FREE-FLIGHT INVESTIGATION OF THE FULL-SCALE HUGHES FALCON MISSILE, D CONFIGURATION, TO DETERMINE AILERON EFFECTIVENESS AND DAMPING IN ROLL

By Reginald R. Lundstrom

Langley Aeronautical Laboratory
Langley Field, Va.

CLASSIFIED DOCUMENT

This material contains information affecting the National Defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
WASHINGTON
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

U. S. Air Force

FREE-FLIGHT INVESTIGATION OF THE FULL-SCALE HUGHES FALCON MISSILE, D CONFIGURATION, TO DETERMINE AILERON EFFECTIVENESS AND DAMPING IN ROLL

By Reginald R. Lundstrom

SUMMARY

A free-flight investigation was conducted over the Mach number range from 0.8 to 1.8 near zero lift to determine the aileron effectiveness and damping in roll of the full-scale Hughes Falcon missile, D configuration. Drag-coefficient data were also determined. Aileron-effectiveness coefficient per degree aileron \( C_{\delta} \) based on body diameter and body cross-sectional area had a peak value of 0.094 at Mach number 0.96 and decreased to a value of 0.037 at the maximum Mach number of the test. The damping-in-roll derivative \( C_{Dp} \) based on body diameter and body cross-sectional area had approximately a constant value of 23 over the Mach number range of the test. The drag coefficient based on body cross-sectional area was about 0.4 up to a Mach number of 0.9 and gradually increased to about 0.8 at a Mach number of 1.2 and remained at 0.8 up to the maximum Mach number of the test.

INTRODUCTION

At the request of the U. S. Air Force, the Langley Pilotless Aircraft Research Division is conducting free-flight tests of the full-scale Hughes Falcon missile in an effort to obtain stability and control effectiveness information. Results obtained from rocket model tests of the C configuration of the Hughes Falcon missile to obtain longitudinal stability information may be found in reference 1.
The present report gives results from a flight test conducted to determine aileron effectiveness and damping in roll of the D configuration of the Falcon missile near zero lift over the Mach number range from 0.8 to 1.8 and corresponding Reynolds number range of approximately $4 \times 10^6$ to $12 \times 10^6$ per foot. The approximately zero-lift drag as obtained from this flight test is also included.

Inasmuch as these tests were conducted at low altitude, the model as furnished by the Hughes Company was made much heavier than the tactical missile in order that the deceleration would be lower over that part of the flight during which the data were obtained. The desired Mach number was obtained by using a booster made up of two solid-fuel ABL Deacon rockets with suitable-size stabilizing fins.

**SYMBOLS**

- $d$  
  body diameter, 0.533 ft
- $q$  
  dynamic pressure, lb/sq ft
- $g$  
  acceleration due to gravity, 32.2 ft/sec$^2$
- $M$  
  Mach number
- $S$  
  maximum body cross-sectional area, 0.223 sq ft
- $V$  
  free-stream velocity, ft/sec
- $W$  
  model weight, 179.5 lb
- $a_L$  
  model acceleration along flight path, ft/sec$^2$
- $\gamma$  
  model flight-path angle measured from the horizontal, deg
- $\delta$  
  aileron deflection, deg ($\delta = 2^\circ$ means one aileron up $2^\circ$ and other down $2^\circ$; positive $\delta$ will cause model to roll clockwise, viewed from rear)
- $\delta_p$  
  positive $\delta$
- $\delta_n$  
  negative $\delta$
- $I_X$  
  moment of inertia about body longitudinal axis, slug-ft$^2$
I_y \quad \text{moment of inertia about Y-axis, slug-ft}^2

