REPORT ON
WIND TUNNEL TESTS ON A 1/4TH SCALE MODEL OF
THE CURTISS-WRIGHT XP-76
NOTE

Because of the Emergency National Defense Program the GAlCIT wind tunnel operations have been considerably intensified, and the supervisory staff has been reduced through calls on some of its members for government service. In view of the pressure for rapid presentation of wind tunnel results to government contractors and the shortage of wind tunnel staff personnel it has been found necessary to modify the usual GAlCIT Report procedure for the duration of the emergency. During this period experimental data will be analysed as carefully as possible and the Reports will remain self-contained and complete, but the detailed discussion of results, which has been a feature of GAlCIT reports, will be greatly shortened or omitted. The following Report has been prepared in accordance with this procedure.

Clark B. Millikan

January 18, 1941
REPORT ON
WIND TUNNEL TESTS ON A 1/4TH SCALE MODEL
OF THE CURTISS-WRIGHT XP-55 AIRPLANE

PREPARED BY

[Signature]

No. of pages 91
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Date July 21, 1941

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### Definition of Tests

- **P** = Complete polar
- **MDP** = Minimum drag + complete polar
- **Tuft pict.** = Photographs of stall patterns using tufts
- **HM** = Elevator hinge moments
- **HMP** = Elevator hinge moments + P
- **HEDP** = Elevator hinge moments + MDP
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Notation Used to Describe Configurations Tested

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<tr>
<td>A</td>
<td>Ailerons</td>
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<td>A&lt;sup&gt;*&lt;/sup&gt;</td>
<td>A, with gaps sealed with tape</td>
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<td>F&lt;sup&gt;45&lt;/sup&gt;</td>
<td>Split flaps, down 45°</td>
<td>24-313</td>
<td>13</td>
<td>2e</td>
</tr>
<tr>
<td>S&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Inboard spoiler on each wing of 1/16&quot; welding rod 1-1/2&quot; long, placed 1/4&quot; above wing leading edge, centered 2&quot; from wing-fuselage fillet (model scale)</td>
<td>24-279</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S&lt;sub&gt;2&lt;/sub&gt;</td>
<td>6&quot; spoiler of 1/16&quot; welding rod, placed 1/4&quot; above wing leading edge, (model scale) with inboard end at same position as inboard end of S&lt;sub&gt;1&lt;/sub&gt;</td>
<td>24-281</td>
<td>15</td>
<td>2e</td>
</tr>
<tr>
<td>S&lt;sub&gt;m&lt;/sub&gt;</td>
<td>Same as S&lt;sub&gt;1&lt;/sub&gt;, but centered midway between fillet and vertical surface</td>
<td></td>
<td>14</td>
<td>2e</td>
</tr>
<tr>
<td>S&lt;sub&gt;A&lt;/sub&gt;</td>
<td>2&quot; spoiler with equilateral triangle cross-section 1/8&quot; per side, placed 1/3&quot; above wing leading edge, centered midway between side of fuselage and vertical surface. (model scale)</td>
<td>24-281</td>
<td>22, 23, 24</td>
<td>2e</td>
</tr>
<tr>
<td>S&lt;sub&gt;1&lt;/sub&gt;'</td>
<td>Spoiler similar to S&lt;sub&gt;A&lt;/sub&gt;, but 1/4&quot; per side (model scale) in same position as S&lt;sub&gt;1&lt;/sub&gt;</td>
<td>24-279</td>
<td></td>
<td>2e</td>
</tr>
<tr>
<td>S&lt;sub&gt;2&lt;/sub&gt;'</td>
<td>S&lt;sub&gt;1&lt;/sub&gt;' in same position as S&lt;sub&gt;A&lt;/sub&gt;</td>
<td>24-281</td>
<td></td>
<td>2e</td>
</tr>
<tr>
<td>S&lt;sub&gt;3&lt;/sub&gt;'</td>
<td>Spoiler similar to S&lt;sub&gt;1&lt;/sub&gt;' but 4&quot; long (model scale), in same position as S&lt;sub&gt;A&lt;/sub&gt;</td>
<td>24-281</td>
<td>22, 23, 24</td>
<td>2e</td>
</tr>
<tr>
<td>L</td>
<td>Main landing gear wheels</td>
<td>24-281</td>
<td>22, 23, 24</td>
<td></td>
</tr>
<tr>
<td>L&lt;sub&gt;N&lt;/sub&gt;</td>
<td>Nose wheel</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
### TABLE 1 (Cont'd)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Drawing No.</th>
<th>Photo No.</th>
<th>Fig. No.</th>
</tr>
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<tbody>
<tr>
<td>(H_1)</td>
<td>Nose elevator</td>
<td>24-312</td>
<td>25,26</td>
<td>2f</td>
</tr>
<tr>
<td>(V_1)</td>
<td>Vertical surfaces without fin extension (99.69&quot; outboard, full scale)</td>
<td>24-293</td>
<td></td>
<td>2d</td>
</tr>
<tr>
<td>(f_1)</td>
<td>Very small wood fin extension fairing on (V_1)</td>
<td></td>
<td>1</td>
<td>2d</td>
</tr>
<tr>
<td>(f_2)</td>
<td>Larger &quot; &quot; &quot; &quot; &quot;</td>
<td></td>
<td>2</td>
<td>2d</td>
</tr>
<tr>
<td>(f_3)</td>
<td>Next larger &quot; &quot; &quot; &quot; &quot;</td>
<td></td>
<td>3</td>
<td>2d</td>
</tr>
<tr>
<td>(f_4)</td>
<td>Largest &quot; &quot; &quot; &quot; &quot; extending ahead of leading edge of wing</td>
<td></td>
<td>4</td>
<td>2d</td>
</tr>
<tr>
<td>(f_5)</td>
<td>(f_4) with metal extension</td>
<td></td>
<td>5</td>
<td>2d</td>
</tr>
<tr>
<td>(P_{F/P}^{1})</td>
<td>Front propeller at (\beta = 30^\circ), left-hand rotation, windmilling</td>
<td></td>
<td>16,17</td>
<td></td>
</tr>
<tr>
<td>(P_{R/P}^{1})</td>
<td>Rear propeller at (\beta = 30^\circ), right-hand rotation, windmilling.(\quad) Propellers have high-speed airfoil section blades</td>
<td></td>
<td>16,17,18, 19</td>
<td></td>
</tr>
<tr>
<td>(\alpha_u)</td>
<td>Angle of attack relative to fuselage reference line (relative to root chord for wing alone), uncorrected for wind tunnel wall interference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\alpha)</td>
<td>Angle of attack relative to fuselage reference line (relative to root chord for wing alone), corrected for wind tunnel wall interference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i)</td>
<td>Angle of incidence of root chord relative to fuselage reference line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\alpha_r)</td>
<td>Right aileron angle, relative to wing chord plane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\alpha_l)</td>
<td>Left aileron angle, relative to wing chord plane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\epsilon)</td>
<td>Nose elevator angle relative to fuselage reference line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\epsilon_t)</td>
<td>Elevator tab angle, relative to elevator chord</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(r)</td>
<td>Rudder angle relative to plane of symmetry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\beta)</td>
<td>Propeller blade angle measured at 0.75R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(q)</td>
<td>Dynamic pressure ((p/2 v^2, \text{ gm/cm}^2))</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2

