NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 688

AERODYNAMIC CHARACTERISTICS OF HORIZONTAL TAIL SURFACES

By ABEL SILVERSTEIN and S. KATZOFF

1940
NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM THE BEST COPY FURNISHED US BY THE SPONSORING AGENCY. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE.
REPORT No. 688

AERODYNAMIC CHARACTERISTICS OF HORIZONTAL TAIL SURFACES

By ABE SILVERSTEIN and S. KATZOFF
Langley Memorial Aeronautical Laboratory
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.
LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

VANNEVAR BUSH, Sc. D., Chairman, Washington, D. C.
GEORGE J. MEAD, Sc. D., Vice Chairman, West Hartford, Conn.
CHARLES G. ABBOTT, Sc. D., Secretary, Smithsonian Institution.
HENRY H. ARNOLD, Major General, United States Army, Chief of Air Corps, War Department.
GEORGE H. BREE, Brigadier General, United States Army, Chief Material Division, Air Corps, Wright Field, Dayton, Ohio.
LYMAN J. BRIGGS, Ph. D., Director, National Bureau of Standards.
ROBERT E. DOWERTY, M. S., Pittsburgh, Pa.

CLINTON M. HESTER, A. B., LL. B., Administrator, Civil Aeronautics Authority.
ROBERT H. HINCKLEY, A. B., Chairman, Civil Aeronautics Authority.
SYDNEY M. KRAUS, Captain, United States Navy, Bureau of Aeronautics, Navy Department.
FRANCIS W. REICHELDERFER, Sc. D., Chief, United States Weather Bureau.
JOHN H. TOWERS, Rear Admiral, United States Navy, Chief, Bureau of Aeronautics, Navy Department.
EDWARD WARNER, Sc. D., Washington, D. C.
ORVILLE WRIGHT, Sc. D., Dayton, Ohio.

GEORGE W. LEWIS, Director of Aeronautical Research
S. PAUL JOHNSTON, Coordinator of Research
JOHN F. VICTORY, Secretary
HENRY J. E. REID, Engineer in Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.
JOHN J. IDE, Technical Assistant in Europe, Paris, France

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS

COORDINATION OF RESEARCH NEEDS OF MILITARY AND CIVIL AVIATION
PREPARATION OF RESEARCH PROGRAMS
ALLOCATION OF PROBLEMS
PREVENTION OF DUALITY
CONSIDERATION OF INVENTIONS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY
LANGLEY FIELD, VA.

Unified conduct, for all agencies, of scientific research on the fundamental problems of flight.

OFFICE OF AERONAUTICAL INTELLIGENCE
WASHINGTON, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics.

4-1-40
REPORT No. 688

AERODYNAMIC CHARACTERISTICS OF HORIZONTAL TAIL SURFACES

By Abe Silverstein and S. Katzoff

SUMMARY

Collected data are presented on the aerodynamic characteristics of 17 horizontal tail surfaces including several with balanced elevators and two with end plates. Curves are given for coefficients of normal force, drag, and elevator hinge moment. A limited analysis of the results has been made. The normal-force coefficients are in better agreement with the lifting-surface theory of Prandtl and Blenk for airfoils of low aspect ratio than with the usual lifting-line theory. Only partial agreement exists between the elevator hinge-moment coefficients and those predicted by Glauser's thin-airfoil theory.

INTRODUCTION

The balance, control, and stability problems that attend the use of wing flaps on airplanes require for their solution accurate methods of predicting the forces on the horizontal tail surfaces. In order to aid in the development of such methods, the available data for 17 horizontal tail surfaces have been collected from various sources (see table I) and are herein presented. These data refer to the tail surfaces alone, exclusive of fuselage and slipstream interference. Some analyses, particularly with reference to normal-force and elevator hinge-moment coefficients, have been made within the limitations imposed by low test Reynolds Numbers and variations in section and in plan form. The data are not entirely satisfactory because the usual uncertainty exists in the extrapolation to higher Reynolds Numbers and the experimental precision is, in most cases, unknown. The results should be useful, however, until more comprehensive investigations are made.

