Southern New Hampshire University | School of Engineering, Technology, and Aeronautics

Preliminary Design Review

Alexia Hnatowicz, Alexandra Friebolin

Project Team & Roles

Alexandra Friebolin
Program Lead
(M.E.)

Jacob Morrissette
Chief Test Engineer
(M.E.)

Nik DiLullo
Chief Analyst
(E.E.)

Joe Sedutto
Systems Engineer
(E.E.)

Alexia Hnatowicz
Project Engineer
(M.E.)

Agenda

- Overview
- Feasibility Tests
- Driving Requirements
- System Design
- Subsystem Design
- Trade Studies
- Budget
- Timeline
- Open Design Items
- Next Steps…

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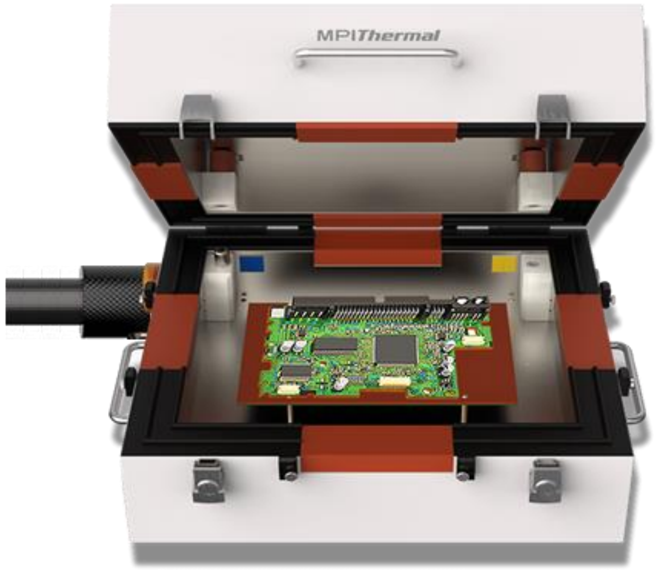
System Overview

- Thermally-controlled Printed Circuit Board ("PCB") testing chamber
  - Table-top system
  - User-control & automatic operation
  - Spanning 0C – 70C commercial temperature range
- Purpose: evaluating operation, functionality, & performance of electronic components in an enclosure replicating environmental conditions.



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Driving Requirements

- **1.1** - The system shall accommodate a 12x12" PCB as a device to be tested.
- **2.1.1** - The PCB shall successfully operate while temperature is fluctuating.
- **3.2.1** - The system shall cover commercial temperature range (0-70°C)
- **3.2.4** - The system shall maintain a temperature ±3°C of setpoint.
- **3.4.5** - The system shall be capable of sweeping the temperature range in a 24-hour cycle.

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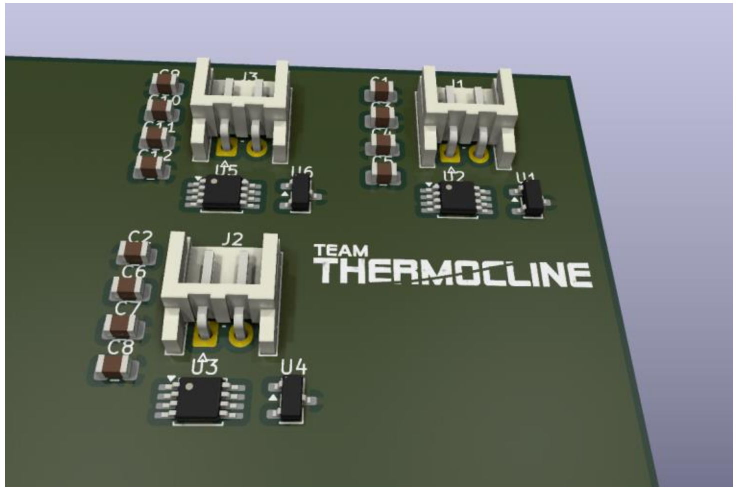
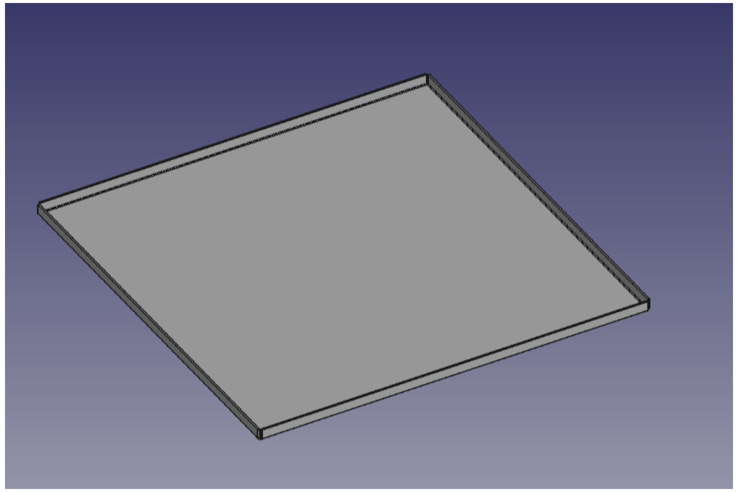
System Design

Primary Components and Drivers of the system design:

- Hardware
- Software
- Structure
- Thermal
  - Heating
  - Cooling
- Safety Features





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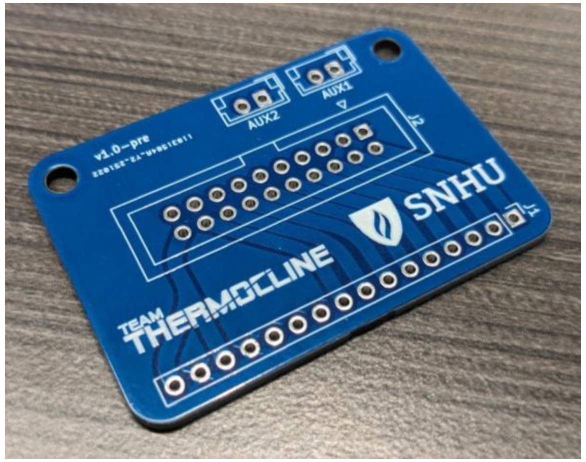
Feasibility Test: 1/3

Supply Chain Capability

- **Objective(s):**
  - To evaluate effectiveness & efficiency of logistics for sourcing materials
- **Test Article(s):**
  - PCB prototype & mechanical structural handle
- **Data to be Collected:**
  - Manufacturer lead time, price, & company/product information

JLCPCB



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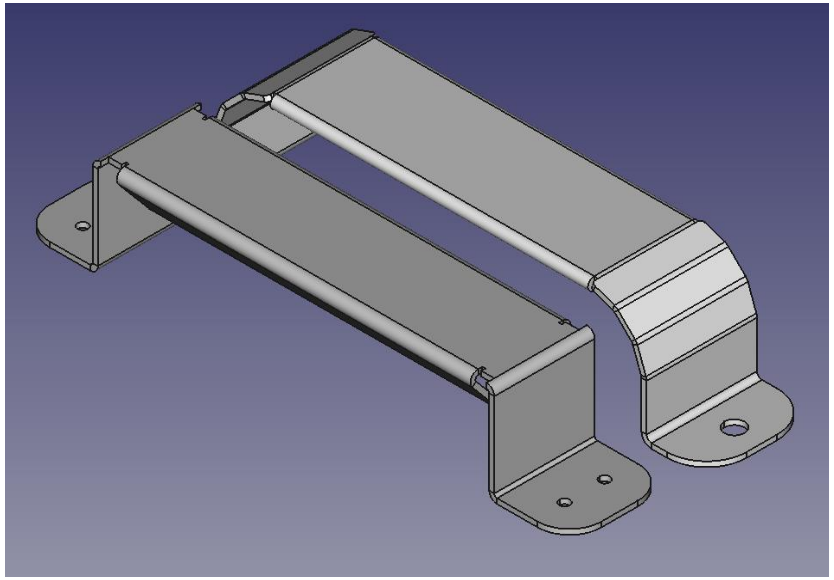

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Manufacturer Feedback

- **SCS** Gave us some helpful feedback on our sheet metal design
  - Notes about max bend radius, part complexity and unfolding.
  - Relief and complexity
- **JLCPCB** didn't have any feedback for us, but Ruben gave us some other advice
  - Consider stackup and copper plating thickness
  - Consider increasing the space between traces
  - Perhaps a 4 layer board in the future for increased capability

