Experiment- 8

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Turbojet Engine

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18 November,2022

1. Aim:

- To construct an approximate Brayton cycle for a micro gas turbine engine on a T-S plot.
- To discuss the role of after-burner in turbojet engine.

2. Apparatus:

A micro-gas-turbine called The TecQuipment Turbojet Trainer with Reheat (GT100RS).

3. Theory

3.1 Parts

Its different components of turbojet engine are :

Diffuser: The air is first drawn into the diffuser. A diffuser is a device that increases the pressure of a fluid at the expense of its kinetic energy.

Compressor: The air pressure is further increased by the compressor by reducing its volume. In a compressor, work is done on the fluid and its enthalpy increases by an equal amount.

Turbine: In a turbine, work is done by the fluid and its enthalpy decreases by an equal amount. The fluid is expanding here.

ustion chamber: The combustor is fed with high pressure air by the compression system, adds fuel and burns the mix and feeds the hot, high pressure exhaust into the turbine components of the engine and out the exhaust nozzle.

Nozzle: The air finally leaves through the nozzle. A nozzle is a device that increases the velocity or kinetic energy of a fluid at the expense of pressure drop.

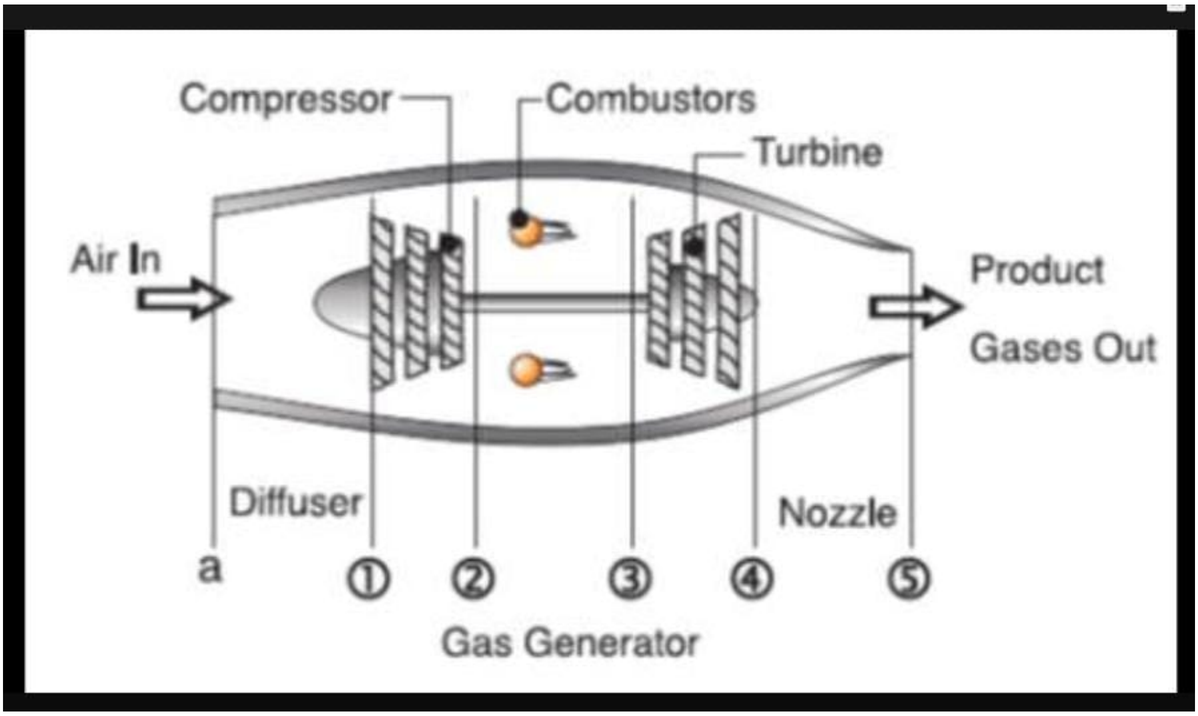

Figure 1: Diagram representing A turbojet engine

After-burner: The afterburning process injects additional fuel into a combustor in the jet pipe behind the turbine, reheating the exhaust gas.

