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SOME AERONAUTICAL EXPERIMENTS.

BY

WILBUR WRIGHT.

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(WITH PLATES I-IV).

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SOME AERONAUTICAL EXPERIMENTS.[a]

Mr. WILBUR WRIGHT, Dayton, Ohio.

[Presented to the Western Society of Engineers September 18, 1901.]

INTRODUCTION BY PRESIDENT CHANUTE.

"Engineers have, until recent years, fought shy of anything relating to aerial navigation. Those who ventured, in spite of the odium attached to that study, to look into it at all became very soon satisfied that the great obstacle in the way was the lack of a motor sufficiently light to sustain its weight and that of an aeroplane upon the air. Fifteen years ago the lightest steam motor was the marine engine, weighing 60 pounds to the horsepower, while the gas engine weighed very much more; the locomotive weighed 200 pounds per horsepower. During the past fifteen years a great change has taken place. Steam motors have been produced weighing only 10 pounds per horsepower, and gas engines have been lightened down to 12½ to 15 pounds per horsepower, so that the status, so far as engineers are concerned, is very greatly changed, and there is some hope that, for some limited purposes at least, man will eventually be able to fly through the air. There is, however, before that can be carried out—before a motor can be applied to a flying machine—an important problem to solve—that of safety or that of stability.

"I had the honor of telling you, some four or five years ago, something about the progress that had been made up to that time. Since then further advances have been made by two gentlemen from Dayton, Ohio—Mr. Wilbur Wright and Mr. Orville Wright—who tried some very interesting experiments in October, 1900. These experiments were conducted on the seashore of North Carolina, and were again resumed last July. These gentlemen have been bold enough to attempt some things which neither Lilienthal, nor Pilcher, nor myself dared to do. They have used surfaces very much greater in extent than those which hitherto had been deemed safe, and they have accomplished very remarkable results, part of which it was my privilege to see on a visit which I made to their camp about a month ago.

"I thought it would be interesting to the members of this society to be the first to learn of the results accomplished, and therefore I have the honor of presenting to you Mr. Wilbur Wright."

[a] Reprinted by permission, after revision by the author, from Journal of the Western Society of Engineers, December, 1901.

The difficulties which obstruct the pathway to success in flying-machine construction are of three general classes: (1) Those which relate to the construction of the sustaining wings; (2) those which relate to the generation and application of the power required to drive the machine through the air; (3) those relating to the balancing and steering of the machine after it is actually in flight. Of these difficulties two are already to a certain extent solved. Men already know how to construct wings or aeroplanes which, when driven through the air at sufficient speed, will not only sustain the weight of the wings themselves, but also that of the engine and of the engineer as well. Men also know how to build engines and screws of sufficient lightness and power to drive these planes at sustaining speed. As long ago as 1894 a machine weighing 8,000 pounds demonstrated its power both to lift itself from the ground and to maintain a speed of from 30 to 40 miles per hour, but failed of success owing to the inability of the operators to balance and steer it properly. This inability to balance and steer still confronts students of the flying problem, although nearly eight years have passed. When this one feature has been worked out, the age of flying machines will have arrived, for all other difficulties are of minor importance.

The person who merely watches the flight of a bird gathers the impression that the bird has nothing to think of but the flapping of its wings. As a matter of fact this is a very small part of its mental labor. To even mention all the things the bird must constantly keep in mind in order to fly securely through the air would take a considerable part of the evening. If I take this piece of paper, and after placing it parallel with the ground, quickly let it fall, it will not settle steadily down as a staid, sensible piece of paper ought to do, but it insists on contravening every recognized rule of decorum, turning over and darting hither and thither in the most erratic manner, much after the style of an untrained horse. Yet this is the style of steed that men must learn to manage before flying can become an everyday sport. The bird has learned this art of equilibrium, and learned it so thoroughly that its skill is not apparent to our sight. We only learn to appreciate it when we try to imitate it. Now, there are two ways of learning how to ride a fractious horse: One is to get on him and learn by actual practice how each motion and trick may be best met; the other is to sit on a fence and watch the beast a while, and then retire to the house and at leisure figure out the best way of overcoming his jumps and kicks. The latter system is the safest, but the former, on the whole, turns out the larger proportion of good riders. It is very much the same in learning to ride a flying machine; if you are looking for perfect safety, you will do well to sit on a fence and watch the birds; but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial.

