University of Colorado Boulder

Department of Aerospace Engineering Sciences
ASEN 4018

Offset S-duct PRopulsion Inlet
(OSPRI)

Project Definition Document (PDD)

September 16th, 2020

College of Engineering & Applied Science
UNIVERSITY OF COLORADO BOULDER

1 Project Information

1.1 Project Approval

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2 Problem or Need

The P100-RX is a micro turbojet engine developed by JetCat. It is a popular propulsion platform for many small-scale fixed-wing UAV applications. Weighing only 2.38 lbs., it is capable of supplying 22.5 lbf of thrust at 152,000 RPM. Its power-to-weight ratio is superior to traditional propeller-driven propulsion systems. In order to maximize freestream air entering the engine, this off-the-shelf engine is commonly mounted offset from the airframe centerline. Integrating the engine into the fuselage would reduce the exposed surface area and overall drag. This requires diverting freestream airflow into the engine intake via an inlet duct.

Well-designed inlet ducts for aircraft with non-podded engines are of interest to the aviation community. The Lockheed P-80 Shooting Star was a first-generation jet-powered fighter aircraft that integrated a single jet engine into the fuselage. It utilized a bifurcated S-duct inlet that directed airflow to the engine inlet (Figure 1). Modern military aircraft such as the F-22 and F-35 also utilize S-duct inlets.

Figure 1: Lockheed P-80 on tarmac.

The thrust requirements for transport category aircraft are much different than those required for fighter aircraft, which is reflected in the number and types of engines they utilize. There have been several successful three-engine (trijet) commercial aircraft, including the Boeing 727 and Lockheed L-1011. Both of these aircraft utilized an internal, centerline-mounted engine mounted in the tail of the aircraft. Like the military aircraft mentioned above, an S-duct inlet was required to direct airflow to the inlet of the centerline-mounted engine. (Figure 2)

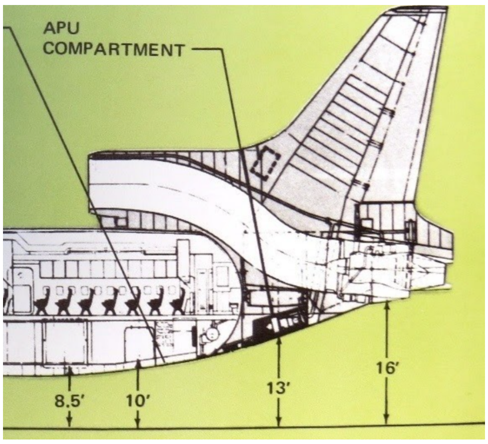

Figure 2: Lockheed L-1011 with centerline-mounted engine in tail.

The goal of the OSPRI research and development project is to design and build a low-loss ducted inlet, offset from the compressor face of the engine, with minimal thrust and total pressure losses. Specifically, the project's goal is to develop an S-duct inlet for the JetCat P100-RX engine with a minimum of a 6-inch offset from the engine centerline, and to design and build a test rig capable of measuring the total pressure recovery of the inlet. Total pressure losses below 2% between the inlet exit and freestream, and a reduction of thrust output and increment of Thrust Specific Fuel Consumption (TSFC) below 5% are customer objectives for engine performance with the inlet modification. In addition, the inlet design should reduce axial distance from inlet entrance to exit, reduce compressor face pressure distortions, and minimize manufacturing and modification costs. If successful, this project will enable the integration of the JetCat P-100RX into the fuselage of future UAVs.

3 Previous Work

The Air Force Aerospace Propulsion Outreach Program (APOP) is sponsored by the Air Force Research Laboratory and began in 2010 for the purpose of engaging undergraduate engineering students in the study of gas turbine engines. Each year participating undergraduates are tasked with designing, building and/or modifying a different aspect of a JetCat turbojet engine. Universities across the country participate in the APOP competition, with the University of Colorado, Boulder, participating in several past competitions.

In 2015, the focus of the APOP competition was to increase fuel efficiency without sacrificing thrust or significantly increasing weight. A new exhaust nozzle, optimized for supersonic flow, was the focus of the 2016 competition. In 2017, the competition focused on ignition at very low temperatures. Designing a new engine control unit (ECU) was the focus in 2018 and, in 2019, the competition focused on designing and building a thrust vectoring system, as well as developing an anti-windmilling system. This year's competition to design and build an S-duct inlet for the JetCat P100-RX engine continues the APOP's pursuit of engaging undergraduate engineering students in the study of gas turbine engines.

