Manufacturing **S**tatus **R**eview

REcuperating **A**dvanced **P**ropulsion **E**ngine **R**edesign

Customer: Air Force Research Lab — **Advisor**: Dr. Ryan Starkey

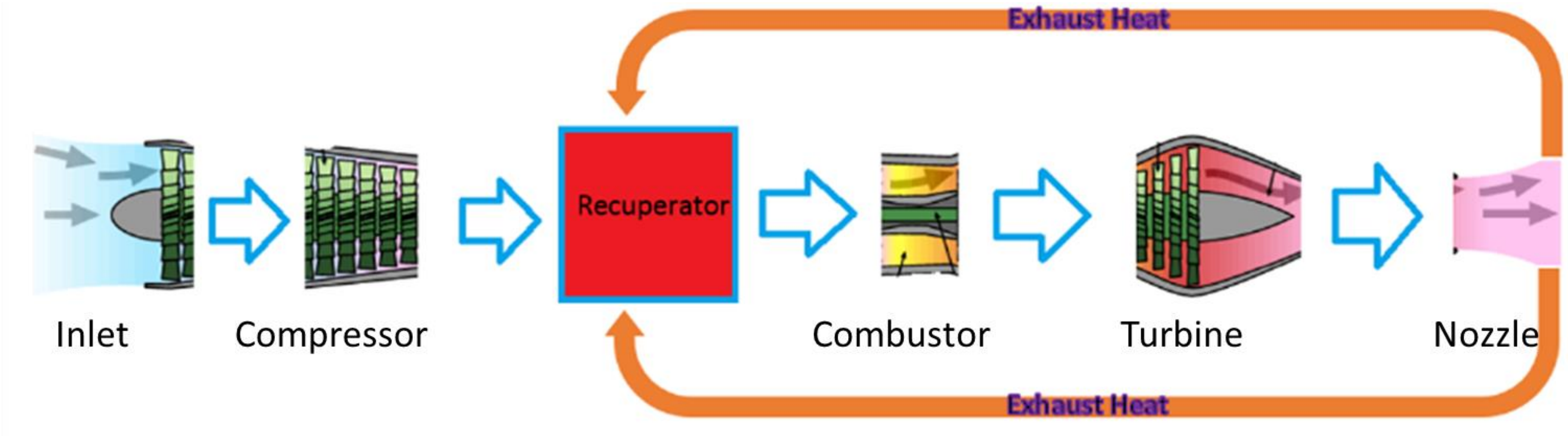
Team: Kevin Bieri, David Bright , Kevin Gomez, Kevin Horn, Becca Lidvall, Carolyn Mason, Andrew Marshall, Peter Merrick, and Jacob Nickless

Presentation Agenda

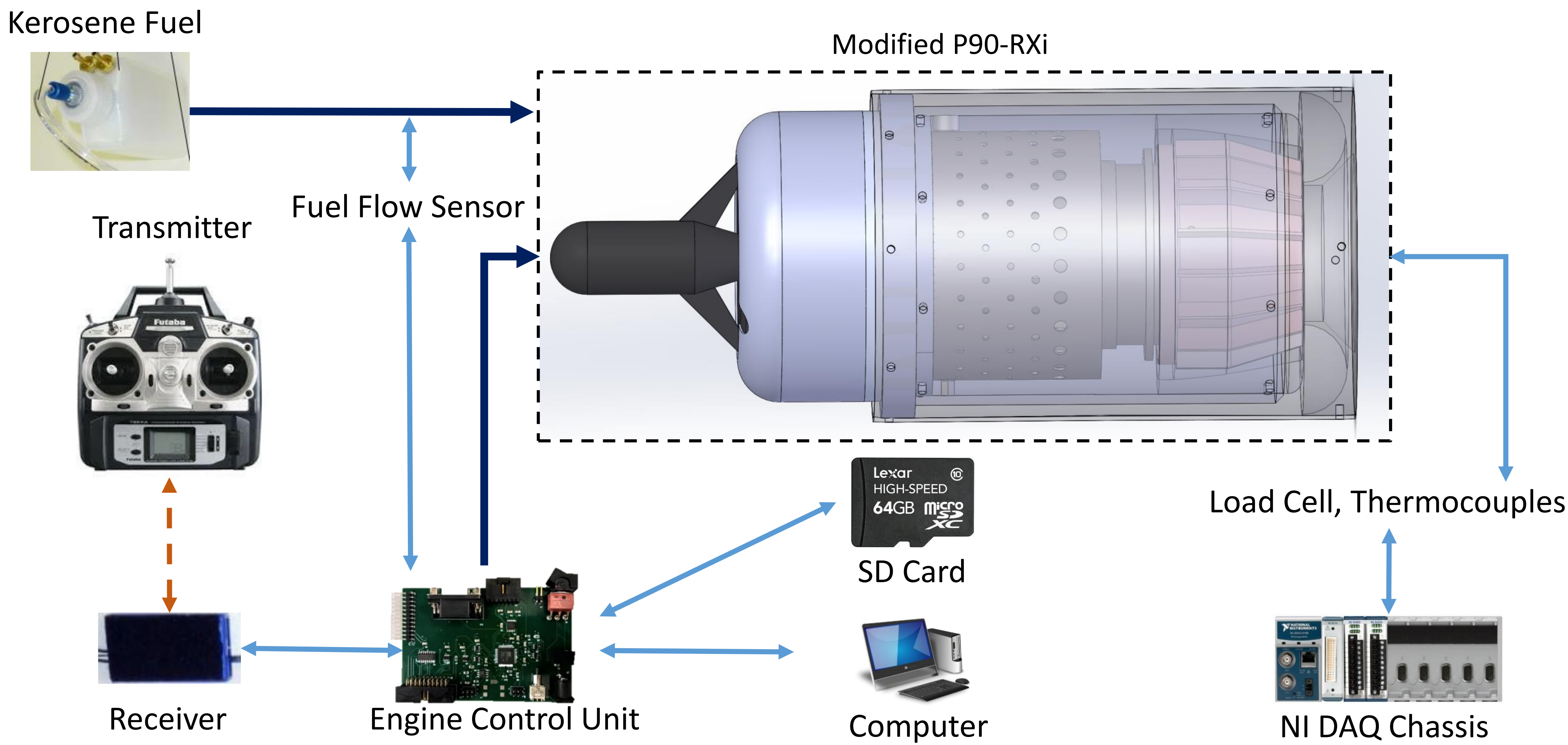
- Project Overview
- Schedule
- Manufacturing
- Budget

Overview

Model, build, implement, and verify an integrated recuperative system into a JetCat P90-RXi miniature turbojet engine for increased fuel efficiency from its stock configuration.

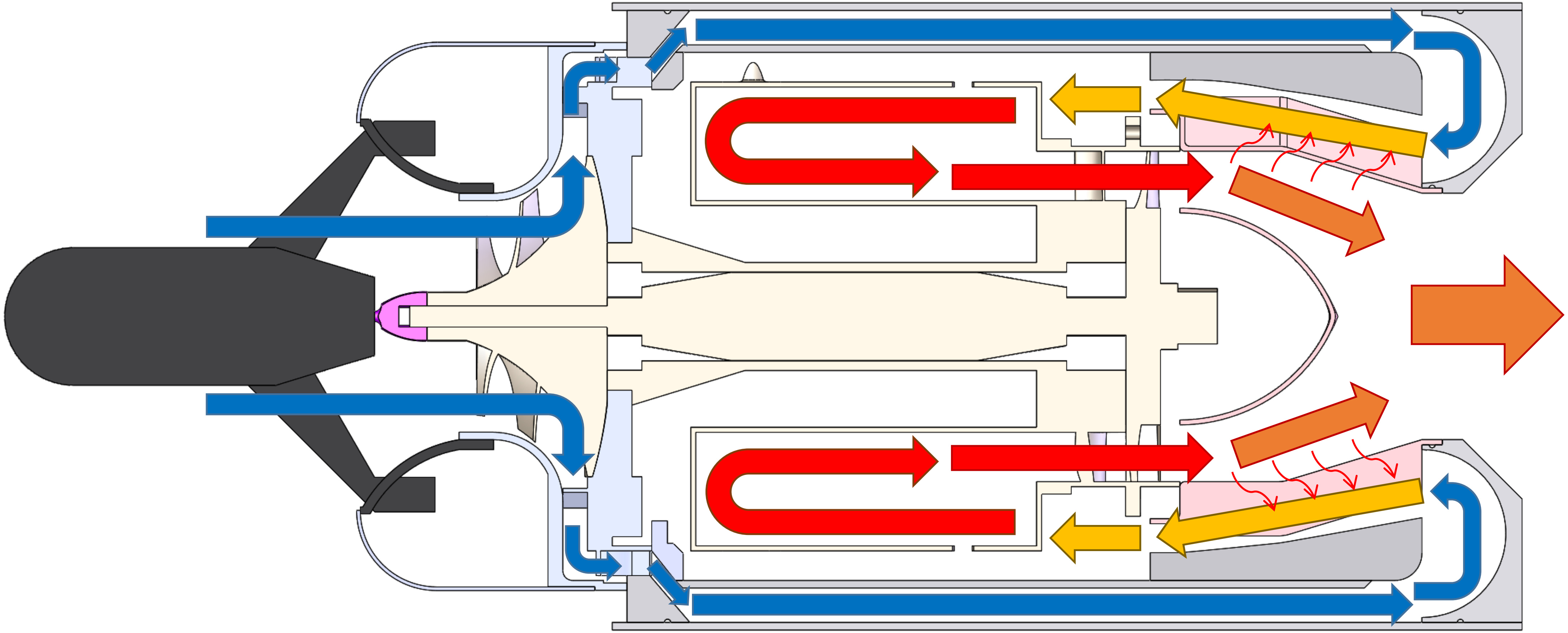


Concept of Operations

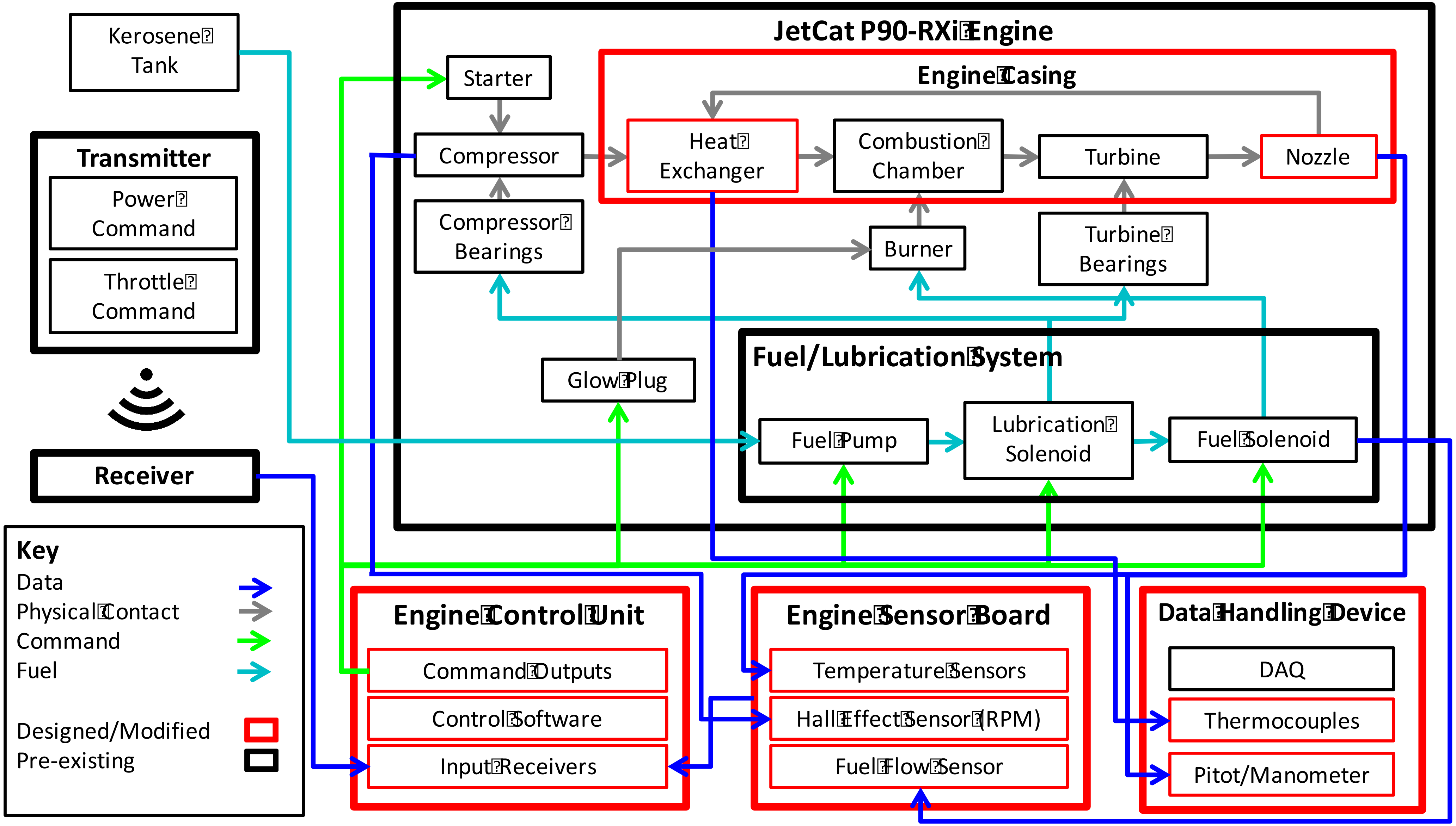


Baseline Design: Flow Path

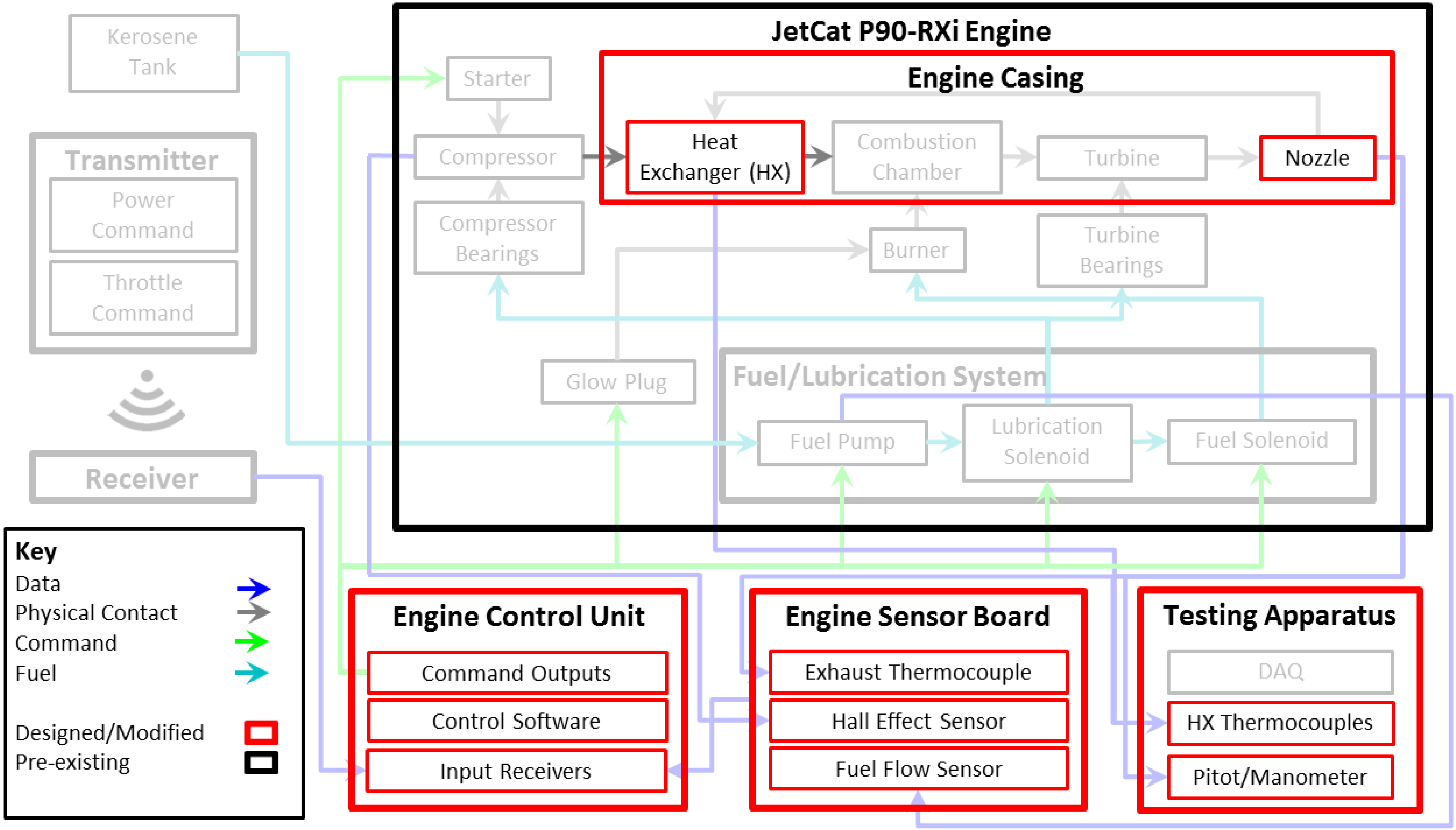
1. Engine Starts Up
2. Air Enters Compressor
3. Air Passes Along Outside of Casing
4. Air Enters Recuperator
5. Recuperator Heats Passing Air
6. Air Enters Combustor
7. Exhaust Passes through Turbine
8. Exhaust heats Recuperator Manifold