Herr Otto Lilienthal seems to have been the first man who really comprehended that balancing was the first instead of the last of the great problems in connection with human flight. He began where others left off, and thus saved the many thousands of dollars that it had theretofore been customary to spend in building and fitting expensive engines to machines which were uncontrollable when tried. He built a pair of wings of a size suitable to sustain his own weight, and made use of gravity as his motor. This motor not only cost him nothing to begin with, but it required no expensive fuel while in operation, and never had to be sent to the shop for repairs. It had one serious drawback, however, in that it always insisted on fixing the conditions under which it would work. These were, that the man should first betake himself and machine to the top of a hill and fly with a downward as well as a forward motion. Unless these conditions were complied with, gravity served no better than a balky horse—it would not work at all. Althougth Lilienthal must have thought the conditions were rather hard, he nevertheless accepted them till something better should turn up; and in this manner he made some two thousand flights, in a few cases landing at a point more than 1,000 feet distant from his place of starting. Other men, no doubt, long before had thought of trying such a plan. Lilienthal not only thought, but acted; and in so doing probably made the greatest contribution to the solution of the flying problem that has ever been made by any one man. He demonstrated the feasibility of actual practice in the air, without which success is impossible. Herr Lilienthal was followed by Mr. Pilcher, a young English engineer, and by Mr. Chanute, a distinguished member of the society I now address. A few others have built gliding machines, but nearly all that is of real value is due to the experiments conducted under the direction of the three men just mentioned.

The balancing of a gliding or flying machine is very simple in theory. It consists in causing the center of gravity to coincide with the center of pressure. But in actual practice there seems to be an almost boundless incompatibility of temper which prevents their remaining peaceably together for a single instant, so that the operator, who in this case acts as peacemaker, often suffers injury to himself while attempting to bring them together. If a wind strikes a vertical plane, the pressure on that part to one side of the center will exactly balance that on the other side, and the part above the center will balance that below. But if the plane be slightly inclined, the pressure on the part nearest the wind is increased and the pressure on the other part decreased, so that the center of pressure is now located, not in the center of the surface, but a little toward the side which is in advance. If the plane be still further inclined the center of pressure will move still farther forward, and if the wind blow a little to one side it will also move over as if to meet it. Now, since neither the wind nor the machine for even an instant maintains exactly the same direction and velocity, it is evident that the man who would trace the course of the center of pressure must be very quick of mind; and he who would attempt to move his body to that spot at every change must be very active indeed. Yet this is what Herr Lilienthal attempted to do, and did do with most remarkable skill, as his two thousand glides sufficiently attest. However, he did not escape being overturned by wind gusts several times, and finally lost his life as the result of an accidental fall. The Pilcher machine was similar to that of Lilienthal. On one occasion, while exhibiting the flight of his machine to several members of the Aëronautical Society of Great Britain, it suddenly collapsed and fell to the ground, causing injuries to the operator which proved sadly fatal. The method of managment of this machine differed in no important respect from that of Lilienthal, the operator shifting his body to make the centers of pressure and gravity coincide. Although the fatalities which befell the designers of these machines may have been due to the lack of structural strength rather than to lack of control, nevertheless it had become clear to the students of the problem that a more perfect method of control must be evolved. The Chanute machines marked a great advance in both respects. In the multiple wing machine the tips folded slightly backward under the pressure of wind gusts, so that the travel of the center of pressure was thus largely counterbalanced. The guiding of the machine was done by a slight movement of the operator's body toward the direction in which it was desired that the machine should go. The double-deck machine, built and tried at the same time, marked a very great structural advance, as it was the first in which the principles of the modern truss bridges were fully applied to flying-machine construction. This machine, in addition to its greatly improved construction and general design of parts, also differed from the machine of Lilienthal in the operation of its tail. In the Lilienthal machine the tail, instead of being fixed in one position, was prevented by a stop from folding downward beyond a certain point, but was free to fold upward without any hindrance. In the Chanute machine the tail was at first rigid, but afterwards, at the suggestion of Mr. Herring, it was held in place by a spring that allowed it to move slightly either upward or downward with reference to its normal position, thus modifying the action of the wind gusts upon it, very much to its advantage. The guiding of the machine was effected by slight movements of the operator's body, as in the multiple-wing machines. Both these machines were much more manageable than the Lilienthal type, and their structural strength, notwithstanding their extreme lightness, was such that no fatalities or even accidents marked the glides made with them, although winds were successfully encountered much greater in violence than any which previous experimenters had dared to attempt.