I_z \quad \text{moment of inertia about Z-axis, slug-ft}^2

C_D \quad \text{drag coefficient, Drag/qS}

\phi \quad \text{body roll angle, radians}

\dot{\phi} \quad \text{roll rate, radians/sec}

\ddot{\phi} \quad \text{roll acceleration, radians/sec}^2

C_l \quad \text{rolling-moment coefficient, Rolling moment qSd}

C_{l0} \quad \text{out-of-trim rolling-moment coefficient}

C_{l\phi} = \frac{\partial C_l}{\partial \phi}

C_{lp} = \frac{\partial C_l}{\partial \ddot{\phi}}

\text{APPARATUS AND METHOD}

\text{Model Description and Test}

The Hughes Falcon D configuration is a cruciform winged missile with small forward lifting surfaces of low aspect ratio and larger rear lifting surfaces of very low aspect ratio. The aerodynamically balanced flap controls are at the trailing edge of the rear lifting surfaces. The body is cylindrical except for the nose and boattail sections. A sketch of the model is shown in figure 1 and a photograph, in figure 2. Details of the lifting surfaces and controls are shown in figure 3. The body coordinates are listed in table I. The model was constructed from steel except for the nose section which was made of brass for ballast purposes and the rear wings which were made of 24S-T4 aluminum alloy. The control surfaces were made of steel. Physical characteristics of the model are presented in table II.
The ailerons were programmed in a square-wave pattern by means of a hydraulic pulse system, and the control surfaces were against the stops for longer periods of time at the lower Mach numbers in order to allow the roll rate to build up close to the steady-state value during each pulse. About $1/4^\circ$ of free play existed in one of the control surfaces. Since unpublished wind-tunnel data show these control surfaces to be aerodynamically underbalanced, it has been assumed that this play would at all times be taken up so as to make the control deflection closer to zero. The measured aileron deflections at the stops were $\delta = -1.87^\circ$ and $\delta = 2^\circ$.

**Instrumentation**

The model was equipped with an NACA eight-channel telemeter. Quantities measured were normal, transverse, and longitudinal accelerations, roll rate and acceleration, control position, total head pressure, and body static pressure. A Doppler velocimeter was used to obtain velocity, and tracking radar was used to obtain the position of the model as a function of flight time. Atmospheric conditions at the time of flight were obtained from a radiosonde.

**Reduction of Data**

Reduction of data was made using the single-degree-of-freedom roll equation:

$$\frac{I_X}{qSd} \ddot{\phi} - C_{l_p} \left(\frac{d}{2V}\right) \dot{\phi} = - \left( C_{l_5} \delta + C_{l_0} \right)$$

Since the quantity $C_{l_p}$ desired was the roll-damping derivative of the entire configuration rather than the particular wing plan form, no effort was made to account for interference effects. As the controls were pulsed between approximately $2^\circ$ and $-2^\circ$, at some time during each pulse, $\dot{\phi} = 0$.

When $\dot{\phi} = 0$, $C_{l_5} \delta + C_{l_0}$ was plotted as a function of Mach number for both the positive and negative control deflections. A curve was faired through the points obtained from the positive control deflection and another through the points of negative control deflection. The difference between these curves is as follows:
\[
\left( C_{l6} \delta_p + C_{l0} \right) - \left( C_{l6} \delta_n + C_{l0} \right) = C_{l6} \delta_p - C_{l6} \delta_n = C_{l6} (\delta_p - \delta_n)
\]
This equation divided by \((\delta_p - \delta_n)\) gave the desired quantity \(C_{l6}\). With \((C_{l6} \delta + C_{l0})\) known as a function of Mach number, \(C_{lp}\) then became the only unknown in the roll equation and could be determined. Greatest accuracy in determining \(C_{lp}\) could be obtained by substituting values of \(\delta\) and \(\delta\) near the end of each pulse when \(\delta\) was closest to its steady-state value.

Drag data were reduced from the relationship 
\[
C_D = \frac{-W(a_z + g \sin \gamma)}{gq^3}
\]

The acceleration \(a_z\) was determined by differentiation of the velocity-time curve obtained from the Doppler radar because the longitudinal accelerometer did not operate properly.

Accuracy

The point accuracy of the quantities listed is believed to be within the following limits:

- \(C_{l6}\) ............... \(\pm5\) percent
- \(C_{lp}\) ............... \(\pm10\) percent
- \(C_D\) ............... \(\pm3\) percent
- \(V\) ............... \(\pm1\) percent
- \(M\) ............... \(\pm1\) percent

RESULTS AND DISCUSSION

The Reynolds number per foot for these tests varied from \(3.85 \times 10^6\) at \(M = 0.8\) to \(12.15 \times 10^6\) at \(M = 1.8\). Some transient pitching and yawing motion resulted from the abrupt change in aileron position. The angle of attack or sideslip in almost all cases was determined to be less than \(1^\circ\) and the peaks of the normal and lateral oscillations about \(90^\circ\) out of phase. A sample time history of \(\dot{\phi}, \ddot{\phi}, \text{ and } \delta\) as the model coasted through the Mach number range is presented in figure 4. Because of the relatively slow response of the instrument measuring roll acceleration, it was necessary to apply a time-lag correction to the values.
of roll acceleration used in reducing the data. The corrected roll-acceleration values were in very good agreement with values obtained by differentiating the roll rate. In figure 4 no attempt was made to correct the roll acceleration during or immediately after the time the control surfaces moved from one position to the other. It may be noted that $\dot{\phi}$ did not pass through zero during the first pulse because the out-of-trim moment was in the same direction as the pulse. Values of $(C_l\delta + C_{\ell_0})$ and $C_{\ell_p}$ were reduced from this pulse by using a method of least squares.

