Robotic Microgravity Joint Friction Characterization

Organization Chart

Team Member	Responsibilities
Cody Paige	Advisor and Research Professor
Sebastian Abreu	Materials Selection, Research
Emiliano Villicaña Brugada	Materials Selection, CAD
Alexander Lim	Materials Selection, Safety
Matthew Nunez	Materials Selection, Organizational
Andres Permuy	Materials Selection, Electronics Layout
Jonathan Pierre	Materials Selection, Requirements

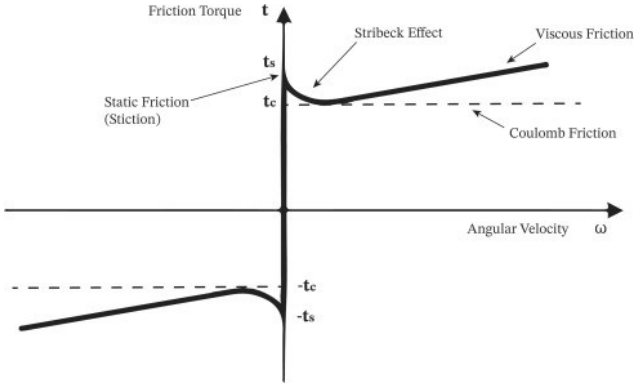
Overview

Our experiment investigates how gravitational loading affects friction within a robotic actuator and joint



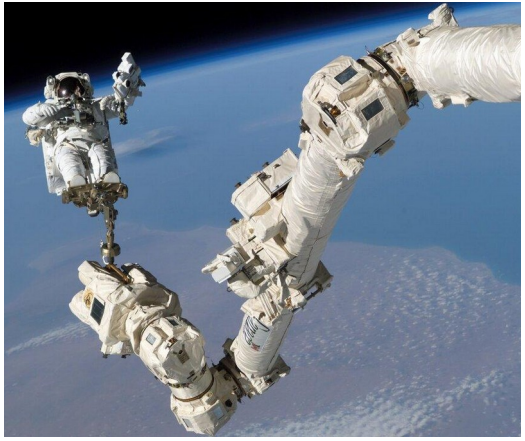
Purpose

Identify which components of the Stribeck friction model, whether it be static, Coulomb, and viscous friction, are most sensitive to changes in gravitational loading

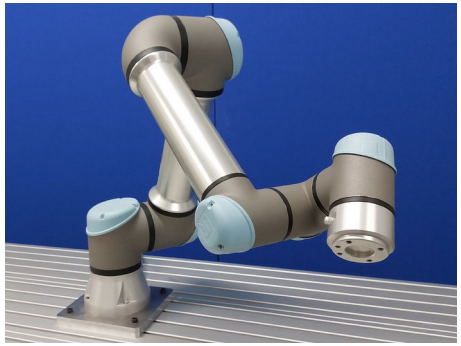


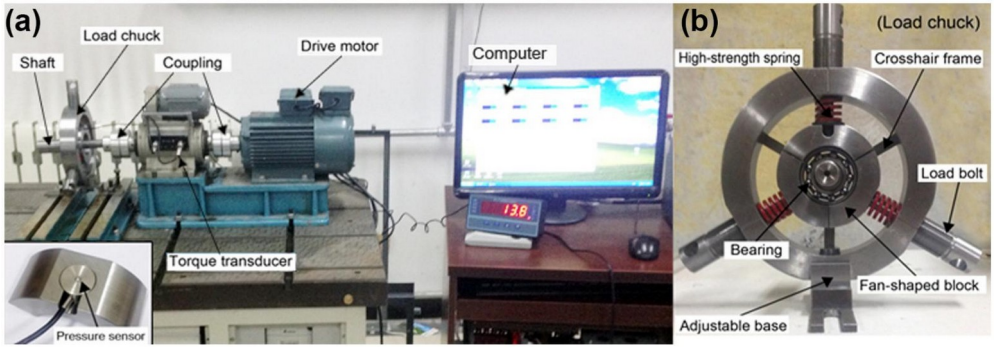
Merit

Improve our understanding of gravity-dependent friction to inform more accurate friction modeling and control of robotic actuators in space environments



Prior Art





Fabris et al. (2026) experimentally compared 25 friction models on a UR5e robotic manipulator, investigating how velocity, load torque, and temperature influence friction behavior

