Jet Engine Project Proposal

Worcester Polytechnic Institute AIAA Branch

AIAA
WPI STUDENT BRANCH

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1 Team Members

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2 Abstract

The goal of this project is to create a test stand for safe operation and monitoring of a miniature jet engine. The model of this jet engine is the WREN 75, the manual of which can be found in section 7.8. Design requirements of this test stand will involve the measuring of temperature and pressure at different points within the engine, safe control of startup and power down sequences, and allowing for real time monitoring of the engine system during user operation. An example of the desired test stand can be seen below in Figure 1. While common uses of these engines are powering appropriately sized aircraft, this model will serve as a demonstration and teaching tool to improve student learning and promote engineering development within the WPI chapter of the AIAA. The test stand will be used as part of the WPI Fundamentals of Air-breathing Propulsion course AE-4711 and for AIAA outreach events. To accomplish this task, a team of students listed in section 1 was organized and evenly divided into two sub-teams based on need and interest. These sub-teams deal with the design and implementation of the physical test stand and control system respectively. The test stand team will work on the safe implementation of the necessary mechanical mounting systems for the sensors and engine itself, while the controls team will focus on the electrical control system, which integrates the sensors to a data acquisition system and generates control signals based on proper data interpretation. The following sections go into further detail regarding how these teams will organize and complete these tasks.

Figure 1 Commercial Example of Test Stand and Control System for WREN 75.

3 Test Stand

3.1 Engine Mount

The team will either purchase a commercial part or manufacture our own. Turbine Solutions, a vendor based in the U.K., sells parts and accessories for our WREN 75 engine. This includes an engine mount for the WREN 75 jet engine for which a portion of the budget will be allocated. It is anticipated that the team will decide against buying a pre-made mount due to high shipping cost, in which case one will be manufactured using the same budget. In pursuing the latter case, the team would need to acquire a type of u-fastener that would be able to withstand high temperatures, as well as the thrust applied to them.

3.2 Casing

The main casing of the test stand will be constructed out of standardized T-slots. These were chosen due to their ease of construction and wide range of customization, as they include a wide array of standardized joints, fasteners, and attachments. If the final test stand needs to be modified, reinforced, or upgraded, the T-slots will enable future users to simply make changes with a hex wrench. The standardized construction style makes mounting items such as sensor equipment easier later in the construction process. The chosen T slots will be 40mm by 40mm in size, with a slot width of 8mm as seen in Figure 2. Of the T-slot options, it was determined that a solid internal rail would be desirable over the less-strong hollow T-slot options.

Figure 2 Example of T-Slots.

The use of T-slots will also allow for the installation of casters with brakes rated at a capacity of 265 pounds per wheel to ensure movement of the test stand. Casters will allow the stand to be safely moved between laboratories or other safe environments and securely locked in position during tests. As mentioned earlier, clear plastic sides measuring 6ft by 4ft will be used for the front of the test stand to allow students to see the jet engine in action. The back will be a similarly sized panel made of solid plastic to save costs. The front of the test stand facing the inlet will have a PVC coated steel mesh measuring 4ft by 4ft to ensure sufficient airflow while blocking large objects from entering the test stand. The back of the test stand facing the exhaust outlet will either be left empty or have a mesh of its own depending on if the material is able to handle the exhaust temperatures of the jet engine.

3.3 Sensor Integration

The sensors will be integrated onto the WREN 75 engine and t-slot frame through 3D printed mounts. The mounts will either be located directly on the engine or a certain distance from it depending on the type of sensor. The tubes and wires connected to the sensors will be funneled through similar 3D printed slots and holders. Ideal 3D mounts will use NylonX filament rather than PLA to withstand higher temperatures. In the case temperatures near the engine will exceed the safe range for NylonX filament, metal Bracket will be manufactured and used instead. There will also be T-slot bars running across the top of the engine to allow for easier sensor mounting.

4 Sensors

The sensors will have probes mounted to the engine body externally, the image below shows an example of how Turbine Technologies integrated temperature and pressure sensors into a turbojet engine. When measuring static and stagnation pressure, a pitot static tube connected to a pressure sensor will be used to measure the data at each section. These sections include upstream of the compression stage and downstream of the exit nozzle. The static pressure will be directly measured from the pitot tube, while the stagnation temperature will require the addition of the measured free stream static pressure to the free stream dynamic pressure. To predict the pressure and temperature conditions in the other stages the measured pressure, temperature, thrust, velocity of air at the exit, and RPM will be used to preform calculations for each of the internal stages. With these measured parameters a state-space representation of the engine will be developed to include all variables of interest. This model will be computed in real time while including the measured sensor readings so that after a short time the state variables converge to those of the actual engine. This technique will allow for estimation of the unmeasured stage temperatures and pressures, the accuracy of which will depend on the complexity of the mathematical model, and thus enabling cycle analysis of the entire engine. Using this model will be beneficial because avoiding physical modification to the engine removes any sealing issues and creating turbulent airflow by inserting sensor probes into each of the stages.

