CubeSat Evaluation and Design

Abhay Menon, Ananthakrishna Ayankalath Thekkepat, Dannel Jacob, Harun Gungør, Samantha Rosenberg

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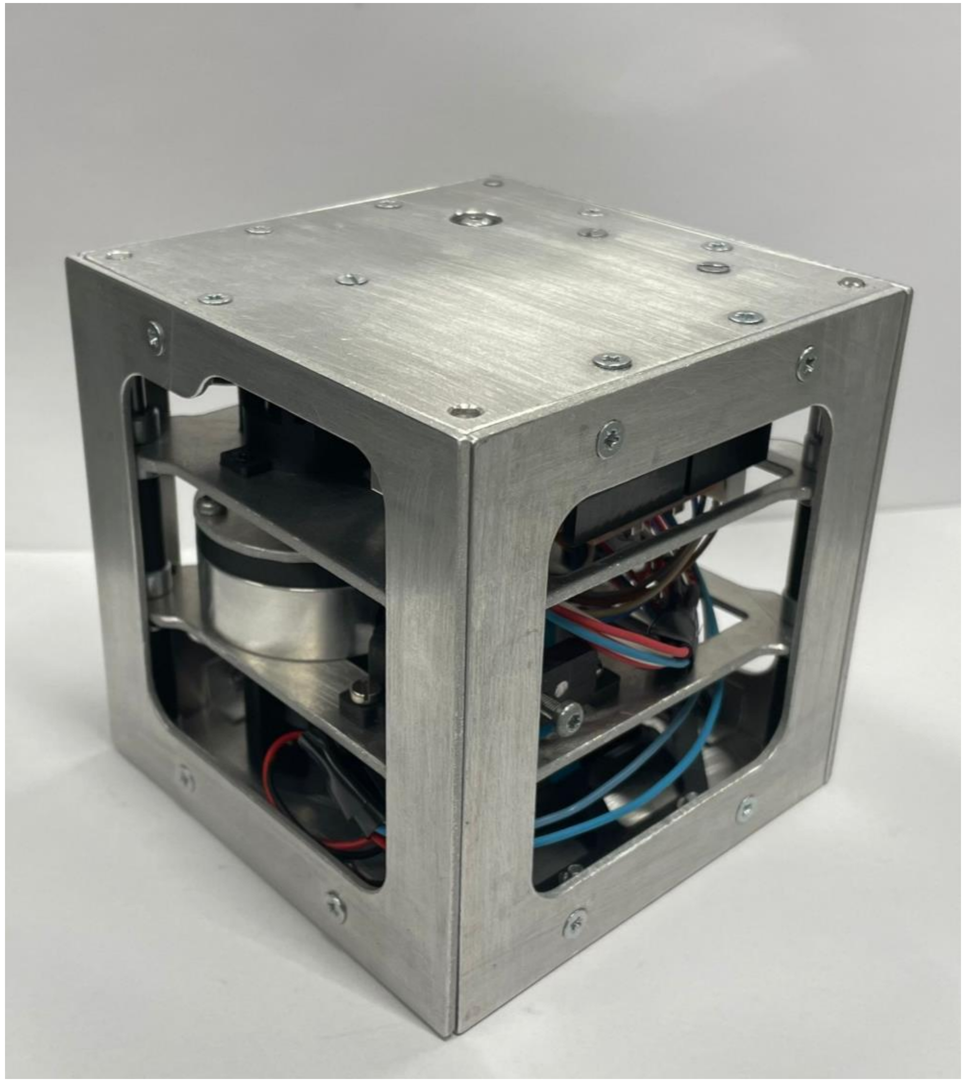
Contents

Introduction

CubeSats

- CubeSats are a class of 'Nano satellites'
- Compact & economic design – lowers barrier of entry into space technology
- Extremely versatile –
  - Design modularity
  - Ease of assembly & testing
  - Standardized sizes
  - Units can be coupled
- Space tribology is extremely important to ensure smooth operation of interacting components in space,
- Requires accurate and intensive testing of Tribological elements in the harsh environment of space



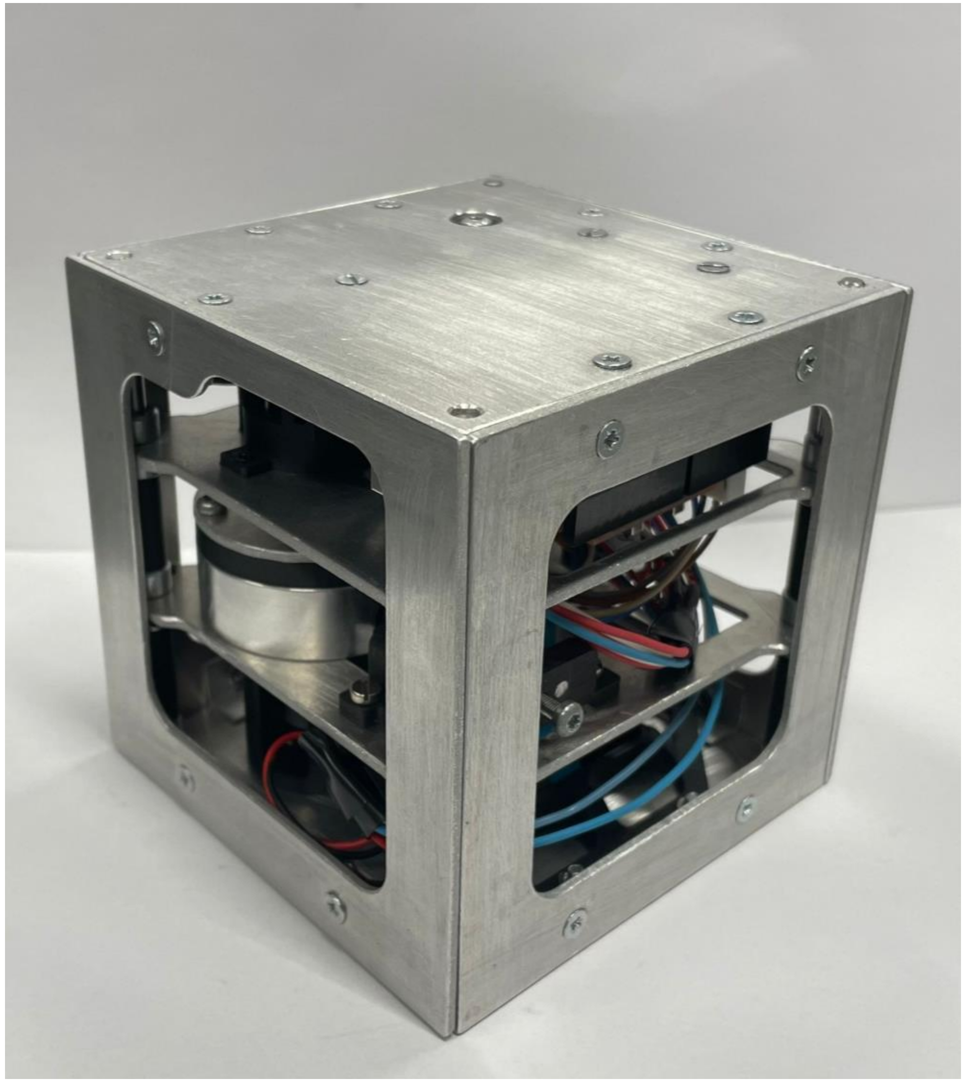
Project Description

Project Goals

- Evaluation of the existing CubeSat design
- Develop concepts for tribometers
- Redesign of theoretical space borne system
- Commission, calibrate and test the terrestrial design twin

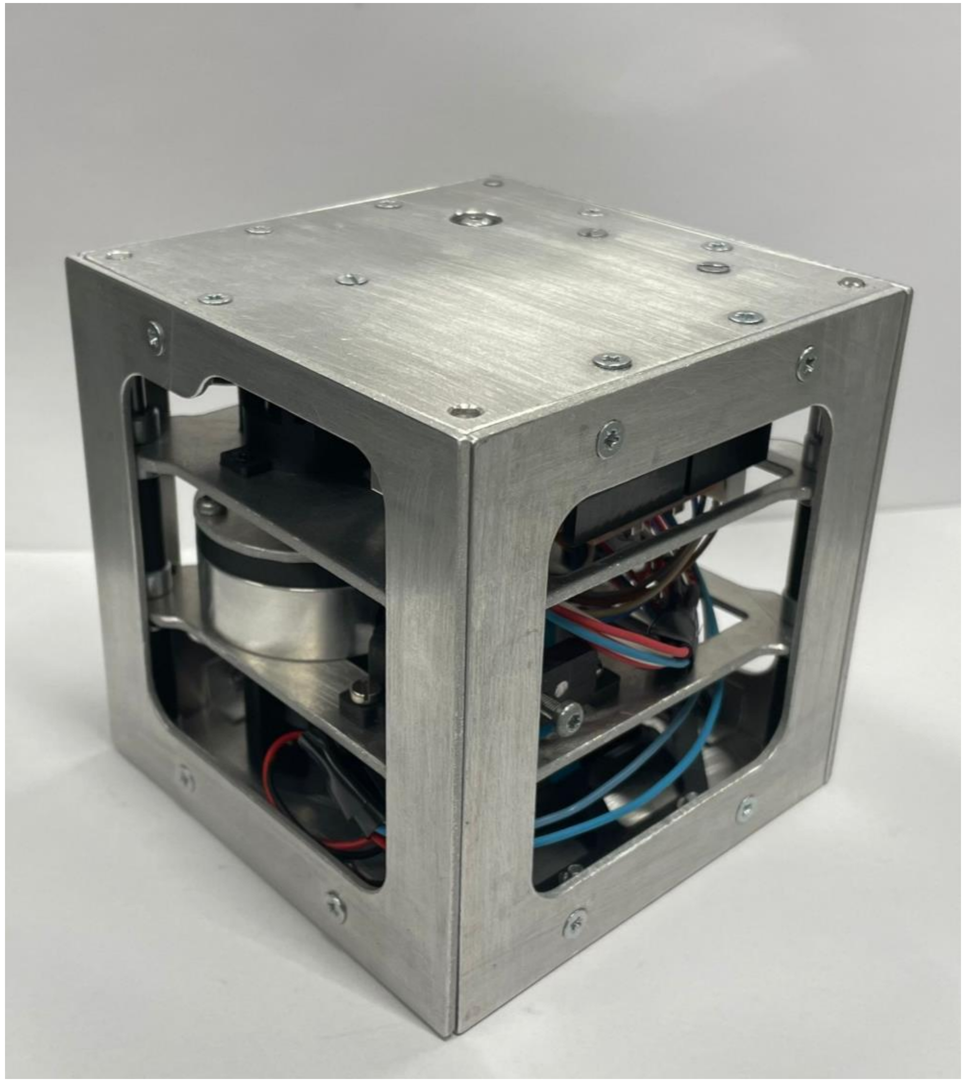
Scope

- Prepare PDS and time plan.
- Concept development, evaluation and selection.
- Detailed design of components – mechanical and electrical
- Manufacturing and assembly .
- Basic functional tests to commission the system.



CubeSat Tribometer – Requirements

Design Property	Parameter
Size	10×10×10 cm
Weight	1.33 kg
Power	10 W
Current	4 A
Voltage	2.5 V
Tribometers	Bearing & Pin-on-Disc
Load application	3 Presets
Measurement modules	Load & Temperature
Bearings	Preloaded
Redundancy	Yes
Modularity	Yes
Maximum load	1 N
Working torque	2-5 mNm



Project Overview

Project Start

Week 6
2023

Start-up meeting
Project development
Literature survey

Design Review

Week 9
2023

Critical Design Review
Desing Evaluation

Concept

Week 14
2023

Concept Generation
Concept Evaluation
Concept Selection

Design

Week 36
2023

Mechanical Design
Electrical Design

Ordering Parts

Week 40
2023

Purchase of
key components

Manufacturing

Week 46
2023

3D printing
Machining

Assembling

Week 48
2023

Prototype assembly

Testing

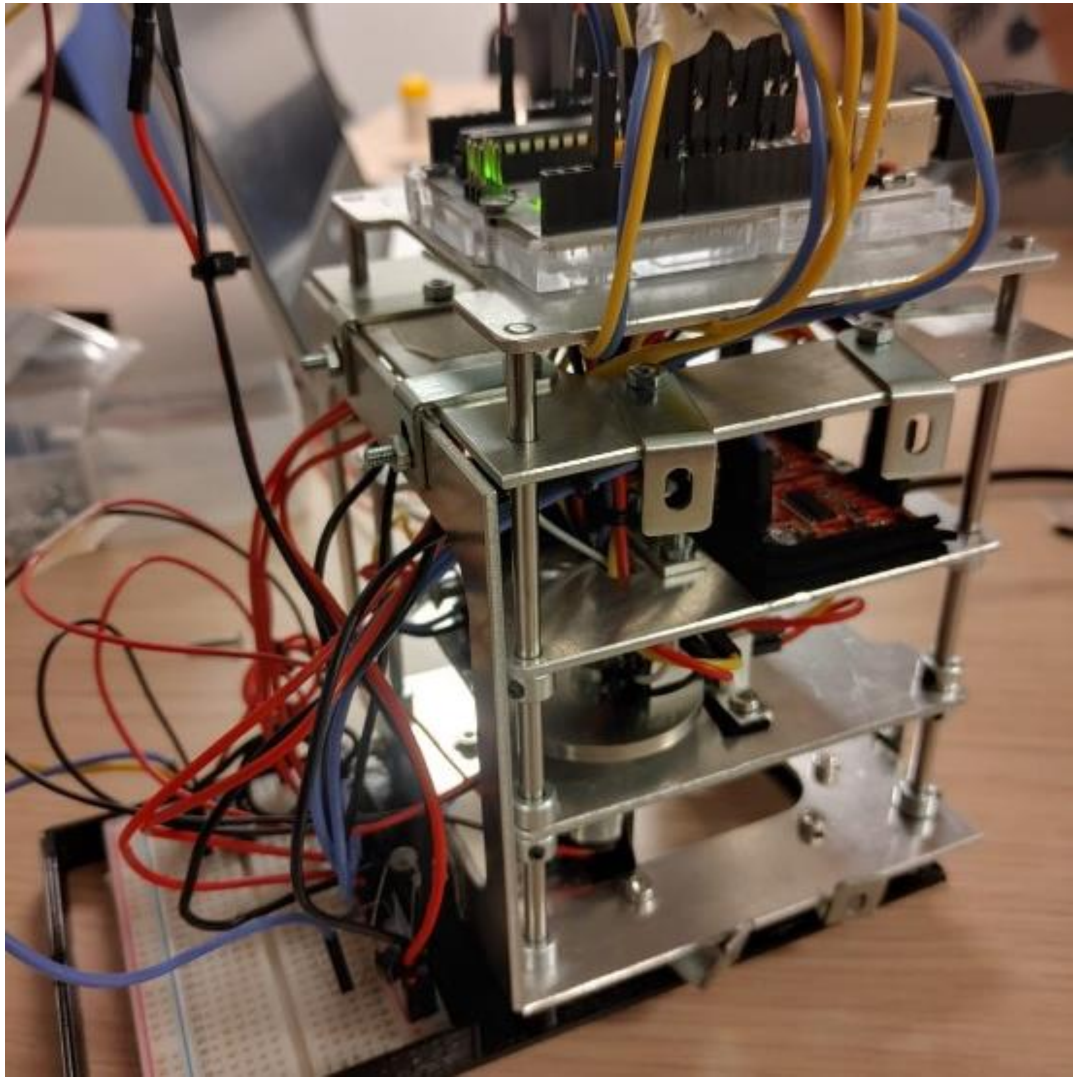
Week 50
2023

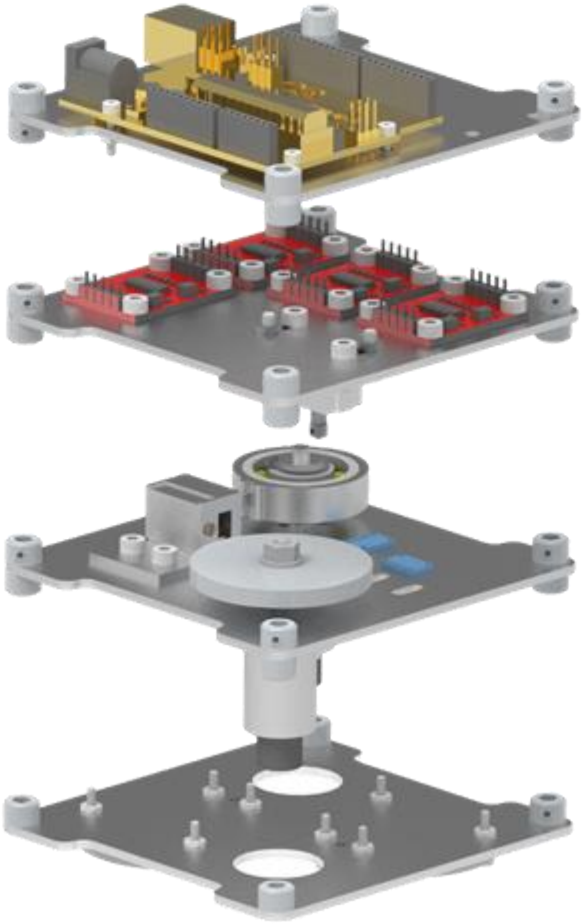
Calibration
Testing

Concept

Design evaluation
Concept Generation
Concept Selection

Design Evaluation of CubeSat 2022





First floor:
Control Board and Temperature Sensor

Second floor:
Load Cells Amplifiers

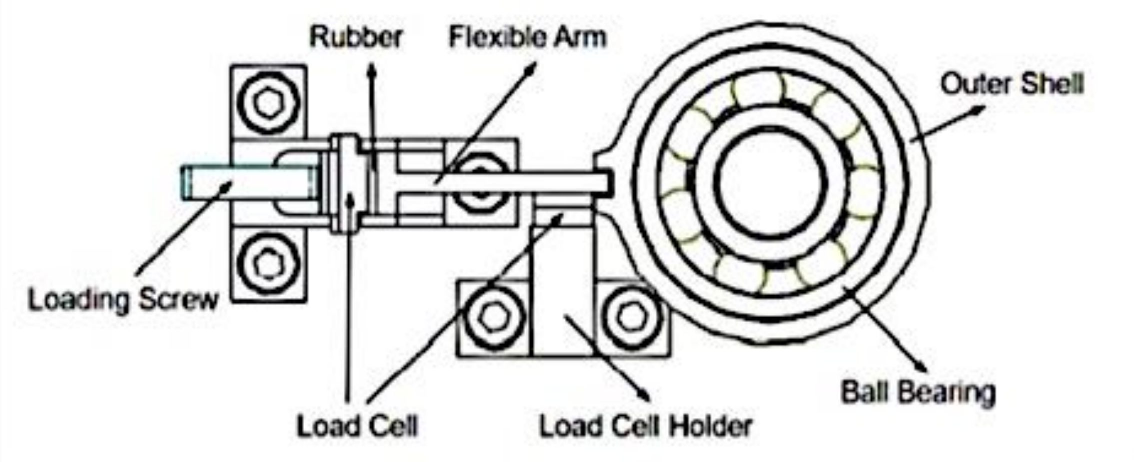
Third floor:
Pin-on-Disc and Ball Bearing tribometer setup

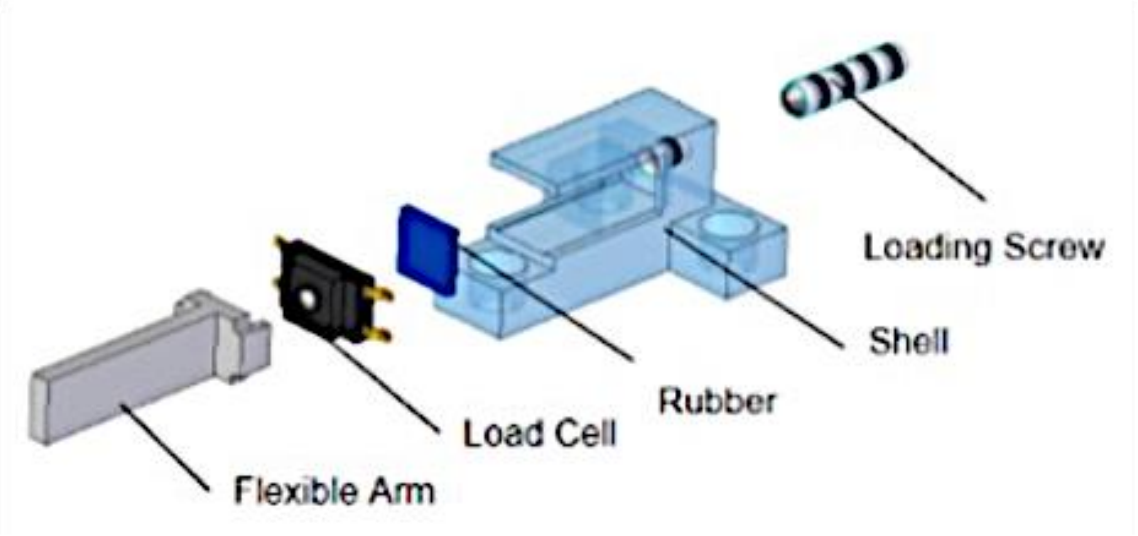
Fourth floor:
Motor driver

Design Evaluation of CubeSat 2022

Ball Bearing Tribometer

- The inner ring is rotated by motor shaft and outside ring was free to rotate.
- Load was applied on the outer ring.
- Forces related to loading and defection of flexible arm was measured by load cell.
- Disadvantages include manufacturing, assembly and misalignment due to manufacturing tolerances
- Load cell was damaged due to overload.

