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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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WIND VANE WITH VARIOUS APPLICATIONS.

By M. Louis Constantin.

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Let us consider two disks S and S_1, shown in cross-section in Fig. 1, placed symmetrically with respect to the plane y y'. These disks preferably have such cross-sections that their Ky increases rapidly with the angle of attack of the relative wind to which they are exposed.

Let us connect these two disks by a rigid rod t.

Let us assume that the relative wind flows in the direction y' y parallel to the plane of symmetry. It will produce on these two disks two thrusts p and p_1 equal and opposite in direction and the system will remain in equilibrium.

Let us now assume that the relative wind blows in the direction f, at an angle ω with the original direction. The thrust p is then diminished and becomes p'. The thrust p_1 increases and becomes p'_1 and the whole system tends to turn toward the right.

If this system were mounted on a hinged parallelogram, it would continue to move to the right until something stopped it.

Let us mount it, not on a parallelogram but on a hinged trapezium, as shown in Fig. 1. The relative wind f' will always tend to turn it toward the right. The disks S and S_1 will become S' and S'_1 and the rod t will become t'. It is clear that equilibrium will be established when S' and S'_1 are in the new relative wind, i.e. when the rod t has turned exactly the angle ω.

* From "Premier Congres International de la Navigation Aerienne," Paris, November, 1921, Vol.II, pp. 91-95.

We will then have a real wind vane whose indications will be simply a function of the direction of the relative wind (and not at all of its velocity), provided, of course, that there is enough energy to overcome the passive resistance of the pivots. It is, however, evident that this energy is considerable.

Let us now consider the radius vector om, m being the middle of the rod t, and let u be the angle it must make with $y'y$.

By making the calculation, we find between u and ω the relation

$$\tan u = \tan \omega \; {\frac{1}{1 - \frac{a}{b}\,(1 + \tan^2 \omega)}}^{\frac{1}{2}}$$

In order to give some idea of the relative order of magnitude of u and ω, we may note the following: The angles ω to be measured being very small, $\tan^2 \omega$ is an infinitely small quantity of the second order and may be disregarded in practice.

If then we make $a = 0.99b$, a and b being the lengths of the parallel sides of the trapezium, we find $\tan u = 100 \tan \omega$.

If we have any means of measuring the angle u, we will have a wind vane with the following advantages.

1. <u>Great precision</u>.- The system of multiplication of angles employed has, in fact, this valuable characteristic, that the energy increases at nearly the same rate as the ratio of multiplication adopted. Furthermore, the angle u by actual measurement being very large compared with ω, the relative errors committed will be of only little importance..

2. <u>Insensibility to vibrations</u>.- In an ordinary wind vane, the small vibrations exert a direct action on the angles of deviation to be measured and render their reading extremely difficult. Here it is evident, however, that small vibrations of the disks S and S' have but a very slight effect on the value of ω and consequently of u.

A P P L I C A T I O N S.

I. GENERAL AERODYNAMICS.

Whenever it is desired to find the exact direction of an air current.

It should be noted here that the value of each type depends only on the ratio of the lengths of the two parallel sides of the trapezium and not on their absolute values nor the distance between them. We can therefore easily construct instruments of very small size, thus enabling investigations almost everywhere.

II. AVIATION.

1. Here again, whenever it is desired to conduct investigations on the direction of an air current, e.g., to study the deviation of the relative wind produced by an airplane cell from the point of view of the action on the tail members.

2. As <u>slip indicator</u>.- It may be noted that the indication is practically instantaneous and as accurate as desired.

3. As <u>indicator of angles of attack</u>.- Let us consider an airplane polar as given in Fig. 2. It would be extremely useful for the pilot to know the angle of attack at which he is flying.

For example, at 0° the mechanical stresses on the various parts of the airplane are large and there is danger of rupture.

At 13° the airplane is approaching a dangerous zone and at 14° it is already in this zone. This angle of 14° is also the one which must not be exceeded in landing.

