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MR. McCURDY'S COPY.

BEINN BHREAGH, NEAR BADDECK, NOVA SCOTIA

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Bulletins of the Aerial Experiment Association.

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Beinn Bhreagh, Near Baddeck, Nova Scotia.

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BULLETIN No.XXXIX

CONDITIONS OF SUCCESS IN THE DESIGN OF FLYING MACHINES:

By O. Chanute.

1898.

After many centuries of failure, it is believed that we are at last within measurable distance of success in Aerial Navigation; that there will be two solutions, one with dirigible balloons, which will chiefly be used in war, and the other with dynamic, bird-like machines which will possess so much greater speed and usefulness that they should preferably engage the attention of searchers.

I have, of late years, experimented with six full-sized gliding machines carrying a man, comprising three different types, and having reached some definite opinions as to the conditions of eventual success with power driven machines, it is ventured to state them briefly for the benefit of other experimenters; for, final success will probably come through a process of evolution, and the last successful man will need to add but little to the progress made by his predecessors.

It is true that the most important component of the future flying machine will be the very light motor. It is the lack of this which has hitherto forbidden dynamic flight and restricted dirigible balloons to inefficient speeds, but it is also true that dynamic flight is impossible unless the stability be adequate. The progress made in light motors within the last ten years has been very great; Maxim, Langley and Hargrave have produced steam engines weighing but about five kilogrammes to the horse-power, and hundreds of ingenious men are now improving the gas engine so rapidly that there is good hope that we shall soon be in possession of a prime mover which shall approximate in lightness the motor muscles of birds, which are believed to weigh but 3 to 9 kilogrammes per horse-power developed.

But even with a very light motor, success cannot be attained until we have thoroughly mastered the problem of equilibrium in the air. This fluid is so evasive, the wind so constantly puts it into irregular motion, that it imposes great difficulties even upon a bird, endowed as he is both with an exquisite organization, with life-instinct and with hereditary skill. It is to this one problem of equilibrium that I have devoted all my attention, in the belief that an inanimate artificial machine must be endowed with automatic stability in the air, and that experiments indicate that this can be achieved.

The wind is constantly in a turmoil; it strikes the apparatus at different points and angles, and this changes the position of the center of pressure, thus compromising the equilibrium. To re-establish the latter requires either that the center of gravity, (or weight) shall be shifted to correspond, or that the supporting surfaces themselves shall be shifted, thus bringing back the center of pressure over the center of gravity. Birds employ both methods; they shift the weight of parts of their bodies, or they shift either the position or the angle of their wings. It is believed that only the shifting of the wings is open to use for an artificial apparatus.

GENERAL CONDITIONS.

It is inferred, therefore, that inventors who begin by working upon an artificial motor, and who endeavor to evolve a complete flying machine at once, are beginning at the wrong end, and are leaving behind them two very important pre-requisites.

1st. That the apparatus shall possess automatic stability and safety under all circumstances.

2nd. That the apparatus shall be so light and small as to be easily controlled in the wind by the personal strength of the operator.

The general stability in the line of flight, the steering, can be obtained by a rudder, but the automatic equilibrium must be secured in two directions; first transversely to the apparatus, and secondly fore and aft. Very good results have been automatically obtained for the transverse stability by imitating the attitude of the soaring birds, the underlying principle of which consists in a slight dihedral angle of the wings with each other, either upward or downward, but the very best application of this principle is not yet evolved, and it requires more experimenting. Experimenters have found but little difficulty in securing stability in this transverse direction, but it must be worked out more thoroughly.

The longitudinal equilibrium is, however, the most precarious and important. I have tested three methods of securing it automatically.

First, by setting the tail at a slight upward angle with the supporting surfaces, so as to change the angle of incidence of the latter through the action of the "relative wind" on the upper or lower surface of the tail. This is known as the "Penaud" tail; it is susceptible of great improvement in details of construction, as has been adundantly proved, but it is not yet certain that it will counteract all movements of the center of gravity in meeting sudden wind gusts.

Secondly, by pivoting the wings at their roots, so that they may swing backward and forward horizontally, thus bringing back automatically the center of pressure over the center of gravity, whenever a change occurs in the "relative wind". The so-called "multiple-wing" gliding machine was of this type, and it reduced the movement of the aviator required to meet wind gusts to about 25 millimeters. It cannot, however, be said its construction is perfected.

Thirdly, by hinging vertically the supporting surfaces to the main-frame of the apparatus, so that these surfaces shall change their angle of incidence automatically when required. This last method has only been tested in models, other engagements having prevented experiments this year (1898). The other two methods have been applied to full-sized machines carrying a man. They have given such satisfactory results that not the slightest accident has occurred in two years of experimenting, but their adjustment has not yet reached the consummation originally aimed at, i.e. that the aviater on the gliding machine shall not need to move at all, and that the apparatus shall automatically take care of itself under all circumstances except in landing.