Full Scale Dimensions          Model Scale = 1/4

Wing: Wn

Root section

Profile = Modified NA-73 symmetrical section, maximum thickness 15% at 40% chord

Chord = 92 in.

Tip section

Profile = Modified NA-73 symmetrical section, maximum thickness 15% at 40% chord

Chord = 29.40 in.

Taper ratio = 3.13:1

Sweepback of 25% chord line = 28.5° in chord plane

Dihedral = 4.5° measured to trailing edge

Geometric twist

0°, root chord to 99.69" outboard of fuselage center line

-1.5° (washout), 99.69" outboard of fuselage center line to tip, twisted about trailing edge

Mean aerodynamic chord (MAC) = 66.52 in.

Location: 39.45" outboard fuselage center line, 7.06" above root chord, leading edge 55.92" aft of leading edge of root chord at fuselage center line

Incidence = 0° relative to root chord

<table>
<thead>
<tr>
<th></th>
<th>Wing</th>
<th>Vertical Surfaces</th>
<th>Flaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, ft.²</td>
<td>183.5</td>
<td>25.2 **</td>
<td>9.00*</td>
</tr>
<tr>
<td>Span, ft.</td>
<td>36.58</td>
<td>4.58</td>
<td>6.67*</td>
</tr>
<tr>
<td>Aspect ratio, AR</td>
<td>7.3</td>
<td>1.67**</td>
<td>--</td>
</tr>
</tbody>
</table>

* Includes both surfaces

** Without fairing

Vertical surfaces located 99.75" outboard fuselage center line
### TABLE 2 (Cont'd)

<table>
<thead>
<tr>
<th></th>
<th>Nose elevator</th>
<th>Rudders</th>
<th>Ailerons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, ft.²</td>
<td>10.31*</td>
<td>11.44**</td>
<td>13.06**</td>
</tr>
<tr>
<td>Span, ft.</td>
<td>3.16</td>
<td>4.58</td>
<td>14.70 (tot.)</td>
</tr>
<tr>
<td>Area aft of hinge line, ft.²</td>
<td>8.76*</td>
<td>11.44</td>
<td>13.06</td>
</tr>
<tr>
<td>Percent balance</td>
<td>15 %</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Area affected by movable surfaces, ft.²</td>
<td>10.3</td>
<td>25.2</td>
<td>--</td>
</tr>
<tr>
<td>Mean chord aft of hinge line, ft.</td>
<td>1.48</td>
<td>1.25</td>
<td>0.85</td>
</tr>
<tr>
<td>Total Tab area, ft.²</td>
<td>3.16</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Movable surface  
** Both surfaces

Distance from trunnion axis to nose elevator hinge line = 136.12"