The angle of 6° is also a very remarkable angle which it is well to know, since it is the optimum angle. It is, in fact, known that this is the angle which enables the longest glides. Moreover, if a propeller has its maximum efficiency at this angle, the optimum angle will always be the economical angle.

It is known that, when there is no wind, the fuel consumption for a given flight is proportional to the expression

$$\frac{Kx}{Ky}\ \frac{1}{\eta}$$

η being the propeller efficiency. The fuel consumption is therefore least for the optimum angle, the angle for which we have at the same time the minimum value of $\frac{Kx}{Ky}$ and the maximum value of η. As soon as we leave this angle, the value of the expression $\frac{Kx}{Ky}\ \frac{1}{\eta}$ increases and the increase offsets the saving which might be made, either with a favorable wind by flying at a larger angle or with a contrary wind by flying at a smaller angle.

This holds true even for quite strong winds, those attaining, for example, one-third of the speed of the airplane. In most cases, therefore, pilots may be instructed to fly at the optimum angle under all conditions of weight, altitude and wind. No other instrument known can give so sure and simple indications from this point of view.

4. For testing airplanes and propellers during flight.- Using known notations, we have:

In gliding.

(1) $W \cos\theta = Ky\, V^2 \rho$

(2) $W \sin\theta = Kx\, V^2 \rho$

In straight horizontal flight.

(3) $W = Ky\, (V')^2 \rho'$

(4) $T = Kx\, (V')^3$

The weight W of the airplane is known. An inclinometer will give θ. The value of $V^2 \rho$ is given directly, for positive or negative pressure, by the speed indicators. We can therefore, by using either of the equations (1) and (2) or both at the same time, determine the polar of the airplane in a few gliding flights.

The only apparent necessary correction is the one due to the drag produced by the propeller. If the r.p.m. of the propeller is also noted at the same time as θ and $V^2\rho$, the correction is easily made.

Equation (3), by means of horizontal flights, renders it possible either to verify the values of Ky, or, if we do not have a good inclinometer, to calculate θ by using the expression

$$\cos\theta = \frac{V^2}{(V')^2} \; \frac{\rho}{\rho'}$$

Lastly, equation (4) renders it possible, by means of horizontal flights at various angles of attack, with chronometry of the corresponding speeds, to determine the propeller efficiency at different flight speeds. This greatly simplifies airplane tests during flight.

5. As turn indicator.- Let us consider an airplane whose lon-

gitudinal axis AB and center of gravity G are represented in Fig. 3. Let us assume that the airplane is making a turn with a radius of OG. Evidently the relative wind at the point A no longer flows in the direction f, as in rectilinear flight, but in the direction f' forming, with relation to f, an angle ω equal to the parallax of the distance AG viewed from the point O. Every turn is accordingly manifested at the point A by a deviation of the relative wind and it will only be necessary to signal this deviation to the pilot to inform him that the course is no longer straight.

In practice, unfortunately, every turn is accompanied by skidding or slipping, which perverts the indications of the vane.

In order to correct this error, we may place a second wind vane to the right of the center of gravity and with the two vanes control pointers mounted on the same axis. When there is only a slip, the pointers will remain superposed and will indicate this slip. When there is also a turning at the same time, there will be a certain angle between the pointers. The pilot can then correct both the slip and the turn.

AUTOMATIC STABILIZATION OF AIRPLANES.

As just explained, the wind vane may be employed as an indicator both of slips and of angles of attack. These two properties enable us to conceive a very simple method for the automatic stabilization of airplanes.

LATERAL STABILIZATION.

At a certain distance from the ground, an airplane is in danger laterally when it skids. In this event the wind vane gives warning.

It can do still better. We have seen that the energy involved is considerable. Let us give to our vane a total area of one square meter and the cross-section of the Eiffel wing No. 4, for which Δ Ky corresponding to 1° is about 0.0087. Adopting a reduction coefficient of 0.8 to allow for interaction, the stress on the vane for a speed of 50 m/sec at 1° will be

$$f = 0.0087 \times 1 \times 50^2 \times 0.8 = 17.4 \text{ km.}$$

This is more than we require for controlling the ailerons directly without the aid of a servo-motor.

