Application of Computational Tools to Analyze and Test Mini Gas Turbine

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Abstract. Performance analysis and testing of the Mini Gas Turbine was carried out in Wentworth Institute of Technology's Thermodynamics Laboratory. The computational tool allows students to focus on more design-oriented problems. Furthermore, students had the ability to see immediate results to variations of the design conditions as well as different parameters that would affect the mini turbine. This project was carried out as a senior design project (Capstone), the students updated the existing data acquisition system, writing a new data acquisition program in LabVIEW, installing new pressure and temperature sensors, and performing a first and second law of thermodynamics analysis on the engine in Engineering Equation Solver. In order to update the existing data acquisition system, new NI SCB-68 connector blocks were implemented along with NI USB-6251 terminals. The new hardware is operated through a LabVIEW program running on a new laptop designated and mounted to the mini jet turbine housing. Instrumentation, testing, and calibration are the three main milestones for this project As a result, The Inlet Mass Flow Rate numeric indicator value is calculated, not measured. The calculated value is dependent on the measured values of Compressor Inlet Temperature (T1), Compressor Inlet Static Pressure (Ps), and Compressor Inlet Dynamic Pressure (Pt-Ps). However, the pressure, temperature and thrust were tested as a function of RPM. The mini turbine engine is ready to be used in student experimental settings. Feedback from students proves that the use of different tools significantly enhances the student learning experience and encourages the students to use different theory from different courses, make the course more dynamic, and motivate the students to learn the material.

Keywords: LabVIEW, Engineering Equation solver (EES), Mini-turbine, Pressure

1. Introduction

The turbine engine discussed throughout this research is a self-contained turbojet engine.This engine operates on a Brayton cycle. The Brayton cycle depicts the air-standard model of a gas turbine power cycle. A simple gas turbine is comprised of three main components: a compressor, a combustor, and a turbine. According to the principle of the Brayton cycle, air is compressed in the compressor. The air is then mixed with fuel, and burned under constant pressure conditions in the combustor. The resulting hot gas is allowed to expand through a turbine to perform work. Most of the work produced in the turbine is used to run the compressor and the rest is available to run auxiliary equipment and produce power [1].

Gas turbine engines include internal passages which serve to channel the cooling air from compressors to the different components to be cooled. The research on the flow in a corotation radial inflow cavity was pioneered by Owen et al. [2]. They used integral momentum techniques for flows in a rotating cylindrical cavity. Firouzian et al. [3, 4] studied the flow and heat transfer in the cavity. Their results revealed the complicated source-sink flow feature in a radial inflow rotating cavity. One of the concerns in turbomachine is the pressure loss in the cavity; different ways to minimize the pressure loss have been explored. Chew et al. [5] has used fins to reduce the pressure loss. On the other hand, X. Liu [6] has studied the flow in a corotation radial inflow cavity between turbine disk and coverplate. Also, the flow field in a preswirled cooling air supply to a turbine rotor has been investigated by Oliver et al. [7, 8].

An analysis on this engine provides important performance characteristics such as thrust, compressor performance, turbine performance (work and power, expansion ratio, turbine efficiency), combustion/emission analysis, and overall isentropic efficiency. In order to perform an analysis on this engine, several quantities at specific locations are needed. Sensors are instrumented on this engine at the compressor inlet, compressor outlet, turbine inlet, turbine exit, and exhaust to collect data on the temperature and pressure at each location. This data is then used to perform a performance analysis on the engine. In addition, there are sensors on this engine to monitor thrust, RPM, and fuel flow rate.

Shown below in Figure 1 is a cross section of the engine with main components labeled.

