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TURBINE ENGINE OPERATING PRINCIPLES

The principle used by a gas turbine engine as it provides :

$$F = m \times a$$

- force to move an airplane is based on Newton's law of momentum.

This law states that

- for every action there is an equal and opposite reaction;

therefore,

- if the engine accelerates a mass of air (action), it applies a force on the aircraft (reaction).

The turbofan generates thrust by

- giving a relatively slower acceleration to a large quantity of air.
- The old pure turbojet engine achieves thrust by imparting greater acceleration to a smaller quantity of air.

This was its main problem with *OLD Engines*

- fuel consumption
- and noise.

The mass of air is accelerated within the engine by the use of a :

- continuous-flow cycle

continuous-flow cycle:

- 1, Ambient air enters the inlet diffuser where it is subjected to
 - changes in temperature, pressure, and velocity due to ram effect.
- 2, The compressor then :
 - increases pressure and temperature of the air mechanically.
- 3, The air continues at constant pressure to the
 - burner section where its temperature is increased by combustion of fuel.
- 4, The energy is taken from the hot gas by
 - expanding through a turbine which drives the compressor,
 - by expanding through an exhaust nozzle designed to discharge
 - the exhaust gas at high velocity to produce thrust.

The formula for thrust can be derived from Newton's second law, which states that:

- force is proportional to the product of mass and acceleration

This law is expressed in the formula:

$$F = M \times A$$

Where:

F = force in pounds

M = mass in pounds per seconds

A = acceleration in feet per seconds

$$\frac{F}{M} = \frac{A}{G} \text{ or } F = \frac{MA}{G}$$

Where:

F = force

M = mass

A = acceleration

G = gravity

The force of gravity is 32.2 feet per second squared (ft/sec²)

Thrust

Thrust of a gas turbine engine can be increased by two methods:

- 1, increasing the mass flow of air through the engine
- 2, increasing the gas velocity

GROSS (STATIC) THRUST

Gross or static thrust is developed when

- the engine is on the ground and stationary
- Velocity of the airflow entering the engine changes and affects thrust when the aircraft is in flight.

My statement: my own explanation

Gross (Static) Thrust refers to the

- force produced by a jet engine when the aircraft is stationary on the ground.

This thrust is generated by

- accelerating the air through the engine, but with no forward motion of the aircraft, the velocity of the incoming airflow is zero.

When the aircraft is in flight,

- the velocity of the incoming air increases,
- reducing the difference between the incoming and outgoing air speeds.

As a result,

- net thrust is typically lower than gross thrust, but the engine efficiency improves as the aircraft moves faster, maximizing thrust at higher velocities.

NET THRUST

My statement: my own explanation

Net Thrust is the :

- actual thrust produced by a jet engine during flight.

It considers the difference between the

- 1, velocity mass of the incoming
- 2, outgoing airflow.

Net thrust can be calculated using the formula:

$$\text{Net Thrust} = \text{Gross Thrust} - \text{Ram Drag}$$

Ram drag is the :

- resistance caused by incoming air as the aircraft moves forward.

The force required to accelerate the airflow through the engine depends on the :

- mass of air flowing per second
- the velocity difference between the intake and exhaust.

Therefore, the engine's thrust must :

- equal the force needed to accelerate the air mass through the engine.

CHOKED NOZZLE THRUST (convergent and divergent air ducts)

The convergent duct :

- increases velocity and decreases pressure.

The divergent duct:

- decreases velocity and increases pressure.

The convergent principle is usually used for : $V \uparrow P \downarrow$

- the exhaust nozzle

The divergent principle is used in the :

1, compressor

2, diffuser

- where the air is slowing and pressurizing $V \downarrow P \uparrow$

When an exhaust nozzle is convergent :

- the velocity of gases leaving the rear of the engine increases

This is desirable for the development of :

- maximum thrust

As the gases approach the speed of sound the nozzle is said to be

- choked and choked nozzle thrust is produced

This means the highest efficiency has been

- obtained in the engine for subsonic flight.

However, at the speed of sound, the exhaust gases will

- produce a shock wave which deteriorates performance

THRUST HORSEPOWER

Thrust horsepower can be computed when

- the net thrust and the speed of the airplane are known

One horsepower is equal to

- 33 000 foot-pounds of work per minute
- which is the same as 375 mile/pounds per hour.

When an airplane is flying at 375 mp, each pound of thrust is

- the equivalent of one horsepower

When the speed of the airplane is doubled

- the amount of horsepower produced by each pound of thrust is also doubled.

