Large Angle Flexure for Oscillating Heat Pipes in Space

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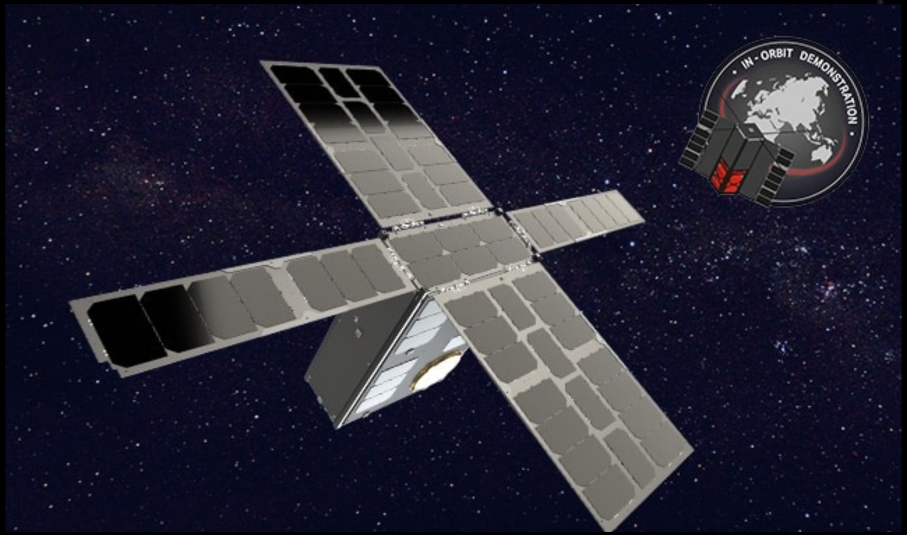
Agenda

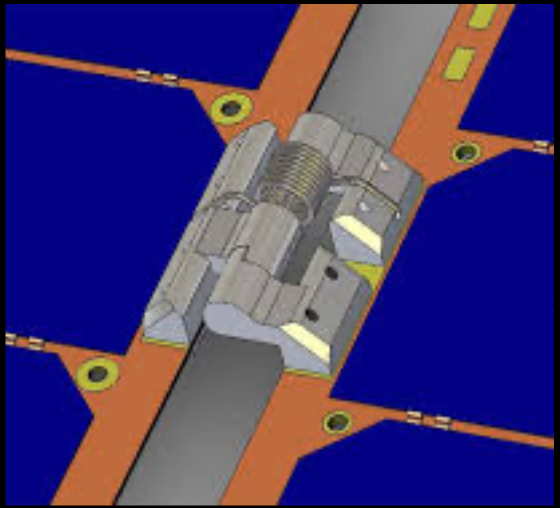
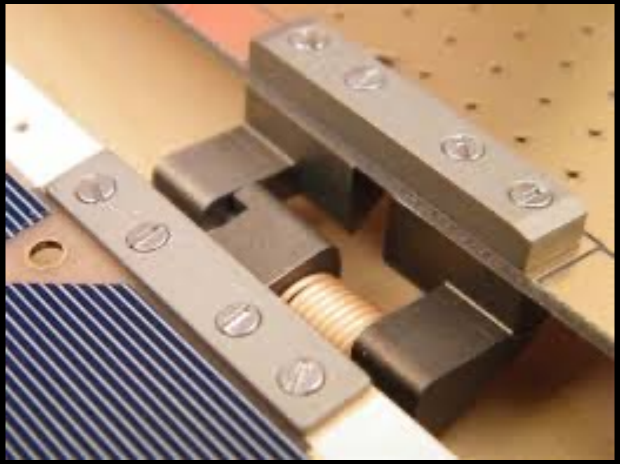
Background

- Project is part of an effort to develop and improve CubeSats
- CubeSats are miniature satellites used for space research
- Internal components generate heat (which is detrimental to performance)
- Cooling done by radiating heat into space

