Developing A Jet Test System on a Shoestring Budget: An Application of Project-Based Learning

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Abstract

The goal of this project was to create a portable instructional jet engine test stand that will integrate into a thermodynamics class at a typical two-year community college. While existing off-the-shelf turnkey products exist, they are often insufficient due to size, weight, and cost. The P-90 rxi microturbine jet engine, marketed for remote control (RC) boats and planes was the engine purchased for the test system used. Design parameters for the test stand consisted of the following requirements: it must be small enough to transport by car, light enough so that one person could transfer all components, and most importantly priced under $1,500 if built by a local machine shop. The operation of the test stand was validated through multiple runs measuring engine thrust at various engine speeds (RPM values) between engine idle (~38000 RPM) and full speed (130,000 RPM).

Keywords

Jet Engine, Test Stand, Thermodynamics

Introduction

Thermodynamics is the study of the relationship of all forms of energy. Its mainstay is the interactions and relationship between heat and all other energy forms such as mechanical, electrical and/or chemical. In both community college and four-year university engineering programs, an introductory thermodynamic class is a requirement for degree seeking students.

Students who develop a hands-on application-based understanding of thermodynamics expand their applicable employment opportunities. Vocational areas include heat, air conditioning and refrigeration (HVAC), power generation facilities, and various components in automobile engines. These jobs come with an attractive livable wage. For this reason, it is necessary to apply fundamental thermodynamic and engineering principles to increase student understanding of course materials.

The development of the jet engine test system presents a number of opportunities in project-based learning. "Project-based learning (PBL) is a student-centered pedagogy that involves a dynamic classroom approach in which it is believed that students acquire a deeper knowledge through active exploration of real-world challenges and problems."[1] The outcome is for students to learn and/or develop key problem-solving skills that are needed in actual engineering projects.

This paper explores a PBL approach with a jet engine serving as the central point for student learning. The designed test stand serves as the integral equipment to allow for accurate thrust measurement, safety and consistency. Once mastery of the initial laboratory activity of thrust measurement is complete, the goal is to expand PBL curriculum to integrate additional instrumentation and laboratory activities with the jet engine test system.

It has been 65 years since the first successful flight using a jet turbine in the Heinkel He 178 aircraft[2]. Since then, Remote Control (RC) hobbyists have come to use what are termed micro jet turbines in small airplanes and boats. Functionally, these jet engines are just like the ones used on real aircraft as they incorporate a compressor, combustion chamber, and a turbine. These jet engines come with a level of functionality and adaptability to be considered as laboratory equipment and are in use at a number of universities throughout the world[3]. These engines have also been used to power experimental aircraft, wingsuits and even a bicycle which are featured in online videos. The appeal from these videos along with the accessibility to the RC jet engine make it a great tool to spark an interest in Science Technology Engineering and Mathematics (STEM) education at both middle schools and elementary schools. For this reason, the RC jet engine can serve as a great recruitment tool for those interested in pursuing a college degree.

Project Objective

The goal of this project is to create an economical, efficient, light-weight, cost-effective, and portable integrated jet engine test system. This system includes the jet engine, fuel system starter, ignition system, and measuring and control equipment. In addition, it requires a test stand on which the jet engine is mounted and incorporates a load cell for thrust measurement.

This project's focus is on the design, construction, and testing of a test stand to integrate with the JetCat P90 rxi (shown in Figure 1) jet engine and the associated JetCat software. Of utmost importance is to develop a test system that is cost effective, portable and light weight so it can be operated and transported by one person.

Figure 1 JetCat P-90 rxi

Existing Jet engine test systems were considered prior to the project being initiated. These systems had prices ranging from $30,000 to $60,000 and were typically sold mounted to stands that limited their ability to be transported. All of the systems reviewed were intended to be used solely in a laboratory setting without regard to mobile deployment.

Jet Engine Selection

The JetCat P-90 rxi was purchased by Chattanooga State Community College and is the central equipment for this project. It comes with an Engine Control Unit (ECU), Data bus, Handheld Controller, associated fuel line and valving, and a LiPo battery. This model is also equipped with an internal kerosene start, internal Exhaust Gas Temperature (EGT) sensor, internal solenoids, and internal fuel pump. Free software is provided by JetCat, which allows for capturing data on a laptop. The software takes advantage of all the display outputs from the handheld display. Available outputs include engine revolutions per minute (RPM), EGT, and fuel quality (indicates presence of air in the fuel lines).

