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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 225

PROPELLER SCALE EFFECT AND BODY INTERFERENCE.

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Washington,
September, 1925.

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By Fred E. Weick.

Summary

This note shows that the main part of the discrepancy between full flight propeller performance and the performance of models in a wind tunnel is due to a scale effect, and that a minor part is caused by body interference. Analyses are made of propeller performances on several standard airplanes, and the actual brake horsepower compared with the power as calculated from model test data. The calculated power is based on that absorbed by a wind tunnel propeller model which is geometrically similar to the full scale propeller and is operating under the same ratio of V/nD.

For the cases investigated, it is found that the ratio of brake horsepower to calculated horsepower varies with the tip speed of the propeller. With average fuselages the greatest deviation from the mean curve is about 2%.

Introduction

Propeller designers have long been seeking a relation between power absorbed by propellers in practice and that calculated either from a wind tunnel model test or by some system of analysis such as the blade element theory.

The difference has been considered as due largely to the interference between the propeller slipstream and the parts of the airplane immediately behind the propeller. However, other factors which enter are deformation of the propeller blades and scale effect, both of which vary with the tip speed. From National Advisory Committee for Aeronautics' Report No. 220, "Comparison of Tests on Airplane Propellers in Flight with Wind Tunnel Model Tests on Similar Propellers," by Durand and Lesley, it seems that, while some of the increase in power is due to interference with the fuselage, most of it is unaccounted for in the test results. It may, therefore, be assumed to be due to deformation and scale effect, and to depend to some extent on tip speed. Since the tip speeds of full scale propellers now used vary from about 500 ft./sec. to 1100 ft./sec., it seems reasonable to assume that for accurate design or analysis, the tip speed or an equivalent velocity should be considered. To support this assumption, a number of actual propeller performance tests on various airplanes have been analyzed. The ratios of the actual or brake horsepowers to the calculated or equivalent model horsepowers of the propellers acting alone are plotted against the tip speed (taken as πnD). The points for airplanes with average fuselages all come within about 2% of a smooth curve, but this accuracy must be considered a matter of chance since the brake horsepower of the engines cannot be determined within less than 3% or 4%.

The method of propeller analysis used was developed by the writer. It is based on tests of a series of Navy standard models by Durand and Lesley. The powers absorbed were resolved into nondimensional coefficients, and plotted in the form of curves. Since the model tests cover only a small range of pitch diameter ratios, blade widths, and blade thicknesses, the blade element theory was used to calculate extreme cases. To make the blade element analysis give results consistent with the model series, calculations were made of the model performances throughout their range. It was found that by using blade interference corrections as given in R.& M. 639 of the British Advisory Committee for Aeronautics, and airfoil section characteristics obtained in McCook Field high speed wind tunnel, the calculated powers and efficiencies came within about 7% of the experimental values over the working range of the models. The calculations were then performed in reverse order using the experimental model values for power and efficiency as a basis, and corresponding blade section characteristics were determined. Now using these blade section characteristics in the blade element theory, the calculations were made again and checked the model results very closely. This method of calculation was then used to expand the model data to a range large enough to include all propellers likely to be found in practice. The actual analysis is made by simply using a few curves in which all of the data are plotted in the form of dimensionless coefficients.

The propellers investigated are all Navy wood standard or similar types, and are thought to distort very little in action.

Distortion and Scale Effect Compared with Body Interference.

In Fig. 1 a comparison is made of the power absorbed by model propellers alone in a wind tunnel, models with a model VE-7 fuselage, and full scale propellers in free flight on a VE-7 airplane. The data are taken from the tests by Durand and Lesley and are presented for three propellers of varying pitch and diameters. In each case, it is shown that except for V/nD's higher than those in normal use, the increase in power of the full scale propellers over the models alone is accounted for in a very small degree by the fuselage interference, if the latter may be considered as the ratio of the power of the model with fuselage to that of the model alone. At high slips it appears that the effect of fuselage interference on power is negligible, but the difference between full scale and model results is quite marked. It may, therefore, be assumed that most of the discrepancy between model and full scale results is due to scale effect and distortion. Furthermore, as both of these are functions of tip speed and as the tip speeds of propellers vary over a wide range, model results cannot merely be "boosted" or "stepped up" to another airplane for full scale work, but must be fitted to the particular tip speed used in every individual full scale propeller.