I shall be glad to furnish more minute descriptions to those who may want to repeat these experiments, or to apply the principles to machines of their own. The stability of an apparatus is the very first thing to work out before it is attempted to apply an artificial motor. This cannot be too strongly insisted upon, and the best way of accomplishing this pre-requisite is to experiment with a full-sized gliding machine carrying a man. This utilises the ever reliable force of gravity until such time as the automatic equilibrium is fully attained. Then, and not till then, it becomes safe to apply a motor.

When artificial power comes to be applied, it is probable that the best motor to use at the beginning will be found to be a compressed air engine, supplied from a reservoir upon the apparatus. This is not a prime mover, but it is reliable and easily applied. It will probably afford a flight for but a few seconds, but this will enable the aviator to study the effects of the motor and propeller on the equilibrium of his machine. When this is thoroughly ascertained another motor may be substituted, such as a steam or a gasoline engine, which will produce longer flights, but this will require long and costly experimenting to obtain a light and reliable engine.

Another most important requisite is that the first apparatus with a motor shall be of the smallest dimensions which it is possible to design, and shall therefore carry only one man. This is requisite for four reasons: 1st. in order to keep down the relative weight which increases as the cube of the dimensions, while the supporting surfaces increase approximately as the square; 2nd. In order to secure adequate control of the apparatus in the wind; 3rd. To diminish the power required for the motor, and 4th to have as little inertia as possible to overcome in landing. The whole apparatus should be so light and small that the aviator shall carry it about on his shoulders and control it in the wind. This can easily be accomplished with a gliding machine. My double-decked machine was of ample strength, with 12.5 square meters of supporting surface, weighing 11 kilograms, and carried a man perfectly on a relative wind of 10 meters per second. It showed an expenditure of 2 horse-power obtained from gravity. It is believed that a power machine can be built with 16 square meters of carrying surface, and a weight of 41 kilograms, which will carry a man and a motor of 5 horse-power, if the latterwith its propellers and shafts does not weigh more than 5 or 6 kilograms per horse-power. In fact this has been done with a compressed air motor machine, but the apparatus thus far has produced doubtful results, in consequence of defects in the motor. It is firmly believed that it will be a great mistake to begin experiments with a large and heavy machine, for it would probably be smashed upon its first landing, before its possibilities could be ascertained.

The speed first aimed at should be about 10 meters per second, and to achieve this the following are good proportions;

Sustaining surfaces 0.15 square meters per kilogram.
Sustaining surfaces 3.00 square meters per horse-power.
Equivalent head surface 0.25 square meters per horse-power.
Weight sustained 20.00 kilograms per horse-power.

DETAILS OF CONSTRUCTION.

The general arrangement and details of construction will conform of course, to the particular design to be tested by the experimenter, but some useful hints may be given. There need be no hesitation as to the materials to employ. The frame should be of wood, which although weaker than bamboo is more reliable and permits the shaping of the spars so as to diminish the head resistance. It has been found by experiment that the best cross-section resembles that of a fish, with the greatest thickness about one-third of the distance from the front edge; this reduces the resistance to co-efficients of one-sixth to one-tenth that of a plane of equal area, while a round section, such as that of bamboo, gives a co-efficient of about one-half. The spars of the frame can best be joined together with lashings of glued twine or with very thin steel tubing, preferably silvered or nickel-plated. The stays or tension members should be of the best steel wire, also nickeled-plated and oiled to prevent rust. A very important detail, not yet worked out, consists in connecting the wires to the framework so that they shall pull alike. The supporting surfaces should preferably be of balloon cloth or Japanese silk, varnished with two or three coats of Pyroxelene (collodion) varnish which possesses the property of shrinking the fabric upon drying, so as to make it drum-like.

(A good recipe for this varnish is as follows:- Take 60 grams of gun cotton No.1 dampen it with alcohol to make it safe to handle, and dissolve it in a bottle containing a mixture of 1 liter of alcohol and 3 liters of sulphuric ether. When well dissolved, add 20 grams of castor oil and 10 grams of Canada Balsam. This is to be kept in a corked can, and poured in small quantities into a saucer, whence it is applied thinly with a flat brush. Two coats will generally be sufficient. It dries very quickly, glues together all the laps in the fabric, and shrinks it in drying).

An expeditious way of fastening the surfaces to the frame consists in stretching them as tight as possible and then doubling them back around the spar, the flap so made is then fastened temporarily with pins; the first coat of varnish will glue the surfaces together, and the pins may be withdrawn if desired.

