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AN EXPERIMENTAL INVESTIGATION OF GRID FIN DRAG REDUCTION TECHNIQUES

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ABSTRACT

A wind tunnel test program was conducted to investigate various techniques for reducing grid fin drag levels. Six different grid fin configurations were tested to determine the effects of outer frame cross-section shape and web thickness. The fins were mounted on four individual fin balances near the aft end of a body-of-revolution. Test parameters included: angle of attack (-8 to 20 degrees), fin deflection (0, 10 and 20 degrees), and Mach number (0.5 to 2.5). Test results obtained indicate that frame cross-section shape and web thickness have a significant effect on grid fin drag characteristics at all Mach numbers tested. The effects of these design parameters on grid fin normal force and hinge moment characteristics are shown to be small. From the results presented in this paper, the observation is made that grid fin drag levels can be tailored considerably with a minimal impact on other grid fin aerodynamic properties.

I. INTRODUCTION

A grid fin, also known as a lattice control surface or wing with internal framework, is an unconventional aerodynamic control device that consists of an outer frame which supports a unique, internal grid structure. Figure 1 shows a sketch of the baseline grid fin design evaluated for this investigation.

The fundamental design of a grid fin allows a highly effective aerodynamic control device to be stowed along the body of a missile without causing a large increase in overall dimensions. In addition to efficient packaging, the internal grid structure (webbing) of a grid fin provides it with a remarkably high strength-to-weight ratio. The small chord dimensions of these devices result in near zero hinge moments and small center of pressure variations over wide Mach number ranges, thereby reducing control actuator requirements.

Conclusions drawn from experimental results published in References 1 through 5 have shown the grid fin concept to be an excellent aerodynamic control device to consider for application to weapon airframes requiring compact storage. The principle concern which has restricted the application of this technology has been the relatively high drag levels of grid fins when compared to conventional fins.

An experimental wind tunnel test program was developed and implemented in order to investigate two different techniques for reducing grid fin drag levels. A total of six variations of the baseline grid fin design shown in Figure 1 were tested for Mach numbers ranging from 0.5 to 2.5. The principle objective of the test was to evaluate the effects of outer frame cross-section shape and web thickness on grid fin drag levels. This paper first provides a brief summary of the wind tunnel test program. Test results are then presented that show the effects of these design parameters on grid fin aerodynamic characteristics.

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II. WIND TUNNEL TEST PROGRAM

Test Articles

Test data were obtained on a total of six different grid fin configurations. All of the grid fins tested had the same internal grid pattern with elements parallel to the air flow at zero angle of attack. Referring back to Figure 1, the baseline configuration (F1) had an internal web thickness of 0.008 inches with no frame cross-section shaping. Four variations of the baseline configuration were designed to isolate the effects of frame cross-section shape with the internal web thickness held constant at 0.008 inches. The four frame cross-sections evaluated included a modified double wedge (F2), a modified single wedge (F3), a half diamond (F4), and a thin modified double wedge (F6). A thick web grid fin configuration (F5) was designed to be identical to F2 except for an increased internal web thickness 0.012 inches.

A dimensioned sketch of the MICOM Grid Fin wind tunnel model used for the test is shown in Figure 2. The model is a 52 inch long, 5 inch diameter body-of-revolution with a 3.0 caliber tangent ogive nose faired into a 7.4 caliber afterbody. Up to four fins were mounted sufficiently forward of the base to insure that the flow fields around the fins were not affected by the base region.

Test Facility and Instrumentation

The wind tunnel test was conducted during November 1993 at the National Testing Service's (NTS) 4 X 4 foot Transonic/ Supersonic Wind Tunnel located in Saugus, California. The test facility is an intermittent blowdown-to-atmosphere wind tunnel with an operating Mach number range from 0.2 to 5.0.

The model was sting mounted on a main six component balance, provided by NTS. Four fin balances were furnished by MICOM. The numbering sequence used to identify the fin balances is shown in Figure 2. Fin balances 2 and 4 were gauged to measure complete six component force and moment loads. The other two balances (1 and 3) were not gauged to measure axial force. The repeatability accuracy of the axial force measurements obtained from the two fin balances is estimated to be less than 0.10 lb., while the absolute accuracy of the fin balance axial force measurements is approximately 0.25 lb.

Test Conditions

Data was taken in the pitch plane at angles of attack from -8 to +20 degrees. Fin deflection angles were set at 0, 10 or 20 degrees. Roll angles were fixed at either 0 or 45 degrees. Typical tunnel operating conditions for each test Mach number are listed below in Table 1.