Tables I and II contain the descriptive data for the 17 surfaces. The tails have symmetrical sections; elliptical, rectangular, and trapezoidal plan forms; aspect ratios between 3 and 4:1; and elevator areas of from 30 to 50 percent of the total tail area. Two cases of tail assemblies with twin rudders as end plates are included. In some cases, groups of tail surfaces were tested in which only one characteristic, such as the elevator balance area or the ratio of the elevator area to the tail area, was systematically varied.

A symbols
R aspect ratio.
V Reynolds Number.
CN normal-force coefficient (C_n = C_T cos a + C_D sin a).
H_e elevator hinge moment.
C_h elevator hinge-moment coefficient (H_e/q_e a b).
a_e angle of attack of the tail, deg.
\delta_e elevator angle (downward deflection positive).
S area.
b span.
c chord.
\bar{c} average chord.
\bar{c}^2 average of chords squared.
a_o section slope of lift curve (deg measure).
k slope of tail normal-force curve (dC_n/d\alpha).
r factor in the expression for the slope of the normal-force curve for tail surfaces with end plates.
\eta_e elevator effectiveness.
h height of end plate.
u, v coefficients of C_N and \delta, in the hinge-moment equation.

Subscripts:
t entire tail.
e elevator, excluding balance.
b balance.

NORMAL-FORCE COEFFICIENT

The tail-surface characteristic necessary for stability calculations is the rate of change of normal force with angle of attack. For control problems, the most essential characteristic is the rate of change of normal force with elevator angle. The normal-force coefficients C_n are plotted in figures 1 to 17 against angle of attack \alpha, with elevator deflection \delta as a parameter. The curves are straight and parallel over most of the useful range; nonlinearity or nonparallelism at low values of \alpha is associated with large elevator deflections or protruding balances. (Cf. figs. 1 and 9.) Cross plots of C_n against \delta, for several values of \alpha, are shown for tail surfaces 1, 2, and 3 in figures 18 to 20. Curves of this type are of particular value in showing the variation of elevator effectiveness with elevator deflection.
TABLE I—DIMENSIONS OF TAIL SURFACES

Tail surface 1, unpublished data from files of full-scale wind tunnel.

Tail surface 2, unpublished data from files of 7- by 10-foot wind tunnel.

Tail surface 3, unpublished data from files of 7- by 10-foot wind tunnel.

Tail surface 4, reference 1.

Tail surface 5, reference 1.

Tail surface 6, reference 1.

Tail surface 7, reference 1.

Tail surface 8, reference 1.

