Team members:
Julia Contreras-Garcia
Eric James
Matthew McClain
Benjamin Woeste
Emily Ehrle
Jonathan Lumpkin
Megan O'Sullivan
Kevin Wong
Customer: Lt. Joseph Ausserer, USAF
University of Colorado Boulder
Outline

- Project overview
  - Objectives
  - Requirements
  - System block diagram
- Schedule
- System Components
  - JetCat P90-RXI Engine
  - Mechanical attachment system
    - Shaft coupling
    - Generator-engine alignment harness
  - Generating motor
  - Motor controller
  - Power regulation
  - Power dissipation
- Budget
Project Description

• Design and build a Power Extraction Unit (PEU) for a JetCat P90-RXI mini-turbojet engine (shown below) that will generate 500 Watts of electrical power at 24 VDC.

• Sponsored by Air Force Research Laboratory’s Aerospace Propulsion Outreach Program (APOP)

Solid Works model

JetCat P90-RXI in stock configuration
Objectives

• Level one
  ▫ PEU must generate power at 24 Volts DC
  ▫ PEU must produce this power after the engine has been running no longer than 1 min 20 s, twice the average start up time
  ▫ Engine and PEU must be compatible with the WPAFB test stand

• Level two
  ▫ Reducing thrust by no more than 25%
  ▫ Increasing specific fuel consumption by no more than 50%

• Level three
  ▫ Adding no more than the weight than an equivalent battery pack with 30 minutes of power (8 lbs)
  ▫ Producing 500 W throughout the engine’s RPM operating range

• Level four
  ▫ PEU to be entirely external to the JetCat engine, making the most modular solution.

• Red will not be met, Orange is at risk, Green are predicted to be met
Project Changes

• JetCat could not provide starter/generator in time, project moving forward with off ramp
  ▪ Use lower speed motor as generator (limit of 60,000 RPM)
  ▪ High speed flexible shaft coupling rated for continuous use at 42,000 RPM (limit on operational range)
  ▪ Will not generate 500W; model predicts 48W

• Alignment harness further designed
  ▪ Replace generator clamps with mounting plate to stop axial and rotational motion
  ▪ Replace engine clamps with ring to reduce amount of adjustments needed
Schedule
Current Schedule Status: Overall
Current Schedule Status: Mechanical

- Mechanical Subsystem
- Coupling system and engine harness
- Generator Alignment Harness
  - Manufacture clamp for engine
  - Manufacture clamp for starter generator
  - Manufacture harness legs
  - Attach harness with starter and P60
- Last machining day
- Off-Ramp
  - Receive P99 engine - prepare for engine test fire
  - Waiting to hear from JetCat Germany regarding order status of starter generator
  - Officially decided to take off-ramp
  - Research alternative coupling system (lower max RPM)
  - Purchase coupler
  - Research RPM alternator (lower max RPM)
  - Purchase motor
  - Receive coupling system
  - Find stiffness of the original motor
  - Remove original motor
  - Receive motor
  - Modify coupling system to fit drive shafts of our engine and motor
  - Integrate alternator, engine, and coupling system
  - Test alignment with dial gauge
- Spring Break
- Off-Ramp: Integrate differential screws

Task Name

- Ben
- Matt
- Kevin, Matt, and Eric
- Ben
- Ben
- Julie and Emily
- Ben
- Kevin and Matt
- Team
- Julie and Eric

Timeline:
- Jan 19
- Jan 26
- Feb 2
- Feb 9
- Feb 16
- Feb 23
- Mar 2
- Mar 9
- Mar 16
- Mar 23
- Mar 30

Budget

Subsystems
Current Schedule Status: Mechanical

At risk

Critical path
Mechanical: At Risk Tasks

- **Off-ramp:** Incorporate differential screws
  - Pending the alignment test of the engine with the coupler, new generator, and generator alignment harness
- **How to address?**
  - Manufacture the holes earlier, despite whether differential screws needed
    - Generator alignment harness manufactured ahead of schedule (6 days, including margin)
      - No dependencies on harness until motor is received
      - Have time and human resources to manufacture holes now rather than later
Current Schedule Status: Electrical

