Note the Warped Wings.

The Glider Poised in the Air.

ORVILLE WRIGHT HOLDING HIS GLIDER STATIONARY IN THE TEETH OF A GALE

The Undeveloped Art of Soaring

Its Theory and Practice

By Dr. A. F. Zahm

For many decades two kinds of passive flight have been recognized in nature and have been understood to be achievable by man. One is volplaning, or gliding downward by the force of gravity; the other is soaring, or gliding by force of the wind without loss of altitude. Human volplaning has been so far perfected as to no longer be a novelty, if indeed it does not excel the master performances in nature. Human soaring is a much neglected art, though capable of astonishing development, an art of perennial and fascinating interest, which may now be cultivated with enhanced facility by reason of the increased efficiency of the glider and the aeroplane.

The permanent art of passive flight dates from Otto Lilienthal's experiments near Berlin, in the early nineties of the last century, though long previous to that time some wonderful feats of gliding and soaring, of both men and models, were reported by reliable witnesses. Lilienthal made numerous glides several hundred feet in length, down hill slopes, sometimes pausing in the air, or rising considerably above the level of his launching place. Sometimes also he wheeled about and returned nearly to his starting point. He was succeeded by various disciples, who improved the control of the glider and to some extent its efficiency. A contemporary of his, rather than a disciple, Prof. Montgomery,¹ after twelve years of study, launched a glider in 1905 from a balloon 4,000 feet in the air, bearing on its back a dauntless aeronaut, Maloney, who by means of wing warping and a double rudder guided it, with many a playful dip and wheel, securely down to a designated spot, where he landed in safety. With a like aerial glider, another Montgomery aeronaut cut corkscrews in the air. These feats far surpass in altitude and endurance all glider records up to the present time. The record for volplaning in a power machine, which really becomes a glider when the motor stops, is held by Lincoln Beachy,

the wind some forty feet high, then landed almost in his tracks without serious shock. Lateral glides along the hillside were also made, one forty-eight seconds in length, which showed the possibility of patrolling to and fro in such places. Mr. Atwood relates that while flying over a mountainous country he once encountered an upsloping current which lifted him over a thousand feet high. As described in a recent issue of the SCIENTIFIC AMERICAN, Orville Wright was supported on such an ascending current above a hill slope for nearly ten minutes, sometimes stationary, again gliding forward or backward, and sometimes rising to considerable elevation above the starting point. These various experiments are good indications of what may be expected when the possibilities long ago revealed by science are put to the test of adequate experiment.

The fundamental postulates of the mechanical theory of passive flight are very simple. They are well expressed by Lord Rayleigh in the following paragraph:²

"I premise that if we know anything about mechanics, it is certain that a bird, without working his wings, cannot, either in still air or in a uniform horizontal wind, maintain his level indefinitely. For a short time such maintenance is possible at the expense of an initial velocity, but this must soon be exhausted. Whenever, therefore, a bird pursues his course for some time without working his wings, we must conclude, either (1) that the course is not horizontal, (2) that the wind is not horizontal, or (3) that the wind is not uniform."

Rayleigh's first postulate covers the case of volplaning which is accomplished on a generally downward course. The second and third postulates comprise all cases of soaring ever yet adequately observed in art or nature. In our present state of science no other cases are admissible. Many observers, it is true, testify that a bird can soar in a uniform horizontal wind, or in a dead calm which is its mechanical equivalent for that purpose; but such

ents the relative wind, and the other arrows the horizontal and vertical components of its pressure on the flier, this will hover still in space when the vertical component just equals the weight, and the horizontal component just neutralizes the head resistance. Obviously also the flier will advance or recede, rise or fall, according as these components of wind force prevail or be overpowered. If further the surface be tilted, it will have a third or lateral wind force tending to produce motion sidewise, so that the flier may glide to right and left across the wind

Fig. 1.—Diagram of Wind Pressure on Aeroplane.

as well as in the other two rectangular directions. In an ascending wind therefore a passive flier can hover still, or advance in any direction. This species of flight has been understood from time immemorial; for it is practiced by all kinds of birds, even poor sailers, and is easily accomplished by any skilled aviator in favorable conditions.