Longitudinal distance from trunnion axis to rudder hinge line = 62.43"

Proper area of fuselage = 13.34 ft.²

Propellers, P:

Curtiss-Wright 101330 Design (NACA 16 Sections), full-scale and model

Diameter = 9 ft. (27" model scale); three blades; \( \beta = 30^\circ \) at 0.75R; right- and left-hand rotation
I. Introduction, General Description of Model and Tests

This Report describes the results of wind tunnel tests on a 1/4th scale model of the Curtiss-Wright XP-55 Airplane. The experiments were made in the closed working section of the 10-foot wind tunnel of the GALCIT (Guggenheim Aeronautics Laboratory at the California Institute of Technology).* The tests were made at a wind speed of approximately 150 m.p.h. (dynamic pressure 25 gm/cm²), corresponding to Reynolds Number based on mean wing chord of about 1,670,000. The critical Reynolds Number at which a 15 cm. sphere has a drag coefficient of 0.3 is about 325,000, indicating a wind stream with rather low turbulence. The model was lacquered and rubbed down to a fairly high polish.

During the course of the investigation, many modifications were made. Table 1 (page 10) gives the notation employed throughout the Report in designating the various elements and configurations.

A three-view of the model with full-scale dimensions is given in Fig. 1. Diagrams of various model components appear in Figs. 2a - 2f. On Fig. 3 are indicated the trunnion location which represented the axis relative to which moments were determined, and the root and mean chord locations and dimensions. The full-scale data which were furnished by the Curtiss-Wright Corporation and used throughout the Report are given in Table 2 (page 12). For other details of the model and its parts, reference must be made to the original drawings.

The tests were divided into the following broad groups:

1) Wing alone characteristics
2) Effects of model build-up and miscellaneous modifications
3) Horizontal tail effects
4) Investigation of flow conditions and pitching moments, especially near the stall

The figures are collected in terms of the above grouping at the end of the Report.
II. Method of Making Tests and Calculations, and of Presenting Results; Notation

The normal experimental setup is indicated schematically in Figs. 4 and 5, and is illustrated by the Photos at the end of the Report. The tare drag and moment of the supporting system were estimated from the experimental results of previous GALCIT investigations. The tare drag at cruising attitudes was approximately 60% of the minimum net parasite drag.

The model was equipped with counter-rotating propellers which were mounted and allowed to windmill freely in certain tests. Because of trouble with the propeller shaft bearings it was necessary, for most of the tests with rotating propellers, to remove one propeller and use only a single propeller.

Elevator hinge moments were measured by an electrical strain gage developed by Curtiss-Wright and mounted on the elevator control arms. This system operated very well and gave very satisfactory hinge moment results.

All drags and angles of attack were corrected by the Millikan theory of tunnel wall interference* to give free-air conditions. No correction was made for the influence of wind tunnel wall interference on the tail pitching moment.

All observations were reduced to the standard American system of absolute units.

\[
\begin{align*}
C_L &= \text{Lift} \\
C_D &= \text{Drag} \\
C_M &= \text{Stalling Moment} \\
C_H &= \text{Hinge Moment}
\end{align*}
\]

where

\[
q = \text{dynamic pressure, } \rho/2 \times v^2, \text{ in grams per cm}^2.
\]

\[
\rho = \text{mass density of air (note: a correction was applied to the experimental observations so that in this formula } \rho \text{ is to be taken as the free air density uncorrected for compressibility effects, at least up to 200 m.p.h.}
\]

\[
V = \text{Velocity}
\]

\[
S = \text{main wing area (see Table 2)}
\]

\[
t = \text{mean chord (see Table 2)}
\]

\[
b = \text{span (see Table 2)}
\]

\[
S_{aft} = \text{Area of movable control surface aft of hinge line (see Table 2)}
\]

\[
t_{aft} = \text{Mean chord of movable control surface aft of hinge line (see Table 2)}
\]

The conventions and signs are the same as those used by the N.A.C.A. and are as follows: \(C_L\) is positive when it tends to raise the nose; control surface and tab angles are positive when they tend to increase the lift on

---

the surface; hinge moments are positive when they tend to increase the angle of the movable surface in question.

In certain cases the parasite drag coefficient, $C_{D_p}$, was determined. For the wing alone the profile drag coefficient, $C_{D_0}$, and the effective angle of attack were also obtained. The formulae employed in obtaining these quantities were:

$$C_{D_p} \quad \text{(or} \quad C_{D_0}) = CD - \frac{C_L^2}{\pi AR}$$

$$c_o = c - \frac{C_L}{\pi AR}$$

where $AR = \text{aspect ratio} = \frac{(\text{span})^2}{\text{area}}$. It will be noticed that the lift distribution was assumed to be elliptical.

Pitching moments are referred to an axis through the trunnion position, cf. Fig. 3, except for the wing-alone, infinite aspect ratio results which are referred to a point on the M.A.C. 30% of its length aft of its leading edge. The angle of attack is referred to the thrust line of Fig. 3, except for the wing-alone, infinite aspect ratio data which are referred to the root chord line. Elevator hinge moments refer to the hinge axis (Fig. 2f).

