OSPRI

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

Team:

- Tim Breda
- Joey Derks
- Zak Dmitriyev
- Ryan Joseph
- Dishank Kathuria
- Harrison Methratta
- Joshua Seedorf
- Michael Vogel
- William Watkins
- John Wissler

Advisor: Professor John Mah
Customer: Air Force Research Laboratory
POC: Capt. Riley Huff

Section 1

Project Description

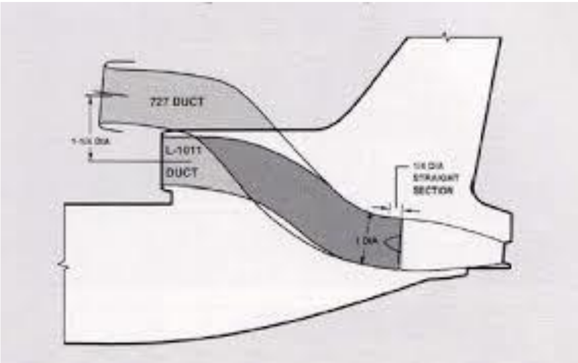
Problem Statement

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)
- Design and build a testing apparatus to measure total pressure and distortion distributions, and measure fuel flow and thrust produced

Motivation

- Integrating engines into the fuselage would reduce exposed surface area and overall drag
- S-ducts are susceptible to severe flow separation and poor total pressure recovery
- The Air Force Research Lab (AFRL) has asked 12 schools to come up with potential solutions
- Design point is a static test at standard conditions at Wright-Patterson AFB, Ohio



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 design requirements.
2. Design, build, and validate a test rig capable of measuring critical inlet performance metrics and inform inlet design.

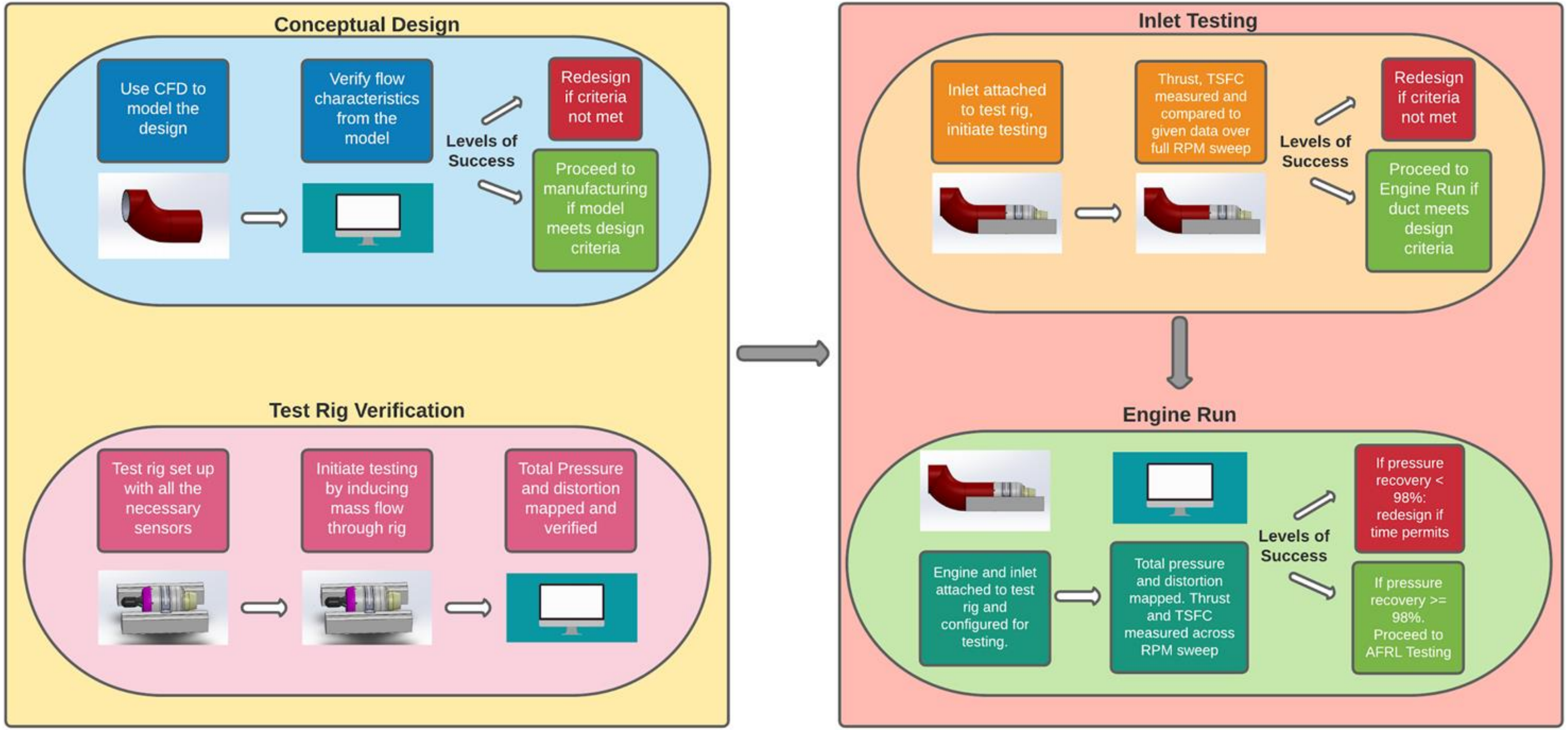
Inlet Design Requirements

1. The inlet shall interface with the AFRL transition piece.
2. The nearest outside edge of the capture area shall have a 6-inch offset from the centerline of the engine.
3. The inlet shall have a total pressure recovery ≥98% across the RPM sweep of the engine.
4. The maximum thrust decrement of the engine shall be ≤5% with inlet attached.
5. The maximum TSFC increment of the engine shall be ≤5% with inlet attached.
6. The inlet should have an axial length no greater than 24 inches, with the objective being 12 inches (or shorter, if feasible).

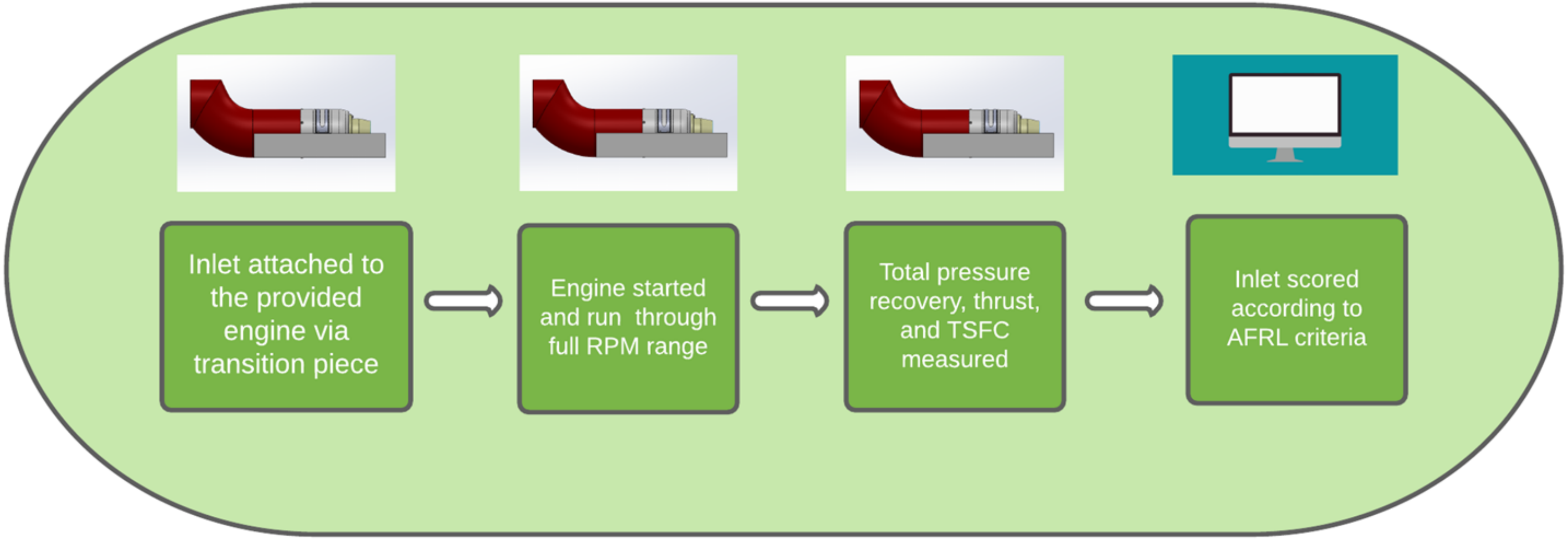
Test Apparatus (TA) Design Requirements

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 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.

Design Concept of Operations (CONOPS)