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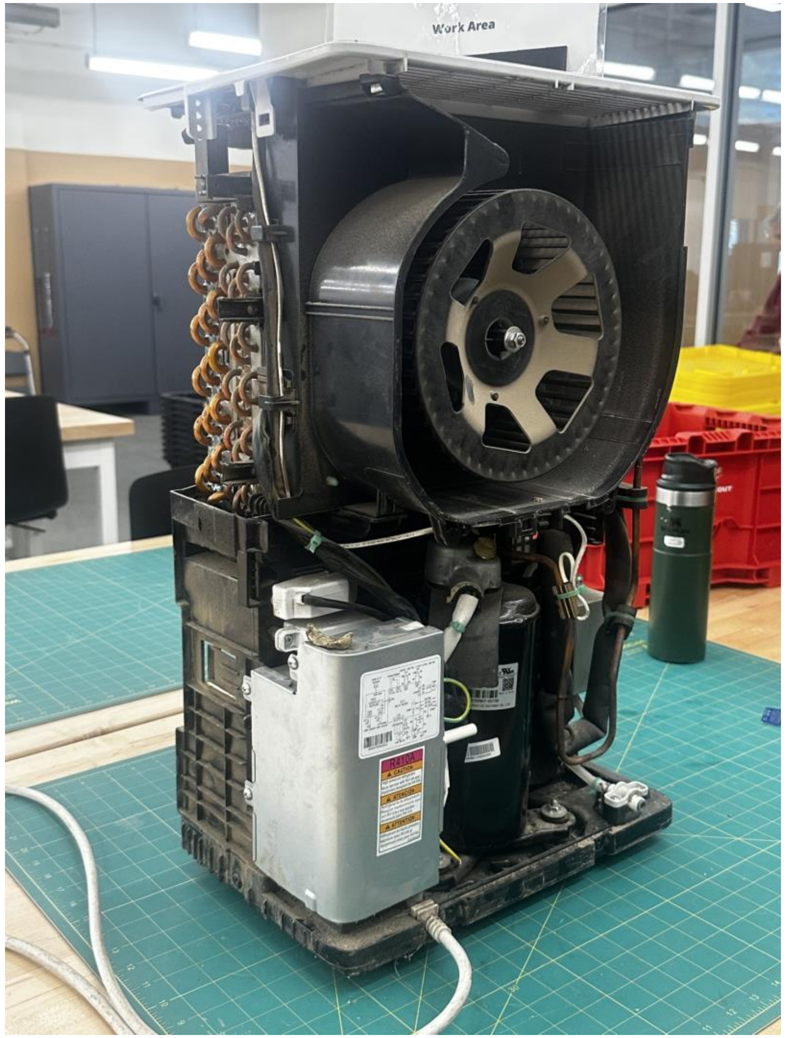
Feasibility Test: 2/3

<u>Component Performance</u>

- **Objective(s):**
  - To verify simultaneous operation of compressor with controller, and confirm performance meets initial system requirements
- **Test Article(s):**
  - Compressor component
- **Results:**
  - Condenser Temperature: **0°C (< 30min until steady)**
  - Compressor Temperature: **74°C (< 30min until steady)**
  - Current Draw: **5A (~ 2s until steady)**



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Ramp Rate and Results

- For (estimated) volume and mass of cold side, without accounting for proximity of hot side.
- Results are at least as good as this.
- Not accounting for efficiency loss below –2, this is already sufficient ramp for our 0 to 70 requirements.

Interperting our test results, estimation of the thermal energy moved here

$$Q = mc_p\Delta T \tag{1}$$

$$\dot{Q} = \frac{Q}{t} \tag{2}$$

where m is the mass of the evaporator, c_p is the specific heat capacity, ΔT is the temperature change, and t is the time interval.

I estimated an evaporator mass $m = 0.34$–0.45 kg, a temperature change of $\Delta T = 22$ °C, and a mixed aluminum–copper construction with an average $c_p \approx 745\ \mathrm{J\,kg^{-1}\,K^{-1}}$,

$$Q = (0.34\text{–}0.45)(745)(22) = 5.6\text{–}7.4 \times 10^3\ \mathrm{J} \tag{3}$$

$$\dot{Q} = \frac{Q}{180\ \mathrm{s}} = 31\text{–}41\ \mathrm{W} \tag{4}$$

So, for a 3-minute temperature ramp from 20 °C to −2 °C, the average cooling rate is approximately 31–41 W, or 106–140 $\mathrm{btu\,h^{-1}}$ at least.

Feasibility Test: 3/3

<u>Control System Quality</u>

Objective(s):

To verify Human Machine Interface (“HMI”) screen performs as designed, and the control process from HMI to external wiring functions as predicted.

Test Article(s):

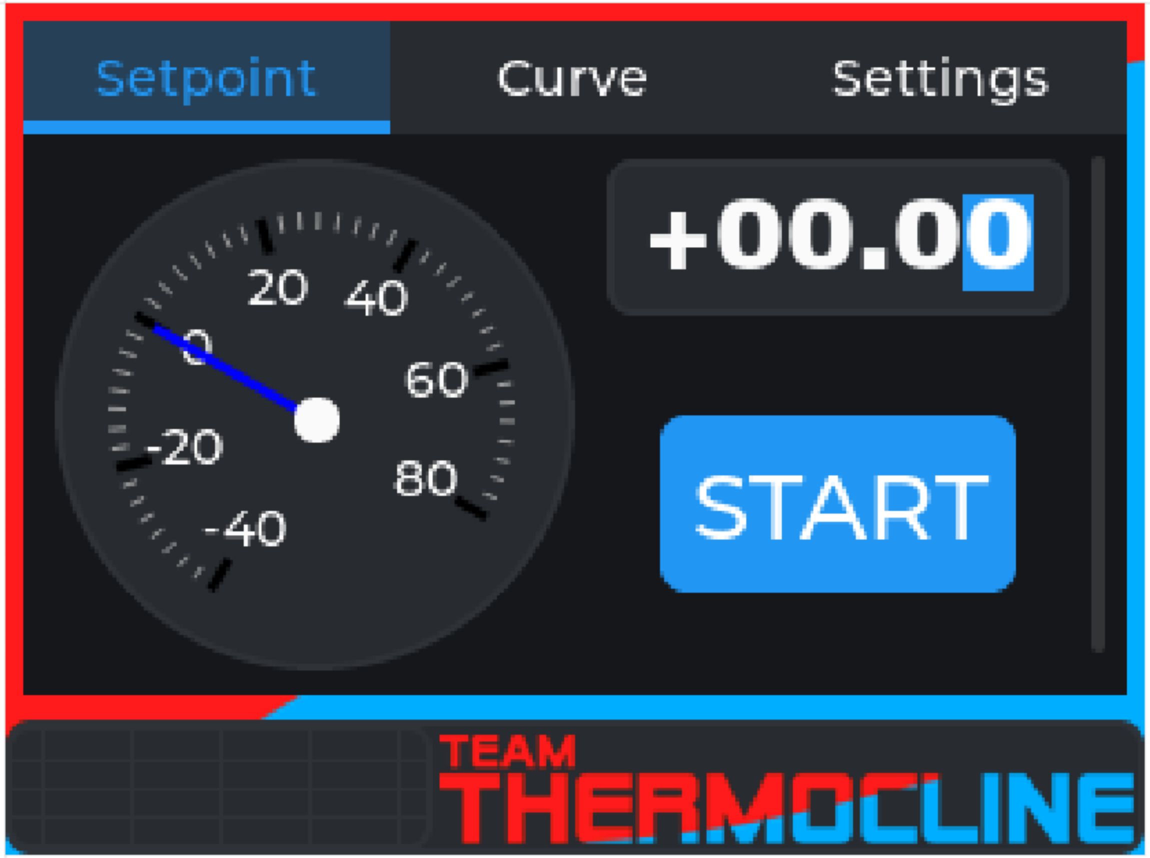
HMI screen prototype with touch display and software.

Data Collected:

Touch Works (not fully implemented)

Graphics platform (lvgl) implemented

CI/CD (github) implemented



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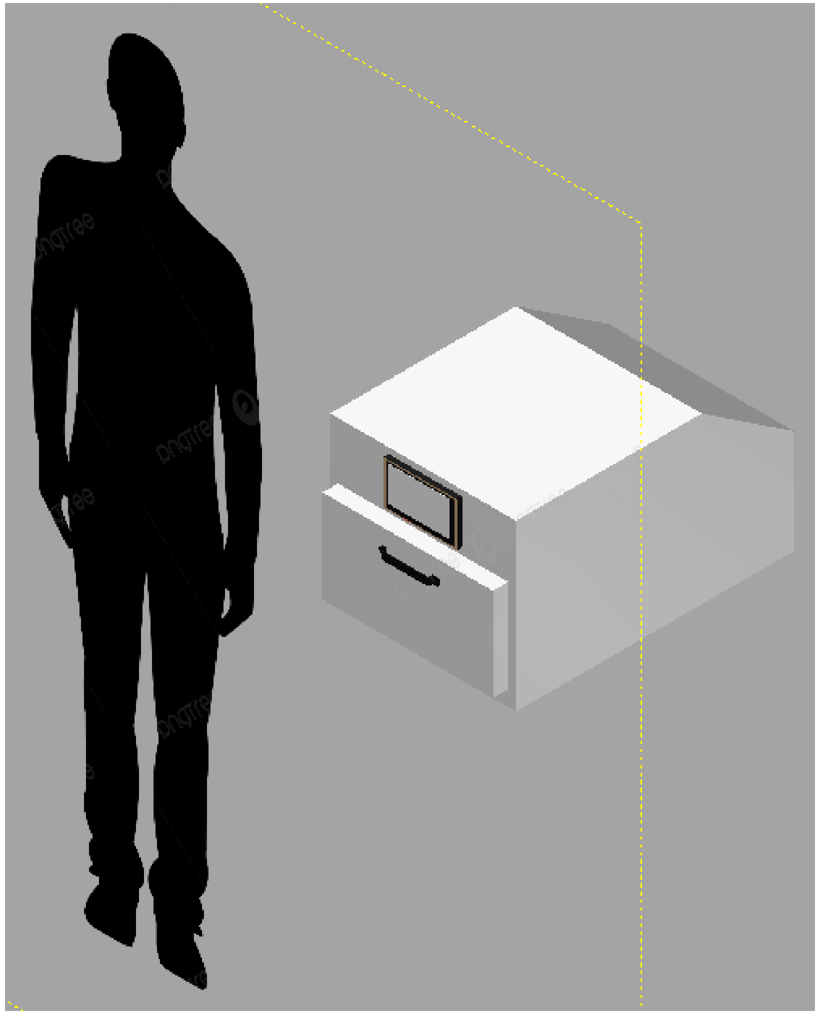
Subsystem Design: Structural



Requirements:

- STR-01: The system shall have external base dimensions of no more than 30x30 inches.
- STR-03: The chamber opening(s) shall include proper thermal sealing according to ASTM F1886.

