

# TurboGen™

## Gas Turbine Electrical Generation System

### Sample Lab Experiment Procedure

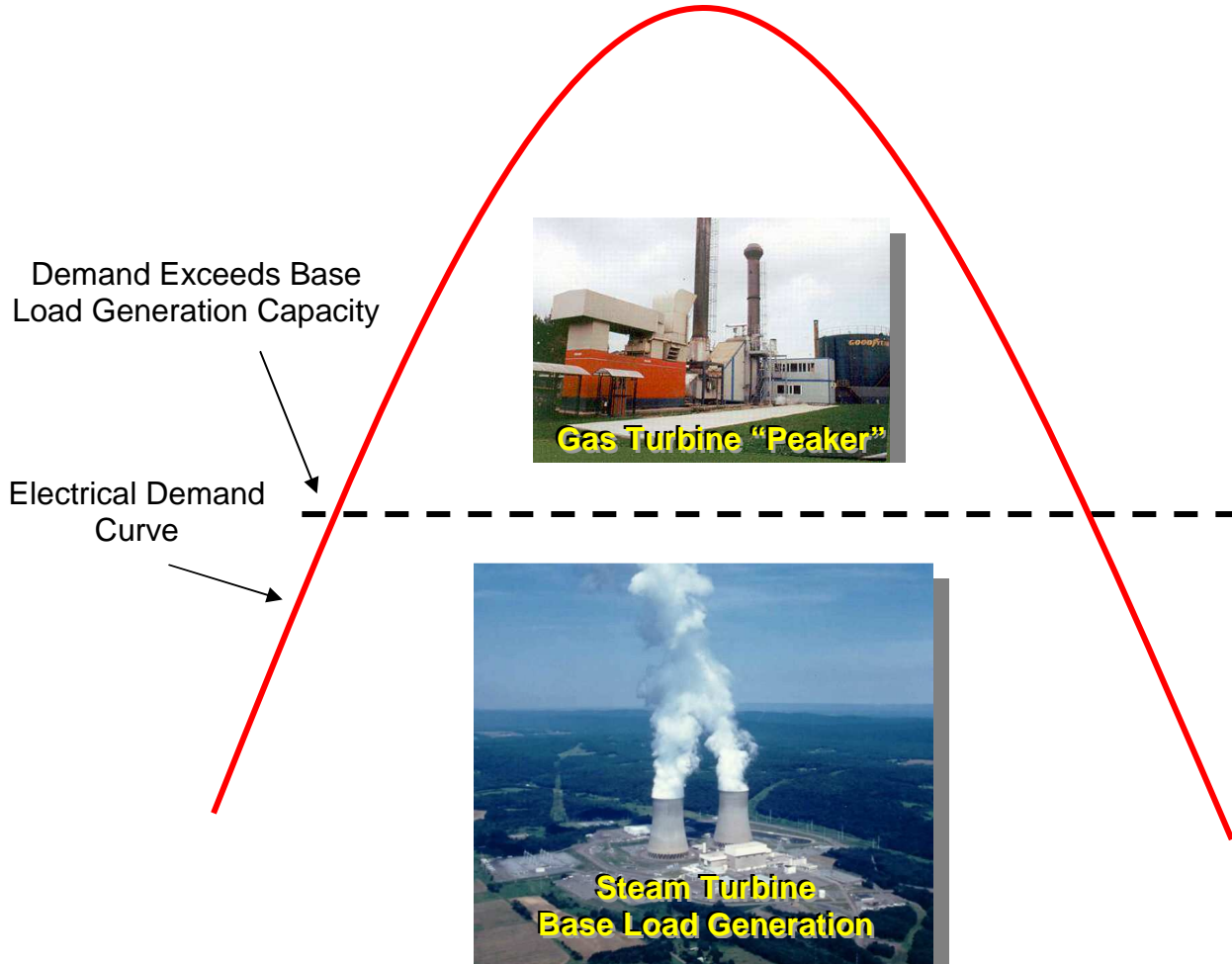
#### **Lab Session #1: System Overview and Operation**

**Purpose:** To gain an understanding of the TurboGen™ Gas Turbine Electrical Generation System as a whole and details of engine and generator sensors and controls making up the system. This will prepare for operation of the system.

