NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

REPORT No. 506

TESTS OF NACELLE-PROPELLER COMBINATIONS
IN VARIOUS POSITIONS WITH REFERENCE TO WINGS
V—CLARK Y BIPLANE CELLULE—
N.A.C.A. COWLED NACELLE—TRACTOR PROPELLER

By E. FLOYD VALENTINE

1934
# Aeronautic Symbols

## I. Fundamental and Derived Units

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Metric</th>
<th>Unit</th>
<th>Abbreviation</th>
<th>English</th>
<th>Unit</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>L</td>
<td>meter</td>
<td>m</td>
<td>foot (or mile)</td>
<td>ft. (or mi.)</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>t</td>
<td>second</td>
<td>sec. (or hr.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force</td>
<td>F</td>
<td>weight of 1 kilogram</td>
<td>kg</td>
<td>weight of 1 pound</td>
<td>lb.</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>P</td>
<td>horsepower (metric)</td>
<td>k.p.h.</td>
<td>horsepower</td>
<td>hp.</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>V</td>
<td>kilometers per hour</td>
<td>m.p.h.</td>
<td>miles per hour</td>
<td>m.p.h.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>meters per second</td>
<td>f.p.s.</td>
<td>feet per second</td>
<td>f.p.s.</td>
<td></td>
</tr>
</tbody>
</table>

## 2. General Symbols

- $W$: Weight = $mg$
- $g$: Standard acceleration of gravity = 9.80665 m/s$^2$ or 32.1740 ft./sec.$^2$
- $m$: Mass = $\frac{W}{g}$
- $I$: Moment of inertia = $mk^2$. (Indicate axis of radius of gyration $k$ by proper subscript.)
- $\nu$: Coefficient of viscosity

## 3. Aerodynamic Symbols

- $\rho$: Kinematic viscosity
- $\rho$: Density (mass per unit volume)
- $\nu$: Standard density of dry air, 0.12497 kg-m$^{-1}$-s$^2$ at 15°C and 760 mm; or 0.00238 lb.-ft.$^{-1}$-sec.$^2$
- $\nu$: Specific weight of “standard” air, 1.2255 kg/m$^3$ or 0.07651 lb./cu.ft.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>Area</td>
</tr>
<tr>
<td>$S_n$</td>
<td>Area of wing</td>
</tr>
<tr>
<td>$C$</td>
<td>Gap</td>
</tr>
<tr>
<td>$b$</td>
<td>Span</td>
</tr>
<tr>
<td>$c$</td>
<td>Chord</td>
</tr>
<tr>
<td>$b'$</td>
<td>Aspect ratio</td>
</tr>
<tr>
<td>$V$</td>
<td>True air speed</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Dynamic pressure = $\frac{1}{2}\rho V^2$</td>
</tr>
<tr>
<td>$L$</td>
<td>Lift, absolute coefficient $C_L = \frac{L}{qS}$</td>
</tr>
<tr>
<td>$D$</td>
<td>Drag, absolute coefficient $C_D = \frac{D}{qS}$</td>
</tr>
<tr>
<td>$D_{s}$</td>
<td>Profile drag, absolute coefficient $C_{D_s} = \frac{D_s}{qS}$</td>
</tr>
<tr>
<td>$D_i$</td>
<td>Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$</td>
</tr>
<tr>
<td>$D_p$</td>
<td>Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$</td>
</tr>
<tr>
<td>$C$</td>
<td>Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$</td>
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<tr>
<td>$R$</td>
<td>Resultant force</td>
</tr>
</tbody>
</table>

- $\alpha$: Angle of attack
- $\alpha_{a_s}$: Angle of attack, infinite aspect ratio
- $\alpha_{a_i}$: Angle of attack, induced
- $\alpha_{a_s}$: Angle of attack, absolute (measured from zero-lift position)
- $\gamma$: Flight-path angle
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By E. Floyd Valentine

SUMMARY

This report is the fifth of a series giving the results obtained in the N.A.C.A. 20-foot wind tunnel on the interference drag and propulsive efficiency of nacelle-propeller-wing combinations. The first report gave the results of the tests of an N.A.C.A. cowled air-cooled engine nacelle with tractor propeller located in 21 positions with reference to a thick monoplane wing. The second and third reports gave the results with several engine cowlings and nacelles with tractor propeller located in four positions with reference to the thick wing and a Clark Y wing, respectively. Results with several engine cowlings with tandem nacelle arrangements in various positions with reference to the thick wing were given in the fourth report. The present report gives results of tests of an N.A.C.A. cowled air-cooled engine nacelle with tractor propeller located in 12 positions with reference to a Clark Y biplane cellule.

The biplane cellule consisted of two wings of Clark Y section with a 38-inch chord and a 15-foot 10-inch span. It had a gap of 3 feet and no stagger or decalage. Conventional N-struts of streamline steel tubing, together with streamline lift wires, were used between the wings.

A 4/9-scale model of a Wright J-5 radial air-cooled engine, was installed in an N.A.C.A. cowled nacelle. A 4-foot model of a Navy no. 4412 adjustable metal propeller was used.

The lift, drag, and propulsive efficiency were determined at several angles of attack in each nacelle position. The net efficiency was computed by the method of the first report. The results are compared with those for a monoplane wing of the same section and chord given in the third report.