Wang et al. (2015) experimentally investigated frictional torque in deep-groove ball bearings under varying radial loads and rotational speeds, demonstrating the significant influence of bearing loading on friction

Unlike prior studies, our experiment directly investigates how reducing *gravitational bearing loads* in microgravity affects individual Stribeck friction parameters

System Requirements (to meet 0g deployment success)

ID	Type	Requirement (SHALL)	Verify	Subsystem
R1	Functional	The system shall synchronously record shaft velocity, motor current, orientation, and temperature throughout each experimental run.	Test	Sensor
R2	Functional	The system shall provide motor commands to the ESCON controller through the Teensy and MCP4725 DAC interface.	Test	Motor Control
R3	Functional	The flywheel mount shall support manual reorientation between discrete test angles from 0° to 90° and shall lock securely at each selected angle.	Demo	Mech Assy
R4	Functional	The system shall provide rotary-switch operator input for mode or orientation selection.	Demo	User Interface
R5	Performance	The system shall sample encoder and motor-current signals at a rate of at least 100 Hz to characterize breakaway, constant-velocity, and coast-down behavior during the available microgravity interval.	Test	Sensor
R6	Performance	The current measurement and motor-command interfaces shall provide sufficient resolution to characterize motor loading over the intended operating range.	Test	Motor Control
R7	Performance	The battery system shall provide sufficient energy for the planned flight and ground-operation timeline without requiring a mid-flight battery replacement.	Test	Elec Power
R8	Interface	The electrical system shall provide compatible power rails for motor-drive and logic electronics	Test	Elec Power
R9	Interface	The Teensy and Raspberry Pi shall exchange commands and telemetry through a defined USB or serial interface.	Test	Comms
R10	Safety	Wiring shall be secured and strain-relieved to minimize chafing, disconnection, and short-circuit risks under anticipated flight vibration.	Inspection/ Test	Elec P/Wiring
R11	Safety	The flywheel, hub, shaft, and mounting assembly shall be secured and rated for the maximum permitted test speed and associated loads.	Inspection/ Analysis	Mech Assy
R12	Operational	The system shall associate recorded data with the applicable flight phase, including hypergravity, microgravity, and level flight.	Test	Data
R13	Operational	The system shall inhibit flywheel orientation changes while the motor is rotating or energized.	Test/Demo	Mech Assy
R14	Operational	The system shall support execution of the planned test sequence and data logging within the available microgravity interval	Test/Demo	Data