Table 1. Tunnel Operating Conditions

Mach Number	Dynamic Pressure (psf)	Static Pressure (psi)	Total Pressure (psi)	Static Temp (deg. R)	RN/L $x 10^{-6}$ (per ft)
0.5	524	21.8	25.6	502	5.35
0.7	739	15.3	21.0	479	5.66
0.8	802	12.7	19.2	469	5.53
0.9	936	11.6	19.5	451	6.01
1.2	1295	9.0	21.7	415	6.93
1.8	1439	4.3	25.4	316	7.36
2.5	1400	2.2	38.0	232	8.05

Data Reduction and Sign Conventions

The body cross sectional area (19.635 in.^{2}), and diameter (5.0 in.) are used as the reference area and reference length, respectively, for non-dimensionalizing all main and fin balance coefficient data. The moment reference center for the main balance data is located 26 inches aft of the nose.

The hinge moment reference point for the fins is located at 50% of the grid fin chord. The bending moment reference point is located at the intersection of the body surface moldline and the hinge moment reference point. The sign conventions used for the main and fin balance force and moment coefficient data are shown in Figure 3.

III. RESULTS AND ANALYSIS

Unless otherwise noted, all data presented in this section were obtained from fin balance 4 positioned as shown in Figure 2. The presentation of data obtained from a single balance insures consistency between various grid fin data comparisons. An additional note is that for all data presented in this section, grid fins were not mounted on balances 1 and 3 to eliminate the chance of any mutual fin-fin interference effects.

Normal Force

Figure 4 presents grid fin normal force coefficient (C_N) data versus angle of attack for Mach numbers of 0.7, 1.2, 1.8 and 2.5. External frame cross-section shape is observed to have the greatest effect on the subsonic C_N data. At Mach 0.7, there is a variation in the C_N data of approximately 10% due to frame shape effects. The variation between different fin configurations is consistent over the entire angle of attack range. At Mach 0.7, the effect of web thickness is shown to cause a slight reduction in C_N at angles of attack greater than 10 degrees. The effects of frame shape and web thickness are relatively small at Mach 1.2 and can be distinguished only at higher angles of attack.

Referring back to Figure 4, an increase in web thickness from 0.008 inches to 0.012 inches is shown to cause a reduction in C_N at Mach 1.8. The reduction is at a maximum value of approximately 13% at an angle of attack of 5 degrees. At Mach 2.5, web thickness is shown to cause an unexpected increase in fin C_N for angles of attack between 3 and 14 degrees. Review of the Mach 1.8 and 2.5 C_N data measured by fin balance 2 confirmed the effects of web thickness. Frame shape is observed to have a minimal effect on grid fin C_N characteristics at the supersonic Mach numbers tested.

Hinge and Root Bending Moments

Grid fin root bending moment coefficient (C_{RBM}) and hinge moment coefficient (C_{HM}) data for the six grid fin configurations are presented in Figures 5 and 6, respectively. Data are plotted versus angle of attack for Mach numbers of 0.7 and 2.5. The C_{RBM} data mirrors the C_N data previously presented and indicates a near constant spanwise center of pressure location.

The C_{HM} data presented in Figure 6 indicate that there are significant differences in grid fin hinge moment characteristics at subsonic (Mach 0.7) and supersonic (Mach 2.5) Mach numbers. The Mach 0.7 data shows continual increases in C_{HM} with angle of attack. For angles of attack greater than 5 degrees, the modified single wedge (F3) and half diamond (F4) C_{HM} curves break away from the rest of the data. This implies (in conjunction with the C_N data) that the grid fin chordwise center of pressure location of the F3 and F4 configurations is slightly further aft than the other configurations. This difference is approximately 5% of the grid fin chord length of 0.384 inches.

The Mach 2.5 C_{HM} data indicates much lower values than the Mach 0.7 data. This difference is due to the fact that the Mach 0.7 data indicates a chordwise center of pressure location near the 1/4 chord while the Mach 2.5 data shows the center of pressure to vary between 45 and 50 percent of the grid fin chord. As before, the center of pressure of the F3 and F4 configurations are approximately 5% (of the chord length) further aft than the other configurations. Web thickness is observed to have no significant effect on grid fin hinge moment characteristics.

Drag and Axial Force

Figure 7 presents axial force coefficient (C_A) data versus angle of attack for Mach numbers of 0.7, 1.2, 1.8 and 2.5. The first and most obvious conclusion drawn from the data is that the level of grid fin axial force can be varied considerably by altering the frame cross section, the web thickness or a combination thereof. Two additional observations are that grid fin C_A values are essentially constant for small angles of attack and that differences in configuration

C_A levels remain consistent with variations in angle of attack.

The baseline grid fin configuration with no frame shaping (F1) and the thick web configuration (F5) generate the highest C_A levels for all Mach numbers tested. There are small differences between the modified single wedge (F3), half-diamond (F4), and thin frame (F6) configurations. The subsonic data show a significant increase in C_A values at higher angles of attack. The transonic and supersonic C_A data show a moderate reduction in C_A at higher angles of attack - approaching a 30% reduction at Mach 2.5.

Figure 8 presents a plot of zero angle of attack drag coefficient (C_D) data versus Mach number for all grid fin configurations tested on fin balance 4. The trends observed are typical of conventional fins. From Figure 8, C_D values rapidly increase as Mach number increases from 0.5 to 0.9. For Mach numbers greater than 0.9, C_D values gradually decrease with increases in Mach number.

