TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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DRAG OR NEGATIVE TRACTION OF GEARED-DOWN SUPPORTING PROPELLERS IN THE DOWNWARD VERTICAL GLIDE OF A HELICOPTER.

By

A. Toussaint.

Resume translated from the French
by Paris Office, N.A.C.A.

September, 1920.

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The translation of this Resumé was prepared by the Paris Office of the National Advisory Committee for Aeronautics in view of the general interest now being evidenced in the development of the Helicopter.

In the case of a propeller of a helicopter in vertical descent, the author calls the value F/V^2D^2 the UNIT COEFFICIENT OF DRAG. In this expression F is the thrust of the propeller turning as a windmill, the thrust being directed in the sense opposite that of the forward movement; V is the speed of descent, and D the diameter of the propeller.

The ratio of the surface S' of the orthogonal plane which produces the same thrust as the propeller, to the surface S of the circle swept by the propeller, he calls QUALITY OF DRAG (q_f).

Experiments made at the Eiffel Laboratory on windmills of constant relative width equal to 1/12 of the diameter and of circular dorsal profile, the ventral profile being flat, but of different pitches, have shown:

* Paper read by M. Toussaint, Engineer of the Aerotechnical Institute of the University of Paris, (St.-Cyr l'Ecole), before the Scientific Commission of the Aero Club of France, January 24th, 1920.

1. That the maximum of F/V^2D^2 occurs for each windmill for a value of V/nD greater than that corresponding to zero motive power; in other words, in order to obtain F/V^2D^2 maximum, drag must be introduced.

2. That the maximum values of F/V^2D^2 increase from 0.0057 to 0.0357 Kg/sq.m/m:sec when the relative pitch decreases from 1.5 to 0.28.

Also the automatic rotation experiments made by M. Riabouchinski showed that the maximum of F/V^2D^2 for a flat double sector (propeller with zero pitch) exposed in a current of air perpendicular to the plane of the sector, was obtained by making this sector revolve, and that this maximum was 0.0625 Kg/m:sec/sq.m.

The author believes that for a windmill with zero pitch having a profile similar to that of the windmills tested by the Eiffel Laboratory, the value of F/V^2D^2 would be well above 0.0625.

He points out that if we adopt $F/V^2D^2 = 0.0357$ and $V = 3.16$ m/sec, which is the normal speed of descent supportable by the human organism, we obtain for diameters of 2, 4, and 6 meters, values of F equal respectively to 1.4, 5.7, and 12.9 Kg.

The author concludes that such reactions could not support even the weight of these propellers.

He then seeks to calculate, by means of Froude's Theory, the maximum value of the drag of a windmill. For the motive power supplied by the windmill (P_m) and the thrust (F), he gives the following expressions:

$$P_m = \frac{a\,K_y\,V^5}{2.66\,l\omega^2}\left(1 - 0.75\,\frac{K_x}{K_y}\cdot\frac{R\omega}{V}\right)\left(\frac{R\omega}{V}\right)^{3.95}$$

$$F = \frac{a\,K_y\,V^4}{2.66\,l\omega^2}\left(1 + 0.562\,\frac{K_x}{K_y}\,\frac{V}{R\omega}\right)\left(\frac{R\omega}{V}\right)^{3.95}$$

where a is the number of blades, l the relative width assumed constant, K_x and K_y the unit elements of resistance assumed constant along the blade.

V - the speed of translation of the windmill.
R - the radius of the rim of the blade.
ω - the angular speed of rotation.
F - will be maximum for the maximum value of ω, which corresponds to $P_m = 0$.

We then find

$$\omega = \frac{4}{3}\,\frac{V}{R(K_x/K_y)}$$

which shows that the angular speed is limited and connot exeeed a certain value depending on V, R, and K_x/K_y.

On the other hand we have:

$$\frac{F}{V^2D^2} = \frac{0.166\;K_y}{l(K_x/K_y)^{1.95}}$$

NUMERICAL APPLICATION

The author admits a = 2; l=6 and $K_y = 0.0315$, $Kx/K_y = 0.083$, values determined by the application of Froude's Theory to Professor Durand's Propeller Tests made in the laboratory or in actual flight, by the calculations of M. Pillard.

Under these conditions we find for the windmill giving the maximum drag:

H/D = 0.0865; V/nD = 0.196 and $F/V^2D^2 = 0.222$.

The author plots a curve of the values of F/V^2D^2 as function of H/D, linking up the values obtained in the Eiffel Laboratory tests (mentioned above) with the values calculated for $H/D = 0.0865$ and for an intermediary value of $H/D = 0.2$ for which we find $F/V^2D^2 = 0.074$.

Assuming $F/V^2D^2 = 0.222$, $V = 3.16$ m/sec., that a wooden propeller with a diameter of 2 m 50 weighs 5 kg. and that the weight of a propeller is proportional to the cube of the diameter and to the number of blades, the author compares the values of F and of the weight of propellers for 2, 4, and 6 blade propellers with diameters of 2 m 50 and 6 m.

He finds that the difference between the drag and the weight is proportional to the number of blades and is larger for propellers of small diameter; thus it is 25 kg. for a six blade propeller with a diameter of 2 m. 50.

The author says that " if we are to adopt large propellers we must have recourse to a different method of construction, giving large dimension propellers much lighter than those made of wood.

"Finally, this drag appears insufficient, even with small propellers to assure the normal downward glide, in a vertical line, of a helicopter carrying a certain useful weight in addition to the weight of the airplane itself, the engine, the tank, and all the organs of the machine".

The author concludes that:

"This question of the drag of geared down, supporting propellers can only be decided by experiment.

"Such experiments, must, of course, be made in aerodynamical laboratories, where they can be carried out with greater exactitude and more methodically, and also with less expense and risk than would be involved by the complete realization of a helicopter.

"It will be particularly interesting to find out whether drag reaction cannot be increased in an oblique glide. In point of fact, we know from Riabouchinsky's experiments that the quality of a supporting propeller is notably improved in an air-stream parallel to its plane of rotation.

"To sum up, we should carefully guard against considering the downward glide of helicopters as being a settled question. The latent possibilities of the question can only be indicated by the aerodynamical laboratories."