RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE SPINNING CHARACTERISTICS OF A $\frac{1}{21}$-SCALE MODEL

OF THE DOUGLAS AD-2W AIRPLANE

TED NO. NACA DE329

By

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An investigation has been conducted in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of the Douglas AD-2W airplane which has a large radome installation. Spin tests were performed with a \( \frac{1}{21} \)-scale model simulating the normal gross weight of the airplane.

The results indicate that the AD-2W airplane will have satisfactory erect and inverted spin-recovery characteristics. A comparison of the results with those obtained for spin tests of a model of similar design, the Douglas XBT2D-1 airplane, showed that the radome installation on the subject model had little effect on the spin-recovery characteristics.
Direct and inverted spin and recovery tests were performed with the model simulating the normal gross-weight loading of the airplane for maximum and intermediate control deflections.

SYMBOLS

- $b$: wing span, feet
- $S$: wing area, square feet
- $c$: mean aerodynamic chord, feet
- $x/c$: ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
- $z/c$: ratio of distance between center of gravity and thrust line to mean aerodynamic chord (positive when center of gravity is below thrust line)
- $m$: mass of airplane, slugs
- $\rho$: air density, slugs per cubic foot
- $\mu$: relative density of airplane ($\mu = \frac{m}{\rho Sb}$)
- $I_x$, $I_y$, $I_z$: moments of inertia about $X$-, $Y$-, and $Z$-body axes, respectively, slug-feet$^2$
- $\frac{I_x - I_y}{mb^2}$: inertia yawing-moment parameter
- $\frac{I_y - I_z}{mb^2}$: inertia rolling-moment parameter
- $\frac{I_z - I_x}{mb^2}$: inertia pitching-moment parameter
- $\alpha$: angle between thrust line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
- $\phi$: angle between span axis and horizontal, degrees
- $V$: full-scale true rate of descent, feet per second
\( \Omega \)  
full-scale angular velocity about spin axis, revolutions per second

\( \sigma \)  
helix angle, angle between flight path and vertical, degrees  
(For this model, the average absolute value of the helix angle was approximately 3.5°.)

\( \beta \)  
approximate angle of sideslip at center of gravity, degrees  
(Sideslip is inward when inner wing is down by an amount greater than the helix angle.)

APPARATUS AND METHODS

The model used for the current tests was the \( \frac{1}{21} \)-scale model of the XBT2D-1 airplane which had been used for the tests reported in reference 1. It was modified to represent in mass and dimensions a \( \frac{1}{21} \)-scale model of the AD-2W airplane. The canopy, however, was not altered inasmuch as it is generally believed from spin-tunnel experience that the effect of a canopy on the spin-recovery characteristics of an airplane is negligible. A photograph of the model as tested is shown as figure 2 and the dimensional characteristics are given in table I.

The model was ballasted to simulate dynamically the AD-2W airplane at an altitude of 15,000 feet \((p = 0.001496 \text{ slug per cubic foot})\) and a remote-control mechanism was installed in the model to actuate the controls for recovery tests. Sufficient hinge moments were exerted on the rudder during recovery tests to ensure its full and rapid movement.

Wind Tunnel and Testing Technique

The model tests were performed in the Langley 20-foot free-spinning tunnel in a manner similar to that described in reference 1. The testing procedure and technique for obtaining and converting the data to full-scale values were the same as those used in reference 1.

PRECISION

The model test results presented herein are believed to be the true values given by the model within the following limits:
\[ \alpha, \text{ degrees} \] ............................. \( \pm 1 \)
\[ \phi, \text{ degrees} \] ............................. \( \pm 2 \)
\[ V, \text{ percent} \] ............................. \( \pm 5 \)
\[ \Omega, \text{ percent} \] ............................. \( \pm 2 \)

Turns for recovery:
When obtained from film records ............................. \( \pm \frac{1}{4} \)
When obtained visually ............................. \( \pm \frac{1}{2} \)

The preceding limits may have been exceeded for certain spins in which it was difficult to handle the model in the tunnel because of the high rate of descent or because of the oscillatory nature of the spin.

