A.C.E.S.

Air-breathing Cold Engine Start

Manufacturing Status Review

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Outline

- Overview
- Schedule
- Manufacturing
- Budget

Overview

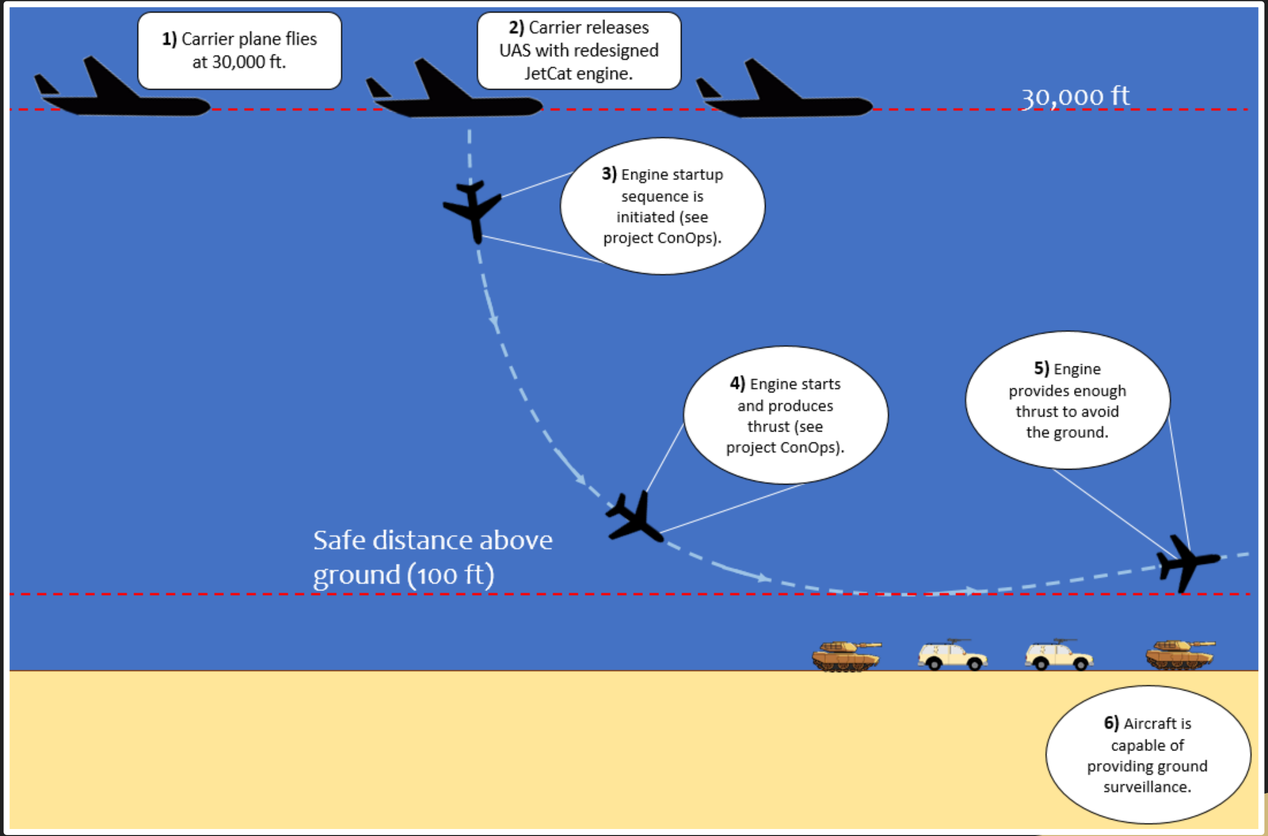
Project Description

- Design, build, and test a system to facilitate starting a JetCat P90-SXi jet engine at a temperature of -50°F by:
    - Controlling the temperature and mass flow rate of the fuel into the engine
    - Ensuring that the engine electronics are within their operating temperature range
    - Ensuring that the heating system has sufficient power to heat the fuel delivery system and engine electronics
- Motivation
    - Air Force Research Lab (AFRL) conference
    - Proof of concept for high-altitude (cold-temperature) restart for jet-powered UAS

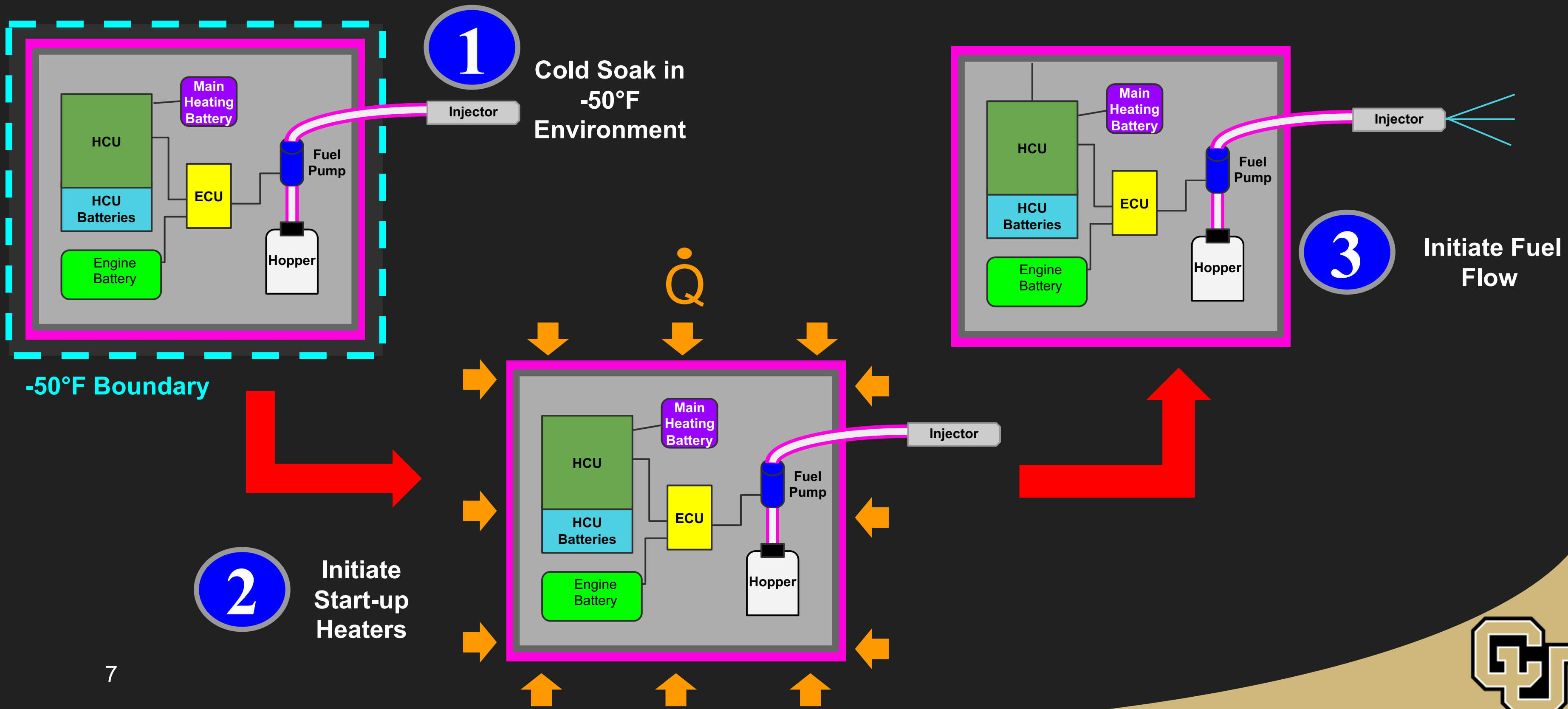
Course Project Objectives

	Fuel Delivery System (FDS)	Electronics Heating	Startup Time	AFRL Conference
Level 1	System will control mass flow rate & temperature of fuel when placed in an environment cold-soaked to -30°F.	The electronics will be heated to 60°F after being placed in an environment cold-soaked to -30°F.	The fuel delivery and electronics heating systems objectives will be completed in less than 3 hours.	
Level 2	System will control mass flow rate & temperature of fuel when placed in an environment cold-soaked to -40°F.	The electronics will be heated to 60°F after being placed in an environment cold-soaked to -40°F.	The fuel delivery and electronics heating systems objectives will be completed in less than 1.5 hours.	
Level 3	System will control mass flow rate & temperature of fuel when placed in an environment cold-soaked to -50°F.	The electronics will be heated to 60°F after being placed in an environment cold-soaked to -50°F.	The fuel delivery and electronics heating systems objectives will be completed in less than 8 m 42 s	
Level 4				Entire system will be integrated with engine and successfully start within 3 hours.

Mission CONOPS

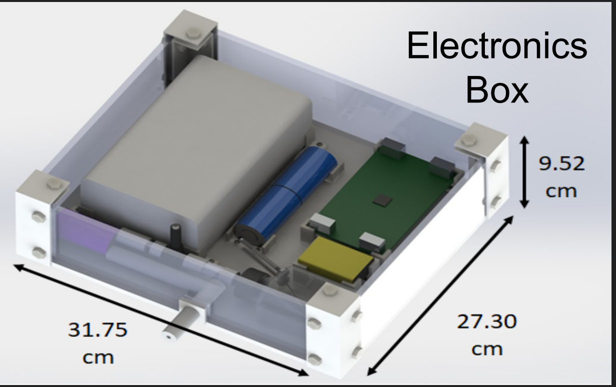


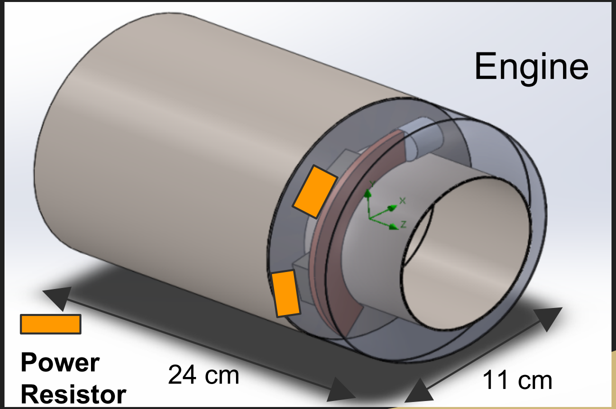
Project Conops



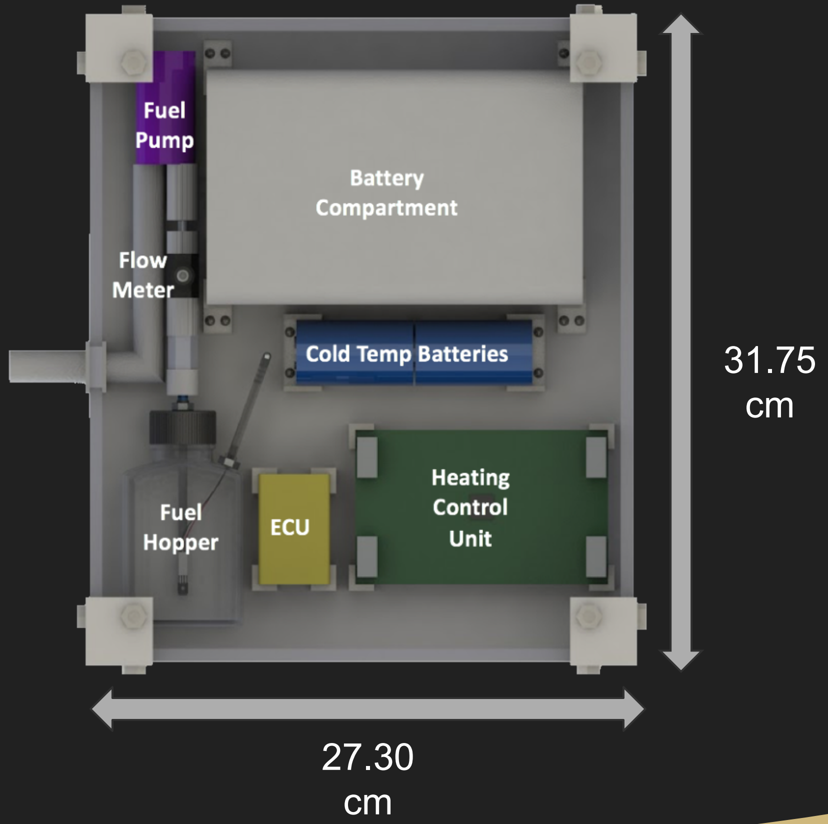
Baseline Design

- **Initial Energy:** Cryogel insulated battery
- **Fuel Delivery System:** Resistive heating wire wrapped around fuel delivery components insulated in Cryogel
- **Electronics Heating:** Resistive heating within manufactured plastic box, ESB heated by power resistors in engine cowling
- **Heating Control Unit (HCU):** Microcontroller powered by cold temperature batteries, controls temperatures and fuel flow rate

