Gas Turbine Engine-AE345

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1 Objective

To calculate various performance parameters using the data obtained from operating a gas turbine engine.

2 Precautions

- Always adhere to fundamental safety precautions when using any laboratory equipment.
- Hearing protection is required when operating equipment, and appropriate footwear must be worn in the laboratory.
- Keep the windows open for the duration of the experiment.
- Never operate the engine with any loose items near the engine inlet or exhaust.
- Both the operator and all observers must always stay clear of the engine inlet and exhaust.
- Do not touch any engine parts while it is running or after shutdown, as some parts may be extremely hot and could cause severe burns.
- Do not attempt to adjust or bypass safety devices or controls to operate the engine beyond its limits. The system must not be operated above 74,000 rpm.
- Do not switch off the system until it has properly cooled down. After taking measurements, return the system to its initial state and power it off only once the screen displays 0 rpm on the GSU.

3 Theory

Gas Turbine Engines convert thermal power into mechanical power. Most GTE operate on Braytons cycle which consists of 4 steps:

1. Compression: Air is drawn into the engine and compressed by the compressor. This process increases the air's pressure and temperature.

2. Combustion: The high-pressure air flows into the combustor, where it is mixed with fuel and ignited, initiating the combustion process that releases energy, significantly raising the temperature and expanding the air-fuel mixture.

3. Expansion: The turbine extracts energy from the expanding gases, reducing their pessure and temperature.

4. Exhaust and Thrust Generation: The remaining high-velocity exhaust gases are expelled through a nozzle, generating thrust.

4 Thermodynamic Analysis

The performance of gas turbine engines is evaluated using the principles of thermodynamics. Key performance parameters include (Hill and Peterson 1992):

- Thermal Efficiency: The ratio of useful work output to the heat input from the fuel.
- Specific Fuel Consumption (SFC): The fuel required to produce a unit of thrust or power. Lower SFC indicates higher engine efficiency.

5 Apparatus

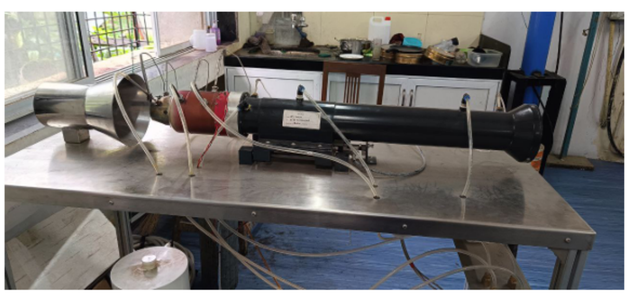

Figure 1: Gas Turbine Engine

6 Specifications

Data Given:

- Ratio of specific heat of air, $\gamma_{air} = 1.4$
- Ratio of specific heat of flue gas, $\gamma_{gas} = 1.33$
- Calorific value, $Q_f = 42580\ kJ/kg$

- Density of air, $\rho = 1.29\ kg/m^3$
- Area of nozzle, $A_f = 0.00419\ m^2$
- Characteristic gas constant of gas, R = 287 J/kgK

7 Observations

The following is the data observed during the GTE experiment Pressure is measured in bar and Temperature in °C:

Time(s)	**N(rpm)**	**h(mmWC)**	**V_f(LPH)**	**F(N)**	**T_a**	**T_1**	**T_2**	**T_3**	**T_4**	**T_4**	**P_1**	**P_2**	**P_3**	**P_4**
9	35800	8.57	6.42	23.74	32.21	37.64	67.31	644.39	590.63	577.26	-0.01	0.08	0.12	0.02
12	59400	21.8	11.33	25.93	32.26	37.23	69.28	669.3	619.44	589.74	-0.01	0.35	0.36	0.03
15	64200	39.57	11.55	33.72	32.18	36.83	75.3	702.66	651.98	617.77	0	0.45	0.45	0.04
18	64300	39.87	11.69	34.2	32.12	36.78	83.97	699.23	656.95	610.67	0	0.46	0.47	0.04
21	69400	50.13	12.85	38.46	32.01	36.55	90.05	691.26	654.8	594.94	0	0.55	0.55	0.44
24	71100	51.37	13.36	47.07	32.06	36.44	94.65	688.26	654.19	587.27	0	0.6	0.57	0.04
27	53300	37.41	8.57	46.64	31.98	36.1	102.61	682.83	652.66	575.2	-0.01	0.24	0.27	0.03
30	38000	15.52	5.96	27.45	31.95	35.83	99	664.87	643.78	555.11	-0.01	0.08	0.12	0.02