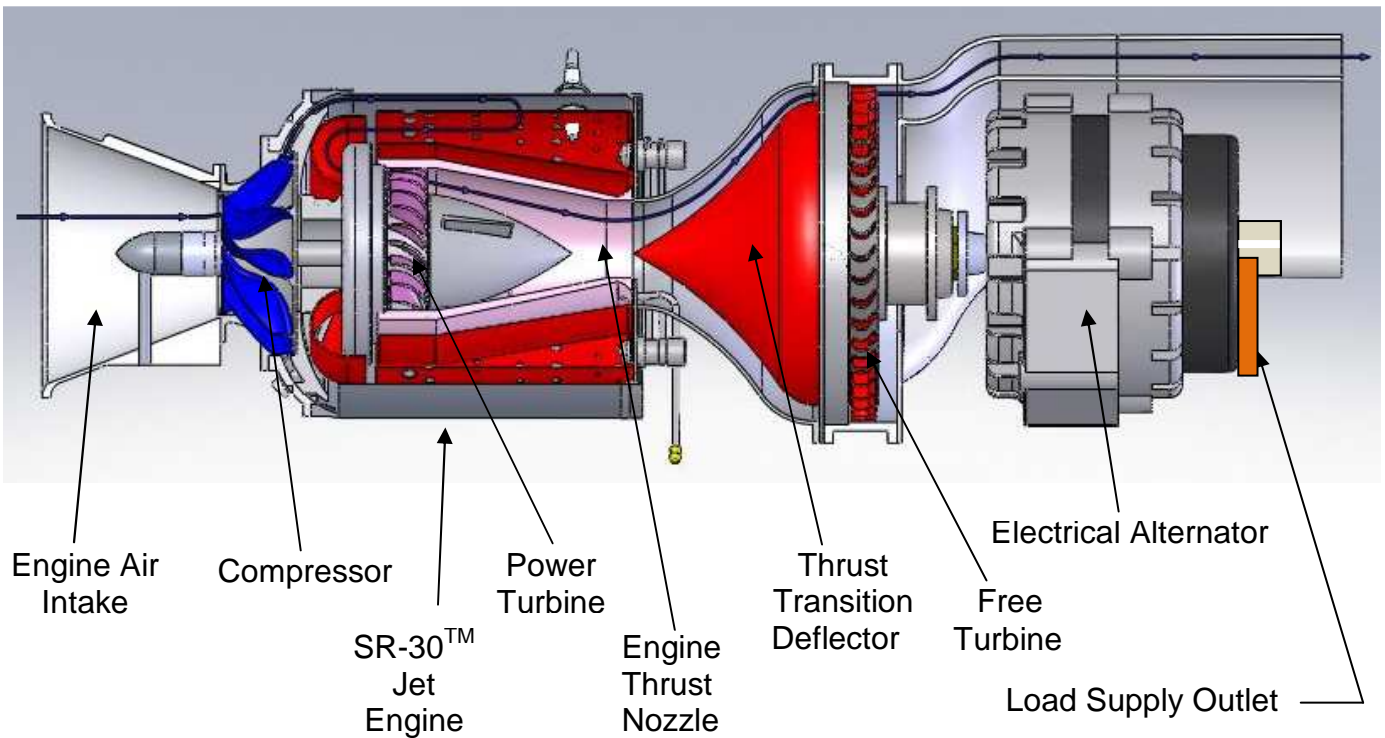


## TurboGen™ is a jet engine powered electrical generation system.

This type of generation is typically used by the Electrical Power Generation Industry as supplemental or “peaking” generation. Most electricity is generated by large coal, hydro or nuclear power plants. These are known as “base load” plants and supply the majority of electricity needs (typically known as demand). On high demand days (i.e., hot day with high air conditioning use), the demand can exceed the base load supply capabilities. When this happens, peaker plants start up to generate enough electricity to make up for the base generation shortfall. The term “peaker” relates to the electrical demand curve for the day; if the curve exceeds the base generation abilities, the peakers are started to supply the “peak”, and are used until demand drops enough where base supply can handle it.



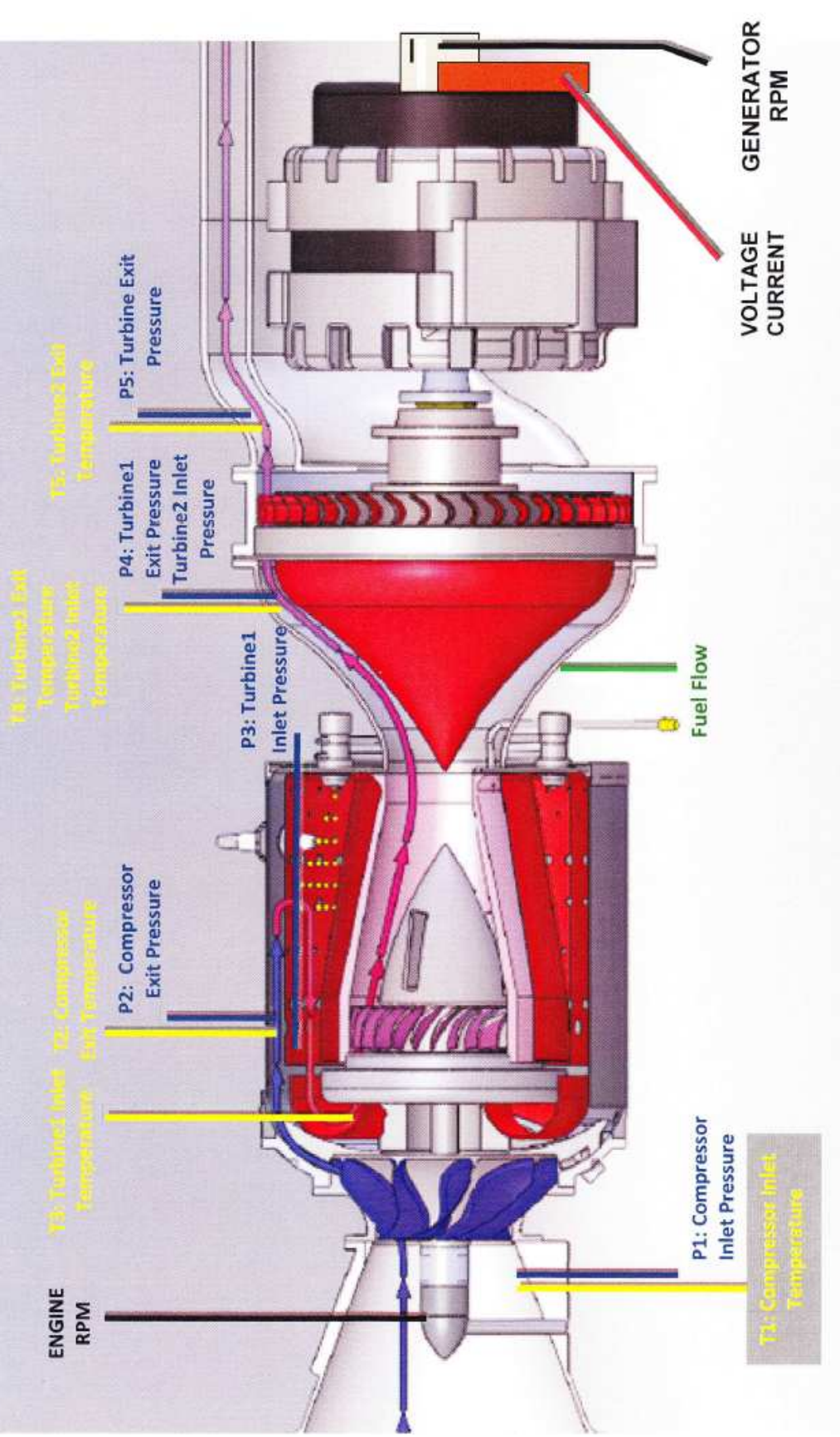
# How it works!



Following the cutaway schematic; Air enters the intake of the SR-30™ Engine. It is compressed by the centrifugal compressor, mixed with fuel and combusted in the combustion chamber, creating thrust which drives the power turbine (the power turbine is connected directly to the compressor and drives it). The thrust then accelerates out the thrust nozzle. In a straight thrust engine, this would be the propelling force to move the object the engine is attached to (such as an aircraft). With TurboGen™, we direct the thrust through a thrust transition deflector, causing the thrust to drive another turbine wheel called a free turbine (not mechanically connected to engine, only thermodynamically connected). The free turbine drives an electrical alternator which generates electricity to drive an electrical load.

Strategic sensors measure operational conditions of the engine and generation system. The following shows sensor details (first for engine, then for generator).

