SPECS

Specialized Propulsion Engine Control System

Preliminary Design Review

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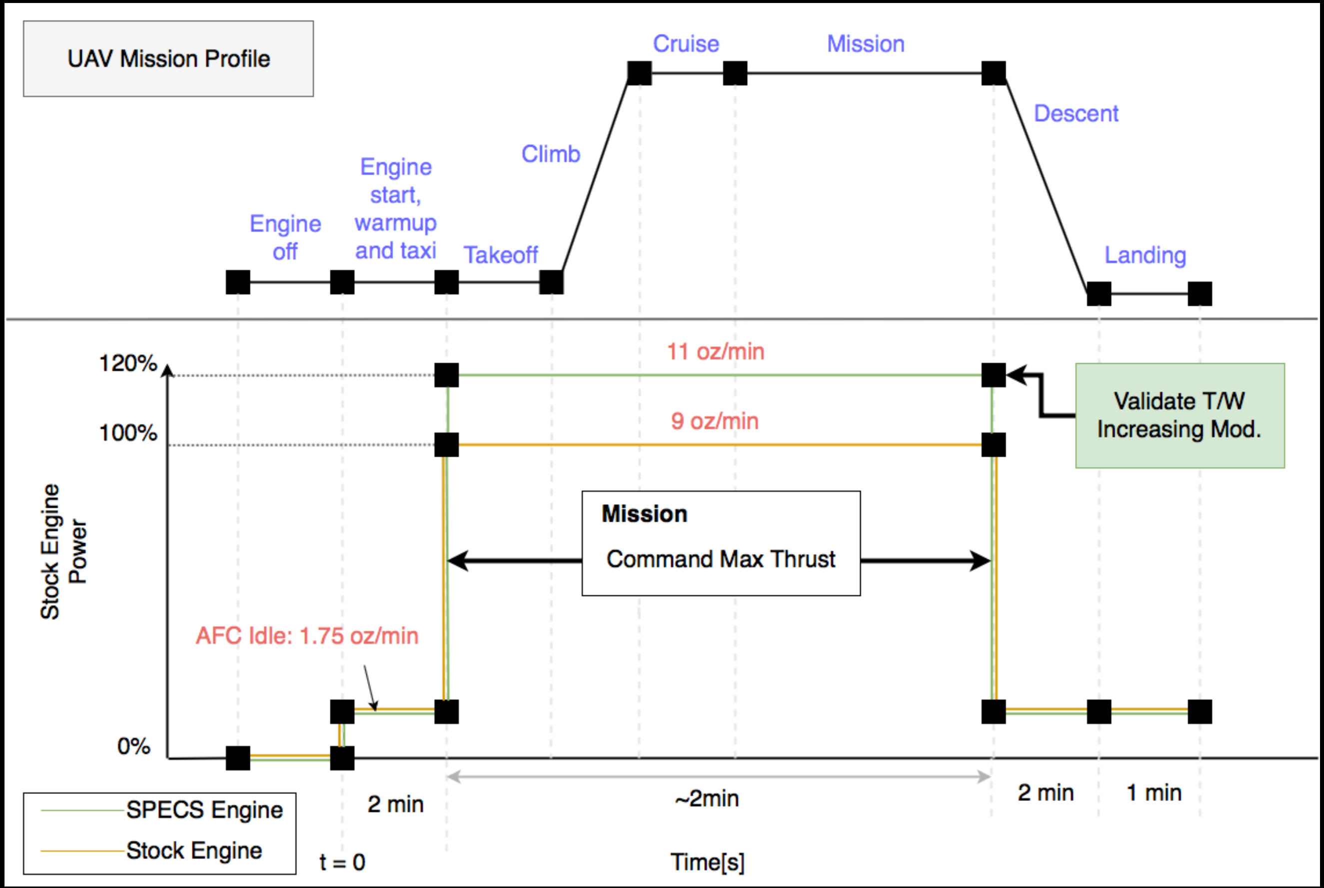
PROBLEM STATEMENT

- Increase Thrust-to-Weight (T/W) Ratio of the JetCat P90-RXi Engine
- The engine must run for an extended period of time

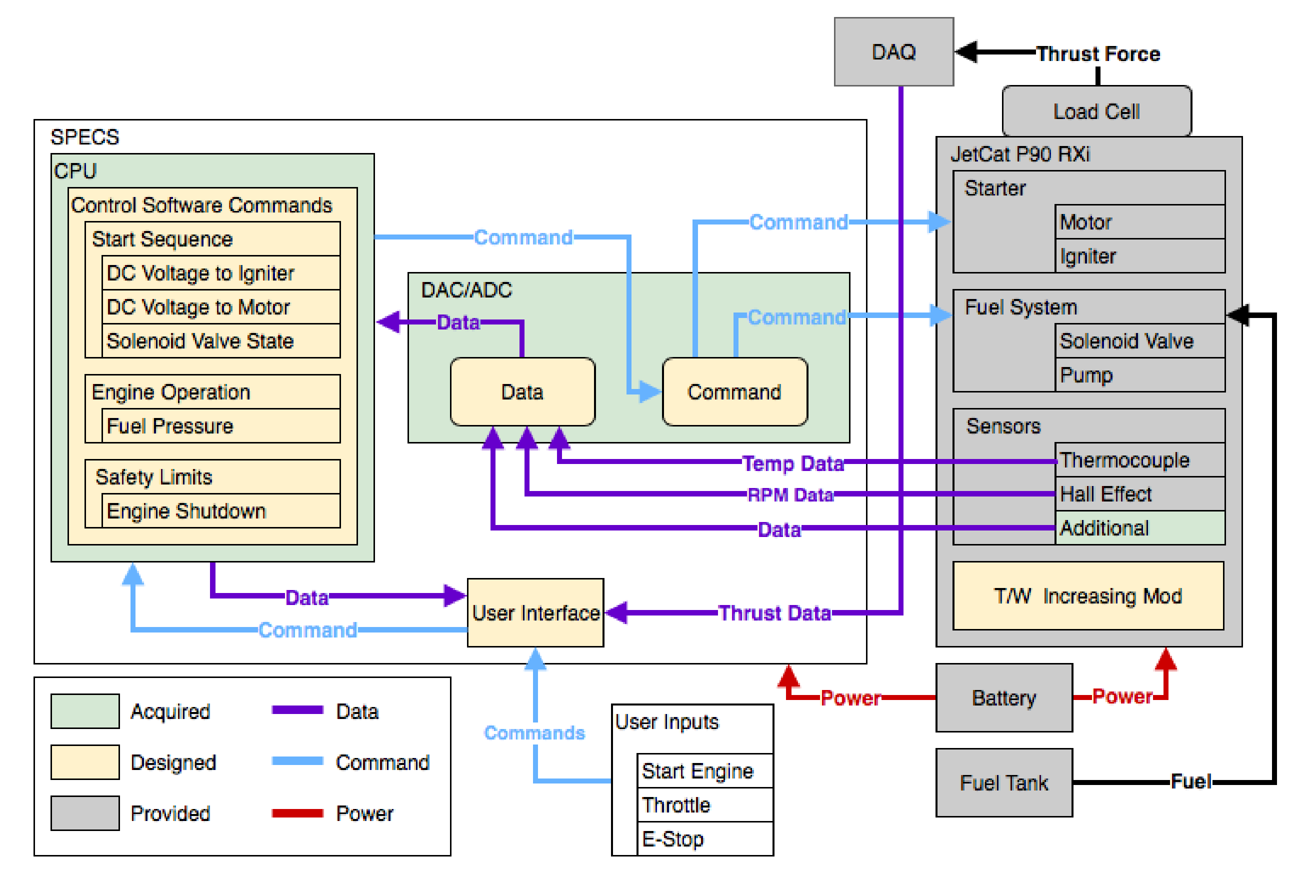
<u>Motivation</u>

- The United States Air Force (USAF) would like to implement a T/W increasing modification into their fleet of Unmanned Aerial Vehicles (UAV)
- Ideal solution would be low cost and easy to implement with minimal modification to existing engine

CONCEPT OF OPERATIONS



FUNCTIONAL BLOCK DIAGRAM



FUNCTIONAL REQUIREMENTS

1. The JetCat P90-RXi engine shall have an increased T/W ratio of 20% from stock parameters.

2. SPECS shall control the engine over the entire operational envelope.

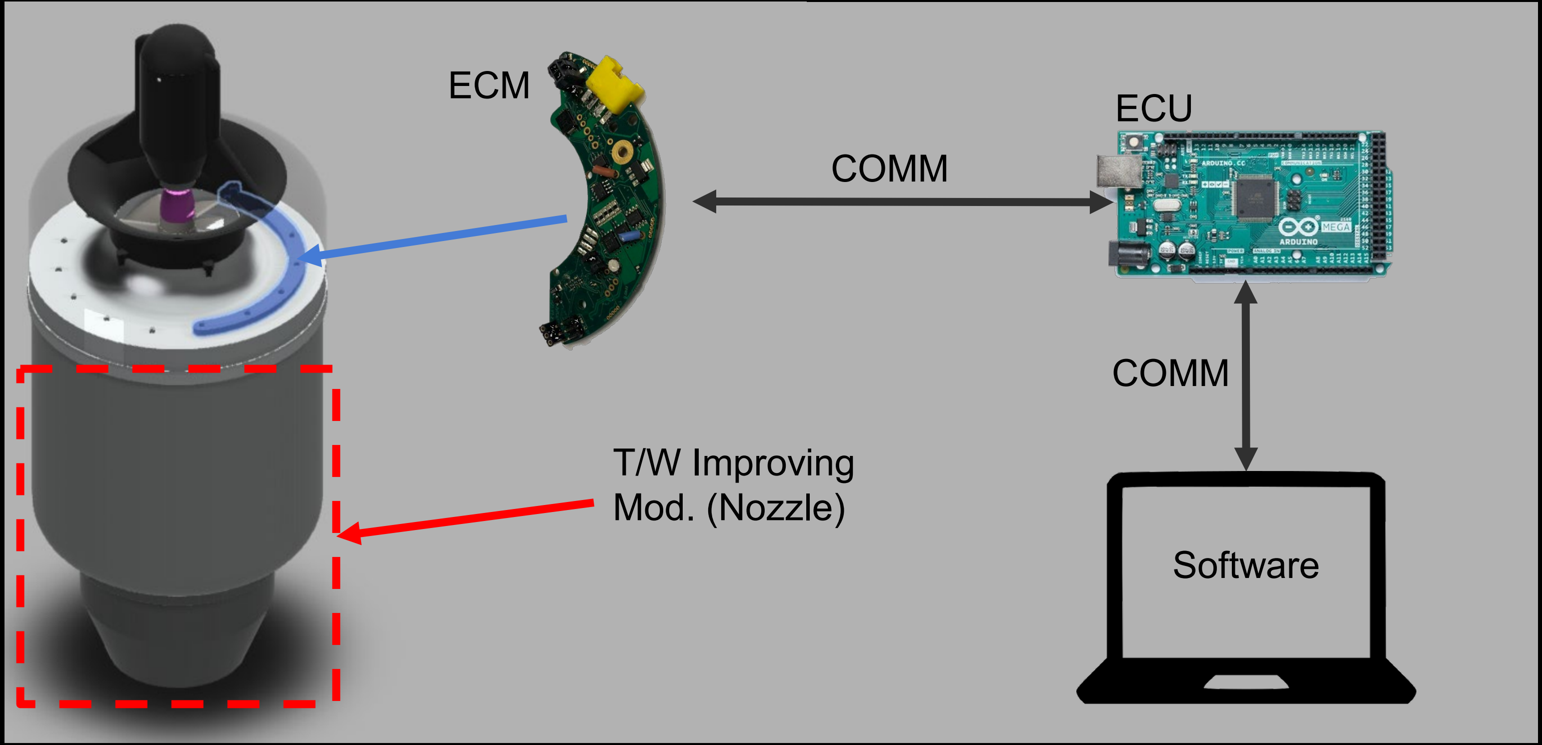
3. SPECS shall run the engine in a safe manner.

4. SPECS shall have a user interface for engine control.

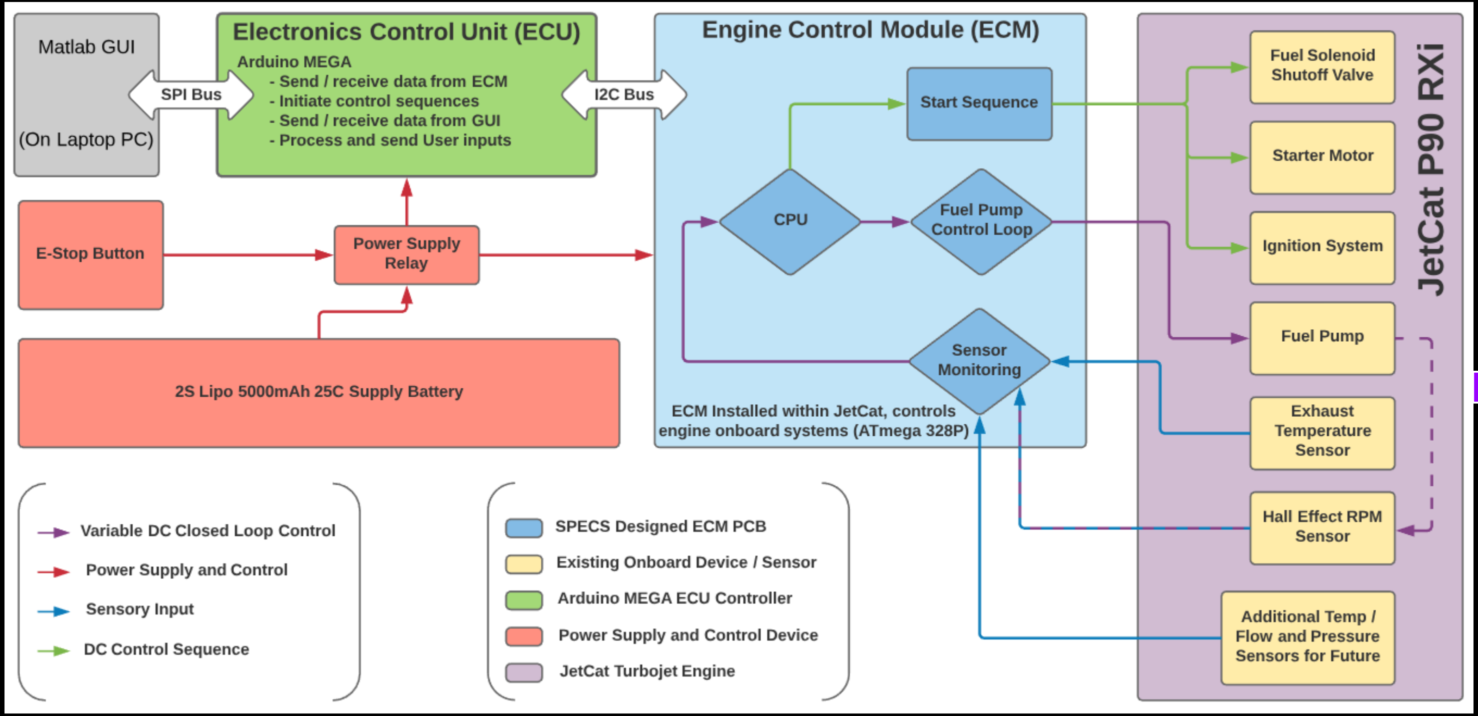
CRITICAL PROJECT ELEMENTS

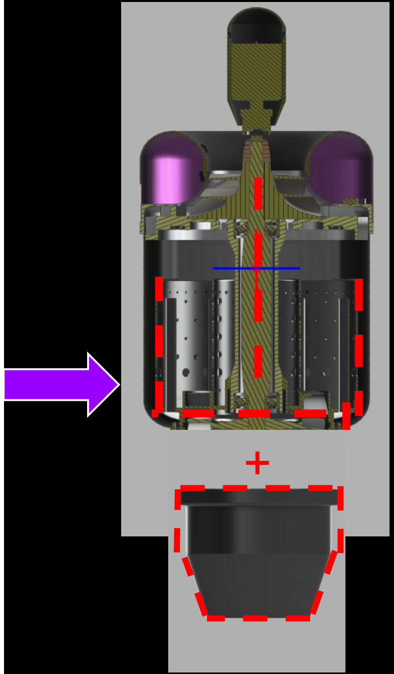
- Thrust Improvement Modification (π_C + Nozzle)
    - Compressor Pressure Ratio (π_C)
    - Material Properties
- Engine Control Module (ECM)
    - Engine Control Loop
    - Engine Sensors
- Electronic Control Unit (ECU)
    - Communication from User to Engine

BASELINE DESIGN - OVERVIEW I



BASELINE DESIGN - OVERVIEW II





Thrust Improving Modification

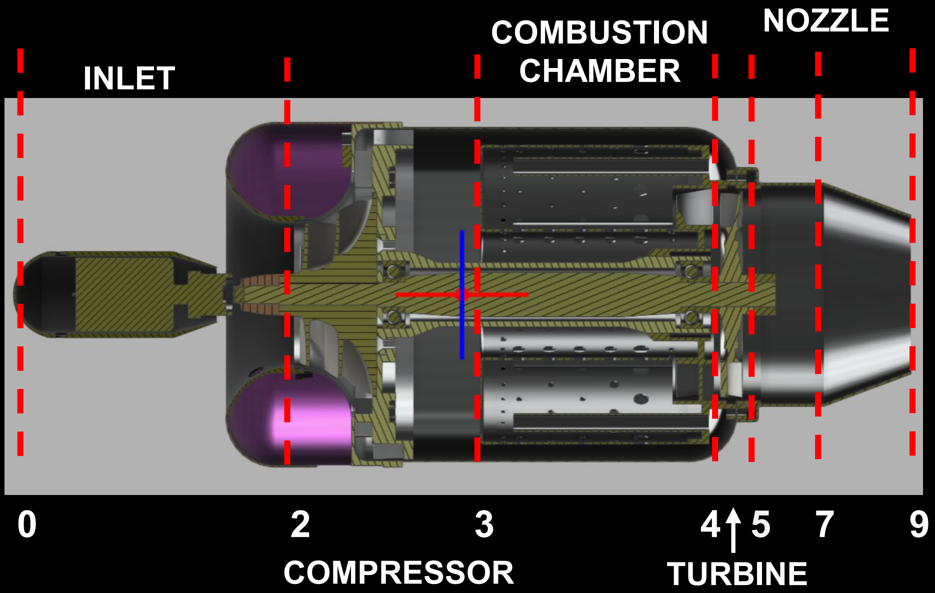
BASELINE DESIGN - THRUST IMPROVING MOD (π_C)

- To increase thrust by 20%, a higher total temperature is required in the combustion chamber (T_{t4}) which directly increases pressure ratio across the compressor (π_C)
- To increase T_{t4}, must increase fuel flow which increases thrust from stock 100 N @ 130,000 RPM

Needs: Increased compression ratio in combustion chamber from stock π_C = 2.35

Capabilities: Increase pressure ratio in combustion chamber by increasing engine compressor RPM

$$\pi_c = \frac{P_{t_3}}{P_{t_2}}$$



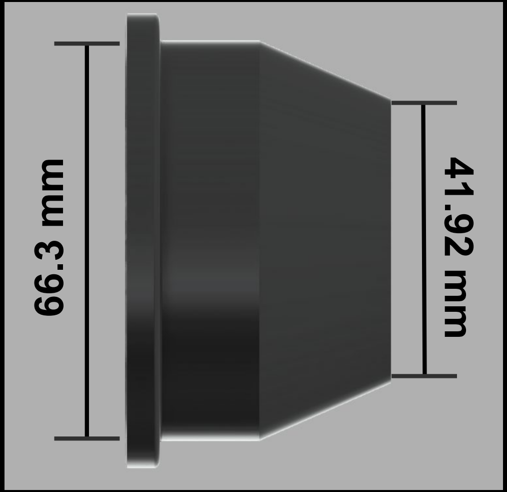
BASELINE DESIGN - THRUST IMPROVING MOD (NOZZLE)

- With a new π_C, the exhaust flow must be perfectly expanded at the nozzle exit for max thrust