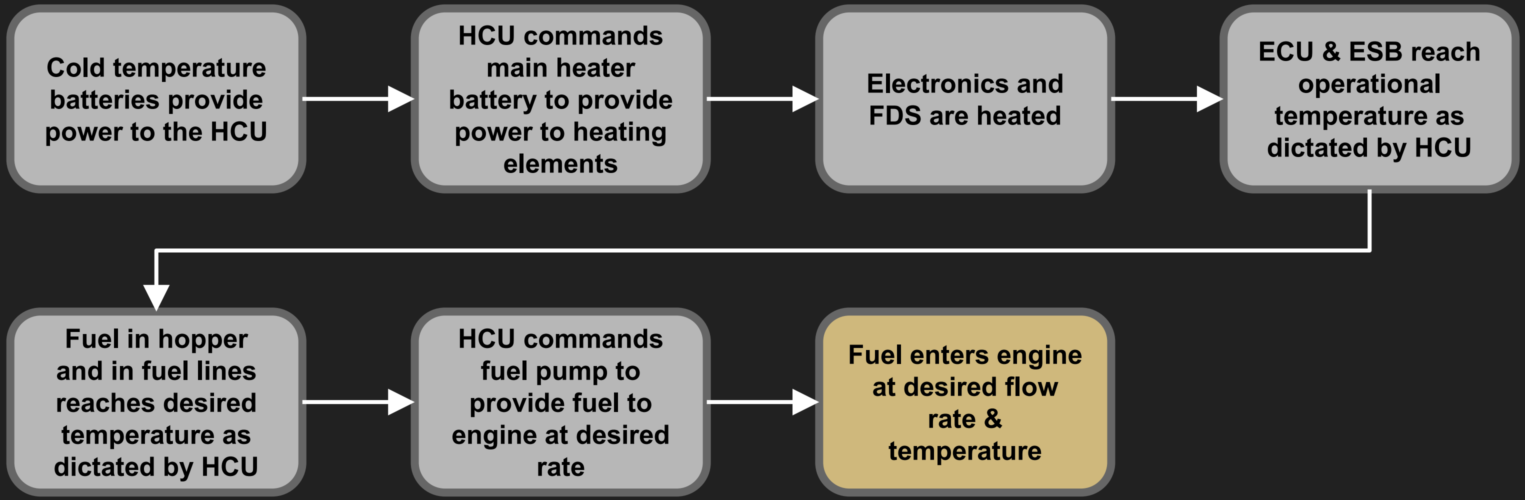




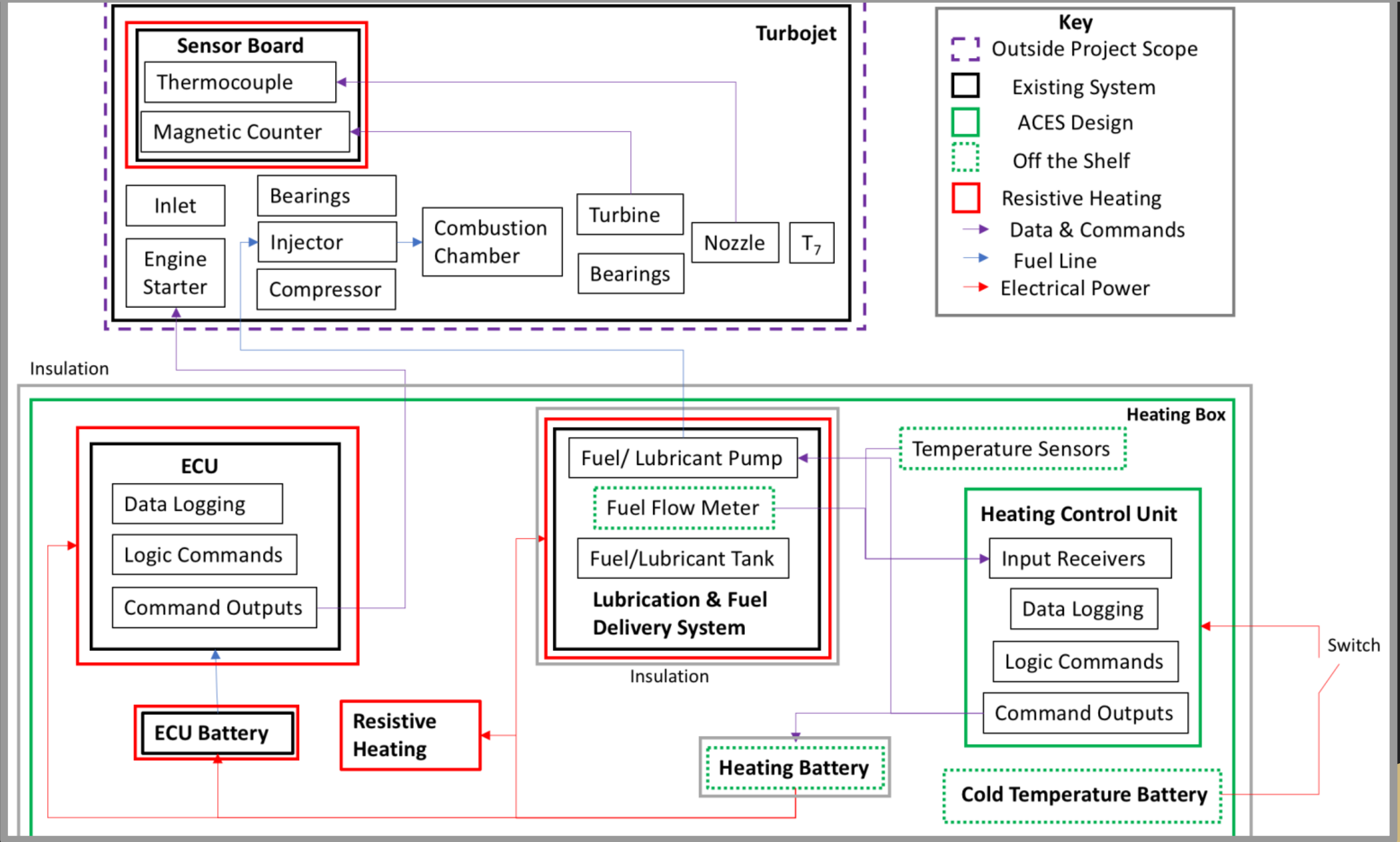
Baseline Design



Process Flow Diagram



Functional Block Diagram



Critical Project ELements

CPE 1: Temperature of main heater battery must be > 30°F and < 122°F

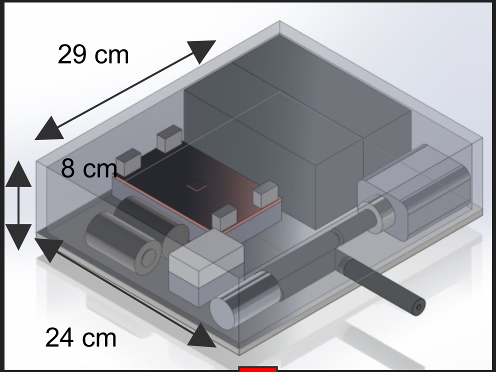
CPE 2: ECU, ESB, and engine battery must be 60°F while not exceeding 122°F for the battery and 150°F for the ECU and ESB

CPE 3: Temperature of fuel in fuel delivery system must be > 60°F and < 115°F

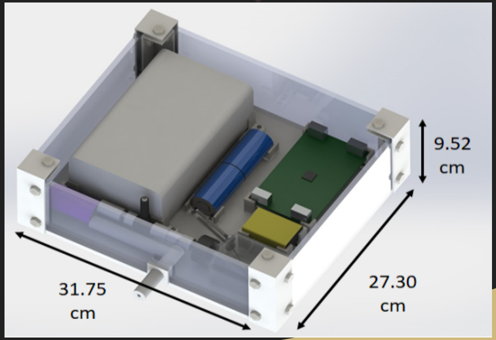
CPE 4: A Heating Control Unit (HCU) must control the mass flow rate of fuel and heating systems

Executive Summary

- Design Changes Since CDR
  - Multiple HCU PCB changes
    - Removed slave microcontroller
  - Refined electronics housing design
  - Changed resistive wire wrapping pattern
  - Added flow meter to CAD model
  - Refined fuel delivery system design
- Schedule
  - HCU PCB schedule has slipped
  - With margin, still on schedule
- Budget
  - $2037.71 spent to date
  - On budget



CDR Design

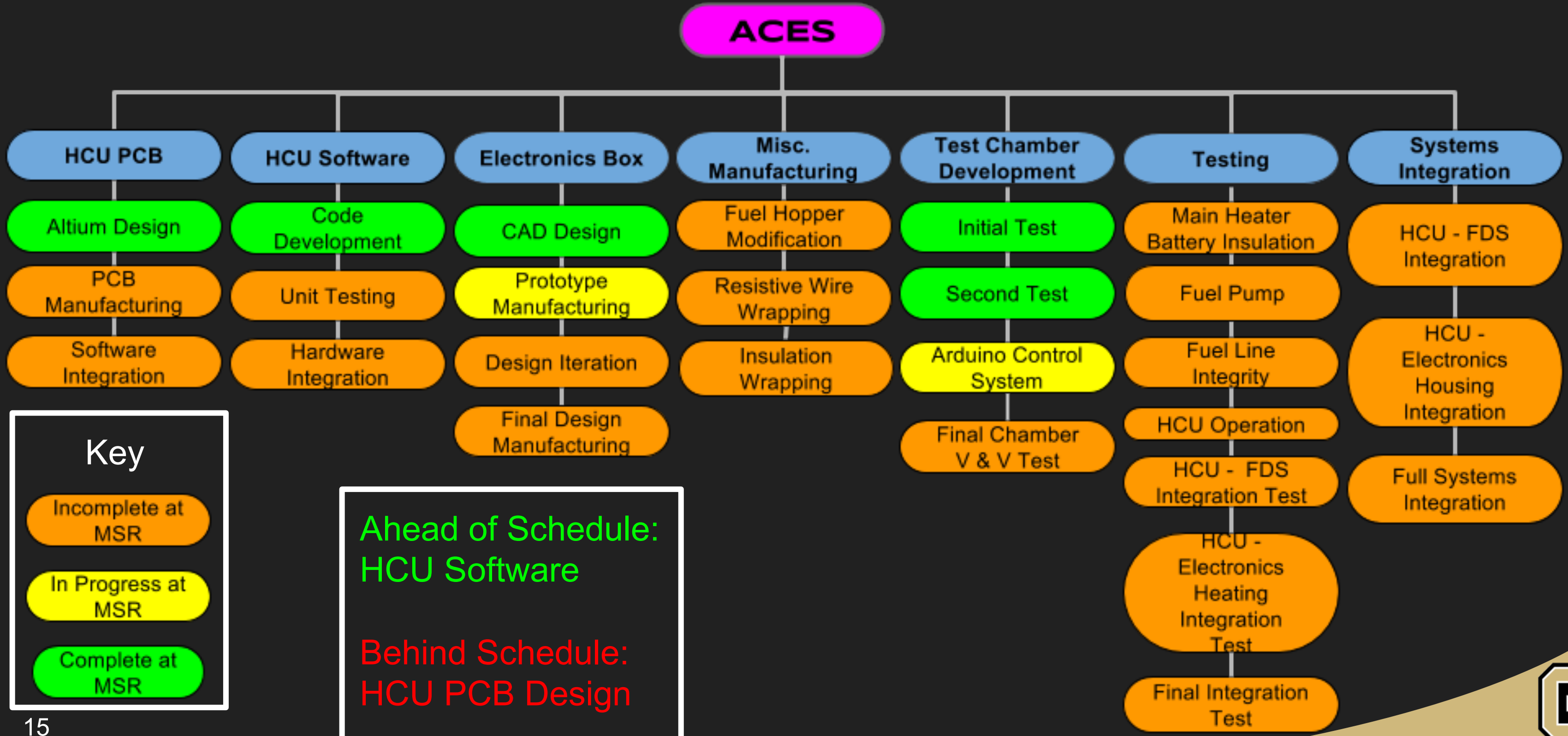


Current Design

Schedule

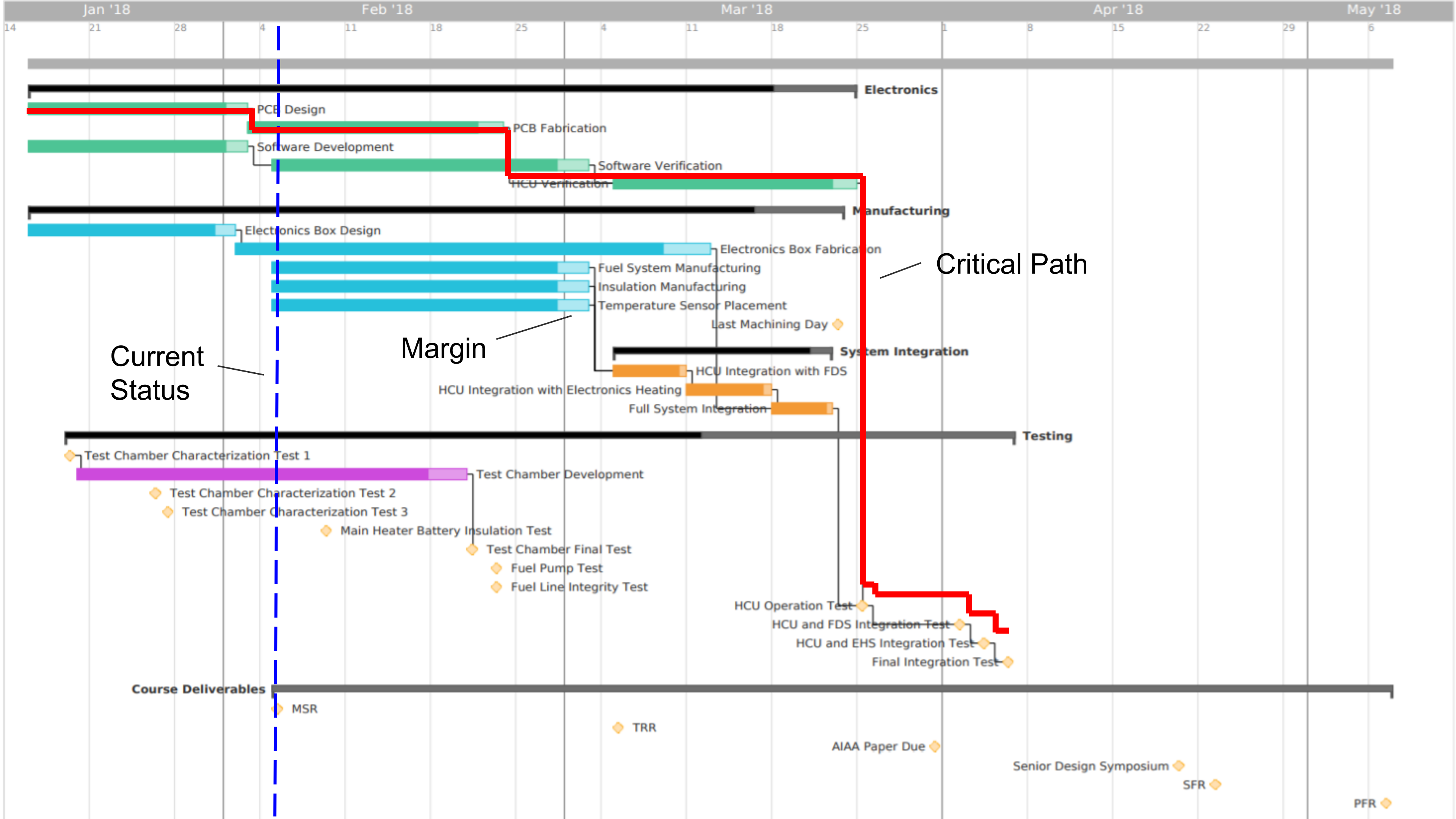
Overview | Schedule | Manufacturing | Budget