Analysis of Free Flight Tests:

In order to substantiate the above assumption, the results of several propeller tests on different types of airplanes were analyzed and the data collected in the accompanying table. All of the first series fall within the average tractor biplane class, but those in the second group, the MO-1, PN-7, and PN-9, are extreme cases. In Fig. 2, the ratio of actual brake horsepower over calculated horsepower is plotted against tip speed. The points for airplanes with average fuselages lie within 2% of a smooth curve. The MO-1, which has an exceptionally large fuselage and thick wings immediately back of the propeller shows higher power than the average, which is to be expected from the high fuselage interference. Even in this extreme case, the power is only 5% above the average, and the average is 13% above the model or calculated power, which gives an indication of the relative values of body interference and scale effect. The points for the PN-7 and PN-9 fall below the line as is to be expected on account of their outboard engines and small nacelles. In the PN-9 with its large geared propellers and compact Packard 1A-1500 engines, the interference is very little greater than for a model alone as arranged for testing in the wind tunnel.

The curve as drawn is very similar to a cubic, and it is possible that the true curve for propellers acting alone would be a cubic passing through the origin. Since the power varies as the cube of the tip speed for geometrically similar propellers at the same V/nD, this may indicate that the scale effect is such that the characteristics of the airfoil sections vary directly as the speed. Such a variation does not agree with the results found in the variable density wind tunnel, but it is not at all certain that changing the Reynolds Number by varying the density of the air produces the same effect on airfoil characteristics as changing it by varying the velocity, when the velocities are of the order of the velocity of sound. There is very little known about airfoil characteristics at the high velocities used in propeller work and a thorough research on this subject would be helpful indeed.

Conclusions

The data in this paper are very limited and the following conclusions are made tentatively and subject to revision when more complete data become available.

(a) The combination of scale effect and distortion is a more important consideration than body interference in the determination of power absorbed by full-scale propellers.

(b) The power absorbed by propellers depends upon the tip speed, all other conditions remaining constant.

An extended full-scale research covering scale effect, distortion, and body interference will be required in order to determine the validity of these conclusions.

Symbols

V = Airspeed in ft./sec.

n = Revolutions per second.

D = Diameter in feet.

P = Power in ft. lb. per sec.

ρ = Density of atmosphere in mass units.

C = Power coefficient = $P/\rho n^3 D^5$

A.R.= Aspect Ratio = Diameter/Total maximum blade width.

C.R.= Camber or Thickness Ratio, based on Navy standard minimum camber = 1.

B.HP.= Brake horsepower of engine.

C.HP.= Calculated horsepower of propeller.

Reference

1. Wm. F. Durand and E. P. Lesley : Comparison of Tests on Airplane Propellers in Flight with Wind Tunnel Model Tests on Similar Propellers. N.A.C.A. Report No. 220 - 1925.

Data Used for Fig. 2.

Ship	Engine	B.HP.	M.P.H.	R.P.M.	Prop. No.	Dia.	Pitch	A.R.	C.R.	C.HP.	$\frac{B.HP.}{C.HP.}$	Tip Speed= πnD	Notes
VE-7	E-4				B'	8.5'	5.1'	6	1.2		1.10	830	D. & L. tests
"	"				I	8.17	5.72'	6	1.2		1.08	770	D.& L. tests
"	"				D'	7.83'	6.27'	6	1.2		1.06	750	D.& L. tests
"	"	190	109	1800	2956	7'	5.75'	3 4 blades	1.1	181	1.05	660	Navy test
UO-1	J-4	203	116.6	1850	2956	7'	5.75'	3 4 blades	1.1	191	1.06	680	" "
DH-4	Liberty	410	123.2	1700	37593	9.83'	6.91'	7.05	1.20	370	1.11	875	Army "
DT-4	T-2	536	114.5	1780	2935	10.5'	5.65'	6	1.1	450	1.19	980	Navy "
"	"	545	112.2	1830	631	10'	6'	6	1.15	483	1.13	960	" "
DT-4 Racer	T-3	620	120.4	1890	631	10'	6'	6	1.15	534	1.16	990	" "
"	"	622	124	1900	632	9.83'	6.25'	6	1.15	530	1.17	980	" "
MO-1	D-12	360	100	1840	324	9.5'	5'	6	1.1	306	1.18	916	Navy test large fuselage
PN-7	T-2	543	113	1820	378	10.5'	5.5'	6	1.15	484	1.12	1000	Navy test small nacelle
PN-9	1A-1500	540	119	1200	3511	12.67'	9.23'	5	1.0	525	1.03	795	Navy test nacelle geared 2:1