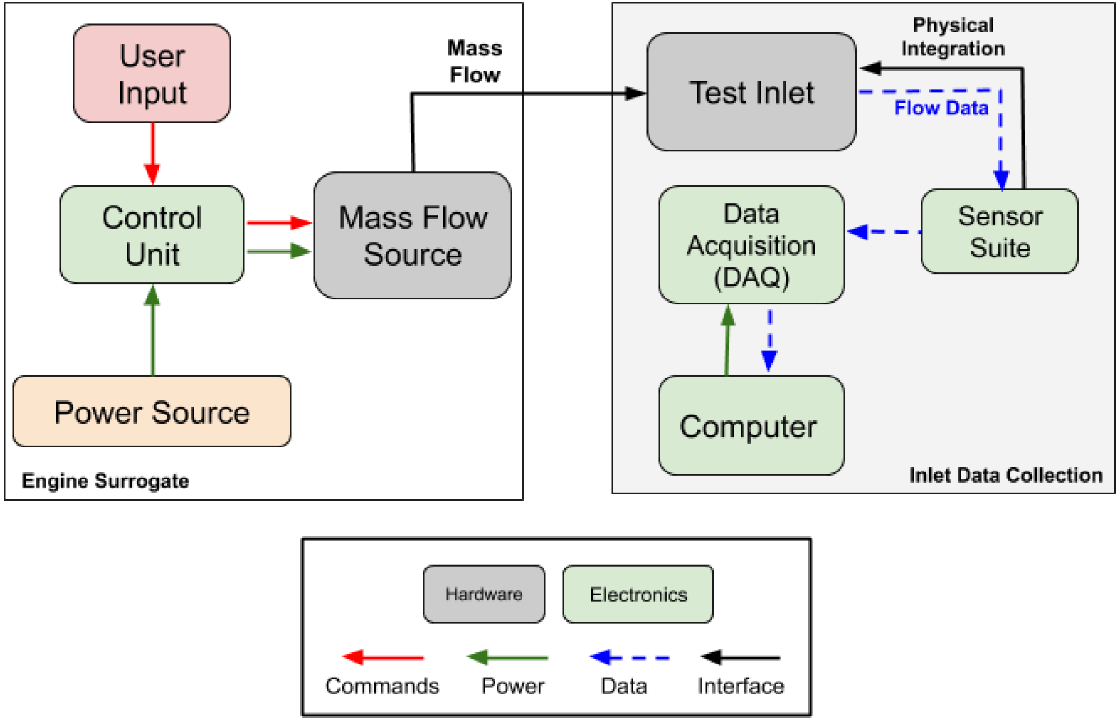


AFRL Testing CONOPS

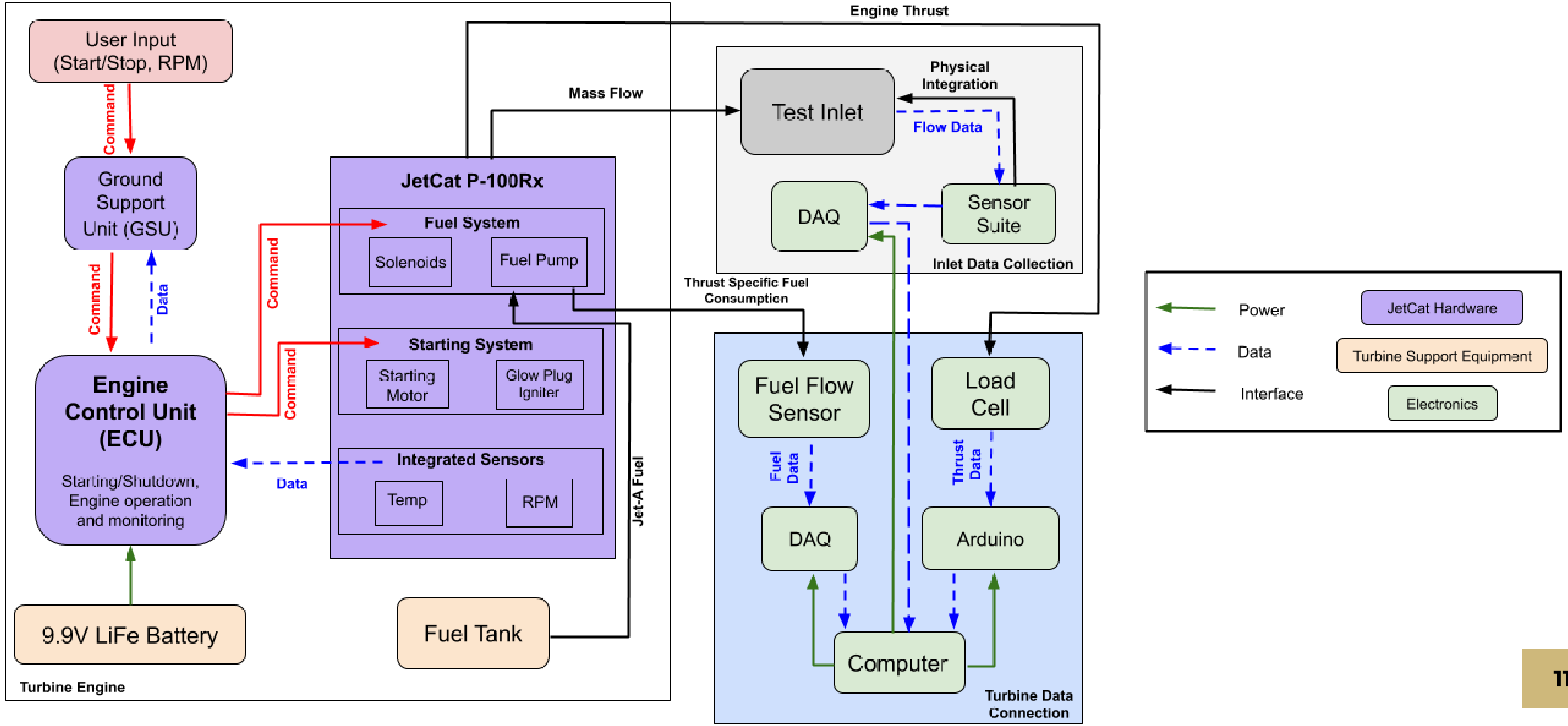


Testing Conditions:
-Static Test
- Standard conditions at Wright-Patterson Air Force Base, Ohio

Functional Block Diagram Testing Apparatus



Functional Block Diagram Engine Integration



Critical Project Feasibility Elements

Inlet

- CFD Simulations and Modelling
- Passive Flow Control System
- Geometry/Shape of S-Duct
- Manufacturing

Inlet Test Apparatus

- Slotted Inlet Concept
- Pressure Measurement
- Mass Flow Surrogate
- Data Acquisition & EDF Control

Section 2

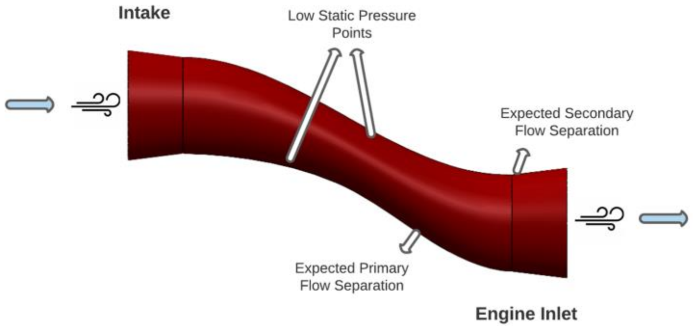
Baseline Design

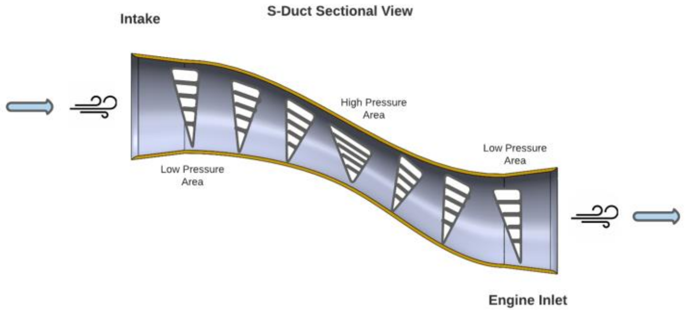
Baseline Design - Inlet

Needs: Flow control system to minimize separation and flow losses while maintaining steady mass flow for optimal engine performance. Optimizing the shortest inlet length for maximum total pressure recovery is paramount.

Considerations:

- Converging-Diverging Shape
- Circular Cross Section
- Vortex Generators



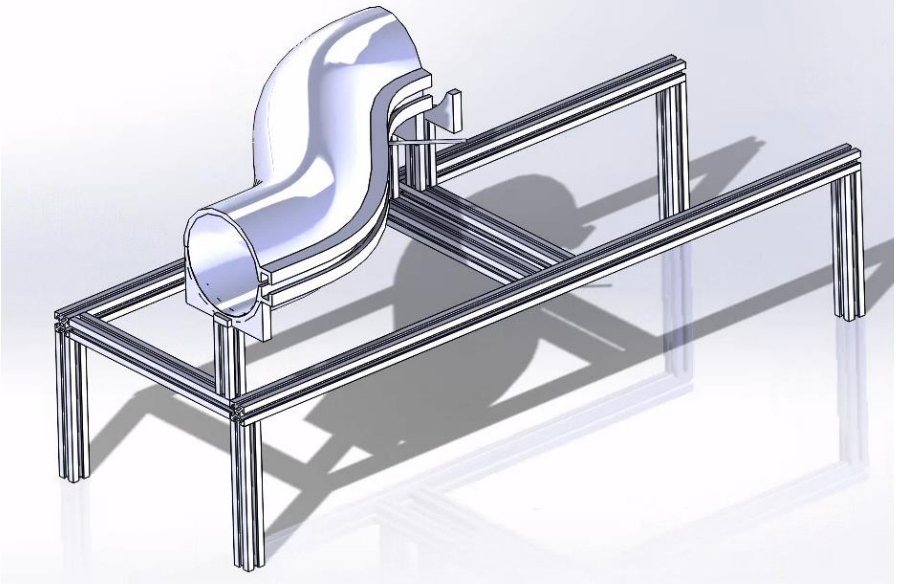


Baseline Design - Test Apparatus

Needs: Flow separation and adverse compressor face pressure distributions must be identifiable within the inlet. Capable of fuel flow sensor readings.

Capabilities:

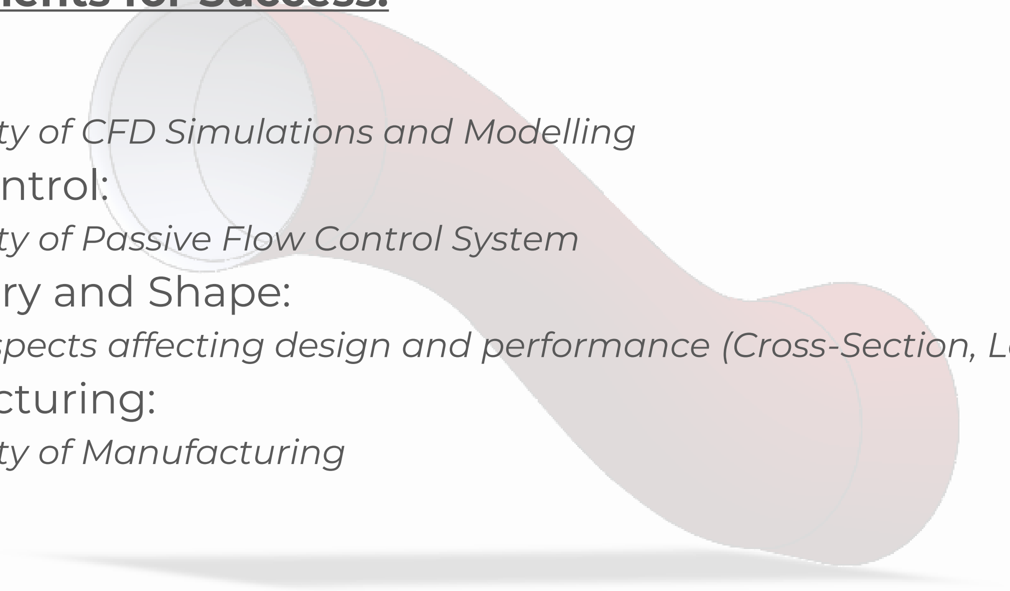
- Discrete Surface Static Pressures
- Continuous Total Pressure along 2 axes
- Equflow fuel flow sensor (when applicable)