Test Stand Design

A test stand was designed and built for this project. The initial concept is shown in Figure 2. The stand consists of 2 rail slides, vertical uprights that capture the rails, a base plate, a load cell mount, and an interface between the jet engine and the load cell. A 100 lb. load cell was chosen for the test system as a maximum thrust of 24 lbs. was specified by JetCat. The load cell selected was a Model MLP-100 which was to be used with a digital panel mount meter (DPM-3) both manufactured by Transducer Technologies. The load cell is self-identifying which makes its operation very straightforward.

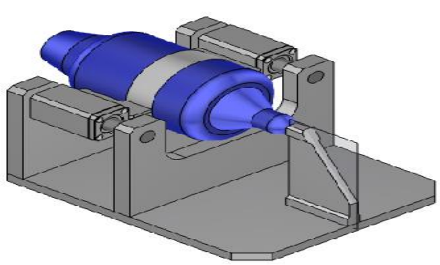

Figure 2 Initial Concept Design

Design considerations for the initial concept were:

Alignment

To accurately measure thrust, the mounted jet engine has to be free to move without binding. This meant the stand required considering the effects of roll, pitch and yaw. Any binding of the jet engine would reduce the thrust readings from the load cell.

Weight

The test stand needed to be light enough to be portable but heavy enough so it would not move as the engine enters into the higher RPM range.

Cost Consideration

Market pricing was essential for the success of the test stand due to the limited resources at most community colleges. The initial plan was to keep the materials and machining costs to under $850 to allow for a total price of $1,500. This was necessary to keep the total system cost around $3,500 which was well within our laboratory budget and did not require other funding sources.

Adaptability

The test stand was developed so it could be scaled in size and adapted for bench testing of a variety of RC jet engines. Given this feature, it could be used to verify peak thrust and fuel consumption to ensure the engine is performing as intended by the manufacturer.

Construction Materials

The original design shown in Figure 2 specified hardened steel rails and cast aluminum plate for the base plate and the two aluminum uprights. The engine is mounted in the steel "clamshell" that comes with the jet engine and is bolted to aluminum slides that ride on the parallel steel rails. Subsequent testing required the use of a steel base plate for added weight to minimize sliding of the system during operation at higher engine speeds.

Figure 3. below shows the completed thrust stand with the mounted jet engine.

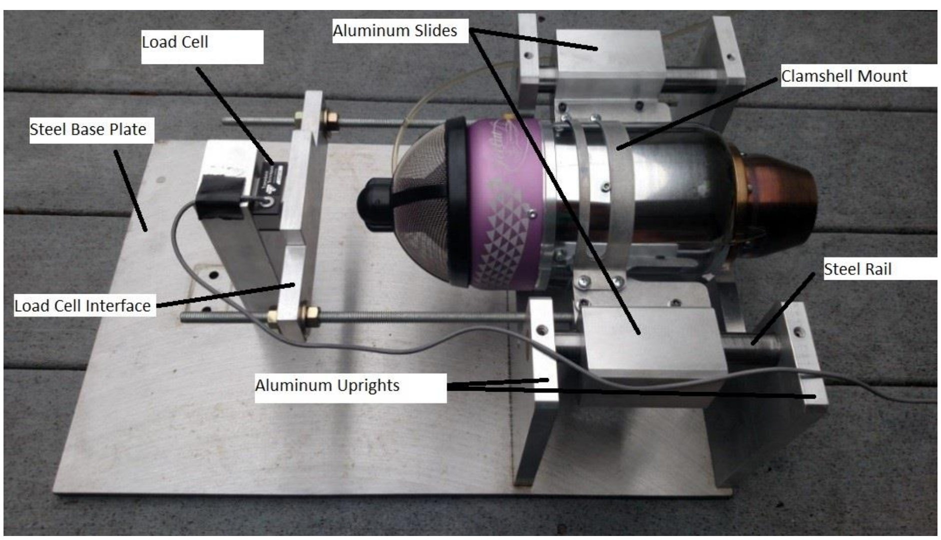

Figure 3. Jet Stand with Engine Mounted and Load Cell in Place

Verification of Test Stand Performance:

The jet engine was operated at a number of speeds and the thrust was measured with the load cell on the jet engine stand. Verification of the ability of the test stand to accurately measure thrust was determined by comparing the published peak thrust with that measured by the load cell on the test stand. A peak thrust of 24 lbs. was specified by JetCat in Germany. However, a peak thrust of 23 lbs. was deemed as a more realistic value from the JetCat distributor in North America. For this reason, 23 lbs. is used as the published peak thrust in our performance calculations. Measured thrust values are provided in Figure 4.