Needs: New exit area of nozzle to perfectly expand the exhaust flow due to new π_C

Capabilities: Expand flow to sea level atmospheric conditions at the nozzle exit

$$(1 - M^2)\frac{dV}{V} = -\frac{dA}{A}$$



New Nozzle

BASELINE DESIGN - ECU

Purpose: Offboard communication device between ECM and user interface. Performs computation of system parameters to output to GUI

Needs:

- Send engine state requirements to ECM
- Send engine throttle commands from user to ECM
- Receive sensor data from ECM for processing

Capabilities: (Arduino Mega)

- I2C communication
- 54 Digital I/O pins
- 256 kB Flash Memory (store program and data)
- 4 x 16 bit timers (control complex timing sequence)
- 4 UART (connect many devices)

Arduino Mega

BASELINE DESIGN - ECM

Purpose:

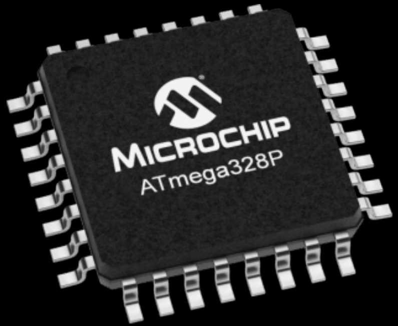
- Control engine sequence operation: Start, Run, Shutdown.
- Control engine to commanded throttle setting from ECU

Needs:

- Read RPM and temperature data from Hall effect and thermocouple respectively
- Perform DAC/ADC
- PWM motor control
- I2C & SPI communication

Capabilities: (ATmega 328P)

- 6 PWM channels
- 20 MHz oscillator
- 32 kBytes flash memory
- 8-channel 10-bit ADC
- I2C and SPI capable
- 500 kHz internal sampling rate for digital inputs



ATmega 328P

BASELINE DESIGN - ECM (HALL EFFECT SENSOR)

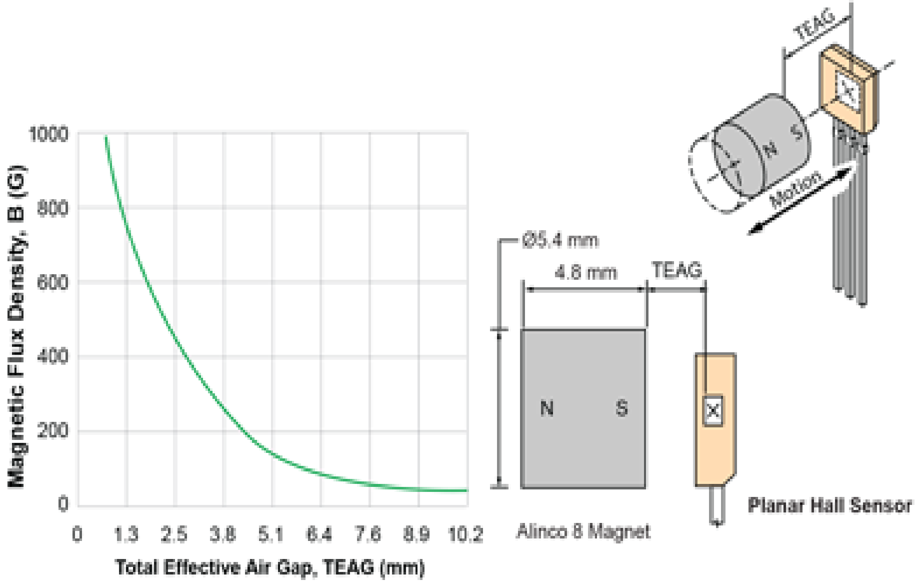
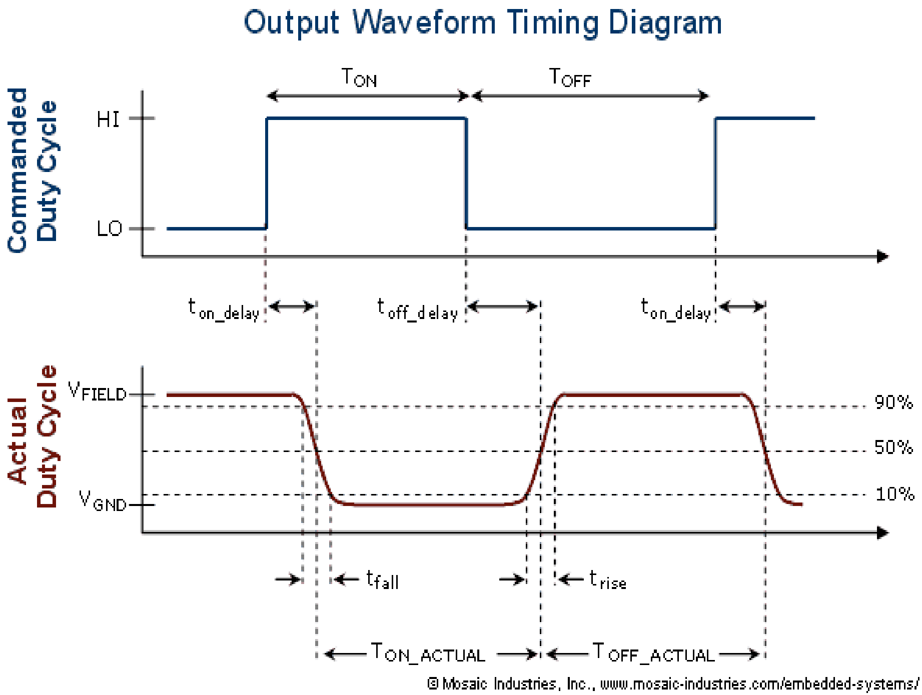


Figure 12B. Demonstration of head-on mode of operation



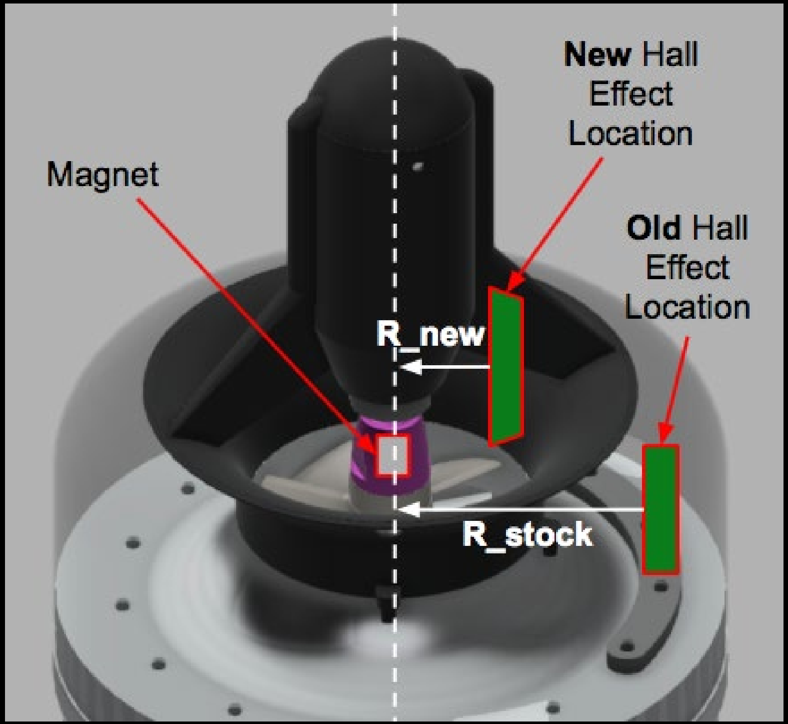
BASELINE DESIGN - ECM (HALL EFFECT SENSOR)

Purpose: Sense RPM, output square wave for engine control

Needs: Sense RPM >130 kRPM, output to microprocessor, read pulse width to calculate RPM

Capabilities: Hall effect Honeywell SS40A - Measured pulse width duty cycle at 42.5% for 5 kRPM. Pulse width at 130 kRPM is 197.5 µs; 13 µs minimum pulse width for rise / fall and response time of Hall effect sensor

Application Note: Starter assembly - redesign and 3D print to capture Hall effect sensor and route wire to ECM without inlet obstruction

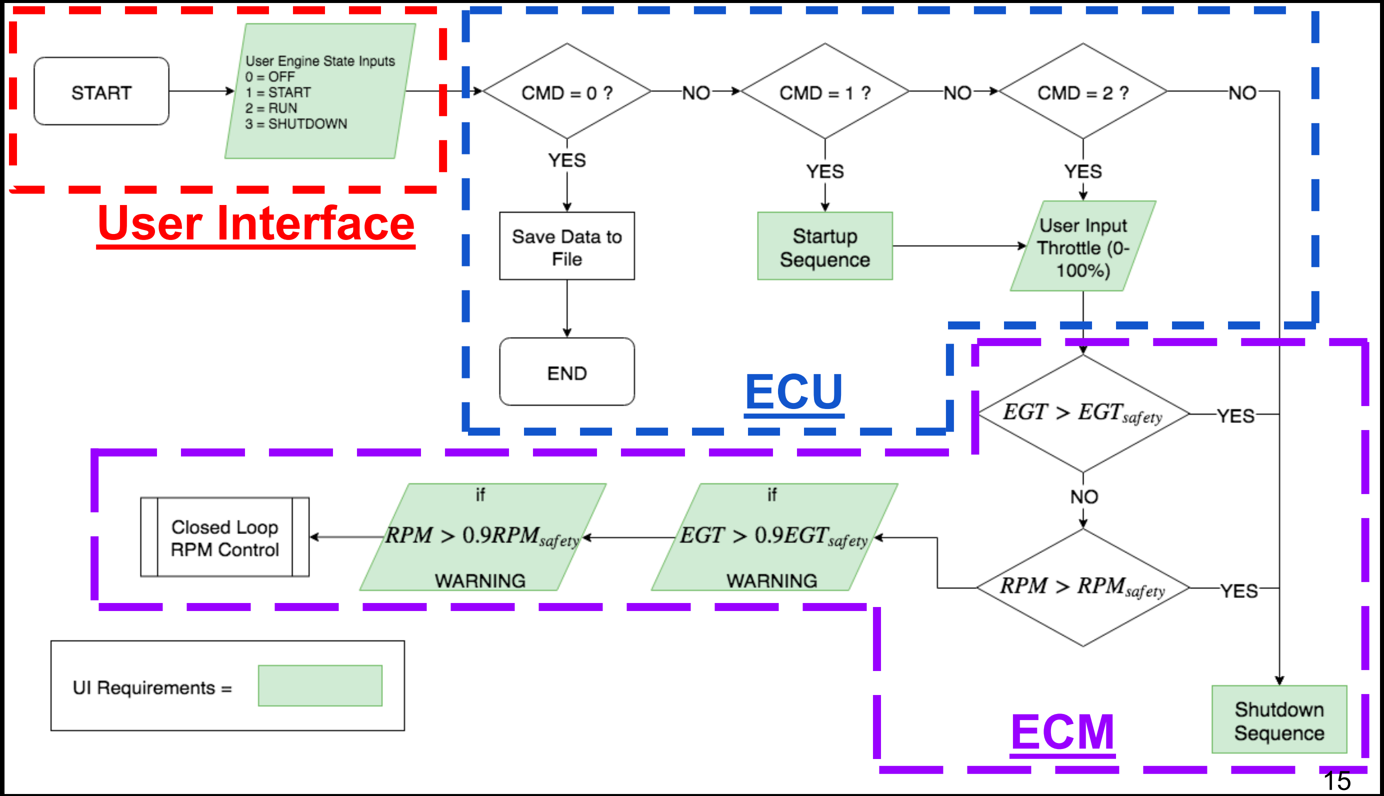


BASELINE DESIGN - SOFTWARE

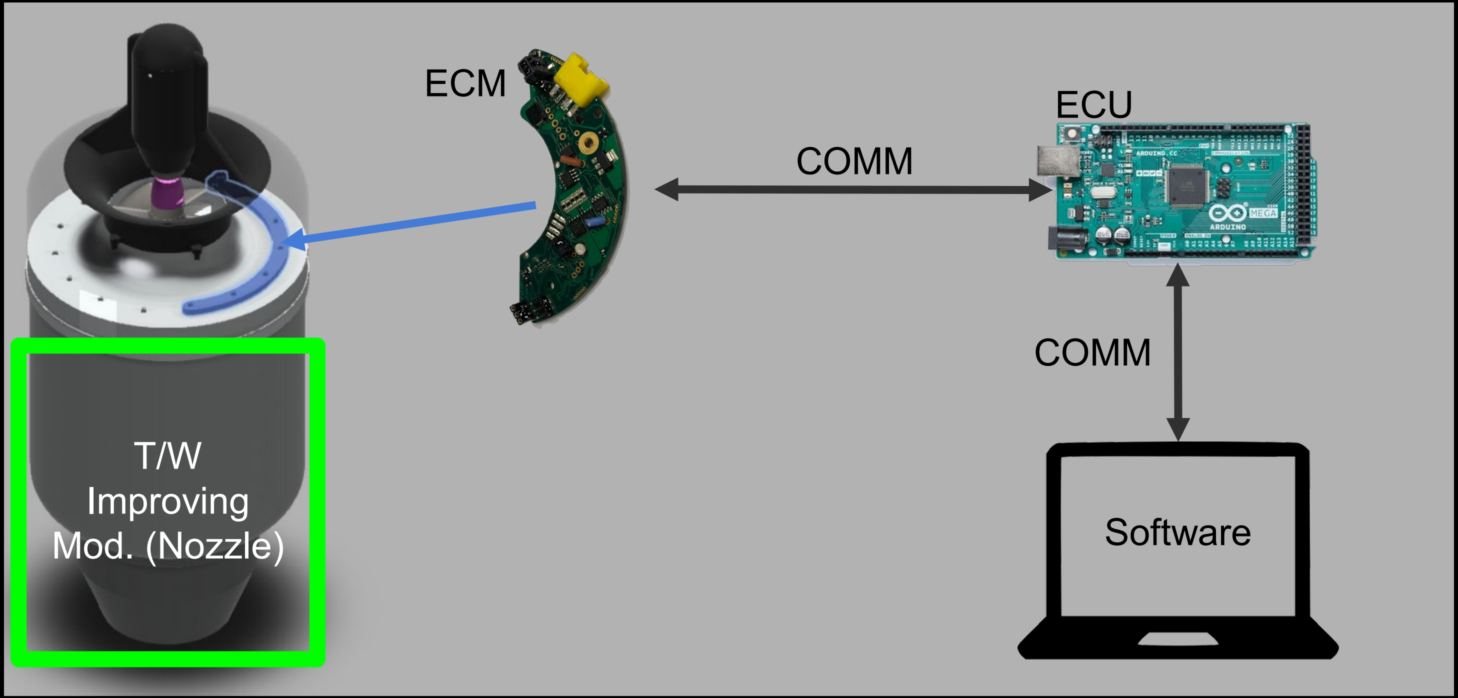
- **Purpose:** Implements user input commands, closed loop control
- **Needs:** Allow user to control the state of the engine
- **Capabilities:**

- RPM from Hall effect sensor, fed back through a closed loop controller, modifies signal to the fuel pump to match commanded RPM

- Checks RPM and EGT for safe operating conditions

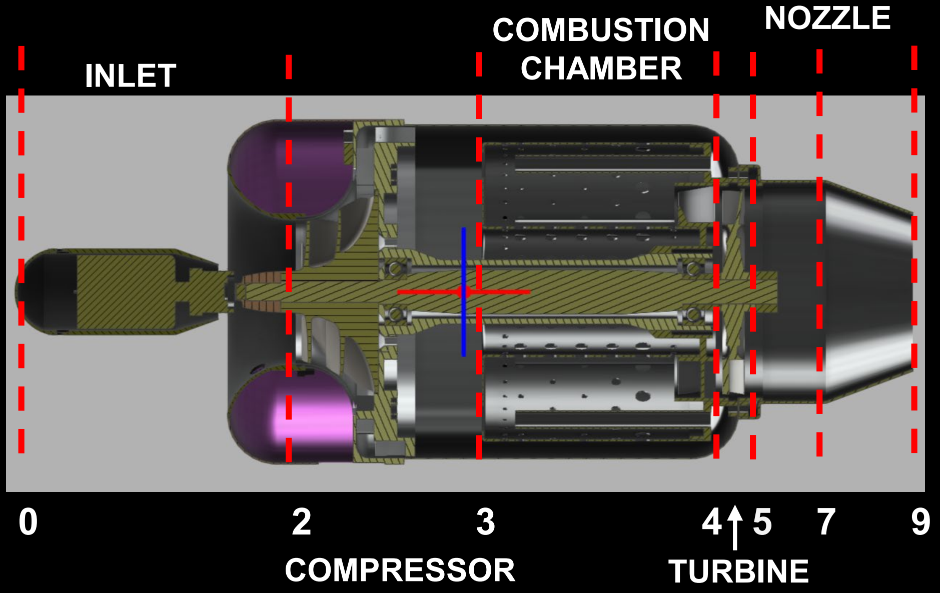


SUBSYSTEM FEASIBILITY - THRUST IMPROVEMENT



THRUST IMPROVEMENT FEASIBILITY OVERVIEW

1. Fuel flow is increased
2. T_{t4} increases
3. Turbine is driven to higher RPM
4. Compressor pulls in more air with new RPM
5. π_C increases
6. Flow is underexpanded with stock nozzle
7. Nozzle is redesigned with smaller exit area (increased flow velocity, decreased pressure ⇨ perfectly expanded at the exit)



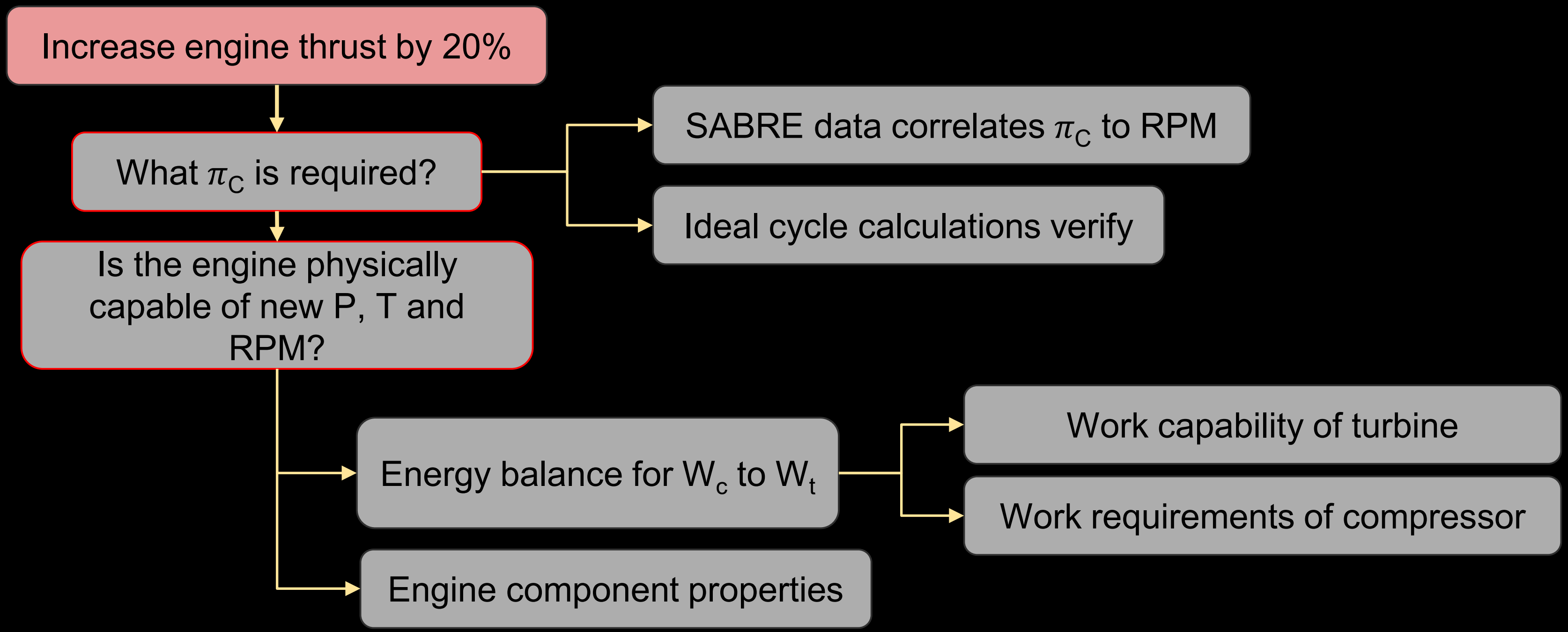
THRUST IMPROVEMENT REQUIREMENTS

FR.1: The JetCat P90-RXi engine shall have an increased T/W ratio of 20% from stock parameters.