Section 3

Inlet Feasibility

Inlet Feasibility Overview

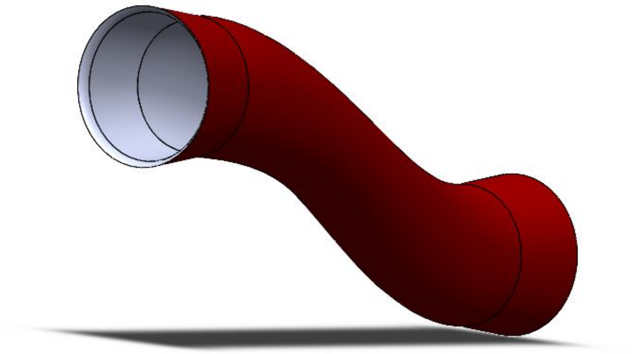


Critical Elements for Success:

1. CFD:
   Feasibility of CFD Simulations and Modelling
2. Flow Control:
   Feasibility of Passive Flow Control System
3. Geometry and Shape:
   Major aspects affecting design and performance (Cross-Section, Length, Area Ratio)
4. Manufacturing:
   Feasibility of Manufacturing

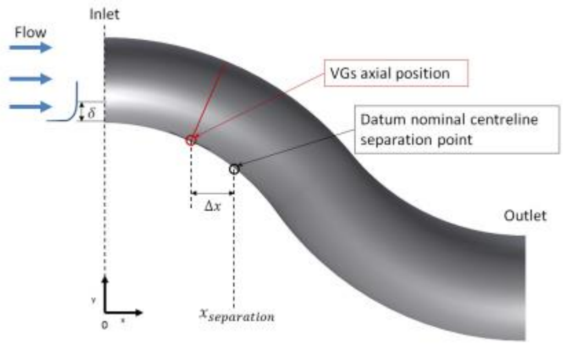
CFD Simulations and Modelling

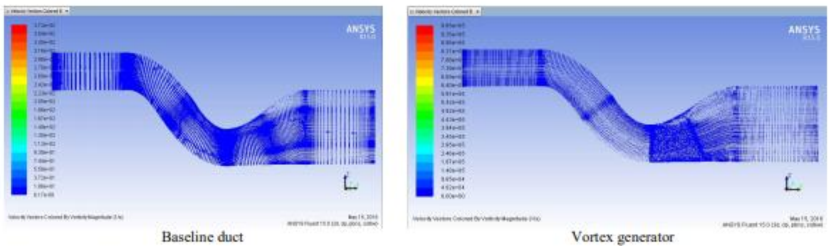
- CFD Software
  - BlueCFD-Core from openFOAM
  - Commercial Products
  - 2D flow analysis of pressure and velocity
    - Estimate potential pressure losses
    - Estimate boundary layer separation
    - ~ 60%-90% accuracy
- Assumptions
  - Conservation Laws
  - Steady Flow
  - Ideal Gas
  - Incompressible



Passive Flow Control System

- Passive Control
  - Geometry
  - Vortex Generators
    - Hard to design for or simulate
    - Likely to be installed post manufacturing and compared to baseline
    - Proven experimentally to lessen exit flow distortion & increase total pressure recovery [3][8]
  - Converging-Diverging

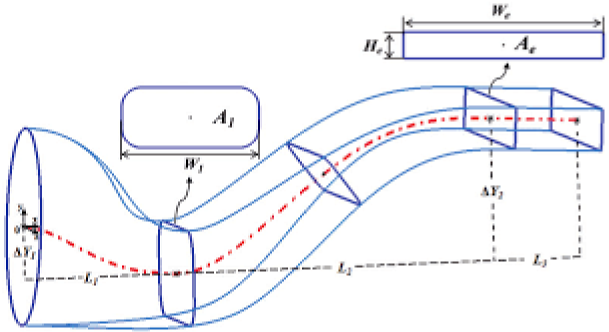




[9]

Cross Sectional Inlet Entrance

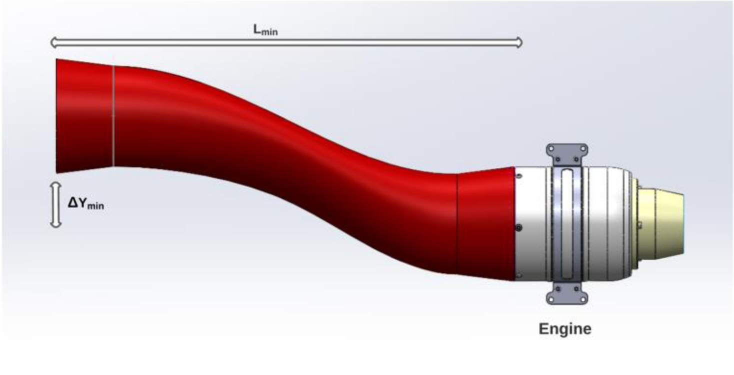
- Aspect Ratio
  - Uniform Circular
    - Lower Performance
    - Easier Manufacturing
  - Non-Circular Inlet Entrance
    - Higher Performance
    - Harder Analysis
    - Harder Manufacturing
- Implementing uniform AR will make TA integration and measurement recording simpler.



$$AR = \frac{H_{inlet}}{W_{inlet}}$$

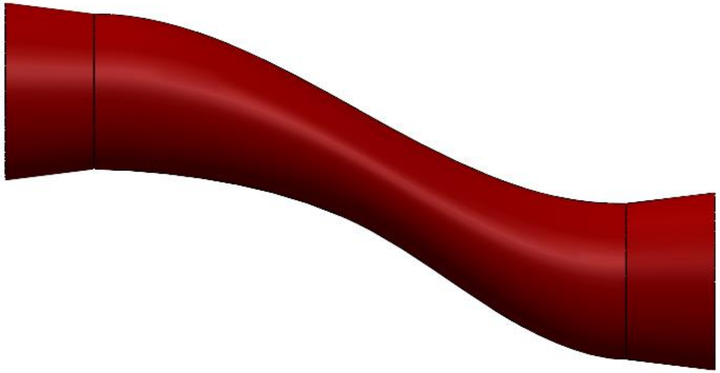
Length

- OSPRI
  - ΔY_{min} = 6 in (~150mm)
  - L_{min}= 15 in (~300 mm)
- Length Considerations for shorter inlet
  - Shorter is desired by customer (higher score)
  - Induces more flow separation
  - Design modifications (vortex generators) will be added to compensate for flow separation



Shape & Interior Geometry

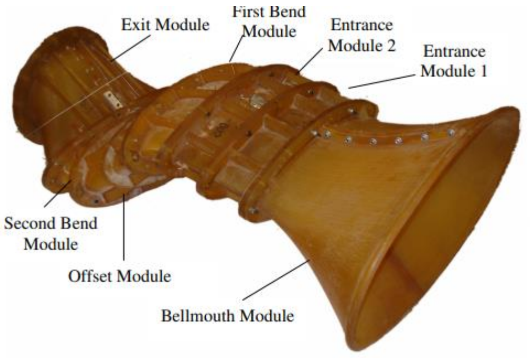
- Converging-Diverging Shape
  - Increases flow speed while turning
  - Accelerating the flow will delay and help prevent separation bubble formation
  - Slowing flow into AIP will prevent engine malfunction
  - Helps avoid large distortion at JetCat compressor face



Manufacturing Feasibility

- Constructed in sections
  - Feasible with smaller manufacturing footprint
  - Allows for modular design iterations

- Stereolithography (SLA) Printing (Resin)
  - Accurate to ±35 microns
  - Printing can be done autonomously
  - Form 3L print space
    - 13.2 × 7.9 × 11.8 in
  - Resin is brittle and difficult to alter



SLA Resin[5]

Manufacturing Feasibility

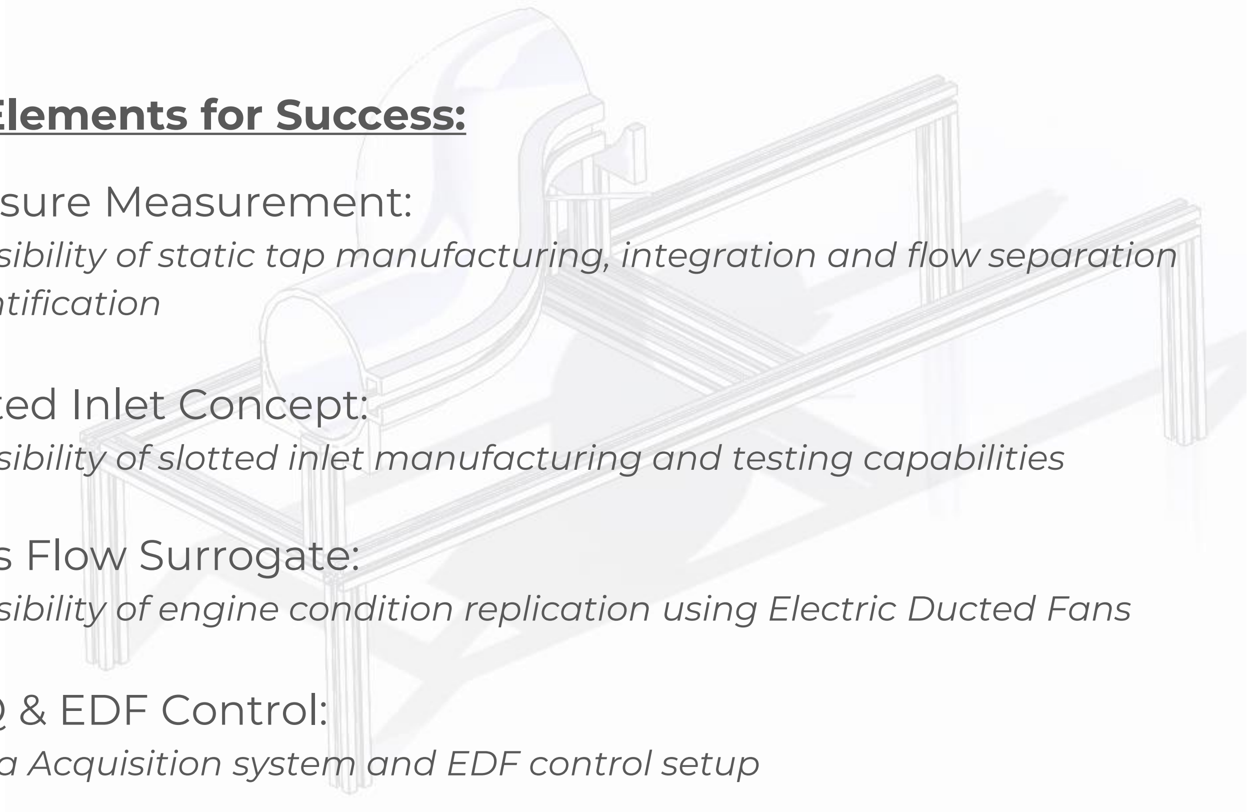
- Molded Fiberglass
  - Inexpensive
  - Easily procured
  - Requires reinforcement
    - Wood
  - Requires molds
- Other
  - CNC Machining
  - 3D printing