Although it is preferable that some of the rear portions shall be flexible, the supporting surfaces and the framework must be sufficiently stiff not to change their general shape when under motion. This indicates bridge construction for the framework and therefore the super-imposing of surfaces. Very little supporting or parachute action will be lost by this, for even when struck at right angles by the wind, Thibaut found that a square plane placed behind another of equal size, and spaced at a distance equal to the length of its side, still experienced a pressure of 0.7 that on the front plane. The supporting surfaces will of course be arched in the direction of flight in accordance with the practice inaugurated by Lilienthal, who showed that they possessed at angles of incidence of 3 degrees, five times the lifting power of planes. It is not probable that success will be achieved in Aerial Navigation with flat sustaining surfaces.

PROPORTION OF PARTS.

In proportioning the parts the factor of safety for static loads should generally be 3, never less than 2, and preferably 5 for the parts subject to the more important strains. These are to be computed in the same way as they are for bridges, with the difference, however, that the support (on the air), is to be considered as uniformly distributed, and the load is to be assumed as concentrated at the center. It is not believed that it is practicable to calculate the strains due to possible shocks upon landing. They must be taken into consideration in a general way, but the utmost efforts will be made to avoid them.

The sustaining power will be calculated in the manner given by Lilienthal in Moedebeck's "Taschenbuch fur Flugtechniker und Luftschiffer". He does not, however, fully explain how to calculate the resistance; this consists of the "drift" or horizontal component of normal pressure, plus or minus the tangential pressure, and of the "head resistance" of the framework, of the motor if any, and body of the operator.

As an example how to compute this I may give the calculations for the "multiple wing" gliding machine of 1896, which was constructed before experiments, showed how the head resistance could be further reduced by adopting better cross-sections for the framework.

AREA HEAD RESISTANCE, MULTIPLE WING MACHINE.

Description	No.	Dimensions Millimeters	Square Meters	Co-efficient Resistance	Equivalent sq. Meters.
Front edge of Wings......	10	2225 x 12.70	.28257	1/2	.14128
Main Wing Arms.........	10	1956 x 12.70	.24841	1/3	.08280
Ribs of top Aeroplane.....	3	1346 x 6.35	.02564	1	.02564
Posts of top Aeroplane....	4	1829 x 12.70	.09291	1/3	.03097
Posts connecting front Wings	8	1280 x 12.70	.12995	1/3	.04332
Posts carrying pivots.....	2	823 x 19.05	.03135	1/3	.01045
Curved prow pieces.......	3	914 x 24.50	.06717	1	.06717
Front bow braces.......	2	731 x 12.70	.01857	1/3	.00619
Rear bow braces........	2	841 x 12.70	.02136	1/3	.00712
Cross struts bow & Frame....	2	670 x 12.70	.01702	1/3	.03613
Rear wing braces.......	4	2134 x 12.70	.10840	1/3	.03613
Rudder braces..	2	1219 x 12.70	.03096	1/3	.01032
Rudder struts..	2	548 x 12.70	.01392	1/3	.00464

(Table continued on next page).

(Table Continued).

Description	No.	Dimensions Millimeters	Square Meters	Co-effi- cient Re- sistance	Equiva- lent sq. Meters.
Wire stays 61 Meters....		61000 x 1.27	.07747	1-1/2	.11620
Spring wire stays 8 meters		8000 x 1.27	.01016	1-1/2	.01524
Rubber springs.6		1300 x 1.00	.00780	1	.00780
Sundry projecting parts.......		Say	.01198	1	.01198
Aviator's body..		Say	.46450	1	.46450
			1.66014		1.08742

In order to calculate the resistance, we must first ascertain the requisite speed for support and the consequent "drift". The front wings measure 13.34 square meters and carry all the weight, they are set at a positive angle of 3 degrees, for which the Lilienthal normal co-efficient η is 0.546. Using the well known formula $W=k\ s\ v^2\eta\cos\alpha$ in which W is the weight, k the air co-efficient, s the surface, v the velocity, η the Lilienthal co-efficient (0.11) and α the angle of incidence, and calling W=86 kilos we have for the support:

$$86=0.11 \times 13.34 \times v^2 \times 0.546 \times \cos 3°;$$ and

as $\cos 3°=0.9986$, we have for the speed:

$$v=\sqrt{\frac{86}{0.11 \times 13.34 \times 0.546 \times 0.9986}} = 10.37 \text{ meters}$$

Whence we have for the front wings: Rectangular pressure $0.11 \times 10.37^2 = 11.829$ kilos. per square meter. Normal pressure at 3° $11.829 \times 13.34 \times 0.546 = 86.16$ kilograms.

Lift at 3° 86.16 x 0.9986 =86 kilograms.
Drift " " 86.16 x Sine 3° =4.51 kilograms.