DR 1.1: Implement a T/W improving modification that does not affect the overall operation of the engine and its ability to run for an extended period of time (2 minutes).

DR 1.2: Any modifications to the engine will not reduce the factor of safety of any engine component below 1.3 per USAR.

MODIFICATION FEASIBILITY PROCESS



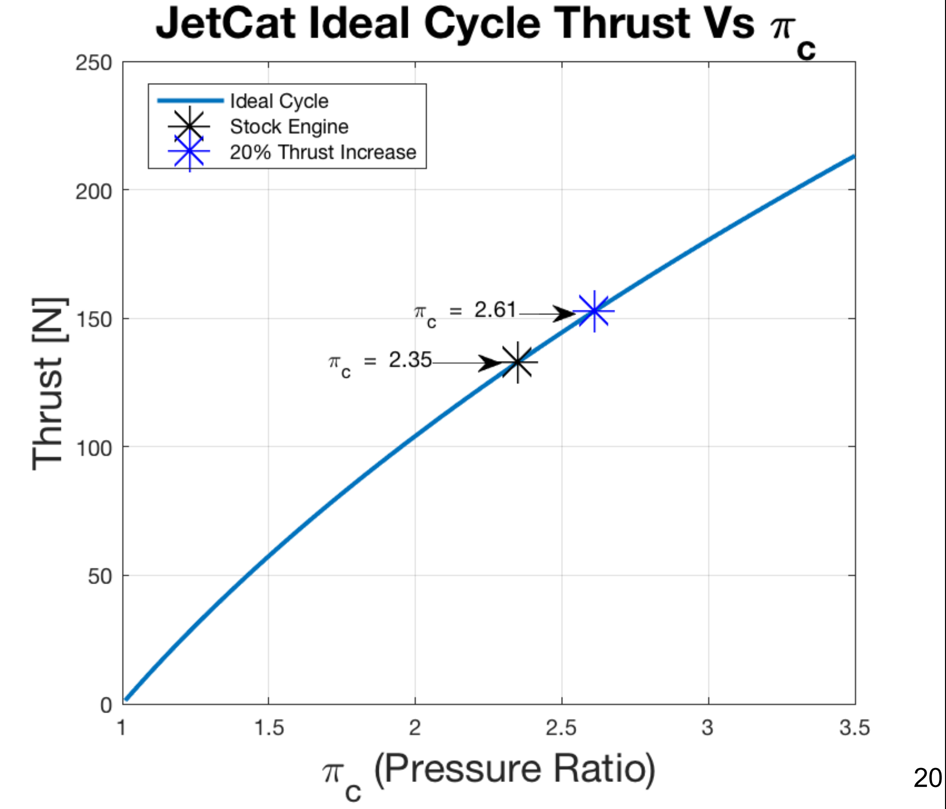
IDEAL COMPRESSOR PRESSURE RATIO

Pressure ratio (π_C) calculation for 20% increase in thrust assuming:

- Ideal Brayton cycle
- Axial compressor

$$F_{uninstalled} = \dot{m}_0(V_9 - V_0)$$

<u>Model results:</u> Ideal Brayton cycle requires π_C = 2.61 to feasibly obtain 20% thrust increase

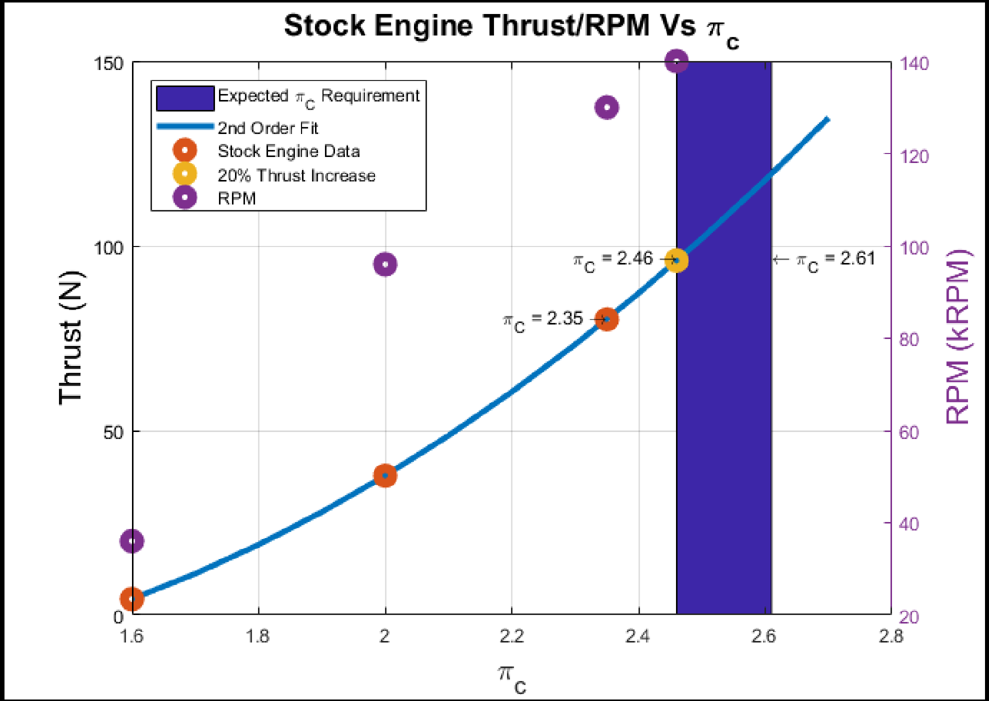


STOCK ENGINE COMPRESSOR PRESSURE RATIO

Pressure ratio observation for 20% increase in thrust:

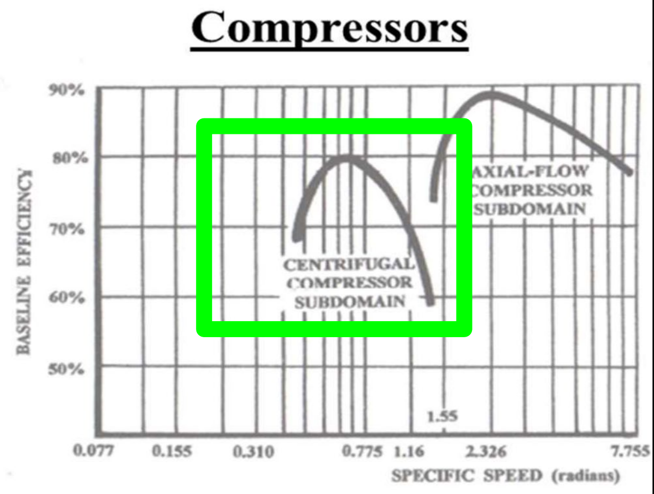
- Observed in SABRE data
  - Provides a lower bound for expected value of π_C
- Required π_C therefore expected to fall between:
  - 2.46 (real) - 2.61 (ideal)

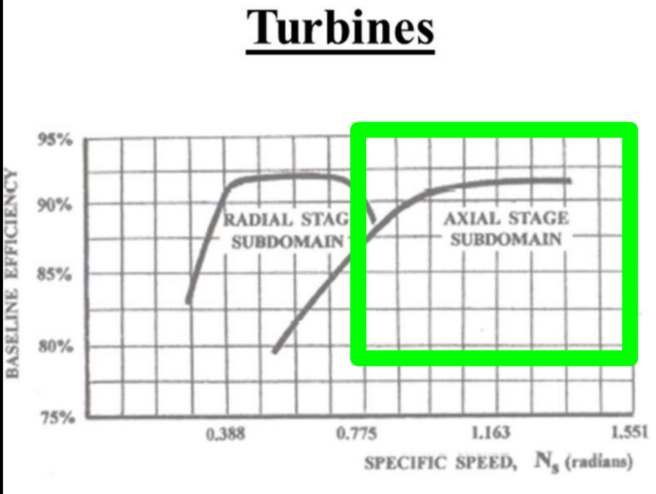
<u>Model results:</u> Increased thrust with π_C = 2.46 is feasible to obtain with ~10,000 RPM increase



PRESSURE RATIO FEASIBILITY

Ideal	Compressor Work (required)	Turbine Work (available)
Stock	19.99 kW	48.01 kW
20% Increase	22.3 kW	46.1 kW

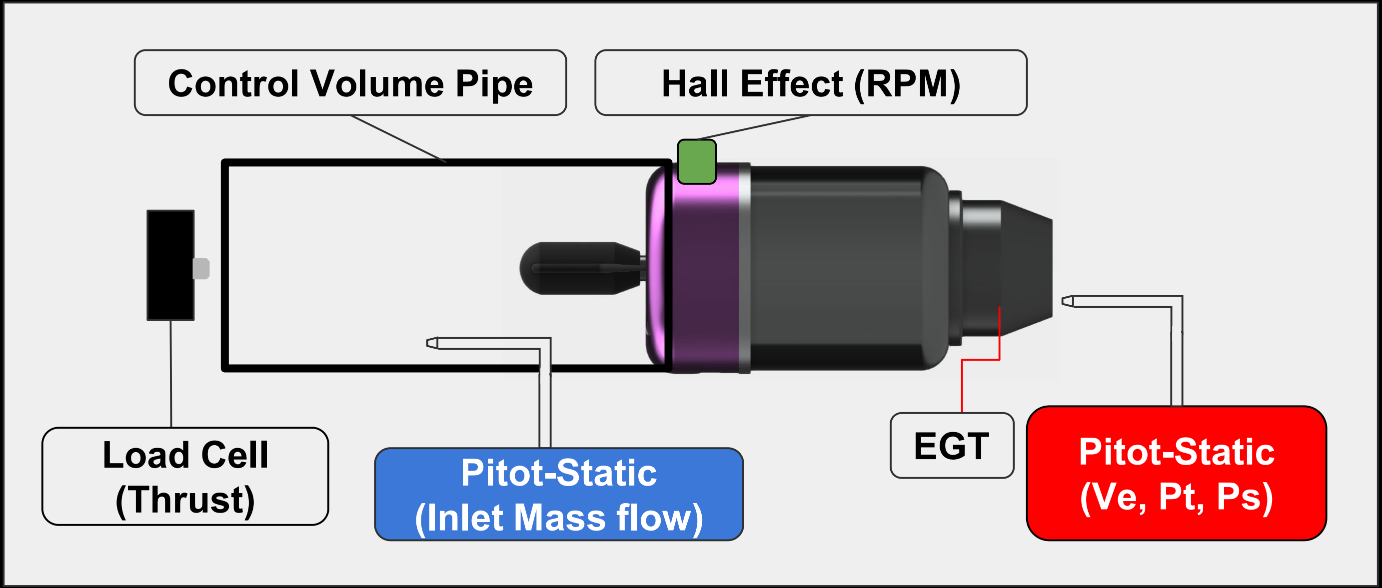




Result: Thrust increase is feasible since there is excess work available from the turbine

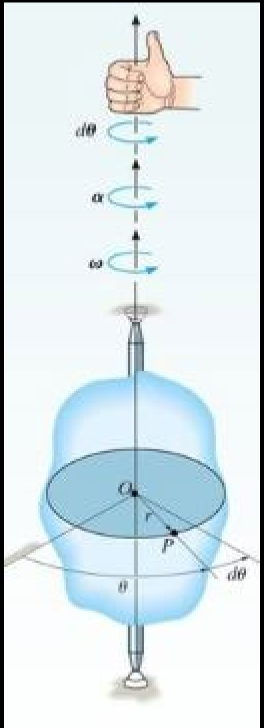
OVERALL IDEAL CYCLE FEASIBILITY (SUMMARY)

- Excess Work Available ⇨ Increase Pressure Ratio ⇨ Increase Thrust
- Improving the engine cycle model requires engine test runs to gather: Inlet Mass Flow, Thrust, EGT, RPM, Exit Velocity, Total & Static Exit Pressure

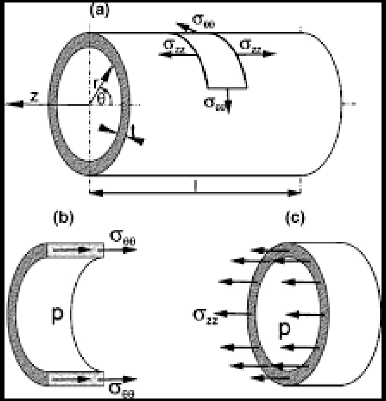


ENGINE COMPONENT ANALYSIS MODEL

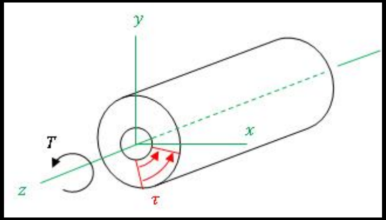
- Compressor/Turbine
  - Angular Motion
    - Low angular acceleration, high angular velocity
    - Stress at blade tip compared to material yield stress to verify integrity
- Nozzle/Engine Case
  - Thin Wall Pressure Vessel
    - Stresses calculated with total pressure at corresponding stations, compared to yield strength for estimated materials
- Shaft
  - Power-Torque Relation
    - Shear stresses from compressor and turbine calculated and compared to ultimate shear for assumed material



Angular Motion



Thin Wall Pressure Vessel



Torque About Shaft

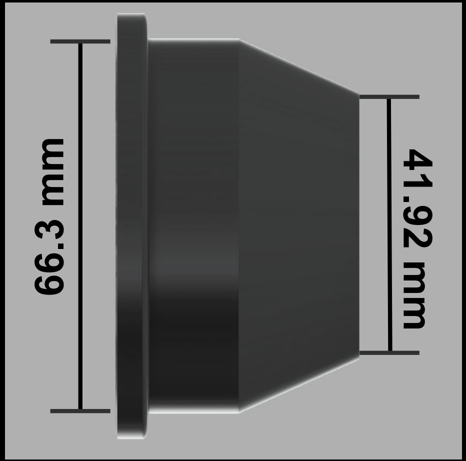
CRITICAL ENGINE COMPONENTS

Component (Stock)	MATERIAL	YIELD STRENGTH OF MATERIAL	ACTUALLY EXPERIENCED	S.F.
COMPRESSOR	Al 7075	440.57 MPa	23.99 MPa	18.36
ENGINE CASE	AISI 301	1089.31 MPa	31.43 MPa	34.66
SHAFT	AISI 301	2123.60 MPa	2.9 MPa	735.87
TURBINE	Inconel 718	289.45 MPa	**700.72 MPa**	**0.41**
NOZZLE	Inconel 718	661.6 MPa	6.68 MPa	99.04

- Component materials were determined from Alibaba, a vendor of JetCat replacement parts
- All material properties were found in
  - Military Handbook-5H --- Metallic Materials and Elements for Aerospace Vehicle Structures

NOZZLE FEASIBILITY

- With new pressure ratio, the required exit area for perfectly expanded flow at sea level is 0.00138 m^2
- This is a 26% decrease in stock nozzle exit area
- New dimensions can be manufactured



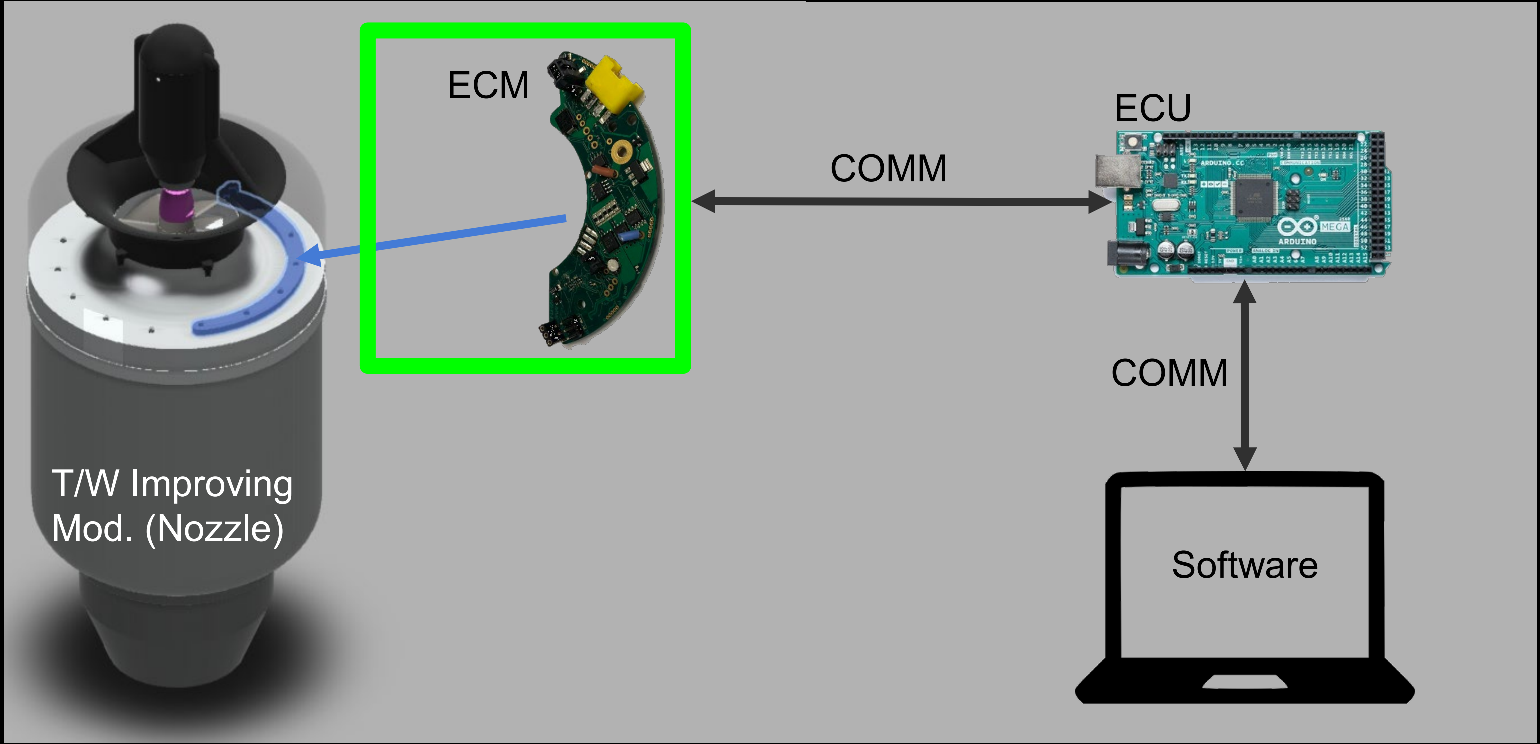
	MATERIAL	TENSILE YIELD FAILURE	ACTUALLY EXPERIENCED	S.F.
NOZZLE DESIGN	CoCrMo	350 MPa	5.8 MPa	60.34

- Material property was found from The Japan Institute of Metals --- Mechanical Properties of Biomedical Co-33Cr-5-Mo-0.3N Alloy at Elevated Temperatures

FUTURE WORK NEEDED: MATERIAL & MECHANICAL

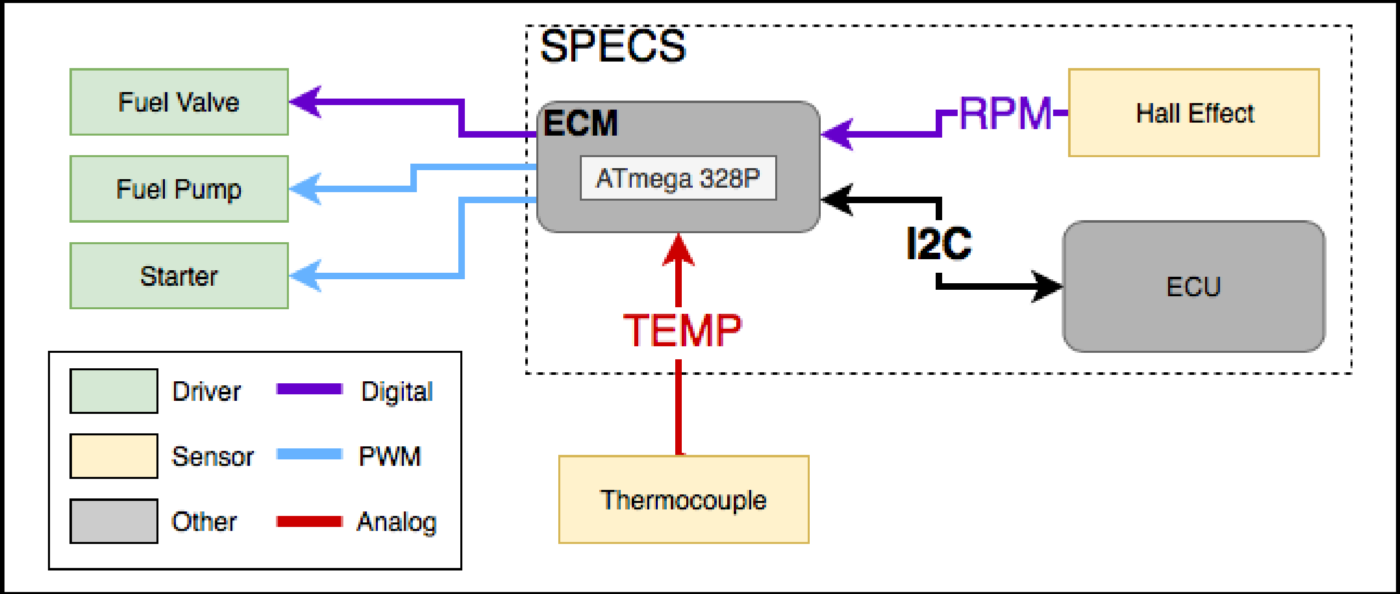
- Component material investigation
  - Critical engine component materials to be identified through Colorado Metallurgical Services
  - Thermal properties characterized through heat and destructive testing to simulate engine environment
  - Explore heat treatments and ablative (thermal) coatings
- Engine testing
  - Measure pressure, temperature, mass flow, thrust, thermocouple (front and back of chamber), nozzle exit velocity

SUBSYSTEM FEASIBILITY - ECM



ECM DESIGN OVERVIEW

- Engine Control Module (ECM) - controls engine state
- Fuel Pump Voltage ⇨ RPM
- Monitors on-board safety limits to initiate automatic engine shutdown



ECM REQUIREMENTS

FR 2: SPECS shall control the engine over the entire operational envelope.