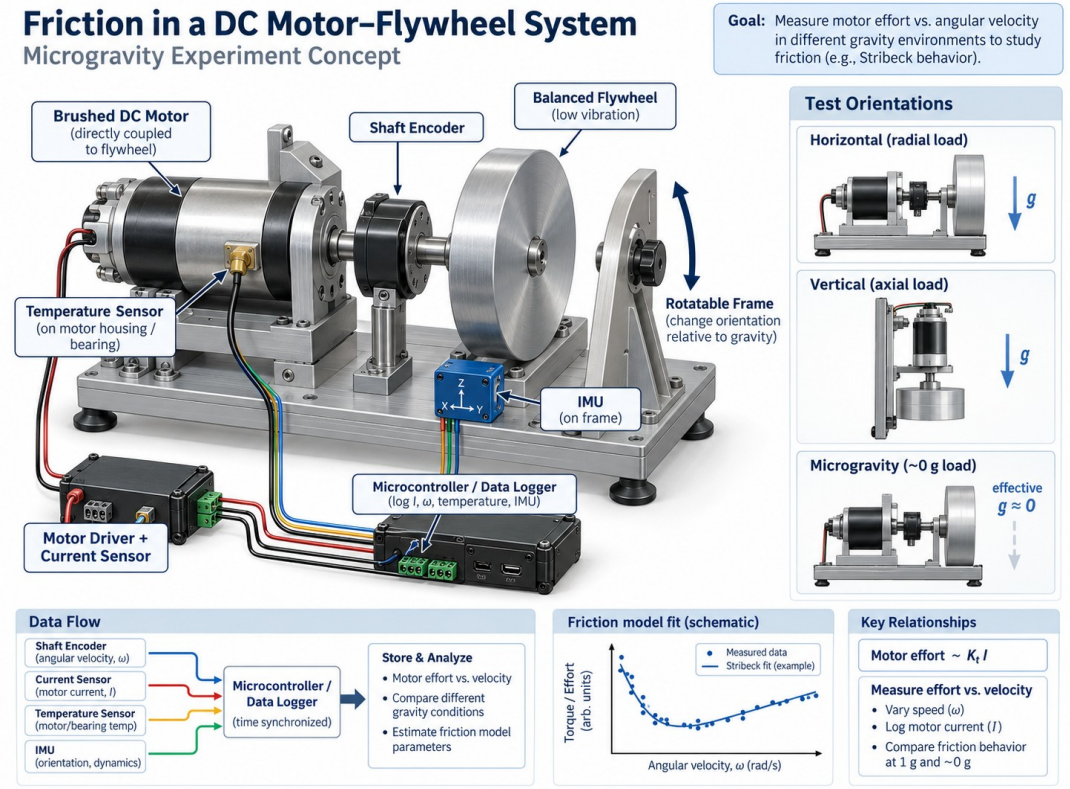
Baseline Design & Integration

For Aircraft Deployment

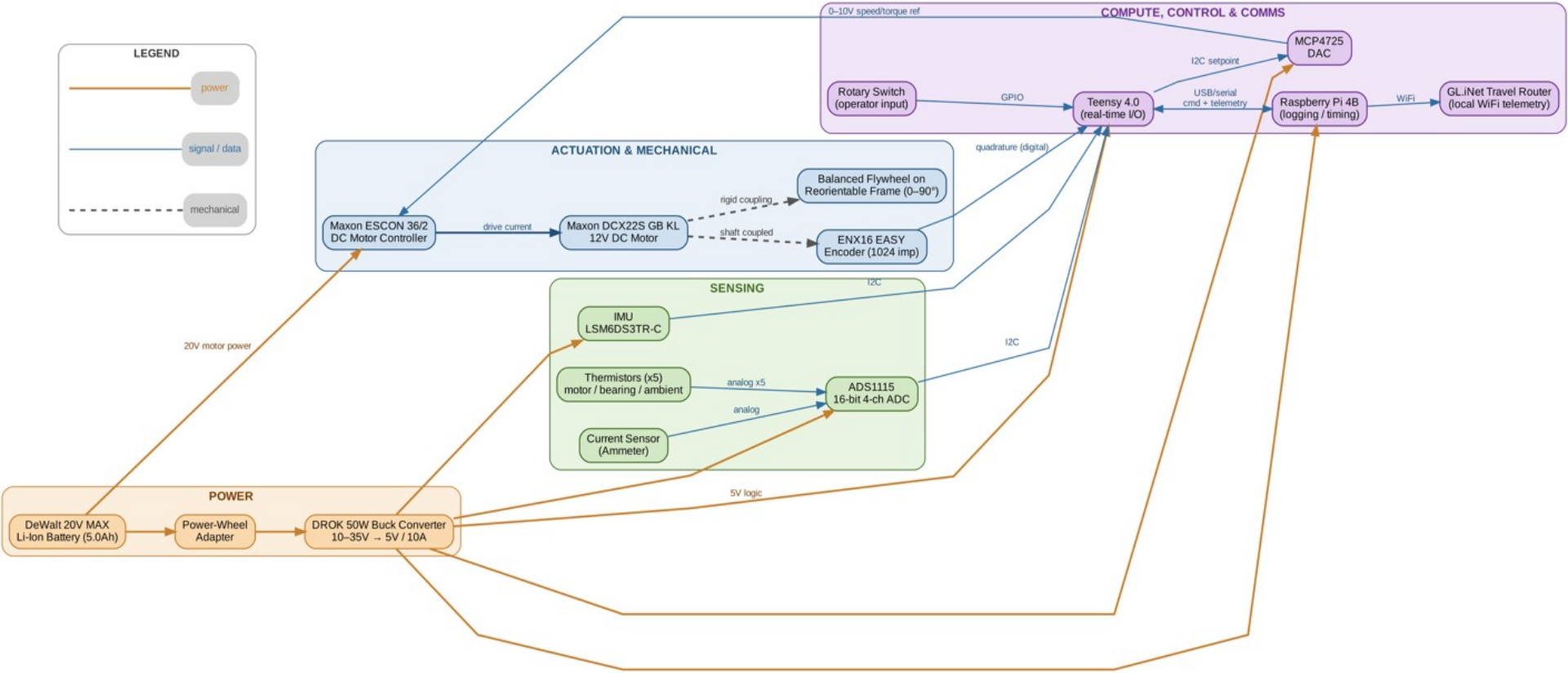
- Vibration dampeners for aircraft attachment
- Enclosure for flywheel containment

