Parametric Analysis and Optimization of an Elastocaloric Refrigeration Cycle

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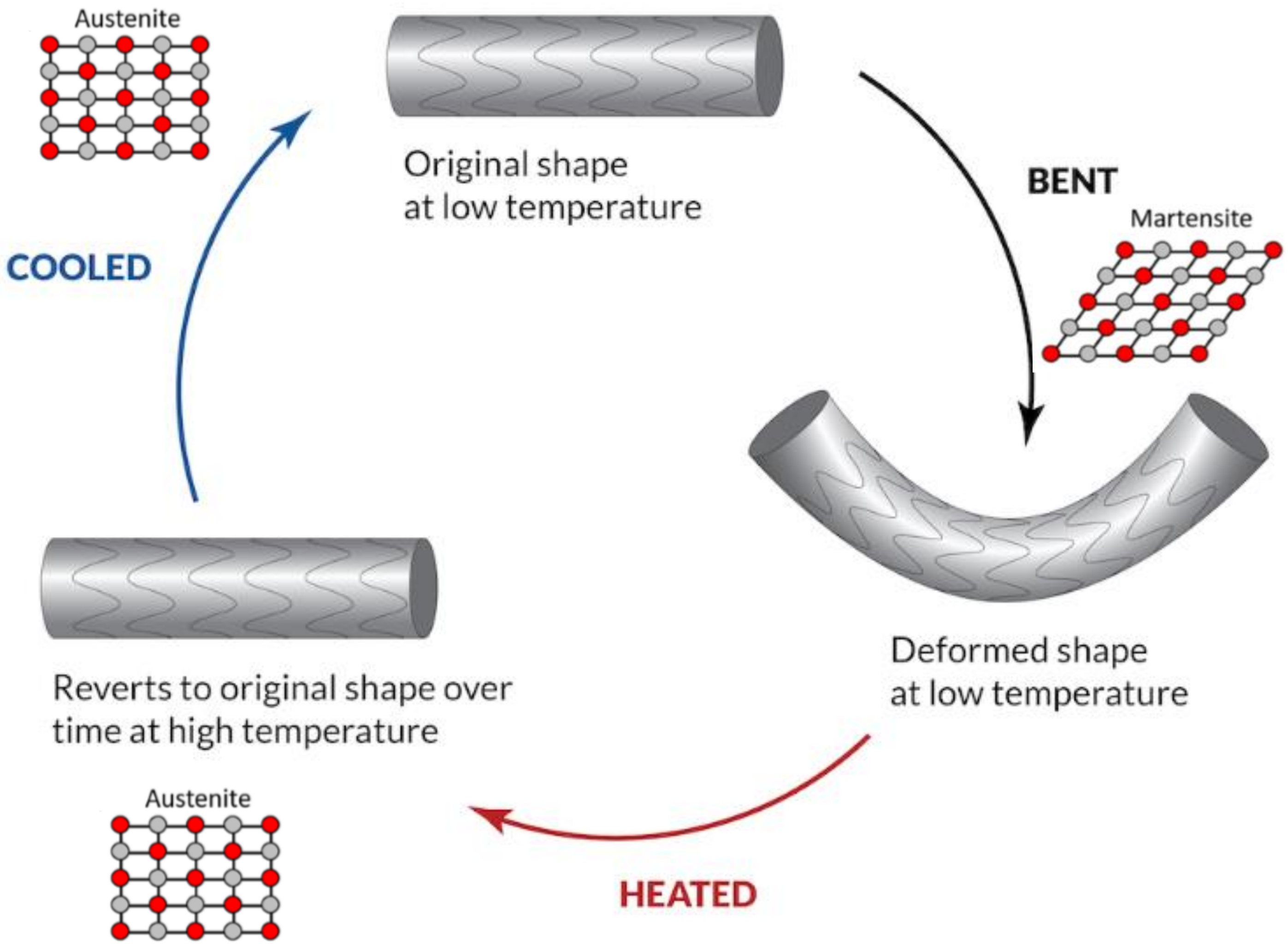
Topic Overview

1. Elastocaloric heating and cooling
2. Elastocaloric Continuous Flow Loop – System of Interest
3. COMSOL Multiphysics – Design and Solution

Elastocaloric Heating/Cooling: Martensitic Transformation



Completely Reversible:

$\varepsilon \leftrightarrow q$

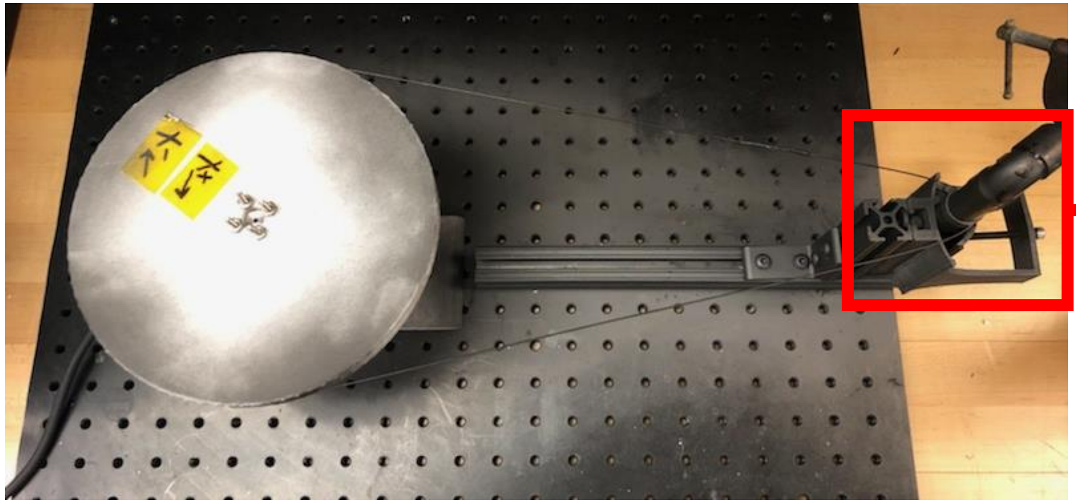
$\varepsilon \rightarrow q$

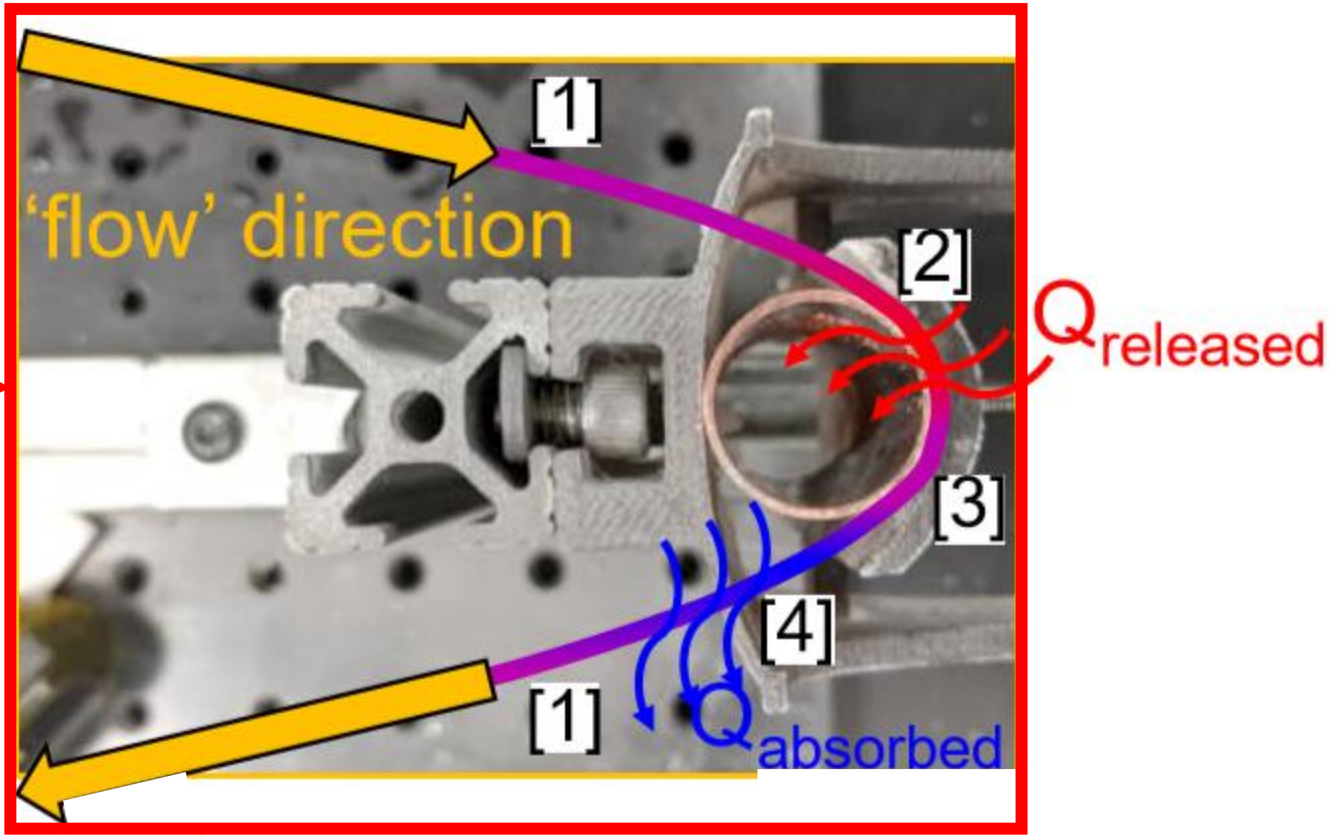
* Transformation occurs at a critical strain (~2%)

https://www.comsol.com/blogs/the-elephants-of-materials-science-smas-never-forget-their-shape/

Application: Elastocaloric ‘Flow Loop’ at Army Research Lab

NiTi wire strained continuously in bending mode





Images taken at ARL

Modelling Challenges

1. SMA's have complex behaviors (strain and heat release relationship)
2. Modelling heat transfer while the system is in motion

