OSPRI

Offset **S**-duct **PR**opulsion **I**nlet

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Customer: Air Force Research Laboratory
POC: Capt. Riley Huff

Section 1

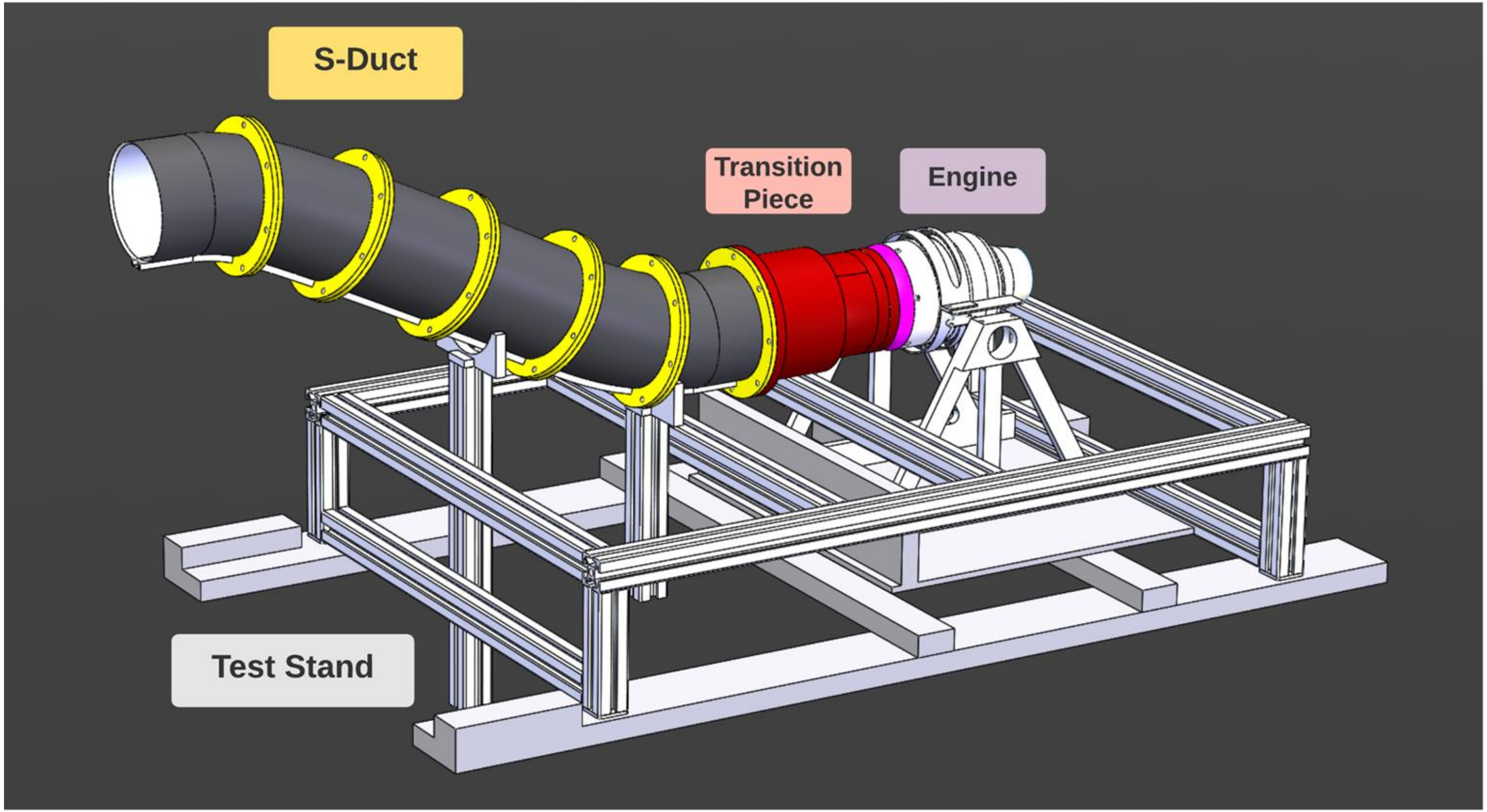
Overview

Problem Statement

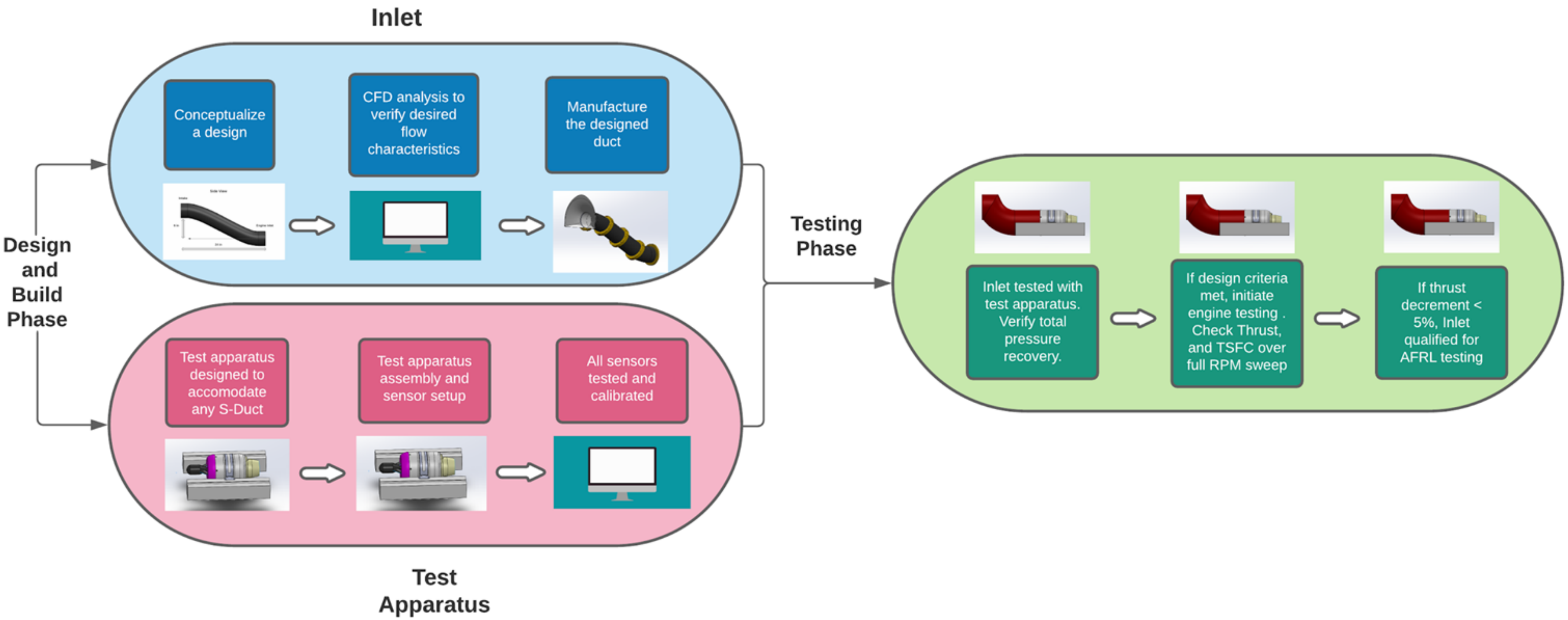
The purpose of the OSPRI project is to:

- Design and build an S-duct inlet for use with the JetCat P100-RX turbojet engine, for the Air Force Research Lab's (AFRL's) Aerospace Propulsion Outreach Program (APOP)
- Additionally, OSPRI will design and build a testing apparatus to measure total pressure and distortion distributions in the inlet, and measure fuel flow and thrust produced by the JetCat

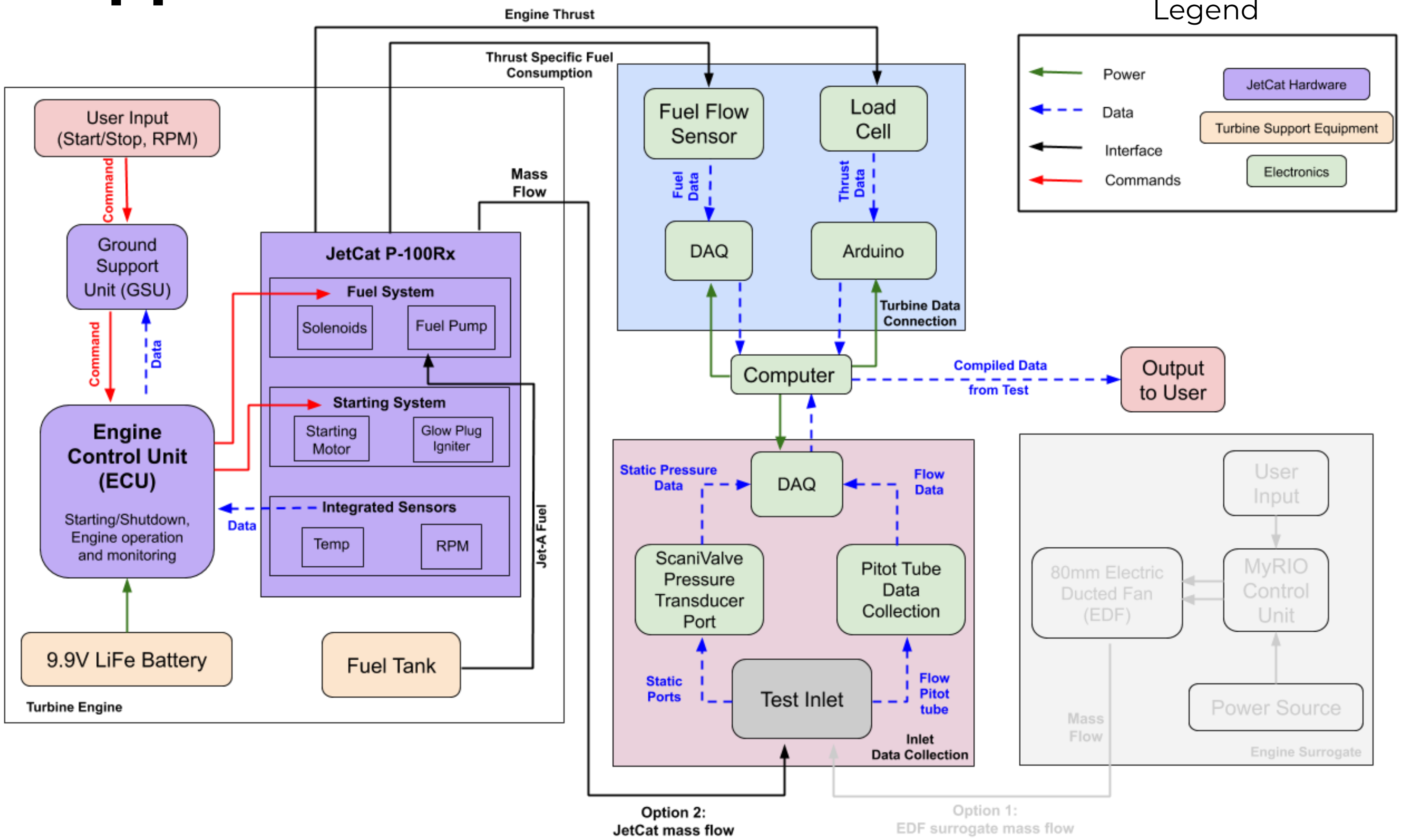
Project Model



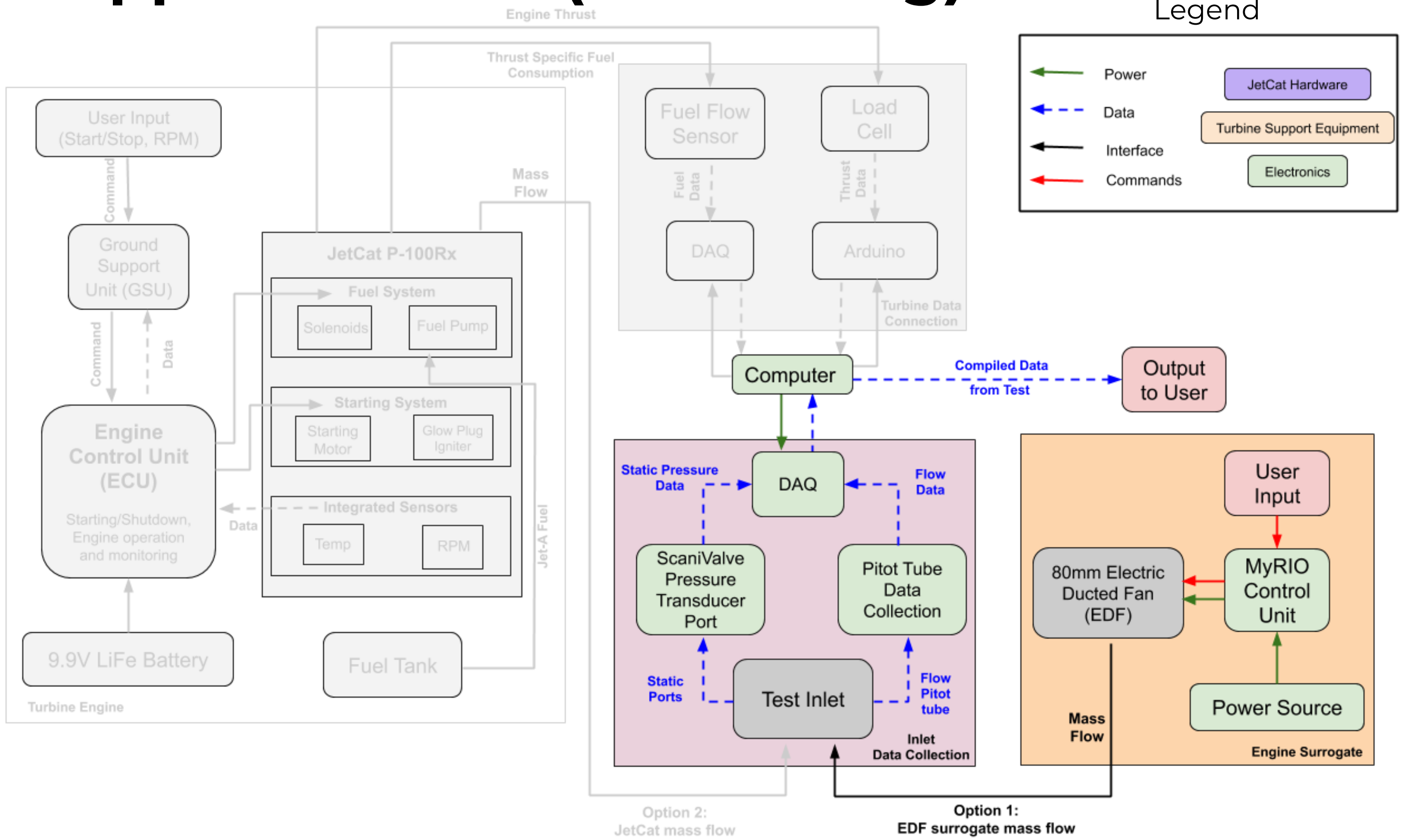
Concept of Operations (CONOPS)