DR 2.2: SPECS shall maintain idle at or near 33,000 ± 100 RPM.

DR 2.2.1: SPECS shall measure input from the thermocouple concurrently with RPM and fuel pump Pulse Width Modulation (PWM).

DR 2.2.2: SPECS shall measure input from the Hall effect sensor up to 5 kHz rate.

DR 2.2.3: SPECS shall send PWM fuel pump command rate as a percentage of full power.

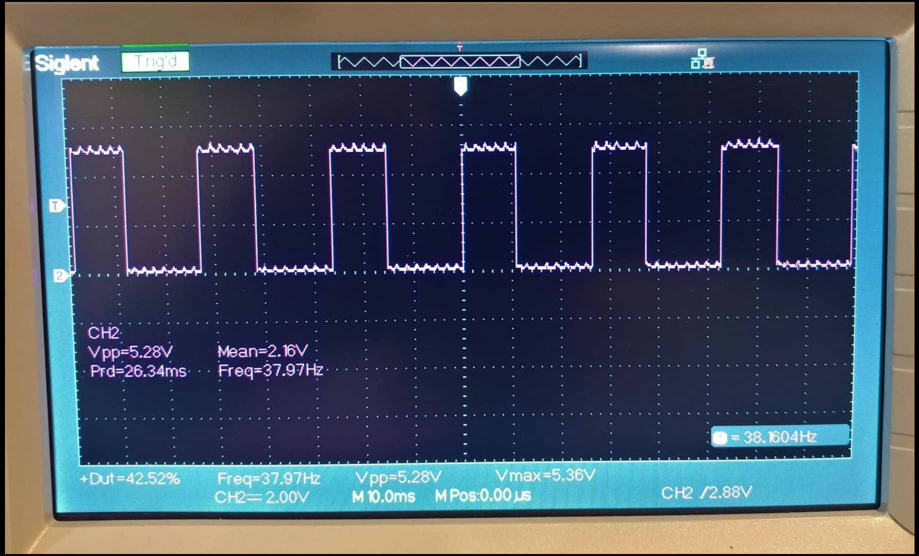
ECM HALL EFFECT SENSOR TESTING

Hall Effect Honeywell SS40A

System Settings: TEAG = 5 mm

Method: Commanded starter to run. Measured Hall effect waveform properties using oscilloscope. Duty cycle 42.52%, Freq = 37.97Hz. ECU LCD readout = 2275 RPM (37.91Hz), RPM calculation confirmed

Test Results: Verified Hall effect sensor functional, communicates and maps correct RPM

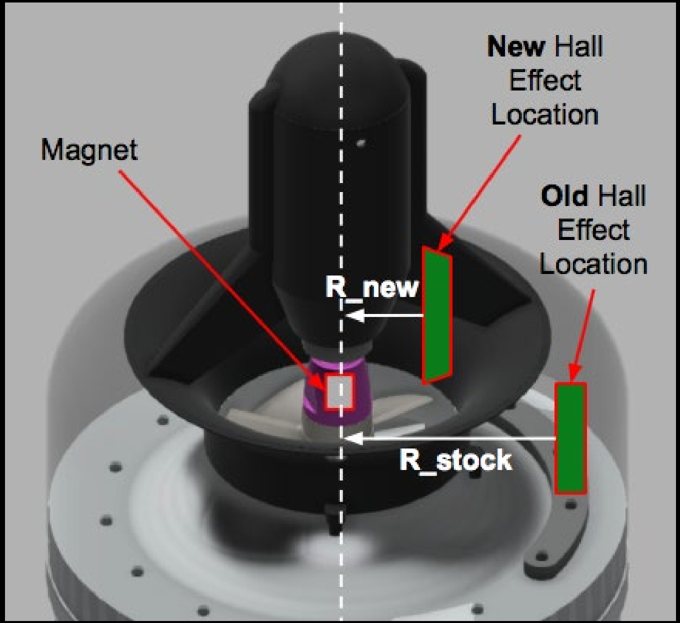


HALL EFFECT SENSOR FEASIBILITY

JetCat implementation of Hall effect sensor has been problematic. Sensor set beyond datasheet max distance for estimated magnetic field (35mm). Sensor measured <20% duty cycle (high RPM near sensor limit DC varied).

Specs Solution:

- Upgrade Hall effect sensor, relocate closer to magnet for precision
- New location provides 42% or better duty cycle with higher accuracy
- **Verified new sensor will read RPM up to 300 kRPM (5 mm away)**

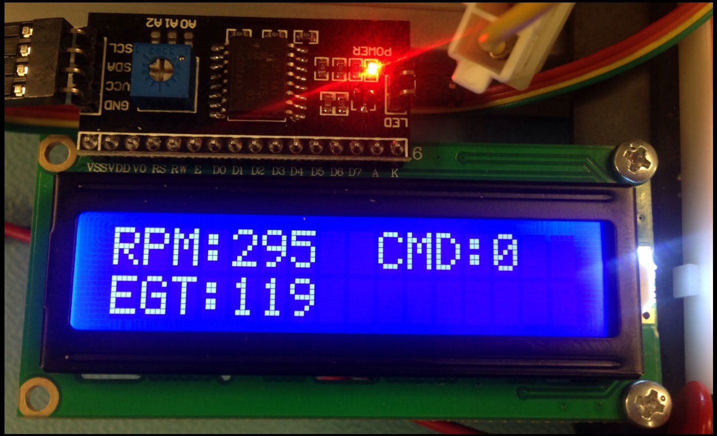


ECM DATA SAMPLING RATE: RPM

Microprocessor Pulse Injection

<u>System Settings</u>: Square wave duty cycle = 35% benchtop waveform generator

<u>Method</u>: Using waveform generator, supplied frequencies from 50 Hz to 5 kHz (3 - 300 kRPM). Waveform measured on ECM, then transmitted to ECU, then converted to RPM and sent to LCD. Total communication time <20ms.



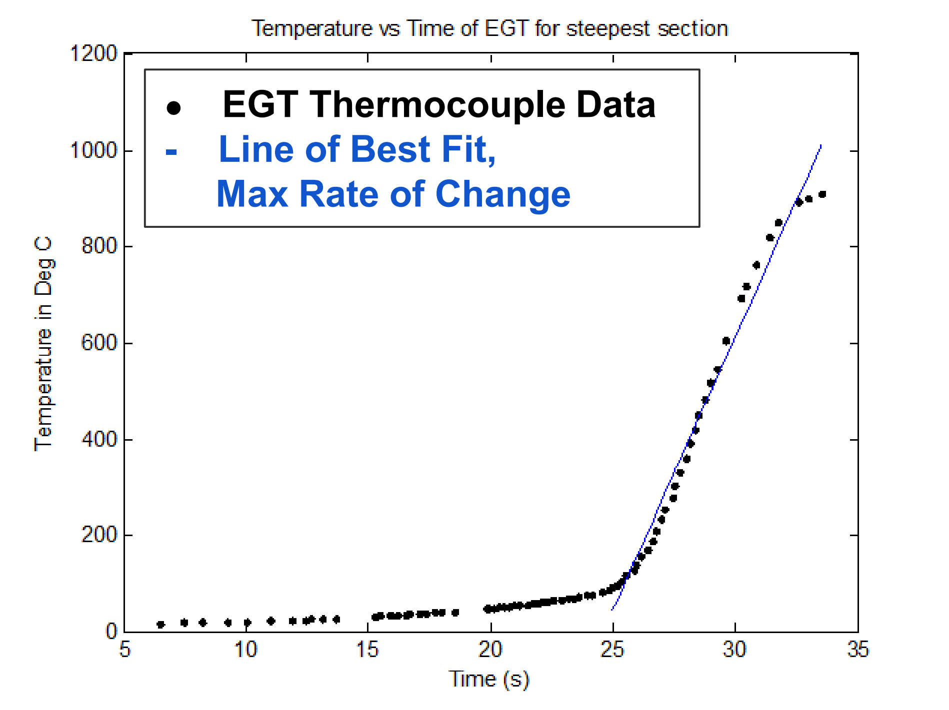
<u>Test Results:</u> Verified ECM can measure RPM in excess of 300 kRPM

ECM DESIGN THERMAL TRANSIENTS: EGT

Method: MEDUSA engine run EGT data showing max temp rate of change from throttle command

Needs: Design controller to limit temperature change to less than 113.7˚C/s

Future Test Requirements: Use proportional linear ramp controller to characterize fuel delivery and correlate to temperature rate of rise across RPM spectrum. Adjust fuel pump ramp rate to maintain less than 113.7˚C/s temperature increase.



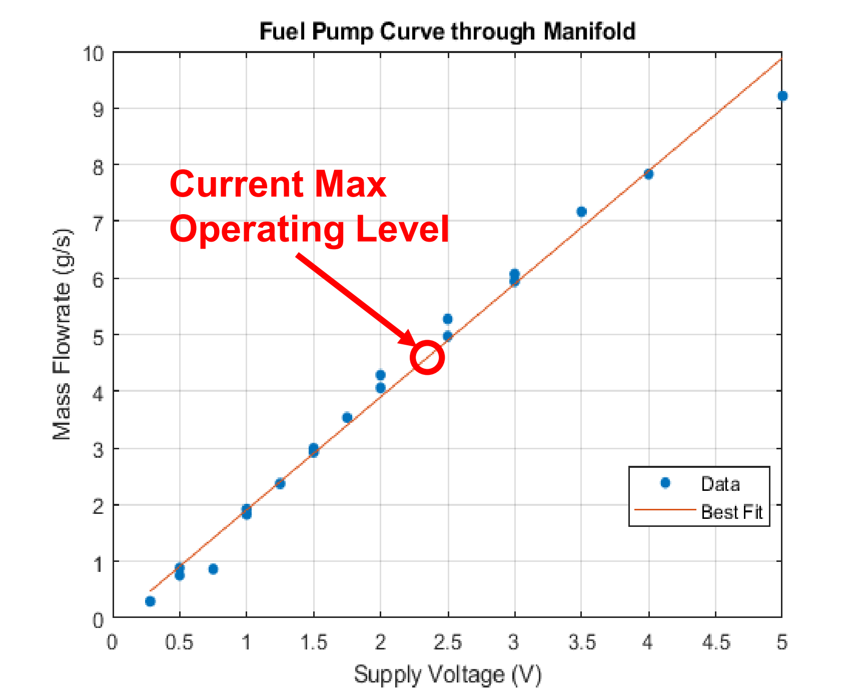
FUEL PUMP CHARACTERIZATION TESTING

DR 2.2.3: SPECS shall send PWM fuel pump command rate as a percentage of full power

Methods:

- Applied 0.28-5V to fuel pump, 0.5V increments for 10 seconds
- Video recorded weight of fuel tank and stop clock simultaneously
- Analyzed change in weight to find mass flow & voltage relationship

Test Results: Stock fuel flow at max thrust: 4.7 g/s. Pump can support higher fuel flows needed to increase T_{t4} & RPM



ECM DESIGN SUMMARY

ECM Completed Testing:

- Communication between all scoped systems verified
- Data transfer rates within design standards at 100 kHz standard mode rate

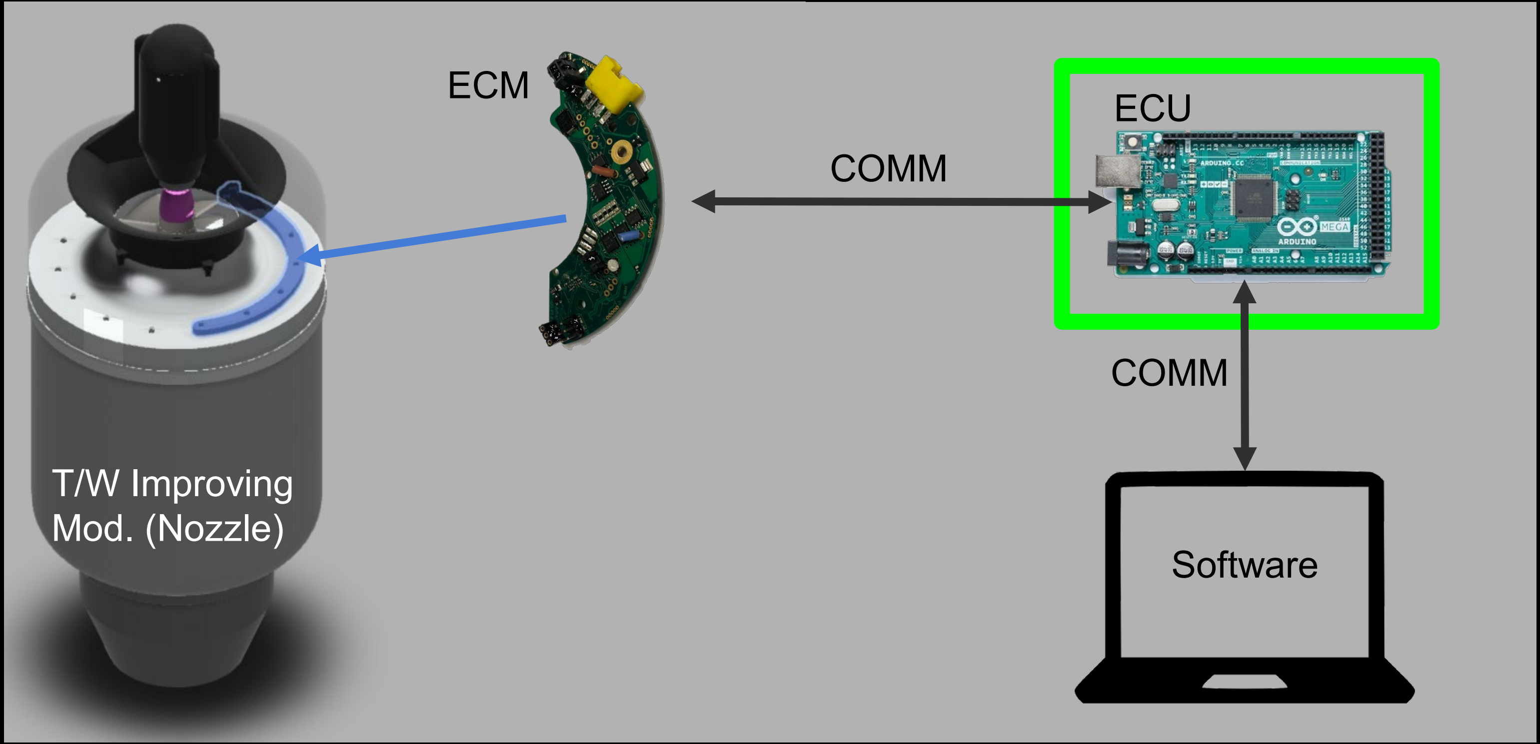
Future Work:

-Test bed implementation

-Design inlet to relocate Hall effect

-Testing, Thermocouple, Hall effect, Fuel Pump

SUBSYSTEM FEASIBILITY - ECU



Project Description | Baseline Design | Modification Feasibility | ECM Feasibility | **ECU Feasibility** | Project Summary

ECU DESIGN OVERVIEW

- The Electronics Control Unit (ECU):
  - Accepts user inputs from GUI and sends to ECM
  - Collects sensor data from ECM to process into RPM, temperature
  - Off engine connection point for DAQ, GUI
  - Allows for offboard processing

Arduino Mega

ECU REQUIREMENTS

FR 4: SPECS shall have a user interface for engine control.

DR 4.2: The SPECS user interface shall take user throttle inputs.

DR 4.3: The SPECS user interface shall have the ability to initiate the engine start up and shutdown sequences.

ECU DATA LINK FEASIBILITY

Communications testing:

1. Verify communications protocol GUI⇨ECU⇨ECM to send command and execute.
2. Calculate minimum data transfer values, test ECM to evaluate processing time.
3. Test at maximum data transfer quantity, test ECM to evaluate processing time.

