Mini-Lab Gas Turbine Power System[TM] Sample Lab Experiment Manual

**Lab Session #1: System Overview and Operation**

Purpose: To gain an understanding of the Mini-Lab[TM] Gas Turbine Power System as a whole and details of engine sensors and controls making up the system.   This will prepare you for operation of the system.

**System shown with optional Hush Kit[TM]
Sound Suppressor System**

Note: Sample lab does not replace Mini-Lab[TM] Gas Turbine Power System Operator's Manual. Please refer to manual for detailed system operational and safety instructions.

SR-30 Gas Turbine Cutaway
Engine Sensor Locations
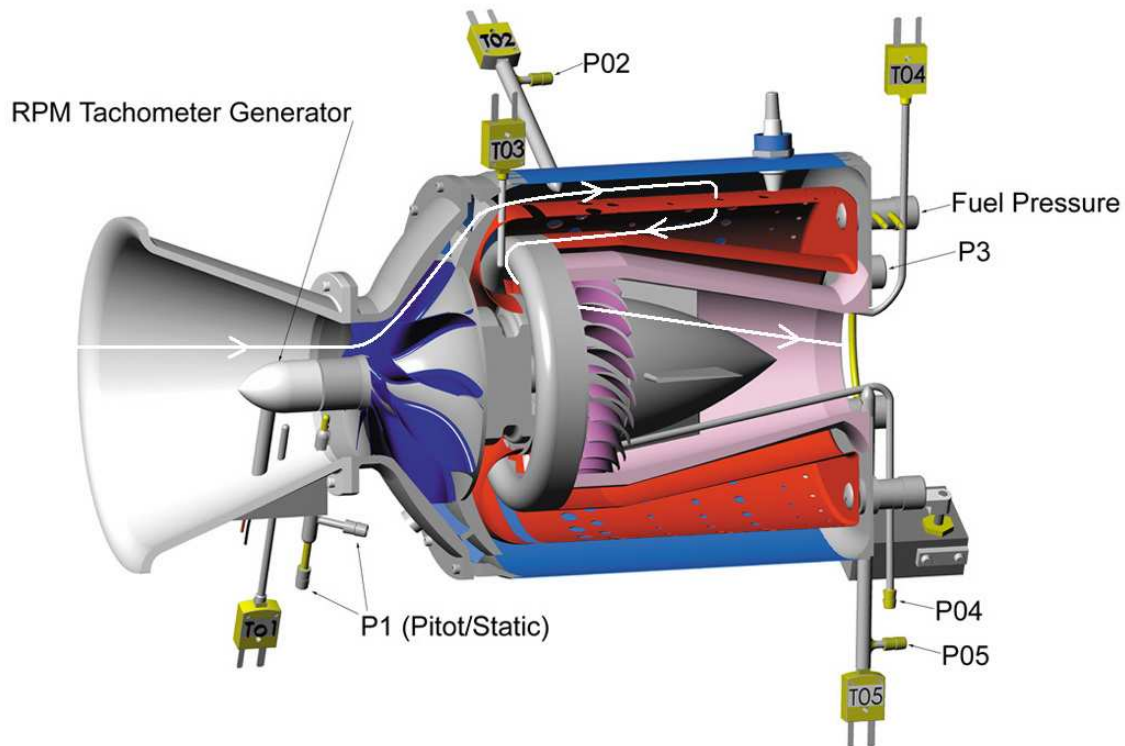
RPM Tachometer Generator: (Displayed on Panel as RPM and Data Acquisition Screen).

P1: Compressor Inlet Pressure (Displayed on Data Acquisition Screen)

T1: Compressor Inlet Temperature (Displayed on Data Acquisition Screen)

P2: Compressor Exit Temperature (Displayed on Data Acquisition Screen)

T2: Compressor Exit Temperature (Displayed on Data Acquisition Screen)

P3: Turbine Inlet Pressure (Displayed on Panel and Data Acquisition Screen)

T3: Turbine Inlet Temperature (Displayed on Panel as TIT and Data Acquisition Screen)

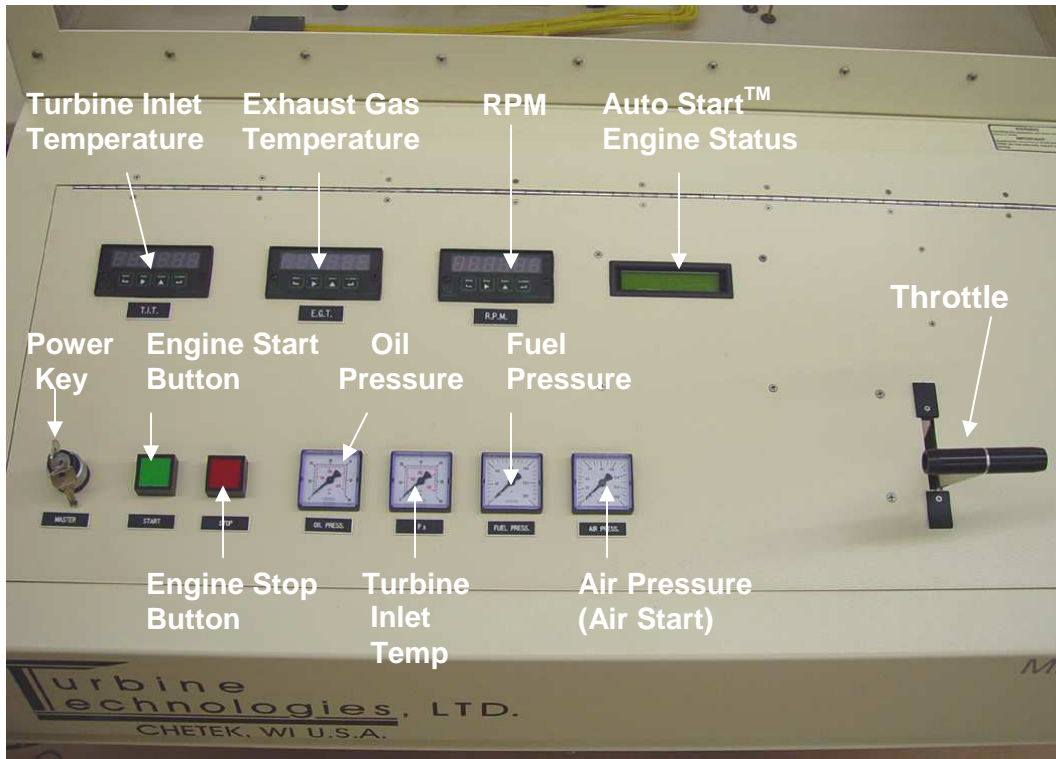**P4**: Turbine Exit Pressure (Displayed on Data Acquisition Screen)

T4: Turbine Exit Temperature (Displayed on Data Acquisition Screen)

P5: Exhaust Gas Pressure (Displayed on Data Acquisition Screen)

T5: Exhaust Gas Temperature (Displayed on Panel as EGT and Data Acquisition Screen)

Fuel Pressure: (Displayed on Panel)

Mini-Lab^{TM} Gas Turbine Power System Control Panel

- **Turbine Inlet Temperature**
- **Exhaust Gas Temperature**
- **RPM**
- **Auto Start^{TM} Engine Status**
- **Throttle**
- **Power Key**
- **Engine Start Button**
- **Oil Pressure**
- **Fuel Pressure**
- **Engine Stop Button**
- **Turbine Inlet Temp**
- **Air Pressure (Air Start)**

Data Acquisition Computer

Connects to unit's data acquisition system via USB port. Displays and captures data for operation and analysis.

