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</thead>
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AERODYNAMIC CHARACTERISTICS AND FIN LOADS OF A BANK-TO-TURN, AIR-TO-AIR MISSILE CONCEPT AT SUPersonic MACH NUMBERS [U]

VON KARMAN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE 37389

May 1977

Final Report for Period 8 - 10 December 1976

Prepared for
AIR FORCE ARMAMENT LABORATORY (DLMA)
EGLIN AIR FORCE BASE, FLORIDA 32542
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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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Chief Air Force Test Director, VKF  
Directorate of Test

ALAN L. DEVEREAUX  
Colonel, USAF  
Director of Test
### Title
AERODYNAMIC CHARACTERISTICS AND FIN LOADS OF A BANK-TO-TURN, AIR-TO-AIR MISSILE CONCEPT AT SUPERSONIC MACH NUMBERS

### Authors
D. H. Flkes, ARO, Inc.

### Report Date
May 1977

### Number of Pages
42

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Distribution limited to U.S. Government agencies only; this report contains information on test and evaluation of military hardware; May 1977; other requests for this document must be referred to Air Force Armament Laboratory (AFATL/DLMA), Eglin Air Force Base, FL 32542.

### Abstract
Static stability, axial-force, and fin-loading data were obtained on a proposed maneuvering air-to-air missile at Mach numbers 1.5, 2.5, and 3.5 with various combinations of fin control surface deflections. The angle-of-attack range was from -2 to 28 deg at constant angles of sideslip of -8, -4, 0, 4, and 8 deg. The test Reynolds number was 4.25 million, based on free-stream conditions and model length, at each...
20. ABSTRACT (Continued)

Mach number. Results are presented illustrating the effects of control surface deflections, Mach number, and model attitude on missile and fin aerodynamic characteristics. (U)
PREFACE

(U) The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), at the request of the Air Force Armament Laboratory (AFATL/DLMA), Eglin Air Force Base, Florida, under Program Element 62602F, Project 2069, Task 01. The AFATL project monitor was Mr. Tom Noethen. The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project Number V41A-NOA. The author of this report was D. H. Fikes, ARO, Inc. The final data package was completed on January 10, 1977, and the manuscript (ARO Control No. ARO-VKF-TR-77-17) was submitted for publication on March 21, 1977.

(U) This report contains no classified information taken from other classified documents.
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1.0 INTRODUCTION

(U) A static force test was conducted in the Arnold Engineering Development Center (AEDC) von Kármán Gas Dynamics Facility (VKF) Supersonic Wind Tunnel (A) on a model of a proposed maneuvering air-to-air missile (AAM). The proposed missile will incorporate advances in the state of the art of missile bank-to-turn control and missile maneuvering technology.

(U) Static stability, axial-force, and fin-loading data were obtained at Mach numbers 1.5, 2.5, and 3.5 at a test Reynolds number of 4.25 million based on model length. Fin deflections ranged from -20 to 10 deg. The angle-of-attack range was from -2 to 28 deg at constant angles of sideslip of -8, -4, 0, 4, and 8 deg.

(U) This model configuration was previously tested in Tunnel A over the same range of test conditions and is reported in Ref. 1. For this test, modifications were made to the model to include fin balances for two of the four fins. The fin force and moment data were of primary concern, and the missile aerodynamics obtained were essentially a repeat of data obtained in the previous test, reported in Ref. 1.

(U) Testing of this configuration over the transonic Mach number range was conducted in the Aerodynamic Wind Tunnel (4T) of the AEDC Propulsion Wind Tunnel Facility (PWT). Results of that testing will be covered in a separate technical report.

2.0 APPARATUS

2.1 WIND TUNNEL

(U) Tunnel A (Fig. 1) is a continuous, closed-circuit, variable density wind tunnel with an automatically driven flexible-plate-type
nozzle and a 40- by 40-in. test section. The tunnel can be operated at Mach numbers from 1.5 to 6 at maximum stagnation temperatures up to 750°C at $M_e = 6$. Minimum operating pressures range from about one-tenth to one-twentieth of the maximum at each Mach number. The tunnel is equipped with a model injection system which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel and airflow calibration information may be found in Ref. 2.