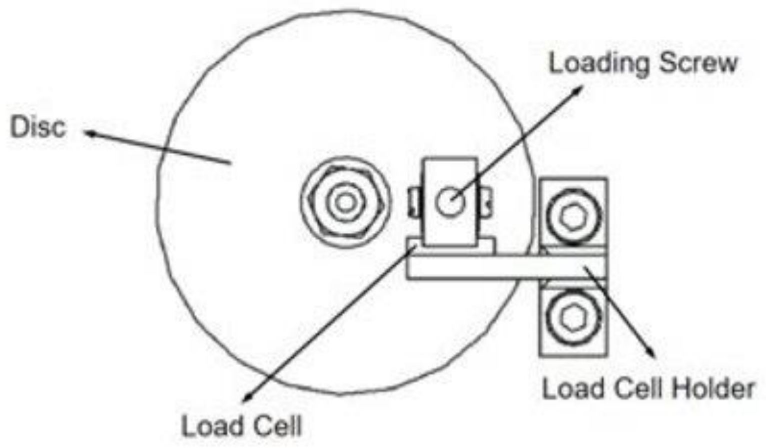


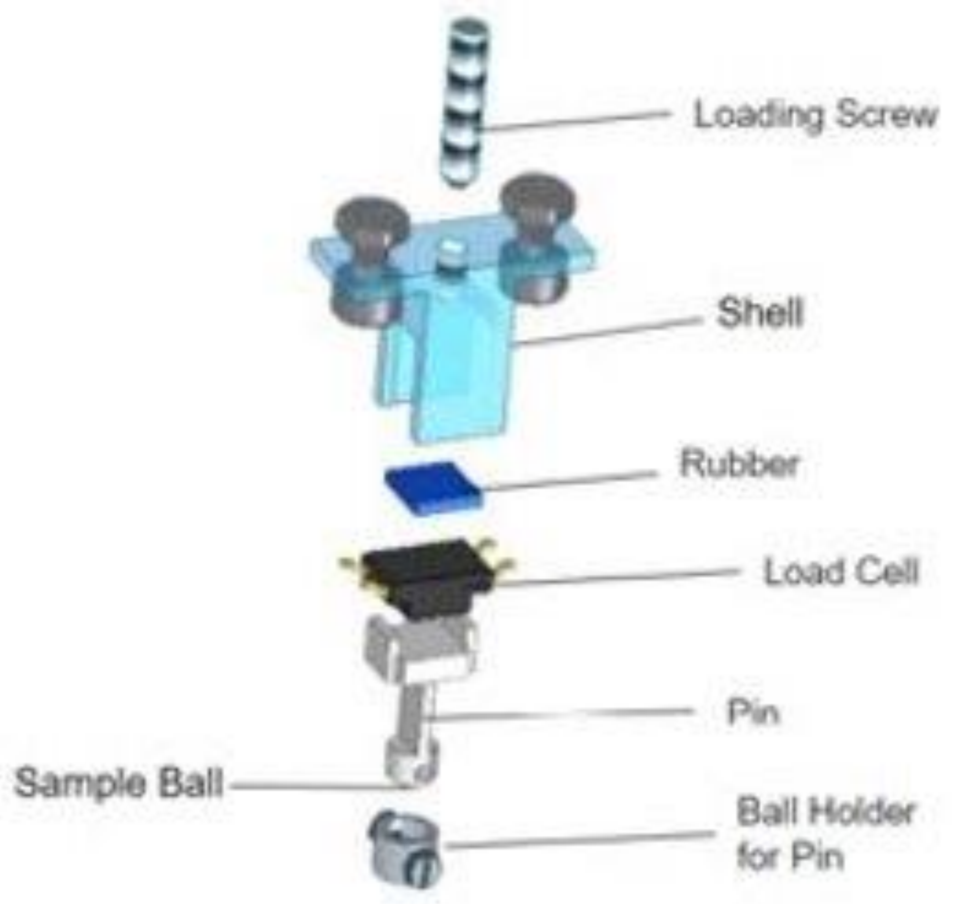


Design Evaluation of CubeSat 2022

Pin-on-Disc Tribometer

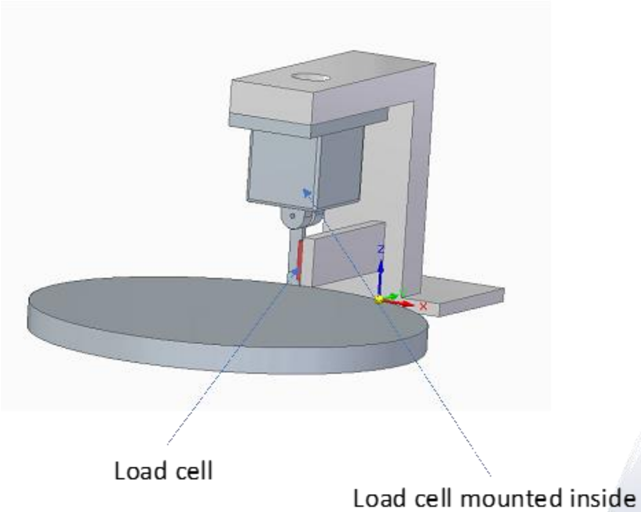
- Contained a single pin loaded by screw.
- Forces of load application and deflection was measured via load cells.
- Deflection of pin was back calculated to measure friction torque.
- Misalignment of motor coupling screw led to no contact with Load cell therefore not collecting any data
- Unbalanced forces due to loading of pin caused wobble and error in measurements.

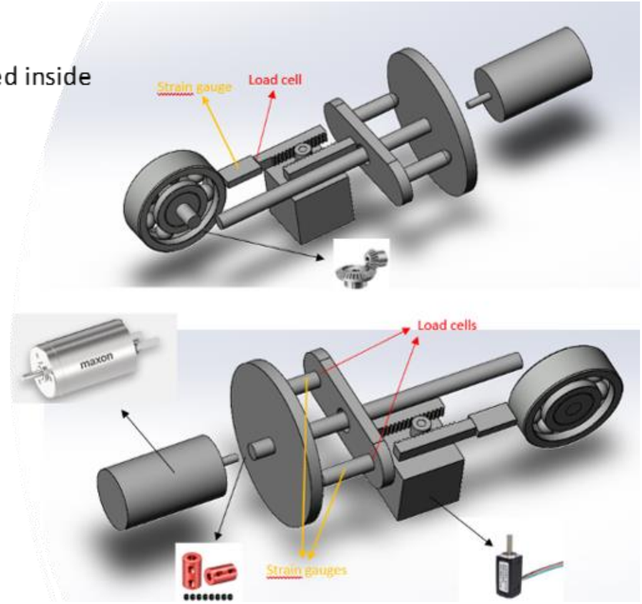


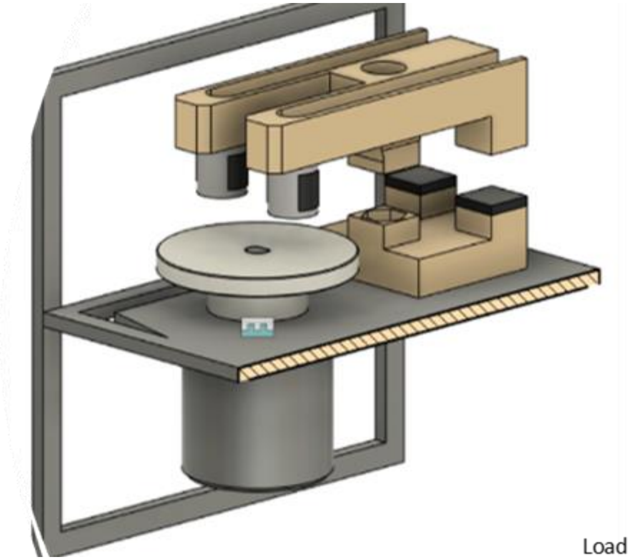


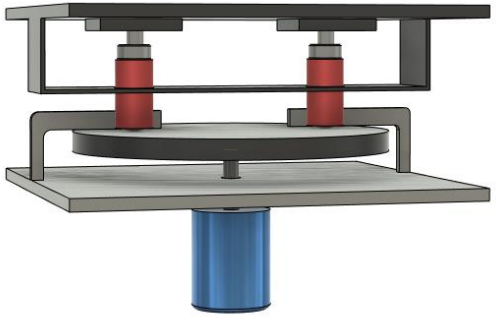
Concept: Pin-on-Disk Tribometers

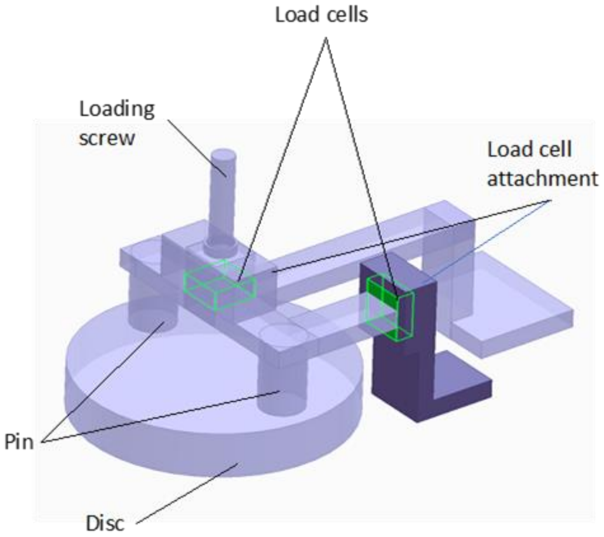
- Key takeaway was the requirement of a focused study and development of diametrically loaded pin system to mitigate previous issues with the Tribometer.





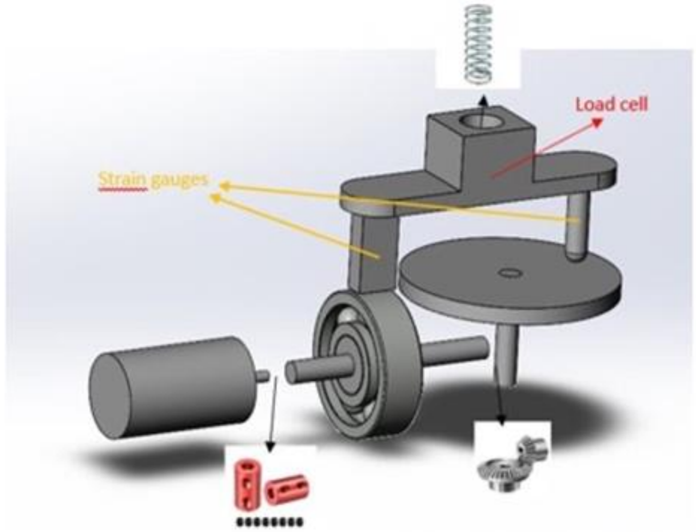


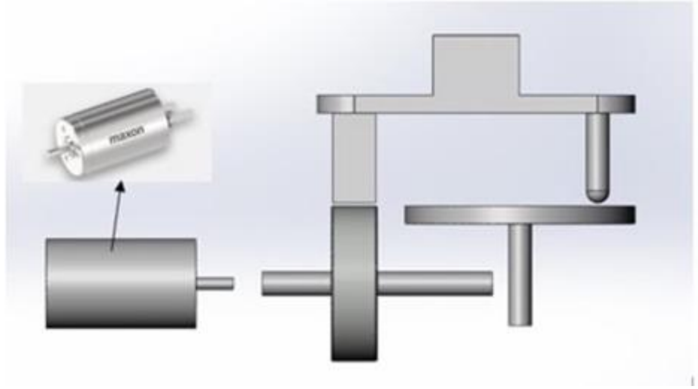


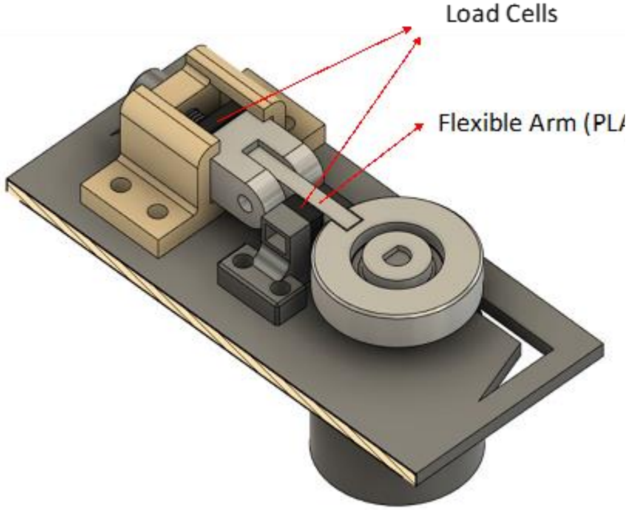


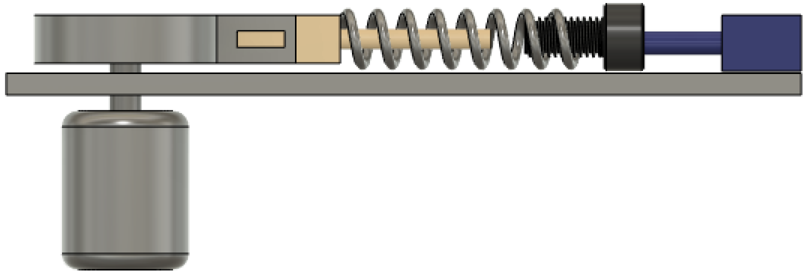
Concept: Ball Bearing Tribometers

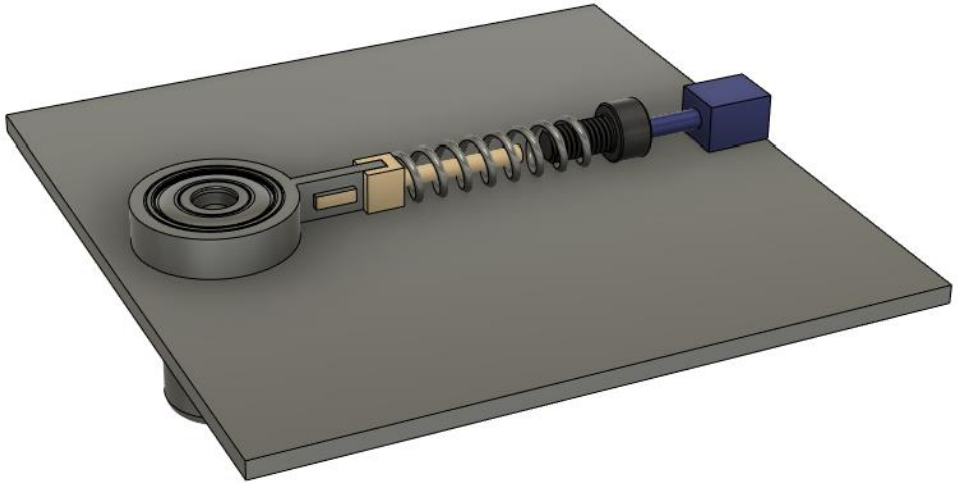
- Takeaways included focus on updating shell for screw loading to optimize manufacturability and ease of applications of load.







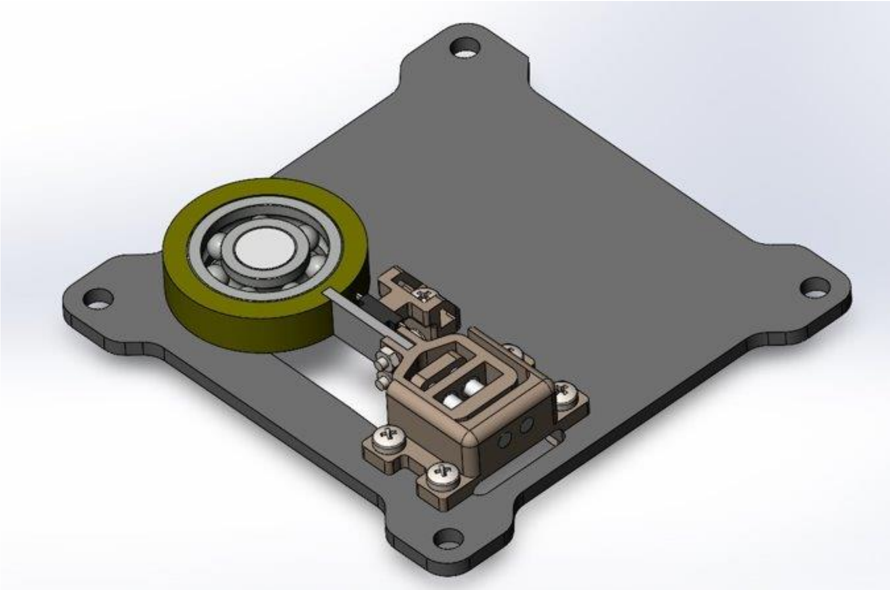




Selected Tribometer Concepts

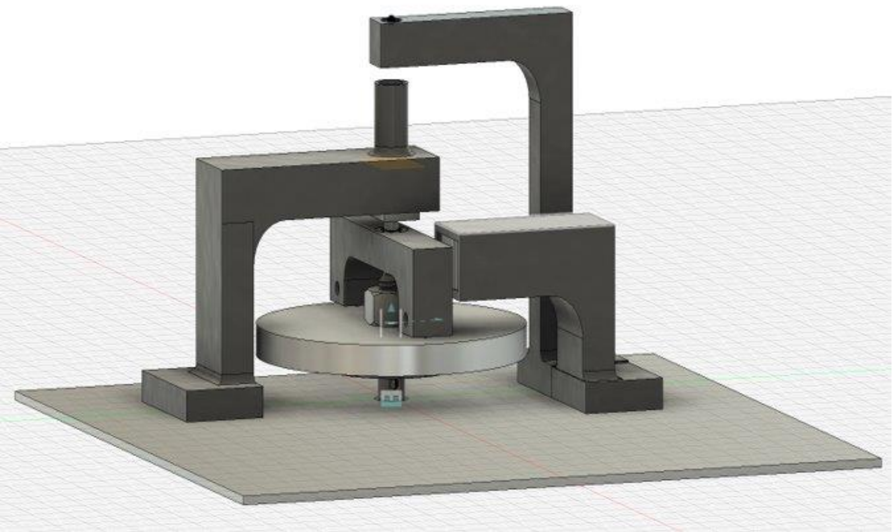
Ball Bearing Tribometer

- Updated tribometer removed one of the load cell related to application of load to prevent cross talk between load cells that could skew the readings.



Pin-on-Disc Tribometer

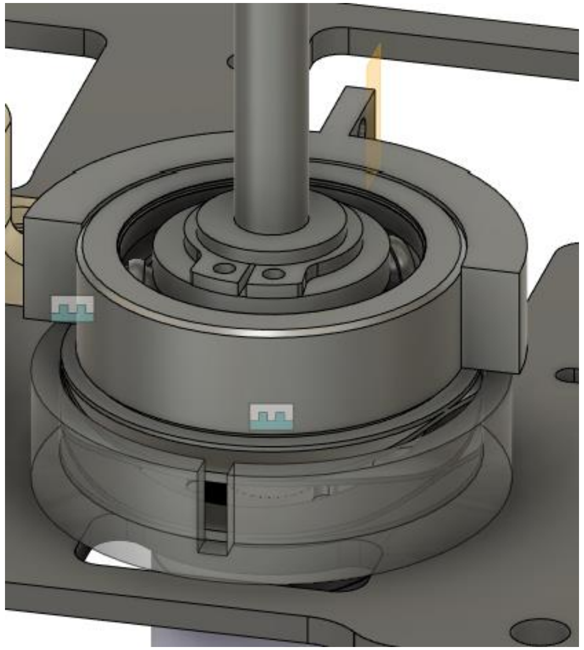
- Diametrically loaded pin system was adopted which allowed for rotation of loading arm to evaluate frictional force.