Fiberglass inlet panes

Section 4

Test Apparatus Feasibility

Test Apparatus Feasibility Overview



Critical Elements for Success:

1. Pressure Measurement:
   Feasibility of static tap manufacturing, integration and flow separation identification

2. Slotted Inlet Concept:
   Feasibility of slotted inlet manufacturing and testing capabilities

3. Mass Flow Surrogate:
   Feasibility of engine condition replication using Electric Ducted Fans

4. DAQ & EDF Control:
   Data Acquisition system and EDF control setup

Essential Data Items

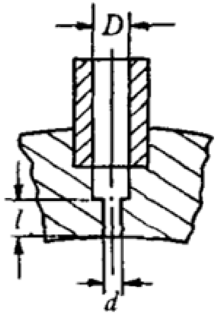
1. ***Total Pressure*** *- direct measurement*
   a. *At the inlet entrance*
   b. *At the inlet exit (AIP)*
   c. *Along interior of inlet (captured via an inlet slot and sliding pitot tube)*
2. ***Static pressures*** *- direct measurement through integrated static ports*
3. ***Density*** *- derived measurement*
   a. *Air Temperature (via room thermometer)*
   b. *Static Pressure (static ports with no airflow or room barometer)*
4. ***Mass flow*** *- derived measurement*
   a. *Cross sectional inlet area (CAD measurements)*
   b. *Density*
   c. *Flow Velocity - derived measurement*

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

$$V_1^{\,2} = \frac{2{a_1}^2}{\gamma - 1}\left[\left(\frac{P_0}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \qquad Eq.7.77a$$ [2]

$$a_1 = \sqrt{\gamma R T} \qquad \gamma = 1.4$$

Static Pressure Taps



Detail of static holes

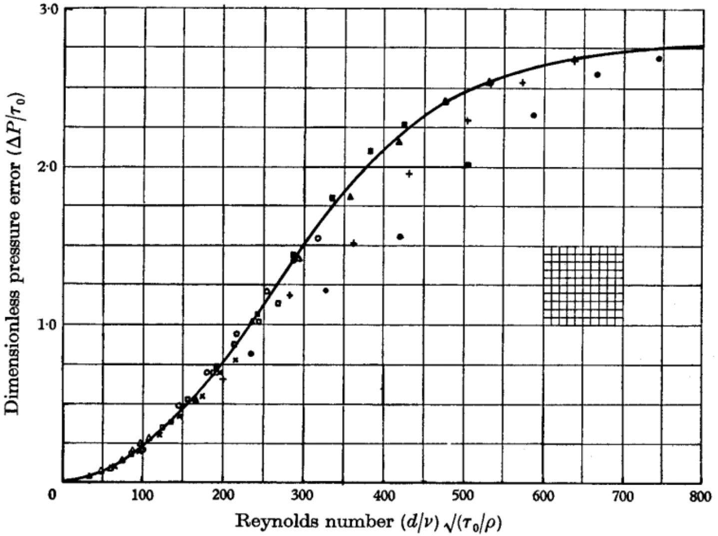


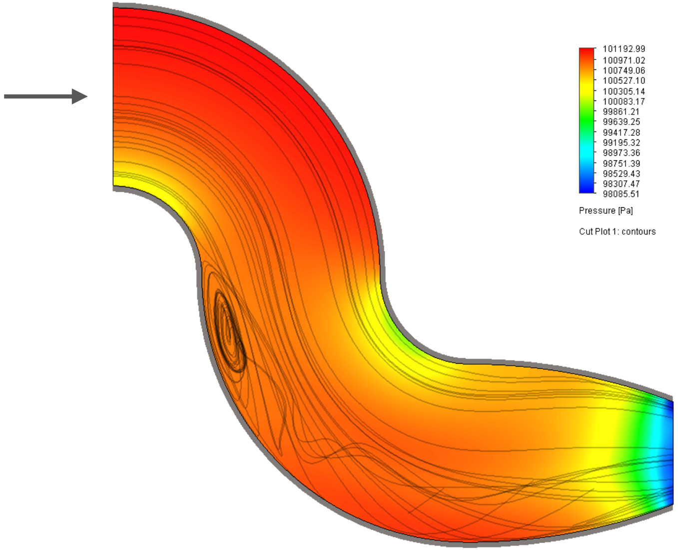
FIGURE 7. Dimensionless pressure error against Reynolds number for l/d ratios 1·5 to 6. Hole diameter (in.): ●, 0·175; +, 0·150; ▲, 0·125; ■, 0·100; ○, 0·075; □, 0·0635; ×, 0·050; △, 0·025.

$$\frac{\Delta P}{\tau_0} = \frac{C}{2}\sqrt{\frac{d}{\nu}\sqrt{\frac{\tau_0}{\rho}}}$$

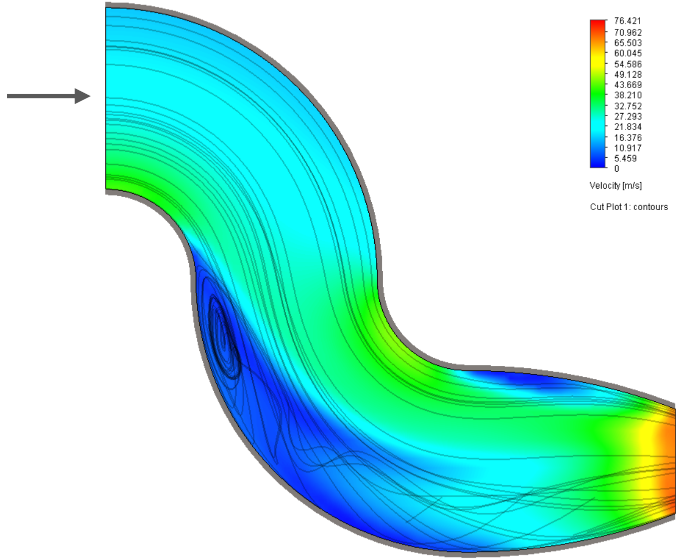
The Influence of Hole Dimensions on Static Pressure Measurements [6]

Static Pressure and Flow Separation

- Adverse Pressure Gradients (Low to High)

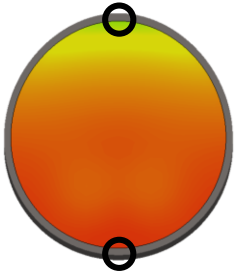


Pressure

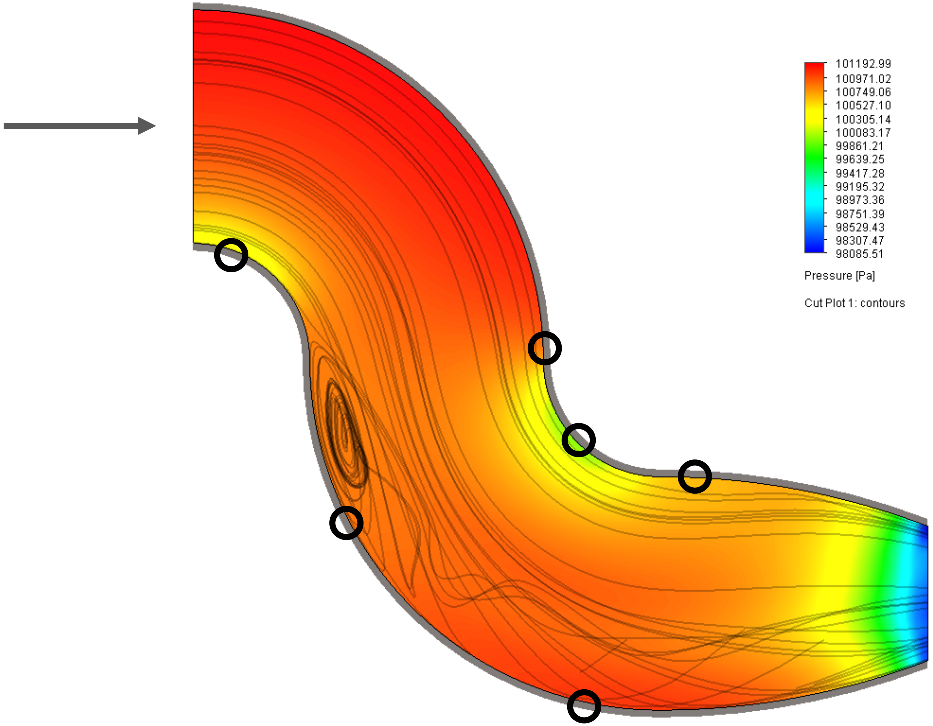


Velocity

Static Tap Locations



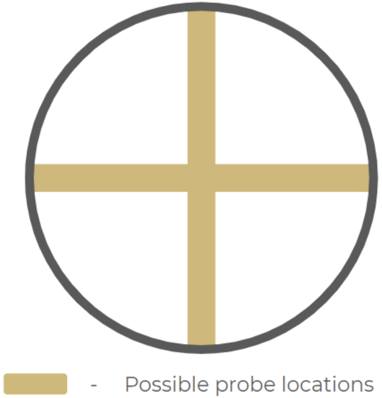
Front On

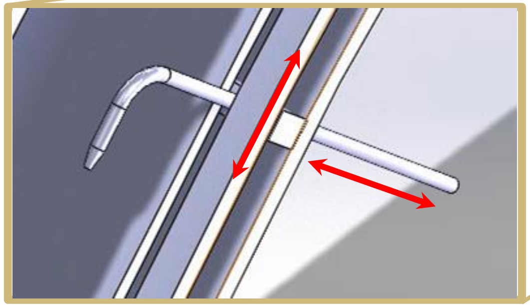


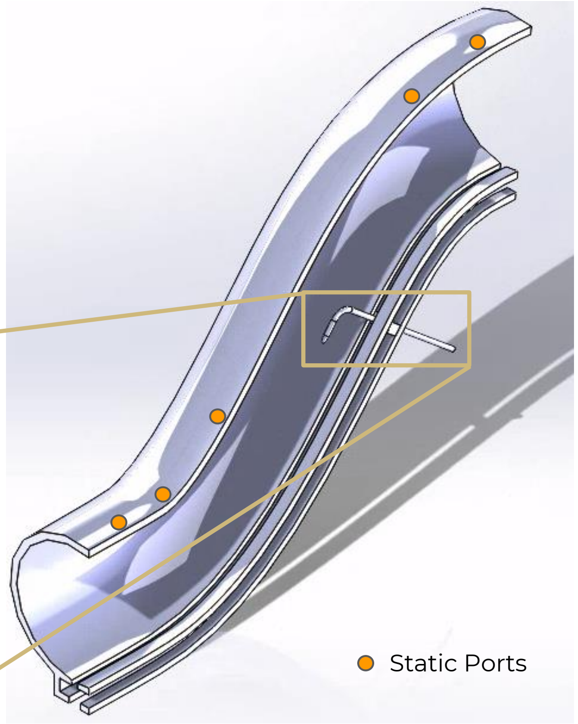
Slotted Inlet Approach Overview

- Pitot Tube used for measurements
  - Needs to be parallel to flow to be accurate
- Inlet pitot rail system (vertical/horizontal orientations)
- Static ports also integrated on the inlet surface
- Single slot in inlet allows for data collection along the entire length of inlet (along 2D plane)