The rolling-moment coefficients for the other pulses were obtained by using the value of $\dot{\phi}$ when $\dot{\phi} = 0$ mentioned under the section "Reduction of Data." Variation of rolling-moment coefficient with Mach number is shown in figure 5. The rolling-moment coefficient is plotted positive for both positive and negative $\delta$ to show the change in out-of-trim moment with Mach number. Aileron effectiveness, $C_{\ell_0}$, as obtained from rolling-moment coefficient is presented as a function of Mach number in figure 6. The trend of $C_{\ell_0}$ against $M$ corresponds closely to the flap lift effectiveness shown in reference 2 and if the spanwise center of pressure of the flap is assumed to be at the center of exposed span of the flap, the order of magnitude is also the same.

The damping-in-roll derivative $C_{\ell_p}$ is presented as a function of Mach number in figure 7. The values of $C_{\ell_p}$ shown are for roll rates of about 20 radians per second. An attempt was made to determine the variation of $C_{\ell_p}$ with $\dot{\phi}$. Although it was in general indicated that $C_{\ell_p}$ was 5 to 10 percent lower at 10 radians per second than at 20 radians per second, this was not always the case and because this is within the probable accuracy band, the results are not presented. It will be noted that $C_{\ell_p}$ is practically independent of Mach number. Direct comparison with theory is impractical for this configuration because of the large radius at the leading edge of the rearward surface body juncture and the effects of interference from the forward surface. Theory, however (for example, see refs. 3 and 4), does indicate the general order of magnitude and the fact that for such a low aspect ratio, $C_{\ell_p}$ is practically independent of Mach number. Reference 5 which gives experimental data on delta wings with leading-edge sweep up to 70° also checks this order of magnitude and trend.

Variation of drag coefficient with Mach number is presented in figure 8. The drag coefficient was about 0.4 up to a Mach number of 0.9, and gradually increased to 0.8 at a Mach number of 1.2 and remained at 0.8
up to the maximum Mach number of the test. This is in very close agreement with unpublished flight-test data obtained from Hughes Aircraft Company. The drag-coefficient curve has the same general shape as that of the Falcon C configuration shown in reference 1; however, the fact that the C configuration model had an angle-of-attack vane in front of the blunt nose which may have affected the drag precludes any possibility for direct comparison of magnitude of drag coefficient.

CONCLUSIONS

A rocket-model test of the full-scale Hughes Falcon missile, D configuration, over a Mach number range from 0.8 to 1.8 gave the following results (coefficients based on body diameter and cross-sectional area):

(1) The rolling-moment coefficient per degree aileron increased to a maximum value of 0.094 at Mach number 0.96 and decreased to a value of 0.037 at the maximum Mach number of the test. The trend with Mach number was much the same as the trend of normal-force coefficient per degree elevator for a similar trailing-edge flap on a 60° delta wing. When the normal-force coefficients are converted to rolling-moment coefficients, the order of magnitude is also the same.

(2) The damping-in-roll derivative $C_{lp}$ was approximately constant at a value of 23 over the Mach number range tested. This trend and order of magnitude is indicated by theory and flight tests on delta wings.

(3) The drag coefficient based on body cross-sectional area was about 0.4 up to a Mach number of 0.9 and gradually increased to about 0.8 at a Mach number of 1.2 and remained at 0.8 up to the maximum Mach number of the test.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,