It should be mentioned that as soon as the slip ceases and the vane is again in the bed of the relative wind, the ailerons will resume their position, and that their action will increase and decrease with the angle of slip.

When the pilot operates the rudder-bar for the purpose of changing his direction, the airplane will not tip enough by itself to avoid a little skidding, but the action of the wind vane will immediately correct it and the pilot will need to give it no attention.

LONGITUDINAL STABILITY.

Since the wind vane can serve as an indicator of the angle of attack, it can, of course, act directly on the elevator.

Suppose, for example, that it is adjusted in the line of the relative wind when the airplane is flying at 6°. If, for any reason, this angle of attack changes, the vane tending to remain in the direction of the relative wind, acts on the elevator controls so as to bring the cell back into its original position and the angle of attack will remain approximately constant.

Furthermore, if the pilot possesses the means for regulating the adjustment of the vane during flight, he can always fly at any chosen angle and even take off or land.

We may therefore conceive the controls of an airplane as follows. A steering wheel, like those on automobiles, controlling an irreversible direction. On the steering wheel, handles for controlling the engines. To the right of the pilot a lever, similar to the lever for changing the speed of an automobile, controls the adjustment of the wind vane.

Piloting, which, aside from taking off and landing, consists in watching the course and the altitude, will be extremely simplified and will impose no physical strain on the pilot.

Translated by the National Advisory Committee for Aeronautics.

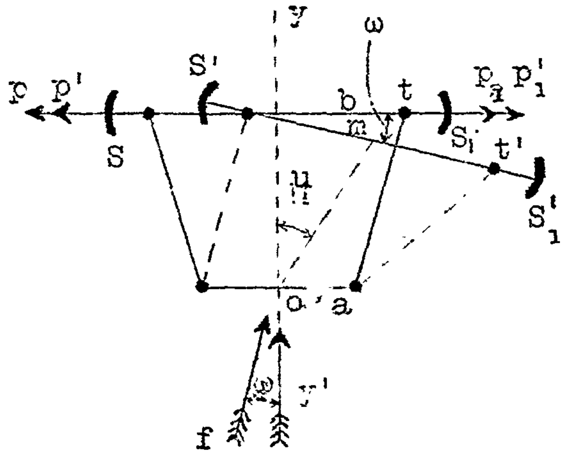

Fig. 1.

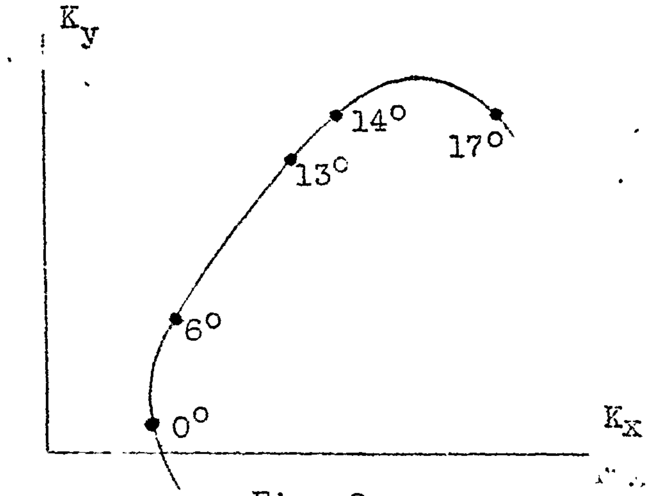

Fig. 2.

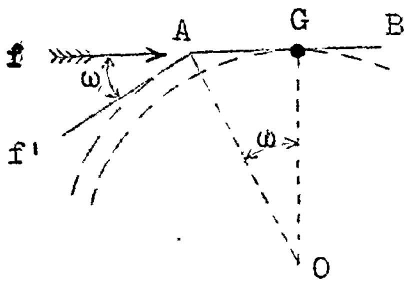

Fig. 3.