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Grid Fins - A New Concept for Missile Stability and Control

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ABSTRACT

The aerodynamic characteristics of two grid fin configurations have been investigated experimentally. The fins were mounted on a body of revolution consisting of a 3.0 caliber ogive nose with a 7.4 caliber cylindrical afterbody. A main balance and four fin balances were used to measure overall model loads and individual fin loads, respectively. Runs were made with fins deflected at both 0 and 15 degrees. Individual fin normal force, hinge moment and root bending moment coefficients were measured at Mach numbers ranging from 0.5 to 3.5. Results indicate that grid fin hinge moments are extremely small, normal force and root bending moments are comparable to planar fins of similar size, and grid fin axial force is greater (for the grid fins tested) than planar fins with comparable lift characteristics.

I. INTRODUCTION

A grid fin is an unconventional aerodynamic lifting device consisting of an outer frame with internal grid framework. Two different grid fin concepts are shown in Figure 1. With proper design, the unique aerodynamic and structural characteristics of the grid fin can provide certain advantages over other conventional fin designs.

The fundamental design of the grid fin allows a large amount of lifting surface area to be housed along the body of the missile without causing large increases in overall dimensions. In addition, the internal framework can be arranged to provide the grid fin with remarkably high strength-to-weight ratios. 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.

An experimental investigation was conducted to examine the aerodynamic characteristics of the two grid fin configurations shown in Figure 1. The objective of this investigation was to evaluate the feasibility of using the devices as aerodynamic stabilizers and/or control surfaces on free rockets and guided antitank missiles. The two grid fin configurations tested had identical outer frames, with different internal grid framework. Wind tunnel models of the grid fins were built and tested (Ref. 1) on an existing ogive cylinder. A main balance and four fin balances were used to measure overall model loads and individual fin loads, respectively.

Test results are presented and analyzed in this paper that show the effect of internal grid framework, Mach number, angle of attack and fin deflection angle on grid fin aerodynamics. Comparisons are also made with experimental data of a planar fin with equivalent lift characteristics (obtained Ref. 2) to qualitatively compare aerodynamic characteristics.

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II. WIND TUNNEL TEST PROGRAM

Test Articles

A sketch of the wind tunnel model hardware used for this investigation is shown in Figure 2. The body measured 5.0" in diameter and consisted of a 3.0 caliber tangent ogive nose with a 7.4 caliber cylindrical afterbody. This model had been used on previous tests and was chosen because it is typical of antitank missile shapes. Four fins can be mounted on the body two calibers forward of the base. The forward location was chosen to avoid any influence of the base region on the fins. The grid fin with the fine internal framework (S1) was mounted opposite of the fin with the "X" internal framework (S2) to minimize fin-fin interference effects.

The planar fin data used for comparison purposes was measured on an ogive cylinder body similar to the grid fin test, as shown in Figure 3. It measured 3.75" in diameter and consisted of a 3.0 caliber tangent ogive nose with a 7.0 caliber cylindrical afterbody. Four planar fins were mounted on fin balances with trailing edges flush with the model base.

Instrumentation

A six-component main balance and four three-component fin balances were used for the grid fin test. The fin balances were calibrated to measure fin normal force, root bending moment and hinge moment. Typical base pressure measurements were made to correct for sting effects on base drag. Main balance data was used to examine fin drag, because the fin balances did not measure fin drag directly. Force and moment coefficients for the grid fins were referenced to the model diameter (5.0 in.) and cross sectional area (19.635 in.^{2}). The sign conventions used for the coefficient data are shown in Figure 4.

A main balance and four fin balances were used in the planar fin test. Coefficients for the planar fins have been converted to the same reference dimensions (body) and sign conventions as the grid fin data.

