Bristol
AERO ENGINE SCHOOL

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# SECTION I
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First Law of Thermodynamics

Broadly speaking this may be stated as follows:- Heat and mechanical energy are mutually convertible, and the 'rate of exchange' is constant and can be measured.

The rate of exchange is known as 'Joule's equivalent' and is usually denoted by the letter J. The value of J is 1,400 ft.lb. That is to say, 1,400 ft.lb of mechanical work would be required to raise the temperature of 1 lb. of water through one degree.centigrade. This equals 1 C.H.U.

For example, if two rotating surfaces are in contact, and are not lubricated, the heat generated by the friction between them will soon raise their temperature by a measurable amount. Thus mechanical energy is converted into heat, but although this process is quite simple, it is far more difficult to convert heat to mechanical energy. The latter indeed, is seldom accomplished without considerable loss, as the comparatively poor efficiency of the majority of heat engines amply demonstrates.

The Second Law of Thermodynamics

This may be stated as:- Heat cannot be conveyed from one body to another which is at a higher temperature, without the expenditure of energy supplied from an external source.

In other words, heat energy always runs down a temperature gradient, like water down a hill, and will not climb up a gradient unless forced to do so by the application of energy from an external source.

Boyle's Law

If the temperature remains constant, the volume of a given mass of gas varies inversely as the pressure exerted upon it.

PV = Constant.

Charles Law

If the pressure remains constant, a given mass of any gas expands one two hundred and seventy-third of its volume at 0°C. for each degree rise in temperature.

Another Definition of Charles Law

If the pressure remains constant, the volume of a given mass of gas varies directly as the absolute temperature.

Newton's Laws of Motion

Law 1. A body remains in a state of rest, or of uniform motion in a straight line unless some external force is applied to it to change that condition.

This law states a principle sometimes known as "the Principle of Inertia", viz that a body has no tendency of itself to change its state of rest, or of uniform motion in a straight line, unless some outside force be applied to bring about such change.

For example: - if, when travelling at speed in a car, the brakes are suddenly applied, the occupants are thrown forward, due to the tendency of a body to continue in a straight line of motion. If a car is driven round a bend so fast that the force tending to change its direction of motion (that is the grip of the wheels on the road) is overcome, the car will continue to travel in a straight line or, in other words, will skid outwards from the periphery of the curve.

The change ..........

Law 2. The change of momentum in a body in a given time when acted upon by an external force is proportional to the applied force and takes place in the direction of that force.

An aeroplane travelling in a straight line in still air has a certain momentum and direction. If a strong gust of wind (an outside force) suddenly strikes it from the right, it will no longer travel in a straight line but will move sideways to the left and the distance it travels in this direction will be in direct proportion to the strength of the gust (or magnitude of the outside force).

Law 3. To every action there is an equal and opposite reaction.

Bernouilli's Theorum

As velocity increases the pressure decreases. Pressure gradient in direction of flow.

As velocity decreases the pressure increases. Reverse flow gradient tends to cause flow in opposite direction.

Force and Mass

FORCE may be defined as anything which changes, or tends to change the state of rest, or uniform motion of a body. That which is capable of setting bodies in motion, or stopping them when they are in motion, or altering the direction or manner of their movement, is called a force.

The unit of force which is used generally in English-speaking countries is the weight of the standard pound. The standard pound is a piece of platinum kept in the Standards

Department of the Board of Trade, which if suspended from a spring balance will deflect the spring and its indicator a certain distance, any other object which will deflect the spring by the same amount when suspended from it is said to weigh one pound. Similarly, any force exerting a pull which will deflect the spring by this same amount is said to be the force of one pound.

MASS is defined as "the quantity of matter contained in a body". Any two bodies will have equal masses when they each weigh the same, irrespective of their size. A pound of lead would be comparatively small in volume when compared with a pound of aluminium, yet each would be of equal mass. If, therefore, two bodies are of equal mass they will also be of equal weight (at the same place) and if one body contains two, three, four etc. times the mass of another, that body will weigh two, three, four etc. times as much as the other.

| | |
|---|---|
| W | = Weight (lbs) |
| M | $= \frac{W}{G}$ = Mass |
| F | = Force = Rate of Change of Momentum |
| T | = Thrust = Force lbs |
| T.H.P. | = Thrust Horse Power |
| S.H.P. | = Shaft Horse Power |
| E.S.H.P. | = Equivalent S.H.P. = S.H.P. + T.H.P. |
| N.P. | = R.P.M. PROP |
| P. | = T.M. Press |
| K | = Constant = 192.86 |
| V | = Velocity at Jet FT/SEC |
| U | = A/C Velocity FT/SEC |

# OLYMPUS GAS FLOW

The turbo jet develops its thrust as a result of a continuous cycle of compression, combustion, expansion and exhaust, applied to the working medium. This is air or a product of combustion after the fuel has been burnt in it.

Physical changes taking place are important as an indication of the way the cycle works; like in a piston engine we should be interested in Pressures, Volumes and Temperatures at critical points in the 4 stroke cycle. In the gas turbine, we are interested in conditions at entry and delivery from the compressor, before and after combustion, at entry and discharge from the turbines and finally at discharge from the exhaust nozzle.