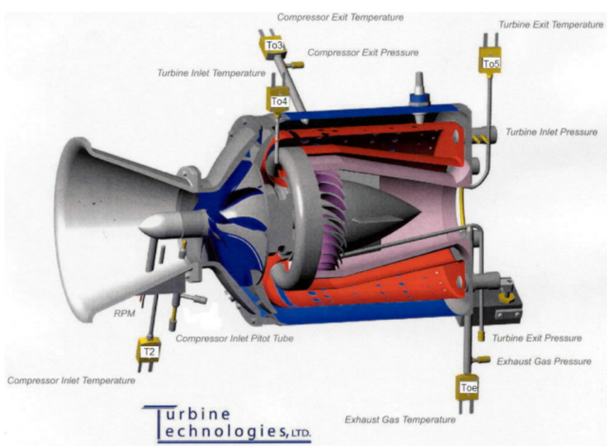

Figure 3 Image of how Turbine Technologies integrated temperature and pressure sensors into a turbojet engine.

4.1 Stagnation and Static Pressure Sensors

A requirement of this project is measuring the stagnation and static pressure up of the compression stage and the nozzle exit. To measure the stagnation pressure, a pitot static tube will be used to measure the velocity at each stage and static pressure at each stage. The Dwyer pitot tubes used will contain specific manufacturer information and conversion charts for how to find the measured velocity. Using the sum of the free-stream dynamic pressure and static pressure will allow for a calculation of stagnation pressure. To measure the static pressure a pitot static tube will be used to measure the velocity and static pressure, the static pressure is directly measured by the pressure transducer connected to the pitot static tube. For the WREN 75 turbojet engine the compression ratio is 3:1, the compression ratio will yield a maximum pressure of around 50 psi. To allow a safety factor of 2 the pressure sensor should be rated up to an absolute pressure range of 0-100 psi which will vary from each stage of the engine. The pressure sensors will output a voltage reading, the expected range of voltages is 0.5V - 4.5V

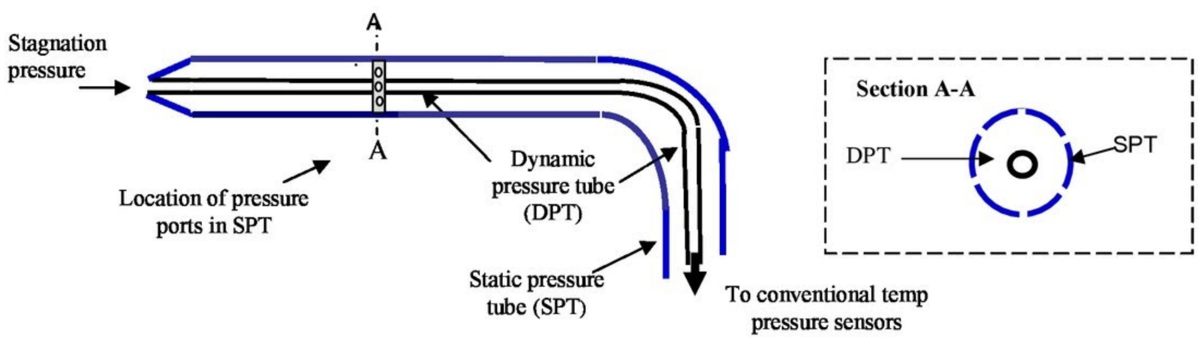

Figure 4 Image of a Pitot-Static tube diagram that shows how the pressures are measured.

4.2 Temperature Sensors

An additional requirement of this project is collecting stagnation temperature data with thermocouple probes inserted up of the compression stage and the temperature of the exhaust gas at the exit nozzle. The temperature probe integration for each stage will be like what was done by Daniel Guggenheim in the Georgia Tech Experimental Fluid Dynamics Lab, this reference can be found in section 7.9. According to the WREN 75 Manual the maximum stagnation temperature achieved by the WREN 75 during start-up occurs at the exhaust and is usually 800 C, the sensors used will need to be able to withstand this temperature with an additional safety factor.