My own active interest in aeronautical problems dates back to the death of Lilienthal in 1896. The brief notice of his death which appeared in the telegraphic news at that time aroused a passive interest which had existed from my childhood and led me to take down from the shelves of our home library a book on Animal Mechanism, by Professor Marey, which I had already read several times. From this I was led to read more modern works, and as my brother soon became equally interested with myself we soon passed from the reading to the thinking, and finally to the working stage. It seemed to us that the main reason why the problem had remained so long unsolved was that no one had been able to obtain any adequate practice. We figured that Lilienthal in five years of time had spent only about five hours in actual gliding through the air. The wonder was not that he had done so little, but that he had accomplished so much. It would not be considered at all safe for a bicycle rider to attempt to ride through a crowded city street after only five hours' practice, spread out in bits of ten seconds each over a period of five years; yet Lilienthal with this brief practice was remarkably successful in meeting the fluctuations and eddies of wind gusts. We thought that if some method could be found by which it would be possible to practice by the hour instead of by the second there would be hope of advancing the solution of a very difficult problem. It seemed feasible to do this by building a machine which would be sustained at a speed of 18 miles per hour, and then finding a locality where winds of this velocity were common. With these conditions, a rope attached to the machine to keep it from floating backward would answer very nearly the same purpose as a propeller driven by a motor, and it would be possible to practice by the hour, and without any serious danger, as it would not be necessary to rise far from the ground, and the machine would not have any forward motion at all. We found, according to the accepted tables of air pressures on curved surfaces that a machine spreading 200 square feet of wing surface would be sufficient for our purpose, and that places could easily be found along the Atlantic coast where winds of 16 to 25 miles were not at all uncommon. When the winds were low it was our plan to glide from the tops of sand hills, and when they were sufficiently strong to use a rope for our motor and fly over one spot. Our next work was to draw up the plans for a suitable machine. After much study we finally concluded that tails were a source of trouble rather than of assistance; and therefore we decided to dispense with them altogether. It seemed reasonable that if the body of the operator could be placed in a horizontal position instead of the upright, as in the machines of Lilienthal, Pilcher, and Chanute, the wind resistance could be very materially reduced, since only 1 square foot instead of 5 would be exposed. As a full half horsepower could be saved by this change, we arranged to try at least the horizontal position. Then the method of control used by Lilienthal, which consisted in shifting the body, did not seem quite as quick or effective as the case required; so, after long study, we contrived a system consisting of two large surfaces on the Chanute double-deck plan, and a smaller surface placed a short distance in front of the main surfaces in such a position that the action of the wind upon it would counterbalance the effect of the travel of the center pressure on the main surfaces. Thus changes in the direction and velocity of the wind would have little disturbing effect, and the operator would be required to attend only to the steering of the machine, which was to be affected by curving the forward surface up or down. The lateral equilibrium and the steering to right or left was to be attained by a peculiar torsion of the main surfaces, which was equivalent to presenting one end of the wings at a greater angle than the other. In the main frame a few changes were also made in the details of construction and trussing employed by Mr. Chanute. The most important of these were (1) the moving of the forward main crosspiece of the frame to the extreme front edge; (2) the encasing in the cloth of all crosspieces and ribs of the surfaces; (3) a rearrangement of the wires used in trussing the two surfaces together, which rendered it possible to tighten all the wires by simply shortening two of them.

With these plans we proceeded in the summer of 1900 to Kitty Hawk, N. C., a little settlement located on the strip of land that separates Albemarle Sound from the Atlantic Ocean. Owing to the impossibility of obtaining suitable material for a 200 square foot machine, we were compelled to make it only 165 square feet in area, which according to the Lilienthal tables would be supported at an angle of 3° in a wind of about 21 miles per hour. On the very day that the machine was completed the wind blew from 25 to 30 miles per hour, and we took it out for trial as a kite. We found that, while it was supported with a man on it in a wind of about 25 miles, its angle was much nearer 20° than 3°. Even in gusts of 30 miles the angle of incidence did not get as low as 3°, although the wind at this speed has more than twice the lifting power of a 21-mile wind. As winds of 30 miles per hour are not plentiful on clear days, it was at once evident that our plan of practicing by the hour, day after day, would have to be postponed. Our system of twisting the surfaces to regulate the lateral balance was tried and found to be much more effective than shifting the operator's body. On subsequent days, when the wind was too light to support the machine with a man on it, we tested it as a kite, working the rudders by cords reaching to the ground. The results were very satisfactory, yet we were well aware that this method of testing is never wholly convincing until the results are confirmed by actual gliding experience.

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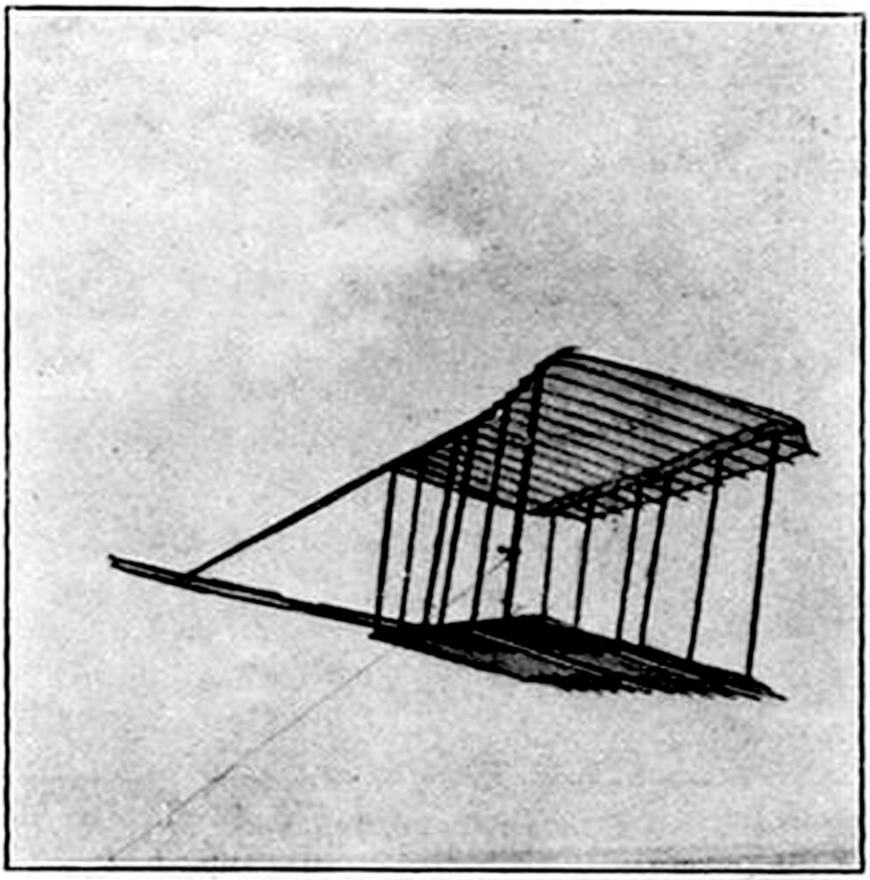