Comparison between spin results of airplanes and their corresponding models (references 2 and 3) indicates that spin–tunnel results are not always in complete agreement with full-scale spin results. In general, the models spin at somewhat smaller angles of attack with higher rates of descent and with \( 5^\circ \) to \( 10^\circ \) more outward sideslip than their full-scale counterparts. The comparison made in reference 3 showed that approximately 80 percent of the model recovery tests predicted satisfactorily the corresponding airplane turns for recovery while 10 percent underestimated and 10 percent overestimated them.

Because of the impracticability of exact ballasting, the measured weight and mass distribution of the model varied from the true scaled-down values by the following amounts:

| Weight, percent | ............................. 0 |
| Center-of-gravity location, percent \( \bar{c} \) | ............................. 1 forward |
| \( I_x \), percent | ............................. 15 high |
| \( I_y \), percent | ............................. 22 high |
| \( I_z \), percent | ............................. 16 high |

The limits of accuracy of the measurements of the mass characteristics are believed to be:

| Weight, percent | ............................. \( \pm 1 \) |
| Center-of-gravity location, percent \( \bar{c} \) | ............................. \( \pm 1 \) |
| Moments of inertia, percent | ............................. \( \pm 5 \) |

The controls were set with an accuracy of \( \pm 1^\circ \).

TEST CONDITIONS

The mass characteristics and inertia parameters for the normal gross-weight loading of the AD-2W airplane and for the equivalent loading tested on the model are listed on table II and plotted on figure 3. For
comparison, the corresponding values for the XBT2D-I airplane are also
given. As discussed in reference 4, figure 3 can be used in predicting
the relative effectiveness of the controls on the recovery characteristics
of airplanes.

For the tests, the maximum control deflections used were:

- Rudder, degrees .......... 25 right, 25 left
- Elevator, degrees ........... 25 up, 15 down
- Ailerons, degrees ........... 12 up, 12 down

The intermediate control deflections used were:

- Rudder deflected two-thirds, degrees ........ 16\(\frac{2}{3}\)
- Elevator deflected two-thirds up, degrees ........ 16\(\frac{2}{3}\)
- Ailerons deflected one-third, degrees ........ 4 up, 4 down

The tail-damping power factor of the AD-2W airplane was calculated
by the method described in reference 5.

For all tests reported herein, the landing flaps were neutral, the
landing gear retracted, and the cockpit canopy closed.

RESULTS AND DISCUSSION

Erect Spins

The results of the spin tests simulating the AD-2W airplane in its
normal gross-weight loading (loading 3 on table II and fig. 3) are
presented on chart 1. The model data are presented in terms of the
full-scale values for the airplane at a test altitude of 15,000 feet.
The tests were performed for both right and left spins but only the
results of the right spins, which yielded slightly conservative results,
are presented. The results indicate that the spin-recovery character-
istics of the AD-2W model are satisfactory. For the normal-control
configuration for spinning, (elevator full up, ailerons neutral, and
rudder full with the spin) the AD-2W model spun at a moderate attitude
and recovered in 1 turn or less upon full rapid rudder reversal. For
the "criterion" spin (elevator two-thirds up, ailerons one-third against
the spin) recovery was effected in \(1\frac{1}{4}\) turns when the rudder was reversed
from full with the spin to only two-thirds against the spin. Aileron-
against control settings were found to have a slightly adverse effect
on the recovery characteristics, particularly when the elevator setting
was neutral or down.
Comparison of the data on chart 1 with the results obtained on the XBT2D-1 model in its normal loading (loading 2 on table II and fig. 3) as presented in reference 1 shows generally good agreement between the results of the models. This comparison shows, therefore, that the radome installation of the AD-2W had very little effect on the spin and recovery characteristics of the airplane.

Inverted Spins

Brief inverted spin tests were performed on the model. These results, not presented in detail in this report, showed the model to have satisfactory inverted spin-recovery characteristics and the results were similar to those presented in reference 1.