2.2 MODEL

(U) Photographs and details of the Air Force Armament Laboratory (AFATL) Bank-to-Turn, Air-to-Air Missile Model are shown in Figs. 2 and 3. The model was designed by AFATL/DLMI and was fabricated at AEDC. Basic model components consisted of a body, wings, and fins. The model body was of elliptical cross section (Fig. 3a). The cross section was of increasing ellipticity from the nose to MS 13.125 and was of decreasing ellipticity from MS 13.125 to MS 18.900. Details of the wings are shown in Fig. 3b. The four identical tail fins (Fig. 3c) were of nearly triangular shape and were arranged in a split x shape configuration (Fig. 4) at zero model roll. Fin deflection angles were set using angle pins for $\pm 0, 5, 10, 15$, or 20 deg. Fin orientation and deflection conventions are shown in Fig. 4. Fins 1 and 3 were mounted to fin balances. The aerodynamic coefficient sign conventions of these fins are presented in Fig. 5.

2.3 INSTRUMENTATION AND PRECISION

(U) Tunnel A stilling chamber pressure is measured with a 15, 60, 150, or 300-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the uncertainty (a bandwidth which includes 95 percent of the residuals) of these transducers is estimated to be within $\pm 0.2$ percent of reading or $\pm 0.015$ psia,
whichever is greater. Stilling chamber temperature is measured with a copper-constantan thermocouple with an uncertainty of ±3°F based on repeat calibrations.

(U) Aerodynamic forces and moments on the total vehicle were measured with a six-component, moment-type strain-gage balance supplied and calibrated by VKF. Prior to the test, static loads in each plane and combined static loads were applied to the balance to simulate the range of loads and center-of-pressure locations anticipated during the test. The following uncertainties represent the bands of 95 percent of the measured residuals, based on differences between the applied loads and the corresponding values calculated from the balance calibration equations included in the final data reduction. The range of check loads applied, and the measurement uncertainties follow.

<table>
<thead>
<tr>
<th>Component</th>
<th>Balance Design Loads</th>
<th>Calibration Load Range</th>
<th>Range Of Check Loads</th>
<th>Measurement Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal force, lb.</td>
<td>± 700</td>
<td>± 700</td>
<td>± 700</td>
<td>±1.50</td>
</tr>
<tr>
<td>Pitching moment,* in.-lb</td>
<td>±3,645</td>
<td>±3,645</td>
<td>± 800</td>
<td>±3.00</td>
</tr>
<tr>
<td>Side force, lb.</td>
<td>± 700</td>
<td>± 700</td>
<td>± 150</td>
<td>±1.75</td>
</tr>
<tr>
<td>Yawing moment,* in.-lb</td>
<td>±3,645</td>
<td>±1,822</td>
<td>±1,120</td>
<td>±5.00</td>
</tr>
<tr>
<td>Rolling moment, in.-lb</td>
<td>± 320</td>
<td>± 200</td>
<td>± 300</td>
<td>±0.80</td>
</tr>
<tr>
<td>Axial force, lb.</td>
<td>150</td>
<td>150</td>
<td>25 to 100</td>
<td>±1.10</td>
</tr>
</tbody>
</table>

*About balance forward-moment bridge.

(U) The transfer distance from the balance forward-moment bridge to the model moment reference location was 2.020 in. along the longitudinal axis and was measured with an estimated precision of ±0.005 in.

(U) Aerodynamic loads on the two instrumented fins were measured with five-component force- and moment-type balances supplied by AFATL.
and calibrated by VKF. Prior to the test, static loads in each plane and combined static loads were applied to each balance to simulate the range of loads and center-of-pressure locations anticipated during the test. The uncertainties listed below were determined in the same manner as were the balance uncertainties for the total vehicle. The fin balance number indicates the balance location (see Fig. 5).

<table>
<thead>
<tr>
<th>Component</th>
<th>Design Loads</th>
<th>Calibration Loads</th>
<th>Check Loads</th>
<th>Measurement Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Force, lb.</td>
<td>± 60</td>
<td>± 40</td>
<td>±20</td>
<td>±0.54 ±0.63</td>
</tr>
<tr>
<td>Hinge Moment, in.-lb*</td>
<td>±166</td>
<td>±115</td>
<td>±10</td>
<td>±0.80 ±0.30</td>
</tr>
<tr>
<td>Bending Moment, in.-lb</td>
<td>±130</td>
<td>±100</td>
<td>±10</td>
<td>±0.55 ±0.53</td>
</tr>
</tbody>
</table>

*About balance forward-moment bridge.

