REPORT No. 301

FULL SCALE TESTS
OF WOOD PROPELLERS ON A VE-7 AIRPLANE IN THE
PROPELLER RESEARCH TUNNEL

By FRED E. WEICK
Langley Memorial Aeronautical Laboratory
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SUMMARY

The investigation described in this report was made primarily to afford a comparison between propeller tests in the new Propeller Research Tunnel and flight tests and small model tests on propellers. Three wood propellers which had been previously tested in flight on a VE–7 airplane, and of which models had also been tested in a wind tunnel, were tested again on a VE–7 airplane in the Propeller Research Tunnel. The results of these tests are in fair agreement with those of the flight and model tests.

Tests were also made with the tail surfaces removed, and with both the wings and tail surfaces removed. It was found that the effect of the tail surfaces on the propeller characteristics was negligible, but that the wings reduced the maximum propulsive efficiency about 5 per cent.

INTRODUCTION

Heretofore aerodynamic tests on propellers have been made either in flight or on small models in a wind tunnel. Full scale tests are highly desirable, but flight tests to obtain the aerodynamic characteristics of propellers are difficult to make and have not been sufficiently accurate to be useful in bringing out small differences in propellers.

The tests reported in this paper are the first wind-tunnel investigations on full-size propellers. They were made in the 20-foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics, which is described in detail in Reference 1. Three wood propellers of standard Navy form were tested on a Vought VE–7 airplane with a Wright 180 HP, E–2 engine. These particular propellers were selected for this investigation because they had been previously tested on a VE–7 airplane in flight (References 2 and 3) and models of the propellers had also been tested with a model VE–7 airplane in the Stanford University wind tunnel; thus, a direct comparison of the full-scale wind tunnel results with the results of the flight and the model tests was afforded.

In addition to the aerodynamic characteristics of the three propellers on the complete airplane, the effects of the wings and tail surfaces on the characteristics of one propeller were measured at one angle of attack. Also, the angle of twist of one section of each propeller was measured in operation.

METHODS AND APPARATUS

The Propeller Research Wind Tunnel is of the open jet type with an airstream 20 feet in diameter, in which velocities up to 110 M. P. H., can be obtained. A complete description of the tunnel, balances, and other measuring apparatus is given in Reference 1.
Fig. 1.—The VE-7 airplane
FULL SCALE TESTS OF WOOD PROPELLERS


Fig. 3.—Experimental propeller B' for VE-7 airplane


Fig. 4.—Experimental propeller I for VE-7 airplane


Fig. 5.—Experimental propeller D' for VE-7 airplane
The VE–7 airplane (fig. 1) had a span of 34 feet. When mounted in the center of the air stream the wings projected approximately 7 feet outside the air stream. Figure 2 is a photograph of the airplane mounted in the experiment chamber. It is considered that a sufficient portion of the wing structure was in the air stream to include all parts which would react on or be influenced by the propeller.

The general dimensions of the three propellers tested are given in Figures 3, 4, and 5, and the ordinates of the various sections shown in the drawings are given in Table I. The propellers, which are of standard Navy wood type, form a series varying in pitch ratio. Propeller I, the central one of the series, has a ratio of pitch to diameter of 0.7, and the other two propellers, B' and D', have pitch ratios of 0.6 and 0.8, respectively. The blade width, thickness, and angle were measured for each section of each propeller after the tests were completed. In nearly all cases the measured blade widths and thickness were about $\frac{1}{16}$ inch greater than those shown on the drawings, probably due to the fabric with which the propellers were covered. The measured blade angles over the working section or outer portion of the blade averaged 0.3° less than the drawing for propeller B', 0.5° greater than the drawing for propeller I, and the same as the drawing for propeller D'.

The VE–7, as mounted in the tunnel, had inclosed within it a special steel skeleton fuselage with a built-in dynamometer scale to measure the engine and propeller torque directly. (Reference 1.) The engine was mounted in such a manner that it was free to turn about its own axis, but was restrained by means of a torque arm and system of knife-edge linkages leading to a Toledo scale dial, upon which the torque was indicated directly in pound-feet.