Table 1: Observation Table

7.1 Sample Calculation for 64300 RPM

Formula used to calculate the required parameters:

$$\eta_c = \frac{\pi_c^{\frac{\gamma-1}{\gamma}} - 1}{\frac{T_2}{T_1} - 1} \tag{1}$$

$$\pi_c = \frac{P2}{P1} \tag{2}$$

$$\dot{Q}_{in} = \dot{m}_f Q_R \tag{3}$$

$$\eta_{th} = \frac{\frac{1}{2} * (\dot{m}_f + \dot{m}_a) * \frac{F^2}{(\dot{m}_f+\dot{m}_a)^2}}{\dot{Q}_{in}} = \frac{F^2}{2 * \dot{Q}_{in} * (\dot{m}_f + \dot{m}_a)} \tag{4}$$

$$TSFC = \frac{\dot{m}_f}{F} \tag{5}$$

Rotational speed, N = 64300 rpm
Fluid flow rate, V_f = 11.69 LPH
Force, F = 34.2 N
Ambient temperature, T_α = 305.27 K
Temperature at point 1, T_1 = 309.93 K
Temperature at point 2, T_2 = 357.12 K
Temperature at point 3, T_3 = 972.38 K
Temperature at point 4, T_4 = 930.1 K
Temperature at point 5, T_5 = 883.82 K
Pressure at point 1, P_1 = 1.013 bar
Pressure at point 2, P_2 = 1.473 bar
Pressure at point 3, P_3 = 1.478 bar
Pressure at point 4, P_4 = 1.053 bar
Air flow rate, $\dot{m}_{air} = 0.135\ kg/s$
Fuel flow rate, $\dot{m}_f = 0.003\ kg/s$
Specific heat capacity of the fuel, $Q_f = 42580\ kJ/kg$
Density of the fuel, $\rho_f = 801.29\ kg/m^3$
The density of the air, $\rho_{air} = 1.29\ kg/m^3$
Specific heat ratio of air, $\gamma_{air} = 1.4$
Specific heat ratio of the fuel gas, $\gamma_f = 1.33$
Characteristic gas constant, R = 287 J/kgK
Calculated Parameters:

Air to fuel ratio, $\frac{\dot{m}_a}{\dot{m}_f}$	45
Compressor Pressure Ratio, π_c	1.454
Isentropic efficiency of compressor, η_c	74.15%
Heat supplied, $\dot{Q}_{in}$	127740 W
Thrust Specific Fuel Consumption, TSFC	$8.77E-05 s/m$
Thermal Efficiency, η_{th}	3.31%

7.2 Calculations

Time	N(rpm)	$\dot{m}_{air}(kgm^{-3})$	$\dot{m}_f(kgm^{-3})$	AF	η_{comp}	$Q_{in}(W)$	π_c	η_{th}	TSFC(s/m)*10^-5
9	35800	0.062	0.001	62	26.03	42580	1.089	10.50	4.21
12	59400	0.1	0.003	33.33	88.68	127740	1.358	2.55	11.57
15	64200	0.134	0.003	44.67	89.23	127740	1.444	3.25	8.89
18	64300	0.135	0.003	45	74.15	127740	1.454	3.31	8.77
21	69400	0.151	0.003	50.33	76.36	127740	1.543	3.76	7.80
24	71100	0.153	0.003	51	75.60	127740	1.592	5.55	6.37
27	53300	0.13	0.002	65	30.52	85160	1.249	9.67	4.29
30	38000	0.084	0.001	84	12.15	42580	1.089	10.40	3.64

NOTE: Pressure obtained is actually gauge pressure. So we have to add the atmospheric pressure (1.013 bar) to get actual pressure.

8 Conclusion

- **Impact on $\dot{m}_f$**: Increasing RPM increases the incoming air. This is because it creates negative gauge pressure at the inlet of the compressor and thereby increasing pressure difference leading to increase in $\dot{m}_a$.
- **Impact on Compressor efficiency**: Compressor efficiency increases with RPM in a gas turbine engine because higher speeds improve airflow and pressure ratios, reduce relative aerodynamic losses, optimize blade aerodynamics, enhance flow stability, and increase thermodynamic efficiency, all of which contribute to more effective compression and energy utilization.
- **Impact on Compressor Pressure ratio**: The compressor pressure ratio increases with RPM because higher speeds enhance airflow, improve blade aerodynamics, and reduce flow separation, allowing the compressor to achieve greater pressure differentials and compression efficiency.
- **Understanding GTE Performance**: Analyzing gas turbine engine (GTE) performance parameters like thermal efficiency, specific fuel consumption, and compressor efficiency helps in understanding the open non-ideal Brayton cycle and thermodynamic processes, accounting for losses such as friction.
- **Factor affecting Gas Turbine Performance**: Ambient temperature, airflow density, and the mass that is entering the compressor.
- **Impact of Compression Ratio**: It affects the gas turbine's operational efficiency, effective power, and specific fuel consumption.

9 Inference

- **Effectiveness of Cooling Air**: The effectiveness of cooling the air at the compressor inlet to maintain power output and reduce fuel consumption infers that optimizing cooling techniques could lead to significant improvements in gas turbine efficiency and operational stability. This could encourage further research into advanced cooling methods and their integration into turbine designs.

- **Broader Implications for Gas Turbine Efficiency**: The overall findings from the study imply that improvements in turbine performance are closely tied to both material advancements and operational adjustments.