Reginald R. Lundstrom
Aeronautical Research Scientist

Approved: Joseph A. Shortal
Chief of Pilotless Aircraft Research Division

rwh
REFERENCES


### TABLE I

**BODY CONTOUR ORDINATES OF MODEL TESTED**

*All dimensions in inches*

<table>
<thead>
<tr>
<th>Station</th>
<th>Radius</th>
<th>Station</th>
<th>Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.658</td>
<td>0</td>
<td>11.808</td>
<td>2.690</td>
</tr>
<tr>
<td>8.758</td>
<td>0.663</td>
<td>11.908</td>
<td>2.708</td>
</tr>
<tr>
<td>8.858</td>
<td>0.927</td>
<td>12.008</td>
<td>2.724</td>
</tr>
<tr>
<td>8.958</td>
<td>1.122</td>
<td>12.108</td>
<td>2.739</td>
</tr>
<tr>
<td>9.058</td>
<td>1.281</td>
<td>12.208</td>
<td>2.753</td>
</tr>
<tr>
<td>9.158</td>
<td>1.414</td>
<td>12.308</td>
<td>2.765</td>
</tr>
<tr>
<td>9.258</td>
<td>1.530</td>
<td>12.353</td>
<td>2.771</td>
</tr>
<tr>
<td>9.317</td>
<td>1.591</td>
<td>12.453</td>
<td>2.782</td>
</tr>
<tr>
<td>9.408</td>
<td>1.677</td>
<td>12.553</td>
<td>2.792</td>
</tr>
<tr>
<td>9.508</td>
<td>1.762</td>
<td>12.653</td>
<td>2.802</td>
</tr>
<tr>
<td>9.608</td>
<td>1.840</td>
<td>12.753</td>
<td>2.812</td>
</tr>
<tr>
<td>9.708</td>
<td>1.911</td>
<td>12.853</td>
<td>2.821</td>
</tr>
<tr>
<td>9.808</td>
<td>1.976</td>
<td>13.042</td>
<td>2.837</td>
</tr>
<tr>
<td>9.908</td>
<td>2.037</td>
<td>14.604</td>
<td>2.958</td>
</tr>
<tr>
<td>10.108</td>
<td>2.093</td>
<td>15.832</td>
<td>3.034</td>
</tr>
<tr>
<td>10.208</td>
<td>2.146</td>
<td>17.442</td>
<td>3.110</td>
</tr>
<tr>
<td>10.308</td>
<td>2.196</td>
<td>18.506</td>
<td>3.147</td>
</tr>
<tr>
<td>10.408</td>
<td>2.242</td>
<td>19.642</td>
<td>3.175</td>
</tr>
<tr>
<td>10.508</td>
<td>2.286</td>
<td>20.495</td>
<td>3.190</td>
</tr>
<tr>
<td>10.608</td>
<td>2.327</td>
<td>21.179</td>
<td>3.197</td>
</tr>
<tr>
<td>10.708</td>
<td>2.366</td>
<td>21.842</td>
<td>3.200</td>
</tr>
<tr>
<td>10.808</td>
<td>2.403</td>
<td>23.00</td>
<td>3.200</td>
</tr>
<tr>
<td>10.908</td>
<td>2.437</td>
<td>80.00</td>
<td>3.200</td>
</tr>
<tr>
<td>11.008</td>
<td>2.470</td>
<td>81.00</td>
<td>3.200</td>
</tr>
<tr>
<td>11.108</td>
<td>2.501</td>
<td>81.50</td>
<td>3.193</td>
</tr>
<tr>
<td>11.208</td>
<td>2.530</td>
<td>82.00</td>
<td>3.173</td>
</tr>
<tr>
<td>11.308</td>
<td>2.557</td>
<td>82.50</td>
<td>3.143</td>
</tr>
<tr>
<td>11.408</td>
<td>2.583</td>
<td>83.00</td>
<td>3.106</td>
</tr>
<tr>
<td>11.508</td>
<td>2.607</td>
<td>83.50</td>
<td>3.064</td>
</tr>
<tr>
<td>11.608</td>
<td>2.630</td>
<td>84.00</td>
<td>3.019</td>
</tr>
<tr>
<td>11.708</td>
<td>2.651</td>
<td>86.5</td>
<td>2.793</td>
</tr>
</tbody>
</table>

*CONTINUED*
TABLE II

PHYSICAL CHARACTERISTICS OF MODEL TESTED

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight, lb</td>
<td>179.5</td>
</tr>
<tr>
<td>Center-of-gravity station</td>
<td>51.44</td>
</tr>
<tr>
<td>$I_x$, slug-ft$^2$</td>
<td>0.43</td>
</tr>
<tr>
<td>$I_y$, slug-ft$^2$</td>
<td>18.71</td>
</tr>
<tr>
<td>$I_z$, slug-ft$^2$</td>
<td>18.71</td>
</tr>
<tr>
<td>Body diameter (cylindrical section), ft</td>
<td>0.533</td>
</tr>
<tr>
<td>Body cross-sectional area, sq ft</td>
<td>0.223</td>
</tr>
<tr>
<td>Total wing area per plane forward surface,</td>
<td></td>
</tr>
<tr>
<td>(total wing area of forward surface includes the fuselage profile area between station 13.70 and 21.40), sq ft</td>
<td>0.446</td>
</tr>
<tr>
<td>Total wing area per plane rearward surface</td>
<td></td>
</tr>
<tr>
<td>including control, (total wing area of rearward surface includes the fuselage profile area between station 42.50 and 81.95), sq ft</td>
<td>4.129</td>
</tr>
<tr>
<td>Exposed area of two control surfaces, sq ft</td>
<td>0.301</td>
</tr>
</tbody>
</table>
Figure 1.- General model arrangement. All dimensions in inches.
Figure 2.- Model tested. L-81365.1
Figure 3.- Lifting-surface details.
Figure 4.- Sample time history of aileron position, roll rate, and roll acceleration.
Figure 5.- Rolling-moment coefficient as a function of Mach number for positive and negative aileron deflections.
Figure 6.- Variation of $C_{16}$ with Mach number.
Figure 7.- Variation of $C_{lp}$ with Mach number.
Figure 8.- Variation of $C_D$ with Mach number.