DR. S. P. LANGLEY'S EXPERIMENTS IN AERODYNAMICS.*

"So far as the mere power to sustain heavy bodies in the air by mechanical flight goes, *such mechanical flight is possible with engines we now possess.*" These words, coming as they do from the Secretary of the Smithsonian Institution, a gentleman who prominently represents the dignity of official science in this country, and who is everywhere recognized as a physicist of known reputation, carry with them a weight of authority. Nearly five years ago Prof. S. P. Langley, then the director of the Observatory at Allegheny, Pa., commenced there a series of experiments in aerodynamics, the results of which he has recently placed before the public, and of which we here give abstracts.

Mr. Hiram S. Maxim, inventor of the well known Maxim machine gun, has been conducting in England within the past two years experiments in some respects similar, and has independently and with remarkable coincidence reached some of the same important conclusions as Dr. Langley. The experiments common to each have been to determine the lifting power of inclined aeroplanes when driven horizontally through the air at high velocities. In the experiments of Mr. Maxim the aeroplane used had a spread of 12 feet, and was thus relatively large with respect to the radius (30 feet) of the circle in which it was moved. In Dr. Langley's experiments, though the whirling arm was of approximately the same length, the aeroplanes were designedly made so small that, for any small portion of their path, the whole would move approximately in a straight line, and the disturbing effects of centrifugal force be rendered quite negligible.

As only Dr. Langley's novel experiments and discoveries are as yet before the public in any detailed form, these only can here be particularly described. They were made with the object of taking nothing on trust, but of putting everything to the test of actual trial, even at the risk of superfluous experiment, and they were concerned with the scientific aspect of the subject rather than with the particular new art of aerodromics or air-running which they pointed to.

The whirling table which was used as an auxiliary in all the experiments (see engravings) consisted essentially of a horizontal arm thirty feet long, driven ordinarily by a 10 horse power engine, at varying speeds up to one hundred feet per second, or about 70 miles an hour, its rate of rotation being registered on a stationary chronograph, by the action of quadrant electric contacts placed around the axis of the revolving arm. The chronograph sheets, therefore, preserved a permanent exact record of the velocity of rotation for every revolution and quarter of a revolution throughout every series of experiments. By means of a series of step pulleys, all velocities at the end of the arm from rest up to this 70 miles an hour were actually attained in experiment. It was also possible by means of the reaction of the wind from a small propeller at the end of the arm to drive it independently of the engine, but the latter was generally used.

With this apparatus a number of different accessory pieces of mechanism were devised for measuring the power expended, and for recording resistances overcome while driving through the air aeroplanes placed at the end of the rotating arm. The subjects of investigation covered phases of pressure and resistance on inclined planes of different form, size, and weight, together with power necessary to sustain and propel them through the air.

The description may be inaugurated with an illustrative experiment giving one factor of demonstration. In this case a heavy metal plane was suspended from the movable horizontal arm by a spring balance, which, when all was at rest, was drawn out a distance corresponding to the weight. It had been a tacit assumption underlying the calculation of previous investigators that when such a plane surface was not only suspended, but also dragged along in rapid motion, the tension or strain would be increased, and that the spring balance would be drawn out still further. Applying this idea to the flight of birds, Navier and other eminent men of science had calculated that it would take nearly fifty times the power which a bird expended in sustaining its own weight in the air by hovering over one spot, to not only sustain the weight, but move it along in rapid flight; and on this very natural but erroneous assumption they reached the conclusion that it would take one-thirteenth of a horse power to sustain the flight of a model no bigger than a swallow, and by implication it followed plainly enough that no known mechanical power could be strong enough consistent with the necessary lightness to ever make a flying-machine. In Dr. Langley's illustration, which is essentially an introduction to more demonstrative experiments, the heavy metal plane suspended by a spring from the motionless arm drew out that spring to a carefully noted distance by its dead weight; but, as soon as the whirling table was put in motion, and the plane was not only suspended but dragged along with the lateral movement, the spring was seen to *contract* more and more instead of lengthening, showing that the pull *diminished* with each increment of speed.