The Tangential pressure upon the front wings is zero at 3°. The "drift" on the rear wings, which measure 2.74 sq. meters, and were set at a negative angle of 3°, consists in the product of their surface by the rectangular pressure, multiplied by the difference between the tangential pressure, (Lilienthal's θ) which at this angle is positive, and the horizontal component of the normal (Lilientahl's η) which is negative at 3°, the latter being obtained by multiplying η by the sine of 3°. We have therefore:

Drift rear wings = 11.829 x 2.74 (0.043 - 0.242 x 0.05233) = 0.98 k.

The head resistance is the important factor, and depends upon the shapes which are adopted for the framing to evade air resistance and to secure low co-efficients. It has to be calculated in detail, and the table herewith given recapitulates the various elements of the area of head resistance of the multiple wing machine, reduced by co-efficients to an equivalent area for further calculations.

The rectangular pressure for a speed of 10.37 meters per second being 11.829 kilos per square meter, we have therefore for the whole resistance:

Drift front wings 11.829 x 13.34 x 0.546 0.38533 = 4.51 kilos
Drift rear wings 11.829 x 2.74 (0.043 - 0.0126) = 0.98 "
Tangential component at 3°...................... = 0.00 "
Head resistance 11.829 x 1.087.................. =12.86 "
Total resistance...... =18.35

As the speed is 10.37 meters per second, the power required to overcome this total resistance is:

Power 18.35 x 10.37 = 190.28 kilogrammeters or 2.53 horse-power, and as the weight is 86 kilos the angle of descent as a gliding machine ought to be:

$$\text{Angle } \frac{18.35}{86} = 0.2134 \text{ or tangent of } 12°.$$

In point of fact the apparatus glides generally at this angle andfrequently at angles of descent of 10 or 11 degrees, this being probably due to an ascending wind along the hill-sides, and fully verifying this mode of calculating the resistance.

In the "double-decked" gliding machine, in which the framing was better designed, the resistance was calculated at 14.46 kilos, and it absorbed a horse-power in gliding in still air. By employing still better cross sections of framework, and especially by placing the aviator in a horizontal position the head resistance could be reduced by at least one-third, but this particular attitude of the man would involve some risk of accident in landing, and is considered to be too dangerous to be employed in preliminary experiments. It will be noticed in the table that the resistance of the wire stays is given a co-efficient of 1-1/2, while theoretically, being cylindrical, their co-efficient should be about 1/2. This allowance is based upon experience, wire stays produce undue resistance, and this is probably due to the fact that they vibrate like violin strings when the apparatus is under rapid motion, and thus produce a greater resistance than that due to their rounded cross-section.

The power required will be seen to differ very materially from that indicated by the formula recently proposed in France, which is based upon the assumption that the total wing surface, in square meters, multiplied by the co-efficient of air resistance (i.e. the number of kilogrammes carried by a square meter, at a speed of one meter per second) must at least be equal to the cube of the weight of the apparatus in kilogrammes; divided by the square of the power exerted by the motor in kilogrammes, or, $K\ S\ T^2 = P^3$ from which in our own case we would draw:

$$0.11 \times 13.34 \times T^2 = 86^3 \text{ , or}$$

$$T \sqrt{\frac{86^3}{0.11 \times 13.34}} = 658.4 \text{ klgm.}$$

or 8.78 horse-power, which is more than three times the power calculated by the method here given and tested by actual experiment and measuring.

It must be remembered, however, that the 2.53 and the 2 horse-power, which have been found sufficient to sustain 86 kilogrammes in the air, are the <u>net</u> horse-power absorbed by the gliding machines. When a propeller and a motor are added, it will be necessary to allow for the losses in efficiency incident to those adjuncts, and so provide about twice the power at the engine which is indicated by the resistance multiplied by the speed. A safe rule of approximation will be to allow that each nominal horse-power at the engine will sustain 20 kilogrammes, and that each kilogramme of the total weight of the apparatus will require 0.15 square meters of surface to sustain it at speeds of about 10 meters per second. When greater speeds become practicable and safe, the surfaces may be reduced below this so that at 20 meters per second they may be but about 0.05 square meters per kilo., instead of the 0.15 square meters per kilo above indicated, and this would permit reducing the head area of the framing, but unless the co-efficient for the aviator's body was in some way reduced the resistance and power required would be greater, because of the higher speed.

These are the conditions and considerations which experiments with full-sized gliding machines, carrying a man, have thus far indicated as necessary to observe in order to achieve success with a dynamic flying machine provided with a motor. The most important of them are:

FIRST, that the automatic equilibrium and safety shall first be secured before an attempt is made to apply a motor, and

SECOND, that the apparatus shall be made as small and light as possible, so that the aviator may sustain its weight before taking his flights.

