NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 271

PRESSURE DISTRIBUTION TESTS ON PW-9 WING MODELS SHOWING EFFECTS OF BIPLANE INTERFERENCE

By A. J. FAIRBANKS

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

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REPORT No. 271

PRESSURE DISTRIBUTION TESTS ON PW-9 WING MODELS SHOWING EFFECTS OF BIPLANE INTERFERENCE

By A. J. Fairbanks

SUMMARY

In this report tests are described in which the distribution of pressures over models of the wings of the PW-9 airplane was investigated. The wing models were tested individually and in the biplane combination. The investigation was conducted in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics. It is concluded in this paper that the effect of biplane interference on the pressures on the wings is practically confined to the lower surface of the upper wing and the upper surface of the lower wing; that the overhanging portion of the upper wing is not greatly affected by the presence of the lower wing; and that a slight washin at the center section of the upper wing satisfactorily compensates for a reduced chord at this section (providing the airfoil section is not mutilated) and prevents a large reduction in the normal force over this portion of the wing.

INTRODUCTION

At the request of the Army Air Corps, the distribution of pressures over the wings and the tail surfaces of a modern pursuit airplane (PW-9) is being investigated by the National Advisory Committee for Aeronautics. In order to study some of the phases of the problem which can not be undertaken in flight and to further correlate the results of wind tunnel and flight tests, pressure distribution tests have been made in the atmospheric wind tunnel on models of the wings of the PW-9. The models were tested individually and together in the mutual relation they have in the airplane.

In this paper the results of the model tests are presented and discussed.

TESTS

The wings of the PW-9 airplane are of the Göttingen 436 airfoil section throughout (fig. 1). The details of the models and the arrangement of the cellule are illustrated by Figure 2. The most unusual features of the cellule are the difference between the plan forms of the two wings and the washin of the center section of the upper wing.

Half span, laminated wooden models with inlaid pressure tubes, similar to those used in previous pressure distribution tests (reference 1) were employed in this investigation (fig. 3). The effect of the missing half span was reproduced by the use of a reflecting plane (fig. 4).

A new liquid multiple manometer (fig. 5) which has 117 tubes of approximately 15 inches clear height, was developed for and used in these tests. A photographic record obtained with this manometer is reproduced as Figure 6.

Static and dynamic pressure surveys were made two chord lengths ahead of the models (fig. 7). The integrated means of the survey values were used as a reference static pressure and the effective dynamic pressure, respectively.

The tests, which were made at approximately 30 meters per second air stream velocity, covered the range from -6 degrees through $+24$ degrees angle of attack.

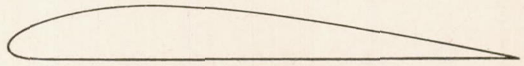


FIG. 1.—Göttingen 436 airfoil section

Airfoil ordinates

Station per cent chord	Upper per cent chord	Lower per cent chord
0	2.85	2.85
1¼	4.59	1.21
2½	5.54	0.69
5	6.86	0.37
7½	8.02	0.21
10	8.92	0.05
15	10.03	0.00
20	10.82	0.00
30	11.08	0.00
40	10.55	0.00
50	9.60	0.00
60	8.28	0.00
70	6.60	0.00
80	4.70	0.00
90	2.59	0.00
95	1.43	0.00
100	0.26	0.00