The best results were obtained with the propeller, 50 percent of the chord directly ahead of the upper wing. The same position relative to the lower wing is nearly as good. Positions about half-way between the two wings with the propeller near the leading edges are the poorest. There is a fair agreement between the results with biplane combinations and those for similar monoplane combinations.

INTRODUCTION

This report is the fifth of a series giving the results of a general investigation of the mutual effects of wings, nacelles, and propellers. The program includes tests of nacelles with tractor, pusher, and tandem propellers in combination with monoplane and biplane wings.

The first report (reference 1) gave the results obtained with an N.A.C.A. cowled air-cooled-engine nacelle with a tractor propeller located in 21 positions with reference to a thick wing. The second and third reports gave the results for several engine cowlings and nacelles with tractor propeller located in four positions with reference to a thick wing (reference 2) and to a Clark Y wing (reference 3). In the fourth report (reference 4) results are given for various engine cowlings with tandem nacelle arrangements in several positions with respect to a thick wing.

This report gives the results for an N.A.C.A. cowled nacelle with tractor propeller in 12 positions with reference to a biplane cellule. The manner of presenting the results is similar to that used in the previous reports. Sufficient information is given in the tables to permit the reader to reduce the results by other methods if desired.

APPARATUS AND METHODS

The propeller-research tunnel in which the tests were made is described in reference 5. The cellule consisted of two wooden airfoils of Clark Y section with a 38-inch chord, a 15-foot 10-inch span, a gap of 36 inches, but no stagger or decalage. Conventional N-struts of streamline steel tubing, together with streamline lift wires, were used between the wings.

A 4/9-scale model of a Wright J-5 radial air-cooled engine was mounted in an N.A.C.A. cowled nacelle of the same scale. Figure 1 shows the dimensions of the nacelle. The propeller used was a 4-foot diameter model, geometrically similar to the Navy no. 4412 9-foot adjustable propeller. For these tests the blades
were set 17° at 0.75 \( R \). A 25-horsepower 220-volt direct-current motor was mounted inside the nacelle and the propeller mounted directly on its shaft. Wires from the motor were led down the nacelle-supporting struts into the wing and from the wing down the sup-

porting struts to the control equipment. The motor was calibrated with a Prony brake. Curves of armature current against torque were obtained for several values of the field current. The revolution speed was indicated by a condenser-type tachometer which was connected by wires to an indicating instrument at the controls below.

The test set-up, mounted as described in reference 8, was pivoted about the 25-percent chord point of the lower wing. Figure 2 shows a combination mounted for testing.

All the tests of this investigation were made at Reynolds Numbers varying from 1,360,000 at the lowest speed (50 m.p.h.) to 2,750,000 at the highest speed (100 m.p.h.). The biplane cellule alone was tested at several angles of attack ranging from \(-5^\circ\) to \(23^\circ\). When the cellule was tested without the nacelle it was braced at the midspan by N-struts. Tare-drag tests were made with the biplane cellule supported independently of the balance system. Tests had already been made on the nacelle alone; the results are given in reference 6.

Figure 3 shows the relative location of the nacelle with respect to the cellule in the 12 positions tested. Two were close together. Consequently, in positions 4, 5, 7, and 8 the nacelle was faired into the wing.

Figures 4 and 5 are photographs showing the details of each combination. In all cases the thrust line was parallel to the chord.

Previous tests (reference 1) showed that it was advantageous to fair the nacelle into the wing when the
CI, ARK Y BIPLANE CELLULE—N.A.C.A. COWLED NACELLE—TRACTOR PROPELLER

Figure 2—Biplane cellule with nacelle in position 11 mounted for test.
RESULTS

The measurements with the propeller removed were reduced to the usual coefficients

\[ C_L = \frac{\text{lift}}{qS}, \quad C_D = \frac{\text{drag}}{qS}, \quad C_m = \frac{\text{moment}}{qSc} \]

where

- \( q \), dynamic pressure \((\% \rho V^2)\).
- \( \rho \), mass density of air.
- \( V \), velocity.
- \( S \), area of wing.
- \( c \), chord of wing.

The moments were taken about the geometric mean quarter-chord point. The preceding coefficients for each angle of attack were plotted against dynamic pressure and fairied values from these curves were then cross-plotted against angle of attack at 50, 75, and 100 miles per hour. Values from these fairied curves are given in the tables. Values of \( C_L \) and \( C_D \) are given in tables I and II, respectively. Table III gives the moment coefficients at 100 miles per hour only, as there was no observable scale effect on the moments.

The final results are not affected by the fact that jet-boundary corrections were not applied, since all drag differences are taken at equal values of lift.

The usual coefficients are used for presenting the results with the propeller operating:

\[ C_T = \frac{T - \Delta D}{\rho n^2 D^3}, \quad C_D = \frac{P}{\rho n^2 D^3} \]

where

- \( T \), thrust of propeller operating in front of a body (tension in crankshaft).
- \( \Delta D \), change in drag of body due to action of propeller.
- \( T - \Delta D \), effective thrust (reference 7).
- \( n \), revolutions per unit of time.
- \( D \), propeller diameter.
- \( P \), motor power.

and

\[ \eta = \frac{T - \Delta D}{P} \times \text{velocity of advance} = \frac{C_T}{C_D} \times \frac{V}{nD} \]

Lift and moment coefficients were obtained in the same manner as with the propeller removed, but are designated \( C_{LP} \) and \( C_{MP} \). Coefficients read from fairied curves at different values of \( V/nD \) are given in the tables for several angles of attack as follows: Table IV, Thrust Coefficient \( (C_T) \); Table V, Power Coefficient \( (C_P) \); Table VI, Propulsive Efficiency \( (\eta) \); Table VII, Lift Coefficient with Propeller Operating \( (C_{LP}) \); Table VIII, Moment Coefficient with Propeller Operating \( (C_{MP}) \). A typical example of the propeller curves may be found in reference 1.