Task Name

- Electrical Subsystem
  - Prepare for baseline characterization test
- Power dissipation system
- Power regulation and motor controller system
  - Refine design of ECU
  - Change ECU design to be the power regulation and motor controller system
  - Change design to encompass use of DAQ as motor controller
  - Change the power regulation and motor controller system (PR/MC) to be held on a single PCB
  - Change the design so that PR/MC system held on a fiber-glass/epoxy circuit board - manufactured in-house
- Characterize engine output signals
- Consider redesign of PR/MC system to use 555 timer instead of DAQ to change signal from motor driving signal to throttle signal
- Address technical issues surrounding motor controller
- Check output signals from motor controller components on bread board. Verify LTSpice model
- "Footprint" layout of power regulation system
- Purchase vector board
- Vectorboard the power regulation/motor controller systems.
- Place vector boards on glass-fiber board
- Spring Break

Project Overview  Schedule  Subsystems  Budget
Current Schedule Status: Software

- Research how to implement vibration analysis - found in scope method of rotor dynamics analysis
- Rotor dynamics
  - Research whether to use LabView or Jetronics for flow meter measurements
  - Program LabView for load cell
  - Test LabView V1 for load cell
  - Program LabView V1 to collect fuel flow data; use Jetronics to collect supplemental measurements (see Comments column for more info)
  - Test V1 for flow meter
  - Program LabView V1 to measure voltage signals
  - Compare Matlab engine model to baseline characterization to verify accuracy of model
  - Program V1 for the current and voltage sensor
- Use 555 timer (hardware-based motor control)
  - Create LTSpice model of motor controller (with 555 timer)

Spring Break
# Testing Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Mar 16</th>
<th>Mar 23</th>
<th>Mar 30</th>
<th>Apr 6</th>
<th>Apr 13</th>
<th>Apr 20</th>
<th>Apr 27</th>
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<tbody>
<tr>
<td>Systems Testing and Integration</td>
<td></td>
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<tr>
<td>Spring Break</td>
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<tr>
<td>Motor controller circuitry functionality test</td>
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<td></td>
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<tr>
<td>Power dissipater</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Shaft coupler torque tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ben Weste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage rectifier (on the power regulation circuit)</td>
<td></td>
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<tr>
<td>Generator alignment harness: Assembly and inspection (of tolerances)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Julia and Emily</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generator alignment harness: Low RPM test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Julia and Emily</td>
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<tr>
<td>AIAA Student Paper Conference</td>
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<tr>
<td>Test switching mechanism</td>
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<tr>
<td>Full system</td>
<td></td>
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<tr>
<td>Torque measurement</td>
<td></td>
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<tr>
<td>Full-system check-out</td>
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<td>Spring Final Review</td>
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<td>Ohio rehearsal</td>
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<td>Final Checkout</td>
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</tbody>
</table>
Work Breakdown Structure (WBS)

<table>
<thead>
<tr>
<th>Structures</th>
<th>Electrical</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Manufacture engine clamps for CU test stand</td>
<td>• Updated test stand with load cell, flow meter, DAQ</td>
<td>• MATLAB model of JetCat engine</td>
</tr>
<tr>
<td>• Baseline engine characteristic test</td>
<td>• Power dissipation system</td>
<td>• Testing VI</td>
</tr>
<tr>
<td>• Manufacture engine harness</td>
<td>• Calibrated load cell and flow meter</td>
<td>• Rotor dynamics analysis</td>
</tr>
<tr>
<td>• Integrated motor, coupling, engine system</td>
<td>• Power regulation and motor controller system</td>
<td></td>
</tr>
<tr>
<td>• Power output model</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Green tasks are completed, Orange tasks are on track, Red are at risk
Subsystem Components
Engine

- Engine Characterization: **Completed**
  - Model Predictions Verified with Test Data
Coupling System: Status

