PROSTHETIC SWIMMIMG LEG

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DATE: - 12/16/2024

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Executive Summary:

This project introduces a **prosthetic swimming leg** designed for individuals with lower-limb amputations. The prosthetic enhances swimming performance by ensuring optimal **strength**, **flexibility**, and **hydrodynamic efficiency**. The system consists of two key components:

1. **Prosthetic Leg**: Manufactured from **Carbon-Reinforced Polymer Structure (CRPS)** for structural strength and reduced weight.
2. **Flexible Fin**: Built from **Thermoplastic Polyurethane (TPU)** to provide controlled bending for improved propulsion.
3. **Prototype:** Built from **Polylactic Acid (PLA)** using 3D printing.

Key Highlights:

1. **Design and Modeling:** The prosthetic swimming leg was modeled in SolidWorks, focusing on simplicity and functionality.
2. **Finite Element Analysis (FEA)**: Stress and deformation analysis was performed to evaluate performance under realistic swimming loads.
3. **3D Printing Manufacturing**: Manufacturing was completed using 3D printing with optimized CURA settings for strength and accuracy.
4. **Testing and Performance**: The fin demonstrated effective thrust generation and flexibility while maintaining structural integrity during swimming tests.
5. **Identified Improvements**: Areas for improvement include reinforcing the connection between the leg and the fin to enhance durability.

Functional requirements and concept development:

Purpose:

The purpose of the prosthetic swimming leg is to enable individuals with lower-limb amputations to swim effectively by providing stability, strength, and flexibility for generating thrust in water.

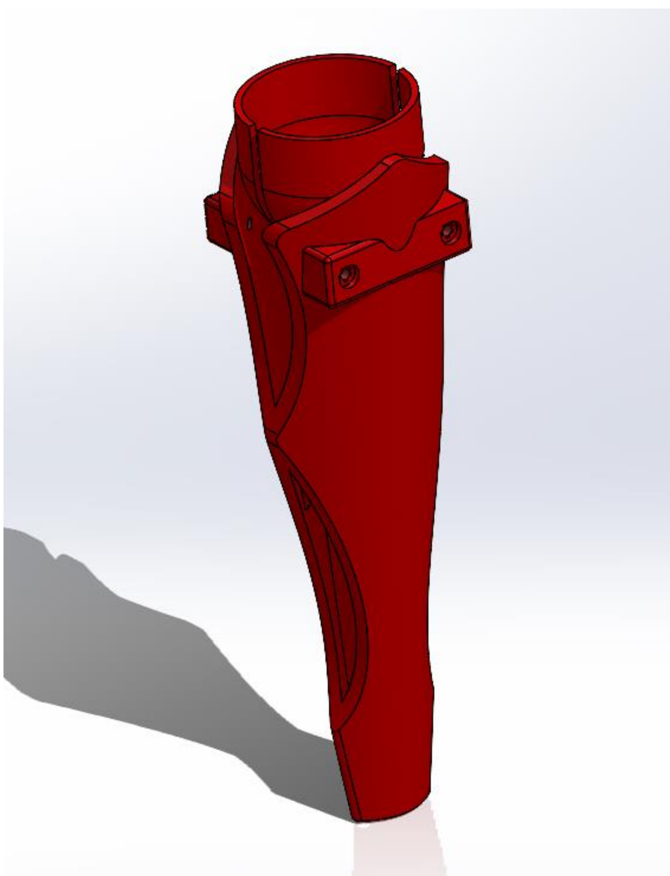
Functional Requirements:

Specifications	Details
Material	Leg: CRPS; Fin: TPU Prototype: LA
Number of Parts	2
Weight	Less than 1.5 kg
Flexibility	Controlled bending of fin for propulsion
Strength	Withstand water resistance up to 50 N

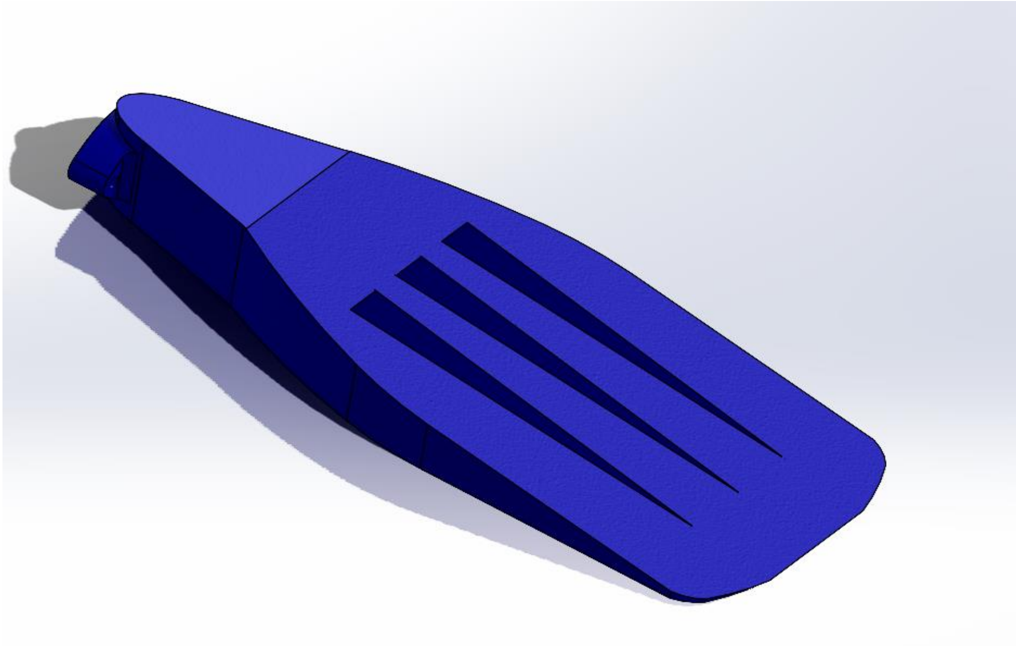
CAD Models and Assemblies:

1. **Purpose of Parts**

   Prosthetic Leg: Provides a rigid structure to support load transfer and stability during swimming.

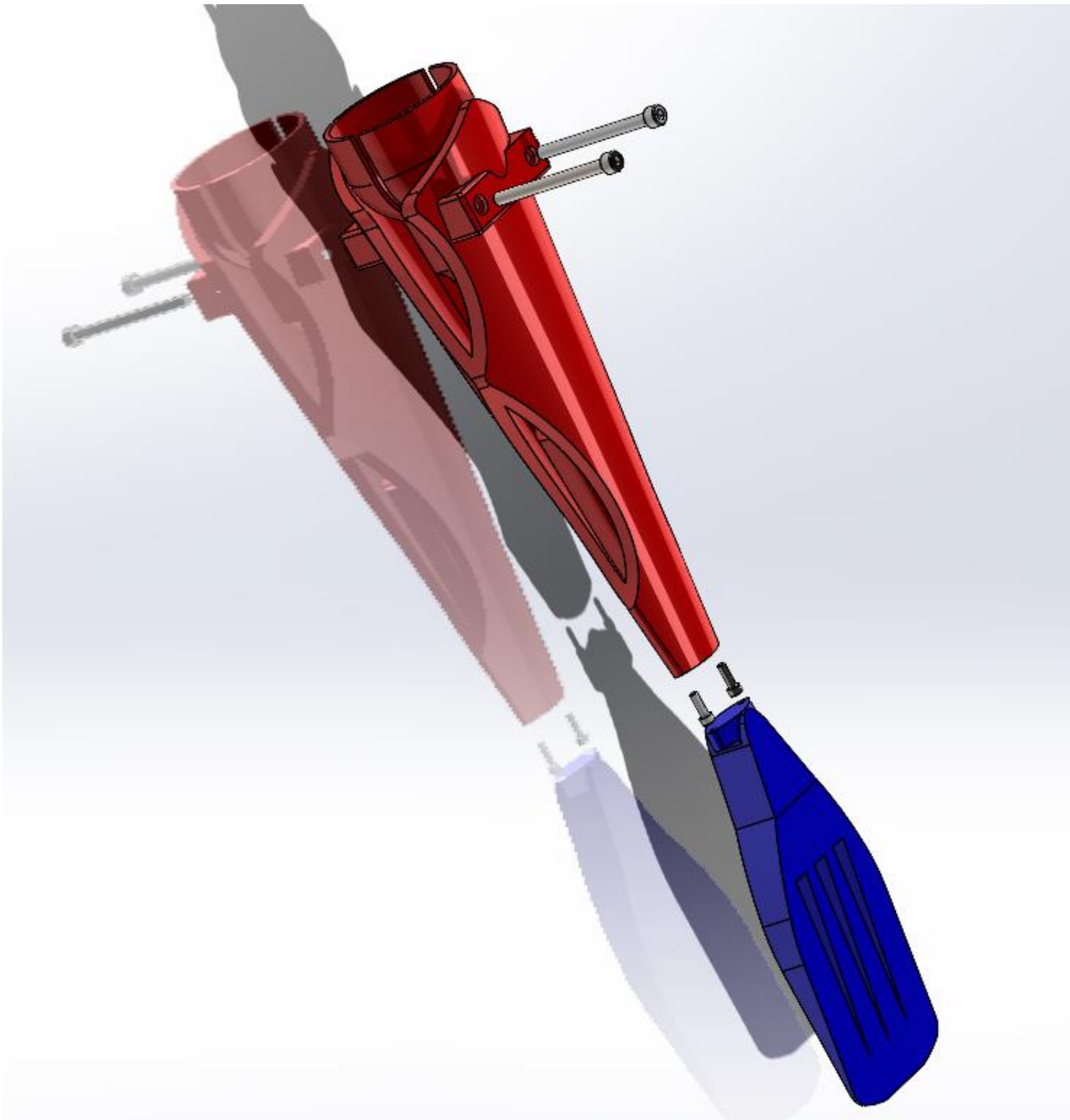


Fin: Offers flexibility to mimic the natural foot motion, enhancing thrust generation.