ACCURACY

The scales and instruments were calibrated frequently during the period over which the tests were run. The angle of attack was set to within 5° by means of an inclinometer. The scattering of the points in the motor calibration indicated a maximum error of 1 percent. The tachometer readings were correct to within 10 revolutions per minute. Lift and drag balances were read to the nearest pound. At high angles of attack in some cases the fluctuation of forces was such that the above accuracy could not be maintained.

DISCUSSION

When considering the relative merits of wing-nacelle-propeller arrangements it is necessary to take several factors into account. The lift and drag of the wing, or cellule, are affected by the presence of the nacelle. Similarly, the characteristics of the nacelle are changed due to the presence of the wing. Not only does the propeller affect the lift and drag of the wing-nacelle combination, but its efficiency in turn depends on the arrangement of bodies in its slipstream. All these factors are, of course, functions of the conditions under which the combination is operating.

A method of comparing one arrangement with another is developed in reference 1, and the following formulas result:

\[ \text{Propulsive efficiency} = \eta = \frac{(T - \Delta D)V}{P} = \frac{C_T}{C_D} \frac{V}{nD} \]

\[ \text{Nacelle drag efficiency factor} = \frac{C_D - C_{DW}}{C_D} \frac{S}{2D^2} \left( \frac{V}{nD} \right)^3 \]

\[ \text{Net efficiency} = \frac{C_T}{C_D} \frac{V}{nD} \frac{C_{DW} - C_{DW}^*}{C_D} \frac{S}{2D^2} \left( \frac{V}{nD} \right)^3 \]

where \( C_{DW} \), drag coefficient of the wing at a given angle of attack.

\( C_{DW} \), drag coefficient of the wing-nacelle combination (propeller removed) at the angle of attack at which the lift coefficient with the propeller operating is the same as the lift coefficient of the wing alone at the given angle of attack.\(^1\)

These formulas are applied to two conditions: One for high speed and cruising with a propeller \( V/nD = 0.65 \) and a lift coefficient corresponding to that of the cellule alone at an angle of attack of 0° \( (C_L = 0.259) \), and one for climbing with a \( V/nD = 0.42 \) and a lift coefficient corresponding to that of the cellule alone at an angle of attack of 5° \( (C_L = 0.480) \). The \( V/nD \)

\(^1\) This definition of \( C_{DW} \) has the same meaning as that in references 1 to 4. The present wording is used to clear up confusion that has arisen from the previous simplified definition.
selected for the high-speed comparison is that at which
the propeller operated at greatest efficiency in the
that the engine delivers its power at a constant
torque. A diagram of the method of obtaining the
drag value used in computing the nacelle drag effi-
ciency factor is given in reference 3. The net effi-
ciency, as defined, is equal to the efficiency that would
be obtained by considering the difference between the
drag of a wing-nacelle-propeller combination and the
drag of the wing alone, at equal lift coefficients, as
part of the drag chargeable to the propulsive unit, in
the same way that $\Delta D$ is ordinarily charged to the
propeller. A proper comparison of two combinations
can only be made at equal values of lift.

At an angle of attack of 0° with the propeller operat-
ing the lift was increased, except with the nacelle in
positions 1, 7, 8, and 9. The greatest increase in lift
was obtained with the nacelle in line with the upper
wing.

Figure 6 shows the lift and drag coefficients of the
biplane cellule with the nacelle in position 4, which
had the poorest net efficiency, and in positions 2 and
11, which had high net efficiencies. A study of figures
6, 7, and 8 shows that the drag is not greatly different
for similar positions ahead of the upper and lower
wings.

Contours of propulsive efficiency, nacelle drag
factor, and net efficiency have been plotted
in figures 9, 10, and 11 for the high-speed and cruising
flight conditions previously mentioned. Values for
intermediate positions can be picked from these charts.
In general, all three factors become increasingly favor-
able with distance ahead of the wings and with dis-
FIGURE 8.—Propulsive efficiency (percent) for cruising and high-speed conditions. 
\((C_L=0.259; \text{propeller set } 17^\circ \text{ at } 0.75 R; \gamma \text{ taken at } V/H \text{ or } 0.65)\)

FIGURE 9.—Nacelle drag efficiency factor (percent) for cruising and high-speed conditions. 
\((C_L=0.259; \text{propeller set } 17^\circ \text{ at } 0.75 R; \gamma \text{ taken at } V/H \text{ or } 0.65)\)

FIGURE 10.—Net efficiency (percent) for cruising and high-speed conditions. 
\((C_L=0.259; \text{propeller set } 17^\circ \text{ at } 0.75 R; \gamma \text{ taken at } V/H \text{ or } 0.65)\)

FIGURE 11.—Propulsive efficiency (percent) for climbing condition. 
\((C_L=0.480; \text{propeller set } 17^\circ \text{ at } 0.75 R; \gamma \text{ taken at } V/H \text{ or } 0.65)\)
tance from the mean chord line. Similar contours are given in figures 12, 13, and 14 for the climbing condition. In this case the propulsive efficiency and the

of charts indicates that the best position for the nacelle is that with the propeller one-half chord ahead of the upper wing.