Test Apparatus FBD



Test Apparatus FBD (For Testing)



Levels of Success

Level	Objective
1	A test rig is designed and manufactured that is capable of measuring all parameters as outlined in the Design Requirements
2	Experimental Verification of the test rig’s ability to measure thrust and TSFC
3	Experimental Verification of the test rig’s ability to characterize the flow within a test inlet
4	Experimental verification of an inlet with total pressure recovery >90%
5	Experimental verification of nominal engine operation with level 4 inlet attached, with decrements to thrust and TSFC of no more than 10%
6	Experimental verification of nominal engine operation with inlet attached, with decrements to thrust and TSFC of no more than 5%, and total pressure recovery ≥98%

Critical Project Elements (Test Apparatus)

1. LabView & Electronics:

    Three main functions from LabView control: Sensor data collection, EDF control, and turbine related sensor data collection

1. Mass Flow Surrogate:

    Engine condition replication using Electric Ducted Fans allows for more inlet testing

1. Support hardware and infrastructure:

    Test apparatus anchor point providing support for inlet, facilitates EDF and turbine tests

1. JetCat integrated testing:

    Testing to calibrate and increase mass flow surrogate fidelity, integrated testing with inlet to provide thrust and TSFC data (customer requested)

Critical Project Elements (Inlet)

1. Print Inlet Sections:

    Print inlet sections in a timely and cost effective manner

1. Print Transition Pieces:

    Print transition pieces provided by AFRL

1. Assembly:

    Assemble the printed sections and get inlet ready for testing

1. Iterative re-design and second printing:

    Utilize data gathered to manufacture improved inlet

Section 2

Schedule

Schedule

OSPRI	start	end
Manufacturing	**01/17/21**	**04/04/21**
Testing	**02/15/21**	**03/19/21**
TRR Deadline	03/08	03/08
TA	**02/15/21**	**03/19/21**
EDF	**02/15/21**	**03/10/21**
Wind tunnel sensor calibration	02/15	02/17
EDF functionality	02/18	02/18
EDF mass flow verification	02/24	02/25
LabView EDF control	02/24	03/01
EDF control verification	03/02	03/05
Turbine to EDF mass flow calibrat...	03/02	03/06
Inlet testing	03/06	03/10
Turbine	**02/16/21**	**03/19/21**
JetCat verification	02/16	02/21
JetCat mass flow verification	02/27	03/03
Labview Equiflow fuel flow sensor...	03/01	03/03
Flow sensor/load cell calibration	03/04	03/05
JetCat baseline	03/06	03/10
Inlet testing	03/15	03/19
Inlet	**03/11/21**	**04/20/21**
EDF Data Analysis	03/11	03/14
Turbine Data Analysis	03/20	03/24
(If necessary) Inlet Redesign	03/15	03/19
Print 2nd Inlet	03/22	04/02
EDF Test	04/03	04/06
EDF Data Anlysis	04/07	04/11
Turbine test	04/12	04/16
Turbine Data Analysis	04/17	04/20
Spring Final Review	**03/29/21**	**04/19/21**
SFR Slides	03/29	04/11
SFR Edits	04/12	04/16
SFR Run-throughs	04/12	04/18
SFR Due	04/19	04/19
Project Final Report	**04/19/21**	**05/05/21**
PFR Writeup	04/19	04/25
PFR Edits	04/27	05/03
PFR Due	05/05	05/05

Schedule (cont’d)

- For SFR deliverables, 3 weeks of margin
  - Unable to incorporate 2nd inlet design before SFR
- For PFR, 2 weeks of margin if 2nd design necessary
- AFRL testing date unknown
  - Will incorporate once provided
  - Date may allow for another iteration (team availability depending)

Section 3

Test Readiness

JetCat Verification Test Status: Complete

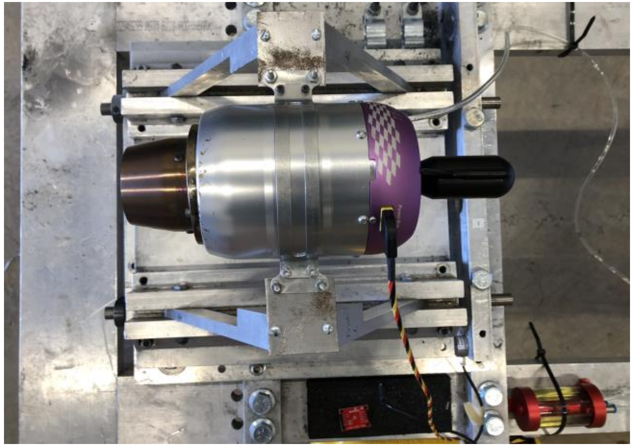
Objective: Ensure that OSPRI has all required facilities and hardware to run turbine in the aerospace building

Test Fixtures: Engine test cell, horizontal engine test stand

Equipment/Setup: JetCat engine, engine support equipment, radios (for communication)

Risk Management:

- Ensure that there is a functioning turbine to conduct live inlet tests
- 2 man system with radio communication
- Blast proof control room
- Exhaust blast shield
- Clearing FOD immediately near turbine



Turbine mounted on engine cell test stand

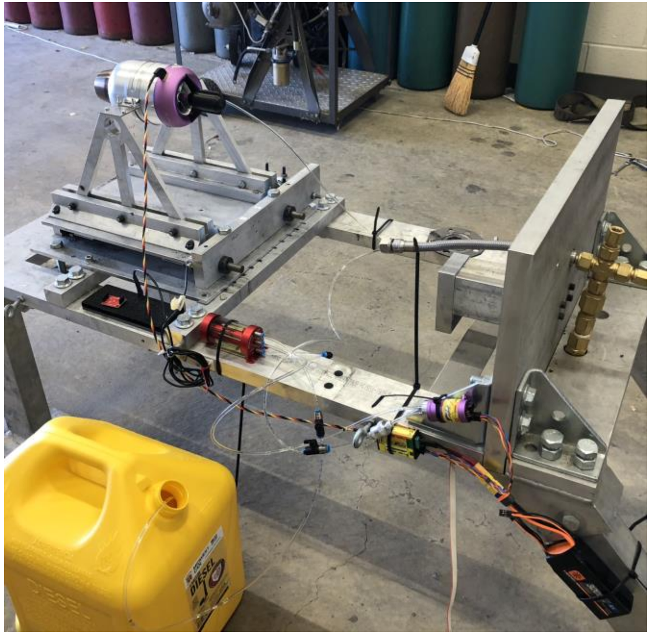
Procedure and Results (JetCat Verification Test)

Procedure

1. Secure turbine and all associated support equipment to the horizontal test stand
   a. Route control cable for GSU into control room
2. Open garage door and set up blast shield
3. Notify professor ready to run turbine
4. Place downrange man outside /radio test ready

Results

- 2 successful test runs (~1 min and 5 min)
- Preliminary thrust data collection failed, arduino error



Turbine setup with support equipment in test cell

JetCat Baseline Test **Status:** In Progress

Objectives: Obtain JetCat thrust and thrust specific fuel consumption data

Test Fixtures: Engine test cell, horizontal engine test stand

Equipment/Setup: JetCat engine, engine support equipment, Scanivalve & pitot probe, radios (for communication)

Risk Management:
- Data collected will provide baseline which will be used in performance analysis
- 2 man system with radio communication
- Blast proof control room
- Exhaust blast shield
- Clearing FOD immediately near turbine

Procedure and Results (JetCat Baseline Test)

Procedure

1. Secure turbine and all associated support equipment to the horizontal test stand
    a. Route control cable for GSU into control room
2. Set up load cell with the data collection arduino for thrust data
3. Set up and connect fuel flow sensor to fuel tubing
4. Open garage door and set up clast shield
5. Notify professor ready to run turbine
6. Place downrange man outside/radio test ready

Results

- Test not conducted
- Goal: Measure corresponding thrust and TSFC

Wind Tunnel Sensor Characterization Test **Status:** Outstanding

Objective: Characterize steady state flow pressure data consistency to calibrate data sampling configuration.

Test Fixtures: Wind tunnel

Equipment/Setup: Pitot Probe, Scanivalve, LabView Pressure DAQ software

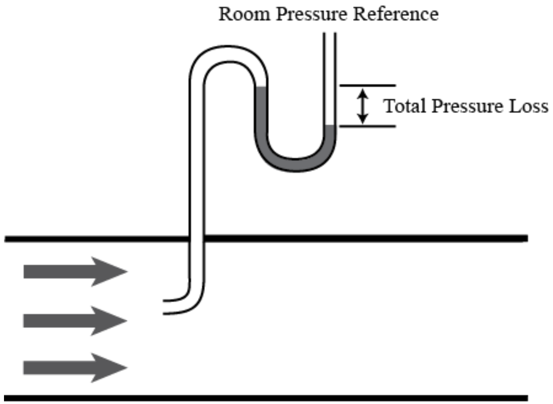
Risk Management:

- Ensures accurate flow data measurements in later experiments
- Operate wind tunnel on existing procedures
- Single operator in the wind tunnel room

Procedure and Results (Wind Tunnel Sensor Characterization Test)

Procedure

1. Secure pitot probe in wind tunnel test section & connect to scanivalve
   a. Measure total pressure referenced against room pressure
   b. Represents the total pressure loss of the Wind Tunnel Inlet
2. Collect pressure data at a variety of steady state flow velocities (5, 10, 15, 20 m/s) using OSPRI device & software



Results

- Test not conducted
- Goal: Characterize pressure measurement uncertainty at steady state conditions

JetCat Mass Flow Data Collection Test **Status:** Outstanding

Objectives: Verify previous JetCat mass flow model calculations.

Test Fixtures: Engine test cell, horizontal engine test stand, inlet test frame, AFRL transition piece

Equipment/Setup: JetCat engine, engine support equipment, bellmouth inlet, pitot probe, scanivalve, labview

Risk Management:

- Data collected reduces error for the mass flow rates of the surrogate
- Prior tests with JetCat to ensure safe operation of the JetCat turbine
- 2 man system with radio communication
- Blast proof control room/exhaust blast shield
- Clearing FOD immediately near turbine

Procedure and Results (JetCat Mass Flow Data Collection Test)

Procedure

1. Secure turbine and all associated support equipment to the horizontal test stand
   a. Route control cable for GSU into control room
2. Secure bellmouth to frame and AFRL transition piece on turbine
3. Connect pitot probe to scanivalve (located in control room for safety)
4. Open garage door and set up clast shield
5. Notify professor ready to run turbine
6. Place downrange man outside/radio test ready

Straight Bellmouth

Results

- Test not conducted
- Goal: Collect mass flow at 5 representative point within the JetCat's RPM sweep

EDF Mass Flow Verification Test **Status:** Outstanding

Objectives: Verify EDF is capable of computed requirements and actual JetCat mass flow data & correlate throttle input to mass flow

Test Fixtures: Bell mouth, Test Apparatus, EDF transition piece

Equipment/Setup: EDF, 4-6 S battery, Pitot Probe, Scanivalve, Wind Tunnel Room

Risk Management:
- Risk reduction by using EDF instead of JetCat for preliminary inlet tests
- Test Apparatus being used to secure the EDF
- Wireless EDF control

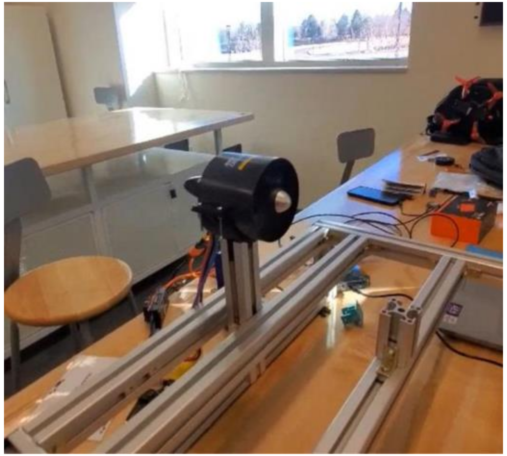
Procedure and Results (EDF Mass Flow Verification Test)

Procedure

1. Attach the EDF to the bellmouth inlet
2. Set up pitot tube to measure dynamic pressure
3. Note distance and position of probe from EDF
4. Calculate mass flow at various total throttle % setting (25%, 50%, 75%, 100%)
    a. Begin with a 4S battery
    b. If necessary, increase power with a 6S battery

Results

- Test not conducted
- Goal: Develop an equation relating throttle to mass flow
- Goal: Confirm that selected EDF is adequate



EDF mounted to test stand

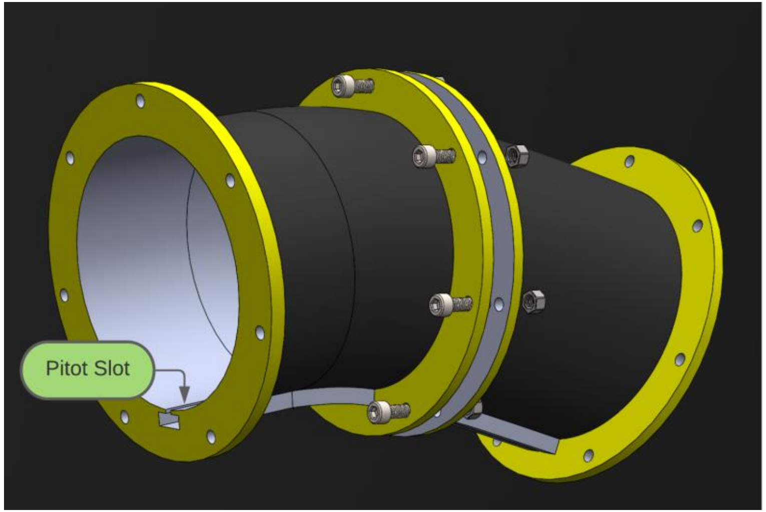
Inlet Verification

Primary Aspects to verify:

- Total pressure recovery from intake to exit (>98%)
- Thrust decrement < 5%
- TSFC decrement < 5%
- Primary scoring criteria

Test Fixtures:

- Slot design to insert a pitot tube
- Test stand attached to a load cell



Inlet Sectional Side View

Inlet Verification EDF

Why the EDF?