<table>
<thead>
<tr>
<th>Tail surface</th>
<th>A</th>
<th>b (in.)</th>
<th>S1 (sq in.)</th>
<th>S1%</th>
<th>ci (in.)</th>
<th>ci+ (in.)</th>
<th>ci+ (sq in.)</th>
<th>ci+ (in.)</th>
<th>ci+ (sq in.)</th>
<th>ci+ (sq in.)</th>
<th>Test 1 (f p s)</th>
<th>Test R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.4</td>
<td>155.0</td>
<td>0.35</td>
<td>0.35</td>
<td>222.0</td>
<td>4.31</td>
<td>0.27</td>
<td>88.0</td>
<td>1,900,000</td>
<td>606,000</td>
<td>117.3</td>
<td>448,000</td>
</tr>
<tr>
<td>2</td>
<td>4.1</td>
<td>150.0</td>
<td>0.38</td>
<td>0.38</td>
<td>11.0</td>
<td>3.27</td>
<td>3.27</td>
<td>0.33</td>
<td>110.0</td>
<td>448,000</td>
<td>100.0</td>
<td>448,000</td>
</tr>
<tr>
<td>3</td>
<td>4.2</td>
<td>150.0</td>
<td>0.39</td>
<td>0.39</td>
<td>9.75</td>
<td>3.27</td>
<td>3.27</td>
<td>0.33</td>
<td>110.0</td>
<td>448,000</td>
<td>100.0</td>
<td>448,000</td>
</tr>
<tr>
<td>4</td>
<td>4.3</td>
<td>150.0</td>
<td>0.39</td>
<td>0.39</td>
<td>9.75</td>
<td>3.27</td>
<td>3.27</td>
<td>0.33</td>
<td>110.0</td>
<td>448,000</td>
<td>100.0</td>
<td>448,000</td>
</tr>
<tr>
<td>5</td>
<td>4.4</td>
<td>150.0</td>
<td>0.39</td>
<td>0.39</td>
<td>9.75</td>
<td>3.27</td>
<td>3.27</td>
<td>0.33</td>
<td>110.0</td>
<td>448,000</td>
<td>100.0</td>
<td>448,000</td>
</tr>
<tr>
<td>6</td>
<td>4.5</td>
<td>150.0</td>
<td>0.39</td>
<td>0.39</td>
<td>9.75</td>
<td>3.27</td>
<td>3.27</td>
<td>0.33</td>
<td>110.0</td>
<td>448,000</td>
<td>100.0</td>
<td>448,000</td>
</tr>
<tr>
<td>7</td>
<td>4.6</td>
<td>150.0</td>
<td>0.39</td>
<td>0.39</td>
<td>9.75</td>
<td>3.27</td>
<td>3.27</td>
<td>0.33</td>
<td>110.0</td>
<td>448,000</td>
<td>100.0</td>
<td>448,000</td>
</tr>
<tr>
<td>8</td>
<td>4.7</td>
<td>150.0</td>
<td>0.39</td>
<td>0.39</td>
<td>9.75</td>
<td>3.27</td>
<td>3.27</td>
<td>0.33</td>
<td>110.0</td>
<td>448,000</td>
<td>100.0</td>
<td>448,000</td>
</tr>
</tbody>
</table>
AERODYNAMIC CHARACTERISTICS OF HORIZONTAL TAIL SURFACES

Tail surface 9, reference 1.

Tail surface 10, reference 2.

Tail surface 11, reference 2.

Tail surface 12, reference 2.

Tail surface 13, reference 1.

Tail surface 14, reference 1.

Tail surface 15, reference 3.

Tail surface 16, reference 3.

Tail surface 17, reference 3.