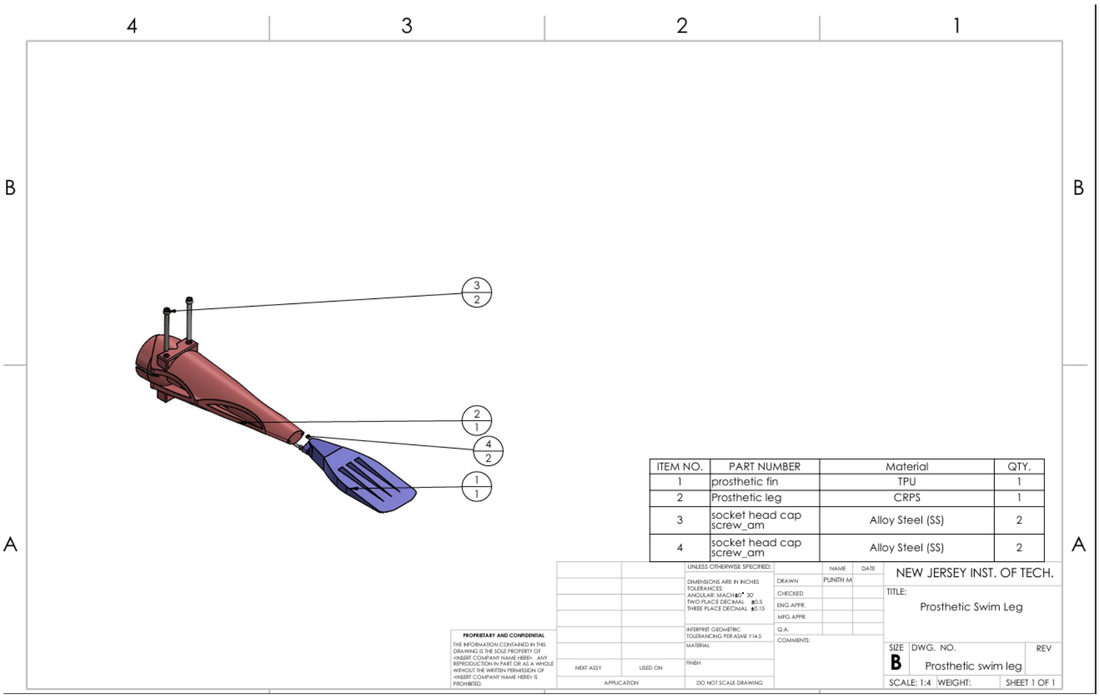


2. Rendered Image:

3. Exploded View:



4. Assembly drawing with BOM



Finite Element Analysis (FEA):

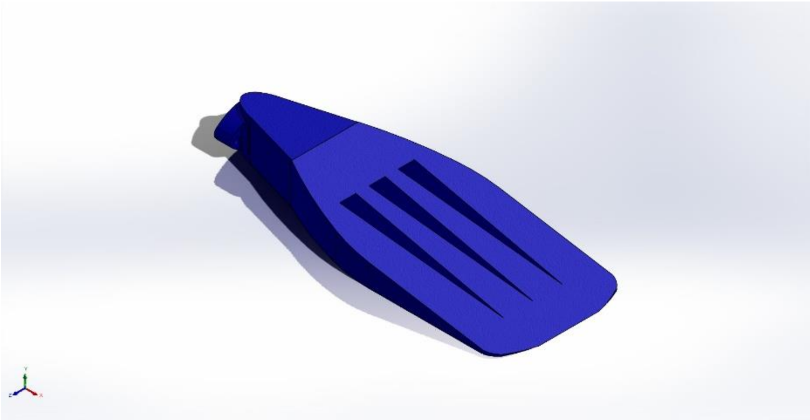
Part Analyzed: Prosthetic Fin

The prosthetic fin was analyzed under swimming forces to evaluate stress distribution and deformation.

Boundary Conditions

1. Fixed Geometry: The fin attachment point (connected to the prosthetic leg) was fixed to simulate real-world conditions.
2. Applied Load: A force of 50 N was applied uniformly on the fin’s surface to simulate water pressure during a swimming kick.