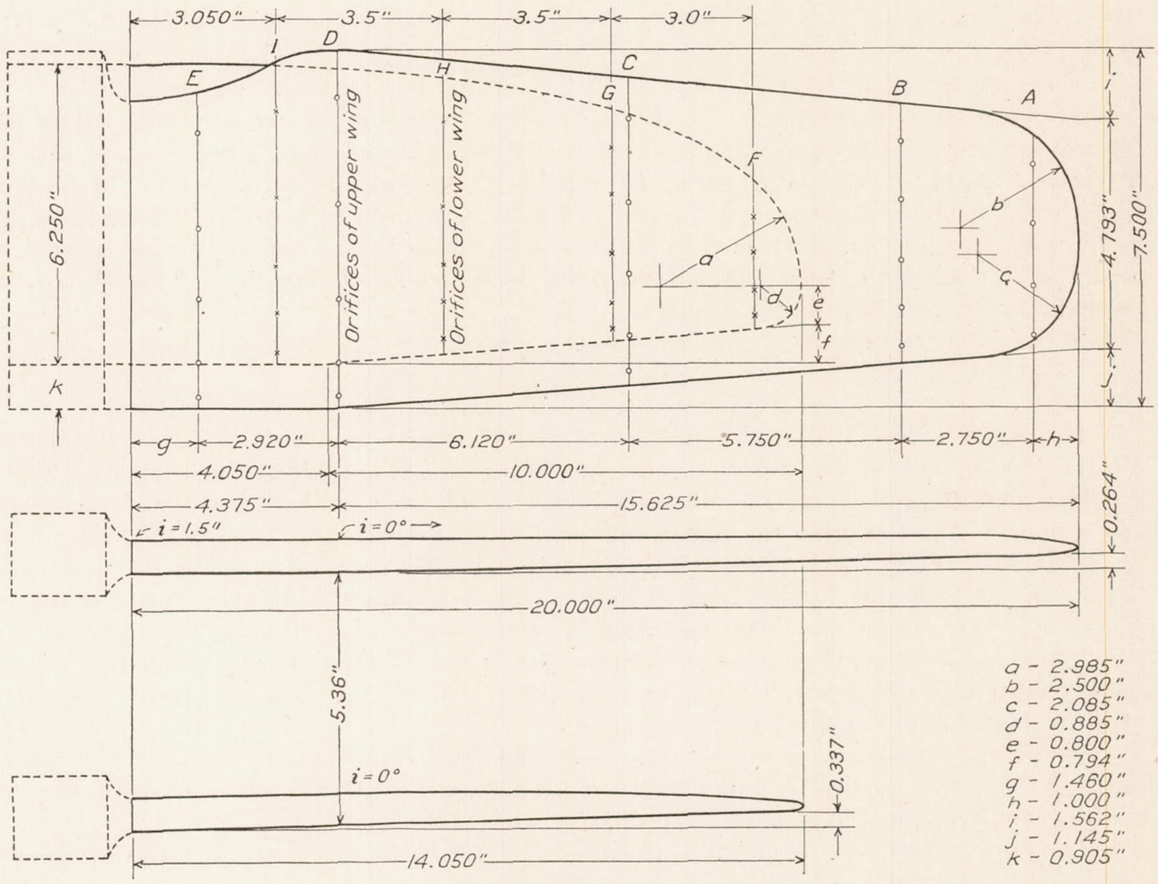


FIG. 2.—Plan and front elevation of PW-9 wing models

FIG. 3.—PW-9 pressure distribution wing models

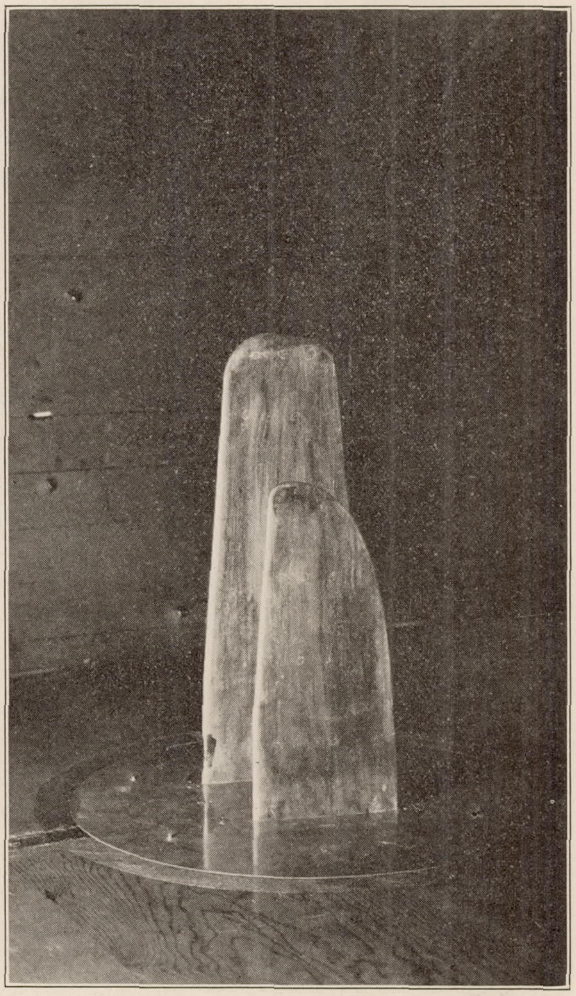


FIG. 4.—PW-9 wing models in wind tunnel

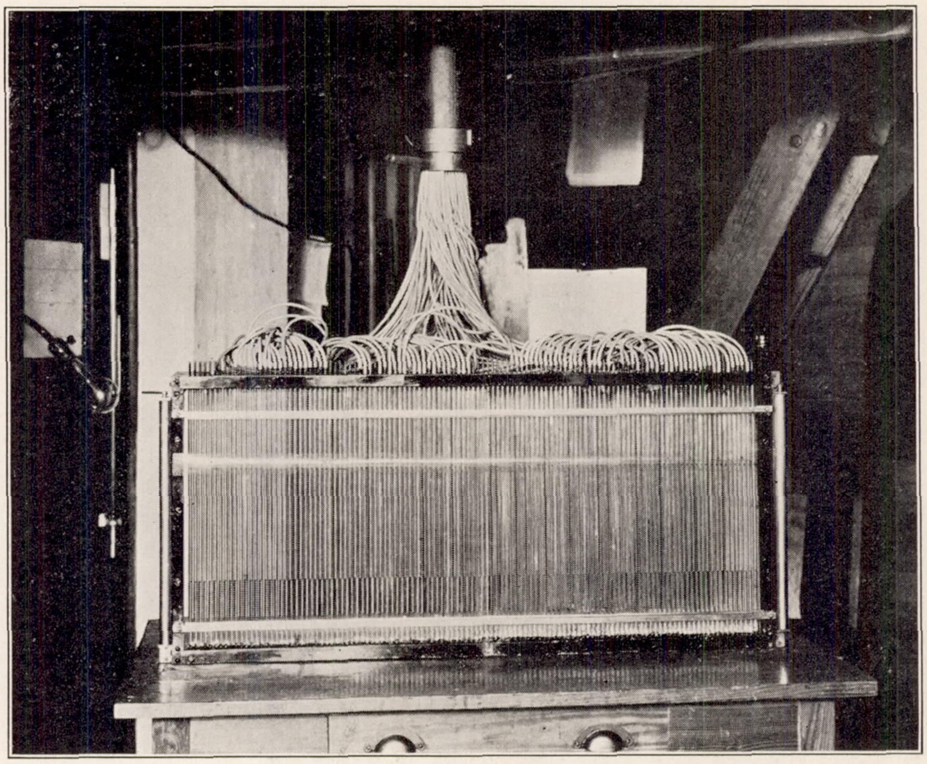


FIG. 5.—Multiple liquid manometer

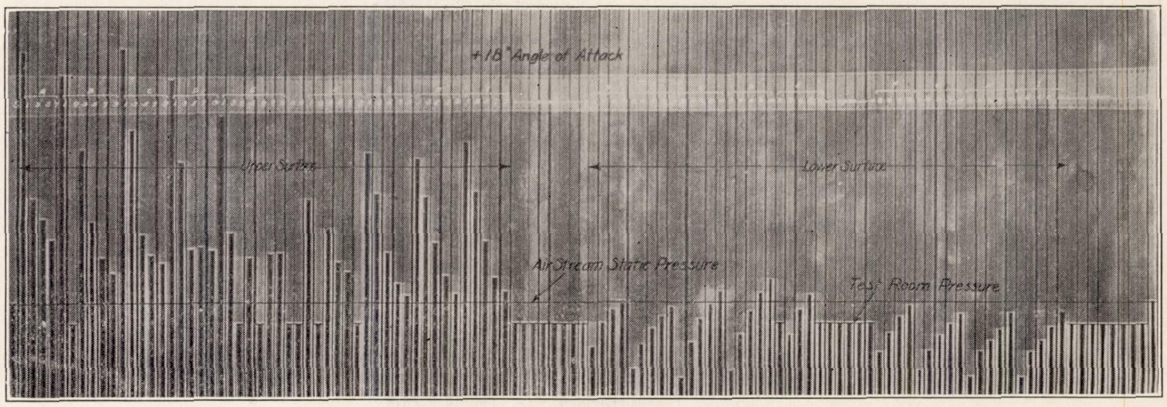


FIG. 6.—Reduced photograph of a manometer record

RESULTS

The results of the tests are presented in Figures 8 through 14. Five forms of representation are used, namely, pressure diagrams for the test sections, curves of normal force vs. span, normal force coefficient vs. span, normal force coefficient vs. angle of attack, and plots of centers of pressure on plan-view drawings of the wings. In each case the results of the tests of the wings in the biplane combination are compared with those of tests of the individual airfoils.

The diagrams of Figures 8 and 9 illustrate the variation of pressure along the test section chords. The pressures are given in terms of the dynamic pressure, $q=\frac{\rho V^2}{2}$.