For the investigation of flow characteristics silk tufts were attached to the wing with cellophane tape. The tufts were observed visually and photographically. The "stall pattern" figures given in the report were prepared as a result of studies of the photographs as well as of the sketches made during the visual observations.

It should be mentioned that the plotted experimental points represent direct observations with no fairing, except that the tare drag results were faired, before being subtracted from the observed total drags to give the final values. All numerical results are presented in the form of experimental points and faired curves. Tabular data are available in the GALCIT files.
III. Experimental Results and Discussion

1) Wing Alone Characteristics (Fig. 7)

The most important infinite aspect ratio characteristics of the wing alone, determined from Fig. 7, are collected in Table 3.

| Table 3 |
| Infinite Aspect Ratio Characteristics of the Wing Alone |
| (R = 1.67 x 10^6) |

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_0 ) (( C_L=0 ))</td>
<td>Angle of attack of root chord for zero lift</td>
</tr>
<tr>
<td>( \eta = \frac{dC_L}{d\alpha} ) (radians)</td>
<td>Airfoil efficiency factor</td>
</tr>
<tr>
<td>( C_{D_{\text{min}}} )</td>
<td>Minimum profile drag coefficient (Fig. 11)</td>
</tr>
<tr>
<td>( C_{L_{\text{opt}}} )</td>
<td>Lift coefficient at ( C_{D_{\text{min}}} )</td>
</tr>
<tr>
<td>( e )</td>
<td>Airplane efficiency factor for wing alone</td>
</tr>
<tr>
<td>( C_{L_{\text{max}}} )</td>
<td>Maximum lift coefficient</td>
</tr>
<tr>
<td>( C_{M_{\text{c}}} )</td>
<td>Moment coefficient at zero lift</td>
</tr>
<tr>
<td>( \frac{C_{L_{\text{max}}}}{C_{D_{\text{min}}}} )</td>
<td>154</td>
</tr>
</tbody>
</table>

In view of the considerable sweepback of the wing the reduction of the data to infinite aspect ratio conditions is of doubtful significance. Certain of the results are, however, of considerable interest. The value of \( C_{D_{\text{min}}} \) is quite low for wings tested in the GALCIT tunnel at Reynolds Numbers of the order of 1.5 x 10^6. This indicates that, in spite of the turbulence level of this tunnel, the advantages of the "laminar flow" airfoil section begin to be apparent. The rapid increase in stalling moment near and above the stall suggests the premature tip stall whose investigation is the subject of Section III, 4 below.
2) Effects of Model Build-Up and Miscellaneous Modifications (Figs. 8 - 12)

A complete model build-up was not one of the primary purposes of the present investigation, and as a result the results of this section are neither complete nor systematic. The most important items, together with certain values obtained from other sections of the report, are collected in tabular form in Table 4. The proper drag coefficients, shown in the table are defined by:

\[ C_{D_{w}} = \Delta C_{D_{p}} \times \frac{S}{S_{w}} \]

where \( S_{w} \) is the "proper" area of the element in question, defined as the projected frontal area for the fuselage, and the normal projected area for horizontal and vertical surfaces (cf. Table 2).

**TABLE 4**

Summary of Lift and Drag Values

**A. Parasite Drag of Various Configurations**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>( C_{D_{p_{\text{min}}}} ) at ( C_{L} = 0.15 )</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_{N}A^{*} )</td>
<td>0.0074</td>
<td>1</td>
</tr>
<tr>
<td>( W_{N}A^{*} + \text{Wing Tufts} )</td>
<td>0.0090</td>
<td>2</td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I} + \text{Wing Tufts} )</td>
<td>0.0111</td>
<td>3</td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I} + \text{Wing Tufts} )</td>
<td>0.0119</td>
<td>4</td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I} )</td>
<td>0.0095</td>
<td></td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I} )</td>
<td>0.0103</td>
<td></td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I}B_{N}D )</td>
<td>0.0158</td>
<td>13</td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I}X_{N}B_{N}D )</td>
<td>0.0159</td>
<td></td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I}X_{N}B_{N}D f_{4} )</td>
<td>0.0163</td>
<td>21</td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I}X_{N}B_{N}D f_{4}H_{2}D )</td>
<td>0.0172</td>
<td></td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I}X_{N}B_{N}D f_{4}P_{SO} )</td>
<td>0.0210</td>
<td>22</td>
</tr>
<tr>
<td>( W_{N}A^{*}V_{I}X_{N}B_{N}D f_{4}P_{SO} )</td>
<td>0.0219</td>
<td>32</td>
</tr>
</tbody>
</table>
**TABLE 4 (Cont’d)**