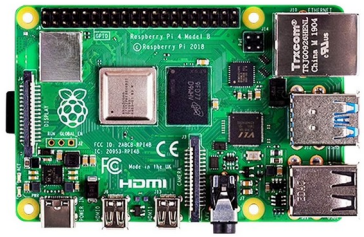
Human handling required:

- Adjust flywheel angle

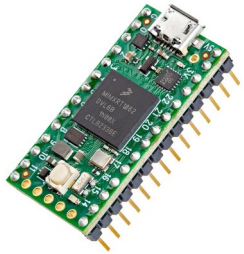


System Block Diagram





Microcomputer



Microcontroller



SSH Network



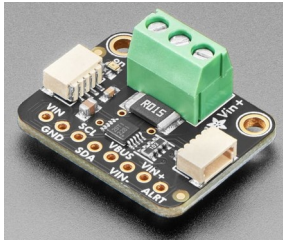
Motor



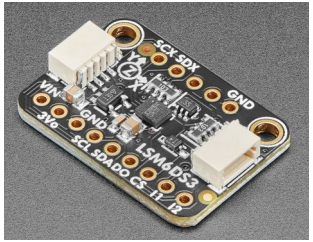
Motor Encoder



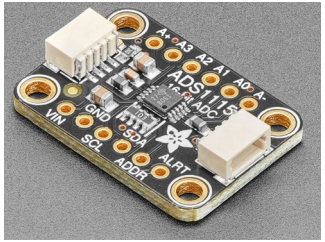
Motor Controller



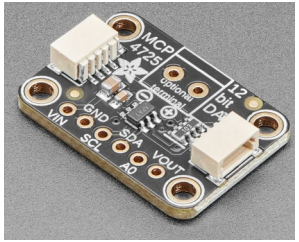
Ammeter



IMU



ADC



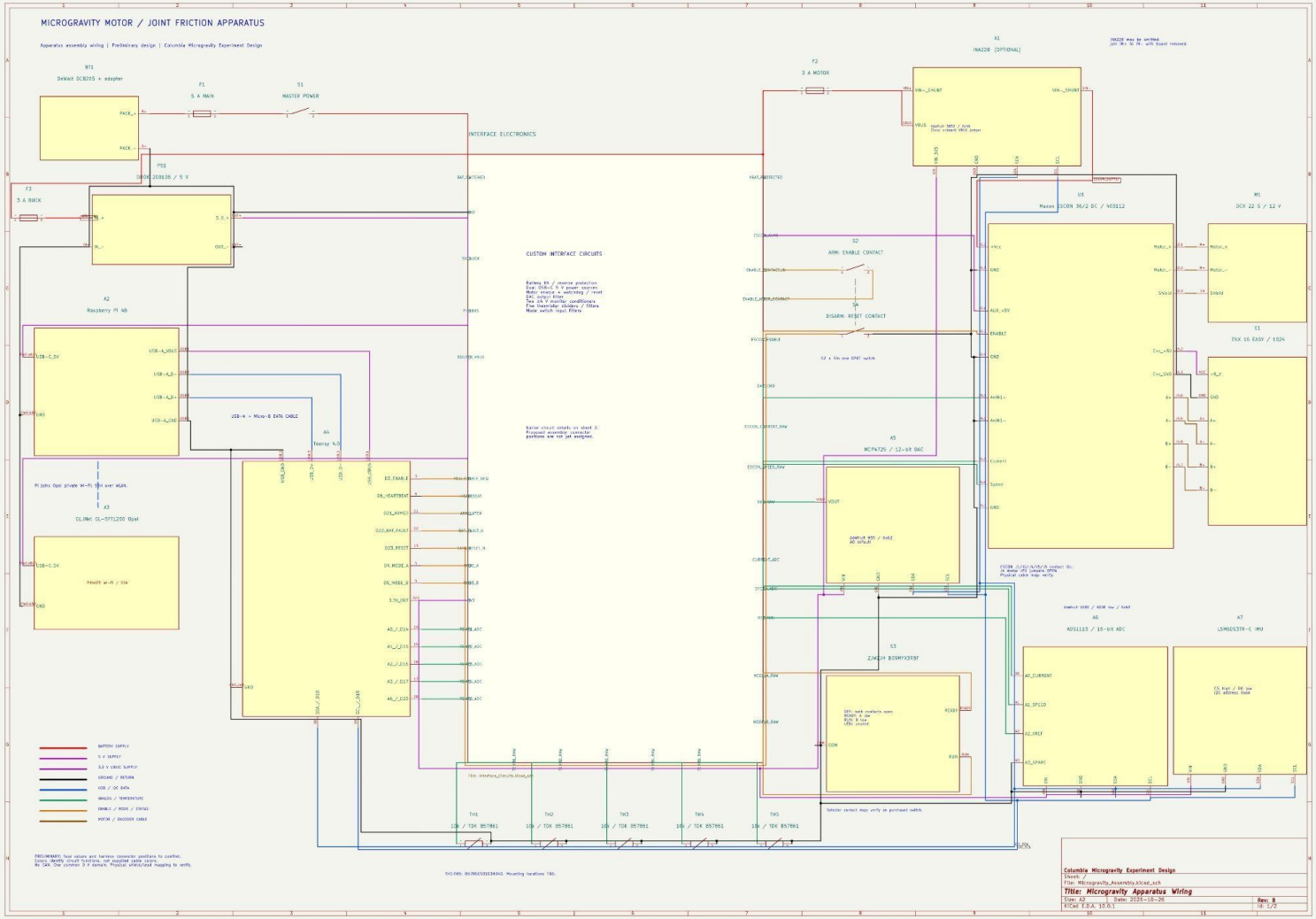
DAC

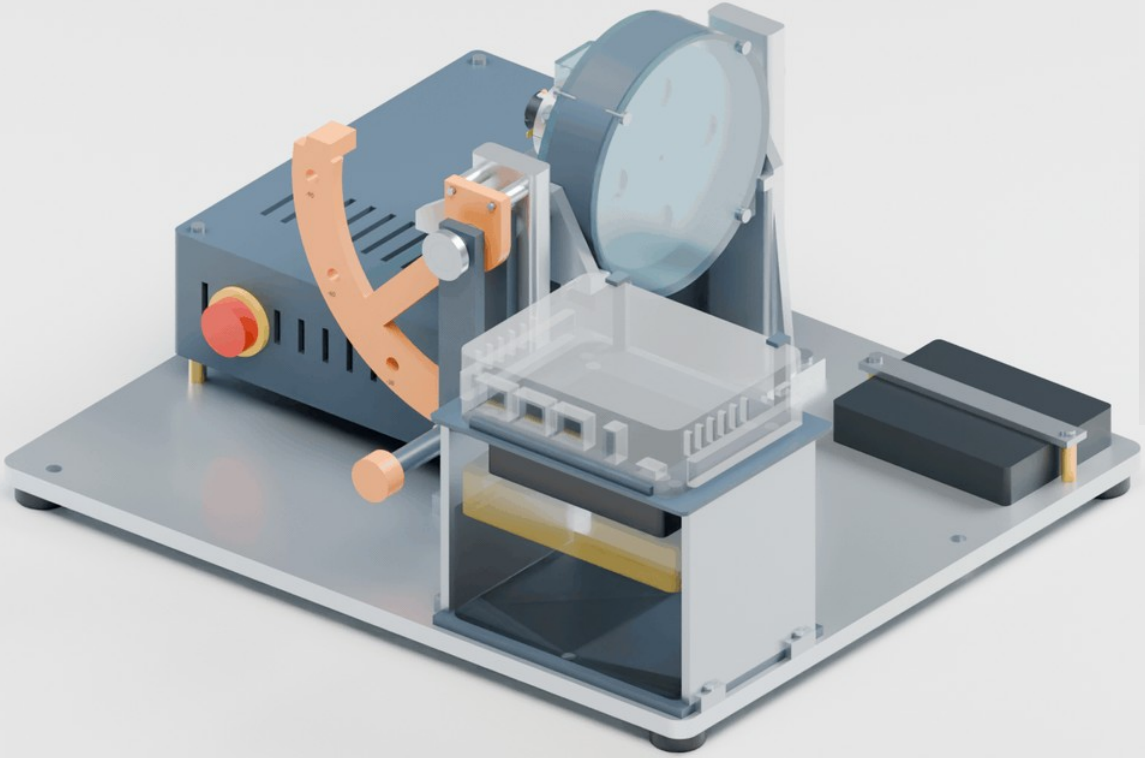


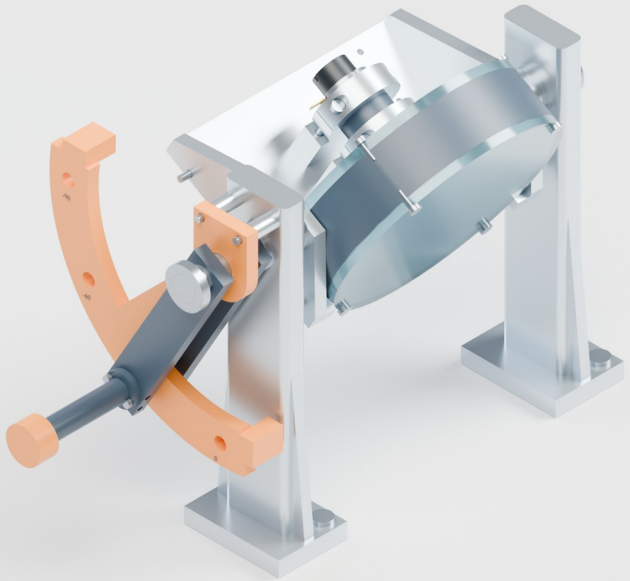
Thermistor



Switch


MICROGRAVITY MOTOR / JOINT FRICTION APPARATUS
Apparatus assembly wiring | Preliminary design | Columbia Microgravity Experiment Design
BT1
Dekwat DCB205 + adapter
PACK_+
PACK_−
F1
5 A MAIN
S1
MASTER POWER
PS1
DROK 200108 / 5 V
F3
5 A BUCK
IN_+
IN_−
OUT_+
OUT_−
A2
Raspberry Pi 4B
USB-C 5V
GND
USB-A_VBUS
USB-A_D−
USB-A_D+