Report:



Simulation of prosthetic fin

Date: Monday, December 16, 2024
Designer: Solidworks
Study name: Static study
Analysis type: Static

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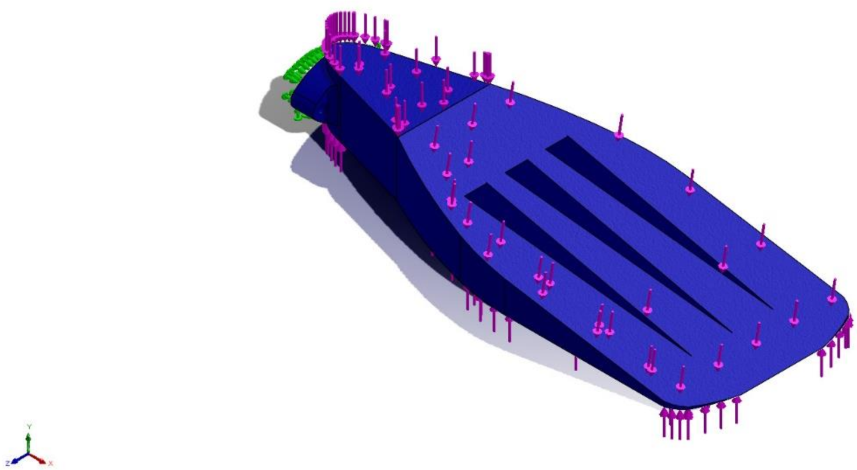
Description

No Data

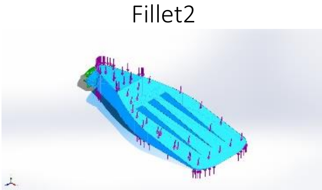
Assumptions

Model Information



Model name: prosthetic fin
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Fillet2 	Solid Body	Mass:0.320238 kg Volume:0.000313959 m^3 Density:1,020 kg/m^3 Weight:3.13834 N	C:\caed\PROJECT FINAL PUNITH\Prosthetic swim leg(step)\prosthetic fin.SLDPRT Dec 16 23:39:42 2024

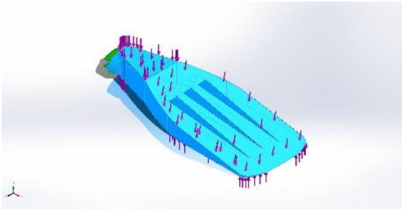
Study Properties

Study name	Static study
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:\caed\PROJECT FINAL PUNITH\Prosthetic swim leg(step))

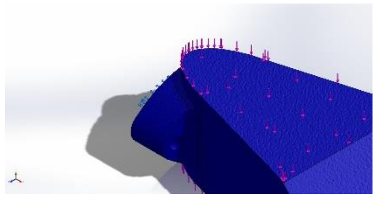
Units

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

Material Properties

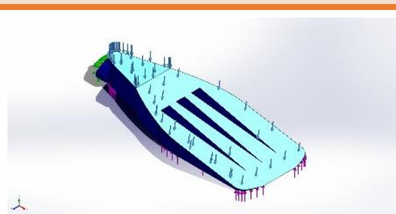
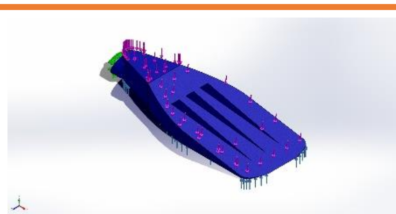
Model Reference	Properties	Components
	Name: **TPU** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Tensile strength: **30 N/mm^2** Elastic modulus: **2,000 N/mm^2** Poisson's ratio: **0.394** Mass density: **1.02 g/cm^3** Shear modulus: **318.9 N/mm^2**	**SolidBody 1(Fillet2)(prosthetic fin)**
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)	**8.22033**	**94.3197**	**4.47035e-08**	**94.6772**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-1		**Entities:** **2 face(s)** **Type:** **Apply normal force** **Value:** **50 N**
Force-2		**Entities:** **1 face(s)** **Type:** **Apply normal force** **Value:** **5 N**

Connector Definitions

No Data

Interaction Information

No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points for High quality mesh	4 Points
Element Size	0.267654 in
Tolerance	0.0133827 in
Mesh Quality	High

Mesh information - Details

Total Nodes	14523
Total Elements	8613
Maximum Aspect Ratio	19.448
% of elements with Aspect Ratio < 3	95
Percentage of elements with Aspect Ratio > 10	0.0813
Percentage of distorted elements	0.139
Time to complete mesh(hh;mm;ss):	00:00:03
Computer name:	

Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	8.22033	94.3197	4.47035e-08	94.6772

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	-6.68865e-05	-4.03253e-05	-4.20958e-06	7.82154e-05