Model Geometry – Fluid model

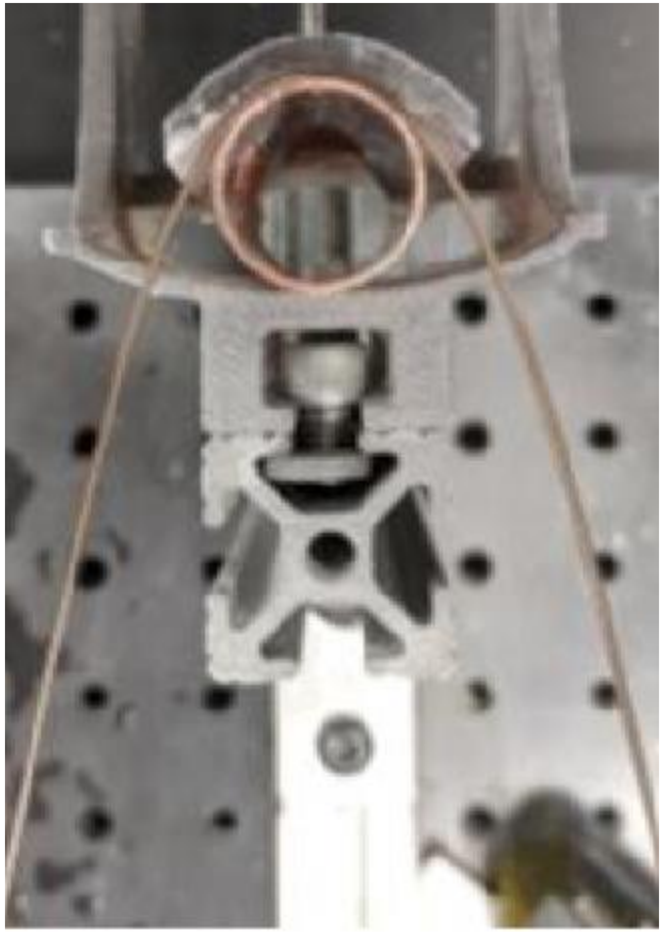
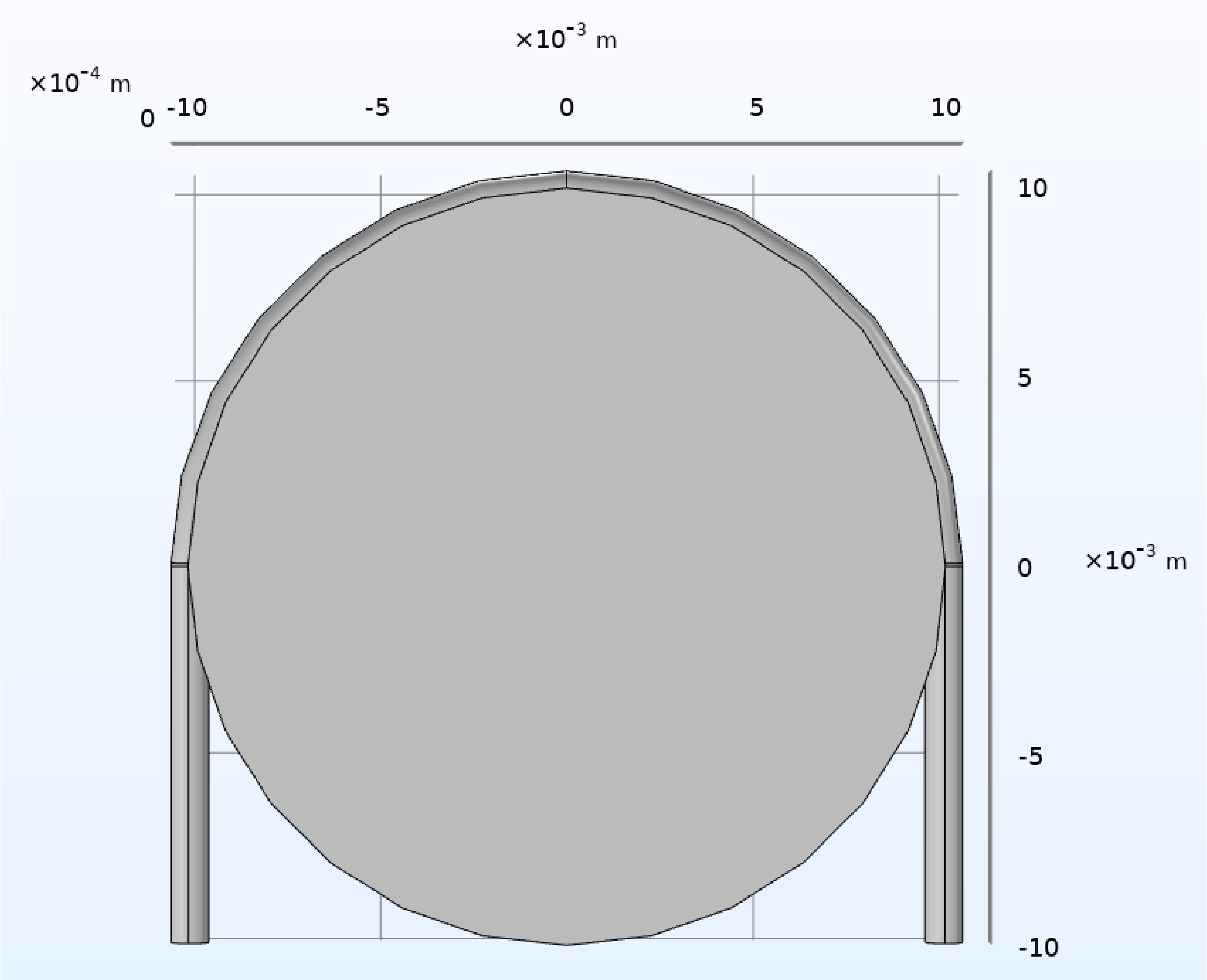
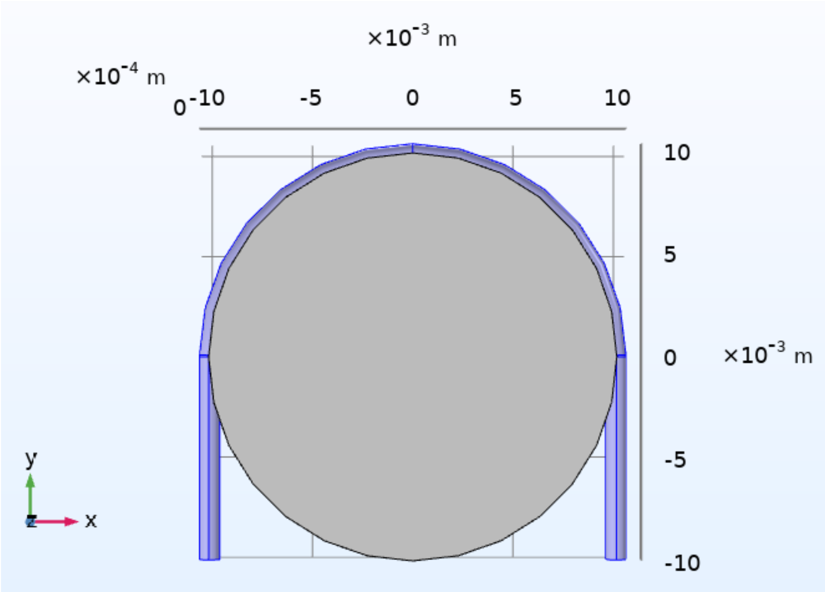


Image taken at ARL



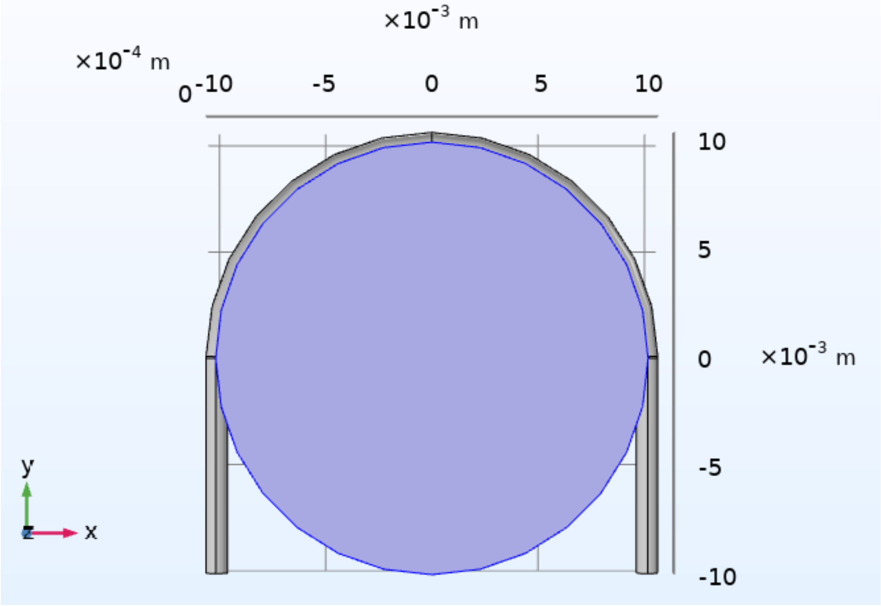
Material Selection – Thermal Properties

Wire - "NiTi Water"