Functional Block Diagram



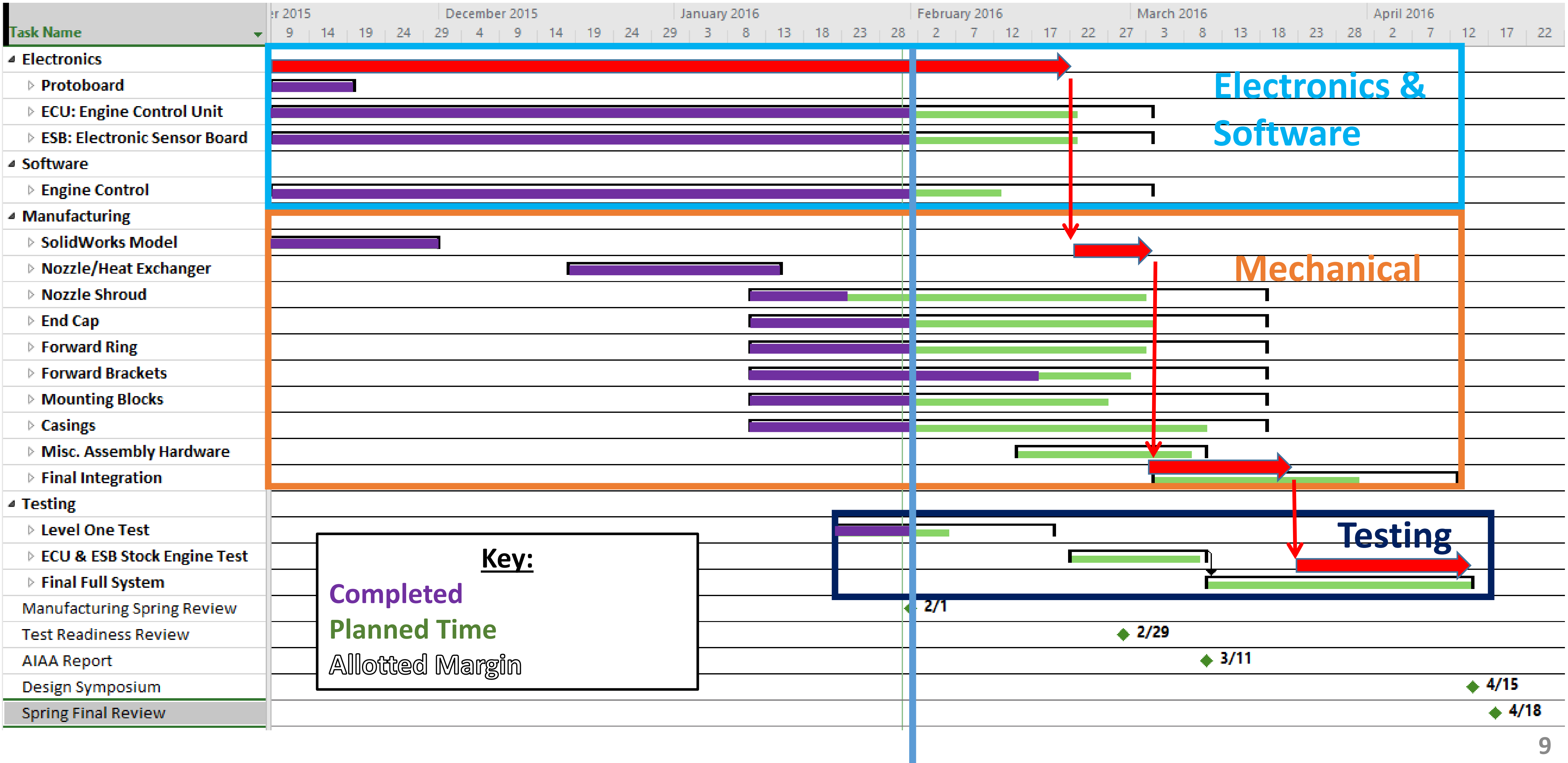
Functional Block Diagram



Levels of Success

	Simulation	Recuperator
Level 1		
Level 2		
Level 3		

Schedule



Task Name
er 2015
December 2015
January 2016
February 2016
March 2016
April 2016
9 14 19 24 29 4 9 14 19 24 29 3 8 13 18 23 28 2 7 12 17 22 27 3 8 13 18 23 28 2 7 12 17 22
Electronics
Protoboard
ECU: Engine Control Unit
ESB: Electronic Sensor Board
Software
Engine Control
Manufacturing
SolidWorks Model
Nozzle/Heat Exchanger
Nozzle Shroud
End Cap
Forward Ring
Forward Brackets
Mounting Blocks
Casings
Misc. Assembly Hardware
Final Integration
Testing
Level One Test
ECU & ESB Stock Engine Test
Final Full System
Manufacturing Spring Review
Test Readiness Review
AIAA Report
Design Symposium
Spring Final Review
Electronics & Software
Mechanical
Testing
2/1
2/29
3/11
4/15
4/18
Key:
Completed
Planned Time
Allotted Margin

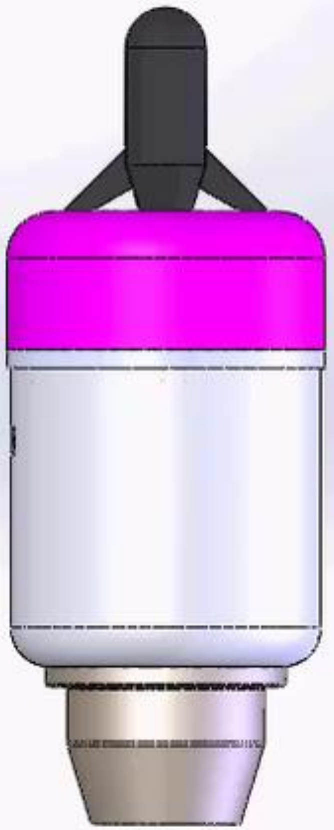
Mechanical

Manufacturing: Parts Video

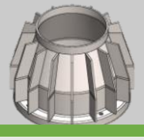
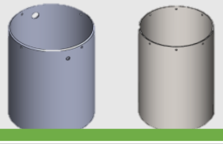
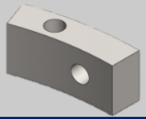
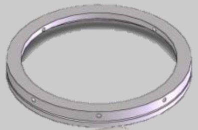
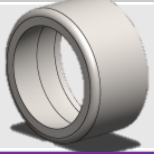
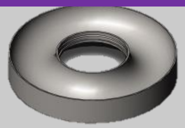
[illegible] (x2)

[illegible] Blocks (x4)

Forward Ring



Manufacturing: Overview

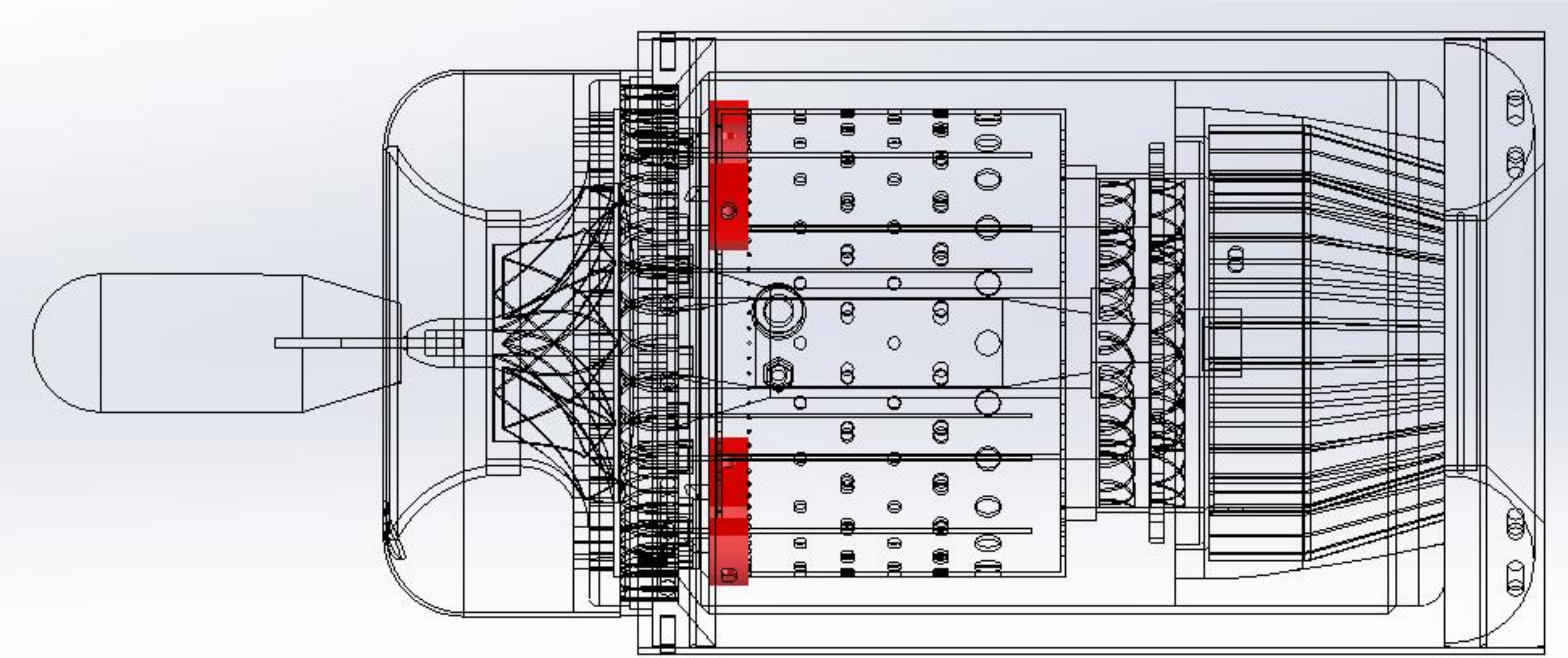
Part		Manufacturing Method	Tolerance (inches)	Man Hours Remaining
Finned Nozzle		Direct Metal Laster Sintering	0.005	Completed
Inner/Outer Casing		Folsom Sheet Metal Roller	0.05	8 hours
Four Mounting Blocks		CNC Mill	0.005	7 hours
Two Forward Brackets		CNC Lathe, Manual Lathe, CNC Mill	0.005	11 hours
Forward Ring		CNC Mill and Lathe	0.005	9 hours
Nozzle Shroud		CNC Lathe	0.005	8 hours
End Cap		CNC Mill and Lathe	0.005	14 hours

Tolerance Issues

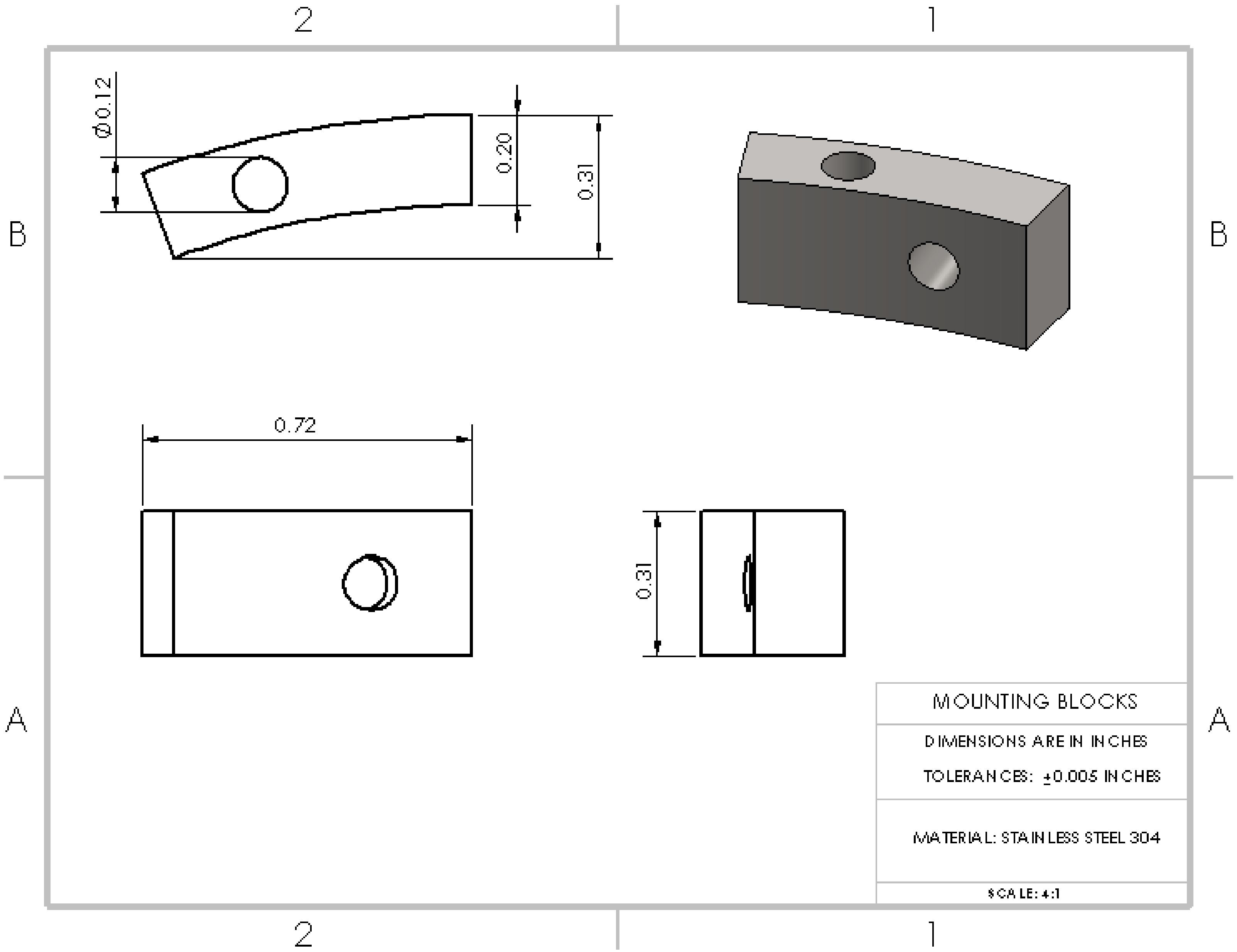
Time Consuming

Potential Redesign

Mounting Blocks: Location



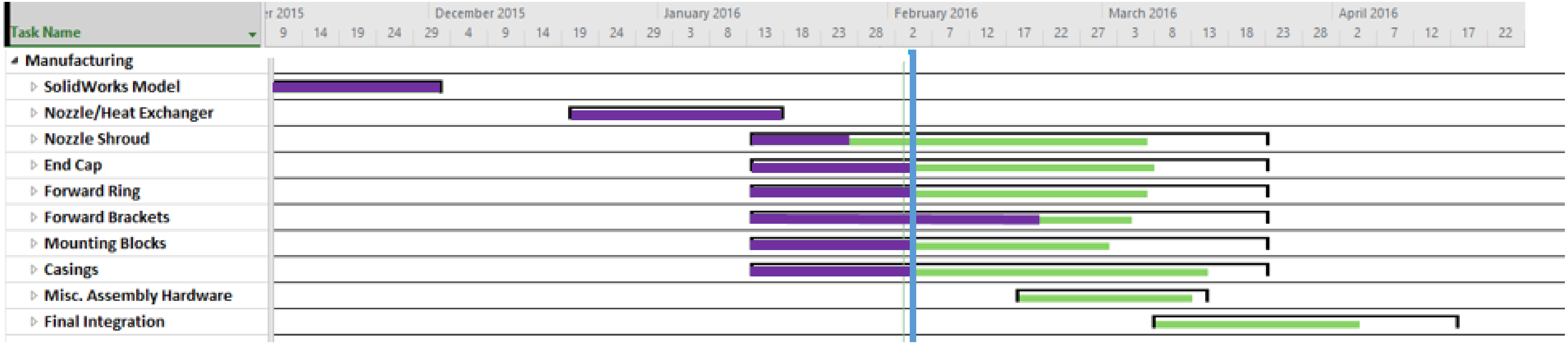
Mounting Blocks: Dimensioned Drawing



Mounting Blocks: Manufacturing

- Use manual mill to square off stock piece
  - 2 hours
- Use CNC mill to cut part out of stock and drill vertical holes
  - 1.5 hours (x4)
- Band saw newly created piece from stock
  - 0.5 hours (x4)
- Create fixture to hold mounting block while drilling horizontal hole
  - 3 hours
- Drill horizontal hole
  - 0.5 hours (x4)