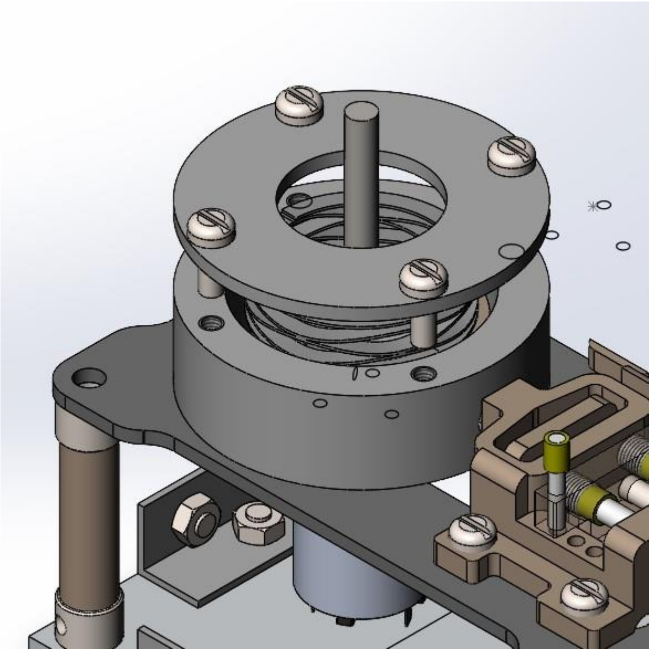


Design Iterations

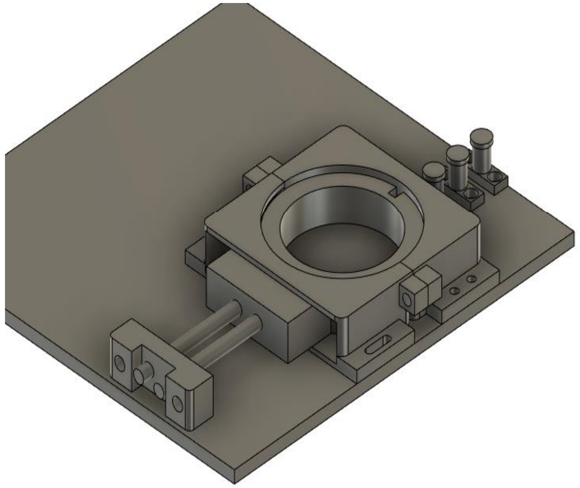
Ball Bearing Tribometer

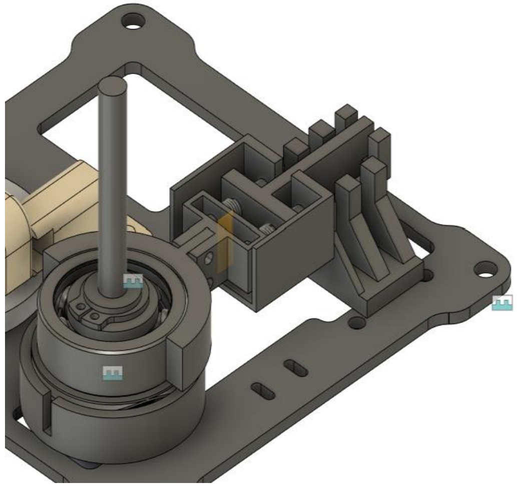
Axial Loading – Iterations

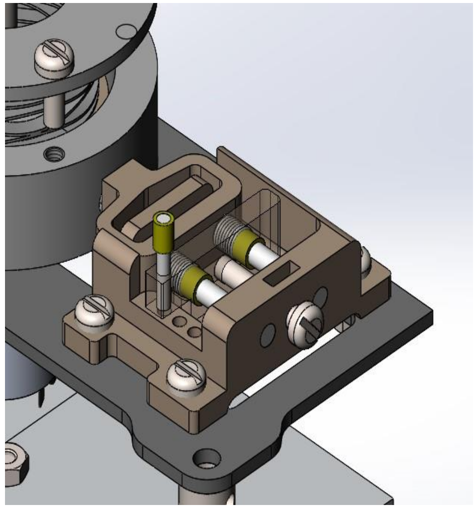




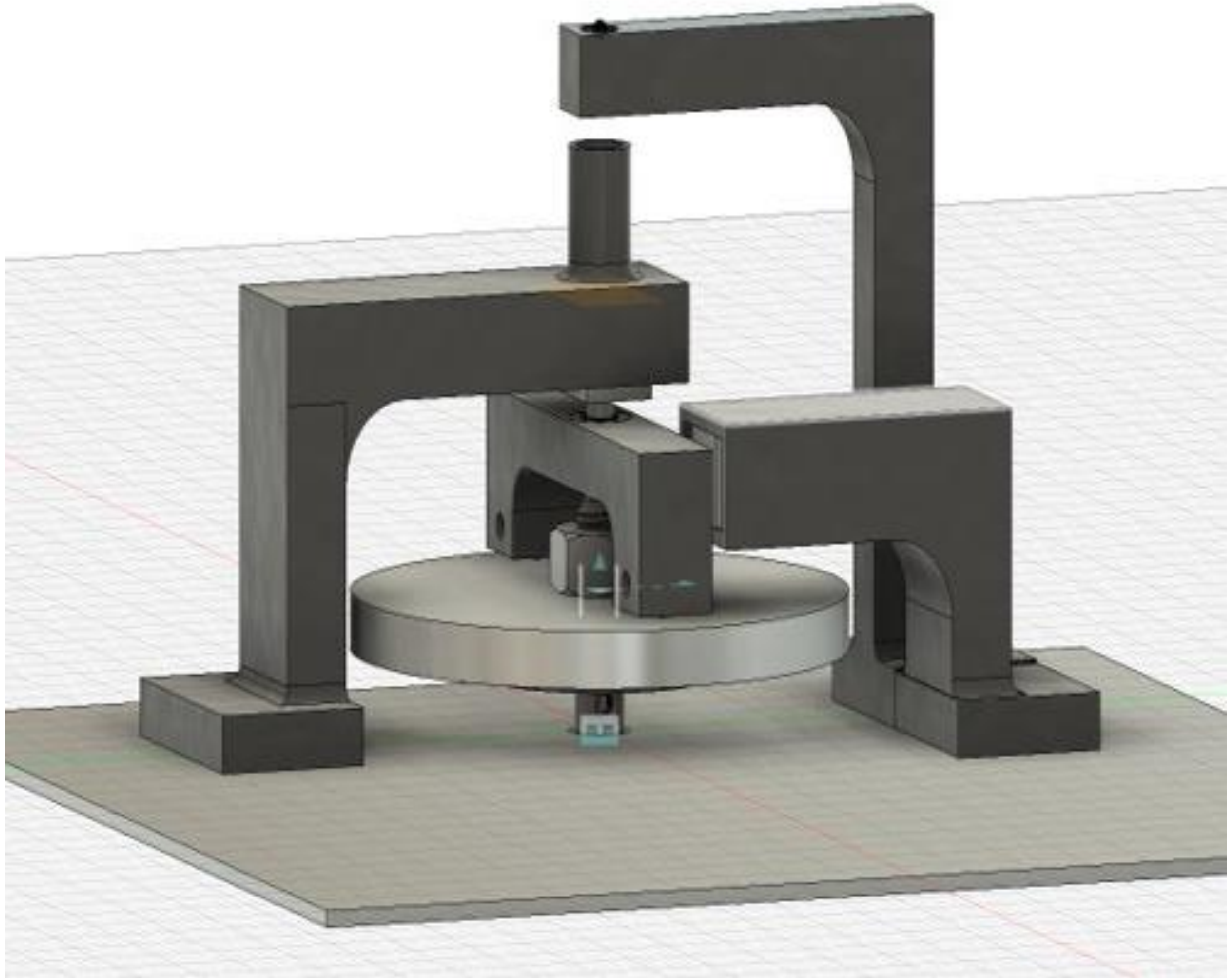
Radial Loading - Iterations

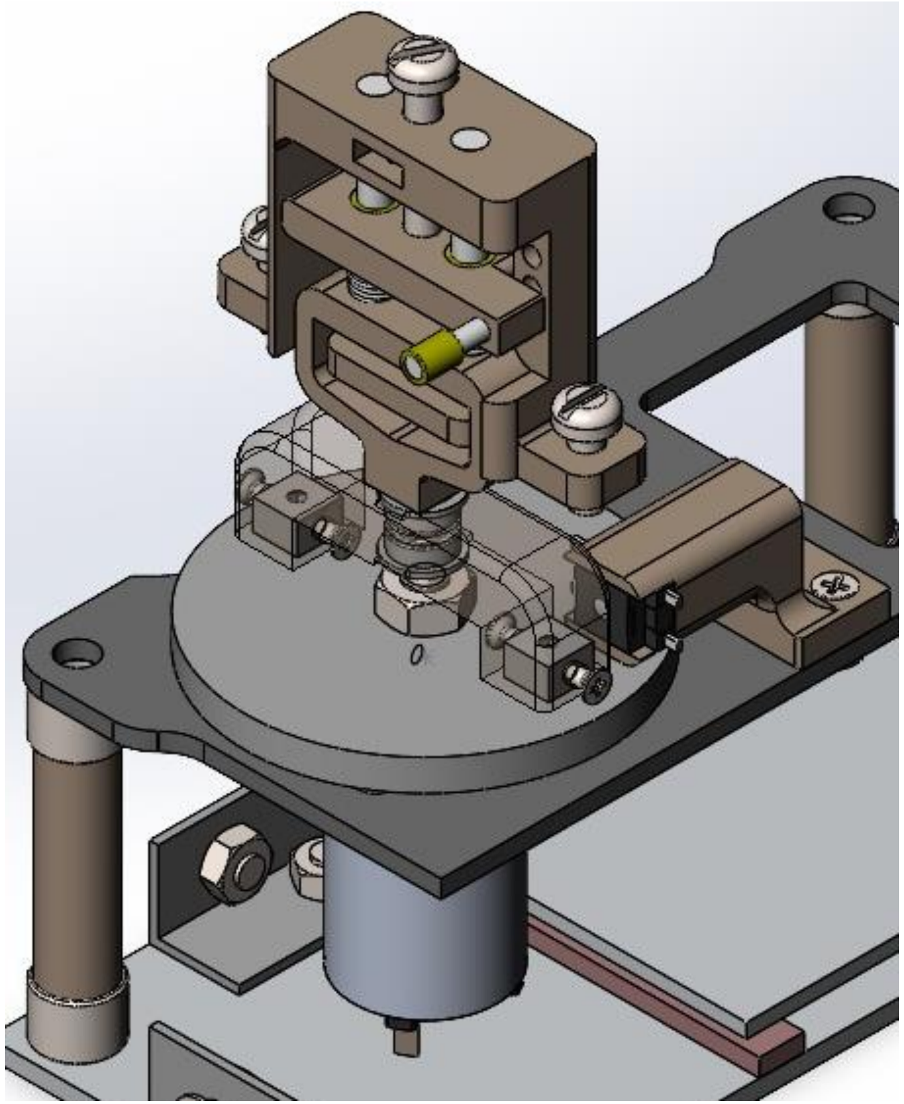






Pin-on-Disc Tribometer

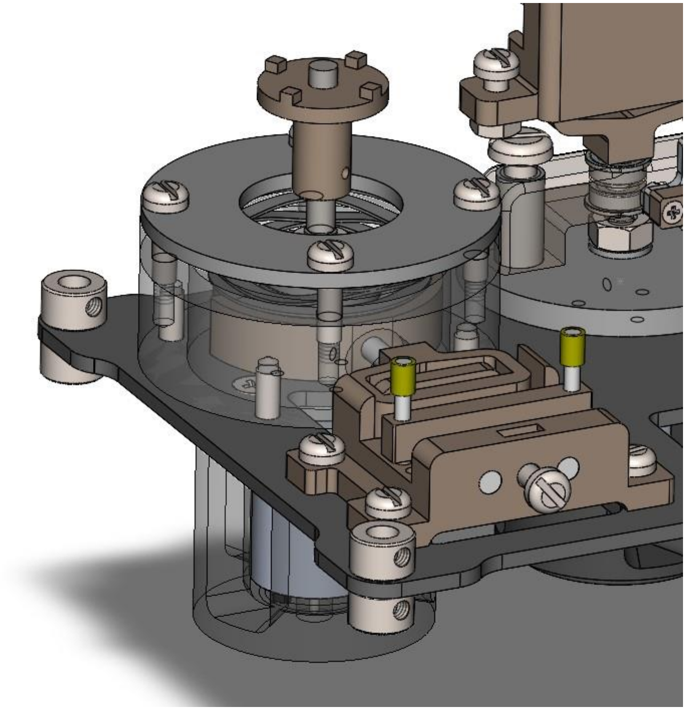


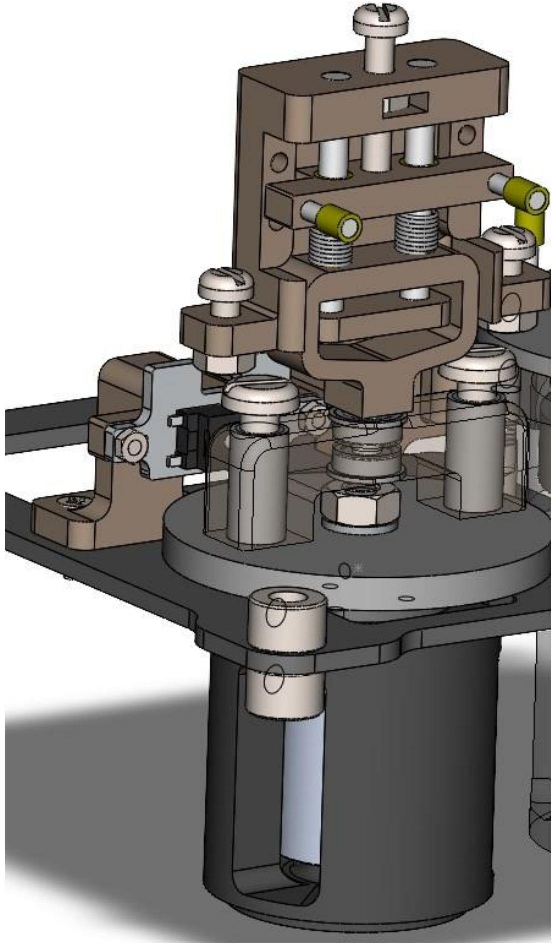


Final Design Iteration

Pin-on-Disc Tribometer

- Spring loading mechanism with presets is introduced in the final design
- Removing the need of load cell (measuring of applied load)
- Two flanged bearings has been integrated into the U-shaped arm to facilitate free rotation of the arm



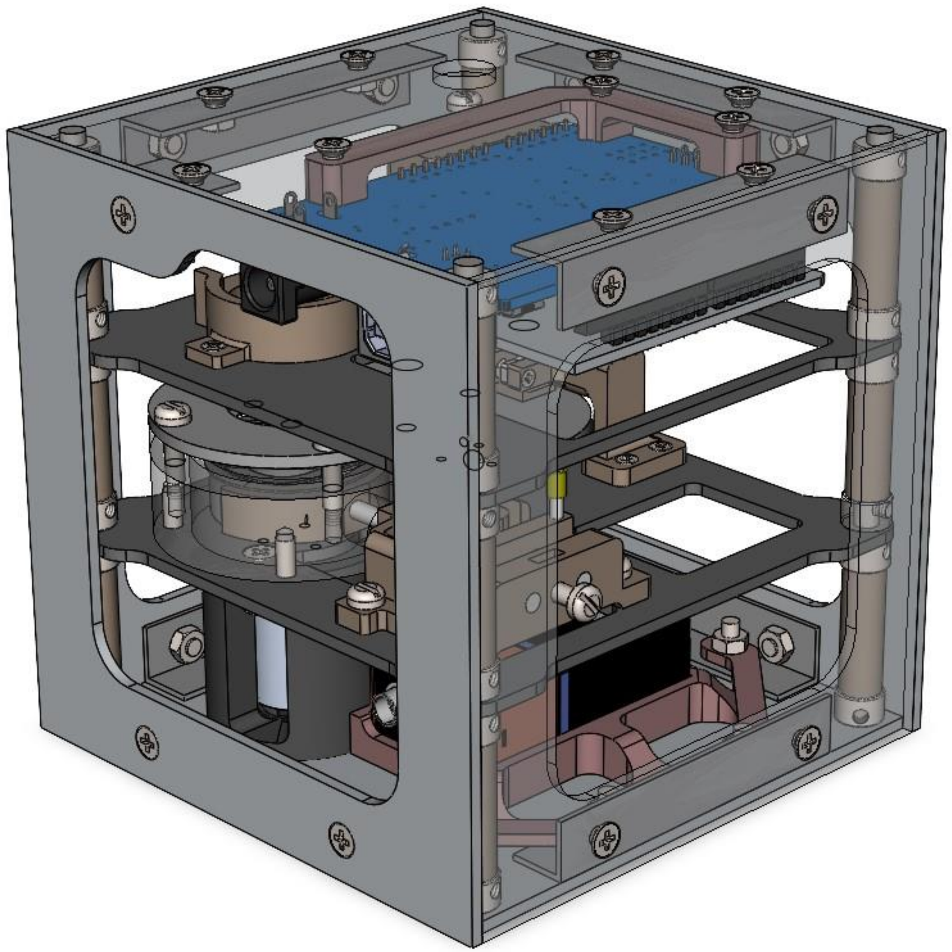


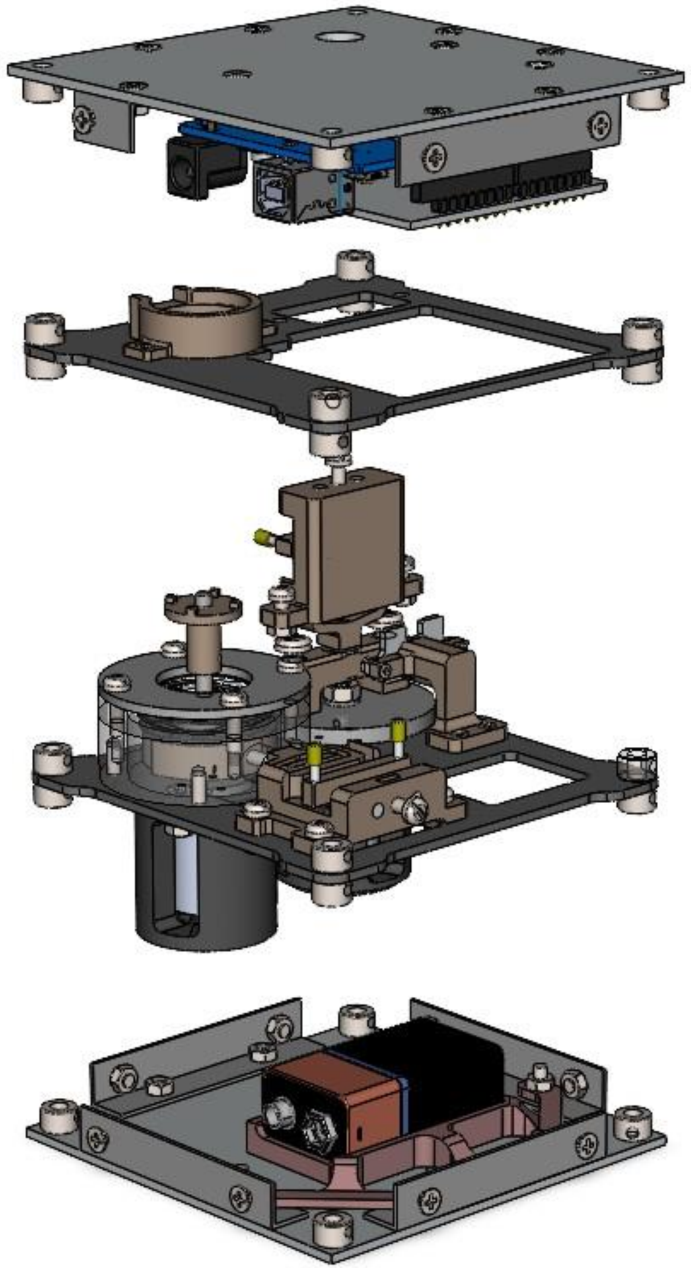
Ball Bearing Tribometer

- The final design axially preloads the bearing from the top.
- Spring based load mechanism with presets and cylindrical rod to account for buckling.

