and very different from the desert condition which it possesses to-day. While nothing was found in Palestine of the same type as the Samarra ruins, the ancient Græco-Roman temples of Jupiter and Bacchus at Baalbek, in Central Syria, furnished some interesting photographs. A vertical view from about 3000 ft. gives a remarkably good ground plan of the present state of these beautiful remains (see Fig. 3).

FIG. 3.—Temples of Jupiter and Bacchus at Baalbek in Central Syria, showing the ground plan and some remains of later Saracenic building.

Meteorology.—The study of clouds by the photography from aeroplanes of their forms and features has been recently discussed by meteorologists, and need not be further mentioned.

It would be outside the scope of the present article to deal with the methods of obtaining, using, and interpreting the aerial pictures which have been referred to. It may be seldom possible for a scientific expedition to employ aeroplanes, owing to their expense; but, when it can be done, useful knowledge is bound to accrue. In other cases, however, as in Palestine, photographs may be taken for mapping or other purposes, which will also yield important scientific material to those who can make use of it; and possibly photographs taken for the purpose of training airmen may become of great value, even in this country, if certain areas are included. Sometimes the evidence furnished is clear and unmistakable, but in other cases the photographs have to be examined by a trained and experienced worker. The general public has not been very fully informed of the work of the R.A.F. photographers during the war, and to most people the air photograph is a curiosity which seems to have little value in times of peace. Though in some countries the civil importance of aerial photographic survey is realised, in England air photography is in a somewhat languishing condition. In these circumstances it is well to remember that, though the aerial camera has not been extensively employed apart from military work, it nevertheless appears to have no inconsiderable value in the domain of pure science.

The Dynamics of Shell Flight.

By R. H. FOWLER.

THE object of this article is to give a short account of some features of the motion of a spinning shell through air. Our knowledge of this phenomenon has been somewhat increased by war-time researches. To determine the motion of a shell from the equations of rigid dynamics, we require to know the complete force system which represents the reaction of the air on the moving shell; but, just as in the case of an aeroplane, the components of this reaction are utterly unknown *a priori*. The problem that arises, therefore, is that of determining these components by observation and analysis of the actual initial motion of shells. Once they have thus been determined, they can be applied, provided the essential conditions remain similar, to the calculation of the complete motion of a shell along its trajectory.

In the simplest case of all this procedure is classical. The air resistance to a shell, moving so that the directions of its axis and the velocity of its centre of gravity coincide, has long been determined thus as a function of the velocity, and trajectories have been computed assuming that this coincidence subsists throughout the motion. Under this assumption the problem is merely one of particle dynamics, of which the solution may be regarded as completely known. The comparison of calculations and observations shows good agreement in range and height when the shells are suitable and the total angle turned through by the tangent to the trajectory is less than, say, 50°. The calculated trajectory, however, is a curve lying in the vertical plane containing the original direction of projection, while the observed positions of the shells do not lie in this plane, but appreciably to the right of it when their axial spin is right-handed. This well-known departure from the original vertical plane is called *drift*, and converts the trajectory into a twisted curve. It cannot be accounted for on the original assumption.

It is with these cases, in which particle dynamics fails to explain the observations—such as the drift, trajectories of large total curvature, and (as we shall see) initial motions—that we are mainly concerned here. For their study we must abandon the assumption that the direction of motion of the centre of gravity and the direction of the axis of symmetry coincide, and study the whole motion as a problem in rigid dynamics.

In order to do this we must, first of all, determine experimentally the complete reaction of the air on the moving shell when the directions of its axis and the motion of its centre of gravity no longer coincide. In such a case the angle between these two directions is called the *yaw*. Until recently the reaction on a yawed shell had never been studied experimentally. The necessary data, however, can be obtained by observation and analysis of the initial motion of the shell in the first few hundred feet after leaving the muzzle of the gun, for in this interval the axis of a shell oscillates periodically over an appreciable range of yaw.[1] The motion is a little complicated, and its interpretation is not yet completely worked out in terms of the reaction of the air. Moreover, a really satisfactory experimental method has not yet been devised. But a start has been made on the problem, and approximate values of the more important components have been determined.[2]