Mechanical: Summary



Estimated Hours Remaining: 57 hours

Workforce: 5

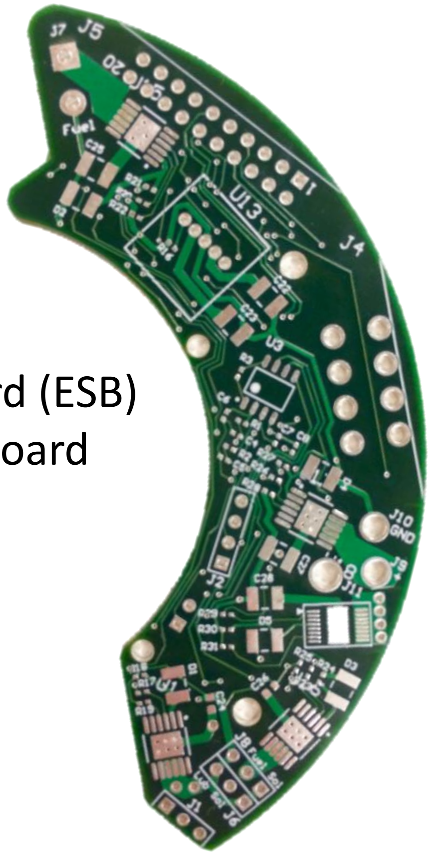
Weekly Scheduled Hours: 53 hours

Scheduled Time after MSR: 159 hours

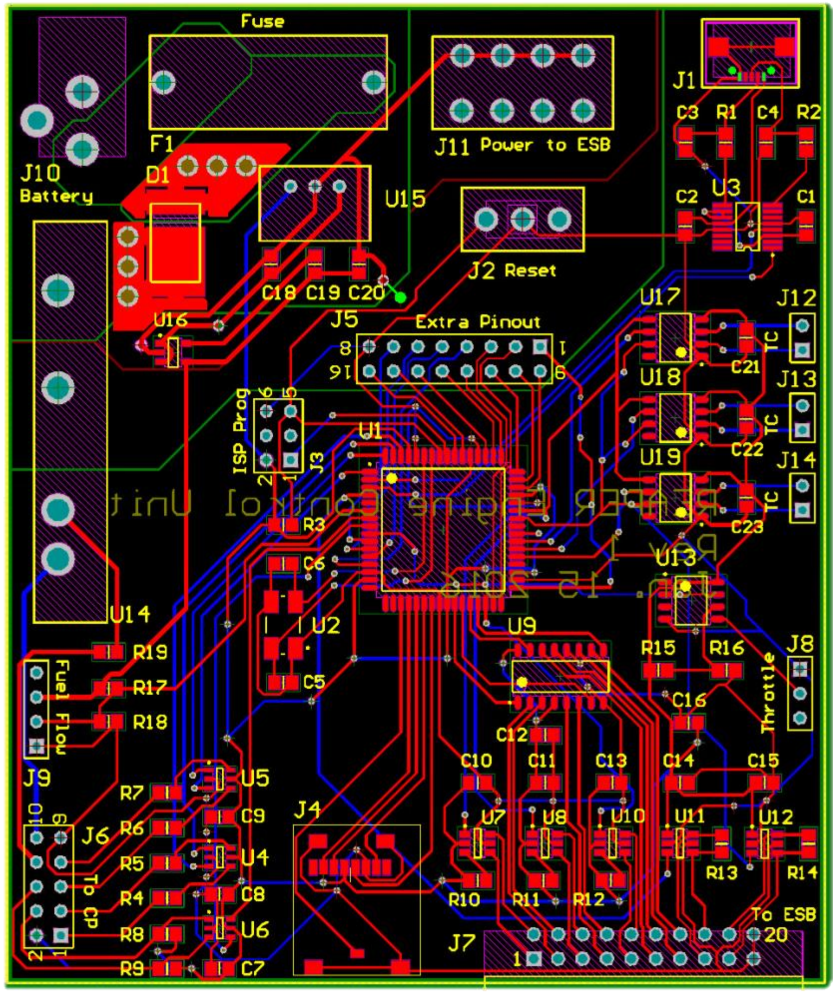
Engine Electronics

Engine Electronics

- 2 custom Printed Circuit Boards (PCBs)
- Designed in Altium
- Manufactured by Advanced Circuits
- Populated in house
- 1st revision received

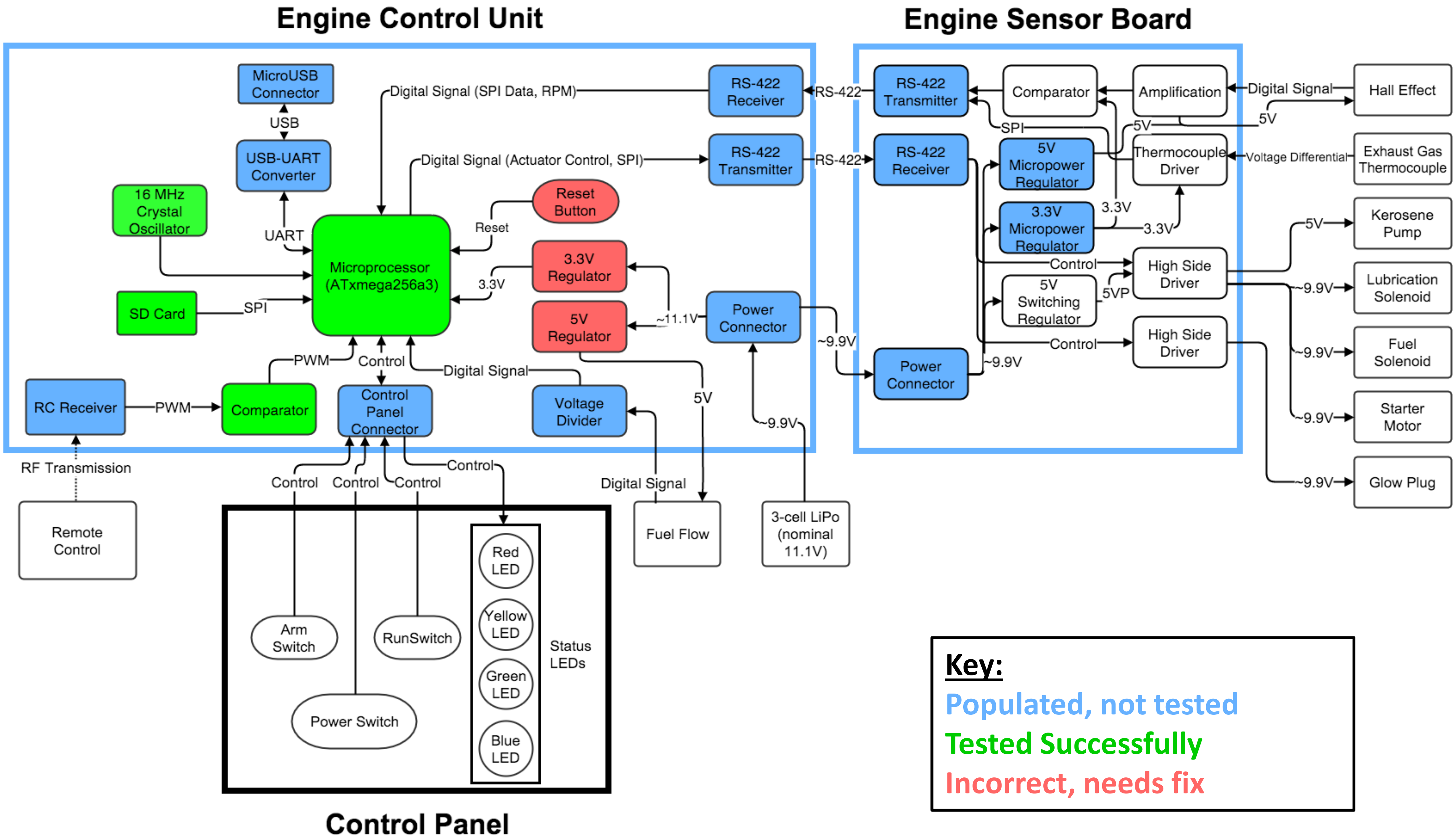


Engine Sensor Board (ESB)
- Printed Circuit Board



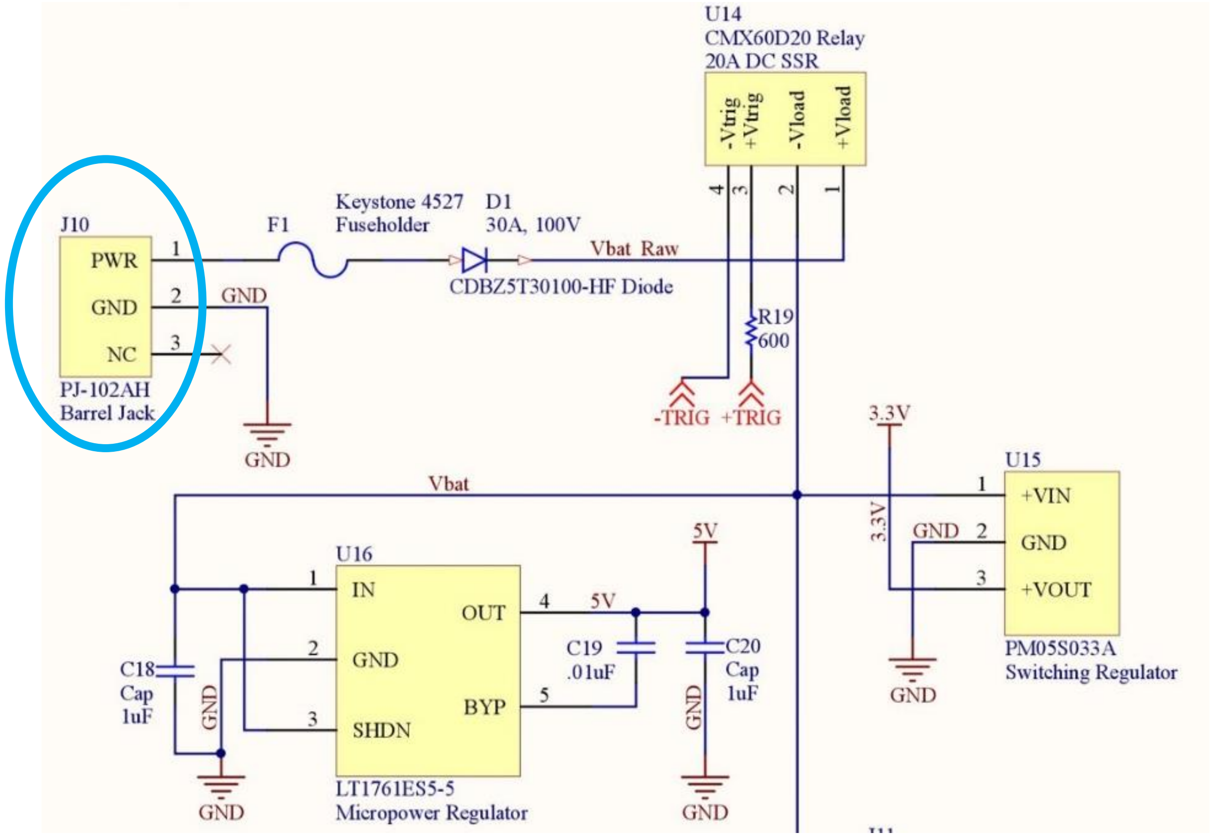
Engine Control Unit (ECU) - Altium Design

Engine Electronics: Status Update



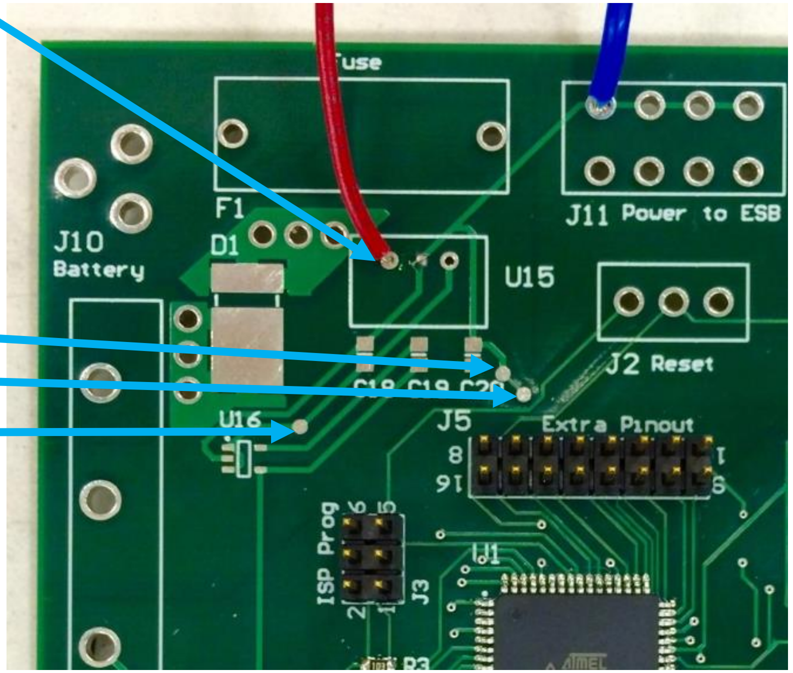
Key:
Populated, not tested
Tested Successfully
Incorrect, needs fix