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AIR PROPELLERS: By H.C. Vogt.

(Copy of a communication to London "Engineering", forwarded by Mr. Chanute, Oct. 13, 1906, see Bulletin XX, 43).

As most of the experiments performed with the air-propeller were brought before the British Association in September 1888, and published in the "Engineer" of September 28, 1888, and in the "Industries" of October 5, 1888, there is no reason to repeat all this here, but rather to present only the conclusions drawn from those experiments. A number of articles relating to this were subsequently published in most of the leading English technical journals, but all these are collected in the "Steamship" published at 2 Custom House Chambers, Leith, Scotland, and need not be reproduced either. The intention in this paper being only to present a general view of the most important facts.

When the idea of the air-propeller or revolving sails, for the use of ships was first originated, I imagined that it, working in the elastic air, ought to be more efficient than the water propeller; experiments proved, however, that the results came as near as possible to the same, that is: when a water propeller is at hand, yielding a certain thrust at a certain power, then a two-bladed air-propeller with 6 times the diameter and with its pitch reduced to something about the half or two thirds that of the water propeller, gives the same thrust at a somewhat smaller number of revolutions when the engine power is the same and the weather calm.

As soon as there is wind, this power is utilised, if the pitch of the air-propeller is changed accordingly (but of course only when this propeller is mounted on a ship, not when mounted on a balloon driving with the wind). The wind, when straight against the course, does some harm although not very much; suppose a storm blowing with the speed of 60 feet per sec., and let us also consider a speed of 60 feet per sec. given to the points of effort of the revolving sails in which the points the whole pressure is concentrated, then the result is exactly as when sailing 4 points from the wind with stationary sails; in the course of a year in our latitude, there is not a wind strong enough to prevent an air-propeller, driven with only one horse-power, to go straight against it, and 3 points from the wind its power is again. Let us for the sake of estimating the influence of the natural wind consider the same blowing with a speed V, and let the points of effort of the revolving sails possess a speed W, then in a two-bladed propeller, as in the sketch below (1), one blade will be working against a component V_c of the natural wind, while (2) the opposite blade will be working with the same; the aggregate influence on both blades will therefore be respectively a function of:

$$(W + V_c)^2 + (W - V_c)^2 = 2(W^2 = V_c^2)$$

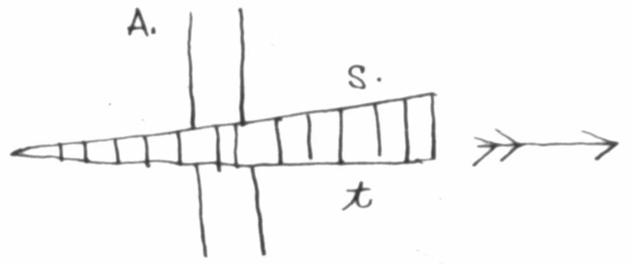
from which expression the considerable influence of the natural wind is seen. Even when the blades are passing the horizontal position, the influence of the natural wind is great because the normal pressure depends much more on the speed of the air, than on the angle of incidence, we only need remember that an angle of incidence of 15° gives a normal pressure which is half as great as when the angle of incidence is 90°. Quite 80% of the different wind directions, when sailing in a circular path, are a benefit, whereas nearly 20% do some harm to the progress.

The best material for making an air-propeller is thin steel plate which enables the highest efficiency to be reached, but it is often a mere chance to hit the best shape, a true mathematical screw surface is for instance very inferior, whereas a shape, such that sections through the blades form a feeble curvature, similar to that of an Albatross' wing is very successful. The only feature in this shape resembling that of a screw is, that sections through the blades, parallel with the axis, should have their angles with a plane perpendicular to the axis, decreasing proportionately with their distances from the axis. It being so difficult to obtain correct shapes in steel plates, it is recommended to use canvas covered with oilskin in the following manner:- y - y is a yard fixed in its middle perpendicularly to a shaft A, the two sails S are stiffened by means of thin bobbers or booms, put in pockets in the sails, which are fastened to the said yard y -y by means of buttons working in a groove made in the yard; the pitch of the sails can be regulated by means of elastic sheets t, s are stays to support the yard y. The whole system is turned by means of a crank c an a connecting rod e; the vertical engine is indicated by E; the crank c must be perpendicular to the yard y, because the greatest influence of the natural wind will just take place when the sails are perpendicular. For the sake of not straining the leeches of the sails too much, extra leeches are fastened between the neks of the said booms. A close fit between the sails and the yard y -y is essential, also the canvas should be doubled or tripled according to the strength required and covered with oilskin or coutchouc to make it as impermeable for the air as possible and as smooth as possible to reduce friction.

