

LEONARDO DA VINCI'S FLYING MACHINE A. D. 1490, FROM A MODEL IN THE U. S. NATIONAL MUSEUM AT WASHINGTON
Actual size: Length from tip to tip, 24 inches; beam, 12 inches. Total wing surface, 100 square inches.

Leonardo Da Vinci as Aviation Engineer

The Man Who First Suggested the Helicopter and the Motor to Drive Flying Machines

By Albert A. Hopkins

IN the March issue of the *SCIENTIFIC AMERICAN MONTHLY* we touched briefly upon the achievements of Leonardo as a scientist and inventor. There was one subject—aviation—which was left for fuller treatment. This was necessary because of the immense number of drawings and great amount of data which have come down to us.

The following presentation is timely for two reasons: first, the U. S. National Museum has just recreated a model of Leonardo's approved flying machine, and second, there has been great attention recently given to the helicopter of which we have incontestable proof that Leonardo was the real inventor, as will be shown in this article.

The writer wishes at this point to thank Mr. John W. Lieb for cooperation in allowing his magnificent collection of facsimiles of Leonardo's manuscripts, works on Leonardo and other data to be drawn on freely and all the illustrations are from this source except the National Museum model. His own writings are quoted freely in the article as are also the writings of Mr. Edward McCurdy who published a classic article on the subject in the *Nineteenth Century* a few years ago.

We do not know where Leonardo first obtained his idea of aerial flight, but we know he was occupied with the study of the exact workings of the forces of nature in every manifestation and of their application to human purposes. In the case of Leonardo, considered as the pioneer of the modern science of aviation, it is possible to define very narrowly the character of his researches and the nature of his conclusions. A sentence of Otto Lilienthal's, that great explorer in the realm of mechanical flight, who paid for his devotion with his life, expresses succinctly the measure of contempt which the practical inventor is apt to affect for the mere theorist however much he may be indebted to his researches: "To conceive of a flying machine is nothing, to construct one is something, but to make trial of it is everything." That Leonardo put his knowledge of theory to the proof is to be inferred from the only reference to these researches which is found in contemporary record. It occurs in the *De Subtilitate* of that somewhat empirical physician and philosopher, Jerome Cardan, who after including the invention of flight in a list of "the excellent arts which are hidden," continues: "It has turned out badly for the two who have recently made a trial of it: Leonardo da Vinci, of whom I have spoken, has

attempted to fly, but he was not successful; he was a great painter." The laconic antithesis suggests—it almost summarizes—the attitude of contemporary criticism with regard to Leonardo's scientific and mechanical pursuits. The standpoint is the same as that of Vasari, who regarded them as deviations from those purposes which Leonardo alone could accomplish. The criticism has been justified by the march of events. One by one the mechanical and scientific problems to which a great part of Leonardo's creative power was devoted have been solved. He stands revealed as "the forerunner."

The researches on the science of flight which Leonardo's manuscripts contain are of themselves sufficient to reveal the unflagging zeal with which he devoted himself to the study of primary causes. The subject has given its name to one of the two of his treatises which exist in a more or less complete form (*Il Codice Sul Volo degli Uccelli*); but this would seem to be only an early draft of the results of his observations. It is also treated of in the *Codice Atlantico*, and in seven of the twelve Leonardo manuscripts which are now in Paris in the Library of the Institut de France. Some of these references consist of a few lines, or a diagram with a brief note in explanation, but many consist of pages or half-pages of closely written matter, the contents of which are far more voluminous than the writings of any other student of the subject down to Leonardo's time.

The material falls naturally into two groups, the first being a series of investigations of the laws which govern the power of flight as manifested in nature by birds and other winged creatures, the second consisting of deductions from these principles in the construction of a mechanism which should be capable of sustaining man and being worked by him. The interdependence of the two parts of the inquiry is stated with great succinctness in a passage in the *Codice Atlantico*:

"A bird is an instrument working according to mathematical law, which instrument it is within the capacity of man to reproduce with all its movements, but not with a corresponding degree of strength, though it is deficient only in the power of maintaining equilibrium. We may therefore say that such an instrument constructed by man is lacking in nothing except the life of the bird, and this life must needs be supplied from that of man.