Test Facilities

The grid fin test was conducted at the LTV Aerospace and Defense Company high speed wind tunnel facility. The tunnel is a blowdown, trisonic facility, with a Mach number range of 0.2 to 5.0. Reynolds number capability ranges from 2 to 38 million per foot. Equivalent pressure altitudes range from below sea level to 80,000 feet. The test section is 4 x 4 x 5 feet with adjustable walls for supersonic Mach numbers.

The planar fin test was conducted at the McDonnell Douglas Aerophysics Laboratory Trisonic Tunnel and the Arnold Engineering Development Center Von Karman Facility (AEDC-VKF) Tunnel A. Mach numbers of 0.8 to 1.2 were tested at McDonnell Douglas and 1.8 to 3.0 were tested at AEDC.

Test Conditions

Reynolds numbers for both tests are shown in Table 1. This data was used to adjust skin friction drag of the planar fin for comparison with the grid fins.

Table 1. Test Reynolds Numbers.

MACH NO.	GRID FIN RN/FT, X10^6	PLANAR FIN RN/FT, X10^6
0.5	4.36	-
0.6	4.90	-
0.7	5.36	-
0.8	5.66	6.9
0.9	6.15	-
1.0	-	8.6
1.1	6.45	-
1.3	7.01	-
1.8	5.52	2.7
2.0	-	2.8
2.5	7.18	3.0
3.0	-	4.6
3.5	11.3	-

III. RESULTS AND ANALYSIS

Normal Force

Grid fin normal force coefficient data (C_{NF}) were obtained with the fins mounted in the horizontal plane (180 degrees apart). C_{NF} data for both grid fin configurations tested are presented in Figure 5. These data are presented as a function of angle of attack (α) for Mach numbers of 0.5, 0.8, 1.1, 1.8, 2.5 and 3.5. The fine mesh grid fin (S1) is clearly superior to the "X" pattern grid fin (S2) at subsonic and supersonic speeds. Fin S1 produces at least 50% more normal force than fin S2 at subsonic speeds and at least 150% more normal force at supersonic speeds. At transonic speeds, fin S1 loses efficiency and produces essentially the same C_{NF} values as fin S2.

Two trends with angle of attack are evident. First, the change in C_{NF} with angle of attack is nonlinear at subsonic speeds, but tends to become more linear as Mach number increases through transonic to supersonic conditions. Second, the typical fin stall characteristics of conventional planar fins are not evident at angles of attack up to 15 degrees. This trend makes the grid fin more attractive as a control device. This observation becomes much more evident from the fin deflection data presented in the next section.

Figure 6 presents zero angle of attack fin normal force slope (C_{NF_α}) values as a function of Mach number (M_∞) for the S1 configuration. The C_{NF_α} data follows trends exhibited by conventional fins at subsonic ($M_\infty<0.75$) and higher supersonic ($M_\infty>1.60$) Mach numbers. However, a "bucket" exists in the C_{NF_α} data through the transonic and lower supersonic Mach number range. This "bucket" is attributable to two separate flow phenomena and is a function of the grid fin internal cell geometry, freestream Mach number and Reynold's number.

For analysis purposes, it is valid to view a grid fin as a collection of individual cells acting as separate inlets. Referring to Figure 7, the reduction in the inlet cross sectional area caused by the presence of the cell structural members and the build-up of the boundary layer on the cell walls will cause the flow passing through the cell to accelerate to sonic conditions at freestream Mach numbers less than 1.0. Using conventional terminology, the cell becomes choked at this point. The cell remains choked as the freestream Mach number increases past Mach 1.0. While the individual cells are choked, part of the flow spills around the grid fin which causes a reduction in normal force generated by the fin.

Further increases in freestream Mach number will eventually enable the cell to swallow the shock and will result in a shock wave attaching to the leading edge of the cell. Once a shock wave attaches to the leading edge of a cell, further increases in Mach number will sweep the shock backward causing it to reflect within the cell as shown in Figure 7. The internal reflection of the shock wave also tends to reduce C_{NF_α} values.