Any skilled volplaner who wishes to practice soaring would therefore do well to follow the long standing advice of mathematicians, and choose a sandy slope up which a wind blows at any angle rather in excess of the flattest angle of descent possible in still air. The slope should preferably face the sea or a broad even stretch of land. If, furthermore, the slope be wide, the aviator may soon learn not only to hover, to advance and recede, but also to patrol the entire slope to and fro laterally. As an instance of such procedure, the writer has seen a crow, which usually beats its wings continually in flight, soar to and fro on rigid wings along a stone wall across which a stiff breeze was blowing, and at times also rise and descend, advance and recede, then instantly take to violent beating when caught in the general current away from the wall.

Obviously, continuous soaring is possible on a rising current whose vertical component equals, or exceeds, the slowest possible rate of descent of the glider when coasting down still air. If, for example, a bird in calm air can glide at a speed of twenty miles an hour down a slope of one in ten, it can soar continuously in a current rising with a vertical component of two miles per hour, while an equally efficient flier moving sixty miles an hour would require, to maintain soaring, a current rising at the rate of no less than six miles an hour. From this it follows that the slowest and most amply surfaced gliders like butterflies require the least ascensional trend of air for soaring. Still such fliers are far from being good soarers because of their incapacity to acquire sufficient speed and momentum to cleave swift winds and drive their way for a considerable time in spite of unfavorable conditions.

Ascending winds due mainly to uneven temperature distribution and to inequalities of terrene prevail very generally over the globe. Lilienthal concluded from instrumental observation that the general trend of the wind is three degrees upward. His was of course a local and empirical study. But on principle it may be quali-

Fig. 2—Records of Wind Variation in Horizontal and Vertical Direction.

who, during the Chicago meet of 1911, glided sheer down to earth in a Curtiss biplane from an elevation of 12,654 feet.

The records for soaring are briefer, and some are not so well attested. In 1859 Capt. Le Bris, piloting a glider patterned after an albatross, soared 300 feet high and descended safely to earth. This on the authority of De la Landelle, who wrote a history of aeronautics published in 1884, and who had the account from Le Bris's neighbors. Mouillard, nearly twenty years ago, soared 138 feet over a prairie after an initial run and jump across a roadside ditch with a glider strapped to his waist.³ Many recent aeroplanists have been carried well upward by rising wind currents. During the gliding experiments of Chanute and Herring one of the operators was raised by

¹ It is with deep regret that we note the death in the cause of science, of Prof. Montgomery, which occurred on October 21st., 1911.—Ed.

² Chanute, "Progress in Flying Machines," p. 130.

flight is beyond the power of aerodynamics to explain, if indeed, it be not equivalent to perpetual motion.

Soaring then is possible only in ascending air or in a wind of variable velocity.⁴ In other words, it is possible, (1) in an ascending flow of air, (2) in a horizontal striated flow, in which the stream-lines are all parallel but the velocity varies in neighboring strata, or strata, (3) in a horizontal wind of fluctuating speed, (4) in a horizontal wind of fluctuating direction, either horizontal or vertical. The chief types of maneuver for such conditions may be considered briefly here, as also the prevalence of such conditions. Of course, this classification does not hold rigorously in nature, but may be assumed for the purpose of simplifying the analytical treatment.

Fig. 1 presents the well-known graphic analysis of soaring in an ascending current. If the oblique arrow repres-

³ Nature, April 5th, 1883.

⁴ Let it be technically explained that a wind of variable velocity is one that varies in speed, in direction, or in both.

tatively affirmed that the general course of the wind is slightly upward. For the rising air is, on the average, warmer than the descending air; hence its volume displacement is greater; hence its general direction of flow is slightly upward. This effect is intensified where the air from a surface of water or vegetation passes over a barren or desert soil. Ascending vortices are very abundant, particularly over a heated terrain exposed to direct sunshine. Meteorology teaches that every isolated cumulus and thunder-head marks the top of an uprising column of hot air. All heated slopes, especially in the early part of the day, produce updrafts, particularly if they be long and barren. Precipitous islands and coastlands cause strong ascending currents which the sea birds know so well how to use. Over the desert numerous columns of sand, reveal the rising vortices continually. On torrid planes large isolated trees have a powerful uprush of air above them, initiated doubtless by the tree itself from the hot stratum of air beneath. Thus the skillful soaring bird finds abundant elevators as he coasts about the atmosphere, which he may use to gain sufficient altitude to prolong his meandering glide till he encounters the next elevator, whether this be a vortex or merely an upward deflected wind.