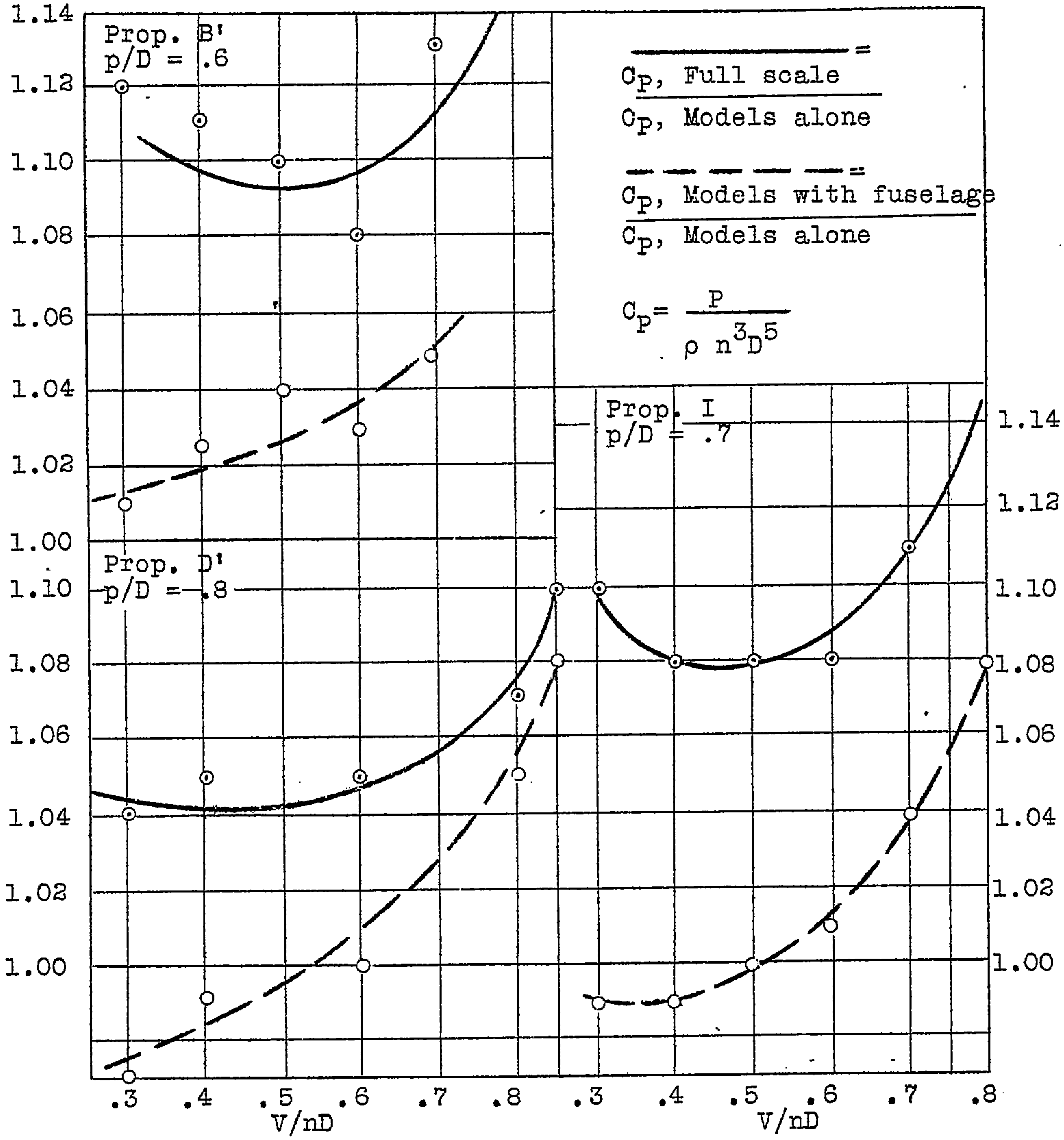

Fig.1 Comparison of power absorbed by full scale and model propellers with VE-7 fuselages.
Based on C_P of model propellers alone = 1.
Data from tests by Durand and Lesley.