<table>
<thead>
<tr>
<th>Tail surface</th>
<th>A (in.)</th>
<th>h (in.)</th>
<th>S1 (sq in.)</th>
<th>S2 (sq in.)</th>
<th>S1/S2</th>
<th>C1 (ft)</th>
<th>C2 (ft)</th>
<th>C3/C4</th>
<th>C5/C6</th>
<th>C7/C8</th>
<th>S/Sx</th>
<th>Test V (fps)</th>
<th>Test R</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>3.0</td>
<td>23.9</td>
<td>192</td>
<td>81</td>
<td>0.43</td>
<td>6.03</td>
<td>3.40</td>
<td>0.42</td>
<td>12.0</td>
<td>2.28</td>
<td>0.25</td>
<td>110.0</td>
<td>470.000</td>
</tr>
<tr>
<td>10</td>
<td>3.0</td>
<td>23.9</td>
<td>192</td>
<td>81</td>
<td>0.43</td>
<td>6.03</td>
<td>3.40</td>
<td>0.42</td>
<td>12.0</td>
<td>2.28</td>
<td>0.25</td>
<td>110.0</td>
<td>470.000</td>
</tr>
<tr>
<td>11</td>
<td>3.6</td>
<td>17.6</td>
<td>96</td>
<td>33</td>
<td>0.47</td>
<td>4.94</td>
<td>1.62</td>
<td>0.28</td>
<td>3.6</td>
<td>0.0</td>
<td>0.0</td>
<td>98.4</td>
<td>250.000</td>
</tr>
<tr>
<td>12</td>
<td>3.8</td>
<td>17.7</td>
<td>97</td>
<td>33</td>
<td>0.47</td>
<td>4.94</td>
<td>1.62</td>
<td>0.28</td>
<td>3.6</td>
<td>0.0</td>
<td>0.0</td>
<td>98.4</td>
<td>250.000</td>
</tr>
<tr>
<td>13</td>
<td>3.8</td>
<td>17.7</td>
<td>97</td>
<td>33</td>
<td>0.47</td>
<td>4.94</td>
<td>1.62</td>
<td>0.28</td>
<td>3.6</td>
<td>0.0</td>
<td>0.0</td>
<td>98.4</td>
<td>250.000</td>
</tr>
<tr>
<td>14</td>
<td>3.1</td>
<td>17.7</td>
<td>90</td>
<td>30</td>
<td>0.33</td>
<td>3.93</td>
<td>1.94</td>
<td>0.32</td>
<td>3.1</td>
<td>0.0</td>
<td>0.0</td>
<td>98.4</td>
<td>250.000</td>
</tr>
<tr>
<td>15</td>
<td>4.3</td>
<td>39.4</td>
<td>381</td>
<td>81</td>
<td>0.23</td>
<td>6.15</td>
<td>2.77</td>
<td>0.36</td>
<td>5.4</td>
<td>0.0</td>
<td>0.0</td>
<td>110.0</td>
<td>340.000</td>
</tr>
<tr>
<td>16</td>
<td>4.3</td>
<td>39.4</td>
<td>381</td>
<td>81</td>
<td>0.23</td>
<td>6.15</td>
<td>2.77</td>
<td>0.36</td>
<td>5.4</td>
<td>0.0</td>
<td>0.0</td>
<td>110.0</td>
<td>340.000</td>
</tr>
<tr>
<td>17</td>
<td>4.3</td>
<td>39.3</td>
<td>386</td>
<td>82</td>
<td>0.45</td>
<td>6.06</td>
<td>4.20</td>
<td>0.46</td>
<td>10.3</td>
<td>48.13</td>
<td>15</td>
<td>110.0</td>
<td>321.000</td>
</tr>
</tbody>
</table>
### TABLE II—THICKNESSES OF TAIL-SURFACE SECTIONS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>10</td>
<td>0.0</td>
<td>20</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>20</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tail surface 1**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12.0</td>
<td>10</td>
<td>12.0</td>
<td>20</td>
<td>12.0</td>
</tr>
<tr>
<td>10</td>
<td>12.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>12.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tail surfaces 2 and 3—N. A. C. A. 0012.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>10</td>
<td>0.0</td>
<td>20</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>20</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tail surfaces 4, 5, and 6.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.0</td>
<td>10</td>
<td>5.0</td>
<td>20</td>
<td>5.0</td>
</tr>
<tr>
<td>5</td>
<td>5.7</td>
<td>20</td>
<td>5.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tail surfaces 7, 8, and 9.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>10</td>
<td>0.0</td>
<td>20</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>20</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tail surfaces 10, 11, 12, 15, 16, and 17—Göttingen 409.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8.0</td>
<td>10</td>
<td>8.0</td>
<td>20</td>
<td>8.0</td>
</tr>
<tr>
<td>5</td>
<td>8.8</td>
<td>20</td>
<td>8.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>9.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>10.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tail surfaces 13 and 14.**

---

**FIGURE 1**—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 1.

**FIGURE 2**—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 2.
AERODYNAMIC CHARACTERISTICS OF HORIZONTAL TAIL SURFACES

Figure 3.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 1.

Figure 4.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 1.

Figure 5.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 5.

Figure 6.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 6.
Figure 7.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 7.

Figure 8.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 8.

Figure 9.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 9.

Figure 10.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 10.
AERODYNAMIC CHARACTERISTICS OF HORIZONTAL TAIL SURFACES

Figure 11.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 11.

Figure 12.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 12.