It does not appear that this experiment, simple as it is, has ever before been tried, though, as soon as it has been tried, the result is seen to be so immediate a consequence of a known principle that it is apt to appear self-evident and superfluous. It becomes evident, by Dr. Langley's experiment, that the faster the motion in the air the less is the pull, contrary to what is obtained in transport on land or in water. The faster the inclined plane goes, the more it tips forward, and the smaller is the effective resisting surface that it offers.

Now, since the power exerted is measured, not by the tension alone, but by the product of tension into the distance through which this is exerted in a given time, this experiment, while noteworthy for the simplicity of its illustration, proves only that one of these factors diminishes while the other increases, as higher velocities are attained, and is so far incomplete. But it suggested to Dr. Langley the inquiry whether the second factor might not increase less rapidly than the first diminished, so that the product of the two factors, stress and distance, namely, the *power* expended, might not also diminish with increasing speed, with the startling consequence that, except for friction with such heavy planes, the greater the horizontal speed, the *less* would be the power required to maintain it, a conclusion which, if reached, would be apparently paradoxical in its novelty and of far-reaching importance in its consequences.

So novel a conception as that there might exist a practicable mode of transport in which, through a wide range of velocities of horizontal motion, the greater the speed, the less the power required to maintain it, evidently demands the most convincing experimental demonstration. For this purpose a number of pieces of special apparatus were devised so as to test the fact, if true, and repeat the demonstration in numerous different ways. The first quantitative experiments were made with an instrument devised by Dr. Langley and called by him the "resultant pressure recorder" (see cut), for measuring the total normal pressure on an inclined plane moving in the air, and to examine an assumption made by Newton, which had stood in the way of previous investigators. This assumption (see Principia, proposition xxxiv, book ii) was that this pressure varies with the square of the sine of the angle between the surface and the direction of advance. From the results obtained by it, Newton's assumption is shown to be widely erroneous.

It has always been known that an inclined plane can be supported in the air by being pulled along on it, as a kite by its string, and it is theoretically possible that the kite could be moved without a string by propellers or other means worked by an engine, if the latter were light enough, in proportion to its strength, to be supported by the upward air pressure in question. By Newton's formula and Smeaton's constant of wind pressure, each square foot of a kite or plane held at the angle of five degrees with the horizon, and moved along at a rate of 35 miles an hour, would support, by the reaction of the air, a weight of only about one-twentieth of a pound. If the engine, then, weighed even an ounce for each foot of supporting surface, it could not sustain its own weight. One conclusion of the experiments with the Langley resultant pressure recorder was that Newton's assumption was wrong, and that in the supposed case the actual weight capable of being supported is twenty times as great as that so computed, while for smaller angles and better disposed rectangles the error is still larger. It followed, then, that if reasonably light engines could be built, what was before impossible now becomes possible; and to demonstrate that within certain limits the power required for horizontal flight actually diminished as the speed increased, a piece of apparatus called the "plane dropper" was devised (see cut). It is designed to show (1) that a horizontal plane falls slower in horizontal motion than when at rest; (2) to make actual measurements of the time of fall of variously shaped planes; (3) to determine for different angles of inclination the speed necessary in order to derive an upward thrust from the air just sufficient for sustaining the planes.

With this apparatus, with planes horizontally disposed, a plane 30 inches long, 4 inches wide, and of 1 pound weight, was driven horizontally in the direction of its width. When allowed to fall from rest, the time of falling was 0·53 second, the retardation due to the resistance of the air being 0·03 second. When driven forward through the air, the time of fall increased until with a velocity of 66 feet per second (45 miles an hour) the time of fall was 2 seconds. The results with the planes inclined at various angles are presented in Dr. Langley's memoir in graphic curves which show at a glance, for the differently shaped planes used, the speed necessary in order that they shall be supported in the air at angles of inclination ranging from 2° to 30°. The resistance of these planes to advance while thus supported, and the horse power necessary for maintaining the motion, are derived from the preceding experiments. These results confirm by experimental demonstration, up to velocities of 50 miles an hour, the proposition of which the first experiments with the suspended plane gave a prevision, namely, that in the horizontal flight of an aeroplane it takes less power to maintain a high speed than a low one.

