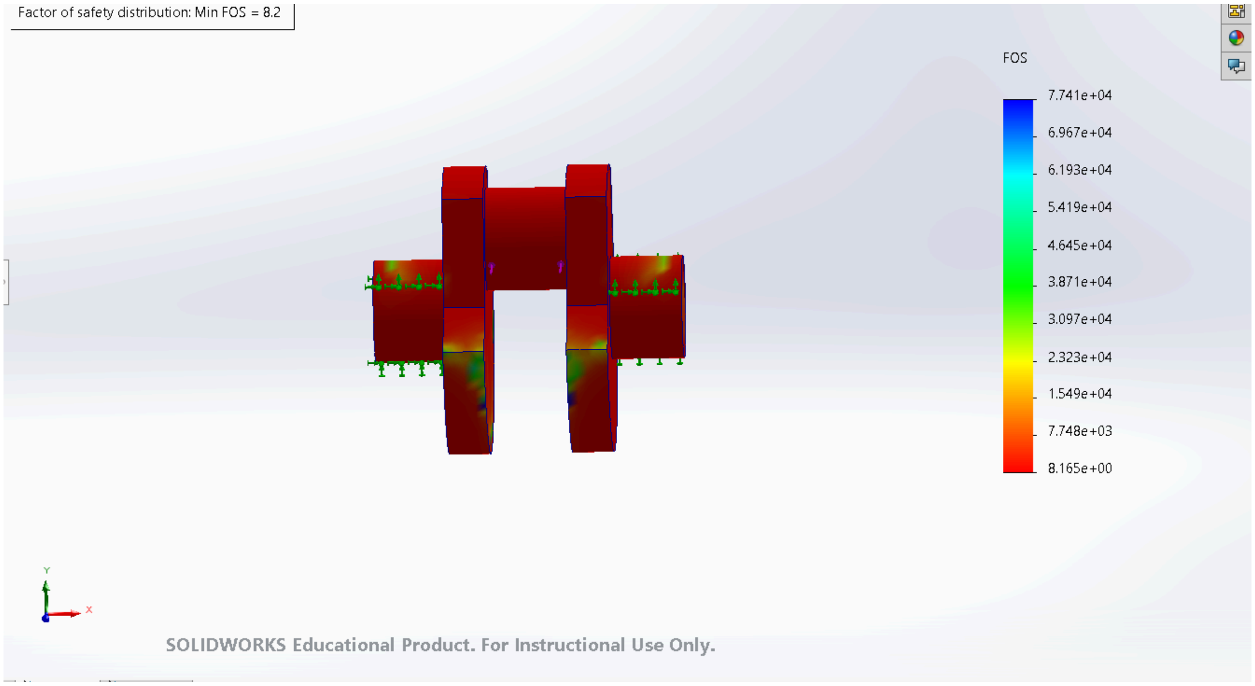
Strain follows the same pattern as stress, with peak values in the fillet regions. The overall strain levels are small, indicating that the crankshaft undergoes only minor elastic deformation. This suggests the component maintains good rigidity and is not at risk of excessive bending under the applied vertical force.

Displacement



For an ICE component under load, the critical maximum displacement is often observed at the thinnest or least supported sections, such as the piston skirt or the big end bearing bore of the connecting rod, depending on the constraints used. Although the overall magnitude of the displacement is usually small (often measured in fractions of a millimeter), its value is vital for engineering validation, as it confirms that the component remains within the tight dimensional tolerances required to maintain proper functionality and operational clearances within the engine assembly.

FOS:

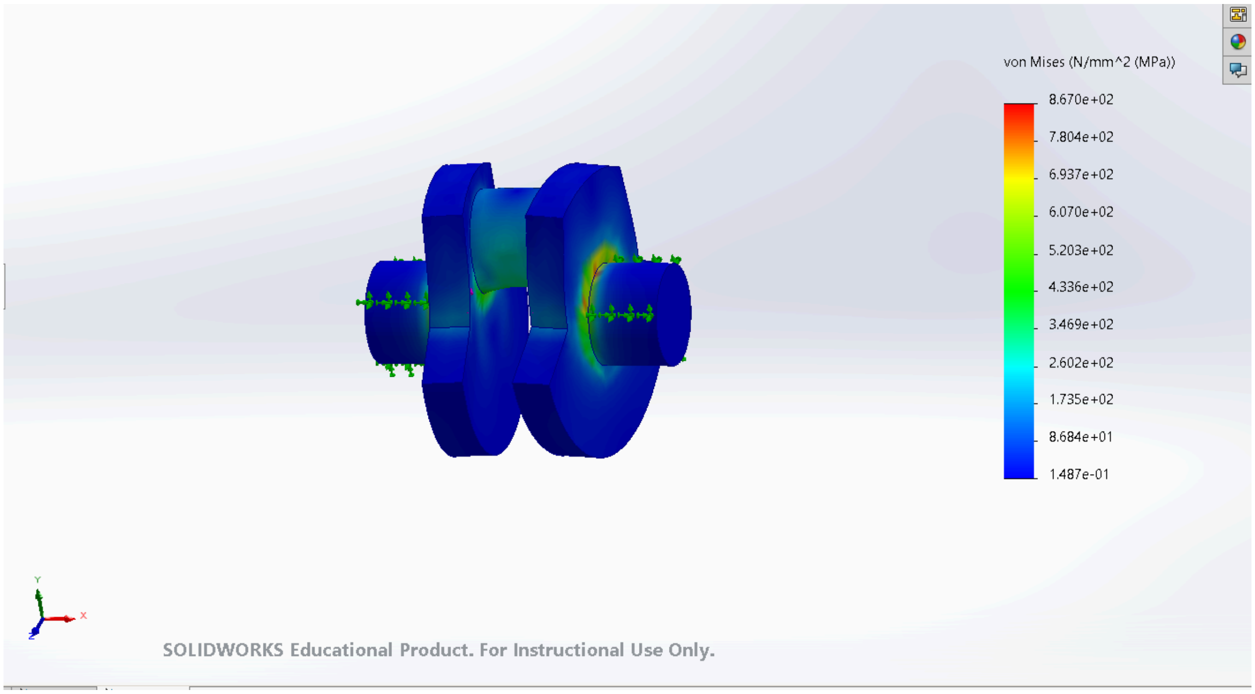


Factor of safety distribution: Min FOS = 8.2

Strain follows the same pattern as stress, with peak values in the fillet regions. The overall strain levels are small, indicating that the crankshaft undergoes only minor elastic deformation. This suggests the component maintains good rigidity and is not at risk of excessive bending under the applied vertical force.

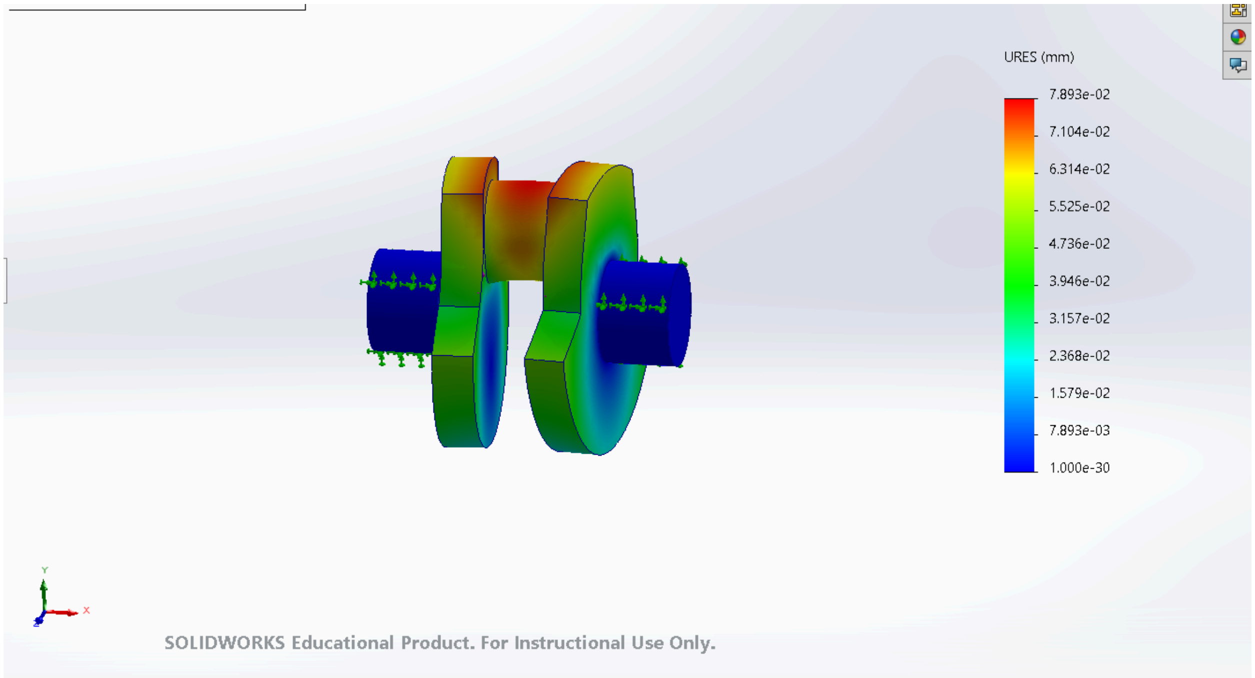
Crankshaft (Horizontal)