USB-A_GND
USB-A → Micro-B DATA CABLE
A4
Teensy 4.0
A3
GL.iNet GL-SFT1200 Opal
Pi joins Opal private Wi-Fi (SSH over WLAN).
USB-C 5V
GND
PRIVATE Wi-Fi / SSH
INTERFACE ELECTRONICS
BAT_SWITCHED
5V_BUCK
P3V3_RAIL
VSYS_VIN_RAIL
CUSTOM INTERFACE CIRCUITS
Battery ESC / reverse protection
Dual USB-C 5 V power sources
Motor inrush + switching / reset
3.3 V logic supply
Two 24 V rectifier conditioners
Fine thermistor dividers / filters
Mode switch input filters
Button circuit details: see sheet 2.
Proposed assembly; connector
positions are not yet assigned.
EN_ENABLE
D4_HEARTBEAT
D21_ARMED
D22_BAT_FAULT
D23_RESET
D4_MODE_A
D5_MODE_B
3.3V_OUT
A0_/_D14
A1_/_D15
A2_/_D16
A3_/_D17
A6_/_D20
SDA / D18
SCL / D19
A1
HMA228 (OPTIONAL)
HMA228 may be omitted.
Jdn IN+ to IN- with board removed.
F2
3 A MOTOR
VIN+_CHAINT
VIN−_CHAINT
VBUS
Adafruit 5832 / 0x44
Close solder VBUS jumper
SCL
SDA
GND
VIN_SENS
MOTOR_SUPPLY
U1