"The life which resides in the bird's members will without

doubt better conform to their needs than will that of man which is separated from them, and especially in the almost imperceptible movements which preserve equilibrium. But since we see that the bird is equipped for many obvious varieties of movements, we are able from this experience to deduce that the rudimentary of these movements will be capable of being comprehended by man's understanding, and that he will to a great extent be able to provide against the destruction of that instrument of which he has himself become the living principle and the propeller."

Flight is a natural phenomenon, and consequently its laws are to be deduced by observation of nature. In acting on this principle Leonardo followed the course marked out by Aristotle in the chapters on the flight of birds in the treatise "On the Method of Progression of Animals," with which treatise it is at least reasonable to suppose him to have been somewhat acquainted.

References to Aristotle in his manuscripts are more numerous than to any other classical writer, and a note in the *Codice Atlantico* allows us to infer that he either possessed or had access to translations in manuscript or works which had not then been printed.

"In order (he says) to give the true science of the movement of birds in the air, it is necessary to give first the science of the winds, which we shall prove by means of the movements of the water: this science is in itself obvious to the senses; it will serve as a ladder to arrive at the knowledge of winged creatures in the air and the wind."

And again:

"Of the bird's movement—in order to speak of this subject it is necessary that in the first book you treat of the nature of the resistance of the air; in the second the anatomy of the bird and of its feathers; in the third the action of these feathers in various of its movements; in the fourth the strength of the wings and tail without beating the wings with the help of the wind to serve as guide in various movements."

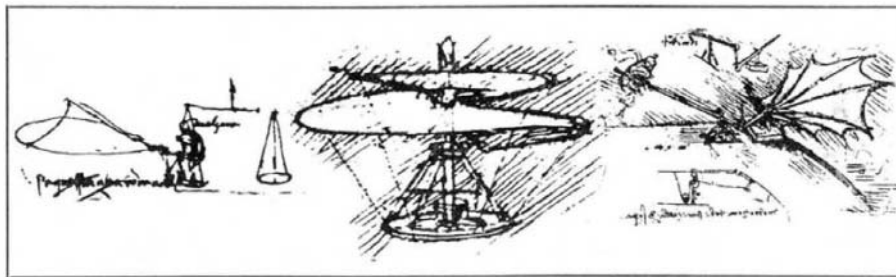
And again:

"Before writing about winged creatures, make a book about how inanimate things descend through the air without wind, and another about their descent with the wind."

In treating of the science of the winds he shows how the wind varies in power according to its altitude, as is proved by the fact that birds always fly low when the course of the wind is contrary. The movement of the wind is similar in all respects to that of the water. The rudder behind the ship is copied from the tail of birds; and swimming upon the water teaches men how birds float on the air.

He also defines the resistance of the air, and shows how there is as much pressure exerted by a substance against the

air as by the air against the substance; and he shows how the fact of a bird remaining motionless on its wings in the air is due to an equilibrium of forces; and he illustrates how the air beneath the movable substance which descends in it is compressed and the air above it is rarefied.



SUGGESTIONS FOR
WEIGHING WIND
PRESSURE

HELICOPTER OR FLY-
ING MACHINE FOR
RISING VERTICALLY

MACHINE FOR TESTING
WINGS OF VARIOUS
SHAPES

In his designs we find worked out in small detail, particularly as to the wings and mechanisms for operating and balancing, flying machines with two and four wings, operated by one or more persons with and without mechanical propelling power. We find some driven by

spring motors, some by the arms and legs of the operator while lying prone or standing upright. We also find interesting sketches for a screw flying machine or helicopter and a sketch with descriptive details of a parachute.

In reading over the following extract and comparing it with the latest theories of airplane design, we cannot but feel that Leonardo was certainly well aware of the principles underlying aerial flight, in this detail if in no other.

"To Escape the Peril of Destruction When Flying.—The destruction of such instruments can happen in two ways, of which the first is that the instrument may break apart; the second would be if the instrument turned itself on edge or nearly on edge, because it should always descend on a very oblique path and nearly on a horizontal line."