Inlet Cross section

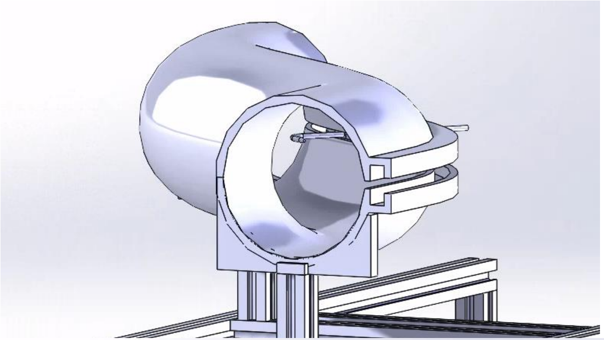


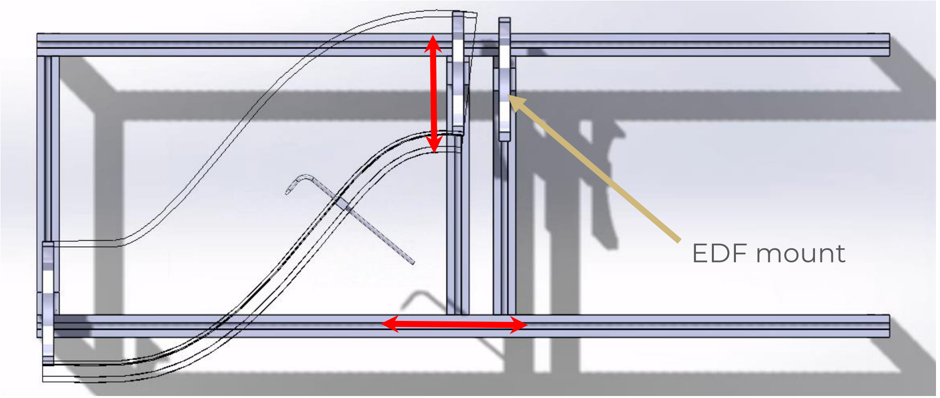


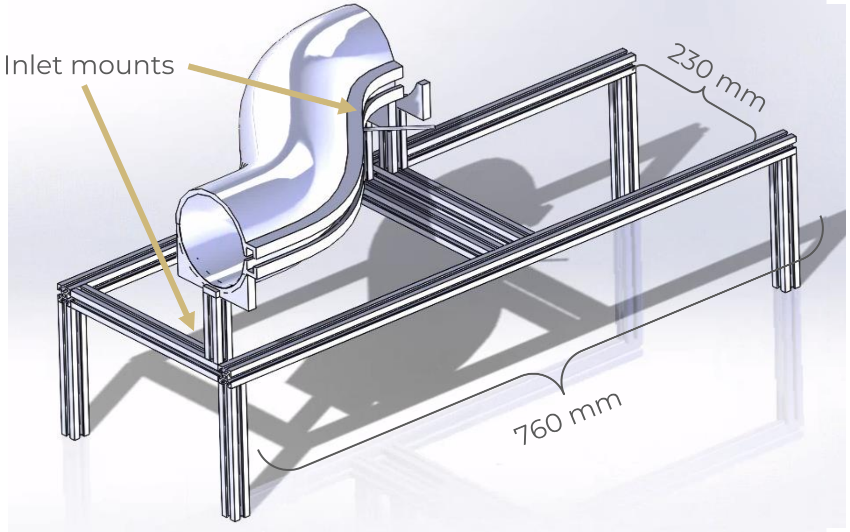


Inlet Test Frame

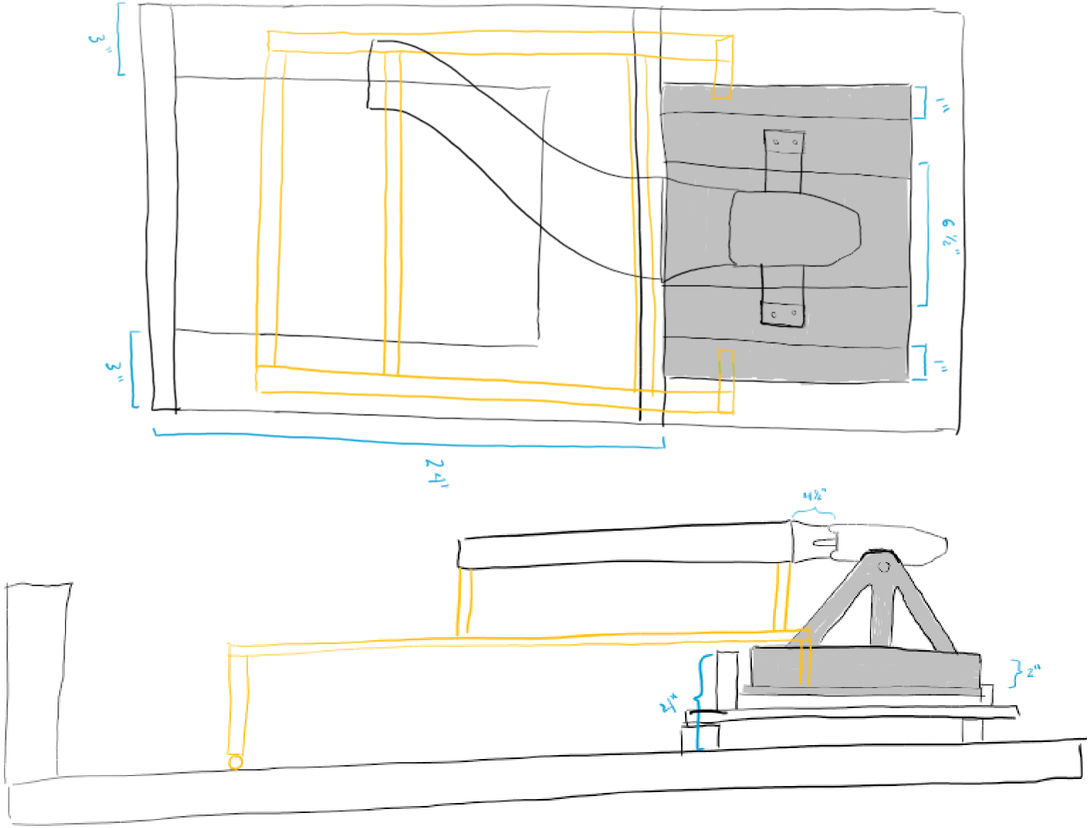
- Modular aluminum extrusion framing material
- Adaptable to a variety of inlets for testing
  - Different lengths, offsets, etc
- Capable of vertical and horizontal test configurations (important for sensors)
- Initial estimate of $90 for materials
  - Factory precut
- One frame for EDF tests and JetCat tests







JetCat Test Stand Integration



- Dual purpose test stand (will work with EDF and JetCat)
- Minor alterations required (with bolt-on attachments)
- Modular aluminum framing allows for flexibility
- Vertical and horizontal inlet testing
- No effect on the test stand load cell

- Sliding JetCat tray
- Modular Aluminum Framing

Mass Flow Surrogate

$$T = \dot{m}(v_e - v_\infty) + A_e(p_e - p_\infty)$$

Assumptions: $p_e = p_\infty$ and $v_\infty = 0$

$$\dot{m} = \rho \cdot A_e \cdot v_e$$

Assumptions: constant v_e across fan

$$T = \rho \cdot A_e \cdot {v_e}^2$$

$$\dot{m} = \sqrt{T \cdot \rho \cdot A_e}$$

→ **70mm EDF with 1200g of thrust**

Typical small EDF

Mass Flow Surrogate

Minimum of 1200g of thrust

- Additional thrust required as $p_e > p_\infty$

70mm EDF with 2300g of thrust

- Dr. Mad Thrust 70mm EDF - 1200W (4S)
- Nearly twice the estimated required thrust
  - Some higher thrust options are available

The required mass flow is achievable

70mm EDF [7]

TA Data Acquisition

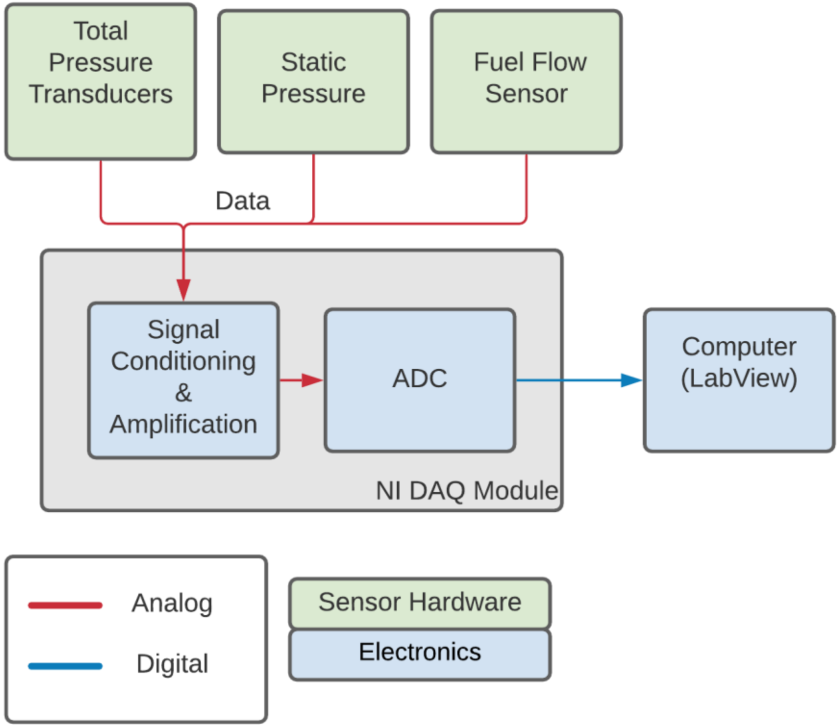
Data Collection Needs:

- Total Pressure (x1)
- Static Pressure (x6-10)
- Fuel Flow (x1)