Tables 2 and 3 summarize the effects of frame shape and web thickness in terms of percent reduction in grid fin drag as measured by fin balances 2 and 4, respectively. Frame cross-section shape percentages are presented with respect to the baseline (F1) configuration, i.e., the configuration with no frame shaping. Web thickness percentages are with respect to the thick web configuration (F5).

The results presented in Tables 2 and 3 show good agreement between balances 2 and 4. The greatest differences are at Mach 0.5 where the fin drag forces are small - on the order of 2 lb. For supersonic Mach numbers, the half diamond configuration (F4) has the greatest impact on reducing drag. Frame thickness is also shown to be a critical design parameter for minimizing drag.

Figure 9 is a bar chart which compares the drag characteristics of each grid fin tested on balance 4. The data presented illustrate that differences in C_D values are relatively uniform and consistent with Mach number.

Figure 10 correlates induced grid fin C_D with grid fin lift coefficient (C_L) for Mach numbers of 0.7, 1.2 and 2.5. The variation of C_D with C_L^2 is observed to be fairly linear over regions for which the fin C_L versus angle of attack data is linear. The trends observed are similar to trends exhibited by conventional fins.

IV. SUMMARY AND CONCLUSIONS

The following observations are made from the results of this study:

1. Frame cross-section shape and web thickness have been found to have a minimal effect on grid fin normal force characteristics. Frame shape has the greatest effect on C_N characteristics at subsonic Mach numbers while web thickness appears to have the greatest effect on C_N at supersonic Mach numbers.

Table 2. Drag Reduction Percentages - Fin Balance 2

Mach No.	F1 to F2	F1 to F3	F1 to F4	F1 to F6	F5 to F2
0.5	n/a	45	32	37	n/a
0.7	n/a	25	21	23	n/a
1.2	n/a	14	20	20	n/a
1.8	9	16	23	19	18
2.5	10	22	26	20	14

Table 3. Drag Reduction Percentages - Fin Balance 4

Mach No.	F1 to F2	F1 to F3	F1 to F4	F1 to F6	F5 to F2
0.5	19	33	29	29	16
0.7	20	29	26	29	18
1.2	8	13	19	19	16
1.8	8	16	21	21	14
2.5	13	23	27	23	13

2. Frame cross-section shape has a small effect on grid fin chordwise center of pressure location. The effect is greatest at higher angles of attack and is typically less than 5% of the grid fin chord length. Root bending moment characteristics are essentially unaffected with variations in frame cross-section and web thickness.

3. Frame cross-section shape and web thickness have a significant effect of grid fin drag characteristics. Simple shaping of the frame cross-section has been shown to considerably reduce drag levels for all Mach numbers tested. Likewise, web thickness has also been found to be a critical design parameter affecting grid fin drag.

4. Differences between grid fin drag values due to frame cross-section shape and web thickness remain relatively consistent with variations in both angle of attack and Mach number.

5. Grid fin induced drag varies linearly with C_L^2 up to moderate angles of attack. The trends observed are similar to conventional planar fins.

The observations noted above indicate that grid fin drag levels can be tailored considerably with only a minimal impact on grid fin lift and other aerodynamic properties. The results obtained from this investigation appear to indicate that further design trade studies optimizing grid fin frame cross-section, web thickness and support structure may enable grid fin drag levels to approach the drag levels of conventional fins with equivalent lift characteristics. It is important to reiterate that the objective of the test was only to evaluate the sensitivity of grid fin drag levels to changes in frame cross-section shape and web thickness. No attempt was made to minimize or maximize the drag levels of the grid fin configurations tested.

The results presented in this paper provide new insight into the aerodynamic characteristics of grid fins which will enable future system application studies to be performed with greater accuracy and a higher degree of confidence. Such studies should examine the drag characteristics of grid fin design concepts within the constraints and requirements of a weapon system prior to making a decision on the suitability of their application.