Results:

1. I2C communications verified through start/shutdown sequence and LCD display.
2. Minimum data transfer found to be 5 bytes, transfer time <20ms.
3. 32 byte (I2C maximum) tested time <50 ms per request (<200ms maximum)

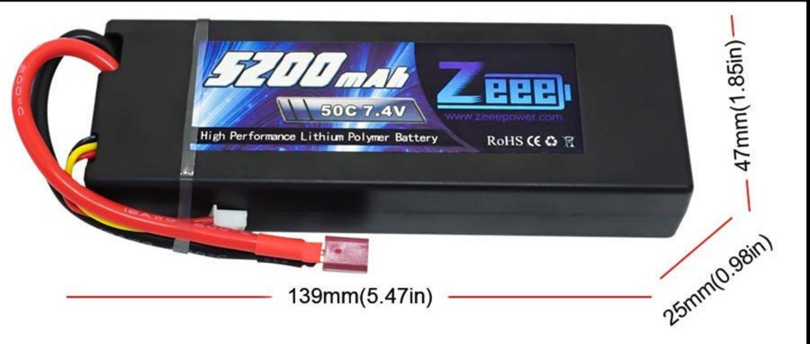
POWER SYSTEM FEASIBILITY

At 8.4VDC (2S LiPo full charge) or 5V (Vcc), used large benchtop power supply to measure component current consumption during design operation

- 11.2A cumulative total
- Select 2S 5200mAh battery with 50C rating
  - 260A peak current
  - ~20 min runtime at full 100% power
  - Less heating for motor control compared to 3S
  - Starter exceeded 5k RPM at 5V

Test Result: Supplied amperage from battery exceeds max current demand by SPECS

Component	Voltage (VDC)	Current (A)	Power (W)
Starter	8.4	6.2	52.08
Fuel Pump	8.4	4.8	40.32
Fuel Valve	5	0.07	0.35
ECU	5	0.02	0.1
Other	5	0.11	0.55
	Total:	11.2	93.4



ECU DESIGN SUMMARY

ECU Testing Results:

- I2C communications verified through start/shutdown sequence and LCD display
- Minimum data transfer found to be 5 bytes, transfer time <20ms
- 32 byte (I2C maximum) tested time <50 ms per request (<200ms maximum)

Future Work:

- Implement closed loop control with Hall effect sensor feedback
- Design Start, Run and Stop sequences based on operational guidelines
- Implement GUI control of ECU and display system parameters on GUI

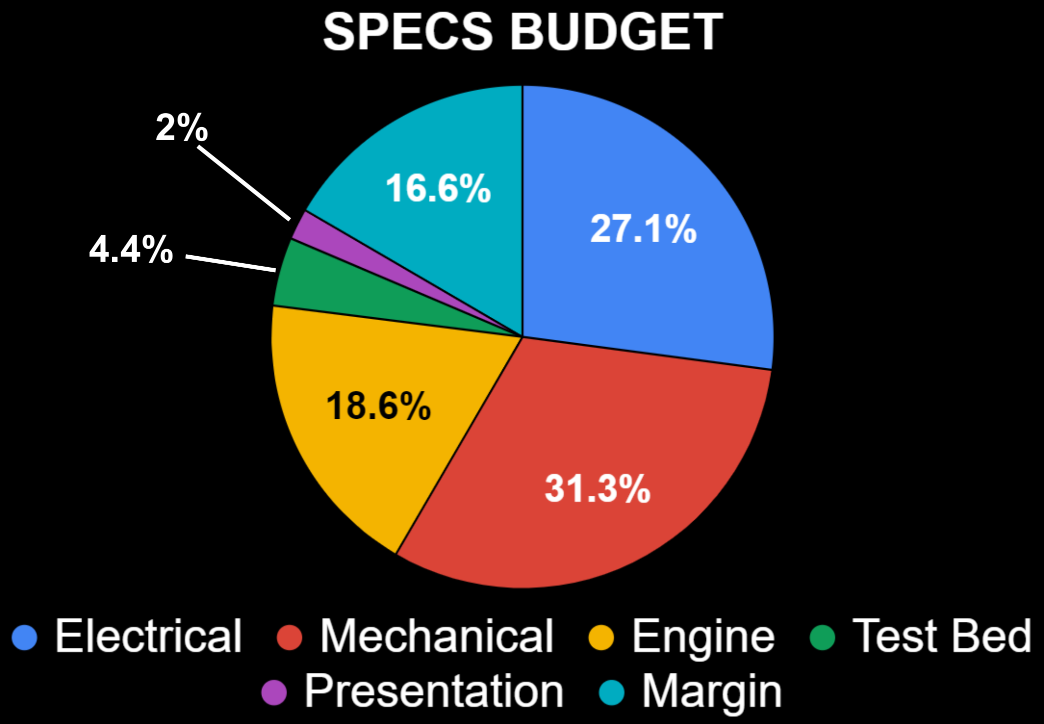
OVERALL ELECTRONICS FEASIBILITY

- Testing verified on:
  - Verified maximum power requirement attainable with readily available LiPo battery
  - Communication protocols work within specified time limits at the same time
  - ECU and ECM meet minimum simulated processing requirements to run system components
  - Communication from PC to ECU does not interfere with communication from ECU to ECM
  - Hall Effect sensor works at more than twice the maximum anticipated input frequency at new position
- Further Testing needed on:
  - Using MatLab as GUI development platform
  - ECM modular programming for component control with interrupts

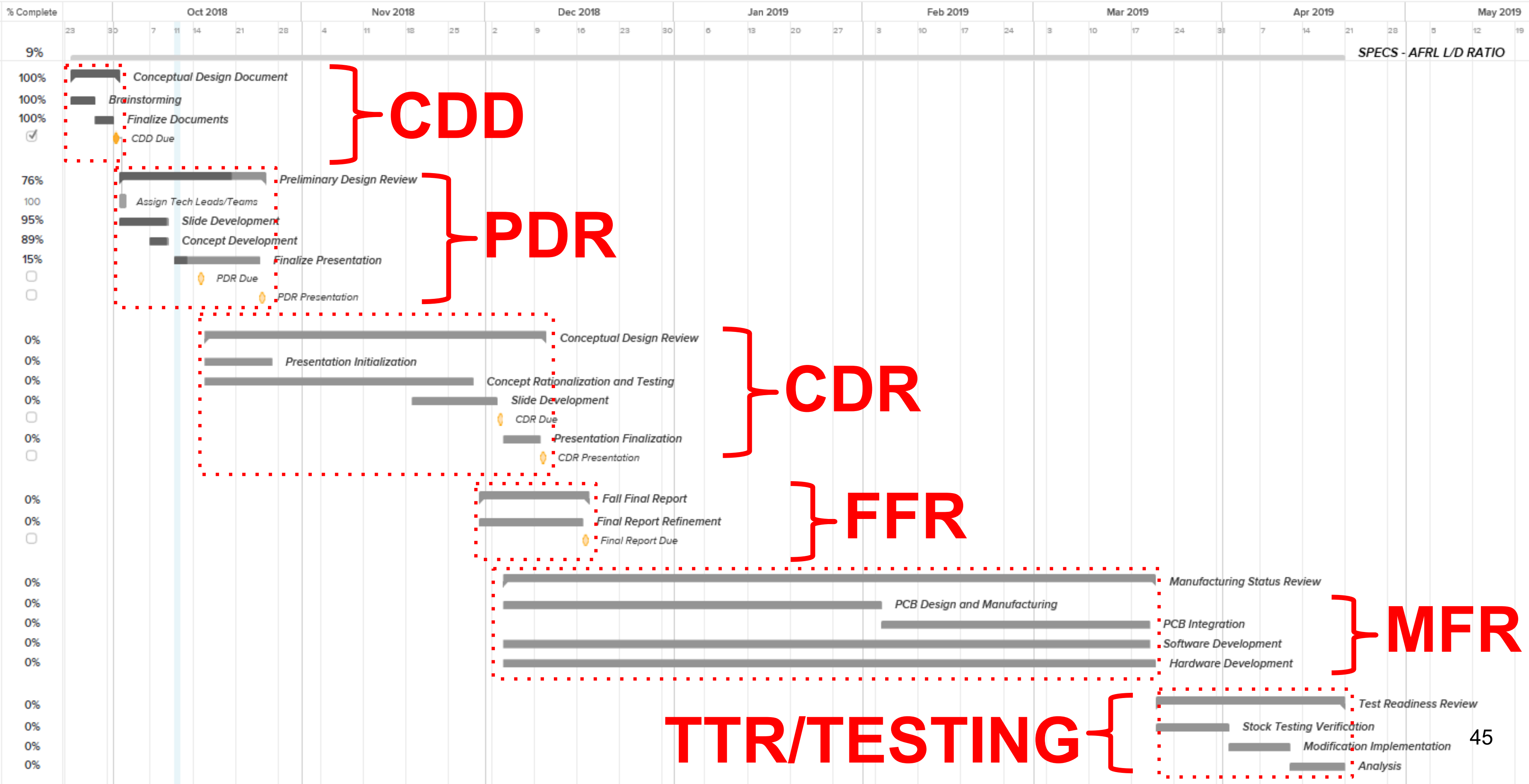
FINANCIAL FEASIBILITY

	Costs
Electrical	$ 1354.70
Mechanical	$ 1565.00
Engine	$ 930.00
Test Bed	$ 220.00
Presentation	$ 100.00
Total	$ 4169.70
Budget	$ 5000.00
Margin	$ 830.30

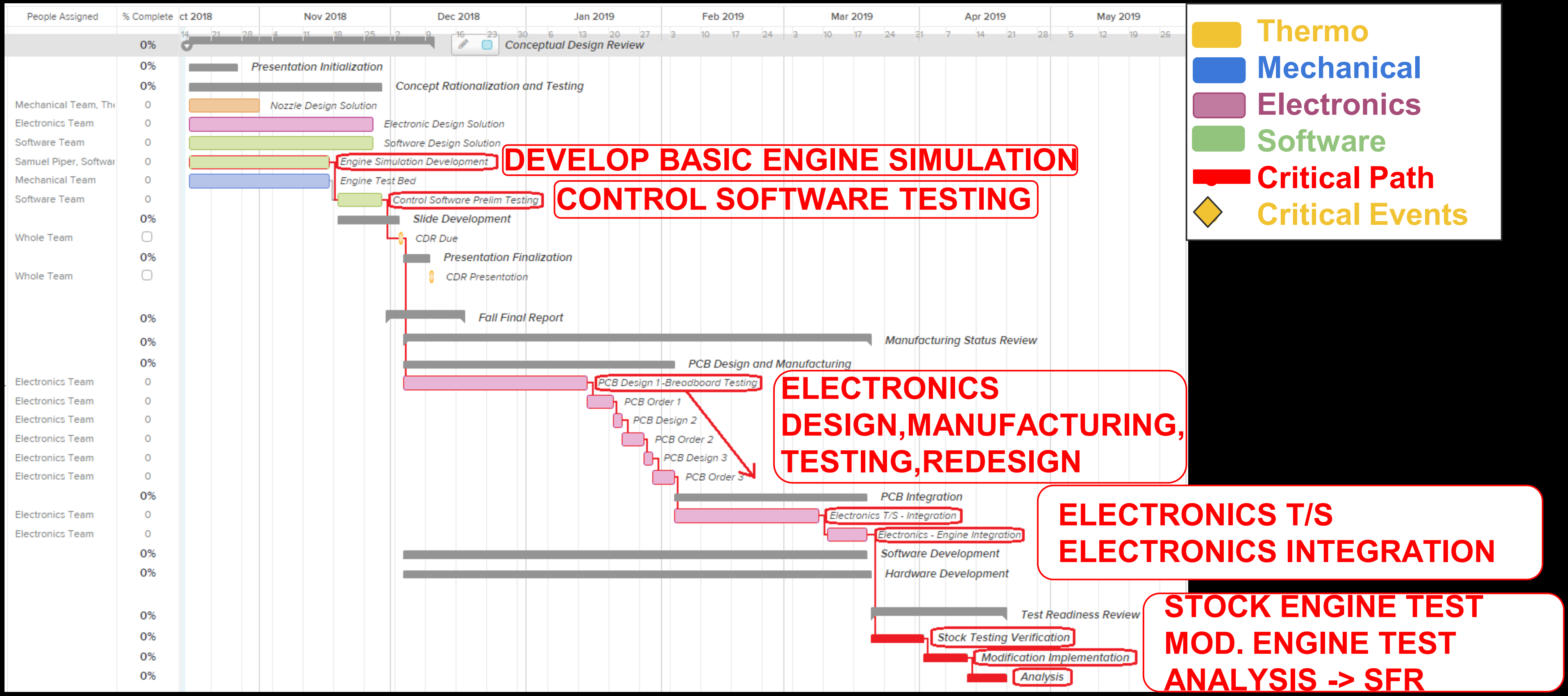
- Margin is positive, therefore the project is financially feasible



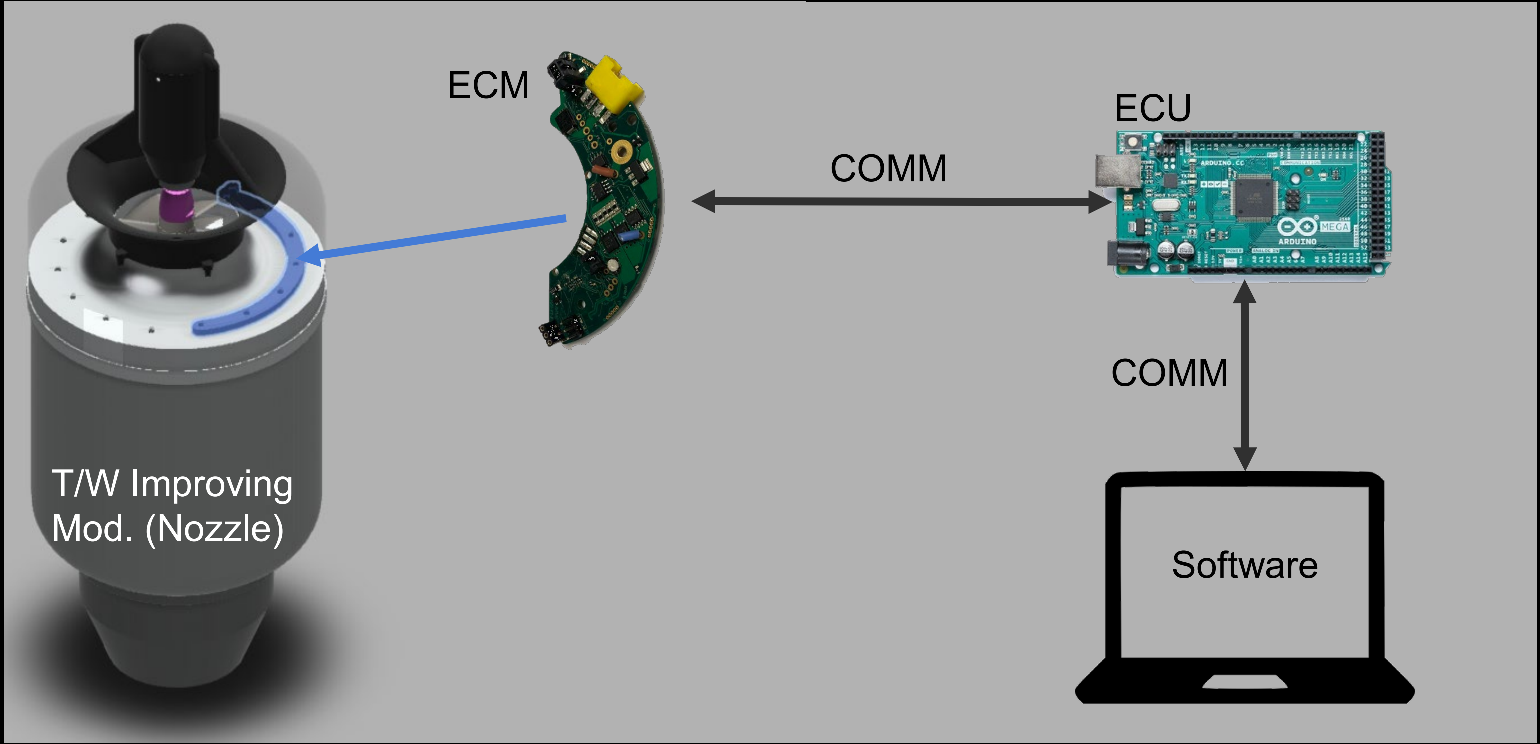
TIME BUDGET - OVERVIEW



TIME BUDGET: FUTURE WORK & CRITICAL PATH



BASELINE DESIGN - RECAP



Project Description | Baseline Design | Modification Feasibility | ECM Feasibility | ECU Feasibility | **Project Summary**

BASELINE DESIGN - RECAP FEASIBILITY

- Thrust Improving Modification (Increasing π_C)
- Thrust Improving Modification (Materials)
  - Turbine Materials Analysis
  - New Nozzle Design
- Electronic Control Unit
- Electronic Control Module
- Hall Effect Sensor
- Financially
- Time

- Feasible
- **Requires more investigation**

QUESTIONS?

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Backup Slides

Requirements (FR 1)

FR 1: The JetCat P90-RXi engine shall have an increased T/W ratio by 20\% from stock parameters.

DR 1.1: Implement a T/W improving modification that does not affect the overall operation of the engine and its ability to run for an extended period of time (2 minutes).

ECM REQUIREMENTS (FR 2 - FR 3)

FR 2: SPECS shall control the engine over the entire operational envelope.

- DR 2.1: SPECS will be capable of implementing the engine start up sequence but will modify start up parameters if needed to adapt to engine modifications.
- DR 2.2: SPECS shall maintain idle at or near 33,000 ± 100 RPM.
  - DR 2.2.1: SPECS shall measure input from the thermocouple concurrently with RPM and fuel pump Pulse Width Modulation (PWM).
  - DR 2.2.2: SPECS shall measure input from the Hall effect sensor up to 5 kHz rate.
  - DR 2.2.3: SPECS shall send PWM fuel pump command rate as a percentage of full power.

FR 3: SPECS shall run the engine in a safe manner.

- DR 3.1: SPECS will maintain operation below 130,000 RPM unless a new upper safety limit is determined from the engine characterization.
- DR 3.2: SPECS will maintain EGT below 700 Celsius unless a new upper safety limit is determined.
- DR 3.3: Should upper limits of operation be reached for RPM or EGT, SPECS shall command a software automatic engine shutdown.

Requirements (FR 4)

FR 4: SPECS shall have a user interface for engine control.

DR 4.1: The SPECS user interface shall display to the user the EGT

DR 4.2: The SPECS user interface shall take user throttle inputs.

DR 4.3: The SPECS user interface shall have the ability to initiate the engine start up and shutdown sequences.

DR 4.4: The SPECS user interface shall display warnings for operation within 10\% of safety limits to the operator.

DR 4.5: The SPECS user interface shall have an Emergency Stop (E-Stop) function.