# Engine/Generator Sensor Locations



# SR-30 Gas Turbine Engine / TG-2000 Electrical Generator

## System Sensor Locations

**Engine RPM Tachometer Generator:** (Displayed on Panel and Data Acquisition Screen as N1 RPM).

**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:** Turbine1 Inlet Pressure (Displayed on Panel and Data Acquisition Screen)

**T3:** Turbine1 Inlet Temperature (Displayed on Panel as TIT and Data Acquisition Screen)

**P4:** Turbine1 Exit Pressure/Turbine2 Inlet Pressure (Displayed on Data Acquisition Screen)

**T4:** Turbine1 Exit Temperature/Turbine2 Inlet Temperature (Displayed on Data Acquisition Screen)

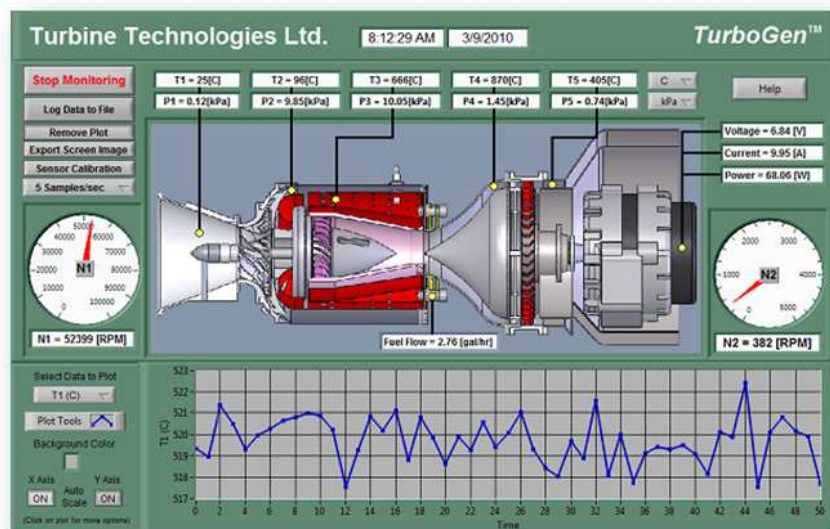
**P5:** Turbine2 Exit Pressure (Displayed on Data Acquisition Screen)

**T5:** Turbine2 Exit Temperature (Displayed on Panel as EGT and Data Acquisition Screen)

**Fuel Pressure:** (Displayed on Panel)

**Generator RPM Tachometer Generator:** (Displayed on Panel and Data Acquisition Screen as N2 RPM).

**Voltage and Current:** Displayed on Data Acquisition Screen as Voltage, Current and Power



**TurboGen Virtual Instrument Panel**

## TurboGen™ Power System Control Panel



### **OPERATIONAL CONTROLS –TurboGen Operator Panel**

1. **MASTER SWITCH, KEYED:** Secured control of access and engine operation
2. **GREEN START BUTTON:** Automated Engine Start, Multiple Functions
3. **RED STOP BUTTON:** Immediate EngineStop, Multiple Functions
4. **T-HANDLED POWER LEVER:** Engine RPM/Thrust Control, Forward Increases
5. **LOAD LEVER (Blue Handle):** Controls Excitation Loading on Electric Alternator
6. **AUTOSTART LCD DISPLAY:** Real Time System Status Automatically Shuts Off Unit if Parameters Exceeded.

### **DIGITAL and ANALOG OPERATOR DISPLAY: Direct visual indication of the following:**

7. **Digital Turbine Inlet Temperature (TIT)**
8. **Digital Engine Rotational Speed (RPM)**
9. **Digital Generator Turbine Rotational Speed (RPM)**
10. **Analog Oil Pressure**
11. **Analog Engine Pressure (P3)**
12. **Analog Fuel Pressure**
13. **Analog Starting Air Pressure**
14. **Generator Overspeed Warning Light**

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

Determine the fuel you are using to power your system. \_\_\_\_\_

What is the energy content per unit volume of fuel? \_\_\_\_\_

What is the fuel's density per unit volume? \_\_\_\_\_

**Barometric Pressure**

What is the present barometric pressure in your area?

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

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

**System Operation**

**Purpose:** Conduct pre-start, start-up, operation, data gathering and shut down of TurboGen™ Gas Turbine Electrical Generation System.

**Procedure:**

Utilize TurboGen™ **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**).

**Run Engine throttle up to full speed with Load Lever in pinned position (Fixed Excitation Current).**

**Optional: After full run-up in pinned position, unpin Load Lever and slowly bring it forward (increasing Excitation Current) and then slowly pushing it back (decreasing Excitation Current). A variety of speeds and operating load condition scenarios can be run during this time.**

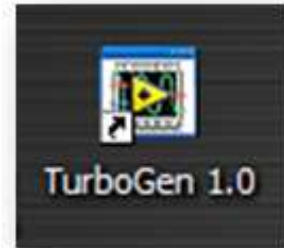
**WARNING!! CHECK OPERATOR'S MANUAL FOR LOAD LEVER/GENERATOR OVER-SPEED CAUTIONS!**

## 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 TurboGen Software and default settings as supplied with the TurboGen. 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 TurboGen Software by double-clicking on the TurboGen 1.0 shortcut icon located on the Windows Desktop. TurboGen 1.0 will start with the *Main Display/Control* and *Channel Configuration Window* displayed.

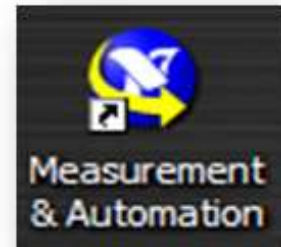


TurboGen Launch Icon

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

The TurboGen configuration software is dependent upon the specific DAQ Module serial number as installed in the TurboGen 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.



