

ME 252 Lab – Turbojet Engine Experiment

Objective: to measure and analyze the performance of a small turbojet engine. Specifically,

- determine the air mass flow rate, compressor and turbine isentropic efficiencies, air-fuel ratio, thrust, thrust specific fuel consumption, and specific thrust of the SR-30 turbojet engine operating at steady-state for five different operating speeds over the range of 44,000 to 80,000 rpm.

Background: Refer to the course web site for several documents that describe the physical attributes of the Turbine Technologies SR-30 Turbojet Engine Mini-Lab™. These include the specifications (TTL_MiniLab_LX4000spec.doc) and a cutaway drawing of the SR-30 that reveals the sensor locations (TTL_SR-30SensorLocations.pdf, TTL_SR-30SensorList.doc). Review these documents to become familiar with the equipment.

Theory: The SR-30 turbojet engine consists of an inlet bell, a centrifugal compressor, a combustion chamber, an axial-flow turbine stage, and a thrust nozzle. A pitot-static tube inside the bell near the compressor inlet (station 1) allows calculation of the inlet air velocity from the measured pressure drop (ΔP_1), from which the air mass flow rate can be determined:

$$V_1 = \sqrt{\frac{2\Delta P_1}{\rho_1}} \quad , \quad (1)$$

$$\dot{m}_{air} = \rho_1 A_1 V_1 \quad , \quad (2)$$

where $A_1 = 30.6 \text{ cm}^2$. The isentropic efficiency of the compressor is determined from the air enthalpies at the compressor inlet (station 1) and exit (station 2):

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} \quad . \quad (3)$$

The isentropic efficiency of the turbine is determined from the air enthalpies at the turbine inlet (station 3) and exit (station 4):

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \quad . \quad (4)$$

The air enthalpies can be found from the recorded temperature and pressure data at each station. The combustor air-fuel ratio is determined from the measured fuel (kerosene) volumetric flow rate:

$$AF = \frac{\dot{m}_{air}}{\rho_{fuel} \dot{V}_{fuel}} \quad . \quad (5)$$

The kerosene mass density is 814 kg/m^3 .

The engine thrust (F) can be computed from the nozzle exit velocity (station 5) and velocity at the inlet to the bell (station 0):

$$F_{comp} = \dot{m}_{air+fuel} V_5 - \dot{m}_{air} V_0 \quad , \quad (6)$$

$$V_5 = \sqrt{\frac{2(P_5 - P_{atm})}{\rho_5}} \quad , \quad (7)$$

$$V_0 = \frac{\dot{m}_{air}}{\rho_0 A_0} \quad , \quad (8)$$

where $A_0 = 175 \text{ cm}^2$. The computed thrust can then be compared to the measured thrust. Two additional performance parameters related to the thrust are the Thrust Specific Fuel Consumption ($TSFC$) and the Specific Thrust (ST):

$$TSFC = \frac{\dot{m}_{fuel}}{F_{meas}} \quad , \quad (9)$$

$$ST = \frac{F_{meas}}{\dot{m}_{air}} \quad . \quad (10)$$

Turbojet Engine Operating Procedure:

Required:

- Hearing protection
- Eye protection
- Fire extinguisher easily accessible
- Trained operator present

Special Warnings:

- Do not stand at the engine's inlet or exit locations during operation.
- Make sure that no foreign objects can be ingested through the inlet bell.
- Do not touch the exhaust ducting during or immediately after operation.
- Do not start engine if EGT is above 100°C

Pre-Start:

1. Turn compressor rotor by hand to ensure smooth rotation.
2. Check fuel level; should be 1-2" from top of filler; refill if necessary.
3. Check turbine oil level; no more than 3-4" from top of filler; refill if necessary.
4. Ensure adequate room ventilation – leave combustion room door ajar.
5. Check that Master Key switch and all other switches are turned off.
6. Check that starting air pressure reads between 100 to 160 psig on the panel gage.