<table>
<thead>
<tr>
<th>Req #</th>
<th>Requirement Text</th>
<th>Verified by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.2</td>
<td>Connection shall be secure from 0 to 60,000 RPM (operating limit of generator)</td>
<td>Coupler torque test</td>
</tr>
<tr>
<td>3.3.1</td>
<td>Electric motor and engine shafts shall be held in alignment so the shafts are not</td>
<td>Coupling system integration/inspection</td>
</tr>
<tr>
<td></td>
<td>offset by &gt;0.1 mm (0.0039 inches) and 1.5°</td>
<td></td>
</tr>
</tbody>
</table>

- **Commercial-off-the-shelf coupler selected and ordered**
  - Rated to run at 42,000 RPM, above idle speed (35,000)
  - Bore diameters of 5 mm and 3 mm
  - Will be modified for bore diameters of 5.93 mm and 3.17 mm

- **Alignment Harness**
  - Design completed, currently manufacturing
  - Will be precision milled without allowing for adjustments and tested for adherence to tolerances with dial indicators
    - If tolerances not met, arms will be re-milled to allow adjustment screws
  - Stock starter: deflection of 2.5 mm from 277 g
  - COMET’s harness: predicted deflection of 0.05 mm from 277 g
Coupling System: Main Tests

Integration and Inspection: **On Schedule** (Start Date 3/3)

- Assemble alignment harness and check tolerances
- Integrate shaft coupler, generator alignment harness, and generator onto engine
- Inspect entire generator harness and coupling assembly

Low RPM Test: **On Schedule** (Start Date 3/31)

- Verify motor driver circuitry and shaft connection
- Use motor controller circuitry & engine GSU to drive generator to ~6,000 RPM
- Record frequency response with accelerometer to detect modes
Selection of New Starter/Generator

<table>
<thead>
<tr>
<th>Req #</th>
<th>Requirement Text</th>
<th>Verified by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>PEU shall generate electrical power (off ramp predicts 48 W)</td>
<td>Full-system test</td>
</tr>
<tr>
<td>1.3</td>
<td>PEU must operate above 35,000 RPM, the bottom edge of the engine idle range.</td>
<td>Full-system test</td>
</tr>
</tbody>
</table>

**Motor Torque vs RPM**

- Old Starter: 401 mNm (75A)
- Starting torque: 61.13 mNm (45A)
- Starter/Generator: 112.5 mNm (45A)
- Continuous torque limit: 60,000 rpm (2.31A)

**RPM vs Time**

- Actual RPM: 28,000 RPM (0.85A)
- RPM Signal From ECU: 60,000 rpm (2.31A)
Motor and Controller System: Status

Motor Driving System: Max 11.1V 14.14A

Generating Circuitry: Max 16V 15A
Motor Controller System Circuitry

- Control with NI DAQ is no longer being used
- New design will utilize a PWM generating timing chip
Motor Controller System: Main Tests

Motor Controller Circuitry Functionality: On Schedule (End Date 3/4)

- Verify circuitry input and output signals
- Input 2 kHz 9V square wave into circuitry and verify output signal is 50Hz 5V

Motor Controlling to Power Regulating Switching: On Schedule (Start Date 4/14)

- Verify switching between motor controlling and power generating circuitry
- Use motor controlling circuitry and engine GSU
- Stop driving signal and verify relay switching
- Probe motor controlling circuitry and power regulator circuitry to verify signal switching

Test Stand ➔ Engine ➔ Shaft Coupler ➔ Motor & Controller ➔ Power Regulator ➔ Power Dissipater

- Models

Function Generator

2 kHz 9V

Motor Controller Circuitry

Voltage divider
Avg. passive circuit
Comparator
Summing amp
MOSFET
Timing Circuit
Motor Driver
Relays

50 Hz 5V

LabView VI

NI 9205 DAQ

*Low RPM Test

GSU

Motor Controller Circuitry

Relays

Voltage Rectifier

Power Regulator Circuitry

Test Stand

ACC

DAQ Chassis

LabView VI

Budget

Schedule

Subsystems

Project Overview
## Power Regulation

<table>
<thead>
<tr>
<th>Req #</th>
<th>Requirement Text</th>
<th>Verified by:</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>Power generated shall be transmitted at 24 VDC</td>
<td>Full-system test</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Power regulator shall keep the max ripple below 2.4V</td>
<td>Power reg. funct. test</td>
</tr>
<tr>
<td>2.2.3</td>
<td>Power regulator shall accept voltage input from generator</td>
<td>Motor Controlling-Power Regulating switching test</td>
</tr>
<tr>
<td>2.2.4</td>
<td>Power regulator shall accept input frequencies of 1750 - 6250 Hz</td>
<td>Full-system test</td>
</tr>
</tbody>
</table>