Recommended Recovery Technique

On the basis of the test results the use of the following spin-recovery technique is recommended:

For erect spins, the stick should be held full back and laterally neutral. The rudder should be reversed fully and rapidly against the spin. When reversing the rudder, extreme care should be exercised to avoid entering a spin in the opposite direction after recovery. Approximately 1/2 turn after rudder reversal, the stick should be moved forward of neutral. In moving the stick forward, care should be exercised to avoid excessive rates of acceleration in the ensuing recovery dive.

For inverted spins, the rudder should be reversed rapidly against the spin and the stick should be neutralized (laterally and longitudinally).

CONCLUSIONS

On the basis of the results of free-spinning tests of a $\frac{1}{21}$-scale model of the Douglas AD-2W airplane and a comparison of these results with the results obtained for spin tests of a $\frac{1}{21}$-scale model of the Douglas XBT2D-1 airplane, the following conclusions regarding spin and recovery characteristics have been made:

1. The erect and inverted spin-recovery characteristics of the AD-2W airplane will be satisfactory.
2. The radome installation had very little effect on the spin and recovery characteristics of the airplane.

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Approved:

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REFERENCES


SUPPLEMENTARY REFERENCES

3. Martinez, J. F.: Airplane Moments of Inertia, Model XAD-1W.
### TABLE I. -- DIMENSIONAL CHARACTERISTICS OF THE AD-2W AIRPLANE

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall, ft</td>
<td>39.64</td>
</tr>
<tr>
<td>Propeller diameter, ft</td>
<td>13.5</td>
</tr>
<tr>
<td>Propeller, number of blades</td>
<td>4</td>
</tr>
<tr>
<td><strong>Wing:</strong></td>
<td></td>
</tr>
<tr>
<td>Span, ft</td>
<td>50.19</td>
</tr>
<tr>
<td>Area, sq ft</td>
<td>400.3</td>
</tr>
<tr>
<td>Section, root</td>
<td>NACA 2417</td>
</tr>
<tr>
<td>Section, tip</td>
<td>NACA 4413</td>
</tr>
<tr>
<td>Incidence:</td>
<td></td>
</tr>
<tr>
<td>Root, deg</td>
<td>3.75</td>
</tr>
<tr>
<td>Tip, deg</td>
<td>0.25</td>
</tr>
<tr>
<td>Dihedral, deg</td>
<td>6</td>
</tr>
<tr>
<td>Mean aerodynamic chord (c), in.</td>
<td>100.05</td>
</tr>
<tr>
<td>Leading edge of mean aerodynamic chord rearward of leading edge of wing, in.</td>
<td>14.125</td>
</tr>
<tr>
<td><strong>Ailerons:</strong></td>
<td></td>
</tr>
<tr>
<td>Area aft of hinge line, sq ft</td>
<td>33.4</td>
</tr>
<tr>
<td>Hinge line to trailing edge (outboard tip), percent of chord</td>
<td>19.0</td>
</tr>
<tr>
<td>Span, percent of wing span</td>
<td>24.3</td>
</tr>
<tr>
<td><strong>Horizontal tail surfaces:</strong></td>
<td></td>
</tr>
<tr>
<td>Total area, sq ft</td>
<td>86.97</td>
</tr>
<tr>
<td>Span, ft</td>
<td>19.83</td>
</tr>
<tr>
<td>Elevator area (aft of hinge line), sq ft</td>
<td>22.3</td>
</tr>
<tr>
<td>Distance from normal center of gravity to the elevator hinge line, ft</td>
<td>22.3</td>
</tr>
<tr>
<td>Section, modified</td>
<td>NACA 0012-64</td>
</tr>
<tr>
<td><strong>Vertical tail surfaces:</strong></td>
<td></td>
</tr>
<tr>
<td>Offset, deg (leading edge to left)</td>
<td>3</td>
</tr>
<tr>
<td>Total area, sq ft</td>
<td>39.9</td>
</tr>
<tr>
<td>Total rudder area (aft of hinge line), sq ft</td>
<td>19.66</td>
</tr>
<tr>
<td>Distance from normal center of gravity to rudder hinge line, ft</td>
<td>23.6</td>
</tr>
<tr>
<td>Section</td>
<td>Modified NACA 0012 and 13</td>
</tr>
<tr>
<td><strong>Tail-damping power factor:</strong></td>
<td>737 \times 10^{-6}</td>
</tr>
</tbody>
</table>
TABLE II.—MASS AND INERTIA CHARACTERISTICS FOR LOADING CONDITIONS OF THE
DOUGLAS AD-2W AND XB2D-1 AIRPLANES AND FOR THE LOADING TESTED
ON THE $\frac{1}{21}$-SCALE MODEL OF THE AD-2W