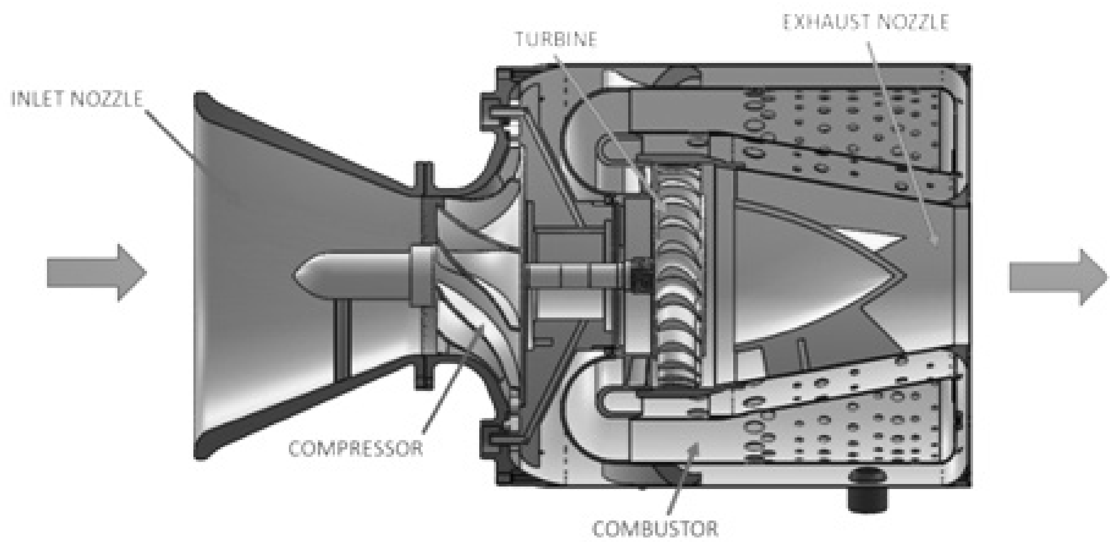

Figure.1 Turbine Engine Layout (Brayton Cycle)

Figure 2 below shows the location of each temperature and pressure being measured on the engine.

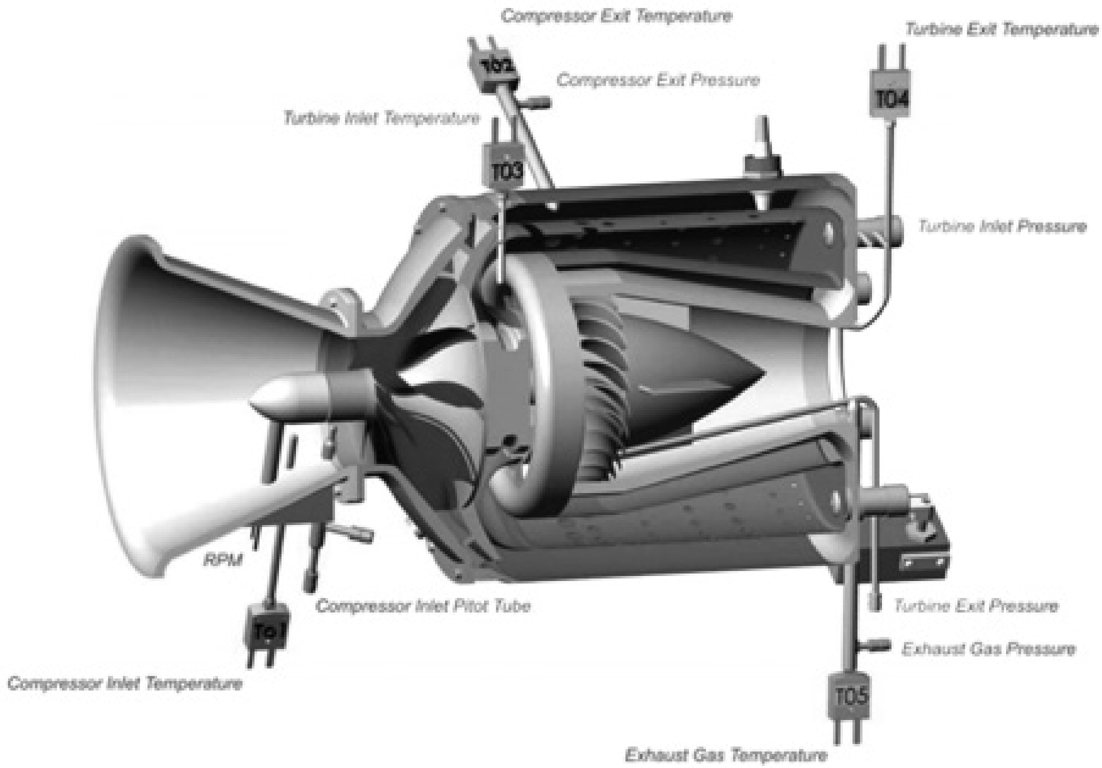

Figure.2 Engine Instrumentation Locations

Shown below in Table 1 are the specifications of the engine.