At a certain Mach number, the shock wave will pass through the cell undisturbed. Further increases in Mach number will have no qualitative effect on the grid fin flow field. It is at the point where the shock first passes undisturbed that the grid fin begins to exhibit supersonic normal force characteristics similar to conventional fins.

The Mach numbers for the onset of choked flow, shock attachment and undisturbed flow have been calculated for the S1 configuration using one-dimensional isentropic flow relations derived for grid fin applications (Ref. 3). A comparison of predicted flow field regimes is made with experimental data in Figure 6 and shows excellent correlation with the trends observed in the experimental data.

Control Force

Opposite fins in the horizontal plane were deflected -15 degrees to evaluate grid fin control effectiveness. Fin deflection data presented in Figure 8 (for Mach numbers of 1.8 and 3.5) indicate that the grid fin concept is probably more attractive as a control device than typical planar fins. At a fin deflection (δ) of -15 degrees and angle of attack of -13 degrees (an equivalent fin angle of attack greater than 25 degrees), the grid fin C_{NF} data still does not indicate a typical planar fin type stall. Test results show that at higher supersonic Mach numbers, the incremental change in C_{NF} due to fin deflection is essentially independent of angle of attack for equivalent fin angles of attack in excess of 30 degrees. Both S1 and S2 grid fin configurations exhibit similar trends at other Mach numbers. This data appears to indicate that the grid fin concept is very attractive as a control device at supersonic speeds.

Center of Pressure

Clearly, one of the biggest advantages of the grid fin concept is its low hinge moment characteristics. Figure 9 summarizes the chordwise center of pressure locations (XCP) as a function of Mach number for both the S1 and S2 configurations. As shown in Figure 9, the chordwise center of pressure for fin S1 is essentially at 30% of the chord (measured from the grid fin leading edge), and varies no more than 10% in either direction. Chordwise center of pressure location for fin S2 is approximately 40% at subsonic speeds and 60% at supersonic speeds.

Figure 10 presents grid fin hinge moment (C_{HM}) data, measured relative to the fin centerline, as a function of angle of attack at Mach 2.5. As one might expect, hinge moment values increase with angle of attack. When one considers that the chord of a grid fin is very small in comparison to a typical planar fin, then it is easy to understand why grid fins have such low hinge moment values.

Figure 11 summarizes the spanwise center of pressure locations as a function of Mach number for both the S1 and S2 configurations. The spanwise center of pressure locations (YCP) for both grid fin configurations are very consistent with typical planar fins (i.e., about 40% of span, measured outboard from fin base). This means that the root bending moment characteristics of grid fins are similar to planar fins. Unlike planar fins where normal force acts through the plane of least rigidity, the grid fin normal force acts through the plane of greatest rigidity. This implies that for a given load requirement, a grid fin will be somewhat lighter and substantially more rigid than a conventional fin.

Planar Fin Comparison - Normal Force

In order to provide insight into the magnitude of normal force generated by the S1 grid fin, a comparison has been made with experimental data obtained on a planar fin with similar lift characteristics (Ref. 2). The direct comparison of C_{NF} data is valid since both sets of data are based on the model body cross sectional areas. Figure 12 shows a scaled geometric comparison between the two fins.

Figure 13 presents C_{NF} data for both fin configurations at Mach numbers of 0.8, 1.8 and 2.5. The grid fin produces essentially the same normal force as the planar fin for Mach numbers 0.8 and 1.8, and approximately 50% more normal force at Mach number 2.5. Data was not available for a direct one on one comparison at transonic speeds. This data seems to indicate that the grid fin concept can be very comparable to planar fins in the production of fin normal force, and may be even better at higher supersonic speeds.

Planar Fin Comparison - Drag

Perhaps the greatest disadvantage of the grid fin configurations tested is their high drag characteristics. As shown in Figure 14, the drag of the S1 grid fin is 3 to 4 times higher than the planar fin with comparable lift characteristics.