For the speeds now being attained by modern high-speed transport airplanes other factors may have to be taken into account. At high speeds using a high-pitch propeller, changes in propeller efficiency with speed become so small as to be negligible. The propeller slipstream also has a smaller relative effect on the flow over the wing and nacelle, thus making the drag of the wing-nacelle combination the dominant factor in selecting the most favorable arrangement.¹

Figure 15 shows contours of the effective nacelle drag in terms of the drag of the nacelle alone at 0°. The effective nacelle drag used here is the difference in drag between the biplane-nacelle combination and the cellule alone, both drag values being taken at a

nacelle drag efficiency factor is negative when the nacelle is in line with either wing and positive for intermediate positions. An examination of both sets

Figure 13.—Nacelle drag efficiency factor (percent) for climbing condition. (C_L=0.480; propeller set 17° at 0.73 R; y taken at V/nD=0.42.)

net efficiency improve with distance from a point one-third of the gap above the lower leading edge. The

Figure 14.—Net efficiency (percent) for climbing condition. (C_L=0.480; propeller set 17° at 0.73 R; y taken at V/nD=0.42.)

lift coefficient of 0.259 corresponding to the high-speed and cruising condition. A ratio of 1.0 in figure 15 indicates an interference drag of zero. Position 1 in which the nacelle was mounted in line with the lower wing and close to the leading edge is the only one having a negative interference drag. With the nacelle in positions 3, 10, and 11 the interference drag is zero. A location of the nacelle halfway between the two chord lines with the propeller back close to the wing is most unfavorable.

¹ This conclusion is evident from the fact that the nacelle drag efficiency factor varies as V/nD² or for a given engine at rated r.p.m. as V². At high speeds the nacelle drag efficiency factor becomes large and the net efficiency low, finally becoming zero. The efficiencies here given for the high-speed condition hold for speeds of approximately 120 m.p.h. and 140 m.p.h. for the J-5 and Wasp Jr. engines respectively.
For each nacelle position with respect to the Clark Y monoplane wing for which the results are given in reference 3 there is a corresponding biplane-nacelle location which is in a similar position with reference to either the upper or the lower wing. This relationship is illustrated in figure 16. It is seen that positions 2, 4, 5, 7, and 11 are similar to previously tested monoplane positions.

A comparison of the efficiency factors of similar monoplane and biplane positions is given in the following table:

<table>
<thead>
<tr>
<th>BIPLANE POSITION</th>
<th>High-speed and cruising condition</th>
<th>Climbing condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Biplane cellule</td>
<td>2 Monoplane wing</td>
</tr>
<tr>
<td>Propulsive efficiency</td>
<td>0.703</td>
<td>0.760</td>
</tr>
<tr>
<td>Nacelle drag efficiency factor</td>
<td>0.056</td>
<td>0.046</td>
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<tr>
<td>Net efficiency</td>
<td>0.757</td>
<td>0.714</td>
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<table>
<thead>
<tr>
<th>BIPLANE POSITION 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsive efficiency</td>
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<tr>
<td>Nacelle drag efficiency factor</td>
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<tr>
<td>Net efficiency</td>
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<table>
<thead>
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<tbody>
<tr>
<td>Propulsive efficiency</td>
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<tr>
<td>Nacelle drag efficiency factor</td>
</tr>
<tr>
<td>Net efficiency</td>
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</tbody>
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<table>
<thead>
<tr>
<th>BIPLANE POSITION 5 1</th>
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</thead>
<tbody>
<tr>
<td>Propulsive efficiency</td>
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<tr>
<td>Nacelle drag efficiency factor</td>
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<tr>
<td>Net efficiency</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>BIPLANE POSITION 11</th>
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</thead>
<tbody>
<tr>
<td>Propulsive efficiency</td>
</tr>
<tr>
<td>Nacelle drag efficiency factor</td>
</tr>
<tr>
<td>Net efficiency</td>
</tr>
</tbody>
</table>

1 Nacelle fairing into airfoil.

Under the conditions of high speed and cruising, the maximum difference in net efficiency is 4.5 percent. For climbing conditions the maximum difference is 8.4 percent. It appears that the similarity of characteristics is less marked for positions in line with the wing than for other positions. Positions in line with the wing being excepted, the greatest difference in net efficiency is 2.2 percent for high speed and 2.6 percent for climbing conditions. Closer agreement is hardly to be expected because the monoplane and biplane wings were of different effective aspect ratios and the comparisons were not made at the same lift in both cases.