Engine Electronics: Power

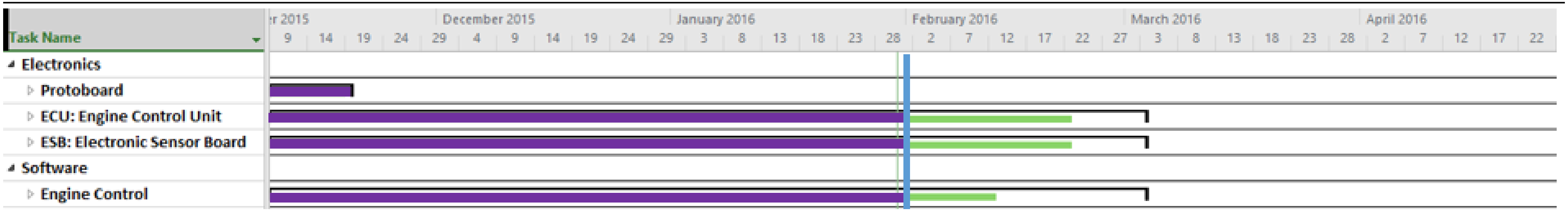


Power Plane Issue

Incorrectly Designed Vias



Engine Electronics: Summary



Estimated Hours Remaining: 60 hours

Workforce: 2

Scheduled Time after MSR: 90 hours

Engine Electronics: Software Progress

High Level

Final Implementation

Hardware Interface Layer

SD Card

Hall Effect

Thermocouples

Fuel Flow

Glow Plug

Starter motor

Low Level Interface

SPI

Oscillator

Interrupts

USART

PWM

I2C

EEPROM

KEY

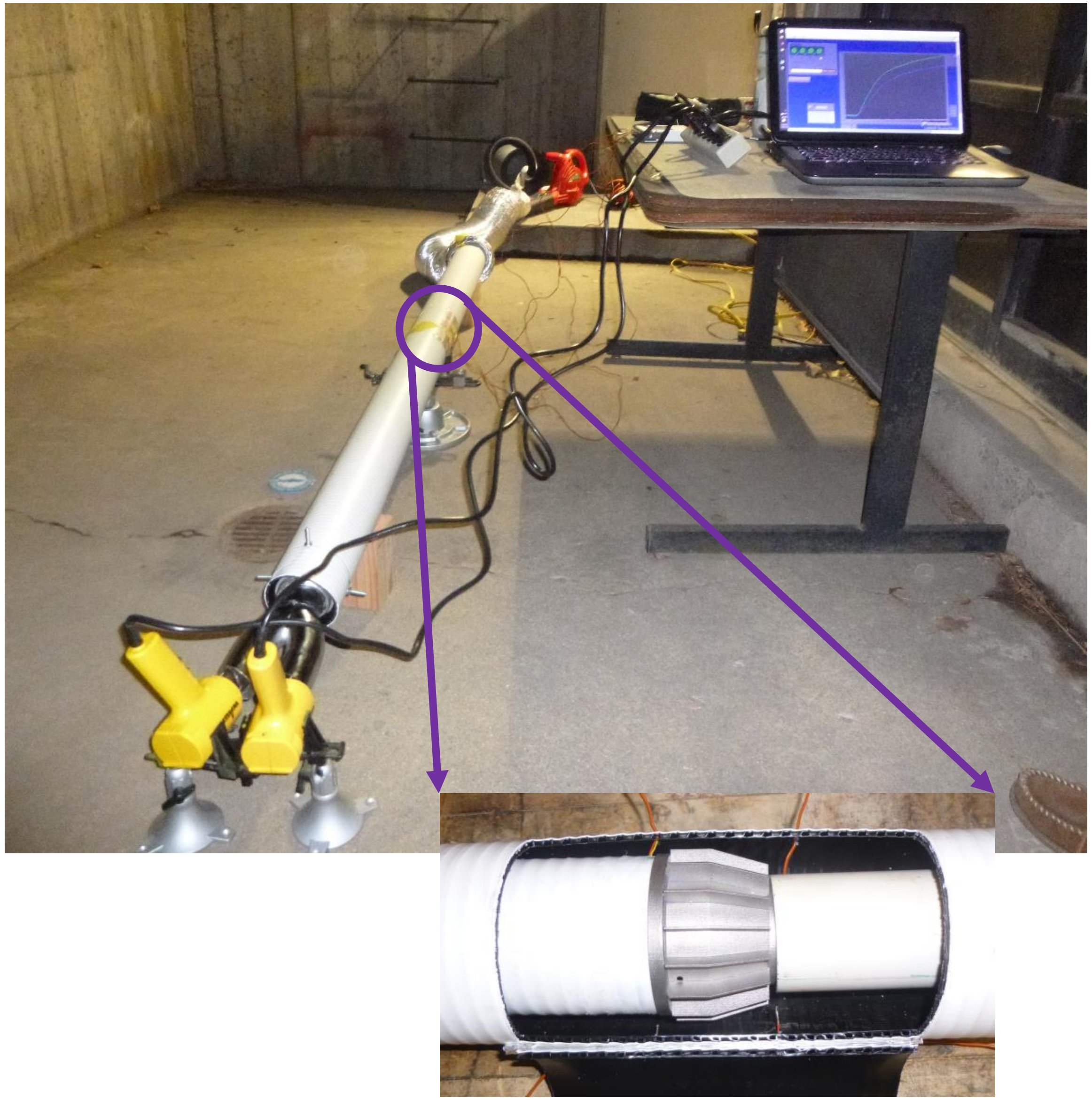
Validated

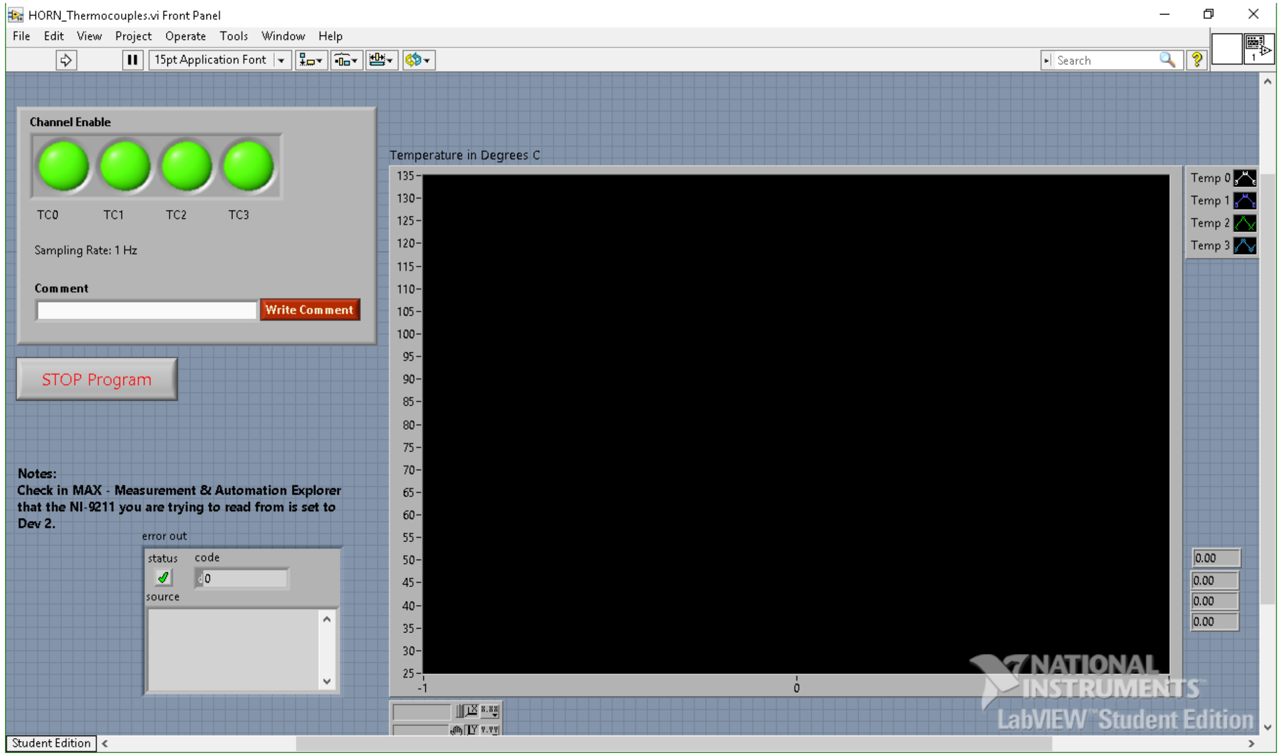
Written

Incomplete

Testing

Testing: Level 1

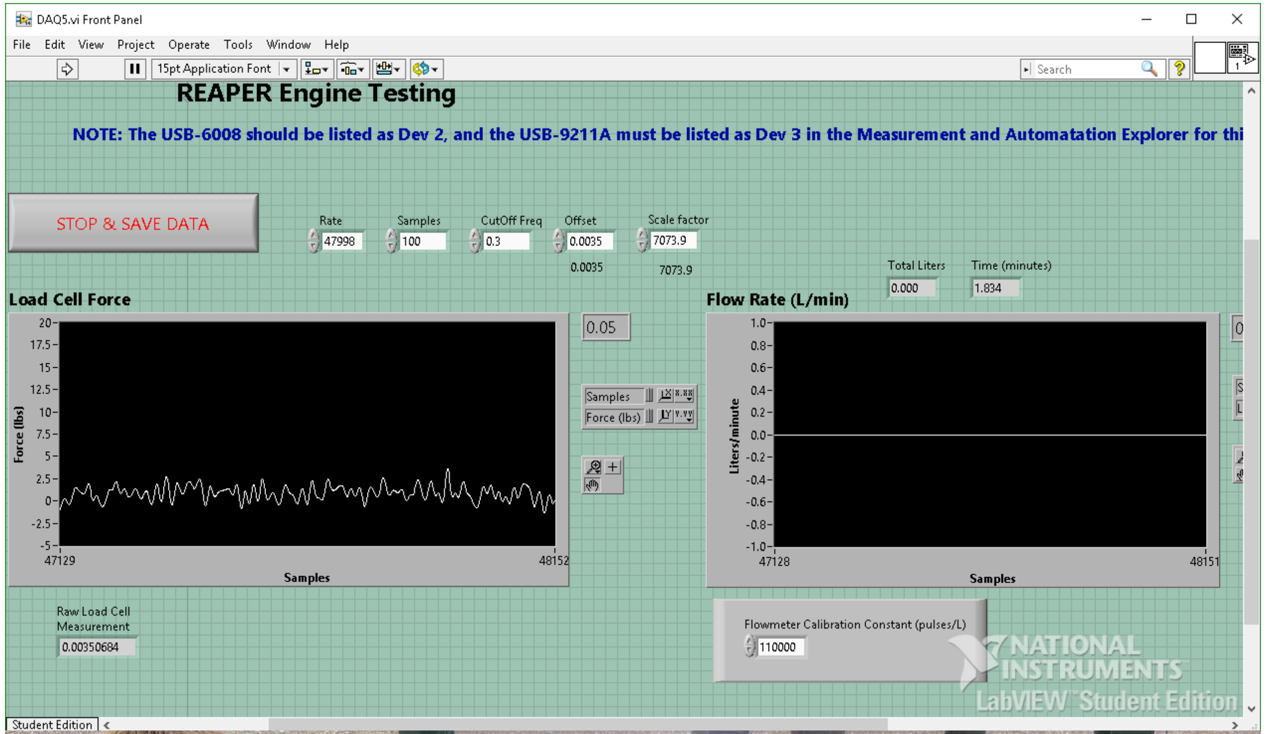


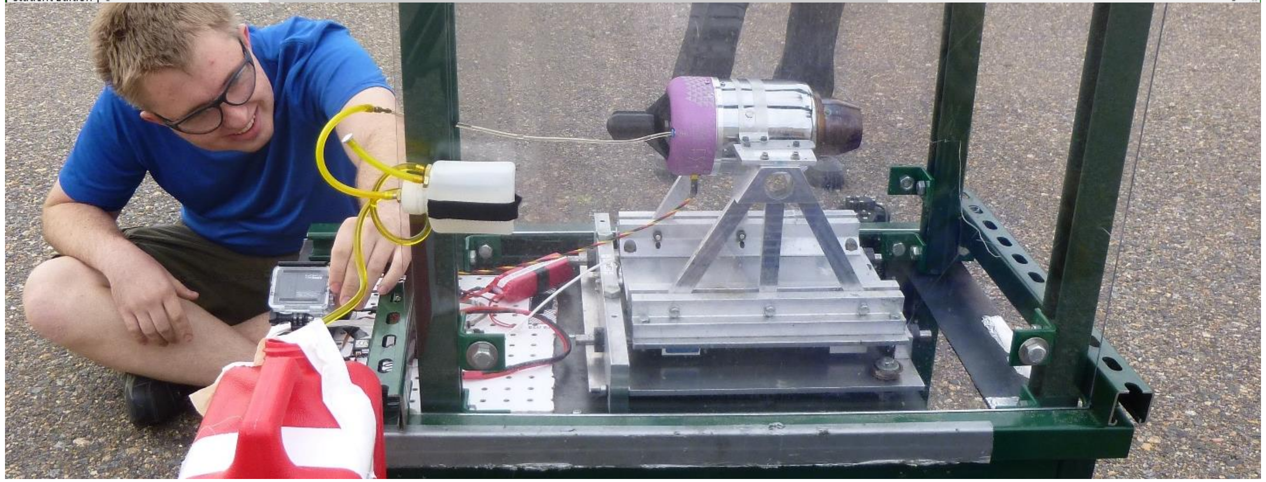


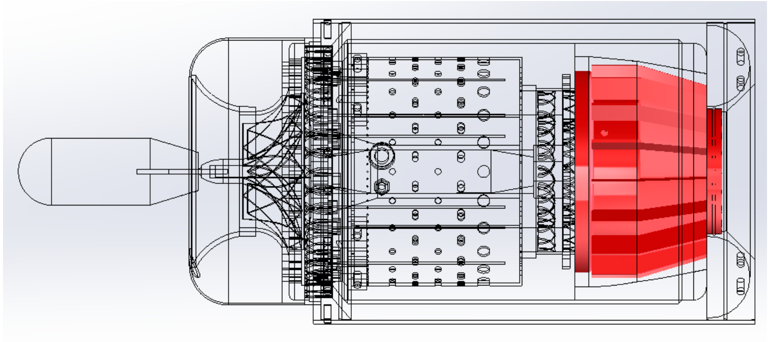
Key Components:

- Verification of Thermal Model & Heat Exchanger
- Heat exchange data analysis
- Thermocouple VI
- Pitot Probe Velocity Recording

Testing: Level 3 (Full System Test)



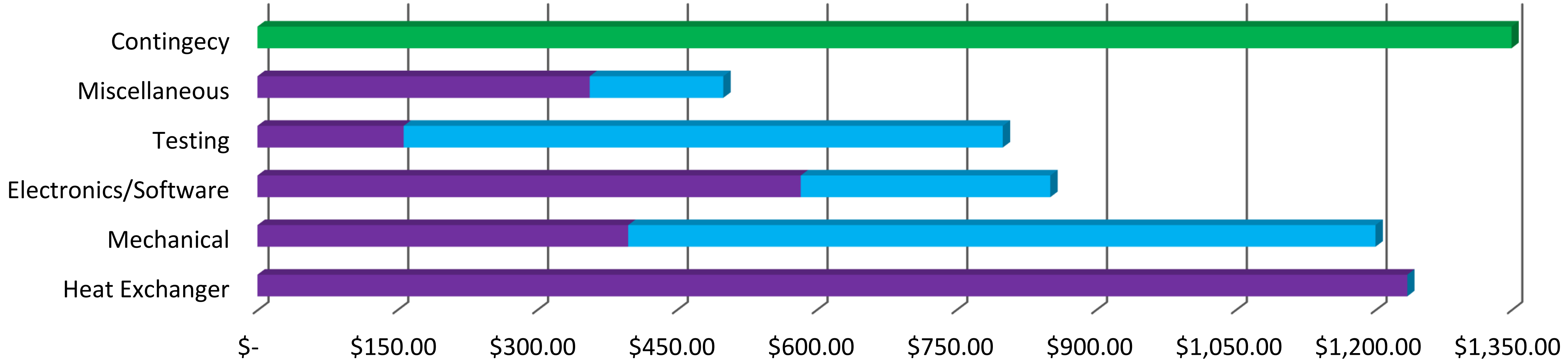




- Fully Integrated Engine Test
- Ready:
  - Test stand available
  - LabVIEW VI’s created
- In Progress:
  - Sensor calibration
  - Stock engine with fuel flow
  - Engine electronics
  - Mechanical components
  - Data analysis code

Budget

Budget



	Heat Exchanger	Mechanical	Electronics/Software	Testing	Miscellaneous	Contingecy
Spent	$1,234.22	$397.96	$583.15	$156.94	$356.64	$-
Remaining Budget	$0.00	$802.04	$267.85	$643.06	$143.36	$1,389.78

■ Spent ■ Remaining Budget

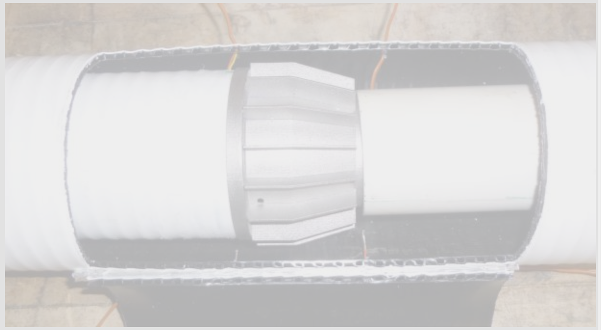
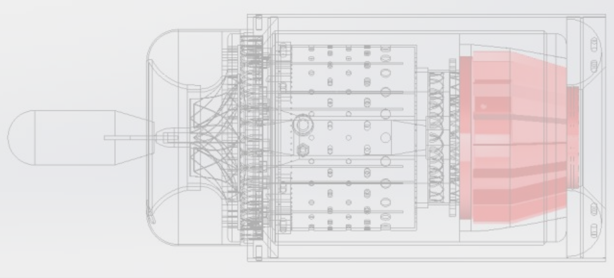
Total Budget **$5,975**
Total Spent **$2,729**
Remaining Expenses **$1,856**
Contingency **$1,390**

Questions?