[Model values given as corresponding full-scale values; moment-of-inertia values
are about the center of gravity.]

<table>
<thead>
<tr>
<th>Number Loading</th>
<th>Weight (lb)</th>
<th>Airplane relative density, $\mu$</th>
<th>Center-of-gravity location</th>
<th>Moments of inertia (slug-ft$^2$)</th>
<th>Inertia parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>15,000 ft Sea level $x/c$ $z/c$</td>
<td></td>
<td>$I_X$ $I_Y$ $I_Z$ $I_X - I_Y$ $I_Y - I_Z$ $I_Z - I_X$</td>
<td>$mb^2$ $mb^2$ $mb^2$</td>
</tr>
<tr>
<td>Airplane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$mb^2$ $mb^2$ $mb^2$</td>
</tr>
<tr>
<td>AD-2W 1 Normal gross weight</td>
<td>16,154</td>
<td>16.72</td>
<td>10.50</td>
<td>0.286</td>
<td>0.053</td>
</tr>
<tr>
<td>XB2D-1 2 Normal</td>
<td>15,558</td>
<td>16.07</td>
<td>10.11</td>
<td>0.215</td>
<td>-0.07</td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$mb^2$ $mb^2$ $mb^2$</td>
</tr>
<tr>
<td>AD-2W 3 Normal gross weight</td>
<td>16,230</td>
<td>16.51</td>
<td>10.57</td>
<td>0.276</td>
<td>0.037</td>
</tr>
</tbody>
</table>
**CHART 1. SPIN AND RECOVERY CHARACTERISTICS OF THE 3/20-SCALE MODEL OF THE DOUGLAS AD-2W AIRPLANE**

Normal gross weight loading (loading 3 on table II and figure 3); landing gear retracted; cockpit canopy closed; recovery attempted by rapid full rudder reversal except as otherwise indicated (recovery attempted from, and steady-spin data presented for, rudder-with spin);

right erect spin)

<table>
<thead>
<tr>
<th>Allerons</th>
<th>Elevator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3 against</td>
<td>2/3 up</td>
</tr>
</tbody>
</table>

Ailerons full against (Stick left)

Ailerons full with (Stick right)

Elevator full down (Stick forward)

Recovery attempted by reversing the rudder from full with to 2/3 against the spin.

Recovery attempted before model reached its final spin attitude.

**Model values**

- c (deg)
- \( \theta \) (deg)
- \( V \) (fpm)
- \( \tau \) (fpm)

- Inner wing up
- Inner wing down

Turns for recovery

<table>
<thead>
<tr>
<th>Model recovery inverted.</th>
<th>349</th>
</tr>
</thead>
</table>
Figure 1.- Three-view drawing of the $\frac{1}{21}$-scale model of the Douglas AD-2W airplane with the center-of-gravity location shown for the normal gross-weight loading.
Figure 2. - The \( \frac{1}{24} \)-scale model of the Douglas AD-2W airplane as tested in the Langley 30-foot free-spinning tunnel.
Figure 3. - Mass parameter for the normal gross-weight loading tested on the AD-2W model and for corresponding loading of the airplane and for the normal loading of the XBT2D-1 airplane. (Points are for loadings listed on table II.)