Status Summary



Ahead of Schedule: HCU Software

Behind Schedule: HCU PCB Design



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Feb '18
Mar '18
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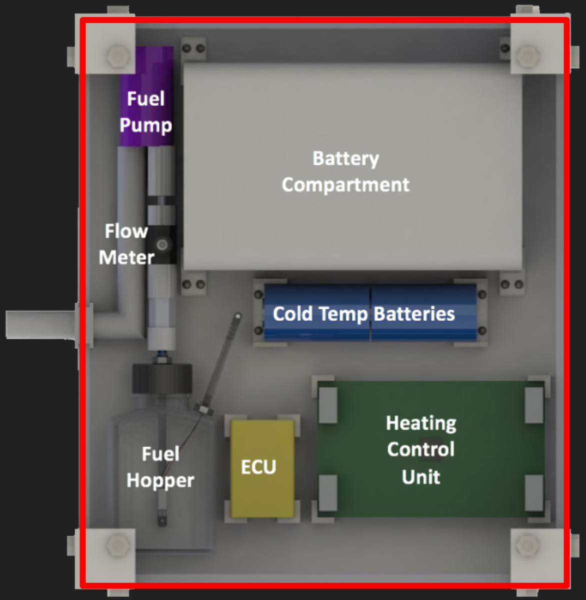
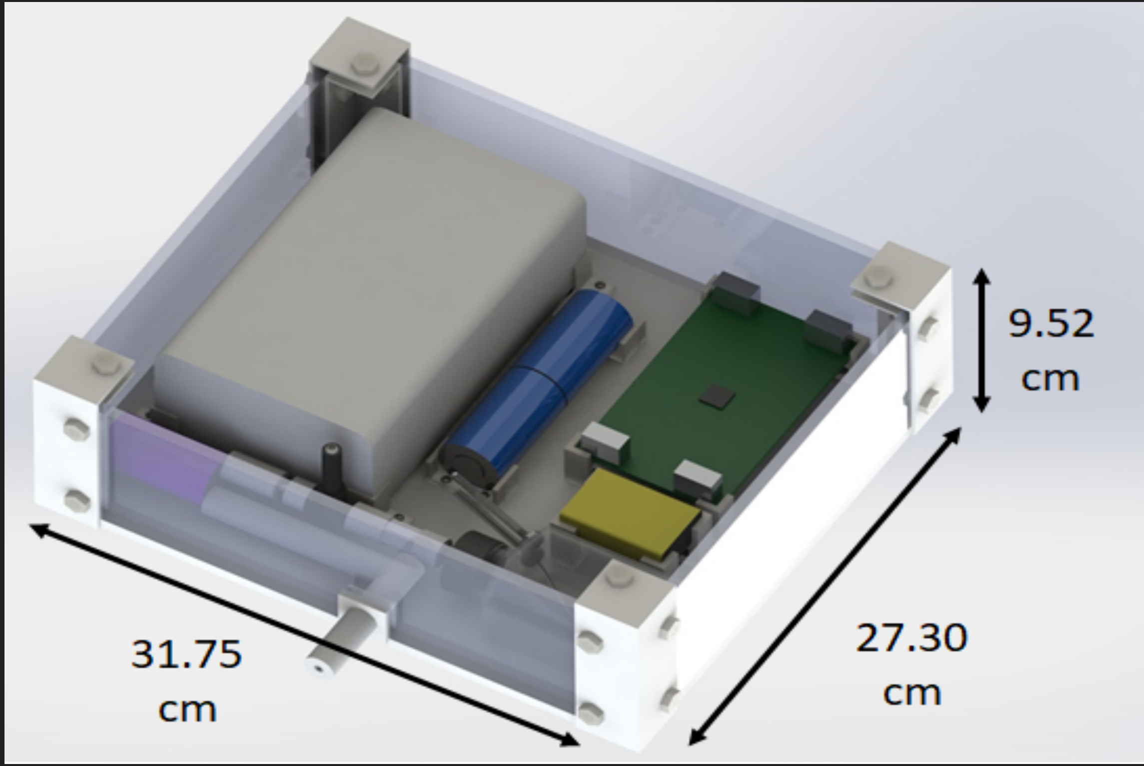
Electronics
PCB Design
PCB Fabrication
Software Development
Software Verification
HCU Verification
Manufacturing
Electronics Box Design
Electronics Box Fabrication
Fuel System Manufacturing
Insulation Manufacturing
Temperature Sensor Placement
Last Machining Day
System Integration
HCU Integration with FDS
HCU Integration with Electronics Heating
Full System Integration
Testing
Test Chamber Characterization Test 1
Test Chamber Development
Test Chamber Characterization Test 2
Test Chamber Characterization Test 3
Main Heater Battery Insulation Test
Test Chamber Final Test
Fuel Pump Test
Fuel Line Integrity Test
HCU Operation Test
HCU and FDS Integration Test
HCU and EHS Integration Test
Final Integration Test
Course Deliverables
MSR
TRR
AIAA Paper Due
Senior Design Symposium
SFR
PFR
Critical Path
Margin
Current Status

Manufacturing

Electronics Box
HCU Hardware
HCU Software
Testing Apparatus



Electronics Box



Electronics Box ProGrEss

Status:

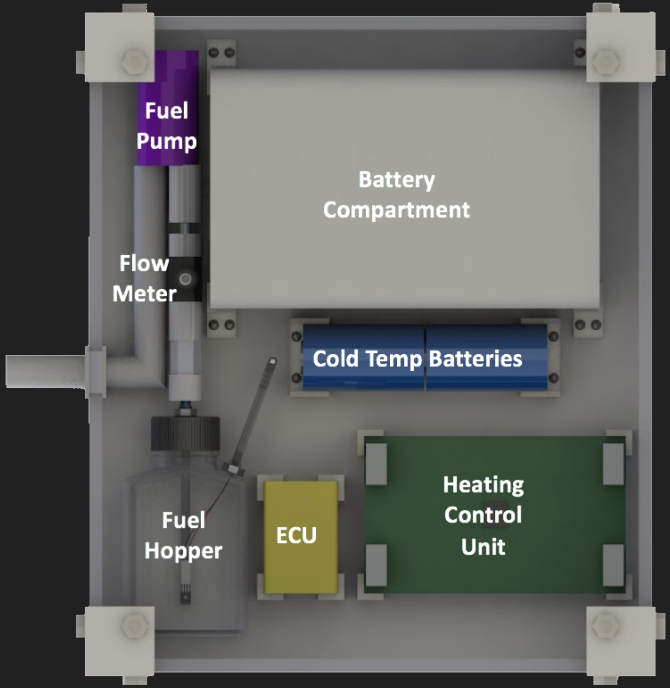
- Electronics box fully designed, including joints and mounting brackets
- Component layout has been finalized

Tasks Still to be done:

- Updating of thermal simulations (for test comparisons)
- Layout design for wiring connections
- 3D Printing L-brackets, corner brackets, and mounting brackets
- Confirm resistor wire length after updated thermal simulations
- Construction of shell prototype and iterate as necessary

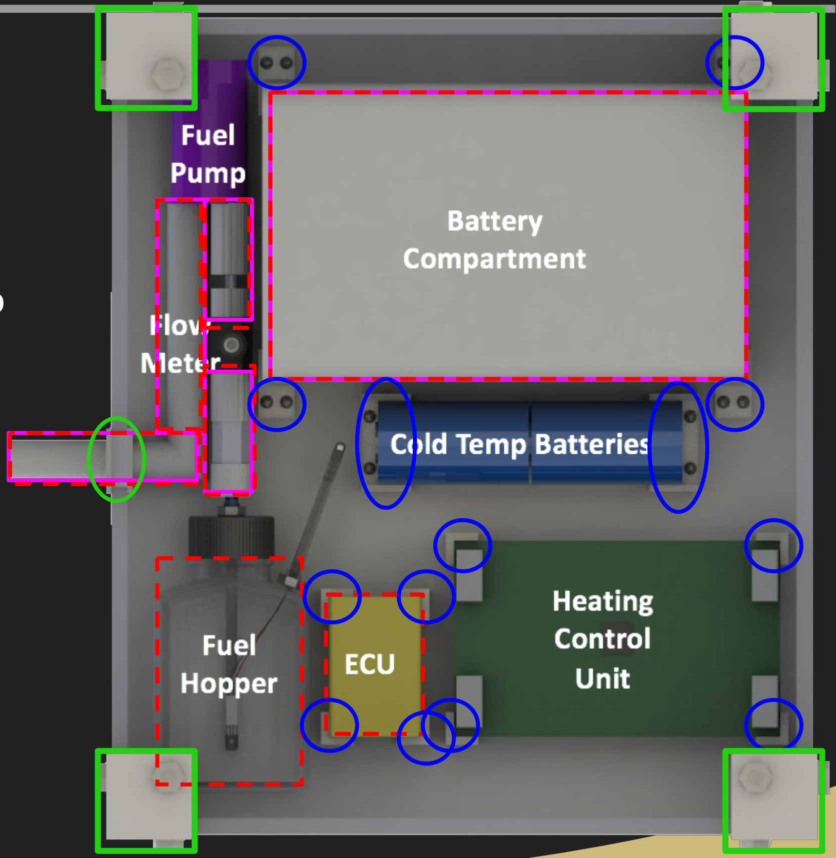
Expected Lead Times:

- 3D Printing Brackets: 1 week,
- Prototype: 2 weeks,
- Final Construction: 4 weeks



Components

- **Insulation**
- **Resistive heating elements**
- **Internal Component Mounts**
- **Electronics Box Corner Brackets & Clip**



Insulation Manufacturing

Status:

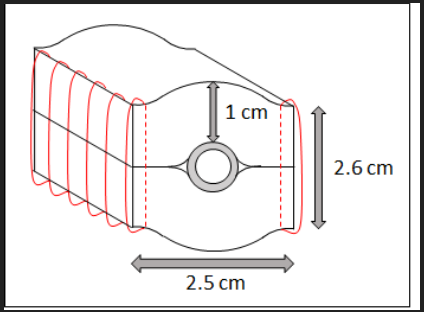
- Cryogel purchased and received
- Cryogel pieces will be sewn together; see diagrams

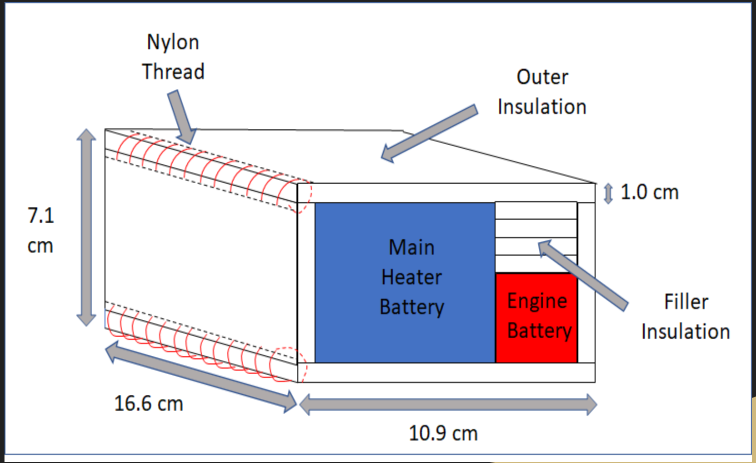
Concerns:

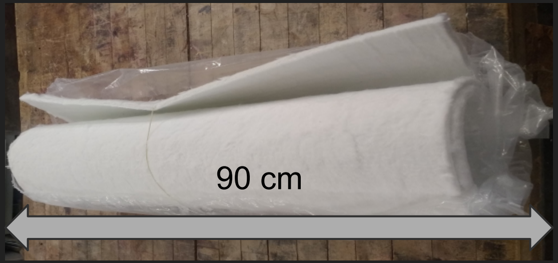
- Cannot be bent easily at small scale
- Produces more dust than anticipated
- Airborne dust is an irritant but not hazardous

Mitigation Strategies:

- Wear gloves, eye protection, long sleeve clothing, and respirator during manufacturing
- Wrap insulation in cellophane







Resistive Elements Manufacturing

Status:

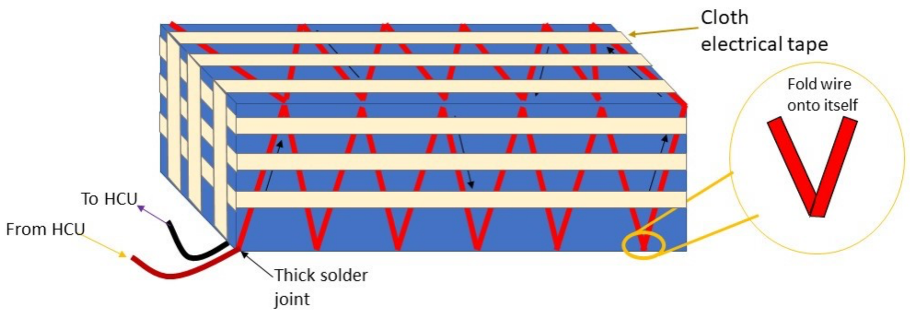
- Resistive wire ordered, ETA 2-3 wks
- Power resistors to be ordered, 1-2 wks lead time
- Wire will be wrapped around electronic components & batteries as shown on right
- Power resistor configuration within hopper shown on right

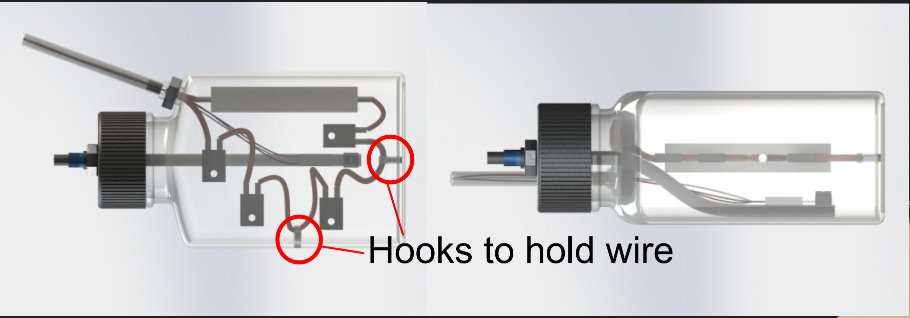
Concerns:

- Induced magnetism from wire coils could affect electronics and batteries
- Little room inside fuel hopper to place resistors

Mitigation Strategies:

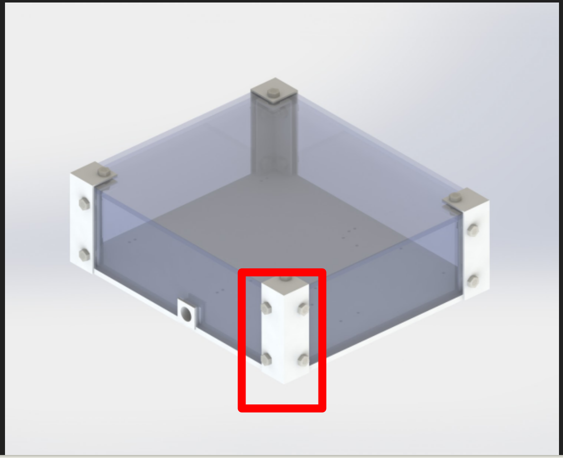
- V shaped wrap pattern eliminates wire coils around electronic components
- Bulky fuel filter within hopper removed, replaced with inlet at bottom of hopper





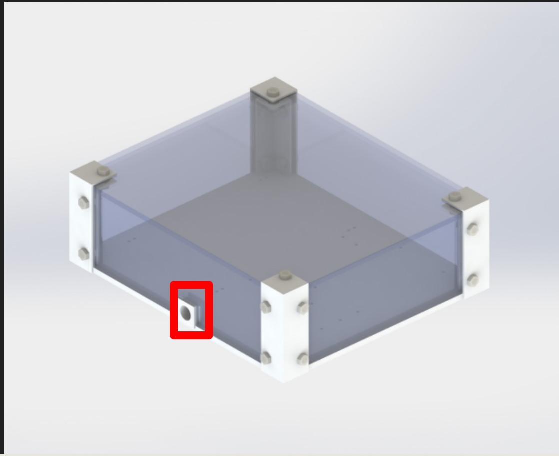
Electronics Box Hardware - brackets

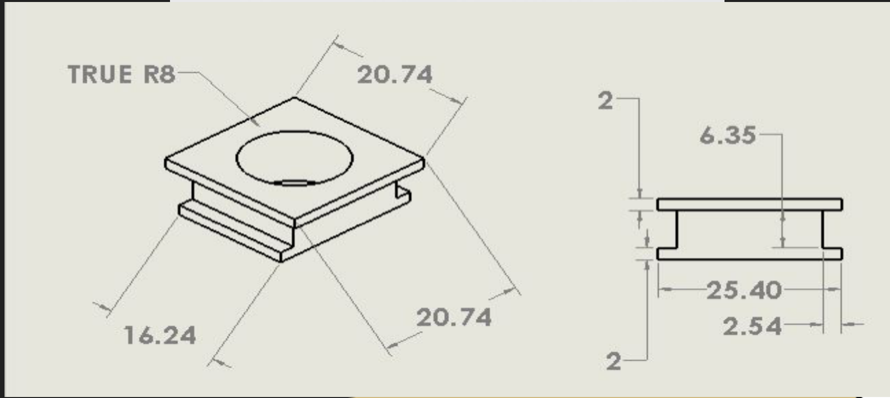
- **3D printed with ABS plus-P430 thermoplastic using uPrint SE Plus printer**
    - *Alternative option: PolyLite ABS plastic with Lulzbot Taz5 printer*
- All dimensions in millimeters
- Tolerances for all dimensions are +/- 1 mm



ELectronics Box Hardware - Clip

- **3D printed with ABS plus-P430 thermoplastic using uPrint SE Plus printer**
  - *Alternative option: PolyLite ABS plastic with Lulzbot Taz5 printer*
- All dimensions in millimeters
- Tolerances for all dimensions are +/- 1 mm





TEMPERATURE SENSORs

Status:

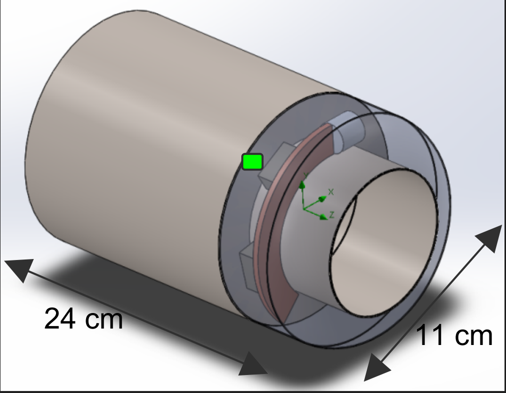
- TMP-36 temperature sensors purchased and received
- Sensors will be placed as shown in diagrams
- Sensors will be mounted using low temperature adhesives

Concerns:

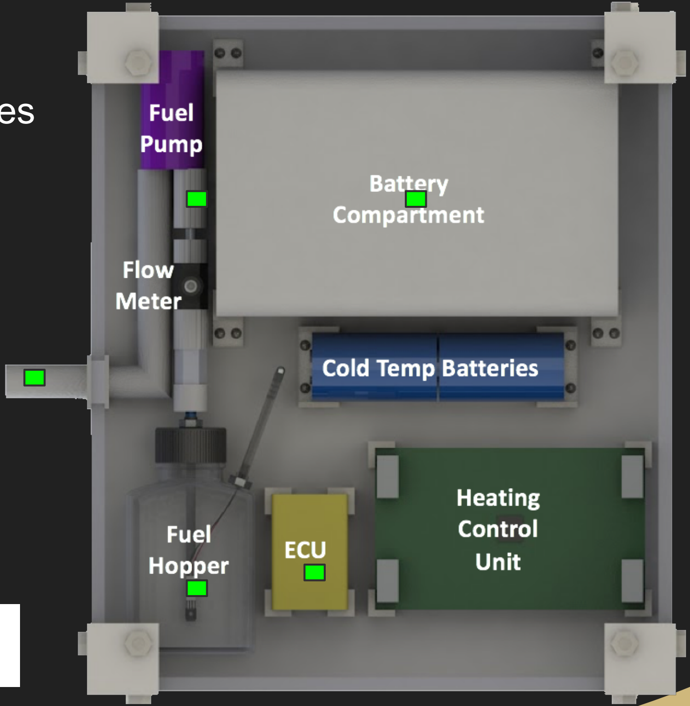
- Noise between sensors and HCU

Mitigation Strategies:

- Digital sensor with onboard ADC an option to eliminate noise concerns

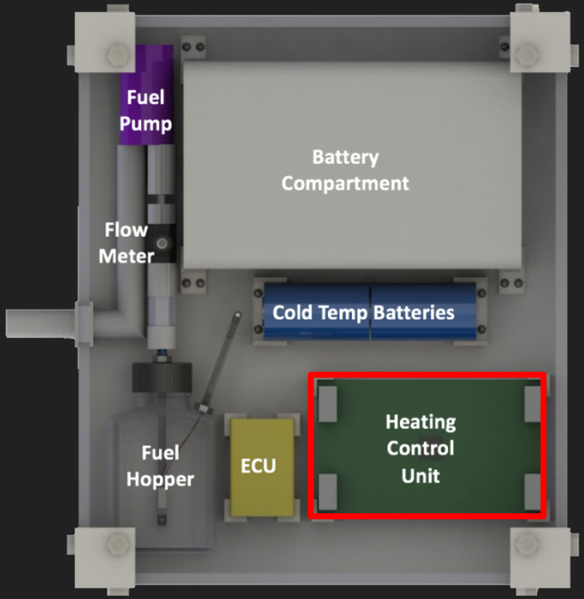


TMP36



Manufacturing

Electronics Box
HCU Hardware
HCU Software
Testing Apparatus



Overview | Schedule | Manufacturing | Budget

HCU PCB Fabrication

Status:

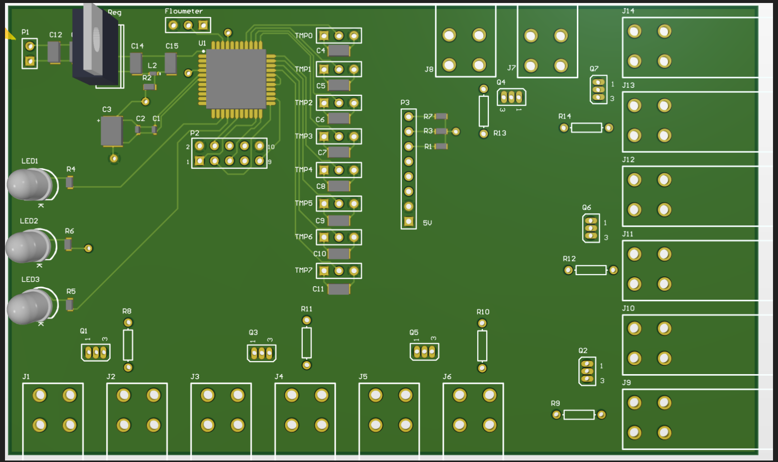
- Board completely designed in Altium
- Submitted to Advanced Electronics this week (lead time 1 week)

Concerns:

- Population of the board will produce errors.
- Noise will produce inaccuracies with the ADC.

Mitigation Strategies:

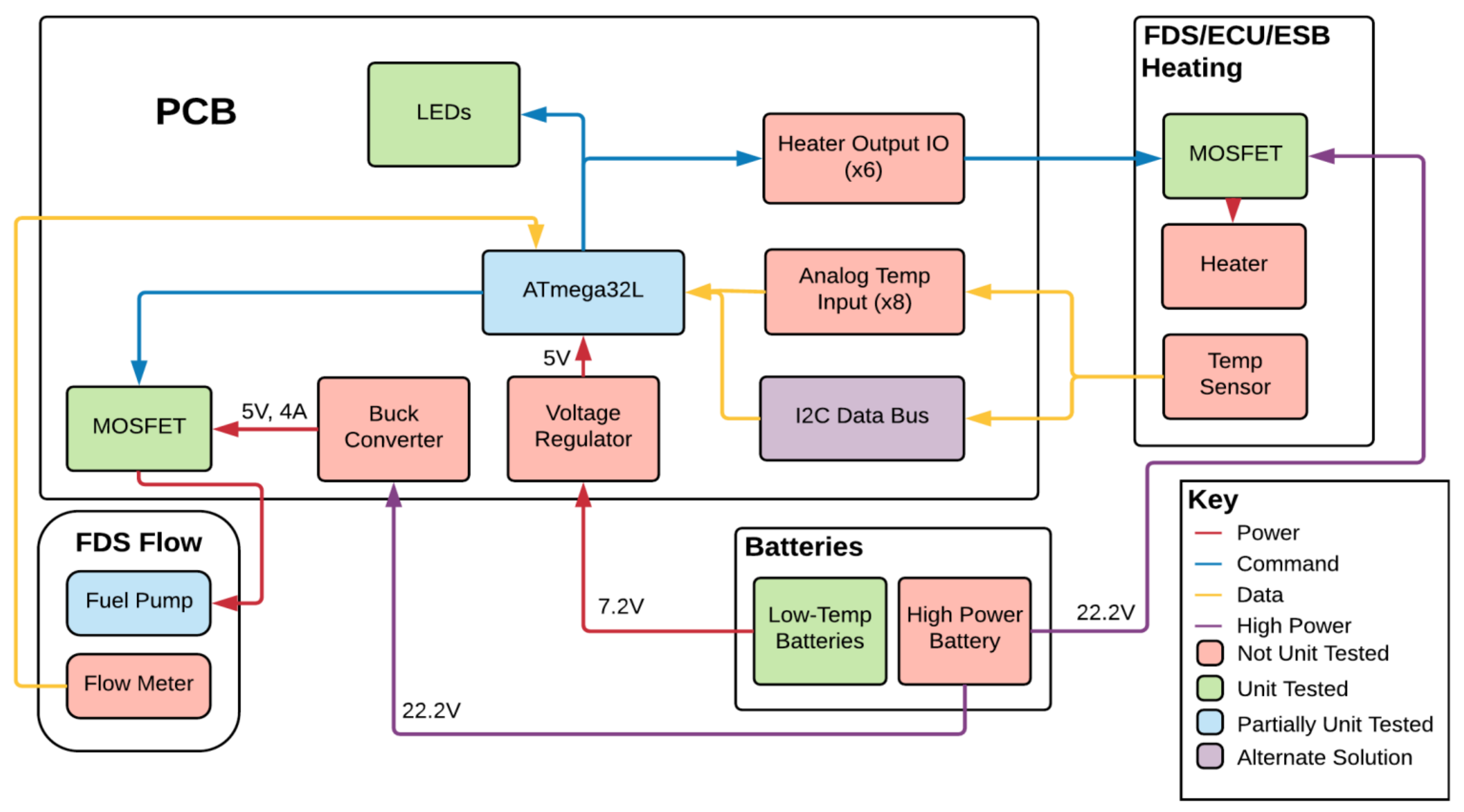
- Population of the board will occur in the ITLL or Bobby's lab (w/ supervision)
- 0 Ω resistors have been placed within the design to allow for debugging capabilities.



7.6 cm

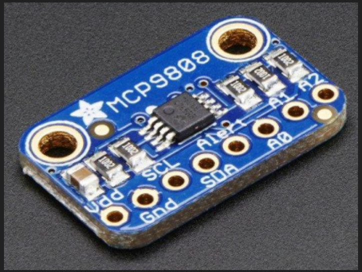
12.7 cm

Heating Control Unit: FBD



HCU: Biggest Concerns

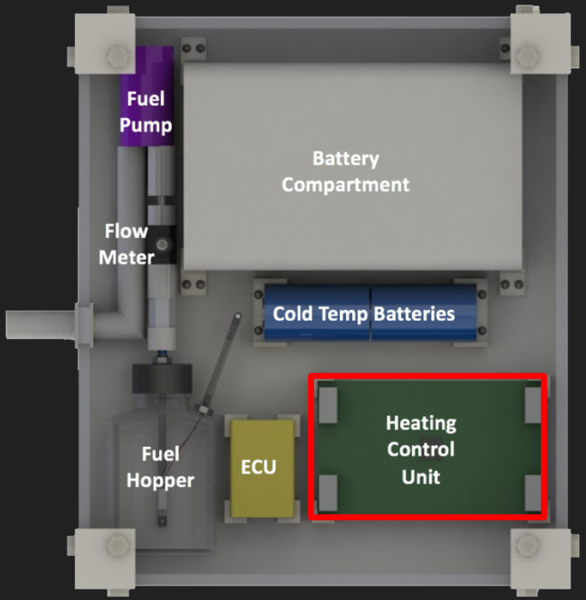
- Noise in the analog temperature sensors.
    - Long lead wires from sensor location to board (ESB->HCU) will act like antennas.
- Solution
    - Use temperature sensors which on board ADC which will then communicate with the HCU over I^2C lines.
- Magnetic field caused by resistor wire coils
    - Faraday's Law states that a magnetic field will be induced by a coil of wire with a current flow through it.
- Solution
    - Surround component in Faraday Cage and electrically insulate from resistor wire.



From adafruit.com

Manufacturing

Electronics Box
HCU Hardware
HCU Software
Testing Apparatus



Overview | Schedule | Manufacturing | Budget

HCU Software Development

Status:

- Code has been completely written
- Only Alive_LED has been unit tested

Concerns:

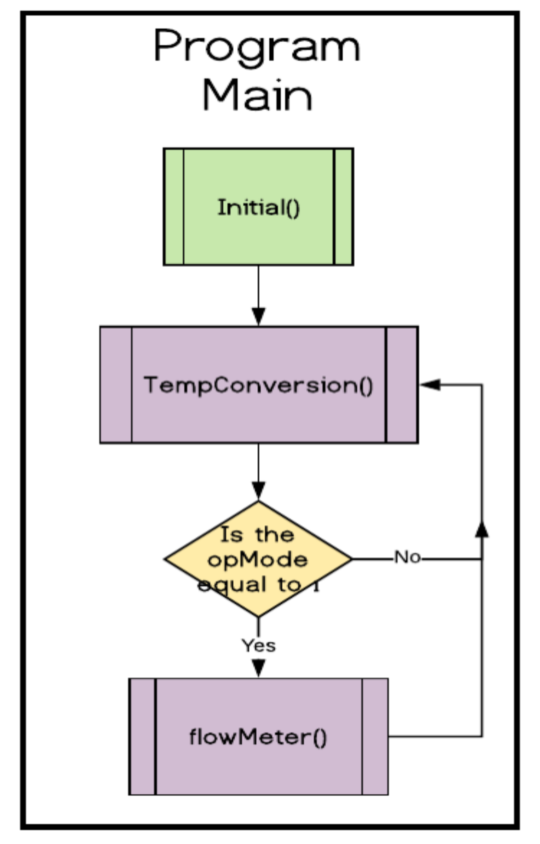
- Relying on one person for code writing and debugging could result in unresolved bugs

Mitigation Strategies:

- Documentation for the code is being autogenerated by Doxygen
  - Will greatly decrease the amount of time debugging as other group member will be able to understand the code much faster
- Debugging wire harness is due to arrive by Mon Feb. 5 (JTAG)

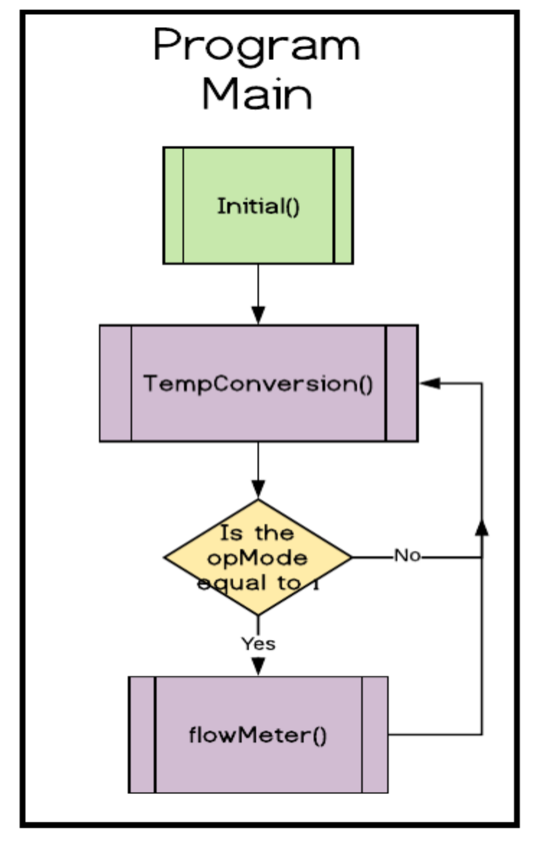
HCU: SoftwARE

1. Performs TempConversion() on loop until all components reach desired temperature.
2. Performs TempConversion() and flowMeter() during the pumping phase.
3. TempConversion() only once fuel is exhausted.



HCU: SoftwARE

- TempConversion()
  - Measures temperature of all sensors
  - Compares temperature to desired and toggles MOSFETs for heating circuits
- flowMeter()
  - Counts pulse train from flow meter
  - Compares flow rate to desired and alters PWM duty cycle

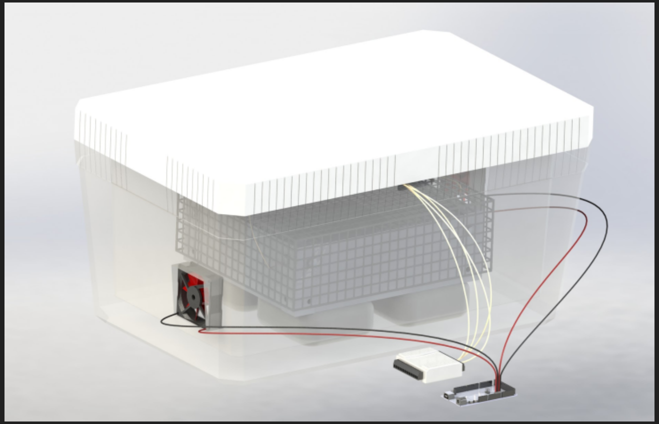


HCU: SoftwARE Timing

- Software timing is not an issue
    - There are no exact timing constraints for code execution
    - The only ISR’s are very short and will be completed within ~10 clock cycles
        - ISR for Alive_LED
        - Flow meter pulse train ISR
    - All 6 temperature conversions should occur within 3 ms
        - This was tested in the Atmel Simulator, built in feature of the IDE
    - Flow meter code should take 0.262 sec
        - This is because the sampling period is this amount of time.

Manufacturing

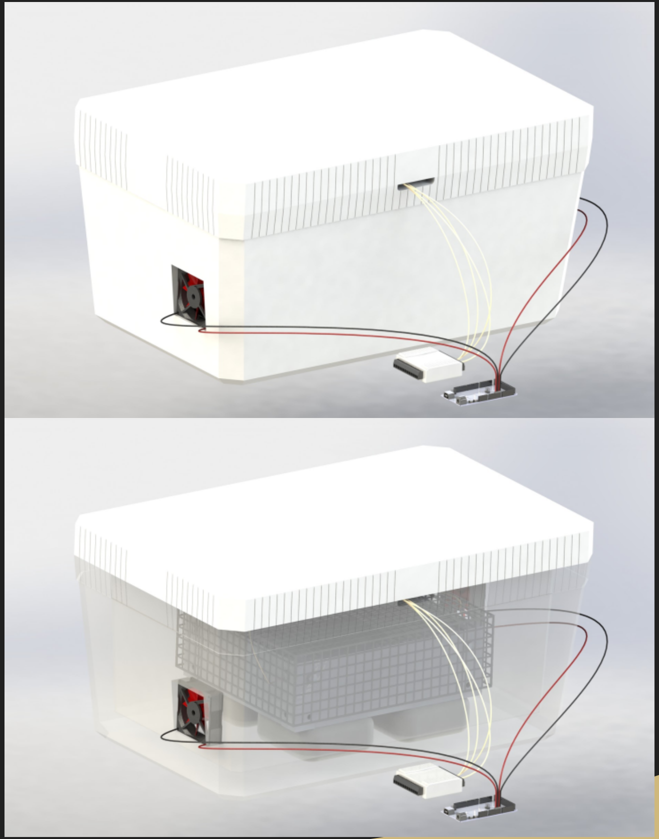
Electronics Box
HCU Hardware
HCU Software
Testing Apparatus

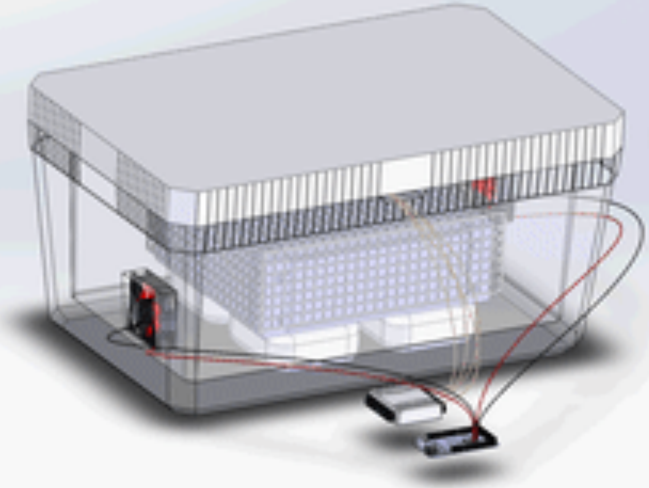


Test Apparatus

Summary:

- Dry ice chamber with active temperature control
- Capable of sustaining -50 ± 5°F for 1 hour
- Ability to house full electronics box and engine
- Computer fans for temperature control
- Thermocouples for temperature validation and model verification
- Fully constructed



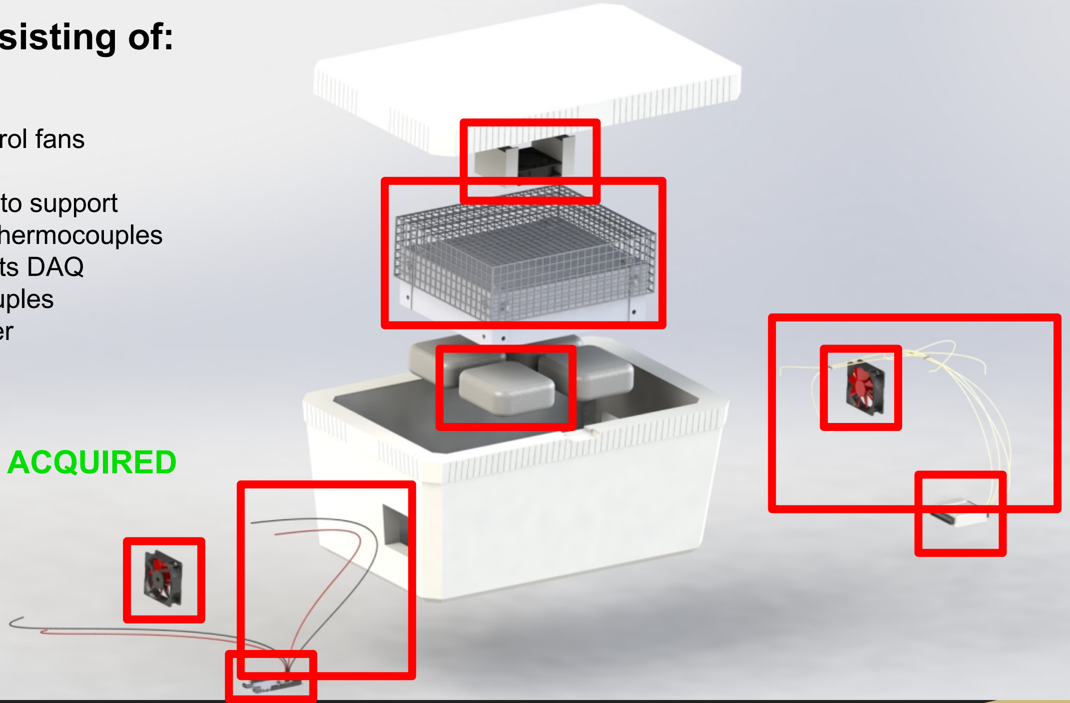


Test Chamber Components

Foam cooler consisting of:

1. Dry ice blocks
2. 2 temperature control fans
3. 1 circulation fan
4. Chicken wire cage to support additional ice and thermocouples
5. National Instruments DAQ
6. 4 type K thermocouples
7. Wiring for fan power
8. Arduino MEGA

ALL COMPONENTS ACQUIRED



Test Apparatus Progress

Status:

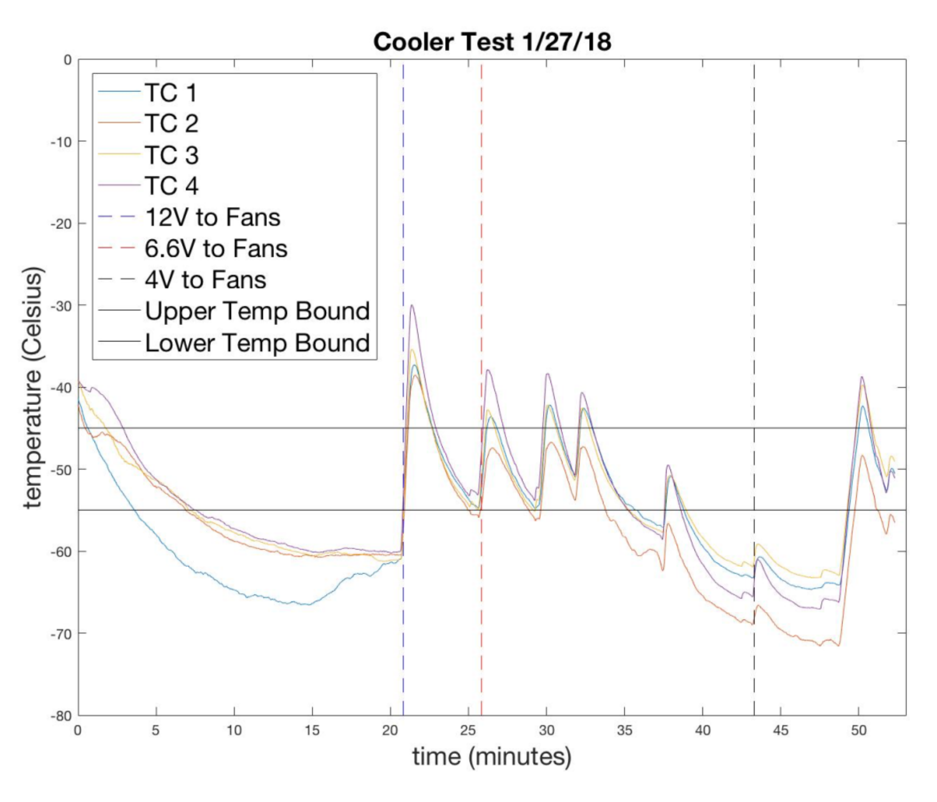
- Conducted initial trials with test chamber (see plot for results)
- Test chamber feasibility demonstrated
- Test chamber fully constructed

Concerns:

- Test chamber warms too quickly to control when fans are operated
- Fans become very cold, could cease to function

Mitigation Strategies:

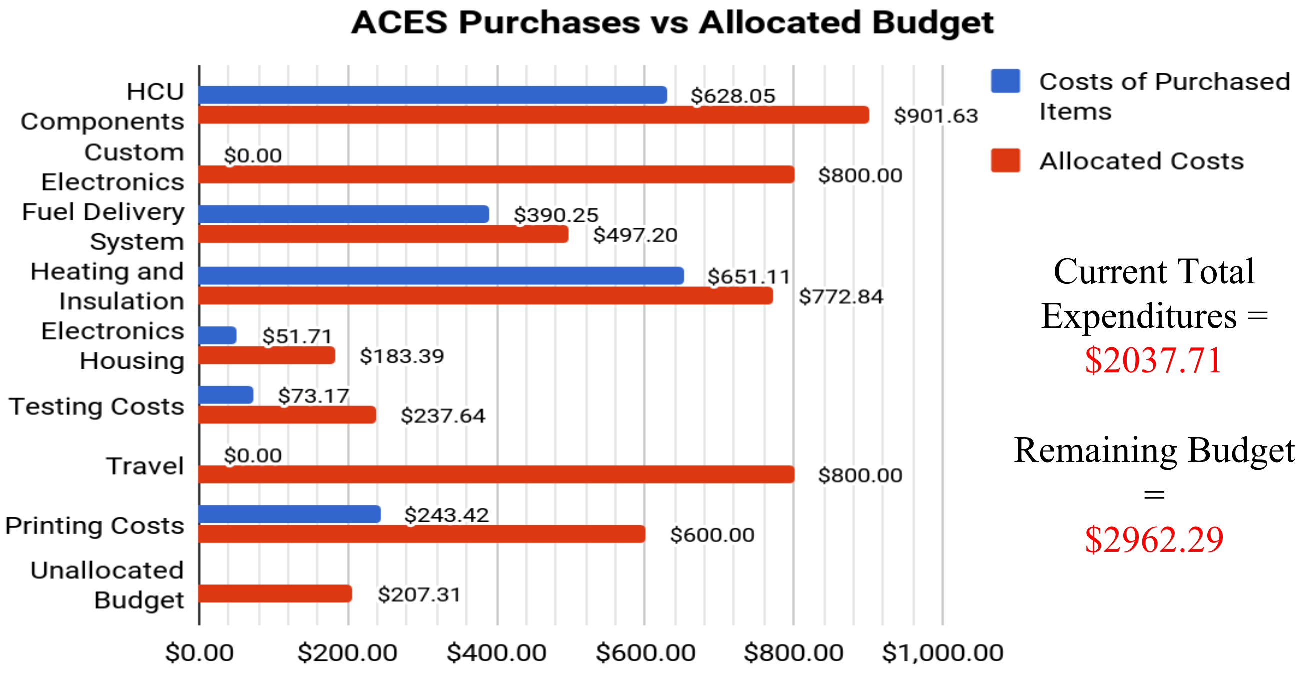
- Arduino fan control to be implemented
- Fans can be replaced between tests



Budget

Overview → Schedule → Manufacturing → Budget

Cost Plan



Current Total Expenditures = $2037.71

Remaining Budget = $2962.29

Critical Parts Received

Part	Cost (Including Shipping)
Fuel Pump with Cable	$383.90
ATMEGA32L, In circuit Debugger, Adapter Cable	$290.58
Cryogel Insulation	$319.84
Resistive Heaters	$249.91
Altium License	$124.01
Turnigy Heavy Duty Lip (Heater Battery)	$81.36
HCU Batteries	$92.91
Total	**$1,542.51**

Pending/Planned orders

Item	Price
PCB Printing	$300
3D Printing L-Brackets	$150 (U-print)
4 Thermocouple Breakout Boards	$60
Miscellaneous Electronic Components	$100
Custom Electronics	$800
Travel Expenses	$800
Printing	$300
Total	**$2,510**

Lead Time for Ordered Components

Component	Lead Time
Resistive Wire	2-3 Weeks (Already Ordered)
PCB Printing	1 Week per iteration
3D Printing L-Brackets	1 Day per iteration
Thermocouple Breakout Board	1-2 Weeks

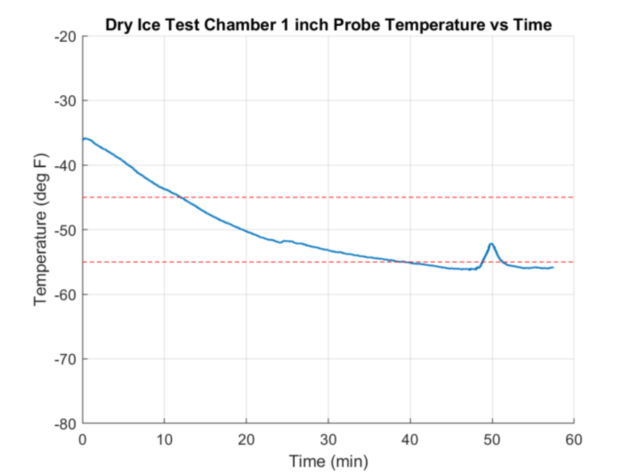
Questions?

BACKUP SLIDES

Test Apparatus Progress

First Run 1/19:

- Initial test conducted to establish feasibility of dry ice test chamber
- No active temperature control
- Two thermocouples placed with 5 inch vertical displacement
    - Placed at 1 inch and 6 inches above dry ice
    - Easy to maintain one, but proved test-bed was unhomogenized



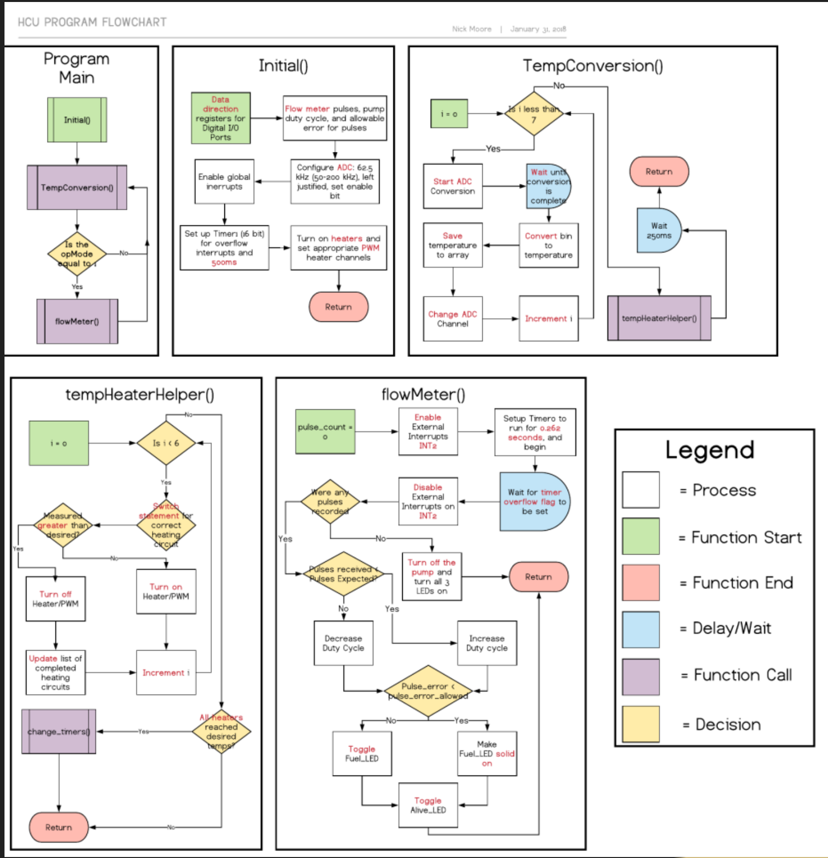
Takeaways and lessons learned:

- Issues with temperature control and uniform temperature distribution
- Surprisingly good temperature consistency
- **Sublimation a non issue**
- **Active temperature control necessary**

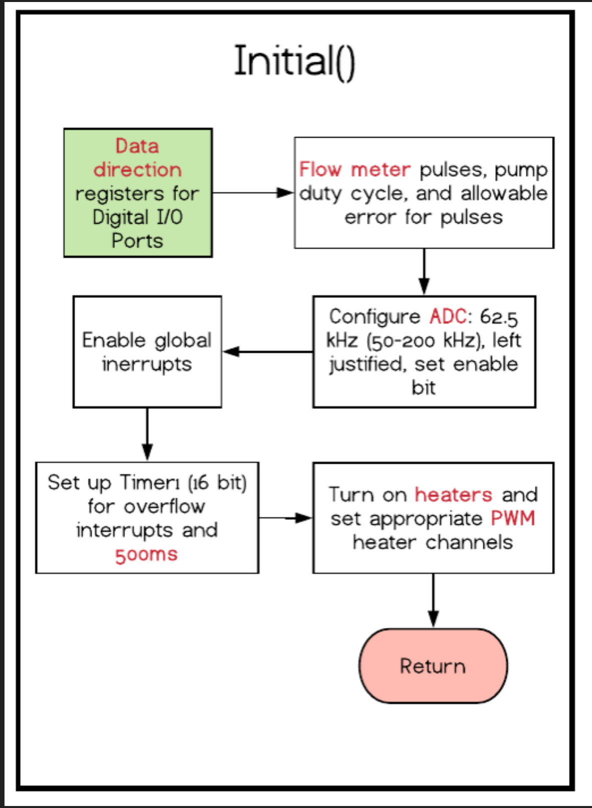
Functional Requirements

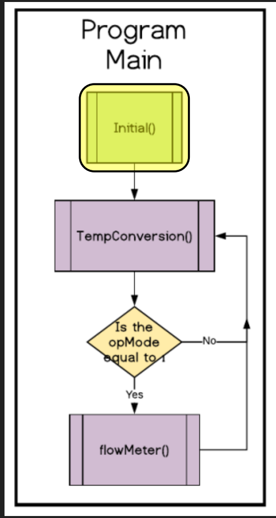
- ***FR 1) ENERGY:*** An initial energy source shall provide adequate power for the fuel delivery system heating and electronics heating.
- ***FR 2.1) FDS:*** The Fuel Delivery System shall provide a specified fuel flow rate from 0 to 4.8 g/s ± 0.13 g/s to the engine.
- ***FR 2.2) FDS:*** The Fuel Delivery System shall provide fuel at a specified temperature from 60 to 110°F ± 3.6°F to the engine.
- ***FR 3) Electronics Heating:*** The electronics (ECU, ESB, batteries) shall be heated to their operating temperature of 60°F.
- ***FR 4.1) HCU:*** The Heating Control Unit (HCU) shall monitor and regulate the temperature of the electronic components and fuel delivery heating systems.
- ***FR 4.2) HCU:*** The Heating Control Unit (HCU) shall monitor and regulate the mass flow rate of the fuel delivery heating system.

HCU SOFTWARE OVERVIEW

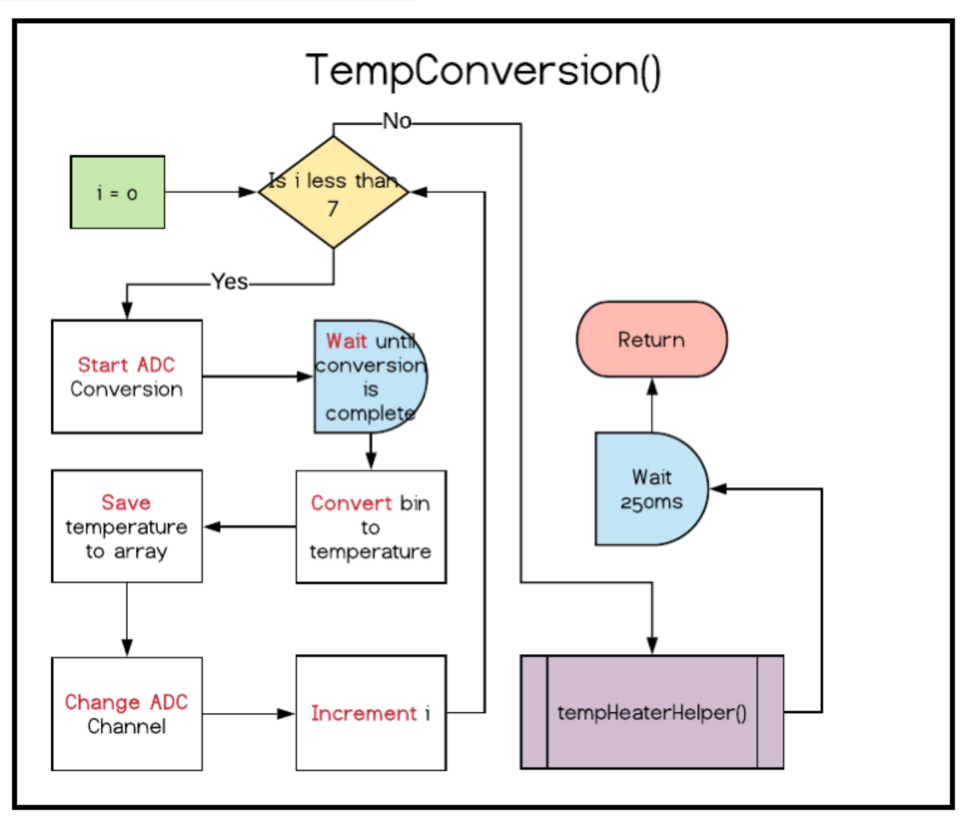


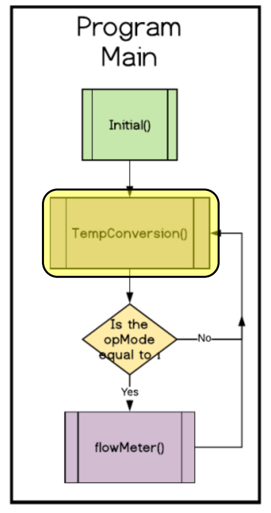
HCU: SoftwARE

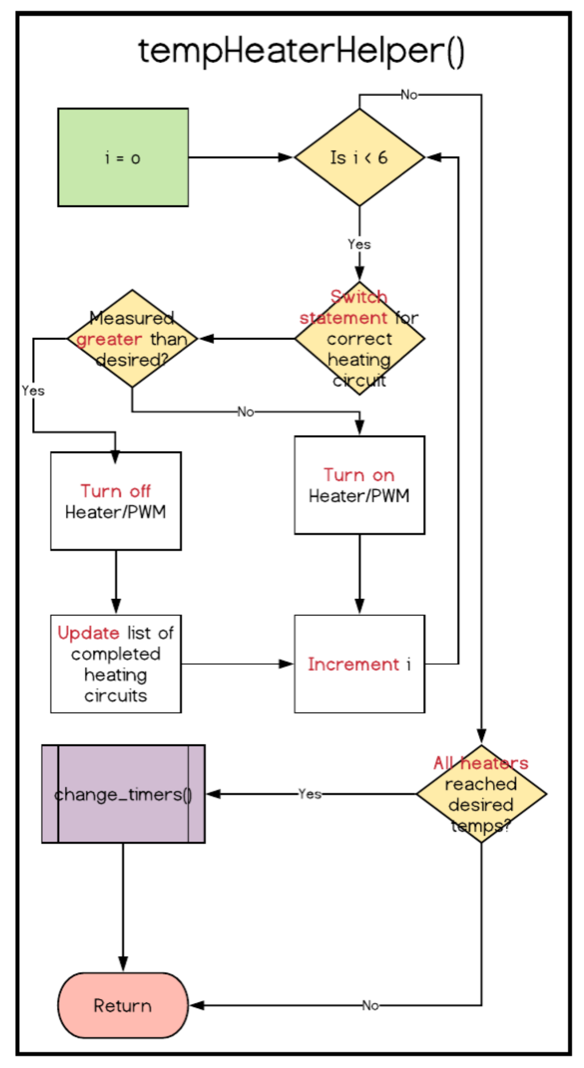


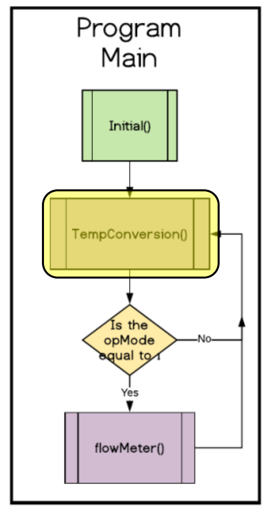


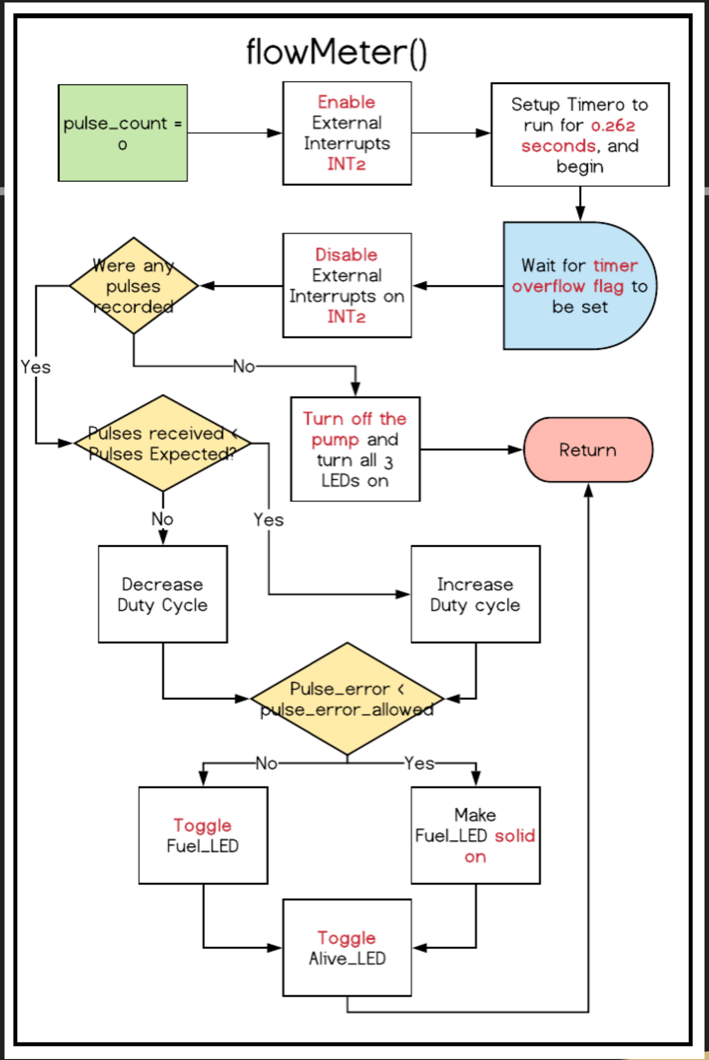
HCU: SoftwARE

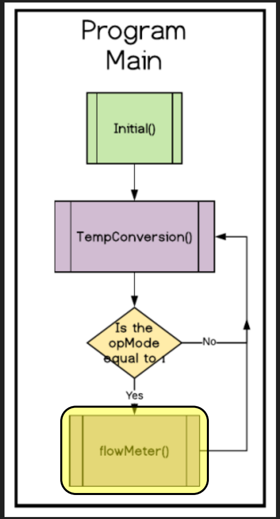


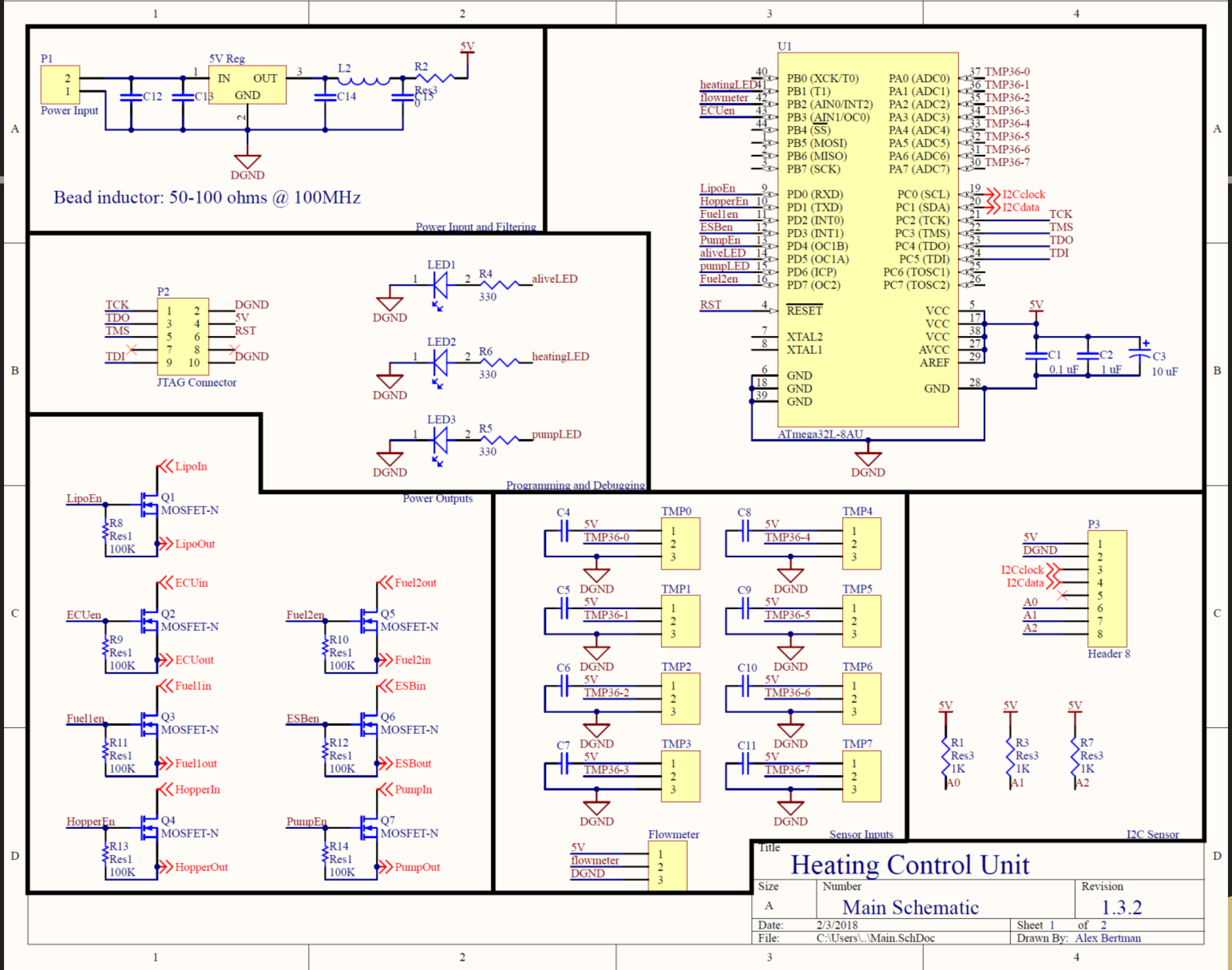



tempHeaterHelper()
i = 0
Is i < 6
No
Yes
Switch statement for correct heating circuit
Measured greater than desired?
Yes
No
Turn off Heater/PWM
Turn on Heater/PWM
Update list of completed heating circuits
Increment i
change_timers()
Yes
All heaters reached desired temps?
Return
No


Program Main
Initial()
TempConversion()
Is the opMode equal to 1
No
Yes
flowMeter()

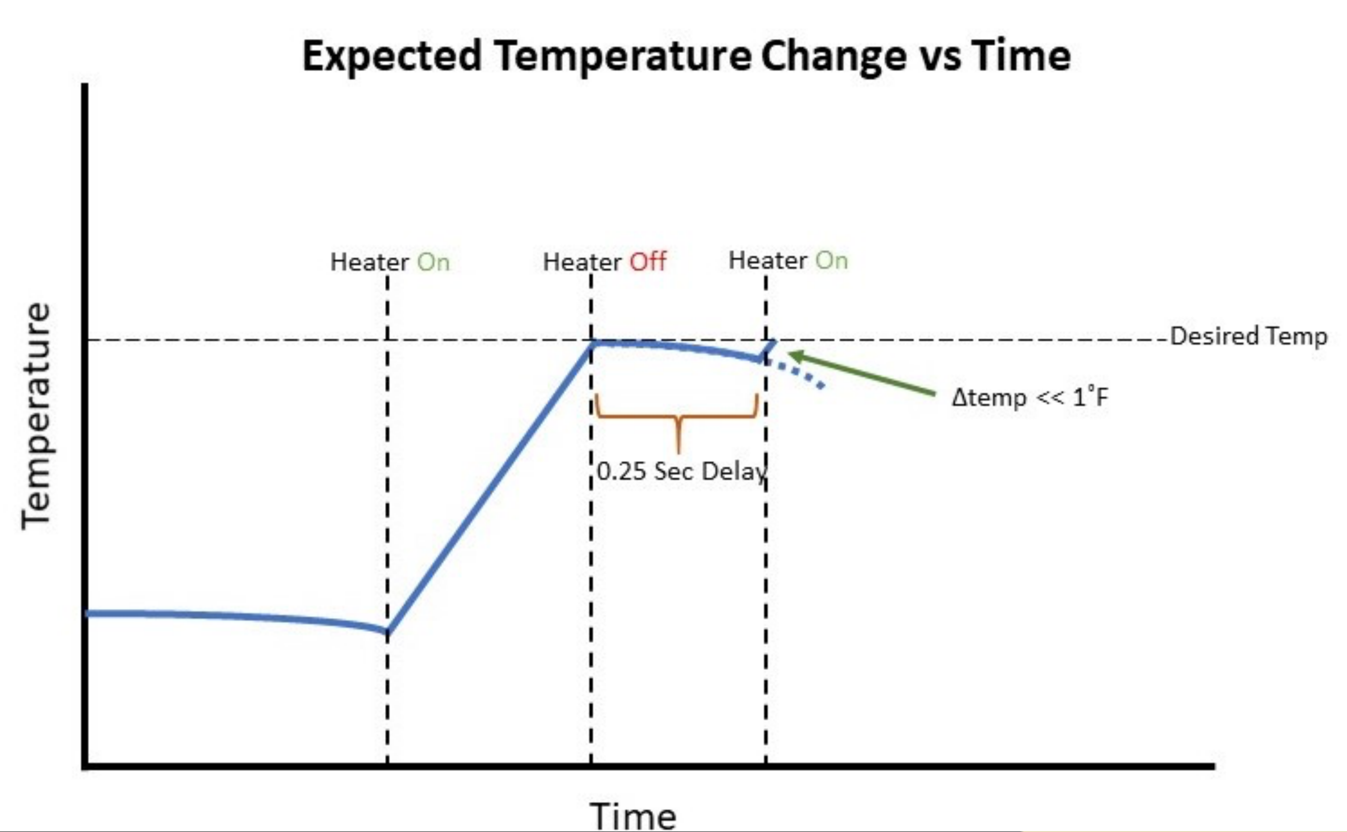

flowMeter()
pulse_count = 0
Enable External Interrupts INT2
Setup Timer0 to run for 0.262 seconds, and begin
Wait for timer overflow flag to be set
Disable External Interrupts on INT2
Were any pulses recorded
Yes
No
Pulses received < Pulses Expected?
Turn off the pump and turn all 3 LEDs on
Return
No
Yes
Decrease Duty Cycle
Increase Duty cycle
Pulse_error < pulse_error_allowed
No
Yes
Toggle Fuel_LED
Make Fuel_LED solid on
Toggle Alive_LED

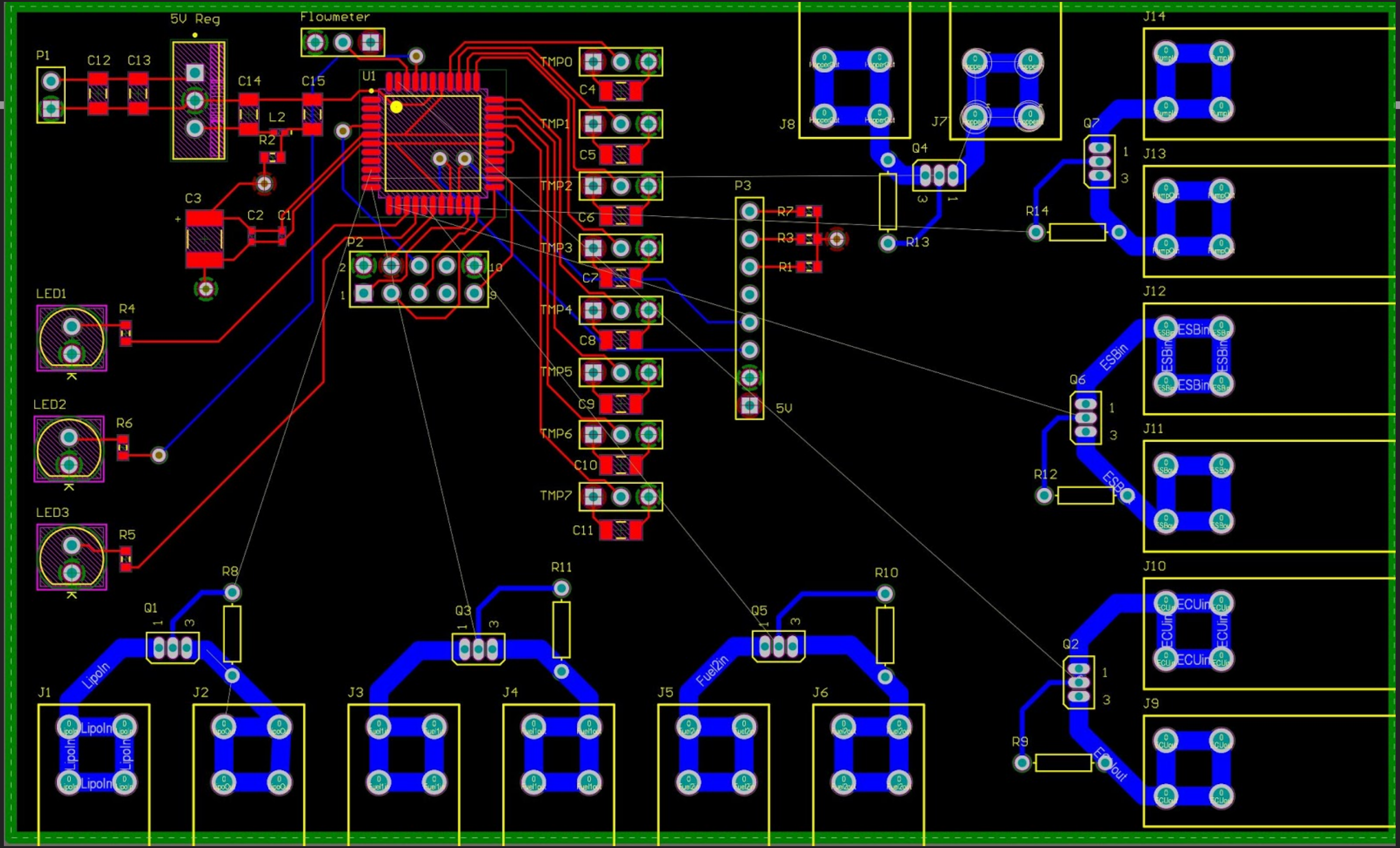

Program Main
Initial()
TempConversion()
Is the opMode equal to
No
Yes
flowMeter()



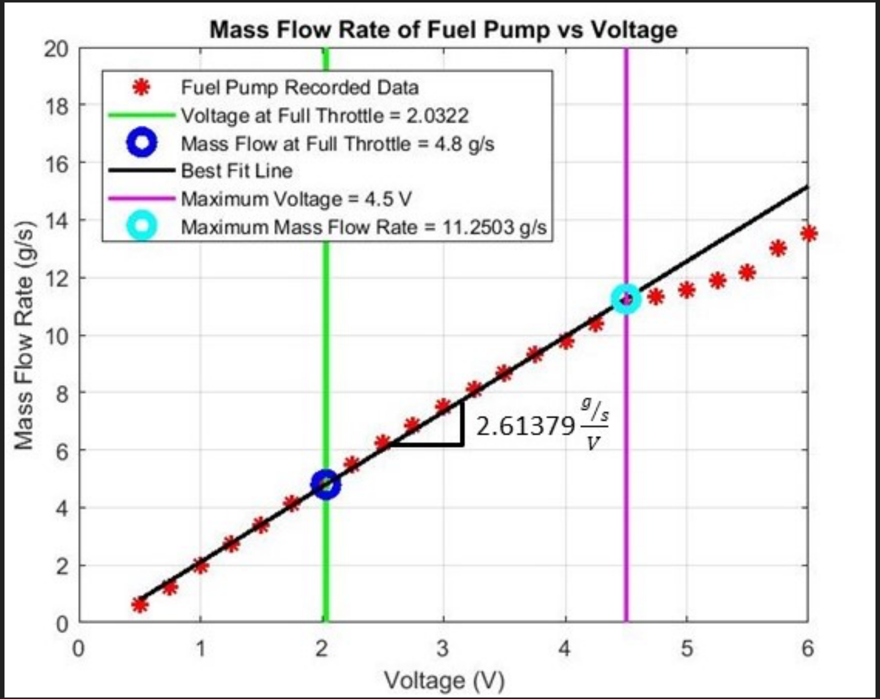
Power Input and Filtering
P1
Power Input
5V Reg
IN
OUT
GND
C12
C13
C14
C15
L2
R2
Res3
0
5V
DGND
Bead inductor: 50-100 ohms @ 100MHz
Programming and Debugging
P2
JTAG Connector
TCK
TDO
TMS
TDI
DGND
5V
RST
LED1
LED2
LED3
R4
R6
R5
330
aliveLED
heatingLED
pumpLED
U1
ATmega32L-8AU
PB0 (XCK/T0)
PB1 (T1)
PB2 (AIN0/INT2)
PB3 (AIN1/OC0)
PB4 (SS)
PB5 (MOSI)
PB6 (MISO)
PB7 (SCK)
PD0 (RXD)
PD1 (TXD)
PD2 (INT0)
PD3 (INT1)
PD4 (OC1B)
PD5 (OC1A)
PD6 (ICP)
PD7 (OC2)
RESET
XTAL2
XTAL1
GND
PA0 (ADC0)
PA1 (ADC1)
PA2 (ADC2)
PA3 (ADC3)
PA4 (ADC4)
PA5 (ADC5)
PA6 (ADC6)
PA7 (ADC7)
PC0 (SCL)
PC1 (SDA)
PC2 (TCK)
PC3 (TMS)
PC4 (TDO)
PC5 (TDI)
PC6 (TOSC1)
PC7 (TOSC2)
VCC
AVCC
AREF
TMP36-0
TMP36-1
TMP36-2
TMP36-3
TMP36-4
TMP36-5
TMP36-6
TMP36-7
I2Cclock
I2Cdata
heatingLED
flowmeter
ECUen
LipoEn
HopperEn
Fuel1en
ESBen
PumpEn
aliveLED
pumpLED
Fuel2en
C1 0.1 uF
C2 1 uF
C3 10 uF
Power Outputs
Q1 MOSFET-N
Q2 MOSFET-N
Q3 MOSFET-N
Q4 MOSFET-N
Q5 MOSFET-N
Q6 MOSFET-N
Q7 MOSFET-N
LipoIn
LipoOut
ECUin
ECUout
Fuel1in
Fuel1out
HopperIn
HopperOut
Fuel2out
Fuel2in
ESBin
ESBout
PumpIn
PumpOut
Res1
100K
Sensor Inputs
TMP0
TMP1
TMP2
TMP3
TMP4
TMP5
TMP6
TMP7
Flowmeter
I2C Sensor
P3
Header 8
A0
A1
A2
R1
R3
R7
Res3
1K
Title
Heating Control Unit
Size
A
Number
Main Schematic
Revision
1.3.2
Date: 2/3/2018
File: C:\Users\..\Main.SchDoc
Sheet 1 of 2
Drawn By: Alex Bertman

HCU: SoftwARE Temp Control




5V Reg
Flowmeter
P1
C12
C13
C14
C15
U1
L2
R2
C3
C2
C1
P2
TMP0
C4
TMP1
C5
TMP2
C6
TMP3
C7
TMP4
C8
TMP5
C9
TMP6
C10
TMP7
C11
P3
R7
R3
R1
5V
LED1
R4
LED2
R6
LED3
R5
R8
Q1
R11
Q3
Q5
R10
J1
J2
J3
J4
J5
J6
LipoIn
Fuel2in
J8
J7
Q4
R13
Q7
J14
J13
R14
J12
ESBin
Q6
J11
R12
J10
ECUin
Q2
R9
J9
ECUout

HCU: Software Mass flow



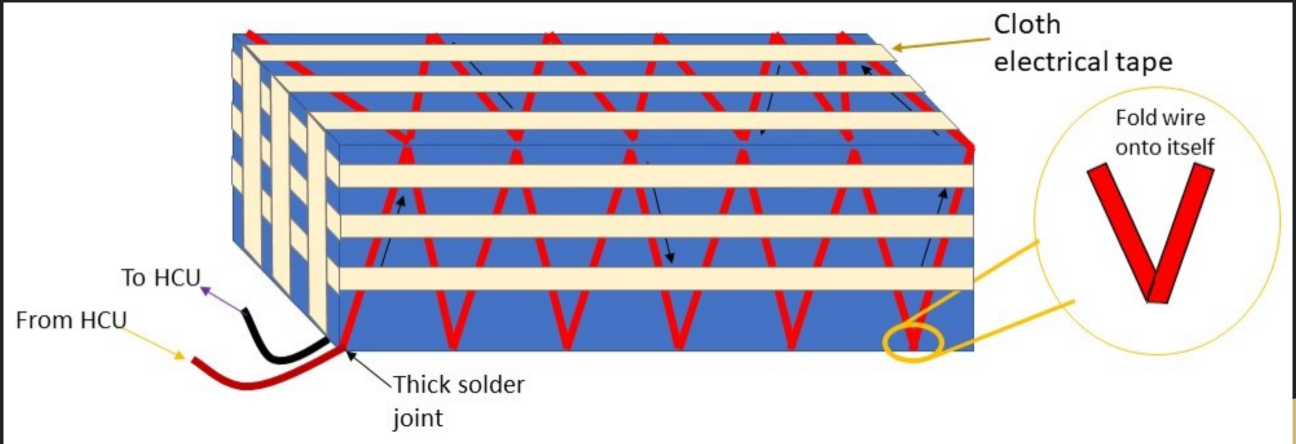
$$\frac{4.8\text{ g}}{1\text{ s}}\cdot\frac{1\text{ mL}}{0.81\text{ g}}\cdot\frac{1\text{ L}}{1000\text{ mL}}\cdot\frac{110{,}000\text{ pulses}}{1\text{ L}}\cdot\frac{0.262144\text{ s}}{1\text{ period}} = 171\text{ pulses per period}$$

$$\frac{4.8\text{ g}}{1\text{ s}}\cdot\frac{1\text{ period}}{171\text{ pulses}} = 0.02807\text{ g/s error per pulse}$$

$$\frac{1\text{ pulse}}{}\cdot\frac{0.02807\text{ g/s}}{1\text{ pulse}}\cdot\frac{0.382587\text{ V}}{1\text{ g/s}}\cdot\frac{}{6\text{ V}}\cdot\frac{20{,}000\text{ counts}}{} = 35.797\ \Delta\text{OCR1B per pulse error}$$

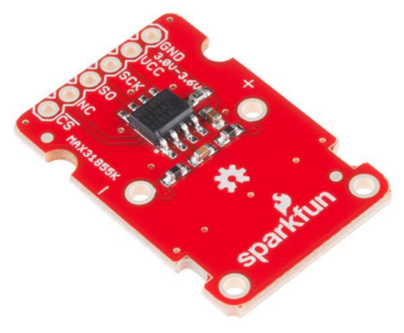
Wire Wrapping

- Need to prevent wire wrapping from being an electromagnet.
    - Could/probably will disrupt the Lipo battery equalizing circuits and ECU
        - This configuration will produce destructive B fields.
    - Fuel lines do not have this concern so they will be wrapped in the more traditional sense.



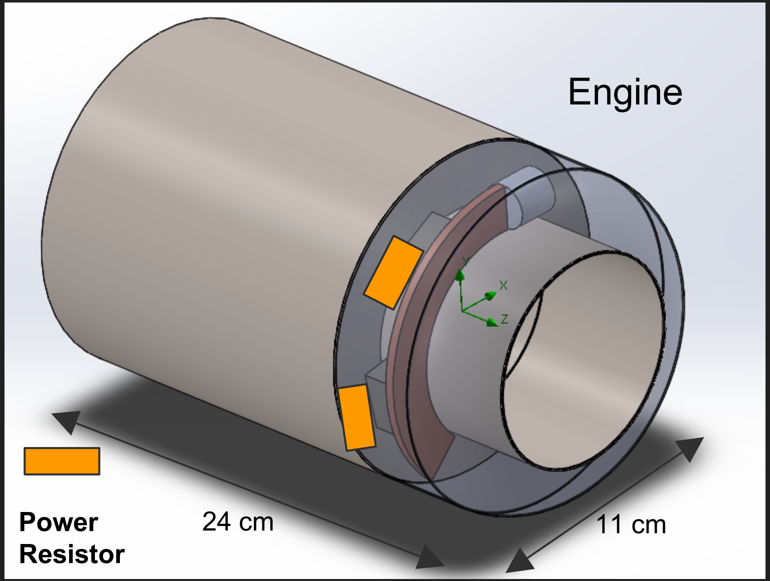
Test Chamber Software

- Software is currently not written or tested
  - However, this is not a concern.
- Same conditional control law as for the heater circuits (controlled by the HCU)
  - Makes implementation very simple.
- Need to interface with the SparkFun Thermocouple Breakout Board - MAX31855K
  - This is done over the SPI lines for the Arduino.
  - Arduino has built in libraries which makes this incredibly easy.



Power Resistors for ESB

- **Vishay/Dale 12 Ohm 15W** power resistors to heat ESB (x2)
- These will be mounted to the underside of the ESB using a Cyanoacrylate
  - An example of this is super glue
  - These have temperature ranges of -67 to 482 F.



Lengths of Resistor Wire

- 14 ft (0.88Ω/ft) for both Lipo batteries
- 3.86 ft (3.17 Ω/ft) for the ECU
- 11.92 ft (3.17 Ω/ft) for outside the hopper
- 0.54 ft (3.17 Ω/ft) for Fuel line section 1
- 0.83 ft (3.17 Ω/ft) for Fuel line section 2
- 2.69 ft (3.17 Ω/ft) for Fuel line section 3