- To prevent damages to the JetCat in case of poor inlet performance

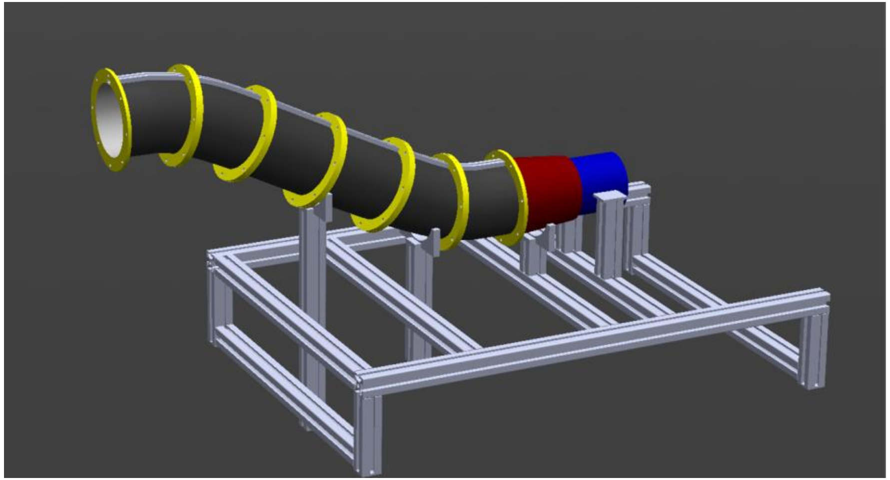
Equipment/Setup:

- Extensively uses test apparatus
- EDF: Preliminary Test
- Engine test room used for testing

Risk Management:

- Sensors calibrated using wind tunnel in the aerospace building
- Additional support structure to hold the inlet

Anticipated Start Date: March 6th



Experimental Setup with EDF

Inlet Verification JetCat

Verification:

- Measure thrust and TSFC performance
- Final testing before AFRL testing

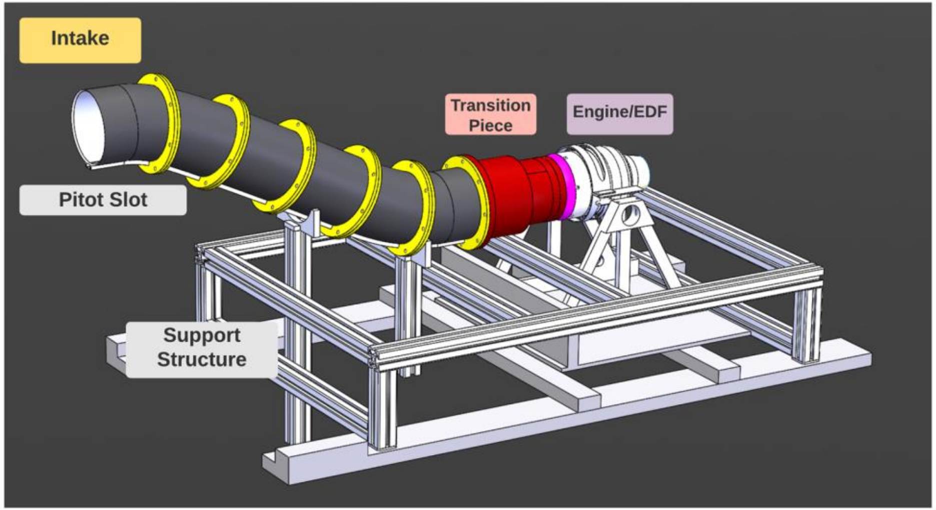
Equipment/Setup:

- Test apparatus plus the existing experimental stand
- Engine test room used for testing

Risk Management:

- Inlet pressure recovery verified and tested on the EDF
- Same sensors used for consistent data

Anticipated Start Date: March 15th

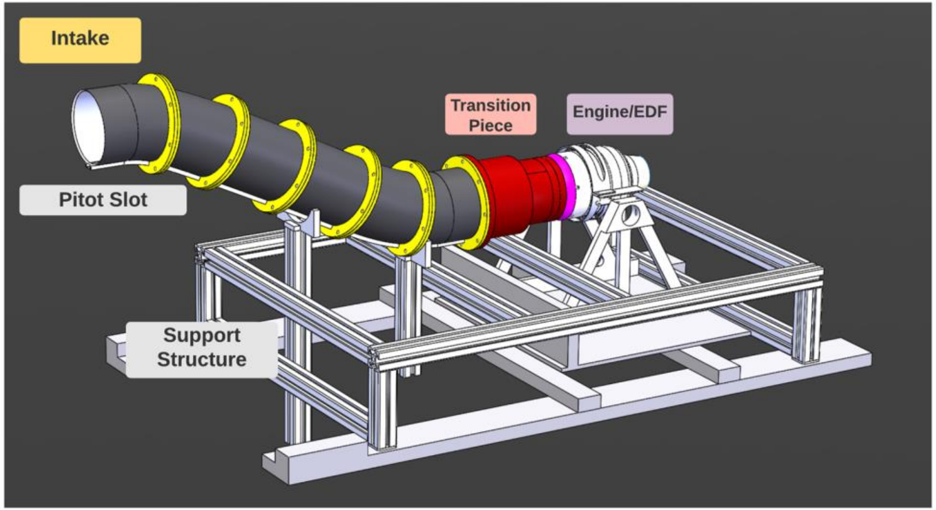


Inlet Experimental Setup

Procedure and Results (Inlet Verification)

Testing Procedure

1. Verify inlet and EDF/engine assembly is seated in TA.
2. Insert pitot tube into slotted inlet section
   a. Perpendicular to sidewalls
   b. 5 test points
   c. Patch slot(s) with HVAC tape
3. Power EDF, collect dynamic pressure data.
4. Collect thrust data from load cell
5. Repeat steps 2, 3 and 4 moving toward compressor face



Inlet Experimental Setup

Results

- Goal: Have an array of pressure values along inlet
- TSFC calculated using data

Expected Result and Model Verification

Verification:

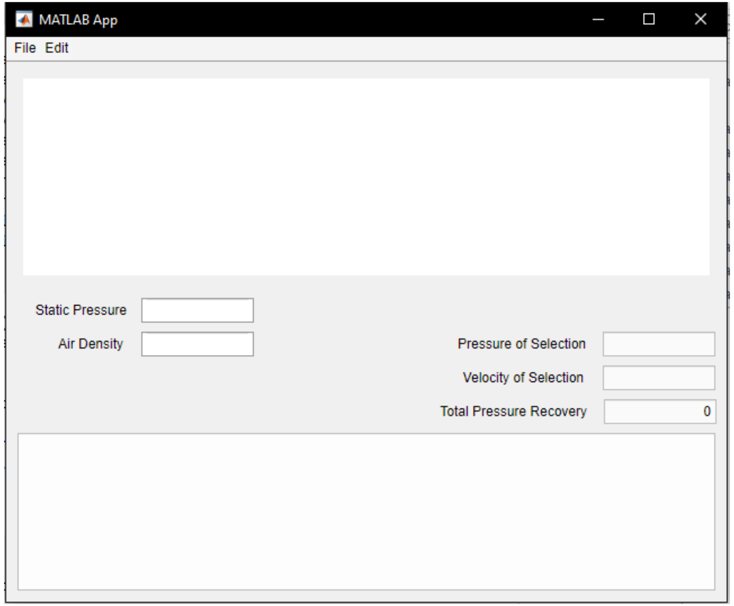
- Using the pitot tube, EDF, and jet engine to capture cross-sectional dynamic pressure profiles of the inlet.

Expected Success:

- Verify high Total Pressure Recovery % > 98%.
- Verify flow separation points and boundary layer formations as predicted.

Further Developments:

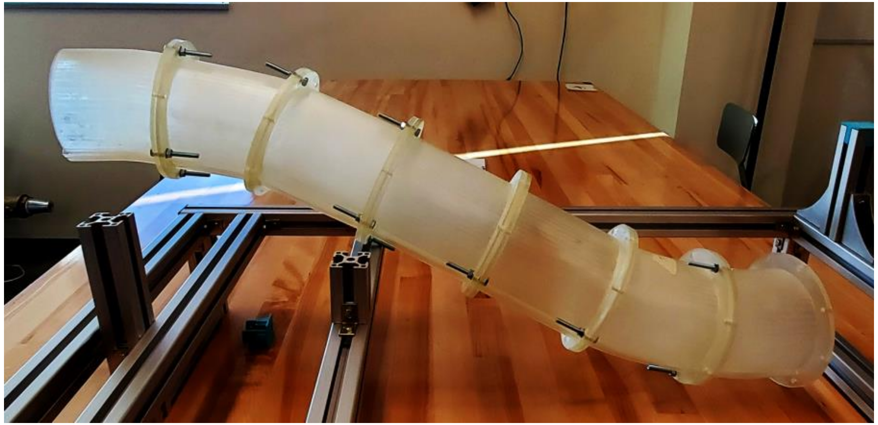
- Working on 3D CFD to further improve the fidelity of the CFD models, as well as improve the redesign workflow.



MATLAB GUI that will help calculate total pressure recovery from the data expected

Current Status

- Inlet Assembled
- Ready for initial verification test

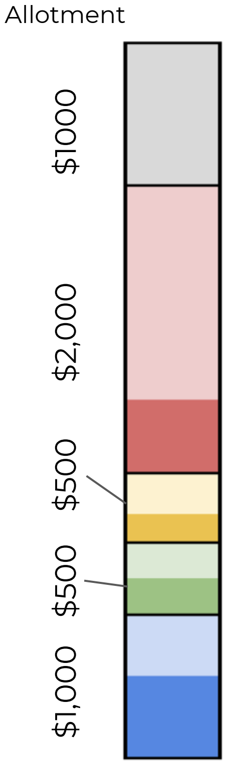


First Inlet Iteration Assembly

Section 4

Budget

Cost Plan



Unused Funds - ($ -) Plenty of extra room in budget to be reallocated

Inlet Manufacturing - ($560) Enough room for ~4 prints at current estimates

Test Apparatus - ($203) Test stand fully purchased, room for another if necessary

Instrumentation - ($229) Most instruments borrowed from Aero Dept, plenty of budget in case

Engine Maintenance - ($586) Engine sent to JetCat & fixed twice, extra budget given engine

Major Costs

- **Inlet**
  - SLA Printing 6 pieces ($50 - $60 each) ~ $360
  - Transition Pieces 4 pieces ($40 each) ~ $160
  - Bolts, nuts, and tape ~ $40
  - Total budget for Inlet iterations: $2000
  - Leftover money: $1440
- **Test Apparatus**
  - Mounting Cradles 4 ($25-30 each) ~ $120
  - Set screws, nuts, hardware ~ $30
  - Total budget for Test Apparatus: $500
  - Leftover money: $300

Resources

- [1] Lee, J., Cho, J. ”Effect of aspect ratio of elliptical inlet shape on performance of subsonic diffusing S-duct,” J Mech Sci Technol 32, 1153–1160 (2018). https://doi.org/10.1007/s12206-018-0218-5.
- [2] Anderson, J., Introduction to Flight Eighth Edition, New York City:McGraw Hill education, 2016
- [3] Sun, S., Guo, R.W. 2006. “Serpentine Inlet Performance Enhancement Using Vortex Generator Based Flow Control,” Chinese Journal of Aeronautics
- [4] Tanguy, G. 2016. “Passive flow control study in a convoluted intake using Stereo Particle Image Velocimetry,” The French Aerospace Lab
- [5] Kirk, A. M. 2006. “Active flow control in an advanced serpentine jet engine inlet duct Master's thesis”, Texas A&M University
- [6] Shaw, R., “The Influence of Hole Dimensions on Static Pressure Measurements,” Department of Mechanical Engineering, University of Liverpool, 1 July 1959.
- [7] “Delta-V 32 80mm (EFLDF32) Fan Unit Instructions,” Horizon Hobby, retrieved November 12, 2020.
- [8] Reichert, B.A., and Wendt, B.J., 1994, “Improving Diffusing S-Duct Performance by Secondary Flow Control,” AIAA 32nd Aerospace Sciences Meeting and Exhibit.
- [9] Basawaraj, Hosur, S., 2016. “CFD Analysis of Serpentine Inlet Duct to Enhance the Flow Properties Using Vortex Generator,” International Journal of Innovative Research in Science, Engineering and Technology
- [10] Rabe, A. 2003. “Effectiveness of a Serpentine Inlet Duct Flow Control Scheme at Design and Off-Design Simulated Flight Conditions,” Virginia Polytechnic Institute and State University
- [11] Anderson, B. H., and Gibb, J., "Vortex Generator Installation Studies on Steady State and dynamic Inlet Distortion," AIAA Paper 96-3279, July 1996.
- [12] Dudek, J. C., "Empirical Model for Vane-Type Vortex Generators in an Navier-Stokes Code", AIAA Journal, Vol. 44, No. 8, pp 1779-1789,August 2006.

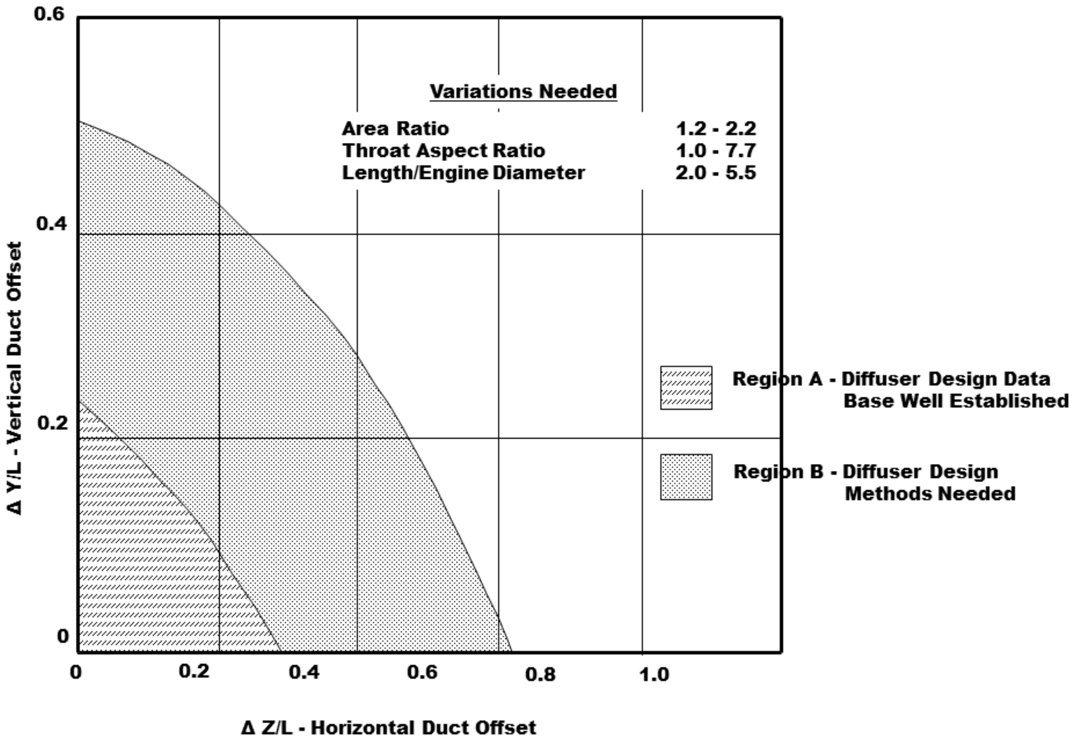
Resources

- [13] HARRINGTON-CRESSMAN, PETER J.M., "AIRCRAFT SYSTEM COMPARTMENT DIAGRAM." Retrieved 10 September 2020. https://www.airlinereporter.com/2015/09/requiem-trijet-masterpiece-lockheed-l-1011-tristar/aircraft-system-compartment-diagram/