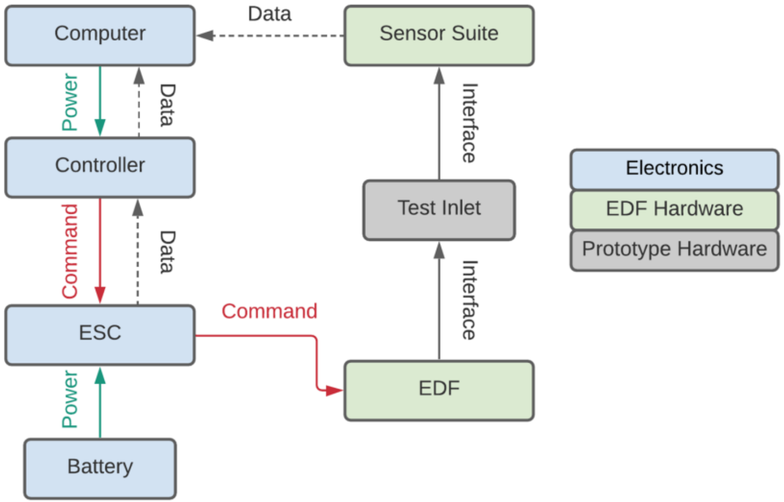
NI DAQ module

Heritage LabVIEW Sensor Code

Direct data import into Matlab



EDF Control

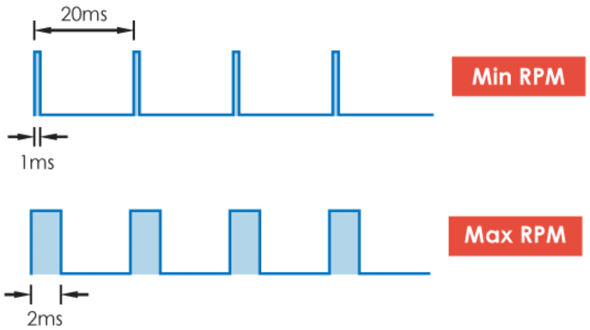


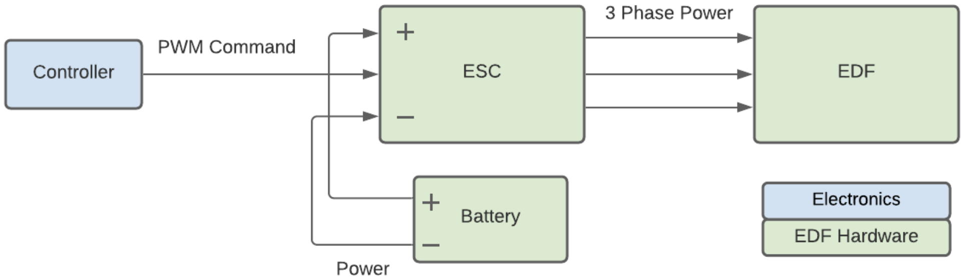
Electronic Speed Control (ESC)

- Exact components dependant on EDF

ESC Signal for RC EDFs

- 50 Hz PWM, 5-10% duty cycle





Section 5

Other Considerations

Other Considerations

Critical Elements for Success:

1. Time Budget:

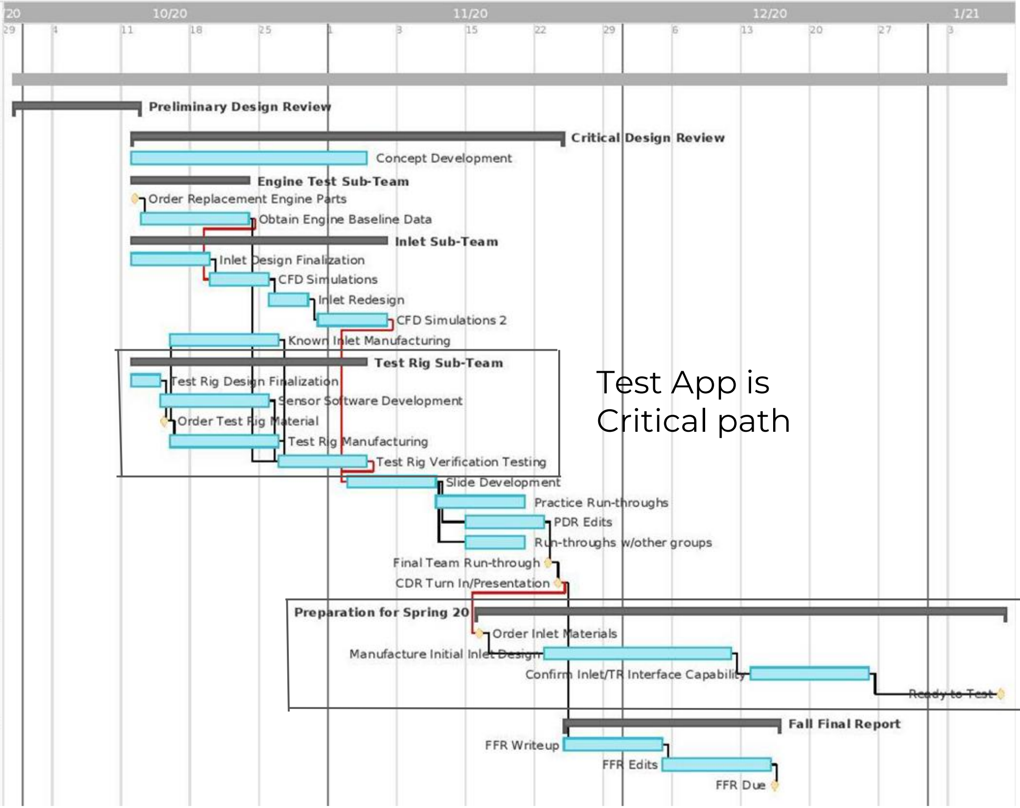
   Feasibility of manufacturing completion by January

2. Financial Budget:

   Preliminary budget analysis

Time Budget Feasibility

OSPRI	start	end
Preliminary Design Review	**09/30/20**	**10/12/20**
Critical Design Review	**10/12/20**	**11/24/20**
Concept Development	10/12	11/04
Engine Test Sub-Team	**10/12/20**	**10/23/20**
Order Replacement Engine Parts	10/12	10/12
Obtain Engine Baseline Data	10/13	10/23
Inlet Sub-Team	**10/12/20**	**11/06/20**
Inlet Design Finalization	10/12	10/19
CFD Simulations	10/20	10/25
Inlet Redesign	10/26	10/29
CFD Simulations 2	10/31	11/06
Known Inlet Manufacturing	10/16	10/26
Test Rig Sub-Team	**10/12/20**	**11/04/20**
Test Rig Design Finalization	10/12	10/14
Sensor Software Development	10/15	10/25
Order Test Rig Material	10/15	10/15
Test Rig Manufacturing	10/16	10/26
Test Rig Verification Testing	10/27	11/04
Slide Development	11/03	11/11
Practice Run-throughs	11/12	11/20
PDR Edits	11/15	11/22
Run-throughs w/other groups	11/15	11/20
Final Team Run-through	11/23	11/23
CDR Turn In/Presentation	11/24	11/24
Preparation for Spring 20	**11/16/20**	**01/08/21**
Order Inlet Materials	11/16	11/16
Manufacture Initial Inlet Design	11/23	12/11
Confirm Inlet/TR Interface Capability	12/14	12/25
Ready to Test	01/08	01/08
Fall Final Report	**11/25/20**	**12/16/20**
FFR Writeup	11/25	12/04
FFR Edits	12/05	12/15
FFR Due	12/16	12/16



Test App is Critical path

Inlet manufacturing for Spring 20

Financial Budget Feasibility

$500	$1,000	$1,500	$250	$1,000	$750

$0 — $5000

Prototyping

New Starter Motor
New Batteries
Experimentation with manufacturing tech

Inlet Manufacturing

Rapid prototyping

Instrumentation

DAQ hard/software
Pressure sensors
Temperature sensors
Mass Flow Surrogate

Test stand

Aluminum extrusions
Fasteners
Budget for 2 or 3 versions

Engine Maintenance

Jet Fuel
Allocated funds in case of engine failure

Unused Funds

Comfortable margin within all sections
Unused funds can be reallocated

Section 6

Project Summary

Project Feasibility Summary

Inlet		
Critical Element	**Feasible**	**Further Study**
CFD Simulation & Modelling	X	X
Passive Flow Control System	X	
Geometry & Inlet Shape	X	
Manufacturing	X	

Project Feasibility Summary

Inlet Test Apparatus		
Critical Element	**Feasible**	**Further Study**
Pressure Measurement	X	
Slotted Inlet	X	X
Mass Flow Surrogate	X	
Data Acquisition & EDF Control	X	X

Project Summary

- Utilizing an S-duct inlet for an aircraft can deliver significant benefits, but successful design is difficult to achieve
- Project is feasible, but with caveats
  - Several inlet and test apparatus elements require further study
- Timeline is accelerated
  - Critical path is clear, but accelerated timeline will be challenging
- Budget adequate to complete project

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
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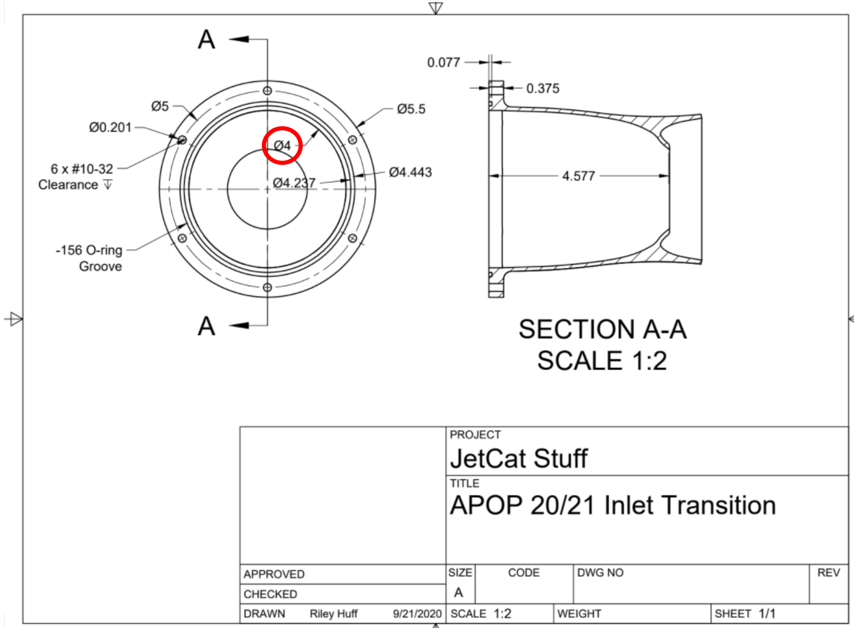
- [7] “Dr. Mad Thrust 70mm 10-Blade Alloy EDF 3000KV Motor - 1200W (4S),” HobbyKing.com, retrieved 11 Oct. 2020.
- [8] Reichert, B.A., and Wendt, B.J., 1994, “Improving Diffusing S-Duct Performance by Secondary Flow Control,” AIAA 32nd Aerospace Sciences Meeting and Exhibit.
- [9] Basawaraj, Hosur, S., 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

