NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 254

DISTRIBUTION OF PRESSURE OVER MODEL OF THE UPPER WING AND AILERON OF A FOKKER D-VII AIRPLANE

By A. J. FAIRBANKS

WASHINGTON
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1927

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 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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DISTRIBUTION OF PRESSURE OVER MODEL OF THE UPPER WING AND AILERON OF A FOKKER D-VII AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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REPORT No. 254

DISTRIBUTION OF PRESSURE OVER MODEL OF THE UPPER WING AND AILERON OF A FOKKER D-VII AIRPLANE

By A. J. Fairbanks

SUMMARY

This report describes tests made in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics for the purpose of determining the distribution of pressure over a model of the tapered portion of the upper wing and the aileron of a Fokker D-VII airplane. Normal pressures were measured simultaneously at 74 points distributed over the wing and aileron. Tests were made throughout the useful range of angles of attack with aileron setting ranging from $-20°$ to $+20°$. The results are presented graphically.

It was found that the pressure distribution along the chord is in general similar to that of thick tapered airfoils previously tested. The maximum resultant pressure recorded was five times the dynamic pressure. The distribution of the air load along the span may be assumed to be uniform for design purposes.

Aileron displacements affect the pressures forward to the leading edge of the wing and may increase the air load on the outer portion of the wing by a considerable amount. With the wing at large angles of attack, the overhanging portion of the aileron creates usually a burbled flow and therefore a large drag. The balance reduces the control stick forces at small angles of attack for all aileron displacements. At large angles of attack it does this for small displacements only. With the airplane at its maximum speed, an angle of attack of 18°, and a down aileron displacement of 20°, the bending moment tending to break off the overhanging portion of the aileron will be greater than that caused by a uniform static load of 35 pounds per square foot.

INTRODUCTION

This is a report on the continuation of the tests on thick tapered airfoils which were requested by the United States Army Air Service. The object of the investigation is to determine the distribution of pressure over representative wings of this type. A previous report (Reference 1) covers tests on three airfoils which were tapered both in thickness and in plan form

In these tests a model of the tapered portion of the left upper wing and the aileron of a Fokker D-VII airplane was used. The wing, which is rectangular in plan form, has an aspect ratio of 5.2 and is equipped with ailerons of the horn balance type. The center section is 25.3 per cent of the span and has a constant thickness. The outer portions of the wing are tapered linearly to a tip thickness of 62 per cent of that at the center. Because the model represents only the tapered portion of the wing and the effect of the dividing plane is to reflect the action of a similar opposite model, the result is actually a model of a wing with an aspect ratio of approximately four. It is not thought, however, that the omission of the central portion of the wing will greatly affect the results. The model aileron was made movable in order that the effect of such a balanced control might be investigated.

METHOD AND APPARATUS

In these tests the method used was to record the heights of columns of alcohol in multiple photomanometers which were connected by air-tight tubes to orifices in the model's surface. The tests were made in the 5-foot atmospheric wind tunnel at the Langley Memorial Aeronautical Laboratory. The tests covered a range of angles of attack of from $-6°$ to $+24°$. The aileron angles investigated were 0°, and $\pm 10°$, and $\pm 20°$.

The wing was made by hand of laminated mahogany in which small brass tubes were inlaid. Figure 1 is a drawing of the model on which is shown the location of the pressure orifices. The aileron was constructed of brass. Two blanks were milled to contours and grooved; pressure tubes were inlaid, and then sweated together. The surfaces were finished by hand. The tubes were led through a channel in the wooden part of the wing. This channel was left open during assembly and was later covered by a steel plate which formed part of the

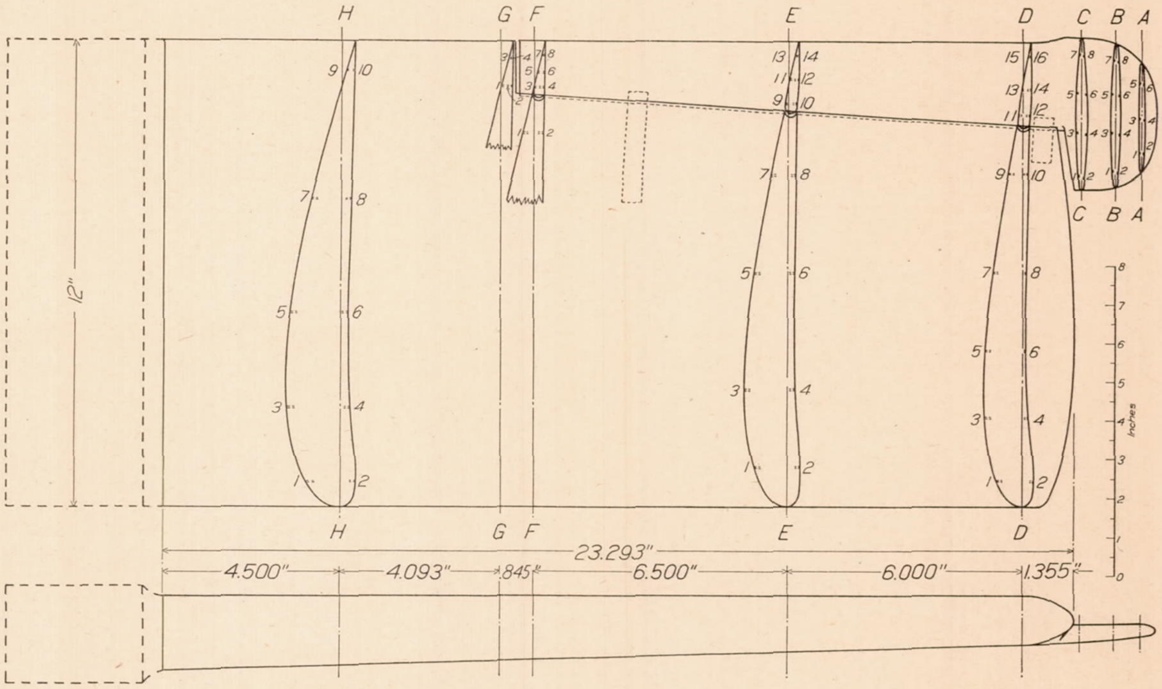


FIG. 1.—Pressure distribution model of the upper wing and aileron of Fokker D-VII Airplane

model's surface. Figure 2 is an illustration of this assembly with the cover removed. In all 74 tubes were used.

The model was mounted vertically at its root and could be rotated about a vertical axis. It passed through a horizontal plane fixed in the wind tunnel at the level of the root section. Figure 3 is a general view of this installation. The general details of construction and installation are the same as those of the former tests. (Reference 1.)

