WIND-TUNNEL TESTS OF SINGLE- AND DUAL-ROTATING TRACTOR
PROPELLERS AT LOW BLADE ANGLES AND OF TWO- AND THREE-
BLADE TRACTOR PROPellers AT BLADE ANGLES UP TO 65°

By W. H. Gray

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SUMMARY

Tests were conducted in the propeller-research tunnel of the Langley Memorial Aeronautical Laboratory to determine the characteristics at low blade angles of propellers for which data at high blade angles are already available. In addition to the low-blade-angle results there are included data on two- and three-blade propellers of the same blade design, which have not been published and which cover a range of blade angles from 20° to 65°.

A chart lists the NACA reports in which data on related tests of the same blade design may be found.

INTRODUCTION

With the advent of high altitude airplanes, operation of propellers at low blade angles becomes necessary for the take-off condition. Results of tests at blade angles applicable to this condition are presented herein. Inasmuch as the tests were made at low speeds, the effects of compressibility could not be measured. Reference 1, however, presents results for propellers embodying several sections at high tip speeds with low blade angles and also presents a method of correcting propeller characteristics for compressibility effects at tip speeds below 0.9 the speed of sound. In the results reported in references 2, 3, and 4, charts are presented of data on single- and dual-rotating propellers of different number of blades. These charts included results for blade angles ranging from 20° to 65°. The data presented herein extend the results to include blade angles of 10° and 15°.

Because a part of the data for two- and three-blade
propellers has not previously been published, all such data are included in this report.

APPARATUS AND METHODS

The tests were made with the test setup used in previous dual-rotating propeller investigations in the propeller-research tunnel (reference 2). A photograph and a dimensioned drawing of the test setup are shown in figures 1 and 2. A symmetrical wing was mounted in the slipstream for all the tests except those of the two-blade propeller at blade angles ranging from 20° to 65°. The average length of the spinner was 5 inches greater for the 10° and 15° blade-angle tests than for the tests at higher blade angles. (See fig. 2.)

The propeller blades were of Hamilton-Standard design designated 3155-6 (right hand) and 3156-6 (left hand). The plan-form and the blade-form curves are given in figure 3.

For the six- and eight-blade single- and dual-rotating propellers and for the four-blade dual-rotating propellers, the blades were mounted in separate hubs spaced 15 inches. For the two-, three-, and four-blade single-rotating propellers, however, the blades were mounted in the rear hub for the low blade angle tests. For the single-rotation tests, the front blades led the rear blades by 75.0° for the six-blade propeller and by 52.5° for the eight-blade propeller.

In order to facilitate reading values from the charts, the test points have been omitted from most of the curves. The general accuracy of the fairings is indicated, however, by the plotted points for the 15° curves of figure 4. The test limitations of tunnel speed (110 mph) and propeller rotational speed (550 rpm) resulted in a tip speed below 300 feet per second and no effects of compressibility would therefore be expected.

In a few preliminary dual-rotation tests at blade settings of 10° and 15°, setting the front and rear blades at the same angle was found to result in nearly equal power absorption at peak efficiency for each component. The front and rear blades were consequently set at the same blade angle for the entire series of low blade-angle tests.
RESULTS

The results are presented in the usual nondimensional form of thrust coefficient, power coefficient, and propulsive efficiency,

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

\[ C_p = \frac{P}{\rho n^3 D^5} \]

\[ \eta = \frac{C_T V}{C_p n D} \]

- \( P \) power absorbed by propeller, foot-pounds per second
- \( V \) airspeed, feet per second
- \( n \) propeller rotational speed, revolutions per second
- \( D \) propeller diameter, feet
- \( \rho \) mass density of the air, slugs per cubic foot
- \( \beta_T \) front blade angle at 0.75R, degrees
- \( \beta_R \) rear blade angle at 0.75R, degrees
- \( C_{pF} \) power-coefficient for front propeller
- \( C_{pR} \) power-coefficient for rear propeller

The effective thrust is the measured thrust of the propeller-body combination plus the drag of the body measured without a propeller.

The figures giving the propeller characteristics are listed in the following table:
<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Blades</th>
<th>Blade angle at 0.75R (deg)</th>
<th>Rotation</th>
<th>Test condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2</td>
<td>10 to 15</td>
<td>Single</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>10 to 15</td>
<td>Single</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>10 to 20</td>
<td>Dual</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>7 and 8</td>
<td>4</td>
<td>10 to 20</td>
<td>Single</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>10 to 20</td>
<td>Dual</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>10 and 11</td>
<td>6</td>
<td>10 to 20</td>
<td>Single</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>10 to 20</td>
<td>Dual</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>13 and 14</td>
<td>8</td>
<td>10 to 20</td>
<td>Single</td>
<td>Rear hub, with wing</td>
</tr>
<tr>
<td>15 to 17</td>
<td>2</td>
<td>20 to 65</td>
<td>Single</td>
<td>Rear hub, without wing</td>
</tr>
<tr>
<td>18 to 20</td>
<td>2</td>
<td>20 to 65</td>
<td>Dual</td>
<td>Rear hub, without wing</td>
</tr>
<tr>
<td>21 to 23</td>
<td>3</td>
<td>20 to 65</td>
<td>Dual</td>
<td>Rear hub, with wing</td>
</tr>
</tbody>
</table>

No attempt has been made to present comparisons between dual and single rotation at the low blade angles since no appreciable gain in thrust from dual rotation would be expected. Curves of propeller characteristics at blade angles of 20° (from references 2 and 4) have been included with the 10° and 15° curves whenever the data were available in order to give a clearer picture of the relation of the 10° and 15° blade-angle data to the data for the higher blade angles.