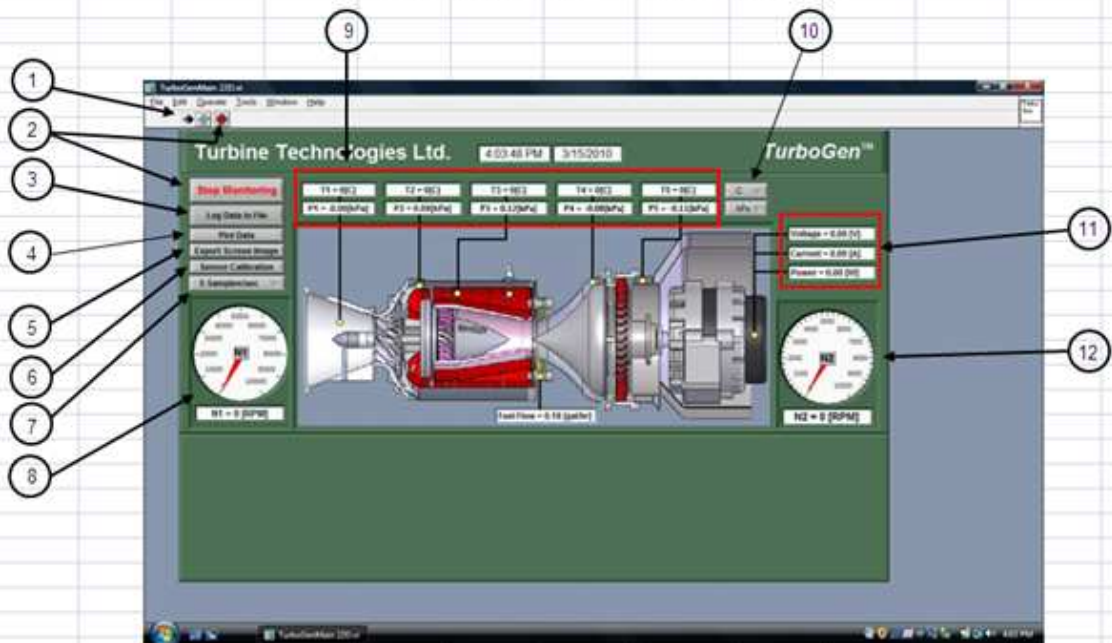
Measurement and Automation Launch Icon

### TO PERFORM THE FOLLOWING FUNCTIONS:

- **Virtual Instrument Panel Software Controls overview are on page 9**
- **Logging Data to File is shown on Page 10**
- **Displaying Plot Feature is shown on Page 10**



## Overview of the Software Controls



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

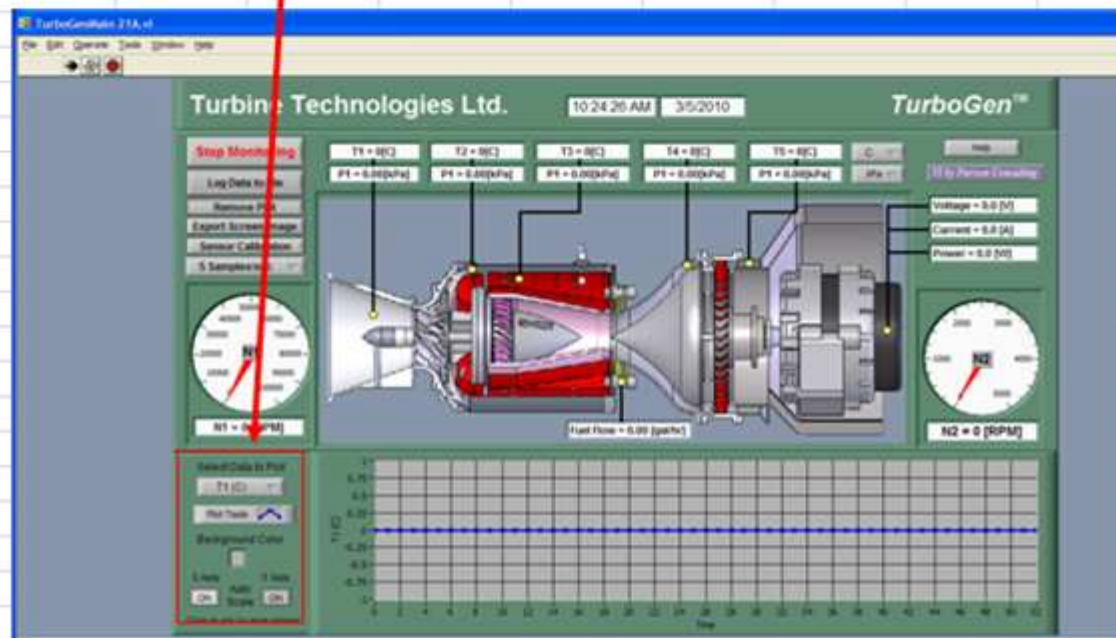
- 9 Real time Temperatures and pressures display.
- 10 °C to °F and Psig to kPa toggle.
- 11 Displays real time generator power output
- 12 Displays real time free Turbine/Generator RPM.

## Logging Data to a File and Displaying the Plot Feature



To log data to a file for later viewing and analysis, click "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:\desktop\My Documents\TurboGen". Click on it again to stop saving data.

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, background color and auto scaling for both X and Y axis.



## **TurboGen™ Gas Turbine Electrical Generation System Experiment Manual**

### **Lab Session #2: TurboGen™ Data Run Plots**

Purpose: Graphically plot TurboGen™ 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.

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Plot the following, utilizing MS-Excel Spreadsheet Program:

- Compressor Inlet/Outlet Pressure vs. Time
- Compressor Inlet/Outlet Temperature vs. Time
- Turbine1 (N1) Inlet/Outlet Pressure vs. Time
- Turbine1 (N1) Inlet/Outlet Temperature vs. Time
- Turbine 2 (N2) Inlet/Outlet Pressure vs. Time
- Turbine 2 (N2) Inlet/Outlet Temperature vs. Time
- Fuel Flow vs. Time
- Engine RPM vs. Time
- Generator RPM vs. Time
- Generator Voltage vs. Time
- Generator Current vs. Time
- Generator Power vs. Time

Print out plots and order them as listed.

**Choose and mark an analysis point 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: \_\_\_\_\_
- Time: \_\_\_\_\_
- Atmospheric Pressure: \_\_\_\_\_
- Compressor Inlet Pressure: \_\_\_\_\_
- Compressor Exit Pressure: \_\_\_\_\_
- Turbine1 Inlet Pressure: \_\_\_\_\_
- Turbine1 Exit Pressure: \_\_\_\_\_
- Turbine2 Inlet Pressure: \_\_\_\_\_
- Turbine2 Exit Pressure: \_\_\_\_\_
- Fuel Flow: \_\_\_\_\_
- Engine RPM: \_\_\_\_\_
- Compressor Inlet Temperature: \_\_\_\_\_
- Compressor Exit Temperature: \_\_\_\_\_

- Turbine1 Inlet Temperature: \_\_\_\_\_
- Turbine1 Exit Temperature: \_\_\_\_\_
- Turbine2 Inlet Temperature: \_\_\_\_\_
- Turbine2 Exit Temperature: \_\_\_\_\_
- Turbine2 RPM: \_\_\_\_\_
- Generator Voltage: \_\_\_\_\_
- Generator Current: \_\_\_\_\_

### **Importing Acquisition Data into MS-Excel Spreadsheet**

A convenient way to analyze TurboGen 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: Program Files**