The angle of attack of the wing was set with the aid of a vernier scale and the aileron angle with the aid of a small telescopic sight. To take a record the wing and the aileron were brought to the required angles. When the velocity had become uniform at the desired value, the manometers were loaded with photostat paper, and simultaneous records were then taken. A sample of the photostat records is reproduced in Figure 4.

The air speed was approximately 66 feet per second. This gave maximum pressures that did not exceed the recording range of the manometers. Velocity surveys were made along a vertical diameter of the tunnel one chord length ahead of the wing with the wing at 0° and 18° angle of attack. The mean dynamic pressure was used in computations. Because no difficulty was experienced in fairing the pressure diagrams to the full dynamic pressure at the leading edge of the lower surface, it is not felt that the interference of the wing on the velocity measurement caused any perceptible error.

REDUCTION OF DATA

The photostat paper recorded the heights of the columns of alcohol, which represent the differences between the pressures at the orifices and the pressure at the wall of the tunnel opposite the leading edge of the wing, which is indistinguishable from the static pressure in the air stream opposite the leading edge of the model and at some distance from it. These pressure heads were divided by the mean dynamic pressure head and the resulting ratios were plotted along the test section chords.

In these pressure charts the resultant pressure at any point along the chord is represented by the vertical distance between the pressure curves for the upper and lower surfaces. These resultant pressures were plotted along the chords of the test sections. The curves of constant resultant pressure were then determined from the pressure charts and mapped on a plan view of the model.

When the inclosed area of the pressure charts are divided by a characteristic length, i. e., the wing chord, a nondimensional coefficient is obtained, which is proportional to the air load per unit span at the test section. These values are plotted against the span.

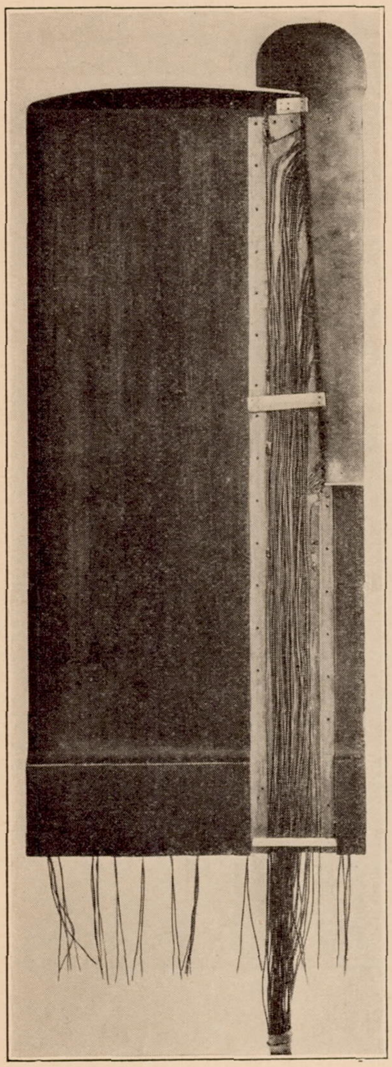


FIG. 2.—Model with plate removed, showing attachment of aileron

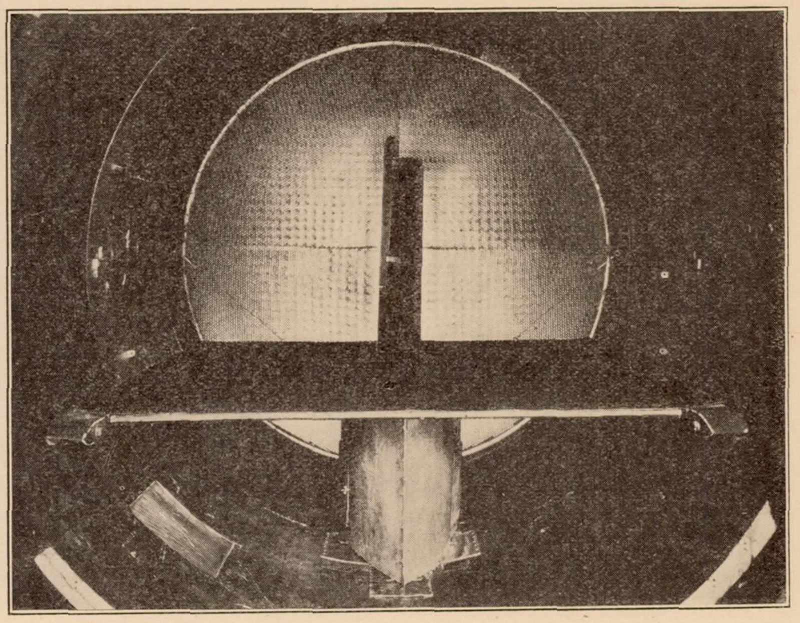


FIG. 3.—View of installation in the wind tunnel

The aileron hinge moments per unit span were obtained from the individual pressure charts with the aid of a mechanical moment integrator. The total hinge moment was obtained by integrating the hinge moments per unit span along the span. Omitting the moment of the overhanging portion, we obtain the approximate hinge moment of an unbalanced aileron. A plot of the hinge moments per unit span against the aileron span showed that the moment approached zero in every case at the point at which the tip of an unbalanced aileron would have been. Thus it is thought that this approximation is permissible. By dividing the moment of two interconnected balanced ailerons by the moment of two interconnected unbalanced ailerons, ratios were obtained which express approximately the effectiveness of the balance in reducing the required coutrol stick force.

The bending moment tending to break off the overhanging portion of the aileron was determined similarly from plots of loading along the span of the aileron.

PRESENTATION OF RESULTS

The results are presented by Figures 5 to 26. Figures 5 and 6 are charts of pressures on the upper and lower surfaces at the test sections. Figure 7 is a plot of the air loading per unit span against span, showing the effect of angle of attack. The effect of aileron displace-