Pump: The pump gets the compressed air and air the lean amount of fuel is provided for a mixture of air and fuel.

Shafts: The shaft is connected between the compressor and the turbine.

3.2 Brayton Cycle:

The Brayton cycle is a thermodynamic cycle that describes the operation of certain heat engines that have air or some other gas as their working fluid. Modern gas turbine engines and air-breathing jet engines follow the Brayton cycle. This cycle is usually run as an open system.Gas turbines are Brayton engines, with three components: a gas compressor, a burner (or combustion chamber), and an expansion turbine.

3.2.1 Ideal Cycle:

In an ideal gas turbine, gases undergo four thermodynamic processes: an isentropic comppression, an isobaric (constant pressure) combustion, an isentropic expansion and heat rejection. Together, these make up the Brayton cycle.

1. Isentropic compression (1-2) : Ambient air is drawn into the compressor, where it is pressurized.
2. Isobaric Heating (2-3) : The compressed air then runs through a combustion chamber, where fuel is burned, heating that air a constant-pressure process, since the chamber is open to flow in and out.

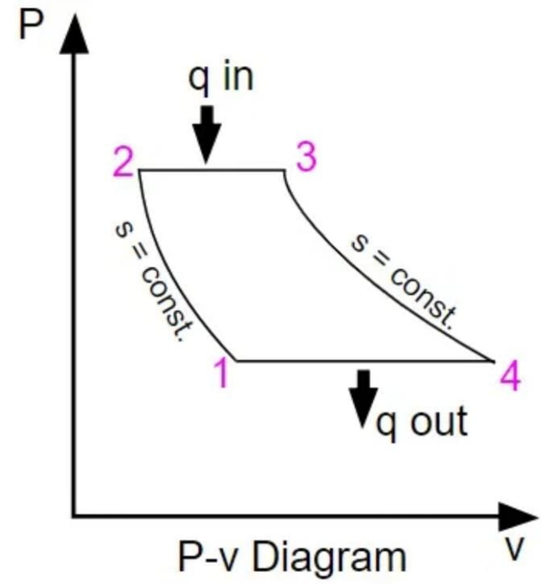

Figure 2: PV diagram of an Ideal Brayton Cycle

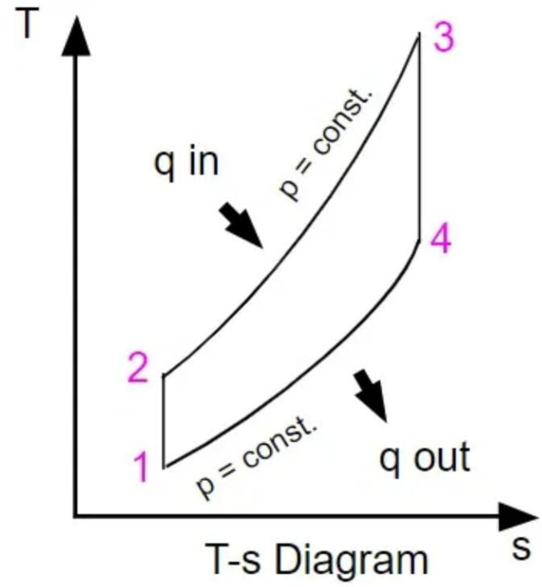

Figure 3: T-S Diagram of an Ideal Brayton Cycle

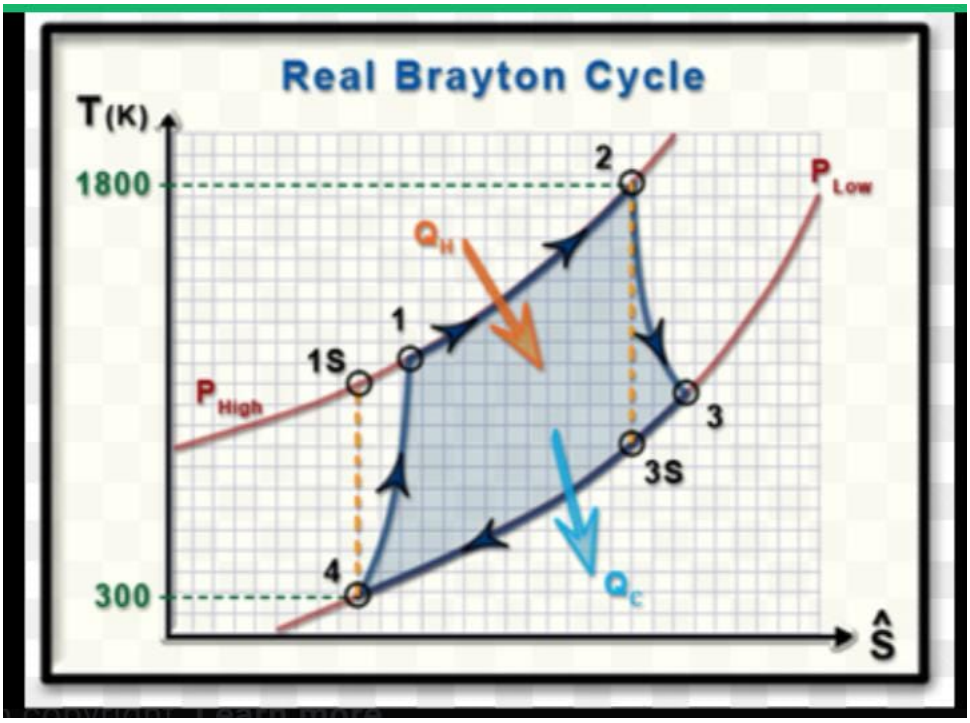

Figure 4: Real Brayton Cycle

3. Isentropic Expansion (3-4) : The heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.

4. Isentropic Expansion (4-5) : The heated, pressurized air then further loses its energy by expanding through a nozzle and is responsible for producing thrust.

5. Isobaric Cooling (5-1) : Heat rejection into the atmosphere.

3.2.2 Real Cycle:

Actual Brayton cycles differ from the ideal cycles in all the four processes. The comppression process and expansion processes are non-isentropic. Also, the pressure drops during the heat addition process. The presence of irreversibilities (due to internal friction and turbulence) causes the above deviations. Fresh air is taken up in place of the isobaric heat rejection. The T-S Diagram for the real Brayton cycle is represented in the Fig. 4. Here, as each process in non-ideal, we make use of Eq. 4 directly to calculate the Entropy change in the Real Brayton Cycle.

3.3 Working:

The micro-gas-turbine GT100RS from TecQuipment works on the principle of the **Brayton Cycle**.
The working of Turbojet Engine, Air is first supplied into the diffuser. The diffuser work is to diffuse the air hence the molecular of the air get together.
Now from the diffuser, air comes into the compressor. The compressor compresses the air hence the pressure energy is increased.
Now from the compressor it sends to the combustion chamber where a pump is fitted and with the help of the pump there is a small hole or you can say the fuel injector is fitted. The fuel is supplied here with very less amount (lean mixture the ratio of air to fuel is 50:1).

In the combustion chamber, the mixture of air and fuel gets completely burned. The burning gas has high-pressure energy which is directly send to the turbine.
Here the turbine blades rotate and shafts are connected between the compressor and the turbine. The charges of pressure energy are reduced and kinetic energy increased.
The turbine also works s for a rotating compressor for getting much air from outside.
Then from here it directly comes to the nozzle here with the thrust of the charge is created.
Thrust moves the engine into the perpendicular direction and From nozzle, the exhaust gases are released.