THRUST DISTRIBUTION



The thrust developed by an engine can be thought of as being contributed by the various sections of the engine during the continuous combustion cycle

Thrust distribution can be seen by

- examining the loads produced in a representative turbojet engine

the forward part of the engine, due to Newton's second law, loads are in the

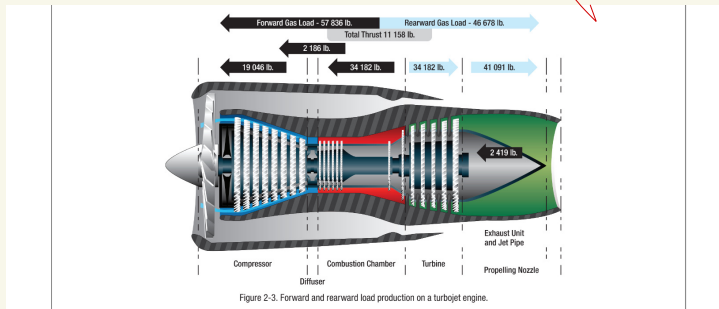
- forward direction

As the gases go throughout the nozzle guide vanes and the turbine, loads shift to the

- rearward direction

Power is extracted and drag occurs

Drag, which continues as the gases make their way throughout the exhaust section, is a significant force. The resultant thrust is in the forward direction



RESULTANT THRUST

The resultant thrust of the engine is the:

- sum of the thrust forces of all the engine main components including the :
 - compressor
 - combustion chamber
 - turbine
 - the exhaust sections

ENGINE EFFICIENCIES

Thermal efficiency is a

- prime factor in gas turbine performance.

It is the ratio of

- network produced by the engine to the chemical energy supplied in the form of fuel.

The 4 most important factors affecting thermal efficiency are:

- 1, The turbine inlet temperature.
- 2, Compression ratio.
- 3, The component efficiencies of the compressor and turbine.
- 4, Compressor inlet temperature and combustion efficiency.

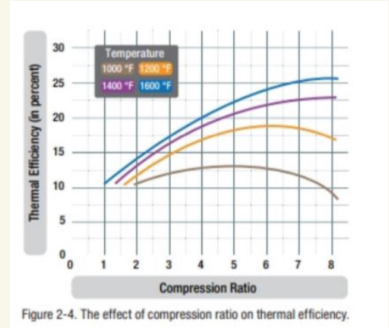


Figure 2-4. The effect of compression ratio on thermal efficiency.

RAM RECOVERY

A rise in pressure above existing outside atmospheric pressure at the engine inlet, as a result of the forward velocity of an aircraft, is referred to as:

- ram pressure

Since any ram effect causes an increase in compressor entrance pressure over atmospheric, the resulting pressure rise causes an

- increase in the mass airflow and gas velocity, both of which tend to increase thrust.

My statement my own explanation

Ram recovery happens when a

- plane moves forward, pushing more air into the engine, which raises the pressure and helps increase thrust.

At first, when the plane speeds up,

- the engine's thrust drops a bit even if the throttle stays the same.

This is because the

- faster speed reduces thrust, but the higher air pressure from ram recovery is working to increase it.

As the plane goes even faster, the extra air pressure wins, and the engine starts to

- produce more thrust again.

BYPASS RATIO:

- The amount of air flow in lbs/sec from the fan bypass compared to the amount of air that flows through the core of the engine is the bypass ratio

My statement: my own explanation

In a turbofan engine, think of two paths for air to move through:

1. The core (engine center): Where air goes through the combustion process to produce power.
2. The bypass (around the core): Where air flows around the engine core without entering the combustion part.

The bypass ratio is just a way of comparing how much air flows around the core (in the bypass) to how much air flows through the core itself. For example, if more air goes around the core than through it, you have a high bypass ratio.

- High bypass ratio = More air around the engine core (more efficient for commercial planes).

- Low bypass ratio = More air through the engine core (better for fighter jets where speed is key).

$$\text{Bypass ratio} = \frac{100 \text{ lb/sec flow fan}}{20 \text{ lb/sec flow core}} = 5:1 \text{ bypass ratio}$$

So, bypass ratio is just comparing the amount of air in the two different paths.

Bypass ducted unducted

Two different exhaust nozzle designs are used with turbofan engines:

- 1, The air leaving the fan can be ducted overboard by a separate fan nozzle
- 2, it can be ducted along the outer case of the basic engine to be discharged through the mixed nozzle core and fan exhaust together

The fan air is either:

- mixed with the exhaust gases before it is discharged (mixed or common nozzle)
- or
- it passes directly to the atmosphere without prior mixing (separate nozzle).