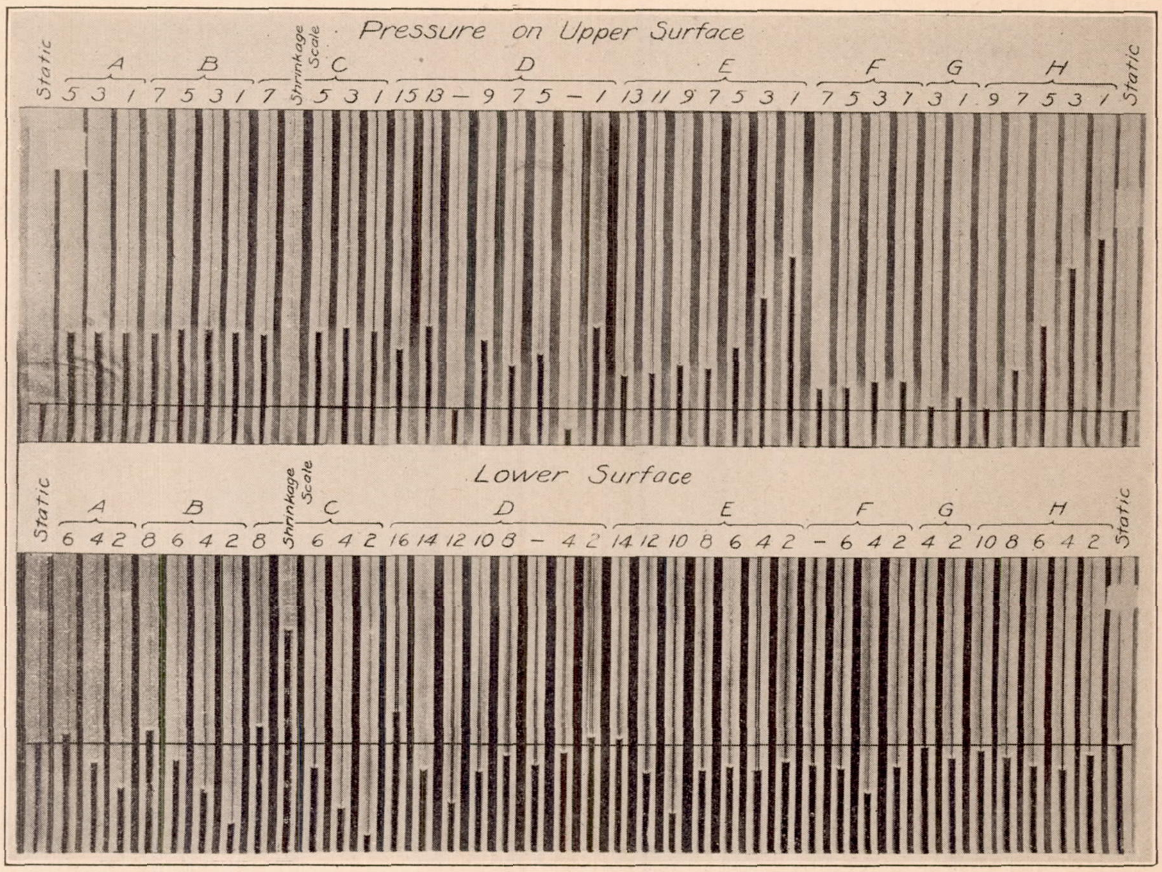


FIG. 4.—A pair of photostat records

ment on the resultant pressures along the chord is pictured in Figure 8. Figures 9 and 10 are plots similar to Figure 7 but illustrate the effect of aileron displacement. Figures 11 to 24 are contour maps of resultant pressures. In Figure 25 the ratio of the hinge moment of two balanced ailerons to the hinge moment of two unbalanced ailerons is plotted against the angle of aileron displacement. In Figure 26 the centers of pressure are plotted against both angle of attack and angle of aileron displacement.

DISCUSSION OF RESULTS

The pressure charts are similar to those for the three previously tested airfoils. (Reference 1.)

The maximum resultant pressure is five times the dynamic pressure and is greater than that recorded for any airfoil previously tested at this laboratory. The results of the tests on this airfoil are in agreement with the conclusion in Reference 1 that the maximum resultant pressure depends upon both the rate of increase of the thickness of the forward part of the airfoil and the shape of its mean camber line.

The distribution of the air load along the span, as shown by Figure 7, demonstrates that tapering an airfoil in thickness only is not necessarily an effective method for reducing the loading toward the tip. This is in agreement with the results of former tests of models which were tapered even more in thickness. (Reference 2.) The span-load curves of Reference 2 illustrate the greater effectiveness of tapering the plan form for obtaining small pressures near the tip.

The distribution of the air load along the span of the Fokker D–VII wing, as shown in Figure 7, may be assumed to be uniform for design purposes.

The effect of aileron displacement on the loading along the chord is illustrated by Figure 8. The pressures are modified forward to the leading edge, but the greatest change is over the aileron itself. A region of increased loading extends along the aileron hinge. (See figs. 11 to 24.) Similar irregularities have appeared in the results of previous tests. (Reference 3.) In the individual pressure charts, Figures 5 and 6, it may be seen that with a neutral or depressed aileron the rapid change of pressure is confined to the lower surface. With a raised aileron both surfaces experience this sudden change.

The effect of aileron displacement on the air loading along the span is shown in Figures 9 and 10. The intensity of loading over the outer portion of the wing is increased by depressing the aileron. With the wing at 18° angle of attack, an aileron depression of 20° will cause an increase in the air load on the tapered portion of the wing of 11.5 per cent. The bending moment at the inner end of the tapered section will be increased 15 per cent. In the design of wing structure, special air loads caused by aileron displacement should not be neglected.

The overhanging portion of the aileron is similar to an airfoil of poor aspect ratio; with the wing at a positive lift, it is always in a region of upflow. The distribution of the pressure along the chord is shown in Figures 5 and 6. The uniformity of pressure over the upper surface (see fig. 6) indicates that the overhanging area has given rise to burble. In this condition its drag is relatively large. The distribution of the resultant pressures over this part of the aileron is shown in Figures 11 to 24.

The most heavily loaded part of the aileron is that beyond the wing tip. As this is a cantilever structure and the thickness of the section at which it is supported is comparatively small, the strength of this section needs particular attention. The bending moment caused by the air forces at 18° angle of attack and 20° down aileron was compared with the bending moment caused by the application of a uniform static load of 35 pounds per square foot. The bending moment imposed by the sand load is smaller than the bending moment caused by the air load, if this airplane is brought to the above-mentioned attitude at its maximum speed.

The comparison of hinge moments shown in Figure 25 illustrates, in general, the effectiveness of the aileron balance. Inaccuracies are introduced by the use of a model of less than half span with a reflecting plane and by the assumption that the forces on the inner portion of the aileron are the same as those on an unbalanced aileron. However, we do not believe that these inaccuracies are of such magnitude as to obscure the principal points of interest. Considering now pairs of interconnected ailerons, the balanced pair requires smaller control forces than the unbalanced pair for all displacements at small angles of attack. At large angles of attack, however, this holds only for small displacements.

This may be explained as follows: At large angles of attack, the forces on the overhanging portion of the aileron always produce a moment tending to lower the trailing edge. The forces on the inner portion of the aileron always produce a moment tending to return the aileron to neutral. Thus, if the aileron is displaced upward, both moments are in the same direction and the resulting moment is greater than the corresponding moment for an unbalanced aileron. On the other hand, if the aileron is displaced downward the two moments will be in opposite directions and the result will be a smaller moment than would be found on the corresponding unbalanced aileron. Whether the control force for interconnected ailerons will be increased or decreased by the balance will depend upon which of these two effects is greater. In Figure 25 it can be seen that at 18° angle of attack either of these two effects can exist according to the angle of aileron displacement.