It should be noted that the power-coefficient curve for the six-blade, single-rotating propeller at 15° blade angle has been obtained by cross-fitting since the test curve appeared to be in error.

Table I is furnished for the purpose of relating the present program with previous work in which the same body and the same basic propeller were used. In the table are listed the important test conditions.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.
<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>Number of blades</th>
<th>Blade location</th>
<th>Other test conditions</th>
<th>Rotation</th>
<th>Blade angle range of tests (deg)</th>
<th>Blades used</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor</td>
<td>3</td>
<td>Tested in both hubs</td>
<td>Without wing</td>
<td>Single</td>
<td>20 to 65</td>
<td>Normal width</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>2 in each hub</td>
<td>With and without wing</td>
<td>Single</td>
<td>20 to 50</td>
<td>Normal width</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>3 in each hub</td>
<td>------do---------</td>
<td>Dual</td>
<td>20 to 50</td>
<td>Normal width</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>------do--------</td>
<td>------do---------</td>
<td>Dual</td>
<td>20 to 55</td>
<td>Normal width</td>
</tr>
<tr>
<td>Tractor</td>
<td>3</td>
<td>3</td>
<td>4 in each hub</td>
<td>With and without wing</td>
<td>Single</td>
<td>20 to 55</td>
<td>Normal width</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>In front hub</td>
<td>------do--------</td>
<td>Single</td>
<td>20 to 70</td>
<td>Normal width</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Tested in both hubs, also 2 in ca.</td>
<td>------do--------</td>
<td>Single</td>
<td>20 to 70</td>
<td>Normal width</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>2 in each hub</td>
<td>------do--------</td>
<td>Dual</td>
<td>20 to 70</td>
<td>Normal width</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>3 in each hub</td>
<td>------do--------</td>
<td>Single</td>
<td>20 to 70</td>
<td>Normal width</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>4 in each hub</td>
<td>------do--------</td>
<td>Single</td>
<td>20 to 70</td>
<td>Normal width</td>
</tr>
<tr>
<td>Pusher</td>
<td>2</td>
<td>3</td>
<td>1 in rear hub</td>
<td>With wing</td>
<td>Single</td>
<td>10 to 65</td>
<td>50 percent wider</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>------do--------</td>
<td>------do--------</td>
<td>------do--------</td>
<td>10 to 65</td>
<td>thicker and thicker</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>2 in each hub</td>
<td>------do--------</td>
<td>Dual</td>
<td>10 to 65</td>
<td>Normal</td>
</tr>
</tbody>
</table>
REFERENCES


Figure 1 - Test set up. Six-blade single-rotating propeller with wing.
Figure 2.- Plan view showing dimensional details of wing and nacelle. Front and rear nacelle lines substantially identical. Spinner A used when a = 10 in.; B used when a = 15 in.
FIGURE 4. - PROPELLER CHARACTERISTICS AT LOW BLADE ANGLES. TWO-BLADE PROPELLER IN REAR HUB.

FIGURE 5. - PROPELLER CHARACTERISTICS AT LOW BLADE ANGLE. THREE-BLADE PROPELLER IN REAR HUB.
Figure 6. - Propeller characteristics at low blade angles. Four-blade single-rotating propeller in rear hub.

Figure 7. - Propeller characteristics at low blade angles. Four-blade dual-rotating propeller.
Figure 8.- Individual power-coefficient curves for four-blade dual-rotating propeller.
Figure 9.- Propeller characteristics at low blade angles. Six-blade single-rotating propeller.

Figure 10.- Propeller characteristics at low blade angles. Six-blade dual-rotating propeller.
Figure 11.- Individual power-coefficient curves for six-blade dual-rotating propeller.

Figure 12.- Propeller characteristics at low blade angles. Eight-blade single-rotating propeller.
Figure 13.- Propeller characteristics at low blade angles. Eight-blade dual-rotating propeller.

Figure 14.- Individual power-coefficient curves for eight-blade dual-rotating propeller.
Figure 17.
Efficiency curves for two-blade propeller in front hub without wing.

Figure 20.
Efficiency curves for two-blade propeller in rear hub without wing.
Figure 21 - Thrust coefficient curves for three-blade propeller in front hub with wing.
Figure 23. - Efficiency curves for three-blade propeller in front hub with wing.