REFERENCES

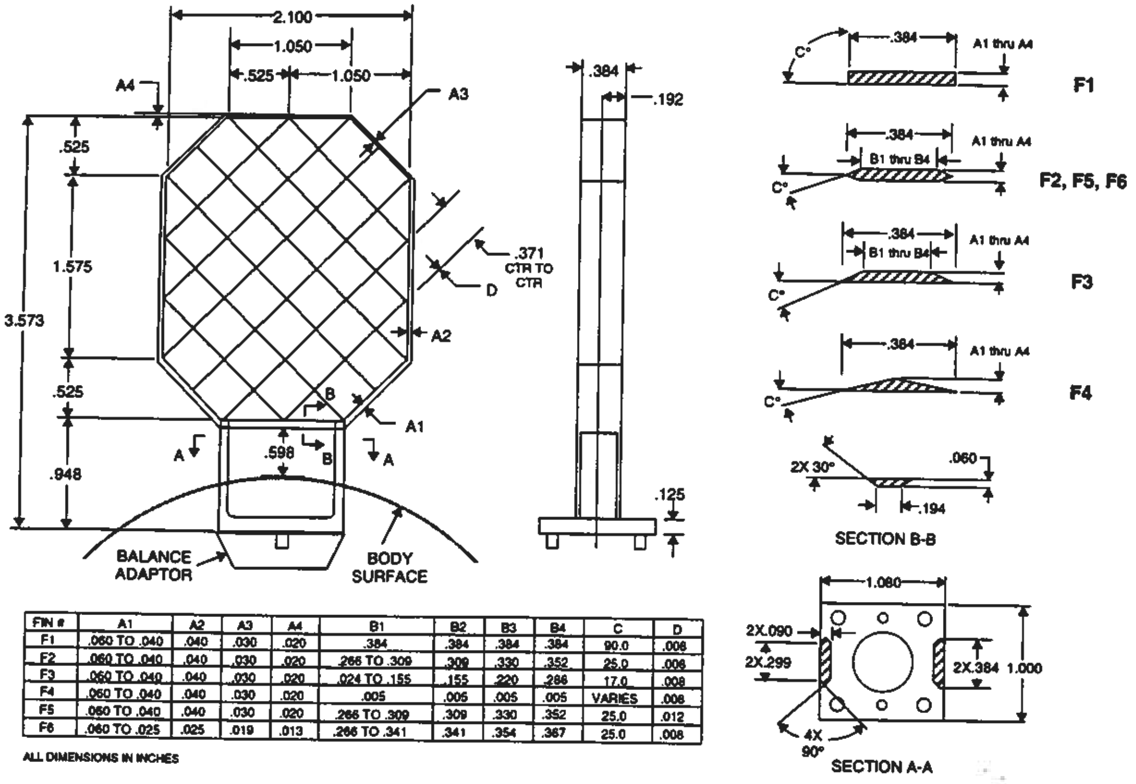
1. Washington, Wm. David, Pamela E. Booth and Mark S. Miller, "Curvature and Leading Edge Sweep Back Effects on Grid Fin Aerodynamic Characteristics," AIAA Paper 93-3480, Presented at the 1993 AIAA Applied Aerodynamics Conference, Monterey, California, August 10, 1993.

2. Miller, Mark S., George M. Landingham and William D. Washington, "Recent Developments and Applications of Grid Fin Missile Airframe Technology," Presented at the 1993 AIAA Missile Sciences Conference, Naval Postgraduate School, Monterey, California, February 23, 1993.

3. Washington, Wm. David and Miller, Mark S., "Grid Fins - A New Concept for Missile Stability and Control," AIAA Paper 93-0035, Presented at the 31st Aerospace Sciences Meeting & Exhibit, Reno, Nevada, January 11, 1993.

4. Miller, Mark S., and Richard L. Burton, "An Innovative Aerodynamic Control Device for Compact Weapon Applications," NWC TP 7137, Presented at the 1990 AIAA Missile Sciences Conference, Naval Postgraduate School, Monterey, California, November 14, 1990.

5. Miller, Mark S., and Richard L. Burton, "Application of Foreign Airframe Technology to Enhance Smart Weapon Flight Characteristics," GACIAC PR 90-02, Vol. 2, Presented at the U.S. Army Smart Weapons Conference, Adelphi, Maryland, August 15, 1990.



FIN #	A1	A2	A3	A4	B1	B2	B3	B4	C	D
F1	.060 TO .040	.040	.030	.020	.384	.384	.384	.384	90.0	.008
F2	.060 TO .040	.040	.030	.020	.266 TO .309	.309	.330	.352	25.0	.008
F3	.060 TO .040	.040	.030	.020	.024 TO .155	.155	.220	.286	17.0	.008
F4	.060 TO .040	.040	.030	.020	.005	.005	.005	.005	VARIES	.008
F5	.060 TO .040	.040	.030	.020	.266 TO .309	.309	.330	.352	25.0	.012
F6	.060 TO .025	.025	.019	.013	.266 TO .341	.341	.354	.367	25.0	.008

ALL DIMENSIONS IN INCHES

Figure 1. Grid Fin Designs Evaluated.

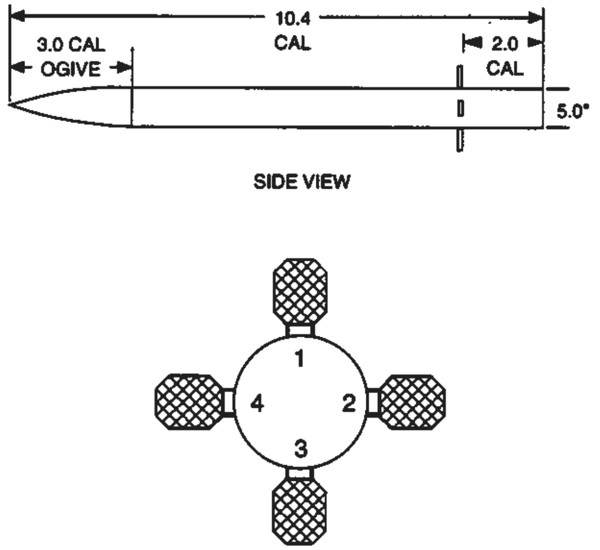


Figure 2. Sketch of Wind Tunnel Model.