Final Design

Final CAD Design





Top floor
- Arduino and custom PCB
- Arduino seat
- Custom L brackets mounting

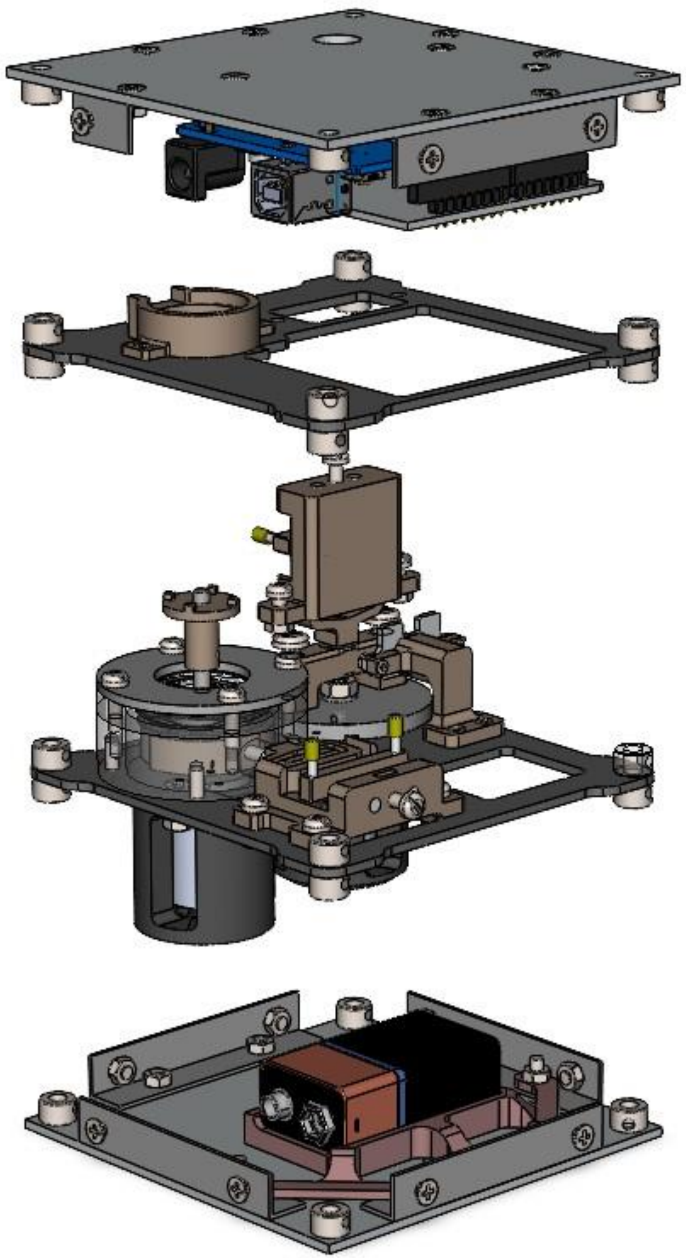
Floor 2
- Pin-on-disc load mechanism
- Encoder seat

Floor 1
- Pin-on-disc tribometer
- Ball bearing tribometer
- DC Motor mounting
- Cage for ball bearing tribometer, load cell arm for pin-on-disc tribometer

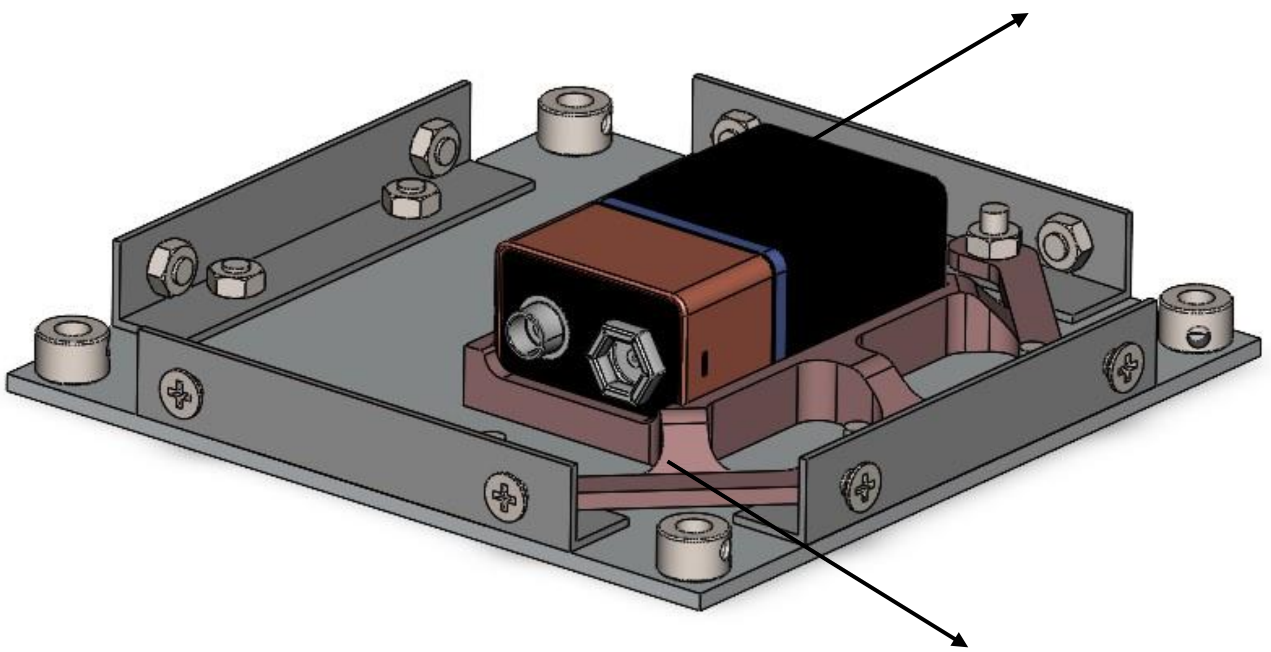
Base Floor
- Battery holder
- Motor support parts
- Custom L brackets mounting

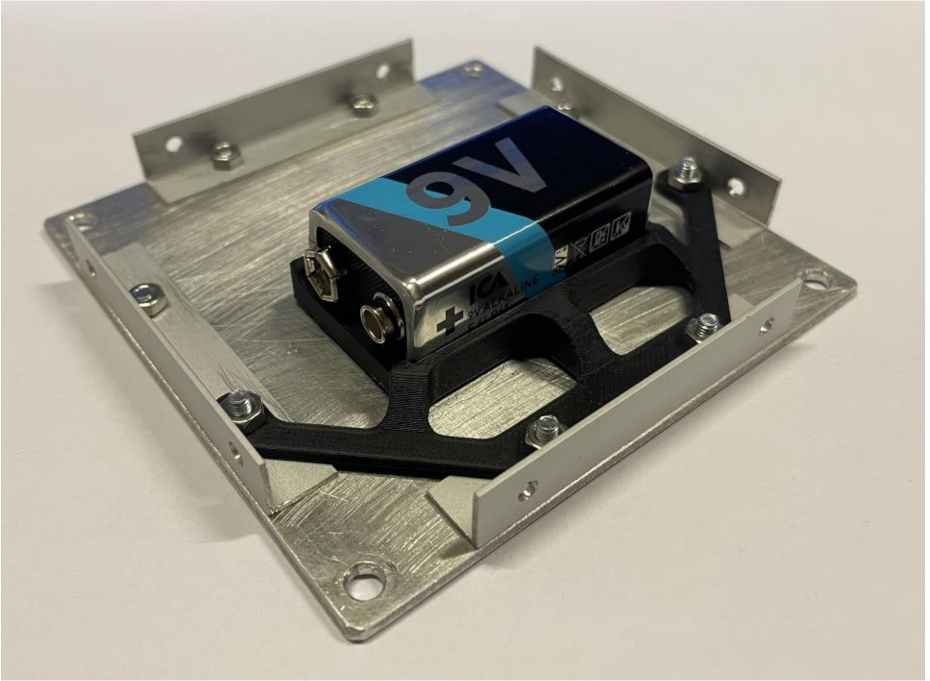
Final CAD Design

- 2 floor assembly
- 2 mm sheet metal for floors and frames
- Custom L-brackets for mounting the frames
- Floors located in right position through 4 mm shafts with collars and 3D printed hollow cylindrical parts

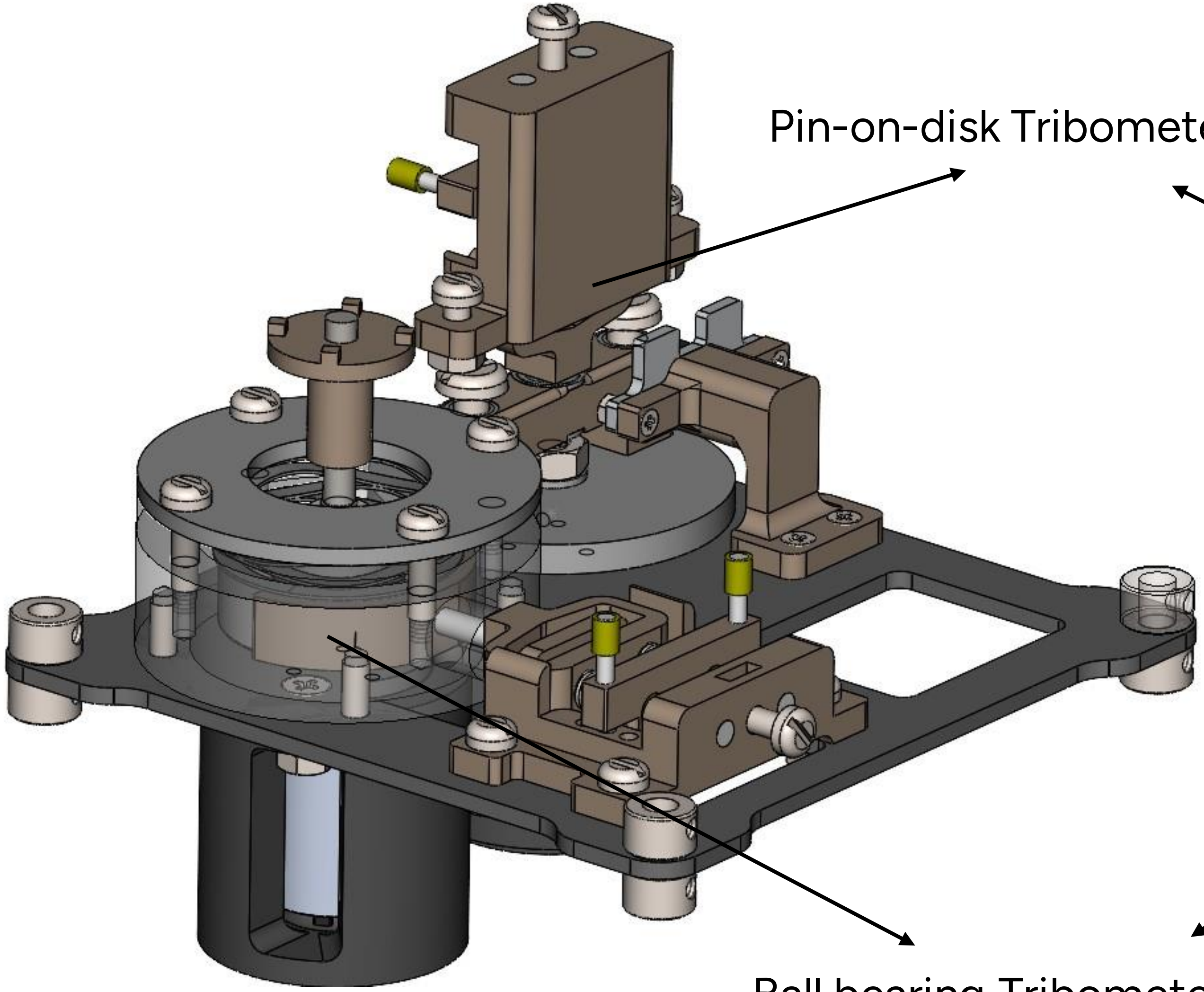


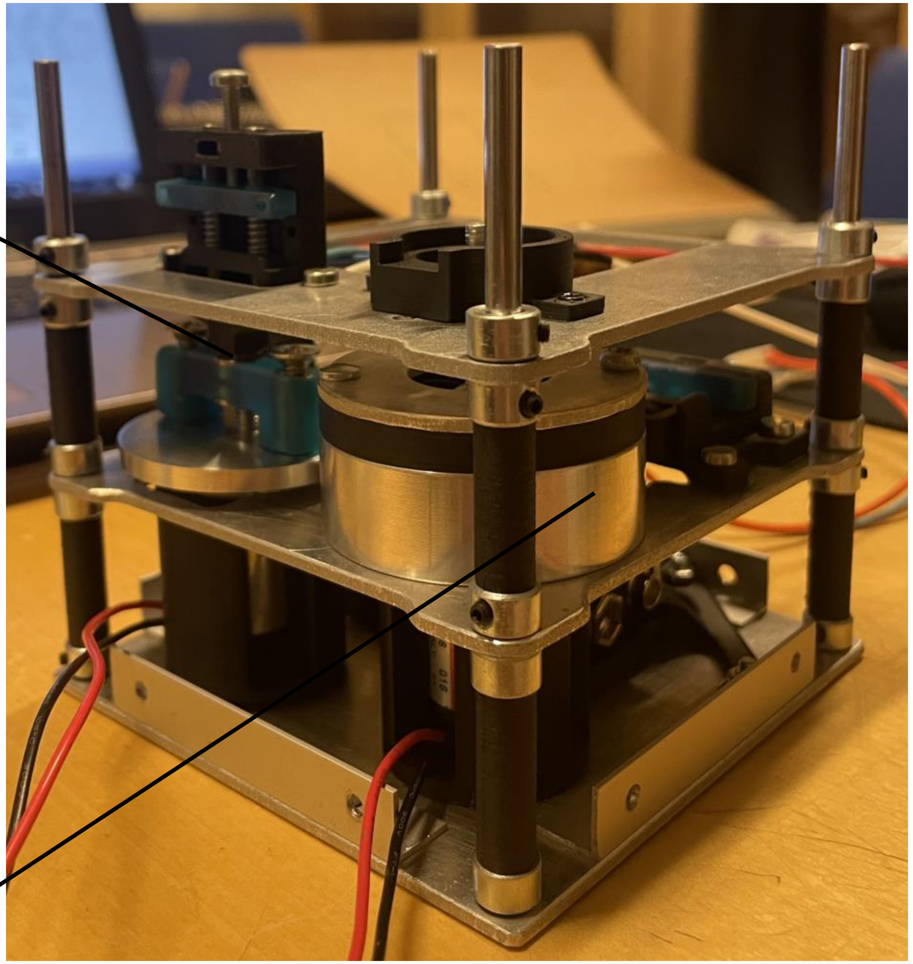
Base Floor





First Floor (Tribometers)

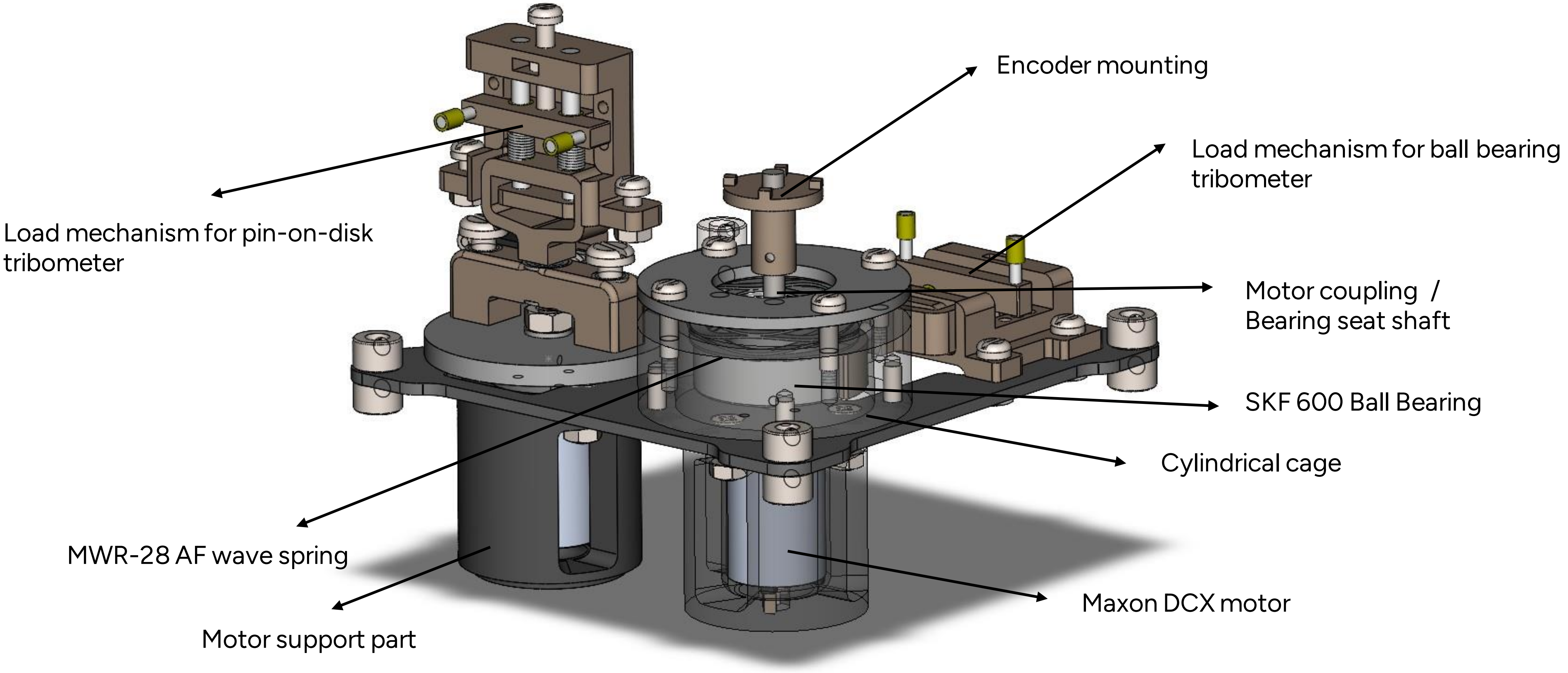




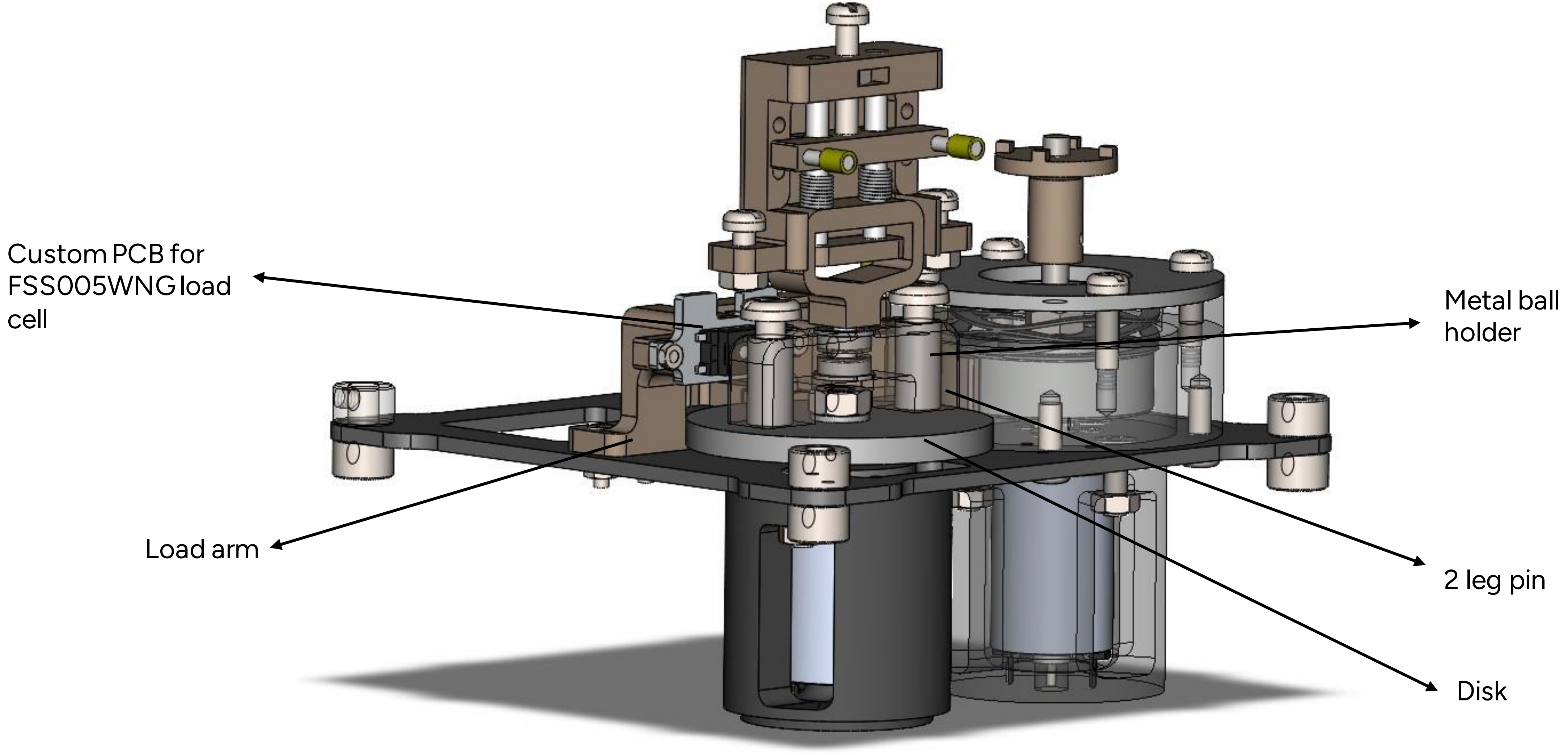
Pin-on-disk Tribometer

Ball bearing Tribometer

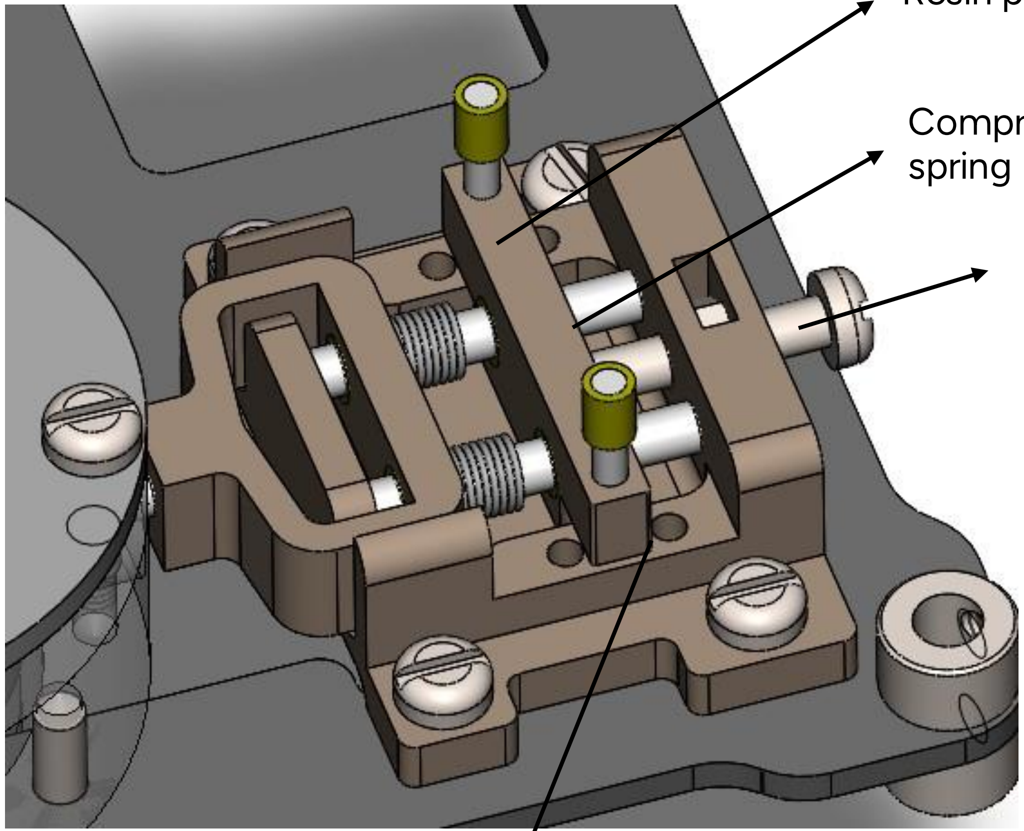
First Floor (Tribometers)