Summary of Problem

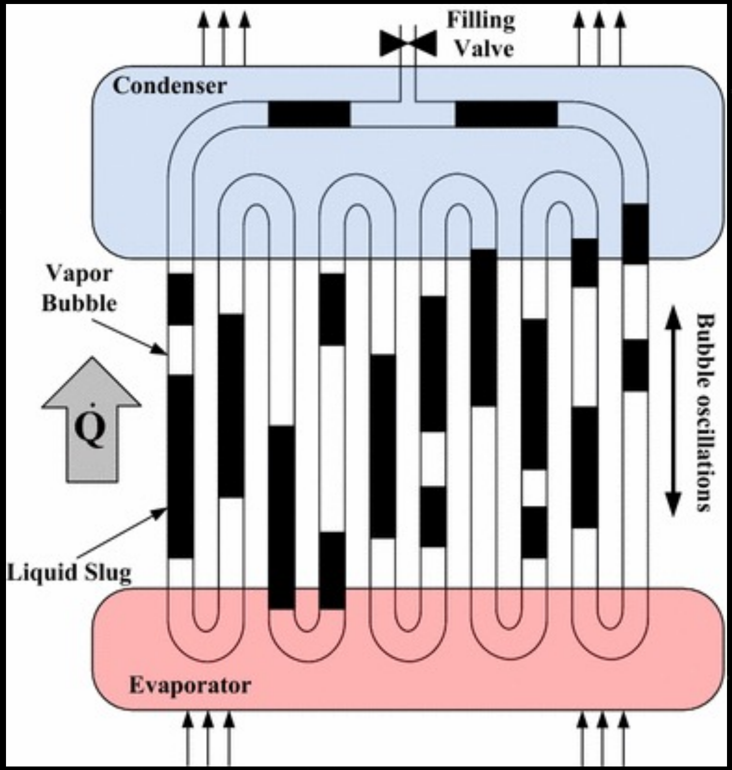
- Current cooling technologies in CubeSats limit power usage
- CubeSats have limited surface area. Use deployable radiator to increase area
- Difficulties in transferring heat across mechanical hinges
- Heat pipes transfer heat via fluid flow



Summary of Problem

- Oscillating Heat Pipes (OHP) are a 2-phase flow device
- Uses an oscillatory motion to transfer heat from evaporator to condenser
- High thermal conductivity, but requires flexible joints

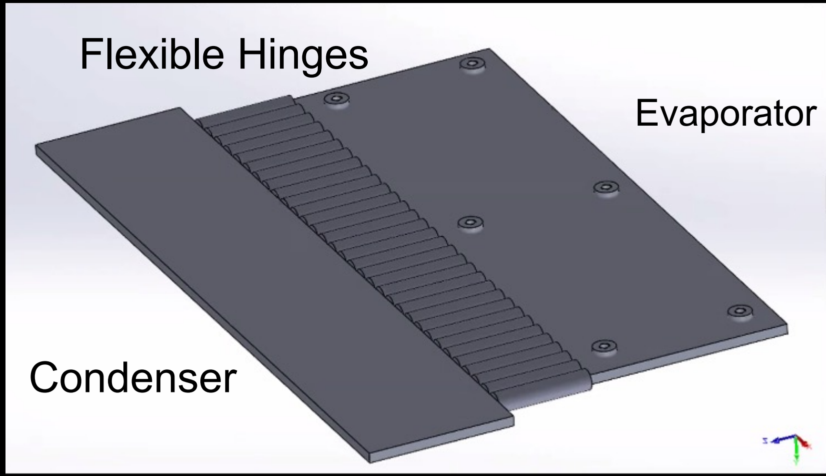


Objective

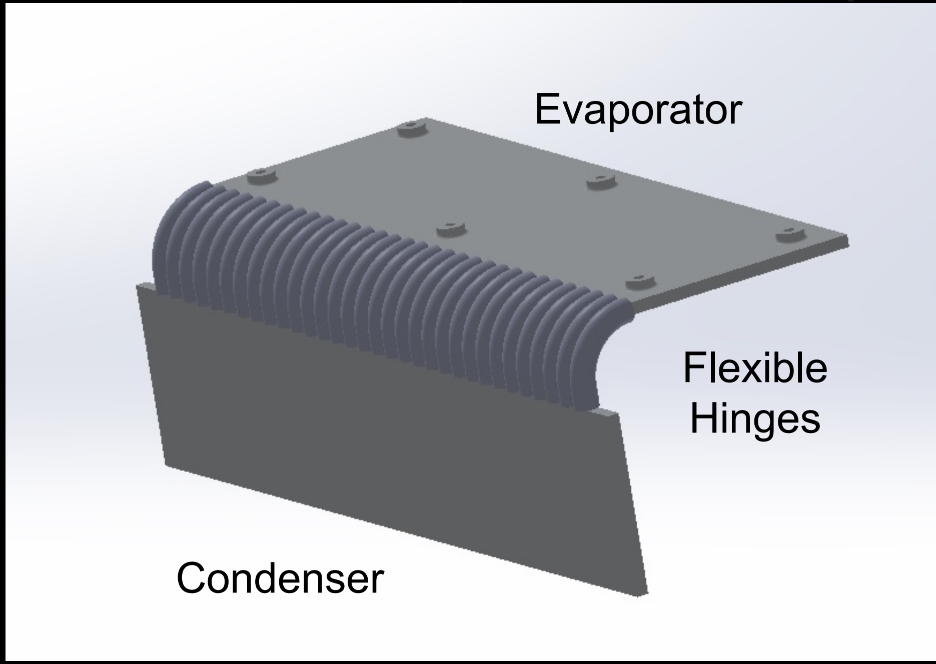
How can we create a flexure that can:

- Bend to allow radiator to be in stowed position
- Allow fluid to flow through
- Be 3D printed in metal