Free body moments

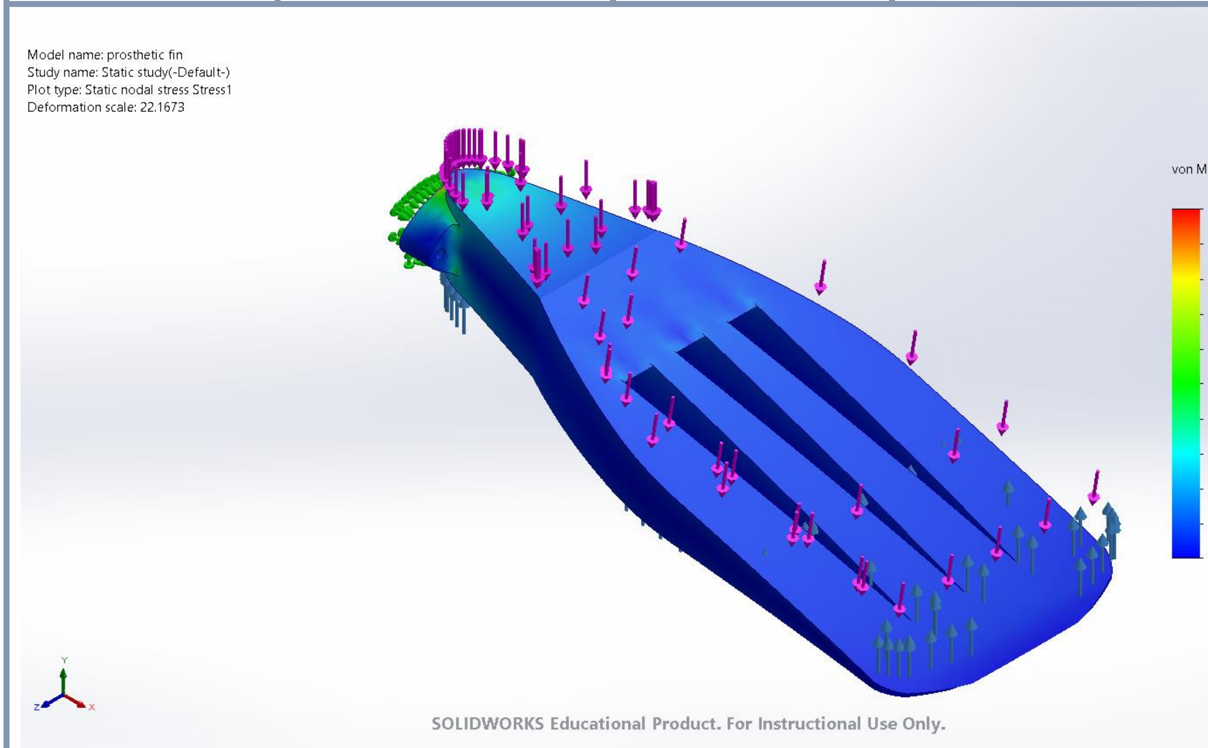
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Beams

No Data

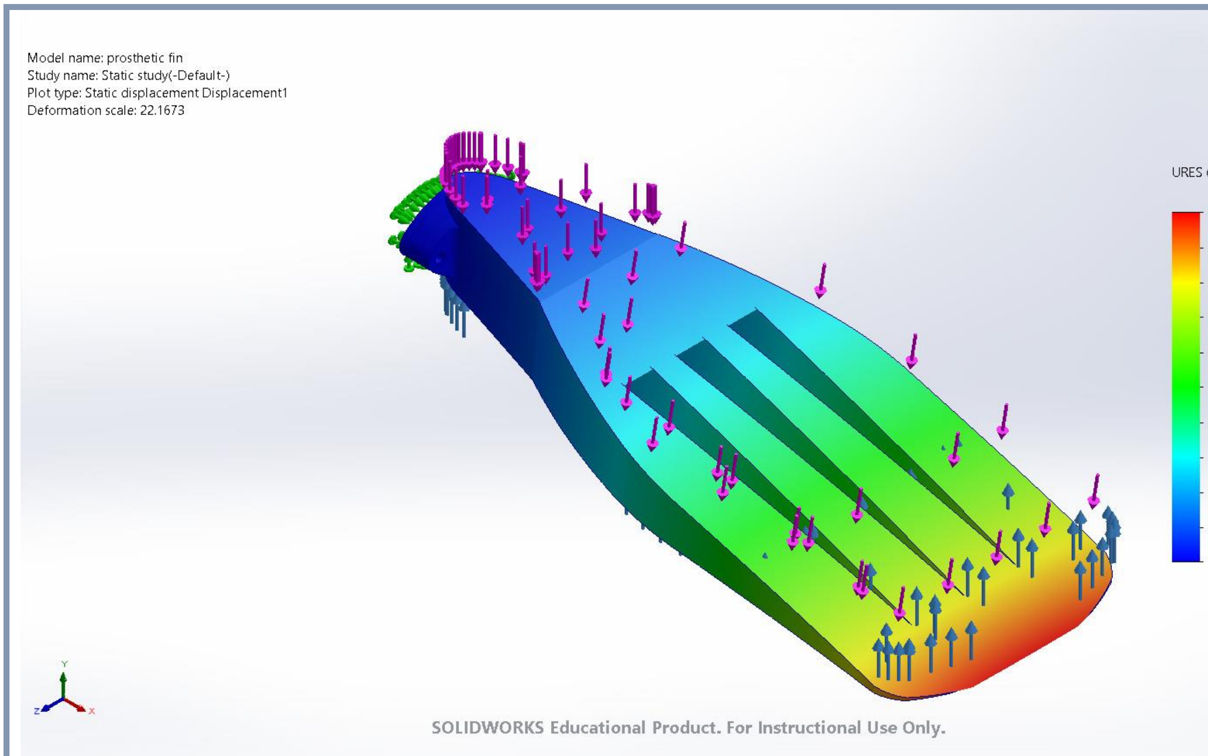
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	5.473e-03N/mm^2 (MPa) Node: 12569	5.658e+00N/mm^2 (MPa) Node: 14037