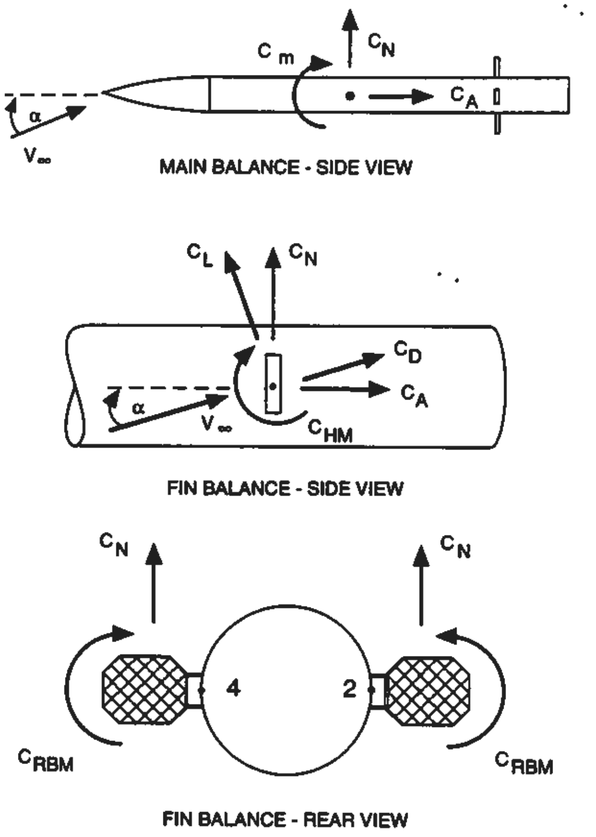


Figure 3. Balance Sign Conventions.

