INTRODUCTORY LECTURE.

BASIC MECHANICS OF JET PROPULSION.

Force, Velocity & Acceleration.

Thrust, pull, push, load, weight, resistance, action, reaction, and several other words all describe something which the engineer recognises to be a force. We define it by reference to the fact that whenever a force is experienced there is either movement or at least "would-be" movement. Resistance is used to describe that class of force which in everyday life, is brought into existence to prevent motion, or is itself a result of motion, such as frictional and air resistances. If an object in motion encountered no such resistance (an ideal never attained), it would go on moving perpetually without deviating from a straight line path and without altering in speed. In any practical case a resistance is encountered which necessitates the application of a force in the direction of the straight line path just sufficient to prevent the inevitable slowing up. If the value of the force producing motion were less than the resistance, the body would slow down till, for example, the rubbing friction or air resistance, which depend on the speed, were reduced to the same amount. Then the body would carry on as before but at the reduced speed.

Let our starting point be this condition of uniform speed in a straight line direction, which we call uniform velocity. A change in velocity can only be brought about by applying external force. Such a change in velocity is called an acceleration (or retardation). We should therefore be able to define some relationship between the magnitude of the force and the rapidity of the change in velocity it produces.

The engineer uses 1 lb. weight as the unit for measuring force, and an increase of velocity of 1 foot per second each second as the unit of acceleration. But if we seek inspiration from that commonest natural phenomenon - a body accelerating during a free fall - we observe that if a weight force of 1 lb. acts freely on the body which has that weight, it causes an acceleration of 32 ft. per sec. per sec., varying slightly over the earth's surface. This is usually denoted by "g" ft/sec/sec. If, however, a weight pull towards the earth of 1 lb. were applied to the mass of material represented by 32 i.e. "g" lb. weight, the acceleration would be only 1 ft/sec/sec., i.e. $\frac{1}{g}$ x g ft/sec/sec. In other words unit force produces unit acceleration on g lb. mass. This quantity is called 1 slug - the unit of mass.

$$\frac{\text{Moving force}}{\text{mass moved}} = \frac{\text{acceleration produced}}{\text{gravitational acceleration}}$$

$$\frac{P}{W} = \frac{a}{g}$$

$$P = \frac{Wa}{g} \text{ lb.}$$

Where P lb. is the externally applied force

W lb is the weight of the mass of material involved

$$\therefore \quad W = \frac{W}{g} \text{ slugs of mass}$$

a = acceleration produced ft/sec/sec.

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Inertia and Momentum.

The word inertia or objection of a body to having its state of rest or uniform motion interfered with is a matter of common experience, as a moment's thought will show. The property possessed by such a moving body of desiring to go on moving except for external disturbing influences, is called its momentum, and obviously this property depends on both the mass and the velocity with which it is moving. To produce a change in velocity and therefore momentum, will need a force, as we have already seen. It will be a braking force to slow up the motion, and an accelerating force in the direction of motion to speed it up. Witness for example the great forces involved in creating the high acceleration and corresponding increase in momentum for catapult take-off of aeroplanes.

Reverting to our inertia equation

$$P = \frac{W}{g} \times a$$

If the velocity of our mass were u and v ft. per sec. at the beginning and end of the acceleration over a time t seconds then

$$(v - u) = \text{total changes in velocity f.p.s.}$$

$$\frac{v - u}{t} = \text{change in velocity (f.p.s.) per sec.}$$

Substitute this for "a" in the equation.

$$\therefore \quad P = \frac{W}{g} \times \left(\frac{v - u}{t}\right) \text{ lb.}$$

$$= \frac{\left(\frac{W}{g} \times v\right) - \left(\frac{W}{g} \times u\right)}{t} \quad \text{lb.}$$

As we have agreed, a change in momentum must always be associated with a force, and the magnitude of the force depends on the magnitude and rapidity or rate of change in momentum. The quantities in brackets are the momentum before and after the change in velocity. The whole expression tells us the rate of change of momentum, and the force to which it is equivalent.

Suppose that it started from rest and acquired the velocity v ft per sec.

The change in momentum is

$$\frac{Wv}{g}, \quad (\text{for } u = o \text{ and } \frac{W}{g} \times u = 0)$$

Stream Flow.

Up to now we have been considering an event happening to a single body of finite weight W lb. The conclusions arrived at apply equally to the case of a stream of such bodies, say a stream of air flowing at the rate of W lb. per second. An increase in velocity of such a stream from 0 to V ft. per sec. would mean an increase in momentum of $\frac{WV}{g}$ lb, and that would be the numerical value of the force required to produce it.

We should call such a stream, issuing from a nozzle at higher speed than it entered, a jet. It does not matter what happens during the passage of the air stream so long as it is not broken down and so long as the end result is obtained, of a high velocity jet efflux. If the duct is full and flow is steady, the same mass of material must pass each point in the path, no matter how the x sectional area may change.

Reaction.

No force can be exerted without giving rise to an equal force reacting in the opposite direction. The gas pressure forcing a bullet forward reacts on the shoulder; the forward thrust of a ship's screws or paddles is a reaction from the rearward force on the water; the aircraft propeller urges air rearward, accelerating its flow from front to rear face of the disc of rotation, and the aircraft feels the forward reaction thrust.

So from the force creating the increase in jet momentum the structural parts feel the reaction thrust, equal numerically and opposite in its direction.

One of the simplest conceptions of reaction propulsion is the rocket.

Rocket Material.

A rocket consists of a convenient cylindrical duct, part filled with a rapidly burning chemical charge, self sufficient in itself to generate a very large volume of gas products. If this is generated in a strictly confined space the pressure will rise until it forcibly finds an outlet. If, on the other hand, it is afforded a properly shaped rearward exit, then, with little or no pressure rise, it begins to hurry out, and the more rapidly it is evolved the more rapid its final exit. The conditions of our requirement are thus fulfilled, and the force causing the increase in rearward momentum is the elastic expansion of the gaseous products. But it must have something to expand rearwards from, and it exerts just as big a force reaction on the front wall of the container as on the gas stream which it is accelerating rearward.

To every action (the rearward expansion force) there is this equal and opposite reaction (the forward thrust). Depending on the effectiveness with which this is applied to the casting, the rocket will continue travelling with substantially the same momentum until the supply of propellant is exhausted. Accelerations to an enormous velocity are possible, but the useful life is reckoned in minutes, and it is extremely wasteful.

The Jet Conception.

In the rocket we have a vehicle containing within itself the necessaries for generating high momentum forces. But our normal conception of a combustion process involves use of the oxygen which forms a proportion of atmospheric air. Our usual idea of fuel is petrol, paraffin, or some similar mixture of hydrocarbons. If, then, we can create a material stream of air along a containing duct, and at some suitable point burn fuel in it to add heat, the free expansion permitted by the open ended duct will have the same general effect of the rocket device in giving the products of combustion a high rearward velocity, with a reaction thrust corresponding to the momentum acquired. As the momentum depends on the mass of material air as well as its velocity we shall need large quantities to produce effectively large thrusts.

Our first requisite thus becomes apparent in the form of a compressor capable of handling the air and the obvious choice is the centrifugal compressor. As we shall see, there is an alternative called axial flow compressor with certain attractive features, notably high efficiency and small diameter.

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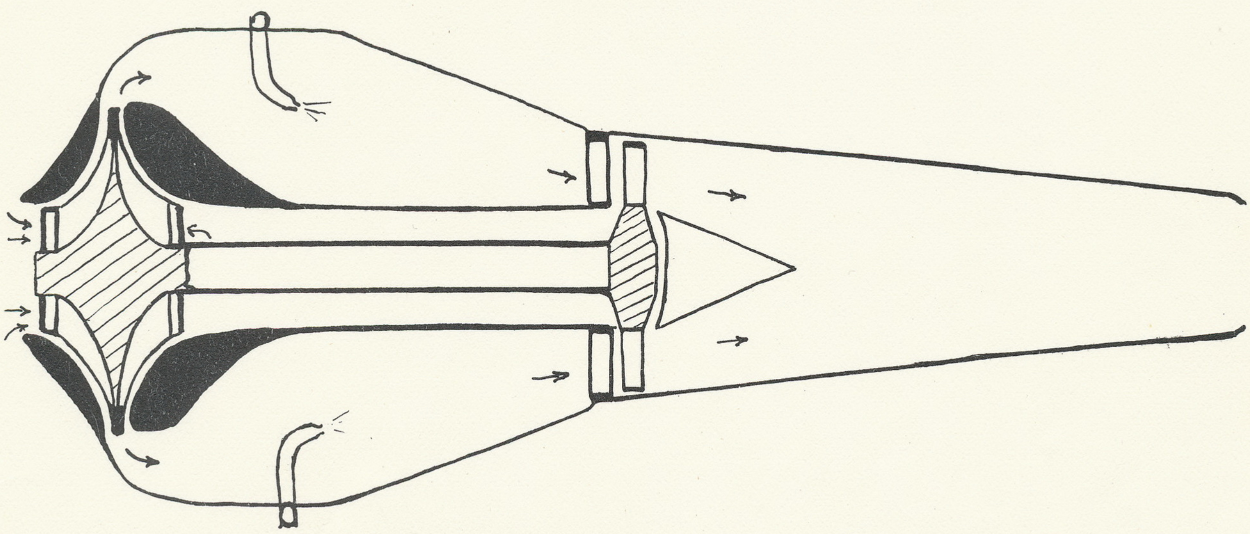
The next functional problem is to provide motive power for driving the compressor, and the choice falls on the turbine type of prime mover, whose principles of operation conveniently make use of the energy of a fast moving stream of working substance to provide mechanical energy of shaft rotation. These principles, as well as the functional working of a compressor, are dealt with in detail in separate notes.

The turbine receives the material stream from the compressor, extracts from it the energy it needs in order to keep the compressor working. It is obvious that the fuel energy supplied must be sufficient to provide for this compressor work, including all losses entailed, and still have a surplus to maintain the fast moving jet efflux.

We are now in a position to lay out our conceptions as in the accompanying diagrams, which we have built up from our basic investigation of momentum-reaction possibilities.




LIGHTNING
COVER PITOT HEAD