Soaring in a truly horizontal wind whose speed varies considerably at neighboring levels, or in different strata at the same level, is easy to understand in theory. The bird or flier acquires sufficient speed in the swifter stratum to enable it to glide into the lower stratum, there reverse its direction and return in the teeth of the swifter current, to be again caught up and given a new high speed as before. Many instances are reported of such flight in nature but none in human art. The theory has been presented

Fig. 3.—Records of Wind Speed Obtained by Langley.

by Lord Rayleigh in his "Mechanical Principles of Flight," by Vogt in London *Engineering*, and by various other writers; but the actual performance still challenges the skill and cunning of the practical aviator. The fact that the wind moves in neighboring strata and strata is well established, but is it still to be proved quantitatively that the rate of change of speed is quite commonly sufficient to support prolonged passive flight?

Soaring in a horizontal wind of pulsating speed has been qualitatively explained by Dr. Langley, and quantitatively studied by Chanute and others. The general theory conceives that the flier faces the direction of the wind, rises and drifts backward when the wind freshens, sinks and advances during the lull. This explanation is valid providing the horizontal acceleration of the wind be sufficient. Langley, therefore, recorded the pulsations of wind speed by means of very light cup anemometers to obtain a physical basis for his theory.

The records, Fig. 3, show quite remarkable fluctuations in speed, but not sufficient to maintain soaring in any flier of art or known nature up to the present. The total forward resistance of a well formed aerial glider, or bird, may be taken as one-eighth of its weight; hence if poised stationary in its normal altitude of flight, it will be just sustained by a direct head wind having a horizontal acceleration of one-eighth that of gravity, or four feet per second. This is obviously true of all gliders, whether swift or slow, whose total resistance equals one-eighth of their weight. Now, the most favorable parts of the record here shown exhibit nowhere an acceleration so great as four feet per second, and on the average show far less than that, as may be seen by scaling the diagram. Hence

the wind here recorded was wholly inadequate to support by its pulsative force either bird or man. As this record is a fair representative of all those published by Dr. Langley, it follows that such pulsations can at best merely aid in soaring when happily and adroitly encountered; but that they cannot fully sustain soaring at any level, much less during ascensional flight to great altitudes, or migrational flight over vast distances. This conclusion is applicable even to those gliders which are reported to require a propulsive force of but one-fifteenth or one-twentieth of their weight. Hence to account for soaring in a horizontal wind of fluctuating speed it seems necessary to postulate a pulsating breeze of far greater acceleration than those recorded by Dr. Langley in his paper on "The Internal Work of the Wind." Fuller and more varied records of pulsations in the wind's velocity may be found in the *Interim Report* for 1909 of the British Advisory Committee for Aeronautics.

In a horizontal wind that pulsates in direction merely from side to side, soaring may be aided by the alternate impulses of the air against the flier, resisted by its inertia. If the wind freshens well from the right quarter and the flier lists to port, it will be driven to port; then if the wind blows promptly from the left quarter, while the flier is tilted to starboard, it will have its acquired component of momentum to port reversed and will drift to the right. In each case the oblique lift on the wings may have a component generally forward tending to overcome the entire head resistance. The magnitude of this forward component of the normal pressure on the tilted flier is easily seen to be, at any instant, equal to the product of such normal force multiplied by the sine of the angle of tilt and by the sine of the angle between the quartering wind and the forward course. If, for example, each of these angles be 30 degrees at any instant, the propulsive component is one-fourth of the whole normal component, which of course would be ample to overcome all resistance. Continuous soaring in such a laterally pulsating current would, however, require phenomenally rapid and wide fluctuations of wind direction, and great alertness on the part of the flier. The case is worth notice as showing that a glider can receive both support and propulsion from a quartering wind, and can even tack successfully like a ship if the horizontal fluctuations in directions be suitable.

In a generally horizontal wind that undulates up and down, soaring may be aided in various ways, if not continuously sustained. If the aerial vibrations be strong and rapid, as in a fluttering wind, they may exert a sculling action on the wing as a whole or on its flexible rear margin. In such case the narrow flexible wing of the bird would be more effective than the broad stiff wing of an ordinary aeroplane, though of course narrow and pliable pinions can be used in aeroplanes and gliders to adapt them to soaring in fluttering winds. Such sculling action may occur in wind undulations of considerable period and amplitude, as where the air follows the contour of the billows in a heaving or tempestuous sea, particularly if the flier glide across the undulations at considerable speed, like the albatross, thus greatly increasing the apparent frequency of the rise and fall of the air.