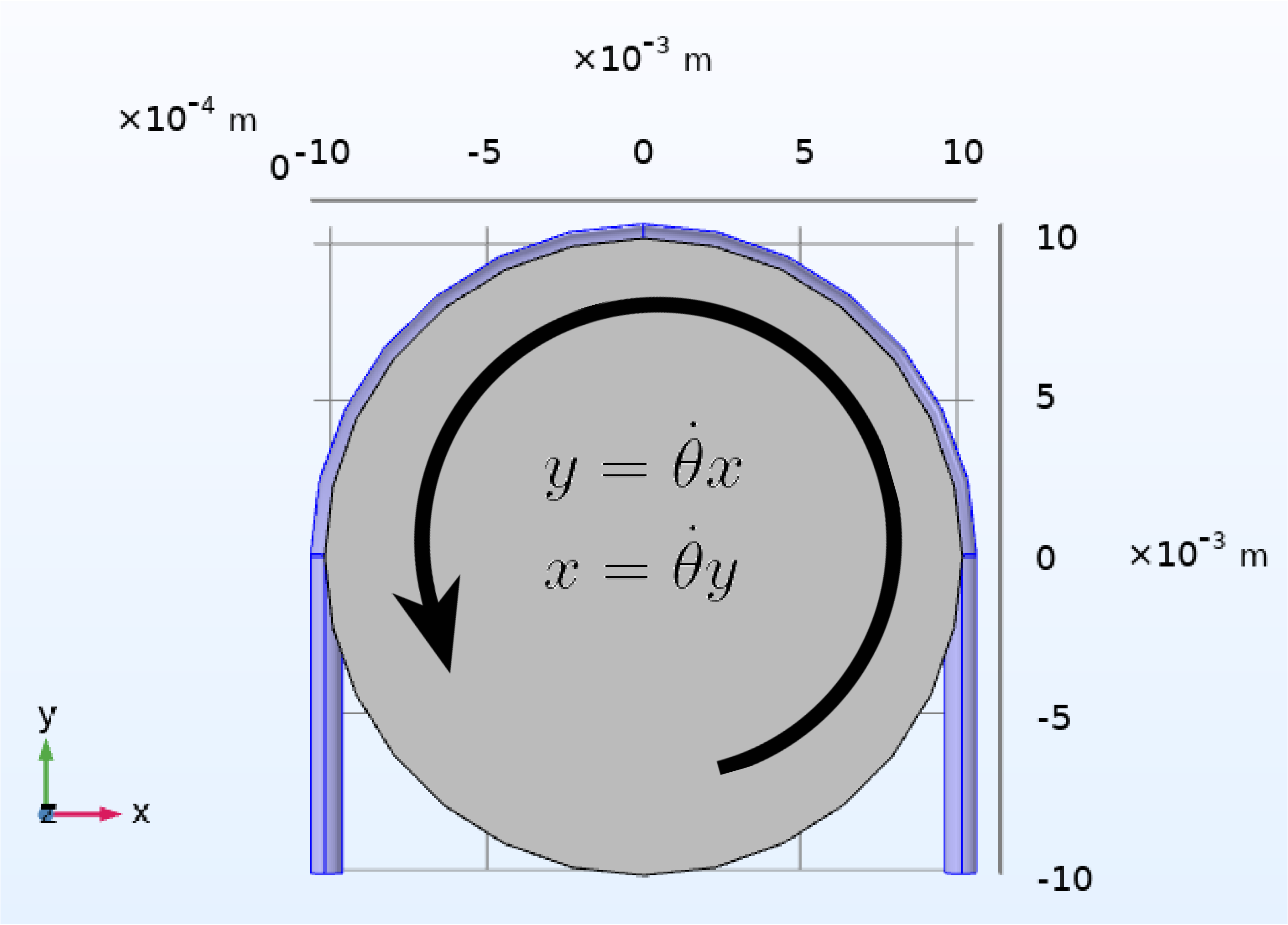
Property	Variable	Value	Unit
Dynamic viscosity	mu	1*1e-12	Pa·s
Ratio of specific heats	gamma	1	1
Heat capacity at constant pressure	Cp	0.46[J/(g*K)]	J/(kg·K)
Density	rho	6.45[g/cm^3]	kg/m^3
Thermal conductivity	k_iso ; k...	0.086[W/(cm*K)]	W/(m·K)
Coefficient of thermal expansion	alpha_is...	alpha_p(T)	1/K
Bulk viscosity	muB	muB(T)	Pa·s
Electrical conductivity	sigma_i...	5.5e-6[S/m]	S/m
Speed of sound	c	cs(T)	m/s

Disk - "Copper Water"



Property	Variable	Value	Unit
Ratio of specific heats	gamma	1	1
Thermal conductivity	k_iso ; ki...	400[W/(m*K)]	W/(m·K)
Density	rho	8960[kg/m^3]	kg/m^3
Heat capacity at constant pressure	Cp	385[J/(kg*K)]	J/(kg·K)
Coefficient of thermal expansion	alpha_is...	alpha_p(T)	1/K
Bulk viscosity	muB	muB(T)	Pa·s
Electrical conductivity	sigma_i...	5.998e7[S/m]	S/m
Speed of sound	c	cs(T)	m/s
Dynamic viscosity	mu	1*1e-12	Pa·s

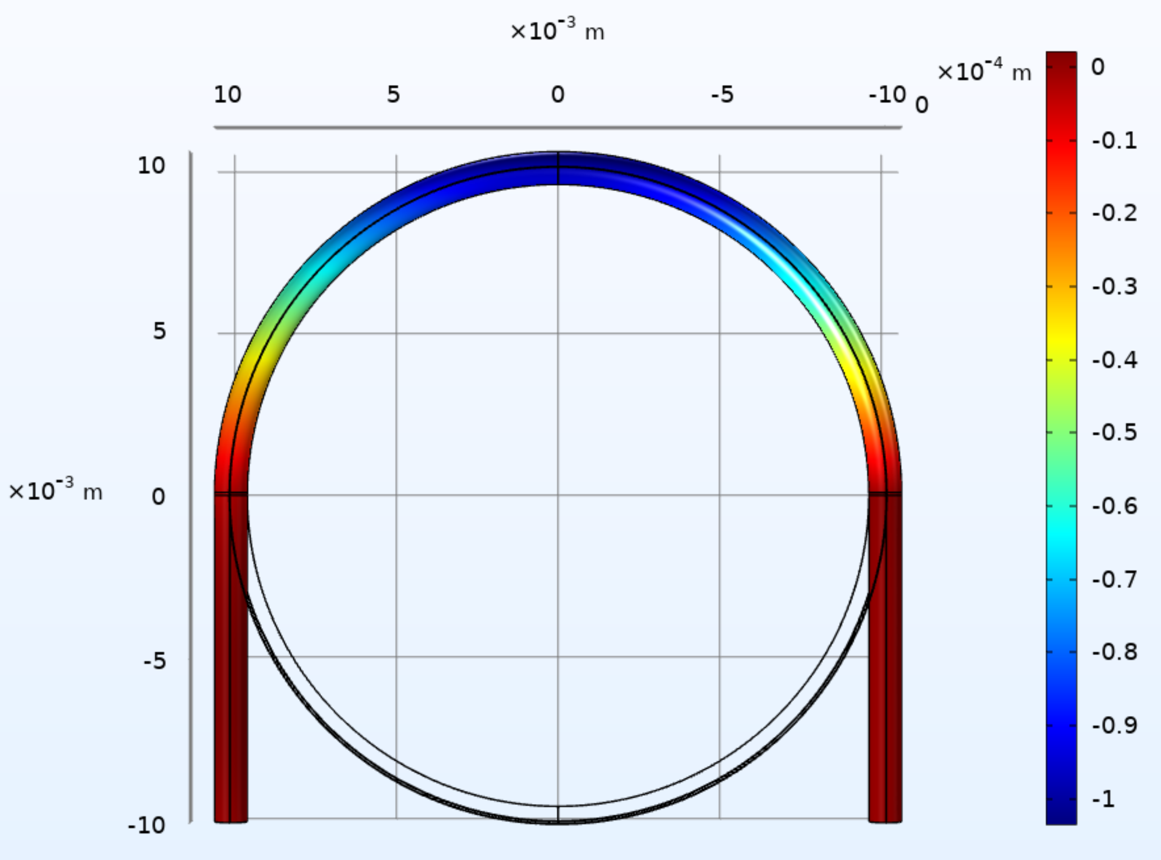
Creeping Flow Module → Rigid Body Motion