Propellers both in air and water work by creating a rarefaction by diminution of pressure or vacuum on the drag or rear side of their blades; this was demonstrated by leading a tube from the rear of the side of the blade of an air-propeller to the hollow shaft on which it (for this purpose) was mounted, the hollow shaft again communicating with a guage; nearly the whole thrust was thus found to result from the rarefaction on the rear side of the blade. The two agents in operation to create this rarefaction are, first, the suction from the rush of air over the drag or leeward side of blade. Second, the centrifugal force. As the pressure on the thrust side of a revolving propeller blade decreases from the tips towards the center, the air must, when the shape is correct, move inwards towards the lower pressure near the center with a speed proportioned to the difference in pressure between the outer and inner parts of a blade; the centrifugal force cannot therefore rarefy the air on the thrust side of a blade; but exactly the opposite takes place on the drag side of a propeller blade, where the centrifugal force therefore assists in rarefying the air. Something like a little storm center is thus created in front of the propeller wherewith there is obtained, as it were, a grasp on the ocean of air in front of it, and a high momentum of air is brought in motion toward the propeller; part of this air passes through and is then acted upon by the thrust sides of the blades. The rarefaction is so intense at high speeds that the air is even literally drawn towards the propeller. An experiment relating to the influence of the rarefaction is published in the "Engineer" of Feb. 6, 1891, and more completely in the "Steamship" of March 2, 1891. It is there explained in what manner the efficiency of a small two-bladed steel propeller weighing 0.35 pounds, diameter and average pitch one foot, area 25 square inches, was determined, the same being found to ascend 200 feet into the air, when driven 70 revolutions per sec.

The determination of the efficiency is too intricate to enter on here, but one curious phenomenon, namely, negative slip, is easily demonstrated. The moment of Inertia I of the small propeller was 0.0012, and the angular velocity W at 70 revolutions per sec. was 440 ft. per sec., so that the energy 1/2 IW^2 became 1/2 x 0.0012 x (440^2) = 116 foot pounds, the whole of this energy could not, however, be used in flying up; because the propeller hovered at 13.5 revolutions, when the highest point was reached, corresponding to an amount of energy equal to 1/2 IW^2 = 1/2 x 0.0012 x $(84.7)^2$ = 4.3 foot-pounds, the whole amount of energy at disposal for lifting the weight is consequently 116 -4.3 or about 112 foot-pounds. The propeller, weighing 0.35 pounds consumed, in flying up to a distance of 200 feet 200 x 0.35 = 70 footpounds, or about 63 per cent of the energy stored in the propeller; the mechanism through which the revolutions were imparted to the propeller consumed considerable work in friction etc; so it was found through experiment that a man had to develop about 130 footpounds in a single pull to give the propeller 70 revolutions per sec. The speed was easily measured and amounted to more than 100 feet per sec. especially while rising between 30 and 130 feet from the ground, which distance was passed in much less than one sec. whereas in accordance with the average pitch, equal to one foot, the speed should not have exceeded 70 feet per sec., the negative slip was therefore considerable in this case, when measured in relation to the average pitch, but when air-propellers were used for driving boats, and consequently had a comparatively greater resistance to surmount, the positive slip became often 3 times greater than with propellers in water ans still the efficiency was about 69%, thus showing that the slip had nothing to do with the efficiency of a propeller.

To prove negative slip in the air in another manner Major Elsdale undertook the following experiment:- A propeller was constructed with blades of such shape, that their thrust sides became parts of a plane perpendicular on the shaft, while the drag sides formed an angle with the thrust side, the figure shows a section through a blade, the shaft



being represented by A, the thrust side, perpendicular to the shaft, by t, so that its pitch is equal to zero; a propeller of this type gave a thrust nearly as great as when the thrust side t became parallel to the drag side s, the blade revolving as shown by the arrow.

When a propeller revolves quickly, the rarefaction often corresponds to a difference in pressure of several inches of water, and the currents produced by centrifugal force seem to prevent the air from striking the drag side, which it would do when negative slip occurs. Mr. Phillips had formerly mentioned the same experiment and explained how he drove a boat with a similar propeller and as the pitch of the thrust side was equal to zero, the negative slip was infinite in relation to that side.