The distribution of the normal force along the span is illustrated by Figure 10. The ordinates of these curves represent the magnitude of the normal force per unit span per unit q. The nondimensional coefficient K is defined by the equation

$$\text{Normal force per unit span} = K \times q \times \text{upper wing span}$$

or

$$K = C_{NF} \times \frac{\text{chord}}{\text{upper wing span}}$$

Figure 11 illustrates the variation of the normal force coefficient (C_{NF}) across the span. C_{NF} is usually defined as normal force divided by $q \times S$ but this may be transformed into

$$C_{NF} = \frac{\text{average pressure}}{q}$$

It will be seen that C_{NF} may, therefore, be interpreted as the ratio of the average normal pressure along a chord to the dynamic pressure.

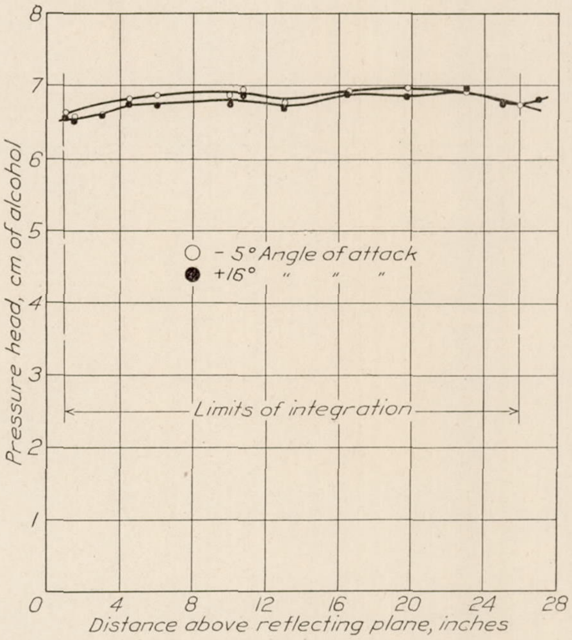


FIG. 7.—Dynamic pressure surveys. (Average dynamic head 6.805 c. m.)