It should be noted that the drag data for the planar fin was adjusted to the grid fin test Reynolds numbers and model scale for direct comparison with grid fin drag data. Incremental differences in fin skin friction drag were calculated using standard boundary layer theory to adjust the planar fin skin friction drag to the grid fin test Reynolds numbers and model size. The increments in drag were then added to the experimental planar fin data to enable drag comparisons with the grid fin data.

In most instances, high drag is undesirable. This grid fin characteristic, however, must be factored into the overall system performance before a definite conclusion can be drawn. For some systems (such as submunitions), a rapid deceleration from high speeds, while maintaining stability and controllability, might be desirable. The advantages and disadvantages of the grid fin concept must be examined within the system constraints, or requirements, and only then can it be judged good or bad.

The grid fins tested here had constant thickness internal elements and frame. The leading and trailing edges of each element and frame were blunt. Significant drag reductions could be realized (especially at supersonic speeds) by reshaping the edges to be sharp, like wedges. Also, the grid fin surface finish could possibly be altered to minimize friction drag. A technology effort is currently in process to investigate techniques to reduce drag of the grid fin concept.

Theoretical Prediction Methods

Considerable work has been performed developing methods to predict the lift and drag characteristics of grid fins. These methods are principally based on classic isentropic flow relations and 2-D airfoil theory. It is beyond the scope of this paper to present details concerning these methods. Additional information can be obtained from References 4 through 6.

IV. CONCLUSIONS

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

1. Grid fin hinge moments are very small. For the test articles in this study, the variation in chordwise center of pressure was less than 0.1 inches (less than 20 percent of chord length).

2. Root bending moments for grid fins and planar fins are similar -- typically 40 to 45 percent of fin span.

3. Grid fins are effective devices for generating normal force at all Mach numbers tested. At higher supersonic Mach numbers, grid fins appear to be more effective than planar fins with comparable planform areas.

4. Drag values for the grid fins tested are greater than for planar fins with comparable lift characteristics. In this study, grid fin drag is approximately 3 to 4 times the drag of a planar fin with comparable normal force. Shaping of the grid fin leading edges would, however, reduce drag significantly.

5. Because of their favorable lift characteristics at high angles of attack and high Mach numbers, grid fins are very attractive as control devices. In this study, grid fin stall did not occur for fin angles of attack up to 30 degrees - the maximum tested.

The observations noted above coupled with the excellent storage characteristics of grid fins lead to conclusion that grid fins are particularly attractive devices to consider for canister launched missiles, ship launched missiles, missiles designed for deployment from aircraft internal bays, compressed carriage weapons and dispensed submunitions. Further research in this area as well as system impact studies must be performed before definitive answers can be obtained.

ACKNOWLEDGEMENTS

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REFERENCES

1. Gills, Pamela F., "Data Base Report For Grid Fin Technology Wind Tunnel Test," Technical Report RD-SS-88-6, U.S. Army Missile Command, Redstone Arsenal, Alabama, March 1988.

2. Chafin, J. M., "User's Guide For High Angle Of Attack (HIALFA) Aerodynamic Data Base," Interim Technical Report TR1003, New Technology, Inc., Huntsville, Alabama, December 1978.

3. Miller, Mark S., "Unpublished Notes Concerning Lift and Drag Prediction Techniques for Grid Fins", 1988-1992.

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.

6. Burton, Richard, L., and Mark S. Miller, "Lattice Control Surfaces - An Alternate Means of Missile Control," 1990 Joint Service Innovative Anti-Air Weapon Systems Conference Proceedings, Presented at Johns Hopkins Applied Physics Lab, Laurel, Maryland, June 28, 1990.