Resources

- [10] 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

Mass Flow Surrogation



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

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

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

Assumptions:

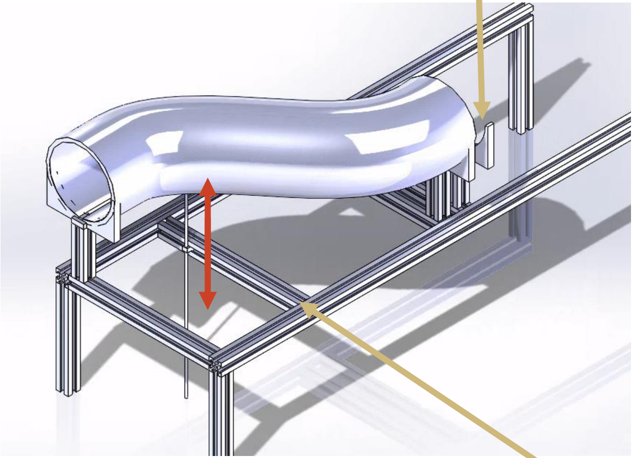
Circular cross section

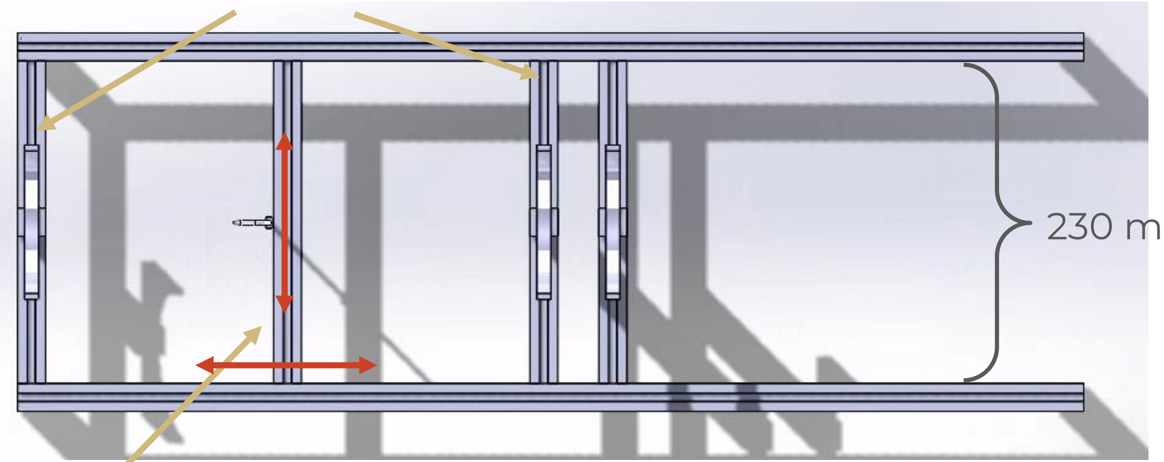
Constant area cross section

Standard atmospheric conditions

Simple Horizontal Slotted Inlet Mechanism

Vertical Test Setup





Probe mount rails

Sensor Trade Study

Criteria	1	2	3	4	5
Flow Obstruction (35%)	The probe obstructs 20% or more of the inlet area	The probe obstructs 15% of the inlet area	The probe obstructs 10% of the inlet area	The probe obstructs 5% of the inlet area	The probe obstructs 0% of the inlet area
Accuracy (20%)	Propagated error less than or equal to 5% for total pressure	Propagated error less than or equal to 4% for total pressure	Propagated error less than or equal to 3% for total pressure	Propagated error less than or equal to 2% for total pressure	Propagated error less than or equal to 1% for total pressure
Pertinence (20%)	No further design relevant data can be obtained from measurements	Data requires processing and design changes are based upon many assumptions	Data requires processing and allows for some identification of design changes	Data requires processing but allows for improvement to design iterations	Data allows for easy identification of design concerns
Complexity (15%)	Sensors are highly complex, difficult to implement and utilize for testing	Sensors are somewhat complex and have significant difficulty being integrated into the test apparatus	Sensors are easy to use but have significant difficulty being integrated into the test apparatus	Sensors are easy to use but have slight difficulty being integrated into the test apparatus	Sensors are easily assembled, mounted and require minimal setup for testing
Cost (10%)	> $500	> $250	> $100	> $50	< $50

Factor	Weight	Pitot Probe	Kiel Probe	Static Ports	Anemometer	Hot Wire A.meter
Obstruction	0.35	4.6	3.6	5	1	3.4
Accuracy	0.20	5	5	4	5	1
Pertinence	0.20	5	5	4	3	4
Complexity	0.15	4	4	5	3	4
Cost	0.10	4	2	5	4	3
Weighted Totals		4.61	4.06	4.6	2.8	3.09

Sensor Utilization Trade Study

Criteria	1	2	3	4	5
Effect on Flow (30%)	Nominal inlet flow heavily affected, data is not representative of inlet performance	Large deviations from nominal flow, data is unlikely to be representative	Some deviations from nominal flow, data may not be representative	Minimal deviations from nominal flow, data is representative of nominal flow	Nominal inlet flow is unaffected
Manufacturing Complexity (20%)	Extreme amount of manufacturing necessary. 2 months and beyond to have sensors fully functioning and ready	Considerable amount of manufacturing necessary. 2 weeks to 2 months to have sensors fully functioning and ready	Fair amount of manufacturing necessary. A few days to 2 weeks to have sensors fully functioning and ready	Little manufacturing necessary. Sensors are ready for testing within a few days	No manufacturing necessary. Sensors are ready for testing immediately
Inlet Coverage (20%)	Sensors can effectively survey and collect data from less than 30 percent of the inlet	Sensors can effectively survey and collect data from 30 to 50 percent of the inlet	Sensors can effectively survey and collect data from 50 to 70 percent of the inlet	Sensors can effectively survey and collect data from 70 to 90 percent of the inlet	Sensors can effectively survey and collect data from more than 90 percent of the inlet
Adaptability (30%)	Sensors and mounting systems cannot be adapted to new designs	Complications will occur adapting to new design, concerns may not be resolvable	Complications may occur adapting to new design, concerns are resolvable	Minor easily resolvable concerns transferring to new design	Sensors can easily be adapted for new design

Factor	Weight	Slotted Inlet Concept	Inlet Sectioning Concept	Discrete Locations
Effect on Flow	0.30	4	3	5
Manufacturing Complexity	0.20	3	3	4
Inlet Coverage	0.20	5	3	1
Adaptability	0.30	4	3	4
Weighted Totals		4	3	3.7

Mass Flow Surrogate Trade study

Criteria	1	2	3	4	5
Previous Experience (10%)	Team/team members have no experience with the system	Team/team members have used system at least 10 times combined	Team/team members have have used system at least 15 times combined	Team/team members have used system at least 20 times combined	Team/team members have routinely utilized the system (more than 30 times combined)
Availability for Testing (30%)	Rare availability/ high competition for use	With extended notice (weeks in advance)/ moderate competition for use	Notice needed (within a week)/ fair competition for use	Short notice (same day)/ light competition for use	Any time/no competition for use
Test Duration (10%)	Test can only be conducted for 10 seconds or less at one time	Test can only be conducted for 11 to 60 seconds at one time	Test can only be conducted for 1 to 3 minutes at one time	Test can only be conducted for 3 to 7 minutes at one time	Test can be conducted for longer than 7 minutes at one time
Mass Flow Control/Tuning (20%)	No means to change/alter mass flow	Mass flow can be changed and altered with significant inconveniences and effort	Mass flow can be changed and altered with inconveniences and moderate effort	Mass flow can be changed and altered with little inconvenience and light effort	Mass flow can be changed and altered with no inconvenience and no effort
Test Turnaround Time (10%)	Delay greater than 1 day between tests	Delay between 1 day and 5 hours between tests	Delay between 5 and 1 hour between tests	No more than 1 hour between tests	No delay between tests
Manufacturing Time (20%)	2 months and beyond to have fully functioning and ready	2 weeks to 2 months to have fully functioning and ready	A few days to 2 weeks to have fully functioning and ready	Fully functioning and ready for testing within a few days	Fully functioning and ready for testing immediately

Factor	Weight	Air Tank System	Wind Tunnel	Electric Ducted Fan
Previous Experience	0.10	1	4	5
Availability for Testing	0.30	5	2	5
Test Duration	0.10	3	5	4
Mass Flow Control/Tuning	0.20	3	5	5
Test Turnaround Time	0.10	3	4	4
Manufacturing Time	0.20	2	5	3
Weighted Totals		3.2	3.9	4.4

Inlet Trade Studies

Criteria	1	2	3	4	5
Anticipated Total Pressure Recovery (35%)	Little to No Anticipated Pressure Recovery	Serious flow losses anticipated	Moderate anticipated total pressure recovery	Theorized total pressure recovery nearing AFRL standards	Guaranteed total pressure recovery equal to AFRL standards
Anticipated Pressure Distortion (20%)	Major distortion, engine may fail	Distortion in Problematic areas	Distortion is present	Little to no Distortion in non-problematic areas	No distortion
Ease of Simulation (15%)	No further design relevant data can be obtained from measurements	Data requires processing and design changes are based upon many assumptions	Data requires processing and allows for some identification of design changes	Data requires processing but allows for improvement to design iterations	Data allows for easy identification of design concerns
Ease of Manufacturing (15%)	Sensors and mounting systems cannot be adapted to new designs	Complications will occur adapting to new design, concerns may not be resolvable	Complications may occur adapting to new design, concerns are resolvable	Minor easily resolvable concerns transferring to new design	Sensors can easily be adapted for new design
Technical Complexity (15%)	Structural or part failure every test run	Structure or part needs replacements every test run	Structure or part requires minor adjustments every test run	Structure or part requires monitoring but no adjustments or replacements every test run	Structure or part needs no monitoring and little to no maintenance

5.2.1 Passive vs. Active Inlet System

Factor	Weight	Passive System	Active System
Anticipated Total Pressure Recovery	0.35	4	4.5
Anticipated Pressure Distortion	0.20	4	4.2
Ease of Simulation	0.15	5	2
Manufacturing Ease	0.15	5	2
Technical Complexity	0.15	5	1
Weighted Totals		4.5	3.2

5.2.2 Inlet Cross Section and Shape

Factor	Weight	Non Circular	Circular
Anticipated Total Pressure Recovery	0.35	4.5	4
Anticipated Pressure Distortion	0.20	3.5	4
Ease of Simulation	0.15	2.5	4.5
Manufacturing Ease	0.15	3.5	4
Technical Complexity	0.15	3	4
Weighted Totals		3.6	4.1