FIG. 1.—THE 1900 MACHINE.

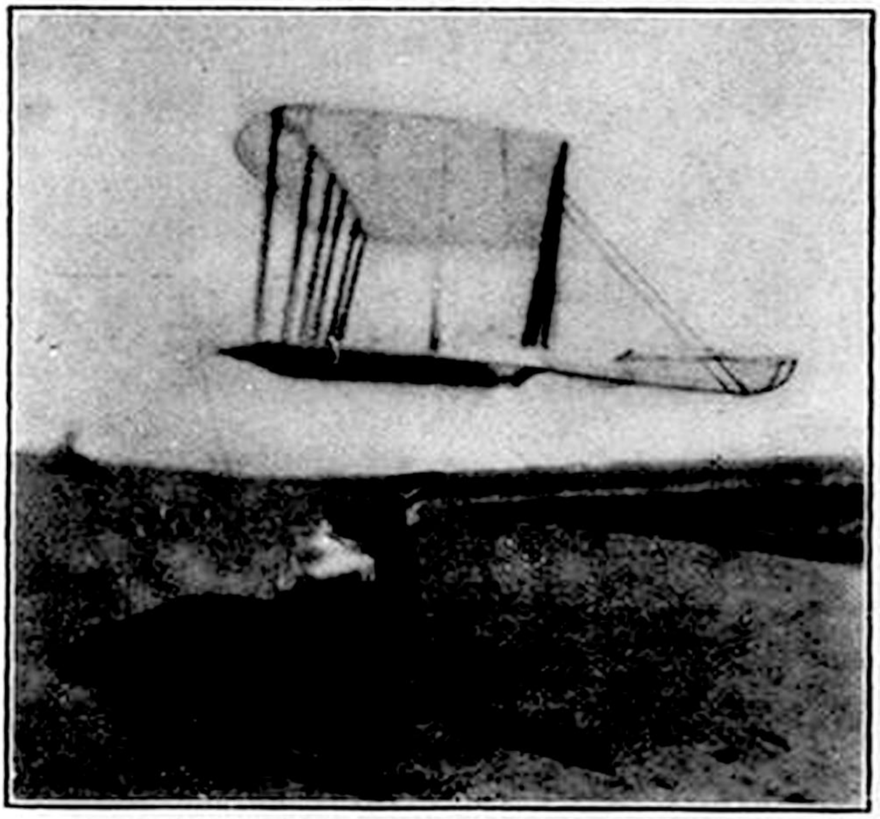

FIG. 2.—KITE SOARING.