Backup Slides

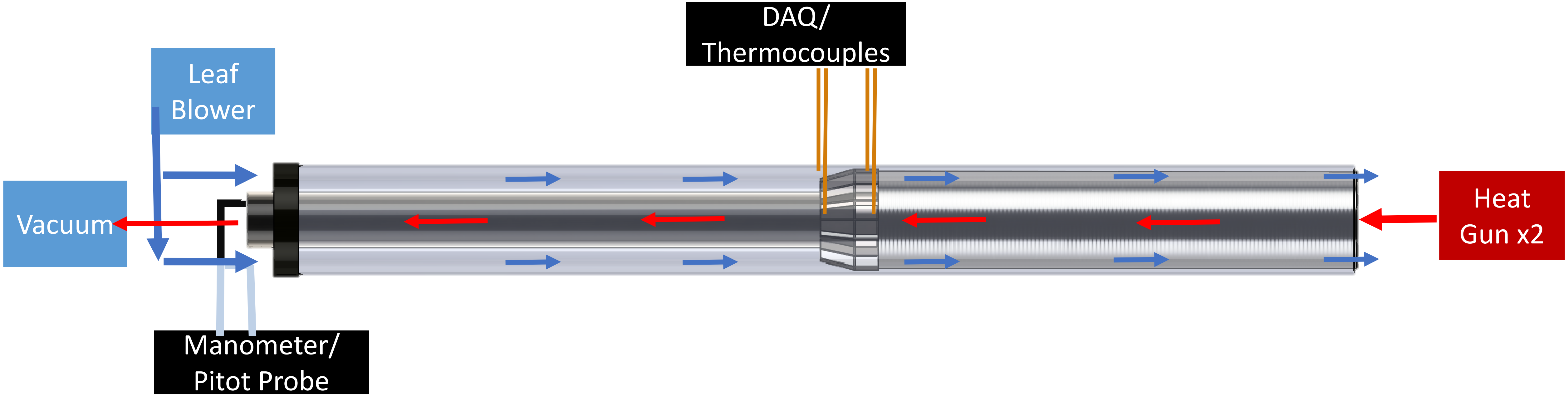
Testing Backup Slides

Planned Tests

Test	Purpose	Required Setup	Status
	• **Level 1 success** • Recuperator operates without critical failure • Verifies heat transfer from model	• Concentric pipe test rig with recuperator integrated • Use heat guns, leaf blowers, thermocouples, and pitot probe from Level 0 testing • Use manometer and Daq/Labview for data collection	• **Built** and withstands high heat tests • **Matlab model complete** • Analysis underway for Level 1 success
	• **Level 3 success** • Engine runs • Meet Throttle time • Effectiveness, Thrust Specific Fuel Consumption (TSFC), and thrust reduction match model	• Manufacturing complete with recuperator integrated onto the engine • Use REAPER electronics • Use thermocouples and pitot probe from Level 0 testing • Use load cell, fuel flow sensors, and hall effect sensor	• **Manufacturing and electronics on track** • Labview GUIS created and tested for thermocouples and load cell • **Matlab and CFD models complete**

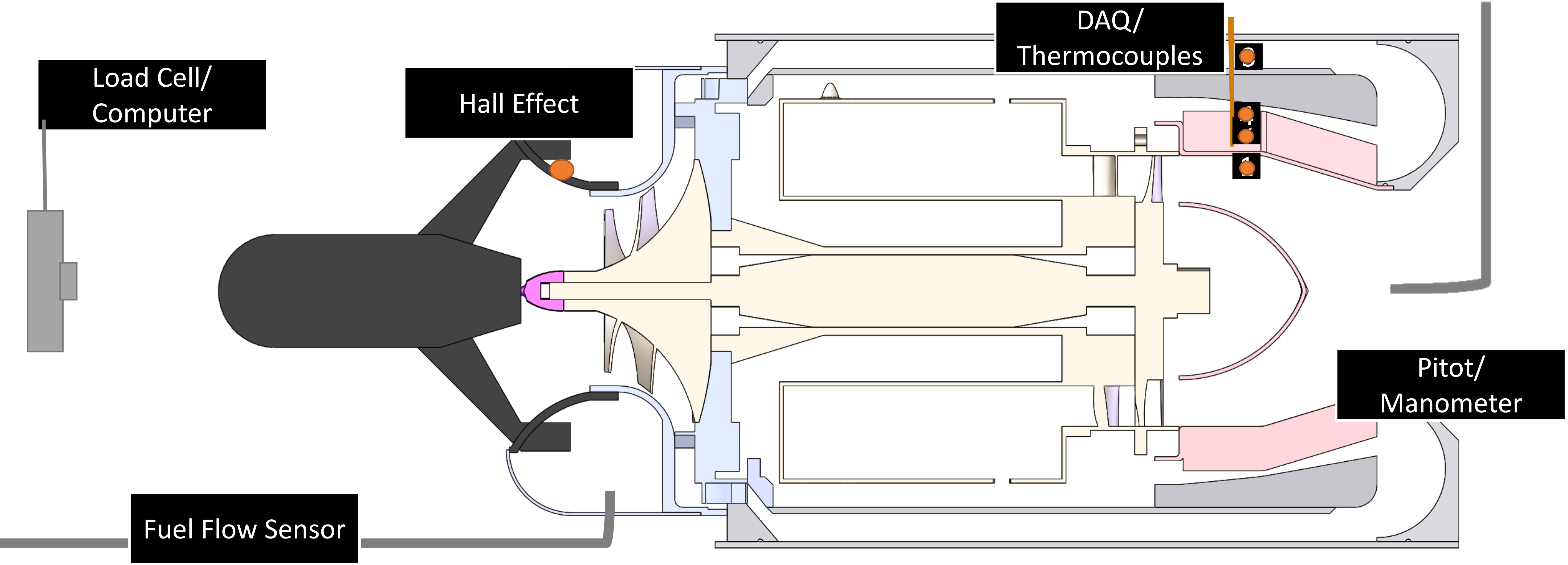
Testing- Level 1

- Recuperator **operates** without critical failure
- Verifies **heat transfer** from **1D Model**



Sensor List	FR Validation	Error	Sample Rate	Acquired/ Tested
Thermocouples	Temperature (DR 3.3)	+/- 1.2 K	1Hz	yes/ yes
Pitot Static Tube	Exit Velocity (DR 3.3)	+/-1.4 m/s	N/A	yes/ yes

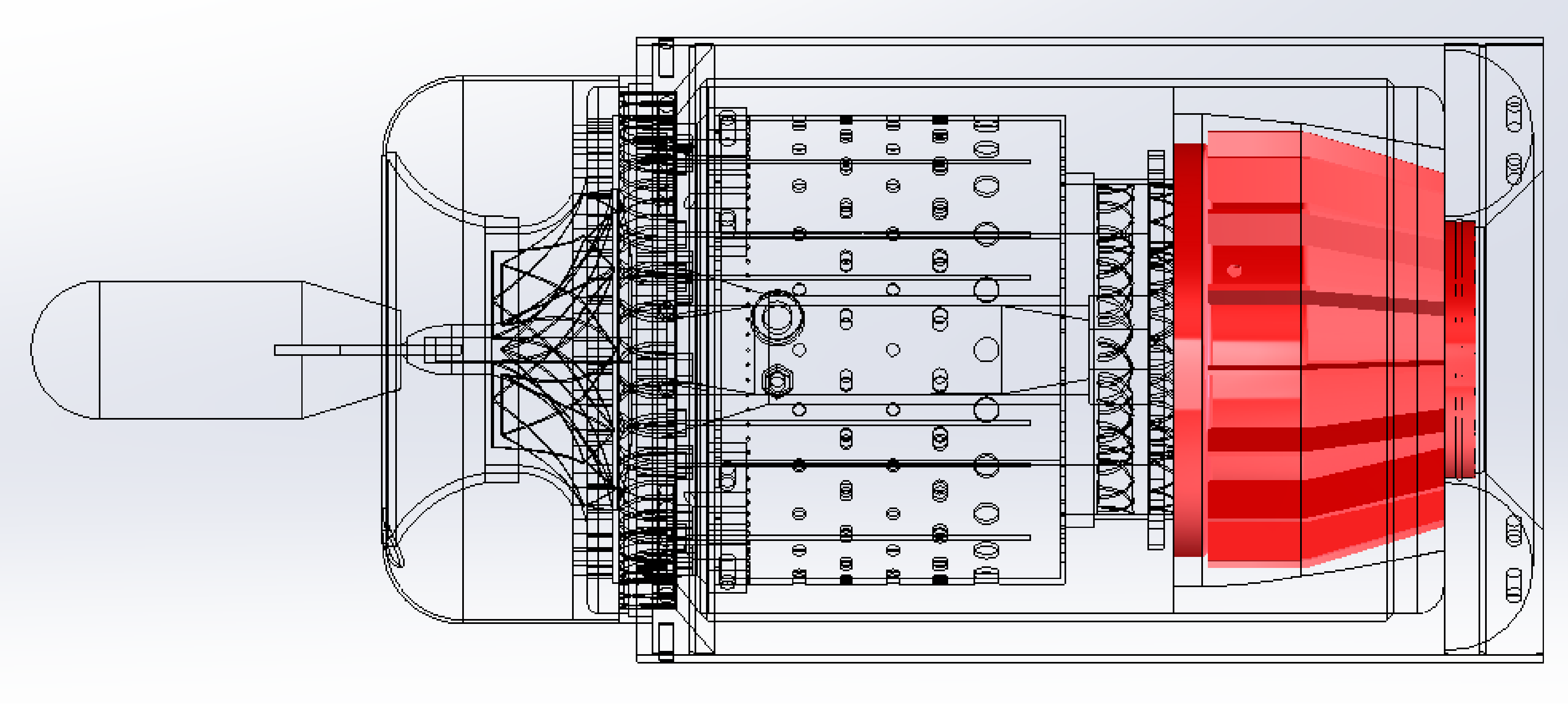
Testing- Level 3



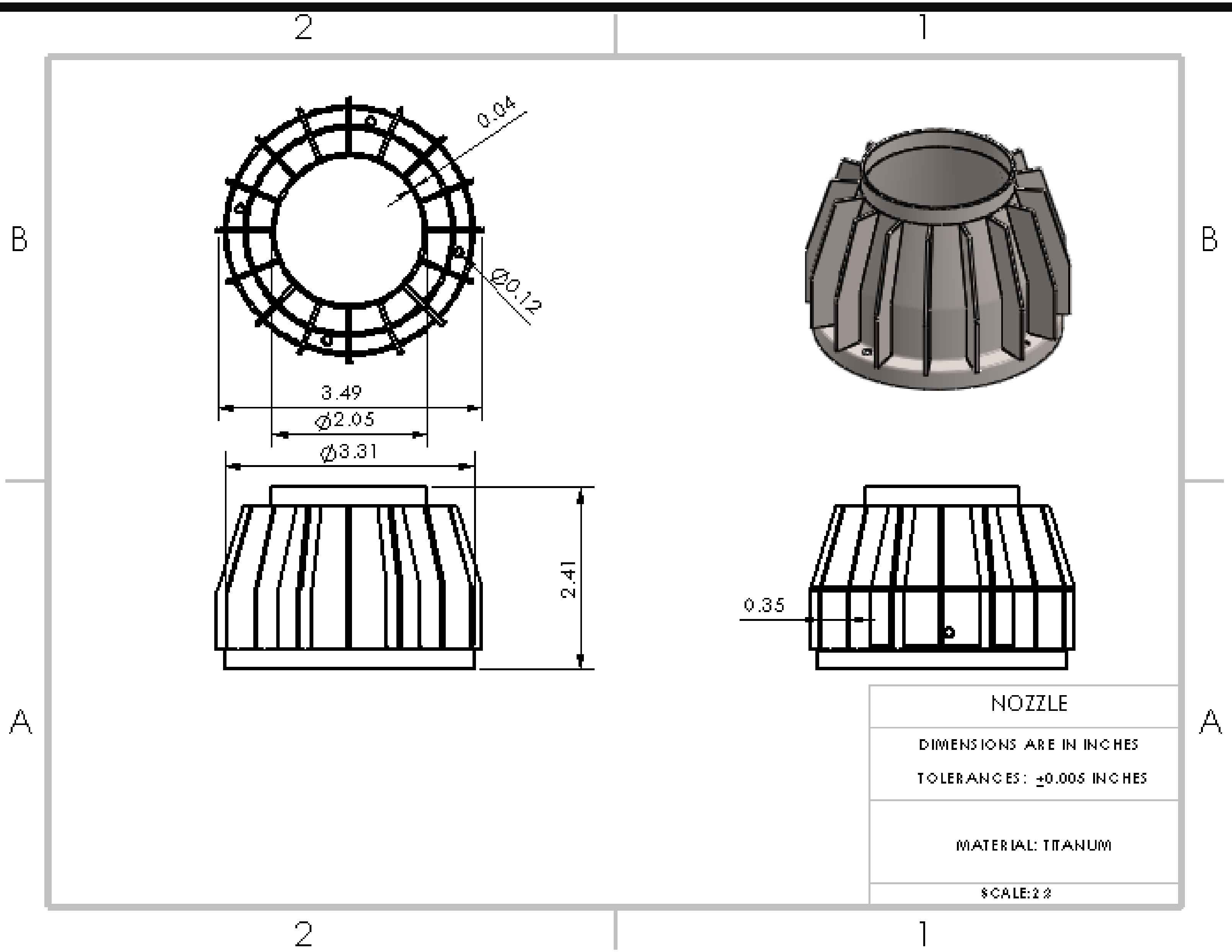
Sensor List	FR Validation	Error	Sample Rate	Acquired/ Tested
Fuel Flow Sensor	TSFC (FR 2)	±1%	31 Hz	No / No
Load Cell	Thrust (DR 2.5)	±0.2%	1 Hz	Yes / No
Hall Effect	RPM (DR 2.4)	±0.05%	31 Hz	No / No

Mechanical Backup Slides

Nozzle/Heat Exchanger: Location



Nozzle/Heat Exchanger: Dimensioned Drawing



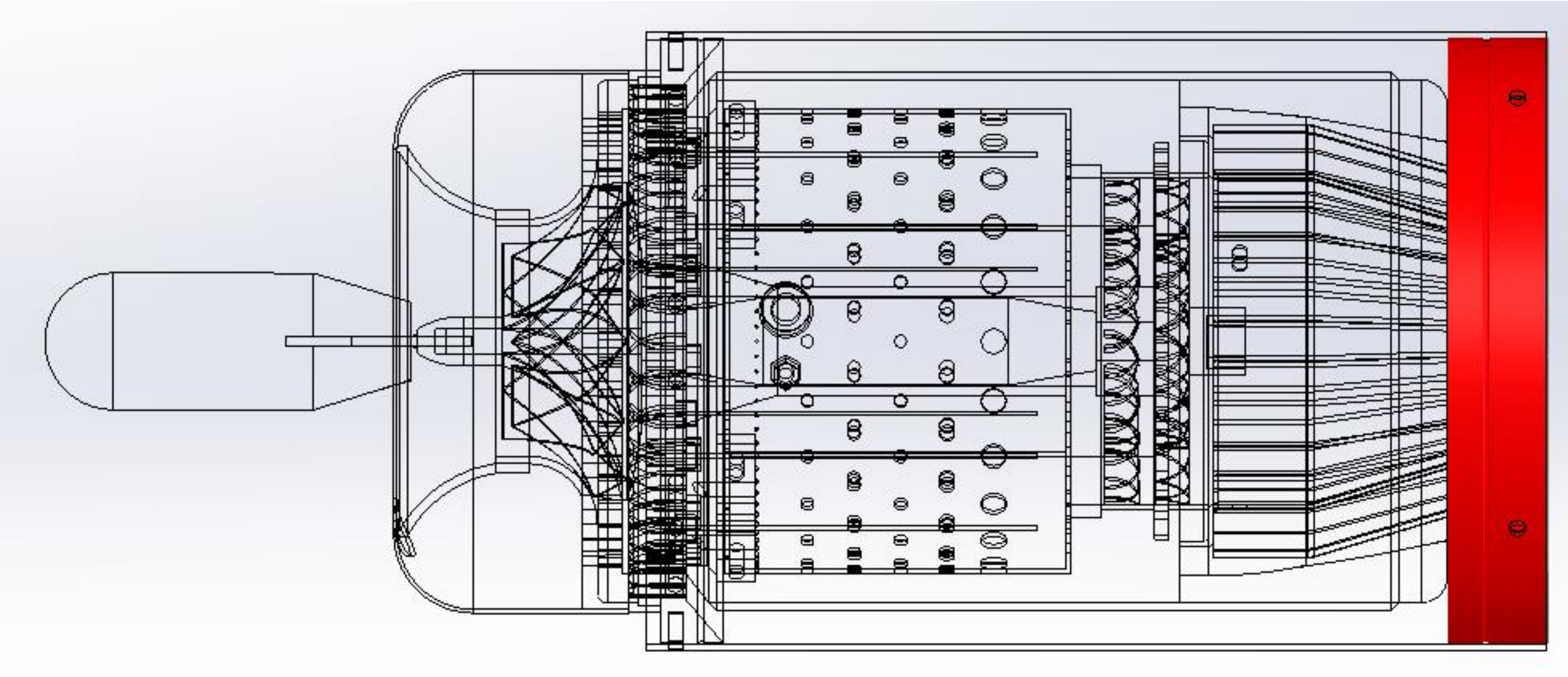
Nozzle/Heat Exchanger: Manufacturing

- Direct Metal Laser Sintered (DMLS) from Titanium → **Done out of House**
- Drill mounting holes → 1 man hr