The S-Ducted inlet has been studied in great computational detail by NASA (Figure 3). The NASA inlet design was modelled using three different approaches: an inviscid model, a viscous vortex generator model, and a viscous BAY model [1]. Each model was tested at a free stream mach number of .78. The simulations yielded data on total pressure recovery, as well as how the inlet affected the throat mach number. The results obtained from this research can be leveraged by the team, as the flow conditions are similar to what will be expected for the JetCat P100-RX. This NASA study characterizes subsonic, viscous, and compressible flow which is the flow regime our team will be dealing with for the project. The values tabulated in their results can be used to inform our design and establish a baseline for our initial design choices.

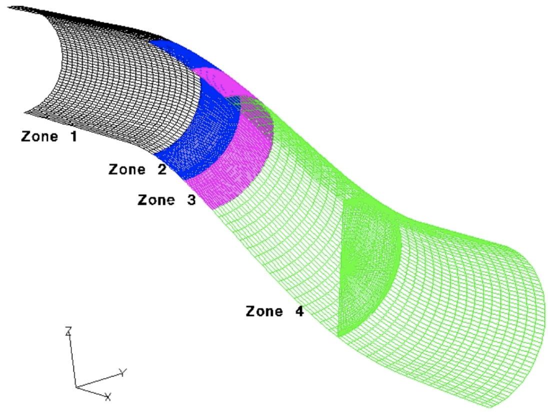

Figure 3: NASA S-Duct Inlet Design

Case	No. Iter.	AIP Total Pressure Recovery	Throat Mach Number
Experiment		0.9735	0.7009
Gridded Vanes	30000	0.9775	0.6620
Wendt Model	20000	0.9871	0.6888
BAY Model	20000	0.9778	0.67153

Figure 4: Results of NASA S-Duct Simulations

Previous work in the area of testing equipment and methodologies for experimental inlet analysis is readily available for most industry scale engines, however, only a small amount of research is directly relevant to the inlets and engines of similar scale to the project's system. The paper "Flow Characteristics of an Ultracompact Serpentine Inlet with an Internal Bump" goes into detail on the experimental methodology and equipment utilized for pressure measurements within the inlet [11]. The paper details the problem of flow seperation in an S-duct of our scale, describing its most common location at the second turn of the inlet, forming two counter-rotating vortices. The team utilized a total pressure rake and a series of surface static taps to characterize the flow structure in the inlet. The rake was placed at the inlet exit to analyze the pressure distribution where the compressor face would be in an integrated engine. The static ports were placed along areas of the inlet where flow was expected to produce adverse boundary layers or separation, primarily the surfaces of the first and second turns.

Similar methods of static surface taps have been utilized by a variety of other teams to analyze the flow characteristics of numerous inlets [12] [13] [14]. Furthermore, the most frequently utilized method of gaining detailed pressure distortion and flow structure measurements are total pressure rakes placed where needed [15].

Another more simplistic methodology utilized before is the use of heated oil vapors to visualize flow. This is common in the automobile industry as well as in the aerospace industry to visualize flow structures (such as vortices, separations and other qualitatively identifiable structures), as seen in the paper "Inlet Flow Control and Prediction Technologies for Embedded Propulsion Systems" [16]. This project utilized all three methods (surface ports, surface oil-flow visualizations, and total pressure rakes) in order to develop a boundary mitigation system for an inlet highly integrated into an airframe.

4 Specific Objectives

Table 1 outlines the levels of success for this project. Since the JetCat P100-RX engine can be unreliable, the lower levels of success focus on the correct operation of the test rig and the pressure recovery in the inlet, but do not include operation of the engine. Higher level objectives focus on the operation of the engine in conjunction with the inlet, and the performance requirements as outlined by AFRL.

Level	Objectives
1	A test rig is designed and manufactured that is capable of measuring inlet performance metrics at discrete locations along the inlet length, the inlet entrance and the compressor face.
2	Experimental verification of inlet's total pressure recovery below 60% across the full simulated RPM range of the engine using a flow surrogate.
3	Experimental verification of inlet's total pressure recovery below 90% across the full simulated RPM range of the engine using a flow surrogate.
4	Experimental verification of nominal engine operation over full RPM sweep with inlet attached, meeting level 3 objectives, increasing TSFC by no more than 10%, and decreasing thrust by no more than 10%.
5	Experimental verification of nominal engine operation over full RPM sweep with inlet attached, with total pressure recovery $\leq$ 98%, TSFC increased by no more than 5%, and thrust decreased by no more than 5%.