In figure 17 the effective drag of the nacelle is compared for similar positions with respect to the monoplane wing and biplane cellule. Since the same nacelle was used in one case with 50 square feet of wing area, and in the other case with 100 square feet of wing area, it was necessary to multiply the drag coefficient referred to the biplane cellule by 2 for comparison. Positions 2 and 11 give results in general agreement with those for similar monoplane positions throughout the range, while positions 4, 5, and 7 give a similar agreement only at low angles. All positions give the same agreement over the normal flying range. The nacelle drag for combinations with the biplane cellule starts to increase at higher values of the lift coefficient for all of the cases compared. The actual differences in nacelle drag are quite large but the statement as to agreement is based on the fact that the nacelle drag is a small part of the total drag. A difference of 50 percent in nacelle drag means only a small percentage difference in the total drag; hence there is only a small change in the over-all performance indicated by the comparative curves of figure 17.

From the agreement between the results for similar monoplane and biplane arrangements, it would seem that there would be little error in predicting the results with the nacelle above or below the biplane cellule on the basis of the results obtained with the nacelle and the monoplane wing.

CONCLUSIONS

1. At a lift coefficient corresponding to the high speed and cruising condition with the propeller removed, the interference drag is favorable only when the nacelle is in a position just ahead of the lower wing. It is most unfavorable with the nacelle in a position just ahead of the leading edges with its axis at the center of the gap.

2. For both the high speed and the climbing conditions, the propulsive efficiency is greatest when the propeller axis is in line with either wing chord, and
least when the axis is between the two wings and the propeller is close to the leading edges.

3. The highest net efficiency, considering both high speed and climbing conditions, is obtained with the propeller axis in line with the chord of the upper wing and the propeller about one-half chord length ahead of the leading edge. A similar position with respect to the lower wing is nearly as good.

4. The poorest nacelle location, considering the net efficiency at high speed and at climbing conditions, is with the propeller near the leading edge and its axis between the two chord lines.

5. The net efficiency of a biplane-nacelle combination agrees fairly well with that of the monoplane arrangement represented by the nacelle and the biplane wing nearest to it.

REFERENCES


TABLE I
LIFT COEFFICIENT WITHOUT PROPELLER

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>50 m.p.h. R.N.=1,360,000</th>
<th>75 m.p.h. R.N.=2,040,000</th>
<th>100 m.p.h. R.N.=2,720,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of attack</td>
<td>−5°  0°  5°  10°  15°</td>
<td>−5°  0°  5°  10°  15°</td>
<td>−5°  0°  5°  10°  15°</td>
</tr>
<tr>
<td>Nacelle alone</td>
<td>−0.006 0.009 0.002 0.007 0.011</td>
<td>−0.006 0.000 0.002 0.007 0.011</td>
<td>−0.006 0.000 0.002 0.007 0.011</td>
</tr>
<tr>
<td>Cellule alone</td>
<td>−0.004 −0.002 −0.003 −0.004 −0.005</td>
<td>−0.004 −0.002 −0.003 −0.004 −0.005</td>
<td>−0.004 −0.002 −0.003 −0.004 −0.005</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

1 Nacelle faired into airfoil.

TABLE II
DRAG COEFFICIENT WITHOUT PROPELLER

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>50 m.p.h. R.N.=1,360,000</th>
<th>75 m.p.h. R.N.=2,040,000</th>
<th>100 m.p.h. R.N.=2,720,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of attack</td>
<td>−5°  0°  5°  10°  15°</td>
<td>−5°  0°  5°  10°  15°</td>
<td>−5°  0°  5°  10°  15°</td>
</tr>
<tr>
<td>Nacelle alone</td>
<td>0.0060 0.0040 0.0040 0.0039 0.0009</td>
<td>0.0035 0.0035 0.0040 0.0045 0.0055</td>
<td>0.0025 0.0030 0.0035 0.0040 0.0045</td>
</tr>
<tr>
<td>Cellule alone</td>
<td>0.0030 0.0010 0.0020 0.0030 0.0040</td>
<td>0.0010 0.0020 0.0030 0.0040 0.0050</td>
<td>0.0005 0.0010 0.0015 0.0020 0.0025</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

1 Nacelle faired into airfoil.

TABLE III
MOMENT COEFFICIENT WITHOUT PROPELLER

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>Angle of attack</th>
<th>−5°  0°  5°  10°  15°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellule alone</td>
<td>−0.002 −0.002 −0.006 −0.008 −0.009</td>
<td>−0.005 −0.005 −0.007 −0.008 −0.009</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

1 Nacelle faired into airfoil.
### TABLE IV

**THrust COEFFICIENT**

\[ C_T = \frac{T - \Delta D}{\rho n^2 D^3} \]

Propeller no. 4113, 4 feet. Set 17° at 0.75 R.

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>Angle of attack = -5°</th>
<th>( V / nD )</th>
<th>( \Delta T / D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>1</td>
<td>0.0852</td>
<td>0.0778</td>
<td>0.0717</td>
</tr>
<tr>
<td>2</td>
<td>0.834</td>
<td>0.0751</td>
<td>0.0739</td>
</tr>
<tr>
<td>3</td>
<td>0.814</td>
<td>0.0729</td>
<td>0.0687</td>
</tr>
<tr>
<td>4</td>
<td>0.461</td>
<td>0.0703</td>
<td>0.0655</td>
</tr>
<tr>
<td>5</td>
<td>0.846</td>
<td>0.0720</td>
<td>0.0687</td>
</tr>
<tr>
<td>6</td>
<td>0.062</td>
<td>0.0615</td>
<td>0.0573</td>
</tr>
<tr>
<td>7</td>
<td>0.846</td>
<td>0.0692</td>
<td>0.0649</td>
</tr>
<tr>
<td>8</td>
<td>0.874</td>
<td>0.0680</td>
<td>0.0649</td>
</tr>
<tr>
<td>9</td>
<td>0.874</td>
<td>0.0680</td>
<td>0.0649</td>
</tr>
<tr>
<td>10</td>
<td>0.867</td>
<td>0.0667</td>
<td>0.0649</td>
</tr>
<tr>
<td>11</td>
<td>0.864</td>
<td>0.0667</td>
<td>0.0649</td>
</tr>
<tr>
<td>12</td>
<td>0.864</td>
<td>0.0667</td>
<td>0.0649</td>
</tr>
</tbody>
</table>