The revolution speed of the engine was measured by means of a special Elgin tachometer which, according to calibration, is accurate within ±2 R. P. M., although during the present tests it was not possible to read it within less than 5 R. P. M. An observer sat in the rear cockpit throughout the tests to operate the engine and read the torque scale and the tachometer. The velocity of the air stream was obtained by means of calibrated static plates.

In order to know the pitch of the propellers in operation, the deflection of one blade of each propeller was measured at the 30-inch radius, by means of a telescope mounted on a graduated base and sighted on first the leading and then the trailing edge. This was done.
while the propeller was standing still and then was repeated for each test point while the propeller was running.

The resultant horizontal force of the propeller-body combination, which may be either a thrust or a drag, was measured on the regular thrust balance (also described in Reference 1).

This resultant horizontal force \( R \) may be thought of as composed of three horizontal components, such that

\[
R = T - D - \Delta D,
\]

where

\( T \) = the thrust of the propeller while operating in front of the body (the tension in the crank shaft).
\( D \) = the drag of the airplane alone (without propeller) at the same air velocity and density.
\( \Delta D \) = the increase in drag of the airplane with propeller, due to the slip stream.

In order to obtain the propulsive efficiency, which includes the propeller-body interference, an effective thrust is used which is defined as

\[
\text{Effective thrust} = T - \Delta D = R + D.
\]

The propulsive efficiency is the ratio of the useful power to the input power, or

\[
\eta = \frac{\text{Effective thrust} \times \text{Velocity of advance}}{\text{Input power}}.
\]

RESULTS

The results of the tests are given in Figures 6 to 10, inclusive, and in Tables II and III. They are reduced to the usual thrust and power coefficients and plotted against \( \frac{V}{nD} \) for convenience in comparing them with the results of flight and model tests. These coefficients are:

\[
C_T = \frac{\text{Effective thrust}}{\rho n^2 D^4}
\]

\[
C_p = \frac{\text{Power}}{\rho n^2 D^2}
\]

\[
\eta = \text{Propulsive efficiency} = \frac{\text{Effective thrust} \times \text{Velocity}}{\text{Power}}
\]

where \( D \) = propeller diameter and \( n \) = revolutions per unit time. Any homogeneous system of units may be used with these coefficients. The propeller characteristics are also given in terms of two other coefficients (sometimes called speed-power coefficients) in Table III.

The points in Figures 6 to 10 have been calculated directly from the observed data. Their dispersion, which it will be noticed is small, is in a general way a measure of the accuracy of the observations.

The angular deflections of one blade of each propeller are plotted against \( \frac{V}{nD} \) in Figures 6, 7, and 8. In general, the deflections of all of the propellers were small. Throughout the working range of \( \frac{V}{nD} \), propeller B' had an average increase of blade angle of about 0.4° which, with its initial set of -0.3°, brought the angles in operation very close to the drawing values. The average curve through the points for propeller I shows practically no twist in operation, leaving the blade angles as they were measured, 0.5° too high. Propeller D' checked the drawing without load, and averaged about 0.2° less in operation. The accuracy of the individual deflection measurements is apparently ±0.5°, and the faired curves are probably correct to within ±0.2°.
Fig. 6.—Propeller B' with VE-7 airplane

Fig. 7.—Propeller I (3714) with VE-7 airplane

Fig. 8.—Propeller D' with VE-7 airplane

Fig. 9.—Propeller I (3714) with VE-7 airplane, without tail surfaces
FULL SCALE TESTS OF WOOD PROPELLERS

Fig. 10.—Propeller I (3714) with VE-7 airplane, without wings or tail surface.

Fig. 11.—Comparison of propeller research tunnel and flight tests on Propeller B'.

Fig. 12.—Comparison of propeller research tunnel and flight tests on Propeller I (3714).