Table 1: Specific objectives and levels of success.

5 Project Requirements

The design of the S-duct inlet for the JetCat P100-RX engine is a self-contained project and does not rely on a larger system, nor does it fit into other design problems. The requirements for the inlet design project stem primarily from the AFRL/APOP competition scoring material. Team 2 will design an inlet for use with the JetCat P100-RX that will produce the desired solution to the requirements and a custom built test rig that will provide total pressure data. The horizontal CU Aerospace engine test stand will provide thrust data. Specifically, OSPRI will meet the following functional requirements:

Req	Description
1	Design and build an S-duct inlet for use with the JetCat P100-RX turbojet engine that performs according to the customer objectives.
2	Design and build a test apparatus to measure critical inlet performance metrics and inform inlet design.

Table 2: Functional Requirements.

5.1 Concept of Operations (ConOps)

After the S-duct inlet is designed and verified computationally, the inlet will be manufactured and tested in a wind tunnel using a custom test rig. After this initial experimental verification, the inlet and test rig will be mounted to the front of the JetCat P100-RX. The engine will be run through its full RPM sweep (idle to full power). The results will be compared to a baseline engine run without the inlet attached. Note that this testing plan is subject to change at the direction of AFRL.

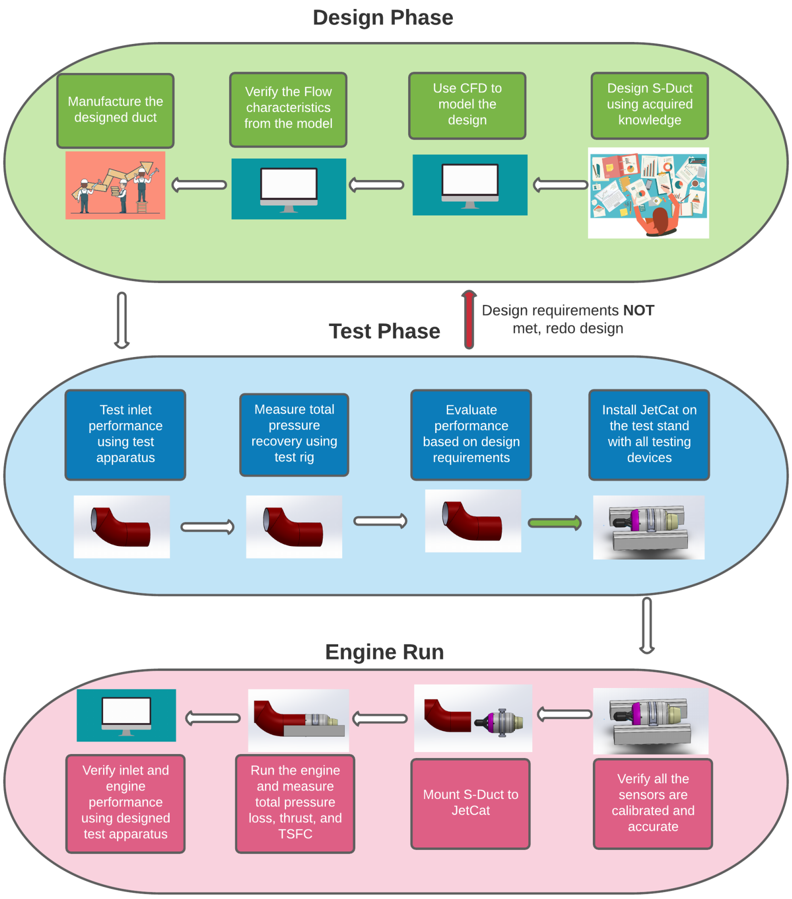

Figure 5: Ground Testing ConOps.

6 Critical Project Elements

6.1 Testing

With the inherent challenges and limitations of modeling internal flow, the physical testing and verification of different inlet models will be key. Different forms of testing and verification that do not use the engine but simulate the correct mass flow will be required to allow for rapid, iterative validation testing of inlet designs as testing with the engine will prove cumbersome and inefficient. Additionally, physical testing will ensure the protection of critical hardware (the JetCat engine) until the inlet and its effects are fully understood. Without a proper testing setup and procedure, good data cannot be collected. Appropriate sensors and data acquisition instruments are also required to adequately measure the performance of various elements and parameters during tests.