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In preparation for system operation and data analysis, please answer the following questions:

Determine the fuel you are using to power your system: _JET A_

What is the energy content per unit volume of fuel? _18,610 $\frac{BTU}{lb}$, 43.28 $\frac{MJ}{kg}$_

What is the fuel's density per unit volume? _6.76 $\frac{lb}{gal}$, 0.81 $\frac{kg}{\ell}$_

Barometric Pressure

What is the present barometric pressure in your area?

TODAY IT IS 30.04 IN. HG ≈ 0.1016 MPa = 14.75 PSI

Why would barometric pressure be important when planning to operate the Gas Turbine System?

ALL PRESSURE READINGS ARE GAGE PRESSURE.
THERMODYNAMIC PROPERTY TABLE DATA IS BASED ON
ABSOLUTE PRESSURE: $P_{ABS} = P_{ATM} + P_{GAGE}$

What will be your reliable source for accurate barometric pressure readings?

ONE SOURCE IS: WWW.WUNDERGROUND.COM
CHECK "CURRENT CONDITIONS" FOR YOUR AREA.

System Operation

Purpose: Conduct pre-start, start-up, operation, data gathering and shut down of Mini-Lab™ Gas Turbine Power System.

Procedure:
Utilize **Mini-Lab™ Operators Manual** and follow **Section 4.2 Expanded Normal Procedures** to perform system pre-start, start-up, operation, data acquisition and shut down.

Utilize the data acquisition system to capture the operational values from startup to shut down **(covered in Section 4.2.3 Data Collection and also covered in detail on the next page of this sample lab).**

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DATA COLLECTION

Recording and using your data properly is an important part of successfully completing the lab.

NOTE*: The following steps assume the use of the standard MiniLab Software and default settings as supplied with the MiniLab. Use of non-default setting or other software may necessitate alternative methods or procedures for data collection. Consult the LabView/National Instruments software specific information as required.*

From Windows, OPEN the MiniLab Software by double-clicking on the MiniLab 1.1 shortcut icon located on the Windows Desktop. MiniLab 1.1 will start with the *Main Display/Control* and *Channel Configuration Window* displayed.

MiniLab 1.1

MiniLab Launch Icon

NOTE: The computer must be connected to the MiniLab USB port prior to opening the MiniLab software.

The MiniLab configuration software is dependent upon the specific DAQ Module serial number as installed in the MiniLab and will not function properly if the DAQ Module cannot be found. If this was done incorrectly, exit the program, attach the USB cable and start over.

To verify that the software is communicating with the DAQ Module, open **Measurement and Automation** from desktop. In menu tree, click on **Devices and Interfaces**, then, click on **NI DAQ 6218.** This provides and verifies the proper serial number for the on board DAQ system and also verifies that a proper connection to that device is being made.
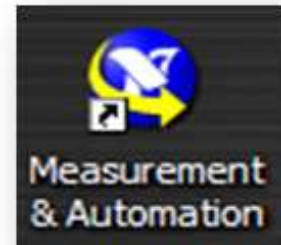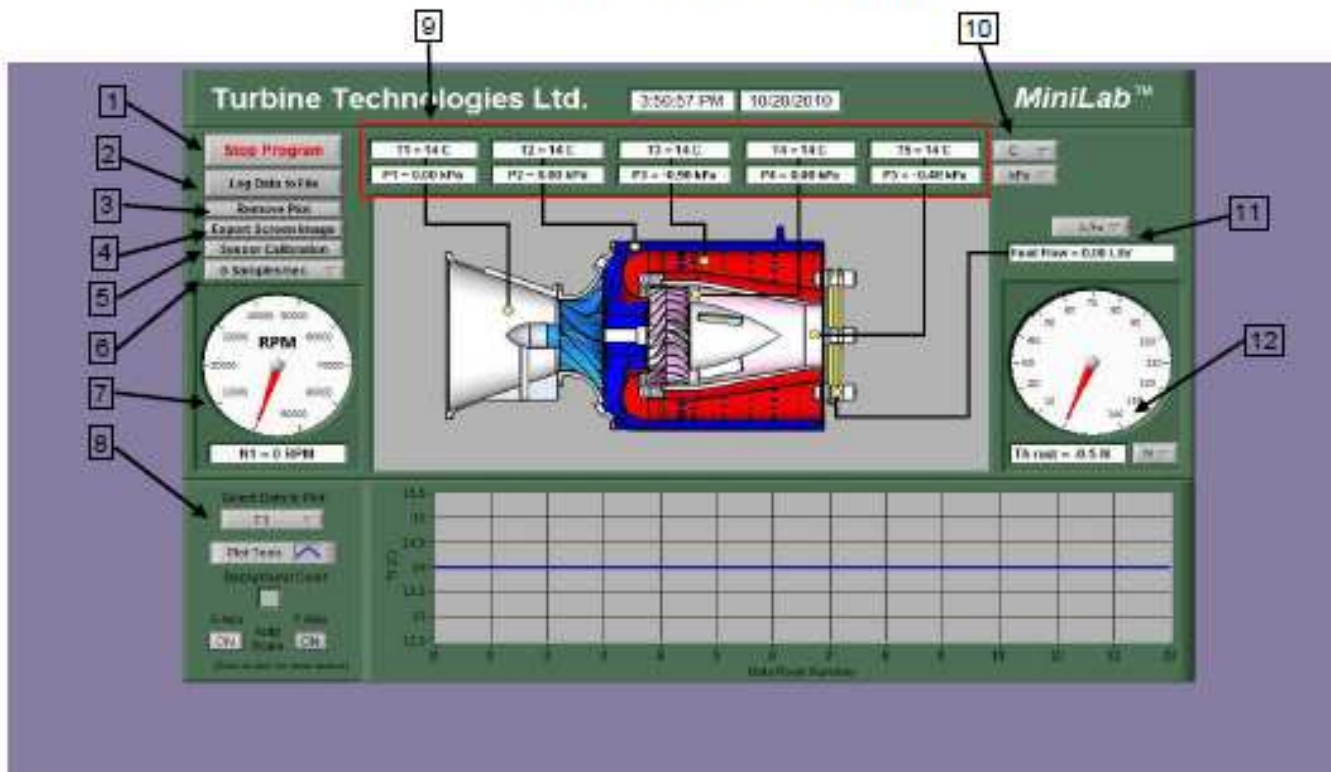

Measurement and Automation
Launch Icon

TO PERFORM THE FOLLOWING FUNCTIONS:

- **Virtual Instrument Panel Software Controls overview are on page 5**
- **Logging Data to File is shown on Page 6**
- **Displaying Plot Feature is shown on Page 6**

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Overview of the Software Controls

1 Click button or stop sign to stop monitoring data.
2 Click to log data to a file.
3 Toggles real time data plot on and off
4 Saves screen shot of all the data at any period of time.
5 Allows reset of any sensor to it's "0" point
6 Select sampling rate from 0.1 to 5 samples per second.
7 Displays real time Gas Turbine RPM
8 Plot area toggle this on or off, use the bottons to control the display

9 Real time Temperatures and pressures.
10 Toggle from ℃ to ℉ and Psig to kPa.
11 Fuel flow toggle from Ltrs./hr or Gals/hr.
12 Thrust toggle from N to Lbs.

Logging Data to a File and Displaying the Plot Feature

2. To log data to a file for later viewing and analysis, click on the "**Log Data to File**" button and this window will appear. Enter a file name and click "**OK**" and the file will be saved in "**C:\Users\ Turbine Technologies**". Click on it again to stop saving data.