## The Compressor

Whenever a compressor does work on the air flowing through it we should expect to see a rise in the pressure, or an increase in the velocity of the flow, or both. As it is the rise in pressure that we are interested in, the increase in velocity should be small and most of the work done on the air will produce a pressure rise. The accompanying rise in temperature is a measure of the amount of work done. Incidentally, if this rise is compared with the rise we ought theoretically to get for that pressure increase, we should be measuring the compressor efficiency.

## The Combustion Chamber

If we prevent the pressure rising at all, in the combustion process, during the addition of fuel or heat energy to the air, all the heat energy added will go towards an increase in temperature and consequent increase in its velocity. These two, added together constitute the increase in the total head of energy that the stream now possesses.

The pressure in the combustion process can be prevented from rising by allowing for an unrestricted flow expansion along the combustion chamber.

The Turbine Assembly

In a way, this is the reverse of the compressor, for the turbine extracts and makes use of the head of energy and converts a proportion of it into mechanical power to drive the COMPRESSOR. The amount of work done by exhaust gases in going through the turbine is measured by the drop in total temperature. The gas may be thought of as giving up some of its stock of internal energy, in order to expand through the turbine, doing work on it and maintaining its own continuous flow.

The Jet

Finally, in the propelling nozzle, a further drop in pressure occurs as the expansion through the nozzle increases the velocity to its final value.

The above sequence is a broad and brief picture of flow conditions. If we go into greater detail, to examine what changes occur in these parts of the engine where the flow is being directed from passages of larger to smaller cross-section and vice versa, we shall find the velocity and pressure changes governed by :-

1. Expansion in which flow from larger to smaller passages produces an increase in velocity and fall in static pressure, (with corresponding decrease in static temperature)

2. <u>Diffusion</u> in which flow from smaller to larger passages produces a decrease in velocity and increase in static pressure (with corresponding static temperature increase)

If these changes occur without any change in the total heat they are called adiabatic or isentropic, and the flow proceeds without any loss. Obviously there will be some loss due to friction.

The Olympus has two stages of axial compressors, the low stage with a compression Ratio of 2.77:1, and the high stage of 3.69:1, each being driven by separate turbines.

We can now trace the actual flow through the engine working under a given set of conditions.

All pressures, temperatures and velocities quoted are based on a nominal low pressure compressor speed of 6,600 R.P.M. at I.C.A.N. sea level static conditions.

1. Velocities in feet per second (FT/SEC)
2. Pressures in pound per square inch absolute (P.S.I.A.)
3. Temperature in degree Kelvin (°K)

The low pressure compressor is a six stage axial unit, the air entering the compressor at 14.7 p.s.i.a., 288°K with a velocity of approximately 550 FT/SEC. The velocity or kinetic energy of the air stream is increased through the moving compressor blades (6 axial stages) but is reduced and converted into pressure energy through the compressor stator blades.

The air stream .......

The air stream enters the intermediate casing from the row of compressor stator exit blades, the velocity or Kinetic energy being converted into pressure energy, the velocity in the intermediate casing having fallen to 548 FT/SEC with a temperature rise across the compressor of 111°K giving 399°K and a pressure rise to 40.7 p.s.i.a.

From the intermediate casing the air now enters the eight stage high pressure compressor, a similar action taking place as in the low pressure compressor, the overall compression ratio being 10.2:1, the velocity having fallen to 486 FT/SEC with a temperature rise across the compressor of 207°K giving 606°K and a pressure rise to 150 p.s.i.a.

Due to the diffusing action of the compressor delivery casing before entry into the combustion chambers the p.s.i.a. and temperature remain constant the velocity having dropped to 224 FT/SEC.

The air stream enters the combustion chambers, where the necessary energy is imparted to the air by the addition of fuel from the atomisers which is ignited in the flame tube.

The greater portion of the air delivered from the compressor flows over the outer conical shaped end towards the secondary portion of the flame tube, the remainder flows through the metering orifice around the burner holder, this air is used for primary combustion.

Due to combustion chamber design, the energy imparted to the air flow by the burning fuel is converted into heat and kinetic energy a slight pressure drop to approximately 142.5 p.s.i.a., due to mixing is experienced, with a decrease in temperature to 1140°K due to air dilution from the secondary portion of the flame tube, the velocity increases to 416 FT/SEC at turbine entry annulus.

The action of the turbine entry guide vane assembly on the air passing through them increases the velocity to 1732 ft/sec at the first stage turbine stator exit, a pressure drop occurs before entering the rotor to 136.8 p.s.i.a., the temperature remaining at 1140°K.

It is this drop and subsequent velocity increase which provides part of the torque to the shaft.

The temperature drops during expansion in the H.P. Compressor turbine, the decrease in total temperature being 183°K. This process repeats itself in the L.P. compressor turbine, after the second stage turbine stator exit the pressure drops to 62.6 p.s.i.a., temperature to 957°K and the velocity to 1532 ft/sec.

At the exit of the L.P. compressor turbine, the pressures and temperatures drop to a final value of approximately 38 p.s.i.a. and 859°K and remain constant to the jet pipe outlet.

The diffusing effect of the exhaust unit and inner cone causes a slight drop in the velocity, but the jet pipe outlet increases the velocity from 702 ft/sec to a final value of 1739 ft/sec.


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