Curves of normal force coefficient vs. angle of attack for each of the wings are presented in Figure 12. Similar curves for the entire cellule appear in Figure 13.

Curves showing the variation of the positions of centers of pressure along the spans of the wings are presented in Figure 14. The lateral positions of the centers of pressure are indicated.

DISCUSSION

In Figures 8 and 9 the effect of combining the wings to form the biplane can be seen in the change of pressures. The greatest change appears on the interior surfaces of the combination, i. e., the lower surface of the upper wing and the upper surface of the lower wing. The positive pressures on the lower surface of the upper wing and the negative pressures on the upper surface of the lower wing are reduced. It appears that the increased pressure below the upper wing partially neutralizes, and is neutralized by, the reduced pressure above the lower wing.

There is a small but consistent reduction of the pressures on the whole upper wing. The reverse is true of the lower wing. This may be explained as a result of placing the upper wing in the region of increased velocity and reduced static pressure which exists above the lower wing. Then by similar reasoning the lower wing is in a region of reduced velocity and increased static pressure.

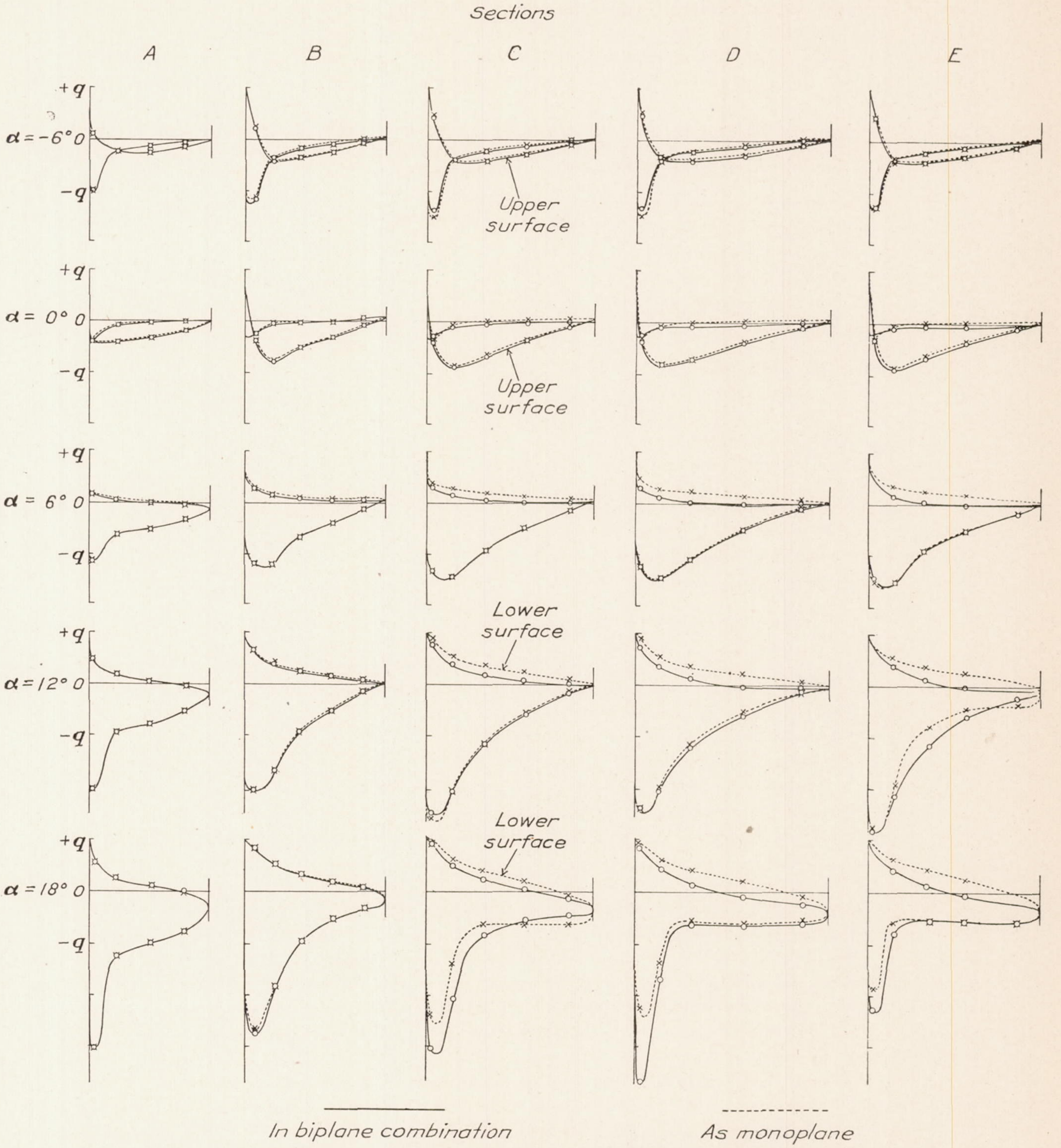


FIG. 8.—Diagrams of pressures at test sections of upper wing. Comparison as monoplane and in biplane combination