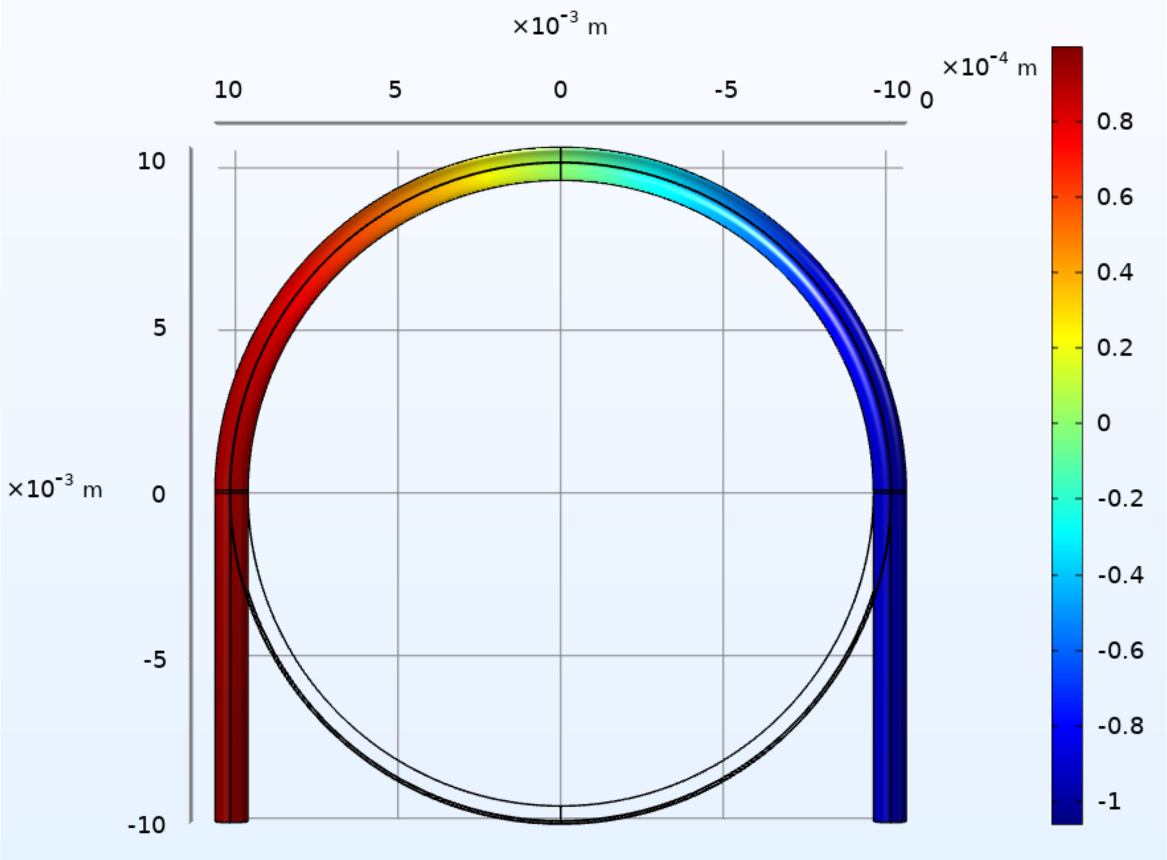
- Dynamic viscosity ~0
- Wall slip condition