Maxon ESCON 36/2 DC / 403112
M1
DCX 22 S / 12 V
E1
ENX 16 EASY / 1024
S2
ARM: ENABLE CONTACT
DISARM: RESET CONTACT
S2 + S3w one DPDT switch
A5
MCP4725 / 12-bit DAC
Adafruit 4595 / 0x62
A0 default
A6
ADS1115 / 16-bit ADC
A7
LSM6DS3TR-C IMU
S3
Z/W/2H B09MYX38ST
Selector contact must verify on pressure switch.
TH1
TH2
TH3
TH4
TH5
10k / TDK B57861
TH1-TH5: B57861S103F40H3. Mounting locations TBD.
Battery supply
5 V supply
3.3 V logic supply
Ground / return
USB / I2C data
Analog / temperature
Enable / mode / status
Motor / encoder cable
PRELIMINARY: Pin values are harness connector positions to confirm.
Colors identify circuit functions, not supplied cable colors.
No CAN. One common 5 V domain. Physical wires/lead mapping to verify.
Columbia Microgravity Experiment Design
Sheets: 2
File: Microgravity_Assembly.kicad_sch
Title: Microgravity Apparatus Wiring
Size: A2
Date: 2025-10-26
KiCad 10.0.1
Rev: B
Id: 1/2