Trade Studies

Trade Study Name: Insulation | TS-03 | Trigger Date: 10/28/025

	Fiberglass	Polyurethane Foam	Polystyrene	Silica Aerogel
Description:				
Conductivity (r-value)	0.032 - 0.036 W/m*K	0.020 - 0.030 W/m*K	0.025 - 0.040 W/m*K	3.2 - 15.0 mW/m*K
Size	6-12 inches	1.18 inches	~3 inches	0.2 - 0.4 inches
Malleability	Most Malleable	Malleable depending on the specific type	When molten it is malleable	Not malleable
Cost	$1.00 - $4.50 per square foot	$0.50 - $4.50 per square foot	$1.00 - $4.50 per square foot	$10,000 per cubic foot

Status: Selected Fiberglass

Subsystem Design: Thermo-fluid

Requirements:

- THE-01: The system shall cover *commercial* temperature range (0°-70°).
- THE-02: The system shall be capable of sweeping all temperature ranges within a 24-hour cycle.

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Trade Studies

Trade Study Name: Cooling | TS-02 | Trigger Date: 10/7/2025

Evaluation Criteria	R410A	Glycol	Propane	Peltier
Description	Common hydrofluorocarbon refrigerant with a boiling point of **-48°c**	Synthetic antifreeze and thermal fluid. When paired with a glycol chiller, can cool external systems.	Flammable petroleum gas. Very common, can be used as a refrigerant although not very safely. Boils at **-42°c**	Effect in which heat can be transferred over a semiconductor layer by DC current
Effectiveness	Moderate	Effective	Moderate	Low
Ease of integration	Moderate	Easy	Moderate	High
Risk	Moderate	Low	High	Low
Cost	$60/lb	$5000+	$2.50/gallon	$100/1000BTU

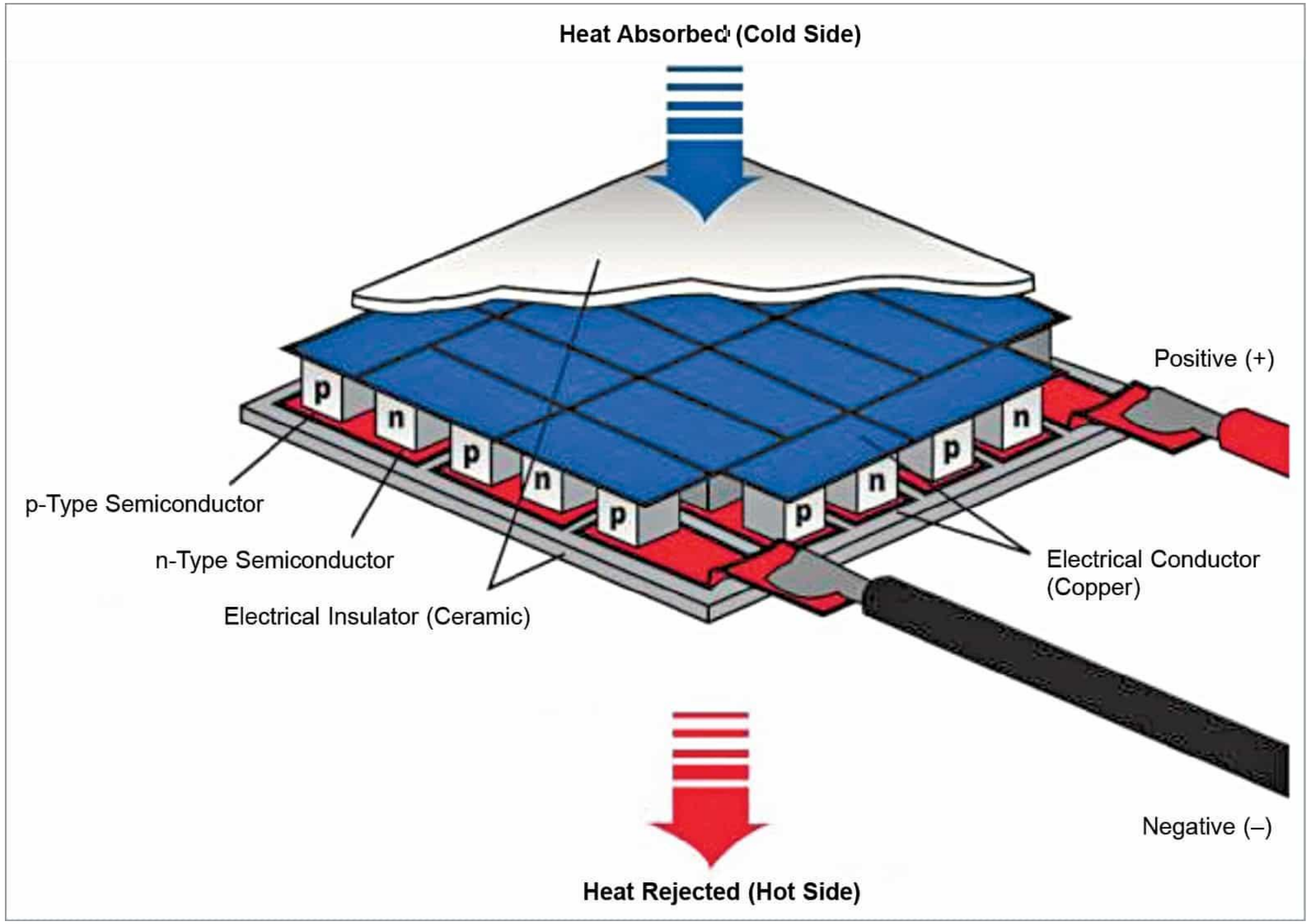
Status: Selected R410A

Peltier Analysis

We explored using electric peltier coolers. Which work by applying electrical current through a semiconductor, to move heat through a ceramic plate.

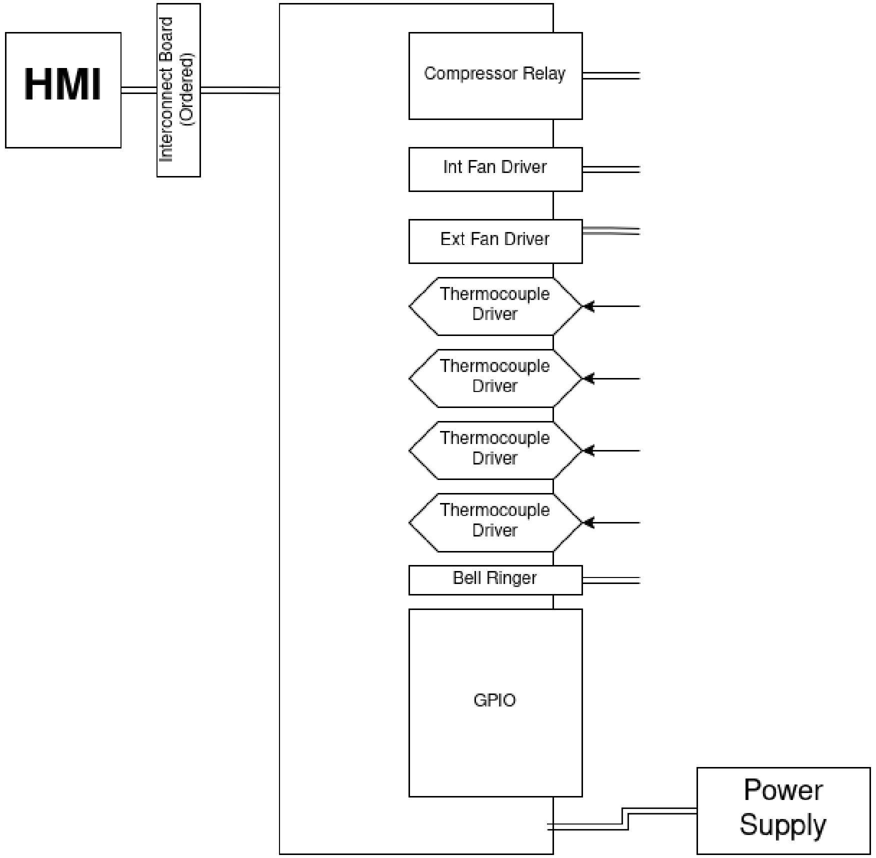
Our analysis found that a peltier system that moves the thermal energy we expect to need, would require upwards of **400BTU/H to maintain temperature** and More than **500BTU/H** to change temperature at project requirement rates.

When weighed against our other avenues of heating and cooling we did not consider peltier as a good fit for our design, specifically.



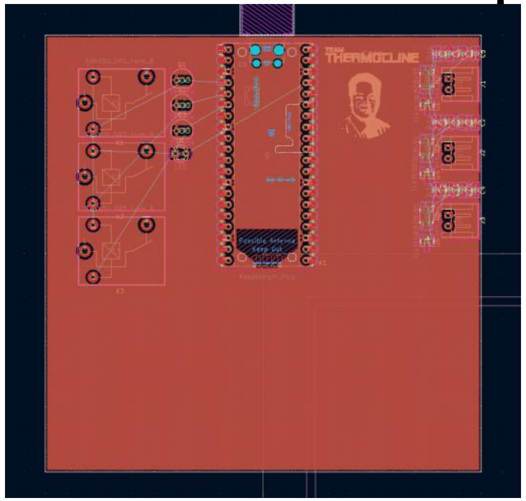
Sources on slides 28-29

Subsystem Design: Electrical Components



Requirements:

- COM-03: The system shall adhere to UL 61010 for test and measurement equipment.