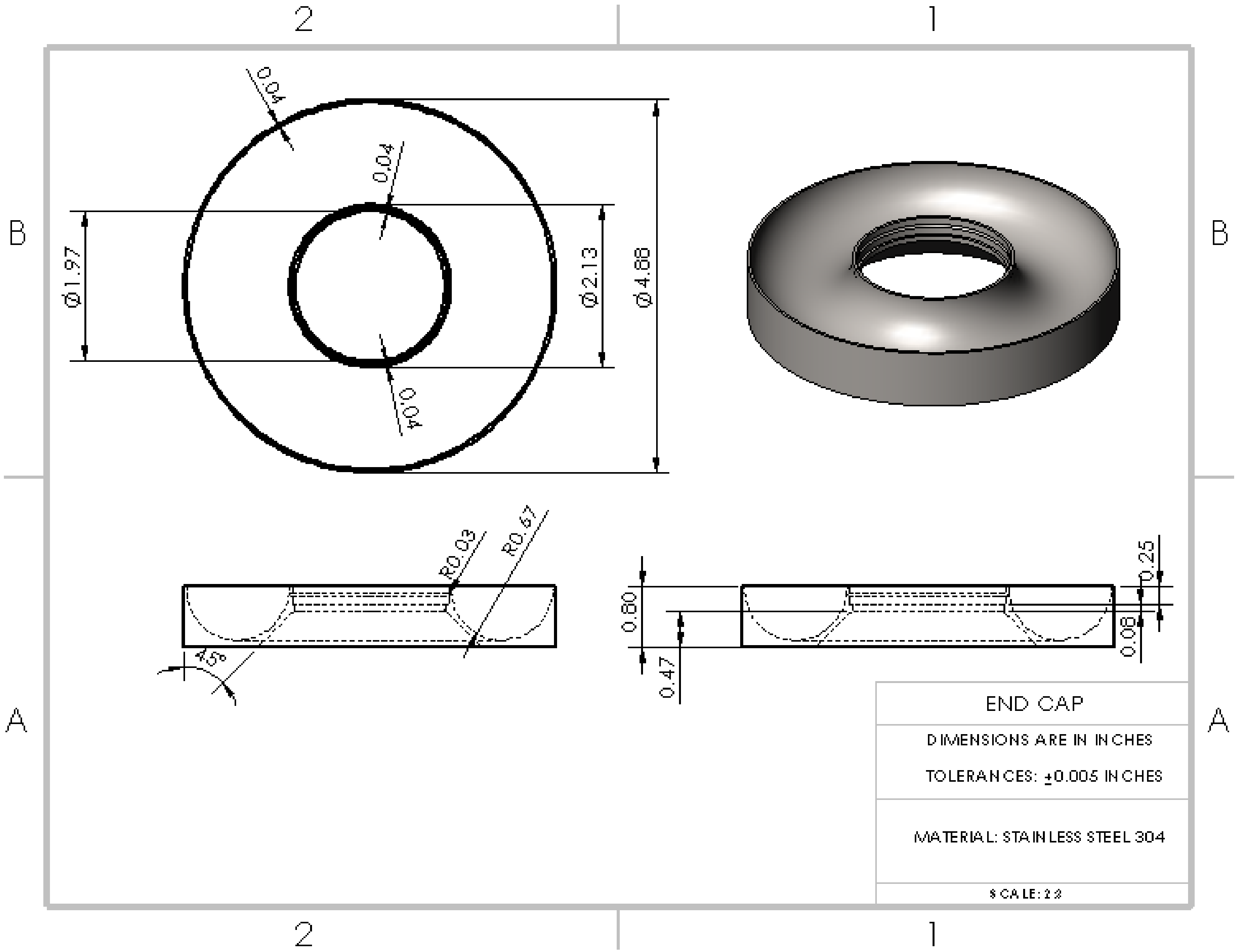
Required Man Hrs: 1

Completed Man Hrs: 0

End Cap: Location



End Cap: Dimensioned Drawing



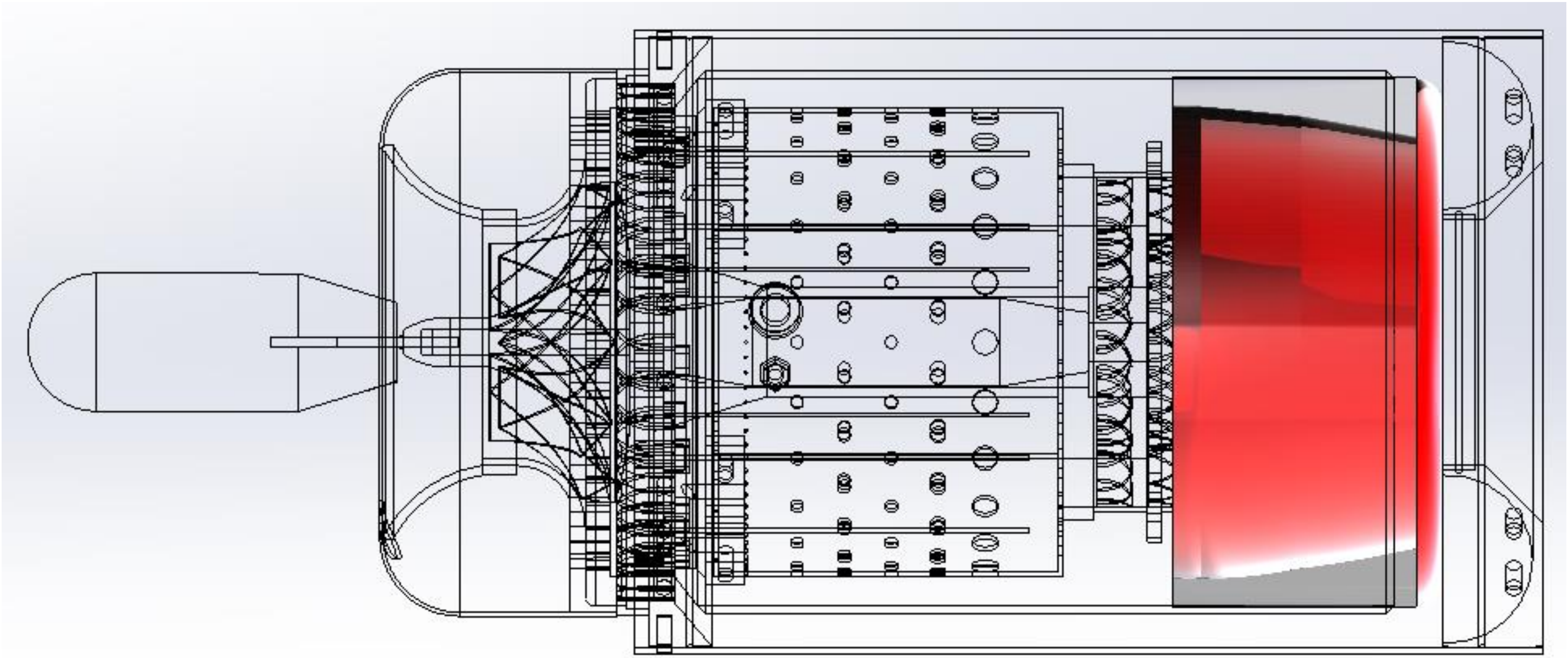
End Cap: Manufacturing

- Band saw off appropriate length from stock → 2 mans hrs
- Drill center hole for Computer Numerical Control (CNC) lathe → 2 man hrs
- Create outer and inner diameters, and inner chamfer, with CNC lathe → 5 mar hrs
- Use CNC nner diamete

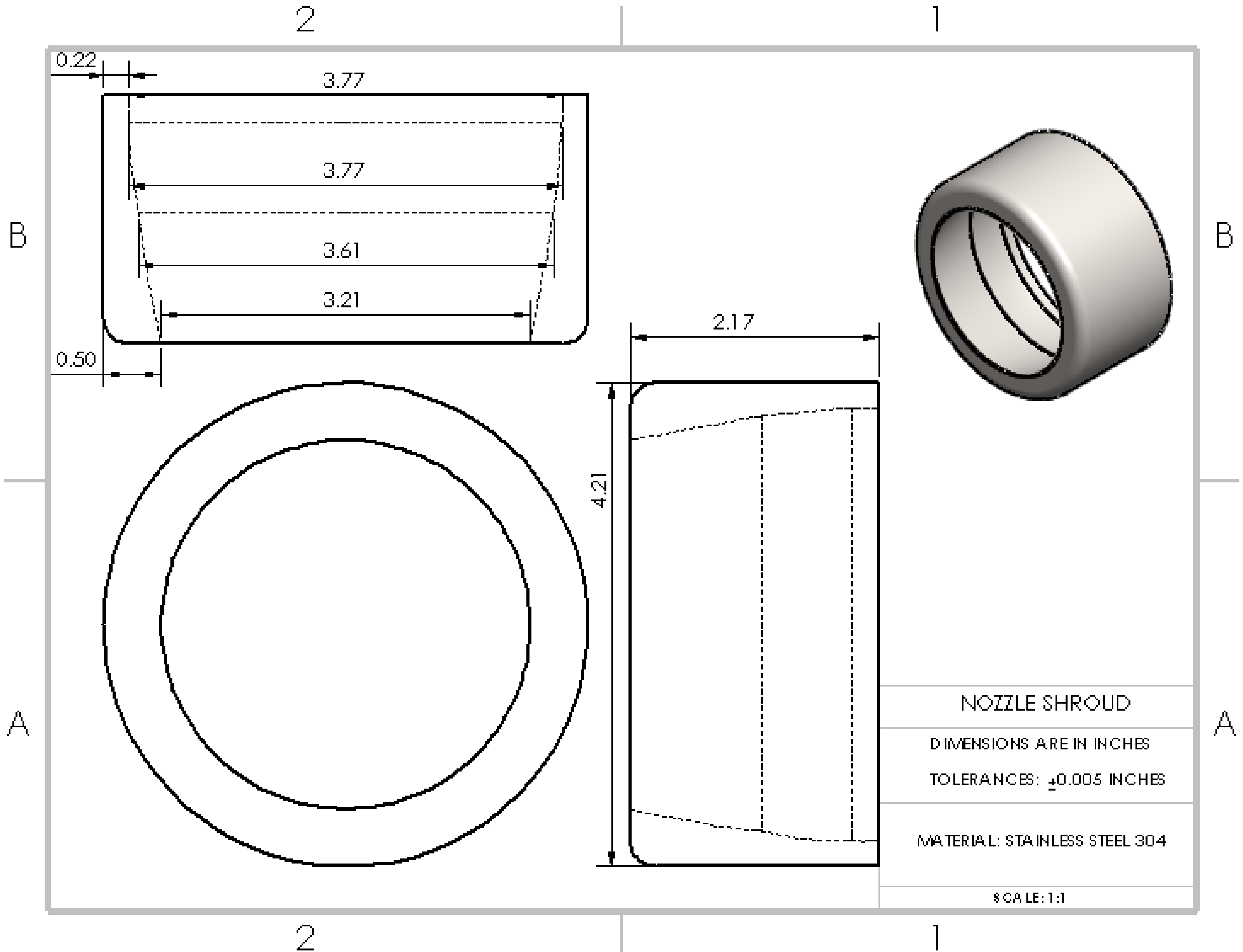
Required Man Hrs: 16

Completed Man Hrs: 0

Nozzle Shroud: Location



Nozzle Shroud: Dimensioned Drawing



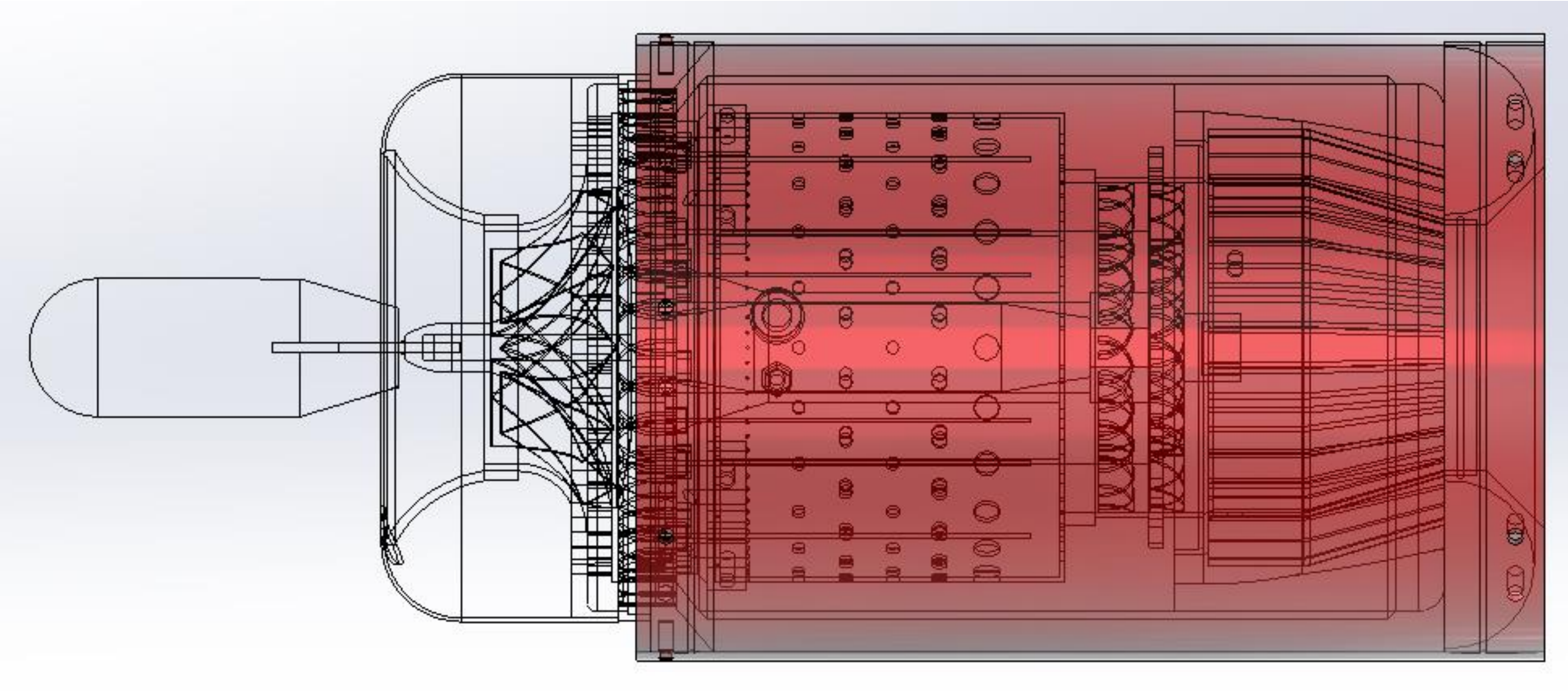
Nozzle Shroud: Manufacturing

- Band saw off appropriate length of material from stock → 2 man hrs
- Drill center hole for (CNC) lathe → 2 man hrs
- Create outer and inner diameters with CNC lathe → 5 man hrs
- Add fillet with CNC lathe → 1 hrs

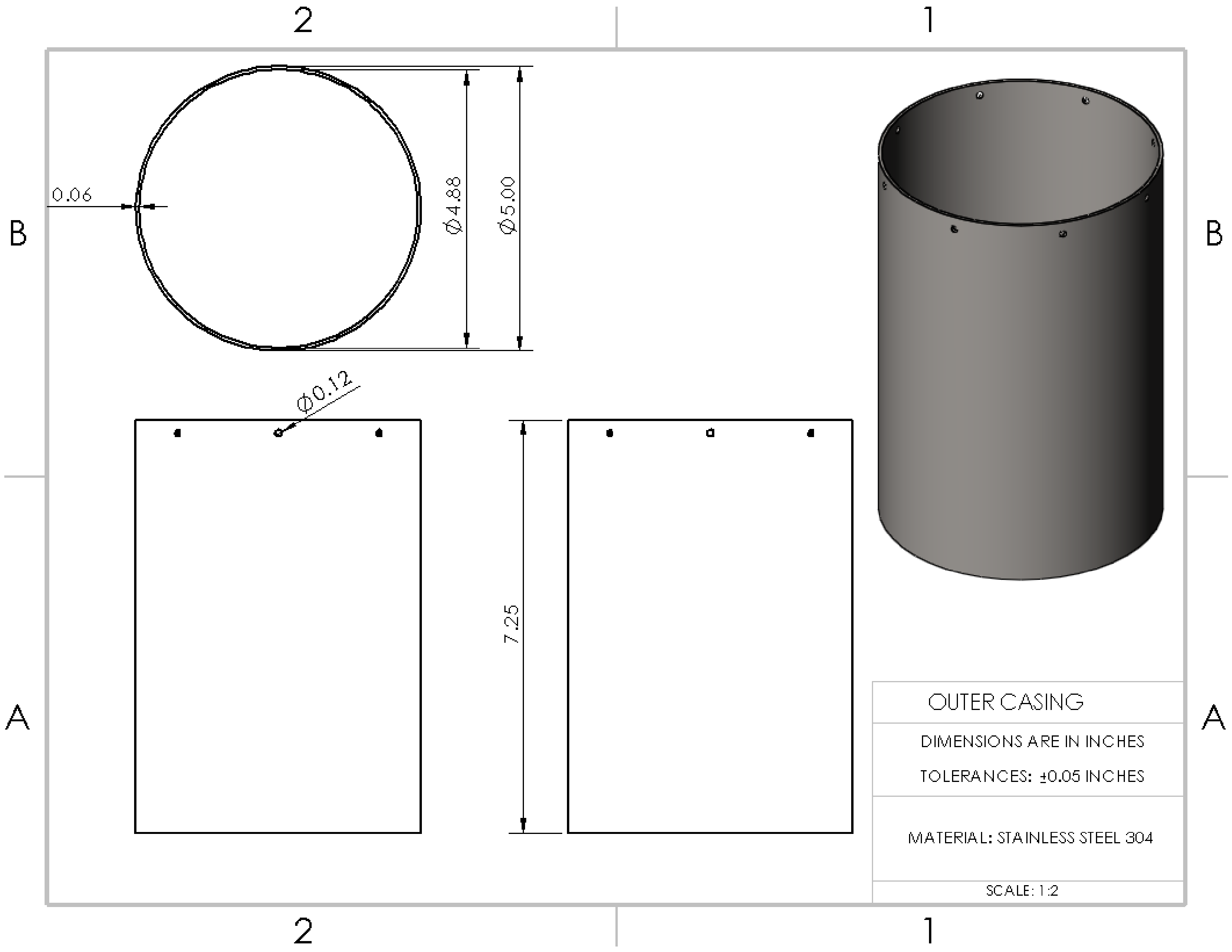
Required Man Hrs: 10

Completed Man Hrs: 0

Outer Casing: Location



Outer Casing: Dimensioned Drawing



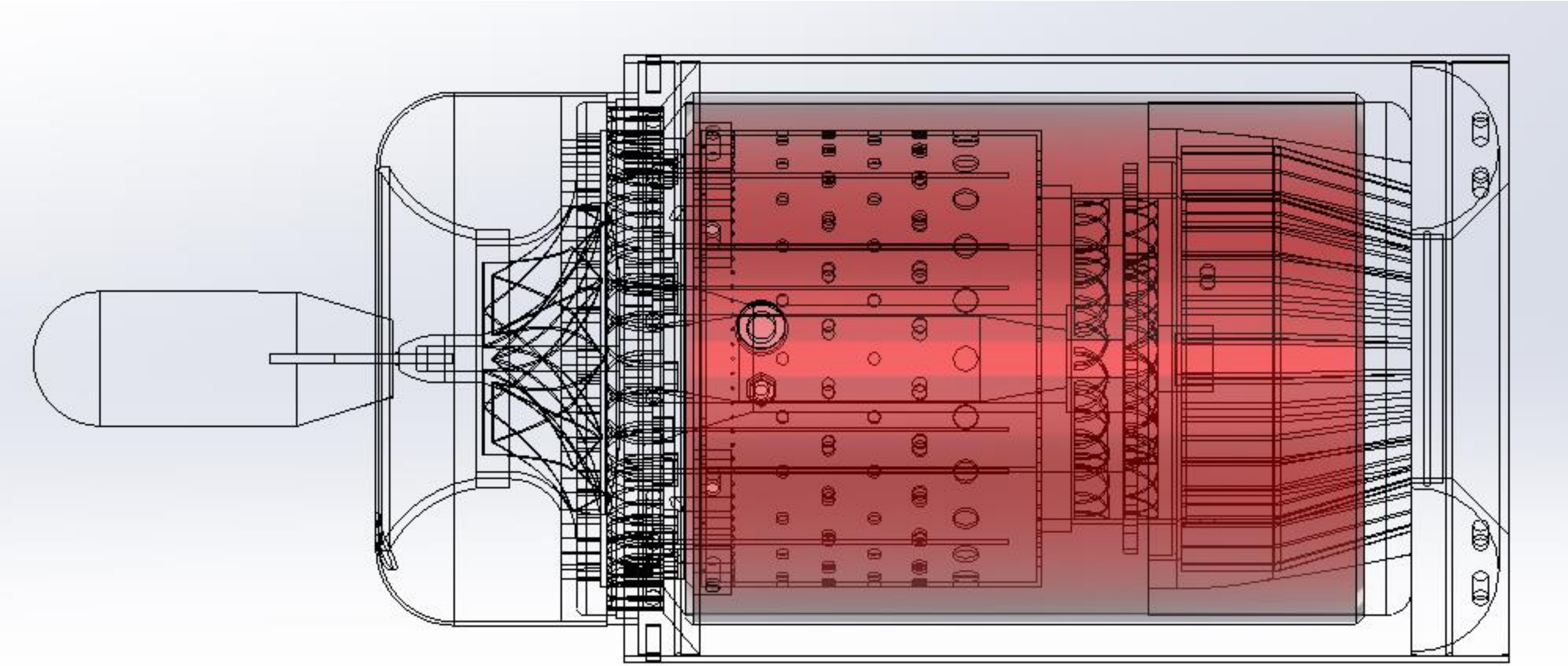
Outer Casing: Manufacturing

- Cut sheet metal to size → 0.5 man hrs
- Drill holes for attachment bolts → 1 man hr
- Roll sheet into tube → 0.5 man hrs
- Weld edges to close tube → 1.5 man hrs

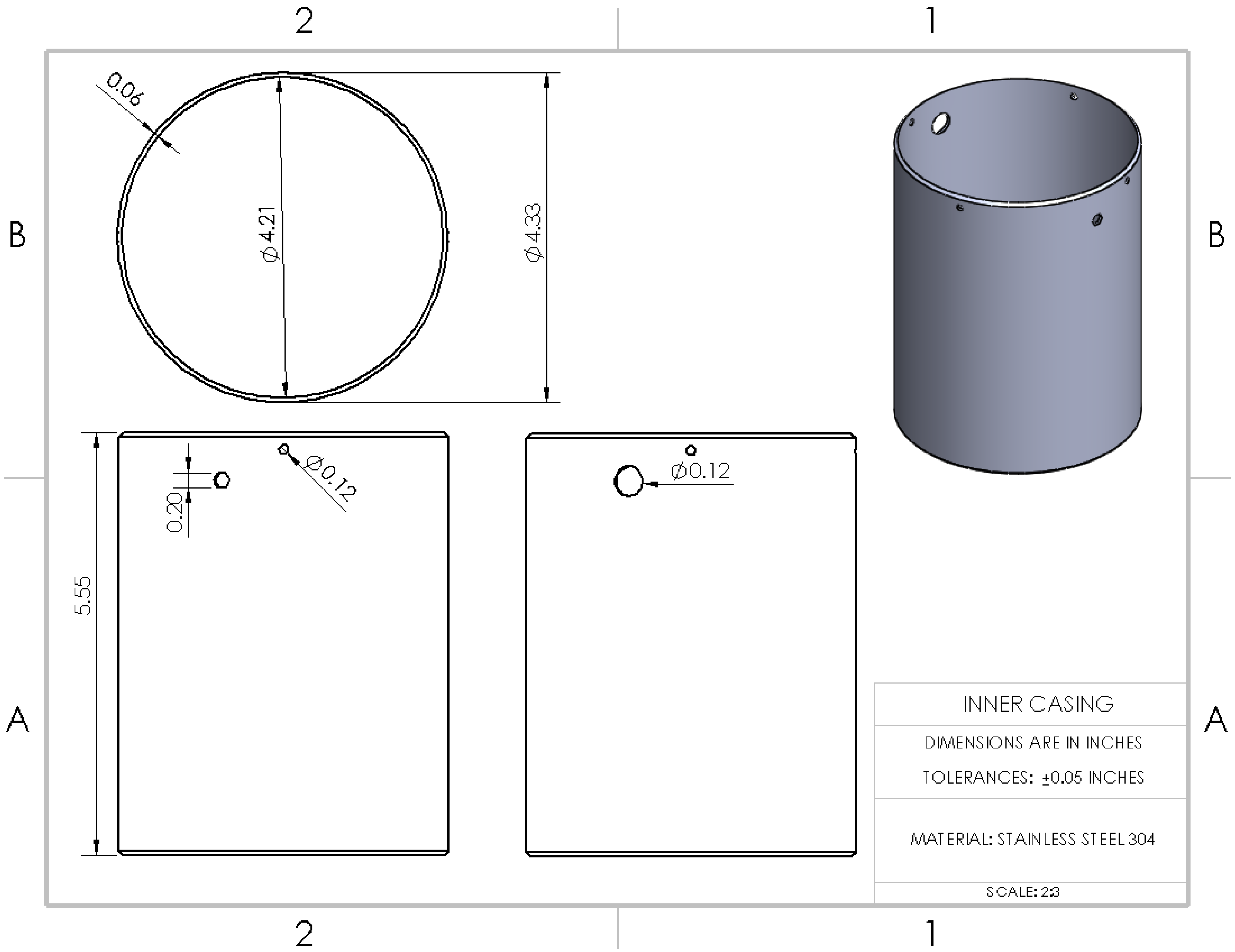
Required Man Hrs: 3.5

Completed Man Hrs: 0

Inner Casing: Location



Inner Casing: Dimensioned Drawing



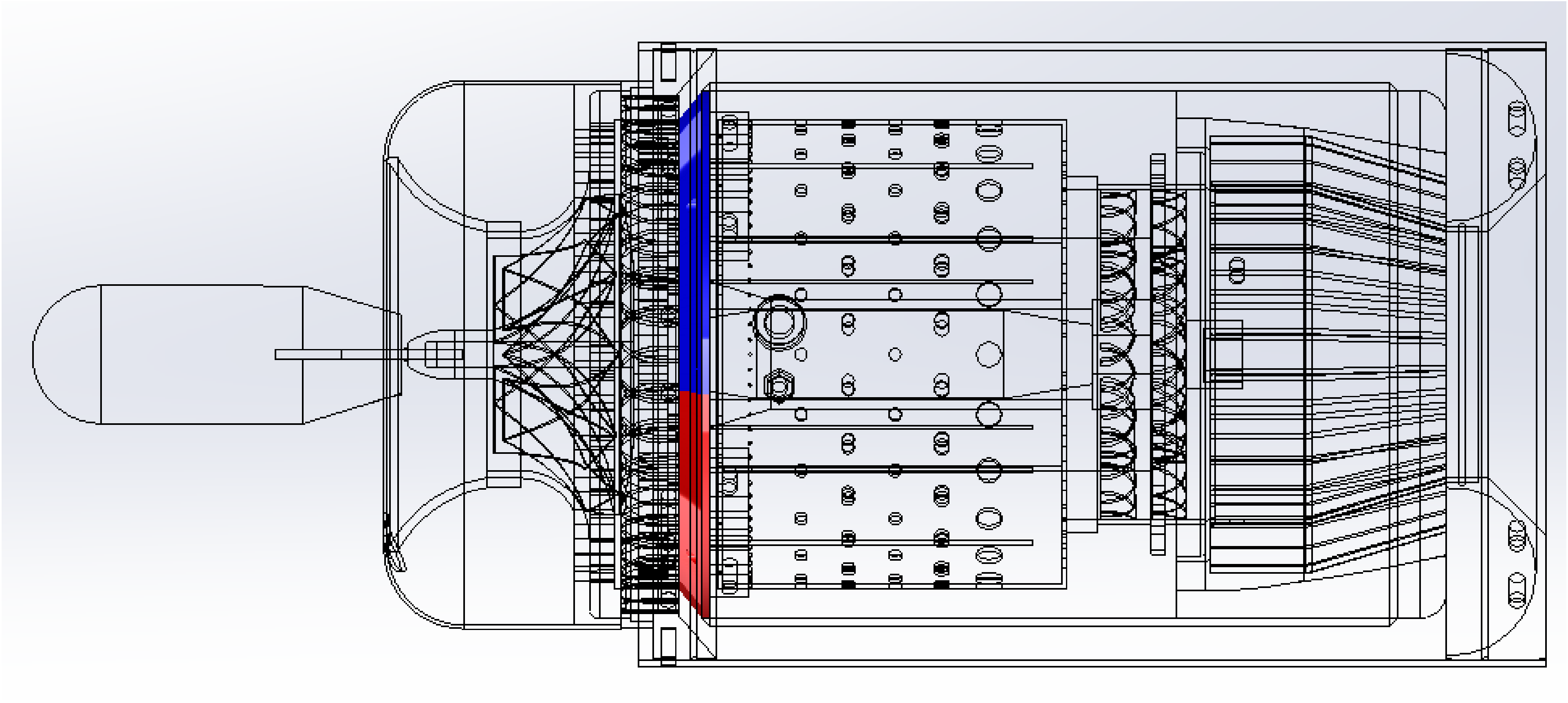
Inner Casing: Manufacturing

- Cut sheet metal to size → .5 man hrs
- Drill holes for attachment bolts and glow plug → 1 man hr
- Create rolling guide part → 2 hrs man
- Roll sheet into tube → .5 man hrs
- Weld edges to close tube → 1.5 man hrs