First Floor (Tribometers)



First Floor (Load Mechanism)

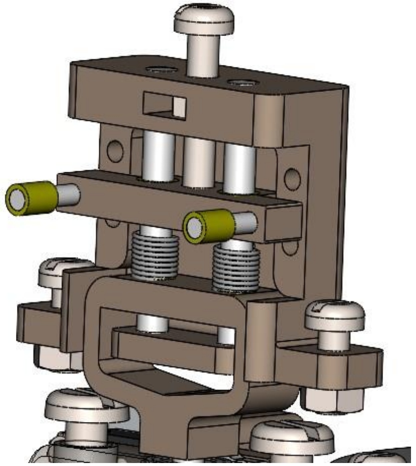


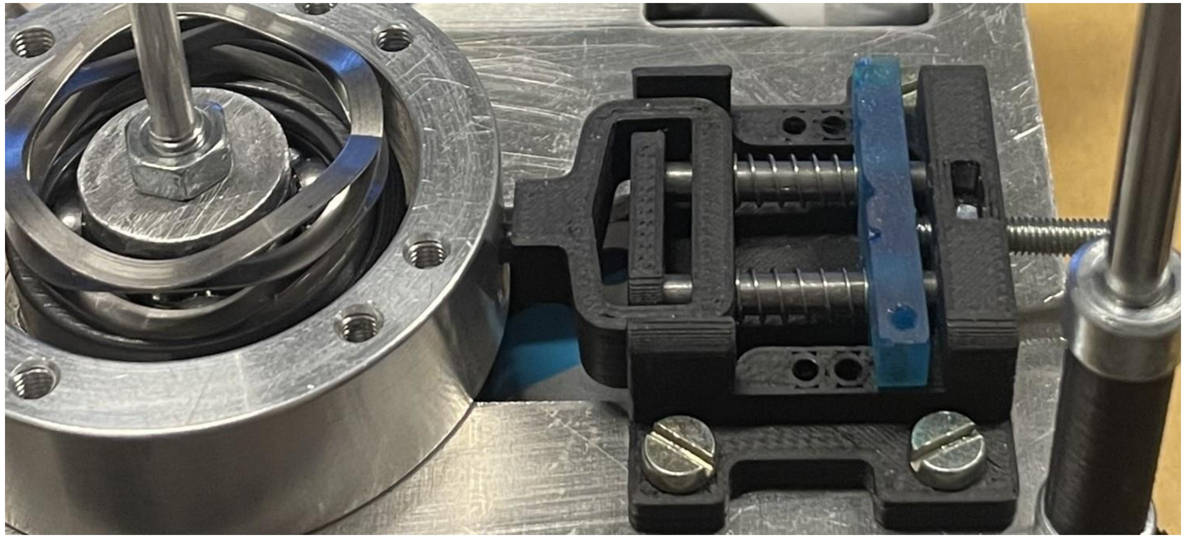
Resin printed moving part

Compression
spring

Changing the load with
M3 bolt

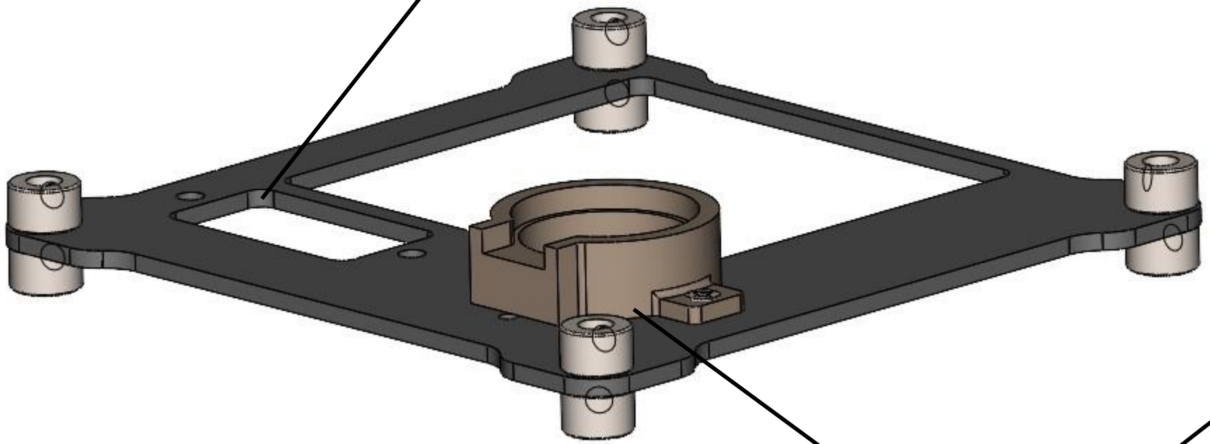
3 differet load
presets

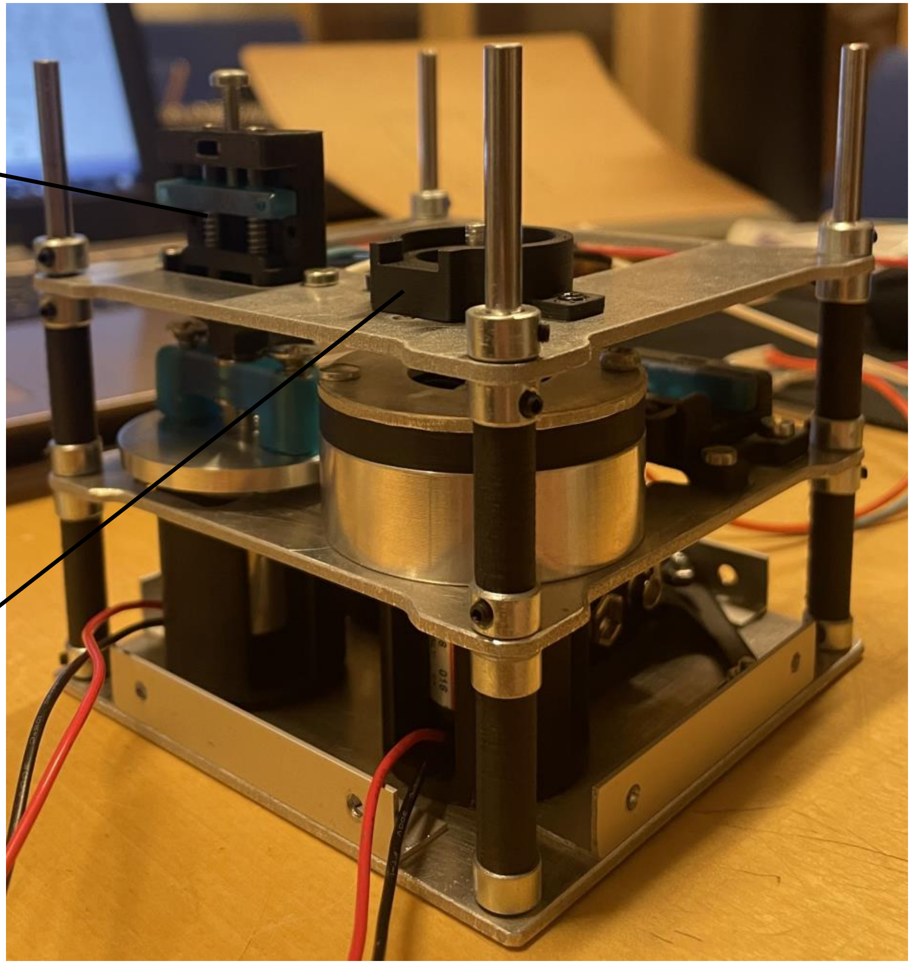




Second Floor

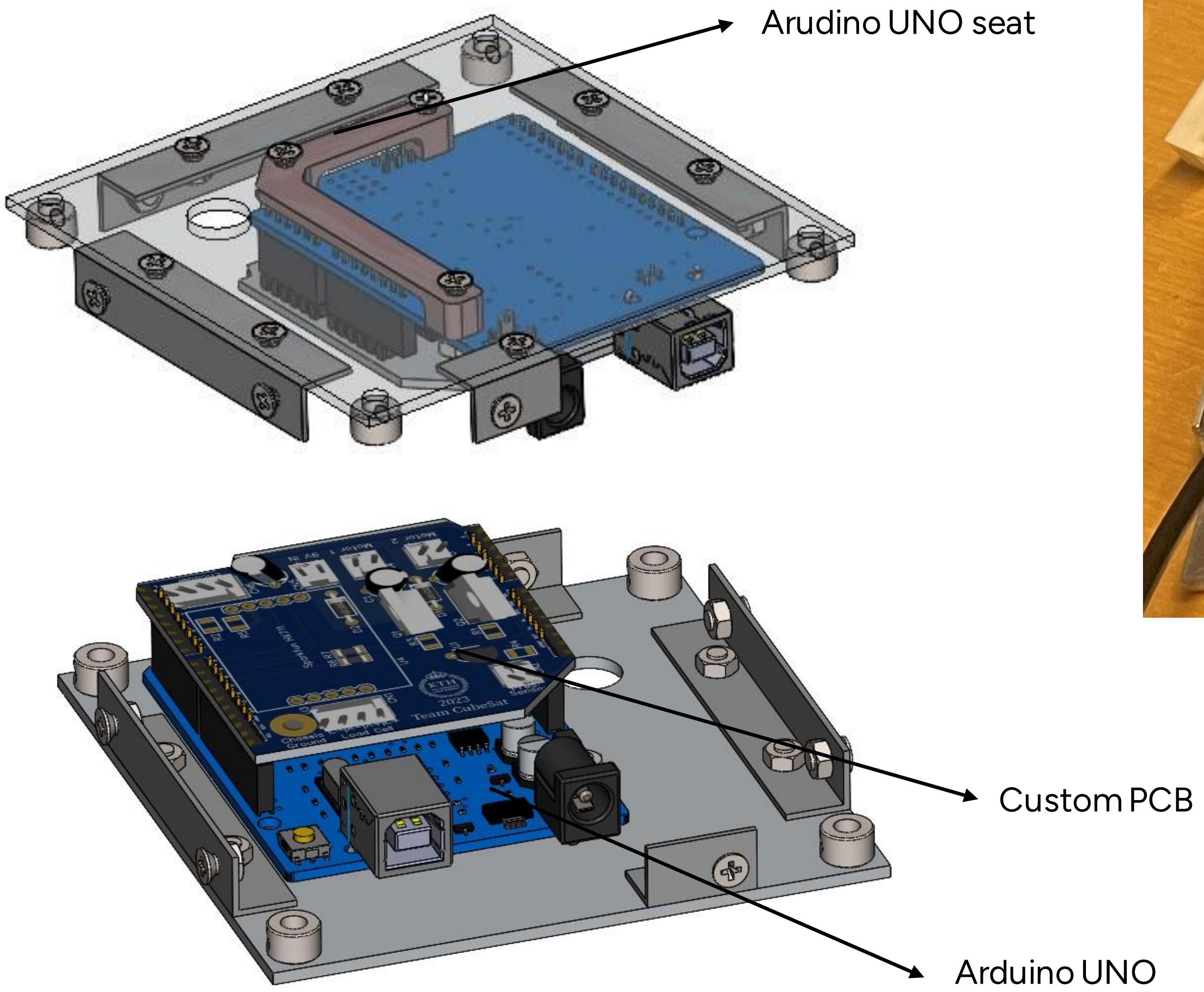
Load mechanism from pin-on-disk tribometer