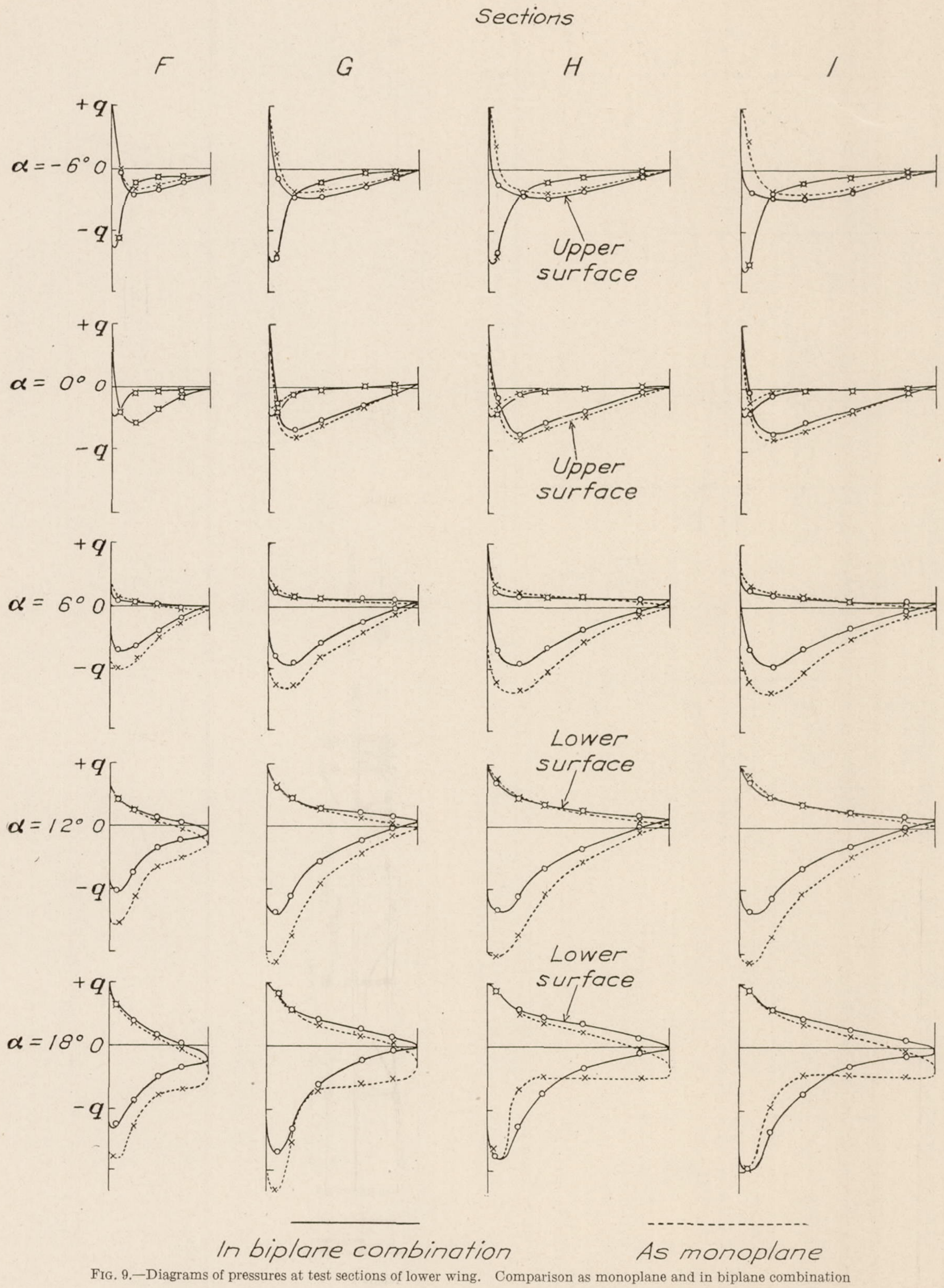


FIG. 9.—Diagrams of pressures at test sections of lower wing. Comparison as monoplane and in biplane combination