Results - Continuous Flow

x velocity



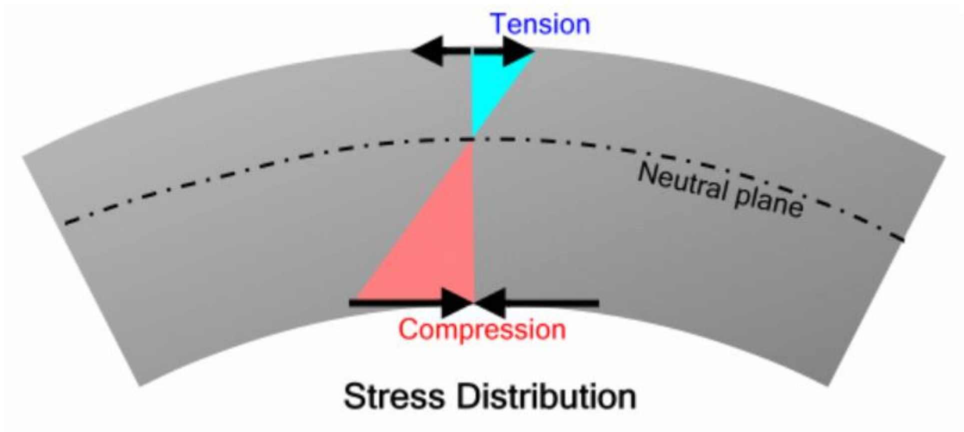
y velocity



Where v0 = 4 mm/s

Heat Transfer in Solids and Fluids
Adding the Volumetric Heat Term

https://www.tutelman.com/golf/shafts/allAboutSpines1_.html



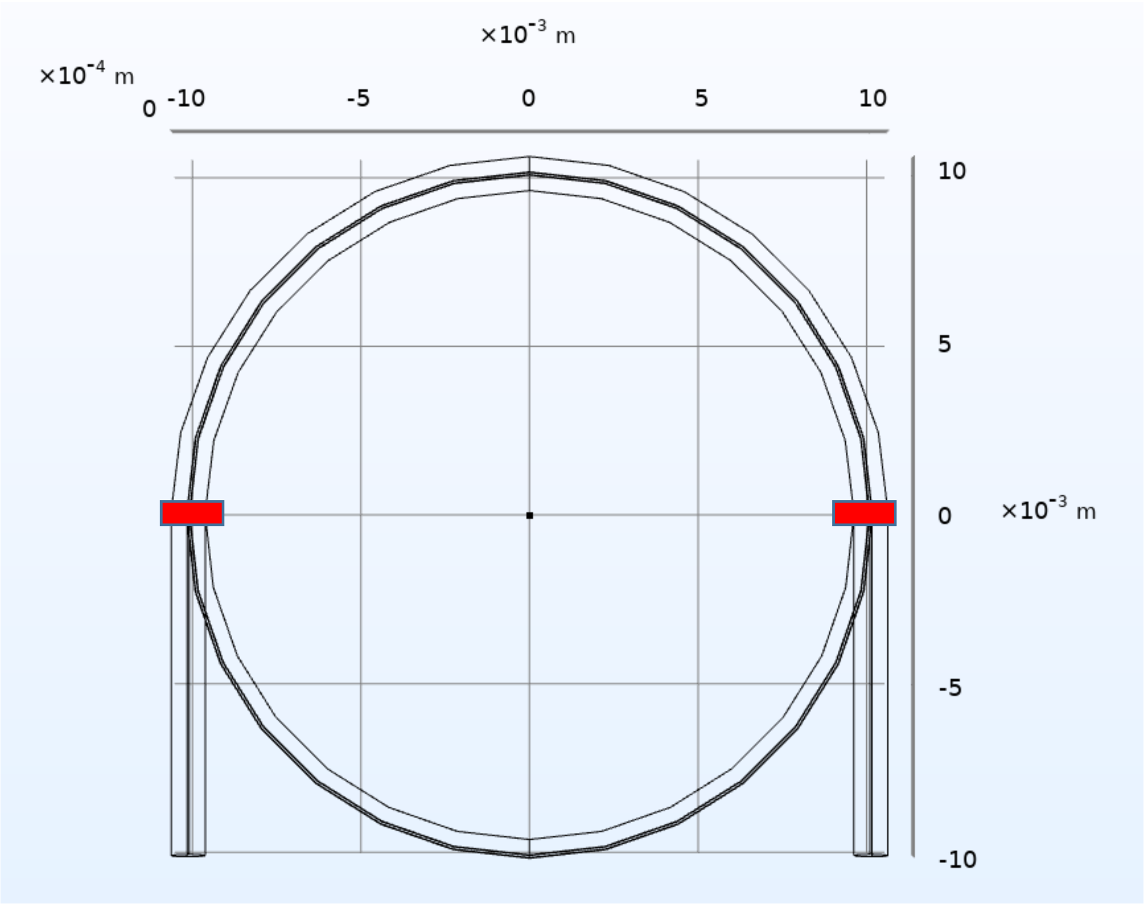
ε

Critical Strain

Heat Release

q

Simplification to Equivalent Boundary Heat Source



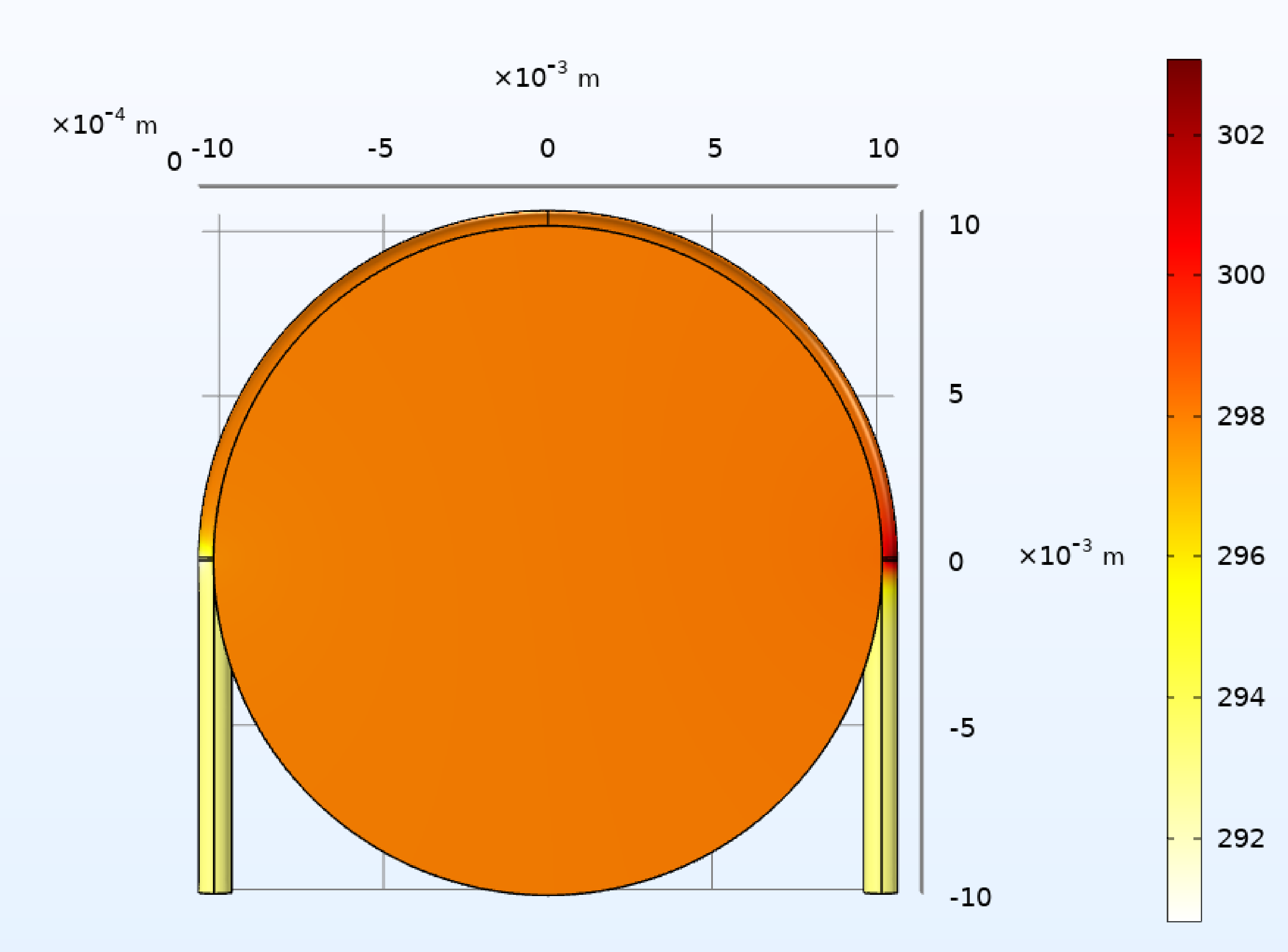
$$q'' = L * v0 * \rho$$

L = energy density [J/g]