3. Click on "**Plot Data**" and the following screen appears along with all the options for formatting the graph. Data will be plotted at the selected sample rate(#6). The options are sensor Selection, line style and background color and auto scaling for both X and Y axis.
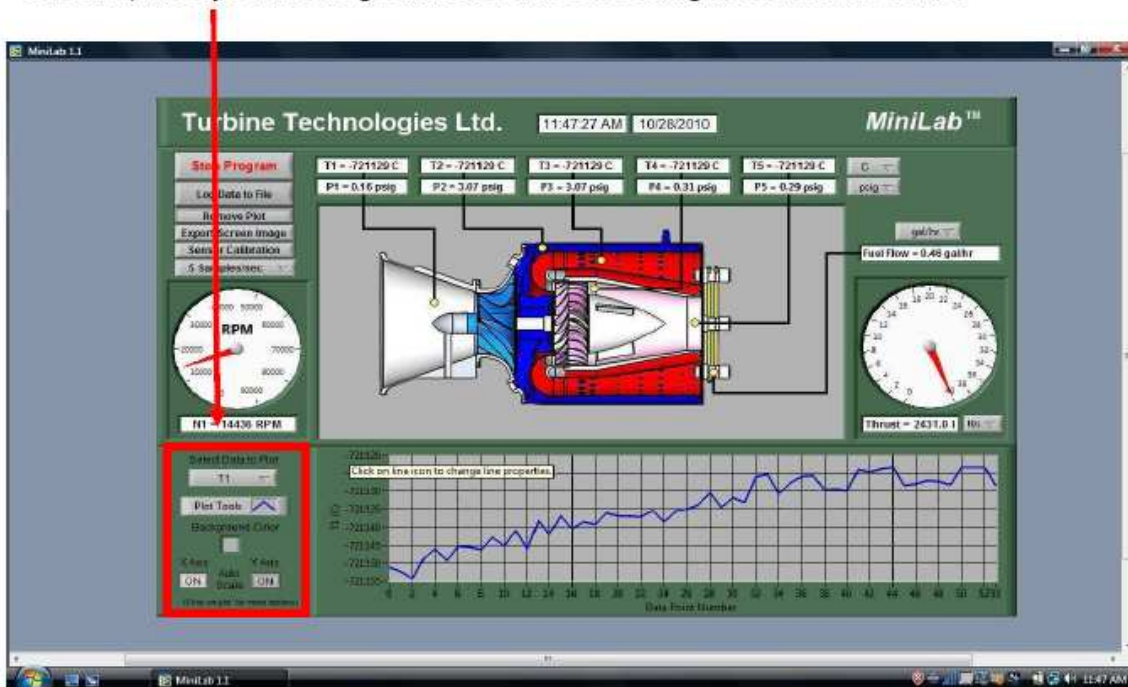
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Purpose: Graphically plot Mini-Lab^{TM} Gas Turbine Run Data in preparation for system analysis and performance calculations.

Procedure: Follow the instructions starting on the following pages of this lab session to plot system run data.

_____

Plot the following, utilizing MS-Excel Spreadsheet Program:
- Compressor Inlet/Outlet Pressure vs. Time
- Compressor Inlet/Outlet Temperature vs. Time
- Turbine Inlet/Outlet Pressure vs. Time
- Turbine Inlet/Outlet Temperature vs. Time
- Exhaust Gas Temperature (EGT) vs. Time
- Fuel Flow vs. Time
- RPM vs. Time
- Thrust vs. Time
- Fuel Flow and Thrust vs. Time (on one plot)

Print out plots and order them as listed.

Choose and mark an <u>analysis point</u> on each plot for the same time point.
For this exercise, pick a spot where engine RPM is at or near its peak during the data run. This will be the basis for system performance analysis calculations.

From your plots (specific time mark) and data collected from system run, please record the following:

- Date of Run: 26-JAN-2011
- Time: 13:30 CST (554.98 ANALYSIS POINT)
- Atmospheric Pressure: 14.75 PSI, 30.04 IN. HG.
- Compressor Inlet Pressure: 0.255 psig, 15.0 psia, 0.1004 MPa
- Compressor Exit Pressure: 22.5 psig, 37.25 psia, 0.2568 MPa
- Turbine Inlet Pressure: 22.96 psig, 37.71 psia, 0.2599 MPa
- Turbine Exit Pressure: 1.60 psig, 16.35 psia, 0.1127 MPa
- Nozzle Exit Pressure: 1.53 psig, 16.28 psia, 0.1122 MPa
- Fuel Flow: 4.32 GPH, 16.37 l/HR
- RPM: 70,700 RPM
- Thrust: 13.33 lbf, 6.06 kgf, 59.30 N
- Compressor Inlet Temperature: -10 °C, 14°F, 263.15°K, 473.67°R
- Compressor Exit Temperature: 135°C, 275°F, 408.15°K, 734.67°R
- Turbine Inlet Temperature: 751°C, 1,383°F, 1024.15°K, 1842.67°R
- Turbine Exit Temperature: 573°C, 1063°F, 846.15°K, 1522.67°R
- EGT: 405°C, 761°F, 678.15°K, 1220.67°R

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Importing Acquisition Data into MS-Excel Spreadsheet

A convenient way to analyze MiniLab performance data is to graph the data points using MS-Excel Spreadsheet. To do this, the ASCII data captured during the lab data acquisition must be imported into Excel.

Open: MS-Excel on computer desktop
Click: File
Click: Open
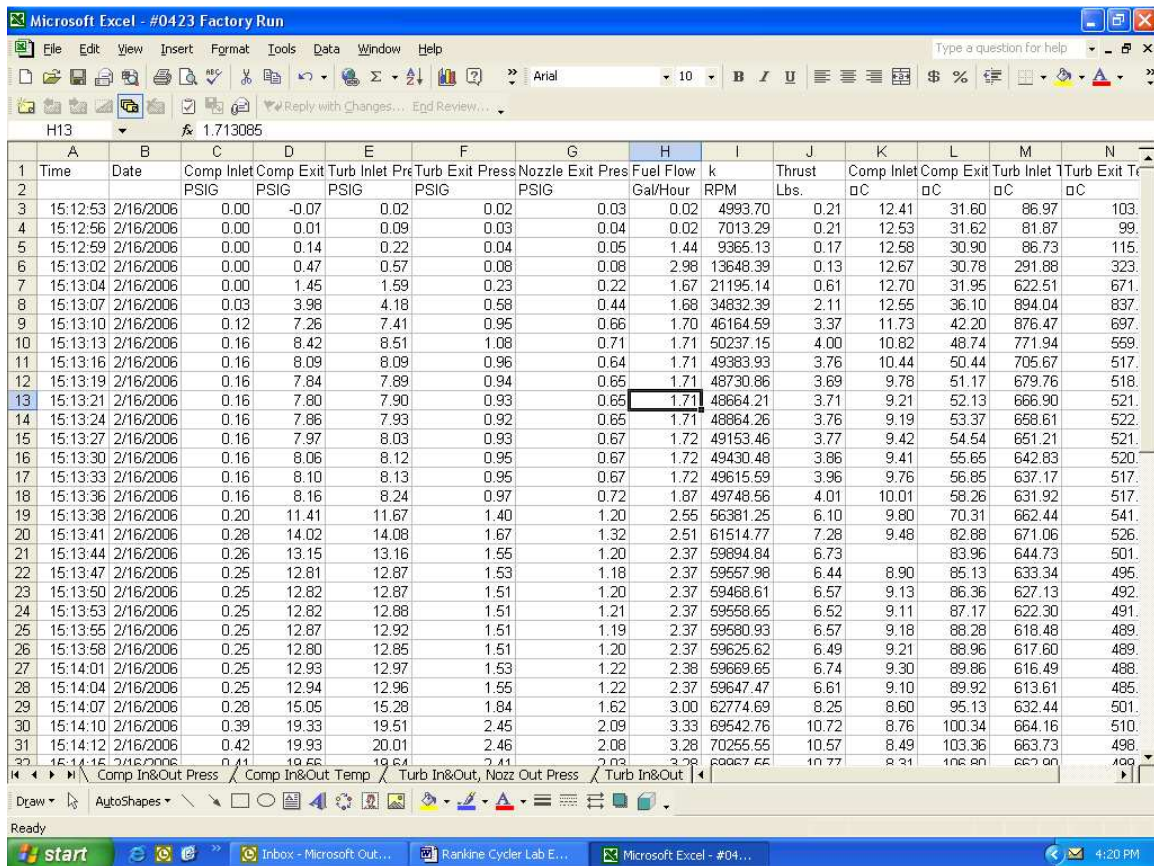**Click: C-Drive**
Click: Users\Turbine Technologies
Click: MiniLab
Click: "All Files" under "Files of Type"
Click: Next (In Text Import Window, Step 1 of 3)
Click: Next (In Text Import Window, Step 2 of 3)
Click: Finish (In Text Import Window, Step 3 of 3)