- **Off Ramp Design**
  - 50 Watt DC-DC regulator outputs 24 Volts
    - Generator Voltage drives power limitation
  - Voltage ripple of 0.1 V<sub>pp</sub> meets ripple requirement

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**Diagrams**

- **Bridge Rectifier**: 8.05-14.72 V Peaks
- **Smoothing Capacitor**: 8.05-14.72 V ~0.4 Volt Ripple
- **DC-DC Regulator**: 24 Volts 0.1 Volt Ripple

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- **Project Overview**
- **Schedule**
- **Subsystems**
- **Budget**
Power Regulation: Main Tests

Power Regulator Functionality: **On Schedule** *(Start Date 4/4)*

- Verify power regulator input and output
- Use 3 synced function generators to generate 3-phase 9.33-16V sinusoidal signal
- Measure 24V DC output using voltage divider on power dissipater board
- Calculate and verify output signal
Power Dissipation: Status

- A 2 ohm and 10 ohm resistors will dissipate the 48 Watts generated
  - Measure voltage drop across resistor to verify 24 Volt output of DC-DC regulator
- Current sensor will be used in conjunction with the voltage measurement to verify power output matches predictions
Power Dissipation: Main Tests

Power Dissipater Functionality: **Behind Schedule (Projected Completion 2/28)**

- Verify Power Dissipater can dissipate 48W of power at 24V DC
- Use power supply to input 5-24V
- Record voltage and current measurements from current sensor and DAQ
- Use current and voltage data to verify power dissipater model
Full System Test

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>Direct DAQ input</td>
</tr>
<tr>
<td>Output Current</td>
<td>Pololu +/- 31 A current sensor</td>
</tr>
<tr>
<td>Fuel Flow Rate</td>
<td>Equiflow PVDF 0045 flow meter</td>
</tr>
<tr>
<td>Engine Thrust</td>
<td>Test Stand Button Load Cell</td>
</tr>
<tr>
<td>Frequency Response</td>
<td>PCB +/- 2300 g accelerometer</td>
</tr>
</tbody>
</table>

**Boulder Bomb Squad Dugout**

- LabVIEW & Engine Control
- USB Webcam
- Earth Berm

**Engine**
- RPM 35,000 to ~56,000
- Motor
- Controlling Circuitry
- Voltage Rectifier
- Relays
- Load Cell
- Fuel Tank
- ECU
- Flow Meter
- ACC
- DAQ Chassis
- DAQ USB cable
- Engine control & data cable
- USB Webcam
- Earth Berm
- LabVIEW & Engine Control

**Models**
- Test Stand
- Engine
- Shaft Coupler
- Motor & Controller
- Power Regulator
- Power Dissipater

**Project Overview**
**Schedule**
**Subsystems**
**Budget**
Engine Model Predictions

Engine Model (no-load) predictions: **Verified**

Engine Model (load) predictions: **To be Tested**
- Predictions from model indicate requirements will be met.
- Predictions will be verified during Full System Test

<table>
<thead>
<tr>
<th>Req #</th>
<th>Requirement Text</th>
<th>Verified by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Not decrease stock thrust by &gt;25%</td>
<td>Full-system test</td>
</tr>
<tr>
<td>1.2</td>
<td>Not increase stock thrust specific fuel consumption by &gt;50%</td>
<td>Full-system test</td>
</tr>
<tr>
<td>3</td>
<td>Derive electrical power from a JetCat P90-RXI engine at 24 V DC.</td>
<td>Full-system test</td>
</tr>
</tbody>
</table>
Financial Budget Status

**Budget Allocations**

- Generator Harness System
- Other
- Power Conditioning
- Testing Costs
- Unallocated
- Generator
- Power Dissipation
- Motor Controlling Circuit