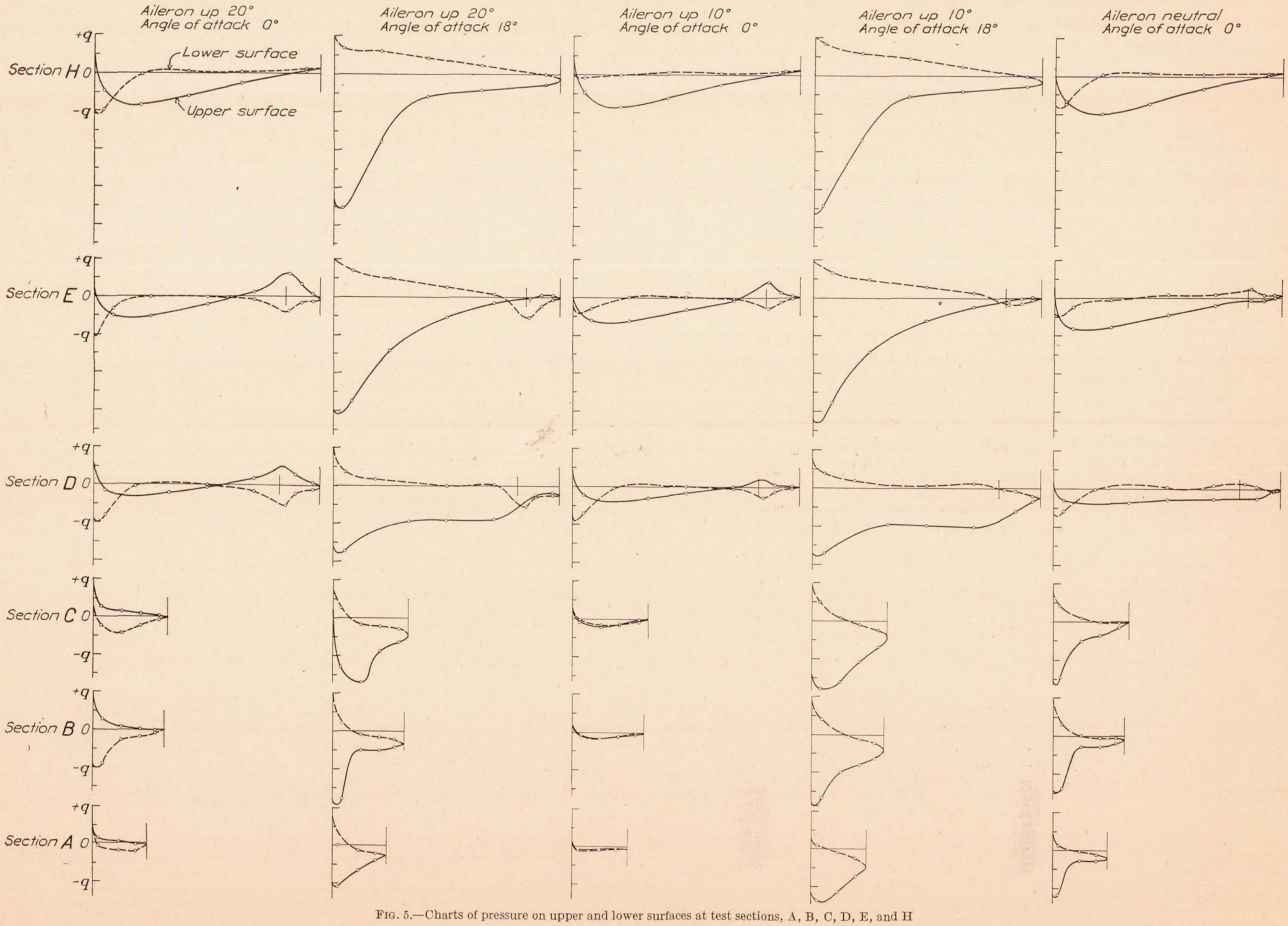


FIG. 5.—Charts of pressure on upper and lower surfaces at test sections, A, B, C, D, E, and H