4. Procedure:

- After switching on the electrical power to the system we have to check for enough fuel, open the feed valve at the side of the fuel tank. Switch the other systems like oil pump, cooling system, etc.
- Then we have to adjust the fuel flow and turn on the ignition button to start the engine. Operate this engine for 15 minutes to stabilize and wait for it to reach the desired RPM.Take down of the all the temperatures and pressure at different points of the engine which is being displayed on the control panel. Some of the pressure which are displayed are gauge pressure. So the actual pressure at those points can be found by adding the observed value with the atmospheric pressure.
- Using this plot and the above theory, we can plot the T-s plot of the thermodynamic cycle.
- To look into the effects of the afterburner, switch on the afterburner in it's respective control panel. We have to repeat this for various desired nozzle area (between 66% and 100%) in both after burner on and off.

5. Results and Observation:

5.1 Observation 1

Without afterburner and 100% nozzle area

Temperature	Pressure
T_0= 300K	P_0= 1.0178 bar
T_3= 372K	P_3= 1.87 bar
T_4= 804K	P_4= 1.69 bar
T_7= 727K	P_7= 1.003 bar

For ideal case: Process 0-3 and 4-7 are adiabatic so:

$$T_3s = T_0(\frac{P_3}{P_0})^{\frac{\gamma-1}{\gamma}} = 357K$$
$$T_7s = T_0(\frac{P_7}{P_4})^{\frac{\gamma-1}{\gamma}} = 692.7K$$

For real case:

0-2

Process is adiabatic and so
$\Delta S = 0$

2-3

Process is adiabatic and so
$\Delta S = 0$

3-4

Process is isobaric heat addition.

$$\Delta S = mC_p \ln \frac{T_4}{T_3}$$

$C_p = 1KJ/Kg.K$ and m=1Kg/s

$$\Delta S = 1 \times 1000 \times \ln \frac{804}{372}$$
$$\Delta S = 770.71J/K.s$$

4-5

Process is isentropic expansion in turbine and so $\Delta S = 0$.

5-7

Process is isoentropic expansion in nozzle and so $\Delta S = 0$.

5.2 Observation 2

Without afterburner and 65% nozzle area

Temperature	Pressure
T_0= 300K	P_0= 1.0175 bar
T_3= 374K	P_3= 1.86 bar
T_4= 822.5K	P_4= 1.69 bar
T_7= 746K	P_7= 1.009 bar

For ideal case: Process 0-3 and 4-7 are adiabatic so:

$$T_3s = T_0(\frac{P_3}{P_0})^{\frac{\gamma-1}{\gamma}} = 356.4K$$
$$T_7s = T_0(\frac{P_7}{P_4})^{\frac{\gamma-1}{\gamma}} = 709.8K$$

For real case:

0-2

Process is adiabatic and so
$\Delta S = 0$

2-3

Process is adiabatic and so
$\Delta S = 0$

3-4

Process is isobaric heat addition.

$$\Delta S = mC_p \ln \frac{T_4}{T_3}$$

$C_p = 1KJ/Kg.K$ and m=1Kg/s

$$\Delta S = 1 \times 1000 \times \ln \frac{822.5}{374}$$
$$\Delta S = 788J/K.s$$

4-5

Process is isentropic expansion in turbine and so $\Delta S = 0$.

5-7

Process is isoentropic expansion in nozzle and so $\Delta S = 0$.

5.3 Observation 3

With afterburner and 100% nozzle area

Temperature	Pressure
T_0= 300K	P_0= 1.01177 bar
T_3= 372K	P_3= 1.86 bar
T_4= 811.5K	P_4= 1.68 bar
T_5= 737K	P_5= 1.003 bar
T_6=1016K	P_6= 1.003 bar

For ideal case: Process 0-3 and 4-5 are adiabatic so:

$$T_3s = T_0(\frac{P_3}{P_0})^{\frac{\gamma-1}{\gamma}} = 356.4K$$
$$T_7s = T_0(\frac{P_7}{P_4})^{\frac{\gamma-1}{\gamma}} = 700.3K$$

For real case:

0-2

Process is adiabatic and so
$\Delta S = 0$

2-3

Process is adiabatic and so
$\Delta S = 0$

3-4

Process is isobaric heat addition.

$$\Delta S = mC_p \ln \frac{T_4}{T_3}$$

$C_p = 1KJ/Kg.K$ and m=1Kg/s

$$\Delta S = 1 \times 1000 \times \ln \frac{811.5}{372}$$
$$\Delta S = 770.71J/K.s$$

4-5

Process is isentropic expansion in turbine and so $\Delta S = 0$.