4.2.1 Expected Pressures and Temperatures

WREN Turbines does not list any values for pressure or temperature at different stages of the turbojet engine, the manufacturers manual for the WREN 75 engine (and similar models) only offer operating conditions. To understand the pressure and temperature at each stage the WPI MQP project of "Design and Manufacturing of a Miniature Turbojet Engine" in section 7.10 was referenced where the engine designed was similar to the WREN 75 in design and performance. The data from the MQP project will serve as a reference in choosing specifications for sensors and will be used as a preliminary guess to the engines operating conditions until testing can be done to evaluate the engines measured conditions.

At 80,000 RPM	Upstream Inlet	Downstream Exit Nozzle
Static Pressure	14.695 psi	20.306 psi
Stagnation Pressure	15 psi	23.511 psi
Static Temperature	15 C	450 C
Stagnation Temperature	21 C	550 C

4.2.2 Safety:

The engine exhaust stagnation temperature should always remain below 800 C. However, for short interval of a few seconds temperature spikes may occur without causing issues. In the case these spikes last for longer than a few seconds an immediate shutdown of the engine and investigation of the cause will be required. Additionally, the engine should not be started if the static temperature at the exhaust is 100 C or higher, this limit is reduced to 80 C on colder days. Finally, a large emergency stop button standard to many industrial systems will be included to immediately bring the engine into a safe state for initiating shutdown procedures in the event of an emergency. The shutdown process involves throttling to around 80,000rpm for about five seconds and then stopping the engine. While the engine comes to a stop the starter will begin to spin the engine gently for the cool-down cycle to around 100 C.

4.2.3 Suggested Sensor to be used for Temperature

The suggested sensor to be used for measuring stagnation temperature throughout the engine is a Thermocouple, Type K (Chromel/ Alumel). Max T~ 1370 C (Provides a safety factor of ~1.7), This type of thermocouple has an average output of 3.9 mV/ 100 C. This data can be found in section 7.4 .

Figure 5 displays the temperature range and accuracy of a type K Thermocouple, note that the range shown here provides a T max of 1260 C, but this thermocouple has an upper operating limit of up to 1370 C, as can be seen in reference table also found in section 7.4 .

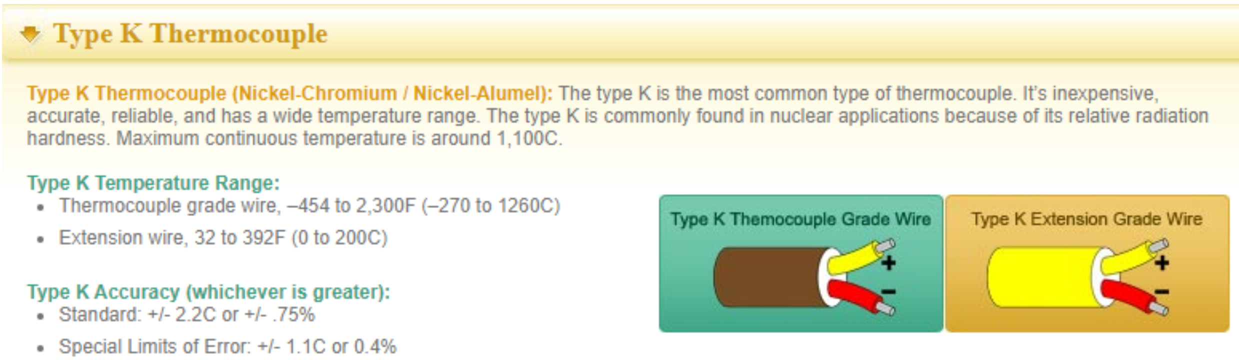

Figure 5 Information on Type K Thermocouple.

Figure 6 shows this Thermocouple, referenced from GeoCorp Inc.'s website which features the ability to "Build your own Thermocouple", and acquire a quote for the build.