Figure 13.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 13.

Figure 14.—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 14.
Figure 15—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 15.

Figure 16—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 16.

Figure 17—Normal-force coefficient against angle of attack at various elevator deflections for tail surface 17.
Some correlation between experimental results and theory has been attempted. The normal force can be expressed (reference 4) in the form

$$C_N = k(\alpha + \tau \delta)$$  \hspace{1cm} (1)

The value of $k$, or $dC_N/da$, depends mainly on the aspect ratio. According to lifting-line theory, this gations (references 6 and 7) for wings and plates of low aspect ratio with rounded tips. The observed reductions in slope, however, somewhat exceed these predictions, probably because of the effects of the cut-outs, generally built to accommodate the rudder, and of the gaps between stabilizer and elevator.

The effect of the cut-out is strikingly shown by the

![Figure 18. Normal force coefficient against elevator deflection at various angles of attack for tail surface 1.](image)

![Figure 19. Normal force coefficient against elevator deflection at various angles of attack for tail surface 2.](image)

![Figure 20. Normal force coefficient against elevator deflection at various angles of attack for tail surface 3.](image)

slope should be approximately $\alpha/\left(1 + 57.3\alpha/\pi A\right)$. Figure 21 shows, however, that the slope decreases much more rapidly with aspect ratio than does the value of this expression. Such behavior has been predicted by Prandtl and by Blenk (reference 5) from theoretical considerations and has been observed in other investi-

comparisons in figures 22 and 23. In both cases, the slope of the lift curve was reduced about 2 percent by the cut-out; whereas, if aspect ratio were the sole determining factor, the slope would have been increased by about 4 percent. The net reduction in $dC_N/da$, due to the cut-outs, was thus about 6 percent in these cases.
Figure 21.—Variation of the parameter k with aspect ratio and comparison with theory.

Figure 22.—Effect of a cut-out on the normal-force coefficient of a Göttingen 409 airfoil (reference 2).

Figure 23.—Effect of a cut-out on the normal-force coefficient on a Göttingen 177 airfoil (reference 2).

Figure 24.—Effect of end plates on the slope of the normal-force curve of tail surfaces 2 and 3.
A gap between the stabilizer and the elevator is, in general, detrimental although the published data on the subject are either merely qualitative or incomplete (references 8 and 9). Seiferth (reference 3) states that, in preliminary tests, the gap was found to have negligible effect; the gap tested was narrow and of the most favorable type, being between a rounded concave trailing edge on the stabilizer and a rounded convex leading edge on the elevator. In the work on flaps reported in reference 8, the effect of the gap was easily measurable. The gap tested was a 0.0032c space between a flat trailing edge on the airfoil and a rounded leading edge on the flap. In the flight experiments reported in reference 9, sealing the gap greatly improved the maneuverability and the landing characteristics of the airplane; the gap, however, was of unusually poor design, consisting of a 0.02c gap between a rounded convex trailing edge on the stabilizer and a rounded convex leading edge on the elevator.

The normal-force curves for tail surfaces 2 and 3 with and without end plates are shown in figure 24. For the two twin-rudder tails (figs. 2 and 3), the value of $dC_n/da$, is about 0.074, which is considerably higher than that for any of the other tail planes. According to the theory of wings with end plates (reference 10),

$$\frac{dC_n}{da} = \frac{a_0}{1 + r_0 x 57.3}$$  \hspace{1cm} (2)

in which $r$ is a factor given by the curve of figure 25 as a function of $h/b$, the ratio of the height of the end plate to the tail span. For tails 2 and 3, $h/b$, = 0.32 so that, from figure 25, $r$ = 0.63. Considering $a_0$ = 0.093, it follows from equation (2) that $dC_n/da$, = 0.074, which is in agreement with the experimental value.