\[ \text{Nacelle faired into airoil.} \]

### TABLE V

**POWER COEFFICIENT**

\[ C_p = \frac{P}{\rho n^2 D^4} \]

Propeller no. 4112, 4 feet. Set 17° at 0.75 R.

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>Angle of attack = -5°</th>
<th>( V / nD )</th>
<th>( \Delta T / D )</th>
<th>Angle of attack = 0°</th>
<th>( V / nD )</th>
<th>( \Delta T / D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>1</td>
<td>0.0833</td>
<td>0.0766</td>
<td>0.0703</td>
<td>0.0622</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>2</td>
<td>0.856</td>
<td>0.0750</td>
<td>0.0687</td>
<td>0.0560</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>3</td>
<td>0.845</td>
<td>0.0728</td>
<td>0.0664</td>
<td>0.0514</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>4</td>
<td>0.245</td>
<td>0.0706</td>
<td>0.0635</td>
<td>0.0464</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>5</td>
<td>0.235</td>
<td>0.0684</td>
<td>0.0602</td>
<td>0.0422</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>6</td>
<td>0.225</td>
<td>0.0667</td>
<td>0.0570</td>
<td>0.0383</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>7</td>
<td>0.215</td>
<td>0.0650</td>
<td>0.0538</td>
<td>0.0346</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>8</td>
<td>0.205</td>
<td>0.0634</td>
<td>0.0505</td>
<td>0.0311</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>9</td>
<td>0.200</td>
<td>0.0619</td>
<td>0.0473</td>
<td>0.0277</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>10</td>
<td>0.195</td>
<td>0.0606</td>
<td>0.0449</td>
<td>0.0244</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>11</td>
<td>0.190</td>
<td>0.0593</td>
<td>0.0426</td>
<td>0.0213</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
<tr>
<td>12</td>
<td>0.185</td>
<td>0.0581</td>
<td>0.0403</td>
<td>0.0184</td>
<td>0.0529</td>
<td>0.0490</td>
</tr>
</tbody>
</table>

\[ \text{Nacelle faired into airoil.} \]
TABLE VI

PROPELLIVE EFFICIENCY

\[ \eta = \frac{(T - \Delta P)V}{P} \]

Propeller no. 4412, 4 feet. Set 17° at 0.75 R.

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>( V )</th>
<th>( nD )</th>
<th>Angle of attack = 5°</th>
<th>( V )</th>
<th>( nD )</th>
<th>Angle of attack = 0°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.208</td>
<td>0.356</td>
<td>0.545</td>
<td>0.659</td>
<td>0.735</td>
<td>0.851</td>
</tr>
<tr>
<td>2</td>
<td>0.210</td>
<td>0.360</td>
<td>0.558</td>
<td>0.679</td>
<td>0.757</td>
<td>0.848</td>
</tr>
<tr>
<td>3</td>
<td>0.209</td>
<td>0.360</td>
<td>0.564</td>
<td>0.685</td>
<td>0.747</td>
<td>0.825</td>
</tr>
<tr>
<td>4</td>
<td>0.211</td>
<td>0.365</td>
<td>0.568</td>
<td>0.725</td>
<td>0.794</td>
<td>0.860</td>
</tr>
<tr>
<td>5</td>
<td>0.208</td>
<td>0.360</td>
<td>0.575</td>
<td>0.699</td>
<td>0.730</td>
<td>0.651</td>
</tr>
<tr>
<td>6</td>
<td>0.209</td>
<td>0.360</td>
<td>0.580</td>
<td>0.729</td>
<td>0.760</td>
<td>0.780</td>
</tr>
<tr>
<td>7</td>
<td>0.210</td>
<td>0.365</td>
<td>0.585</td>
<td>0.734</td>
<td>0.771</td>
<td>0.757</td>
</tr>
<tr>
<td>8</td>
<td>0.211</td>
<td>0.365</td>
<td>0.590</td>
<td>0.752</td>
<td>0.794</td>
<td>0.760</td>
</tr>
<tr>
<td>9</td>
<td>0.208</td>
<td>0.360</td>
<td>0.595</td>
<td>0.759</td>
<td>0.820</td>
<td>0.790</td>
</tr>
<tr>
<td>10</td>
<td>0.209</td>
<td>0.360</td>
<td>0.600</td>
<td>0.764</td>
<td>0.830</td>
<td>0.800</td>
</tr>
<tr>
<td>11</td>
<td>0.211</td>
<td>0.365</td>
<td>0.605</td>
<td>0.788</td>
<td>0.851</td>
<td>0.811</td>
</tr>
<tr>
<td>12</td>
<td>0.212</td>
<td>0.400</td>
<td>0.555</td>
<td>0.700</td>
<td>0.752</td>
<td>0.819</td>
</tr>
</tbody>
</table>

1 Nacelle faired into airflow.

TABLE VII

LIFT COEFFICIENT WITH PROPELLER OPERATING

\[ C_{Lp} = \frac{L_p}{gN} \]

Propeller no. 4412, 4 feet. Set 17° at 0.75 R.