Starting:

1. Turn on Master Key switch; low oil pressure light should be red.
2. Turn on Electronics Master switch; all panel LED displays should be on.
3. Power up data acquisition PC and open *VirtualBench-Logger* on the desktop. Go to the Edit menu, choose Settings, then click Timing Configuration. Make sure Start Manually and Begin Logging on Start are selected. Set Time Interval to "Fast" Reading Rate and Log to Disk Every 10 Time Intervals. Set Display Length to 20 minutes. Click OK and go to File Configuration. Enter the File Name (*.log) that you want the data written to and specify Append. Check the boxes for: Enable logging and Begin Logging on Start. Click OK. Click data logger "Start" and ensure that all sensors are operational.
4. Place throttle lever in start position (push fully forward).
5. Turn on Ignition switch; ignition indicator light should be on.
6. Ensure that panel EGT reads less than 100°C.
7. Place right hand on throttle lever and with left hand turn on Air Start switch.
8. Move left hand to Fuel switch, watch panel RPM display, and turn on Fuel switch when engine reaches 10,000 RPM.
9. **Normal start-** ignition occurs and flames will be seen at the exit nozzle; immediately move throttle lever to idle position and observe normal rise in EGT on panel display.
10. **Abnormal start-** turn off Fuel switch if any of the following is observed:
 - a) failure to light or lack of EGT rise within 3 seconds
 - b) excessive engine vibration
 - c) oil or fuel leakage
 - d) sparks exiting the nozzle
 - e) rapid EGT rise that exceeds engine starting temperature limitations (955°C during 0-4 sec, 800°C during 4-8 sec, 720°C after 8 sec)
11. Turn off Ignition and Air Start switches once engine reaches 45,000 RPM.

Data Collection:

1. Run engine at approximately 44,000 (idle), 50,000, 60,000, 70,000, and 80,000 (max) RPM for about 5 minutes each or until steady-state is reached.
2. Click data logger "Stop" to terminate data recording.
3. Return throttle lever to idle position.
4. Download data file to floppy disk after shutdown.
5. Record the room atmospheric pressure from the mercury barometer near the compressor.

Normal Shutdown:

1. Idle engine ($P_3=10$ psig) for one minute.
2. Turn off Fuel switch.

Emergency Shutdown:

1. Turn off Fuel switch.
2. Turn off Ignition switch if on.
3. Turn on Air Start switch to cool engine if overheated.

Restart following normal shutdown:

1. EGT must be below 100°C.
2. Air Start can be used to cool engine.

Results

Average your steady-state raw data for each RPM condition and complete the following summary tables. Be sure to show all property evaluations and be sure to use consistent units.

Mass Flow Parameters

RPM	ρ_1 (kg/m ³)	V_1 (m/s)	\dot{m}_{air} (kg/s)	\dot{m}_{fuel} (kg/s)	AF (kg air/kg fuel)
<i>idle</i>					
50000					
60000					
70000					
80000					

Compressor & Turbine Parameters

RPM	h_1 (kJ/kg)	h_{2s} (kJ/kg)	h_2 (kJ/kg)	η_C (%)	h_3 (kJ/kg)	h_{4s} (kJ/kg)	h_4 (kJ/kg)	η_T (%)
<i>idle</i>								
50000								
60000								
70000								
80000								

Thrust parameters

RPM	ρ_0 (kg/m ³)	V_0 (m/s)	ρ_5 (kg/m ³)	V_5 (m/s)	F_{comp} (N)	F_{meas} (N)	ST (N/kg air/s)	$TSFC$ (kg fuel/s/N)
<i>idle</i>								
50000								
60000								
70000								
80000								

Questions

- Using the measured thrust value developed at 80,000 rpm, estimate the steady-state speed of an aircraft propelled horizontally by this engine. Assume an air density of 1.1 kg/m³, drag coefficient (C_D) of 0.1, and a projected area of 0.5 m².
- Estimate the propulsive efficiency (η_P) of the aircraft described above:

$$\eta_P = \frac{\dot{W}_P}{\dot{Q}_{in}} \approx \frac{FV_{aircraft}}{\dot{m}_{air}(h_3 - h_2)}$$