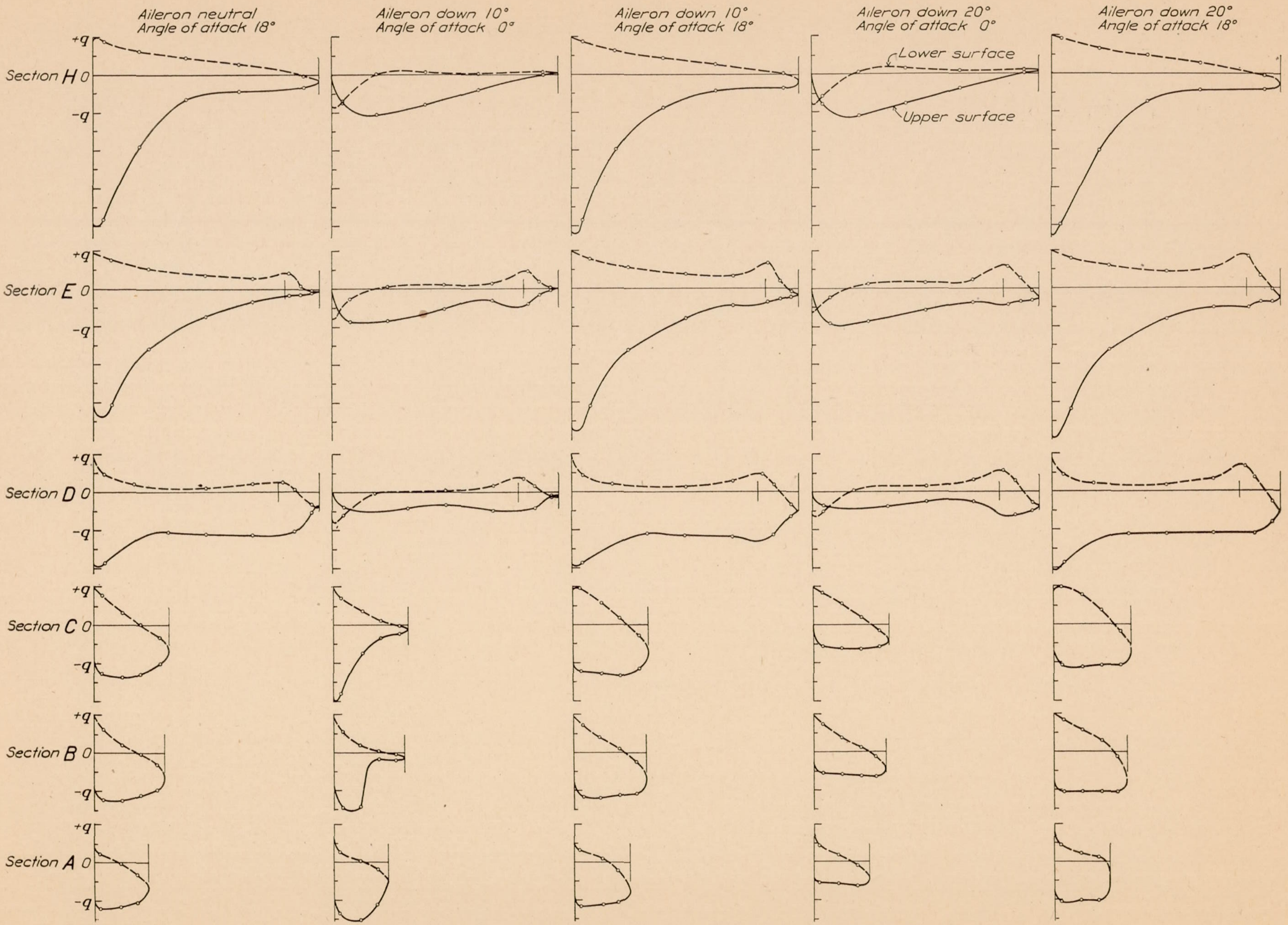


FIG. 6.—Charts of pressure on upper and lower surfaces at test sections, A, B, C, D, E, and H

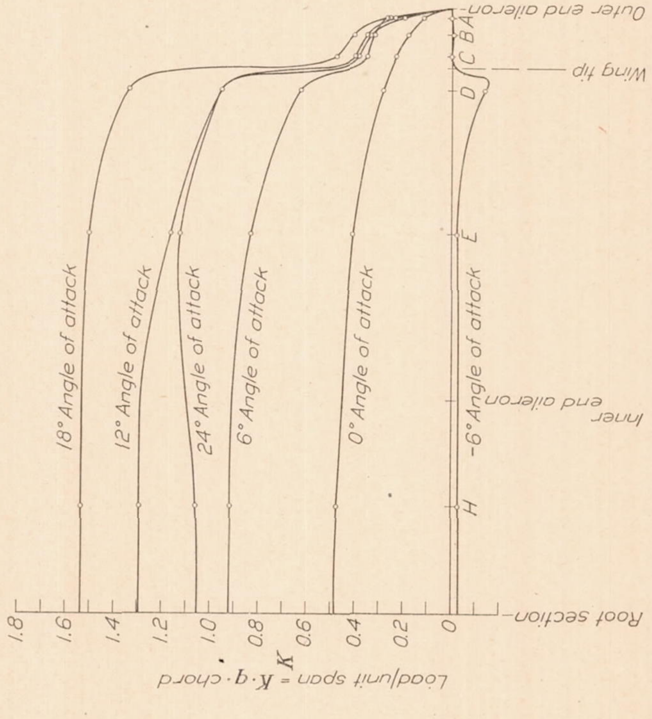
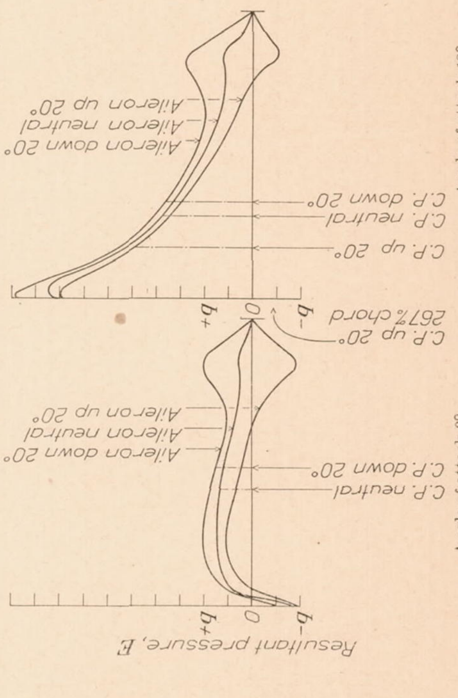


FIG. 7.—Air load distribution along span. Aileron neutral



Angle of attack 0° Angle of attack 18°

FIG. 8.—Effect of aileron displacement on resultant pressure along chord of section E