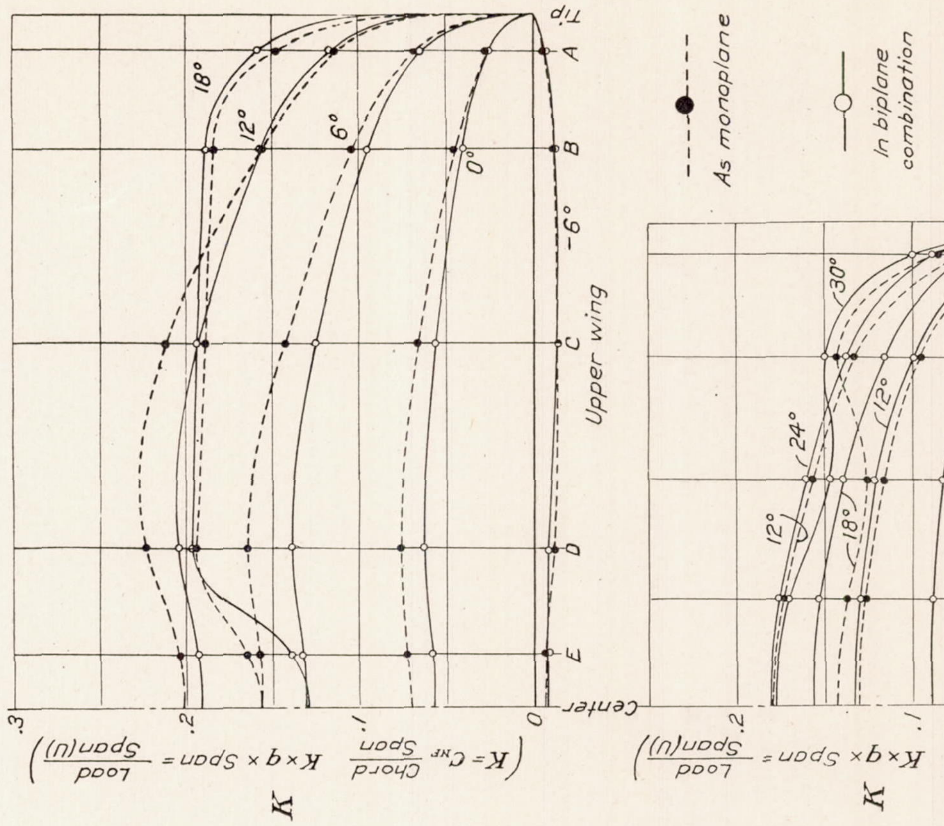


Fig. 10.—Lateral load distribution

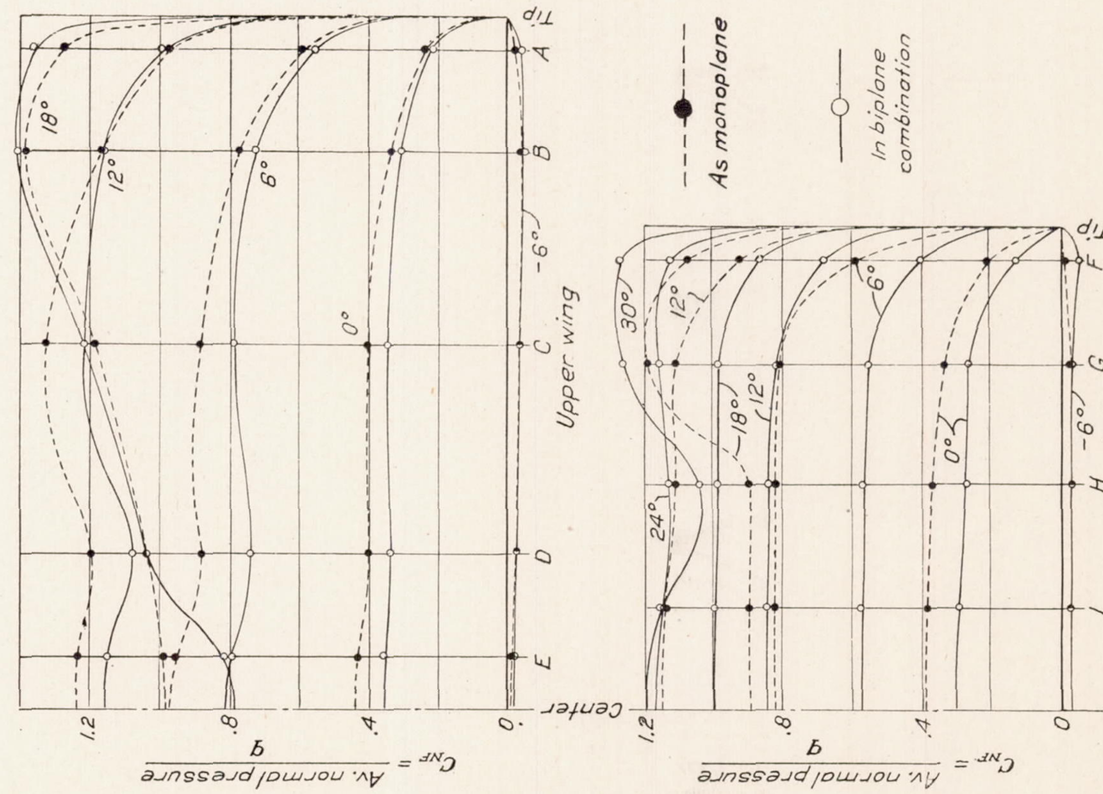
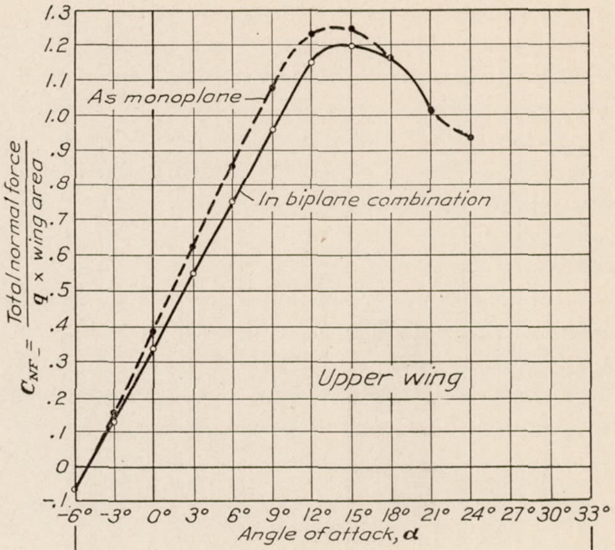