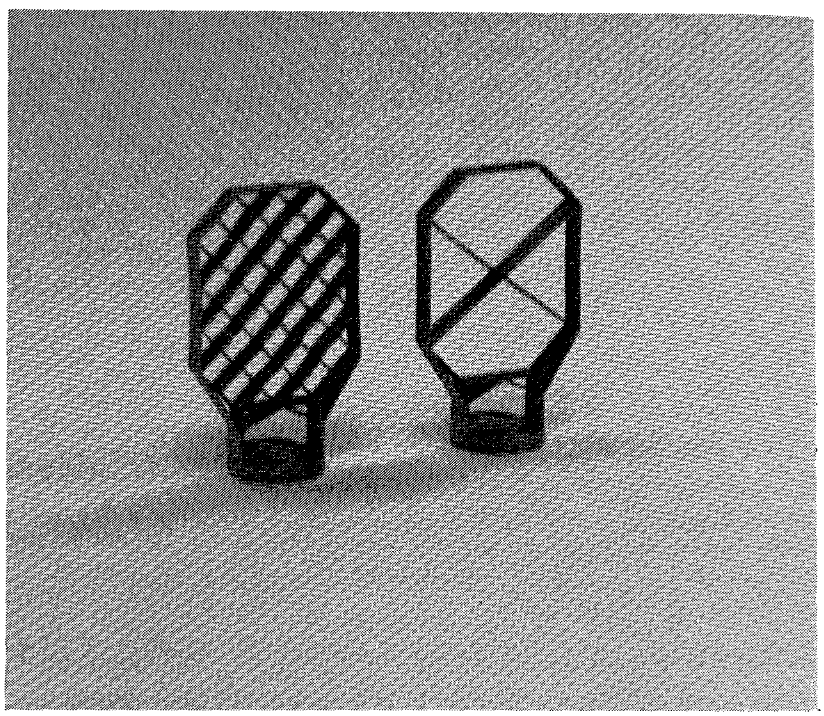

Figure 1. Photograph of Two Grid Fins.

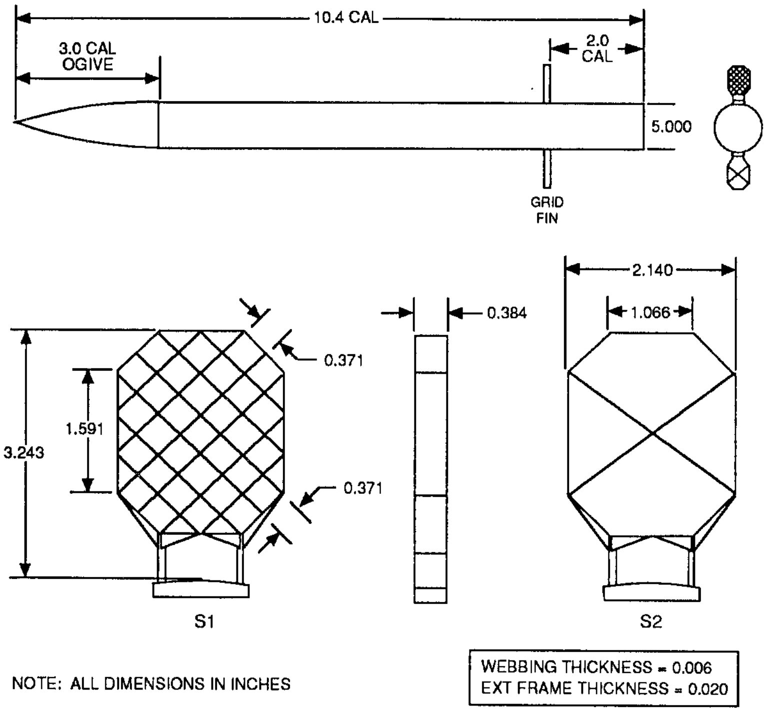

Figure 2. Grid Fin Wind Tunnel Model.