Stress



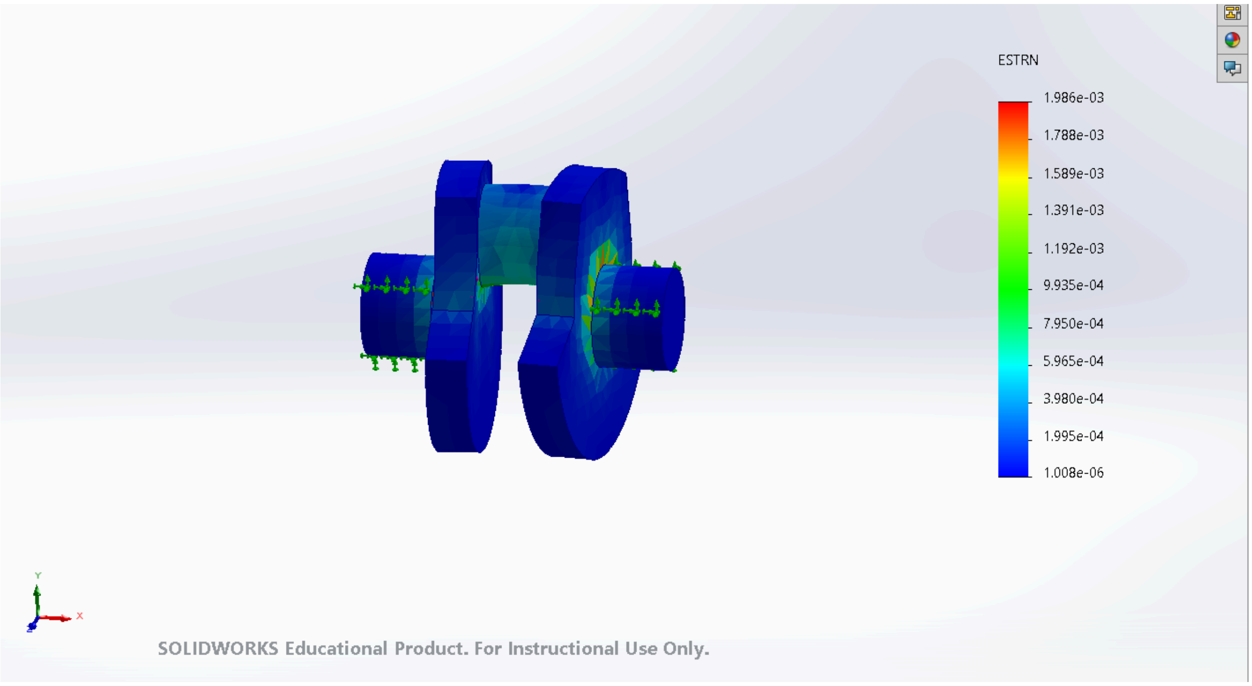
The von Mises stress peaks at the fillet/transition regions between the crank web and the journal (as expected for geometric discontinuities). The color legend shows a very high local maximum (≈8.2×10^2 MPa), so horizontal loading produces far higher stresses than the vertical case and they are concentrated where bending and torsion combine. These local peaks are the most likely initiation sites for yield or fatigue cracks.

Displacement



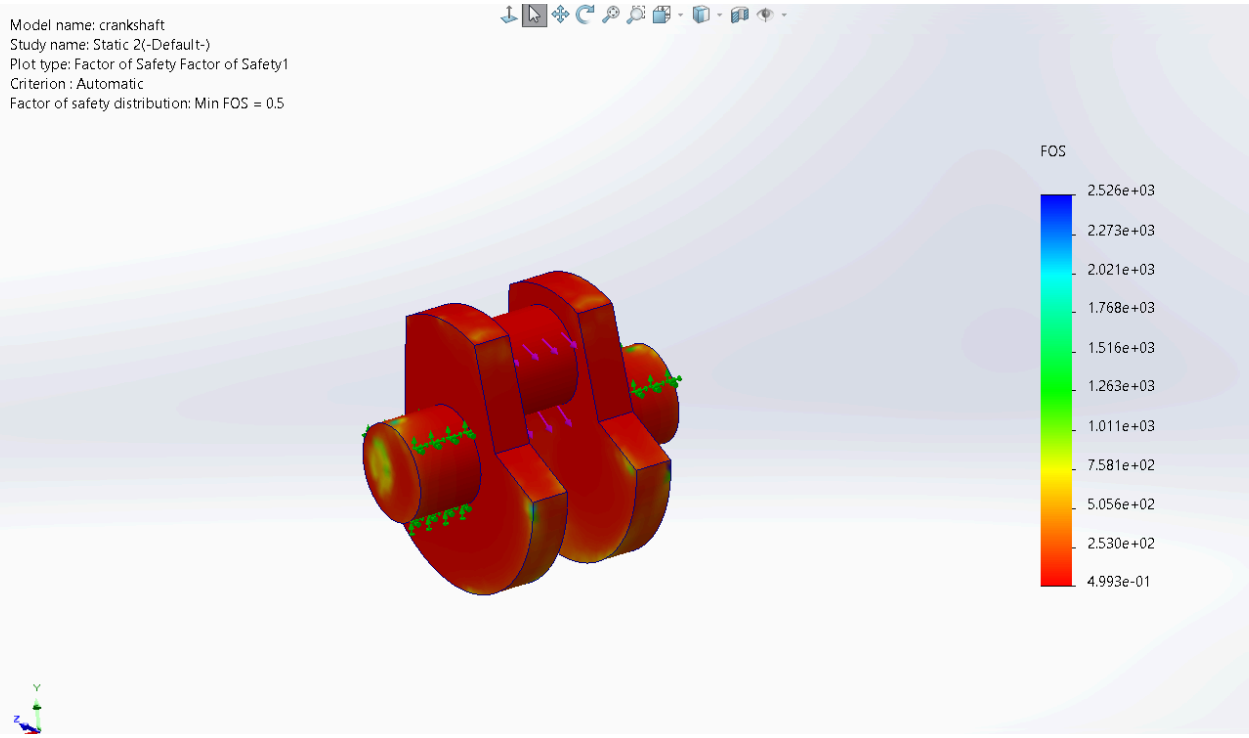
Maximum displacement occurs near the crankpin/journal where the bending moment is largest, with the rest of the shaft showing much smaller deflection. The deformation pattern matches the stress field (largest bending where the crank arm projects), implying the observed displacements are dominated by bending rather than global rigid-body motion.

Strain



train contours mirror the high-stress regions at the fillets and journal transitions. Localized tensile/compressive strains are highest where the crank arm bends, indicating significant elastic (and potentially plastic if yield is exceeded) distortion there. These localized strains are important for fatigue life estimates because repeated cyclic strain in those zones accelerates crack initiation.

FOS

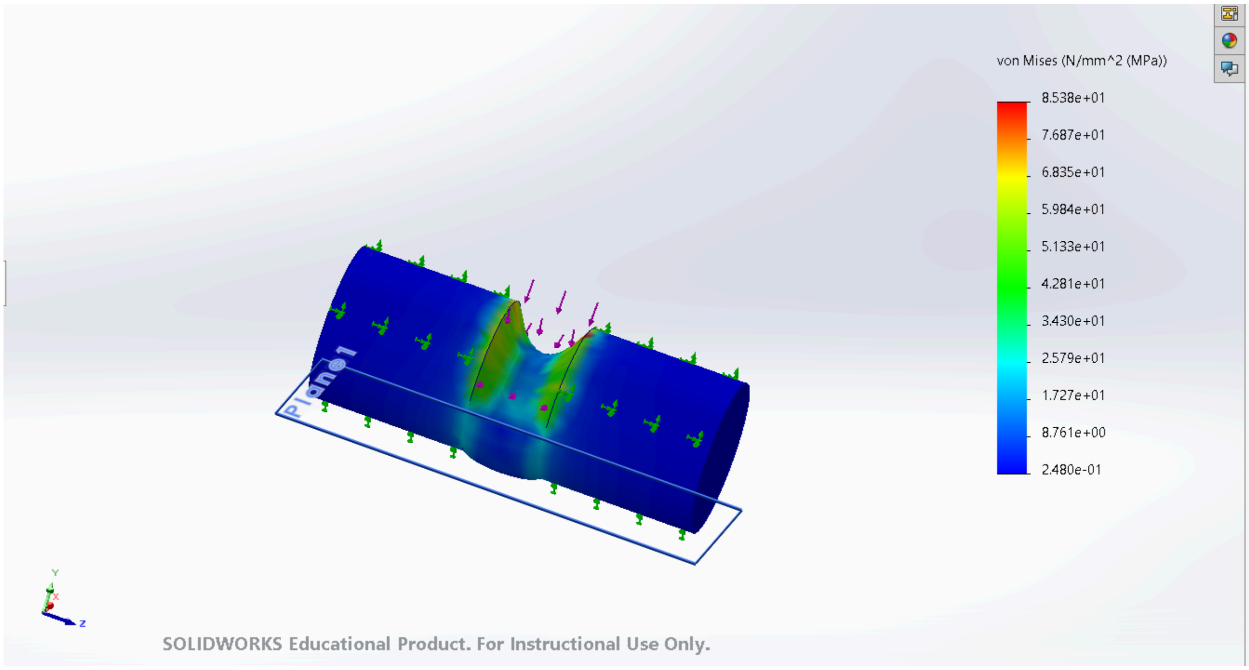


Model name: crankshaft
Study name: Static 2(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 0.5

Because the horizontal loading creates a very high peak stress, the FOS is much lower than in the vertical case. This means the crankshaft is closer to its material limit, and the design is less safe under this type of load. A low FOS suggests that the crankshaft would need either stronger material or reduced loading to operate safely.