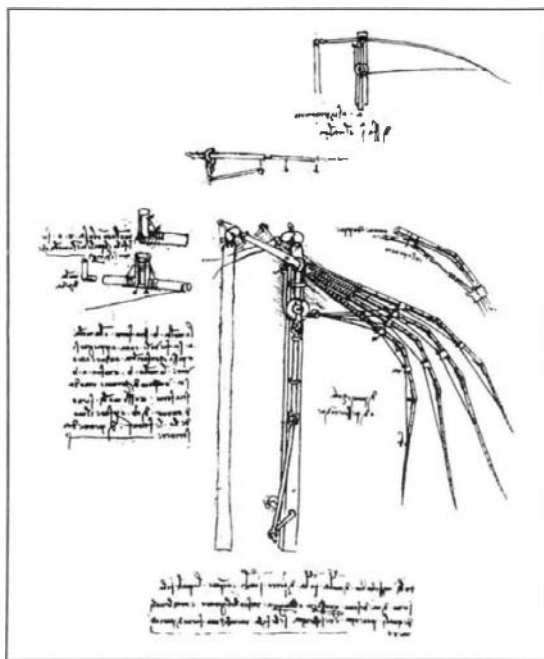
We do not know today how many of Leonardo da Vinci's sketches and drawings were actually original designs or inventions, or how many were merely sketches to aid his mem-

ory of things he had seen. We do know that some small portion of the material given by Leonardo was not original with him, he having specifically mentioned that this or that device or idea was previously used by such and such a people or individual.

It would appear to Mr. Lieb, however, from a study of the manuscripts from an engineering standpoint, that so many of the sketches contain detailed calculations of weights, power required, etc., and so many others contain practical hints, which are really shop instructions for construction and operation, and that many of them could not have been the result of mere observation of apparatus constructed by others, but must have been the result of practical experiment and experience with actual apparatus under working conditions, supporting the contention that a very large part of the sketches are original designs and represent machines actually constructed by him or under his direction.

The first model of a flying machine took the form of a pair of large wings worked by means of the arms, or arms and legs, and attached to the body by a band which passed beneath the armpits.

The type in nature which Leonardo selected to serve as a model was the bat, "because its membranes serve as an armor,

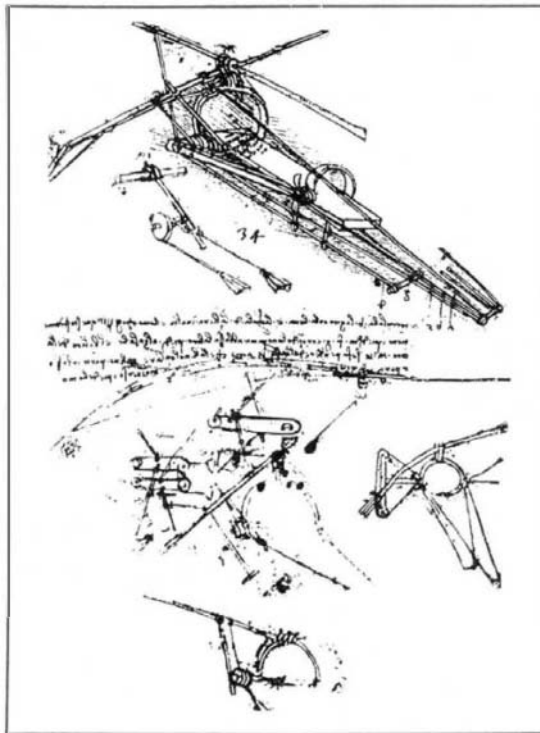


MECHANISM FOR A VERTICAL FLYING
MACHINE, DRIVEN BY CRANKS WITH
SUPPLEMENTARY WING FLEXURE
OR WARPING

or rather as a means of binding together the pieces of its armor, that is the framework of the wings." (*Sul Volo d. Uccelli*.) He admits that the wings of feathered creatures are more powerful in structure of bone and sinew, but attributes this to the fact that they are penetrable; that is, that the feathers are separated so that the air passes through them, whereas the bat is aided by its membrane, which is not penetrated by the air.

He has also shown that birds like the lark which fly high with the rising of their wings, because these are then pierced through with air, have their feathers spread out more widely than birds of prey which can only rise by a spiral or circular movement. He attempted, therefore, to combine both types by making the wing of the instrument like that of the lark as it rises and like that of the bat as it descends—or, as he calls it, "a method by which the wing is full of holes as it rises and closed up when it falls." This he did by attaching various shutters (*sportelli*) to the surface of the wing. A net connected the framework of the wing to the bamboo canes on which the shutters were fastened along their length on the one side, and on the other side were attached to them by cords at either end. The shutters had rims of cane and were covered over with taffeta, which had been either well soaped or rubbed with starch to render it airtight. As the wing rose the air would pass through the net, and force open the shutter to the extent allowed by the cords. As the wing descended the air below it would drive the shutter up against the net, and so close up the holes, and this would cause the wing to present a solid surface to the air beneath it. He considered that in proportion as the shutters were smaller so they were more useful.