The transfer distance from the fin balance forward-moment bridge to the fin hinge line was 1.864 and 1.888 in. for fins 1 and 3, respectively. The transfer distance from the fin balance reference location to the theoretical fin root chord (body surface) was 0.571 and 0.576 in. for fins 1 and 3, respectively. Each transfer distance was measured with an estimated precision of ±0.005 in.

(U) Base pressures were measured with 15-psid transducers referenced to a near vacuum and having full-scale calibrated ranges of 1, 5, and 15 psia. Based on periodic comparisons with secondary standards, the uncertainty is estimated to be ±0.1 percent of full scale of the range being used. Base pressure tap locations are shown in Fig. 6.

(U) Shadowgraphs were obtained on all configurations at selected model attitudes. The shadowgraphs were recorded with a double pass optical flow visualization system with a 35-in.-diam field of view.
3.0 PROCEDURE

3.1 TEST CONDITIONS

The test was conducted at free-stream Mach numbers 1.51, 2.50, and 3.51. The free-stream Reynolds number, based on a model length of 18,900 in., was 4.25 million. A summary of the test conditions at each Mach number is given below.

<table>
<thead>
<tr>
<th>$M_\infty$</th>
<th>$P_o$, psia</th>
<th>$T_0$, °R</th>
<th>$q_\infty$, psia</th>
<th>$p_\infty$, psia</th>
<th>$\text{Re}_m \times 10^{-6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.51</td>
<td>9.5</td>
<td>570</td>
<td>4.1</td>
<td>2.64</td>
<td>4.25</td>
</tr>
<tr>
<td>2.50</td>
<td>14.5</td>
<td></td>
<td>3.7</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>3.51</td>
<td>24.2</td>
<td></td>
<td>2.8</td>
<td>0.32</td>
<td></td>
</tr>
</tbody>
</table>

(U) A test summary showing all configurations tested and the variables for each is presented in Table 1.

3.2 TEST PROCEDURE

(U) In Tunnel A, the model is mounted on a sting support mechanism located in an installation tank directly underneath the tunnel test area. The installation tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors cover the opening to the tank (except for a slot for the pitch sector), and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, and the safety and fairing doors are opened. Then the model is injected into the airstream, and after it reaches tunnel centerline, it is translated forward into the test section. After the data run is completed, the model is returned into the tank, and the fairing and safety doors are closed, sealing the tank from the tunnel. The tank is then vented to
atmosphere with the tunnel running to allow access to the model in preparation for the next run. The sequence is repeated after each configuration or test condition change.

(U) Model attitude positioning and data recording were accomplished with the pitch-pause mode of operation. The VKF Model Attitude Control System (MACS) was used and greatly increased the data acquisition rate. Model pitch and roll requirements were entered into the controlling computer before the test was begun. Model positioning and data recording operations were performed automatically during the test by selecting the list of desired model attitudes and initiating the system. At each model attitude, the control system delayed the data acquisition sequence until the base pressures had time to stabilize.

(U) Data were sampled at a rate of 1,500 channels/sec, and 20 data loops were averaged for each data point. Data were obtained for the angle-of-attack range from -2 to 28 deg at sideslip angles of -8, -4, 0, 4, and 8 deg.

3.3 DATA REDUCTION

(U) Missile and fin static force data (16 channels) were obtained simultaneously, utilizing the high-speed scanning capability of the data acquisition system available in Tunnel A. Missile and fin force and moment measurements were reduced to coefficient form using the values calculated from the averaged data points and corrected for first- and second-order balance interaction effects. Missile coefficients also were corrected for model tare weight and balance-sting deflections. Only fin tare weight corrections were applied to the fin coefficients, since the fin deflection effects were negligible. Model attitude, base pressure, and tunnel pressure and temperature were also calculated from averaged values.
(U) Missile aerodynamic force and moment coefficients are presented in the body axis system. Pitching- and yawing-moment coefficients are referenced to a point on the model centerline 10.998 in. from the model nose (see Fig. 3a). The coefficient reference area was the maximum body cross-sectional area. The coefficient reference length was defined to be the diameter of a circle with an area equal to the reference area. Forebody axial-force coefficients \( (C_A) \) have been adjusted to zero base axial force using measured model base pressures obtained and applied as described in section 3.2.