Additional Slides

Inlet Slides

Inlet Length Guide



Vortex Generator Example Visualization [10]

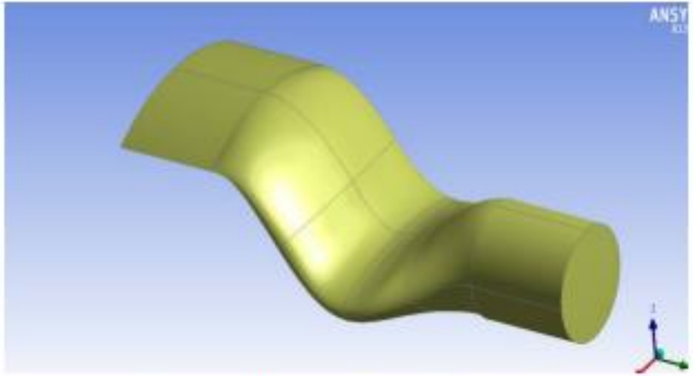


Figure-1 Baseline serpentine duct model

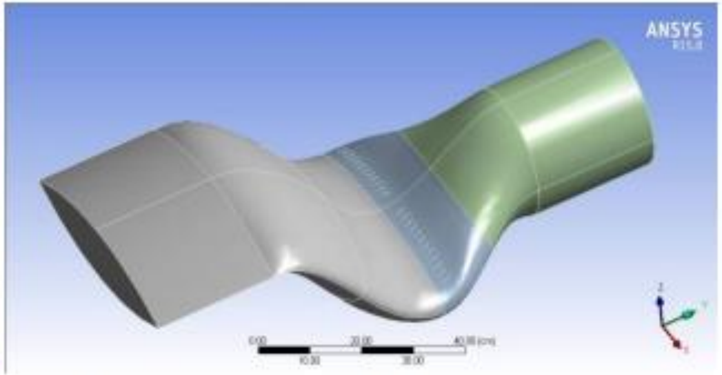
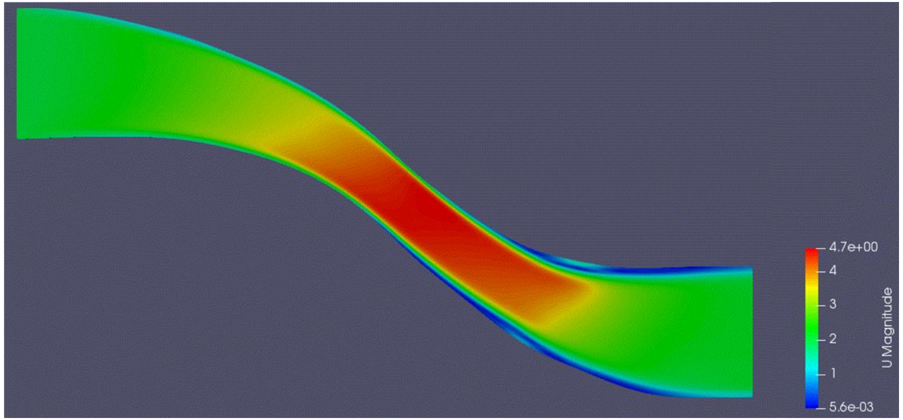


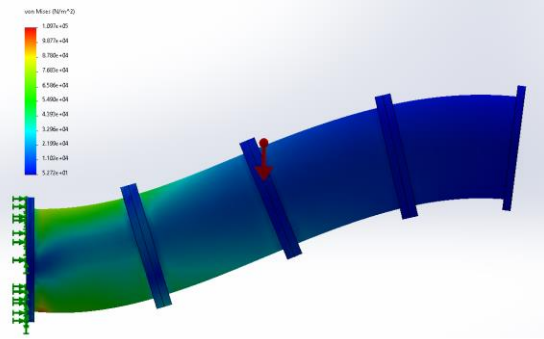
Figure-2 Serpentine duct with vortex generators

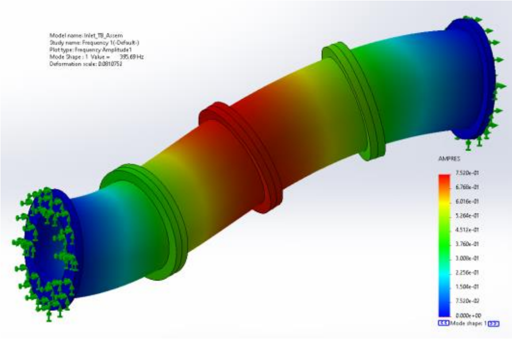
CFD Results (Design 05) using icoFoam

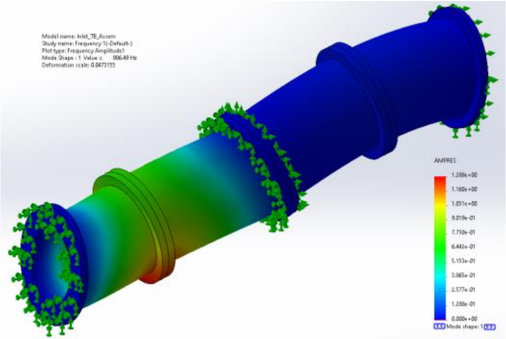


Re#: ~2350 (Transition-Turbulent Flow)

Stress and Vibration Analysis







- Free standing Static

- Restrained at ends only
- 1st failure mode at 396 Hz

- Restrained at ends and throat
- 1st failure mode at 986 Hz

- Tests conducted with Formlabs Standard (Clear) material properties
- Inlet: L = 24 in AR = 1

Challenges

- ➔ Crack in flange of Inlet section
  - 2 cm length
  - Does not extend to the actual inlet
  - Pressing forward with use

Top View

Outsourced Quotes

➔ The 3D Printing Store

Quote

3DPS
3D PRINTING STORE
Powered By

Date:	January 25, 2021
Valid Until	February 24, 2021
Customer:	Tim Breda

Customer Info:	
Company	
Client	Tim Breda
Email	Timothy.Breda@colorado.edu
Number	

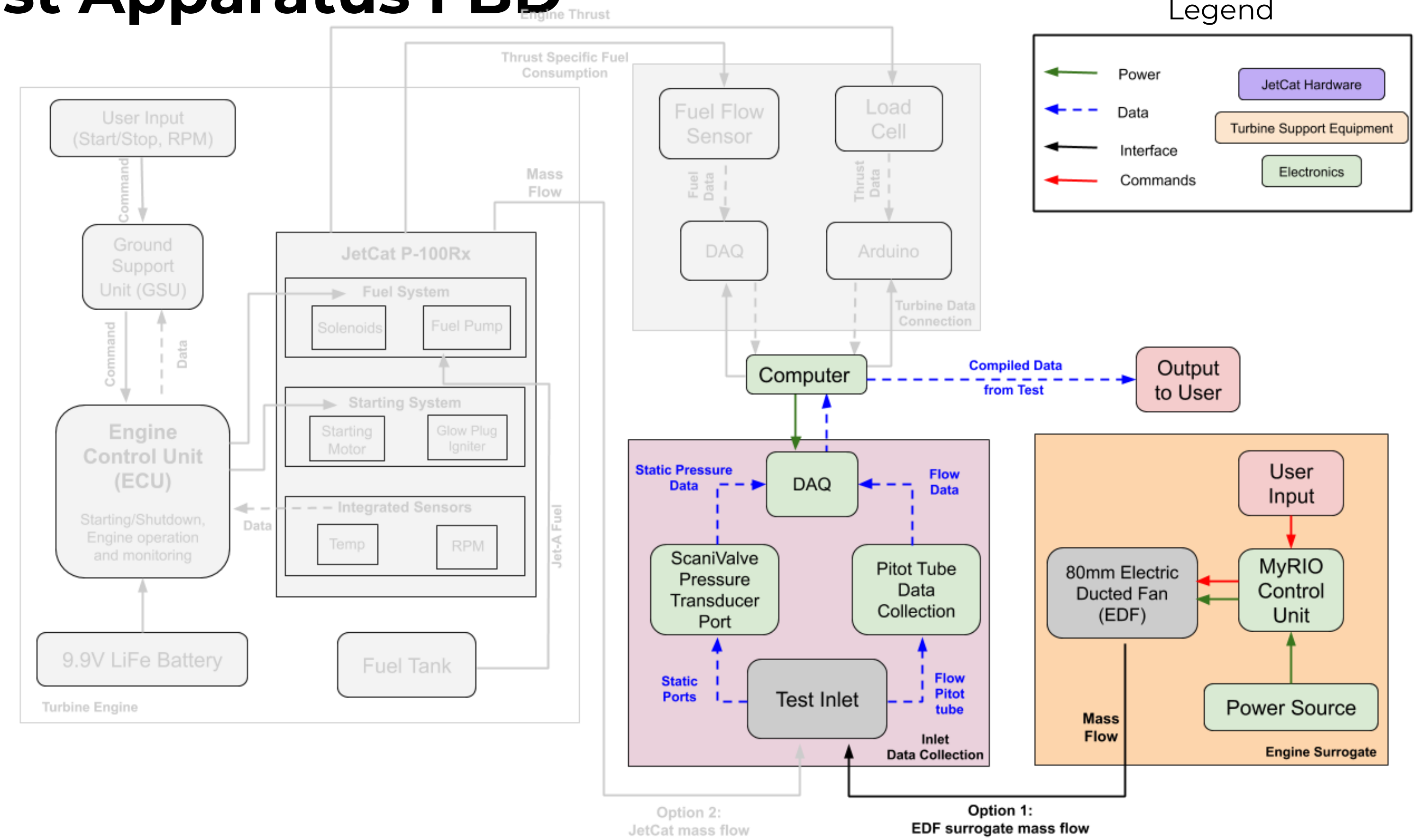
Quote/Project Description

50 um EDF transition and Inlet and Inlet transition and Jetcat 1x each
Hard Black-Photocentric

Line Item	Service	Description	Quantity	Unit	Price	Line Total
1	Print	50 um EDF transition and Inlet and Inlet transition and Jetcat 1x each Hard Black-Photocentric	1.00	Each	$780.09	$780.09
2	Sanding		2.00	Hours	$35.00	$70.00
3	Support Removal		2.00	Hours	$10.00	$20.00
4						
5						

Test Apparatus Slides

Test Apparatus FBD



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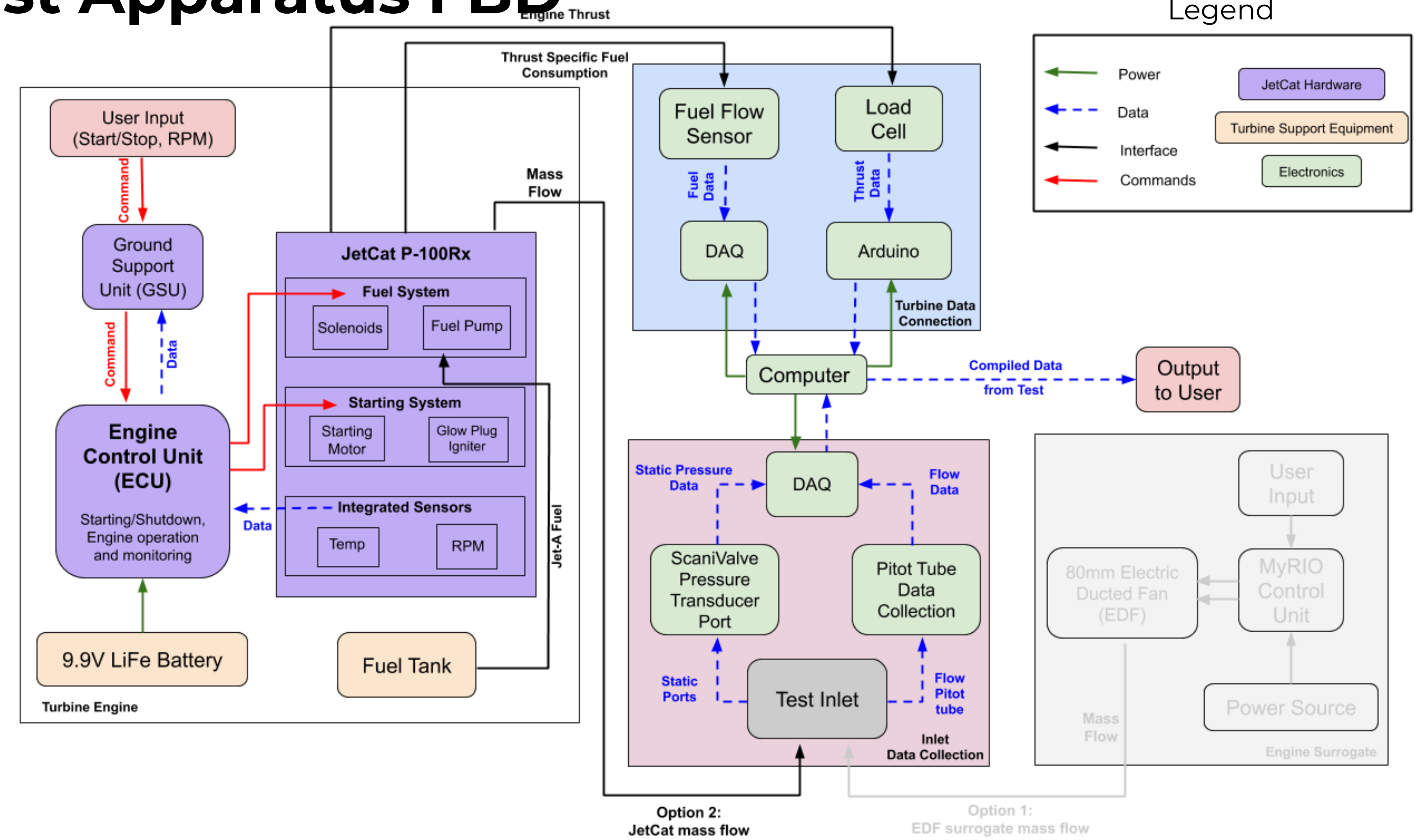
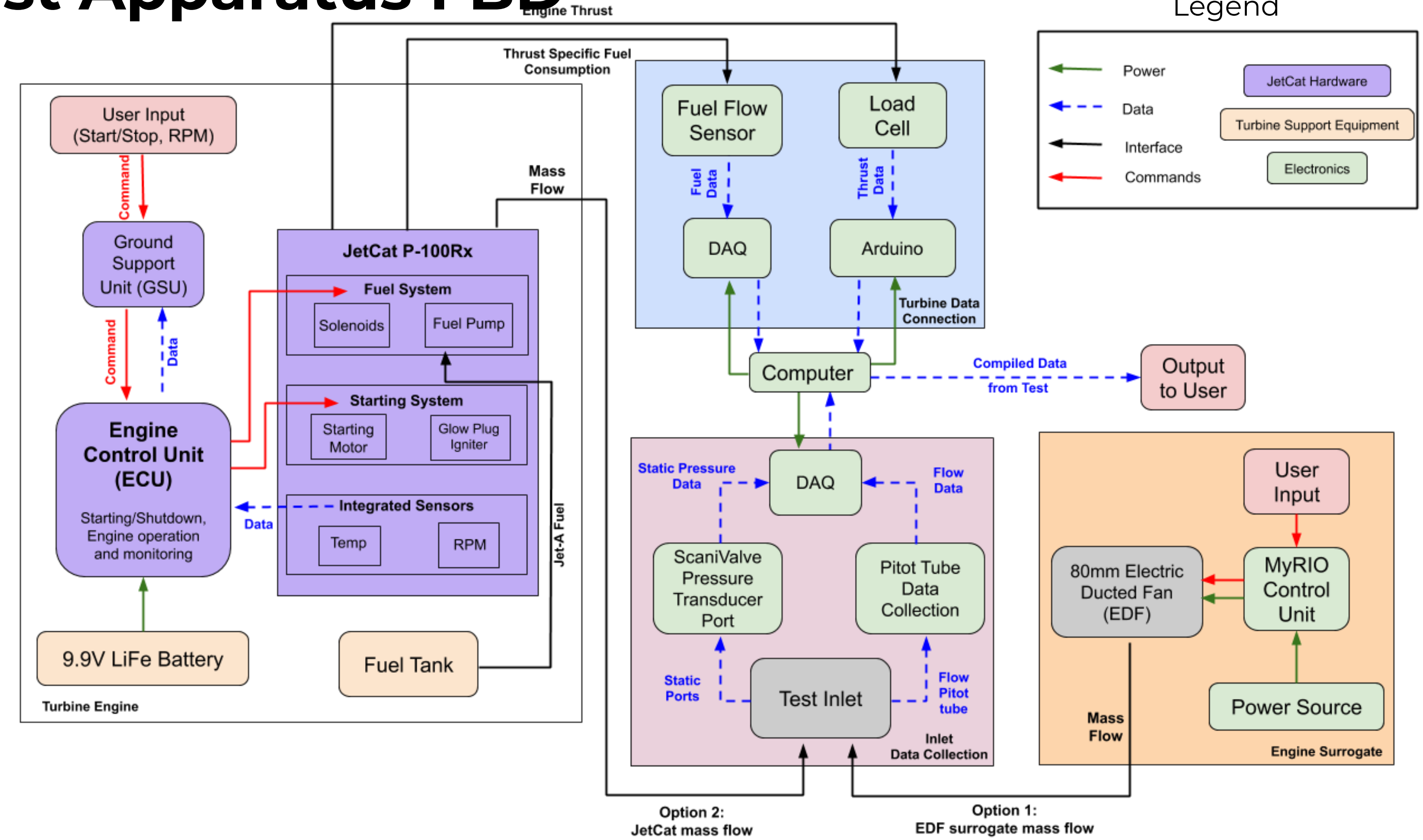
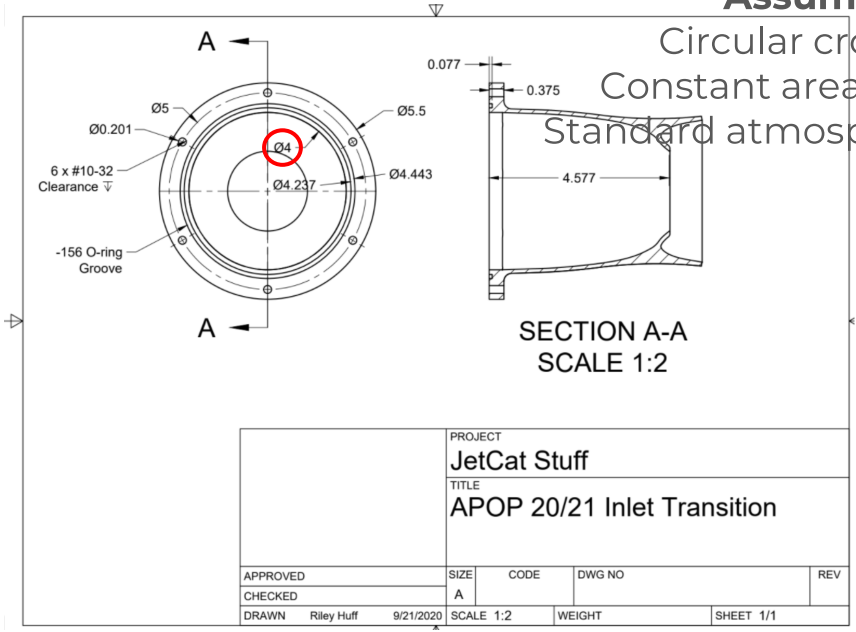