5-6

Process is isobaric afterburn(heat addition).

$$\Delta S = mC_p \ln \frac{T_6}{T_5}$$

$C_p = 1KJ/Kg.K$ and m=1Kg/s

$$\Delta S = 1 \times 1000 \times \ln \frac{1016}{737}$$
$$\Delta S = 321J/K.s$$

5.4 Observation 4

Without afterburner and 65% nozzle area

For ideal case: Process 0-3 and 4-5 are adiabatic so:

$$T_3s = T_0(\frac{P_3}{P_0})^{\frac{\gamma-1}{\gamma}} = 355.4K$$
$$T_7s = T_0(\frac{P_5}{P_4})^{\frac{\gamma-1}{\gamma}} = 714.5K$$

For real case:

Temperature	Pressure
T_0= 300K	P_0= 1.0167 bar
T_3= 371K	P_3= 1.84 bar
T_4= 824.5K	P_4= 1.67 bar
T_7= 751K	P_7= 1.012 bar
T_7= 1050K	P_7= 1.012 bar

0-2

Process is adiabatic and so
$\Delta S = 0$

2-3

Process is adiabatic and so
$\Delta S = 0$

3-4

Process is isobaric heat addition.

$$\Delta S = mC_p \ln \frac{T_4}{T_3}$$

$C_p = 1KJ/Kg.K$ and m=1Kg/s

$$\Delta S = 1 \times 1000 \times \ln \frac{824.5}{371}$$
$$\Delta S = 798.5J/K.s$$

4-5

Process is isentropic expansion in turbine and so $\Delta S = 0$.

5-6

Process is isobaric afterburn(heat addition) $\Delta S = 0$.

$$\Delta S = mC_p \ln \frac{T_6}{T_5}$$

$C_p = 1KJ/Kg.K$ and m=1Kg/s

$$\Delta S = 1 \times 1000 \times \ln \frac{1050}{751}$$
$$\Delta S = 335.1J/K.s$$