### B. Parasite and Proper Drag Increments of Various Components

<table>
<thead>
<tr>
<th>Element</th>
<th>$\Delta C_{D_{p_{min}}}$</th>
<th>$C_{D_n}$</th>
<th>Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A-A^*$</td>
<td>0.0008</td>
<td></td>
<td>4-5</td>
</tr>
<tr>
<td>$V_I$</td>
<td>0.0021</td>
<td>0.0153</td>
<td>3-2</td>
</tr>
<tr>
<td>$B_{ND}$</td>
<td>0.0061</td>
<td>0.034</td>
<td></td>
</tr>
<tr>
<td>$V_{IB_{ND}}$</td>
<td>0.0032</td>
<td></td>
<td>15-1</td>
</tr>
<tr>
<td>$X_N$</td>
<td>0.0003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f_A$</td>
<td>0.0004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$X_N f_A$</td>
<td>0.0007</td>
<td></td>
<td>21-13</td>
</tr>
<tr>
<td>$P_{R/NW}$</td>
<td>0.0047</td>
<td></td>
<td>22-21</td>
</tr>
<tr>
<td>$H_1$</td>
<td>0.0009</td>
<td>0.0160</td>
<td>32-22</td>
</tr>
<tr>
<td>$W_{NA^*}$</td>
<td>0.0074</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{IH_1}$</td>
<td>0.0080</td>
<td>0.0156</td>
<td></td>
</tr>
<tr>
<td>Wing Tufts</td>
<td>0.0016</td>
<td></td>
<td>2-1</td>
</tr>
</tbody>
</table>

### C. Maximum Lift Value or Increment

<table>
<thead>
<tr>
<th>Element or Configuration</th>
<th>$\Delta C_{L_{max}}$ or $C_{L_{max}}$</th>
<th>Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_NA^*V_{I4}B_{ND}$</td>
<td>1.09</td>
<td>21</td>
</tr>
<tr>
<td>$W_NA^*V_{I4}B_{ND}f_{P_{RRW}}$ + Wing Tufts</td>
<td>1.465</td>
<td>29</td>
</tr>
<tr>
<td>$W_NA^*V_{I4}B_{ND}f_{P_{RRW}}$ + Wing Tufts</td>
<td>1.50</td>
<td>29 + 32 - 22</td>
</tr>
<tr>
<td>$H_1$</td>
<td>0.03</td>
<td>32 - 22</td>
</tr>
<tr>
<td>Wing Tufts</td>
<td>0</td>
<td>26 - 23</td>
</tr>
</tbody>
</table>

**NOTE:** The symbol $*$ means "estimated from tuft runs or from normal polars"

The proper drag of both horizontal and vertical surfaces are rather high as would be expected while that of the fuselage is low as is natural in view of its good shape and fineness ratio.
One noteworthy characteristic which does not appear in Table 4 is the fact that the windmilling propellers have a stabilizing effect equivalent to a forward c.g shift of about 3% M.A.C.

The effect of flap and symmetrical aileron deflection on trim (Fig. 12) is discussed in the next section in connection with horizontal tail effects.

3) Horizontal Tail Effects (Figs. 13 - 20)

Certain of the results of this section (and Fig. 12) are so striking as to warrant special mention:

a) The horizontal surface at a fixed incidence has a powerful destabilizing effect reducing the stability until it is roughly neutral.

b) The horizontal surface floating freely has an appreciable stabilizing effect.

c) With fixed controls an elevator deflection of +10° to +15° should permit trim at the stall with flaps up.

d) A tab deflection of -15° does not make it possible for the elevator to quite reach +10° near the stall with zero hinge moment (free control).

e) Elevator deflection giving trim at the stall does not appreciably affect $C_{l_{max}}$.

f) Flap deflection does not appreciably alter the trim.

g) With deflected flaps a symmetrical aileron deflection of -10° produces a stalling moment roughly equivalent to a +10° elevator deflection.

In general the longitudinal trim and stability characteristics would appear to be satisfactory below the stall with elevator free with the single possible difficulty of obtaining trim at the stall. This point should be further investigated with elevator free, flaps up and down, and ailerons neutral and deflected symmetrically up.
4) Investigation of Flow Conditions and Pitching Moments, Especially Near the Stall (Figs. 21 - 56)

This section contains the results of the portion of the investigation which was considered of primary importance: namely the improvement of longitudinal stability conditions at and above the stall. Previous studies had shown that, because of the taper and sweepback, severe tip stall leading to static longitudinal instability occurred near the stall. The inboard location of the vertical surfaces $V_I$ had been found to improve the situation somewhat, and it was hoped that forward extension of $V_I$ might give still more improvement. Figs. 21 and 22 show that the so-called "dorsal" fin extensions did not have much effect until $f_4$ was reached, when the fin extended around the wing leading edge, and the instability above the stall at once disappeared. The stall patterns of Figs. 23 - 29 are very instructive although an exact correlation with the pitching moments of Fig. 22 is somewhat difficult. In general it appears that often portions of the wing which appear to be stalled in the stall diagrams must actually continue to contribute materially to the lift and hence to the pitching moments.

Figs. 30 - 34 show that a further extension of the fins forward ($f_5$) has a deleterious effect and that opening the aileron slot, although it changes the apparent separation picture below the stall, has little effect on the longitudinal stability in the stall region.