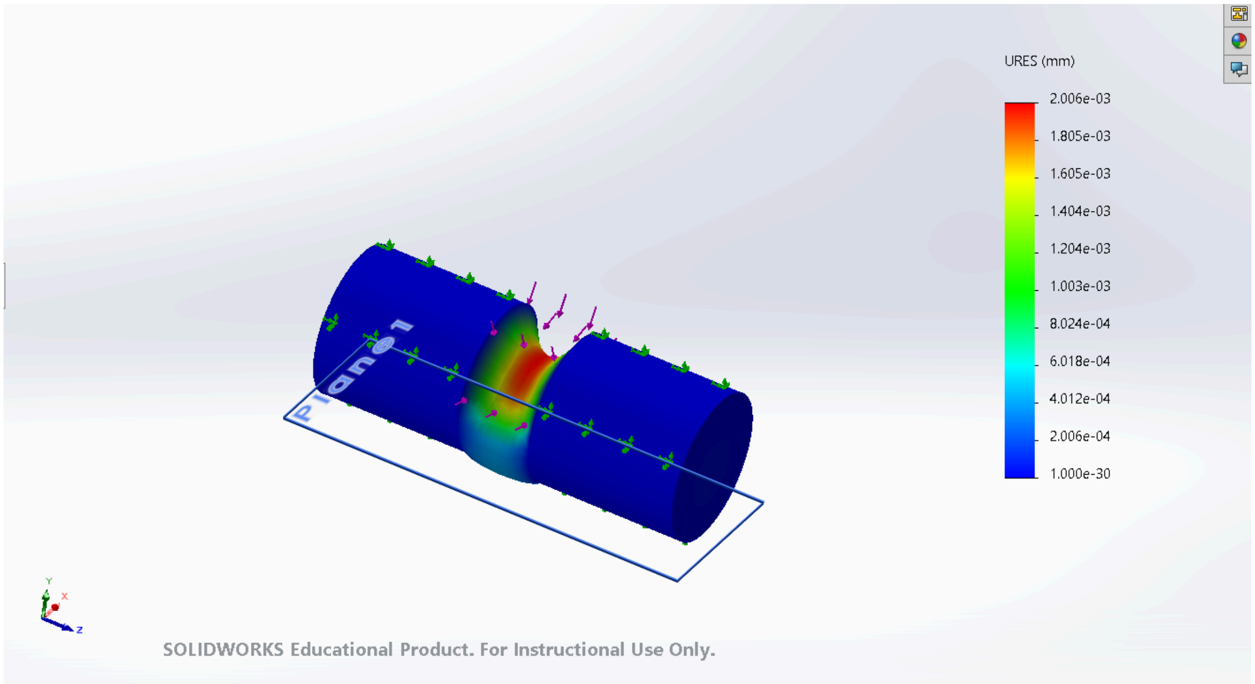
Piston Pin

Stress



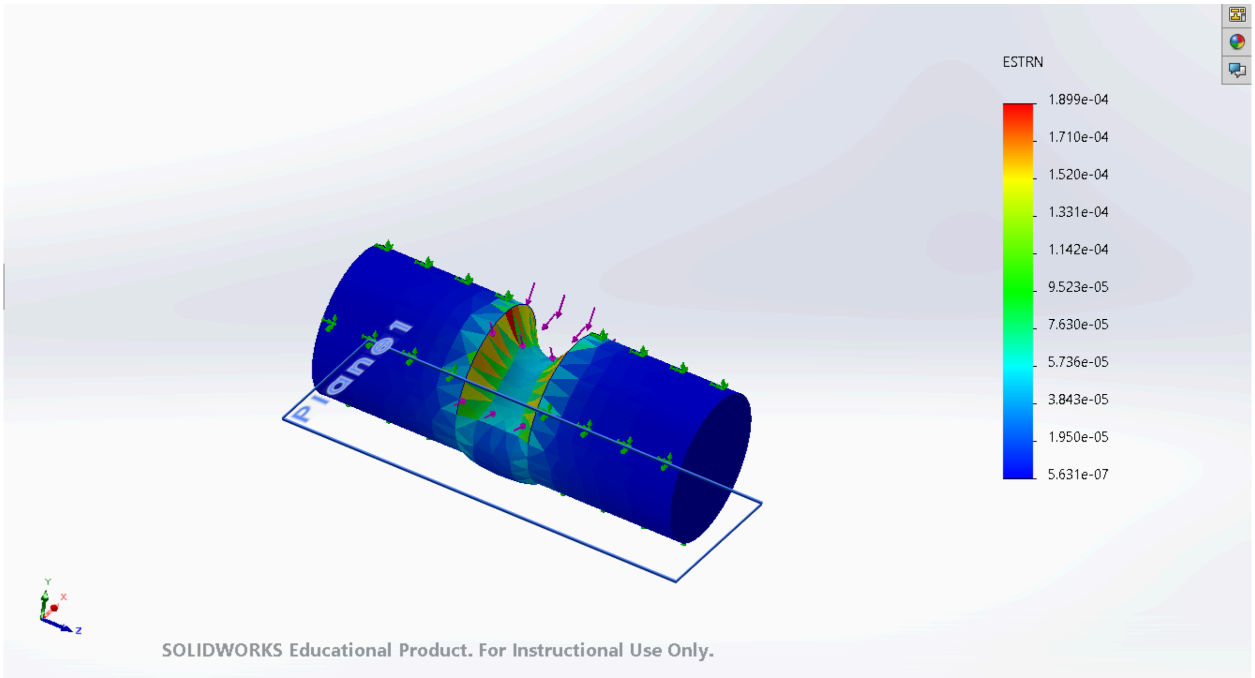
The highest stresses appear around the central contact area where the load is applied. This region shows noticeable concentration due to bending, while the rest of the pin remains in lower stress zones. Overall stress levels are moderate for this loading condition.

Displacement



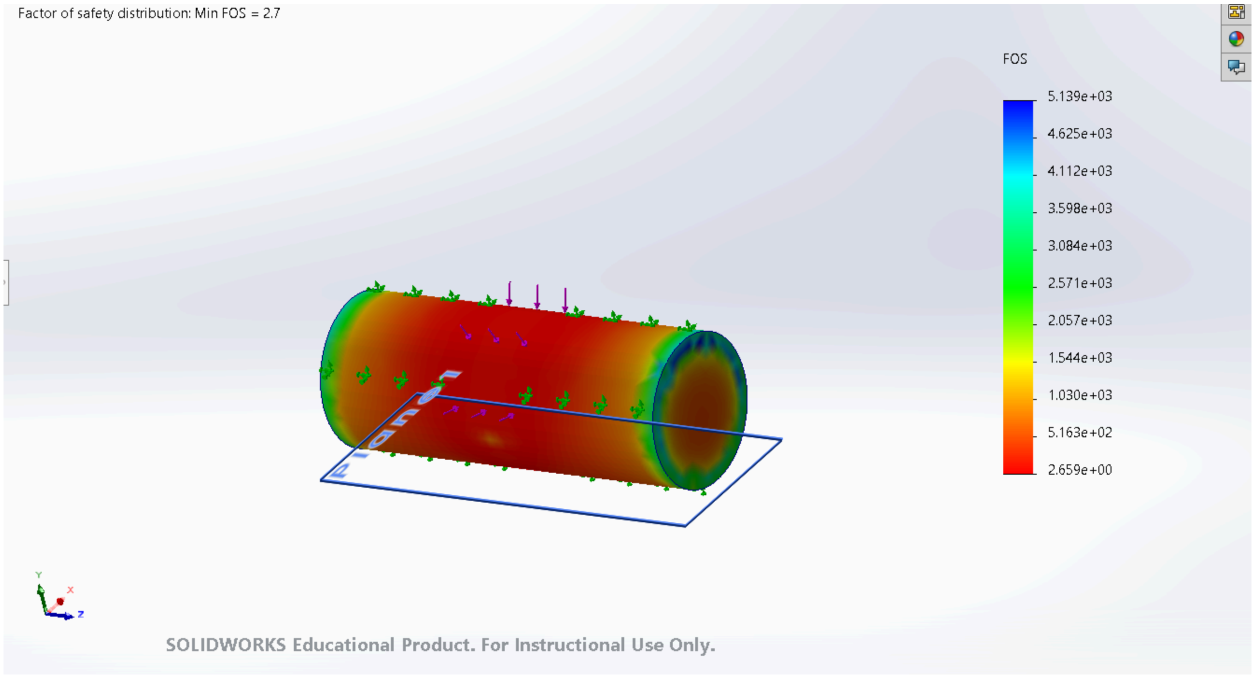
Maximum displacement occurs at the middle of the pin, where the bending load is greatest. The ends show very little movement, indicating the supports are holding the pin rigidly while the center flexes slightly under load.

Strain



Strain follows the same pattern as stress, with the highest strain at the center where bending is strongest. The rest of the pin experiences minimal strain, showing that deformation is mostly localized.