Your data will now be in spreadsheet form.

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Graphing Data using MS-Excel Spreadsheet Graphing Function

Highlight columns of data desired for graph. For this example, the Time and BP column data will be plotted.

Chart Type: Line
Chart Sub Type: Line (first one)
Next

Accept data range listed by choosing: Next

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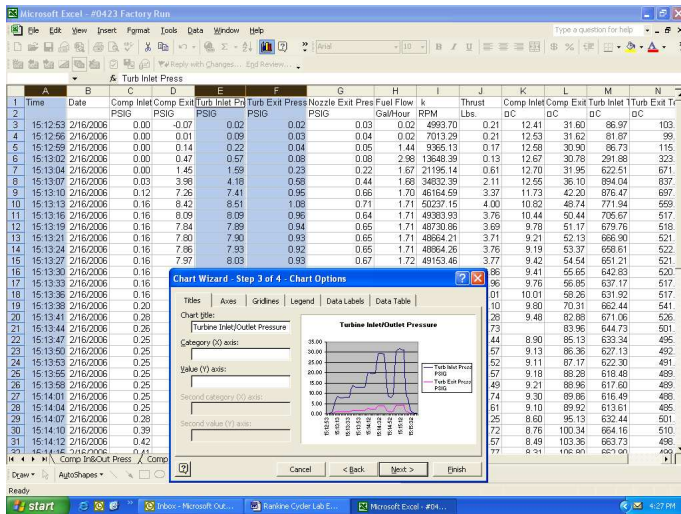
Choose Graph Options and Labels
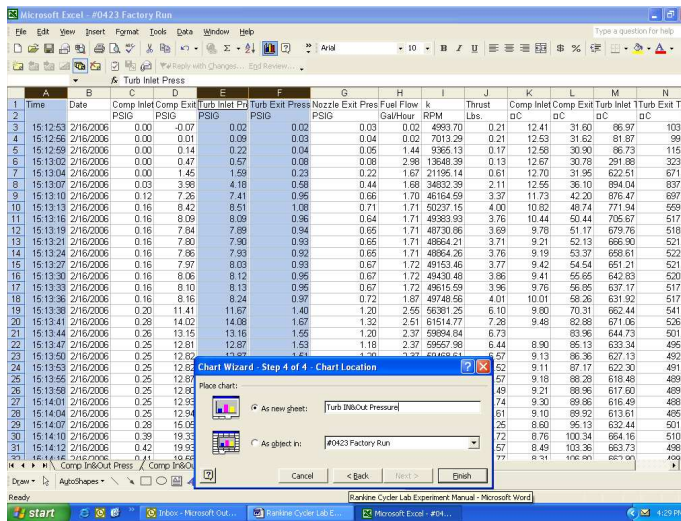
Name Graph, Click as New Sheet, Finish
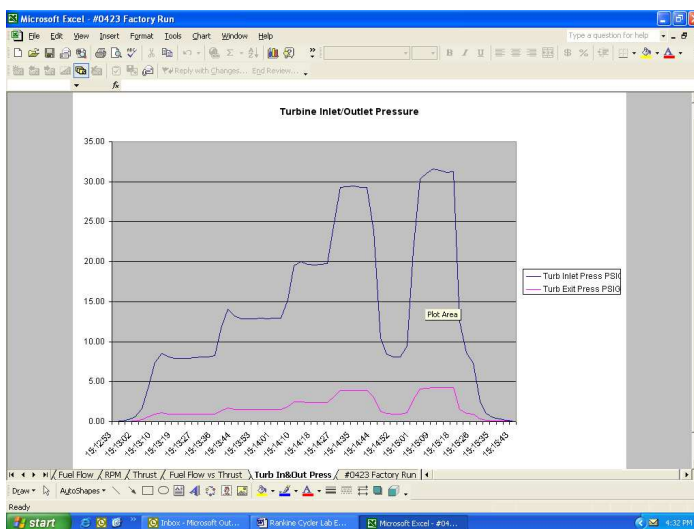
Completed Turbine Inlet and Outlet Pressure Graph

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Purpose: To perform system performance calculations using First Law Energy Conservation Equation for Steady State, Steady Flow Conditions **(SSSF)**. The data for these calculations comes from the information plotted and recorded in the previous lab session

Procedure: Perform requested analysis and calculations.