Fig. 11.—Normal force coefficient



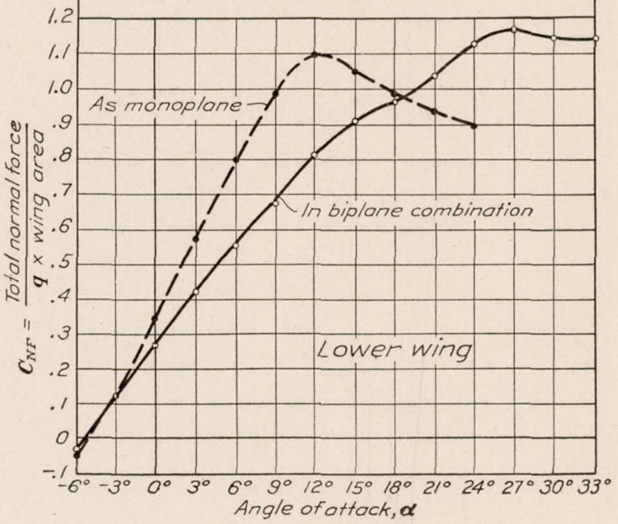


FIG. 12.—Normal force coefficient for wing

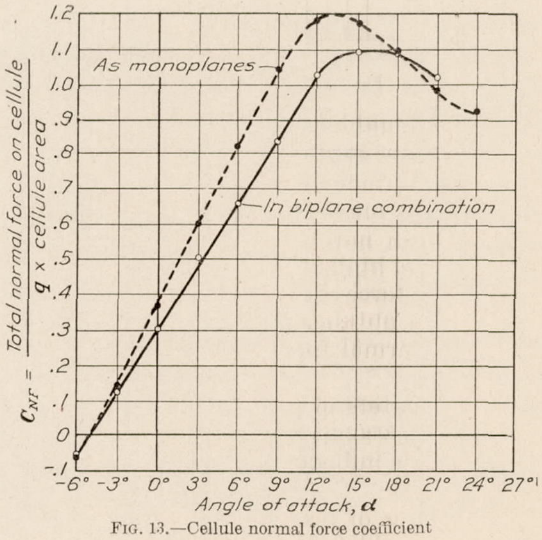


FIG. 13.—Cellule normal force coefficient

In Figure 10 it can be seen that, although the normal forces are not equal for the same angles of attack, their distribution along the span is not greatly affected. The upper wing with its less influenced overhanging portion has a somewhat more uniform distribution in the biplane combination. The distributions along the span of the lower wing are similar.

The washin of the center section of the upper wing serves to prevent a large reduction in the load per unit span over the section in which the chord is reduced. Although the chord is but 87 per cent of the maximum chord, the washin of but 1½ degrees is sufficient.

The curves of Figure 11 show that, with the exception of the tips, the normal force varies along the span in practically the same manner that the chords vary. At 18 degrees angle of attack the flow has begun to burble and the normal force distribution has become irregular.

The maximum ordinates of the curves for the upper wing in Figure 12 occur at practically the same angles of attack. The effect of reduction of pressure on the lower surface of the upper wing of the biplane is apparent. The air flow over the upper surface of the upper wing, being practically uninfluenced by the lower wing, breaks away at the same angle of attack