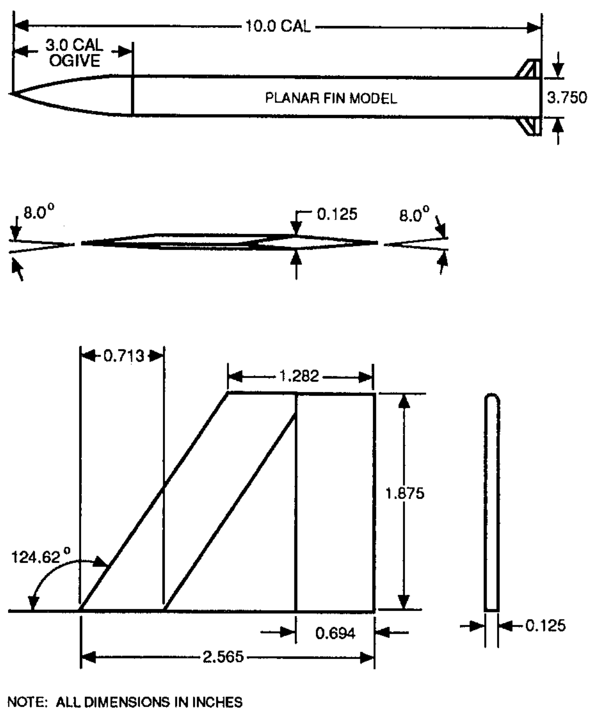

Figure 3. Planar Fin Wind Tunnel Model.

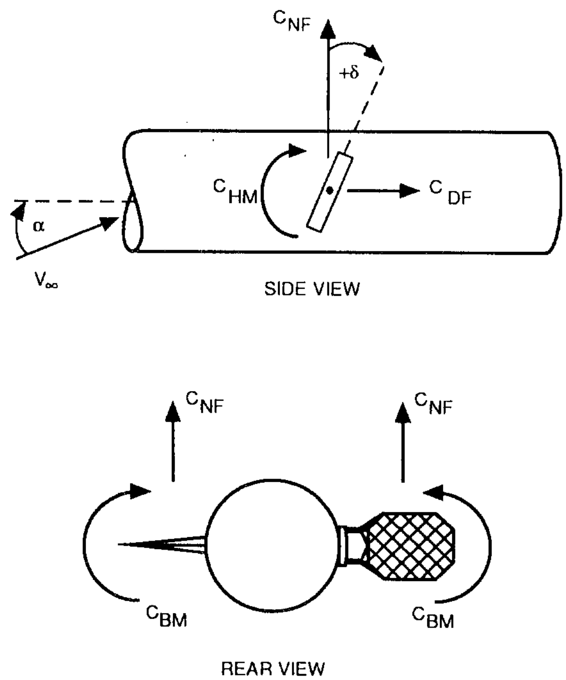

Figure 4. Coefficient Sign Convention.