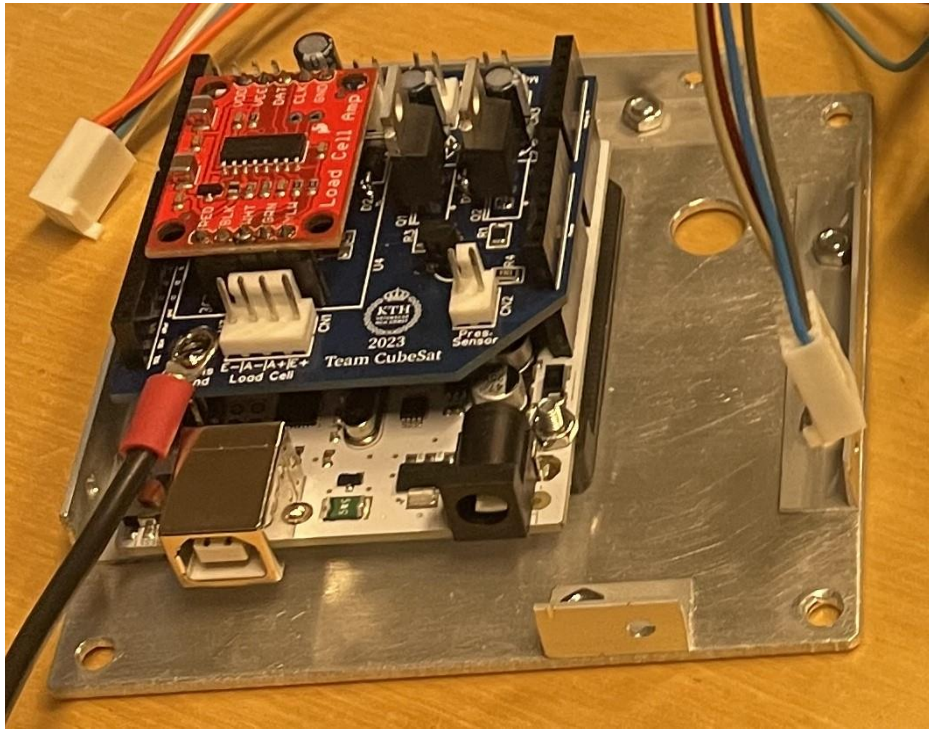




Encoder seat

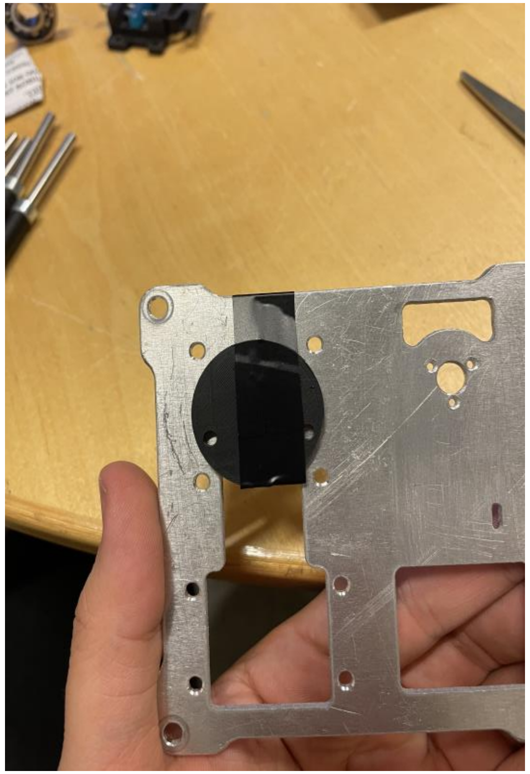
Top Floor

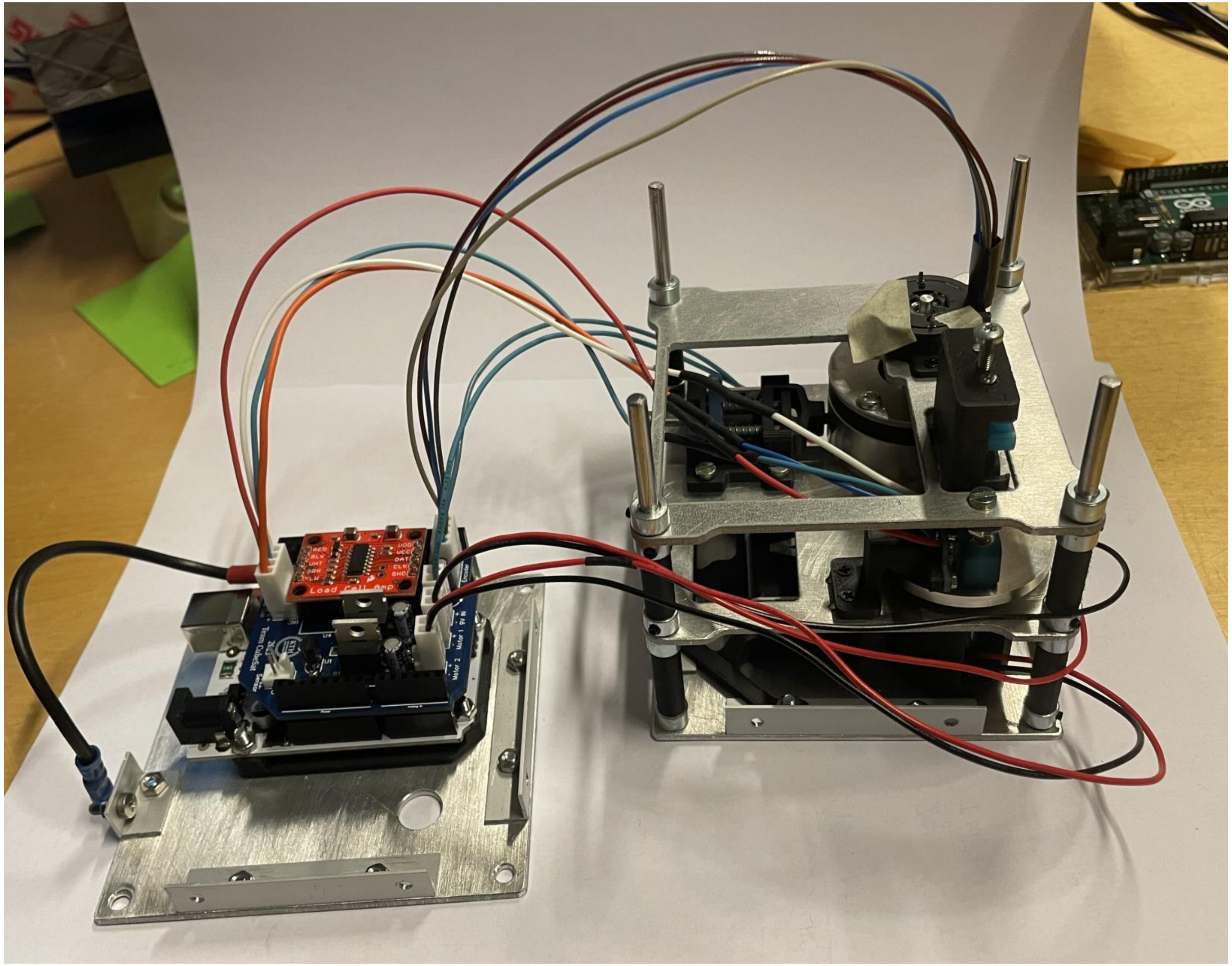

Arudino UNO seat
Custom PCB
Arduino UNO


Load Cell Amp
2023
Team CubeSat

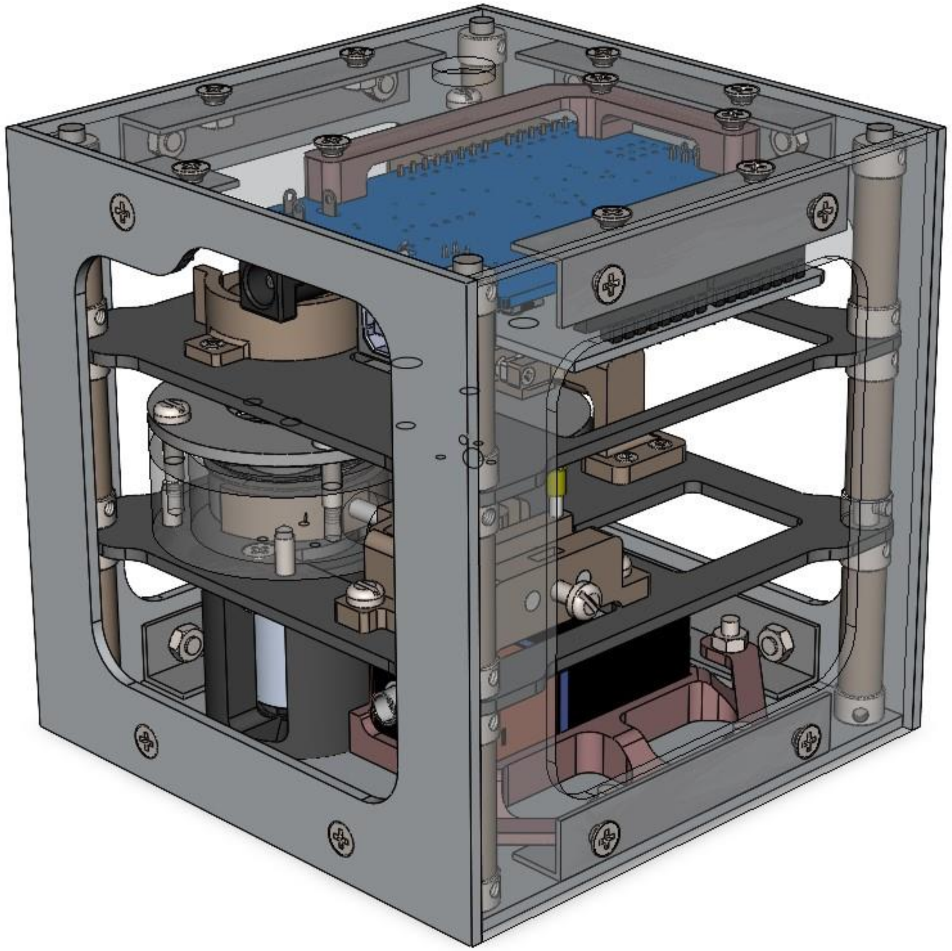
Manufacturing of Parts

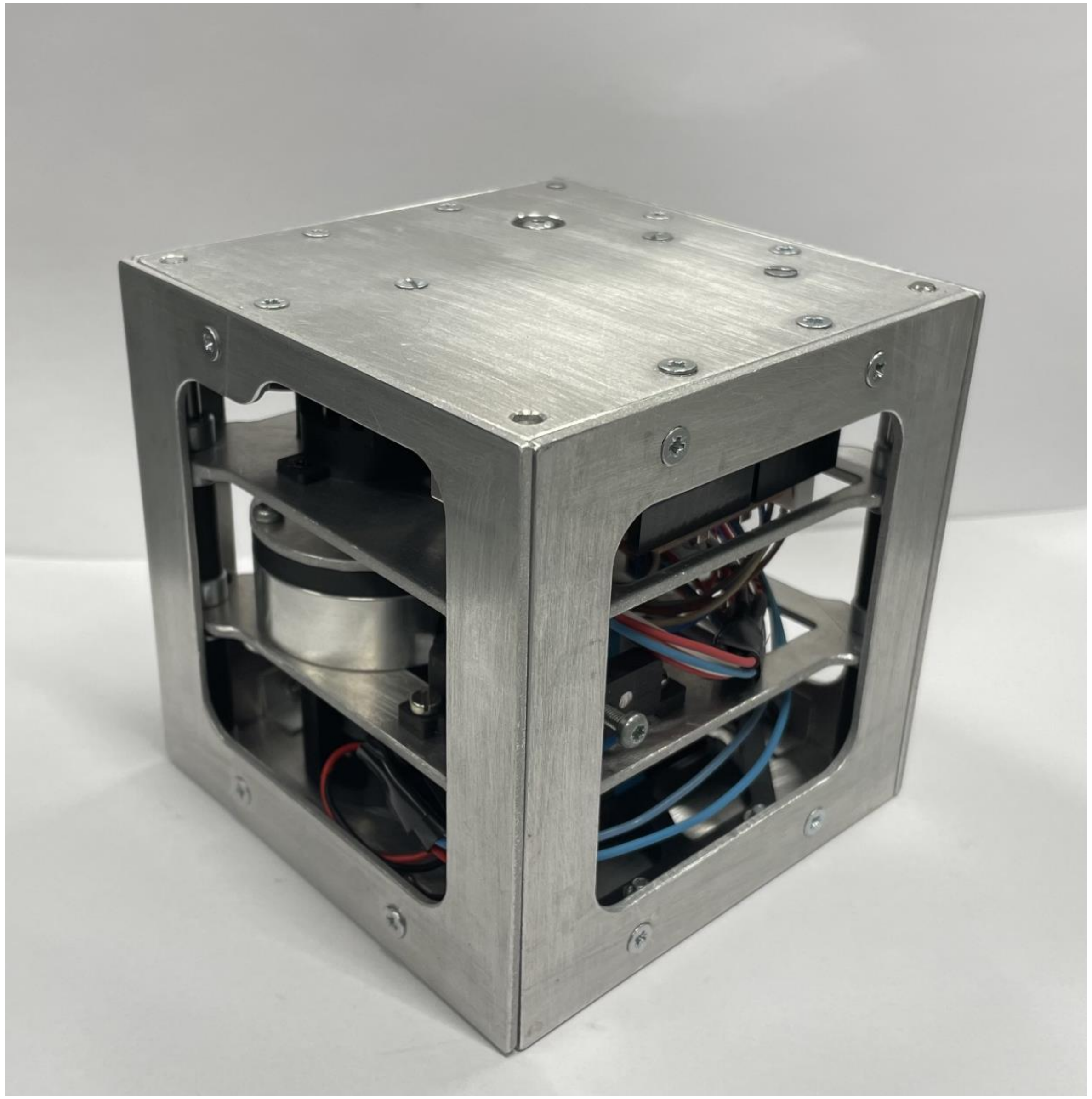
- Machined Parts
- PLA printed parts
- Resin printed parts
- Water jet cutted parts
  (open countersinks, sanding, after editing)
- Custom L bracket manufacturing
- ELAB, KTH Prototype center




Load Cell Amp
RED
BLK
WHT
GRN
VDD
VCC
DAT
CLK
GND
Team CubeSat
Encoder
Motor 1
Motor 2
Sensor