When an air-propeller is required for any purpose, it has already been mentioned, that its diameter should be about 6 times the diameter of a propeller in water, determined for the same thrust, but area, pitch, revolutions, etc. can also be found directly from a model experiment by means of the following formula: two ships, or, in the case to be considered, two propellers are said to move with corresponding speeds H and h, when $H/h = (D/d)^{1/2}$, where D and d are similar lineal dimensions and H and h are the speeds of similar points on the propellers, for instance at their circumferences; under these conditions of speed, the thrusts T and t of the propellers, with areas A and a, are in the relation: $T/t = A \times H^2 / a \times h^2 = D^3 / d^3$; from $A/a = D^2/d^2 = (T/t)^{2/3}$ results the important equation: 1) $A/a = (T/t)^{2/3}$, and by means of $D^3/d^3 = T/t$ we obtain $D/d = (T/t)^{1/3}$ so that $H/h = (D/d)^{1/2}$ gives 2) $H/h = T/t^{1/6}$ which is the second important equation; the two equations $A/a = (T/t)^{2/3}$ and $H/h = (T/t)^{1/6}$ are derived under the assumption that the thrusts vary proportionately with the area and with the square of the speeds, and we are now able to find the revolutions, area, diameter, etc. of any propeller, when we know the qualitites from the model. Let it, for instance, be required to construct a propeller able to yield a thrust of 1000 pounds which is the resistance of a ship of about 1000 tons at a speed of 4 knots; then to determine its number of revolutions and the power required to drive it, a model experiment is necessary. To this and a two-bladed air-propeller quite 5 feet in diameter, 4 square feet area, pitch 2/3 of the diameter was driven by the power of a man to 4.5 revolutions per sec. and gave a 20 ft. boat a speed of 4 feet per sec. in calm weather, the resistance of the boat or thrust of the propeller at that speed, being 9 pounds, and the brake horse-power on the shaft became 1/5 horse-power which consequently corresponds to 45 pounds for each horse-power. The area A of the large propeller (which strictly speaking should move at a corresponding speed to be of the same efficiency) is then:

$A = a\,(T/t)^{2/3}$ as the area a of the model is a = 4 square feet we get,

$A = 4\,(1000/9)^{2/3} = 4 \times 23 = 92$ square feet for the area of the large propeller, intended for a thrust of 1000 pounds, and as the area of the model propeller is 1/5 of the disk area, the same must be the case with the larger similar propeller, whereby its diameter becomes 24 feet. The velocity in the circumference of the small propeller was 75 feet, the velocity in the large similar propeller will therefore be,

$H = h(T/t)^{1/6} = 75(1000/9)^{1/6} = 75 \times 2.19 = 164$ feet per sec. which corresponds to 2.2 revolutions per sec.

When the corresponding speeds for model and large propeller are termed h and H, and the thrust of the model propeller is 45 pounds per horse-power, then the power to drive the large propeller is, $(1000/45)H/h$, and as $H/h = (1000/9)^{1/6} = 2.19$, we obtain the horse-power equal to $22 \times 2.19 = 48$, that is to say, the horse-power is 48, if the large ship moves with a corresponding speed to that of the model, which is $4 \times 2.19 = 8.76$, or quite 8 knots; as the large ship is only intended for 4 knots in calm weather, the power will be somewhat reduced; moreover, the efficiency of the large propeller is greater than that of the smaller, which also tends to reduce the power. Of greater importance, however is the fact, that the resistance of the air varies at a much higher power than that of the square, especially when a surface revolves round an axis in its own plane (when the speed of the points of effort of a surface, revolving round an axis in its own plane, equals that of the same surface, when moving after a straight line perpendicularly on its own plane, then the resistance of the revolving surfaces is about 3 times greater on account of the rarefaction produced through centrifugal force. The resistance also increases more than proportionally with the increase of the area when the speed is unaltered; it is not difficult to take these matters into consideration, but it makes the formula more complicated than is suitable for this paper; let it therefore be sufficient to say that the power in this case would be less than 40 horsepower and 2.2 revolutions per sec. would scarcely be reached at that power with a greater diameter than 20 feet.

Several experiments were made with boats furnished with revolving sails or air-propellers as explained in the article referred to; the largest of these was with a big steam launch belonging to the Royal Dockyard in Copenhagen and furnished with an air-propeller 20 feet in diameter. Any of them of course could have been used as unit or model for the example given, but when a model experiment is required it is not always convenient to drive a propeller with steam for that purpose. It is not difficult at all for a man to drive a very light boat to a speed of 4 knots or about 7 feet per sec. but the model air-propeller to be tested must be removed to different boats until one is found which offers the the required resistance at accertain speed.