THRUST MOD TRADE STUDY

	Custom Nozzle	Water Injection	Afterburner	SABRE Nozzle and Water Injection	Turbine Modification	Compressor Modification
Increase T/W Ratio	4	2.8	2.4	3.9	1.4	2.4
Cost	2.6	2.7	2.1	2.5	2.4	2.3
Development Time	3.3	2.3	1.6	2.3	2	1.8
Current Documentation	3.7	1.6	3	2.5	1.8	1.6
Modularity/Ease of Implementation	4.3	2.8	2.5	2.8	2.6	1.5
Safety	3.4	2.9	1.4	3.3	2.4	2.5
Total	3.7	2.5	2.2	3.1	1.9	1.9

	1	2	3	4	5
Increase T/W Ratio (Weighted 38%)	Limited theoretical and no experimental data showing possible improvement	Limited theoretical and experimental data showing possible improvement	Extensive theoretical and limited experimental data showing possible improvement	Extensive theoretical and limited experimental data directly applicable to P90-Rxi engine showing improvement	Extensive theoretical and experimental data directly applicable to P90-Rxi engine showing improvement
Cost (Weighted 9%)	Estimated Cost > 75% of budget, very high risk of additional expenses being incurred	Estimated Cost > 50% of budget, high risk of additional expenses being incurred	Estimated Cost > 25% of budget, moderate risk of additional expenses being incurred	Estimated Cost > 15% of budget, mild risk of additional expenses being incurred	Estimated Cost < 15% of budget, no risk of additional expenses being incurred
Development Time (Weighted 21%)	Extremely time-consuming, will not finish on time	Highly time-consuming, unlikely to finish on time	Moderate time-consuming, can finish on time	Little time-consuming, likely to finish ahead of time	Not time-consuming, will finish ahead of time
Current Documentation (Weighted 15%)	A single source	Little documentation	Moderate documentation	Substantial documentation	Extensive documentation from both CU teams and academia
Modularity/ Ease of Implementation (Weighted 9%)	Extremely difficult	Highly difficult	Moderately difficult	Little difficult	Not difficult 'Bolt-On' Solution
Safety (Weighted 8%)	Safety limitations unlikely to be determined	Safety limitations may be poorly defined	Safety limitations documented but difficult to determine	Safetly limitations simply defined	Safety limitations predefined by stock engine parameters

CONFIGURATION TRADE STUDY

	1	2	3	4	5
Response Time (Weighted 37%)	Unsustainable response time	Much slower than stock ECU	Slower than stock ECU	Same speed as stock ECU	Faster than stock ECU
Ease of Control (Weighted 43%)	No functions available	Most functions available on engine	All functions available on engine	Most functions available at distance	All functions available at distance
Weight (Weighted 20%)	Much heavier than stock ECU	Heavier than stock ECU	Same weight as stock ECU	Lighter than stock ECU	Much lighter than stock ECU

	Onboard	Offboard	Split
Response Time	4.3	2.2	4.1
Ease of Control	2.5	3.4	3.7
Weight	2.1	3.4	2.3
Total	3.0	2.9	3.6

ECU TRADE STUDY

	1	2	3	4	5
Team Experience (Weighted 32%)	No experience	Some experience	Moderate experience	Great experience	Extensive experience
Compatibility (Weighted 7%)	Cannot accommodate desired sensors	Accommodates sensors with extensive configuration	Accommodates sensors with moderate configuration	Accommodates sensors with current configuration	Accommodates more than base sensors
Development Time (Weighted 24%)	Impossible before April 2019	> 80% of available time	60 – 80% of available time	40 – 60% of available time	20 – 40% of available time
Data Acquisition Rate (Weighted 8%)	Bare minimum speed to run engine	Able to run engine and process some additional sensors	Easily able to run engine and process additional sensors	Just able to run engine, process sensors, and produce GUI	Excess computational abilities to run engine, process sensors, and produce GUI
Current Documentation (Weighted 12%)	No documentation	Sparse documentation	Some documentation	Moderate documentation	Extensive documentation
Software Quality (Weighted 17%)	Extremely complicated	Complicated	Mediocre	Intuitive	Extremely intuitive

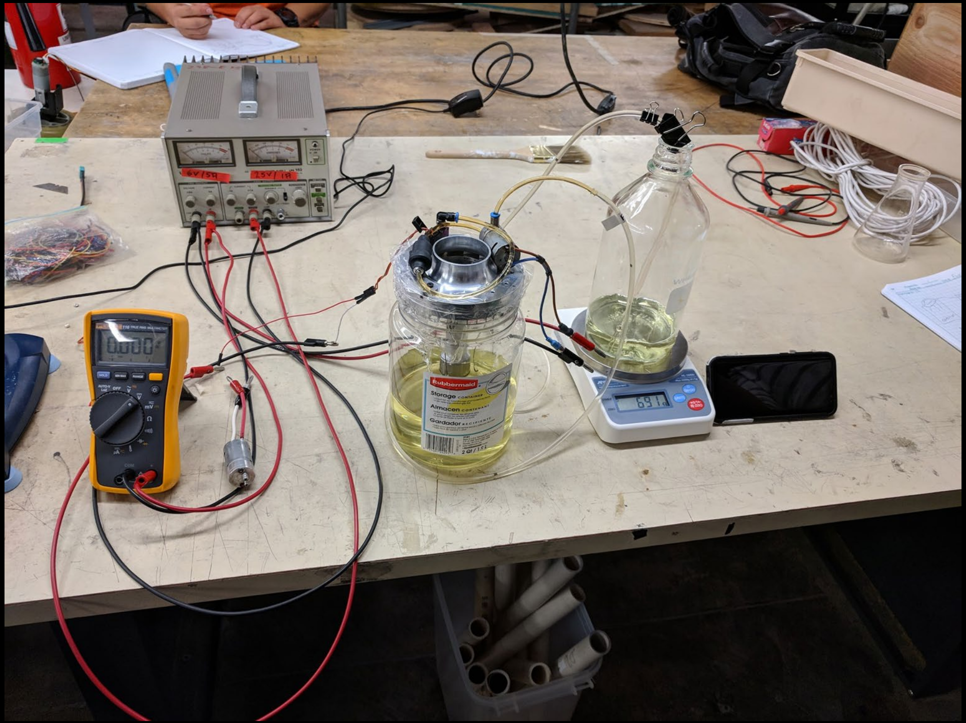
	Arduino	Mojo	LCPXpresso
Team Experience	4.2	1.5	2.5
Compatibility	3.7	2.6	3.3
Development Time	4.0	2.1	2.8
Data Acquisition Rate	2.5	4.0	3.7
Current Documentation	4.5	2.5	3.1
Software Quality	4.1	2.7	3.5
Total	4.0	2.2	2.9

FUEL PUMP CAPACITY TEST SETUP

-Linear Relationship at 2 (g/s)/V

-Mass Flow rate = $-0.11V^2 + 2.57V - 0.57$

-This provides < 5% error throughout the 5V range

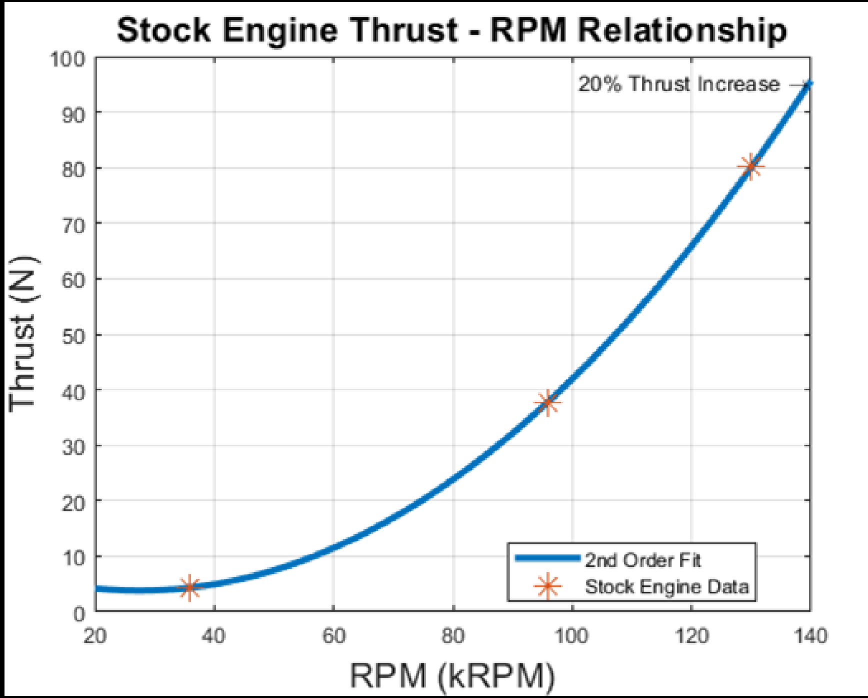


RPM -> THRUST CORRELATION

Second Order fit is:

Thrust = 0.0073(RPM)^2 - 0.4(RPM) + 9.29

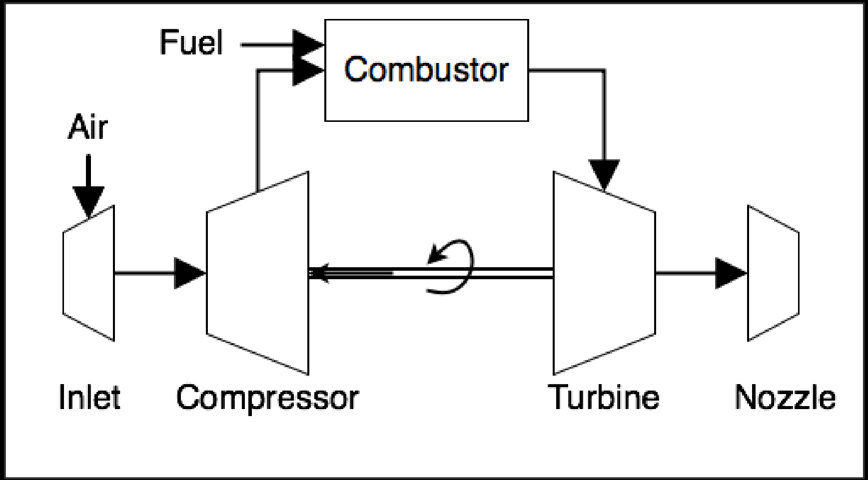
This provides ~20% thrust increase with ~10 kRPM increase

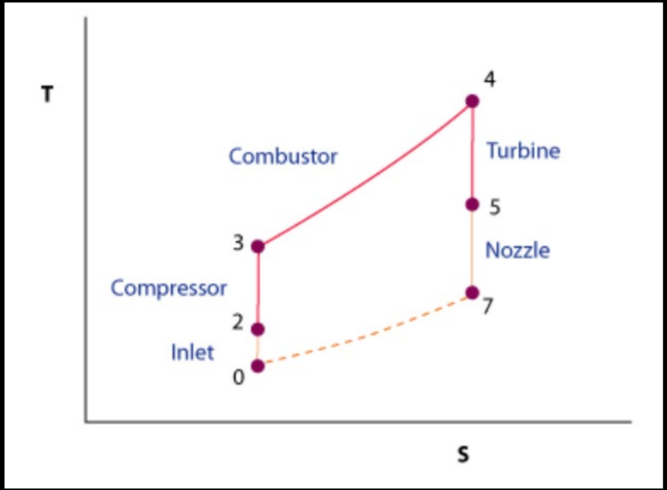


IDEAL CYCLE ASSUMPTIONS

- Ideal Brayton Cycle
  - Standard Air
    - Calorically Perfect Gas
    - Constant Specific Heat
  - Isentropic Inlet, Compression, Turbine, and Nozzle
  - Constant Pressure Heat Addition & Rejection
    - Fuel mass flow << Air mass flow
  - Perfectly Expanded Flow Exiting Nozzle
  - Closed System, no losses
- Steady 1D flow
- Axial Compressor
- Sea Level Atmospheric Conditions
- Compressor Pressure Ratio Scales Linearly with Mass Flow Rate

IDEAL BRAYTON CYCLE ANALYSIS





IDEAL BRAYTON CYCLE ANALYSIS

Calculation of temperature and pressure relationships

$$\pi_c = \frac{P_{t3}}{P_{t2}}$$

$$\tau_c = \pi_c^{\frac{\gamma-1}{\gamma}}$$

$$\tau_r = 1 + \frac{\gamma - 1}{2} M_0^2$$

$$\tau_b = \frac{f h_{pr}}{cpT_0 \tau_r \tau_c} + 1$$

$$T_{t3} = \tau_r \tau_c T_0$$

$$T_{t4} = \tau_b T_{t3}$$

$$\tau_\lambda = \frac{T_{t4}}{T_0}$$

$$\tau_t = 1 - \frac{\tau_r}{\tau_\lambda}(\tau_c - 1)$$

Calculation of uninstalled thrust

$$a_0 = \sqrt{\gamma R T_0}$$

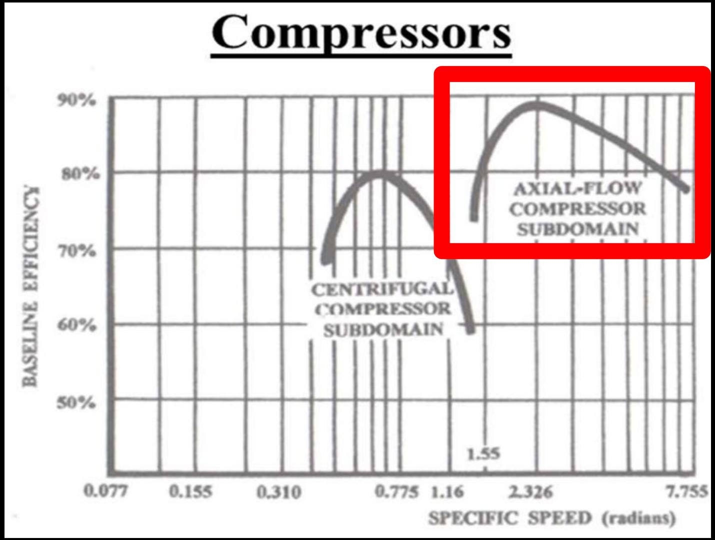
$$\left(\frac{V_9}{a_0}\right) = \sqrt{\frac{2}{\gamma - 1} \frac{\tau_\lambda}{\tau_r \tau_c} (\tau_r \tau_c \tau_t - 1)}$$

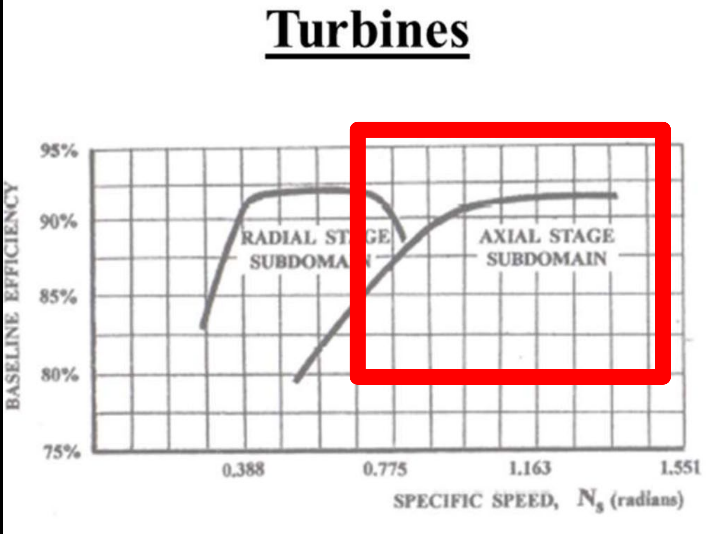
$$F_{uninstalled} = \dot{m}_0 \left(V_9 - a_0 M_0\right)$$

PRESSURE RATIO FEASIBILITY

Ideal	**Compressor Work**	**Turbine Work**	η	**Thrust loss**
Stock	19.99 kW	48.01 kW	1	0%
20% Increase	22.3 kW	46.1 kW	0.98	4.5%

Baseline Compressor efficiency decrease of ~2% (with 10,000 RPM increase)





NOZZLE AREA CALCULATION

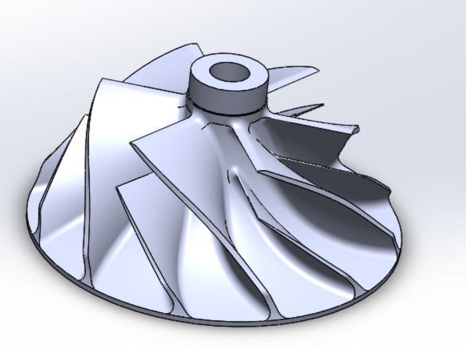
Assumes:

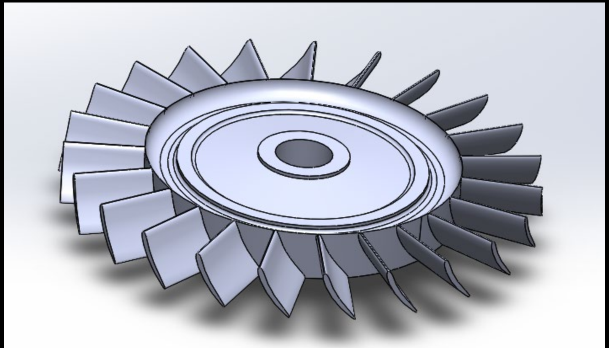
- Perfectly expanded flow
- Fuel mass flow = 0
- Isentropic nozzle expansion

$$V_e = \sqrt{\frac{2(P_t - P_0)}{\rho}}$$

$$\dot{m}_0 = \dot{m}_e = \rho_e A_e V_e$$

CRITICAL ENGINE COMPONENTS





Component Analysis: Nozzle/ Engine Case

- Hoop (σ_h) and longitudinal (σ_l) stresses calculated at location where values are theoretically maximum, inlet:
- Total Pressure at nozzle inlet (P_{t5}), radius of nozzle inlet (R_i), thickness of nozzle inlet (t_i):

$$\sigma_l = \frac{P_T R_i}{2t_i}$$

$$\sigma_h = \frac{P_T R_i}{t_i}$$

- Results compared to material properties, verify structural capability.

Component Analysis: Turbine/Compressor

- Centripetal force calculated at 140 kRPM at blade tips for both compressor and turbine. Force value then applied to stress equation over tip area.
- Variables: blade mass (m_b), blade length (l_b), rotation rate (ω), blade tip (A_t), centripetal force (F)
- Governing expressions:

$$F = m_b l_b \omega^2$$

$$\sigma = \frac{F}{A_t}$$

- Results compared to material properties, verify structural capability.

Component Analysis: Shaft

- Power (P) and rotation rate (ω) known for compressor and turbine.
- Calculate torque for each using:

$$T = \frac{P}{\omega}$$

- Force from both then found using radius of turbine and compressor:

$$F = \frac{T}{R}$$

- Shear stress (τ) then calculated and compared to ultimate shear of assumed material, area of shaft in contact with turbine and fan used (A):

$$\tau = \frac{F}{A}$$

Material Yield Analysis(Al 7075)

Table 3.7.4.0(b₁). Design Mechanical and Physical Properties of 7075 Aluminum Alloy Sheet and Plate

Specification	AMS 4045 and AMS-QQ-A-250/12																				
Form	Sheet							Plate													
Temper	T6 and T62[a]							T651													
Thickness, in.	0.008-0.011	0.012-0.039		0.040-0.125		0.126-0.249		0.250-0.499		0.500-1.000		1.001-2.000		2.001-2.500		2.501-3.000		3.001-3.500		3.501-4.000	
Basis	S	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical Properties:																					
F_{tu}, ksi:																					
L	...	76	78	78	80	78	80	77	79	77	79	76	78	75	77	71	73	70	72	66	68
LT	74	76	78	78	80	78	80	78	80	78	80	77	79	76	78	72	74	71	73	67	69
ST	...	...	...	...	...	...	...	...	...	...	...	...	...	70[b]	71[b]	66[b]	68[b]	65[b]	67[b]	61[b]	63[b]
F_{ty}, ksi:																					
L	...	69	72	70	72	71	73	69	71	70	72	69	71	66	68	63	65	60	62	56	58
LT	63	67	70	68	70	69	71	67	69	68	70	67	69	64	66	61	63	58	60	54	56
ST	...	...	...	...	...	...	...	...	...	...	...	...	...	59[b]	61[b]	56[b]	58[b]	54[b]	55[b]	50[b]	52[b]
F_{cy}, ksi:																					
L	...	68	71	69	71	70	72	67	69	68	70	66	68	62	64	58	60	55	57	51	52
LT	...	71	74	72	74	73	75	71	73	72	74	71	73	68	70	65	67	61	64	57	59
ST	...	...	...	...	...	...	...	...	...	...	...	...	...	67	70	64	66	61	63	57	59
F_{su}, ksi	...	46	47	47	48	47	48	43	44	44	45	44	45	44	45	42	43	42	43	39	41
F_{bru}[c], ksi:																					
(e/D = 1.5)	...	118	121	121	124	121	124	117	120	117	120	116	119	114	117	108	111	107	110	101	104
(e/D = 2.0)	...	152	156	156	160	156	160	145	148	145	148	143	147	141	145	134	137	132	135	124	128
F_{bry}[c], ksi:																					
(e/D = 1.5)	...	100	105	102	105	103	106	97	100	100	103	100	103	98	101	94	97	89	93	84	87
(e/D = 2.0)	...	117	122	119	122	121	124	114	118	117	120	117	120	113	117	109	112	104	108	98	103
e, percent (S-basis):																					
LT	5	7	...	8	...	8	...	9	...	7	...	6	...	5	...	5	...	5	...	3	...
E, 10^3 ksi	10.3							10.3													
E_c, 10^3 ksi	10.5							10.6													
G, 10^3 ksi	3.9							3.9													
μ	0.33							0.33													
Physical Properties:																					
ω, lb/in.³	0.101																				
C, K, and α	See Figure 3.7.4.0																				

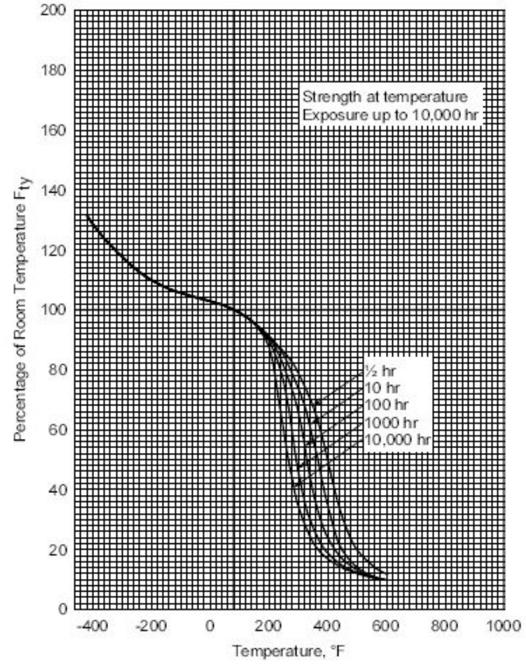


Figure 3.7.4.1.1(d). Effect of temperature on the tensile yield strength (F_{ty}) of 7075-T6, T651, T6510, and T6511 aluminum alloy (all products).