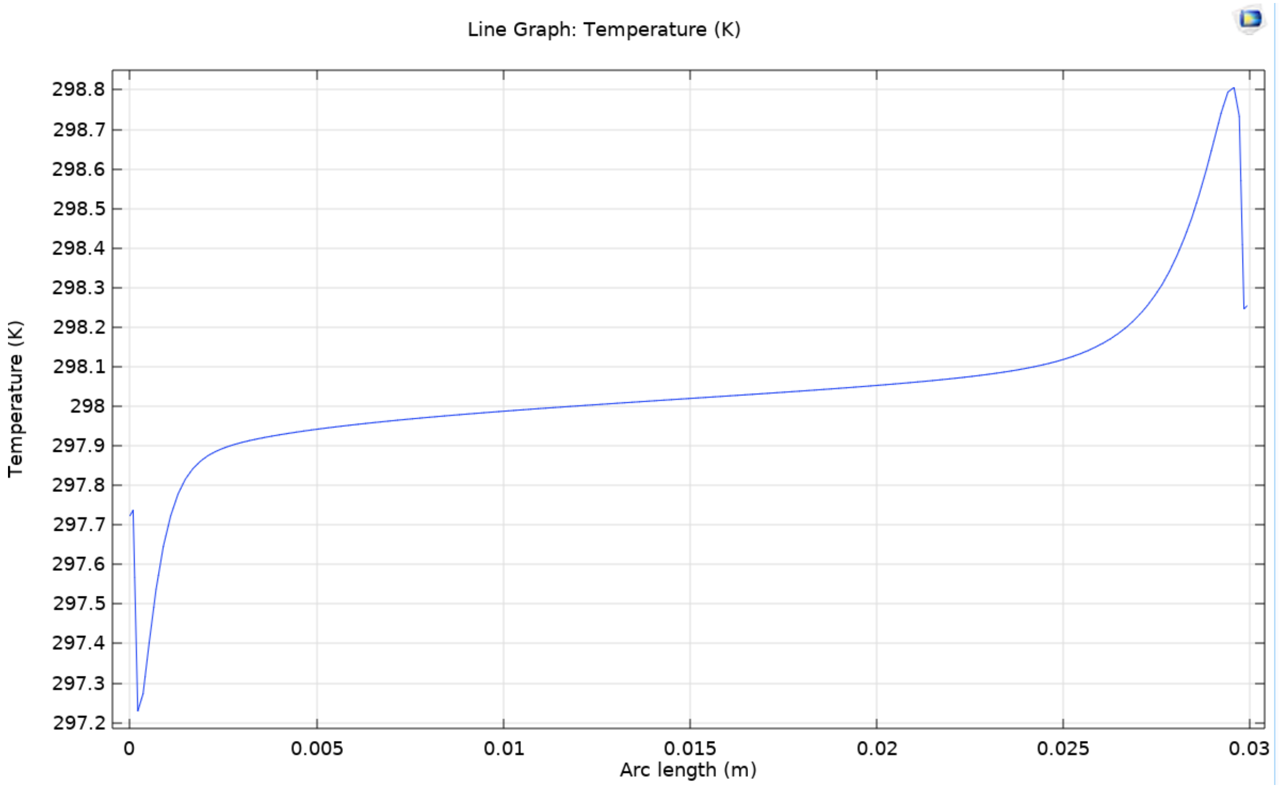
V0 = feed rate [m/s]

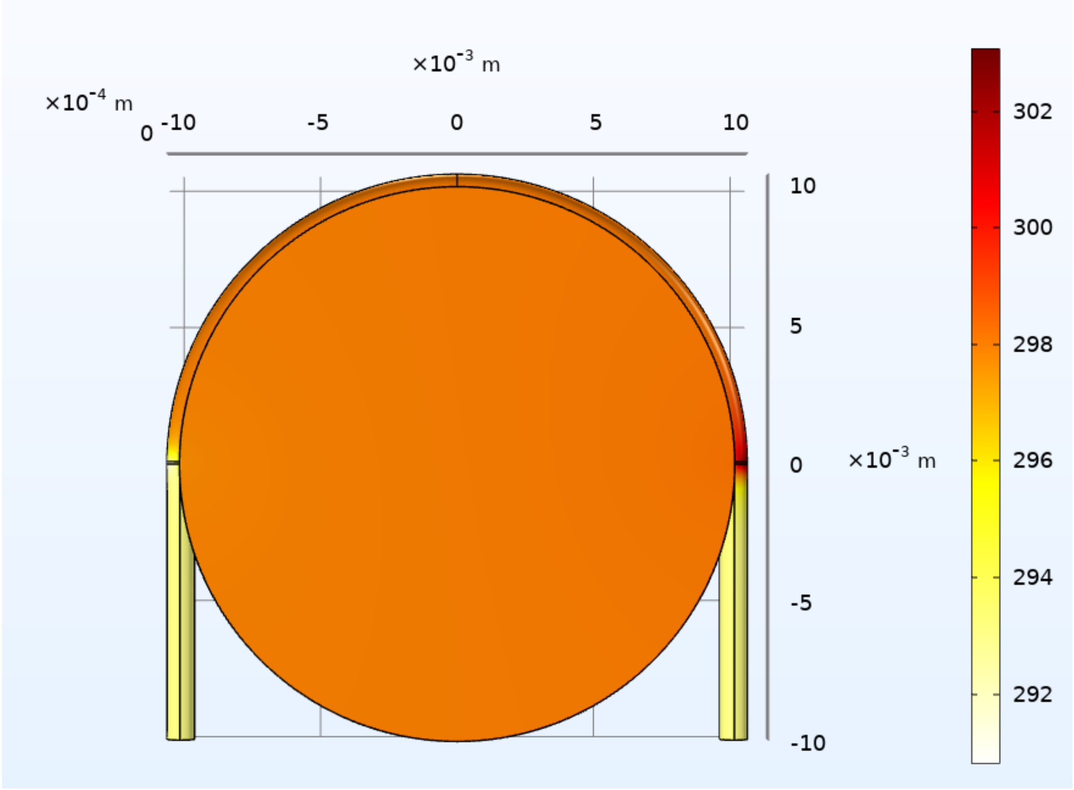
ρ = denstity [kg/m^3]