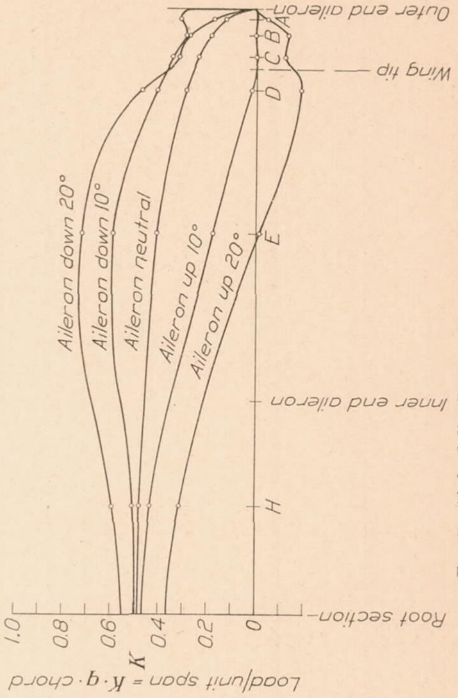


FIG. 9.—Air load distribution along span. Angle of attack 0°

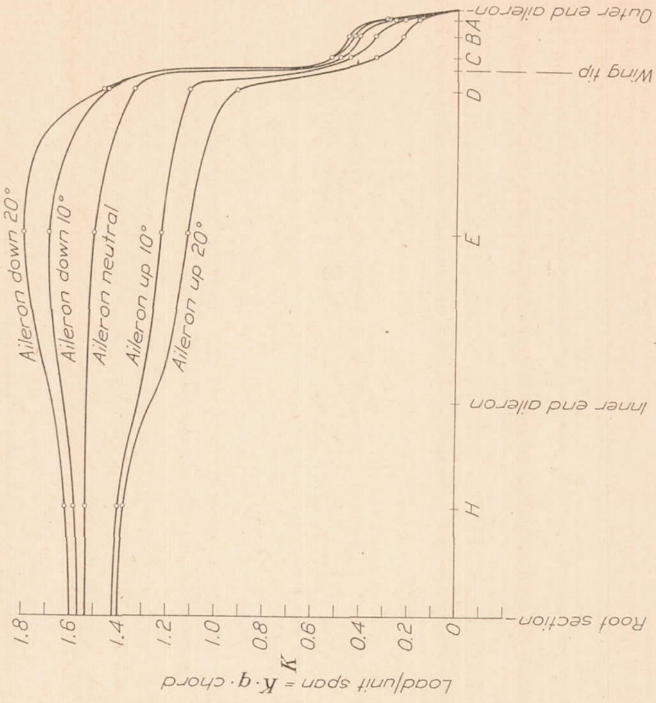


FIG. 10.—Air load distribution along span. Angle of attack 18°

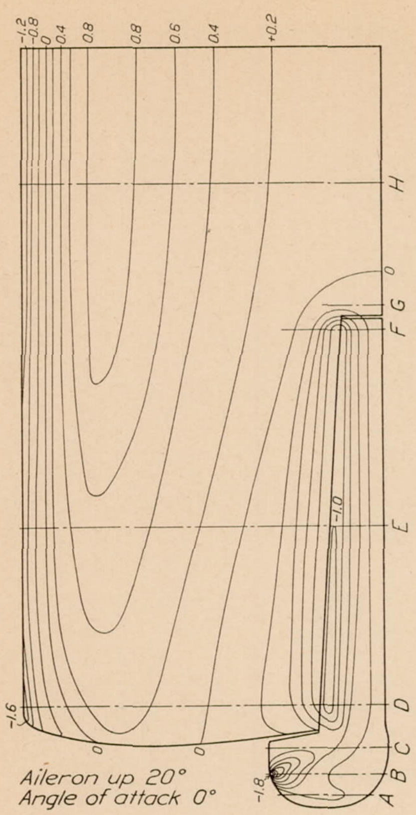


FIG. 11

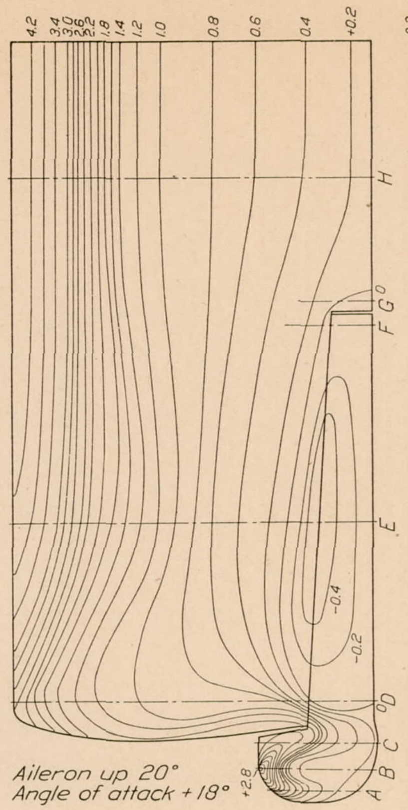


FIG. 12

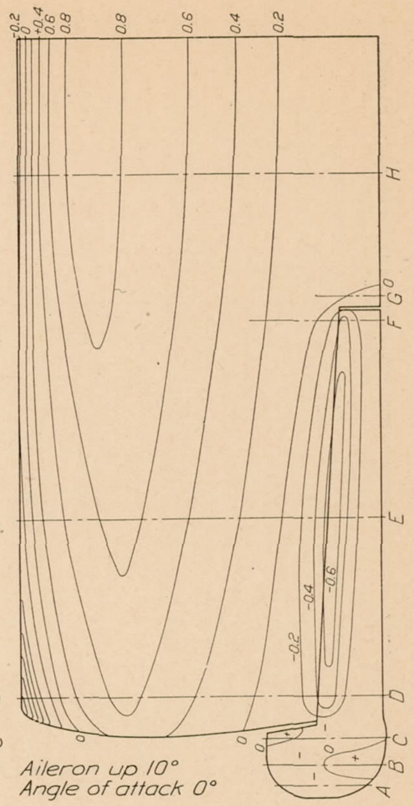


FIG. 13

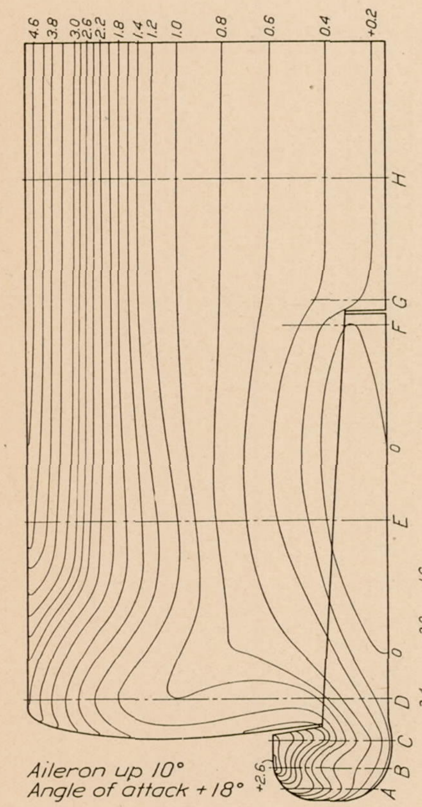


FIG. 14

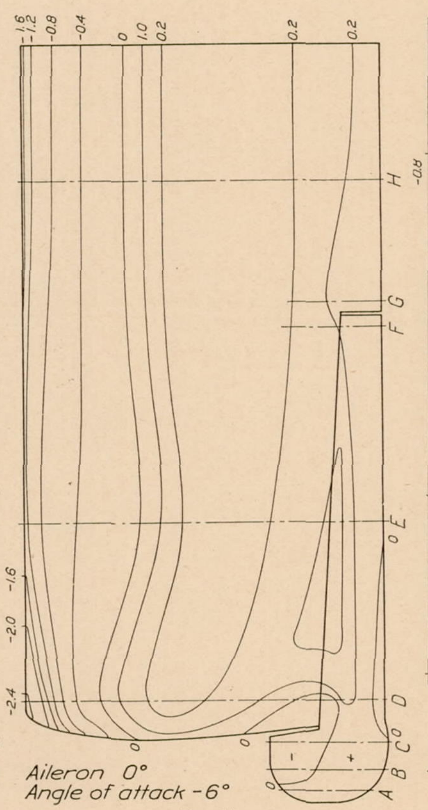


FIG. 15

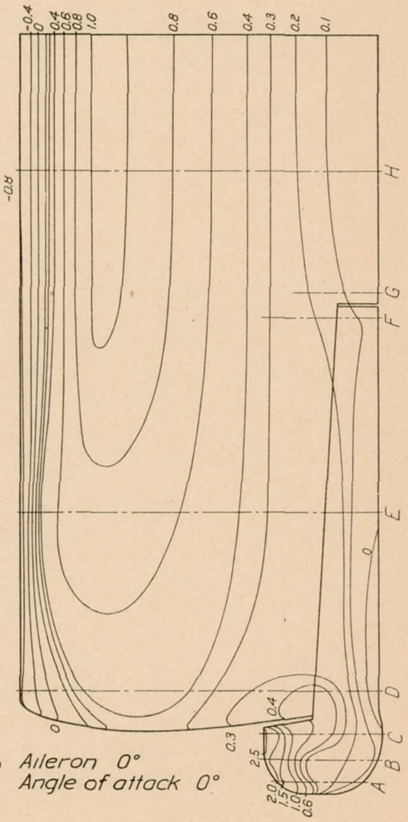


FIG. 16

Contour charts of resultant pressures in terms of q

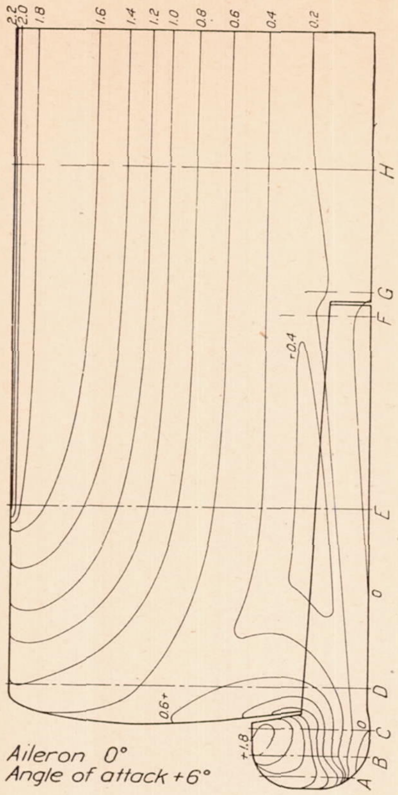


FIG. 17

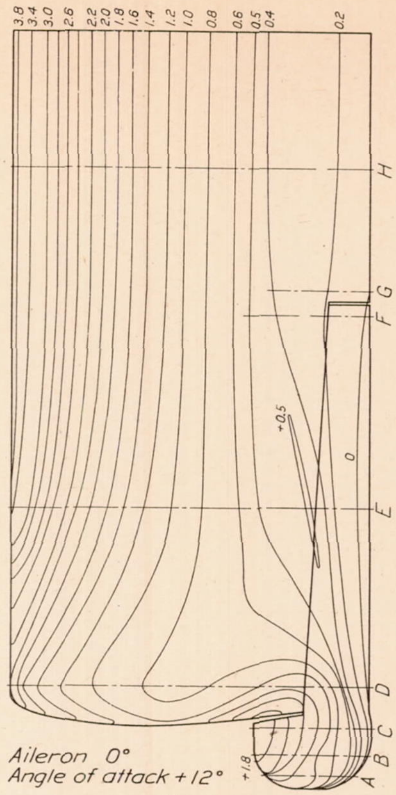


FIG. 18

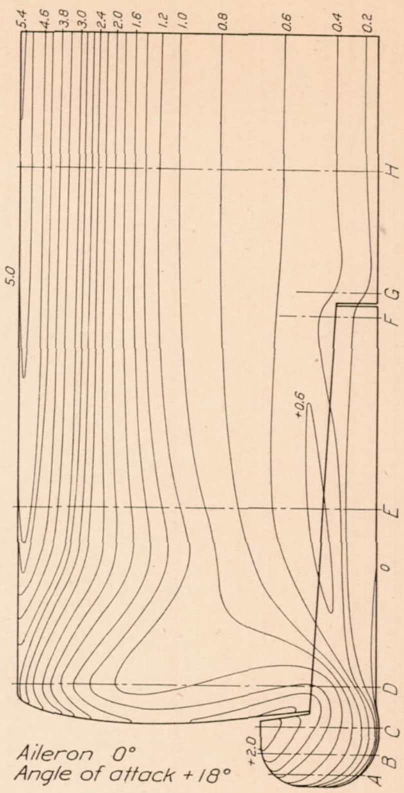


FIG. 19

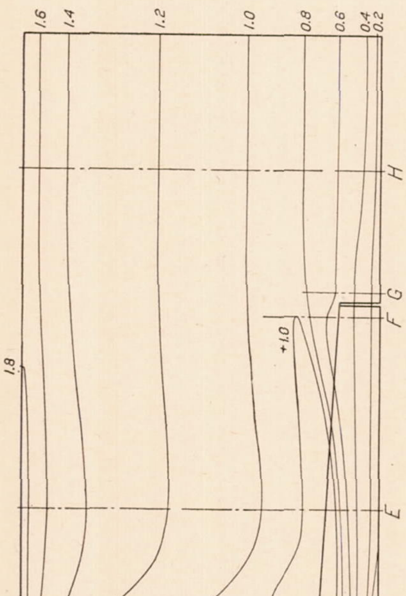


FIG. 20

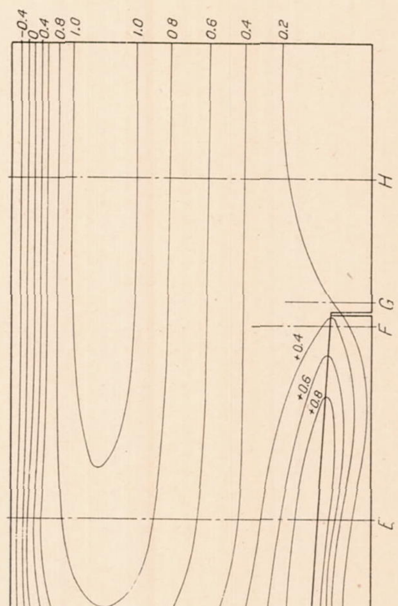


FIG. 21

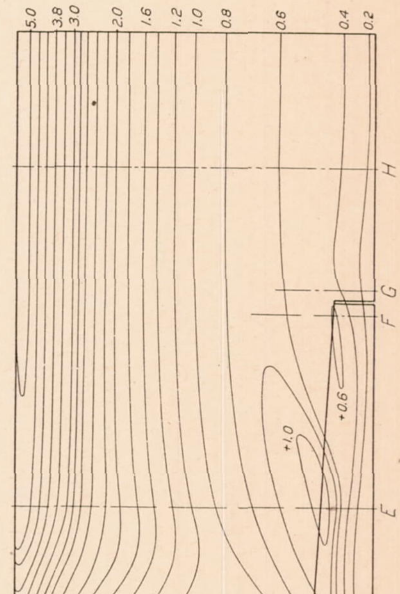


FIG. 22

Contour charts of resultant pressures in terms of q

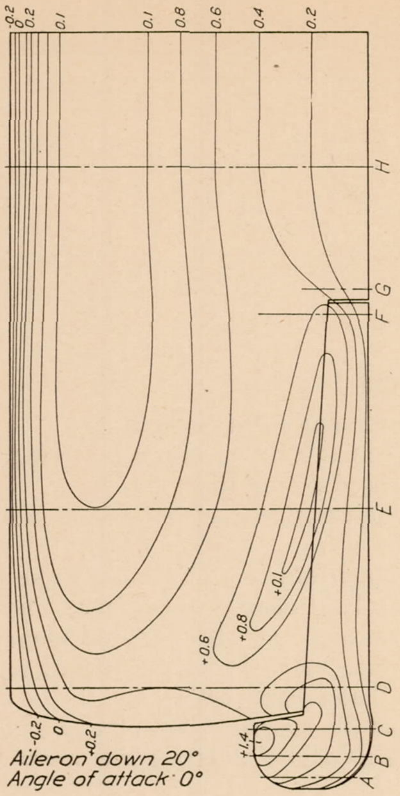


FIG. 23

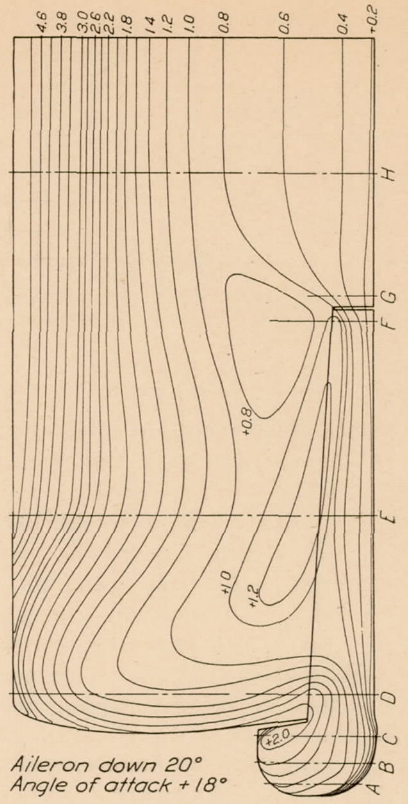


FIG. 24

Contour charts of resultant pressures in terms of q

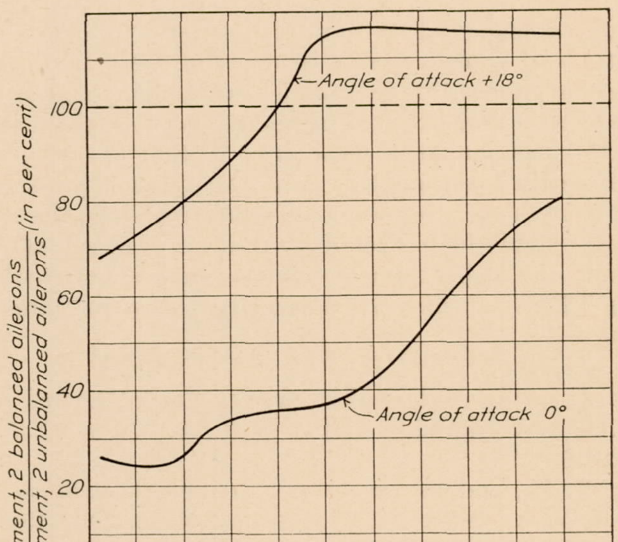


FIG. 25