Schematic of Brayton Cycle for Gas Turbine and Cut Away of SR-30 Engine

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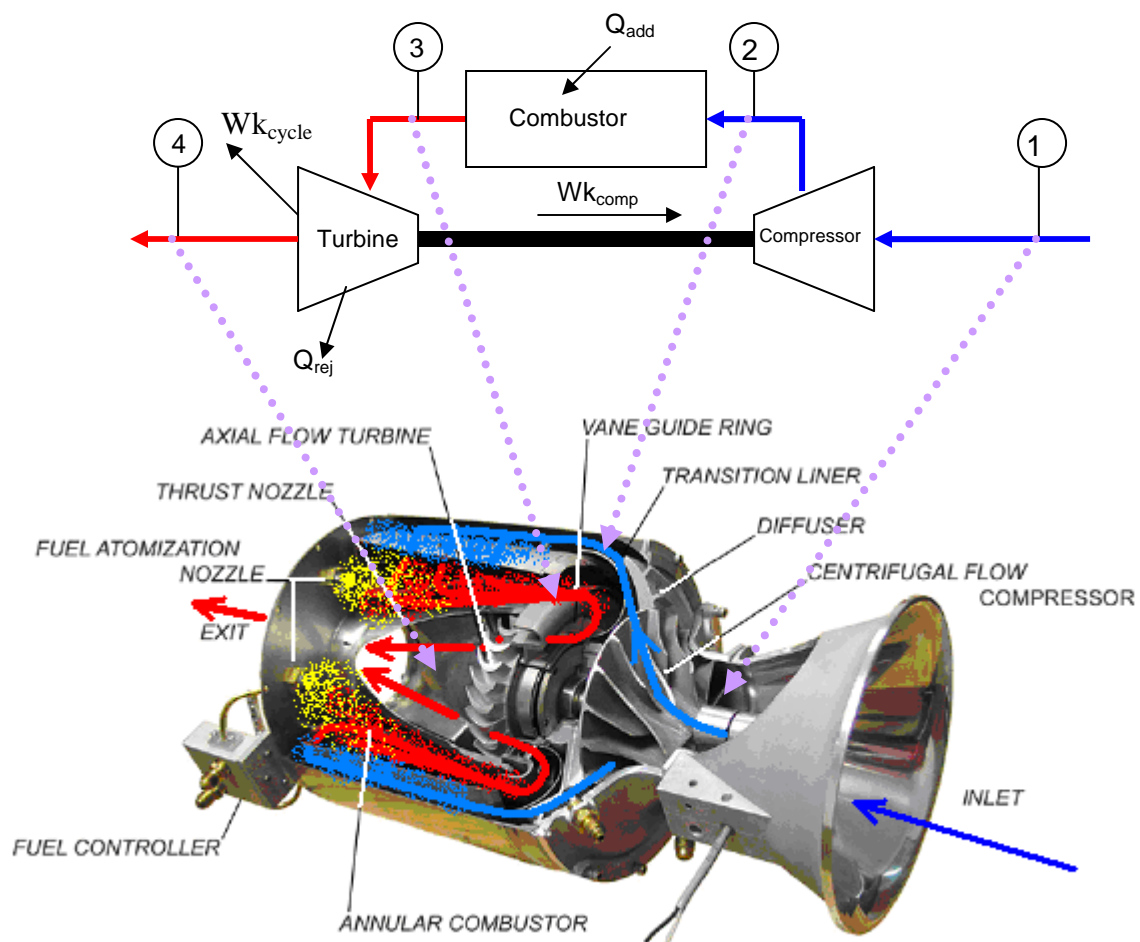
For the analysis point chosen in Lab Session #2, find the Specific Enthalpy at each Cycle Point (using air tables).

$h_1 =$ 7,633 kJ/kg·mol* = 263 kJ/kg
3,218 BTU/lb·mol = 113 BTU/lb

COMPRESSOR INLET: $P = 0.1004$ MPa = 15 PSIA
CONDITIONS: $T = 263.15 °K = 473.67 °R$

$h_2 =$ 11,860 kJ/kg·mol = 409 kJ/kg
5,101 BTU/lb·mol = 176 BTU/lb

COMPRESSOR EXIT: $P = 0.2568$ MPa = 37.25 PSIA
CONDITIONS: $T = 408.15 °K = 734.67 °R$

$h_3 =$ 31,110 kJ/kg·mol = 1074 kJ/kg
13,370 BTU/lb·mol = 461 BTU/lb

TURBINE INLET: $P = 0.2599$ MPa = 37.71 PSIA
CONDITIONS: $T = 1024.15 °K = 1842.67 °R$

$h_4 =$ 25,290 kJ/kg·mol = 873 kJ/kg
10,870 BTU/lb·mol = 375 BTU/lb

TURBINE EXIT: $P = 0.1127$ MPa = 16.35 PSIA
CONDITIONS: $T = 846.15 °K = 1522.67 °R$

* MOLECULAR MASS OF AIR = 28.967

1.) For the Compression Stage, Find Specific Work Done by the Compressor (1-2).

$$wk_{comp} = h_2 - h_1 = 409 \text{ kJ/kg} - 263 \text{ kJ/kg} = \underline{146 \text{ kJ/kg}}$$
$$= 176 \text{ BTU/LB} - 113 \text{ BTU/LB} = \underline{63 \text{ BTU/LB}}$$

2.) For Combustion Stage, Find Specific Energy Added by the Fuel (2-3).

$$q_{ADD} = h_3 - h_2 = 1074 \text{ kJ/kg} - 409 \text{ kJ/kg} = \underline{665 \text{ kJ/kg}}$$
$$= 461 \text{ BTU/LB} - 176 \text{ BTU/LB} = \underline{285 \text{ BTU/LB}}$$

3.) For the Turbine Expansion, Find the Specific Work of the Turbine (3-4).

$$wk_{TURB} = h_4 - h_3 = 873 \text{ kJ/kg} - 1074 \text{ kJ/kg} = \underline{-201 \text{ kJ/kg}}$$
$$= 375 \text{ BTU/LB} - 461 \text{ BTU/LB} = \underline{-86 \text{ BTU/LB}}$$

4.) Find the Specific Work done by the Cycle.

$$wk_{CYCLE} = wk_{TURB} + wk_{comp} = h_3 - h_4 + h_1 - h_2$$
$$= 201 \text{ kJ/kg} + {}^- 146 \text{ kJ/kg} = \underline{55 \text{ kJ/kg}}$$
$$= 86 \text{ BTU/LB} + {}^- 63 \text{ BTU/LB} = \underline{23 \text{ BTU/LB}}$$

5. Find the Thermodynamic Efficiency of the Cycle

$$\eta_T = \frac{wk_{CYCLE}}{q_{ADD}} \times 100 = \frac{55 \text{ kJ/kg}}{665 \text{ kJ/kg}} \times 100 = \underline{8.1\%}$$
$$= \frac{23 \text{ BTU/LB}}{285 \text{ BTU/LB}} \times 100 = \underline{8.1\%}$$

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Purpose: To perform system performance calculations of the engine at the compressor inlet and nozzle exit. The data for these calculations comes from the information recorded and plotted in a previous lab session

Procedure: Perform requested analysis and calculations at this location and operational point.

COMPRESSOR INLET
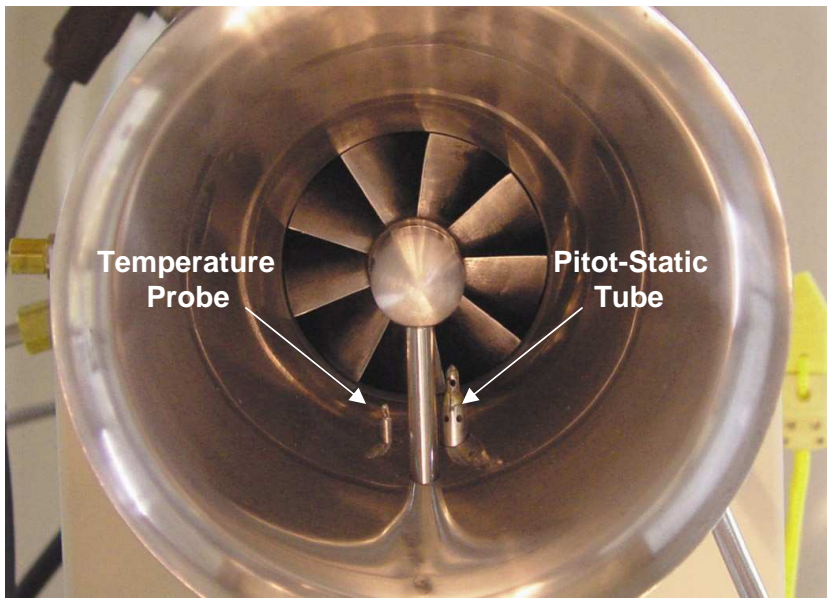
What is the **Pitot-Static Recorded Pressure** (Compressor Inlet Pressure) and **Air Density** at this location and operating condition?