Open Position

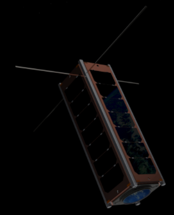


Stowed Position



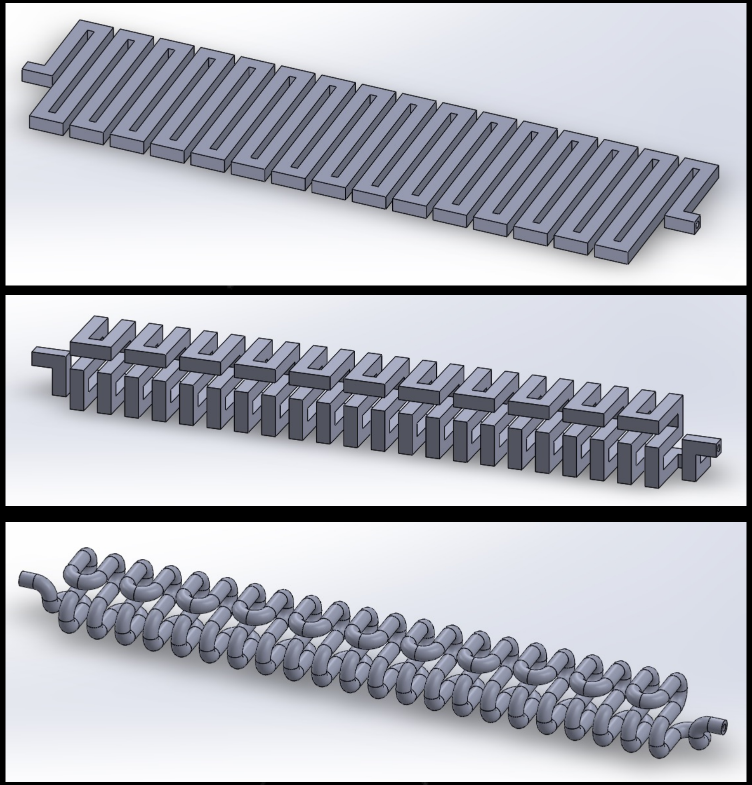
Minimum Requirements Table

Requirement	Minimum Requirement
Flexibility	Be able to bend to put radiator in stowed position
Strength	Have a Factor of Safety of at least 2.0
Coiled Length	Have a maximum length of 8 cm
Uncoiled Length	Efficient fitting of length in volumetric space
Width	Have a maximum width of 8 mm
Height	Have a maximum height of 8 mm
Mass	Have a maximum mass of 2.5 g
Manufacturability	Able to be 3D printed in metal though Powder Bed Fusion

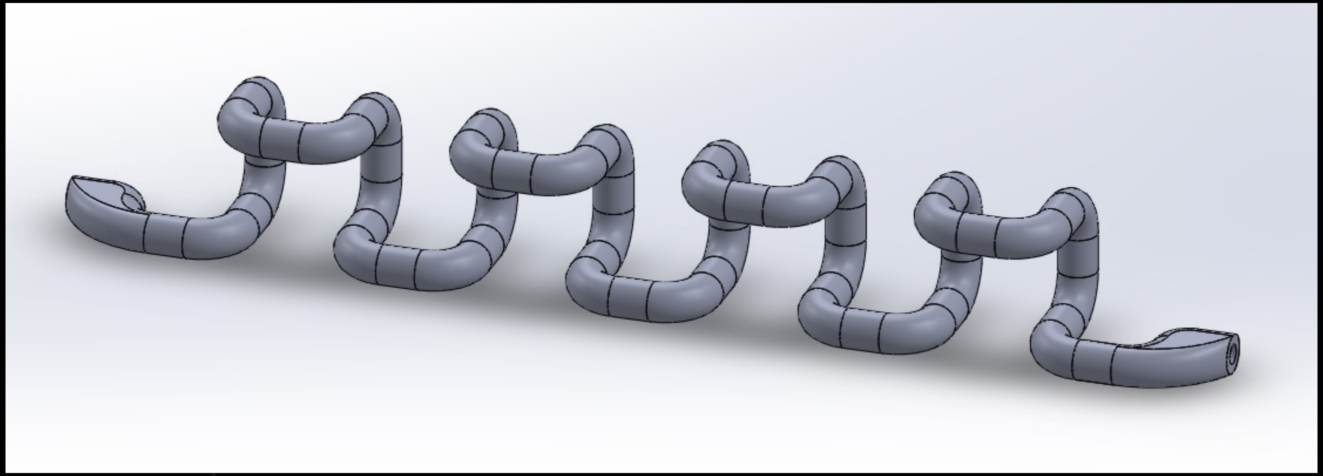


Serpentine Structure

Previous Designs:



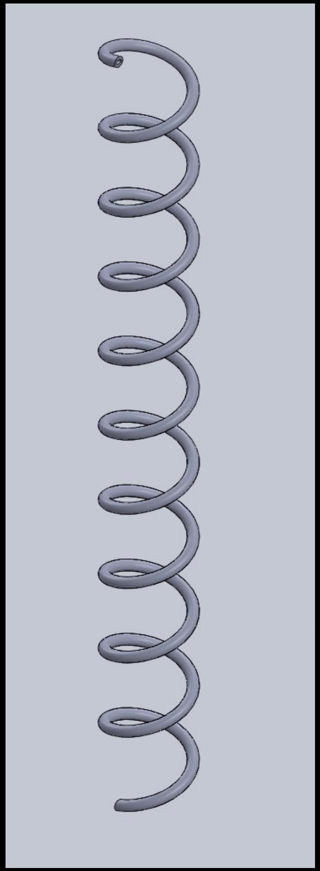
Final Design:

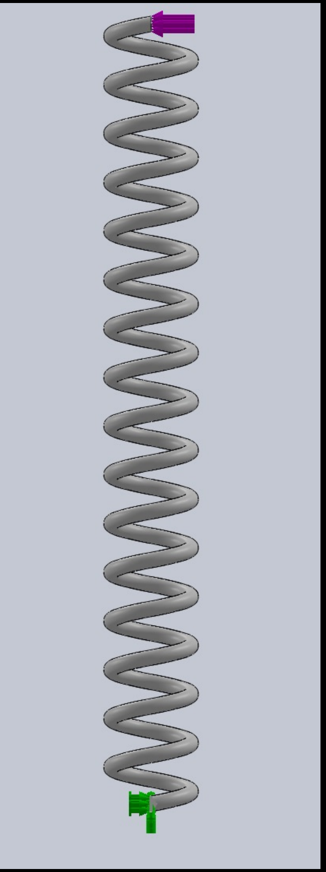


- Commonly used in MEMS (Micro Electro-Mechanical Structures) as flexures
- Lots of freedom of design
- Lots of room for optimization, through changing of different dimensions

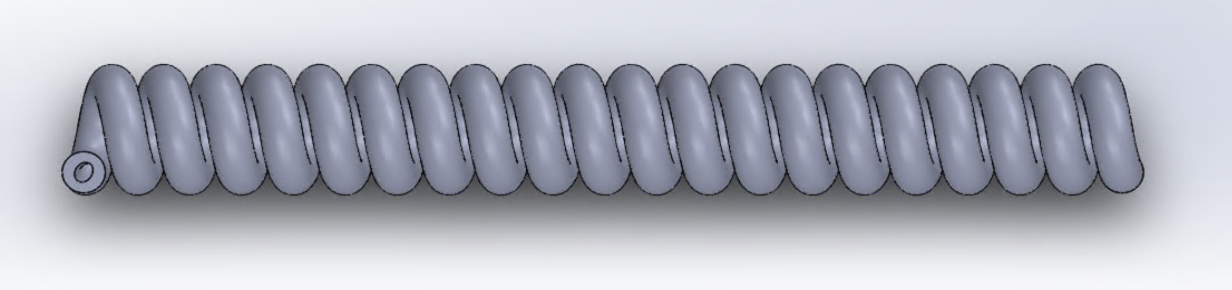
Circle with inner Ellipse Spring

Previous Designs:





Final Design:

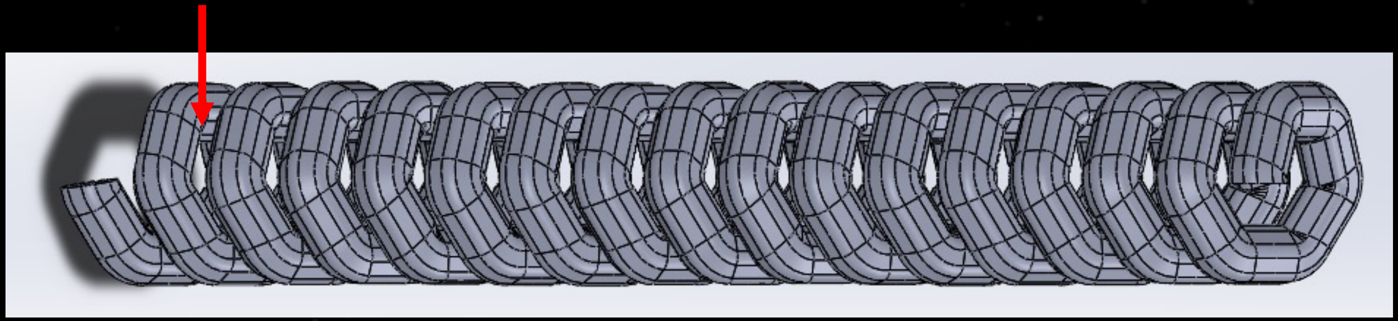


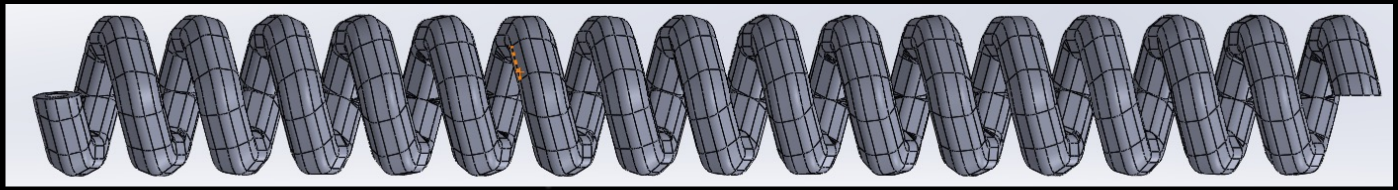
- Thicker walls can help with strength due to ellipse having less area than circle
- More angles increases the deflection, and circle has the most angles for outer
- Most amount of engaging due to not having sharp edges