**Click: TurboGen**

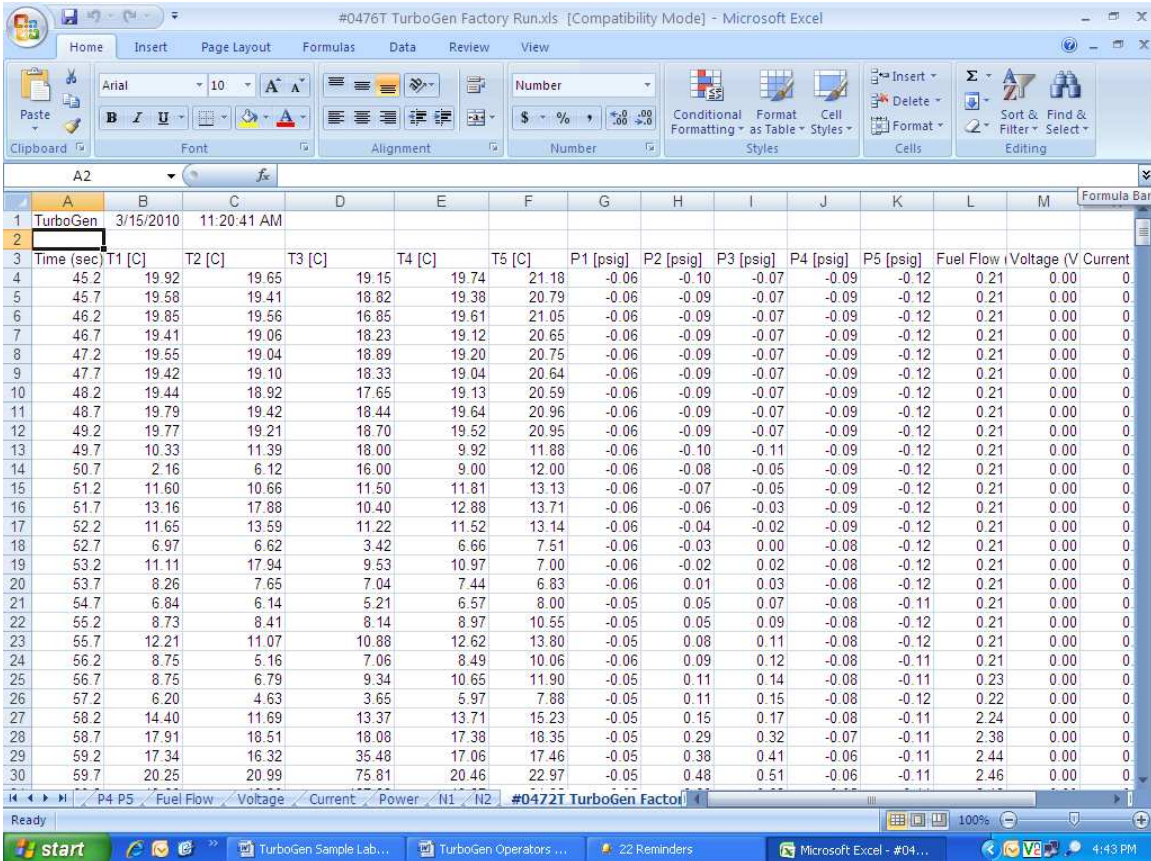
**Click: "All Files" under "Files of Type"**

**Click: Next (In Text Import Window, Step 1 of 3)**

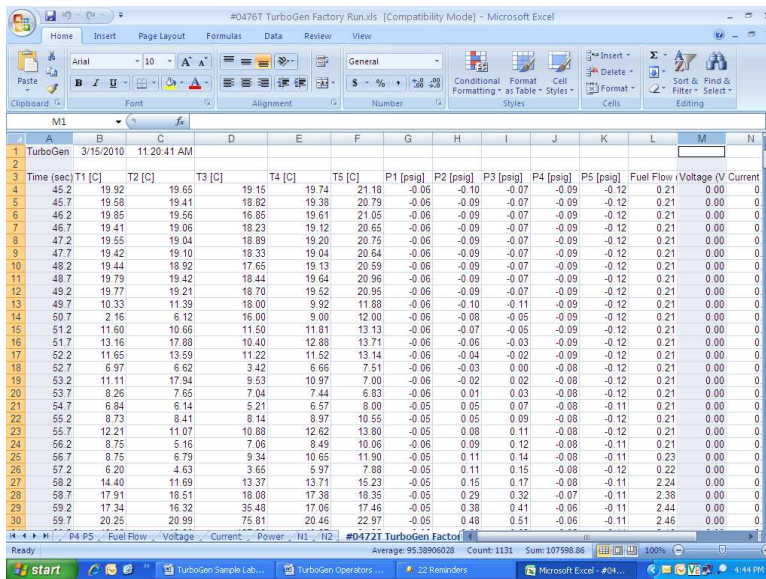
**Click: Next (In Text Import Window, Step 2 of 3)**

**Click: Next (In Text Import Window, Step 3 of 3)**

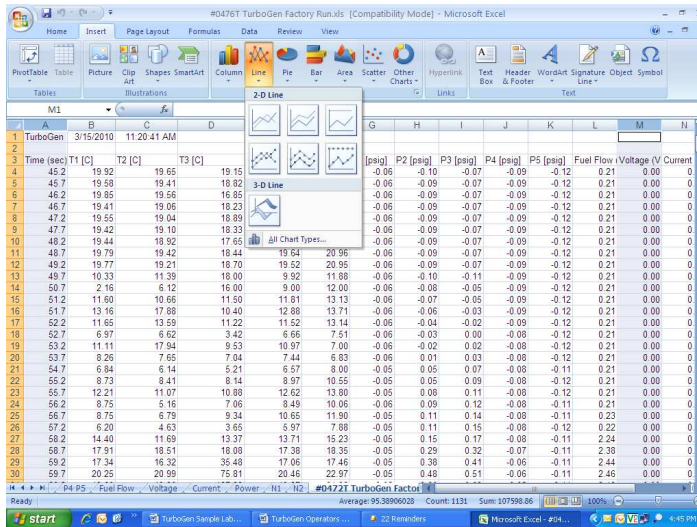
Your data will now be in spreadsheet form.