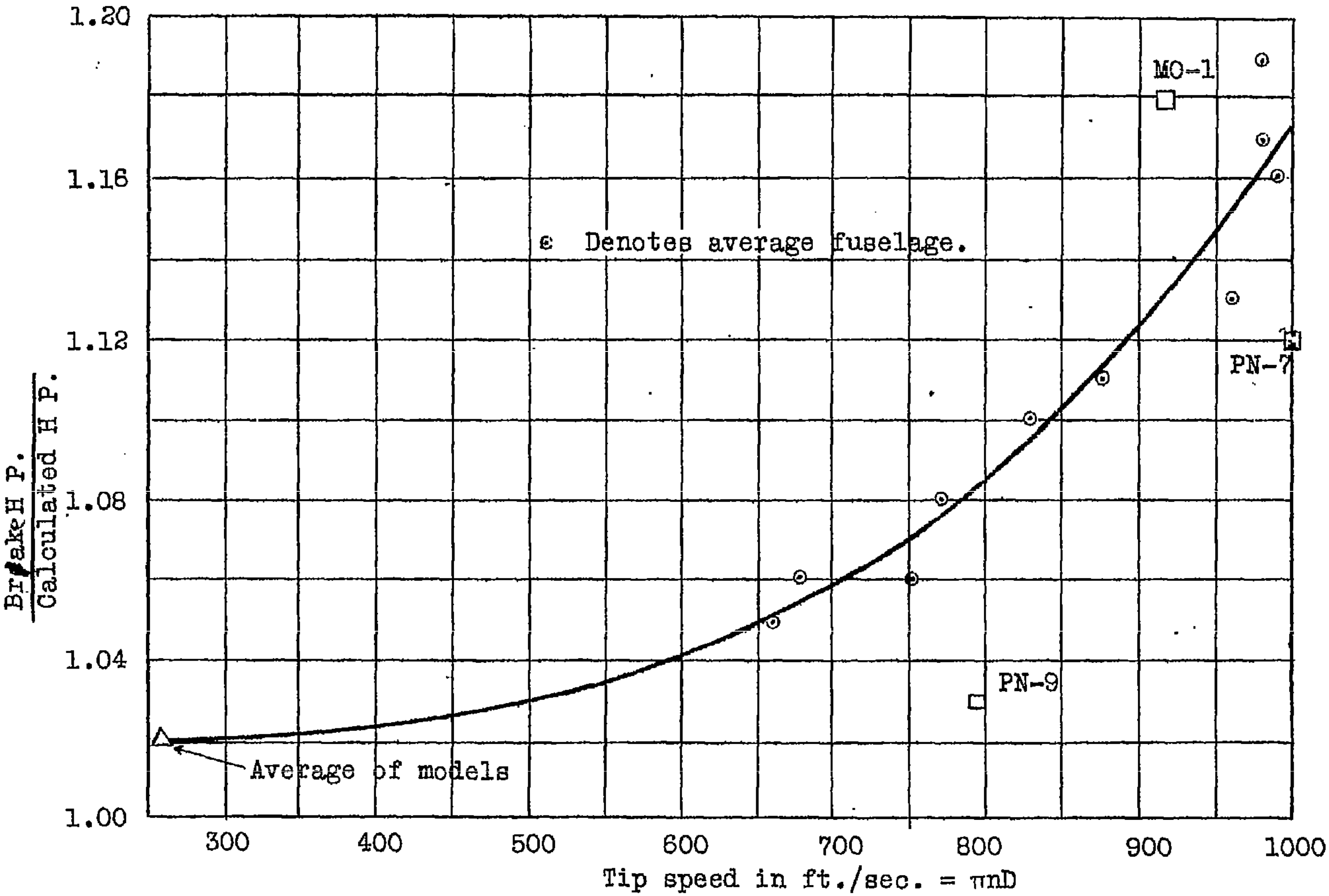

Fig.2 Power vs. Tip speed.