Test Apparatus FBD



Mass Flow Surrogation



Assumptions:

Circular cross section

Constant area cross section

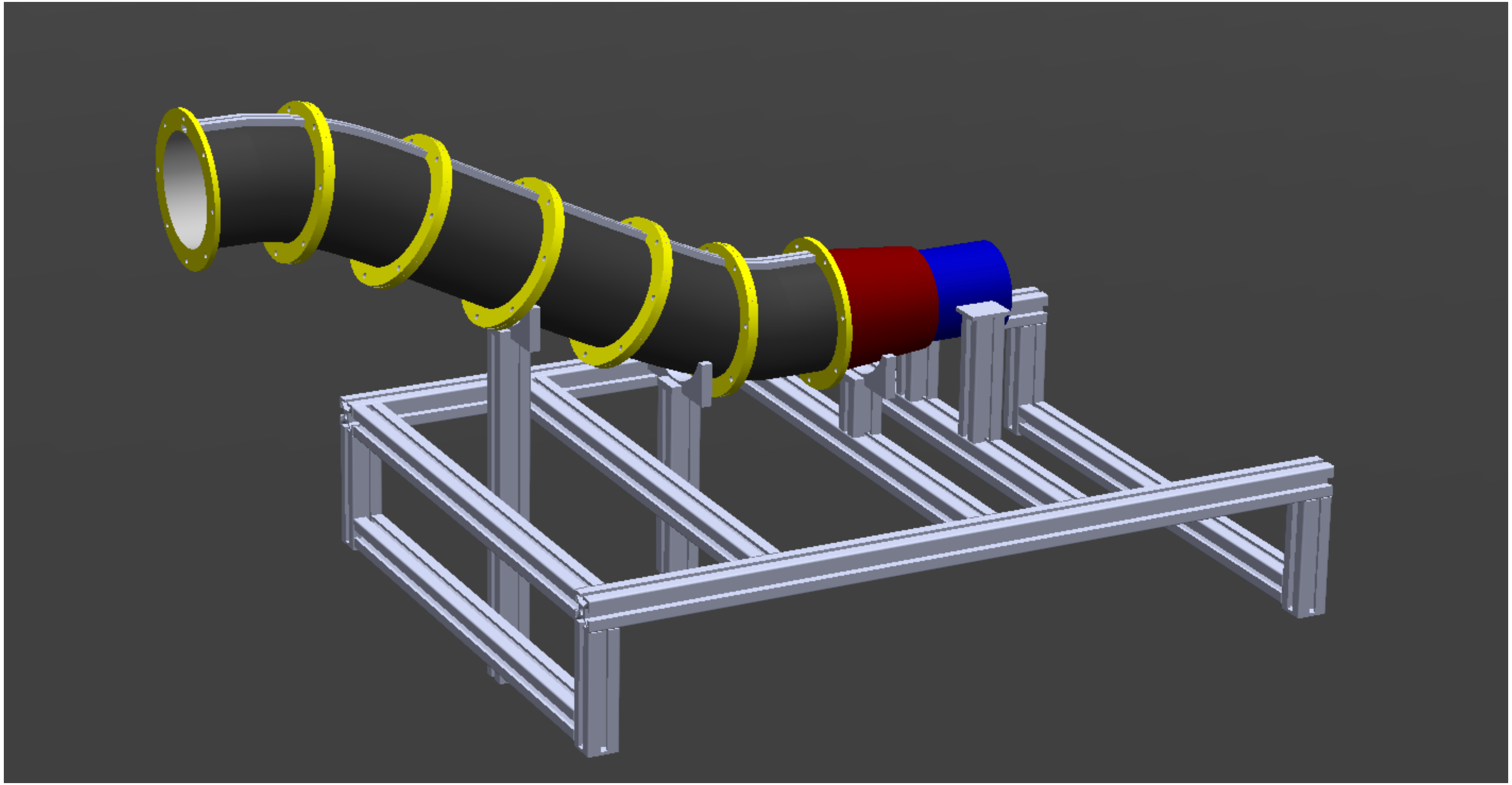
Standard atmospheric conditions

$$\dot{m} = \rho \; v \; a$$

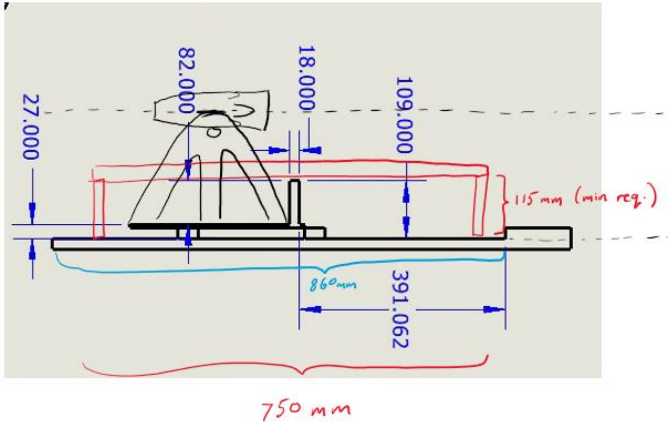
$$v = \frac{.23 \; \frac{kg}{s}}{\frac{\pi}{4} \; (0.1016m)^2 * (1.225 \; \frac{kg}{m^3})}$$

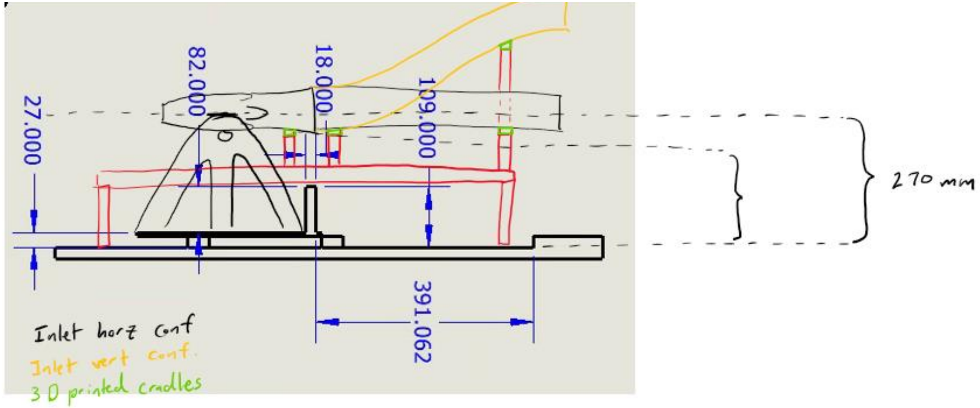
$$v = \mathbf{23.16} \; {}^{\boldsymbol{m}}/_{\boldsymbol{s}}$$