FOS

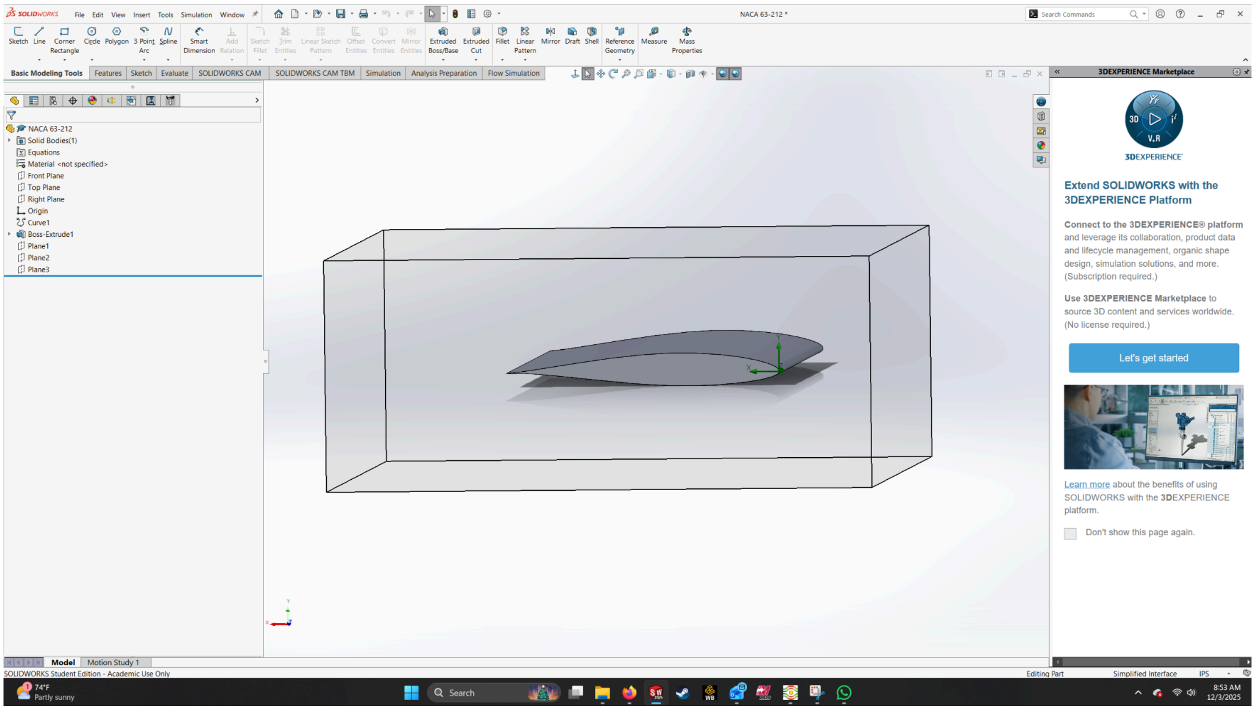


Factor of safety distribution: Min FOS = 2.7

Since the peak stress is well below typical yield strengths for piston-pin materials, the FOS is relatively high. This means the pin can safely handle the applied load with a comfortable safety margin.

Setup of External Fluid Flow of an airfoil to get both drag and lift forces

NACA 63-212 standard airfoil was used, along with an angle of attack of 0° (takeoff angle):



Extend SOLIDWORKS with the 3DEXPERIENCE Platform

Connect to the 3DEXPERIENCE® platform and leverage its collaboration, product data and lifecycle management, organic shape design, simulation solutions, and more. (Subscription required.)

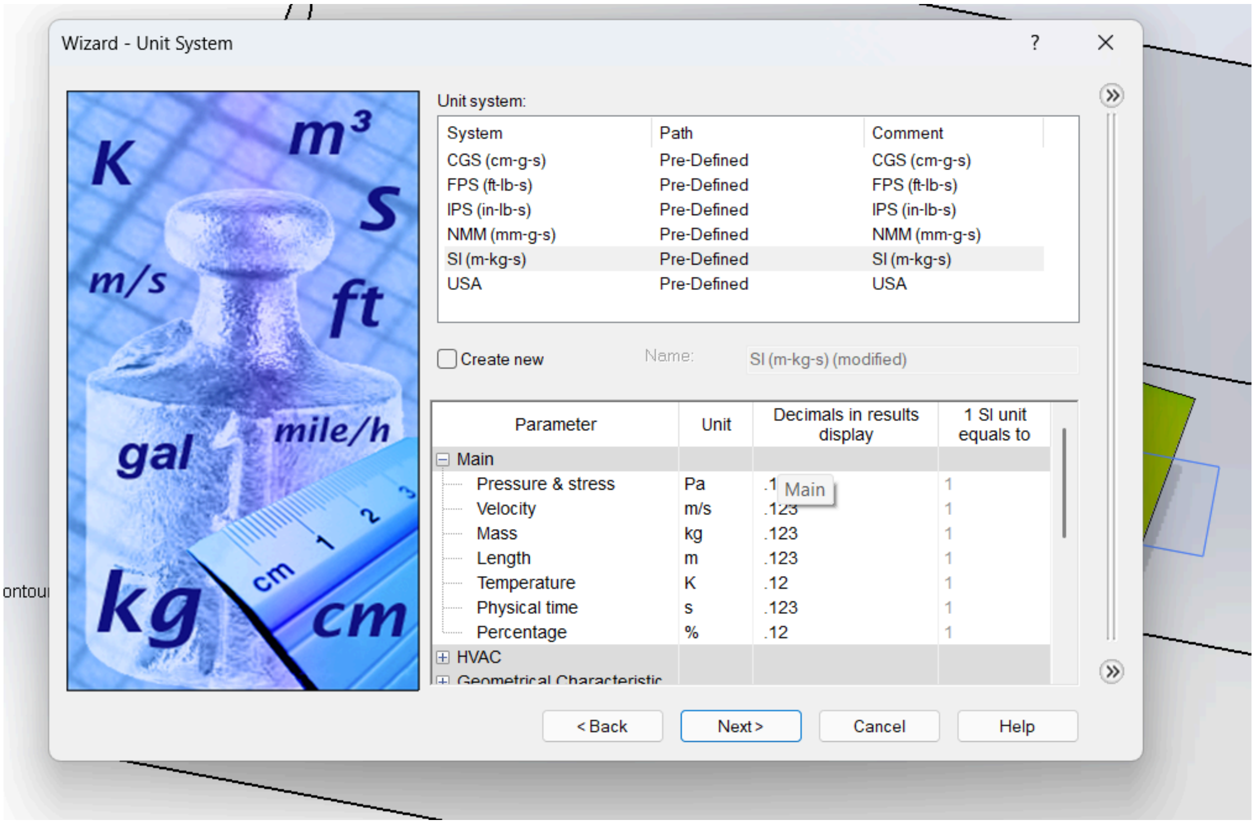
Use 3DEXPERIENCE Marketplace to source 3D content and services worldwide. (No license required.)

Learn more about the benefits of using SOLIDWORKS with the 3DEXPERIENCE platform.

☐ Don't show this page again.

The geometry for the airfoil was downloaded on a numerical basis and then imported into solidworks as an XYZ curve.

Setting up the Flow simulation, its first import to use the flow wizard to set initial conditions and defining parameters, SI units were used:



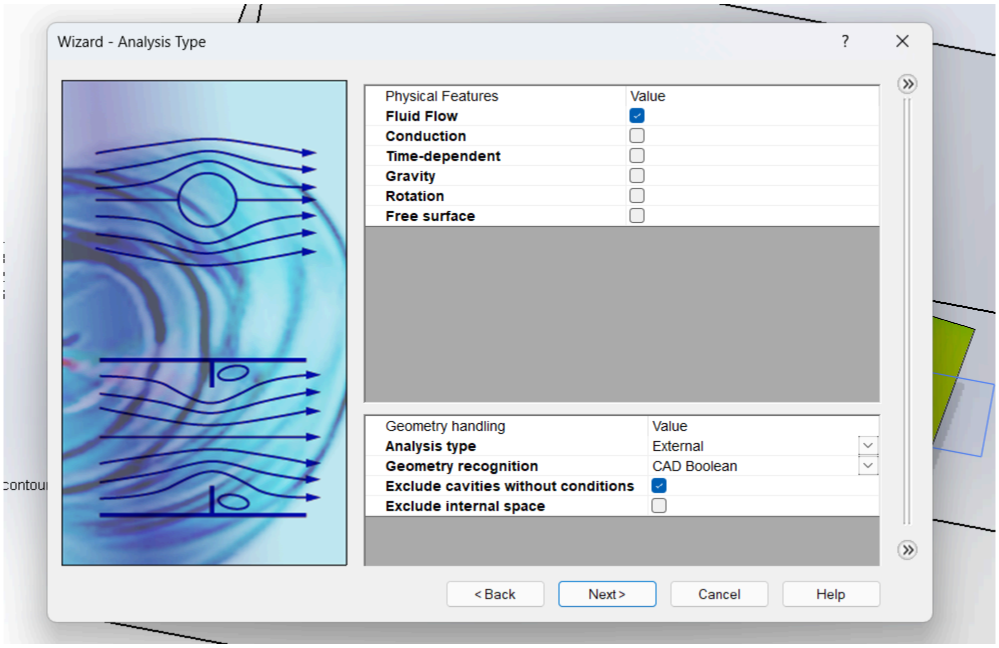
Unit system:

System	Path	Comment
CGS (cm-g-s)	Pre-Defined	CGS (cm-g-s)
FPS (ft-lb-s)	Pre-Defined	FPS (ft-lb-s)
IPS (in-lb-s)	Pre-Defined	IPS (in-lb-s)
NMM (mm-g-s)	Pre-Defined	NMM (mm-g-s)
SI (m-kg-s)	Pre-Defined	SI (m-kg-s)
USA	Pre-Defined	USA