Material Yield Analysis(AISI 301)

Table 2.7.1.0(b). Design Mechanical and Physical Properties of AISI 301 and Other[a] Annealed Stainless Steel

Specification	MIL-S-5059	AMS 5517 & MIL-S-5059		AMS 5518 & MIL-S-5059		MIL-S-5059		AMS 5519 & MIL-S-5059	
Form	Sheet and strip								
Condition	Annealed[a]	¼ Hard		½ Hard		¾ Hard		Full Hard	
Thickness, in.	≤0.187	...		...		...		...	
Basis	S	A	B	A	B	A	B	A	B
Mechanical Properties:									
F_{tu}, ksi:									
L	73	124	129	141	151	157	168	174	185
LT	75	122	127	142	152	163	173	175	186
F_{ty}, ksi:									
L	26	69	83	93	110	118	135	137	153
LT	30	67	82	92	105	113	133	125	142
F_{cy}, ksi:									
L	23	44	54	61	69	75	88	83	94
LT	29	71	88	100	116	127	152	142	164
F_{su}, ksi	50	66	69	77	82	88	93	95	100
F_{bru}, ksi:									
(e/D = 1.5)	...	...	...	...	...	...	...	...	...
(e/D = 2.0)	162	262	273	292	310	327	342	346	361
F_{bry}, ksi:									
(e/D = 1.5)	...	...	...	...	...	...	...	...	...
(e/D = 2.0)	55	123	149	167	189	202	234	222	249
e, percent (S basis):									
LT	40	25	...	b	...	b	...	b	...
E, 10^3 ksi:									
L	29.0	27.0		26.0		26.0		26.0	
LT	29.0	28.0		28.0		28.0		28.0	
E_c, 10^3 ksi:									
L	28.0	26.0		26.0		26.0		26.0	
LT	28.0	27.0		27.0		27.0		27.0	
G, 10^3 ksi	11.2	10.6		10.5		10.5		10.5	
μ	0.27	0.27		0.27		0.27		0.27	
Physical Properties:									
ω, lb/in.^{3}	0.286								
C, K, and α	See Figure 2.7.1.0								

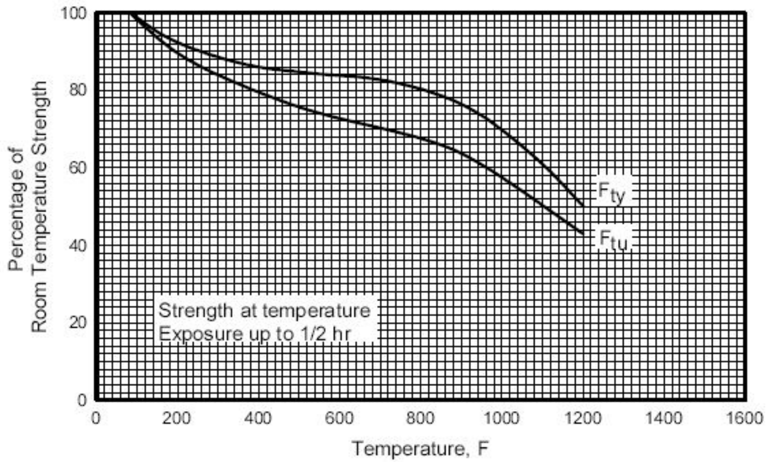


Figure 2.7.1.3.1. Effect of temperature on the tensile ultimate strength (F_{tu}) and the tensile yield strength (F_{ty}) of AISI 301 1/2-hard stainless steel sheet.

Material Yield Analysis(Inconel 718)

Table 6.3.5.0(b). Design Mechanical and Physical Properties of Inconel 718

Specification	AMS 5596				AMS 5597	AMS 5589	AMS 5590
Form	Sheet		Plate		Sheet and plate	Tubing	
Condition	Solution treated and aged per indicated specification						
Thickness, in.	0.010-0.187		0.188-0.249	0.250-1.000	0.010-1.000	O.D. > 0.125 Wall > 0.015	
Basis	A	B	S	S	S	S	S
Mechanical Properties[a]:							
F_{tu}, ksi:							
L	180	192	180	...	...	185	170
LT	180[c]	191	180	180	180	...	...
F_{ty}, ksi:							
L	145	156	148	...	...	150	145
LT	147	158	150	150	150	...	...
F_{cy}, ksi:							
L	155	167	158	...	...	...	...
LT	158	170	161	...	...	...	...
F_{su}, ksi	124	132	124	...	...	...	...
F_{bru}[b], ksi:							
(e/D = 1.5)	291	309	291	...	...	...	...
(e/D = 2.0)	380	403	380	...	...	...	...
F_{bry}[b], ksi:							
(e/D = 1.5)	208	223	212	...	...	...	...
(e/D = 2.0)	241	259	246	...	...	...	...
e, percent (S-basis):							
L	...	...	...	...	...	12	15
LT	12	...	12	12	12	...	...
E, 10^3 ksi	29.4						
E_c, 10^3 ksi	30.9						
G, 10^3 ksi	11.4						
μ	0.29						
Physical Properties:							
ω, lb/in.^{3}	0.297						
C, K, and α	See Figure 6.3.5.0						

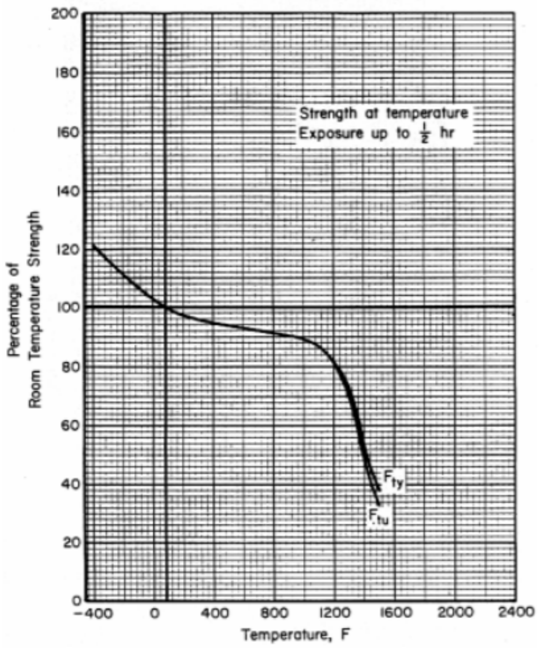


Figure 6.3.5.1.1. Effect of temperature on the tensile ultimate strength (F_{tu}) and tensile yield strength (F_{ty}) of solution-treated and aged Inconel 718.

Inconel Creep and Fatigue

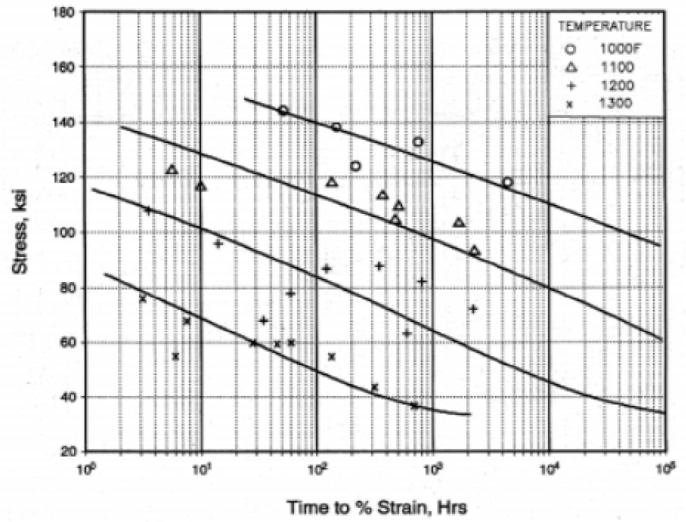


Figure 6.3.5.1.7(a). Average isothermal 0.10% creep curves for Inconel 718 forging.

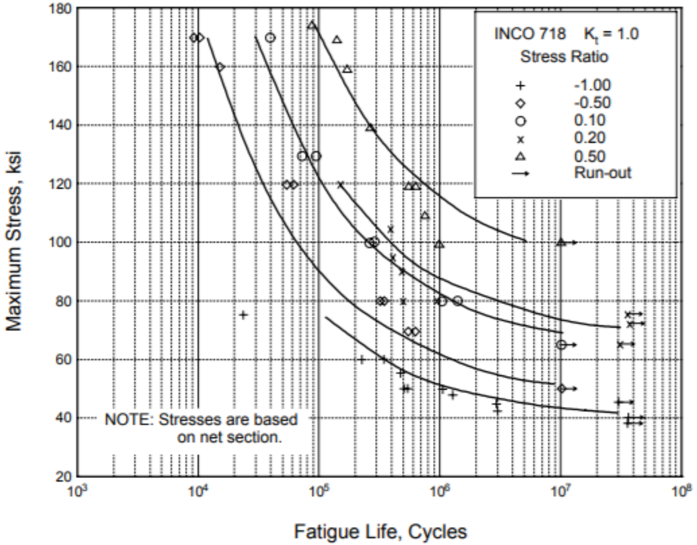


Figure 6.3.5.1.8(a). Best-fit S/N curves for unnotched Inconel 718 sheet at room temperature, long transverse direction.

Fabrication Cost Feasibility: CNC Machine & Tool Room Lathe

Family:	Species:	Dimensions (in):	Cost:
Steel	N60	3” x 10”	$242.45
Aluminum	7075	3” x 10”	$87.20
Titanium	6AL-4V (Grade 5)	3” x 10”	$870.30
Nickel	Inconel 718	3” x 10”	$873.69

- Cost of production solely based on cost of material.
- All materials are round bar, diameter x length

Fabrication Cost Feasibility: Direct Metal Laser Sintering

Family:	Species:	Dimensions (in):	Cost:
Aluminum	ALSi10Mg	3.25'' x 3.25'' x 2.17''	$1017.00
Nickel	Inconel 625	3.25'' x 3.25'' x 2.17''	$822.00
Titanium	Ti64	3.25'' x 3.25'' x 2.17''	$956.00
Cobalt Chrome	CoCrMo	3.25'' x 3.25'' x 2.17''	$983.00

- Cost of production includes the cost of materials, manufacturing and finishing
- The dimension of the nozzle is based on SABRE's nozzle
- It will take approximately three weeks to receive the nozzle from manufacturing facility

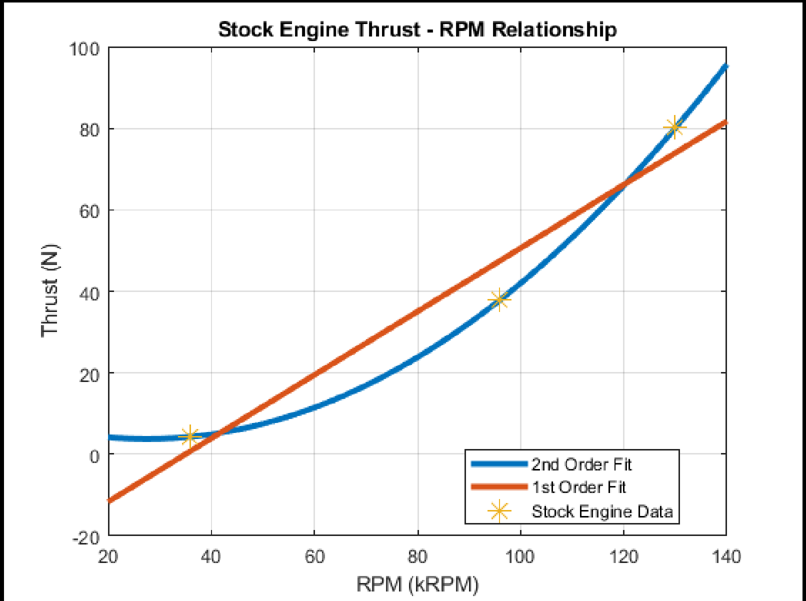
MANUFACTURING MATERIAL PROPERTIES

	N60	Al7075	Ti6AL-4V	Inconel 718	ALSi10Mg	Inconel 625	CoCrMo
Temperature Rating (k)	1422	686	1933	922	933	1563	1670
Density (g/cm^3)	8.5	2.81	4.52	8.22	2.7	8.44	8.28
Volume (cm^3)	10.16						
Mass (gram)	86.36	28.55	45.92	83.52	27.43	85.75	84.12

MANUFACTURING CAPABILITIES

Manufacturing Method	Tool Room Lathe	Computer Numerical Control (CNC) Machine	Direct Metal Laser Sintering (DMLS)
Tolerances	Depends on Measurement Tool	+/- 0.005''	+/- 0.005'' + 0.002 in/in

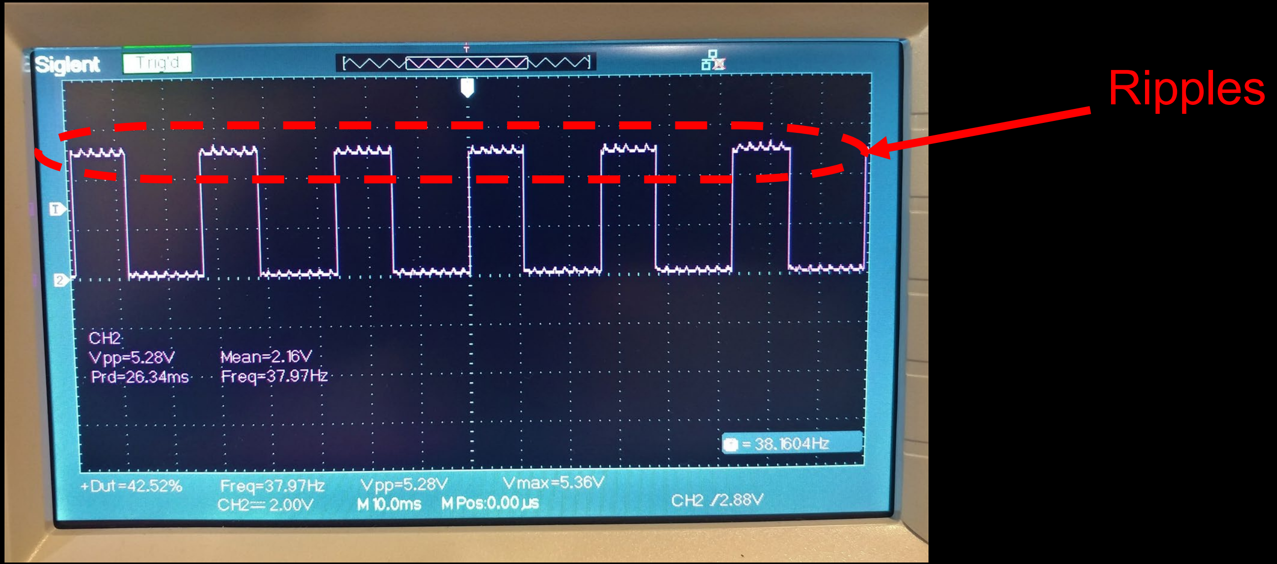
STOCK ENGINE THRUST-RPM LINEARITY



SPECS ECU DESIGN

- Selected based on:
- Easy to use IDE with documentation
- User forum and support for application
- Team familiarity and experience
- Meets all design basis standards
- Available everywhere for quick cheap replacement

ECM HALL EFFECT SENSOR TESTING



Notes: Ripples on waveform are from the power supply maxing out on supply current (5A). The selected battery would be able to supply much higher currents, and allow higher RPM with smaller voltage ripple. This is only present when starter is running (needed for this test but not normal operation) and does not affect functionality or reliability.

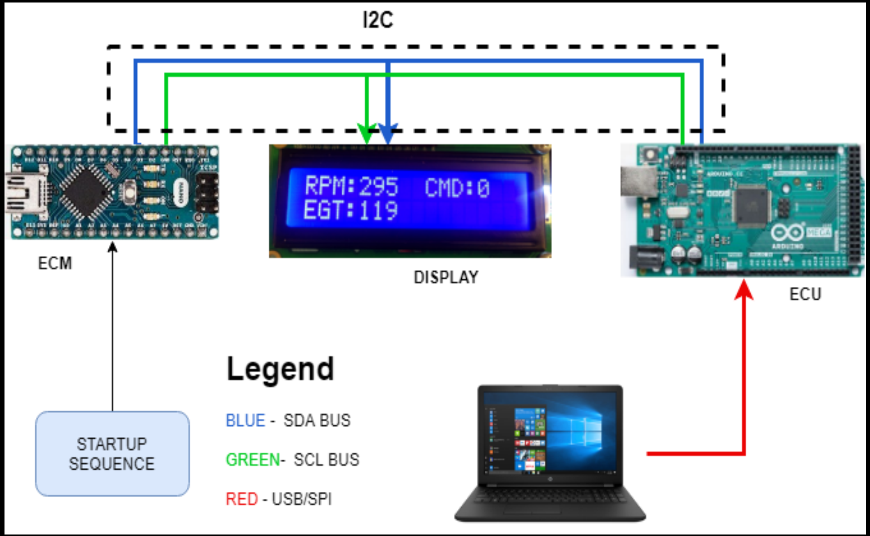
TESTING COMMUNICATION: SPECS

Method: Connected all components and verified I2C and SPI control separately. Designed startup sequence to simulate a "Start" and "Shutdown" command.

Need: Verify application of more than one communication protocol on system. Ensure that specified components can accept multiple commands from different sources and maintain normal operation without conflict or failure.

Results: Test completed successfully. Serial (SPI) command start/shutdown from PC resulted in start/shutdown sequence on ECM.

LCD displayed real time data for RPM, EGT, and command state. Further verifying I2C communication feasibility between ECU and ECM.



ECU/ECM DATA LINK FEASIBILITY

Needs:

- Allotted 3 bytes for RPM value (μs wave period measurement), 1 byte for EGT value (~3℃ resolution 255 values), 1 byte for command status (responds with RPM command input value at state). (At max transmission)

- I2C has a 32 byte maximum transmission per cycle limit, though if needed split transmissions are possible.

- SPI communications are only limited to the extent that they do not block ECU from sending or receiving data from ECM on time.

Method:

- Set up basic communications through I2C to all components.

- Established serial communications with Arduino MEGA.

- Initiated timer on command send.

- Transmitted request event, received data packets from ECM, processed data, wrote to LCD, read timer value at end of write transmission.

Results:

- Minimum Data transfer found to be 5 bytes, total transfer time <20ms.

- 32 byte (I2C maximum) tested time <50 ms per request.

- Verified communications can occur concurrently on time schedule while both microprocessors are tasked with other operations and will respond on schedule within required time constraint of <200ms.

HALL EFFECT SENSOR DATASHEET

Magnetic Position Sensors
Low-Cost, Bipolar, Hall-effect Sensors

SS40A/SS50AT Series

FEATURES
- Small size
- Low cost
- Reverse polarity protection
- Sensitive - bipolar magnetics respond to alternating north and south poles
- Thermally balanced, integrated circuit over a full temperature range
- Stable operation

TYPICAL APPLICATIONS
- Cooling fan control in computers and appliances
- RPM (revolutions per minute) sensing, speed control
- Brushless dc motor commutation
- Position sensing and motor control
- Simple magnetic encoder
- Flow-rate sensor

The SS40A/SS50AT Series sensors are low-cost, bipolar, Hall-effect sensors. These sensitive magnetic sensors offer reverse polarity protection and deliver stable output over a -40 °C to 125 °C [-40 °F to 257 °F] temperature range. Operation from any dc supply voltage from 4.5 Vdc to 24.0 Vdc is acceptable.

The SS40A/SS50AT Series sensors build upon Honeywell's popular magnetic position sensors and offer several competitive advantages. These sensors have been designed with the latest technologies to provide reliable, cost-effective solutions to commercial, computer, medical, and/or consumer applications requiring motor control and RPM sensing.