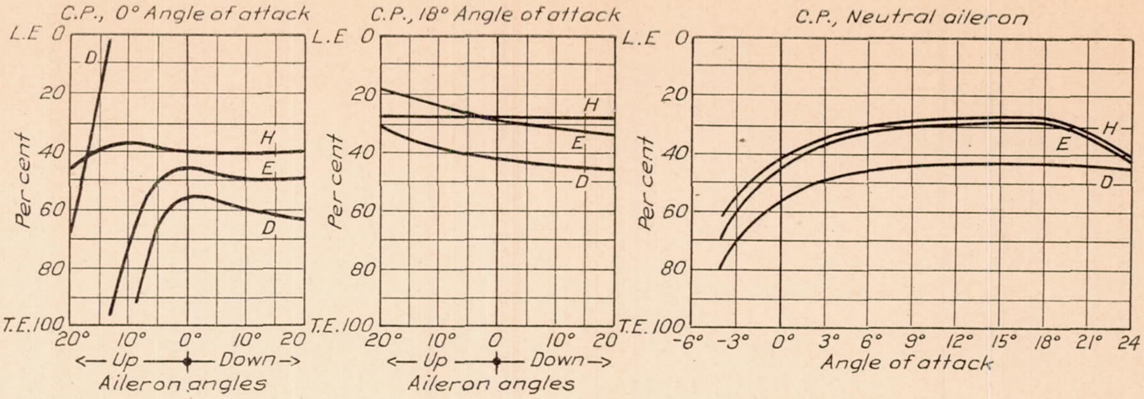


FIG. 26

CONCLUSIONS

The outstanding results of these tests may be summarized as follows:

1. The distribution of the air load along the span may be assumed for design purposes to be uniform for thick wings of rectangular plan form.
2. Tapering a wing in thickness only is not necessarily an effective method for reducing the loading toward the tip.
3. Large aileron displacements introduce important modifications of the distribution of the air load along both the chord and the span of the wing. They should be taken into account in the stress analysis and static testing of airplane wings.
4. When the wing is at a large angle of attack, the overhanging portion of the aileron usually causes burbling and therefore has a large drag.
5. The action of the aileron balance reduces the control stick force at small angles of attack for all displacements, but at large angles of attack the reverse is true for large displacements.
6. For the static testing of the overhanging portion of an aileron of this type, a loading of 35 pounds per square foot is not severe enough.

RECOMMENDATIONS