<table>
<thead>
<tr>
<th></th>
<th>Allocated</th>
<th>Current Expenditures</th>
<th>Future Expenses</th>
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<tr>
<td>Engine Budget</td>
<td>$2,500</td>
<td>$2,530.0</td>
<td>$0.00</td>
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<tr>
<td>Project Budget</td>
<td>$5,000</td>
<td>$2,349.64</td>
<td>$352.97</td>
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<tr>
<td>Travel Budget</td>
<td>$4,359</td>
<td>$0.00</td>
<td>$4,841.00</td>
</tr>
</tbody>
</table>

- Travel funds available for 5 team members
  - 6 currently available to go
  - Final travel roster decided End of March
Questions?
Test Stand

<table>
<thead>
<tr>
<th>Req #</th>
<th>Requirement Text</th>
<th>Verified by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2.1</td>
<td>A method of measurement of fuel flow shall exist.</td>
<td>Inspection</td>
</tr>
<tr>
<td>4</td>
<td>The design solution, shall interface with the test stand designed by the customer</td>
<td>Final Demonstration at WPAFB</td>
</tr>
<tr>
<td>4.1.1</td>
<td>The test stand shall support clamps that are fitted to the engine.</td>
<td>Inspection</td>
</tr>
<tr>
<td>4.1.2</td>
<td>The test stand shall have an axial load cell for means of measuring thrust up to 25 lbs.</td>
<td>Inspection</td>
</tr>
</tbody>
</table>

Engine Test Fire Set Up

- Test Stand
- Engine
- Shaft Coupler
- Motor & Controller
- Power Regulator
- Power Dissipater
- Models
Stock Starter Motor Removal

unscrew

unscrew

unscrew

Pull off
**Engine Models: Status**

- Engine power model completed
  - Provides predictions for thrust and TSFC
  - Predicts torque will be sufficient to power generator

**Commanded RPM**
- Ambient Pressure
- Ambient Temperature

**1D Engine Model**
- Thrust
- TSFC
- Fuel Mass Flow Rate

**Power Model**
\[ A = \frac{P}{V/RPM} \]
\[ \tau = \frac{A}{k_T} \]

**Graphs**
- Calculated Thrust With and Without the Generator
- Calculated TSFC With and Without the Generator
Engine Models: Status

- **Rotor dynamic model:** To be Verified
  - Full FEA model to predict natural modes of unmodified and modified engine

<table>
<thead>
<tr>
<th>Mode Number</th>
<th>Frequency</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>81,000 RPM</td>
</tr>
<tr>
<td>2</td>
<td>210,000 RPM</td>
</tr>
<tr>
<td>3</td>
<td>260,000 RPM</td>
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</tbody>
</table>
Coupling System: Additional Tests

- **Coupler torque test**
  - Test if threaded engine shaft has enough surface area to make a secure connection to coupler
  - Insert engine shaft into coupler and apply known torque using lever arm and known weight
  - Find torque at which shaft slips in coupling
  - If torque reaches 1 Nm (10x greater than expected torque of 0.1 Nm), test will stop without testing to failure
  - Extra coupling purchased in case coupler is marred during test
  - If slip occurs before 1 Nm, shaft will be inserted into other side of coupler and adhesive will be used to fill thread gaps
  - Torque will be applied and measured again after adhesive sets

- **Stiffness test**
  - Verify designed harness system is stiffer than stock system
  - Hang weight from stock starter
  - Measure displacement
  - Calculate displacement expected from designed system using and substituting the force from the physical test
Checking Shaft Alignment

- Conduct test on edge finder table in the shop to ensure dial indicator is mounted consistently normal to the engine/harness assembly
- Use reverse indicator method, standard method of measuring alignment for short, flexible coupling
  - Use two dial indicators mounted on opposite sides of the coupling halves
  - Rotate the shafts and read dials every quarter turn
  - Use known formulas for calculating misalignment at center of coupling

Low RPM Test: Additional Details

Purpose: To ensure shaft connections are stable to ~6,000 RPM
Facility: Senior Projects Room or Buseman Advanced concepts lab