Fig. 13.—Comparison of propeller research tunnel and flight tests on Propeller D'.
The present tests on the above three propellers are compared with flight tests on the same propellers (References 2 and 3) in Figures 11, 12, and 13. Propellers B' and D' are the identical ones used in the tests of Reference 2. Propeller I (3714), which is of the same design as I of Reference 2, was used in the tests of Reference 3 (and called 3714) and also in the present tests. Figures 11, 12, and 13 show that in general the agreement between the full-scale Propeller Research Tunnel tests and the flight tests is fair, probably within the limits of accuracy of the flight tests which are quite difficult to make. In three of the four tests the power coefficients from the flight tests are 3 per cent to 5 per cent higher than those obtained from the Propeller Research Tunnel tests. Since the power developed in flight was taken from a calibration of the engine made with an electric dynamometer on the ground, this difference in power coefficients indicates that the engines, when in flight, were probably not actually delivering the full power developed on the dynamometer.

One possible cause for difference between the flight tests and the full-scale wind tunnel tests is the fact that in the latter the propeller axis was kept level at all times, while in the flight tests it assumed various angles to the flight path from about zero degrees at high speed to 10 degrees near stalling speed.

In Figures 14, 15, and 16 the full-scale Propeller Research Tunnel tests are compared with tests on similar model propellers with a model VE–7 airplane (Reference 2). The model tests agree better than the flight tests with those of the Propeller Research Tunnel.

For the full-scale tests the maximum efficiency occurs at a higher \( \frac{V}{nD} \), and in two of the three cases reaches a noticeably higher value than for the model tests. (In this connection it has been learned that later tests on the same models give somewhat higher efficiencies.) In each case the rate of advance \( \left( \frac{V}{nD} \right) \) at which zero thrust occurs is greater for the full-scale propellers, apparently indicating that the effect of scale is more pronounced in the region of the lower angles of attack of the blade elements. In general, also, the full-scale tests give higher values of the thrust and power coefficients at the lower rates of advance.

The results of the three tests made with propeller I (3714) to obtain the effect of the wings and tail surfaces on the propeller characteristics are plotted in Figure 17. The tail surfaces had no appreciable effect on the propeller characteristics, but the wings increased the power absorbed slightly and decreased the maximum propulsive efficiency approximately 5 per cent. It would naturally be expected, of course, that the effect of the wings would be different at different angles of attack.

**CONCLUSIONS**

1. These, the first complete propeller tests made in the Propeller Research Tunnel, show that the results obtained agree as well as can be expected with both flight tests and model wind tunnel tests.

2. The accuracy of the observations in the Propeller Research Tunnel tests, which are made under full-scale conditions, is apparently of about the same order as that of model propeller tests.

3. From a comparison of these tests with flight tests, it seems likely that the engines used in the flight tests delivered somewhat less power in flight than would have been expected from dynamometer tests.

4. The effect of the tail surfaces on the propeller characteristics is negligible.

5. The effect of the wings on propulsive efficiency is important and deserves further investigation.

**Langley Memorial Aeronautical Laboratory, National Advisory Committee for Aeronautics, Langley Field, Va., June 18, 1928.**
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FIG. 14.—Comparison of model and full-size Propeller Research Tunnel tests on Propeller B'

FIG. 15.—Comparison of model and full-size Propeller Research Tunnel tests on Propeller H (3714)

FIG. 16.—Comparison of model and full-size Propeller Research Tunnel tests on Propeller D'

FIG. 17.—Effect of wings and tail surfaces on the performance of Propeller on VE-7 airplane (Propeller Research Tunnel tests)
### TABLE I

**ORDINATES FOR SECTIONS OF PROPELLER D’ (see fig. 3)**

<table>
<thead>
<tr>
<th>Radius</th>
<th>10.45°</th>
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<th>33.94°</th>
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<td>Upper</td>
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<tr>
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<td>0.877”</td>
<td>0.282”</td>
<td>0.128”</td>
<td>0.053”</td>
<td>0.047”</td>
<td>0.031”</td>
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<td>0.410</td>
<td>0.730</td>
<td>0.047</td>
<td>0.526</td>
<td>0.323</td>
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</tr>
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<td>1.692</td>
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<td>0.786</td>
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<td>1.692</td>
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<td>0.786</td>
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<td>1.454</td>
<td>0.868</td>
<td>1.551</td>
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<td>0.739</td>
<td>1.319</td>
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<td>0.614</td>
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<td>0.558</td>
<td>0.966</td>
<td>0.063</td>
<td>0.720</td>
<td>0.464</td>
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<tr>
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<td>0.872</td>
<td>0.505</td>
<td>0.790</td>
<td>0.047</td>
<td>0.526</td>
<td>0.323</td>
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<tr>
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<td>0.786</td>
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<td>0.623</td>
<td>0.041</td>
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All ordinates in inches. Station in per cent of chord.