The parameter $r$ (equation (1)) is the ratio of the effectiveness of a change in elevator angle $\alpha$, to that of a change in tail angle $\alpha_t$. It is a function mainly of the ratio of the elevator area to the total tail area $S_e/S_t$; however, it also depends to some extent on the relative balance area $S_b/S_e$ and the nature of the gap, and the plan form. The experimental values of $r$ for the 17 tail surfaces are plotted against $S_e/S_t$ in figure 26. Three different curves have been drawn through the points for three different values of $S_b/S_e$. These curves apply to tail surfaces in which the gap between the elevator and the stabilizer is open. It appears that sealing the gap may increase the value of $r$ by about 15 percent. For comparison, the theoretical curve (reference 4) is given.

The maximum normal force of the horizontal tail surfaces is of particular interest for airplanes characterized by early center-section stalls or large ground effects on the downwash. For these cases, the flow may break away on the upper surface of the stabilizer when the elevator is deflected upward. Stalling on the lower surface of the stabilizer, with the elevator de-
reflected upward, may possibly occur when the airplane is near the maximum permissible speed with partial-
span flaps fully deflected. This particular flight condition may occur when an airplane is waved off during an attempted landing on an aircraft carrier or takes off immediately after landing with flaps down. It is most desirable that the elevator effectiveness be maintained at the stall. Values of $dC_{n_{\text{max}}}/d\delta_e$, taken between elevator deflections of $10^\circ$ and $-10^\circ$, are plotted against $S_e/S_1$ in figure 27, together with similar data for plain flaps on the Clark Y airfoil. The values of the maximum normal-force coefficients are given for most of the tail surfaces in figures 1 to 17.

The considerable scatter of the points in figure 27 may be attributed to the many factors upon which the maximum force depends. One important variable is probably the section thickness; thus, in the analogous case of flapped airfoils, the flap effectiveness has been shown (reference 8) to increase with thickness.

The gap between the elevator and the stabilizer is also an important variable. Results obtained with flapped wings showed that the increment of maximum lift due to deflecting $0.20c$ flaps is reduced 20 to 30 percent by a gap of only $0.003c$ between a convex leading edge on the flap and a flat trailing edge on the airfoil (reference 8).
Comparison of the results for tail surfaces 4, 5, and 6 (fig. 28) and for tail surfaces 7, 8, and 9 (fig. 29) shows the effect of elevator balance on the elevator effectiveness at maximum normal force. For the largest offset-hinge balance (fig. 28), the elevator effectiveness begins to decrease after about 10° deflection, and increasing the deflection beyond 20° has little effect. The discontinuity in the surface caused by the protrusion of the balance (shown in fig. 30) probably induces the stall in this case. For the overhang, or horn, type of balance (fig. 29), the effectiveness of the elevator is maintained up to 30° deflection. The rate of increase of the maximum normal force with elevator deflection is lower, however, than for the offset-hinge balance.

The range of Reynolds Numbers over which the data for elevator effectiveness are valid is unknown. Flap tests made in the N. A. C. A. 7- by 10-foot and variable-density wind tunnels (references 8 and 11) indicate, however, that the increment of maximum lift due to flap deflection is not greatly affected by the Reynolds Number.

ELEVATOR HINGE MOMENTS

The hinge-moment coefficients are plotted against elevator deflection in figures 31 to 46 for different values of angle of attack of the tail surface. No hinge moments were measured for tail surface 1. The curves are smoothest, in general, for unstalled conditions and for elevators without balances. Increasing either $\alpha_i$ or $\delta_i$ into the stalled range is generally accomplished by a marked variation, usually a sharp increase, in the hinge moment.

The theoretical hinge-moment coefficients for thin airfoils are derived in reference 4 for elevators without balance. They are expressed in the form

$$C_m = u C_v + v \delta_i$$

(3)

and theoretical curves are given for $u$ and $v$ as functions of the ratio $c_s/c_t$. The theoretical values of $u$ derived from thin-airfoil theory, however, are somewhat higher than the theoretical values corresponding to airfoils of finite thickness. Thus, hinge-moment calculations for $c_s/c_t=0.3$, based on the theoretical pressure distributions for the N. A. C. A. 0006 and N. A. C. A. 0018 airfoil sections, gave values for $u$ about 0.89 and 0.73, respectively, of those given by thin-airfoil theory.