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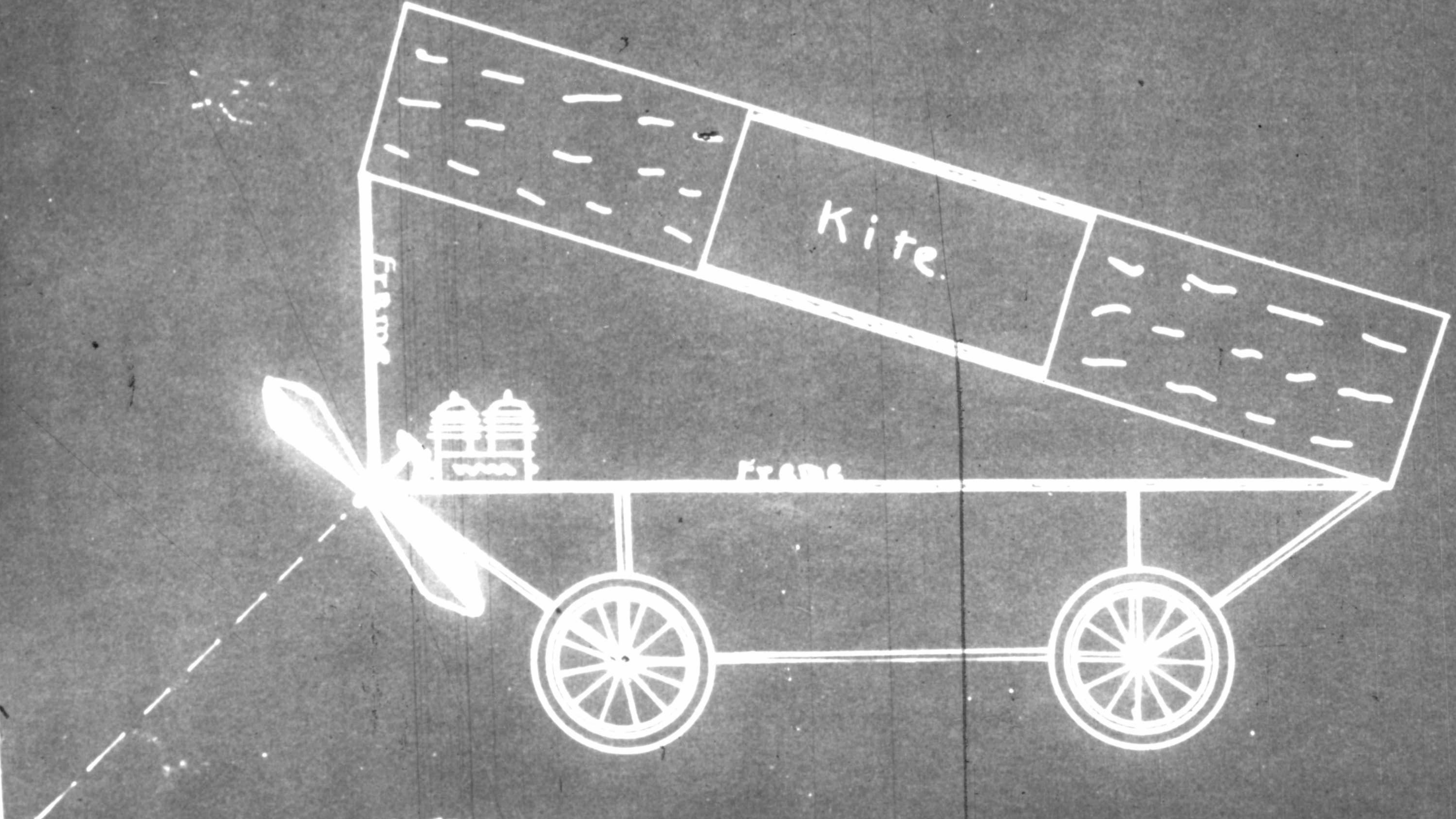
Copenhagen.

LAUDER TO BELL.

Calgary, Alberta, Canada, Nov. 9, 1908:-Having heard that you encouraged and experimented in Aerial Navigation, I therefore venture to submit to your valued consideration an idea which I happened to observe while experimenting with kites. Your are well aware that if an aeroplane could maintain its position in the air as steadily as a well constructed kite the science of flying would be almost solved. Then the question what keeps its flying so perfectly; the reason I saw for it was this, that the power as applied to the kite was not only in a forward direction but also down. Now if the flying line imparts a force that is also down as well as forward as illustrated in drawing I, why not put an engine and propeller, the propeller exerting its force in precisely the same direction as the flying line in drawing No.II. What I base my theory on is this, that as far as I can gather that in the latest aeroplanes for example the "June Bug" of Mr. G.H. Curtiss, the power is applied parallel or nearly so to the planes.

Now if a kite was to be flown you would not attach the flying line to "K" in drawing I, you knew that the kite would under no circumstances fly, yet you are applying the power on a parallel to the plane. But if you wished a successful flight you would fasten the flying line, in other words the power, to the correct spot on the bridle. Then why should not a propeller placed so as to exert its force in the same direction as the flying line, do the same work and keep the kite afloat. I am writing you Dr. Bell from having heard that you are a firm supporter of Aerial Navigation and your highly valued opinion would be very much appreciated.

(Signed) Alfred H. Lauder.



ALFRED LAUDER
NOV. 9. 1908