constituent part of it. Dr. J. B. Collip, of McGill University, and his co-workers, outlined the preparation of the placental hormone emménin, and showed that immature female rats are brought to sex maturity by its injection, thereafter manifesting cyclic changes, while normal adult females are unaffected. R. L. Lutz outlined a method for determining potassium, sodium, calcium, and magnesium in biological material after initial fusion with fuming nitric acid, and described a crystalline organic substance isolated from fuming nitric acid hydrolysates of the protein fraction of beef muscle and of casein.

Drs. V. J. Harding and L. J. Harris, of the University of Toronto, described the production of convulsions and subsequent death in dogs after forced ingestion of large quantities of water. Recovery from the convulsive stage is rapid following intravenous or intraperitoneal injection of ten per cent saline. Dr. John Tait and W. J. McNally, of McGill University, reported that the croaking of frogs is essentially an under-water signal, conveyed by vibration, this vibration occurring when air is

shifted from the lungs to the mouth and air-sacs. The fact that croaking can be heard merely implies that the signalling animal has its head above water at the moment. Dr. B. P. Babkin gave an account of a number of studies of gastric and intestinal digestion by himself and his students. Prof. A. H. R. Buller reported on some further experiments on sex in fungi. Dr. Marie-Victorin gave an account of a study of the literature and of the plant *Elodea canadensis*, leading to greater precision of nomenclature, and Prof. G. W. Scarth presented a series of sinkage studies of floating logs of various trees, the relative amount and distribution of the three phases, wood, water, and gas being studied by gravimetric and microscopic methods. Prof. F. E. Lloyd presented a comparative study of the traps of *Utricularia gibba*, *vulgaris*, and *capensis*.

The Society, under the presidency of Dr. Charles Camsell, Deputy Minister of Mines of the Dominion, has accepted an invitation from the University of Toronto to meet there in 1931, whilst a similar invitation to meet in Vancouver in 1932 was referred to the Council for favourable consideration.

A Study of the Phenomenon of Spin in Airplanes.*

By H. E. WIMPERIS, C.B.E.

METHOD OF STUDY.

SO much for what the spin is and what causes it. We come now to the best way to study it. This can be done by employing models or by the use of full-sized airplanes. The latter method avoids uncertainties due to any possible 'scale effect', that is, failure of the model to represent truly the motions of the full-sized machine, but adds the greater difficulty of making accurate quantitative measurements when in free flight and adds the risk of crash. Experiments with models have been made in wind tunnels and in free flight. Small light models—to one-twelfth or one-twentieth scale—have been made at Farnborough out of balsa wood, and these have been dropped through a free fall of 90 feet in the large balloon shed. Kine-matograph records have been made and the motion afterwards measured up from the films. (One of these films was shown on the screen.) In certain of these model dropping experiments a Bristol Fighter model was used, and success attended the effort to reproduce various types of spin. In this particular machine the rudder was found to be surprisingly effective as a controlling organ, and if the spin were started against this control it was stopped in six turns.

Of all the various controls the aileron is normally the least effective; that is, the ordinary type of aileron. If, however, the possible aileron angle is arranged to be *very* largely increased, the spinning motion is affected. The following account of a model dropping experiment at Farnborough will serve alike to indicate this aileron effect and to illustrate the nature of this mode of this form of experimentation. A 1/20th scale model of a Bristol

Fighter was used. Ailerons were fitted to the upper and lower starboard wings and provision was made for moving any of the controls at a predetermined time during the spin. This was done by means of a spring loaded dash pot with a variable air leak. The model was released from a swinging pendulum just under the roof of the balloon shed in such a way that it was at release moving horizontally at its stalling speed with 10° of sideslip. It was launched with full left rudder and with the elevators fully up. With ailerons neutral the model completed 4½ turns of a left-hand spin in as many seconds. A further test was then made with control release set to move the outer aileron to an angle of 65° after an interval of 2½ seconds, with the result that the model ceased spinning within about half a turn.

The flat spin with this model was found to be one of very small radius, the mean angle of incidence appearing to be about 75° (the smallness of the radius in flat spins is of course well known, as is the consequent extraordinary difference sometimes found in the centrifugal forces acting on the pilot's and observer's bodies). Whereas in the ordinary spins of this model four and a half turns were made in four and a half seconds, in the flat spin, eleven turns were completed in five and a half seconds, and the axis of the spin instead of being well ahead of the nose came close to the centre of gravity.

Sometimes the little model was made automatically to centralise its controls during the fall, and the effect of this on the resulting motion was studied. Sometimes the models were set into a spin at the moment of release and the effect of variations in wing arrangement ascertained. In this way the effects of stagger, wing gap, decalage, and other features can be studied rapidly. This

* Continued from p. 136.

has proved a useful method of investigation; it is safe, speedy, and very picturesque.