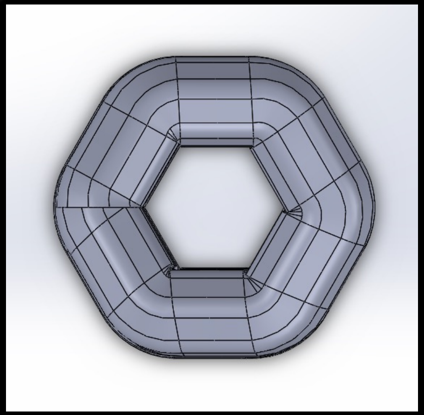
Hexagon Spring

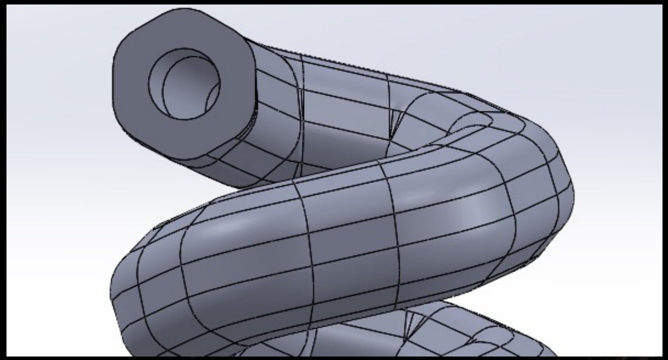
- Findings
  - ↑ turns, ↑ flexibility
  - σ_{max} near fixed end at corner
  - Failure usually occurred at σ_{max} location

- Improvements:
  - Modified # of turns
    - Increased pitch
  - Filet edges on spring and wire



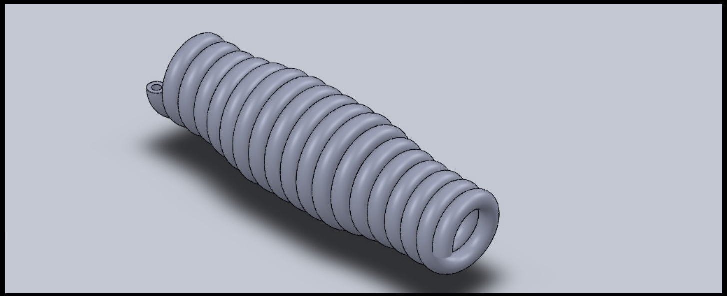




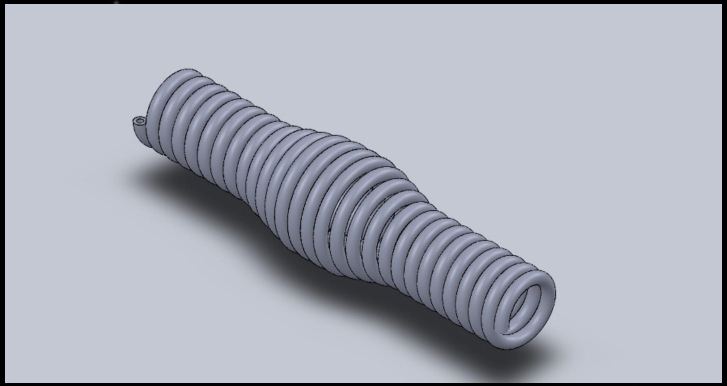


Reverse Hourglass Spring

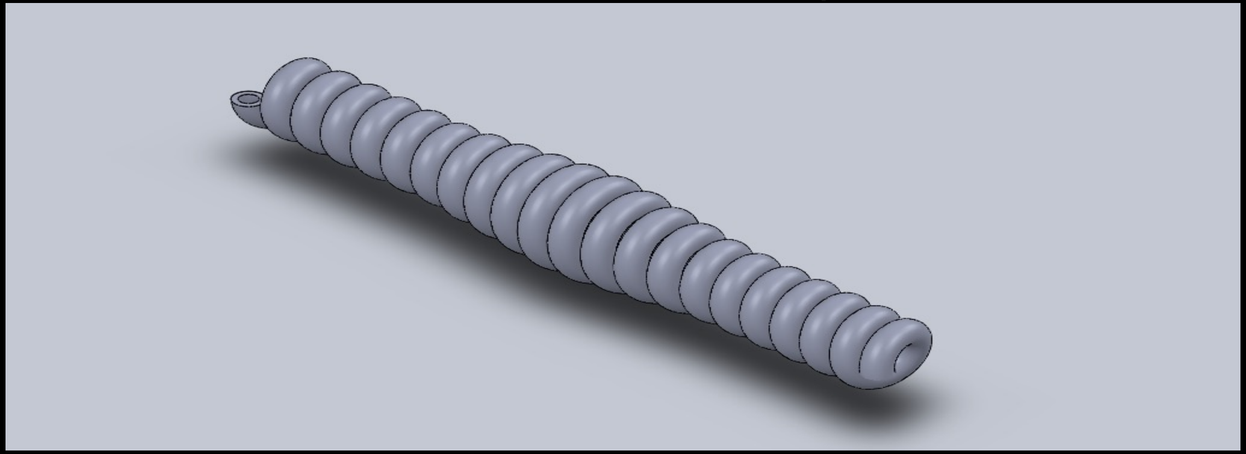
Previous Designs:



1st iteration



2nd iteration

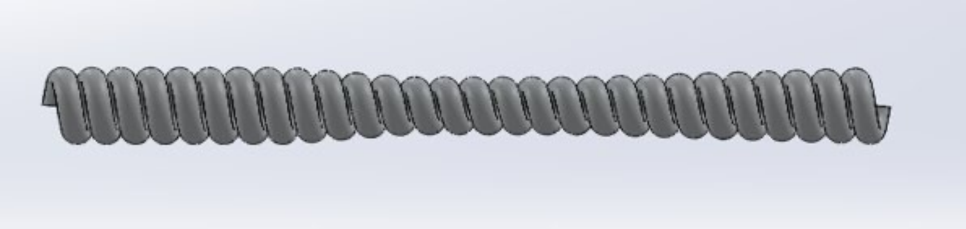


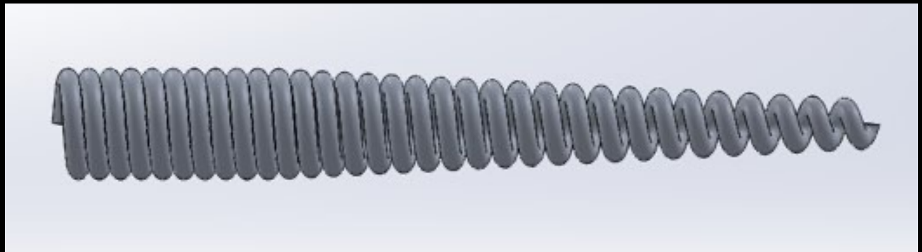
Final Design

- Alternate Design for Helical Compression Spring
  - Results can be compared to a typical helical spring
  - Change of centered height will diminish stress at edges
- Improvements:
  - Optimized length at the edges and decreasing the slope to the center height

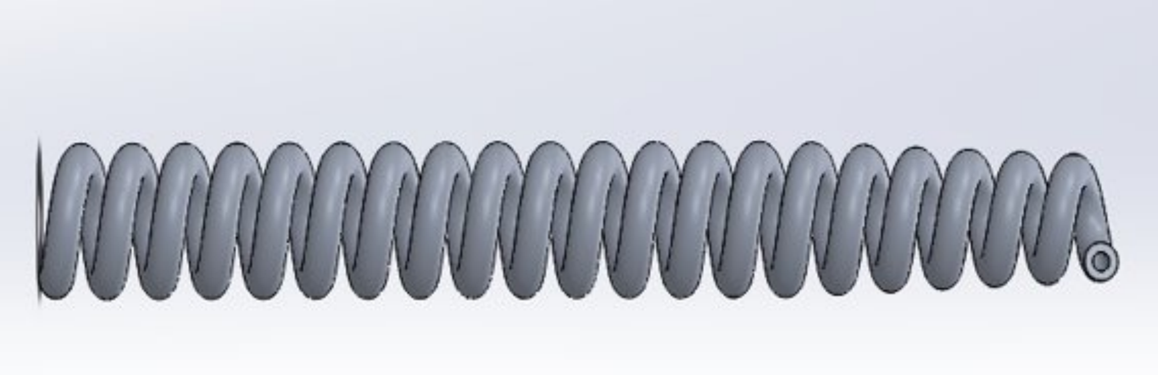
Variable Pitch Spring

Previous Designs:





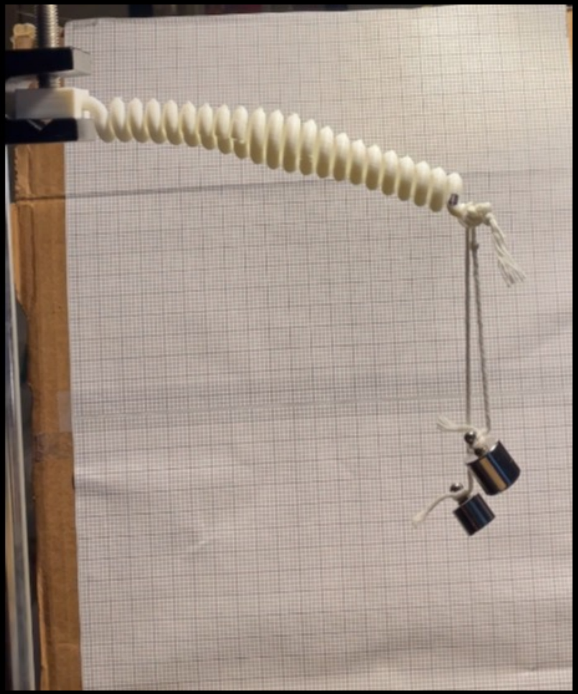
Final Design:

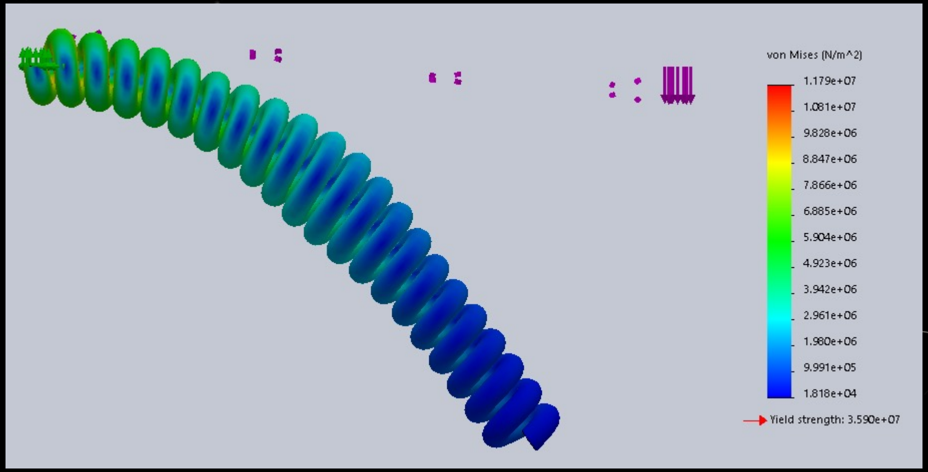


- Classic helical design but explored an important optimization technique
- Larger pitch toward the fixed end where more support is needed
- Smaller pitch toward free end where more bend activation is needed

Testing Overview

- Methods of testing:
  - Experimental Testing of 3D Printed PLA Flexures
  - Finite Element Analysis (FEA) Simulations
- Experimental testing in scaled PLA used to validate PLA FEA simulations
- Aluminum FEA Simulations then to describe flexure



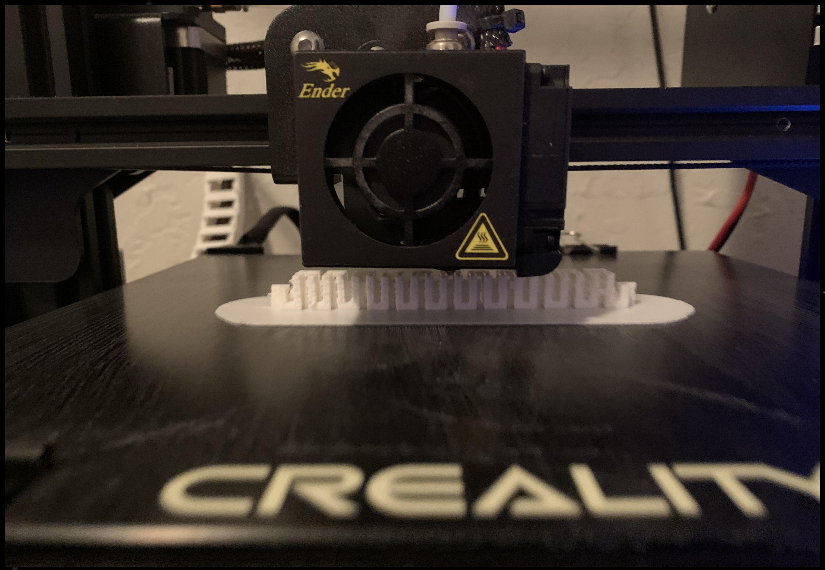


Overview of 3D Printing Flexures

- Final Flexure to be printed in metal (powder bed fusion)