Table 1 Engine Manufacturer Specifications

Manufacturer	Turbine Technologies, Ltd.
Model Number	2000DX
Max. RPM	90,000
Max. Exhaust Temperature	720 C
Pressure Ratio	3.4:1
Specific Fuel Consumption	1.18 lb./lb.-hr

The Turbine Technologies Mini Gas Turbine in the Wentworth Institute of Technology thermodynamics lab is in great need of an instrumentation overhaul. Due to the high cost of replacing the data acquisition system completely, our team will be replacing it ourselves. The current DAQ system is outdated and incompatible with current software on the computer it is paired to. A new set of DAQ hardware will be paired with a new computer running a LabVIEW program to collect the data. Our team's goals also include calibration of pressure transducers and thermocouples for accurate measurement. Our team will then run a 1st and 2nd law of thermodynamics on the system using Engineering Equation Solver (EES).

The mini gas turbine in the thermodynamics lab is a fantastic resource that is going un-used. Many students can benefit from the mini turbine's technical sophistication. Benefits include but are not limited to technical understanding, conceptual understanding, and practical application. With the recent creation of the Aerospace Engineering Minor at Wentworth, this machine could open the eyes to many young engineers and give them the ability to have a future in the aerospace industry. Turbine propulsion is used on various aircraft, but dominates the commercial jet and military jet industries.

The main problem of this project is to overhaul the instrumentation of the mini gas turbine and have it ready to be run for students. Instrumentation, testing, and calibration are the three main milestones for this project. A technical lab will be produced for thermodynamics students to run.

2. Instrumentaion

Figure 3 below shows the laptop system mounted and installed.

Figure.3 Laptop and Monitor Installed

the new DAQ has several additional components which are much larger than the old system a much larger mounting bracket was necessary. After modeling all of the current system components in SolidWorks, a sheet metal bracket was designed to fit all of the DAQ components without interfering with any of the existing surrounding components.

Figure 4 below shows the design of the new DAQ setup.

Figure.4 DAQ Components Installed

During the course of this project, there were many sensors that needed to be changed or added. The preexisting DAQ system was capable of collecting temperature and pressure readings from the various mini-turbine engine stages; however, there was room for improvement. One of the main additions made to the instrumentation was implementing a new pressure transducer to read the static pressure at the inlet of the nozzle. The pitot-static mast style device can be seen below in figure 5:

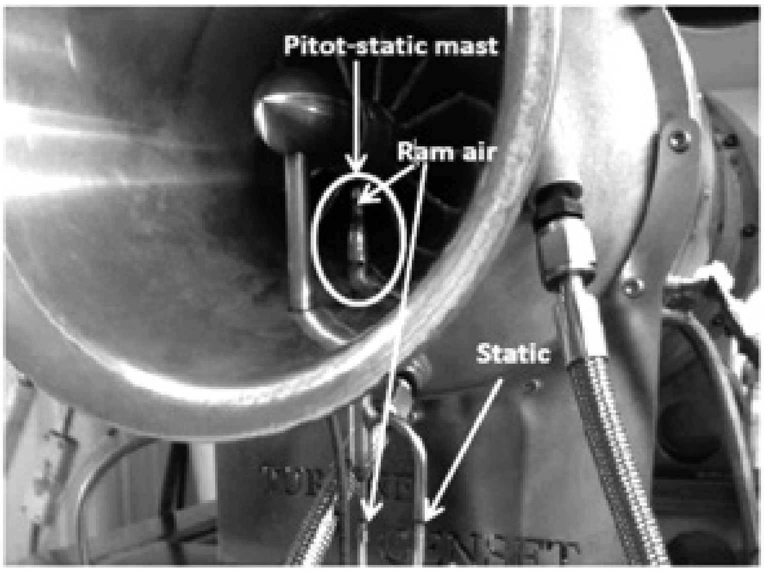

Figure.5 Inlet Pitot Tube Current Set-Up

The basis of this project is to transition the new hardware and supported LabVIEW software. The hardware chosen for the task are the NI SCB-68 and NI USB-6251. Two of each have been implemented in the DAQ system.