For further demonstration an entirely different instrument, called the component pressure recorder, (see cut) was next devised. This instrument gave a direct measurement of the horizontal resistance to the inclined planes while being driven through the air with speeds at which the vertical pressure of the air sustained the weight ("soaring speeds"), and the motion became as if they were entirely free from support or constraint. A long series of experiments was made with this apparatus in which hundreds of observations were obtained, the quantitative data of which render the conclusions very striking. Dr. Langley observes: "Since effective steam engines have lately been built weighing less than 10 pounds to one horse power, and the experiments show that if we multiply the small planes which have been actually used, or assume a larger plane to have approximately the properties of similar small ones, one horse power rightly applied can sustain over 200 pounds in the air at a horizontal velocity of over 20 meters per second (about 45 miles an hour), and still more at still higher velocities."

Having determined the power necessary to be expended in driving forward differently shaped aeroplanes, at soaring speeds, methods and apparatus were devised for investigating the efficiency of propellers in furnishing the end thrust shown to be requisite. This is accomplished by means of the "dynamometer chronograph" (see cut) used in connection with the component pressure recorder. The former instrument is a complete, self-registering dynamometer (placed at the end of the arm of the turntable with the propeller), which gives indicator diagrams, showing the amount of power expended in driving the propeller and the return in end thrust which this gives back. The power for driving was furnished by a small electro motor, located on the rotary arm, but actuated by a stationary dynamo. For this experiment, it is necessary that the propeller shall drive itself through the air at high speeds, while attached to the heavy, massive arm of the turntable, this latter offering a resistance out of all proportion to that of an aerodrome, such as the little propeller is adapted to drive. In the auxiliary use of the component pressure recorder, mounted at the end of the great whirling arm, Dr. Langley has overcome this last difficulty. The instrument has an arm of its own, six feet long, susceptible of oscillation about a vertical axis. Upon the end of *this* arm is placed the dynamometer and propeller, and the whole is set in motion at a high speed by the rotation of the great whirling arm. Then the propeller is actuated by the dynamo at increasing speeds, until its end thrust is so great as to actually begin to drive it ahead of the turntable, this critical instant being observed and recorded by the motion of the recorder's arm about the vertical axis. At this instant, then, the propeller and its aeroplane are no longer being carried forward by the turntable, but the propeller is driving itself ahead independently of it, but at exactly the same speed. The product of this speed by the end thrust, measured on the dynamometer, furnishes the performance of the propeller, and when compared with the power expended, shows its efficiency.

This is an outline of the principal steps in the investigations. Dr. Langley concludes his memoir with the following words: "I am not prepared to say that the relations of power, area, weight, and speed, here experimentally established for planes of small area, will hold for indefinitely large ones; but from all the circumstances of experiment, I can entertain no doubt that they do so hold far enough to afford assurance that we can transport (with fuel for a considerable journey and at speeds high enough to make us independent of ordinary winds) weights many times greater than that of a man. In this mode of supporting a body in the air, its specific gravity, instead of being as heretofore a matter of primary importance, is a matter of indifference, the support being derived essentially from the inertia and elasticity of the air on which the body is made to rapidly run. . . . . I wish, however, to put on record my belief that the time has come for these questions to engage the serious attention, not only of engineers, but of all interested in the possibly near practical solution of a problem, one of the most important in its consequences of any which has ever presented itself in mechanics; for this solution, it is here shown, cannot longer be considered beyond our capacity to reach."

* In the preparation of this article the editor has been placed under obligations to Mr. George E. Curtis, of the Smithsonian Institution, who has exhibited apparatus and placed at his disposal the literature of the subject. Among the latter the following have been freely consulted: "Recherches Experimentales Aerodynamiques et donnees d'experience," S. P. Langley, extracted from *Comptes Rendus des seances de l'Academie des Sciences*, seance du 13 juillet, 1891; small 4to, 4 pp. "Experiments in Aerodynamics." S. P. Langley, *Smithsonian Contributions to Knowledge*, 801, Aug., 1891; large 4to, 115 pp., 10 plates. "The Possibility of Mechanical Flight," S. P. Langley, *Century*, Sept., 1891; 3 pp. "Aerial Navigation; the Power Required," Hiram S. Maxim, *Century*, Oct., 1891; 5 pp., illus.

ACCORDING to Dr. H. A. Kelly, permanganate of potassium and oxalic acid are harmless to the hands and are germicidal. Soap and water plus the permanganate of potassium and oxalic acid are the only true germicides, and the best disinfectants we possess to-day.