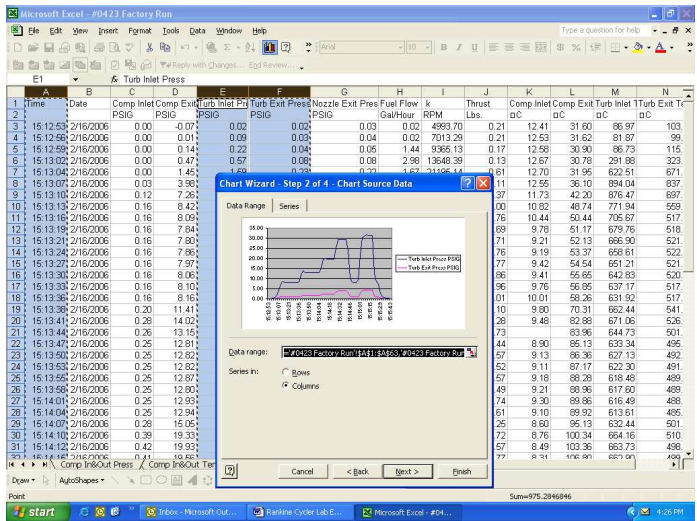
### Graphing Data using MS-Excel Spreadsheet Graphing Function (Example)



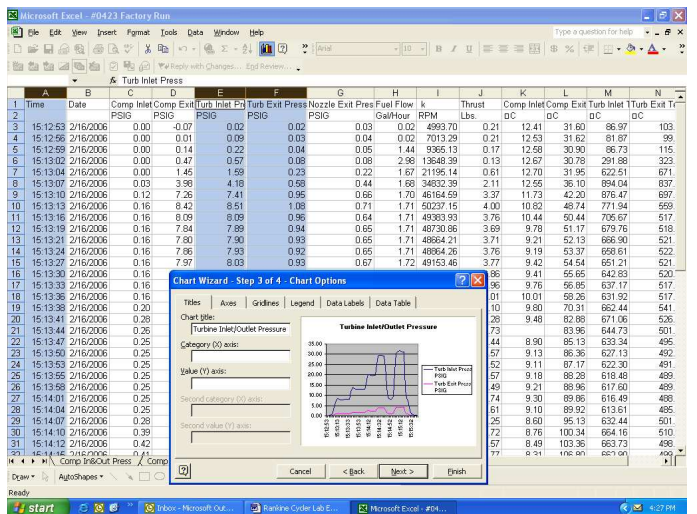
Highlight columns of data desired for graph. For this example, the Time and Voltage column data will be plotted.



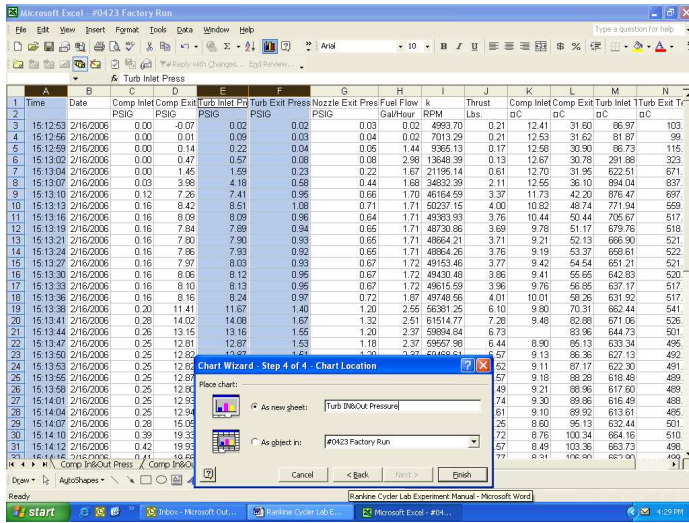
Insert  
Chart Type: Line  
Chart Sub Type: Line (first one)  
Next



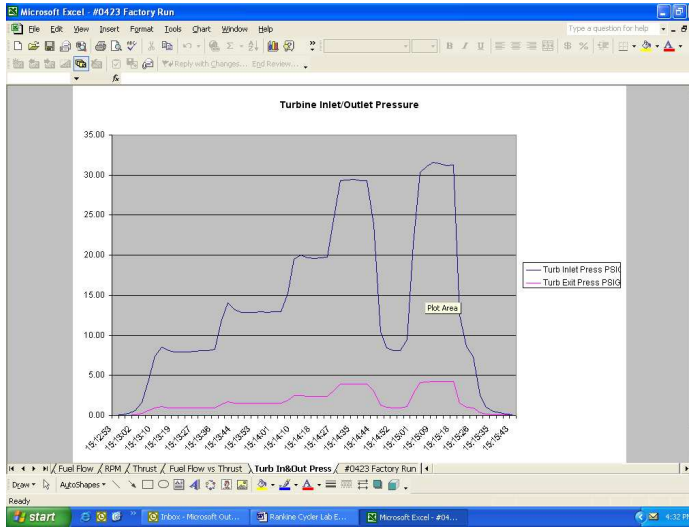
Accept data range listed by  
choosing: Next



Choose Graph Options and  
Labels



Name Graph, Click as New Sheet, Finish



Completed Turbine Inlet and Outlet Pressure Graph

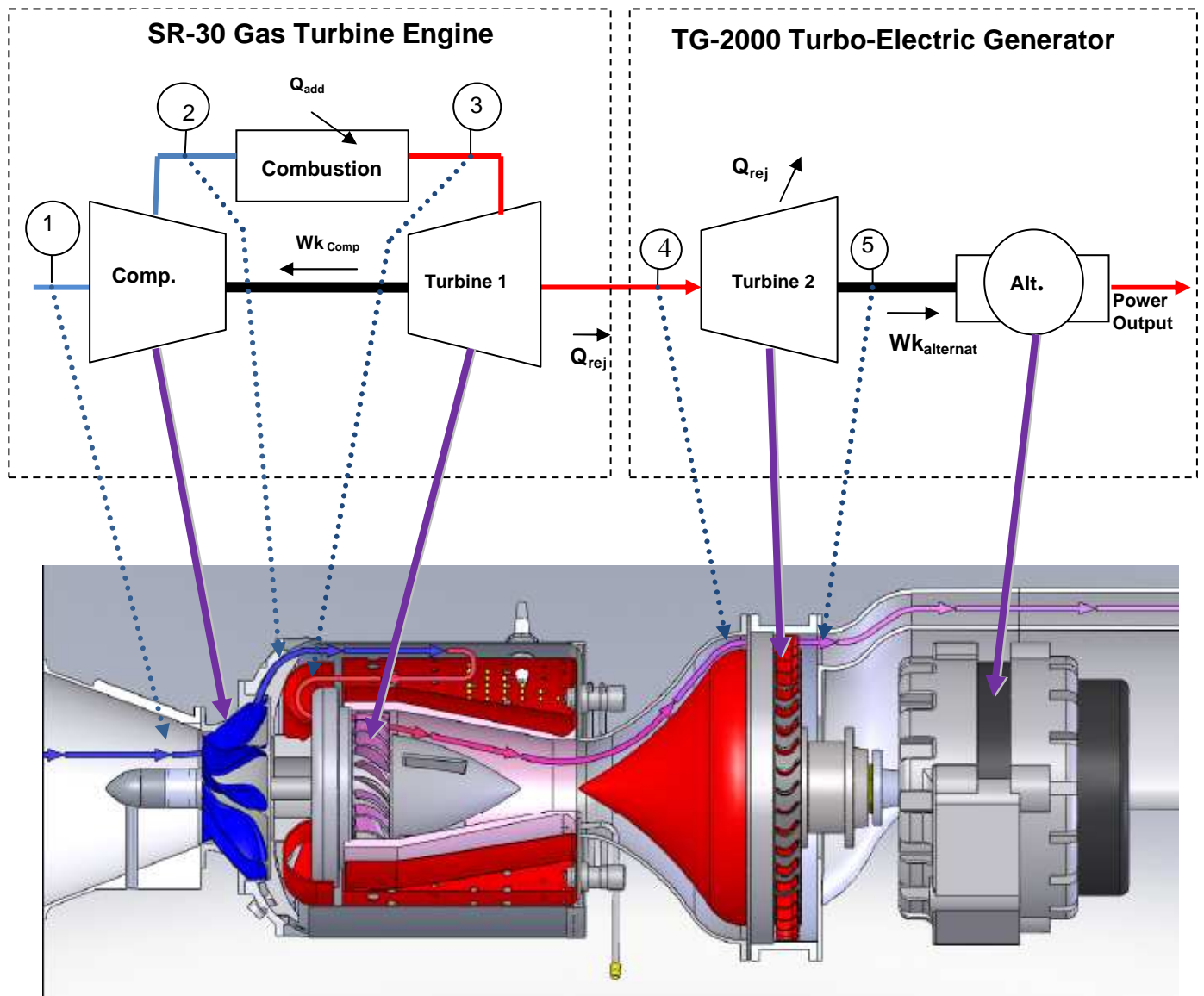
## TurboGen™ Gas Turbine Electrical Generation Lab Experiment Manual