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Trade Studies

Trade Study Name: Heating | TS-01 | Trigger Date: 10/7/2025

	Resistive	Inductive	Convection	Reversable Heat
Description	Current passes through a resistive element which converts energy into heat through the element's resistance.	A quickly alternating magnetic field that induces eddy currents inside a conductive material, generating heat within the material.	Transfers heat through circulating air/fluid, heated by resistive elements.	Add a reversable valve to allow recycling heat from the thermal hot side for use in heating.
Price (USD)	~$100	~$800	~$600	~$500
Risk	Overheating / fire hazard.	Electromagnetic interference (EMI) / magnetic fields.	Temperature non-uniformity/runaway airflow heating.	Adds failure points to the thermal system, risks overheating the oil.

Status: Selected **Resistive Heating**

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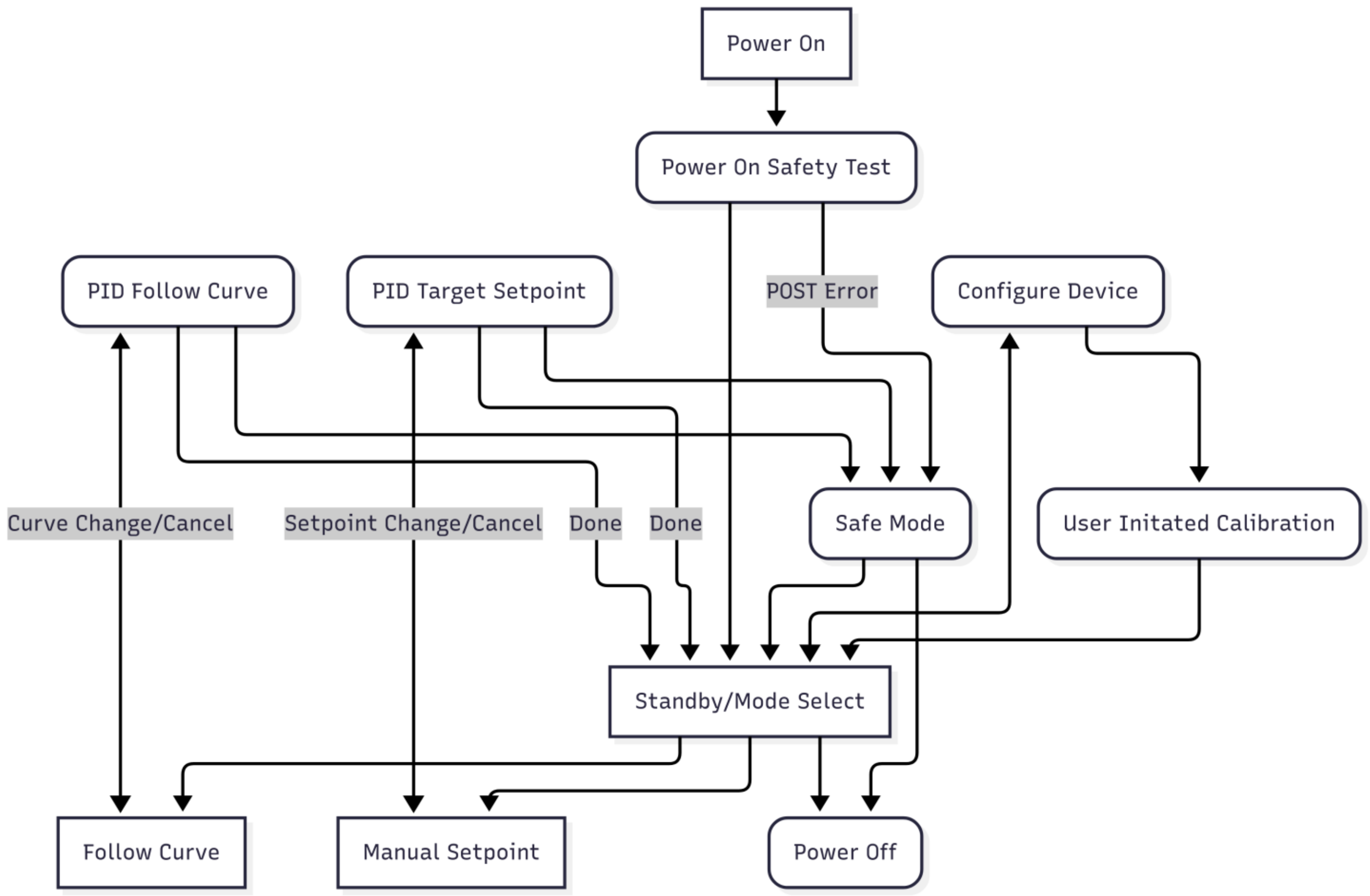
Subsystem Design: Control System



- Multiple Operating Modes
- HMI integration
- Safe and Calibration Modes

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Subsystem Design: Safety

- SAF-01: The internal surfaces shall be safe for electronics according to ASTM D3874-20
- SAF-02: The system external surfaces shall not exceed the safe-touch temperature of 50 C according to ASTM C1055
- SAF-03: The System shall be able to operate in normal environment (external) conditions of 21 C
- SAF-04: The system shall include a safety measure if temperature range & tolerance is exceeded
- SAF-05: The system shall have a "safe" state

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Budget:

Overall Budget

#	Category	Original Budget ($)	Spent ($)	Balance ($)
1	Materials	600	30	570
2	Hardware	600	35	565
3	Software	600	50	550
4	Management Reserve	600	0	600
5	Other	600	0	600
	Total ($):	3000	115	2885

Itemized Expenses

Item	% of Budget	Price
PCB	1%	$35
Compressor	0%	$0
SendCutSend	1%	$30
HMI Screen	2%	$50
Total for FTP:	4%	$115
Total Budget	100%	$3,000

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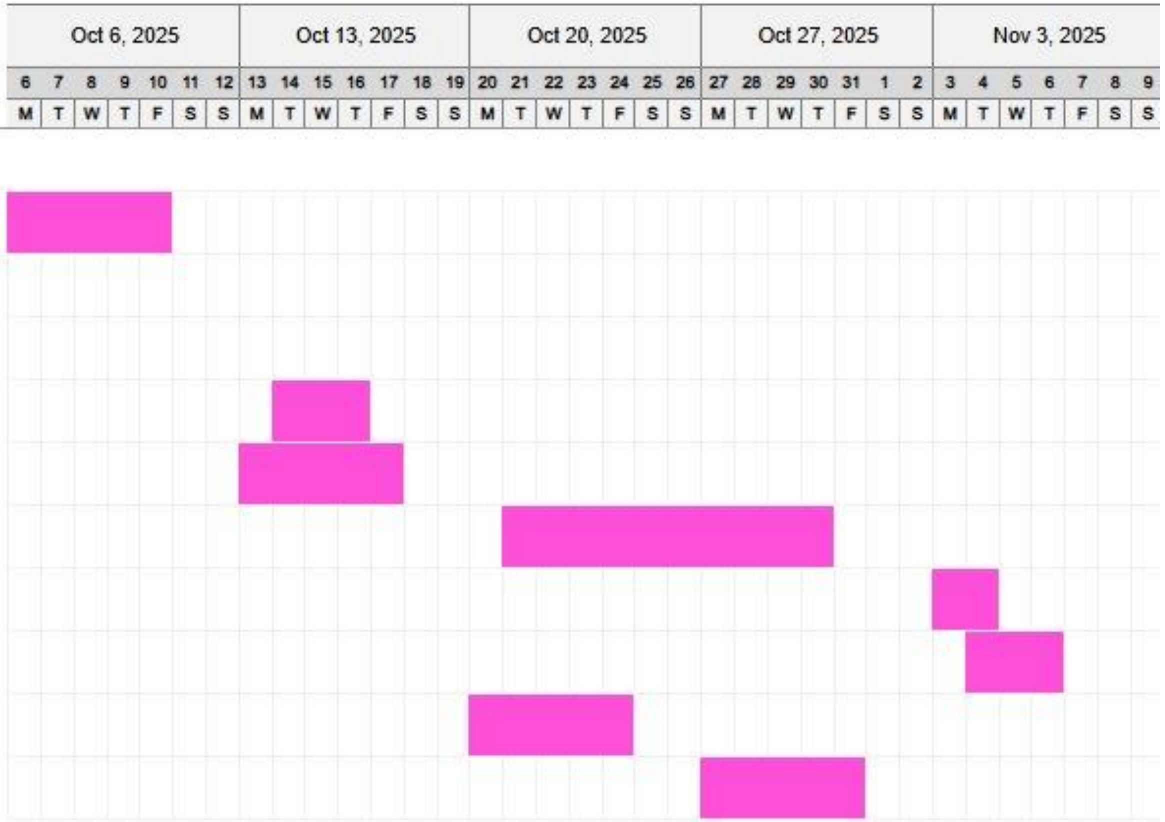
Timeline

GANTT CHART
The Thermocliners

TASK	ASSIGNED TO	PROGRES	START	END
Preliminary Design				
Week 6 Stats Report			10/6/25	10/10/25
Capstone Material Order Form			10/11/25	
Feasibility Test Plan				
Feasibility Test Slides			10/14/25	10/16/25
Week 7 Status Report			10/13/25	10/17/25
PDR Draft Slides			10/21/25	10/30/25
PDR Slides			11/3/25	11/4/25
October Monthly Status Report			11/4/25	11/6/25
Week 8 Status Report			10/20/25	10/24/25
Week 9 Status Report			10/27/25	10/31/25