In the second type the instrument has something of the appearance of the body of a huge dragon-fly, tapering slightly toward the tail, and the framework of the wings arched above the head resembles antennæ. Within the body the aeronaut



FLYING MACHINE USING ARMS AND LEGS, OPERATOR LYING PRONE, MANEUVERING TAIL BY OPERATOR'S HEAD

lies at full length, face downward. His feet are in stirrups, which work the wings by means of cords, one of these causing them to fall and the other to rise. Round the neck is a leather band to which a cord is attached, described as "a rudder which is fixed with a band to the head at the place of the neck." The position of the instrument he states to be such that the wings in descending drop partly downward and partly backward, that is toward the feet of the man. The necessity of increasing the power of control led him so to change the mechanism that the wings were lowered by the force of both feet at one and the same time. By this means the downward pressure becomes twice as great and "you are able to delay and to maintain yourself in equilibrium by lowering one wing more rapidly than the other, according to necessity, as you see done by the kite and other birds."

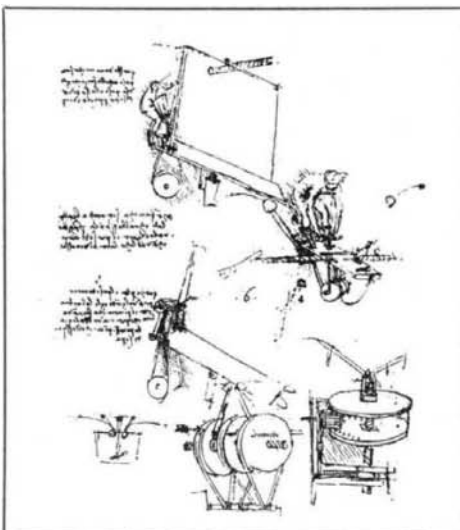
The raising of the wings will then, he says, either be by the force of a spring, or by the hand, or by drawing the feet toward you, the

last being the best method, because then the hands are left free.

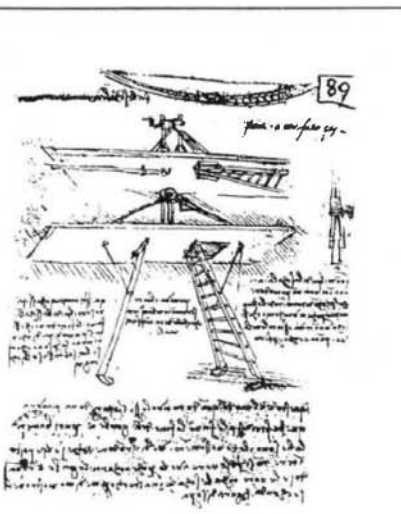
In a passage in the *Sul Volo degli Uccelli* he says that a man in a flying machine should be free from the waist downward to be able to balance as in a boat, so that his center of gravity may balance that of the machine.

With the various drawings of instruments are notes as to the materials of which the parts are to be constructed. Sometimes a word or more is written in the particular part itself, such as "staff of green pine," "fustian," "taffeta," "try first with leaves of chancery," which latter may be interpreted to mean a form of parchment. Two parts of the covering of a wing are described, one as of "fustian stuck over with feathers," the other of "starched taffeta," and "for the experiment," he continues, "you will use fine pasteboard."

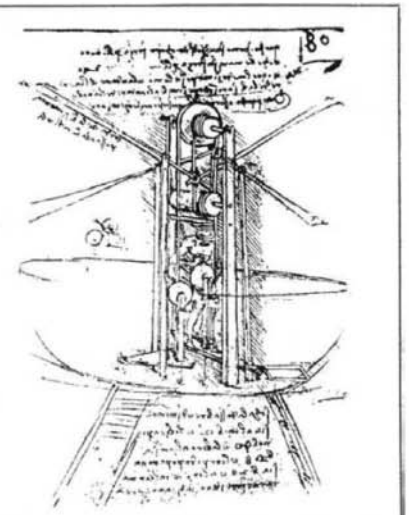
The same forethought prompts a note that the machine should be tried over a lake, and that a long leather bottle