While attempting to calibrate the thrust strain gauge, significant noise to the NI chassis was experienced. The pre-existing set-up had the wires from the strain gauge splitting between the meter and the NI chassis. While the out-put signal from the strain gage was filtered through the DP25-S, it was not filter through the NI chassis. To remedy the issue, the DP25-S was replaced with a DP25-S-A which had the correct analog signal output. With the new signal analog signal output, there was no noise experienced from the thrust strain gage and meter. Below the new meter can be seen:

3. Testing

Figure 6. LabVIEW Data Acquisition Front Panel User Interface (Plot Tab)

In order to calculate the Inlet Mass Flow Rate to the turbine engine, the static pressure is needed. The static pressure is obtained by connecting a pressure transducer directly to the static pressure port on the inlet pitot tube. Next, the density of the air is calculated using this static pressure. The air velocity is calculated next using the Dynamic Pressure which is the difference between the total pressure and the static pressure. The Mass Flow Rate is finally obtained knowing the density, velocity and cross sectional area of the inlet nozzle at the location of the pitot tube. This calculation is performed in the LabVIEW program (Figure 77). See following report section for mass flow rate governing equations.

The fuel flow rate is determined from measuring the fuel pressure. If the fuel pressure as well as the fuel properties are known, the flow rate can be determined. The Inlet Mass Flow Rate numeric indicator

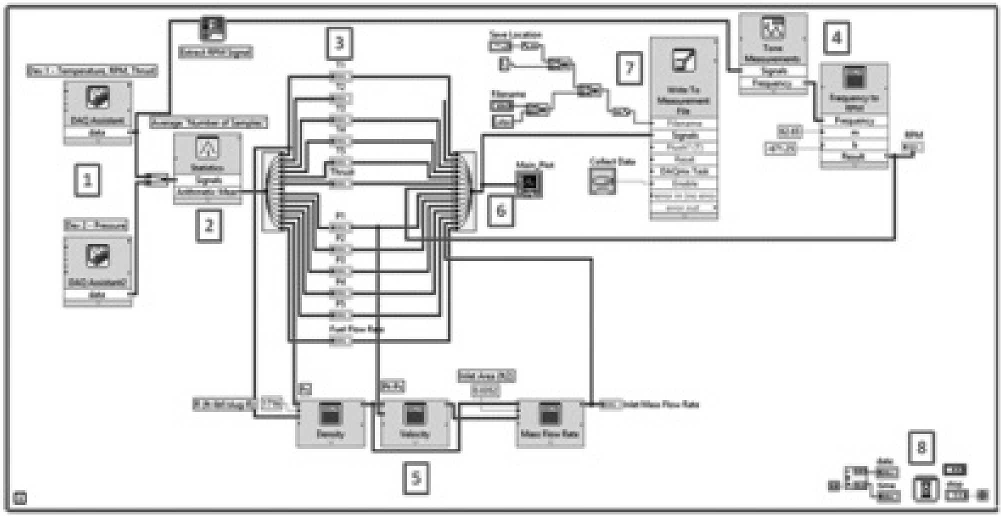

Figure.6 LabVIEW Block Diagram

value is calculated, not measured. The calculated value is dependent on the measured values of Compressor Inlet Temperature (T1), Compressor Inlet Static Pressure (Ps), and Compressor Inlet Dynamic Pressure (Pt-Ps). Using Express Formula functions, the density of the air is first calculated, then the velocity of the air is calculated, and finally the Inlet Mass Flow Rate can be calculated. The following equations are contained within these functions for Density (ρ), Velocity (v) and Mass Flow Rate ($\dot{m}$).