Concept of Operations (ConOps)

1. Preflight: Secure apparatus, power on electronics, and verify all sensors.
2. Post-take off: Initialize experiment and initiate autonomous operation.
3. Pre-Parabola: TECH moves apparatus to next test position, OP arms next script.
4. Microgravity: OP runs test script, SE confirms data status.
5. Post-Parabola: SE confirms if modeled data recorded or failed.
6. Repeated Parabolas: TL determines repeated test configurations.
7. Postflight: Retrieve logging and analyze resulting data.

Flight Crew

Role	Team Member	Call Sign	Flight Responsibilities
Test Lead	Andres Permuy	TL	All calls, communication with Flight Engineer, and re-fly decisions.
Operator	Emiliano Villicaña Brugada	OP	Test Laptop, runs each test script.
Systems Engineer	Alexander Lim	SE	Monitor data health and stream.
Technician 1	Sebastian Abreu	TECH1	Handles apparatus configuration.
Technician 2	Matthew Nunez	TECH2	Performs repairs or power-cycle if needed.
Technician 3	Jonathan Pierre	TECH3	Performs repairs or power-cycle if needed.

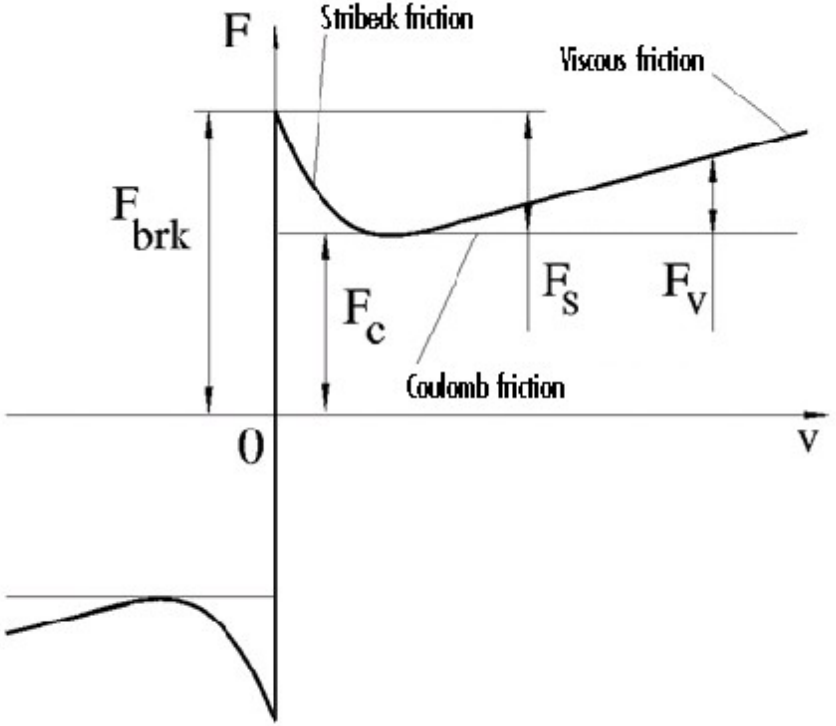
Expected Results

Documentation: Record the setup, procedure, and each trial’s orientation and gravity condition.

Recorded data: Motor current, shaft speed, acceleration, and temperature.

Analysis: Generate torque-speed curves, measure breakaway torque and coast-down rates, and compare fitted Stribeck parameters.

Expected result: Smaller orientation-dependent friction differences in microgravity, especially in breakaway and Coulomb friction.