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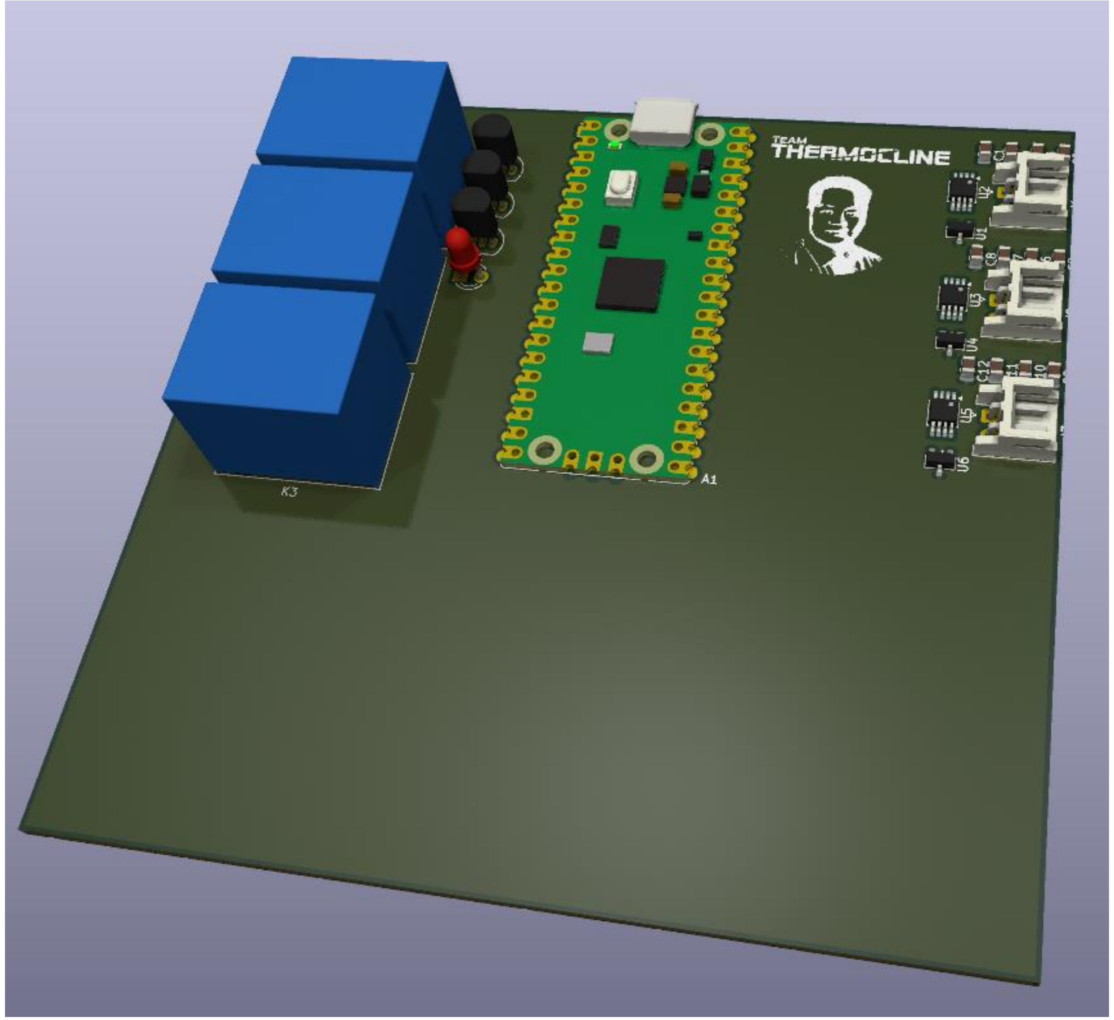
Open Design Items

- Chassis
- Shocks/Vibration Dampening
- Fans and Cooling
- Recovery and Logistics



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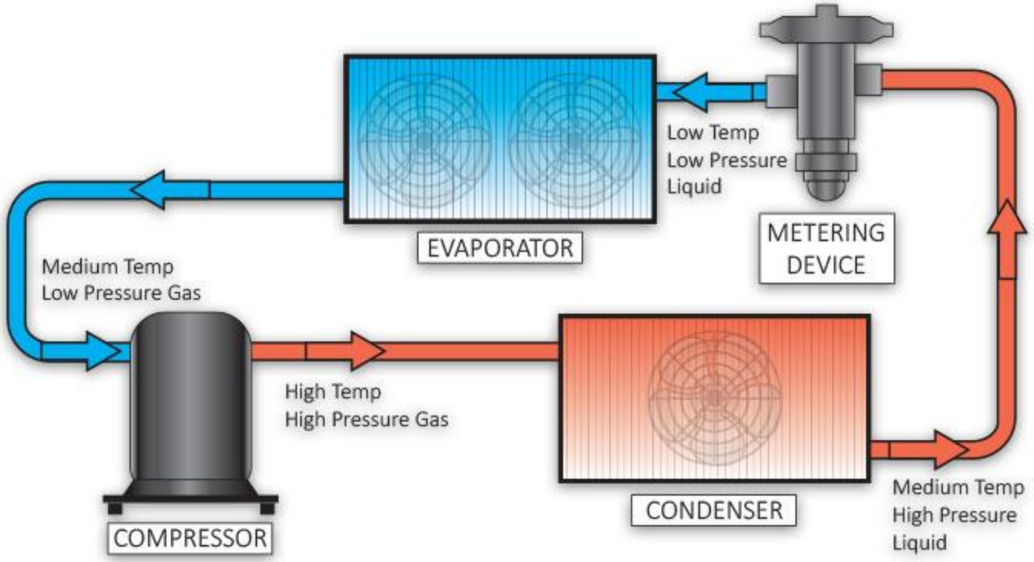
Questions?

BACKUP SLIDES

Control System Exploration

- Time Proportional PID (Duty Cycle PID)
- **Why cant you use normal PID?**
  - You can for **heat** but you cannot for cooling.
  - The reason is the head start problem. At max load, especially around where our system will operate at the –40 mark. The system head pressure ahead of the compressor will be VERY high as refrigerant struggles to boil in the cold environment behind. This is a common problem in HVAC where we cannot simply fast cycle. And must account for a **minimum off-time** to allow the pressure to drop.
- **Will This control method allow for our fine (3deg) control?**
  - Sorta, Kinda. When we charge the system, idealy, we use enough fluid to enable the cold side to **just boil** at our min temperature. This will leave us a **little overcharged at higher temperatures**. But will allow us greater, smoother control down low. And with our capilary metering, enable near cryo temperatures. Its complex to characterize but we may have a band especially at the **–5 to –10** mark where our minumum off time and desired cycle time are at odds.



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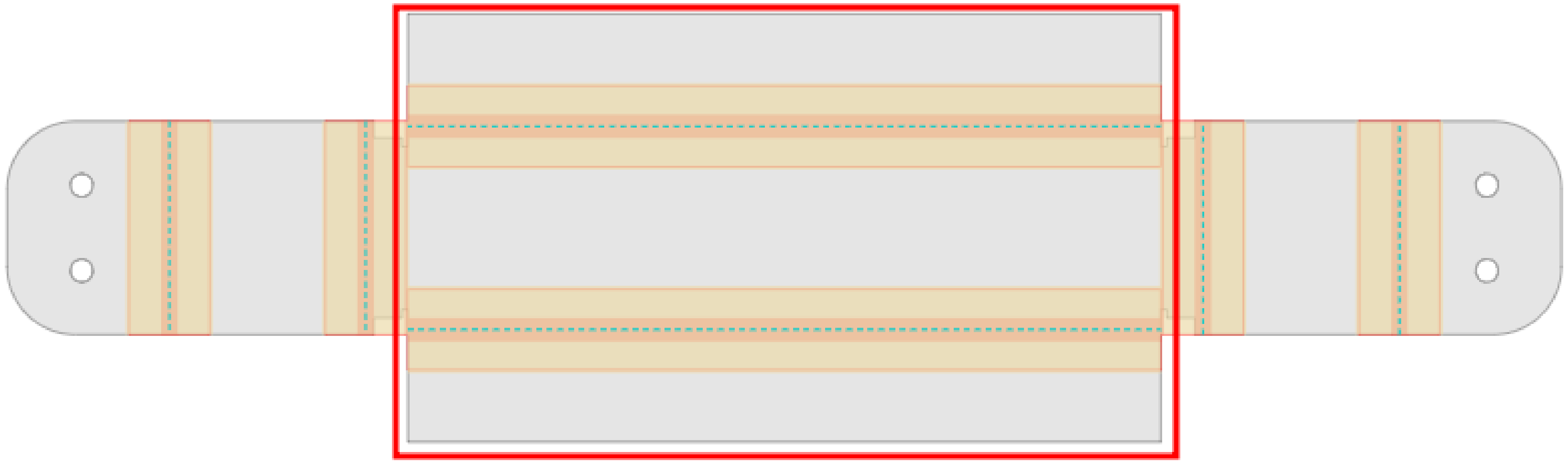
Hi Jason,

Thank you so much for your order! During our preproduction design checks, we noticed an issue that forced us to place **your order on hold**.

There are some limitations to what we can form in a "U" channel configuration before the bent part collides with the bending equipment. To avoid these collisions, we need the base-to-flange ratio to be at least 2:1.

2:1 RATIO FOR SHEET METAL

Tweaks_Repalcement_Body.step



We have your order on hold for now. Would you like to revise your design, or have the bending operation removed and the part shipped flat?

$L_{floor} := 13\ in \quad H_{wall} := 6\ in$

$$A_{internal} := 2 \cdot L_{floor}^{2} + 4 \cdot \left(L_{floor} \cdot H_{wall}\right) = 0.4194\ m^{2}$$

$t_{start} := 20\ °C \quad t_{end} := (-40)\ °C$

$$\Delta_t := t_{end} - t_{start} = -60\ K$$

$U := 5\ \dfrac{W}{m^{2}\ K}$ Overall heat transfer estimate

$$\boxed{Q_{cond} := U \cdot A_{internal} \cdot \Delta_t = -429.2686\ \frac{BTU}{hr}}$$

BTU just to maintain the condition.