The above results were obtained without any fuselage. Figs. 35 - 39 again show the favorable effect of the fin extension $f_4$, although with the complete model a slight instability above the stall remains even with $f_4$ in place.

In an attempt to improve this situation small spoilers with circular cross-section ($S_1$ and $S_m$) were tried (Figs. 2e and 40 - 44). These gave a small improvement if they were not located too close to the fuselage. Larger
triangular section spoilers (Figs. 2e and 45 - 49) placed well out from the fuselage gave a still greater improvement, and the longest ones, $S^5$ led to a moment curve having a very satisfactory slope to the largest angle of attack investigated. However this spoiler appreciably increased drag and decreased maximum lift.

Figs. 50 - 56 indicate that with flaps deflected the stability conditions above the stall are more favorable. Although $f_4$ is still necessary to avoid instability, the spoiler $S^5$ is not required and seriously decreases $C_{l_{max}}$.

The general conclusion to be drawn from these results is that the fin extensions $f_4$ are themselves nearly sufficient to ensure static longitudinal stability for several degrees above the stall. Spoilers may prove advantageous in order to further increase the stability but their effects are so slight that a definite conclusion can probably only be reached by flight tests. It may also reasonably be inferred that satisfactory longitudinal stability in this case also indicates the absence of lateral instability associated with tip stall.

Conclusion

The investigation described above was carried out from June 29 to July 5, 1941 under the direction of Dr. Clark B. Millikan who was largely assisted by Mr. J. E. Smith, Dr. H. J. Stewart, Mr. W. H. Bowen and other members of the GALCIT wind tunnel staff. Mr. L. B. Rumph, Jr. acted as the Curtiss-Wright representative during the investigation.

Guggenheim Aeronautics Laboratory
California Institute of Technology
July 21, 1941
THREE VIEW SKETCH OF CURTISS-WRIGHT MODEL CW-24 (XP-55)
Scale: \(\frac{1}{50}\) Size

Fully-Scale Dimensions

Sketch Showing Wing and Components
Sketch Showing Wing Profiles and Fillet Xn
Sketch of Aileron Cross-Section

Mean Chord Aft of Hinge Line = 0.83 Ft.
Sketch of Vertical Surfaces and Various Fairings
SKETCH SHOWING HORIZONTAL SURFACE H,
2° 15' INCIDENCE

2° 15' THROST LINE

"06.3 5'6" M.A.C. = 66.32"

"06.3 5'6" LEADING EDGE M.A.C.

"06.3 5'6" LEADING EDGE ROOT CHORD

6.44 - x

\[
\frac{4}{2} = \frac{0.0968}{x^2} + 2 + \text{TRUNNIONS}
\]

12.76"
VERTICAL SECTION THROUGH 10 FT. WIND TUNNEL

GUGGENHEIM AERONAUTICS LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA

BALANCE ROOM
SIX COMPONENT SETUP FOR TEN FOOT WIND TUNNEL TESTS
AT GUGGENHEIM AERONAUTICS LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
GALCIT REP. 321

Curtiss Wright 101330 Design (NACA 16 Sections)

Propeller Blade Form Characteristics
\[ W_n A^2, q = 25 \text{ gm/cm}^2, \text{Run 1} \]
\[ C_{D_0} = A + BC_l^2 \]

\[ A = 0.0072 \]
\[ B = 0.0184 \]
\[ C = 0.70 \]
\[ R_n = 1.67 \times 10^6 \]

*Parabola fitted at \( C_l = 0.2 \) & 0.6*

*Infinite Aspect Ratio Characteristics of Wing Alone*
Effect of Wing Tufts, Aileron Gap Opening and Vertical Surfaces on the Wing Alone

Three Component Data
Effects of Model Build-up to Configuration M.A.B.C.D.

Three Component Data
Effect of Model Build-up with Windmilling Propellers
Three Component Data
$q = 2.5 \text{ gm/cm}^2$, $\alpha = \alpha_f = 0^\circ$

Run 1

$1 = 22.5^\circ$, $r = 0^\circ$

For $P_{\text{RAW}}$ and $P_{\text{FLW}}$, $\kappa = 1.59$

Effect of Model Build-up with Windmilling Propellers Parasite Drag
Effects of Split Flaps Down 45°, Landing Gear Down, Aileron Slot Opening, and Δα on Configuration W.A. V.B. V.P. L.P. F.

With and Without Up Ailerons

Three Component Data
Elevator Effectiveness with Complete Model and Windmilling Propeller, \( \beta = 0 \).