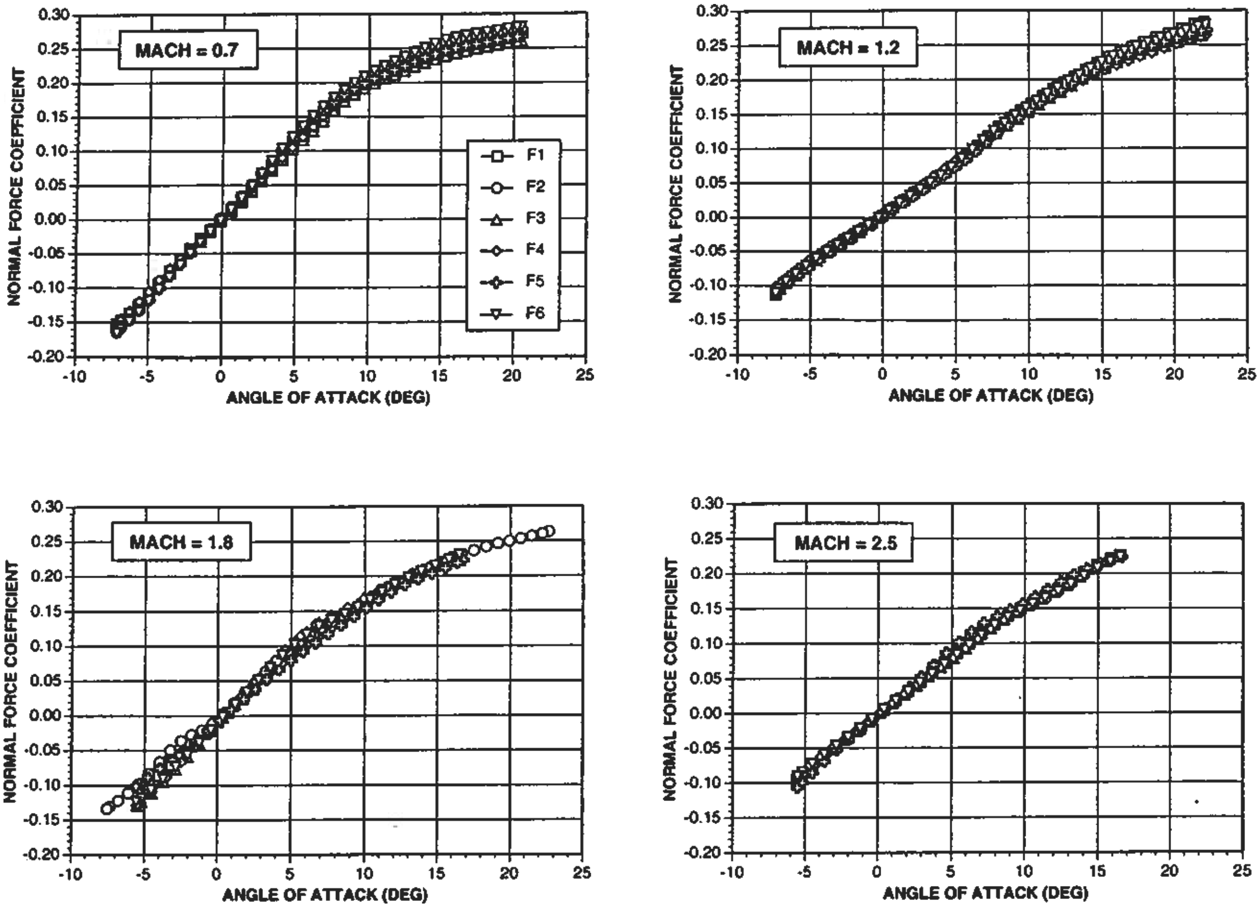


Figure 4. Normal Force Coefficient Versus Angle of Attack.

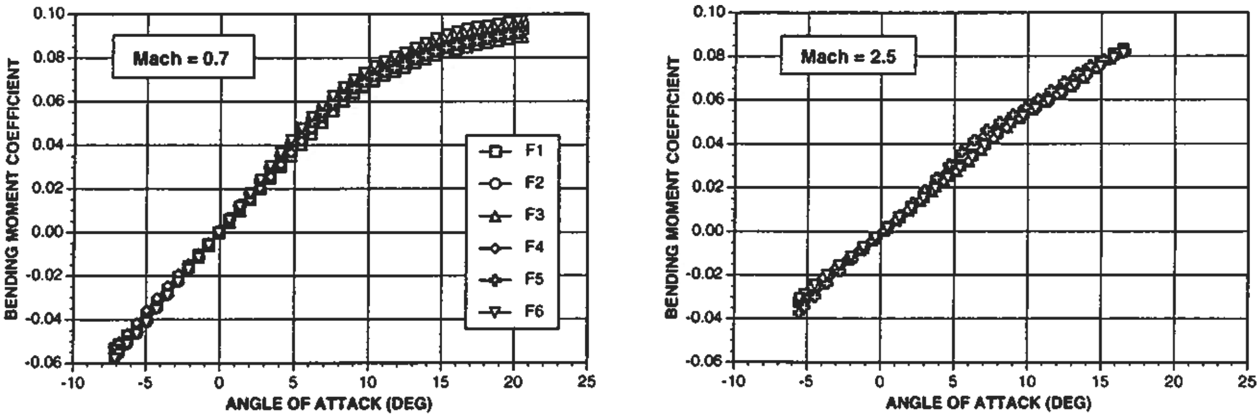


Figure 5. Root Bending Moment Coefficient Versus Angle of Attack.

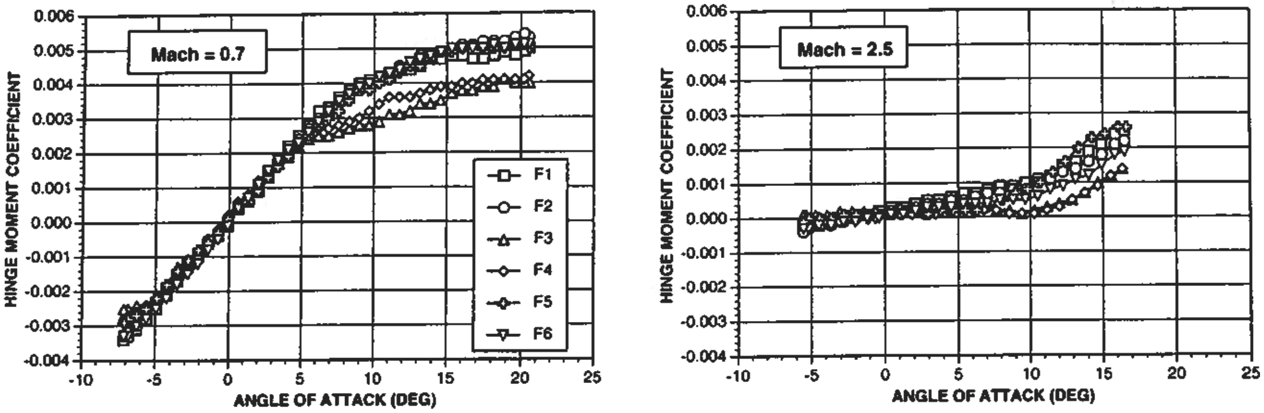


Figure 6. Hinge Moment Coefficient Versus Angle of Attack.