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>( V )</th>
<th>( nD )</th>
<th>Angle of attack = 5°</th>
<th>( V )</th>
<th>( nD )</th>
<th>Angle of attack = 10°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.021</td>
<td>0.022</td>
<td>0.023</td>
<td>0.023</td>
<td>0.024</td>
<td>0.026</td>
</tr>
<tr>
<td>2</td>
<td>0.046</td>
<td>0.047</td>
<td>0.048</td>
<td>0.049</td>
<td>0.050</td>
<td>0.051</td>
</tr>
<tr>
<td>3</td>
<td>0.069</td>
<td>0.070</td>
<td>0.071</td>
<td>0.072</td>
<td>0.073</td>
<td>0.074</td>
</tr>
<tr>
<td>4</td>
<td>0.092</td>
<td>0.093</td>
<td>0.094</td>
<td>0.095</td>
<td>0.096</td>
<td>0.097</td>
</tr>
<tr>
<td>5</td>
<td>0.115</td>
<td>0.116</td>
<td>0.117</td>
<td>0.118</td>
<td>0.119</td>
<td>0.120</td>
</tr>
<tr>
<td>6</td>
<td>0.138</td>
<td>0.139</td>
<td>0.140</td>
<td>0.141</td>
<td>0.142</td>
<td>0.143</td>
</tr>
<tr>
<td>7</td>
<td>0.161</td>
<td>0.162</td>
<td>0.163</td>
<td>0.164</td>
<td>0.165</td>
<td>0.166</td>
</tr>
<tr>
<td>8</td>
<td>0.184</td>
<td>0.185</td>
<td>0.186</td>
<td>0.187</td>
<td>0.188</td>
<td>0.189</td>
</tr>
<tr>
<td>9</td>
<td>0.207</td>
<td>0.208</td>
<td>0.209</td>
<td>0.210</td>
<td>0.211</td>
<td>0.212</td>
</tr>
<tr>
<td>10</td>
<td>0.230</td>
<td>0.231</td>
<td>0.232</td>
<td>0.233</td>
<td>0.234</td>
<td>0.235</td>
</tr>
<tr>
<td>11</td>
<td>0.253</td>
<td>0.254</td>
<td>0.255</td>
<td>0.256</td>
<td>0.257</td>
<td>0.258</td>
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<tr>
<td>12</td>
<td>0.276</td>
<td>0.277</td>
<td>0.278</td>
<td>0.279</td>
<td>0.280</td>
<td>0.281</td>
</tr>
</tbody>
</table>

1 Nacelle faired into airflow.
### TABLE VIII

MOMENT COEFFICIENT OPERATING WITH PROPELLER

\[ C_{p_m} = \frac{M_p}{q S_c} \]

Propeller No. 4412, 4 feet. Set 17° at 0.75 R.

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>Angle of attack = -5°</th>
<th>Angle of attack = 0°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( V \pi D )</td>
<td>( V \pi D )</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
<td>-0.024</td>
<td>-0.041</td>
</tr>
<tr>
<td>2</td>
<td>-0.040</td>
<td>-0.061</td>
</tr>
<tr>
<td>3</td>
<td>-0.025</td>
<td>-0.042</td>
</tr>
<tr>
<td>4</td>
<td>-0.057</td>
<td>-0.060</td>
</tr>
<tr>
<td>5</td>
<td>-0.065</td>
<td>-0.065</td>
</tr>
<tr>
<td>6</td>
<td>-0.006</td>
<td>-0.083</td>
</tr>
<tr>
<td>7</td>
<td>0.010</td>
<td>-0.080</td>
</tr>
<tr>
<td>8</td>
<td>0.015</td>
<td>-0.100</td>
</tr>
<tr>
<td>9</td>
<td>0.010</td>
<td>-0.100</td>
</tr>
<tr>
<td>10</td>
<td>0.014</td>
<td>-0.108</td>
</tr>
<tr>
<td>11</td>
<td>0.015</td>
<td>-0.113</td>
</tr>
<tr>
<td>12</td>
<td>0.018</td>
<td>-0.113</td>
</tr>
</tbody>
</table>

1 Nacelle faired into airfoil.

### TABLE IX

RELATIVE MERITS OF DIFFERENT NACELLE LOCATIONS

Propeller No. 4412, 4 feet. Set 17° at 0.75 R.