### Lab Session #3: System Analysis

**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





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

$H_1 =$

$h_2 =$

$h_3 =$

$h_4 =$

$h_5 =$

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

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

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

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

5. **Find the Thermodynamic Efficiency of the Cycle**

## **TurboGen™ Gas Turbine Power System Lab Experiment Manual**

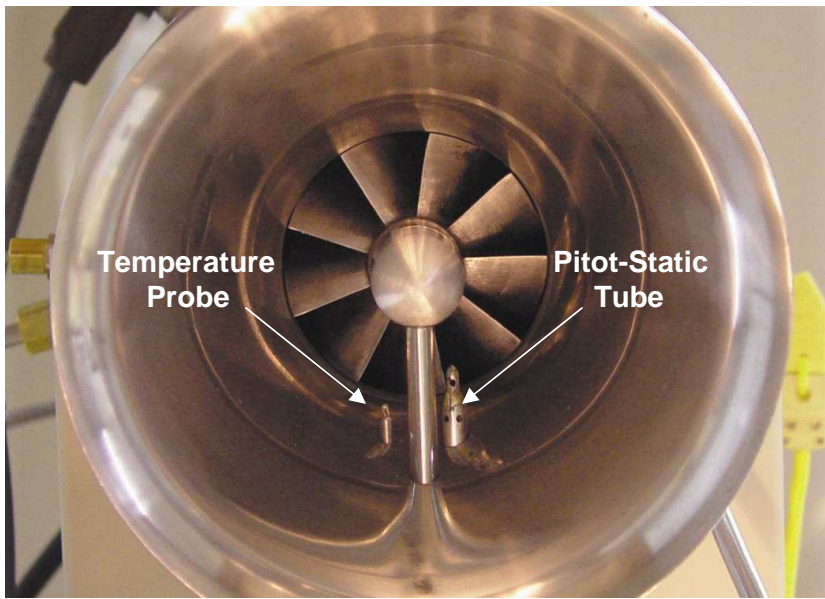
### **Lab Session #4: Engine Performance Analysis**

**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.

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### **COMPRESSOR INLET**



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

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

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

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

## **TurboGen™ Gas Turbine Power System Lab Experiment Manual**

### **Lab Session #5: Electrical Generation Performance Analysis**

**Purpose:** To determine optimal operational settings for the SR-30 Gas Turbine Engine to calculate Power Specific Fuel Consumption in the process of generating Electricity.

**Procedure:** Perform requested analysis and calculations that follow.

TurboGen generates electricity by thermodynamically spinning a turbine wheel, which drives an electric alternator. A basic electric schematic of the electric alternator system is shown in Figure 1.

The alternator consists of two basic components; a rotor and a stator. The rotor is an electromagnet (not permanent), so it needs **Excitation Current** for it to generate electricity. The rotor spins, creating a voltage

The rotor consists of a coil of wire wrapped around an iron core. Current through the wire coil - called "field" current - produces a magnetic field around the core. The strength of the field current determines the strength of the magnetic field. The

field current is D/C, or direct current. In other words, the current flows in one direction only, and is supplied to the wire coil by a set of brushes and slip rings. The magnetic field produced has, as any magnet, a north and a south pole. The rotor is driven by the alternator pulley, rotating as the engine runs, hence the name "rotor."

Surrounding the rotor is another set of coils, three in number, called the stator. The stator is fixed to the shell of the alternator, and does not turn. As the rotor turns within the stator windings, the magnetic field of the rotor sweeps through the stator windings, producing an electrical current in the windings. Because of the rotation of the rotor, an alternating current is produced. As, for example, the north pole of the magnetic field approaches one of the stator windings, there is little coupling taking place, and a weak current is produced. As the rotation continues, the magnetic field moves to the center of