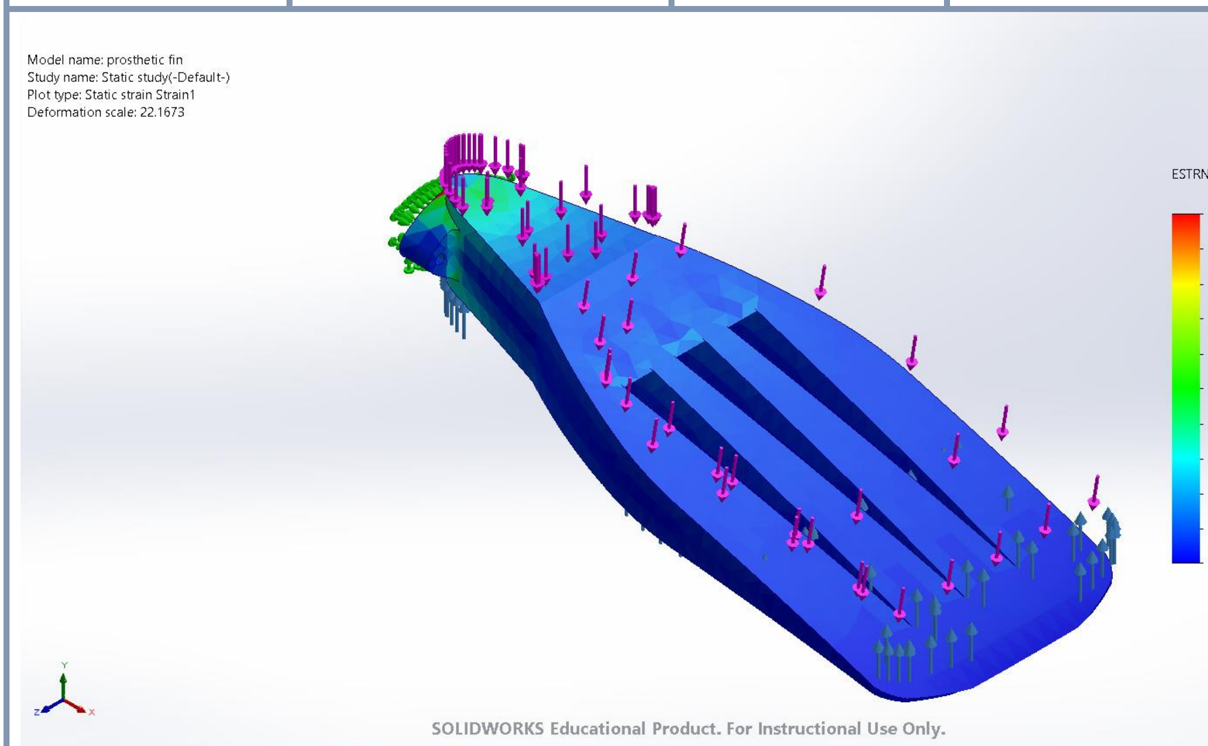
prosthetic fin-Static study-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 6	1.149e+00mm Node: 13003



prosthetic fin-Static study-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.691e-06 Element: 3121	2.050e-03 Element: 3420



prosthetic fin-Static study-Strain-Strain1

Results

- Maximum von Mises Stress: 5.207 MPa
- Material Yield Strength (TPU): 25 MPa
- Factor of Safety (FOS):

$$FOS = \text{Material Yield Strength}/\text{Maximum Stress} = 25/5.207 \approx$$

Conclusion: The fin remains within safe limits under applied forces**.**

Prototype manufacturing:

Equipment Used

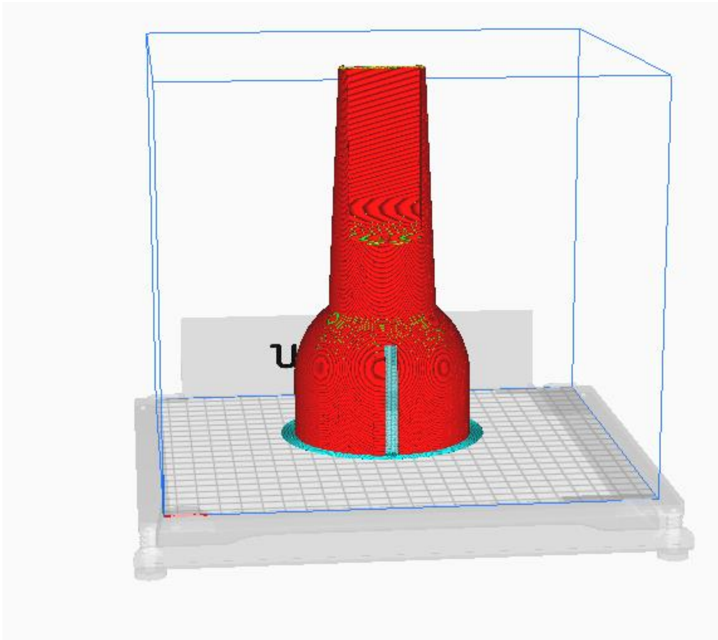
- 3D Printer: Ultimaker S4
- Slicing Software: CURA