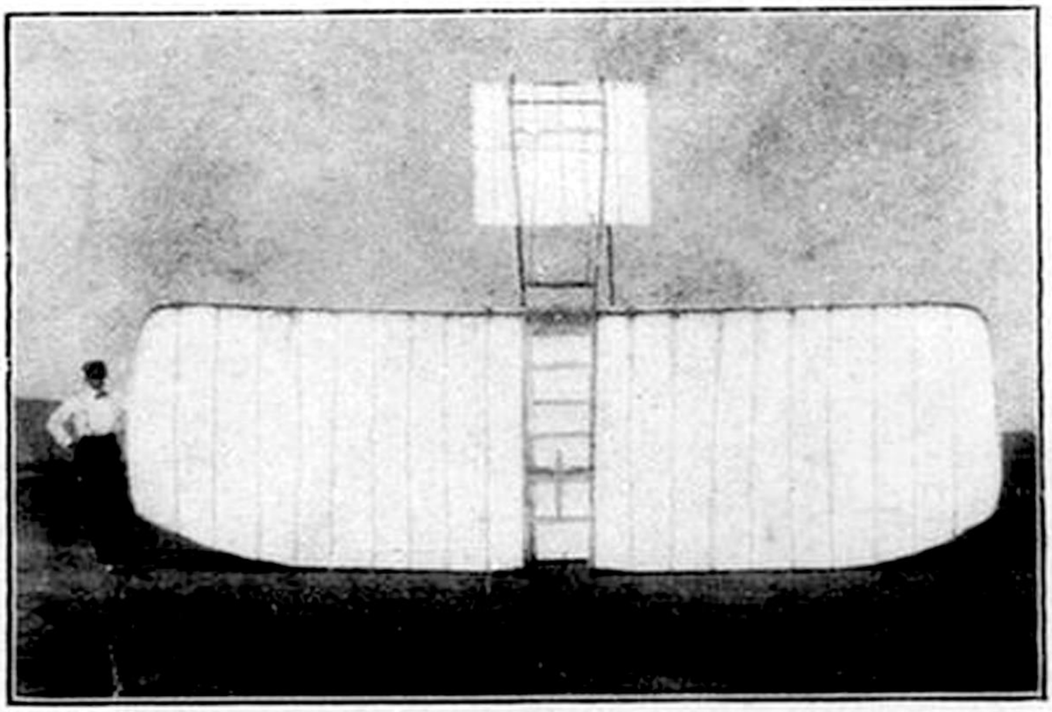

FIG. 1.—A BOTTOM VIEW.

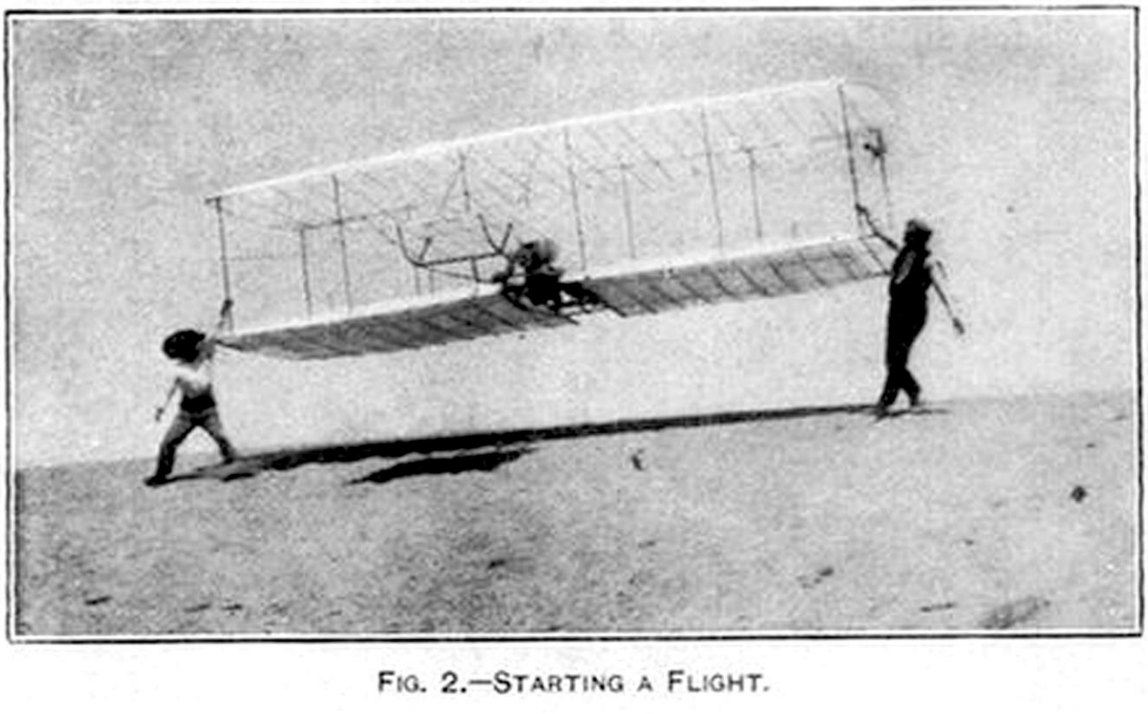

FIG. 2.—STARTING A FLIGHT.

horizontal pull; but when the wind became still stronger it took the lower position shown in the figure, with a strong downward pull. It at once occurred to me that here was the answer to our problem, for it is evident that in the first case the center of pressure was in front of the center of gravity, and thus pushed up the front edge; in the second case they were in coincidence and the surface in equilibrium, while in the third case the center of pressure had reached a point even behind the center of gravity, and there was therefore a downward pull on the