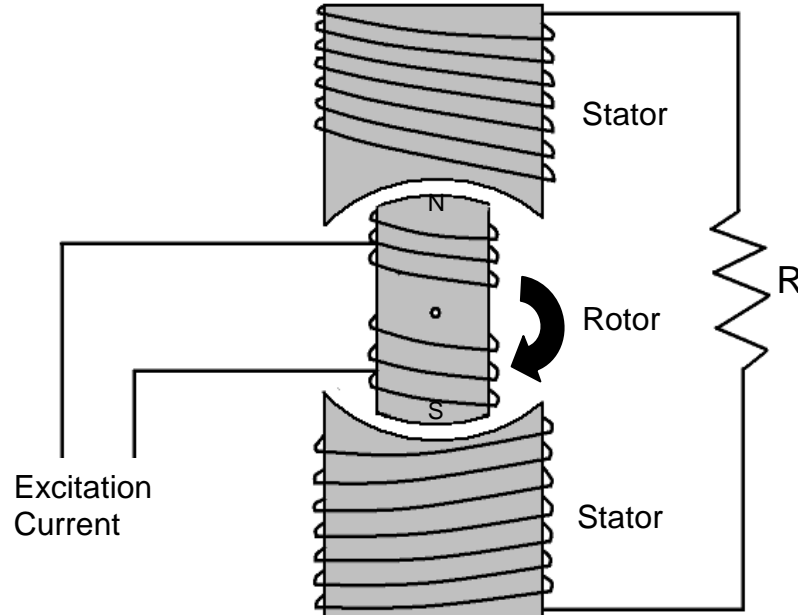
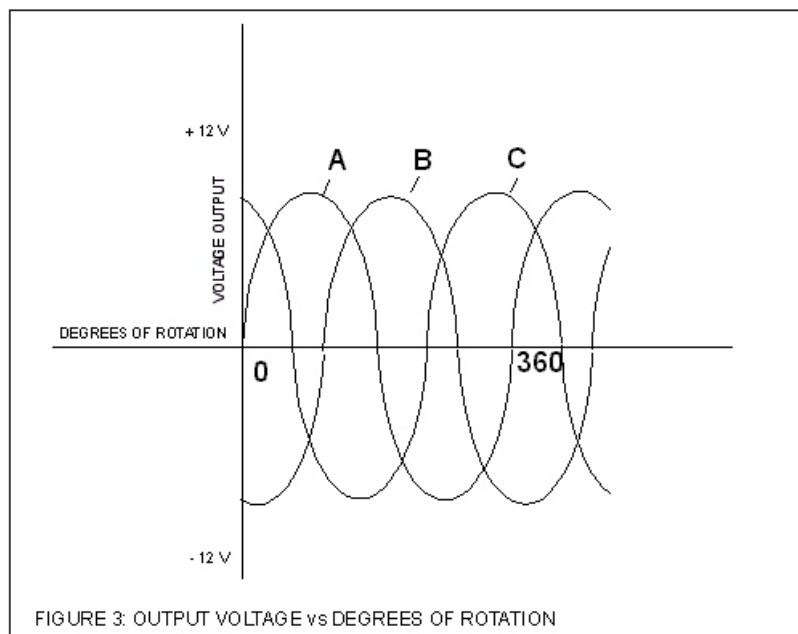
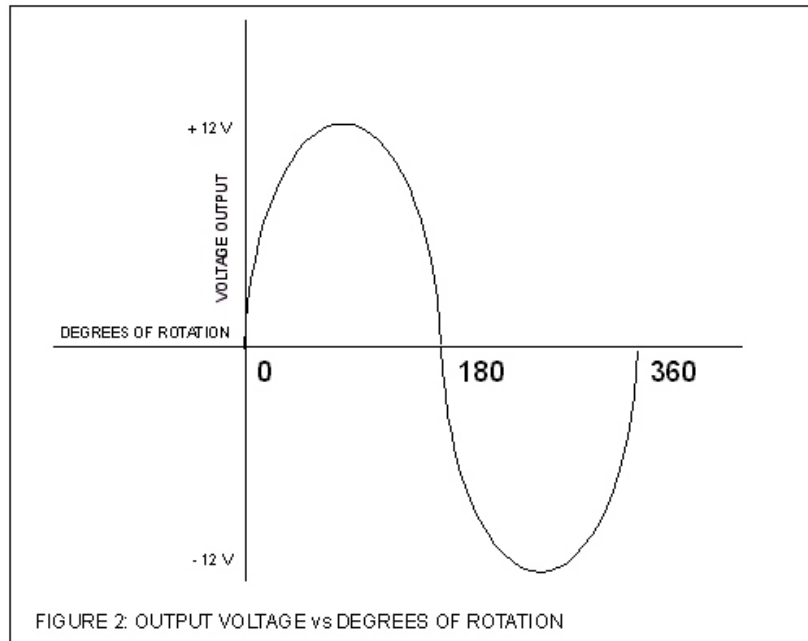


Figure 1: Electric Alternator

the winding, where maximum coupling takes place, and the induced current is at its peak. As the rotation continues to the point that the magnetic field is leaving the stator winding, the induced current is small. By this time, the south pole is approaching the winding, producing a weak current in the opposite direction. As this continues, the current produced in each winding plotted against the angle of rotation of the rotor has the form shown in figure 2. The three stator windings are spaced inside the alternator 120 degrees apart, producing three separate sets, or "phases," of output voltages, spaced 120 degrees apart, as shown in figure 3.

A Resistive Load "R" completes the circuit as shown in Figure 1.



## **Calculating Power Specific Fuel Consumption**

Power Specific Fuel Consumption is a measure of fuel consumption of the engine divided by the electric power produced by the generator.

When the TurboGen was run and data gathered, the optional strategy was to run the system with the Load Lever pinned (mid-range excitation current) and then unpin the lever and increase excitation to maximum current, then reduce it to minimum current. For the following analysis, a data run with all three options is used (**See plotted graphs on pages 25 - 27**). It can be seen that a pinned-only option can still be analyzed.

1. Using your operational run data plots, pull up and print the following graphs:
  - N1 RPM (Engine RPM) plotted over Time.
  - N2 RPM (Generator RPM) plotted over Time
  - Voltage over Time
  - Current over Time
  - Power over Time
  - Fuel Flow over Time
2. Plot analysis points of interest (similar to those shown on graph) for
  - Load Lever Pinned
  - Load Lever Maximum Excitation
  - Load Lever Minimum Excitation

Reasonably exact values can be extracted from your Excel data by lining up a graphical time stamp with a particular time line in the data.

3. Looking at data values while the excitation current Load Lever was in the pinned position, pick a specific time marker to view conditions: ●●●●●●●●●●

Time Marker:

Gas Turbine RPM (N1):

Generator Turbine RPM (N2):

Speed ratio:

Fuel Flow:

Voltage Output:

Current Output:

Resistance of fixed Resistive Element:  $R=V/I$ :

Power Output =  $IV$ :

To hold at this RPM, calculate Power Specific Fuel Consumption:

4. Let's go to a marker where excitation current Load Lever was loaded to maximum excitation current: ●●●●●●●●●●●●●●●●

Time Marker:

Gas Turbine RPM (N1):

Generator Turbine RPM (N2):

Speed ratio:

Fuel Flow:

Voltage Output =  $V$ :

Current Output =  $I$ :

Resistance of fixed Resistive Element:  $R=V/I$ :

Power Output =  $IV$ :

To hold at this RPM, calculate Power Specific Fuel Consumption:

5. Let's go to a marker where excitation current Load Lever was loaded to minimum excitation current: ●●●●●●●●●●●●●●●●

Time Marker:

Gas Turbine RPM (N1):

Generator Turbine RPM (N2):

Fuel Flow:

Voltage Output:

Current Output:

Resistance of fixed Resistive Element:  $R=V/I$ :

Power Output =  $IV$ :

To hold at this RPM, calculate Power Specific Fuel Consumption:



