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ROCKETS.*

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The rockets of world war II represented, not the invention of a new weapon, but the modernization of a very old one. As early as 1232 A.D. the Chinese launched rockets against the Mongols. About a hundred years later the knowledge of rockets was quite widespread and they were used to set fire to buildings and to terrorize the enemy. But as cannon developed, rockets declined in warfare. However rockets were used occasionally as weapons till about 1530 A.D. About this time improvements in artillery—rifled gun barrel and mechanism to absorb recoil—established a standard of efficiency with which rockets could not compare until world war II brought new conditions.

In world war II, every major participant used rockets. Each nation developed rockets weapons in answer to its tactical and combat needs. The Russians pioneered in the firing of antitank rockets from planes and in the use of massed banks of rockets for pre-assault barrages. The British used rockets for defence against attack from air at a time when there were only 500 anti-aircraft guns in the United Kingdom. With the Luftwaffe driven from the skies, the Germans employed long range V-2 weapons to attack English cities. The Japanese attempted to use rocket artillery to defend their island outposts.

Because of the complete absence of recoil and the lower pressures developed inside rocket motors, the rockets can be fired from light launchers which could be easily mounted on planes and boats and also taken to difficult positions unaccessible to guns. This is the principal advantage in using rockets. Because of the high dispersion, rockets are much too inferior to artillery guns when used against point targets. However this is of little consequence when an area target is to be attacked.

The rocket motor essentially consists of a chamber in which the propellant burns and is converted rapidly into gases. These gases escape at high velocity through a suitably constructed nozzle or nozzles which is/are attached to the chamber at its rear end. Sometimes the nozzles are drilled at a cant so that the gases cause the rocket to spin also. Broadly speaking, the forces which act on the rocket due to these rearward escaping gases could be distinguished as the "momentum forces" and "pressure forces". The momentum forces are equal to $\dot{m} \times v_e$ (where $\dot{m}$ is the rate at which the propellant is being consumed and v_e is the velocity of the escaping gases at the nozzle exit), and are applied in the direction just opposite to the direction of the gas flow. The "momentum forces" arise from the transfer of momentum due to the flow of gas out of the exit of the nozzle. The pressure forces arise from the fact that because of jet action the pressure across the exit area Ae is (Pe—Pa) greater than it would be if jet were not acting. Here Pe and Pa are the pressures due to jet and the atmosphere respectively. The pressure forces are thus equivalent in value to (Pe—Pa) Ae, and applied in a direction perpendicular to the direction of the nozzle exit, pointing inward.

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The equations of motion for the centre of gravity of the rocket are obtained as usual by equating the total of the exterior and jet forces acting on the rocket to mass of the rocket x the acceleration of the rocket.

The motion of rotation of the rocket can be supposed to be compounded of two motions—the rotating motion about the axis of the rocket—this motion is called spinning—and the rotating motion about a transverse axis perpendicular to the rockets axis. When a rocket is having such motion it is said to be yawing.

So far as the spinning motion is concerned, it is obtained by equating the moments of the jet forces and the exterior forces about the rockets axis to the moments of inertia of the rocket x the angular acceleration of the rocket about its axis.

When we consider the yawing motion of the rocket, it is found that a term due to jet action is to be added to the moment of the external forces and jet forces before equating these to movement of inertia of the rocket x angular acceleration of the rocket about the transverse axis.

The additional term tends to decrease yaw and hence the effect is usually termed ' jet damping '.

The ballistic effects of yawing and spinning motion are quite different. When the rocket yaws the result is to turn it more or less crosswise in flight. The air resistance increases and the rocket is considerably deflected from the path it would have followed were it not yawing. The range is reduced as also the striking velocity. Further a yawing rocket is more likley to miss the target rather than hit at it. Thus yawing is to be avoided as far as possible.

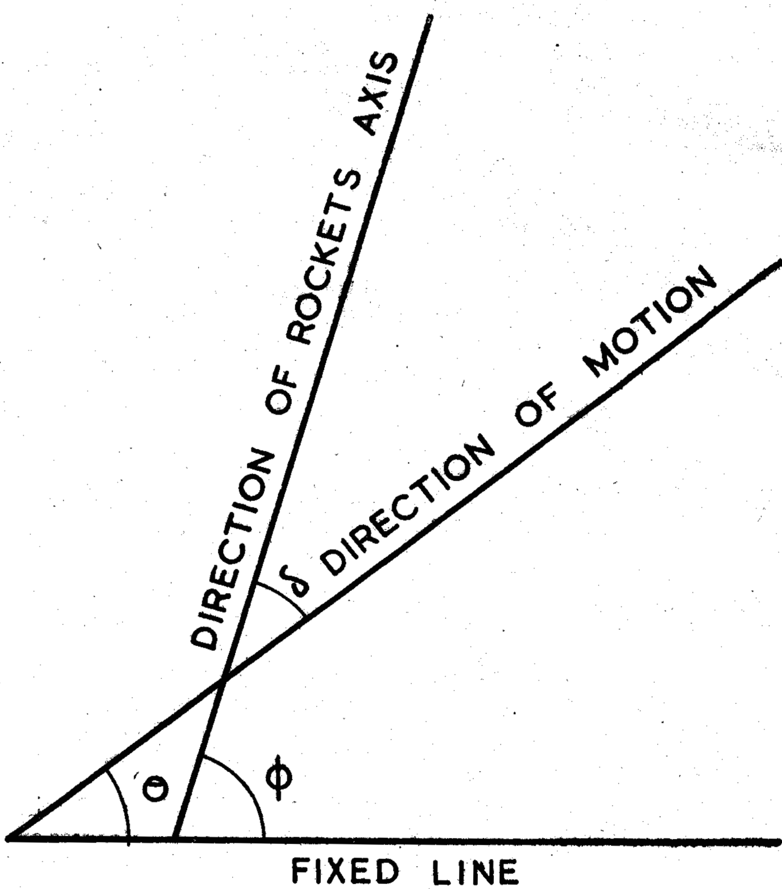
On the other hand the spinning motion makes the rocket stable in flight, prevents it from developing yaw and hence is to be desired. Rockets are given spin either by passing the gases through inclined nozzles or by making it pass through a spiral launcher or by fitting it with fins whose blades are inclined at a definite angle to the axis of the rocket.

The aerodynamic forces acting on the rocket consist of five forces and five couples. For non-rotating or slowly spinning rockets, these reduce to five as follows. Let θ and ϕ be the angles which the tangent to the trajectory and rockets axis make with a line fixed in space.

Before we pass on to the equations of motion, it is necessary to mention some of the asymmetrics associated with the action of the jet as well as these associated with the external form of the rocket.

There are three types of thrust malalignment that can take place. The thrust may make an angle δ_T with the axis of the rocket or it may miss the centre of gravity by a distance L or it may supply a torque tending to spin the rocket about its axis at a rate of r revolutions for each wave length of yaw travelled.

In addition to the jet and the aerodynamic forces we have, of course, the force of gravity acting vertically downwards through the centre of gravity.



Then $\delta = \phi - \theta$ is the yaw. The five forces and couples are, —(*a*) The drag $D = -K_D \, pd^2 v^2$ in the direction of motion. (*b*) The lift $L = K_L \, pd^2 v^2 \sin \delta$, acting perpendicular to the direction of the rocket's axis. (*c*) The cross Spin forces, $S = K_S \, pd^3 v\phi$, acting perpendicular to the direction of the rockets axis. (*d*) The restoring moment, $M = -K_M \, pd^3 v^2 \sin \delta$, acting in the plane of yaw. (*e*) The damping moment $H = -K_H \, pd^4 \, v\phi$ tending to decrease the numerical value of ϕ. The forces all act through the centre of gravity. Here v is the velocity, p the air density, d the calibre of the rocket and K_D, K_L, K_S, K_M and K_H are dimensionless coefficients.

As the external form of the rocket is seldom perfectly symmetrical, the lift force will not be zero when the angle of yaw is zero but would be zero when the yaw has a definite small value δ_L. Thus the left force will be given by

$$L = -K_L \, pd^2 v^2 \sin (\delta - \delta_L)$$

Similarly, the restoring moment will be given by

$$M = -K_M \, pd^3 v^2 \sin (\delta - \delta_E)$$

These asymmetrics, particularly these due to the jet action cause considerable deflection of the rocket from its normal path and are the sources of dispersion which is characteristic of the rocket.

The equations of motion are obtained in a form suitable for numerical computation by assuming that the actual yawing motion of the rocket consists of two independent yawing motions in two planes perpendicular to each other. One of these is the vertical plane through the direction of motion and the other is the plane perpendicular to the first and passing through the tangent to the particular trajectary at the instant. This is continually changing. However it changes slowly as compared to the yawing motion of the rocket. Suitable carterian reference axis are chosen and the equations of motion are written down in the usual way. It is found that they are not solvable in closed form and recourse has to be taken to numerical integration. In this connection the properties of the following function have to be studied in detail :

$$rc\ (\omega = je^{j\omega} \int_{\omega}^{\infty} \frac{e^{-jx}\, dx}{\sqrt{x}}$$

where $j = \sqrt{-1}$, , $rc\ (\omega)$ being a complex function of its argument ω.

The motion of the rocket is divided into three parts (1) motion on the launcher, (ii) motion while the propellant burns, (iii) motion after all burnt.

After all burnt, the motion of the rocket can be studied by the familiar methods utilized for the study of the motion of a shell ; the initial conditions of motion are supplied from the study of the motion during burning.

The motion on the launcher has to be studied as it gives the initial conditions for the study of the motion during burning.

During the first two stages the thrust on the rocket is the largest single force acting on the rocket, hence the trajectory of the rocket is very nearly a straight line, and the detailed study has to be made of the deviation from this straight line as even such small deviations can cause a large dispersion in the end.

We define the dispersion of a single round as its deviation from the standard trajectory which a perfectly symmetrical rocket would follow under standard conditions. In other words the standard trajectory is the path of a particle fired under the same initial conditions possessing the same mass and subject to no other forces except the forces of gravity and the drag due to air at zero angle of yaw. A usual measure of dispersion as we have defined it above is the angle between the actual point of impact and the point of impact of the standard rocket, this angle being measured from the point of firing.

It is found that most of the dispersion arises during the early part of the burning period. The main factor contributing to the dispersion is the distance L by which the thrust misses the centre of gravity. Of the remaining factor which contribute to dispersion after all burnt, the main is due to the lift force and the asymmetry caused by δ_L.

One of the main purposes of rocket ballistics is to calculate the dispersion caused by the different asymmetrics and hence prescribe certain limits within which these must be, so that the rockets may be fit for service use, the other use being in the construction of sighting tables.