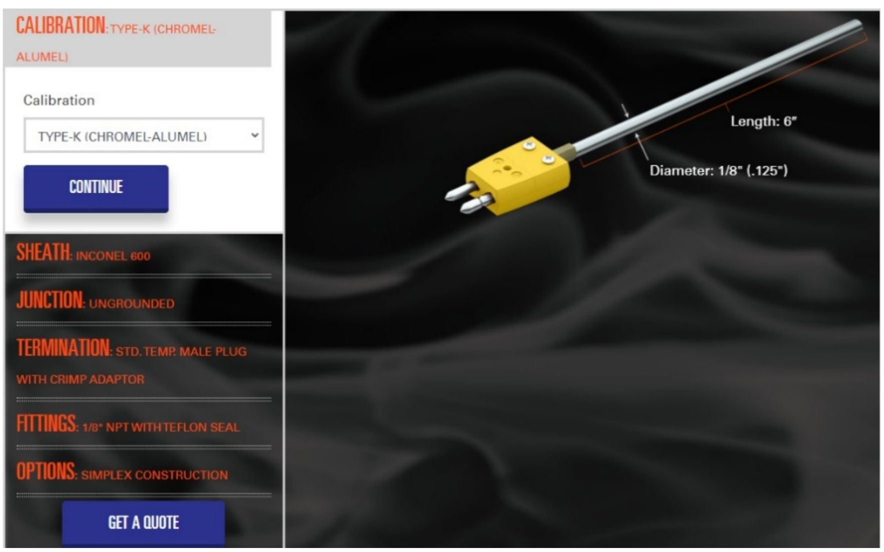

Figure 6 Shows an example of using the Thermocouple Builder Website to design specific thermocouples.

4.2.4 Sensor Table

When referencing the WPI MQP "Design and Manufacturing of a Miniature Turbojet Engine" from section 7.10, stagnation and static temperatures and pressures were found at each of the stages of the turbojet engines. The sensors for this project (listed in the table below) were chosen by using the values in section 4.2.1 with a safety factor included where the values found in section 4.2.1 were calculated when the engine is operating at 80,000 RPM. The safety factor chosen allows deviation from expected limits and for the engine to run at the upper thresholds of 800 degrees Celsius and 50 psi when running the engine at RPM's greater than 80,000.

	Upstream Inlet	Downstream Exit Nozzle

Static Pressure Sensor	Omega -Px119	Honeywell-PX2AG2XX002BAAAX
Stagnation Pressure Sensor	Omega -Px119	Honeywell-PX2AG2XX002BAAAX
Static Temperature Sensor	Perfect Prime -TL3000	PerfectPrime -TL1004
Stagnation Temperature Sensor	Perfect Prime -TL3000	Perfect Prime –TL 0700

5 Controls System

5.1 LabView Display Dashboard

Display GUI (Graphical User Interface) for safe operation of the jet engine will involve real time plotting of data, display windows, and selectable buttons/knobs as displayed in the figure below. The GUI shown in Figure 7 is a monitoring system which will show the different conditions being measured in the engine featuring live feedback. This GUI display will be run on an external laptop and is directly updated by the engine control system receiving this information from its control hardware.

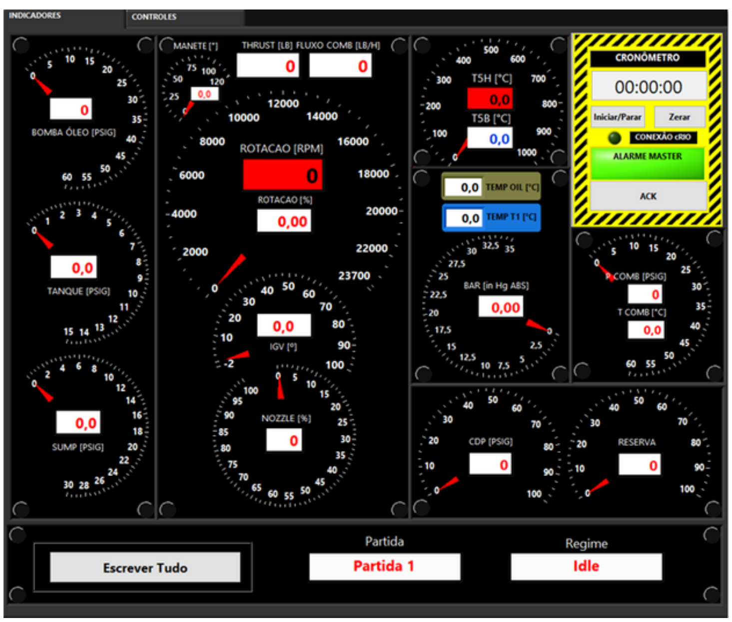

Figure 7 Example of GUI.

5.2 Control System

The control system will be used for safely commanding the engine within its range of thrust while considering performance monitoring, cycle analysis, fault detection, and safety cutoffs. The engine is required to stay within the operating limits as described by the manufacturer, any deviation from the limits impose harm to users, bystanders, and the device. The performance monitoring, cycle analysis and fault detection will all use the same sensors, however, each will follow different logic codes within the control system to export different information to the GUI. LabVIEW will be used to develop this controls system, allowing the team to test the engine and its reaction to different commands and command sequences while recording data to be analyzed and properly characterize the dynamic functionality of the engine. Automatic cutoffs will be implemented using the limits set by the manufacturers with the allowable deviations (such as a temperature spike for a short interval of time). A CompactRIO from NI (National Instruments) will be used to develop and run the LabVIEW software as it is a reputable and popular tool for embedded system design. Paired with a laptop like the one displayed in Figure 1 running Linux, this system will make up the key components of the engine controller which will receive additional user input from a control panel.