Three Component Data.
Elevator Effectiveness with Complete Model and Windmilling Propeller, $\alpha=10^\circ$

Three Component Data
Elevator Effectiveness with Complete Model and Windmilling Propeller. $e^2 - 10^4$

Elevator Hinge Moments.
$Q = 25 \text{ gm/cm}^2$, $\epsilon = 2.25^\circ$, $\alpha = \gamma = \phi = 0^\circ$

$D_{\text{free}}$, $A^r_{\text{v}}$, $B_s$, $X_{\text{w}}$

\text{Run 22}

$+H_i$, $\phi = 0^\circ$, $\gamma = 15^\circ$, $\alpha = 42$

$+H_i$, $\phi = 0^\circ$, $\gamma = 15^\circ$, $\alpha = 41$

$+H_i$, $\phi = 0^\circ$, $\gamma = 15^\circ$, $\alpha = 40$

$+H_i$, $\phi = 0^\circ$, $\gamma = 0^\circ$, $\alpha = 32$

For $D_{\text{free}}$, $\psi = 1.59$

Elevator Effectiveness with Complete Model and Windmilling Propeller, $\psi = 15^\circ$

Three Component Data
ELEVATOR EFFECTIVENESS WITH COMPLETE MODEL AND WINDMILLING PROPELLER, $\alpha_w = 15^\circ$

ELEVATOR HINGE MOMENTS
\( Q = 25 \, \text{ft}^3/\text{sec}, \quad \theta = 225^\circ, \quad \phi = \eta = 0^\circ \)

\[ \frac{W_A}{V} \gamma = 22, \quad \text{Run 22} \]

For \( \lambda = 0^\circ \), \( \phi = 0^\circ \), \( \eta = 0^\circ \)

\[ \text{For } \lambda = 15^\circ, \quad \phi = 0^\circ, \quad \eta = 0^\circ \]

**Longitudinal Stability of Complete Model with Warping Propeller, Elevator, Fixed and Free, \( \eta = 0^\circ \) - Three Component Data**
Basic Configuration: \( W_nA^V \approx f_k B_n X_n \frac{P_{RV}}{25 \text{ gms/cm}^2; \quad L = 2.25^\circ; \quad \alpha = \alpha_2 = \gamma = 0^\circ \)

\[ \frac{dC_{m_h}}{dC_L} = 0.188 \]

Runs (32-22),
\( e = 0^\circ \)

\[ \frac{dC_{m_h}}{dC_L} = 0.110 \]

Runs (43-22),
\( e = \text{free} \)

\[ \frac{dC_{m_h}}{dC_L} = -0.028 \]

Pitching Moments Due to Horizontal Tail \( H \)
Effects of Dorsal Fin Fairings on Wing with Vertical Surfaces

Three Component Data
\[ q = 25 \text{ gm/cm}^2, \quad \alpha_f = \alpha_r = 0^\circ \]

- \( W_N A^* V_1 \)
- \( W_N A V_2 \)
- \( \pm f_1 \)
- \( \pm f_2 \)
- \( \pm f_3 \)
- \( \pm f_4 \)

**Effects of Dorsal Fin Fairings** \( f_1, f_2, f_3, f_4 \) on Wing with Vertical Surfaces

**Pitching Moment vs \( \alpha \)**
Fig. 30

Effects of Dorsal Fin Fairing B and C with and without Aileron Slot Open on Wing with Verticals

Three Component Data
$q = 25 \text{ gm/cm}^2$, $\alpha_1 = \alpha_2 = r_1 = r_2 = 0^\circ$

- $W_4 A V f_4$ + Wing Tufts, Run 8 (See Fig. 29)
- $W_4 A f_4$ + "", Run 9
- $W_4 A V f_5$ + "", Run 11
- $W_4 A f_5$ + "", Run 10

Effects of Dorsal Fin Fairing $f_4$ and $f_5$ with and without Aileron Slot Open on Wing with Verticals
Pitching Moment vs $\alpha$
\[ q = 25 \text{ gm} / \text{cm}^2, \alpha = \alpha_0 = \theta = 0^\circ, \gamma = 225^\circ \]

- \( W_n A_n B_n D \) + Wing Tufts, Run 14
- \( W_n A_n X_n B_n D \)  
- \( W_n A_n X_n B_n D_n \)  
- \( W_n A_n X_n B_n D_n \)  
- \( W_n A_n X_n B_n D_n \)  

Effects of \( X_n \) and Aileron Slot Opening on Configuration \( W_n A_n V_n B_n D \)

Pitching Moment vs \( \alpha \)
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Fig. 40

\( \rho = 28 \text{ gm/cm}^3 \), \( \beta = 9^\circ, \gamma = 0^\circ \), \( \Delta = 224^\circ \)

\( \mathbf{W_{11}, W_{12}, W_{13}, B_{11}} \) *Wing Tufts, Run 17 (See Fig. 39)

\( \mathbf{W} \)

- \( \Delta \)

- \( \gamma \)

- \( \beta \)

- \( \rho \)

Effects of Smokers S.S., S* on Configuration W11, B11, B12

Three Component Data
$q = 25 \text{ gm/cm}^2$, $a_1 = a_2 = r_1 = r_2 = 0^\circ$, $\alpha = 225^\circ$

- $W_N$, $A_N$, $X_N$, $B_N$, $D_N$ + Wing Tufts, Run 17 (See Fig. 39)
- $\circ$ $+ S_1$, $18$
- $\Delta$ $+ S_m$, $19$
- $\triangledown$ $+ S_b$, $20$