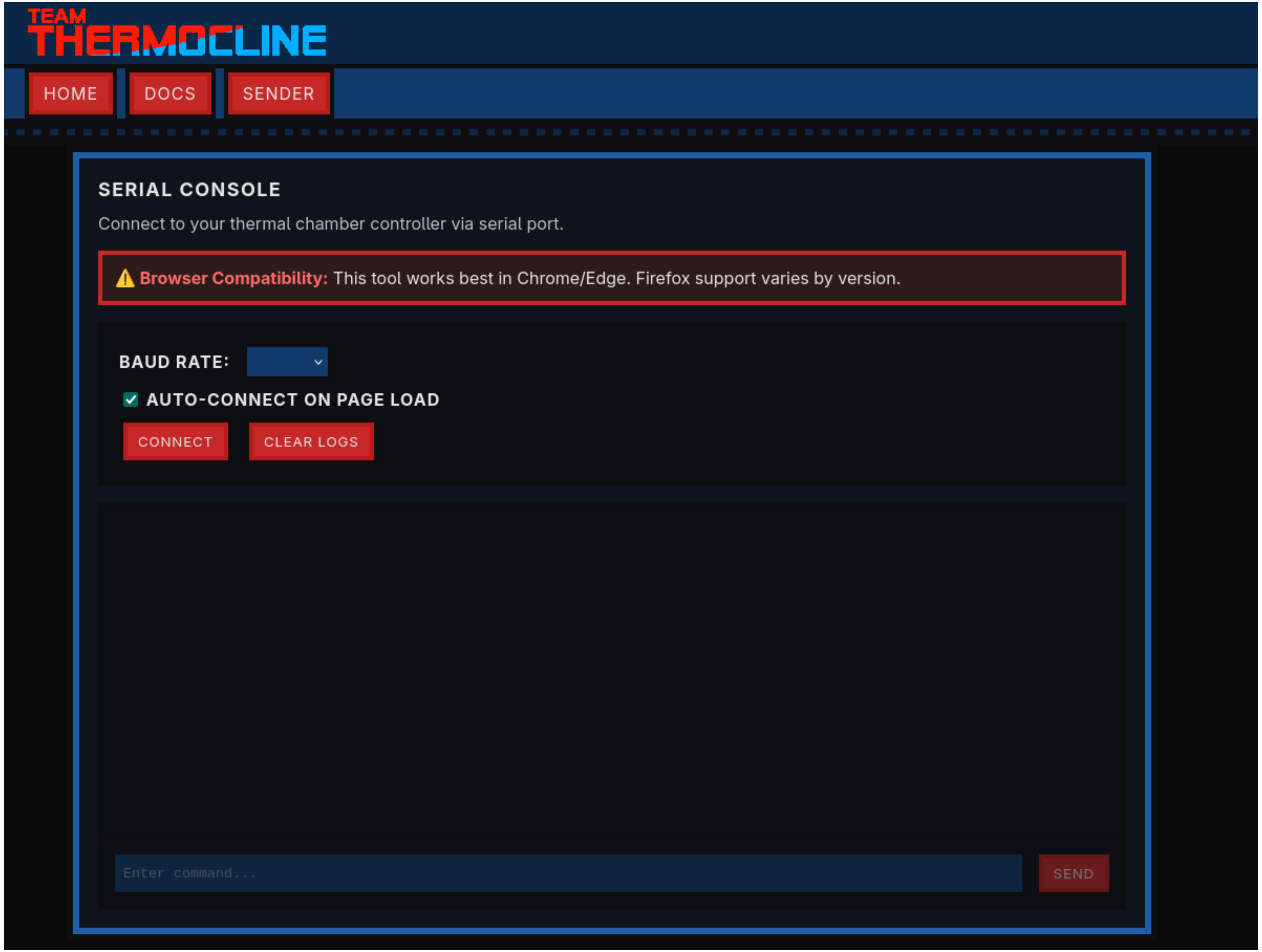
Not accounting for the density of air or anything just asuming contents of box and aluminum walls dominate.

$$c_{p\_aluminum} := 0.9 \frac{kJ}{kg\ K} \qquad m_{aluminum} := 1\ kg$$

$$Q_{pull} := m_{aluminum} \cdot c_{p\_aluminum} \cdot \Delta_t = -51.1821\ BTU$$

$$t_{time\_to\_cool} := 30\ min$$

$$\boxed{Q_{total} := Q_{cond} + \frac{Q_{pull}}{t_{time\_to\_cool}} = -531.6328 \frac{BTU}{hr}}$$


TEAM THERMOCLINE
HOME
DOCS
SENDER
SERIAL CONSOLE
Connect to your thermal chamber controller via serial port.
Browser Compatibility: This tool works best in Chrome/Edge. Firefox support varies by version.
BAUD RATE:
AUTO-CONNECT ON PAGE LOAD
CONNECT
CLEAR LOGS
Enter command...
SEND

Requirements Database- Design

1.1	**The system shall accomodate a 12x12" PCB as device to be tested.**	Demonstration
1.1.1	The system shall have external base dimensions of maximum 30x30 inches.	Measure
1.2	**The system shall include insulation designed for external safety according to ASTM C1055.**	Inspection
1.2.1	The chamber opening(s) shall include proper thermal sealing.	Inspection
1.2.2	The internal thermal control components shall include proper thermal sealing.	Inspection
1.3	**The system's design shall be safe for continual operation.**	Measure
1.3.1	The internal surfaces shall be safe for electronics.	Analysis
1.3.2	The system external surfaces shall not exceed the safe-touch temperature of 50°C according to ASTM C1055.	Analysis
1.3.3	The system shall be able to operate in normal environmental (external) conditions of 21°C.	Demonstration

Requirements Database- System

2.1	**The system shall include a port to allow electrical cables to enter and leave for stimulus and measurement of the PCB.**	Inspection
2.1.1	The PCB shall be operatable while temperature is controlled.	Measure
2.2	**The system shall comply with electrical grounding requirements.**	Inspection
2.3	**The system shall be able to operate on a standard wall-outlet power of 120V (AC).**	Demonstration
2.4	**The system will comply with appropriate NEC and UL rules governing powered and plug in devices.**	Inspection
2.4.1	System will adhere to NEC rules on grounding.	Inspection
2.4.2	System will adhere to NEC rules on appropriate fuses and load wire sizes.	Inspection
2.4.3	System will adhere to UL 61010 for test and measurement equipment.	Inspection

Requirements Database- Functional

3.1	**The system shall monitor temperature inside the chamber.**	Demonstration
3.1.1	The sensors shall be properly rated to withstand internal environmental conditions.	Analysis
3.2	**The system shall control temperature inside the chamber.**	Demonstration
3.2.1	The system shall cover *commercial* temperature range (0°C - 70°C). [Optional]: cover *industrial* temperature range (-40°C - 85°C).	Measure
3.2.2	The system shall allow local temperature setpoint control.	Test
3.2.3	The system shall allow remote temperature setpoint control.	Test
3.2.4	The system shall maintain a toleranced temperature at $\pm 3^{\circ}C$ of setpoint.	Measure
3.2.5	The system shall prohibit thermal control when the chamber door is open.	Demonstration
3.2.6	The system shall prohibit thermal control when a user is handling the PCB.	Demonstration
3.2.7	The system shall include a safety measure if temperature range & tolerance is exceeded.	Demonstration
3.3	**The system shall remain within a specified humidity range (0% - 90%).**	Measure
3.4	**The system shall provide data output.**	Demonstration
3.4.1	The system shall support PC connection for datalogging.	Inspection
3.4.2	The system shall log temperature data.	Test
3.4.3	The system shall log humidity data.	Test
3.4.4	The system shall log faults for safety measures.	Measure
3.4.5	The system shall be capable of sweeping all temperature ranges within a 24-hr cycle.	Test