The other way of using models is to mount them in a wing tunnel and measure the forces which arise during the spinning motion. This is an exceedingly difficult experiment to carry out for the motion is complex, and it is no very easy matter to lead out the connexions which will enable the couples about each of the axes to be measured. It is not so difficult to measure the moment about the autorotation axis, the axis of spin, and this investigation is now in hand. The amount of the autorotation moment will of course give a measure of one at any rate of the forces tending to keep the airplane in the spin. The fuller experiment will, however, be undertaken in one of the N.P.L. wind tunnels as soon as the apparatus is ready.

Yet another form of wind tunnel test is due to Prof. Betz. This consists in measuring the rate of autorotation of a hollow aerofoil in which air can be allowed to pass internally from one wing tip slit to the other. These slits are placed in the upper surfaces and are parallel to the wing spar. Measurements have been made in Germany with these slits in different symmetrical positions and with or without a free internal air passage. The result is found that with the best arrangement there is at some cost of maximum lift a distinct decrease of the tendency to autorotation, and that this gain is directly associated with the free lateral passage of the air inside the wing. The following explanation of the action is given by Schrenk.¹ It is known that the motion of a rotating wing produces different angles of incidence at corresponding sections of the two ends, such that at the rising end the flow adheres to the upper surface whilst at the other end it tends to break away. For this reason the lift on two such corresponding elements is not necessarily the same, and in no case will the pressure distributions on the elements coincide. The flow from slit to slit through the wing is caused by such differences of pressure, and acts in such a way that at the wing tip at which the flow breaks away from the surface the flow is improved by suction of the boundary layer towards the interior of the wing; at the other end the flow is rendered worse by the air streaming out of the slit. It follows that any autorotation there may be will tend to be much slower and therefore more controllable.

The first full scale experimental and mathematical investigation of spinning was that by Lindemann, Glauert, and Harris. This work was carried out at Farnborough, and in their report to the Aeronautical Research Committee, dated March 1918, full details of this very courageous investigation are given. It is noteworthy that they made use of streamers attached to outrigger spars, and by their use measured for the first time the angle of incidence.

At the present time full scale research on spinning is included in the research programme at Farnborough. Indeed, the phenomenon is one which requires continuous study since each new development of airplane design may bring in some new aspect of the spinning problem.

In addition to this work there are the normal 'performance tests' on spinning which are carried out at Martlesham on all new types of airplane, during which each machine is spun through not less than eight turns to right and to left with varying positions of the centre of gravity, and no machine is passed for service unless it can be readily bought out of such a spin by the normal use of the controls. Intrepid pilots are needed for such tests on new machines, and it does sometimes happen that the obstinacy of the airplane in its motion requires the pilot to resort to his parachute, though, curiously enough, the mere rising of the pilot in his seat with the view of leaving the airplane has on more than one occasion caused the machine to come out of its spin at once! Sometimes the engine throttle can be used as a control on the spin, since change of engine torque will of course tend to roll the machine to a new attitude. Spinning tests have also been undertaken by the Cambridge University Air Squadron with the help of Prof. Melvill Jones. In these tests the wool tuft method due to Flight Lieutenant Haslam has been found of use. This consists of mounting numerous little tufts of wool on the upper surface of the wing and watching (in some cases taking cinema records of) what happens when the machine gets into various attitudes. As I have already mentioned, a rather similar method of experiment has been used at Farnborough, in which long streamers have been attached to the wing tips or other airplane parts and their motion studied in the spin.

It is not pretended that the behaviour of these streamers is understood, but it is hoped that the continuation of the research will bring such knowledge as will enable these results to be usefully interpreted. As an example of the complexity the following extract may be given from a Farnborough report:

It was decided to investigate the practicability of recording the direction of the air flow over various parts of the airplane while spinning by photographing streamers. Outriggers were fixed to the lower planes. These were attached to the front spars and projected two feet beyond the wing tips, fabric streamers four feet in length being attached to the ends. Streamers were also fixed to tubes projecting 9 inches in front of the leading edge of the tail plane three feet from the plane of symmetry. . . . The inclination of the wing tip streamers was found to vary in phase with the oscillation of the spin. In the left hand spin the mean inclination of the inner streamer to the wing cord was 73° and that of the outer streamer 24° The photographs of the tail plane streamers were less satisfactory, and it was only possible to determine the inclinations of the inner streamer; . . . the mean inclination of the streamer was about 15° from the Z axis towards the rudder, which implies a natural flow at the streamer which is opposite in direction to that caused by the rotation of the tail. An inward sideslip of the order of 20° would satisfy these conditions.