SKETCHES GIVING DETAILS OF THE MANUALLY OPERATED MECHANISM OF THE FLYING MACHINE



FOLDING LADDER WITH SHOCK ABSORBER FOR LANDING, SHOWING COLLAPSIBLE MECHANISM



A FOUR-WING FLYING MACHINE. OPERATOR STANDING, WITH HEMISPHERICAL BASE AND LANDING

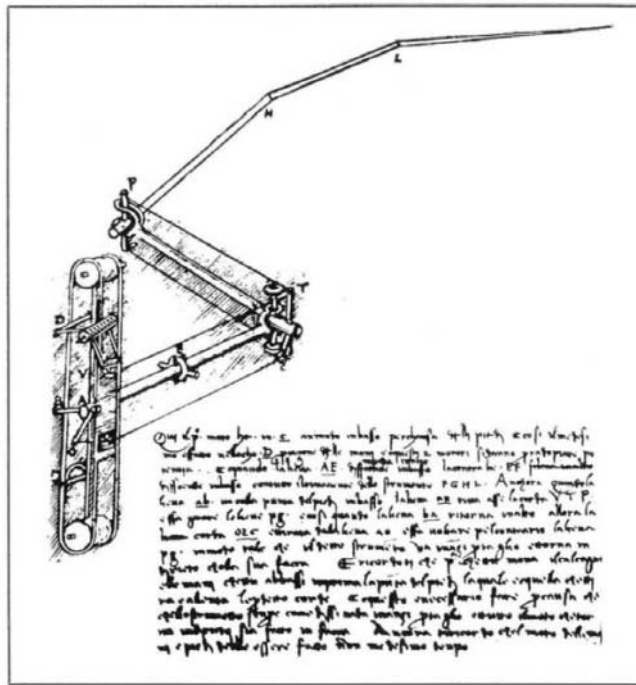
should be carried in the girdle as a safeguard against drowning in case of a fall; and again, in writing of another type of machine, he says: "Try the actual instrument in the water so that if you fall you will not do yourself any harm."

The various notes and drawings which relate to what was probably the latest type of the machine are among the most difficult to interpret. The machinery, although more compact, has become more complicated, and an attempt to define the practical value of the parts of it is only possible to the practised student of mechanics. A drawing of a man suspended by the waist, in an attitude as though swimming immediately below the drum round which the cord is turned, is apparently a preliminary to this latest type: the note below it describes how it may be worked either with one pair of wings or with two, and refers to a ladder or ladders of light thin pine at the base. These ladders are found only in the latest type of the instrument, and he defines their use as serving the purpose of legs when it is desired to rise above a plain, and so rendering it possible to beat the wings. He mentions the instance of the martin, which cannot raise itself by flying when settled on the ground, because it has short legs. A drawing shows how, after the ascent had been commenced, the ladders are to be drawn up so that they lie flat against the bottom of the instrument. They are made with curved ends in order, apparently, to lessen the risk of their becoming fixed in the ground.

"I conclude (he says) that standing upright is more useful than flat on one's face, because the machine can never turn upside down, and moreover the habit created by long use requires it thus. And the rising and falling of the movement will proceed from the lowering and raising of the two legs, and this is of great force, and the hands remain free, and if one had to be flat on one's face the legs in the fastenings of the thighs would have great difficulty in supporting themselves; and the feet have the first shock when it alights."

A drawing in MS. B of the Institute is the most complete representation of this type of the instrument. In it the figure of the man is seen standing on his feet, but bowed like Atlas under his burden.

Above him are two pairs of wings, which are worked by cords and pulleys controlled by his head and limbs. He is placed between two posts, which support a wheel at the top. Cords passed round it raise and lower the wings as the wheel moves. The posts descend to the



DRIVING AND FLEXING MECHANISM FOR WINGS,
WITH UNIVERSAL JOINT

base of a low basket-shaped car, where are pedals on which the man stands. These pedals are connected by cords with the wings. The car is resting on short ladders.

On a page of MS. B of the Institute is a drawing of a large screw constructed to revolve round a vertical axis. The notes at the side and below the drawing tell of the materials and dimensions, and reveal also the purpose which it was intended to serve.