Safety Concerns and Major Hazards

F1 — Electrical short circuit

F2 — Motor or driver overheating

F3 — Fire spreading through surrounding materials

F4 — Battery failure

R1 — Flywheel or hub release

R2 — Shaft, bearing, or mount failure

R3 — Overspeed or excessive vibration

R4 — Contact with rotating parts

Likelihood / Severity	Negligible	Minor	Moderate	Major	Catastrophic
Almost certain					
Likely					
Possible			**R4**	**R1, R2, R3**	
Unlikely					**F1, F2, F3, F4**
Rare					

Gantt Chart

Project:	Microgravity Robotic Joint Characterization	Week 1								Week 2							Week 3						
Task	**Task Due Date***	10/29	10/30	10/31	11/1	11/2	11/3	11/4	11/5	11/6	11/7	11/8	11/9	11/10	11/11	11/12	11/13	11/14	11/15	11/16	11/17	11/18	11/19
PDR	10/29																						
Finalized CAD	11/5																						
Working Electronics	11/12																						
Manufacturing	11/18																						
Finalized Prototype	11/18																						
Data Collection	11/24																						
Data Analysis	12/3																						
CDR	12/5-12/12																						

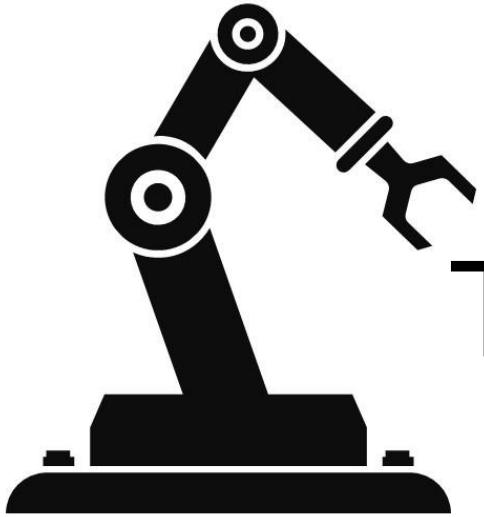
NOTES: *Due Dates are subject to change with arrival of materials*

Gantt Chart (cont.)

Project:	Microgravity Robotic Joint Characterization	Week 4					Thanksgiving Break					Week 5					CDR							
Task	**Task Due Date***	11/20	11/21	11/22	11/23	11/24	11/25	11/26	11/27	11/28	11/29	11/30	12/1	12/2	12/3	12/4	12/5	12/6	12/7	12/8	12/9	12/10	12/11	12/12
PDR	10/29																							
Finalized CAD	11/5																							
Working Electronics	11/12																							
Manufacturing	11/18																							
Finalized Prototype	11/18																							
Data Collection	11/24																							
Data Analysis	12/3																							
CDR	12/5-12/12																							

NOTES: *Due Dates are subject to change with arrival of materials*

Motor: DCX22S GB KL 12V **Encoder: ENX16 EASY 1024IMP** **Controller: ESCON 36/2 DC**	B845DD013EB0	Maxon	1	$595.49	$595.49
Ampmeter (TBD)	5832	Adafruit	1	$15.00	$15.00
Microcontroller	4	Teensy	1	$29.80	$29.80
Raspi	RaspberryPi 4B	RaspberryPi	1	$0.00	$0.00
DEWALT 20V MAX Battery, Lithium Ion, 5.0Ah (DCB205)	DCB205	DeWalt	1	$65.39	$65.39
2 Packs Power Wheel Adapter for Dewalt 20V Battery	-	CHoiKWong Store	1	$14.99	$14.99
50W Power Adapter DC 10~35V 12V/24V to 5V 10A	200108	DROK Store	1	$8.50	$8.50
Thermistor	495-75615-ND	DigiKey	5	$1.57	$7.87
IMU	LSM6DS3TR-C	Adafruit	1	$9.95	$9.95
MCP4725 Breakout Board	935	Adafruit	1	$4.95	$4.95
ADS1115 16-Bit ADC - 4 Channel	1085	Adafruit	1	$14.95	$14.95
GL.iNet GL-SFT1200 Opal Travel Router	-	GL.iNet	1	$39.99	$39.99
Rotary Switch		ZJWZJH	1	$18.99	$18.99



THANK YOU!