These experiments show that in nearly flat spins where the rate of rotation is high and the vertical velocity small, the tail unit has to operate in air previously disturbed by the passage of the wing tips. This disturbance of course does not add to the effectiveness of the tail control organs. The

sole merit to be found in the motion in a flat spin is that the vertical velocity is quite often so small that little more than a crashed under-carriage results from hitting the ground. In this type of spin the wings are acting rather like those of an autogiro, but very inefficiently, of course, since one wing is entering the air by its trailing edge.

Another method of full scale test making use of a cinematograph camera on the ground has been employed in Germany. The size of the image on the film gives a rough measure of the distance away of the airplane, whilst the angular distance and the time are readily noted. Cinema methods are also in use in U.S.A. (A cinema film furnished by the National Advisory Committee for Aeronautics of America, and showing a seaplane performing a flat spin, was shown at the end of the lecture.)

When new types of airplanes are tested at the R.A.F. Station at Martlesham in order to ascertain their performance under all conditions of flight, they need to be spun both to left and right and not merely in one direction only. This is because of the influence of the direction of engine rotation upon the slip stream, and because of the gyroscopic couple due to the rotating engine and airscrew which will try to depress the nose of the craft in one case and raise it in the other. Recovery is required to be simple and sure even when this gyrostatic couple assists the inertia couple in opposing the pilot's actions.

At first it was not realised that an airplane that could easily be brought out of a spin of a few turns would not necessarily be easily brought out if the spin were continued for a large number of turns. The reason for this is not certainly known, but it can scarcely fail to be associated with sheer lapse of time allowing the forces opposing recovery gradually to raise the nose of the machine, and so get it into a condition in which for one reason or another the pilot's controls are less effective. Nor has it long been realised that the effect of small differences in the actual mode of entry into the spin can persist even after many turns, and so sometimes render recovery unexpectedly difficult. This explains the previously puzzling question why pilot A's report on the controllability of a given machine in a spin differs entirely from pilot B's. The explanation no doubt is that the two pilots follow a slightly different technique in putting their airplanes into

spins. For research investigations it is feasible always to employ the same technique, but during the performance testing of new aircraft consideration must be given also to what is likely to happen when this definite technique is not followed.

THE WOOF.

A recent discovery is the 'Woof'. This is a word coined by the Martlesham pilots to describe the unsteady form of spin sometimes met with in which there is an oscillation in pitch combined with an oscillation in spin, so leading to a very uncomfortable motion. This is so little understood at the moment that one of the Air Ministry Scientific Research Staff in a recent report had to admit that "the origin of the air forces necessary to maintain this fluctuation in attitude is at present a mystery, and this obscurity is typical of the present stage of the spinning problem". In one recent test the jerkiness of the motion could be distinctly seen from the ground. The unevenness of rotation was accompanied by an appreciable oscillation in pitch, the rate of rotation decreasing as the nose of the aircraft rose and increasing as it fell. Accelerometer records showed the mean period of the pitch oscillation to be rather more than 5 seconds, whereas the corresponding mean times per turn of these spins was only about $4\frac{1}{2}$ seconds. The complexity of the motion may be inferred from the different periodic times.

It may be of course that, long before these highly complex phenomena are fully understood, some novel constructional device will be produced which will at once render all spins controllable. A device which went so far as to prevent spinning altogether would probably not be desirable since it might also prevent the useful manoeuvre of the 'roll'.

It is true, I fear, that in these matters we ask a great deal. We ask that the airplane shall do everything that the pilot wishes, but shall have no will of its own other than a moderate wish to remain the right way up, but even this not to be thrust too prominently before the pilot's notice. We want a docile machine. We want, in fact, an amount of docility which though often sought is but rarely found, even in humanity.

¹ Z.T.M., Nov. 14, 1929.

Obituary.

MR. W. J. GREENSTREET.

BY the death of William John Greenstreet on June 28 the mathematical world loses, not an explorer or a geographer, but, if the metaphor may be pressed, a traveller familiar with a larger variety of landscape than almost any of his contemporaries. Born in 1861 and educated at St. John's College, Cambridge, he was an assistant master from 1882 until 1889, and headmaster of Marling School, Stroud, from 1891 until 1910, when he retired to Burghfield Common, near

Reading, with the intention of devoting himself to literary work. For many years he had been a regular contributor to *Notes and Queries* and to the *Westminster Gazette*, and editor of the *Mathematical Gazette*, and he had every reason to anticipate a life congenial to his frugal tastes.

The War, however, put an end to Greenstreet's work for the *Westminster Gazette*, and at the same time raised the cost of living to an unforeseen level. The result was an extension of an activity which he had created, namely, the supervision of the