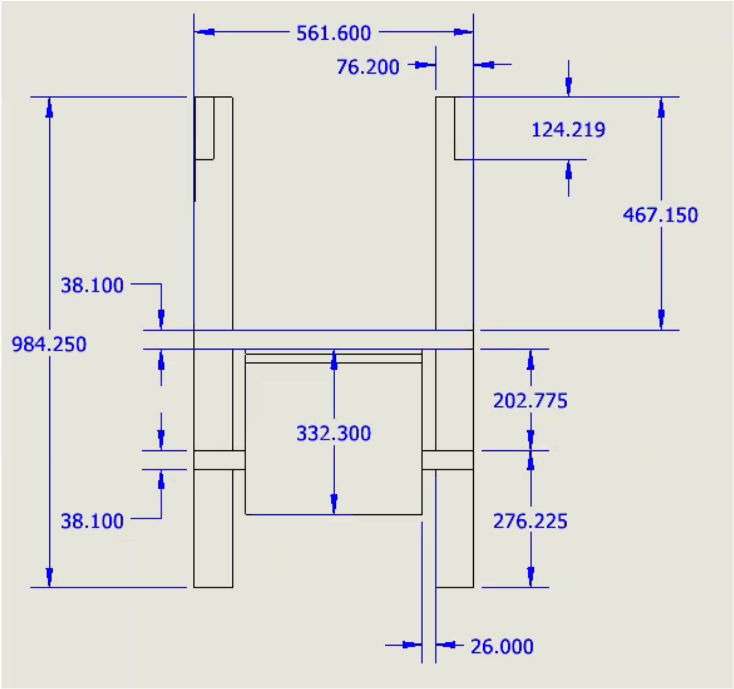
Inlet Testing with EDF



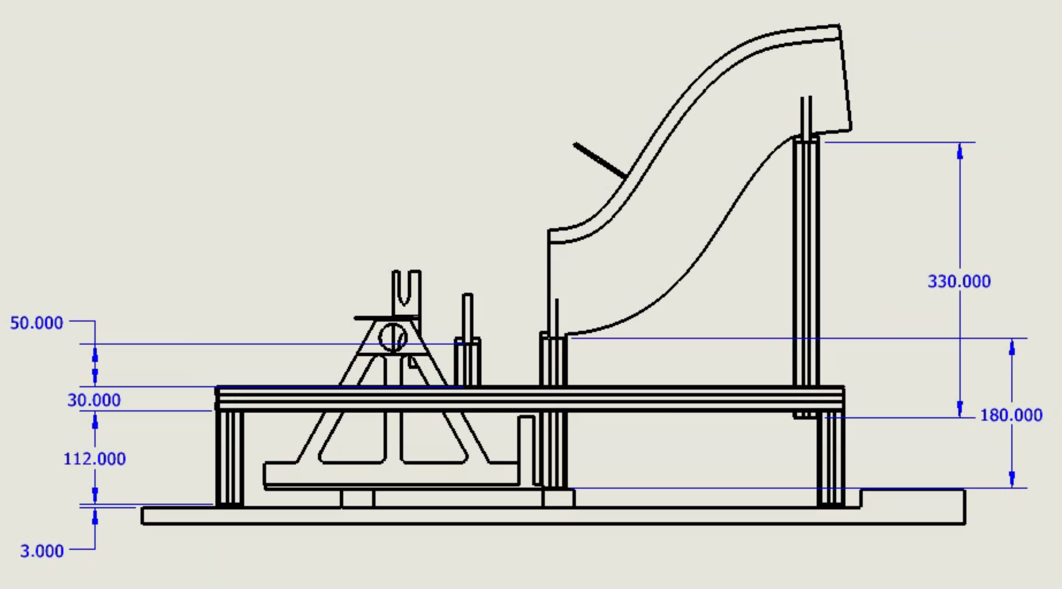
Test Stand Design Process

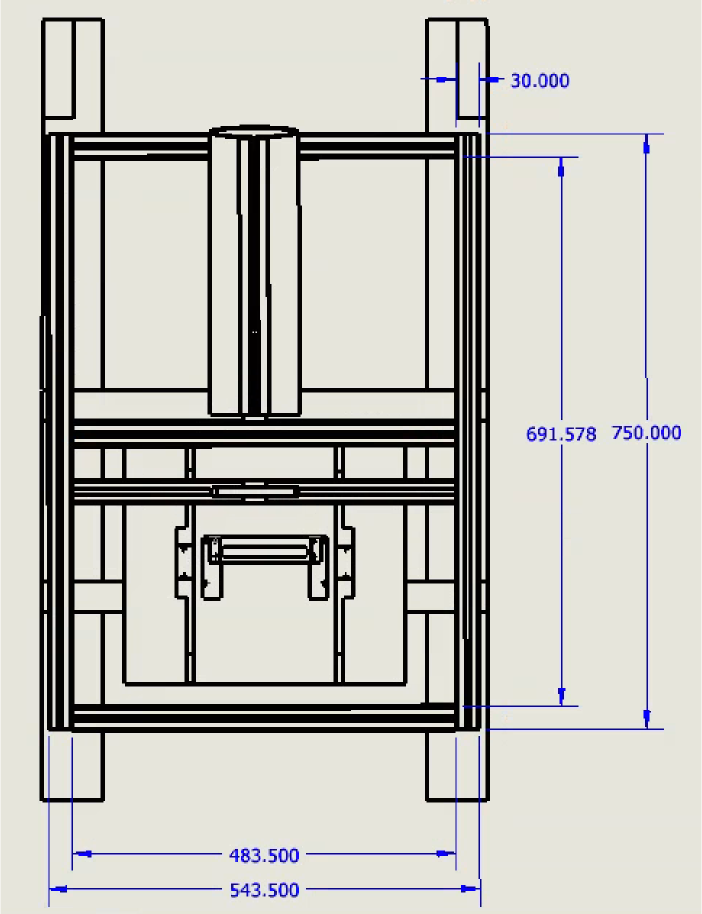




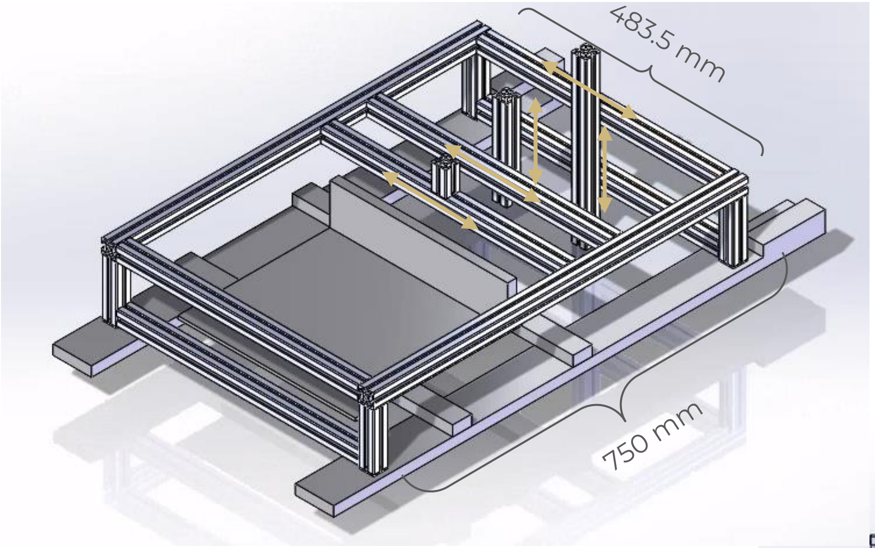


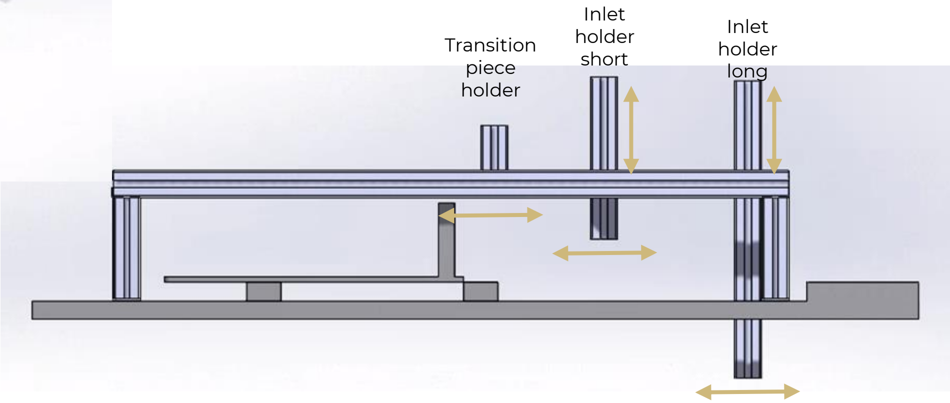
Test Stand Frame





Test Stand Frame





Test Stand Design Process

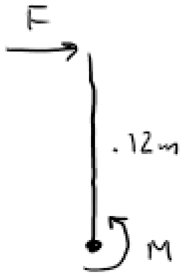
Item	Quantity	Length (mm)	Pice Per	Price Total
Struts Across	6	483.5	$5.31	$31.86
Struts Along	2	750	$8.25	$16.50
Vertical Stand Supports	4	112	$4.47	$17.88
EDF Trans Piece	1	50	$4.47	$4.47
Inlet Trans Piece	1	50	$4.47	$4.47
EDF Holders	2	120	$4.47	$8.94
Inlet Holder Short	2	180	$4.47	$8.94
Inlet Holder Long	1	330	$3.63	$3.63
End Caps	4	HFC6-3030	$1.79	$7.16
EDF mount L brackets	6	HBLFSSW6	$3.13	$18.78
Frame L Brackets	min of 40 (11 packs)	-	$1.98 (4 pack)	$21.78
Channel Nuts	min of 80	HNTT6-4	package of 100	$36.56
M4 screws 10 mm	min of 80 (40 packs)	10	0.98 (2 pack)	$39.20
M4 screws 12 mm (EDF)	min of 8 (5 packs)	12	0.98 (2 pack)	$4.90
			Total	$225.07

Test Stand Design Process

$$M = (dist)(Force)$$

$$F = {\sim}2.3\ kg = 22.5553\ N$$

$$M = (120\ mm)(22.5553N) = 2706.64\ N \cdot mm$$



$$Flexure\ Formula{:}\ \sigma_b = \frac{M \cdot (y\ dimension)}{I_y}$$

$$From\ 30x30\ Aluminum\ Extrusion\ Documentation{:}$$

$$I_y = 2.83\ x\ 10^4\ mm^4$$

$$y\ dimension = 30\ mm$$

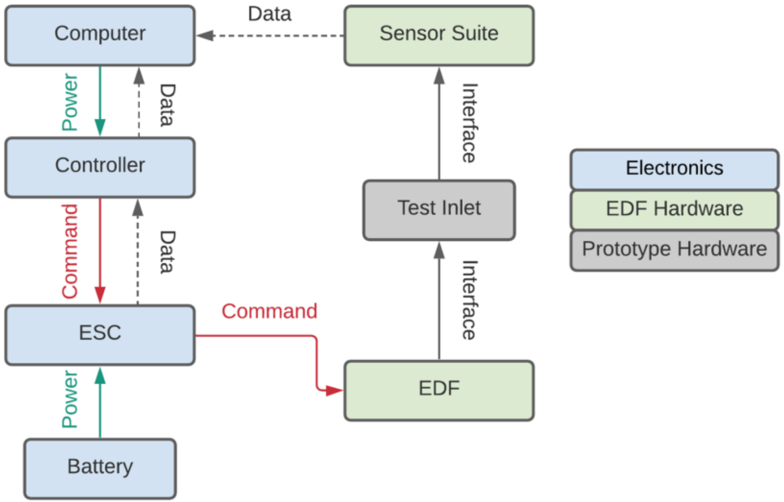
$$\sigma_b = \frac{(2706.64\ N \cdot mm)(30mm)}{2.83\ x\ 10^4\ mm^4} = 2.86923\ {}^{N}/_{mm^2}$$

■Mechanical Properties of Aluminum Extru

	JIS Standard (Reference)	JIS S
Series	HFS Series	
Material (JIS Symbol)	A6N01SS-T5 Aluminum Alloy	
Tensile Strength (N/mm²)	245 or more	
Proof Stress (N/mm²)	205 or more	
Longitudinal Elastic Modulus (N/mm²)	69972	
Brinell Hardness (HB)	88	
Surface Treatment	Anodize 9μm or more	

https://us.misumi-ec.com/pdf/fa/2012/p2_0493.pdf

EDF Control

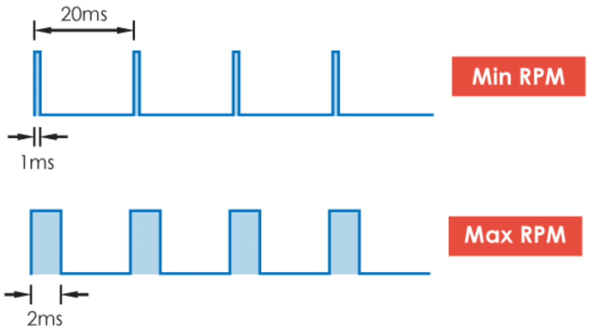


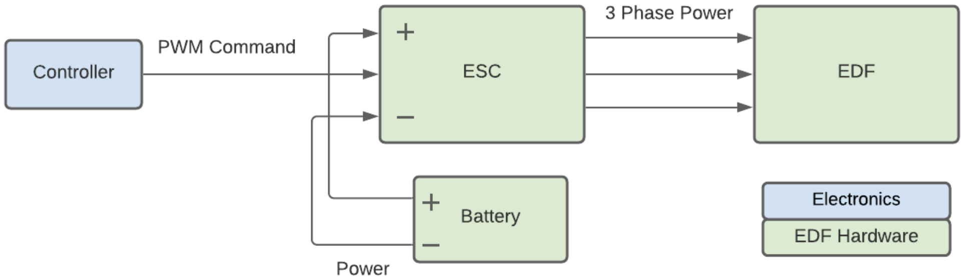
Electronic Speed Control (ESC)

- Exact components dependant on EDF

ESC Signal for RC EDFs

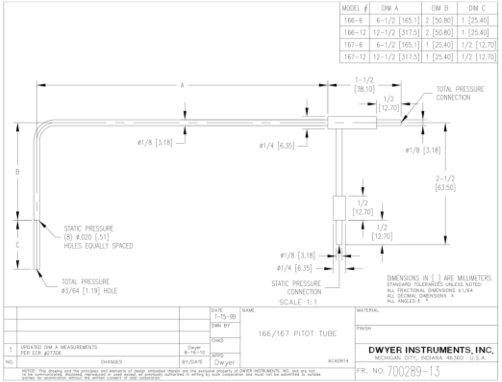
- 50 Hz PWM, 5-10% duty cycle





Total Pressure Measurement: Pitot Probe

- Dwyer 167-6 pitot probe
  - ⅛th inch diameter probe
  - 1.5 inch probe length
  - 6 inch insertion length
- $0.00098 \leq A_{probe}/A_{inlet} \leq 0.0099$
  - Area of probe over area of inlet at minimum and m
  - Minimal flow interference
- Probe accurate to within 0.5%
  - Only accurate at minimum of 5 m/s airflow
  - Accuracy converges above this speed
- Total & static pressure measured using scanivalve



Equflow Flow Measurement Instrument

- Working closely with professor Trudy Schwartz to understand how t
- Instrument output is a square wave and counting the frequency wil
- Typically use a microcontroller or NI DAQ with a counter/timer char square wave, encoder, etc measurements.
- In the past teams have used the NI 9401 digital input module to rea
- Disposable to reduce clogging and inaccuracies. Will need to purch tests.
- Max turbine flow rate: 0.36 L/min
- Min turbine flow rate: 0.06 L/min (at idle)
- 0045 model flow rate: 0.1 - 1.8 L/min (with minimum flow of 0.06 L/m
- Pack of 10 Replacements (€ 400.00 ~ $470)
- https://www.equflow.com/product/pfa-click-housing-flow-sensor
- https://www.equflow.com/product/pfa-flow-tube-4-5-for-click-housing-tub

Test Apparatus Spending

Category	Item	Unit Price (USD)	Amount	Total Price
Test Stand Aluminum	Struts Across	$5.31	6	31.86
	Struts Along	$8.25	2	16.5
	Vertical Stand Supports	$4.47	4	17.88
	EDF Trans Piece	$4.47	1	4.47
	Inlet Trans Piece	$4.47	1	4.47
	EDF Holders	$4.47	2	8.94
	Inlet Holder Short	$4.47	2	8.94
	Inlet Holder Long	$3.63	1	3.63
Test Stand Accessories	End Caps	$1.79	4	7.16
	EDF mount L brackets	$3.13	6	18.78
	Channel Nuts	$36.56	1	36.56
	M4 Screws 10 mm	$0.98	40	39.2
	M4 Screws 12 mm	$0.98	5	4.9
	Corner L Bracket (1)	$2.13	2	4.26
	Corner L Bracket (2)	$2.42	10	24.2
	Set Nut (M3-0.5)	$0.56	6	3.36
	Set Screw (M3-0.5x6)	$0.56	6	3.36
	Shipping	$19.36	1	19.36
Total				203.29

Instrumentation & Maintenance Spending

Category	Item	Unit Price (USD)	Amount	Total Price
Massflow Surrogate	EDF	$39.99	1	39.99
	ESC	$35.49	1	35.49
Test Stand Instrumentation	Pitot Tube	$93.00	1	93
	Tubing	$0.60	100	60
Total				228.48

Category	Item	Unit Price (USD)	Amount	Total Price
Initial Engine Parts	Starter Motor	$89.99	1	89.99
	LiFE Battery	$49.99	1	49.99
	EC3 M to XT60 F Adapter	$1.99	1	1.99
	EC3 F to XT60 M Adapter	1.99	1	1.99
Packaging Supplies	Bubble Wrap	$6.62	1	6.62
	Cardboard Box	$6.99	1	6.99
	Sales Tax	$1.20	1	1.2
Turbine Ground Support	4mm tubing	$1.29	3	3.87
	Festo Ball Valve 4mm	$21.47	2	42.94
	Festo Blanking Cap 4mm	$2.21	3	6.63
	iTrap40 Classic Pro 4mm	$85.54	1	85.54
	Plastic Syringe	$10.38	1	10.38
	Diesel Fuel Can	$26.15	1	26.15
Shipping	Outbound (1)	$34.84	1	34.84
	Outbound	$117.00	1	117
	Inbound	$50.00	2	100
Total				586.12

Test Plan

Test	Materials	Location	Special Access
TA Turbine Operation verification	JetCat Engine	Engine Test Cell	Yes - R2R Schedule*
TA Instrument Verification	Test App, Wind Tunnel	Aero Wind Tunnel	Yes - R2R Schedule*
TA Turbine mass flow test	JetCat Engine, Test App	Engine Test Cell	Yes - R2R Schedule*
TA EDF Verification	Test App, EDF	Aero Wind Tunnel	Yes - R2R Schedule*
TA Turbine sensors calibration test	Test App, Inlet, JetCat	Engine Test Cell	Yes - R2R Schedule*

* - R2R Schedule only allows Team OSPRI to be on campus 2 days/week

Test Plan cont.

