ME 4331: Gas Turbine

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Gas Turbine

Objective: The purpose of this lab is to examine the performance of a small-scale turbojet engine operating at a speed of over 70,000 rpm. Note, that while it might be small, it is real and dangerous! Ear and eye protection must be worn during engine operation.

Experimental Setup: We'll be using SR-30 engine manufactured Turbine Technologies, Ltd. for this experiment. The mounting setup with all the locations of sensing probes (thermocouples and pitot static probes) as well as the flow path within the engine is described in Engine Setup and Flow. All the engine parts can be seen in Engine Parts .

Report Requirements: You are required to make an oral presentation discussing the experimental procedure and results about the working of the engine components. The presentation is required to address the following key issues in the analysis of gas turbine engine.

1. **Intake Nozzle**: Air flow enters the engine through a contoured nozzle prior to contact with the radial compressor. Within the nozzle, at a location where the cross-sectional area is 38.5 cm^2, are placed a thermocouple probe (T_1, $^{\circ}C$) and pitot-static probe (Δp_1, torr). You will record T_1 and Δp1 to compute the ideal intake airflow rate. You will compute the ideal airflow (kg/sec) assuming that the velocity profile at the measurement location is uniform across the nozzle cross section. The actual air flow rate can be measured by taking the difference between the exhaust mass flow (integrated as described below) and the fuel flow rate (through a calibration as described below). From this information we develop a Profile Shape Factor (PSF) for the inlet flow defined as:

   $$PSF = m_{\text{air,actual}} / m_{\text{air, based on ceterline}}$$

2. **Fuel Flow**: Fuel flow rates are obtained by measuring the pressure at the fuel injector manifold. The relationship between volumetric fuel flow rate and manifold pressure is given by:

   $$(VA)_{fuel} = 4.07\ P_{manifold} - 0.013\ P_{manifold}^2 - 3.7$$

   where P is the manifold pressure measured in (psig) and $(VA)_{fuel}$ is the fuel volumetric flow rate (cc/min). This equation was obtained by weighing the fuel tank prior to and after test runs of 30 minutes duration, errors in fuel flow can be attributed entirely to the precision error in $P_{manifold}$. The engine runs on diesel fuel having the following properties:

- LHV = 44,470 kJ/kg
- Specific gravity = 0.85 (at room temperature and pressure)

3. **Radial Compressor**: Air leaving the intake nozzle enters a radial compressor. Conditions exiting the compressor are measured at T_2 ($^{\circ}$C) and p_2 (psig). Compressor assumptions will include:

- Steady state operation
- Adiabatic
- Negligible changes in kinetic and potential energy

Following key components should be analyzed:

- Compute the compressor input power requirements (kW)
- Compute the compressor adiabatic efficiency, η_c
- Show the ideal and actual compressor states on a T-s diagram.

4. **Combustor**: Air leaving the compressor enters a counterflowing combustion chamber. Post-combustion gases are measured at T_3 ($^{\circ}$C) and p_3 (psig). Combustor assumptions include:

- Steady state operation
- No stray heat loss
- Negligible changes in kinetic and potential energy
- Assume that the post-combustion gases have the properties of air

Important things to be considered in the combustor analysis:

- Compute the actual heat released by the fuel (kW)
- Compute the ideal heat released by the fuel (kW)
- Compute the combustor efficiency, η_{comb}

5. **Turbine**: Air leaving the turbine enters a nozzle guide vane and then an axial turbine. Conditions downstream of the turbine are measured at T_4 ($^{\circ}$C) and p_4 (psig). Compressor assumptions will include:

- Steady state operation
- Adiabatic
- Negligible changes in kinetic and potential energy

With an emphasis on the following aspects:

- Compute the turbine output power delivered (kW)
- Evaluate the matching requirement, turbine power = compressor power
- Compute the turbine adiabatic efficiency, η_T.
- Show the ideal and actual turbine states on a T-s diagram.

6. **Exhaust flow**: The exhaust gases exit the engine through a converging nozzle, where we can make the following assumptions:

- Steady state operation
- Adiabatic
- Negligible changes in potential energy
- Negligible kinetic energy at nozzle inlet (state 4).

Like most real engines, the exhaust flow of the SR-30 is not well behaved. There are considerable variations in temperature and velocity across the nozzle exit plane requiring us to integrate the exhaust flow to get reasonable closure on the engine performance. To accomplish this integration we will measure an exhaust profile of T_6 ($^{\circ}$C) and p_6 (dynamic pressure, torr Note: the static pressure at the nozzle exhaust is atmospheric pressure). Measurements will extend across a vertical profile covering the full 54 mm of exhaust nozzle exit diameter. The data sheet provided indicates the locations where the data should be obtained. The following quantities should be derived or provided using the exhaust profile data:

- Plot the exhaust Temperature Profile (Kelvin)
- Plot the exhaust Velocity Profile (m/sec)
- Integrate the data to obtain the exhaust mass flow rate (kg/sec)
- Integrate the data to obtain the engine thrust (Newtons)
- Integrate the data to obtain the kinetic energy of the exhaust gases (kW)

From the integrated data, the following quantities can be computed:

- Actual engine air flow rate (kg/sec)
- Engine air-fuel ratio
- Intake profile shape factor, PSF
- Exhaust nozzle efficiency,

  $\eta_N = KE_{\text{integrated}} / KE_{\text{ideal}}$

- Engine thermal efficiency,

  η_{th} = Kinetic Power / η_{fuel} LHV

7. **General**: Be prepared to discuss:

- all of the quantities computed above and their derivation
- the overall operation of the engine.
- the thermodynamic analysis of each component
- all assumptions that you make in your analysis
- the magnitude and source of losses in each component
- the overall engine thermodynamic analysis
- the fuel handling system
- the oil handling system
- the ignition system and engine start up procedures