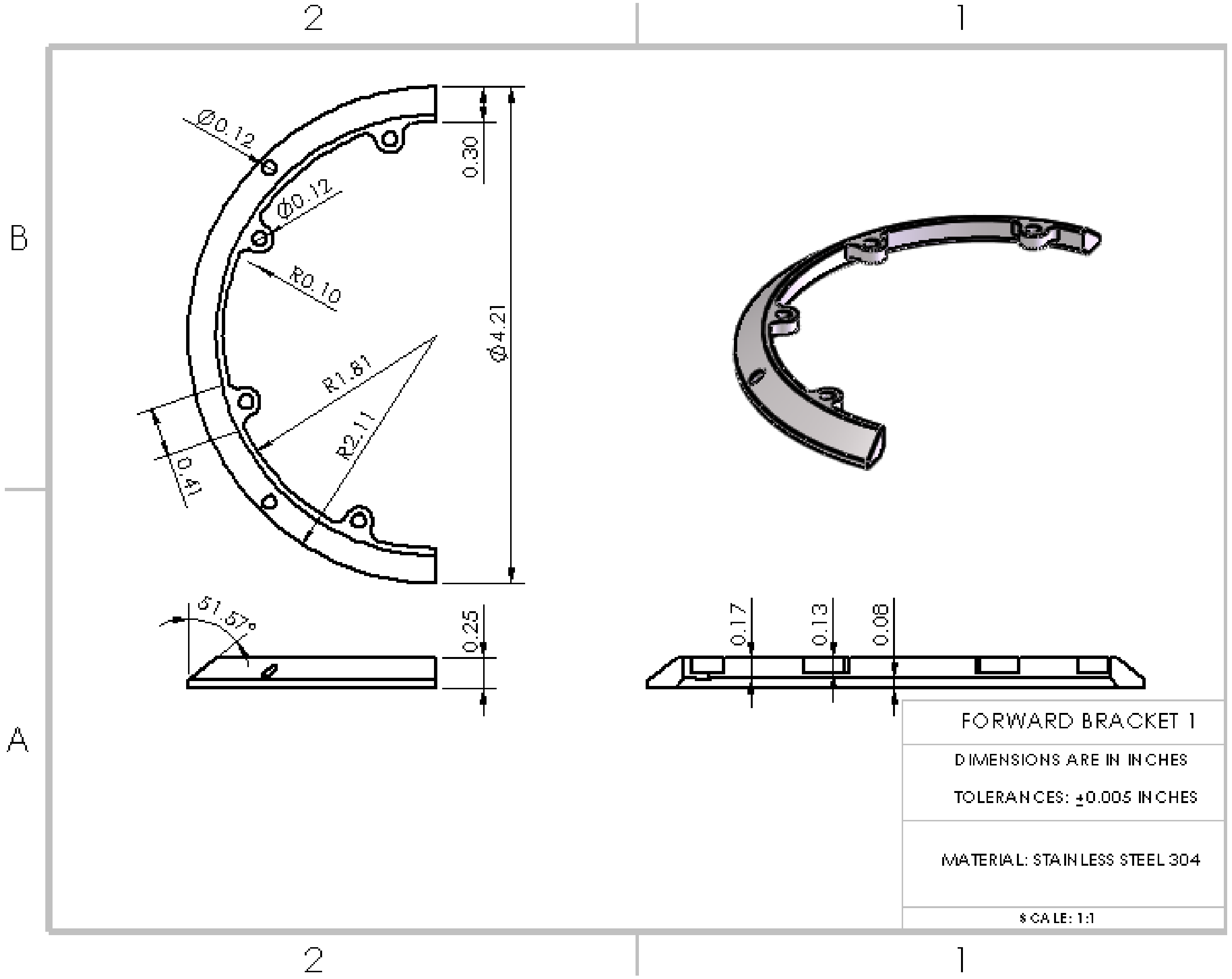
Required Man Hrs: 5.5

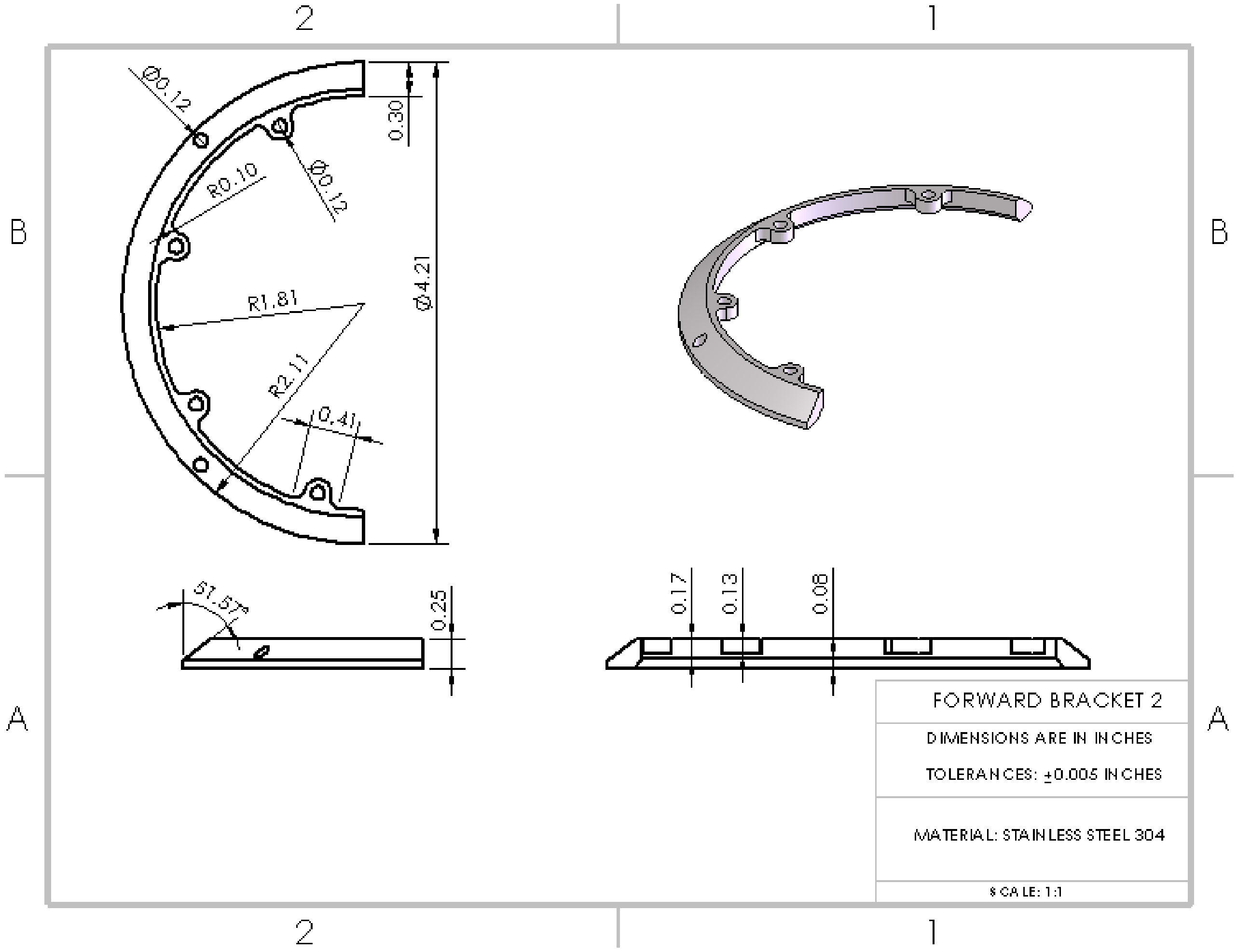
Completed Man Hrs: 0

Forward Brackets: Location



Forward Brackets: Dimensioned Drawing





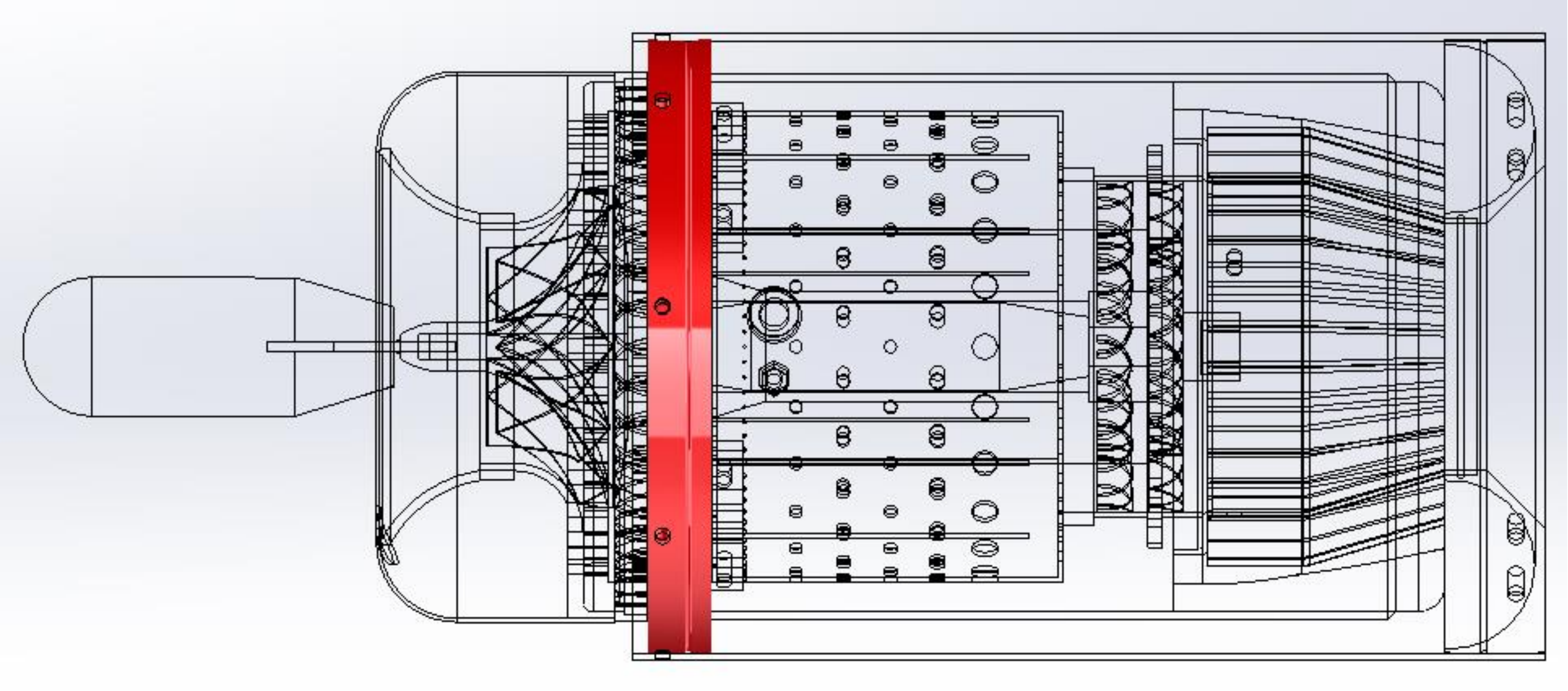
Forward Brackets: Manufacturing

- Band saw off appropriate piece of stock → 2 man hrs
- Drill center hole for CNC lathe → 2 man hrs
- Create outer and inner diameters, and inner chamfer with CNC lathe → 5 man hrs (x2)
- Band saw off newly created ring → 2 man hrs (x2)
- Create o
- Drill all h 2 man hrs (x2)
- Create c → 1 man hr
- Cut off unneeded half of bracket → 1 man hr (x2)

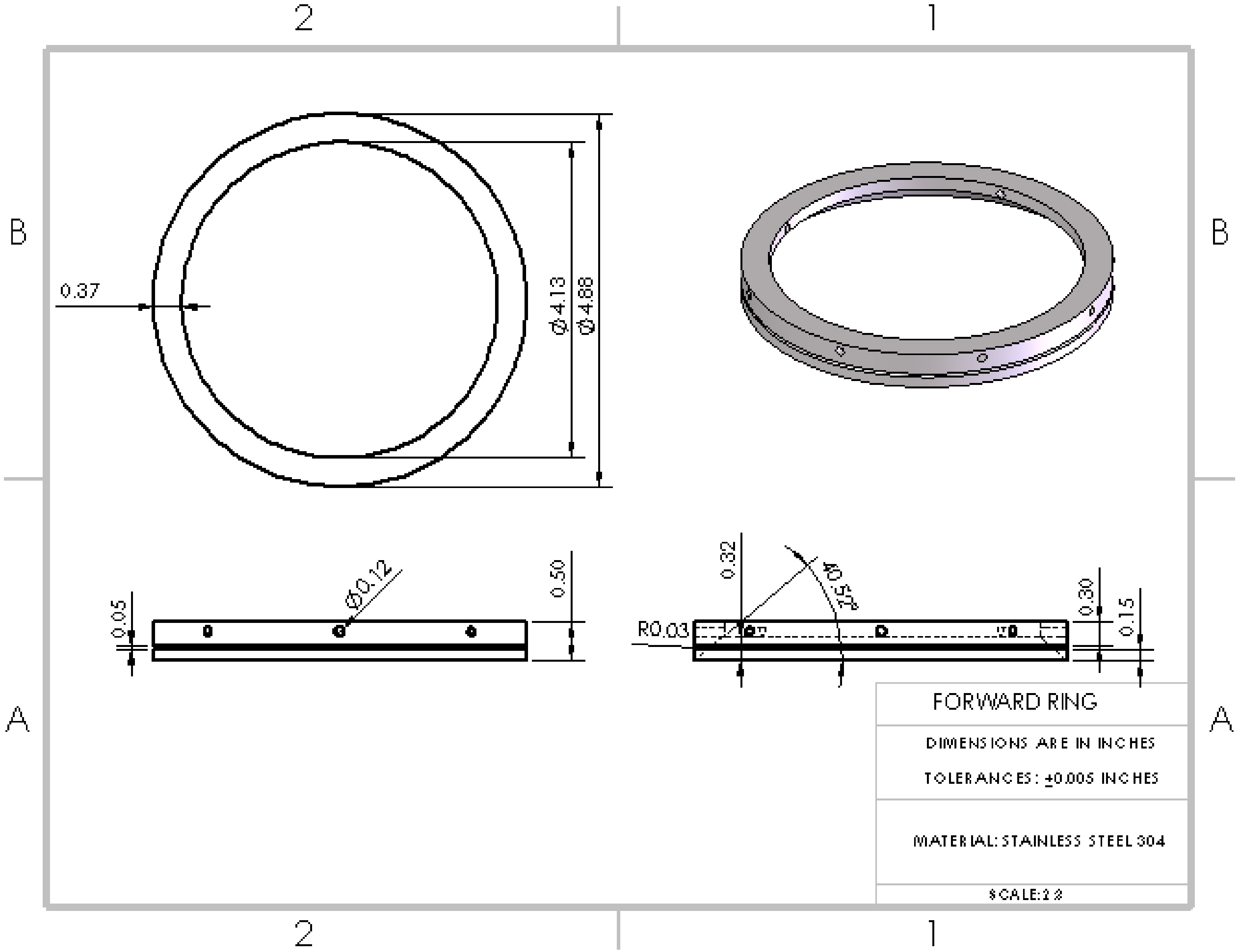
Required Man Hrs: 31

Completed Man Hrs: 4

Forward Ring: Location



Forward Ring: Dimensioned Drawing



Forward Ring: Manufacturing

- Band saw off appropriate length from stock → 2 man hrs
- Drill center hole for CNC lathe → 2 man hrs
- Use CNC lathe to create outer and inner diameters, and inner chamfer → 5 man hrs
- Use CNC mill to drill holes and create channel on outer diameter → 3 man hrs

Required Man Hrs: 12

Completed Man Hrs: 0

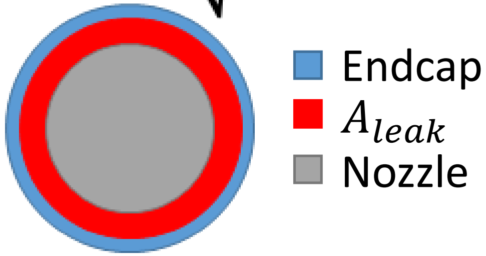
Other Manufacturing

- Weld End Cap to Outer Casing → 1.5 man hrs
- Weld Nozzle Shroud to Inner Casing → 1.5 man hrs
- Assembly of final recuperating engine → 6 man hrs

Required Man Hrs: 9

Pressure Leak: Magnitude

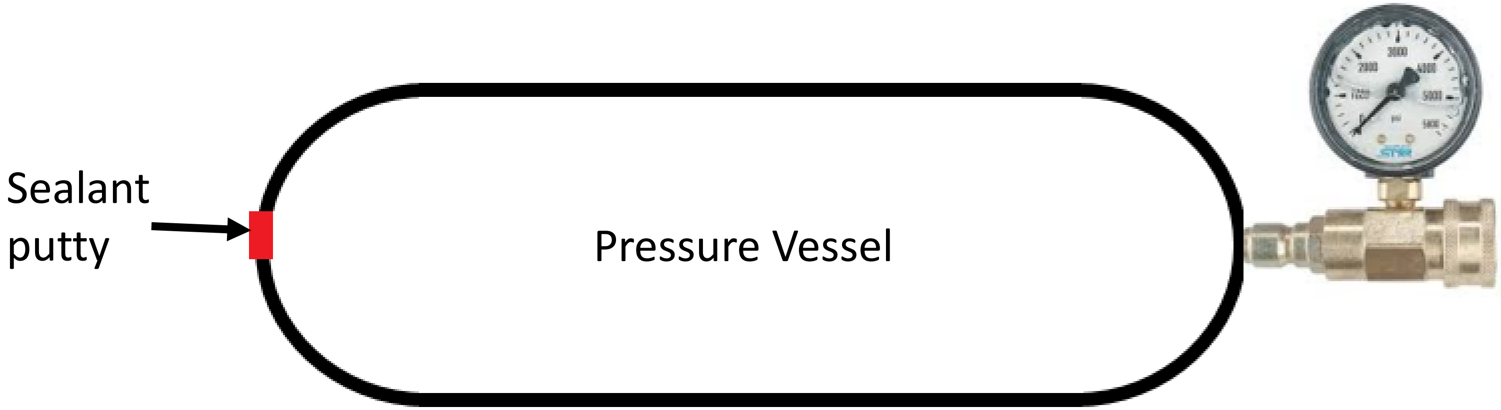
- Most likely to occur at joint of Endcap and Nozzle
- $\dot{m} = C * A_{leak}\sqrt{2\rho_{engine}\left(P_{engine} - P_{atm}\right)}$
- $A_{leak} \rightarrow$



$$A_{leak} = \pi((r_{Nozzle} + gap)^2 - r_{Nozzle}^2)$$
$$A_{leak} = 2E^{-5}\ m^2$$

- $\rho_{engine} = 3.6\frac{kg}{m^3}$
- $P_{engine} = 2.6\ atm = 263445\ Pa, P_{atm} = 1\ atm = 101325\ Pa$
- $C = .625 \rightarrow$ hole flow coefficient, between .6 and .65
- $\boxed{\dot{m} = .014\frac{kg}{s}}$

Leak Analysis – Test Setup



Assume Ideal Gas → $\rho = \frac{P}{RT}$

$$\dot{m} = V\frac{\partial\rho}{\partial t} = V\left(\frac{\partial\rho}{\partial P}\frac{\partial P}{\partial t} + \frac{\partial\rho}{\partial R}\cancel{\frac{\partial R}{\partial t}} + \frac{\partial\rho}{\partial T}\cancel{\frac{\partial T}{\partial t}}\right)$$

$$\dot{m} = \mathrm{V}\left(\frac{1}{RT}\frac{\partial P}{\partial t}\right)$$

Pressure Leak: Performance Impact