(U) Fin aerodynamic force and moment coefficients are presented in the fin axis system. The fin normal force is normal to the plane defined by the fin hinge line and root chord centerline. Fin spanwise bending moment is referenced to the theoretical root chord (model surface) at each fin location. Fin hinge moment is referenced to the fin hinge line (see Fig. 3c). Reference lengths and areas for the fin aerodynamic coefficients were the same as those used for the missile aerodynamic coefficients. The sign convention for the fin aerodynamic coefficients is shown in Fig. 5.

3.4 DATA UNCERTAINTY

(U) An evaluation of the influence of random measurement errors is presented in this section to provide a partial measure of the uncertainty of the final test results presented in this report. Although evaluation of the systematic measurement error (bias) is not included, it should be noted that the instrumentation precision values (given in Section 2.3) used in this evaluation represent a total uncertainty combination of both systematic and two-sigma random error contributions.

3.4.1 Test Conditions

(U) Uncertainties in the basic tunnel parameters \( P_0 \) and \( T_0 \) (see
Section 2.3) and the two-sigma deviation in Mach number determined from test section flow calibrations were used to estimate uncertainties in the other free-stream properties, using the Taylor series method of error propagation.

<table>
<thead>
<tr>
<th>M(_\infty)</th>
<th>M(_\infty)</th>
<th>P(_\infty)</th>
<th>T(_\infty)</th>
<th>P(_\infty)</th>
<th>q(_\infty)</th>
<th>Re(_\ell) x 10(^{-6})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.51</td>
<td>1.3</td>
<td>0.2</td>
<td>0.5</td>
<td>2.9</td>
<td>0.3</td>
<td>0.8</td>
</tr>
<tr>
<td>2.50</td>
<td>0.8</td>
<td>0.2</td>
<td>0.5</td>
<td>3.0</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>3.51</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
<td>2.8</td>
<td>1.7</td>
<td>1.3</td>
</tr>
</tbody>
</table>

3.4.2 Aerodynamic Coefficients

(U) The uncertainty of the aerodynamic coefficients was estimated by using the Taylor series method of error propagation to combine the balance and base pressure uncertainties listed in Section 2.3 with uncertainties in the tunnel parameters. The aerodynamic coefficient uncertainties thus obtained are presented below.

<table>
<thead>
<tr>
<th>M(_\infty)</th>
<th>C(_N)</th>
<th>C(_m)</th>
<th>C(_Y)</th>
<th>C(_n)</th>
<th>C(_\ell)</th>
<th>C(_A)</th>
<th>C(_A_1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.51</td>
<td>0.5</td>
<td>1.0</td>
<td>1.8</td>
<td>1.2</td>
<td>1.1</td>
<td>2.3</td>
<td>1.9</td>
</tr>
<tr>
<td>2.50</td>
<td>1.6</td>
<td>2.4</td>
<td>3.1</td>
<td>2.5</td>
<td>1.9</td>
<td>3.9</td>
<td>3.2</td>
</tr>
<tr>
<td>3.51</td>
<td>1.9</td>
<td>3.2</td>
<td>4.2</td>
<td>3.4</td>
<td>2.1</td>
<td>4.7</td>
<td>4.3</td>
</tr>
</tbody>
</table>

(U) The basic precision of the aerodynamic coefficients was also computed using only the balance and base pressure uncertainties listed in Section 2.3 along with the nominal test conditions; it was assumed
that the free-stream flow nonuniformity is a bias type of uncertainty which is constant for all test runs. These values therefore represent the data repeatability expected and are especially useful for detailed discrimination purposes in parametric model studies.

<table>
<thead>
<tr>
<th>$M_\infty$</th>
<th>$C_N$</th>
<th>$C_m$</th>
<th>$C_Y$</th>
<th>$C_n$</th>
<th>$C_\ell$</th>
<th>$C_A$</th>
<th>$C_{At}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.51</td>
<td>0.028</td>
<td>0.018</td>
<td>0.032</td>
<td>0.027</td>
<td>0.008</td>
<td>0.024</td>
<td>0.020</td>
</tr>
<tr>
<td>2.50</td>
<td>0.030</td>
<td>0.019</td>
<td>0.035</td>
<td>0.029</td>
<td>0.008</td>
<td>0.026</td>
<td>0.022</td>
</tr>
<tr>
<td>3.51</td>
<td>0.039</td>
<td>0.025</td>
<td>0.046</td>
<td>0.038</td>
<td>0.008</td>
<td>0.029</td>
<td>0.029</td>
</tr>
</tbody>
</table>

(U) The fin aerodynamic coefficient uncertainties were determined in the same manner as were the total body aerodynamic coefficient uncertainties. Uncertainty values for each fin are presented below.