AT PITOT STATIC LOCATION IN ENGINE INTAKE BELL, CROSS-SECTIONAL AREA IS:

$$A_{BELL \atop OPENING} = \pi \left(\frac{2.6''}{2}\right)^2 - \pi \left(\frac{0.75''}{2}\right)^2_{RPM \atop GEN \atop HOUSING} = 4.87 IN^2 = 0.0338 FT^2 = 0.0031 M^2$$

PITOT STATIC RECORDED PRESSURE = 0.255 PSIG = 15.0 PSIA = 0.00238 MPa = $\underline{2382.6 \ N/m^2}$

FOR $T = 473.67°R$
$P = 15 \ PSIA$ $\mathcal{V} = 338.8 \ \frac{FT^3}{lb \cdot mo)}$ $\rho = \frac{1}{\mathcal{V}} = \frac{(1LB)(28.967)}{338.8 \ FT^3} \xleftarrow{mol. \ wt.} = \underline{0.085 \ LB/FT^3}$

FOR $T = 263.15°K$
$P = 0.1004 \ MPa$ $\mathcal{V} = 21.78 \ \frac{m^3}{kg \cdot mo)}$ $\rho = \frac{1}{\mathcal{V}} = \frac{(1kg)(28.967)}{21.78 \ m^3} = \underline{1.32 \ kg/m^3}$

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Calculate the gas (air) **Velocity** into compressor at this operating condition.

$$V^* = \sqrt{\frac{2P}{\rho}} = \sqrt{\frac{(2)(0.255 \ LB/IN^2)(144 \ IN^2/FT^2)}{(0.085 \ LB/FT^3)(s^2/32.174 \ FT)}} = \underline{166 \ FT/s}$$

* CORRECTION CONST.
NOT USED

$$= \sqrt{\frac{(2)(1757.7 \ KG \cdot m/s^2 m^2)}{1.32 \ KG/m^3}} = \underline{51.6 \ M/s}$$

Calculate the **Volumetric Flow Rate** of air into compressor at this operating condition.

$$Q = AV = (4.87 \ IN^2)(FT^2/144 \ IN^2)(166 \ FT/s) = \underline{5.61 \ FT^3/s}$$
$$= (0.0031 \ M^2)(51.6 \ M/s) = \underline{0.16 \ M^3/s}$$

Calculate **Mass Flow Rate** of air into compressor at this operating condition.

$$\dot{m} = \rho AV = (0.085 \ LB/FT^3)(0.0338 \ FT^2)(166 \ FT/s) = \underline{0.47 \ LB_m/s}$$
$$= (1.32 \ KG/m^3)(0.0031 \ m^2)(51.6 \ M/s) = \underline{0.21 \ KG/s}$$

Calculate the **Thrust** generated at this location and operating condition.

$$T = \dot{m}V = (0.47 \ LB_m/s)(s^2/32.174 \ FT)(166 \ FT/s) = \underline{2.42 \ LB}$$
$$= (0.21 \ KG/s)(51.6 \ M/s) = \underline{10.83 \ N}$$

Calculate the **Mach Number** of the flow at this location and operating condition.

$$M = \frac{V}{\sqrt{g_c \left(\frac{c_p}{c_r}\right) RT}}_{AIR} = \frac{166 \ FT/s}{\sqrt{\left(32.174 \ \frac{FT \cdot LB_m}{s^2 \ LB_f}\right)(1.4)\left(53.3 \ \frac{FT LB_f}{LB_m \ °R}\right)(473.67 °R)}} = \underline{0.15}$$

$$= \frac{51.6 \ M/s}{\sqrt{(1.4)(287 \ J/KG \cdot K)(263.15 °K)}} = \underline{0.15}$$

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THRUST NOZZLE EXIT
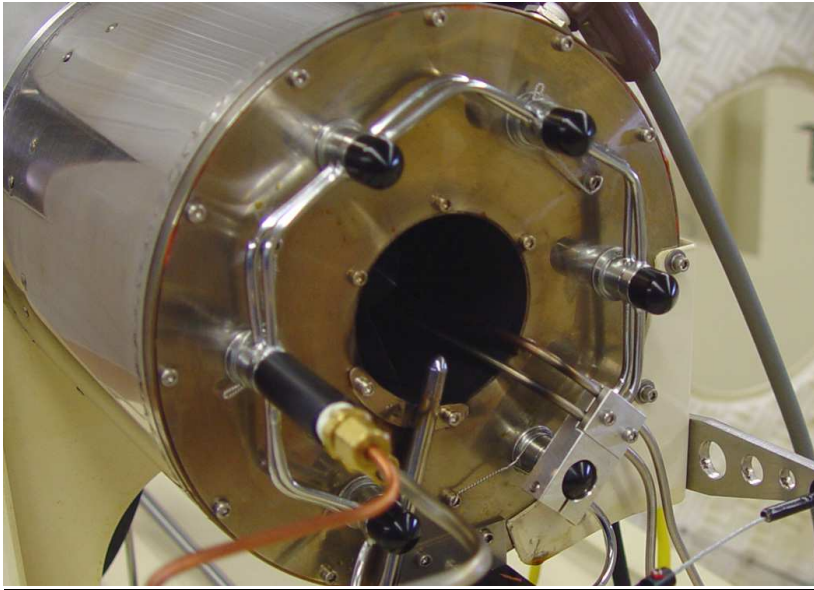
What is the **Pitot Ram Air Recorded Pressure** (Exhaust Gas Pressure) and **Air Density** at this location and operating condition?

$$\text{PITOT RAM AIR RECORDED PRESSURE} = 1.53 \text{ PSIG} = 0.0104 \text{ MPa}$$

$$P_{ABS} = P_{ATM} + P_{GAGE} = 14.75 + 1.53 = 16.28 \text{ PSIA} = 0.1122 \text{ MPa}$$

$$\text{FOR } \left.\begin{array}{l} T = 1220.67\,°R \\ P = 16.28 \text{ PSIA} \end{array}\right\rangle \quad N = 804.6 \frac{FT^3}{lb\text{-}mo} \quad \rho = \frac{1}{N} = \frac{(1\,LB)(28.967)}{804.6 \, FT^3} = 0.036 \, \frac{LBm}{FT^3}$$

$$\text{FOR } \left.\begin{array}{l} T = 678.15\,°K \\ P = 0.1122 \text{ MPa} \end{array}\right\rangle \quad N = 50.25 \frac{m^3}{KG\text{-}mol} \quad \rho = \frac{1}{N} = \frac{(1\,KG)(28.967)}{50.25 \, m^3} = 0.58 \, KG/m^3$$

Calculate the gas (air) **Velocity** exiting the nozzle at this operating condition.

$$V = \sqrt{\frac{2P}{\rho}} = \sqrt{\frac{(2)(1.53 \, LB/IN^2)(144 \, IN^2/FT^2)}{(0.036 \, LBm/FT^3)(s^2/32.174 \, FT)}} = \underline{627 \, FT/s}$$

$$= \sqrt{\frac{(2)(0.0104 \times 10^6 \, KG \cdot m/s^2 \cdot m^2)}{0.58 \, KG/m^3}} = \underline{189 \, m/s}$$

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Calculate the **Volumetric Flow Rate** of air exiting the nozzle at this operating condition.

$$NOZZLE \ CROSS-SECTION \ AREA = \underline{3.88 \ IN^2} = \underline{0.0025 \ M^2}$$

$$Q = AV = (3.88 \ IN^2)(1FT^2/144 \ IN^2)(627 \ FT/s) = \underline{16.9 \ FT^3/s}$$
$$= (0.0025 \ M^3)(189 \ M/s) = \underline{0.47 \ M^3/s}$$

Calculate **Mass Flow Rate** of air exiting the nozzle at this operating condition.