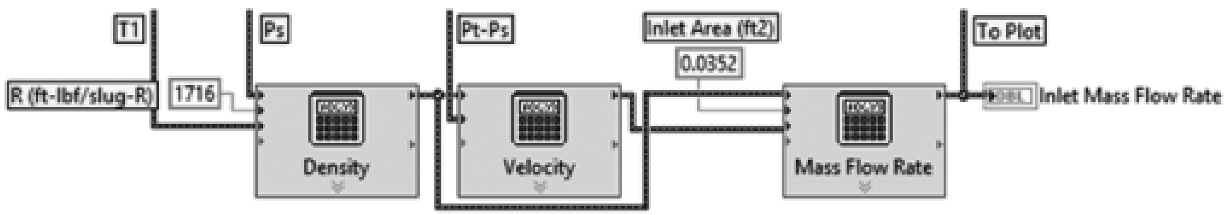

Figure.7 Mass Flow Rate Calibration

Where,
A = Compressor Inlet Area
R = Ideal Gas Constant for Air

$$\rho = \frac{(P_s+14.7)144}{R(T_1+460)} \ (slug/ft^3) \tag{1}$$

$$v = \sqrt{\frac{2P_1*144}{\rho}} \ (ft/s) \tag{2}$$

$$\dot{m} = \rho A v \ (slug/s) \tag{3}$$

Figure 8 shows the inlet mass flowrate vs. RPM

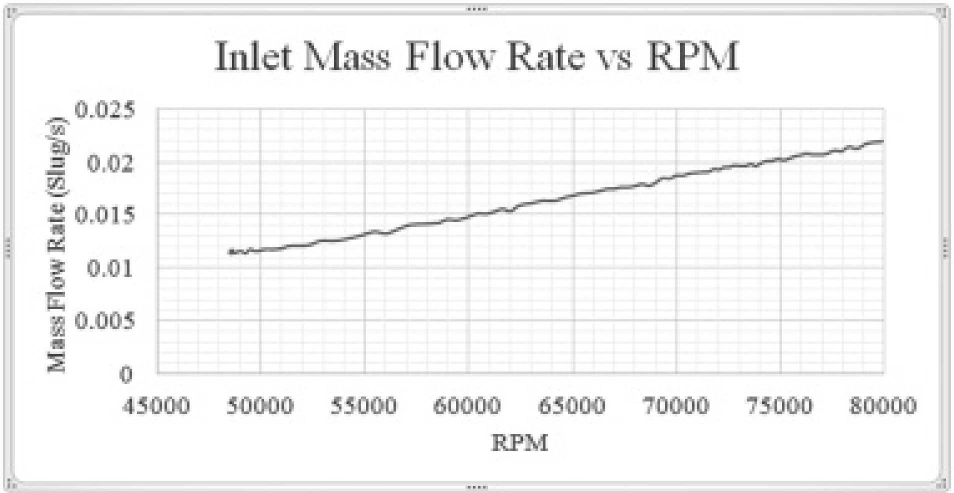

Figure.8 Engine Testing Data Plot – Inlet Mass Flow Rate vs RPM

A sample set of data collected from an engine test run is shown in figure 9 through

Figure 11. These plots contain important characteristics of the engine such as the relationship between engine RPM and Thrust, Temperature, Inlet Mass Flow Rate, and Pressure.