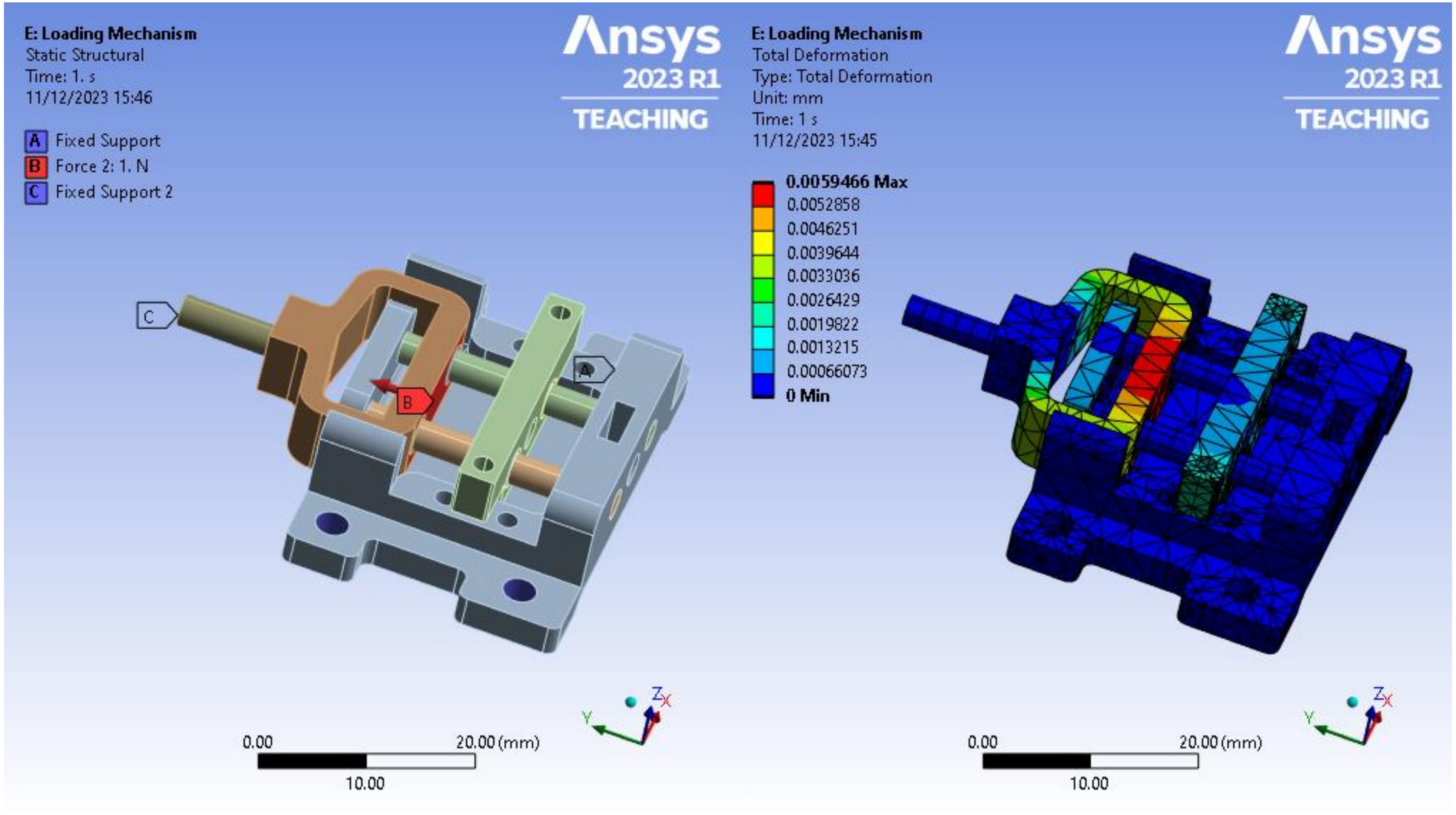
Assembled CubeSat- Design Twin





Simulations

Static Structural – Loading Mechanism

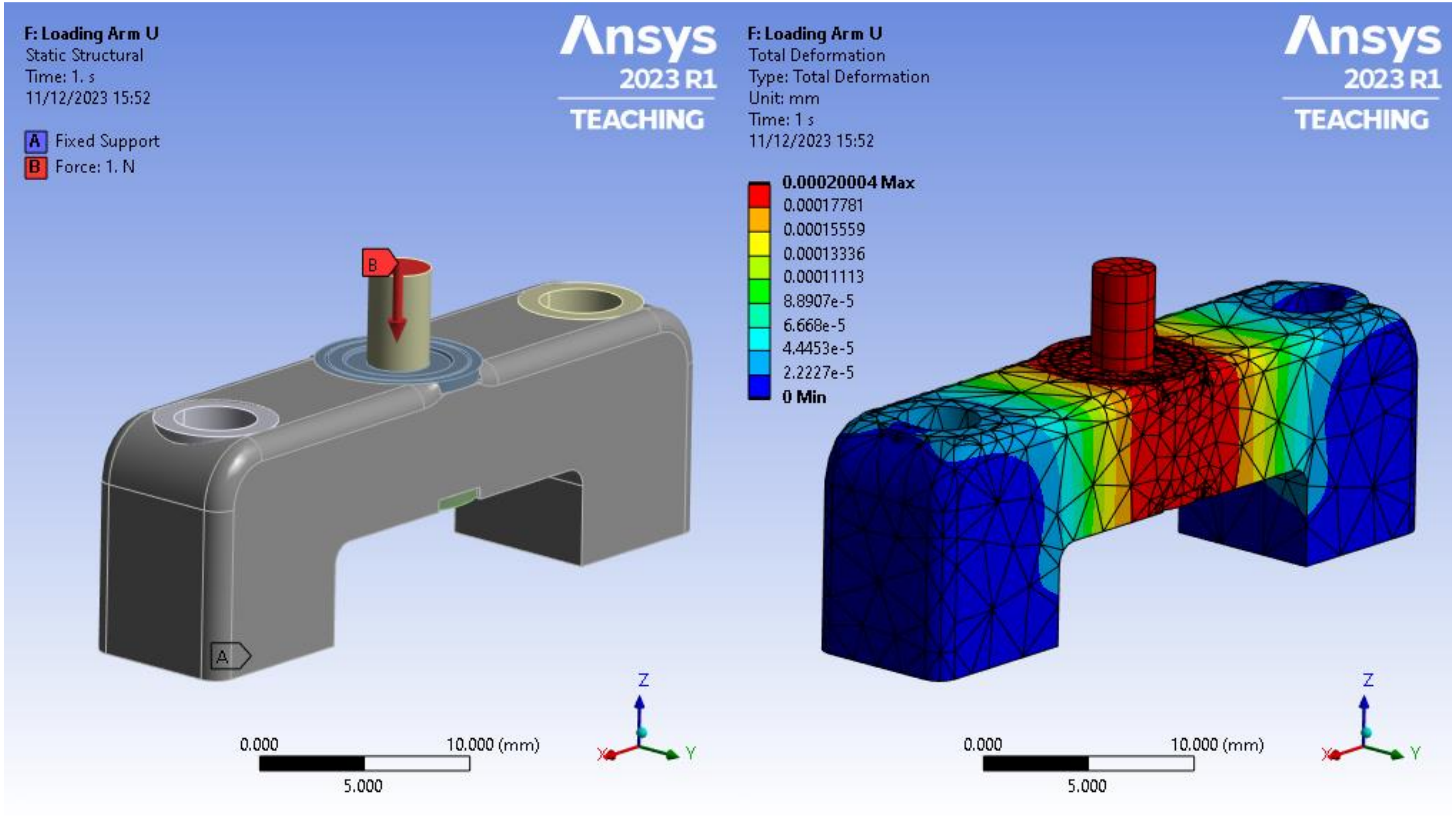


Maximum Allowable Deformation =10 μm

Maximum Deformation = 5.9 μm

Maximum Equivalent Stress = 8.66 MPa

Static Structural – Loading Arm

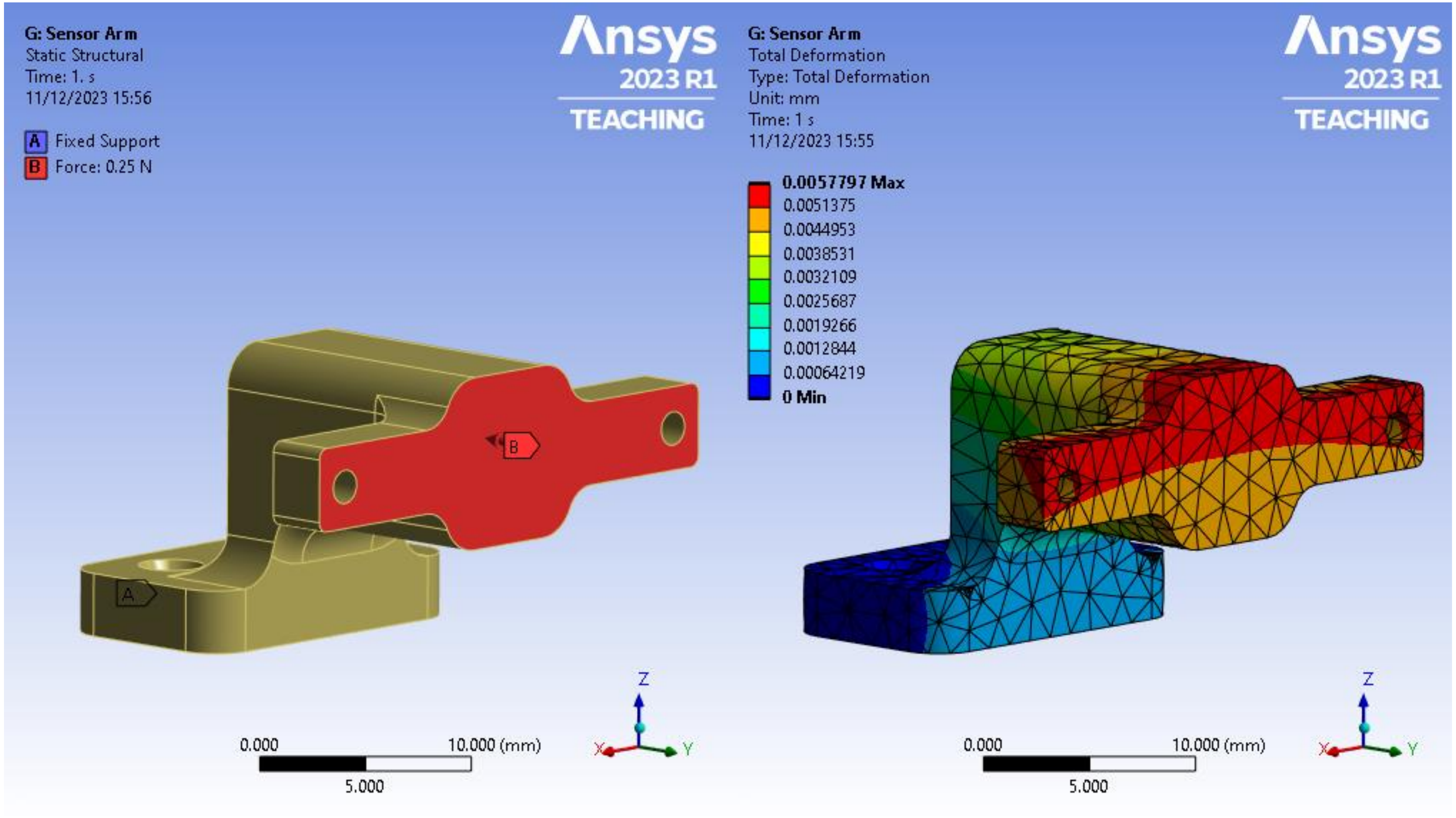


Maximum Allowable Deformation = 10 μm

Maximum Deformation = 0.2 μm

Maximum Equivalent Stress = 0.25 MPa

Static Structural – Sensor Arm

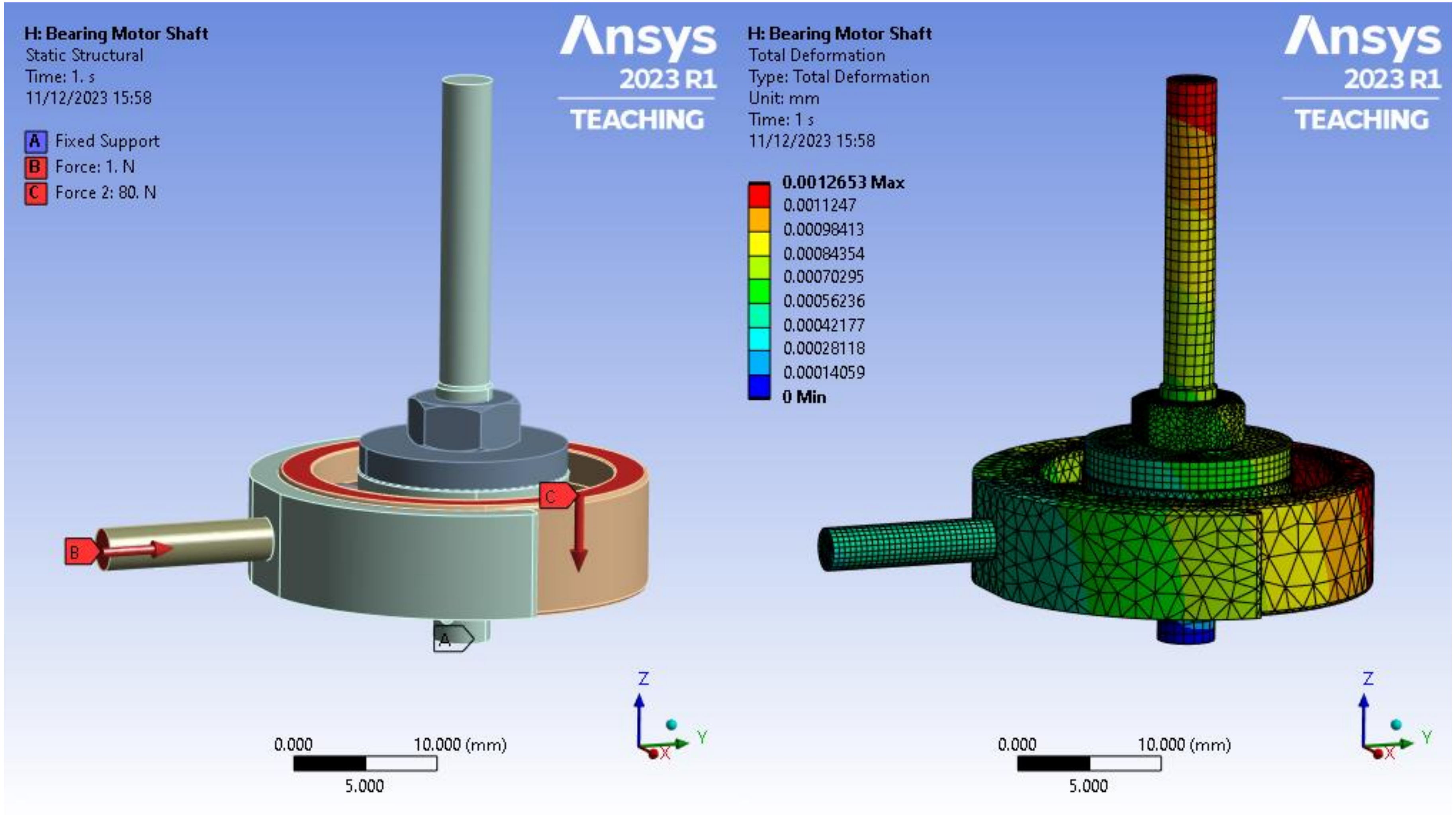


Maximum Allowable Deformation =10 μm

Maximum Deformation = 5.7 μm

Maximum Equivalent Stress = 0.17 MPa

Static Structural – Bearing Shaft

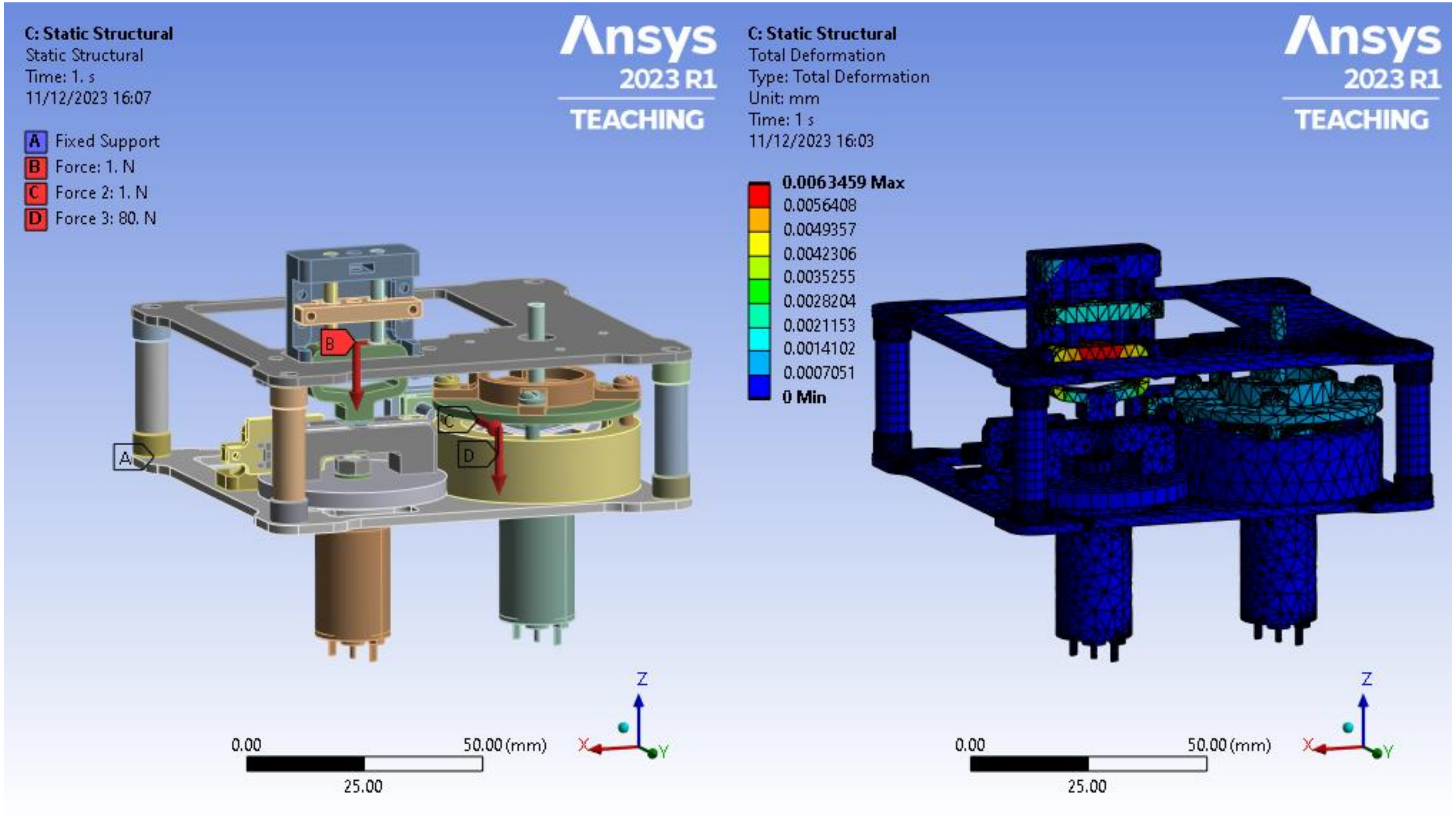


Maximum Allowable Deformation = 5 μm

Maximum Deformation = 1.3 μm

Maximum Equivalent Stress = 23.75 MPa

CubeSat – Assembly

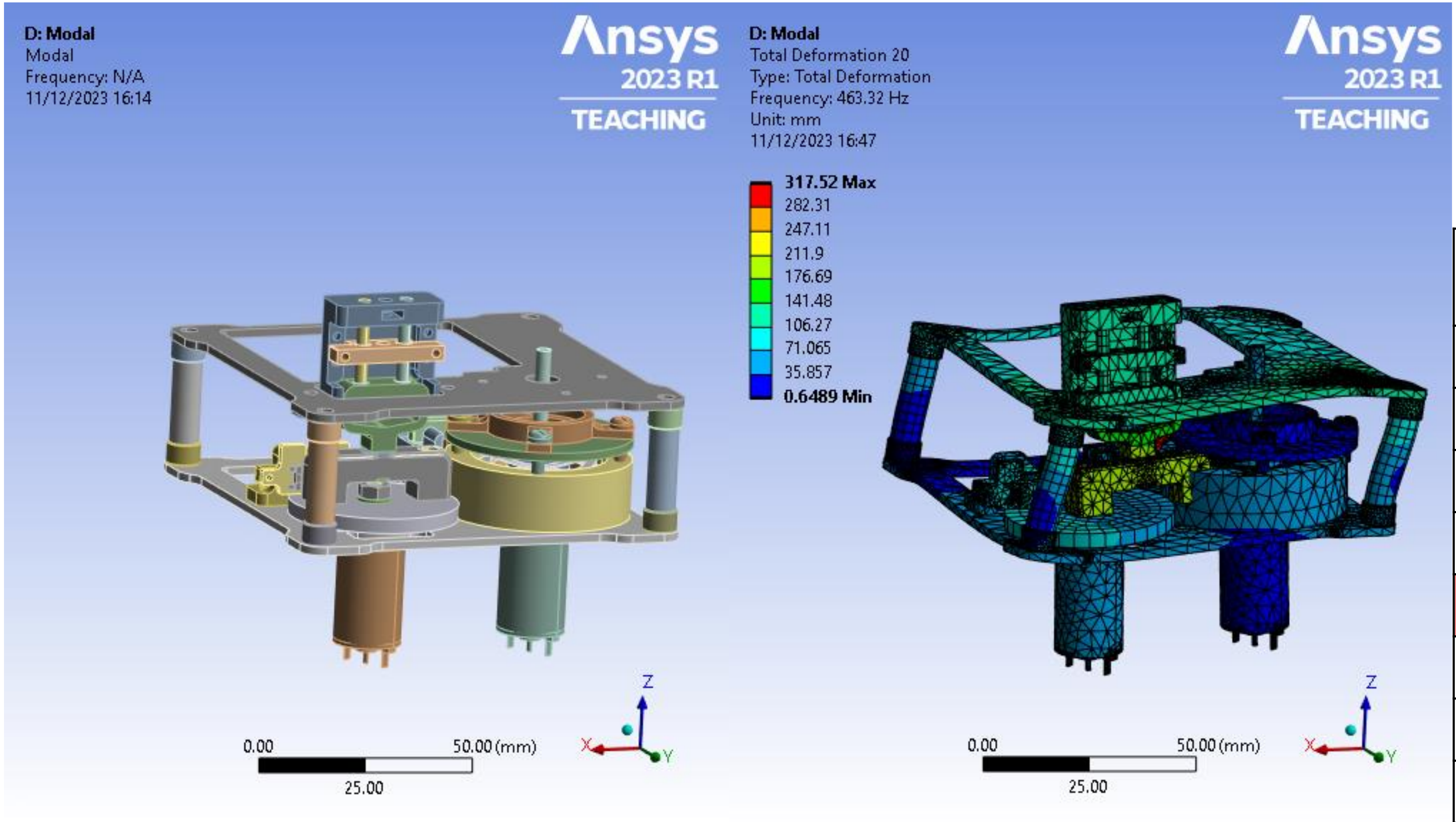


Maximum Allowable Deformation = 10 μm

Maximum Deformation = 6.3 μm

Maximum Equivalent Stress = 23.75 MPa

Modal – Tribometers

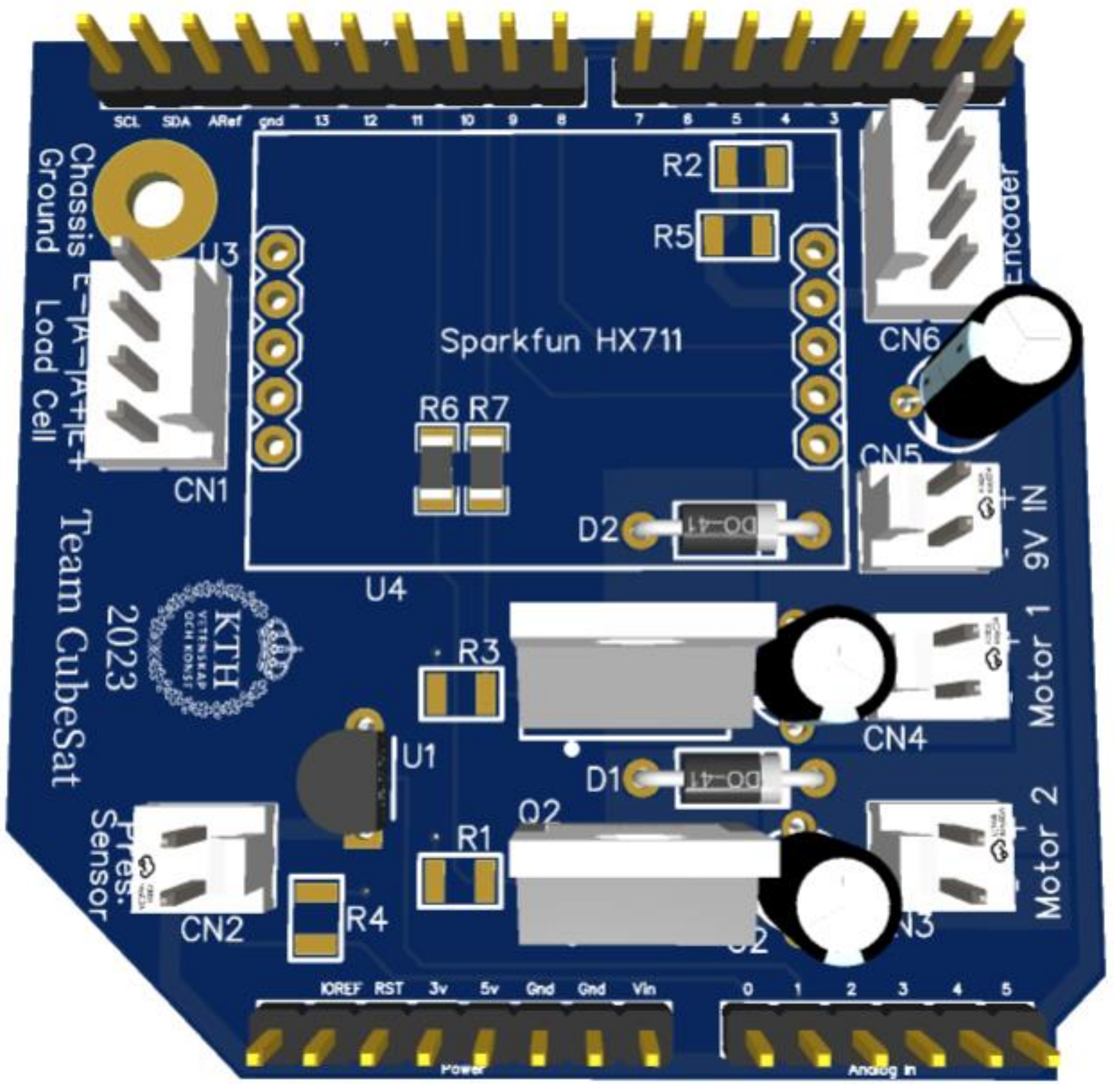


Body Modes	Natural Frequency [Hz]
1	81.097
2	103.67
3	113.43
4	417.5
5	463.32
6	464.12
7	499.47
8	584.25

Electronics & Data Acquisition

Electronics

- **Circuit Board**
  - Designed to fit on top of Arduino
  - Reduces wire run length
  - Reduces electrical component footprint to conserve space
- **Sensors:**
  - LM35 Temp Sensor
  - Loadcell (pin on disc)
  - Encoder (bearing)
- **Motors**
  - 2 motors connected to N channel mosfets
  - Powered by a 9V battery

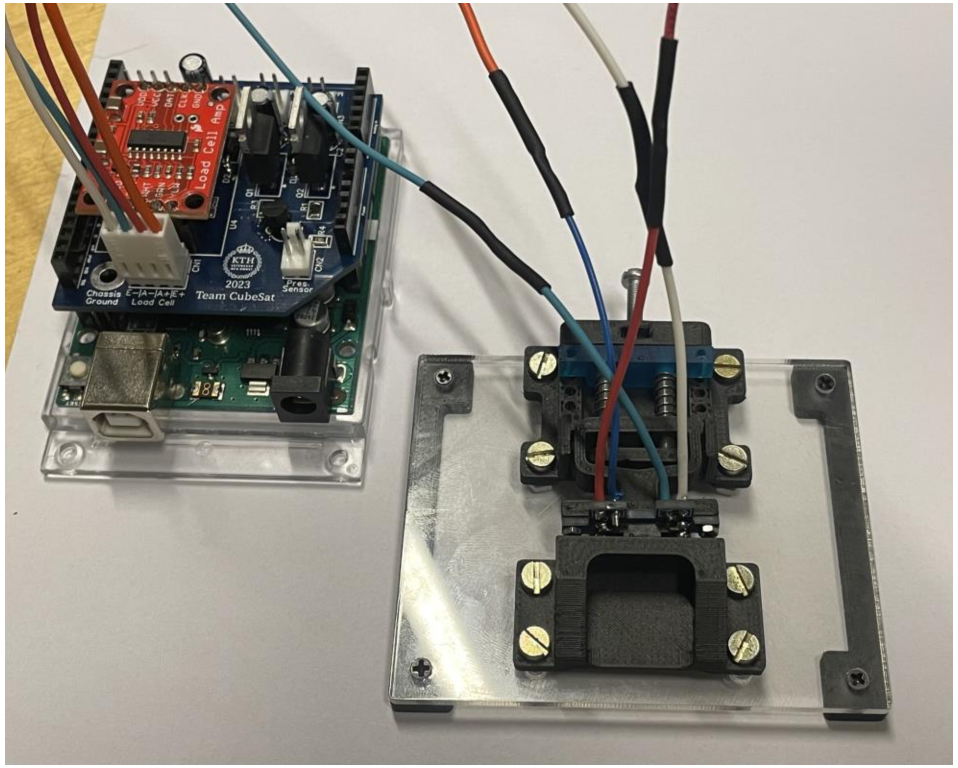


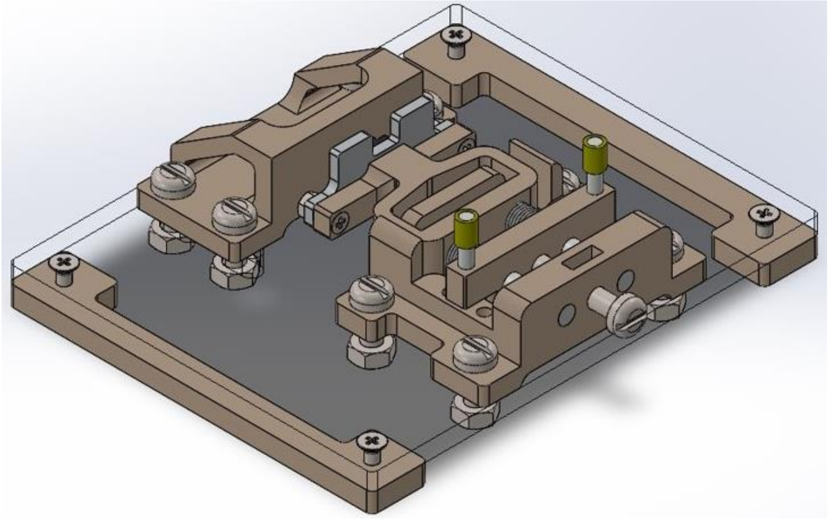
Calibration Setup for Loadcell

- Loadcell calibration
  - Using weights of known value, the calibration factor was computed

$$calibration\ factor = \frac{loadcell\ reading}{known\ weight}$$

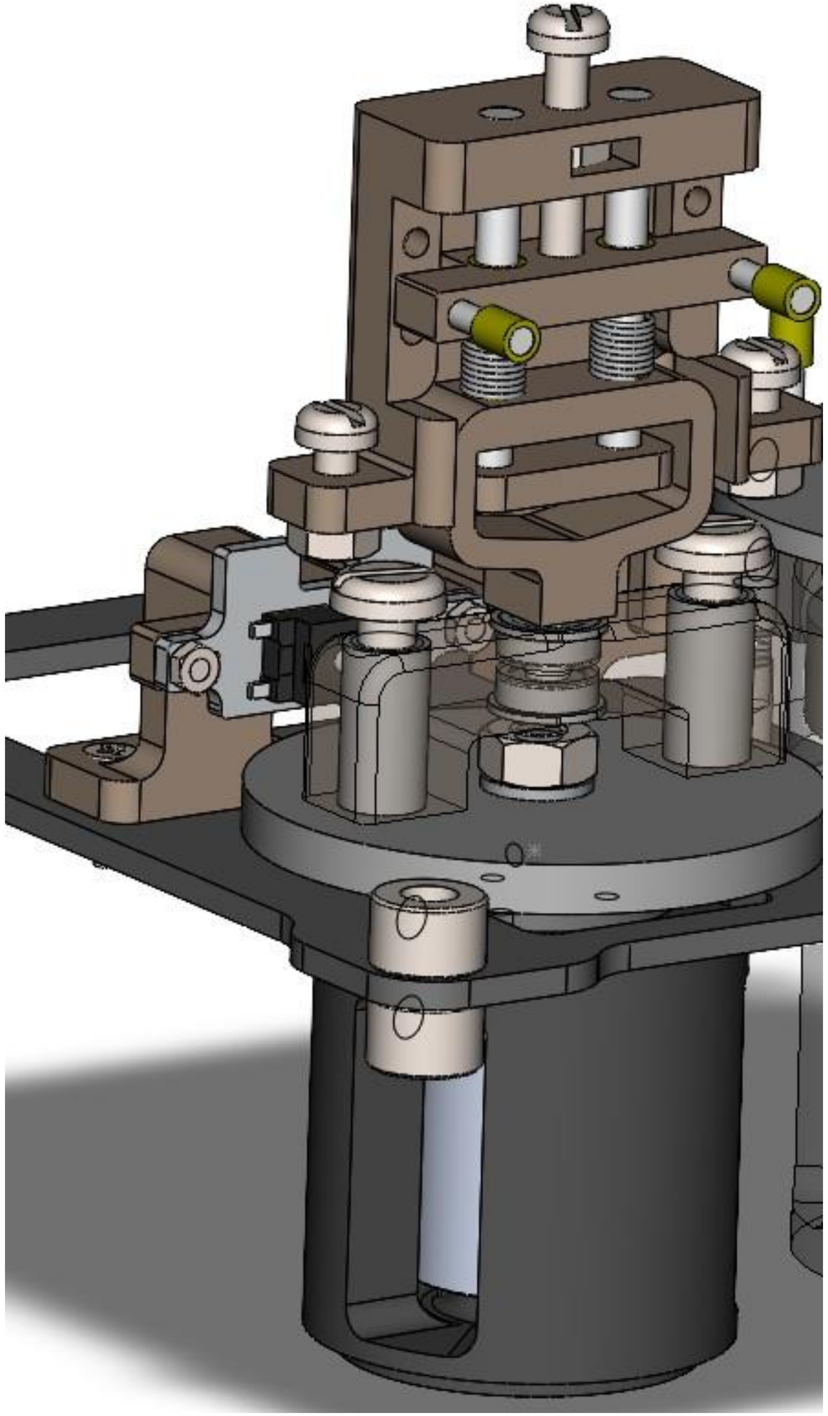
  - This value was implemented in the code to adjust loadcell readout
- Load mechanism calibration
  - Loadcell used to determine presets on load mechanism