In its general outline this instrument has some resemblance to certain examples of the type known as helicopters. But both in this and in the earlier model, of which the general structure has somewhat more resemblance to certain types of the modern airplane, the only motive power to be discerned is derived directly from the strength of the human agent. The capacity of the instrument to overcome the re-

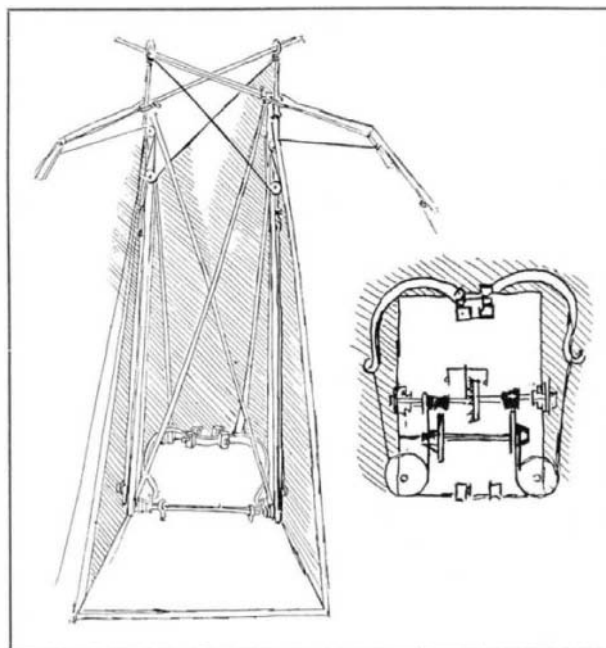
sistance of the air is the capacity of his muscles to lift weights and to endure pressure, transferred to this particular purpose by the use of suitable implements. Numerous passages in the manuscripts show that Leonardo doubted the adequacy of this power to accomplish more than short experimental flights. He contrasted it with that reserve of power possessed by the larger birds, and he sought for a fresh source of motive power to supplement or take the place of that exerted by man.

M. Govi, who first called attention to the significance of these passages in a paper presented to the French Academie des Sciences, speaks of them as proving not only that Leonardo invented the screw-propeller, but that he had considered its application to aerial navigation, and that he had constructed small paper models for this purpose which were

set in motion by fine bent steel wires.

The function of springs in the machinery of some of the flying machines is shown in two important drawings of a flying machine on a page of the *Codice Atlantico*. These show a machine of the vertical type with a planimetric sketch of the base, within which is written *fondamento del moto*. These, together with an elaborate study of the mechanism of the right wing represent the ultimate stage of the conception as found in the manuscripts—which stage is separated from those which preceded it by the addition of mechanical motive power. To this instrument the architect, Luca Beltrami, does not hesitate to apply the word "aeroplane."

"The apparatus consists of a rectangular horizontal plane, from the middle of the longer sides of which rise two vertical struts made firm by two sup-



A REAL "AIRPLANE," SHOWING
IN DETAIL, MECHANISM OF
SPRING MOTOR

"FONDAMENTO
DEL
MOTO"

ports crossed diagonally. The vertical plane so formed is made rigid by two pairs of supports which connect the upper extremities of the struts with the angles of the plane of the base. Two strong springs, each fastened at one end to the center of one of the lesser sides of the horizontal plane, are bent round its sides by means of ropes, which by the interposition of pulleys are made to turn round a horizontal axle placed at the base of the two shafts; a cog-wheel situated in the center of this axle allows the force stored up in the springs in tension to be able gradually to relax the rope, so causing the revolution of a second axle parallel to the first, and at the extremities of this are cranks for the purpose of moving the wings. These wings are poised at the upper extremities of the shafts, the right wing being fixed upon the left shaft and *vice versa*, so that the space between the two shafts, along which the motive power is exerted, forms the arm of a lever of which this power may avail itself." Each wing is moved by a vertical rod which is looped to the shaft by two rings, and gliding through these it may be raised and lowered according as the fastening to one of the above-mentioned cranks is loose or tight. The lowering of the rod not only moves the arm of the lever, of which the wing is a continuation, but displaces a pulley which turns the cords that correspond to the various loose sinews, which together make up the subsidiary structure of the wing: consequently, as the wing is raised and lowered, these sinews and the surface of the wing are expanded and contracted.

All this relates to constructional details of the instrument.