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Instrument</th>
<th>Sampling Rate &amp; expected output</th>
<th>Purpose of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft RPM</td>
<td>Engine Ground Support Unit</td>
<td>~1 Hz 0-6,000 RPM</td>
<td>DATA NOT BEING RECORDED Meant as a display of current RPM, not a data recording device. If resonant frequency found the RPM will be recorded by hand.</td>
</tr>
<tr>
<td>Frequency Response</td>
<td>PCB +/- 2300 g accelerometer</td>
<td>~25kHz 0-2 g’s</td>
<td>Monitoring vibrations during the test will help reveal any shaft misalignments past the tolerances of the shaft coupler. Measurements will either verify that no natural modes are excited and shafts are aligned or show high amplitude vibrations due to shaft misalignment</td>
</tr>
</tbody>
</table>
Motor Controlling to Power Regulator Switching Test: Additional Details

Purpose: To ensure the relays can successfully and properly switch between the motor controlling circuitry and the power regulating circuitry

Facility: Buseman Advanced concepts lab

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Instrument</th>
<th>Sampling Rate &amp; expected output</th>
<th>Purpose of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage into Power Regulator</td>
<td>Multimeter</td>
<td>N/a 0-1.6 V</td>
<td>DATA NOT BEING RECORDED Measurement is to prove that the relays are switching to the power regulator circuitry. Voltage from 6,000RPM is not high enough to pass the DC-DC regulator</td>
</tr>
</tbody>
</table>

See Low RPM Test additional details slide for other measurements
Power Regulator Functionality Test: Additional Details

Purpose: To verify the power regulator is working properly

Facility: Tim May’s Electronics Lab

The Signal: 3-phase sinusoidal wave, 120° phase shift between each sine wave during the test voltage will vary between 9.33-16V to simulate generator signal at 35,000-60,000 RPM

The Function Generators: Three function generators will be used to simulate this signal. All 3 will be synced using the built in syncing channel, then function generator 2 will have a 120° phase shift and function generator 3 will have a 240° phase shift
Power Dissipater functionality Test: Additional Details

Purpose: to verify the power dissipation system can dissipate at least 50W of power. Functionality includes the current and voltage sensors as well as the labview VI to read and record current, voltage, and power.

Facility: Trudy’s Electronics Lab

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Instrument</th>
<th>Sampling Rate &amp; expected output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>Direct DAQ input</td>
<td>5 Hz 5-24 V</td>
</tr>
<tr>
<td>Output Current</td>
<td>Pololu +/- 31 A current sensor</td>
<td>5 Hz 0-5 V (corresponding to 0-2 A)</td>
</tr>
</tbody>
</table>
Selection of New Starter/Generator

Motor Torque/Speed Curve

Current Starter

\[ K_{emf} = \frac{V}{\text{rad/s}} = \frac{Nm}{A} = \frac{0.06313}{28} = 0.0023 \frac{Nm}{A} \]

\[ V_{emf} = \omega K_{emf} = (628.32)(0.0023) = 1.42V \]

\[ R1 = \frac{V_{operating}}{A_{stall}} = \frac{6}{28.08} = .214\Omega \]

\[ V_{drop \ across \ R1} = 3.24_{test} - V_{emf} = 1.82V \]

\[ V = IR \rightarrow I = \frac{V}{R} = \frac{1.82}{.214} = 8.52A \]

\[ \tau_m = K_T I = (0.0023)(8.52) = 0.02Nm \]

\[ I = \frac{\tau_m}{K_T} = \frac{0.02}{0.0025} = 8A + 2.3A = 10.3A \]

\[ FOS = \frac{\text{motor operating current}}{\text{motor current}} = \frac{45}{10.3} = 4.37 \]
Engine: Main Tests

Stock Engine Characterization: Completed

Measured engine fuel flow rate, thrust, and frequency response over operational range

Data used to validate MATLAB Engine Model and Rotor Dynamics Calculations, also provided baseline performance