**Effects of Spoilers $S_1, S_m, S_b$ on Configuration $W_N A_N X_N B_N D_N$**

**Pitching Moment vs $\alpha$**
Flow Diagrams
Approximately the same for $\alpha = 10^\circ$
$g = 25 \text{ gm/cm}^2, \alpha_1 = \alpha_2 = 0^\circ, \gamma = 0^\circ, \phi = 2.25^\circ$

$W_{w_1}A^2\frac{1}{4}\rho X \cos \psi Q_{\text{flap}} + \text{Wing Tufts}$

Run 31

\begin{align*}
&x + + + \quad + S_1 = 44 \\
&+ + + \qquad + S_2 = 45 \\
&+ + + \qquad + S_3 = 46
\end{align*}

For $F_{\text{flap}}$, $J = 1.59$

Effects of spoilers $S_1$, $S_2$, and $S_3$ on configuration $W_{w_1}A^2\frac{1}{4}\rho X \cos \psi Q_{\text{flap}}$

Three Component Data


\[ q = 25 \text{ gm/cm}^2, \ a_r = a_2 = r = 0^\circ, \ i = 22.5^\circ \]

\[ W_n A^* V_B X_n I_4 P_{\text{RRW}} + \text{Wing Tufts}, \quad \text{Run 31} \]

\[ \text{For } P_{\text{RRW}}, \ j = 1.59 \]

*Effects of Spoilers \( S_{1a}, S_{2a}, \text{and } S_{3a} \) on Configuration*  
\[ W_n A^* V_B X_n I_4 P_{\text{RRW}} \]

*Pitching Moment vs OC*
Stall patterns for various angles of attack. The diagrams show the variation of lift coefficient ($C_L$) and drag coefficient ($C_D$) with angle of attack ($\alpha$) for different cases. The graphs illustrate the effects of different conditions on the aerodynamic performance of a wing.
Effect of Spoiler $S_a$ on Configuration $W_{a}A^*V_4B.X.LL..F_{r.\ell.}E^*$
with Ailerons up 10°

Three Component Data
Effect of $\alpha_2$, Aileron Deflection, Aileron Gap, and Spoiler $S_d$

Pitching Moment vs $\alpha$
PHOTO 1.  
$W_{NAV_{1f_1}}$, lower side view showing $f_1$

PHOTO 2.  
$W_{NAV_{1f_2}}$, side view showing $f_2$

PHOTO 3.  
$W_{NAV_{1f_3}}$, side view showing $f_3$

PHOTO 4.  
$W_{NAV_{1f_4}}$, side view showing $f_4$
PHOTO 5.
W_{NA*V_{f5}5}, side view showing f_5

PHOTO 6.
W_{NA*V_{IPND}}, 3/4 front view

PHOTO 7.
W_{NA*V_{IBND}} Wing Tufts, 3/4 rear view

PHOTO 8.
W_{NA*V_{IBND}}, side view
PHOTO 9. \[ W_{NA^{*}}V_{I}B_{N}X_{N}\] + Wing Tufts, side view showing fillet \( X_{N} \)

PHOTO 10. \[ W_{NA^{*}}V_{I}B_{N}X_{N}\] + Wing Tufts, front view showing fillet \( X_{N} \)

PHOTO 11. \[ W_{NA^{*}}V_{I}B_{N}X_{N}\] + Wing Tufts, rear view showing fillet \( X_{N} \)

PHOTO 12. \[ W_{NA^{*}}V_{I}B_{N}X_{N}\] + Wing Tufts, 3/4 rear view showing fillet \( X_{N} \)
PHOTO 13
$W_{NAV_{X_{N}{B_{N}{Df}_{4}S_{1}}} + Wing Tufts, upper front view showing spoiler S_{1}}$

PHOTO 14
$W_{NAV_{X_{N}{B_{N}{Df}_{4}S_{m}}} + Wing Tufts, upper front view showing spoiler S_{m}}$

PHOTO 15
$W_{NAV_{X_{N}{B_{N}{Df}_{4}S_{p}}} + Wing Tufts, upper front view showing spoiler S_{p}}$

PHOTO 16
$W_{NAV_{X_{N}{B_{N}{Df}_{4}P_{30}}} + P_{30}, rear view}$
PHOTO 21
W_NAT_V_tilde_f4_B_N_N^30_r45_s + Wing Tufts, 3/4 side view showing flaps F45

PHOTO 22
W_NAT_V_tilde_f4_B_N_N^30_r45_s + Wing Tufts, front view showing landing gear LLN and spoiler S

PHOTO 23
W_NAT_V_tilde_f4_B_N_N^30_r45_s + Wing Tufts, side view showing landing gear LLN and spoiler S

PHOTO 24
W_NAT_V_tilde_f4_B_N_N^30_r45_s + Wing Tufts, front view of right wing showing landing gear LLN and spoiler S
PHOTO 25
W.A*V—I2 P.N.N.L-RRW, front view showing tail H₁

PHOTO 26
W.A*V—I2 P.N.N.L-RRW, side view showing tail H₁