The somewhat crude experimental method so far used consists in firing a shell through a series of cardboard screens. The shape of the hole in the card determines the size and direction of the yaw at the instant of passing through the card. From such observations the motion of the axis can be plotted out against the time (if the velocity of the shell is known), and the period of its oscillations determined. The disturbing effect of the cards themselves can be determined by suitable control experiments and roughly estimated. Two specimen observed curves [3] traced out by a point on the axis of the shell relative to the centre of gravity are shown in Figs. 1 and 2. These two paths are strictly comparative, as the only difference between their circumstances is an alteration of the axial spin. The slowly spinning shell (Fig. 1) has oscillations of comparatively long period and large amplitude. These curves are closely analogous to the curves which represent the oscillations of a spinning top near its vertical position. They differ only in showing slight damping and variation of period.

Let us consider further this analogy between a shell and an ideal spinning top. The centre of gravity of the shell and the point of support of the top are analogous; so are the moments of inertia about these points and the axial spins. To the direction of motion in the case of the shell corresponds the vertical in the case of the top; to the disturbing couple due to the reaction of the air on a yawed shell corresponds the gravity couple on a displaced top. The analogy so far is practically exact; it is modified by the following facts:—

(1) That the centre of gravity is not a fixed point like the point of a top, for its velocity varies both in magnitude and in direction under the reaction of the air; it describes a helical curve, thus modifying the couple.

(2) That an appreciable frictional couple exists which, in conjunction with the helical motion of the centre of gravity, serves to damp out the axial oscillations completely.

(3) That, in addition to (1) above, the magnitude and direction of the velocity of the shell are steadily altered by gravity.

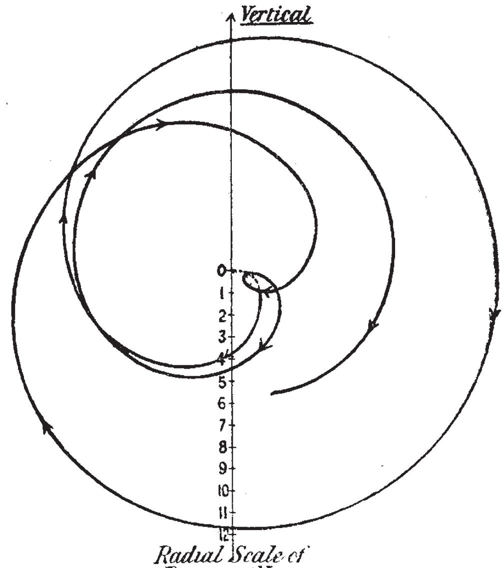

FIG. 1.—Observed path of the nose of a shell, muzzle velocity 1565 f.s. Rifling 1 turn in 40 diameters of the bore. Total time taken to describe curve shown 0.38 sec.

Experiments so far carried out have determined approximately the values of the couple analogous to the gravity couple for velocities from 900 f.s. to 2200 f.s. for two different shapes of shell, when the yaw is not too large. By determining these couples for various different positions of the centre of gravity, rough values of the resulting sideways thrust on a yawed shell were deduced.

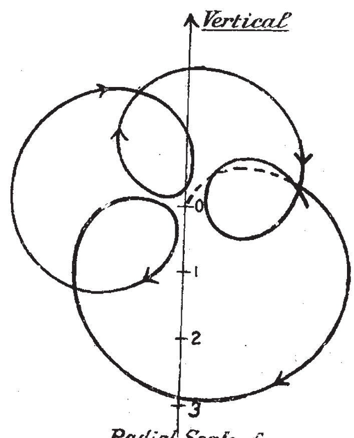

FIG. 2.—Observed path of the nose of a shell, muzzle velocity 1563 f.s. Rifling 1 turn in 30 diameters of the bore. Total time taken to describe curve shown 0.20 sec. [The scale of Fig. 2 is three times that of Fig. 1.]

[1] Such experiments are described in a forthcoming paper in the Royal Society Transactions by R. H. Fowler, E. G. Gallop, C. N. H. Lock, and H. W. Richmond.

[2] The forces on a model shell at rest in a steady current of air of low velocity can also be measured directly in a wind channel; the results are probably applicable to a shell moving at velocities up to 700 f.s.

[3] The observations were made for the Ordnance Committee at H.M.S. *Excellent*, Portsmouth.