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Speed</td>
<td>131,000 RPM</td>
</tr>
<tr>
<td>Max Speed During Startup</td>
<td>53,000 RPM</td>
</tr>
<tr>
<td>Thrust at Max Speed</td>
<td>19.8 lbs</td>
</tr>
<tr>
<td>Max Fuel Flow</td>
<td>~330 mL/min</td>
</tr>
<tr>
<td>Max Temperature</td>
<td>725°C</td>
</tr>
</tbody>
</table>
## Full System Test

<table>
<thead>
<tr>
<th>Req #</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The design solution shall not decrease stock thrust by more than 25%</td>
</tr>
<tr>
<td>1.2</td>
<td>The design solution shall not increase the thrust specific fuel consumption by more than 50%</td>
</tr>
<tr>
<td>1.3.1</td>
<td>The design solution must operate above 35,000 RPM, the bottom edge of the engine idle range.</td>
</tr>
<tr>
<td>2</td>
<td>Power generated shall be transmitted using 24 V DC current</td>
</tr>
<tr>
<td>3</td>
<td>The design solution shall be able to derive power from a JetCat P90-RXI engine.</td>
</tr>
<tr>
<td>3.1</td>
<td>The rotational energy of the engine shaft shall be converted into electrical energy via a generator.</td>
</tr>
<tr>
<td>4</td>
<td>The design solution, when integrated with the JetCat P90-RXI engine, shall interface with the test stand designed by the customer and the test stand available through CU.</td>
</tr>
<tr>
<td>4.1</td>
<td>The dimensions of the design solution and engine shall not exceed those shown below in Figure 2.4-1.</td>
</tr>
</tbody>
</table>

Facility: Boulder Bomb Squad  
Test Duration: 2.5 hours (1 hour travel & set-up, 30 min testing, 1 hour pack up & travel)  
Equipment: Test Stand Assembly, Fuel Flow Sensor, Load Cell, Accelerometer, Design solution
Travel

<table>
<thead>
<tr>
<th>Day</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 20</td>
<td>Travel to Dayton, OH.</td>
</tr>
<tr>
<td>May 21</td>
<td>Demonstrate project</td>
</tr>
<tr>
<td>May 22</td>
<td>Participate in group poster session and return to Boulder, CO.</td>
</tr>
</tbody>
</table>

**Budget Subsystems**

- Currently $500 shortfall on travel for available team members
  - Have funds to take 5 team members and Dr. Starkey

### Itinerary

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### Travel Roster

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Ryan Starkey</td>
<td>Team Advisor</td>
</tr>
<tr>
<td>Matt McClain</td>
<td>Project Manager</td>
</tr>
<tr>
<td>Megan O’Sullivan</td>
<td>Test Engineer</td>
</tr>
<tr>
<td>Ben Woeste</td>
<td>Safety Officer</td>
</tr>
<tr>
<td>Jon Lumpkin</td>
<td>Electrical Lead</td>
</tr>
<tr>
<td>Kevin Wong</td>
<td>System Engineer</td>
</tr>
<tr>
<td>Eric James (Tenative)</td>
<td>Software Lead</td>
</tr>
</tbody>
</table>

### Item Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Quantity</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airfare</td>
<td>$350 round trip</td>
<td>7 people</td>
<td>$2,450.00</td>
</tr>
<tr>
<td>Hotel rooms</td>
<td>$120 per night</td>
<td>2 nights, 3 people per room*</td>
<td>$840.00</td>
</tr>
<tr>
<td>Per diem</td>
<td>$56 per day</td>
<td>8 people, 3 days</td>
<td>$1,176.00</td>
</tr>
<tr>
<td>Rental Car</td>
<td>$125 per day for van</td>
<td>3 days</td>
<td>$375.00</td>
</tr>
</tbody>
</table>

**Total**

- $4,841.00

**Available**

- $4,359.00

* Considerations have been made to give separate rooms to the men and women of the team; additionally the team’s advisor has been given his own single room

* Currently $500 shortfall on travel for available team members
  - Have funds to take 5 team members and Dr. Starkey
New Load Cell for Full System Tests

- Omega LCGD-25 Compression Load cell
- Measurement Range: 0-25 lbf
- Excitation Voltage: 10 VDC
- Output: 2 mV/V nominal
- Linearity: +/- 0.25%
- Repeatability: +/- 0.1%