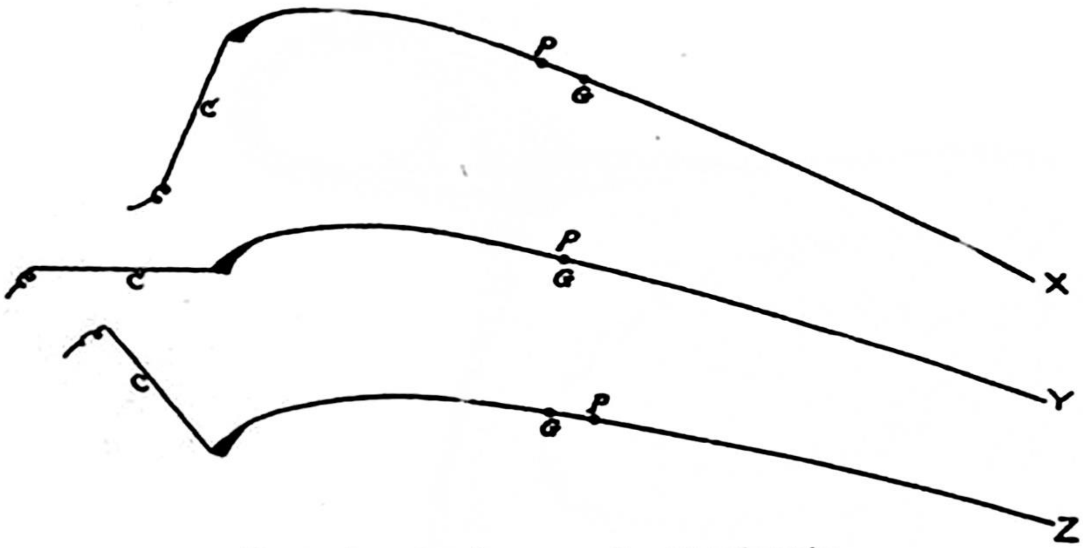

FIG. 1.—P, center of pressure; G, center of gravity.

cord. This point having been definitely settled, we proceeded to truss down the ribs of the whole machine, so as to reduce the depth of curvature. In fig. 2 line 1 shows the original curvature; line 2, the curvature when supporting the operator's weight, and line 3, the curvature after trussing.

On resuming our gliding, we found that the old conditions of the preceding year had returned, and after a few trials made a glide of 366 feet and soon after one of 389 feet. The machine with its new

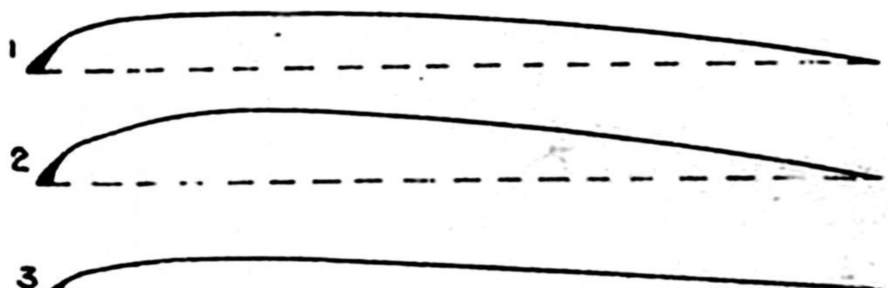

FIG. 2.—Diagrams of pressures and curves.

curvature never failed to respond promptly to even small movements of the rudder. The operator could cause it to almost skim the ground, following the undulations of its surface, or he could cause it to sail out almost on a level with the starting point, and passing high above the foot of the hill, gradually settle down to the ground. The wind on this day was blowing 11 to 14 miles per hour. The next day, the conditions being favorable, the machine was again taken out for trial.

This time the velocity of the wind was 18 to 22 miles per hour. At first we felt some doubt as to the safety of attempting free flight in so strong a wind, with a machine of over 300 square feet, and a practice of less than five minutes spent in actual flight. But after several preliminary experiments we decided to try a glide. The control of the machine seemed so good that we then felt no apprehension in sailing boldly forth. And thereafter we made glide after glide, sometimes following the ground closely and sometimes sailing high in the air. Mr. Chanute had his camera with him and took pictures of some of these glides, several of which are among those shown.

We made glides on subsequent days, whenever the conditions were favorable. The highest wind thus experimented in was a little over 12 meters per second—nearly 27 miles per hour.

It had been our intention when building the machine to do the larger part of the experimenting in the following manner: When the wind blew 17 miles an hour or more we would attach a rope to the machine and let it rise as a kite with the operator upon it. When it should reach a proper height the operator would cast off the rope and glide down to the ground just as from the top of a hill. In this way we would be saved the trouble of carrying the machine up hill after each glide, and could make at least ten glides in the time required for one in the other way. But when we came to try it we found that a wind of 17 miles, as measured by Richard's anemometer, instead of sustaining the machine with its operator, a total weight of 240 pounds, at an angle of incidence of 3°, in reality would not sustain the machine alone—100 pounds—at this angle. Its lifting capacity seemed scarcely one-third of the calculated amount. In order to make sure that this was not due to the porosity of the cloth, we constructed two small experimental surfaces of equal size, one of which was air-proofed and the other left in its natural state; but we could detect no difference in their lifting powers. For a time we were led to suspect that the lift of curved surfaces little exceeded that of planes of the same size, but further investigation and experiment led to the opinion that (1) the anemometer used by us overrecorded the true velocity of the wind by nearly 15 per cent; (2) that the well-known Smeaton coefficient of $0.005 V^2$ for the wind pressure at 90° is probably too great by at least 20 per cent; (3) that Lilienthal's estimate that the pressure on a curved surface having an angle of incidence of 3° equals 0.545 of the pressure at 90° is too large, being nearly 50 per cent greater than very recent experiments of our own with a special pressure-testing machine indicate; (4) that the superposition of the surfaces somewhat reduced the lift per square foot, as compared with a single surface of equal area.