Mouillard likens soaring in such heaving air to the motion of a marble on a wavy groove in a vertical plane which a skilled man moves up and down in such opportune manner as to cause the marble to ascend rapidly on a long wavy slope. The comparison is a good one except for the fact that gliding on the yielding air is less efficient than sliding or rolling on a rigid track. But if the potential energy can be rapidly acquired on the Mouillard track, perhaps also on the aerial track increased, altitude can be attained under favorable circumstances.⁵

In case the undulations of the air be due to a vortex rolling about a horizontal axis while advancing with the wind, as supposed by some writers, the bird or glider might remain on the ascending side of the vortex and thus obtain continuous support while advancing with the speed of the rolling vortex whether fast or slow. Such a performance might seem marvelous or paradoxical to the witness, since the rolling vortex must be quite invisible, but the feat would be no more remarkable than some reported by aviation experts who claim to have witnessed the passive flights of aquatic birds for thousands of feet just over the surface of still water in a hardly perceptible breeze. The rolling vortex of Chanute and Herring offers fascinating possibilities. The aviator need only saddle his glider deftly on this transparent Pegasus to go kiting all over creation. But the fine art is to locate and lasso such a wild wind-horse.

Fig. 2 exhibits typical records of the changes in wind direction, both horizontal and vertical, obtained by the writer by means of a special recording wind vane exposed in a clear open space of 200 acres, and in a wind of eight to twelve miles an hour. The diagram shows that the wind veered quite frequently ten degrees in a short interval of time, and not seldom twenty to thirty degrees. In strong winds the fluctuations of both velocity and direction are generally more marked than in moderate winds, as has been often observed in meteorological rec-

⁵ The present writer has caused a model glider to ascend on a wavy course in the air by pulling vertically down on it intermittently with a thread. Such gliding seems a fair representative of soaring in a wind oscillating rapidly in a vertical plane.

ords. Hence they furnish a good physical basis for the belief that soaring may be materially aided, if not continuously sustained, by pulsating winds.

Giant Twin Stacks.

Two remarkable chimneys at Rochester are seen in the accompanying illustration, both of which are 366 feet high above the top of the foundations. The smaller one measures 9 feet in internal diameter at the top and the larger one 13 feet; both are constructed of radial brick. They have a 4-inch lining throughout, laid in acid-proof cement, with 2-inch air space. Each chimney has a connection for acid fumes in addition to the flue for boiler gases. The foundations run down to rock and are about 22 feet in depth. The Kodak Plant, where these chimneys are located, is equipped with two and three-fourths miles of water mains for fire protection purposes, with thirty-seven hydrants, 4,800 feet of hose and seventeen hose houses. The buildings are all equipped throughout with automatic sprinklers of which there are about 10,600 heads and there is a reservoir with a capacity of 600,000 gallons, used for the storage of clean waste water.

The first chimney when built was the tallest in the United States and is 28 feet in diameter at the base, outside dimensions. The concrete octagonal foundation is 40 feet across, 23 feet deep and contains 915 cubic yards of concrete. The larger chimney also 366 feet high is 31 feet diameter at base, outside dimensions. The combined capacity of the two

These Stacks Are 366 Feet High.

chimneys will equal 18 to 20,000 boiler horse-power. The power house contains 16 boilers with a rated capacity of 4,800 horse-power, actual capacity about 6,000 horse-power. Above the boilers are located coal bunkers having a capacity of 3,200 tons, from which the coal drops through chutes to mechanical stokers. The waste gases from the furnaces pass through fuel economizers.

About 120 tons of coal are burned per day, the ashes being removed by a mechanical conveyer. There are being added to the above equipment 4 boilers of 2,000 rated horse-power which will bring the total rated capacity up to 6,800, and the actual capacity to about 8,500 horse-power. There are five engine-driven generators in service with a total capacity of 1,800 kilowatts, or 3,000 horse-power, furnishing electricity for light and power to the various buildings throughout the plant.

A total of 888 motors, ranging in size from one-twelfth to seventy-five horse-power are required to operate the machinery in these buildings. There is at present being installed in addition to the above equipment one 1,600 horse-power engine connected directly to a 1,000 kilowatt generator, giving a total of 4,600 horse-power. In all, more than 9,000 incandescent lamps and 65 arc lamps are used for lighting. Refrigeration for cleaning and drying air, for cold storage rooms and ice making is provided by eleven ammonia ice making and refrigerating machines with a total capacity of 2,320 tons per day.