Test	Materials	Location	Special Access
Inlet EDF Testing	Test App, Inlet, EDF	Wind Tunnel	Yes - R2R Schedule*
TA Turbine baseline test	JetCat Engine, Test App	Engine Test Cell	Yes - R2R Schedule*
Inlet Turbine integrated inlet testing	JetCat Engine, Test App, Inlet	Engine Test Cell	Yes - R2R Schedule*

* - R2R Schedule only allows Team OSPRI to be on campus 2 days/week

Test Readiness Review

System 1: EDF testing

Task number	Due date	Task/description	Dependent on task:	Building access required	Complete
E.1.a	24 Jan	EDF transition piece design/print	N/A	N	Y
E.1.b	24 Jan	EDF/Transition Piece cradles design/print	N/A	N	Y
E.1.c	24 Jan	Bell Mouth design/print	N/A	N	Y
E.1.d (TA.1)	24 Jan	Inlet frame assembly	N/A	N	Y
E.2 (TA.2)	31 Jan	Labview scannivalve functionality	N/A	Y	Y
E.3 (TA.3)	3 Feb	Wind tunnel sensor calibration test	E.2 (TA.2)	Y	Y
E.4	5 Feb	EDF systems functionality test with temporary control and frame integration	E.1	-	Y
E.5	10 Feb	EDF mass flow verification test	E.1, E.2, E.3, E.4	Y	Y
E.6	12 Feb	Labview EDF control functionality	E.4	N	
E.7.a	19 Feb	EDF control verification tests	E.6, J.5	N	
E.7.b	19 Feb	Turbine to EDF mass flow calibration tests	E.1, E.2, E.3, E.4	Y	
E.8	19 Feb	Inlet testing	E.1-E.8	Y	

System 2: JetCat Turbine testing

Task number	Due date	Task/description	Dependent on task:	Building access required	Complete
J.1.a	24 Jan	AFRL transition piece print	N/A	N	Y
J.1.b	24 Jan	Bell mouth design/print	N/A	N	Y
J.1.c	24 Jan	Transition piece print	N/A	N	Y
J.1.d (TA.1)	24 Jan	Inlet frame assembly	N/A	N	Y
J.3 (TA.2)	31 Jan	Labview scannivalve functionality	N/A	N	Y
J.4 (TA.3)	3 Feb	Wind tunnel sensor calibration test	J.3 (TA.2)	Y	Y
J.2	(Org 27 Jan) 15 Feb	JetCat verification run	N/A	Y	Y
J.5	15 Feb	JetCat mass flow verification test	J.1, J.2, J.3, J.4	Y	
J.6	21 Feb	Labview Equiflow fuel flow sensor functionality	N/A	N	
J.7	24 Feb	Flow sensor/load cell calibration test	J.6	Y	
J.8	26 Feb	JetCat baseline test	J.3, J.4, J.5, J.6, J.7	Y	
J.9	26 Feb	Inlet testing	J.1 - J.8, E.8	Y	

Indicates test which needs scheduling

Current as of 26 Feb 2021

University of Colorado Boulder

OSPRI

Setup	
Required items	
P-100Rx	Proj Room/Test cell
ECU	Proj Room/Test cell
GSU	Proj Room
Long Cord	Proj Room
Battery	Charged
Support items	Proj Room/Test cell
Fuel can	Test cell
Radios	Proj Room/Test cell
Test cell setup	
Professor	Notify
Garage Door	Open
Fume fan	On
Plexiglass	Lean against garage door
Blast area	Clear
Mount engine	x4 bolts
Engine	Secure
Fuel Pump	Secure
ECU	Secure
GSU lead	Routed into control room
GSU	Connected (in control room)
Battery	Connected and secure
Fuel line purge	
Fuel tank	Insert fuel line
UAT	Air Purged
UAT Shuttoff valve	Open
Pump Shuttoff valve	Open
Engine fuel line	Disconnect
ECU Power	Depress for 5 sec
Menu selected	Test Function
Change Value	Hold on purge page
Fuel line	Air purged
Fuel line	Reconnect

Engine start checklist	
Pre start	
Load cell stop block	Remove
Load cell arduino	Powered on (if used)
Sensor/tubing	Secured (if used)
Scannivalve	Connected/Powered on
Data collection	Reading data
Radio check	Good comms
Downrange man	In place outside cell
Downrange	Clear of personnel
Test cell	Clear of personnel
Engine Start	
Professor	Notified/present
ECU power	Depress for 5 sec
Menu selected	Run
Engine control man	Radio start ready
Downrange man	Radio blast area clear
Set and Spool	Depress
Automatic startup	Let self stabilize
Test control	
Throttle Increase	Spool and plus
Throttle decrease	Spool and minus
Immediate max	Spool and min/max
Immediate idle	Spool and run
Shutdown	
Engine control man	Radio test termination
Set and Spool	Depress
Automatic cooling	Let self cool
Pump Shuttoff valve	Close
UAT Shuttoff valve	Close

Management Slides

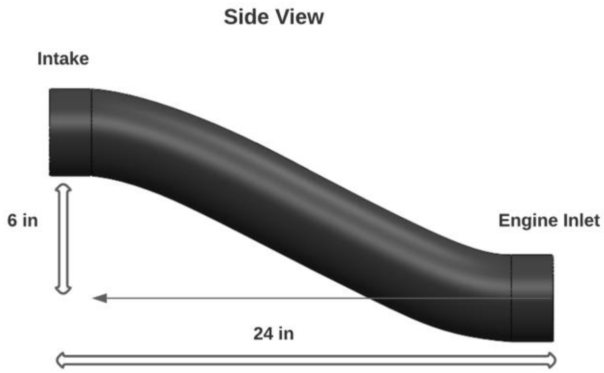
Functional Requirements

OSPRI functional requirements stem from the APOP's Statement of Work provided to the CU Aerospace Engineering Department and the OSPRI team:

1. Design, build, and validate an S-duct inlet for use with the JetCat P100-RX turbojet engine that performs according to AFRL's objectives.
2. Design, build, and validate a test rig capable of measuring critical inlet performance metrics and inform inlet design.

Inlet Design Requirements

1. The inlet shall interface with the AFRL transition piece
2. The nearest outside edge of the capture area sha
   centerline of the engine.
3. The inlet shall have a total pressure recovery ≥98
   engine.
4. The maximum thrust decrement of the engine sh
   attached.
5. The maximum TSFC increment of the engine sha
   attached.
6. The inlet shall have an axial length between 20 inches and 28 inches, with the objective being 20 inches (or shorter, if feasible).*
   a. Requirements changed from PDR

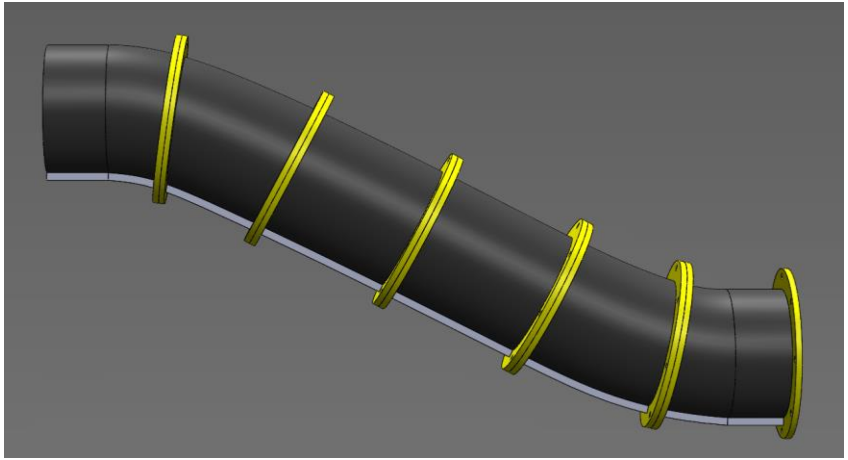


Test Apparatus (TA) Design Requirements

1. The TA shall be capable of mapping the total pressure distribution at the inlet entrance, the Aerodynamic Interface Plane (AIP), and between the first and second turns, at a minimum.
2. The TA shall be capable of mapping the distortion distribution throughout the inlet.
3. The TA shall be capable of measuring key JetCat engine parameters.
    a. TA shall be capable of measuring the thrust produced by the engine.
    b. TA shall be capable of measuring the Thrust Specific Fuel Consumption (TSFC) of the engine.
4. The TA shall be capable of interfacing with multiple different inlet designs.

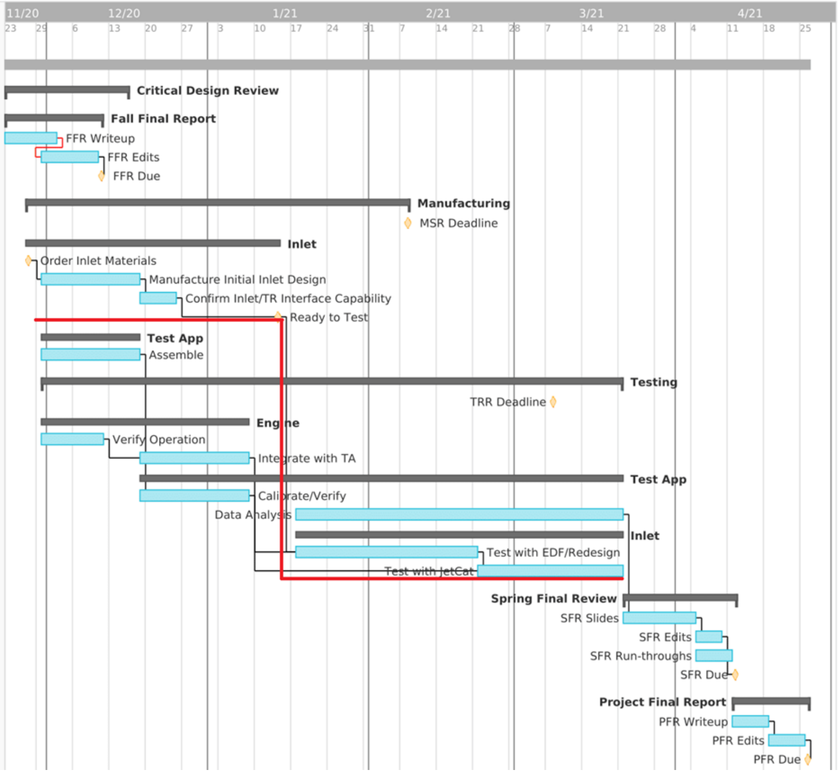
Timeline Moving Forward

1. Printing, post-processing, and assembling the first inlet (Complete by Feb. 14th)
2. Testing the first iteration to measure performance (Complete by Feb. 20th)
3. Start Printing the second iteration (Complete by Feb. 22nd)
4. Performance analysis for second iteration (Complete by Mar. 10th)
5. Finalize and Manufacture Final Design (Complete by Apr. 1st)



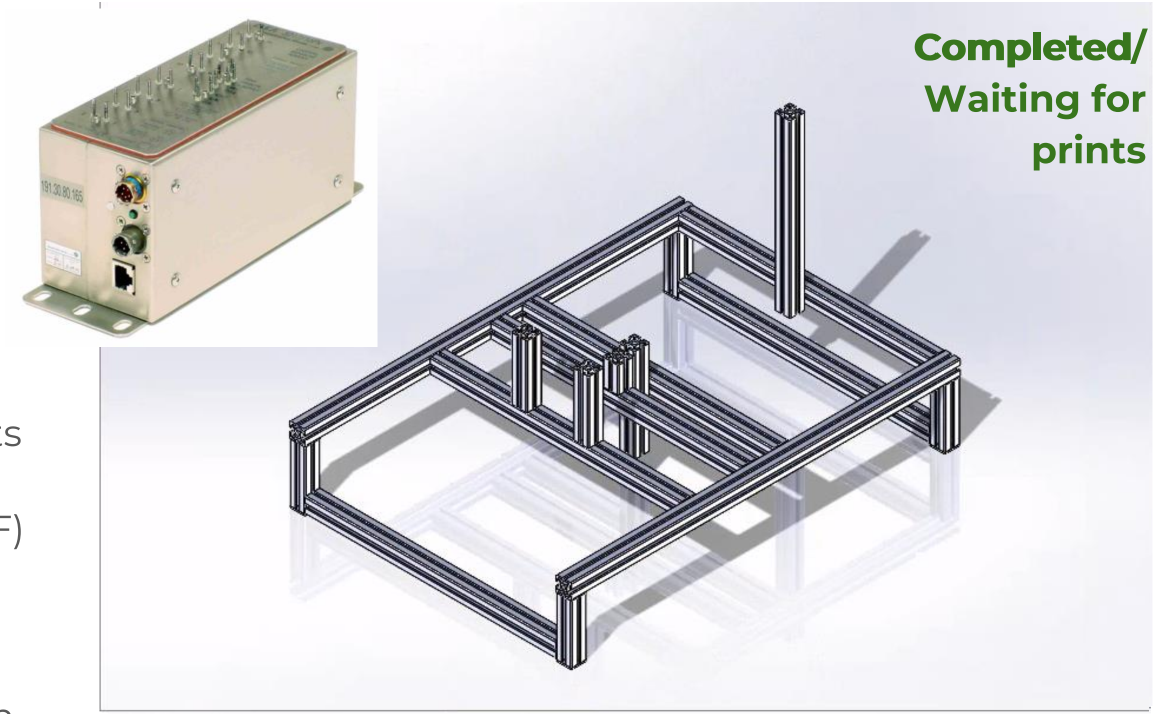
Work Plan

OSPRI	start	end	0h	0%
Critical Design Review	11/20/20	12/16/20	0h	0%
Fall Final Report	11/23/20	12/11/20	0h	0%
FFR Writeup	11/23	12/02	0	0%
FFR Edits	11/30	12/10	0	0%
FFR Due	12/11	12/11	0	0%
Manufacturing	11/27/20	02/08/21	0h	0%
MSR Deadline	02/08	02/08	0	0%
Inlet	11/27/20	01/14/21	0h	0%
Order Inlet Materials	11/27	11/27	0	0%
Manufacture Initial Inlet Design	11/30	12/18	0	0%
Confirm Inlet/TR Interface Capability	12/19	12/25	0	0%
Ready to Test	01/14	01/14	0	0%
Test App	11/30/20	12/18/20	0h	0%
Assemble	11/30	12/18	0	0%
Testing	11/30/20	03/21/21	0h	0%
TRR Deadline	03/08	03/08	0	0%
Engine	11/30/20	01/08/21	0h	0%
Verify Operation	11/30	12/11	0	0%
Integrate with TA	12/19	01/08	0	0%
Test App	12/19/20	03/21/21	0h	0%
Calibrate/Verify	12/19	01/08	0	0%
Data Analysis	01/18	03/21	0	0%
Inlet	01/18/21	03/21/21	0h	0%
Test with EDF/Redesign	01/18	02/21	0	0%
Test with JetCat	02/22	03/21	0	0%
Spring Final Review	03/22/21	04/12/21	0h	0%
SFR Slides	03/22	04/04	0	0%
SFR Edits	04/05	04/09	0	0%
SFR Run-throughs	04/05	04/11	0	0%
SFR Due	04/12	04/12	0	0%
Project Final Report	04/12/21	04/26/21	0h	0%
PFR Writeup	04/12	04/18	0	0%
PFR Edits	04/19	04/25	0	0%
PFR Due	04/26	04/26	0	0%