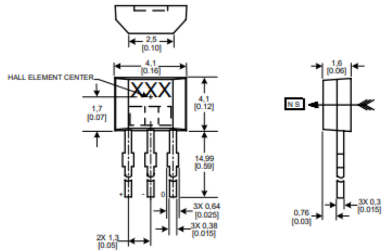
These products are available in a variety of package styles to suit a number of applications. Ammopack versions, along with tape-and-reel, are standard. The surface mount version is mounted directly on the electrical traces on a PC (printed circuit) board. It is attached by an automatic solder reflow operation which requires no hole, so it reduces the cost of the PC board.

ELECTRICAL CHARACTERISTICS

At V_S = 4.5 V to 24 V with 20 mA load with Ta = -40 °C to 125 °C [-40 °F to 257 °F] unless otherwise noted.

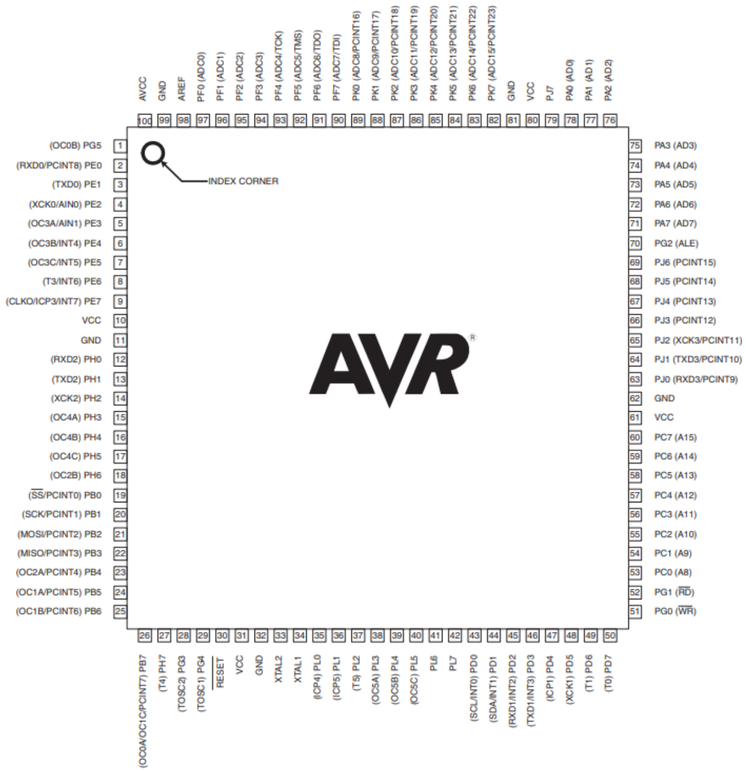
Parameter	Cond.	Min.	Typ.	Max.	Unit
Supply voltage	–	4.5	–	24.0	V
Supply current	25 °C [77 °F]	–	6.8	10.0	mA
Supply current	–	–	–	11.3	mA
Output current	–	–	–	20.0	mA
Vsat @ 15 mA	Gauss >170	–	–	0.4	V
Output leakage	Gauss <-170	–	–	10.0	µA
Rise time	25 °C [77 °F]	–	0.5	1.5	µs
Fall time	25 °C [77 °F]	–	0.2	1.5	µs
Response time	25 °C [77 °F]	–	4.0	5.0	µs
Operate	25 °C [77 °F]	–	45	110	Gauss
Operate	0 °C to 85 °C [32 °F to 185 °F]	–	50	130	Gauss
Operate	–	–	55	170	Gauss
Release	25 °C [77 °F]	-110	-45	–	Gauss
Release	-40 °C to 85 °C [-40 °F to 185 °F]	-130	-50	–	Gauss
Release	–	-170	-55	–	Gauss
Differential	–	50	–	–	Gauss
Operating temperature	-40 °C to 125 °C [-40 °F to 257 °F]				
Storage temperature	-55 °C to 165 °C [-67 °F to 329 °F]				

SS40A SERIES MOUNTING DIMENSIONS (for reference only) mm/[in]



ECU DATASHEET

Figure 1-1. TQFP-pinout ATmega640/1280/2560



8-bit Atmel Microcontroller with 16/32/64KB In-System Programmable Flash

DATASHEET

Features

- High Performance, Low Power Atmel® AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 135 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 × 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16MHz
  - On-Chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 64K/128K/256KBytes of In-System Self-Programmable Flash
  - 4Kbytes EEPROM
  - 8Kbytes Internal SRAM
  - Write/Erase Cycles:10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/ 100 years at 25°C
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
  - Programming Lock for Software Security
    - Endurance: Up to 64Kbytes Optional External Memory Space
- Atmel® QTouch® library support
  - Capacitive touch buttons, sliders and wheels
  - QTouch and QMatrix acquisition
  - Up to 64 sense channels
- JTAG (IEEE® std. 1149.1 compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - Four 16-bit Timer/Counter with Separate Prescaler, Compare- and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four 8-bit PWM Channels
  - Six/Twelve PWM Channels with Programmable Resolution from 2 to 16 Bits (ATmega1281/2561, ATmega640/1280/2560)
  - Output Compare Modulator
  - 8/16-channel, 10-bit ADC (ATmega1281/2561, ATmega640/1280/2560)
  - Two/Four Programmable Serial USART (ATmega1281/2561, ATmega640/1280/2560)
  - Master/Slave SPI Serial Interface
  - Byte Oriented 2-wire Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 54/86 Programmable I/O Lines (ATmega1281/2561, ATmega640/1280/2560)
  - 64-pad QFN/MLF, 64-lead TQFP (ATmega1281/2561)
  - 100-lead TQFP, 100-ball CBGA (ATmega640/1280/2560)
  - RoHS/Fully Green
- Temperature Range:
  - -40°C to 85°C Industrial
- Ultra-Low Power Consumption
  - Active Mode: 1MHz, 1.8V: 500µA
  - Power-down Mode: 0.1µA at 1.8V
- Speed Grade:
  - ATmega640V/ATmega1280V/ATmega1281V:
    - 0 - 4MHz @ 1.8V - 5.5V, 0 - 8MHz @ 2.7V - 5.5V
  - ATmega2560V/ATmega2561V:
    - 0 - 2MHz @ 1.8V - 5.5V, 0 - 8MHz @ 2.7V - 5.5V
  - ATmega640/ATmega1280/ATmega1281:
    - 0 - 8MHz @ 2.7V - 5.5V, 0 - 16MHz @ 4.5V - 5.5V
  - ATmega2560/ATmega2561:
    - 0 - 16MHz @ 4.5V - 5.5V

ECM DATASHEET

ATmega328/P

DATASHEET COMPLETE

Introduction

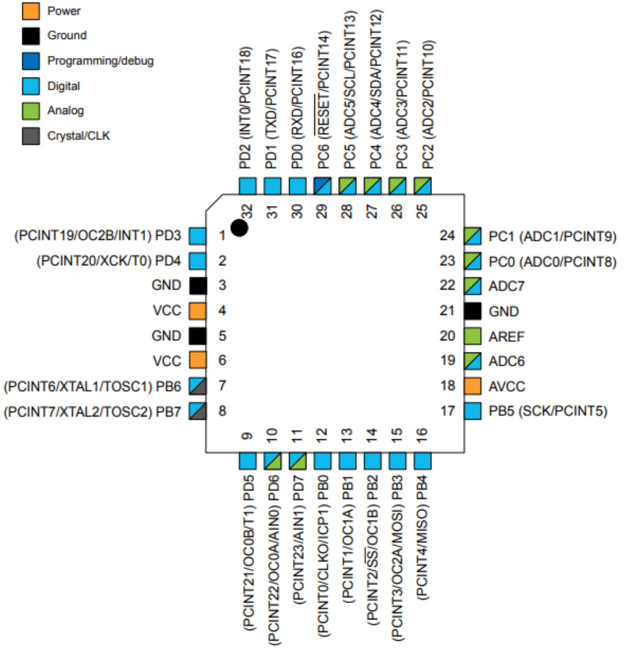
The Atmel® picoPower® ATmega328/P is a low-power CMOS 8-bit microcontroller based on the AVR® enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega328/P achieves throughputs close to 1MIPS per MHz. This empowers system designer to optimize the device for power consumption versus processing speed.

Feature

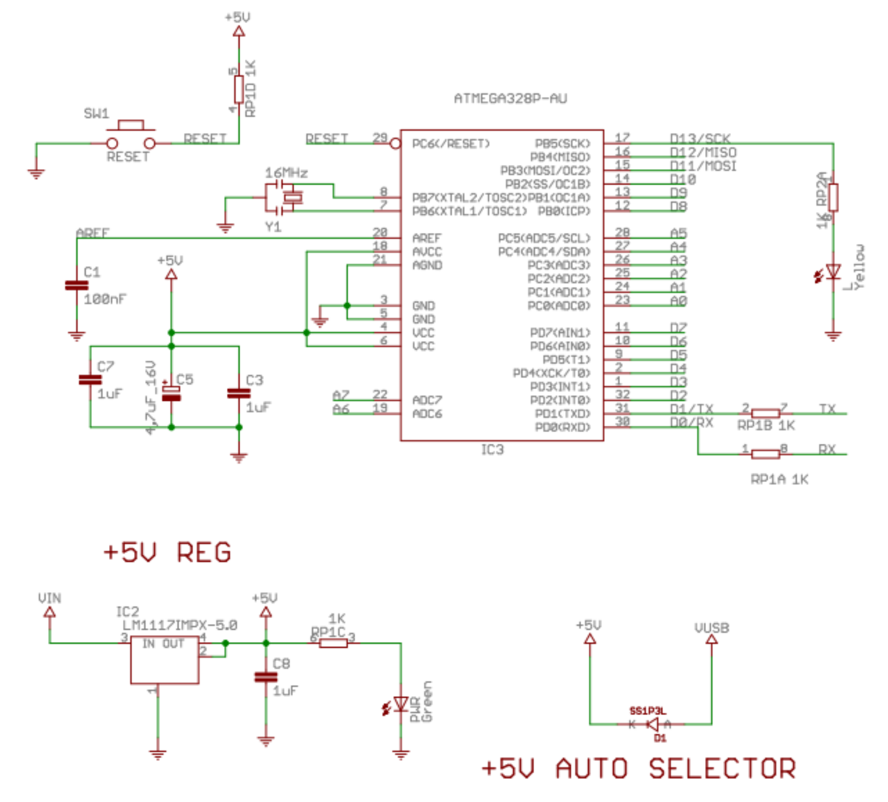
High Performance, Low Power Atmel®AVR® 8-Bit Microcontroller Family

- Advanced RISC Architecture
  - 131 Powerful Instructions
  - Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 20 MIPS Throughput at 20MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 32KBytes of In-System Self-Programmable Flash program Memory
  - 1KBytes EEPROM
  - 2KBytes Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data Retention: 20 years at 85°C/100 years at 25°C[(1)]
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
  - Programming Lock for Software Security
- Atmel® QTouch® Library Support
  - Capacitive Touch Buttons, Sliders and Wheels
  - QTouch and QMatrix® Acquisition
  - Up to 64 sense channels
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    - Temperature Measurement
  - 6-channel 10-bit ADC in PDIP Package
    - Temperature Measurement
  - Two Master/Slave SPI Serial Interface
  - One Programmable Serial USART
  - One Byte-oriented 2-wire Serial Interface (Philips I²C compatible)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - One On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF
- Operating Voltage:
  - 1.8 - 5.5V
- Temperature Range:
  - -40°C to 105°C
- Speed Grade:
  - 0 - 4MHz @ 1.8 - 5.5V
  - 0 - 10MHz @ 2.7 - 5.5V
  - 0 - 20MHz @ 4.5 - 5.5V
- Power Consumption at 1MHz, 1.8V, 25°C
  - Active Mode: 0.2mA
  - Power-down Mode: 0.1μA
  - Power-save Mode: 0.75μA (Including 32kHz RTC)

Figure 5-3. 32-pin TQFP Top View

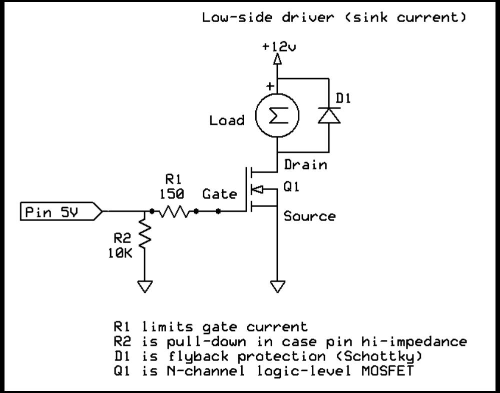


ATmega 328P Basic Application Circuit



Motor Driver MOSFET n-Channel

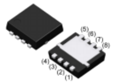
Circuit low side driver application, will measure real drain current for application to verify thermal properties are sufficient for given Rds(on)(Max.) value for PCB mount application.



V_{DSS}	40V
$R_{DS(on)}$(Max.)	14.3mΩ
I_D	±27A
P_D	15W

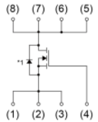
●**Outline**

HSMT8



●**Inner circuit**

(1) Source
(2) Source
(3) Source
(4) Gate
(5) Drain
(6) Drain
(7) Drain
(8) Drain
*1 Body Diode



●**Features**

1) Low on - resistance
2) High Power Package (HSMT8)
3) Pb-free lead plating ; RoHS compliant
4) Halogen Free
5) 100% Rg and UIS tested

●**Packaging specifications**

Type	Packing	Embossed Tape
	Reel size (mm)	330
	Tape width (mm)	12
	Basic ordering unit (pcs)	3000
	Taping code	TB
	Marking	G100GN

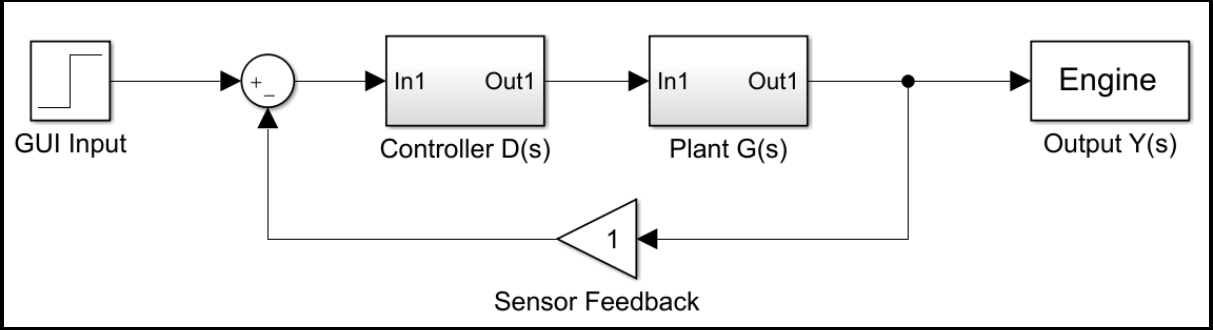
●**Application**

Switching

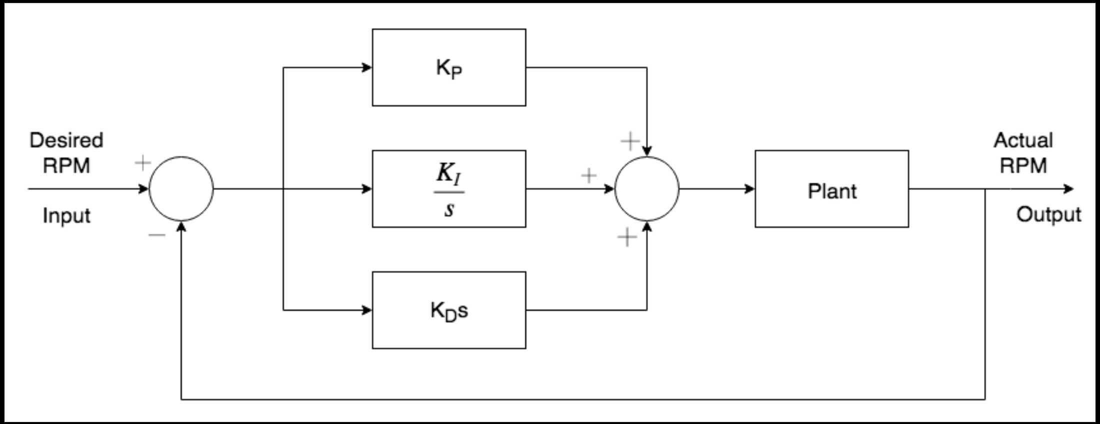
●**Absolute maximum ratings** (T_a = 25°C ,unless otherwise specified)

Parameter		Symbol	Value	Unit
Drain - Source voltage		V_{DSS}	40	V
Continuous drain current	T_c = 25°C	I_D*1	±27	A
	T_a = 25°C	I_D	±10	A
Pulsed drain current		I_{DP}*2	±40	A
Gate - Source voltage		V_{GSS}	±20	V
Avalanche current, single pulse		I_{AS}*3	10	A
Avalanche energy, single pulse		E_{AS}*3	15	mJ
Power dissipation		P_D*1	15	W
		P_D*4	2.0	W
Junction temperature		T_j	150	℃
Operating junction and storage temperature range		T_{stg}	-55 to +150	℃

BASELINE DESIGN - SOFTWARE



<u>Additional Note:</u> Transfer function to be determined with operational testing of engine. Full PID control will only be implemented if absolutely necessary, P or PI is anticipated.



BUDGET ALLOCATION

System	Item	Price (EA) $	Quantity (EA)	Total	Sub-Total	Budget %
Electrical	PCB	88	9	792		
	Processor ATmega 328P	1.3	12	15.6		
	PCB Components	50	6	300		
	Arduino Mega	28	2	56		
	Arduinio Nano	19	2	38		
	Hall Effect Sensor	0.11	10	1.1		
	LCD Screen	3	1	3		
	Battery	33	3	99		
	Battery Charger	50	1	50	1354.7	27.094
Mechanical	Material Testing	65	2	130		
	Nozzle Manufacturing	1000	1	1000		
	Tooling	250	1	250		
	Turbine Manufacturing	185	1	185	1565	31.3
Engine	Refurbishment	400	1	400		
	New ECU	500	1	500		
	Fuel	20	1	20		
	Fuel Line	10	1	10	930	18.6
Test Bed	Pitot-Static	20	1	20		
	Pressure Transducer	100	1	100		
	DAQ	100	1	100	220	4.4
Presentation	Presentation Poster	100	1	100	100	2
			Total:	4169.7		83.394
			Margin	830.3		16.606

TIME BUDGET - CURRENT EFFORTS

	People Assigned	% Complete
SPECS - AFRL L/D Ratio		9%
▼ Conceptual Design Document		100%
▼ Brainstorming		100%
Project Description	Daniel Castillo	100
Design Requirements	Matthew Knickerbock	100
Key Design Options Consi...	Samuel Piper	100
Trade Study Process & Res...	Dan Harthan, Markus	100
Selection of Baseline Design	Madison Junker	100
▼ Finalize Documents		100%
Edit & Refine	Whole Team	100
Review	Whole Team	100
CDD Due		☑
▼ Preliminary Design Review		76%
Assign Tech Leads/Teams	Whole Team	100
▼ Slide Development		95%
Story Board Presentation	Whole Team	100
Team Decide Necessary St...	Whole Team	100
Materials Feasibility	Markus Fuernkranz	100
Thermodynamic Fesibility	Matthew Knickerbock	100
Electronics Feasibility	Dan Harthan, Madisor	100
Cost Budget	Daniel Castillo	100
Time Budget	Gregory Frank, Samue	50
Project Descriptin	Gregory Frank	100
CONOPS Slide	Preston Fitzrandolph	100
FBD Slide	Dan Harthan, Preston	100
Functional Requirements S...	John Cutter, Matthew	100
CPE Slide	Cedric Camacho, Mac	100
Financial Slide	Daniel Castillo	100
Time Budget Slide	Gregory Frank, Samue	100
▼ Concept Development		89%
Nozzle Design	Mechanical Team, The	100
SPECS	Electronics Team, Sof	100
Summary	Whole Team	75
▼ Finalize Presentation		15%
Presentation Edit & Refine	Whole Team	50
Practice Presentation	Whole Team	0
PDR Due	Whole Team	☐
PDR Presentation		☐