In gliding experiments, however, the amount of lift is of less relative importance than the ratio of lift to drift, as this alone decides the angle of gliding descent. In a plane the pressure is always perpendicular to the surface, and the ratio of lift to drift is therefore the same as that of the cosine to the sine of the angle of incidence. But in curved surfaces a very remarkable situation is found. The pressure, instead of being uniformly normal to the chord of the arc, is usually inclined considerably in front of the perpendicular. The result is that the lift is greater and the drift less than if the pressure were normal. Lilienthal was the first to discover this exceedingly important fact, which is fully set forth in his book, Bird Flight the Basis of the Flying Art, but owing to some errors in the methods he used in making measurements, question was raised by other investigators not only as to the accuracy of his figures, but even as to the existence of any tangential force at all. Our experiments confirm the existence of this force, though our measurements differ considerably from those of Lilienthal. While at Kitty Hawk we spent much time in measuring the horizontal pressure on our unloaded machine at various angles of incidence. We found that at 13° the horizontal pressure was about 23 pounds. This included not only the drift proper, or horizontal component of the pressure on the side of the surface, but also the head resistence of the framing as well. The weight of the machine at the time of this test was about 108 pounds. Now, if the pressure had been normal to the chord of the surface, the drift proper would have been to the lift (108 pounds) as the sine of 13° is to the cosine of 13°, or $\frac{.22 \times 108}{.97} = 24+$ pounds; but this slightly exceeds the total pull of 23 pounds on our scales. Therefore it is evident that the average pressure on the surface instead of being normal to the chord was so far inclined toward the front that all the head resistance of framing and wires used in the construction was more than overcome. In a wind of 14 miles per hour resistance is by no means a negligible factor, so that tangential is evidently a force of considerable value. In a higher wind, which sustained the machine at an angle of 10°, the pull on the scales was 18 pounds. With the pressure normal to the chord the drift proper would have been $\frac{.17 \times 98^{a}}{.98} = 17$ pounds, so that, although the higher wind velocity must have caused an increase in the head resistance, the tangential force still came within 1 pound of overcoming it. After our return from Kitty Hawk we began a series of experiments to accurately determine the amount and direction of the pressure produced on curved surfaces when acted upon by winds at the various angles from zero to 90°. These experiments are not yet concluded, but in general they support Lilienthal in the claim

[a] The travel of the center of pressure made it necessary to put sand on the front rudder to bring the centers of gravity and pressure into coincidence. Consequently the weight of the machine varied from 98 pounds to 108 pounds in the different tests.

that the curves give pressures more favorable in amount and direction than planes; but we find marked differences in the exact values, especially at angles below 10°. We were unable to obtain direct measurements of the horizontal pressures of the machine with the operator on board, but by comparing the distance traveled in gliding with the vertical fall it was easily calculated that at a speed of 24 miles per hour the total horizontal resistances of our machine when bearing the operator amounted to 40 pounds, which is equivalent to about 2¼ horsepower. It must not be supposed, however, that a motor developing this power would be sufficient to drive a man-bearing machine. The extra weight of the motor would require either a larger machine, higher speed, or a greater angle of incidence in order to support it, and therefore more power. It is probable, however, that an engine of 6 horsepower, weighing 100 pounds, would answer the purpose. Such an engine is entirely practicable. Indeed, working motors of one-half this weight per horsepower (9 pounds per horsepower) have been constructed by several different builders. Increasing the speed of our machine from 24 to 33 miles per hour reduced the total horizontal pressure from 40 to about 35 pounds. This was quite an advantage in gliding as it made it possible to sail about 15 per cent farther with a given drop. However, it would be of little or no advantage in reducing the size of the motor in a power-driven machine, because the lessened thrust would be counterbalanced by the increased speed per minute. Some years ago Professor Langley called attention to the great economy which might be obtained by using very high speeds, and from this many were led to suppose that speeds of 50 or 60 miles an hour were essential to success; but the introduction of curved surfaces as substitutes for planes has very greatly reduced the speed of greatest economy. The probability is that the first flying machines will have a relatively low speed, perhaps not much exceeding 20 miles per hour, but the problem of increasing the speed will be much simpler in some respects than that of increasing the speed of a steamboat; for, whereas in the latter case the size of the engine must increase as the cube of the speed, in the flying machine until extremely high speeds are reached the capacity of the motor increases in less than simple ratio; and there is even a decrease in the fuel consumption per mile of travel. In other words, to double the speed of a steamship (and the same is true of the balloon type of air ship) eight times the engine and boiler capacity would be required and four times the fuel consumption per mile of travel; while a flying machine would require engines of less than double the size, and there would be an actual decrease in the fuel consumption per mile of travel. But, looking at the matter conversely, the great disadvantage of the flying machine is apparent; for in the latter no flight at all is possible unless the proportion of horsepower to flying capacity is very high; but, on the other hand, a steamship is a mechanical success if its ratio of horsepower to tonnage is insignificant. A flying machine that would fly at a speed of 50 miles an hour with engines of 1,000 horsepower would not be upheld by its wings at all at a speed of less than 25 miles an hour, and nothing less than 500 horsepower could drive it at this speed. But a boat which could make 40 miles per hour with engines of 1,000 horsepower would still move 4 miles an hour even if the engines were reduced to 1 horsepower. The problems of land and water travel were solved in the nineteenth century, because it was possible to begin with small achievements and gradually work up to our present success. The flying problem was left over to the twentieth century, because in this case the art must be highly developed before any flight of considerable duration can be obtained.