In the present analysis, experimental values for $u$ and $v$ were found from the curves of figures 31 to 46. Thus

$$u = \frac{\partial C_m}{\partial C_v} \delta_i$$

$$v = \frac{\partial C_m}{\partial \delta_i} - u \left( \frac{\partial C_m}{\partial \alpha_i} \right)$$

These experimental values, for tail surfaces without balanced elevators, are plotted against $S_i/S_t$ in figures 47 and 48, which also show the theoretical curves from reference 4. The values of $u$ fall considerably below the theoretical curve but the values of $v$ are in fair agreement with the theory. The gap between the elevator and the stabilizer as well as the nonuniform distribution of $c_s/c_t$ across the span of the tail doubtless contributes to the scatter of the points on figures 47 and 48.

Reduction of hinge moments by shifting the hinge back along the elevator (offset-hinge balance) is illustrated by tail surfaces 4, 5, and 6 (fig. 49). The effectiveness of the overhang type of balance in reducing hinge moments is shown in figures 37 and 38.

The flight experiments of reference 9 showed that, by closing the gap between the elevator and the stabilizer, the tail effectiveness was increased and the stick forces were much reduced. The gap in the case tested, however, was unusually wide.

DRAG

Several plots of drag coefficient $C_D$ against $\alpha_i$ are given in figures 50 to 54. They exhibit the usual parabolic increase with angle of attack and the sharp rise after the angle of stall; however, the increase in all cases considerably exceeds that corresponding to the usual induced-drag equation, $C_D = \frac{C_l^2}{\pi \alpha A}$. This larger drag is attributed to the large tip losses of the surfaces of low aspect ratio.
Elevator hinge-moment coefficient against elevator deflection at various angles of attack for tail surfaces 2, 3, and 4.
Elevator hinge-moment coefficient against elevator deflection at various angles of attack for tail surfaces 5, 6, and 7.
Elevator hinge-moment coefficient against elevator deflection at various angles of attack for tail surfaces 8, 9, and 10.

(a) Figure 37.—Tail surface 8.
(b) Figure 38.—Tail surface 9.
(c) Figure 39.—Tail surface 10.
Elevator hinge-moment coefficient against elevator deflection at various angles of attack for tail surfaces 11, 12, and 13.
Elevator hinge-moment coefficient against elevator deflection at various angles of attack for tail surfaces 14, 15, and 16.
AERODYNAMIC CHARACTERISTICS OF HORIZONTAL TAIL SURFACES

Figure 46.—Elevator hinge-moment coefficient against elevator deflection at various angles of attack for tail surface 17.

Figure 47.—Comparison of the theoretical and the experimental values of the parameter $w$.

Figure 48.—Comparison of the theoretical and the experimental values of the parameter $p$.

Figure 49.—Elevator hinge-moment coefficient against elevator deflection at $\alpha=0^\circ$ for tail surfaces 4, 5, and 6.
FIGURE 50.—Drag coefficient against angle of attack at various elevator deflections for tail surface 1.

FIGURE 51.—Drag coefficient against angle of attack at various elevator deflections for tail surface 4.

FIGURE 52.—Drag coefficient against angle of attack at various elevator deflections for tail surface 15.

FIGURE 53.—Drag coefficient against angle of attack at various elevator deflections for tail surface 16.
CONCLUSIONS

1. The lifting-line theory predicts values of the slope of the curve of the normal-force coefficient about 10 percent higher than the experimental ones obtained for tail surfaces with aspect ratios from 3.5 to 4.

2. Experimental results of the effect of end plates are in good agreement with theory.

3. Thin-airfoil theory predicts values of the elevator effectiveness and the hinge moments that are somewhat larger than the experimental values.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., DECEMBER 20, 1938.