6. Graphs

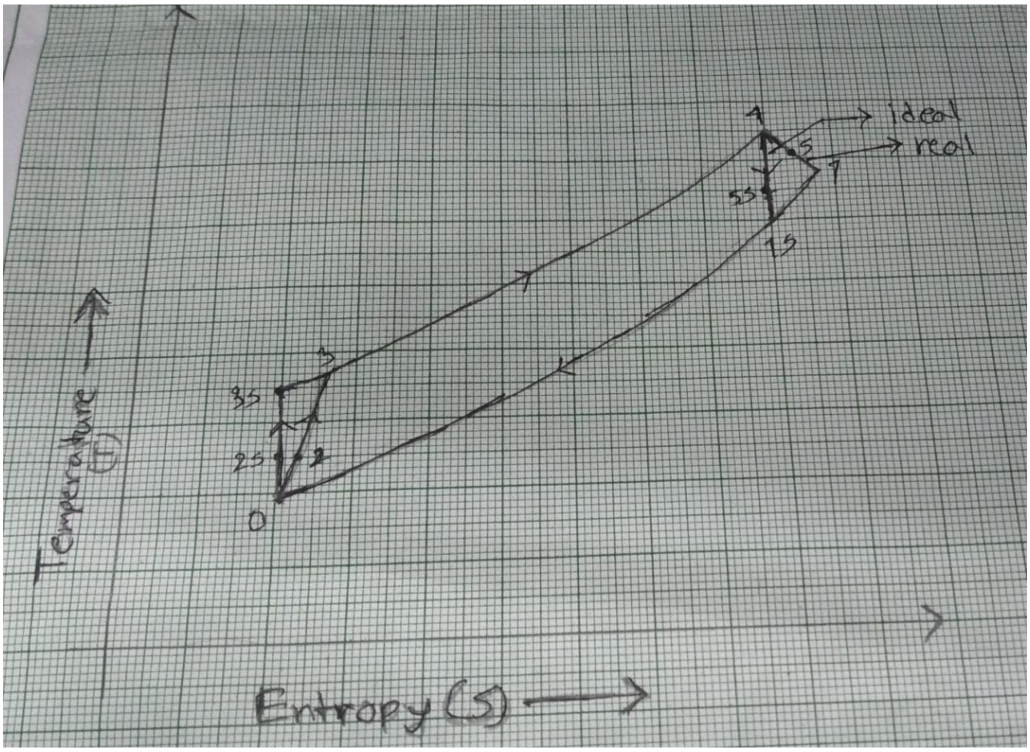

Figure 5: Brayton Cycle without afterburner

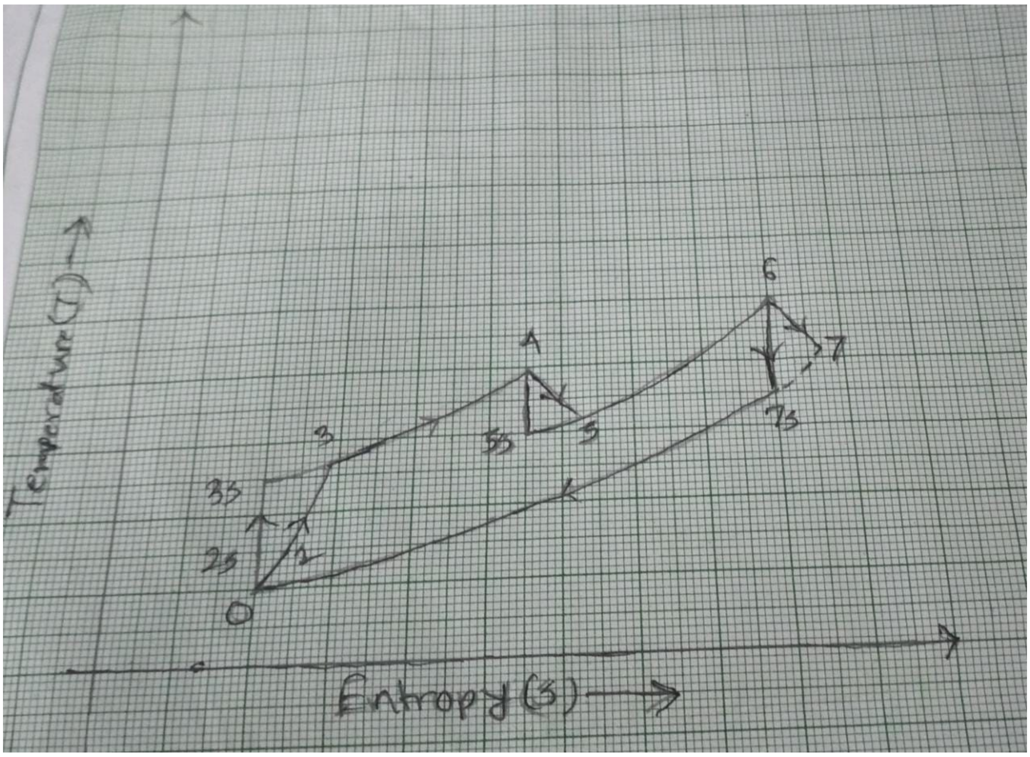

Figure 6: Brayton Cycle with afterburner

7. Sources of Error:

- Valves,Dial and knobs may be faulty.
- Reading may have been taken before the engine had reached steady state.
- Sources of error can be due to external factors.

8. Conclusion

- For a given nozzle exit area ,after switching on the burner,increases the thrust produced by engine.
- The nozzle area and the thrust are related as inversely proportional.
- Real Brayton cycle differ from the ideal cycle in all the four process
- Pressure drop during heat addition and heat rejection.