However, there is another way of flying which requires no artificial motor, and many workers believe that success will first come by this road. I refer to the soaring flight, by which the machine is permanently sustained in the air by the same means that are employed by soaring birds. They spread their wings to the wind, and sail by the hour, with no perceptible exertion beyond that required to balance and steer themselves. What sustains them is not definitely known, though it is almost certain that it is a rising current of air. But whether it be a rising current or something else, it is as well able to support a flying machine as a bird, if man once learns the art of utilizing it. In gliding experiments it has long been known that the rate of vertical descent is very much retarded and the duration of the flight greatly prolonged if a strong wind blows up the face of the hill parallel to its surface. Our machine, when gliding in still air, has a rate of vertical descent of nearly 6 feet per second, while in a wind blowing 26 miles per hour up a steep hill we made glides in which the rate of descent was less than 2 feet per second. And during the larger part of this time, while the machine remained exactly in the rising current, there was no descent at all, but even a slight rise. If the operator had had sufficient skill to keep himself from passing beyond the rising current, he would have been sustained indefinitely at a higher point than that from which he started. The illustration shows one of these very slow glides at a time when the machine was practically at a standstill. The failure to advance more rapidly caused the photographer some trouble in aiming, as you will perceive. In looking at this picture you will readily understand that the excitement of gliding experiments does not entirely cease with the breaking up of camp. In the photographic dark room at home we pass moments of as thrilling interest as any in the field, when the image begins to appear on the plate and it is yet an open question whether we have a picture of a flying machine or merely a patch of open sky. These slow glides in rising currents probably hold out greater hope of extensive practice than any other method within man's reach, but they have the disadvantage of requiring rather strong winds or very large supporting surfaces. However, when gliding operators have attained greater skill, they can, with comparative safety, maintain themselves in the air for hours at a time in this way, and thus by constant practice so increase their knowledge and skill that they can rise into the higher air and search out the currents which enable the soaring birds to transport themselves to any desired point by first rising in a circle to a great height and then sailing off at a descending angle. The last illustration shows the machine, alone, flying in a wind of 35 miles per hour on the face of a steep hill 100 feet high. It will be seen that the machine not only pulls upward, but also pulls forward in the direction from which the wind blows, thus overcoming both gravity and the speed of the wind. We tried the same experiment with a man on it, but found danger that the forward pull would become so strong that the men holding the ropes would be dragged from their insecure foothold on the slope of the hill. So this form of experimenting was discontinued after four or five minutes' trial.

In looking over our experiments of the past two years, with models and full-size machines, the following points stand out with clearness:

1. That the lifting power of a large machine, held stationary in a wind at a small distance from the earth, is much less than the Lilienthal table and our own laboratory experiments would lead us to expect. When the machine is moved through the air, as in gliding, the discrepancy seems much less marked.

2. That the ratio of drift to lift in well-shaped surfaces is less at angles of incidence of 5° to 12° than at an angle of 3°.

3. That in arched surfaces the center of pressure at 90° is near the center of the surface, but moves slowly forward as the angle becomes less, till a critical angle, varying with the shape and depth of the curve, is reached, after which it moves rapidly toward the rear till the angle of no lift is found.

4. That with similar conditions large surfaces may be controlled with not much greater difficulty than small ones, if the control is effected by manipulation of the surfaces themselves, rather than by a movement of the body of the operator.

5. That the head resistances of the framing can be brought to a point much below that usually estimated as necessary.

6. That tails, both vertical and horizontal, may with safety be eliminated in gliding and other flying experiments.

7. That a horizontal position of the operator's body may be assumed without excessive danger, and thus the head resistance reduced to about one-fifth that of the upright position.

8. That a pair of superposed or tandem surfaces has less lift in proportion to drift than either surface separately, even after making allowance for weight and head resistance of the connections.