☐ Create new   Name: SI (m-kg-s) (modified)

Parameter	Unit	Decimals in results display	1 SI unit equals to
⊟ Main			
Pressure & stress	Pa	.1 Main	1
Velocity	m/s	.123	1
Mass	kg	.123	1
Length	m	.123	1
Temperature	K	.12	1
Physical time	s	.123	1
Percentage	%	.12	1
⊞ HVAC			
⊞ Geometrical Characteristic			

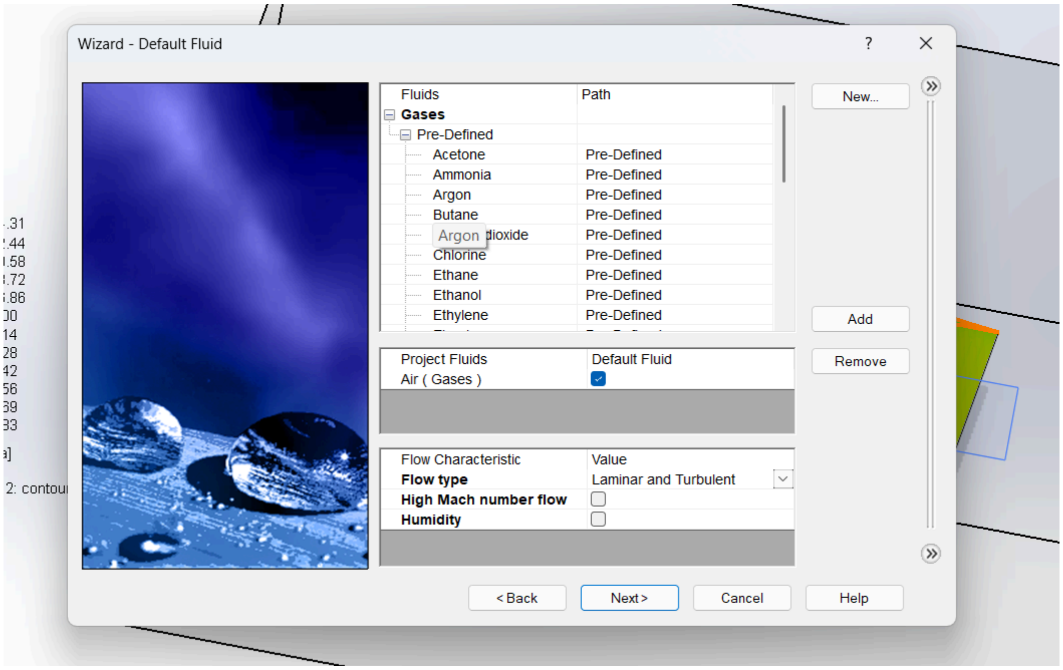
Then, it had to be clarified that it was an external flow simulation, as opposed to internal:



Physical Features	Value
Fluid Flow	☑
Conduction	☐
Time-dependent	☐
Gravity	☐
Rotation	☐
Free surface	☐

Geometry handling	Value
Analysis type	External
Geometry recognition	CAD Boolean
Exclude cavities without conditions	☑
Exclude internal space	☐

Then, the gas to be used was to be set, which was obviously air:

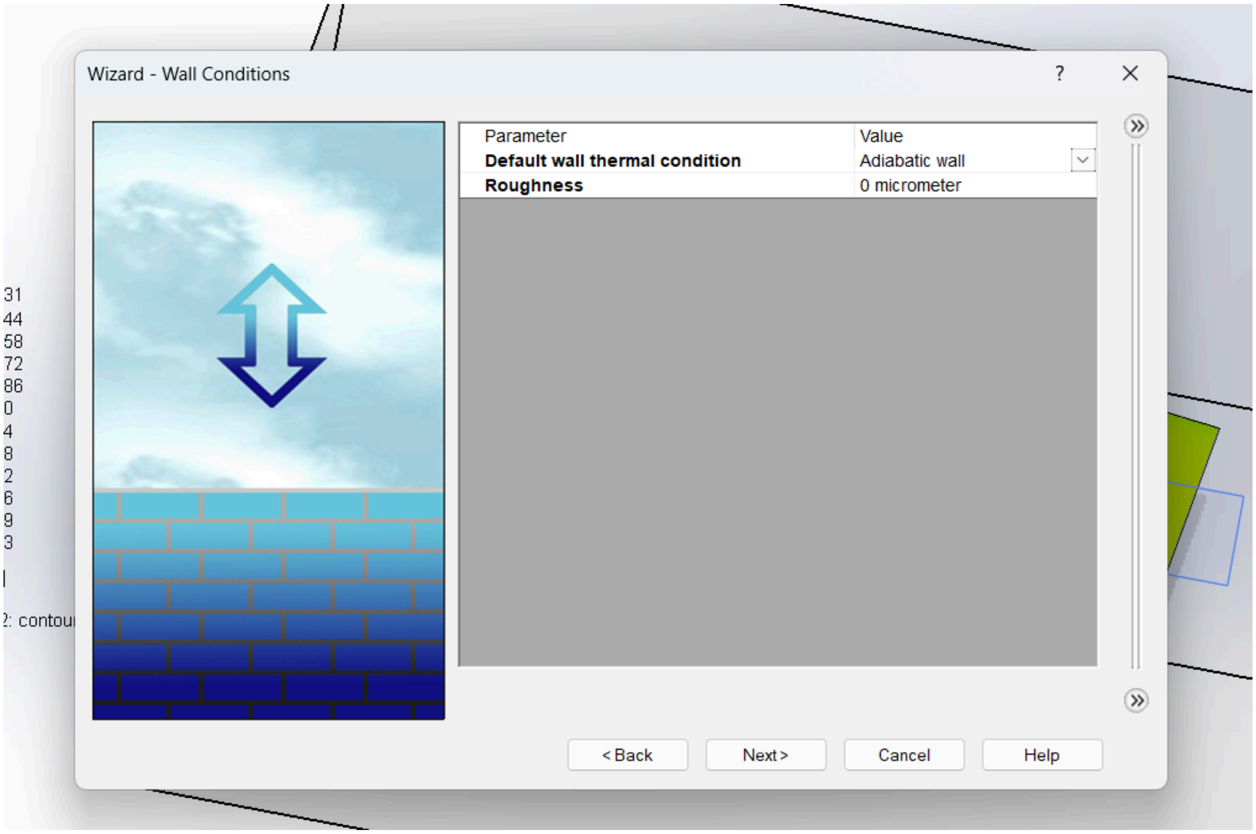


Fluids	Path
Gases	
Pre-Defined	
Acetone	Pre-Defined
Ammonia	Pre-Defined
Argon	Pre-Defined
Butane	Pre-Defined
dioxide	Pre-Defined
Chlorine	Pre-Defined
Ethane	Pre-Defined
Ethanol	Pre-Defined
Ethylene	Pre-Defined

Project Fluids	Default Fluid
Air (Gases)	☑

Flow Characteristic	Value
Flow type	Laminar and Turbulent
High Mach number flow	☐
Humidity	☐

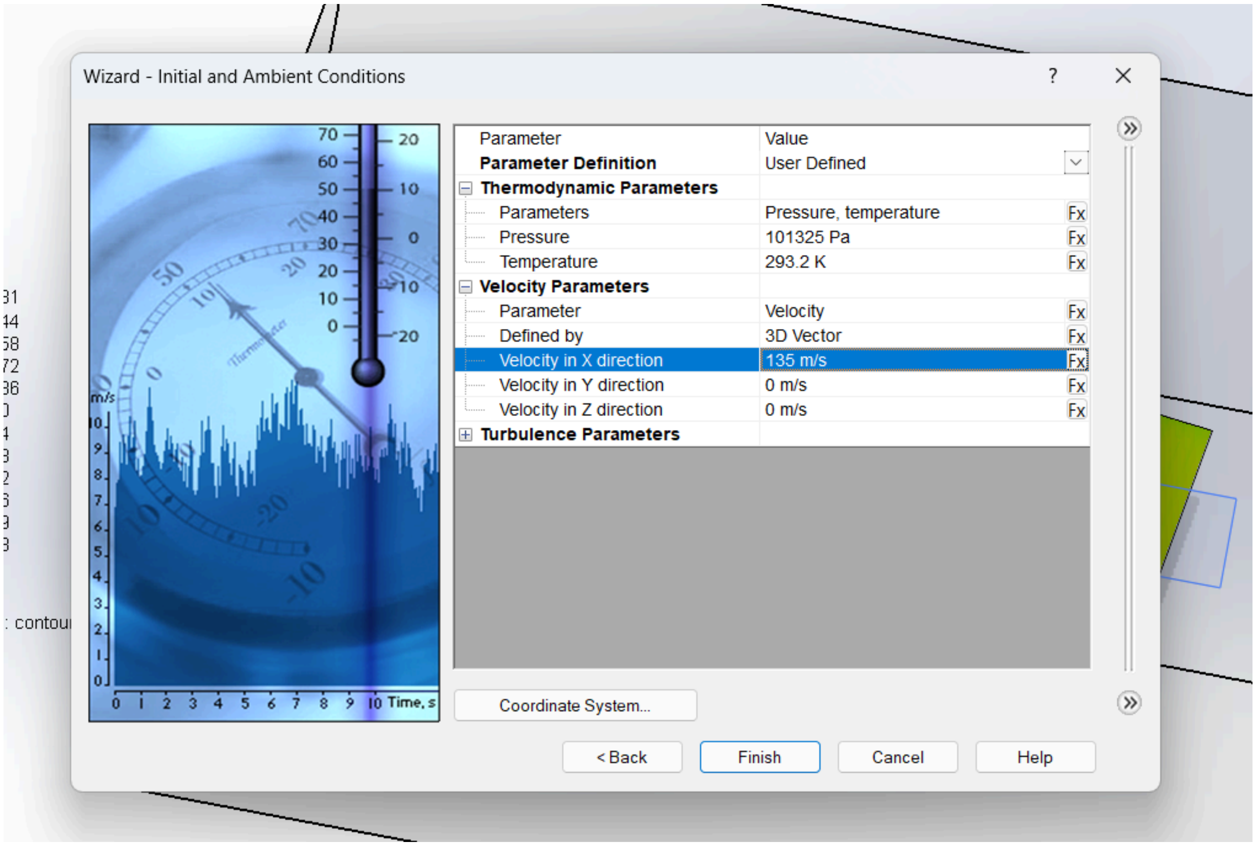
For the sake of simplicity, adiabatic walls were chosen (the airfoil walls):