<table>
<thead>
<tr>
<th>Uncertainty (±)</th>
<th>Maximum Measured Coefficient Value, percent*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fin Balance Number 1</td>
<td>Fin Balance Number 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_\infty$</th>
<th>$C_{NF}$</th>
<th>$C_{nF}$</th>
<th>$C_{HF}$</th>
<th>$C_{bF}$</th>
<th>$C_{NF}$</th>
<th>$C_{nF}$</th>
<th>$C_{HF}$</th>
<th>$C_{bF}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.51</td>
<td>2.39</td>
<td>---</td>
<td>1.65</td>
<td>2.00</td>
<td>---</td>
<td>1.16</td>
<td>---</td>
<td>1.99</td>
</tr>
<tr>
<td>2.50</td>
<td>4.42</td>
<td>---</td>
<td>3.11</td>
<td>2.75</td>
<td>---</td>
<td>1.99</td>
<td>---</td>
<td>2.28</td>
</tr>
<tr>
<td>3.51</td>
<td>8.15</td>
<td>---</td>
<td>5.18</td>
<td>3.52</td>
<td>---</td>
<td>2.28</td>
<td>---</td>
<td>2.28</td>
</tr>
</tbody>
</table>

*Uncertainties for the $C_{bF}$ fin coefficients are not presented, as the maximum moments measured for these components were generally of the order of magnitude of the fin balance repeatabilities presented in the following tabulation.
(U) The uncertainty in model attitude as determined from tunnel sector calibrations and consideration of the possible errors in model deflection calculations is estimated to be ±0.1 deg in model angle of attack (α) and ±0.1 deg in sideslip angle (β).

### 4.0 RESULTS AND DISCUSSION

(U) The objective of this wind tunnel test program was to determine missile and fin static aerodynamic characteristics for a proposed maneuvering air-to-air missile at supersonic Mach numbers. Experimental static force and moment data were obtained on the missile and on two of the four tail fins at Mach numbers 1.5, 2.5, and 3.5, and at a free-stream Reynolds number \((\text{Re}_L)\) of 4.25 million. Variations in model attitude and control surface deflection were investigated.

(=>) Other than the fin-loading measurements, the missile aerodynamic data of this test were a repeat of data from an earlier test documented in Ref. 1. Agreement between the two sets of data is good and is within the data uncertainty given in Section 3.4.2. To keep this report complete, however, the missile stability and axial-force data are presented along with the corresponding fin-loading characteristics for fin pitch, yaw, and roll control deflections. These results are given for Mach numbers 1.5 and 3.5 in Figs. 8 through 10.
Results for various control surface deflections are shown in Fig. 8. Fin normal-force, root-bending-moment, and hinge-moment coefficients are shown in Figs. 8c and d for fins numbered 1 and 3, respectively. The loading on the upper fin, fin number 1, decreases rather abruptly when the fin moves into the shadow of the wing and body, especially at $M_\infty = 1.5$.

The fin-loading trends of the lower (windward) side fin, number 3 (Fig. 8d), were uniform for the various fin deflections over the angle-of-attack range at both Mach numbers. At $M_\infty = 3.5$ it is noteworthy that the angle-of-attack effect decreases with negative fin deflections so that for $\delta_p = -15$ deg the fin loading is essentially constant over the angle-of-attack range.

Results for yaw control deflections given in Fig. 9 show a reduction in fin effectiveness above $\alpha = 15$ deg at Mach number 1.5; this reduction is further amplified by sideslip angle. However, the forces and moments associated with these yaw control deflections were greater than those produced by the pitch control deflections of Fig. 8.

Roll control deflection data in Fig. 10 again show the decrease in fin effectiveness above $\alpha = 15$ deg (fin number 1) at Mach number 1.5. Note that the positive $\delta_r$ commands for fin number 3 correspond to the negative yaw command deflections (see Fig. 4) and that the fin loadings are identical when compared with Fig. 9d.

REFERENCES


Figure 1. Wind tunnel and model injection system.
Figure 2. Model photographs.
Figure 2. Concluded.
All Linear Dimensions in Inches

0.490 R
MS 0.0
0.165 R
1.800
10.998
16.500
18.900
17.550
Fin Hinge Line

Fin 1
Fin 2
Fin 3
Fin 4
4.800
11.100

Moment Reference Location

Note: All body cross sections are 2:1 ellipses.

a. Configuration BWF
Figure 3. Model details.
c. Fin detail

Figure 3. Concluded.
Figure 4. Fin orientation and deflection conventions.
NOTE: Positive fin deflection is in same sense as positive $C_{hF}$.