My statement

1, The ducted exhaust engine mixes the air. It combines the air from the fan with the exhaust gases before releasing it, improving efficiency and reducing noise.

- as the book states: The fan air is either mixed with the exhaust gases before it is discharged (mixed or common nozzle) is this ducted

2, The unducted exhaust engine does not mix the air. The exhaust gases and air remain separate, as the exhaust is open without a cover, focusing on fuel efficiency rather than mixing.

- it passes directly to the atmosphere without prior mixing (separate nozzle).

ENGINE PRESSURE RATIO

The engine pressure ratio (EPR) of an operating turbine engine is a reflection of

- how much power is being developed

EPR is a comparison of the pressure at

- the inlet of the compressor to the pressure at the turbine exhaust area

More information of how the EPR is taken (this has not been discussed in the class)

These two pressure levels are taken with

- pick-ups installed in the engine

The sensors are known as

- the P2 and P7 sensors.

An EPR gauge is located on the

- flight deck.

It is used to set the

- power for takeoff on many types of aircraft.

PRESSURE, TEMPERATURE AND VELOCITY OF EXHAUST GAS FLOW

- The higher the temperature the better



ENGINE RATINGS

The flat rating of a turbine engine is the:

- thrust performance that is guaranteed by the manufacturer for a new engine under specific operating conditions, such as takeoff, maximum continuous climb, and cruise power settings.

The turbine inlet temperature is proportional to the

- energy available to turn the turbine.

This means

- that the hotter the gases are that are entering the turbine section of the engine,
- the more power is available to turn the turbine wheel.

The exhaust temperature is proportional to

- the turbine inlet temperature.

Regardless of how or where the exhaust temperature is taken on

- the engine for the flight deck reading, this temperature is proportional to the temperature of the exhaust gases entering the first stage of inlet guide vanes

My statement about the exhaust temperature:

The exhaust temperature is linked to the turbine inlet temperature.

- **If the temperature increases:** This generally indicates more heat and energy entering the turbine, which can lead to higher thrust. However, excessively high temperatures can risk damaging engine components and may trigger protective measures to reduce power or adjust the engine settings.
- **If the temperature decrease:** This may suggest reduced fuel combustion efficiency or issues with the engine. Lower temperatures can lead to decreased thrust output and might prompt the pilot to investigate potential problems, such as fuel supply issues or airflow restrictions.

In summary, increased exhaust temperature can enhance performance but risks damage, while decreased temperature can signal inefficiency or problems.

A higher EGT corresponds to a

- larger amount of energy to the turbine so it can turn the compressor faster.

This works fine until the

- temperature reaches a point when the turbine inlet guide vanes start to be damaged

Performance rating for turbine engines are given by the

- manufacturer for during :

- 1, takeoff
- 2, maximum continuous operation
- 3, maximum climb
- 4, maximum cruise and idle

There are four thrust rating modes which define the

- available thrust at the existing ambient temperature and airspeed conditions.

T/O-1	Maximum Take Off	(100% N ₁)
CON	Maximum Continuous	(86% N ₁)
CLB	Maximum Climb	(76% N ₁)
CRZ	Maximum Cruise	(70% N ₁)

Table 2-1. Thrust rating modes.

FLAT RATINGS

The flat rating of a turbine engine is the

- thrust performance that is guaranteed by the manufacturer under specific operating conditions, such as :

- 1, takeoff
- 2, maximum continuous climb
- 3, cruise power

INFLUENCE OF SPEED, ALTITUDE AND CLIMATE

1, Temperature and Altitude

Any increase in temperature or altitude means a

- decrease in the aircraft's optimum performance.

Air density decreases with:

- altitude

Air density also decreases with:

- temperature

2, Humidity

Humidity also plays a part in this scenario.

Although it is not a

- major factor in computing density altitude, high humidity has an effect on engine power

The high level of water vapor in the air

- reduces the amount of air available for combustion
- results in an enriched mixture and reduced power

3, Mountain airports

Mountain airports are particularly treacherous when

- temperatures are high, especially for a low performance airplane.

Under some conditions,

- the airplane may not be able to lift out of ground effect
- or maintain a rate of climb necessary to clear obstacles or surrounding terrain.

4, cold weather

- is always better for an aircraft to operate