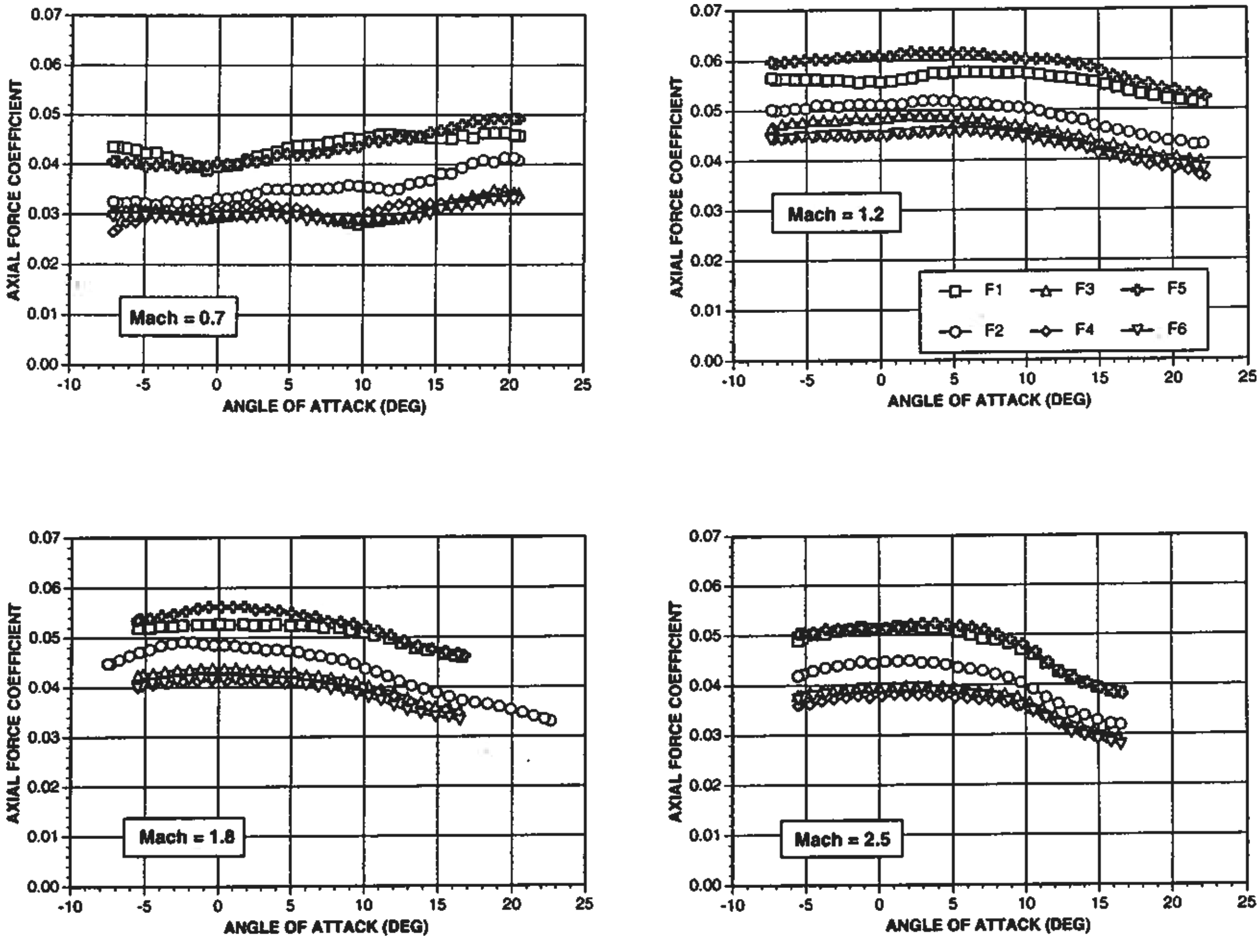


Figure 7. Axial Force Coefficient Versus Angle of Attack.

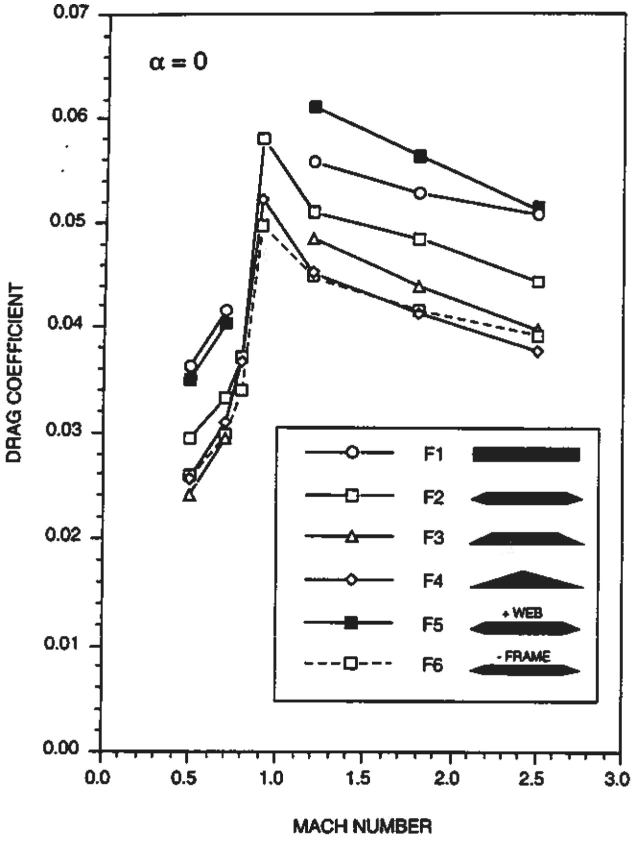


Figure 8. Drag Coefficient Versus Mach Number.