Requirements Database- Interface

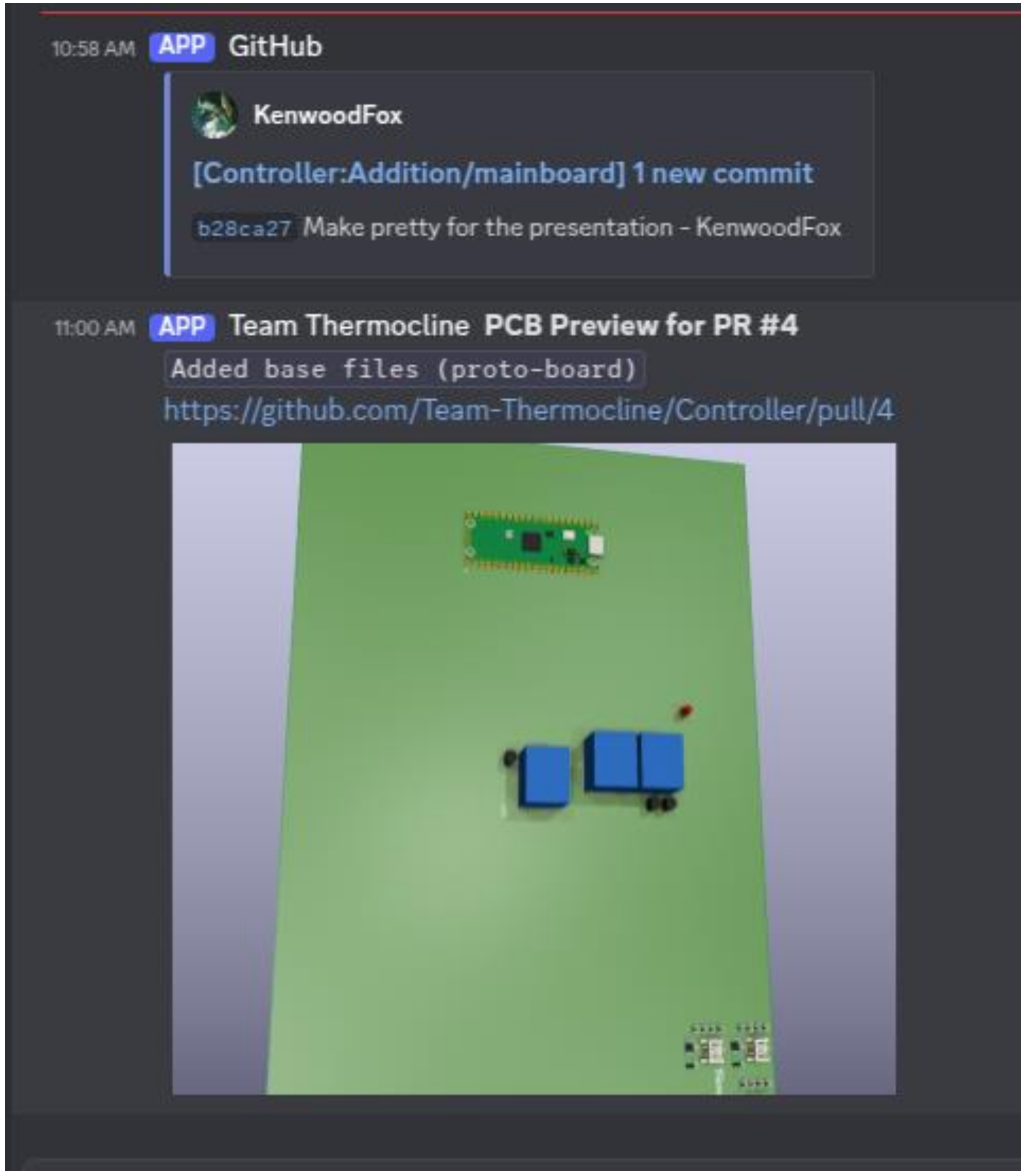
4.1	**The system shall include an HMI for the control system.**	Inspection
4.2	**The system shall include separate operating/control modes.**	Demonstration
4.2.1	The system shall have a "shutdown" state.	Demonstration
4.2.2	The system shall have a "standby" mode.	Demonstration
4.2.3	The system shall have a normal operating "start" mode.	Demonstration
4.2.4	The system shall have a "safe" state.	Demonstration
4.2.5	The system shall allow for manual switching between modes.	Demonstration

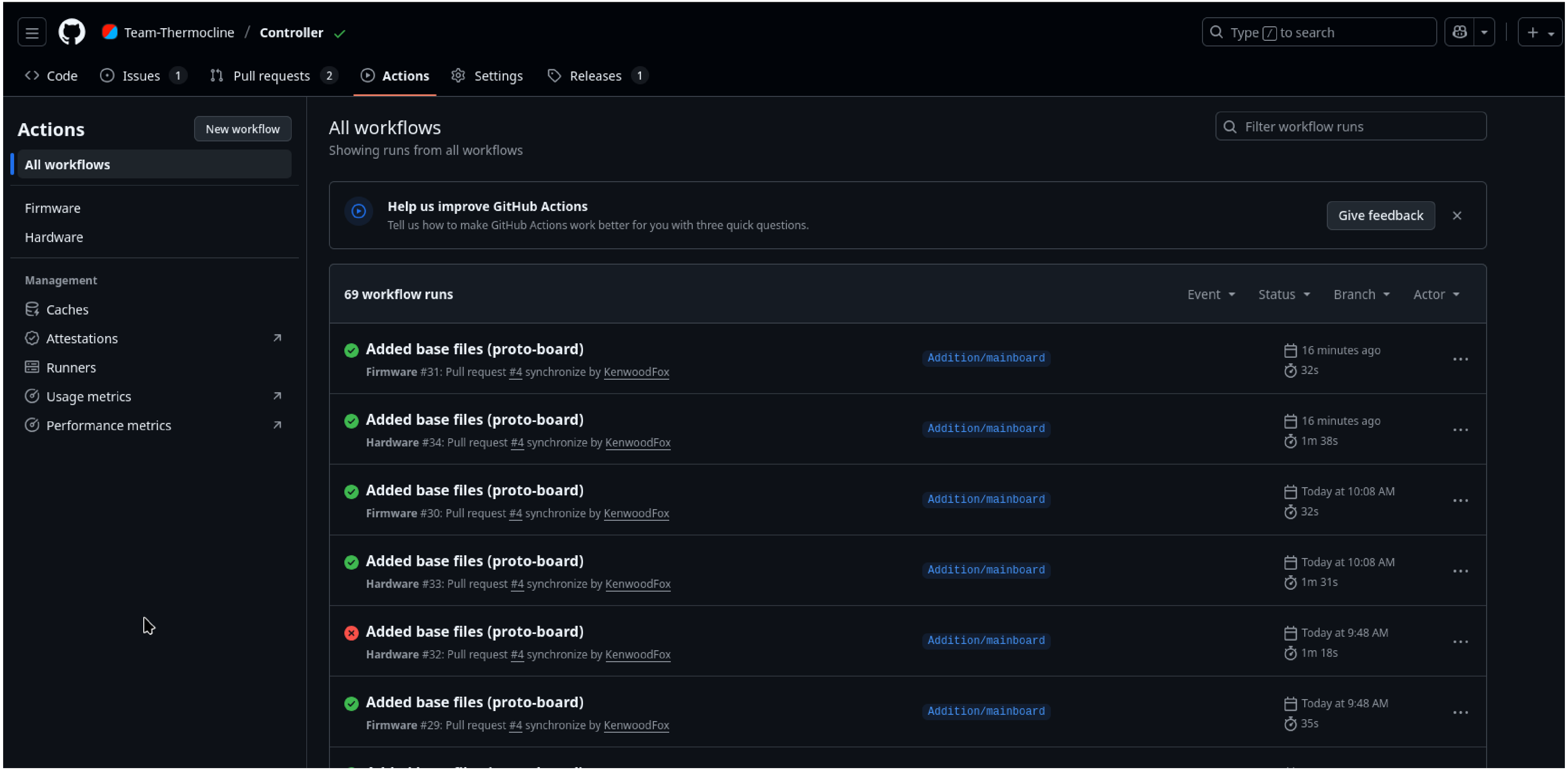
Risk Assessment - List

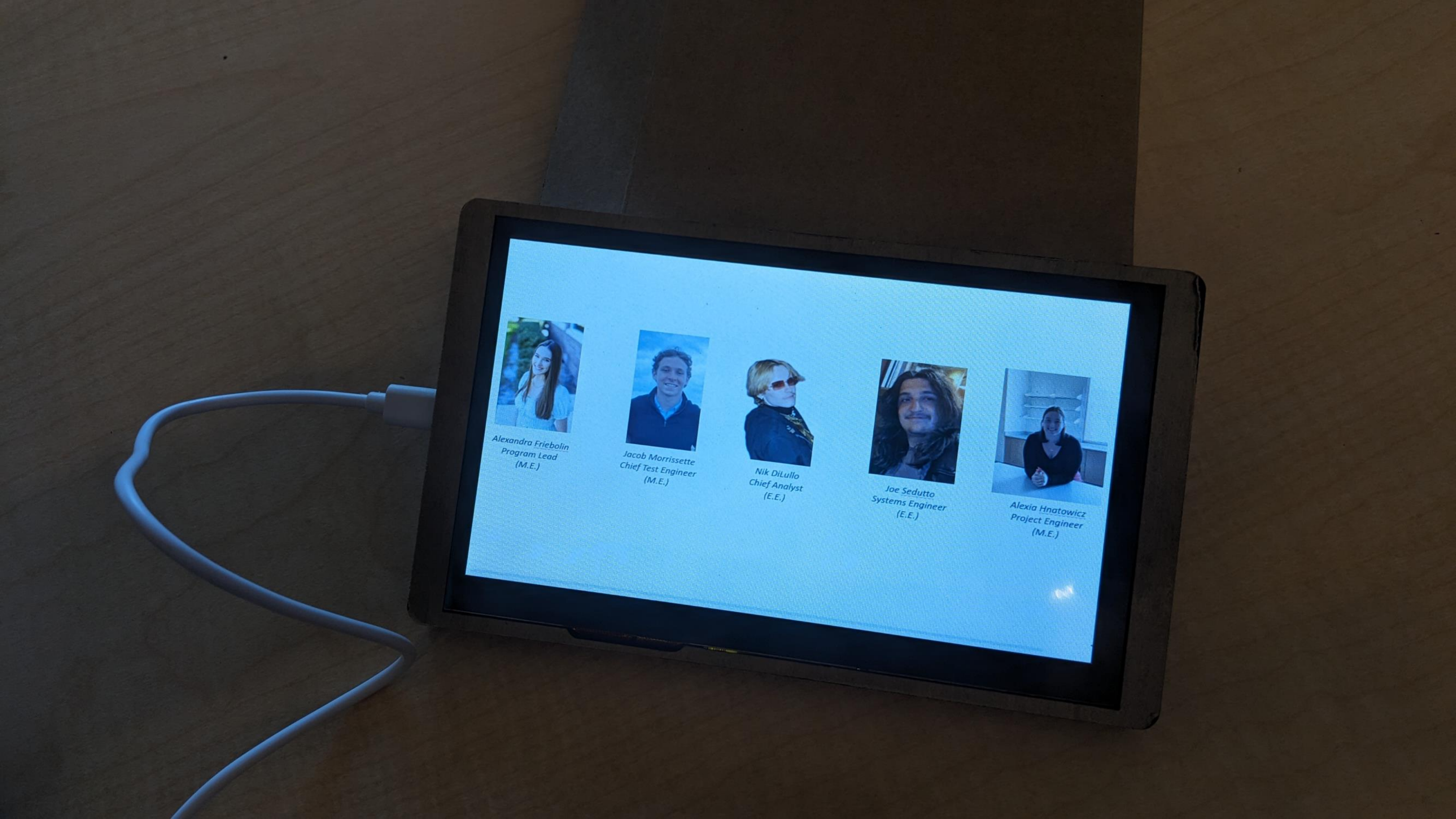
A	Asset	Mechanical Failure of Components (worn, broken)
B	Asset	Insufficient Dimensions for PCB testing (internal, external, cable port, chamber door)
C	Asset, Human Safety	Internal System is Over Temperature Range (fire, melting components)
D	Asset, Human Safety	Internal System is Under Temperature Range (freezed components)
E	Asset, Performance	System's Safety Measure Fails If Outside Temperature Range
F	Asset, Performance	Internal Heating/Cooling System Can't Reach upper/lower boundaries (poor components, inefficient controller)
G	Asset, Performance	Inconsistent Temperature Control (poorly designed microcontroller or interface)
H	Asset, Performance	Failure to Maintain Toleranced Setpoint ($\pm^{o}3$C) (ineffective control system, poor insulation - internal & external)
I	Asset, Performance	Lack of Electronic Protection (excessive moisture buildup)
J	Cost	Spending Past Designated Budget for Equipment & Materials
K	Human Safety	Lack of Human Protection at Critical Temperature Ranges (burns)
L	Human Safety	System Fails to Meet Environmental/Engineering Codes
M	Human Safety	System Fails to Prohibit Temperature Control During Manual User Usage.
N	Human Safety, Performance	Chemical Leaking
O	Human Safety, Performance	Electrical Hazards (short circuits, improper connections)
P	Human Safety, Performance	System Fails to Operate Safely Under Normal Conditions
Q	Performance	Software/HMI Failure
R	Performance	Lack of Refrigerant Fluid in System
S	Performance	Controller not User Friendly (poor HMI design)
T	Performance	Sensor Reading Failure (miscalibration, component issue)
U	Performance	Improper Ventilation (pressure changes, fumes buildup)
V	Performance	Ineffective Insulation (poor materials or design)
W	Performance	Data Measuring, Collecting, and Logging Fail to Work Systematically
X	Performance	System Mode(s) Failures
Y	Schedule	Poor Scheduling for Fabricated Parts or Sourced Materials
Z	Schedule, Cost	Rework of Product (ineffective design from failed systems/components/materials)