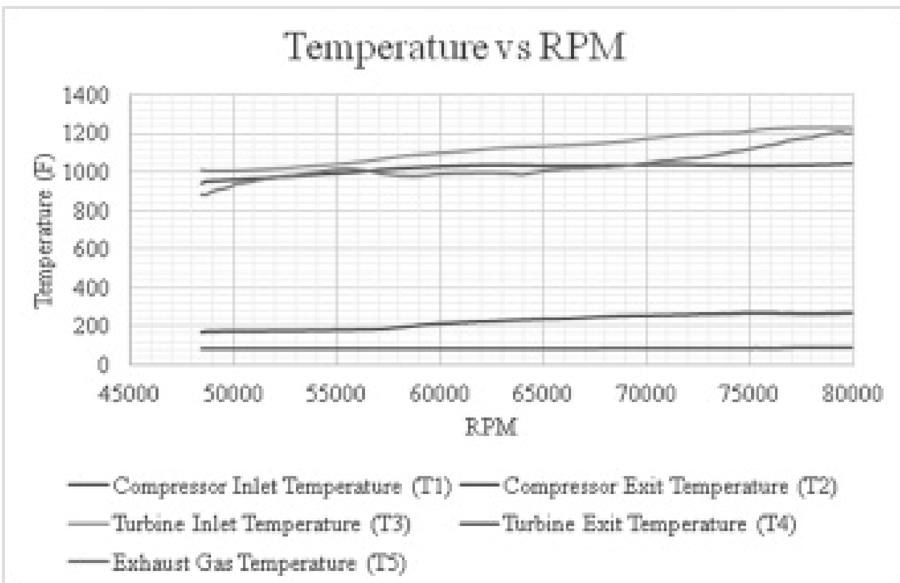

Figure.9 Engine Testing Data Plot – Thrust vs RPM

4. Engineering Equation Solver (EES)

One of the critical tasks was to create a program in EES which analyzes the engine using the first and second laws of thermodynamics. Ideally this program would be displayed on the second monitor so you can take the data directly from LabView and plug it into the EES program. After plugging in the different temperatures and pressures as inputs in the EES program, it will calculate the compressor efficiency, turbine efficiency, overall efficiency of the engine and the thrust of the engine. A diagram window interface was created in EES to make it easy for the user to run the program without understanding the entirety of the code. Figure 12 below shows the equations window section of the EES program. Figure.12 EES code