### ORDINATES FOR SECTIONS OF PROPELLER B’ (see fig. 3)

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<tr>
<th>Radius</th>
<th>11.33”</th>
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<td>Upper</td>
<td>Upper</td>
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<td>Rad. L. E...</td>
<td>0.952”</td>
<td>0.306”</td>
<td>0.139”</td>
<td>0.056”</td>
<td>0.051”</td>
<td>0.034”</td>
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<td>0.792</td>
<td>0.051</td>
<td>0.751</td>
<td>0.367</td>
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<td>0.339</td>
<td>1.142</td>
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<td>0.823</td>
<td>0.500</td>
</tr>
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<td>1.102</td>
<td>0.710</td>
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<td>0.115</td>
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<td>1.928</td>
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<td>0.854</td>
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All ordinates in inches. Station in per cent of chord.

### ORDINATES FOR SECTIONS OF PROPELLER I (see fig. 4)

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<tr>
<th>Radius</th>
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<th>35.39”</th>
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<td>Upper</td>
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<td>0.133”</td>
<td>0.057”</td>
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<td>0.033”</td>
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<td>0.762</td>
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<td>0.550</td>
<td>0.357</td>
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<td>1.032</td>
<td>0.615</td>
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<td>0.789</td>
<td>0.512</td>
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<td>0.991</td>
<td>1.767</td>
<td>0.112</td>
<td>1.271</td>
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<td>0.991</td>
<td>1.767</td>
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<td>0.825</td>
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<tr>
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<td>1.561</td>
<td>0.906</td>
<td>1.617</td>
<td>0.109</td>
<td>1.165</td>
<td>0.757</td>
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<tr>
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<td>1.293</td>
<td>0.770</td>
<td>1.377</td>
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<td>0.748</td>
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</tr>
<tr>
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<td>0.245”</td>
<td>0.120”</td>
<td>0.103”</td>
<td>0.039”</td>
<td>0.024”</td>
<td></td>
</tr>
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All ordinates in inches. Stations in per cent of chord.
FULL SCALE TESTS OF WOOD PROPELLERS

TABLE II

TEST DATA

PROPELLER B', e=D/8.6

VE-7 AIRPLANE, COMPLETE

<table>
<thead>
<tr>
<th>( P )</th>
<th>( V )</th>
<th>( N )</th>
<th>( T )</th>
<th>( C_T )</th>
<th>( C_F )</th>
<th>( V )</th>
<th>( \eta )</th>
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<td>561</td>
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<td>0.510</td>
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<td>1.705</td>
<td>557</td>
<td>557.5</td>
<td>0.0597</td>
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### FULL SCALE TESTS OF WOOD PROPELLERS

#### TABLE II—Continued

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**VE-7 AIRPLANE, COMPLETE**

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TABLE II—Continued

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TABLE II—Continued

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### TABLE III

**FINAL ADJUSTED COEFFICIENTS**

**PROPELLER \( \beta_1, \beta_1 = \beta_0 \)**

**VE-7 AIRPLANE, COMPLETE**

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<th>( C_P )</th>
<th>( \psi )</th>
<th>( \sqrt{\rho V_T} )</th>
<th>( \sqrt{\rho V} )</th>
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**PROPELLER (3714), \( \beta_1 = 0.7 \)**

**VE-7 AIRPLANE, COMPLETE**

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TABLE III—Continued

**PROPELLER D', $=0.3**

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**PROPELLER I (3714), $=0.7**

**VE-7, WITH WINGS, WITHOUT TAIL**

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### Table III—Continued

**PROPELLER I \( (3714), \alpha = 7.7 \)**

**VE-7, WITHOUT WINGS OR TAIL**

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### References