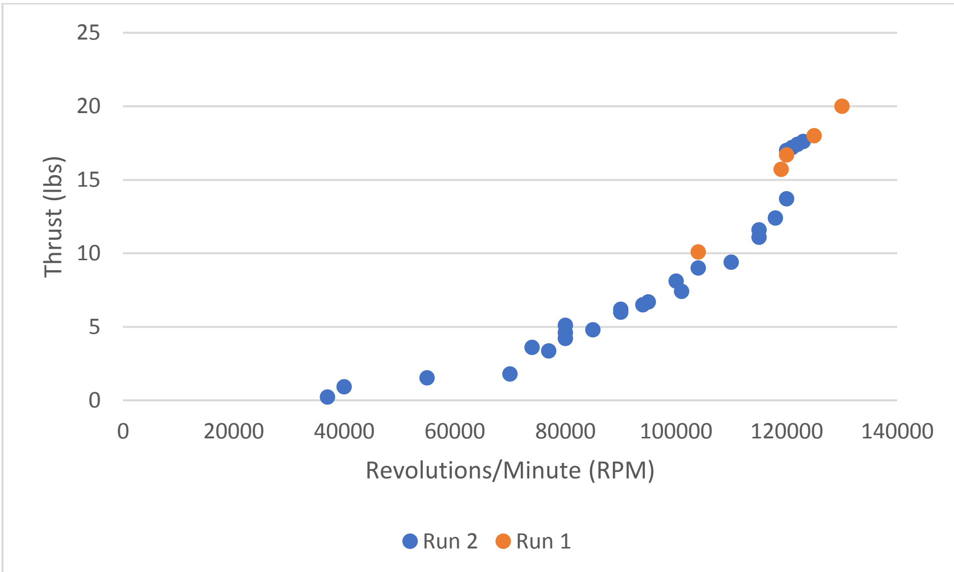

Figure 4. Jet Engine Performance: Engine Thrust (lbs) .vs.Speed (RPM)

The thrust values at 130,000 RPM (20 lbs.) were within 15% of the published value. It is important to consider that the idle speed of this jet engine is 36,000 RPM. At this speed, there was no thrust measured nor movement of the engine on the slide rails. The first significant thrust value is around 55,000 RPM at 1.54 lbs. The thrust develops at a faster rate until achieving maximum thrust at 130,000 RPM. The rate of developing thrust was calculated from test data to be 0.012 lb./RPM around 80,000 RPM increasing to 0.04 lb./RPM at 130,000 RPM. This is commensurate with jet engines developing thrust at a faster rate at higher speeds.

Future Project-Based Learning Opportunities:

Based on the success of this work, the following PBL opportunities have been identified for the jet engine test system.

- Integrate additional instrumentation to the test system to allow for inlet and outlet temperature, pressure and velocity measurement. Provide additional instrumentation to measure fuel consumption.
- Integrate data collection into a centralized system such as LabVIEW.
- Develop additional laboratory activities such as using mass flow calculations to determine thrust and compare with measured values.
- Design and develop a stand that would allow the jet engine to travel across the ground.

Note: the engine is designed to be controlled with an RC control. This would enhance the use of the system for STEM days at secondary schools.

Conclusion

The objective of this design project was to develop a lightweight, low-cost, portable test stand that the JetCat P-90 rxi jet engine could be mounted on for engine thrust testing. The concept for the project occurred with the original purchase of the P-90 rxi jet engine. It was to be a demonstration for a thermodynamics class as well as a piece of equipment that could be shown at open houses.

The total system weighs 37 lbs. and is easily transported by one person as well as compact enough to fit in the trunk of a small sedan. The cost of the jet engine system was less than $3500 and that includes machining costs to fabricate the stand. The ability of the stand to accurately measure engine thrust consistently and accurately has been demonstrated. Peak thrust was found to be within 15% of the manufactures published data. The system is currently being used in a Thermodynamics class at Chattanooga State Community College as well as for demonstrations. Future PBL opportunities, as outlined earlier, will be to grow the functionality of the test system so it can be used in additional laboratory activities and for additional applications.

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