- Flexures for experimental testing done with home PLA 3D printers

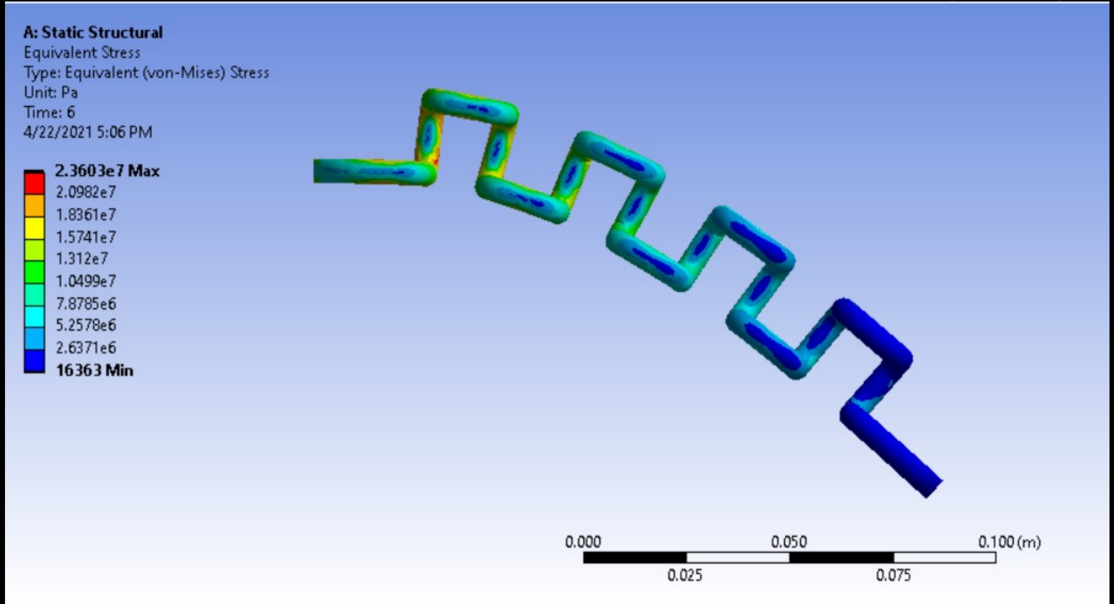
- Challenge to print small flexures with detail and little to no imperfections

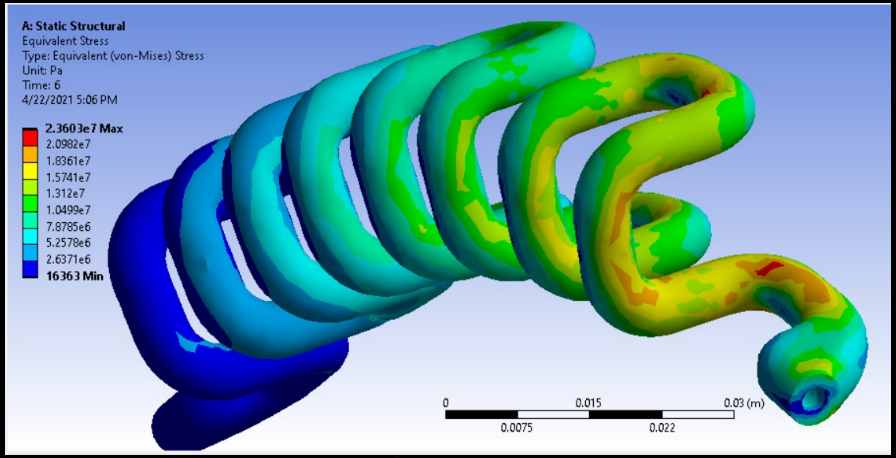


Experimental Procedure

Simulation Procedure

- Performed in ANSYS or SOLIDWORKS
- Mesh sensitivity tests determined mesh size
- Fixed face on one end and applied-force on opposite face
- Large-deflection setting was used
- Force applied in increments
- Acquired Von-Mises Stress and Angle of Deflection





Trade Study

Categories	Importance	Serpentine	Spring with Circle and Ellipse	Variable Pitch Spring	Reverse Hourglass Spring	Helical Hexagonal Spring
Flexibility	0.19	3	1	3	3	1
Strength	0.19	2	1	2	2	1
Coiled Length (mm)	0.09	3	1	1	2	2
Uncoiled Length (mm)	0.14	1	3	2	3	1
Width	0.10	1	2	2	2	2
Height	0.05	1	2	2	2	2
Mass	0.10	3	1	1	2	3
Manufacturability	0.14	3	1	1	1	1
Total Point Weight	1.00	2.23	1.43	1.86	2.19	1.44

Final Design Evaluation

Requirement	Minimum Requirement	Final Design Performance
Flexibility	Be able to deploy a radiator from a stowed position	Flexes up to 24.19° which is not enough for full bend
Strength	Have a Factor of Safety of at least 2	Factor of Safety of 0.27 for full bend or 0.54 for halfway bend
Coiled Length	Have a maximum length of 8 cm	Coiled Length is 6 cm
Uncoiled Length	Efficient fitting of length in volumetric space	Uncoiled Length was about 180 mm which is low
Width	Have a maximum width of 8 mm	Width was 8 mm
Height	Have a maximum height of 8 mm	Height was 8 mm
Mass	Have a maximum mass of 2.5 g	Mass was 1.14 g
Manufacturability	Able to be 3D printed in metal though Powder Bed Fusion	Able to be printed with small adjustments

What's Next for Large Angle Flexures?

- Test metal printed flexures for further result validation
- Further optimize designs to increase FOS
- Design support structure to allow flexure to sustain larger forces for more bend