Steady State Surface Temperature Plot



Results

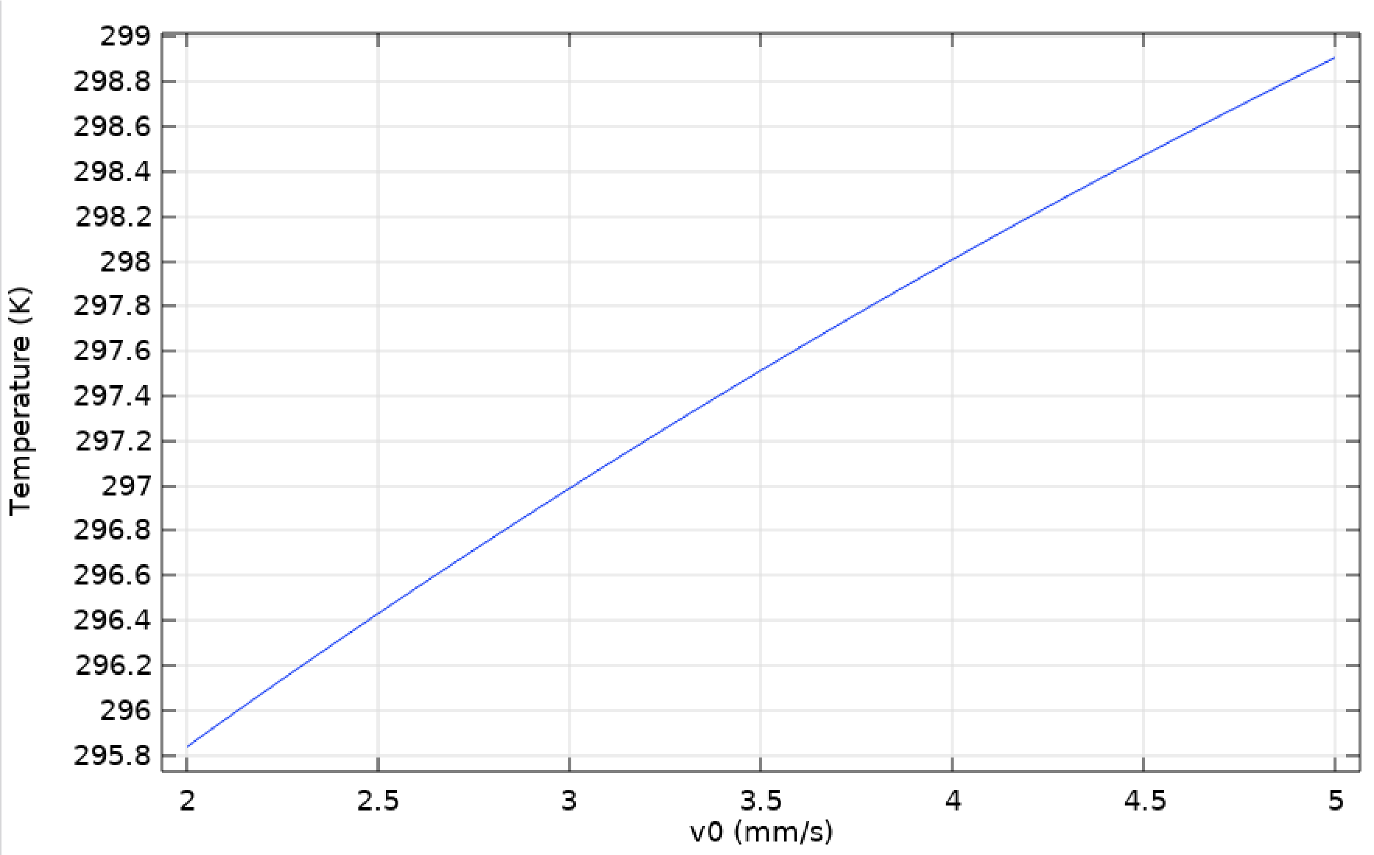


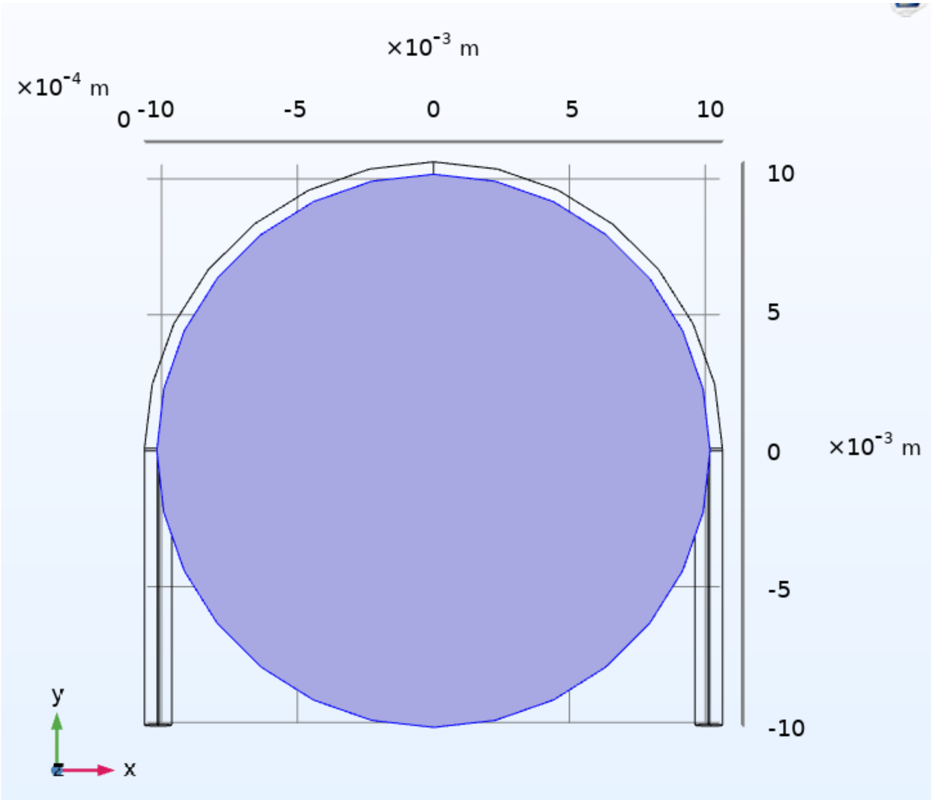


Where v0 = 4 mm/s

ΔT ~ 10°C

Results – Parametric Sweep of v0





Sweep type: Specified combinations

Parameter name	Parameter value list	Parameter unit
v0 (initial velocity)	range(2,0.1,5)	mm/s

$$q'' = L * v0 * \rho$$

Next Steps

- Develop and map strain field over the model, based on experimental data
- Parametric sweep over remaining parameters: contact resistance, wire-disc contact area, feed rate, strain rate
- See how each affects Coefficient of performance, change in wire temperature, change in disk temperature