Figure 8 Example Control Panel.

A physical dashboard like the one shown in Figure 8 above will also be constructed to allow for additional user interfacing and the need for a key to be inserted for the engine systems to power on and run. Using a physical key and engine cutoff system would ensure safe usage and safe storing options by requiring an additional check prior to running the instrument. A button for initiating the startup sequence will be present on this panel so that this crucial phase can be monitored by the final fully autonomous system. This panel will also include the easily accessible emergency cutoff for safety, along with a button for the normal power down sequence of the engine. The throttle of the engine will be controlled using a common RC (Radio Controlled) transmitter as detailed in the WREN 75 user manual, the input commands of which will be received by the dashboard panel and interpreted to safely deliver this user input to the engine. These transmitters will additionally prove useful for testing and tuning the engine with their command trimming and additional power-on safety features.

6 Budget

An estimated budget of $3500 was determined to be necessary for constructing the jet engine test stand and control system. Pricing of specific components was appropriately rounded to account for a range under which the component could potentially cost, and a price of zero indicates an assumed prior ownership of the component.

Items	Unit Price	Quanity	Total Price
Sensors and Controls			$950.25
Prosense THMK-T06L06-02	$35.00	3	$105.00
Dwyer 628-10-GH-P1-E1-S1	$83.22	3	$249.66
Dwyer Instrumernts Pitot tube	$82.20	3	$246.60
Summit Racing® Inline Fuel Pumps SUM-250111	$148.99	1	$148.99
Dashboard Panel	$200.00	1	$200.00
NI Rio	$0.00	1	$0.00
Test Stand			$1,950.00
Engine Mount	$110.00	1	$110.00
Casing T-slots	$700.00	1	$700.00
Casing Connectors	$250.00	1	$250.00
Casing Caster Wheels	$240.00	1	$240.00
Casing Siding (Clear polycarbonate/aluminum mesh/sheet metal)	$650.00	1	$650.00
Miscelaneous			$146.82
Sensor Mounting (3D Filaments/Brackets)	$75.00	1	$75.00
.170" ID x 1/4" OD Blue High Pressure Flexible Nylon 12 Tubing	$53.82	1	$53.82
6x 1/4" Female NPT Brass Fittings	$18.00	1	$18.00
Estimated Total			$3,047.07
Buffer (shipping/unexpected costs)			$452.93
Total Budget			$3,500

7 Reference

The following list of items and links will lead directly to the above cited sources. Please follow them to find specific items previously mentioned.

7.1 StellarTech Sensors Link:

https://www.stellartech.com/markets/test-and-measurement/

7.2 Turbine Technologies Sensor Integration:

https://www.turbinetechnologies.com/Portals/0/Georgia%20Tech%20AE3051Lab.pdf

7.3 Pitot Static tube Link:

https://www.spiedigitallibrary.org/conference-proceedings-of-spie/9157/9157AA/Simulated-Pitot-tube-designed-to-detect-blockage-by-ice-volcanic/10.1117/12.2058220.short

7.4 Thermocouple Link:

https://www.thermocoupleinfo.com/type-k-thermocouple.htm

7.5 Thermocouple Designer Link:

https://www.geocorpinc.com/products/thermocouple-builder/

7.6 Testing Jet Engine Link:

https://forums.ni.com/t5/Showcasing-Student-Innovation/A-Portable-Solution-for-Testing-Aeronautical-Jet-Engines/ta-p/3901208?profile.language=en

7.7 Test Study Link:

https://www.ni.com/en-us/innovations/case-studies/19/upgrading-a-test-bench-for-a-fighter-aircraft-turbojet-engine.html

7.8 WREN 75 Manual Link:

http://www.jmaireland.com/wren75%20manual.pdf

7.9 Daniel Guggenheim, Georgia Tech Experimental Fluid Dynamics Lab Link:

https://www.turbinetechnologies.com/Portals/0/Georgia%20Tech%20AE3051Lab.pdf

7.10 Daniel Alonzo, Alex Crocker, Eric James, John Kingston III, Design and Manufacturing of a Minature Turbojet Engine Link:

https://web.wpi.edu/Pubs/E-project/Available/E-project-032318-100910/unrestricted/MQP_Final_Draft.pdf

8 Acknowledgments

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