Wizard - Wall Conditions

Parameter	Value
Default wall thermal condition	Adiabatic wall
Roughness	0 micrometer

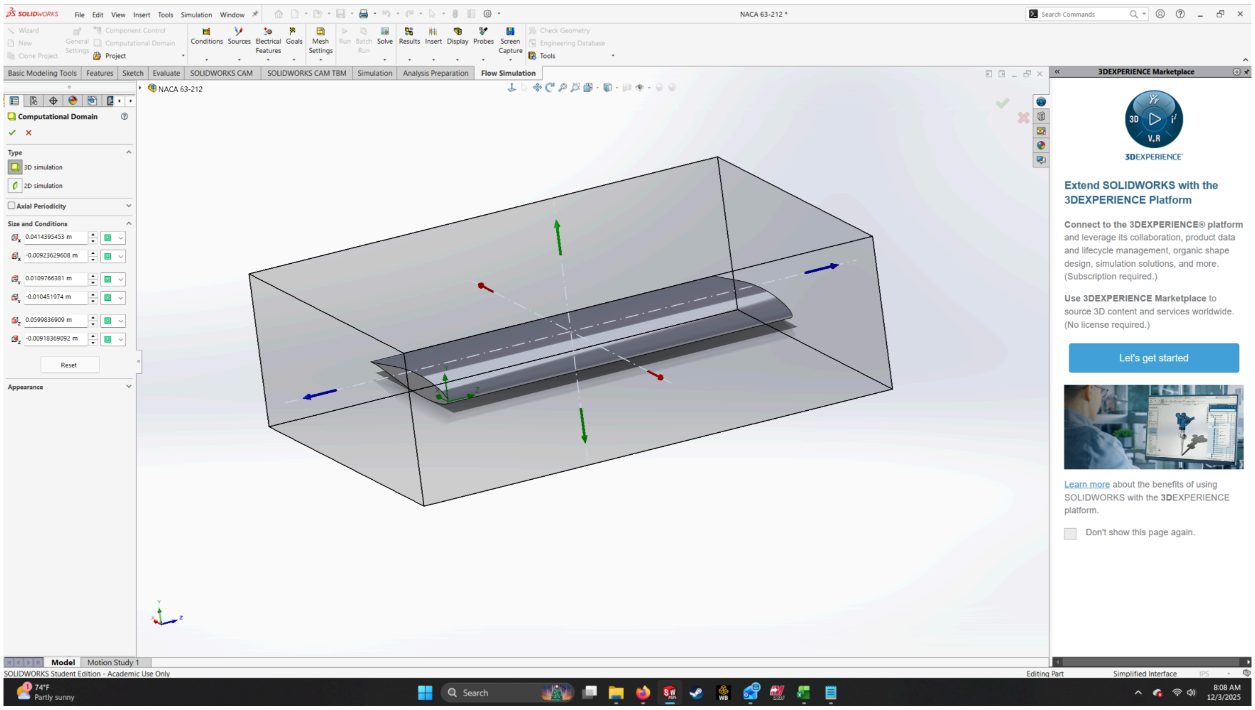
Then, initial conditions have to be set:



Wizard - Initial and Ambient Conditions

Parameter	Value
Parameter Definition	User Defined
Thermodynamic Parameters	
Parameters	Pressure, temperature
Pressure	101325 Pa
Temperature	293.2 K
Velocity Parameters	
Parameter	Velocity
Defined by	3D Vector
Velocity in X direction	135 m/s
Velocity in Y direction	0 m/s
Velocity in Z direction	0 m/s
Turbulence Parameters	

After that, we set up the domain/enclosure (necessary for an external flow case) as such:



Computational Domain

Type: 3D simulation

☐ Axial Periodicity

Size and Conditions

X max	0.0414395453 m
X min	-0.00923629608 m
Y max	0.0109766381 m
Y min	-0.010451974 m
Z max	0.0599836909 m
Z min	-0.00918369092 m

Extend SOLIDWORKS with the 3DEXPERIENCE Platform

Connect to the 3DEXPERIENCE® platform and leverage its collaboration, product data and lifecycle management, organic shape design, simulation solutions, and more. (Subscription required.)

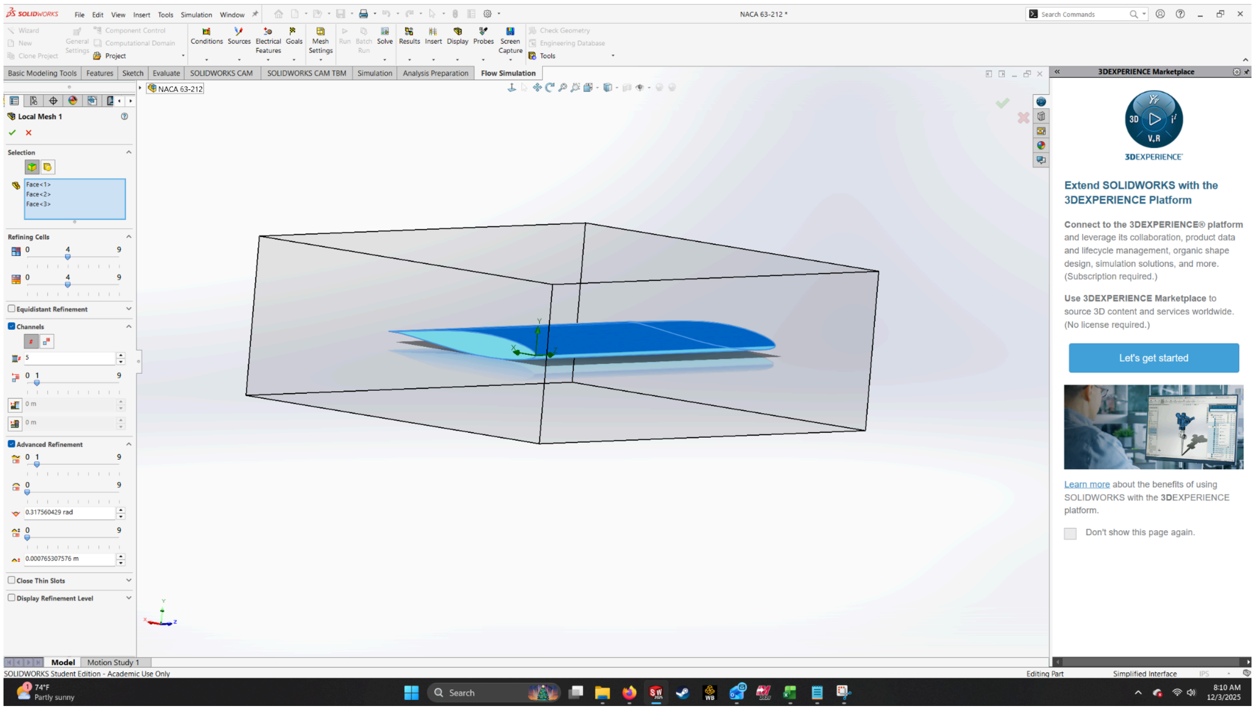
Use 3DEXPERIENCE Marketplace to source 3D content and services worldwide. (No license required.)

Let's get started

Learn more about the benefits of using SOLIDWORKS with the 3DEXPERIENCE platform.

☐ Don't show this page again.

Followed by setting up a local mesh refinement around the airfoil body to get accurate results:



Local Mesh 1

Selection
Face<1>
Face<2>
Face<3>

Refining Cells
0 4 9
0 4 9

☐ Equidistant Refinement

☑ Channels
5
0 1 9
0 m
0 m

☑ Advanced Refinement
0 1 9
0 9
0.317560429 rad
0 9
0.000765307576 m

☐ Close Thin Slots

☐ Display Refinement Level

Extend SOLIDWORKS with the 3DEXPERIENCE Platform

Connect to the 3DEXPERIENCE® platform and leverage its collaboration, product data and lifecycle management, organic shape design, simulation solutions, and more. (Subscription required.)

Use 3DEXPERIENCE Marketplace to source 3D content and services worldwide. (No license required.)

Let's get started

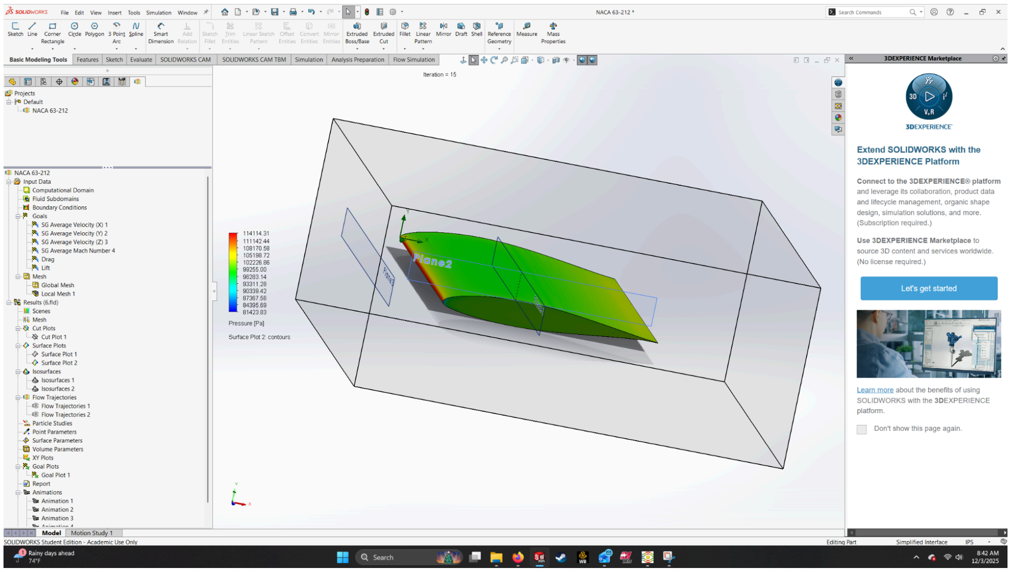
Learn more about the benefits of using SOLIDWORKS with the 3DEXPERIENCE platform.

☐ Don't show this page again.

And the global mesh was left in its default settings. After that, we can run the simulation and extract the results.

RESULTS

Pressure Surface Plot



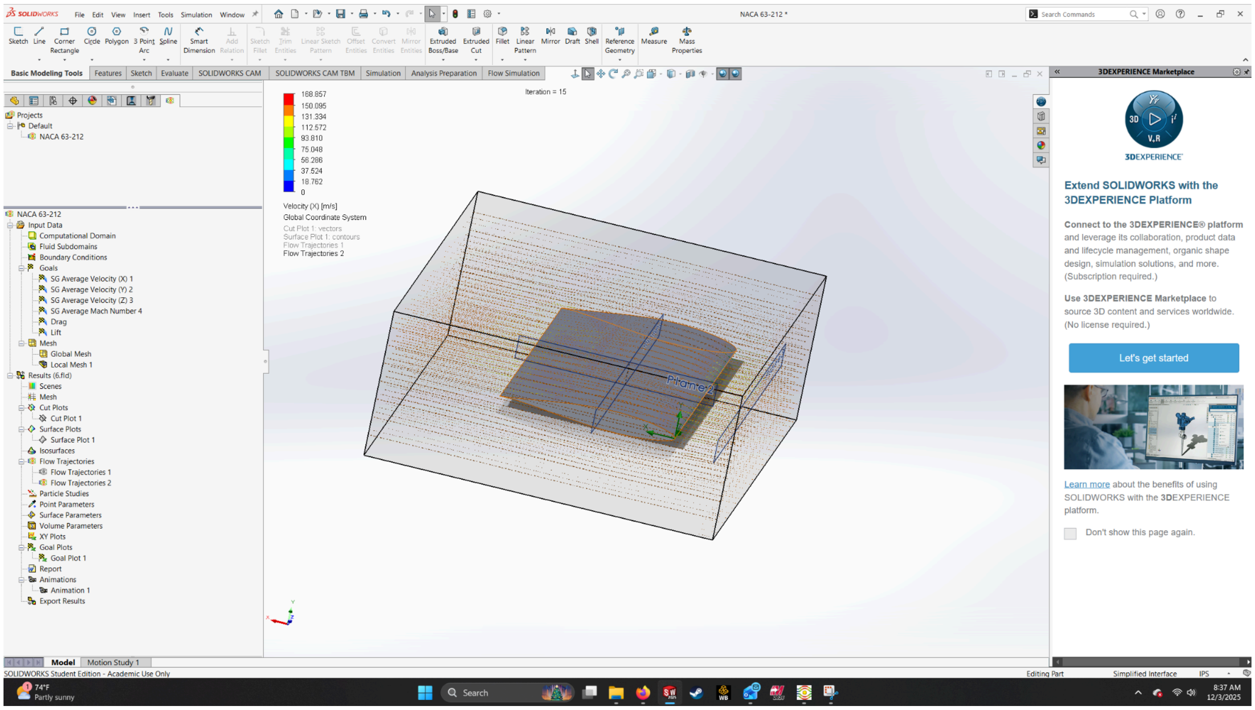
Extend SOLIDWORKS with the 3DEXPERIENCE Platform

Connect to the 3DEXPERIENCE® platform and leverage its collaboration, product data and lifecycle management, organic shape design, simulation solutions, and more. (Subscription required.)

Use 3DEXPERIENCE Marketplace to source 3D content and services worldwide. (No license required.)

Learn more about the benefits of using SOLIDWORKS with the 3DEXPERIENCE platform.

Velocity Magnitude Upstream Trajectory



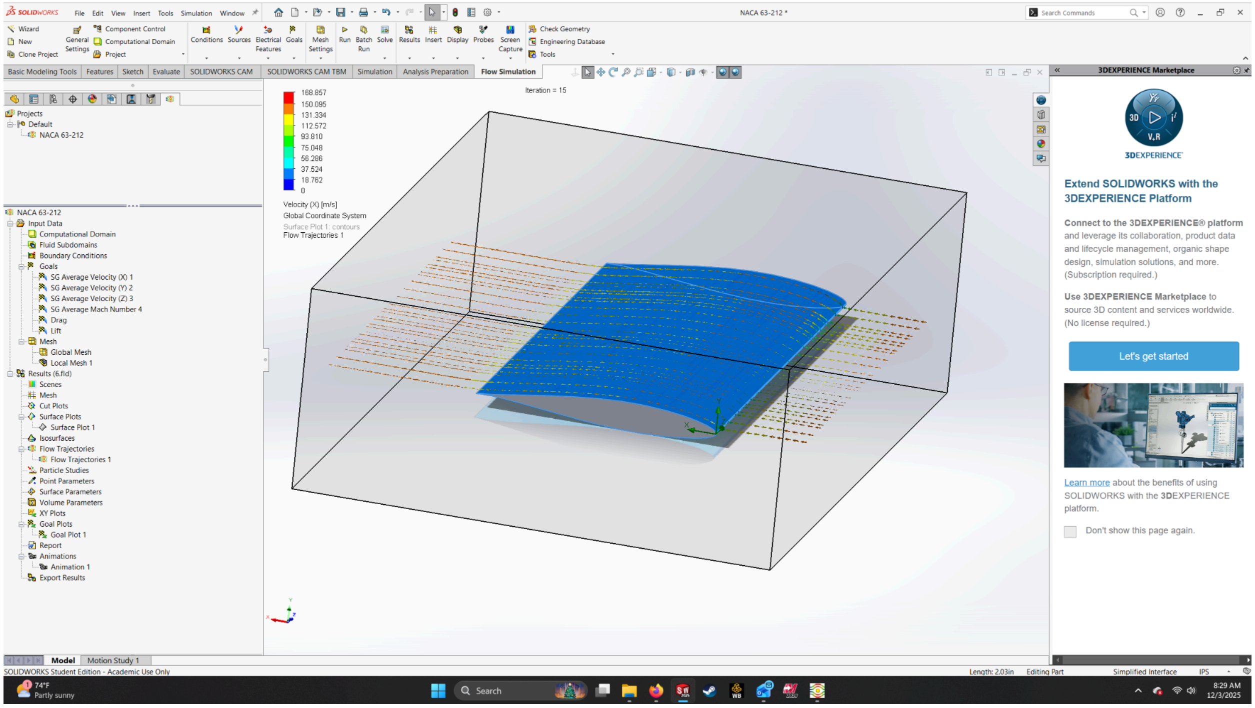
Extend SOLIDWORKS with the 3DEXPERIENCE Platform

Connect to the 3DEXPERIENCE® platform and leverage its collaboration, product data and lifecycle management, organic shape design, simulation solutions, and more. (Subscription required.)

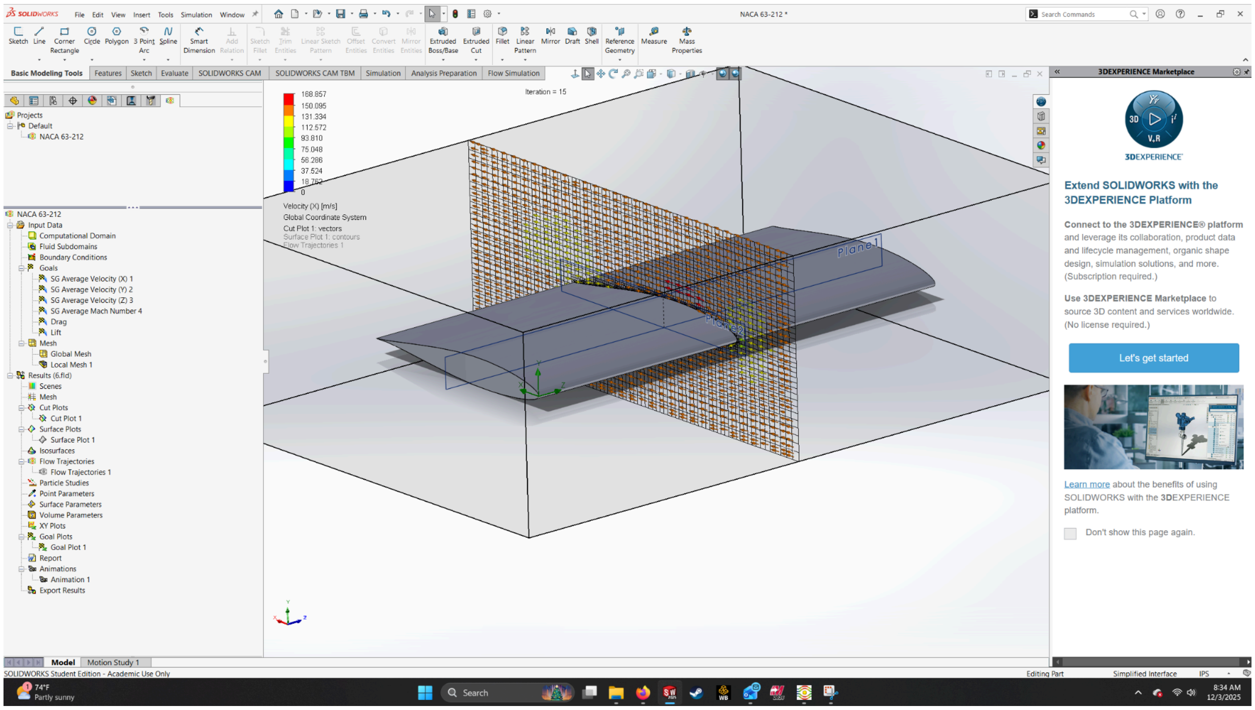
Use 3DEXPERIENCE Marketplace to source 3D content and services worldwide. (No license required.)

Learn more about the benefits of using SOLIDWORKS with the 3DEXPERIENCE platform.

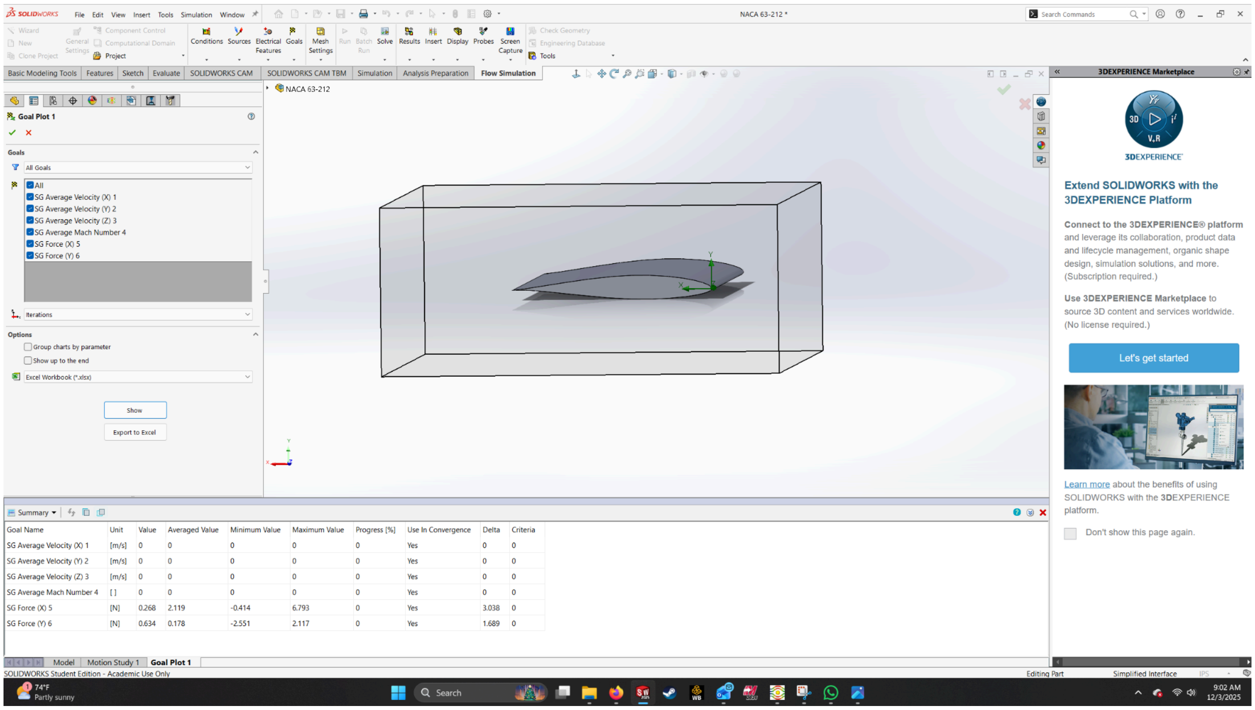
X Velocity Flow Trajectory



Cut plot (velocity)



Goals plot



Goal Plot 1

Goals

All Goals

☑ All
☑ SG Average Velocity (X) 1
☑ SG Average Velocity (Y) 2
☑ SG Average Velocity (Z) 3
☑ SG Average Mach Number 4
☑ SG Force (X) 5
☑ SG Force (Y) 6

Iterations

Options

☐ Group charts by parameter
☐ Show up to the end

Excel Workbook (*.xlsx)

Show

Export to Excel

Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
SG Average Velocity (X) 1	[m/s]	0	0	0	0	0	Yes	0	0
SG Average Velocity (Y) 2	[m/s]	0	0	0	0	0	Yes	0	0
SG Average Velocity (Z) 3	[m/s]	0	0	0	0	0	Yes	0	0
SG Average Mach Number 4	[ ]	0	0	0	0	0	Yes	0	0
SG Force (X) 5	[N]	0.268	2.119	-0.414	6.793	0	Yes	3.038	0
SG Force (Y) 6	[N]	0.634	0.178	-2.551	2.117	0	Yes	1.689	0

Extend SOLIDWORKS with the 3DEXPERIENCE Platform

Connect to the 3DEXPERIENCE® platform and leverage its collaboration, product data and lifecycle management, organic shape design, simulation solutions, and more. (Subscription required.)

Use 3DEXPERIENCE Marketplace to source 3D content and services worldwide. (No license required.)

Learn more about the benefits of using SOLIDWORKS with the 3DEXPERIENCE platform.

☐ Don't show this page again.

SOLIDWORKS Student Edition - Academic Use Only

Drag is just the force generated in the -X direction, and Lift is just the force generated in the Y direction. These values can be directly chosen as **surface goals.**

CONCLUSION & RECOMMENDATIONS

This final project successfully demonstrated the application of advanced simulation software (SOLIDWORKS Simulation and Flow Simulation) to analyze complex engineering problems across both structural mechanics and computational fluid dynamics (CFD). Mechanical Design Analysis: Critical Internal Combustion Engine (ICE) components (e.g., piston, connecting rod, and crankshaft) were modeled and subjected to structural analysis. This study successfully identified maximum stress concentrations, critical deformation regions, and calculated the Factor of Safety under peak operating loads, providing essential data for validating their structural integrity. Flow Simulation: A 2D external flow simulation was executed on a NACA 63-212 airfoil at a 0-degree angle of attack. The CFD analysis, which included defining the computational domain, setting boundary conditions, and implementing local mesh refinement, successfully visualized the velocity and pressure fields and quantified the initial lift and drag forces on the profile. Overall, the project validates the team's proficiency in utilizing industry-standard simulation tools to virtually prototype, analyze, and optimize mechanical designs and aerodynamic profiles.

REFERENCES

Heywood, J. B. (1988). *Internal combustion engine fundamentals*. McGraw-Hill. https://www.iust.ac.ir/files/mech/ayatgh_c5664/files/internal_combustion_engines_heywood.pdf

CFD simulation of NACA airfoils at various angles of attack. (n.d.). *Scribd*. Retrieved from https://www.scribd.com/document/696036635/CFD-simulation-of-NACA-airfoilsat-various-angles-of-attack

Design and topological optimization of an internal combustion engine piston. (n.d.). *ResearchGate*. Retrieved from https://www.researchgate.net/publication/393308734_DESIGN_AND_TOPOLOGICAL_OPTIMIZATION_OF_AN_INTERNAL_COMBUSTION_ENGINE_PISTON

Fatigue failure analysis of crankshafts: A review. (n.d.). ***International Journal of Innovative Science, Engineering & Technology*****. Retrieved from** **https://ijiset.com/vol7/v7s5/IJISET_V7_I5_09.pdf**

McGraw-Hill Education. (n.d.). ***Internal combustion engine fundamentals*****. Retrieved from** **https://www.accessengineeringlibrary.com/content/book/9781260116106**

Modeling and performance analysis of connecting rod and piston with alternate material. (n.d.). ***International Journal of Engineering Research & Technology*****. Retrieved from** **https://www.ijert.org/modeling-and-performance-analysis-of-connecting-rod-and-piston-with-alternate-material**

Stress and deformation analysis of a connecting rod by using ANSYS. (n.d.). ***Dergipark*****. Retrieved from** **https://dergipark.org.tr/en/download/article-file/945529**