Only fins 1 and 3 were instrumented.

Figure 5. Fin aerodynamic coefficient sign convention.
Figure 6. Base pressure tap locations.
Figure 7. Missile aerodynamic coefficient sign convention.
a. Missile longitudinal stability
Figure 8. Pitch control characteristics.
b. Missile axial force

Figure 8. Continued.
c. Fin 1 aerodynamic coefficients

Figure 8. Continued.
d. Fin 3 aerodynamic coefficients

Figure 8. Concluded.
a. Missile lateral stability

Figure 9. Yaw control characteristics.
### Table

<table>
<thead>
<tr>
<th>Sym</th>
<th>( \delta_Y ), deg</th>
<th>( \beta ), deg</th>
</tr>
</thead>
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### Figures

**Figure 9. Continued.**

b. Missile axial force

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c. Fin 1 aerodynamic coefficients

Figure 9. Continued.
d. Fin 3 aerodynamic coefficients

Figure 9. Concluded.
Figure 10. Roll control characteristics.
Figure 10. Continued.

b. Axial force
c. Fin 1 aerodynamic coefficients
Figure 10. Continued.
### Sym $\delta_A$, deg $\delta$, deg

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**Figure 10. Concluded.**

- Fin 3 aerodynamic coefficients

---

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Table 1. Test Summary

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<th>Pin Deflection, deg (see Fig. 4)</th>
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NOTES:
1. Asterisk (*) indicates model rolled 180 deg
2. Angle of attack ranges from -2 to 2 deg
3. $Re = 4.25$ million
4. Configuration BWF (body, -6 wings, -6 fins) for all groups
5. Fin deflection nomenclature redefined from tabulated data for compatibility with Ref. 1
NOMENCLATURE

$C_A$  Model forebody axial-force coefficient, $C_{At} - C_{Ab}$

$C_{Ab}$  Model base axial-force coefficient, $-(P_b - P_m)/q_\infty$

$C_{At}$  Model total axial-force coefficient, total axial force/$q_\infty S$

$C_{bF}$  Fin root-bending moment coefficient, root-bending moment/$q_\infty S\ell$
          (about hinge line, Fig. 3c)

$C_{hF}$  Fin hinge-moment coefficient, hinge moment/$q_\infty S\ell$
          (about hinge line, Fig. 3c)

$C_x$  Model rolling-moment coefficient, rolling moment/$q_\infty S\ell$

$C_m$  Model pitching-moment coefficient, pitching moment/$q_\infty S\ell$
        (see Fig. 3a for model cg)

$C_N$  Model normal-force coefficient, normal force/$q_\infty S$

$C_{NF}$  Fin normal-force coefficient, fin normal force/$q_\infty S$

$C_n$  Model yawing-moment coefficient, yawing moment/$q_\infty S\ell$
        (see Fig. 3a for model cg)

$C_Y$  Model side-force coefficient, side force/$q_\infty S$

DEL-$A$, $\delta_A$  Roll command deflection, deg (see Fig. 4)

DEL-$P$, $\delta_P$  Pitch command deflection, deg (see Fig. 4)

DEL-$Y$, $\delta_Y$  Yaw command deflection, deg (see Fig. 4)
\( \ell \)  
Moment reference length, 4.2363 in.

\( \ell_m \)  
Model length, 18.900 in.

\( M_\infty \)  
Free-stream Mach number

\( MS \)  
Model station, in.

\( P_b \)  
Model base pressure, psia

\( P_o \)  
Tunnel stilling chamber pressure, psia

\( p_\infty \)  
Free-stream static pressure, psia

\( q_\infty \)  
Free-stream dynamic pressure, psia

\( Re_{\ell_m} \)  
Free-stream Reynolds number based on model length

\( S \)  
Model reference area, 14.095 in.\(^2\)

\( T_o \)  
Tunnel stilling chamber temperature, °R

\( \alpha \)  
Model angle of attack, deg

\( \beta \)  
Model angle of sideslip, deg

**SUBSCRIPTS**

1  
Fin 1 (see Figs. 3, 4, and 5)

3  
Fin 3