Signor Beltrami, in a few sure words, shows how these parts would be controlled by the human agent:

"The man who guided the machine had his place in the part of the horizontal plane enclosed within the two springs where the words *fondamento del moto* (foundation of the motor) occur in the sketch. He had the cog-wheel in front of him, and could by a simple turn so adjust its revolution as to allow the ropes pressed by the springs to relax gradually and at his pleasure, and so cause the revolution of the axle where are the two cranks which communicate with the wings: as the slackening of the rope is quicker or slower, so the beating of the wings is more or less rapid, and so the flight is controlled."

If Leonardo did not enter the Promised Land, here, surely, he had a Pisgah-sight of it! In arriving at this stage he was separated from that of ultimate attainment only by the lack of knowledge of a light motor with power sufficient to move the mechanism, such as has only been rendered possible by the use of the explosive engine.

An enigmatic sentence on the cover of *Sul Volo degli Uccelli* which was written in 1505, refers apparently to an attempt at flying which was then shortly to take place:

"The great bird will take its first flight upon the back of the Great Swan* filling the whole world with amazement, and filling all records with its fame; and it will bring eternal glory to the nest where it was born."

*This refers evidently to a mountain near Florence which was known as the "Swan."

"The Automatic Pilot"*

New Airplane Stabilizer That Is Part Electric, Part Pneumatic and Part Aerodynamic

WHILE it must be admitted that the number of aviation accidents directly due to failure on the part of the pilot is extremely small, it is none the less desirable that any means provided to lessen the possibility of such failures should be considered on its merits. A short airplane flight, carried out in normal circumstances, is not a particularly fatiguing operation so far as the pilot is concerned, but a prolonged journey in gusty or misty weather subjects him to a degree of mental and physical strain which it is certainly desirable to avoid by mechanical appliances if possible. We have recently had an opportunity of examining a device, the invention of M. Georges Aveline, which has been fitted to a Handley-Page passenger airplane and is capable of relieving the pilot of the whole work of balancing the machine except during the operations of getting off and landing. The pilot, for practically the whole of the journey, need thus only keep his feet on the rudder bar in order to keep the machine on the correct compass course set, the ailerons and elevator being operated by the apparatus which we propose to describe.

Fig. 1, on the next page, indicates the principle of that part of the apparatus which controls the ailerons, and is mounted transversely in the cockpit or other convenient part of the airplane. The essential part of this device is a disc of red fiber in which a circular channel is formed, the channel being about half filled with mercury. Just above the surfaces of the mercury in the channel an electrical contact is fitted on each side of the disc, and another contact is made with the mercury at the lowest part of the channel; if the machine tilts laterally on either side the circuit between the lowest contact and the contact on that side will thus be completed through the mercury. The upper contacts of the mercury channel are connected to the two coils of a relay and when the circuit is completed through one of the contacts, this relay closes a 12-volt circuit in which are the solenoids controlling

the inlet and exhaust valves of a servo-motor worked by compressed air. This servo-motor, as shown in Fig. 1, contains two opposed pistons connected by a rack, and the rack gears with a quadrant connected to the aileron control wires. When air is admitted to one end of the servo-motor and the exhaust valve at the other end is opened, the pistons move, turn the quadrant, and so operate the ailerons to correct the tilt. As shown in Fig. 1, the disc containing the mercury channel is also geared to the quadrant, so that it turns in the opposite direction and, by this means, the contact is broken and the pistons brought to rest after moving a distance corresponding to the amount of tilt. It should also be explained that the rate of movement can be regulated as desired by means of a valve fitted in the exhaust pipes.

An interesting feature of M. Aveline's invention is the means adopted to counteract the effects of centrifugal force, but to understand the effect of this part of the apparatus it is necessary to consider its action during a turn. To turn the machine, the pilot moves the rudder bar with his foot, and the machine immediately commences to swing round in a more or less horizontal plane—say to the right. The resulting centrifugal force causes the mercury to rise in the left-hand arm of the mercury channel making a contact on that side, and the effect of this is to pull down the outer aileron and raise the inner aileron, thus causing the machine to bank in the correct manner. The fiber disc, of course, moves in the opposite direction to the quadrant and would break the electrical connection and leave the ailerons in the positions above described but for the special device we shall refer to in a moment. It must, however, first be explained that, as soon as the correct banking is reached, it is necessary to replace the ailerons into the neutral position, otherwise the banking would become excessive and the machine would probably side slip. To avoid this, the arrangement illustrated diagrammatically in Fig. 2 is employed. A Venturi tube is mounted on each tip of the upper wing of the machine and the throats

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