Test Apparatus Breakdown/Overview

- Inlet test frame
- Inlet cradles
- Power plant to inlet transition piece
- Sensor suite
  - Scanivalve
  - Pitot probe
  - Static pressure ports
  - LabView controlled
- Electric Ducted Fan (EDF)
- Turbine test stand
- JetCat P100-Rx
- AFRL designed transition piece



Test Apparatus Model Overview

Test Apparatus Status Overview

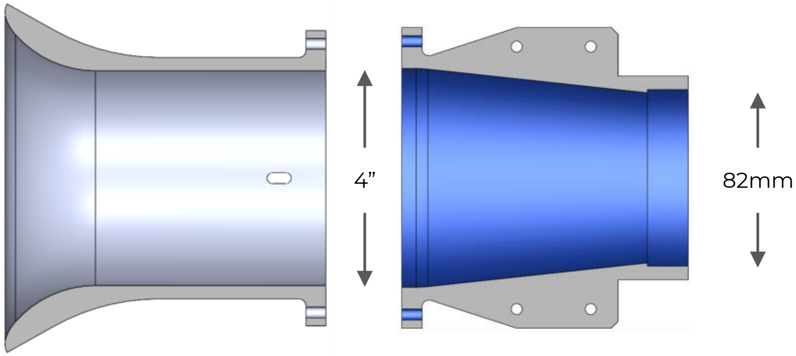
Frame Assembly	**Completed (Due 24 Jan)**
Transition piece/cradles	**Completed (Due 24 Jan)**
EDF Integration and Verification	**On Track (Due 5 Feb)**
Labview Development and Verification	**On Track (Various Due dates)**
Sensors Verification	**On Track (Due 3 Feb)**
JetCat Engine and Testing	**Setback (Various Due dates)**

Frame Assembly Status (Completed)

- Assembly completed
- All sliding posts yet to be tightened
- Extremely rigid, lightweight
- To be moved to Aero Building soon

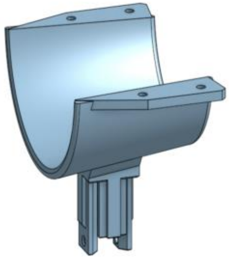
Transition pieces/cradles status Completed

- JetCat Transition Piece
  - Design provided by AFRL
  - **Completed 24 Jan**
- EDF Transition Piece
  - **Completed 24 Jan**
- Straight bell-mouth inlet
  - Mass flow calibration
  - **Completed 24 Jan**
- Cradles
  - Bolted design for EDF Transition
  - Hose Clamp design for Jetcat
  - **Completed 24 Jan (print in progress)**



Straight bell-mouth Inlet and EDF Transition piece

Cradle for the Jet Engine Transition Piece



Cradle for the EDF Transition piece

EDF Integration Status On Track (Due 5 Feb)

- EDF and ESC (Electronic Speed Controller)
  - The finance department did not order last semester
  - Ordered again and **delivered January 27th**
- 6 cell LiPo battery
  - Provided by the electronics lab
- Maximum mass flow validation
  - Targeting 0.23 kg/s
  - Using a servo tester for control
- Mass flow calibration
  - Using Labview for precise control

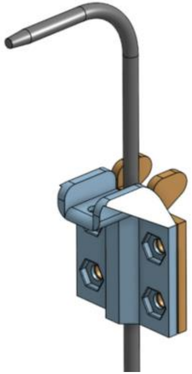
LabView Development Status (On Track)

- Stages of Development
  - Stage 1: **Scanivalve functionality** **(Completed Jan 31st)**
    - For pressure measurements (Sample rate: 500Hz)
    - Extract required existing Wind Tunnel code
  - Stage 2: **EDF Control functionality** **(Complete by Feb 12th)**
    - For fan flow control
    - Integrate cDaq & NI 9401 (digital I/O module)
  - Stage 3: **JetCat Fuel Flow Sensor functionality** **(Complete by Feb 21st)**
    - For fuel flow measurements
    - Integrate NI 9215 (analog in module)

LabView Development Status cont (On Track)

- LabView Software
  - Working closely with Josh Mellin
  - Troubleshooting and debugging
  - Tasks to do:
    - Finalize software for fuel flow
    - Finish VI interface to connect with TA rig
    - Verify data acquisition outputs (graphs, plots, etc)
  - cDaq (+ Digital Module, Analog Module): **Checked Out**
    cDAQ-9171, NI-9401, NI-9215 w/ BNC modules

Sensors & DAQ Status **On Track (Due 3 Feb)**



- cDaq (+ Digital Module, Analog Module): **Checked out**
- Labview Module Development: **Development underway**
- Sensors : **Acquired**
  - Pitot Probe: **Acquired**
    - Slotted Inlet Mount: **Designed & Printed**
  - Fuel Flow Probe: **Acquired**
- Scanivalve: **Available upon request**

Upcoming tests

- Wind tunnel **sensor calibration** test: **(Complete by 3 Feb)**
  - Calibration of pitot probe using 6 or more known airspeeds in the windtunnel

JetCat P-100RX Status (Setback)

- Engine issues (warranted services by JetCat Americas) **(Est. return: 12 Feb)**
  - *Fall semester:* Starter motor and front sensor board burnt out, sticky bearings
  - *27 Jan:* After servicing, surface mounted chip fell off of front sensor board
- Upcoming tests
  - JetCat **initial verification** test: **(Complete by 27 Jan moved to 15 Feb)**
    - Unmodified test to verify functionality with CU facilities and procedure familiarization
  - JetCat **mass flow verification** test: **(Complete by 15 Feb)**
    - Collect mass flow data through entire RPM sweep to calibrate mass flow surrogate
  - JetCat **baseline** test: **(Complete by 26 Feb)**
    - Collect thrust data and fuel flow (TSFC) data through entire RPM sweep

Test Apparatus Future Outlook

System 1: EDF testing					
Task number	Due date	Task/description	Dependent on task:	Building access required	Complete
E.1.a	24 Jan	EDF transition piece design/print	N/A	N	Y
E.1.b	24 Jan	EDF/Transition Piece cradles design/print	N/A	N	Y
E.1.c	24 Jan	Bell Mouth design/print	N/A	N	Y
E.1.d (TA.1)	24 Jan	Inlet frame assembly	N/A	N	Y
E.2 (TA.2)	31 Jan	Labview scannivalve functionality	N/A	Y	Y
E.3 (TA.3)	3 Feb	Wind tunnel sensor calibration test	E.2 (TA.2)	Y	
E.4	5 Feb	EDF systems functionality test with temporary control and frame integration	E.1	?	
E.5	10 Feb	EDF mass flow verification test	E.1, E.2, E.3, E.4	Y	
E.6	12 Feb	Labview EDF control functionality	E.4	N	
E.7.a	19 Feb	EDF control verification tests	E.6, J.5	N	
E.7.b	19 Feb	Turbine to EDF mass flow calibration tests	E.1, E.2, E.3, E.4	Y	
E.8	19 Feb	Inlet testing	E.1-E.8	Y	

System 2: JetCat Turbine testing					
Task number	Due date	Task/description	Dependent on task:	Building access required	Complete
J.1.a	24 Jan	AFRL transition piece print	N/A	N	Y
J.1.b	24 Jan	Bell mouth design/print	N/A	N	Y
J.1.c	24 Jan	Transition piece print	N/A	N	Y
J.1.d (TA.1)	24 Jan	Inlet frame assembly	N/A	N	Y
J.3 (TA.2)	31 Jan	Labview scannivalve functionality	N/A	N	Y
J.4 (TA.3)	3 Feb	Wind tunnel sensor calibration test	J.3 (TA.2)	Y	
J.2	(Org 27 Jan) 15 Feb	JetCat verification run	N/A	Y	
J.5	15 Feb	JetCat mass flow verification test	J.1, J.2, J.3, J.4	Y	
J.6	21 Feb	Labview Equiflow fuel flow sensor functionality	N/A	N	
J.7	24 Feb	Flow sensor/load cell calibration test	J.6	Y	
J.8	26 Feb	JetCat baseline test	J.3, J.4, J.5, J.6, J.7	Y	
J.9	26 Feb	Inlet testing	J.1 - J.8, E.8	Y	

Indicates test which needs scheduling

Current as of 31 Jan 2021

Test Apparatus Future Outlook

- Wind Tunnel Sensor Calibration by 03 Feb
- EDF Function Verification by 05 Feb
- EDF Mass Flow/Systems Verification by 05 Feb
- JetCat Mass Flow Verification by 15 Feb
- EDF Control Verification/ **Inlet Testing** by 19 Feb
- Load Cell, Fuel Flow Sensor Calibration by 24 Feb
- JetCat Baseline by 26 Feb
- **JetCat Inlet Testing** by 28 Feb

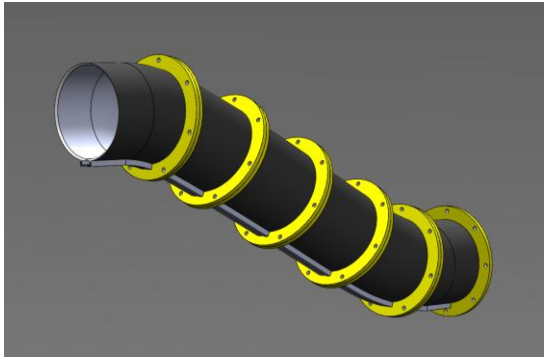
Challenges

- **Timeline**
  - Need to construct and perform verification and validation before any inlet testing can begin
  - Quicker test apparatus is ready, the more inlet iterations can be tested
- Repeated issues with JetCat P-100RX
- Integrating all sensors into cohesive LabView package

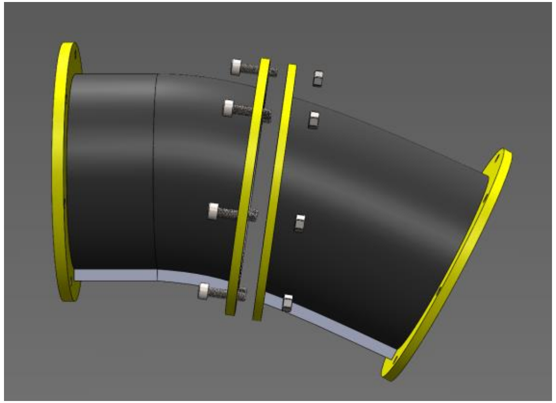
Initial Plan

- ➔ Originally planned FDM printers for prototype
  - Extensive post-processing
  - High chance of inconsistent surfaces
- ➔ Switched gears to SLA
  - Planned for access to 3 FormLabs SLA printers
  - Inlet made to be sectioned to fit smaller print volume
- ➔ Assembly
  - Using 7 M5 bolts and nuts

Model



Assembly



Status

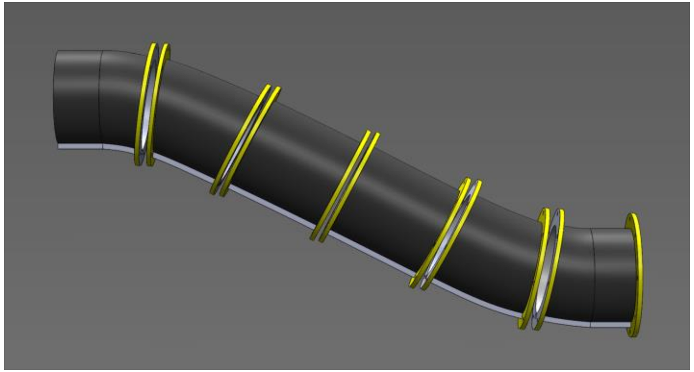
- Currently, initial design is being printed by the PILOT
  - Finished first of six inlet sections **On Track (Due Feb 14)**
  - Paused queue in order to print parts need for test assembly
  - Dealing with upcoming issues with manufacturing

Inlet Section

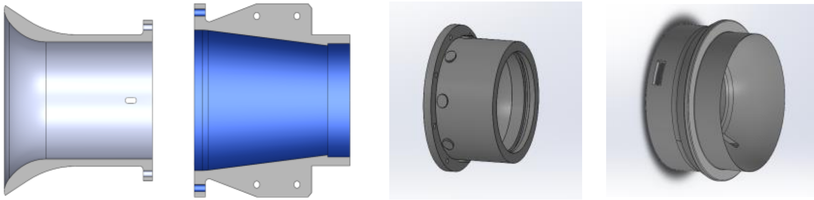
APOP Transition (Inlet Side)

Challenges

- ➔ Printer Reliability Problems
  - IdeaForge printers unuseable
  - Working with only 1 printer
- ➔ Print Quality
  - ~25 microns - 50 microns
  - Limited Print volume
- ➔ Part Prioritization
  - Transition pieces then inlet
  - 10 SLA parts in queue



Inlet Sectional View



Transition Pieces

Challenges

- ➔ Cost
  - ◆ Outside vendor quotes
    - ~$800 for just 4 parts
    - ~$600 in ASEN machine shop for all 10 parts

Line Item	Service	Description	Quantity	Unit	Price	Line Total
1	Print	50 um EDF transition and Inlet and Inlet transition and Jetcat 1x each Hard Black-Photocentric	1.00	Each	$780.09	$780.09
2	Sanding		2.00	Hours	$35.00	$70.00
3	Support Removal		2.00	Hours	$10.00	$20.00
4						
5						

The 3D Printing Store Quote

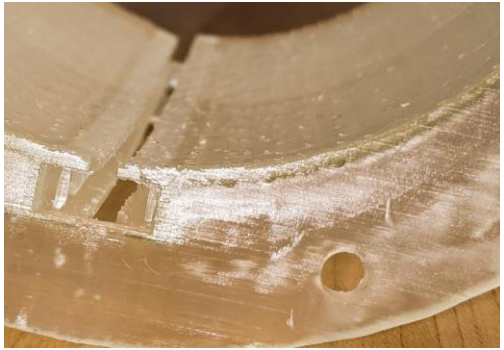
- ➔ Manufacturing Defects
  - ◆ Crack along flange of printed Inlet section
  - ◆ Will fix with epoxy patch

Cracked Inlet Sectional

Challenges

- Post-Processing
  - Sanding inside surface as needed
  - Support structure dependent on individual print

Transition Section



Inlet Section

Inlet Timeline

- Printing, post-processing, and assembling the first inlet by 14 Feb
- Testing the first iteration to measure performance by 20 Feb
- Start Printing Second Iteration by 22 Feb
- Performance Analysis for Second Iteration by 10 March
- Finalize and manufacture final design by 1 April