5.2.3 Length of Inlet

Factor	Weight	Shorter Inlet	Longer Inlet
Anticipated Total Pressure Recovery	0.35	4	4.5
Anticipated Pressure Distortion	0.20	4	4.5
Ease of Simulation	0.15	4	4
Manufacturing Ease	0.15	4	3.5
Technical Complexity	0.15	4	4
Weighted Totals		4	4.2

5.2.4 Area Ratio

Factor	Weight	CD Inlet	D Inlet
Anticipated Total Pressure Recovery	0.35	4	3
Anticipated Pressure Distortion	0.20	4.2	3.5
Ease of Simulation	0.15	4	4
Manufacturing Ease	0.15	3	4
Technical Complexity	0.15	3	4
Weighted Totals		3.7	3.6

Frame Pricing Breakdown

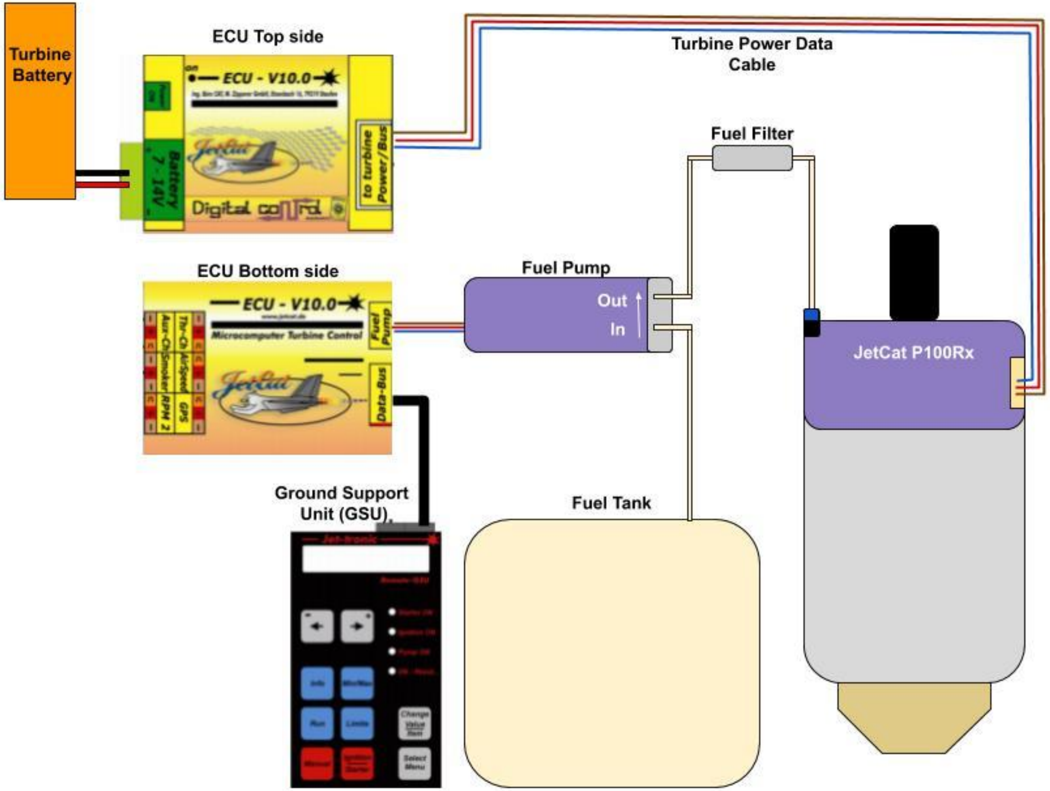
Part	Number needed	Individual price	Total Price
Long sides (760 mm)	2	$6.99	$13.98
Cross members (230 mm)	6	$3.96	$23.76
Legs (6 in/152 mm)	4	$3.96	$15.84
Inlet Support (short 3in/76mm)	3	$3.96	$11.88
Inlet Support (tall 11 in/280 mm)	2	$3.96	$7.92
Connecting nuts	25	$0.51	$12.75 (or $35.42 for package of 100)
Total	-	-	$86.13

https://us.misumi-ec.com/vona2/detail/110302683830/ https://us.misumi-ec.com/vona2/detail/110302246150/

Equflow Flow Measurement Instrument

- Working closely with professor Trudy Schwartz to understand how to properly use the provided sensor
- Instrument output is a square wave and counting the frequency will provide the flow rate measurement
- Typically a microcontroller or NI DAQ with a counter/timer channel is used to read these types of square wave, encoder, etc., measurements
- In the past, teams have used the NI 9401 digital input module to read data
- Disposable to reduce clogging and inaccuracies. Will need to purchase new test sections for subsequent 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/min)
- 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-tubeholder-clamp-10-pack-7-mm-hose-barb

JetCat Engine FBD



Integrated Engine Test

- **Pressure Distribution**
  Continuous 2D pressure data from slotted inlet allows for pressure distribution modelling

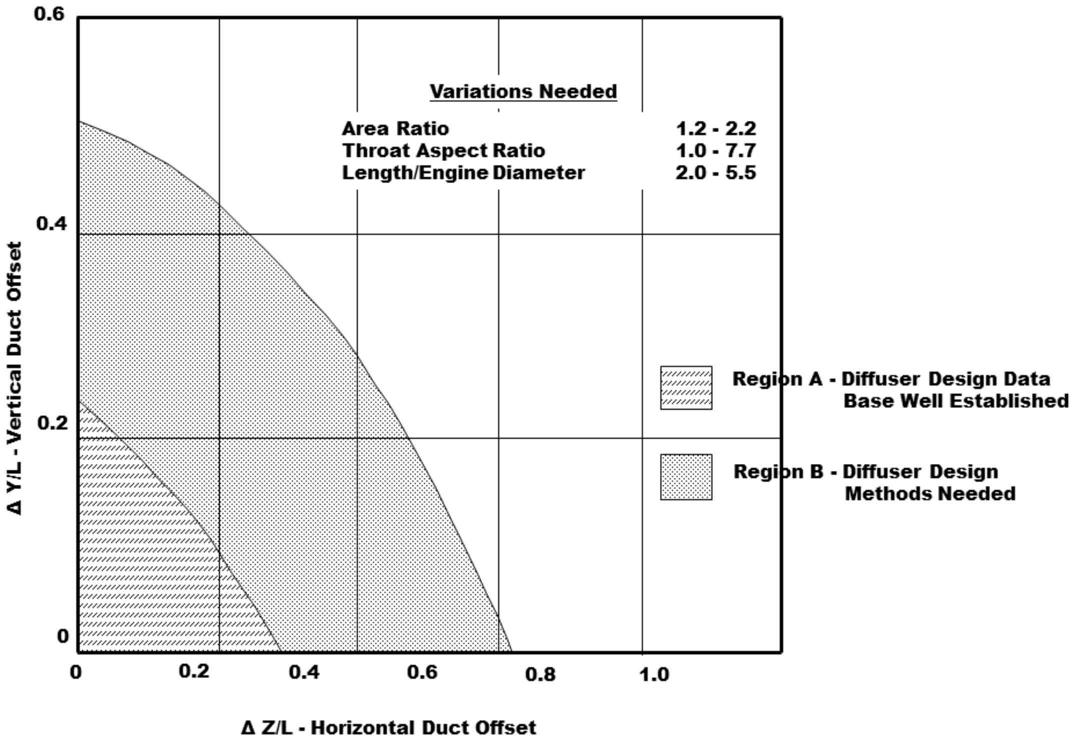
- **Load cell**
  25 lb load cell which functions to measure the turbine's thrust. AES department provided equipment with Arduino to read data into computer program. Already integrated into test stand and functioning from previous years. Engine capable of 22.4 lbf of thrust.

- **Fuel Flow Sensor**
  The fuel flow sensor will only be required for integrated engine tests.

Prototyping Budget Breakdown

Category	Item	Price per Unit	Amount	Sum Total (USD)
Initial Parts List to Run Engine	Starter Motor Assembly, New Style	89.99	1	89.99
	3200mAh 3S 9.9V Smart LiFe ECU Battery Pack	49.99	1	49.99
TOTAL (USD)	EC3 Male to XT60 Female Adapter	1.99	1	1.99
143.96	EC3 Female to XT60 Male Adapter	1.99	1	1.99
Test Rig Structure	Long Sides (760 mm)	6.99	2	13.98
	Cross Members (230 mm)	3.96	6	23.76
	Legs (152 mm)	3.96	4	15.84
	Inlet Support - short (76 mm)	3.96	3	11.88
TOTAL (USD)	Inlet Support - tall (280 mm)	3.96	2	7.92
86.13	Connecting Nuts	0.51	25	12.75
Fuel	Jet-A Fuel (gal)	1.71	5	8.55
TOTAL (USD)	Oil (litre)	30	1	30
38.55				
DAQ & Instrumentation	TBD			
TOTAL (USD)				
0				
Inlet Manufacturing Experimentation	TBD			
TOTAL (USD)				
0				

Inlet Length Guide



Vortex Generator Example Visualization [10]

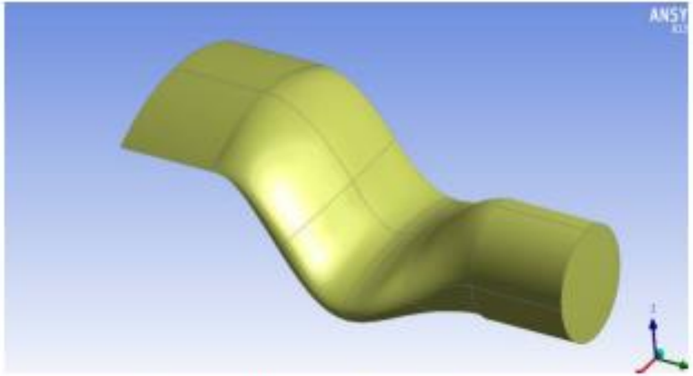


Figure-1 Baseline serpentine duct model

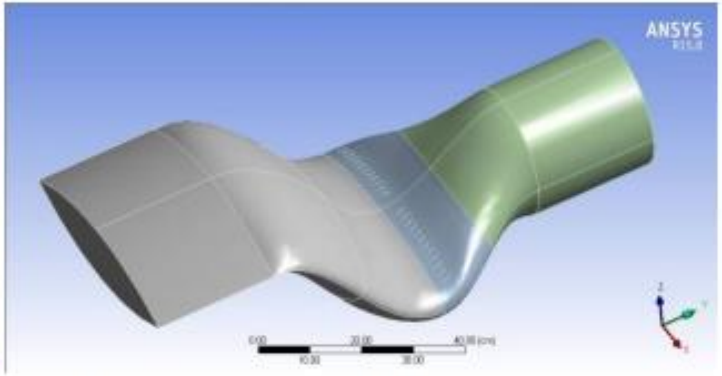


Figure-2 Serpentine duct with vortex generators