The following loading is suggested for the static testing of the overhanging portion of ailerons of this type. The total load applied should be one and one-half times the dynamic pressure (in pounds per square foot) times the area of the overhanging surface (in square feet). The dynamic pressure should correspond to the maximum speed at which the airplane is to be violently maneuvered. The load should be distributed so that the inner end of the leading edge is loaded to an intensity of two and one-half times the dynamic pressure. The loading should taper directly to an intensity equal to the dynamic pressure along the trailing edge and the tip. In these tests the aileron should be horizontal so that the load will act normal to it. The use of any type of balance on any highly maneuverable airplane is not recommended. It is further recommended that the effects of aileron displacement be given careful consideration in the design of wing structures.

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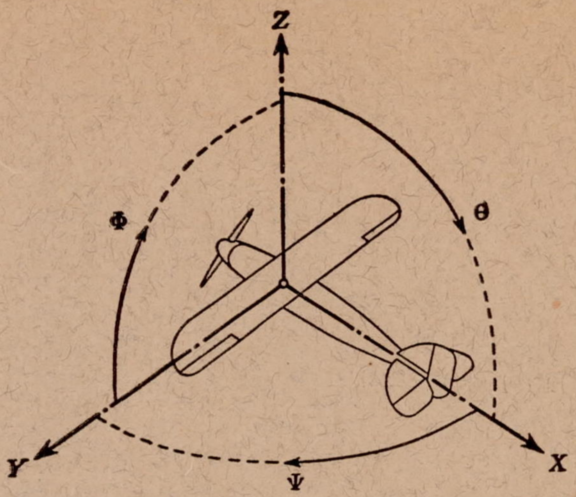

Positive directions of axes and angles (forces and moments) are shown by arrows

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.