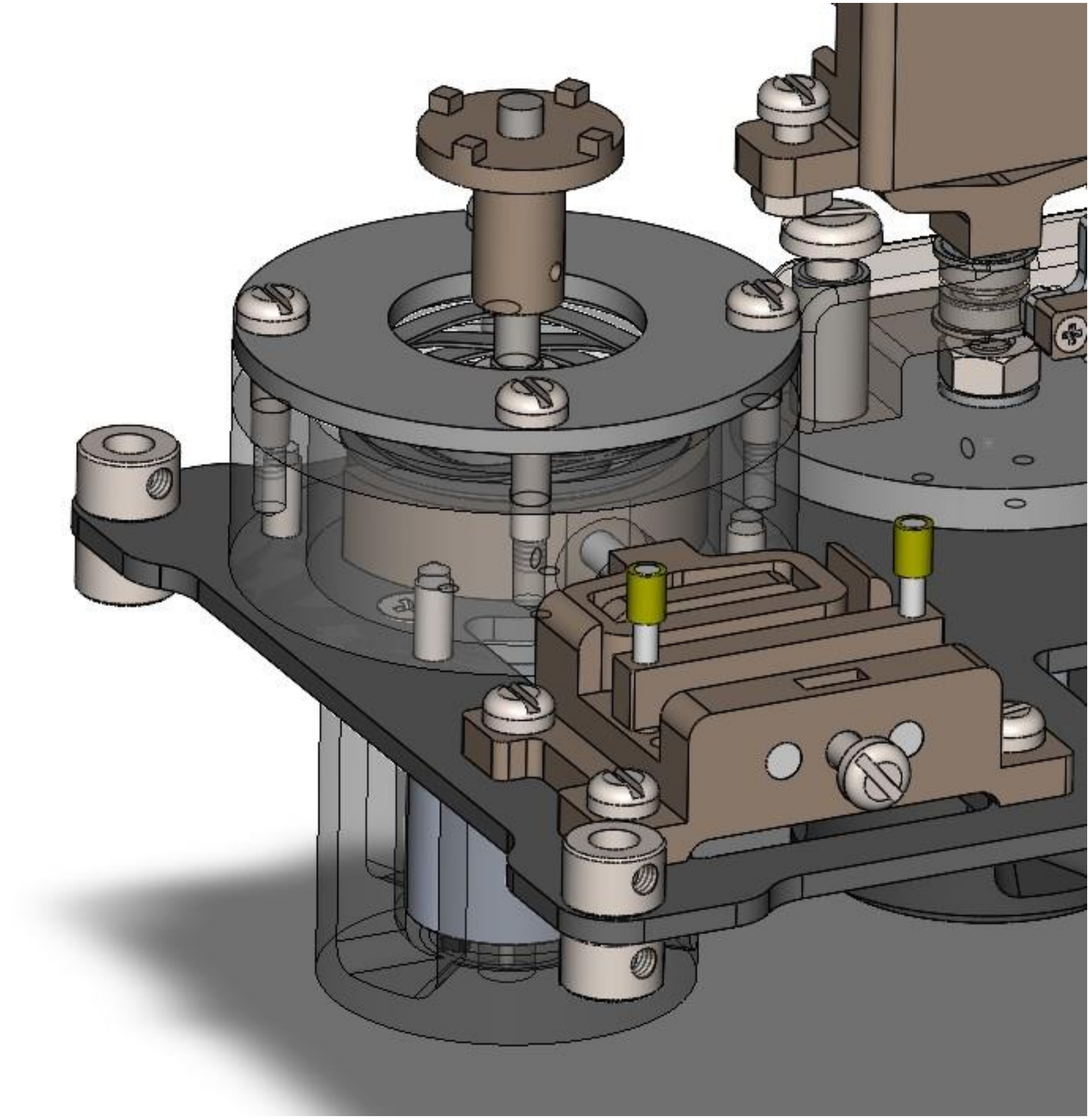
Data Acquisition Pin-on-Disc

- Friction force is measured directly on loadcell
- Axial loading has three presets
- Disc moves at a set speed
- Friction force is used to calculate coefficient of friction



Data Acquisition Bearing Tribometer

- Axial loading has three presents and radial loading has three presets
- An encoder tracks the change in RPM of the motor shaft
- Using the encoder measurement, the friction in the bearing is calculated and the coefficient of friction is calculated



Test Methodology& Results

Calculations
Testing Procedure
Results

Calculations

-Ball Bearing Calculations:

- Friction Torque is the key parameter required to be calculated to be able to approximate values for the coefficient of friction of the entire system
- This torque value can be theoretically estimated using several models, such as the SKF model and Hysteresis model

-Pin on Disc Calculations:

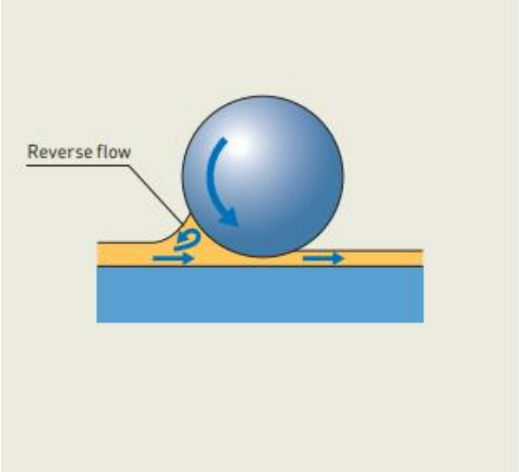
- It involves direct measurement of the friction force using a load cell and calculating it against applied force to find kinetic coefficient of friction

SKF Model

$$M = M_{rolling} + M_{sliding}$$

$$M_{rolling} = \varphi_{ish}\varphi_{ors}G_{rr}(\vartheta n)^{0.64}$$

$$M_{sl} = G_{sl}\mu_{sl}$$



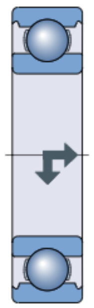
Hysteresis Model

$$T_Z = \frac{MER * d_m}{d_b} + FR * d_m + MP - \frac{F_{ib} * d_m}{4}$$

SKF Model

- The SKF model for calculating the frictional moment closely follows the real behavior of the bearing as it considers all contact areas and design changes and improvements made to SKF bearings, including internal and external influences.
- SKF tool can be used to verify results obtained from code
- This adds another layer of robustness to the project

SKF Tool Calculations



Forces		Speed
Radial kN	Axial	r/min
0.005	0.1	30

+ Add load case

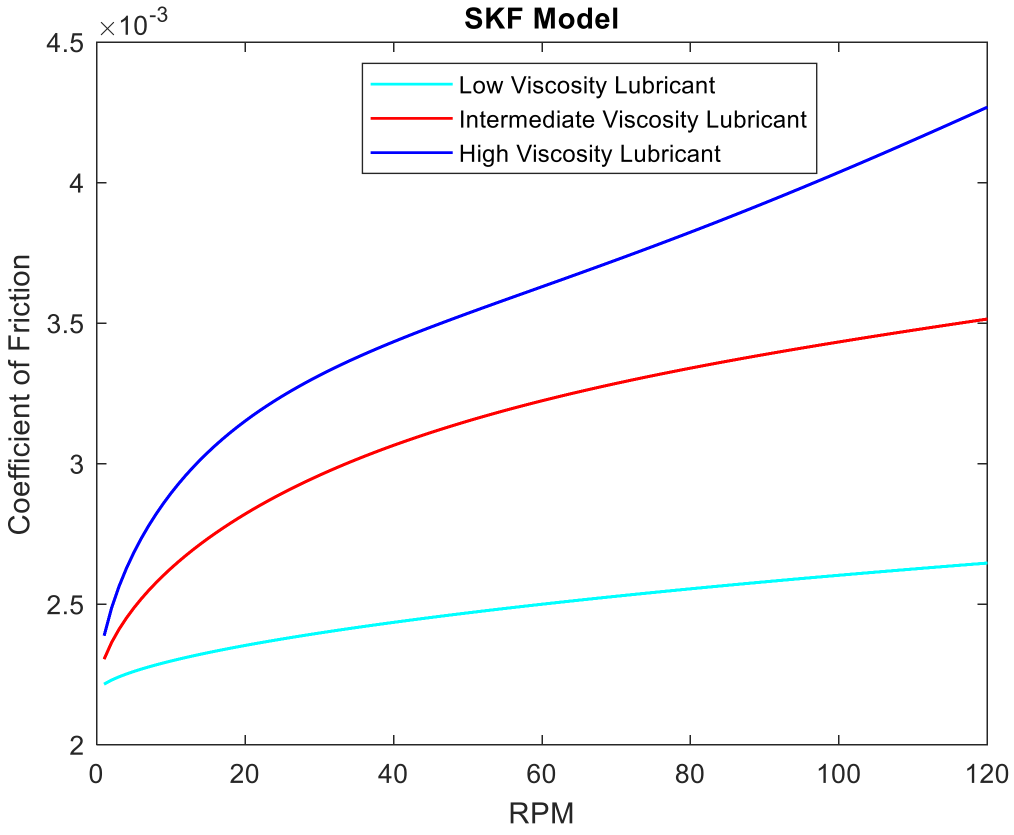
SKF	Frictional moment		Friction sources	
Designation	Total	At start 20-30°C and zero speed	Rolling	Sliding
	M (Nmm)	M_{start} (Nmm)	M_{rr} (Nmm)	M_{sl} (Nmm)
6000	3.4	2.98	1.4	1.99

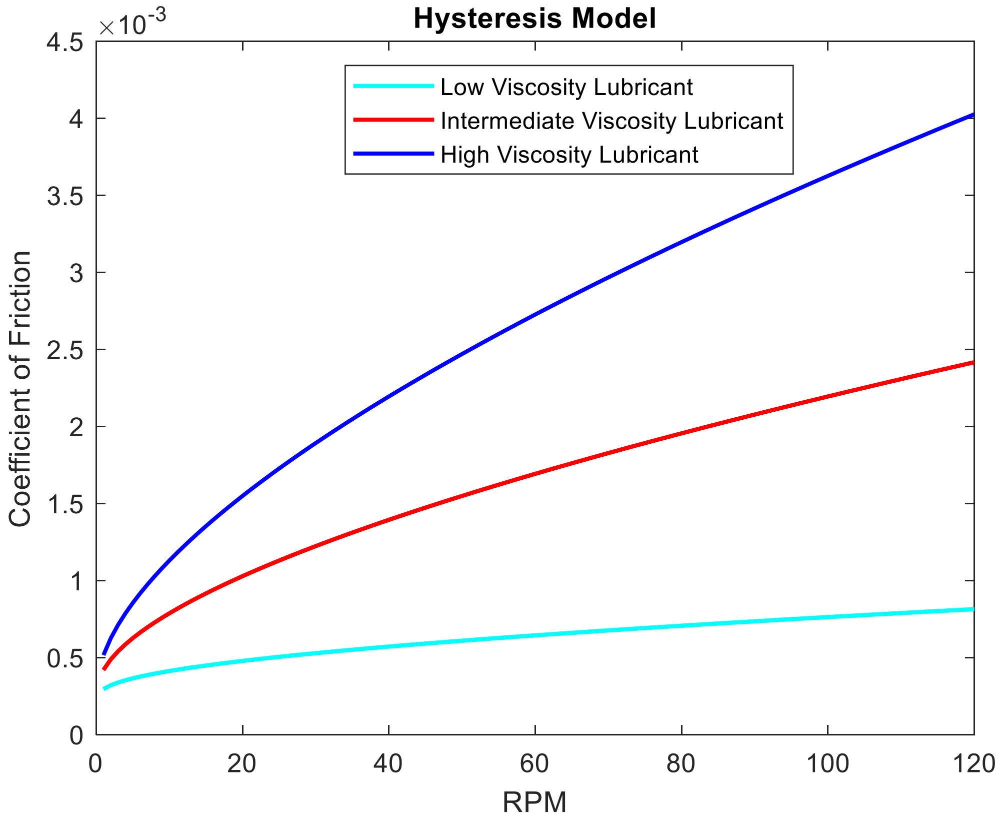
Matlab Calculations

RPM	Total Friction Moment	Rolling Friction Moment	Sliding Friction Moment
30	3.4368	1.4048	1.9983

Results

Viscosity of Lubricants used – [18, 200, 500] (mm^2/s)





Test Methodology

- Calibration of sensors such as load cell, pressure sensor and encoder were performed
- Extensive testing required due to long life of lubricant
- Compounded by low radial force and speeds
- Intermittent testing
- 2-5 mins per iteration
- Measurement begins after constant speed is achieved, and continued till power is supplied to motor
- Pin on Disc system remains un-lubricated, and the value of friction force is measured via a load cell
- The RPM of the ball bearing system is measured using an optical encoder with a resolution of 24

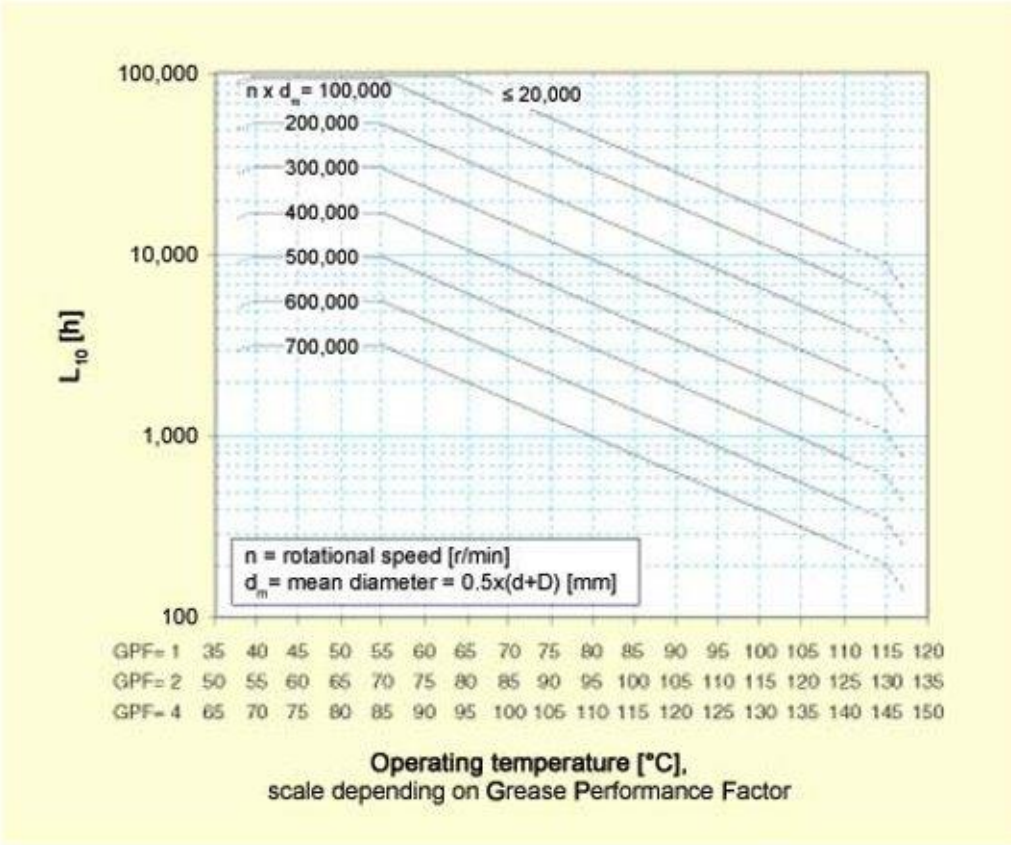
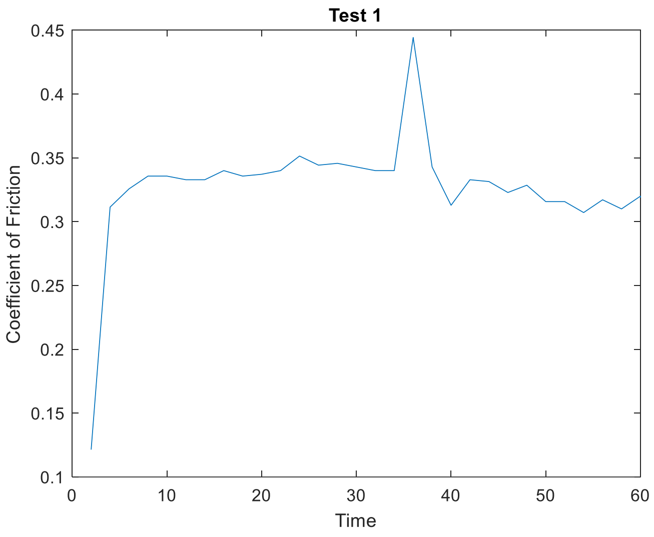
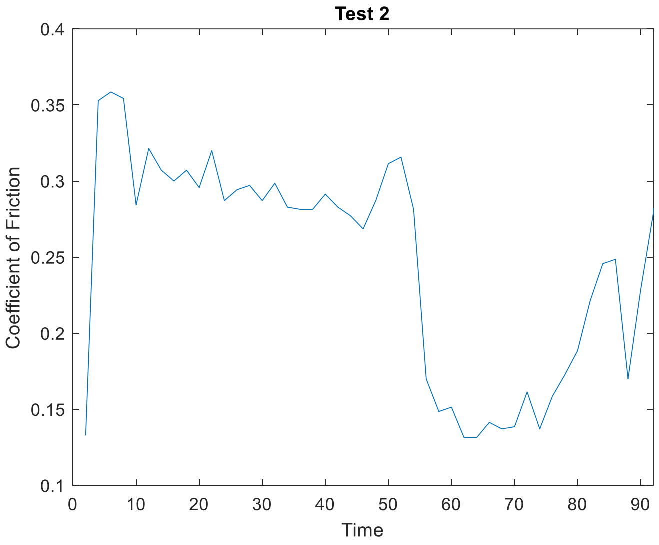
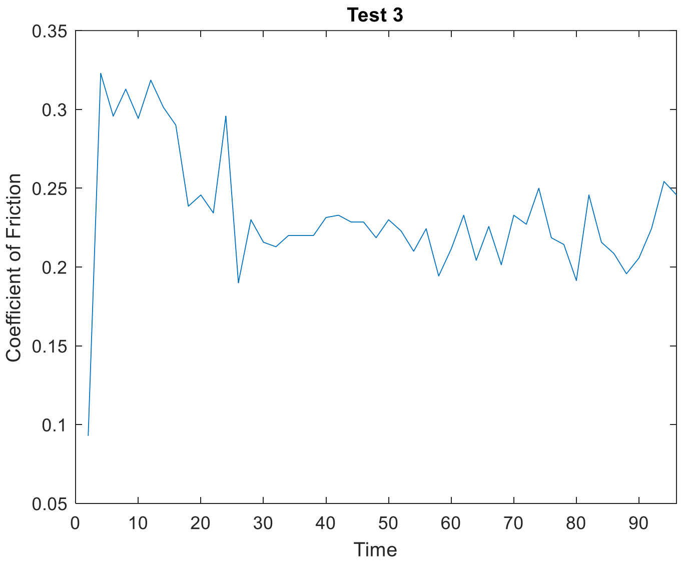


Diagram 1. Grease life in lubricated-for-life radial ball bearings running at low loads (C/P ≥ 15). L_{10} as function of n x d_m, temperature and grease type (GPF = 1, 2, 4, respectively.)

Results: Pin-on-Disc







Discussions and Future Work

Discussions & Future Work

- Friction Models:
  - Pin-on-disc:
    - A theoretical friction model for this Tribometer needs to be constructed
    - A theoretical friction model that considers the effects of temperature on the system needs to be created
  - Ball-bearing tribometer:
    - A friction model that considers the effects of temperature on friction of the system should be created
    - The friction models should be compared to the SKF and Hysteresis models
- Result Accuracy:
  - The friction introduced by other components like the encoder and motor bearings need to be accounted for in the calculations
- Component Accuracy:
  - Calibration of select sensors should be revisited:
    - Calibrate encoder using resor method
    - More data points for other sensors can be added to calibration data to increase accuracy
  - Machined parts need to be examined for imperfections and re-machined until they are within specifications (consider outsourcing for higher accuracy and better tolerancing)

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