$$\dot{m} = \rho AV = \rho Q = (0.036 \ LB_M/FT^3)(16.9 \ FT^3/s) = \underline{0.61 \ LB_M/s}$$
$$= (0.58 \ KG/M^3)(0.47 M^3/s) = \underline{0.27 \ KG/s}$$

Calculate the **Thrust** generated at this location and operating condition.

$$T = \dot{m}V = (0.61 \ LB_M/s)(s^2/32.174 \ FT)(627 \ FT/s) = \underline{11.9 \ LB_F}$$
$$= (0.27 \ KG/s)(189 \ M/s) = \underline{51 \ N}$$

Calculate the **Mach Number** of the flow at this location and operating condition.

$$M = \frac{V}{\sqrt{g_c\left(\frac{C_P}{C_T}\right)R_{AIR}T}} = \frac{627 \ FT/s}{\sqrt{\left(32.174 \ \frac{FT \cdot LB_M}{s^2 \ LB_F}\right)(1.4)\left(53.3 \ \frac{FT \cdot LB_F}{LB_M \ {}^\circ R}\right)(1220.67 {}^\circ R)}} = \underline{0.36}$$

$$= \frac{189 \ M/s}{\sqrt{(1.4)\left(287 \ \frac{J}{KG \ {}^\circ K}\right)(678.15 {}^\circ K)}} = \underline{0.36}$$

Questions:
Why is the calculated value of Thrust using pitot tube reading different than what is captured by system's load cell thrust measurment?

POSITION OF PITOT TUBE IN EXHAUST STREAM CAPTURES CONDITIONS AT THAT PARTICULAR POINT, NOT ACROSS FULL CROSS-SECTION OF FLOW. WITHOUT A CORRECTION FACTOR, READINGS CAN BE OFF WHEN COMPARED TO THRUST LOAD CELL DATA.

Does temperature of exhaust gases affect Mach Number?

YES, IT IS THE ONLY VARIABLE IN SPEED OF SOUND CALCULATION. AS TEMPERATURE INCREASES, FOR A GIVEN VELOCITY, MACH NUMBER INCREASES (THE COLDER THE TEMPERATURE, THE HIGHER THE MACH NUMBER).

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Purpose: To determine the optimal operational setting for the SR-30 Gas Turbine by analyzing the fuel consumption rate verses the amount of thrust generated. The data for these calculations comes from the information recorded and plotted in a previous lab session

Procedure: Perform requested analysis and calculations that follow.

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1. Using your operational run data plots, pull up and print the following graphs:
   - Fuel Flow and Thrust (on one graph) plotted over Time.
   - Engine RPM (on another graph) plotted over Time.

2. Pick 4 RPM settings (from low to highest operating RPM) and mark them on Engine RPM sheet. Write the actual RPM value at each mark on the graph.

3. Transfer the time positions of the Engine RPM Graph to the Fuel Flow and Thrust Graph. Record the values of Fuel Flow and Thrust at each time position.

4. Calculate Thrust Specific Fuel Consumption (T.S.F.C.) at each RPM setting chosen.

$$\text{T.S.F.C.} = \frac{\text{Weight of Fuel Burned / Hour}}{\text{Thrust Force}}$$

① $RPM = 51,281 \Rightarrow TSFC = \dfrac{(2.34\ GAL/HR)(6.76\ lb/GAL)}{6.15\ lb_{THRUST}} = 2.57\ \dfrac{lb_{FUEL}}{lb \cdot HR_{THRUST}} \Rightarrow \dfrac{20.93\ \frac{KG}{HR}}{13.54\ KG} = 1.54\ \dfrac{KG_{FUEL}}{KG \cdot HR_{THRUST}}$

② $RPM = 60,451 \Rightarrow T3FC = \dfrac{(3.21\ GAL/HR)(6.76\ lb/GAL)}{9.04\ lb_{THRUST}} = 2.40$

③ $RPM = 70,737 \Rightarrow TSFC = \dfrac{(4.32\ GAL/HR)(6.76\ lb/GAL)}{13.3\ lb_{THRUST}} = 2.19$

④ $RPM = 77,826 \Rightarrow TSFC = \dfrac{(4.87\ GAL/HR)(6.76\ lb/GAL)}{19.53\ lb_{THRUST}} = 1.68$

Question: Based on your findings, at what power setting does the SR-30 Gas Turbine offer: The best T.S.F.C.?   The worst T.S.F.C.?
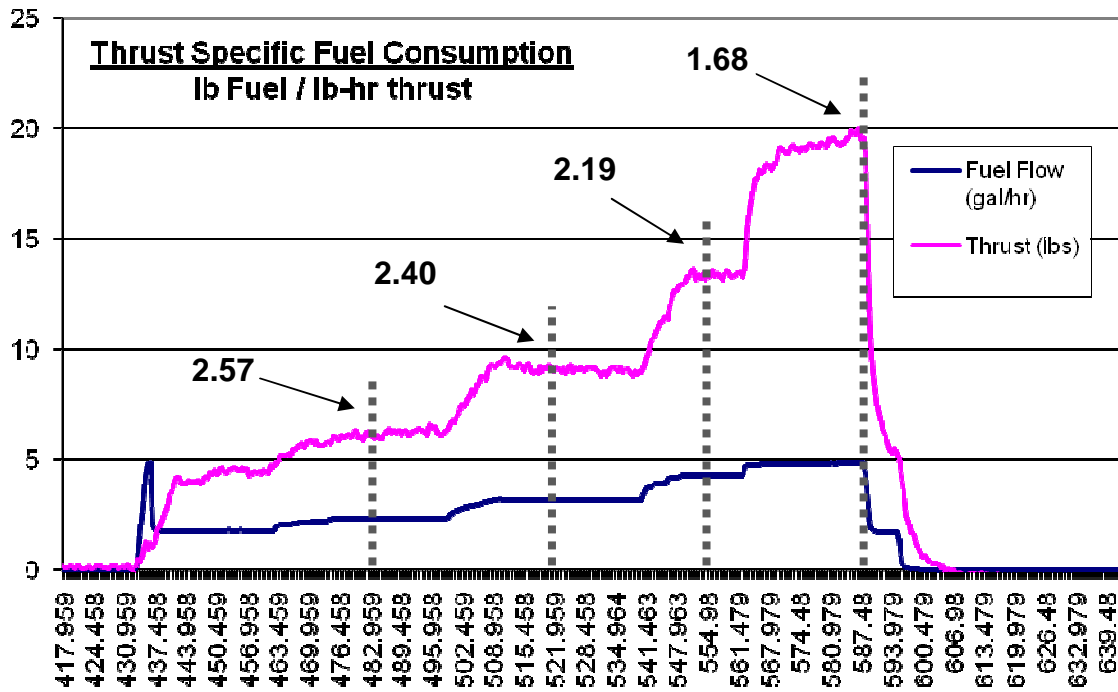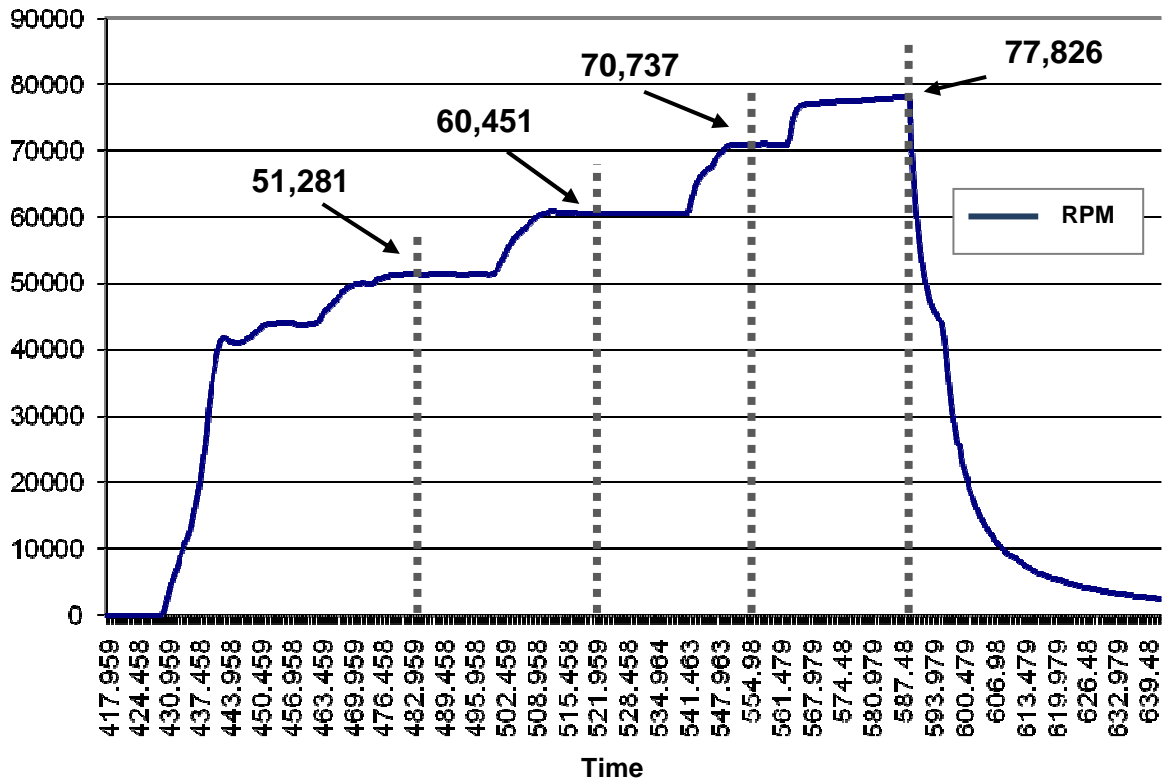
 77,826 RPM   51,281 RPM