6.2 Manufacturing

As physical testing will be the primary means of inlet verification, inlet manufacturing will be key to ensure that the produced inlets accurately represent the intended design. Additionally, quality inlet manufacturing will ensure the tests and data collected are accurate. We want to ensure that the intended design and aerodynamic choices are what are effecting the internal airflow, not variables due to manufacturing errors. The inlets will also need to be manufactured with testing hardware and procedures in mind.

6.3 Design

The overall design of the inlet will be the variable that effects all the other dependent variables that are being evaluated (which will mostly be the customer requirements). The inlet is the main item that will be changed making its design indispensable. The design of the inlet is the only way that any of the customer requirements can be met. Without the inlet, none of the customer's objectives can be met.

6.4 Engine Functionality

While much of the physical inlet testing will be done without the use of the JetCat engine but by using a surrogate source for mass flow, the engine will still need to function. An unmodified functioning engine is needed for baseline data to be collected. This baseline data will then be used through the entire design and testing phases of the project to ensure that the inlet will perform well when attached to the JetCat engine. Additionally, a customer requirement focuses on the effects the inlet has on the thrust specific fuel consumption (TSFC). The TFSC can only be measured accurately during a physical test with the engine and an attached duct, requiring the JetCat engine to function. As the customer has designed this project as a competition among different universities and wants to test all designs on a JetCat engine at Wright Patterson AFB, inlets can not exclusively be tested using the surrogate source for mass flow. There needs to be a functioning engine to ensure that there are no constructive or destructive aerodynamic effects or other interactions when the inlet and the engine interface with each other. These effects may not be present in the surrogate mass flow source testing and may have a significant effect on final results.

6.5 Budget

Completing this project will depend on organized and deliberate financial allocation. Purchase of any software required for simulation, manufacturing costs incurred during prototyping, fuel and oil costs to run the engine, engine maintenance costs, and unforeseen costs need to be considered throughout the life of the project.

7 Team Skills and Interests

Critical Project Elements	Team member(s) and associated skills/interests
Design and Simulation	• Zakhar Dmitriyev: Experience in xFoil, mxFoil, mses, xflr5, airfoil polar analysis, Re# Analysis, Soiling effects, MATLAB. • Tim Breda: Familiar with wind tunnel diagnostics and testing, CFD modeling, aerodynamic analysis in MATLAB. • John Wissler: Experience in aerodynamic modelling in both Ansys Fluent and Matlab. • Michael Vogel: Experience with ANSYS Fluent & Autodesk Fluid. • William Watkins: Experience with Solidworks and Siemens FloEFD.
Engine Functionality	• Joseph Derks: Vast experience with the operation and setup of JetCat engines. • Harrison Methratta: Experience with multiple hardware and power systems, integration and analysis; currently taking propulsions.
Manufacture and Testing	• Joseph Derks: Vast experience designing and building. SolidWorks certified, likes to build with his hands, and experience with 3D printing and other manufacturing techniques. • Dishank Kathuria: Solidworks certified, has experience with wood working and other manufacturing methods. • John Wissler: Some experience with Solidworks and 3D printing. Experience in aerospace maintenance and the use of hand tools. • Harrison Methratta: Robust experience with Matlab, Solidworks, 3D printing, ANSYS Fluent, Arduino. Strong manufacturing experience. • Ryan Joseph: Solidworks and Onshape experience. Works with wood/metal/plastics on designing and manufacturing parts and projects. • Michael Vogel: Experience with manufacturing and live fire testing of composite combustion chambers. • Tim Breda: Holds research position with Dr. Reiker in ME to study wind tunnel testing to study wildfire spread, resources can be available with the project. • Josh Seedorf: Familiar with CAD, FEA, and MATLAB. Has experience building and working with hands. • William Watkins: Interested in manufacturing, experienced with working with hands.
Budget	• Ryan Joseph: Familiar with Excel as well as financial planning. • Joey Derks: Experience in personal life organizational funds.

8 Resources

Critical Project Elements	Resource/Source
Design and Simulation	• John Mah: Previous project experience • James Nabity: ASEN Intro to Propulsion Professor, industry experience • John Farnsworth: Experimental Modelling • John Evans: CFD expertise • Siemens CFD community: Online resource for flow modelling
Engine Functionality	• Matthew Rhodes: JetCat experience • Bobby Hodgkinson: JetCat experience • Trudy Schwartz: Past project experience
Manufacture and Testing	• Bobby Hodgkinson: JetCat experience • Trudy Schwartz: Extensive sensor experience
Budget	• Jenna Snyder: Finalist of Global Platinum Securities conference

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