<table>
<thead>
<tr>
<th>Nacelle position</th>
<th>High-speed and cruising condition ( \frac{V}{\pi D} = 0.65 )</th>
<th>( C_{p_m} = 0.239 )</th>
<th>Climbing condition ( \frac{V}{\pi D} = 0.42 )</th>
<th>( C_{p_m} = 0.489 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Propulsive efficiency</td>
<td>Nacelle drag efficiency factor</td>
<td>Net efficiency</td>
<td>Propulsive efficiency</td>
</tr>
<tr>
<td>1</td>
<td>0.799</td>
<td>0.056</td>
<td>0.743</td>
<td>0.069</td>
</tr>
<tr>
<td>2</td>
<td>0.790</td>
<td>0.056</td>
<td>0.727</td>
<td>0.065</td>
</tr>
<tr>
<td>3</td>
<td>0.800</td>
<td>0.056</td>
<td>0.729</td>
<td>0.065</td>
</tr>
<tr>
<td>4</td>
<td>0.761</td>
<td>0.145</td>
<td>0.616</td>
<td>0.628</td>
</tr>
<tr>
<td>5</td>
<td>0.776</td>
<td>0.119</td>
<td>0.587</td>
<td>0.637</td>
</tr>
<tr>
<td>6</td>
<td>0.797</td>
<td>0.093</td>
<td>0.592</td>
<td>0.670</td>
</tr>
<tr>
<td>7</td>
<td>0.767</td>
<td>0.147</td>
<td>0.630</td>
<td>0.674</td>
</tr>
<tr>
<td>8</td>
<td>0.789</td>
<td>0.145</td>
<td>0.644</td>
<td>0.672</td>
</tr>
<tr>
<td>9</td>
<td>0.910</td>
<td>0.169</td>
<td>0.701</td>
<td>0.673</td>
</tr>
<tr>
<td>10</td>
<td>0.902</td>
<td>0.271</td>
<td>0.731</td>
<td>0.676</td>
</tr>
<tr>
<td>11</td>
<td>0.915</td>
<td>0.266</td>
<td>0.739</td>
<td>0.678</td>
</tr>
<tr>
<td>12</td>
<td>0.911</td>
<td>0.268</td>
<td>0.735</td>
<td>0.678</td>
</tr>
</tbody>
</table>

1 Nacelle faired into airfoil.

U. S. GOVERNMENT PRINTING OFFICE: 1933
Positive directions of axes and angles (forces and moments) are shown by arrows.

<table>
<thead>
<tr>
<th>Axis</th>
<th>Designation</th>
<th>Symbol</th>
<th>Force (parallel to axis) symbol</th>
<th>Moment about axis</th>
<th>Designation</th>
<th>Symbol</th>
<th>Positive direction</th>
<th>Angle</th>
<th>Velocities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>$X$</td>
<td>$X$</td>
<td>Rolling</td>
<td>$L$</td>
<td>$Y\rightarrow Z$</td>
<td>Roll</td>
<td>$u$</td>
<td>Linear (component along axis)</td>
<td></td>
</tr>
<tr>
<td>Lateral</td>
<td>$Y$</td>
<td>$Y$</td>
<td>Pitching</td>
<td>$M$</td>
<td>$Z\rightarrow X$</td>
<td>Pitch</td>
<td>$\theta$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>$Z$</td>
<td>$Z$</td>
<td>Yawing</td>
<td>$N$</td>
<td>$X\rightarrow Y$</td>
<td>Yaw</td>
<td>$\phi$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Absolute coefficients of moment:

\[ C_l = \frac{L}{qS} \]
\[ C_m = \frac{M}{qS} \]
\[ C_s = \frac{N}{qS} \]

Angle of set of control surface (relative to neutral position), \(5\). (Indicate surface by proper subscript.)

### 4. PROPELLER SYMBOLS

- **\(D\)**: Diameter
- **\(p\)**: Geometric pitch
- **\(p/D\)**: Pitch ratio
- **\(V'\)**: Inflow velocity
- **\(V_n\)**: Slipstream velocity
- **\(T\)**: Thrust, absolute coefficient \(C_T = \frac{T}{\rho \eta n^3 D^4}\)
- **\(Q\)**: Torque, absolute coefficient \(C_Q = \frac{Q}{\rho \eta n^3 D^5}\)

**\(P\)**: Power, absolute coefficient \(C_p = \frac{P}{\rho \eta n^3 D^5}\)

**\(C_n\)**: Speed-power coefficient \(= \frac{\frac{V}{\rho V' D^2}}{\rho \eta n^3 D^5}\)

**\(\eta\)**: Efficiency

**\(n\)**: Revolutions per second, r.p.s.

**\(\phi\)**: Effective helix angle \(= \tan^{-1} \left(\frac{V}{2\pi n} \right)\)

### 5. NUMERICAL RELATIONS

<table>
<thead>
<tr>
<th>Unit</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hp.</td>
<td>76.04 kg-m/s = 550 ft-lb./sec.</td>
</tr>
<tr>
<td>1 metric horsepower</td>
<td>1.0132 hp.</td>
</tr>
<tr>
<td>1 m.p.h.</td>
<td>0.4470 m.p.s.</td>
</tr>
<tr>
<td>1 m.p.s.</td>
<td>2.2369 m.p.h.</td>
</tr>
<tr>
<td>1 lb.</td>
<td>0.4536 kg</td>
</tr>
<tr>
<td>1 kg</td>
<td>2.2046 lb.</td>
</tr>
<tr>
<td>1 mi.</td>
<td>1,609.35 m = 5,280 ft.</td>
</tr>
<tr>
<td>1 m</td>
<td>3.2808 ft.</td>
</tr>
</tbody>
</table>