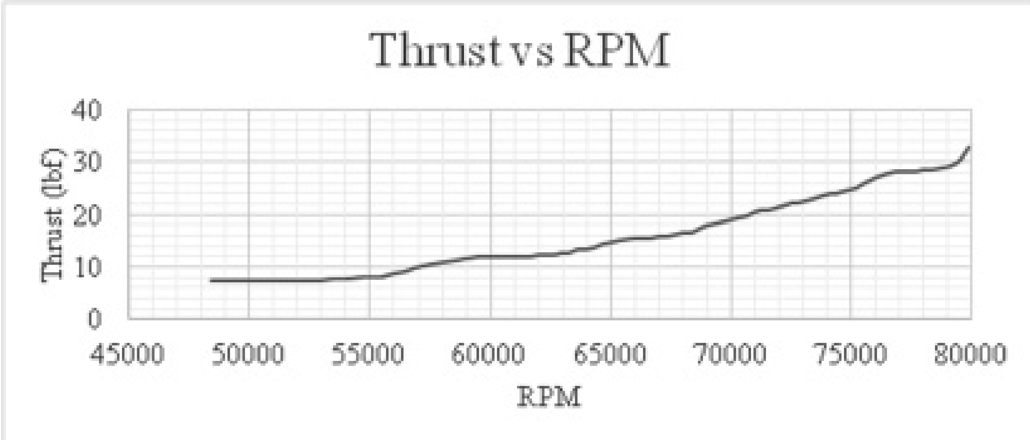

Figure.10 Engine Testing Data Plot – Temperature vs RPM

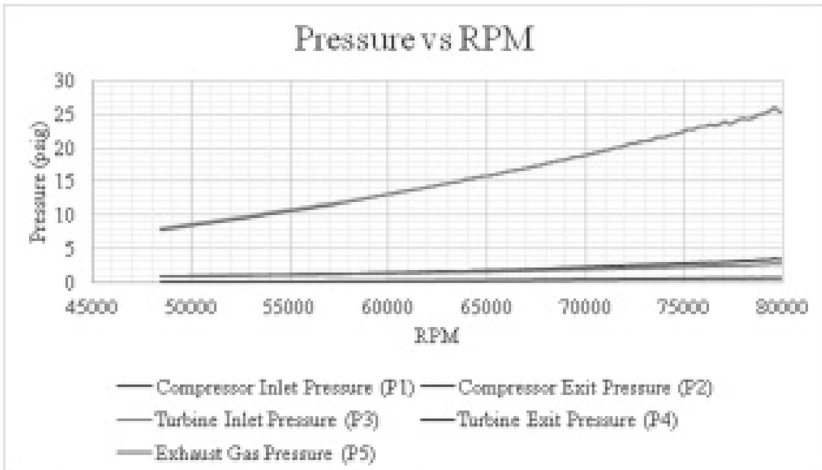

Figure.11 Engine Testing Data Plot – Pressure vs RPM

5. Conclusion

This paper explored the use of computational tools to enhance the students' understanding of the different gas turbine engine processes and apply the theory such as conservation of mass and energy which were learned in different courses such as Thermodynamics and fluid mechanics. The computational tool such as EES allows the students to focus on the fundamental concepts of energy equation and second law of thermodynamics to yield quicker final results. The completion of this capstone project produced quality and timely task completion. The mini turbine engine is now ready to be used in student experimental settings. Each data acquisition component of the system is calibrated including all thermocouples and pressure

transducers, RPM measurement and thrust measurement. The LabVIEW program will be used for real time data display and data acquisition of the complete run cycle of the system. Using this data exported to Excel by the LabVIEW program, these values can be inputted into the first and second law of thermodynamics EES

program to determine the efficiencies of the compressor, turbine, and the overall system as well as the work done by the system in BTU/hr.

The senior students completed their tasks and sub-tasks and achieved their final goal. These tasks and sub-

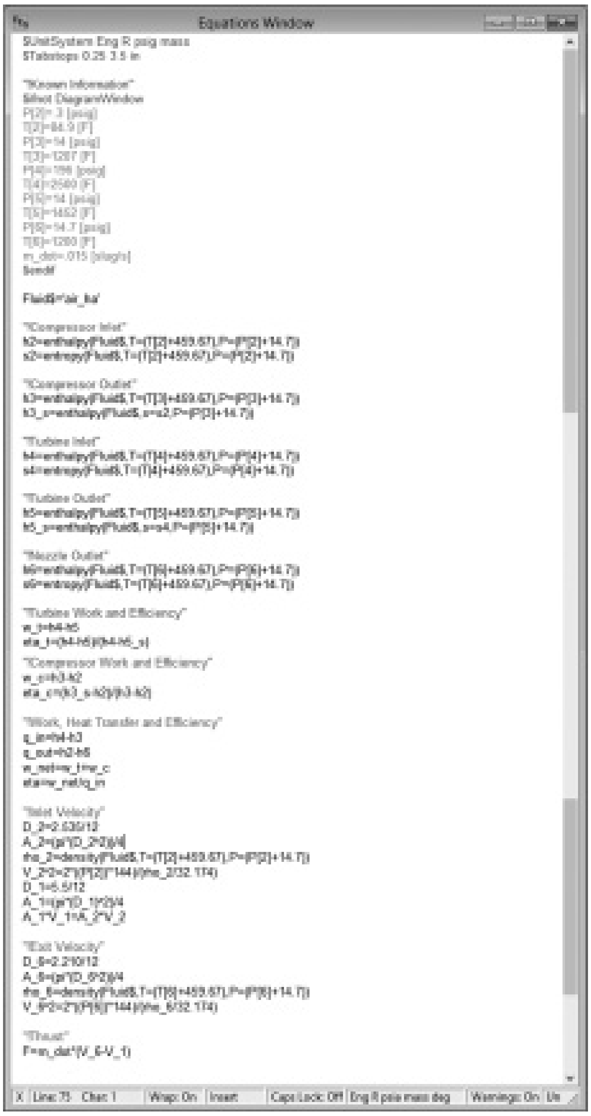

Figure.12 EES code

tasks include but are not limited to preliminary research and component identification, mounting of a new laptop arm and laptop, design and manufacturing of a mounting bracket for the DAQ hardware, an EES program, a DAQ and user-friendly display LabVIEW program. It can be concluded that using senior students. Feedback from students, proved that the use of computational tools significantly enhances the student learning experience while motivating the students to learn the different mini turbine processes.

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