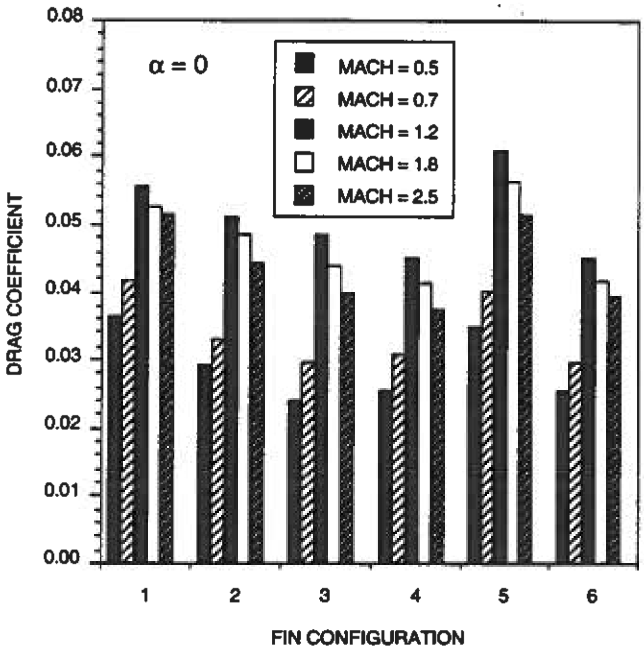


Figure 9. Grid Fin Drag Comparisons.

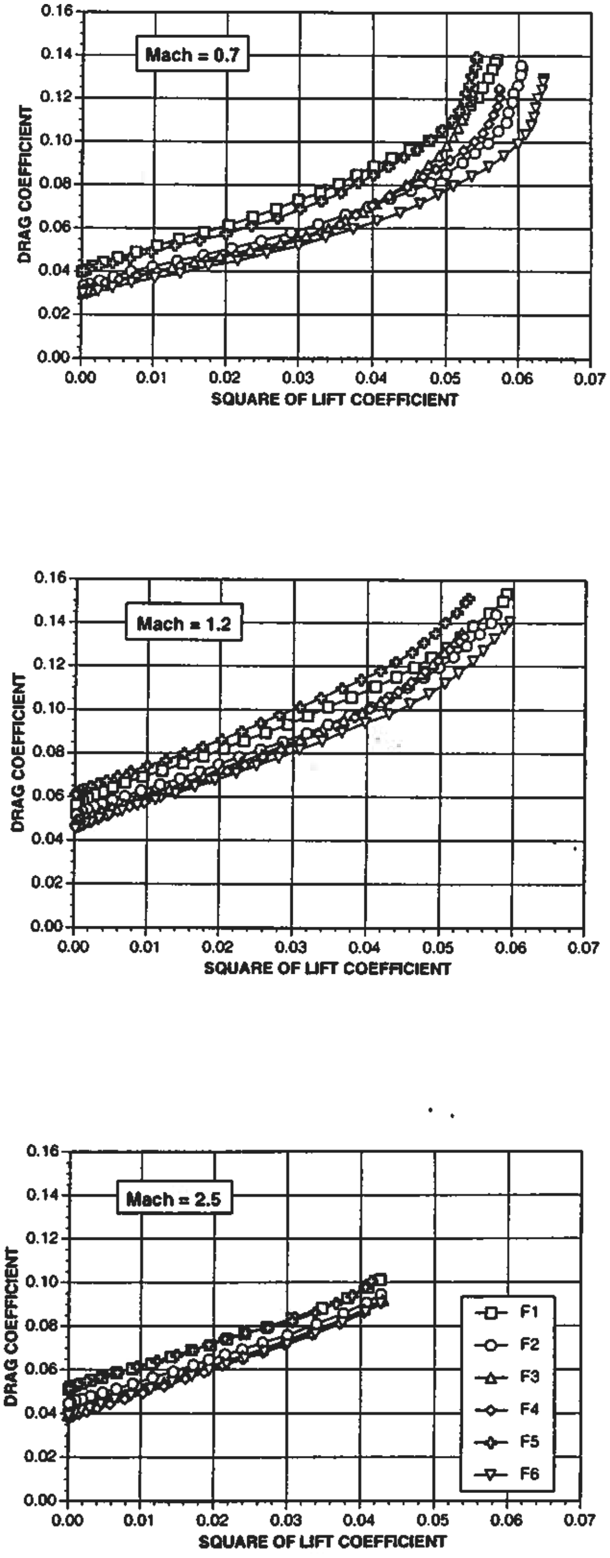


Figure 10. Grid Fin Induced Drag.