The study of initial motions is intimately connected with the question of the *stability* of a spinning shell at zero yaw. The motion of a shell (or a top) is said to be stable if a small disturbance only produces a small maximum displacement from the position of symmetry, proportional to the disturbance. The condition of stability for small disturbances is the same in the two cases; it must be fulfilled in order that the shell may travel along its trajectory approximately at zero yaw as desired. A knowledge of the disturbing couple enables us to lay down how much spin is required to allow a reasonable margin of stability.

We have said that the usual approximation of motion at zero yaw is inadequate in the case of trajectories of large total curvature. The complete theory indicates that, under the effect of gravity (see (3) above), the yaw tends to attain a sort of equilibrium value which increases along the trajectory, and may reach 20° or more at the end of a sufficiently long arc. A study of initial motions with slightly unstable shells in which such values of the yaw can be realised experimentally will provide the material required for the proper discussion of such trajectories.

The following approximate theory accounting for the drift of a shell has long been known. Owing to the change of direction of motion due to gravity (see (3) above), a shell cannot continue to move steadily at zero yaw. The proper equilibrium state of affairs is attained when the yaw is just such as will enable the axis to keep pace with the changing direction of motion by precession about it. This equilibrium value of the yaw depends on the above-mentioned disturbing couple due to the reaction of the air, which may be determined by a study of the initial oscillations. The resulting yaw in ordinary cases is too small to alter seriously the range at any given time, and does not affect the height because the equilibrium position of the yawed axis lies in a plane which is always very nearly at right angles to the vertical plane containing the original direction of projection. It produces, however, the lateral deviation known as drift. This approximate theory leads to a formula for the drift depending on the ratio of the sideways thrust to the disturbing couple. With the values of this ratio recently roughly determined, the drift has been calculated by this classical theory, and compared with direct observations of the drift of similar shells. The observed and calculated values are in fair agreement, and there is no doubt that the classical theory is substantially correct.

In conclusion, it is perhaps worth mentioning that the interest in such investigations mainly arises from the fact that we can thus study the phenomena of motion through a compressible fluid at velocities both greater and less than the velocity of sound in the fluid. The investigation, however, has scarcely begun, and much work will be required before it is possible to describe adequately the complete reaction on a shell of given shape moving through air.

Obituary

PROF. L. DONCASTER, F.R.S.

LEONARD DONCASTER'S death from sarcoma at the age of forty-two has stopped a career of exceptional distinction. When I lately saw him, apparently in his usual health, presiding over his laboratory as the newly elected Derby professor of zoology at Liverpool, I had comfort in the thought that by his appointment a fresh centre of genetics was safely begun. Doncaster was a natural investigator. From his student days there was never a doubt as to the purpose of his life. The problems of biology were always in his mind. For him the materials were everywhere. Though circumstances led him into academic zoology, he was an excellent field entomologist and botanist, with a fair knowledge also of the domesticated forms. Latterly he became more and more drawn towards cytological methods, but he always kept in touch with the other lines, knowing that the next advance may begin anywhere.

Doncaster started at Naples with experiments on hybridisation of Echinoderm larvæ, which produced evidence of value as to the effects of temperature in modifying dominance; but many aspects of that vexed question remained, and still remain, obscure. He returned to England at the moment when the early struggles of Mendelism were acute. Though constitutionally predisposed to caution, he knew enough of the general course of variation and heredity to be in no doubt of the essential truth of the new doctrines, and undoubtedly his adhesion did much to spread confidence among his contemporaries. He at once joined in breeding work, and at various times experimented with many forms, particularly rats, cats, and pigeons. With insects of several orders he was especially successful. The seemingly more fundamental nature of microscopical work made it very congenial to him, and he always had a mass of cytological material on hand. These studies enabled him to take a prominent part in that comprehensive codification by which the confused and contradictory observations as to the sexes of parthenogenetic and other forms in the Hymenoptera and Hemiptera were ultimately reduced to order.

In the history of biology Doncaster's discovery as to the determination of sex in the currant moth (*Abraxas grossulariata*) will have a permanent place. From the Rev. G. H. Raynor, a fancier of the species, he learnt facts which suggested that the variety *lacticolor* was what we now call "sex-linked," being predominantly associated with females, as colour-blindness in man is with males. After verification and extension this mass of facts provided (1906) the first clear genetic proof of