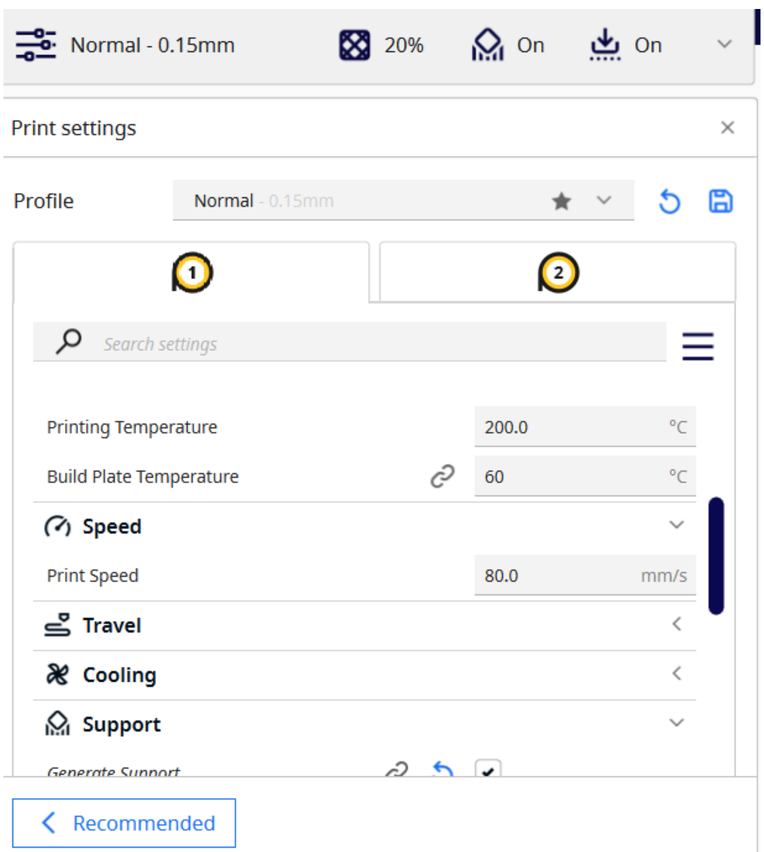
Materials

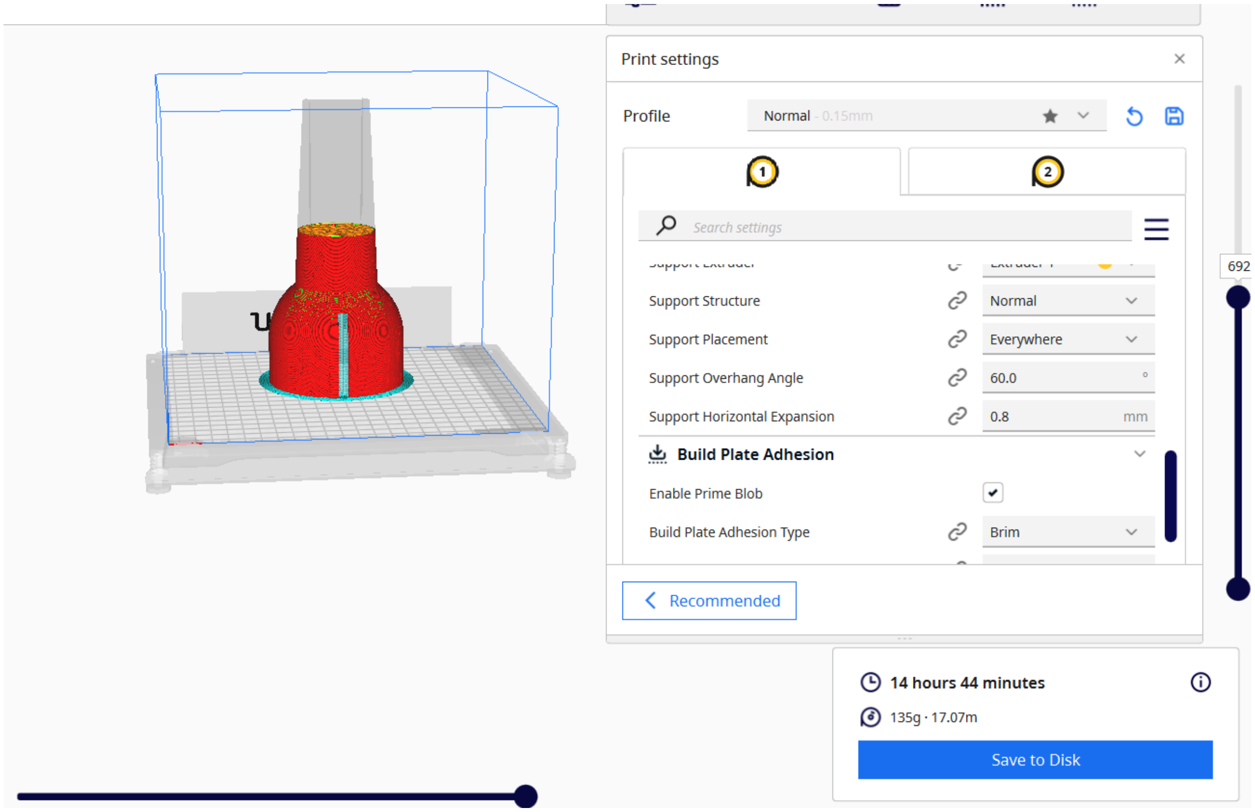
Polylactic Acid **(**PLA)

Manufactured Parts and Device Assembly:

Print preparation in CURA:




Normal - 0.15mm
20%
On
On
Print settings
Profile
Normal - 0.15mm
1
2
Search settings
Printing Temperature
200.0
°C
Build Plate Temperature
60
°C
Speed
Print Speed
80.0
mm/s
Travel
Cooling
Support
Generate Support
Recommended



Manufacturing Process:

- Both parts were printed individually using 3D printing technology**.**
- The parts were cleaned, sanded, and inspected for defects**.**
- The fin was securely attached to the leg structure.

Challenges and Solutions:

- **Challenge**: The size of the part exceeded the build volume of the 3D printer, making it impossible to print in a single piece.
- **Solution**: The part was **split into two sections** to fit within the printer's capacity. These sections were printed individually and later **aligned and assembled** using adhesive and mechanical connections to ensure structural integrity.

Results:

This project successfully developed a simple, lightweight prosthetic swimming leg consisting of only two parts: a rigid leg and a flexible fin. The prototype was manufactured using PLA material due to its ease of printing and availability for initial validation.

Results with PLA Material

1. Strength and Flexibility:
   - PLA provided sufficient structural rigidity for prototyping; however, it lacks the flexibility required for the fin to mimic natural foot motion effectively.
2. Performance Under Load:
   - The PLA prototype demonstrated limitations in handling water resistance forces and showed stress concentration in high-load areas, particularly near the connection between the leg and fin.

Need for Actual Materials

To overcome the limitations of PLA, the following materials will be incorporated into the final design:

1. **Prosthetic Leg**: Carbon-Reinforced Polymer Structure (CRPS)
   - Provides superior strength, rigidity, and lightweight properties to support load transfer.
2. **Fin**: Thermoplastic Polyurethane (TPU)
   - Ensures controlled flexibility, allowing efficient thrust generation and mimicking the natural motion of a swimmer's foot.

The incorporation of these materials will address the prototype's shortcomings, ensuring improved performance, durability, and flexibility under realistic swimming conditions.

Design Evaluation:

Design Principle	Reflection
Innovation	Simple two-part design using advanced materials.
Useful	Meets the need for swimming functionality and thrust generation.
Thorough	Detailed modeling, stress analysis, and manufacturing processes ensure reliability.
Minimal	The design uses only two parts, avoiding unnecessary complexity.

Conclusion:

This project successfully developed a simple, lightweight prosthetic swimming leg consisting of only two parts: a rigid leg and a flexible fin. The prototype was manufactured using PLA for ease of printing and initial validation. For the final design, the intended materials are:

1. **Prosthetic Leg**: Carbon-Reinforced Polymer Structure (CRPS) for high strength, rigidity, and lightweight performance.
2. **Fin**: Thermoplastic Polyurethane (TPU) to provide controlled flexibility and durability for efficient swimming propulsion.

Manufacturing challenges, such as printer size limitations, were effectively addressed by splitting the part into two sections for better printing and securely assembling them. The design achieves an optimal balance of strength, weight, and flexibility, ensuring it meets its intended purpose for swimming applications.

Open-Source Repository:

prosthetic swim leg by punithbunny - Thingiverse