Risk Assessment - Matrix

Consequence	5	B, L	A, E, P	K, M, O	Z	
	4		Y	N	I	Q, W
	3		F, G	T, U, X	V	
	2	R	J		C, D	H
	1	S				
		1	2	3	4	5
		Likelihood				
Notes:	Combined Risk Scores: 0-9 (Green) --> Minor 10-19 (Yellow) --> Moderate 20-29 (Red) --> Major					

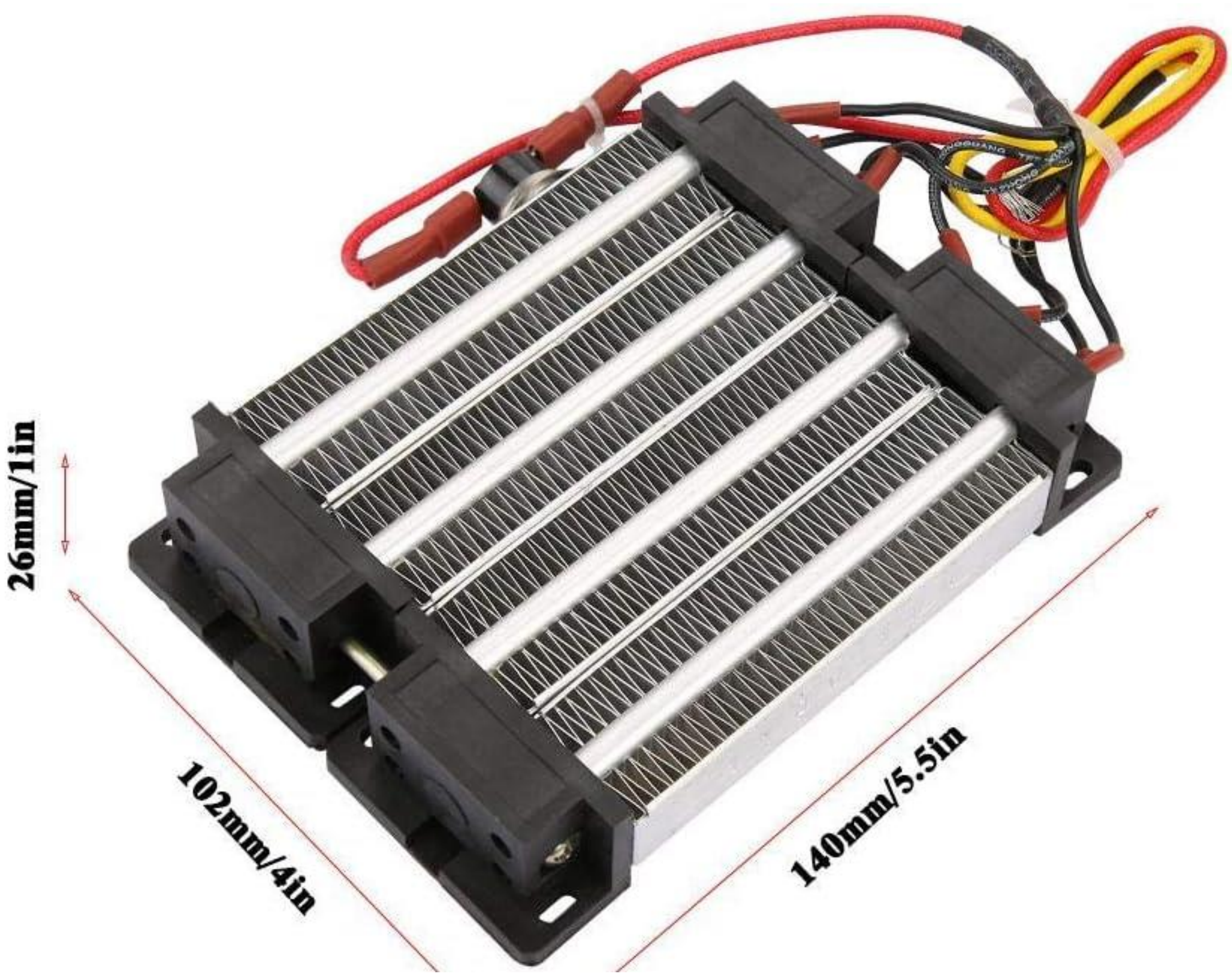

10:58 AM APP GitHub
KenwoodFox
[Controller:Addition/mainboard] 1 new commit
b28ca27 Make pretty for the presentation - KenwoodFox
11:00 AM APP Team Thermocline PCB Preview for PR #4
Added base files (proto-board)
https://github.com/Team-Thermocline/Controller/pull/4


Team-Thermocline / Controller
Type / to search
Code
Issues 1
Pull requests 2
Actions
Settings
Releases 1
Actions
New workflow
All workflows
Firmware
Hardware
Management
Caches
Attestations
Runners
Usage metrics
Performance metrics
All workflows
Showing runs from all workflows
Filter workflow runs
Help us improve GitHub Actions
Tell us how to make GitHub Actions work better for you with three quick questions.
Give feedback
69 workflow runs
Event
Status
Branch
Actor
Added base files (proto-board)
Firmware #31: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
16 minutes ago
32s
Added base files (proto-board)
Hardware #34: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
16 minutes ago
1m 38s
Added base files (proto-board)
Firmware #30: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 10:08 AM
32s
Added base files (proto-board)
Hardware #33: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 10:08 AM
1m 31s
Added base files (proto-board)
Hardware #32: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 9:48 AM
1m 18s
Added base files (proto-board)
Firmware #29: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 9:48 AM
35s


Alexandra Friebolin
Program Lead
(M.E.)
Jacob Morrissette
Chief Test Engineer
(M.E.)
Nik DiLullo
Chief Analyst
(E.E.)
Joe Sedutto
Systems Engineer
(E.E.)
Alexia Hnatowicz
Project Engineer
(M.E.)

- Amazon heater
Sub $50
Super easy to replace
Comes in every size we could want

Power from 800-1.2kw, easily in range



SendCutSend

ORDER SX357091

Est. Delivery
November
5

100%

To get your parts to you as quickly as possible, your order may be fulfilled from multiple SendCutSend locations.

We have received your order and it is being processed
OCTOBER 27, 3:13 PM

Your order is being reviewed
OCTOBER 27, 4:50 PM

Your parts are being produced
OCTOBER 28, 3:29 PM

Your parts are being deburred
NOVEMBER 2, 12:32 AM

Your parts are being bent
NOVEMBER 2, 3:23 AM

Your parts are undergoing quality inspection
NOVEMBER 2, 6:40 AM

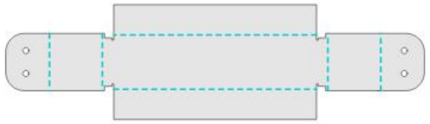
Some of your parts have been shipped
NOVEMBER 2, 7:31 AM

Your parts are on their way
NOVEMBER 2, 1:22 PM

PACKAGE

Show all tracking updates

Nov 4, 4:16 AM ON THE WAY LEXINGTON, KY



5052 H32 Aluminum (.063")
9.094" x 2.507"

TRACK ON UPS

PACKING SLIP 1

Shipping to:
Jason Crowell
Southern New Hampshire University
2500 North River Road

VIEW INVOICE

CONTACT US