Is this what you expected?

 DISCUSS WITH YOUR PROFESSOR.

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Fuel Flow Verses Thrust

Engine RPM

Time

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Mini-Lab^{TM} Gas Turbine Lab Experiment Manual
Lab Session #6: Jet Engine Propulsive Efficiency Analysis

Purpose: To gain an understanding of the propulsive efficiency of a turbo-jet engine. The data for these calculations comes from the information recorded and plotted in a previous lab session

Procedure: Perform requested analysis and calculations that follow.

We have calculated our engine thrust when the unit is standing still in the lab. Now, let's turn our Mini-Lab^{TM} Gas Turbine System into a go-kart (since your professor won't really let you do this, let's just imagine it). Let's assume we've replaced the casters with a remote steering wheel system and we took the unit out to an airport runway.

1.) If we fired the engine at the same maximum power setting we used in the lab and got the unit rolling 50 miles/hour (80.5 km/hr) down the runway, what is the propulsive efficiency of the unit?

$$\eta_P = \frac{THRUST\ POWER}{JET\ POWER} = \frac{\dot{m}\left(V_{JET} - V_{VEHICLE}\right)}{\frac{1}{2}\dot{m}\left(V_{JET}^2 - V_{VEHICLE}^2\right)} = \frac{2}{1 + \frac{V_{JET}}{V_{VEHICLE}}}$$

$$V_{JET} = 627\ FT/s = 189\ m/s$$

$$V_{VEHICLE} = \left(\frac{50\ MILES}{HR}\right)\left(\frac{5,280\ FT}{MILE}\right)\left(\frac{1\ HR}{3600\ s}\right) = 73.3\ FT/s = 22.35\ m/s$$

$$\eta_P = \frac{2}{1 + \frac{627\ FT/s}{73.3\ FT/s}} = \frac{2}{1 + \frac{189\ m/s}{22.35\ m/s}} = 0.21$$

2.) Since the unit is boxy, with a great deal of flat plate area causing drag, someone suggested attaching a sleek nose cone to the front of the vehicle. With the new nose cone, it was sent down the runway at the same power setting, reaching 100 miles/hour (161 km/hour). What is the new propulsive efficiency?

$$V_{JET} = 627\ FT/s = 189\ m/s$$

$$V_{VEHICLE} = \left(100\ \frac{MILES}{HR}\right)\left(5,280\ \frac{FT}{MILE}\right)\left(\frac{1\ HR}{3600\ s}\right) = 146.66\ FT/s = 44.70\ m/s$$

$$\eta_P = \frac{2}{1 + \frac{627\ FT/s}{146.66\ FT/s}} = \frac{2}{1 + \frac{189\ m/s}{44.7\ m/s}} = 0.38$$

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3.) Someone suggested adding a sleek tail cone to the set-up and when it was sent down the runway in this configuration at the same power setting, it reached 150 miles/hour (241.5 km/hour). What is the new propulsive efficiency?

$$V_{JET} = 627 \text{ FT/s} = 189 \text{ m/s}$$

$$V_{VEHICLE} = 150 \text{ miles/HR} = 220 \text{ FT/s} = 67 \text{ m/s}$$

$$\eta_p = \frac{2}{1 + \frac{627}{220}} = \frac{2}{1 + \frac{189}{67}} = \underline{0.52}$$

4.) Finally, a pair of swept wings and tail was added and the unit actually lifted off and flew at 200 miles/ hour (322 km/hour) in ground affect above the runway. What was the new propulsive efficiency?

$$V_{JET} = 627 \text{ FT/s} = 189 \text{ m/s}$$

$$V_{VEHICLE} = 200 \text{ miles/HR} = 293.3 \text{ FT/s} = 89.4 \text{ m/s}$$

$$\eta_p = \frac{2}{1 + \frac{627}{293.3}} = \frac{2}{1 + \frac{189}{89.4}} = \underline{0.64}$$

5.) After it was all over the unit was returned to its original configuration and returned to the lab. It was fired up again and run at the same power setting that was used on the runway. What is the propulsive efficiency now?

$$V_{JET} = 627 \text{ FT/s} = 189 \text{ m/s}$$

$$V_{VEHICLE} = 0 \text{ FT/s} = 0 \text{ m/s}$$

$$\eta_p = \frac{\dot{m}(V_{JET} - V_{VEHICLE})(V_{VEHICLE})^{\,0}}{\frac{1}{2}\dot{m}(V_{JET}^2 - V_{VEHICLE}^2)} = \underline{0}$$

Questions:

Knowing what you have learned about propulsive efficiency, which would be a better use of the same turbo-jet engine; putting it on an ultralight airplane with a maximum airframe speed of 80 miles/hour (129 km/hr) or one on an observation drone that cruises at 300 (483 km/hr) miles per hour?

η_p INCREASES AS THE VELOCITY OF THE VEHICLE INCREASES FOR THE GIVEN AMOUNT OF THRUST VELOCITY

∴ THE OBSERVATION DRONE WOULD BE THE BEST CHOICE.

What is the difference in propulsive efficiency between the two aircraft?

$$\Delta\eta_p = \frac{2}{1 + \frac{627}{440}} - \frac{2}{1 + \frac{627}{117}} = 0.82 - 0.31 = \underline{0.51}$$
$$\text{(OBSERVATION DRONE)} \quad \text{(ULTRALIGHT)}$$

Turbine Technologies, Ltd.