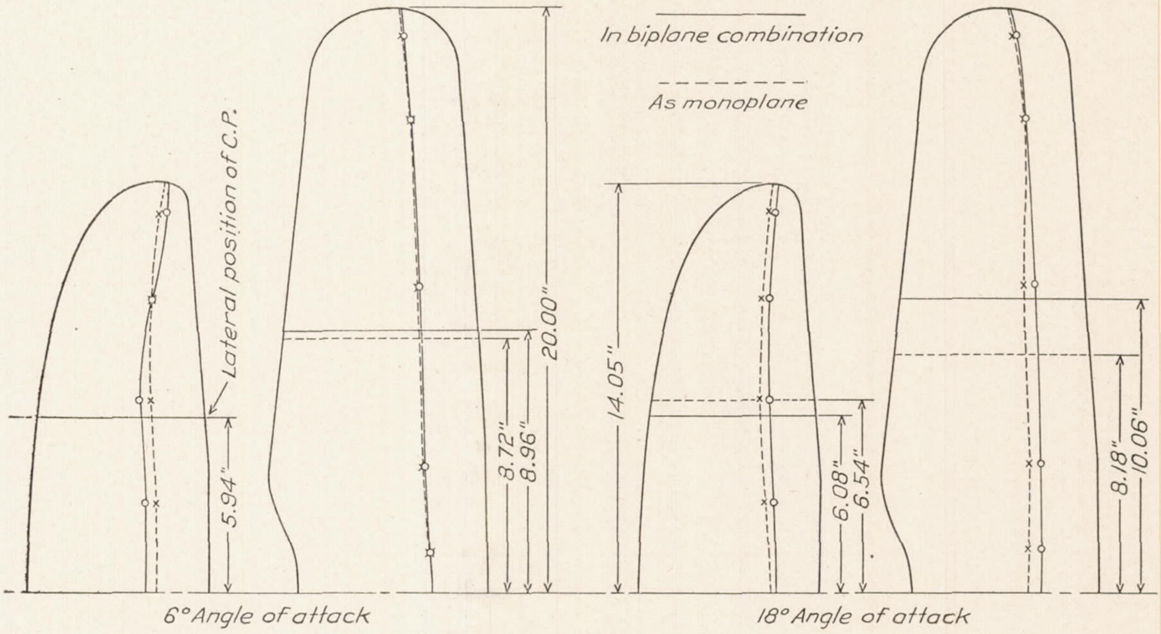


FIG. 14.—Center of pressure

whether the wing is in the biplane combination or by itself. The maximum normal force on the lower wing occurs at a much greater angle of attack when the wing is in the biplane combination. The air flow over the upper surface of the lower biplane wing is restricted by the upper wing and the burbling delayed. The maximum normal force on the lower wing of the biplane is slightly greater than the maximum normal force on the same wing as a monoplane. The normal force on the lower wing of the biplane does not break down suddenly.

The slope of the curve of normal-force coefficient vs. angle of attack (fig. 13) for the complete biplane cellule is less than would be obtained by a summation of the results of the individual monoplane tests. The maximum normal force is also less than that derived from the monoplane tests.

At large angles of attack the centers of pressure are farther forward on both wings of the biplane than they are when the wings are not in combination (fig. 14). At small angles of attack the upper wing appears to be but little influenced, whereas the lower wing has its centers of pressure farther to the rear.

The lateral position of the center of pressure is but little affected at small angles, but at large angles of attack is changed considerably. On the lower wing it is moved inward. The biplane interference on the inner portion of the upper wing and the relatively small influence on the overhanging tip shift the lateral position of the center of pressure outward a considerable amount.

CONCLUSIONS

The conclusions of this paper may be summarized as follows:

1. The effect of the biplane interference on the pressures on the individual wings is almost entirely restricted to the lower surface of the upper wing and the upper surface of the lower wing.

2. The distribution of the normal force along the span of the individual biplane wings is not greatly different from that along the span of the same wings when tested individually. That variation which is apparent is caused by the fact that the overhanging tip of the upper wing is relatively little influenced.

3. The washin of the center section of the upper wing, where the chord is reduced, prevents a large reduction of the normal force across this portion of the wing, providing the airfoil section is not mutilated.

4. The upper wing of the biplane burbles at the same angle of attack at which it burbles when tested individually. The burble of the lower wing of the biplane occurs at an increased angle of attack relative to that at which it burbles when tested as a monoplane.

5. The overhanging tip of the upper wing causes the lateral center of pressure to be farther out along the span than it is when the wing is tested as a monoplane. At large angles of attack the centers of pressure are moved forward by the biplane interference.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *April 7, 1927.*

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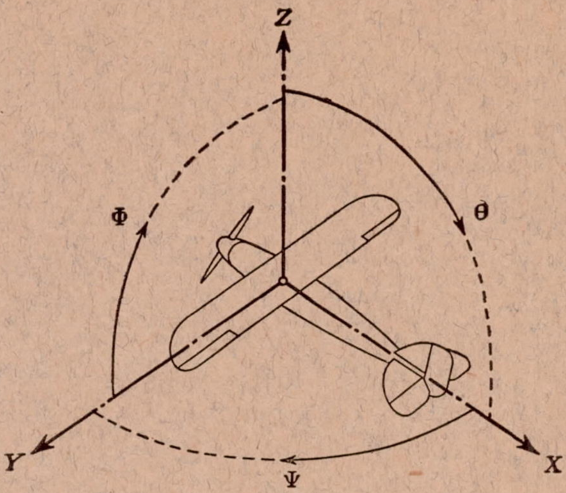

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L = \frac{L}{qbS} \quad C_M = \frac{M}{qcS} \quad C_N = \frac{N}{qfS}$$

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

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.