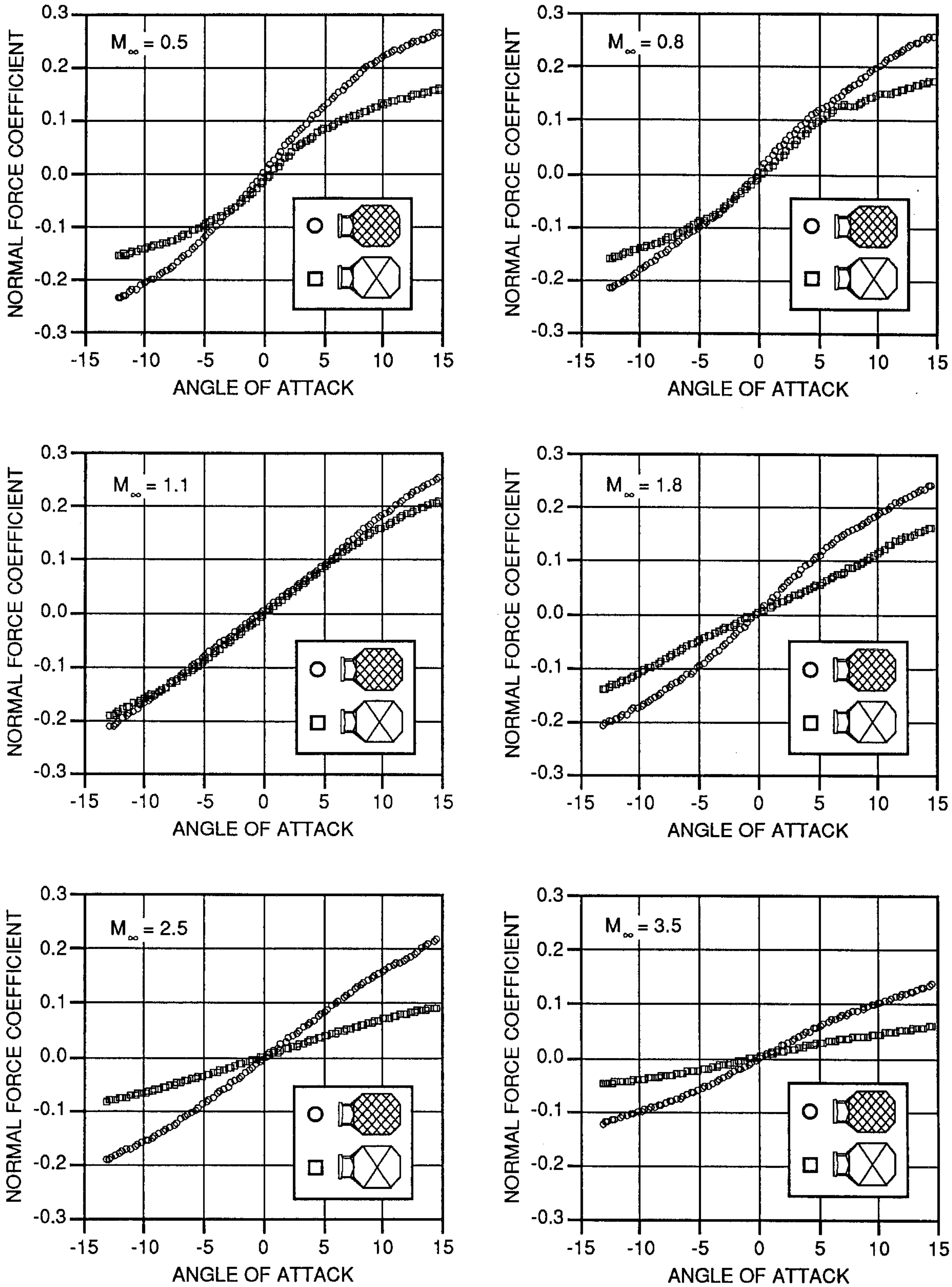

Figure 5. Grid Fin Normal Force Coefficient Versus Angle of Attack.

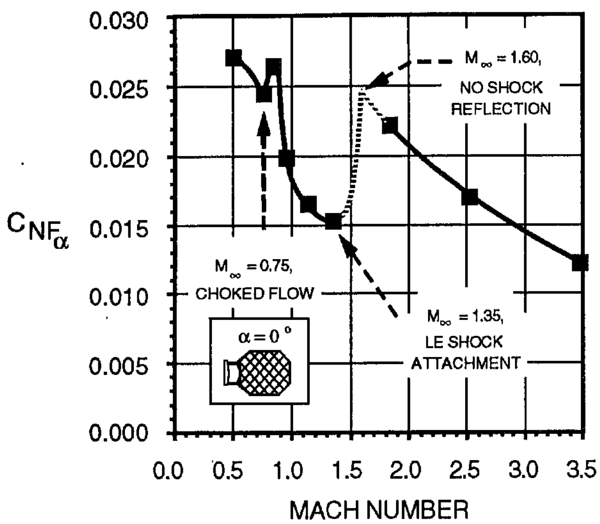

Figure 6. C_{NF_α} Versus Mach Number.

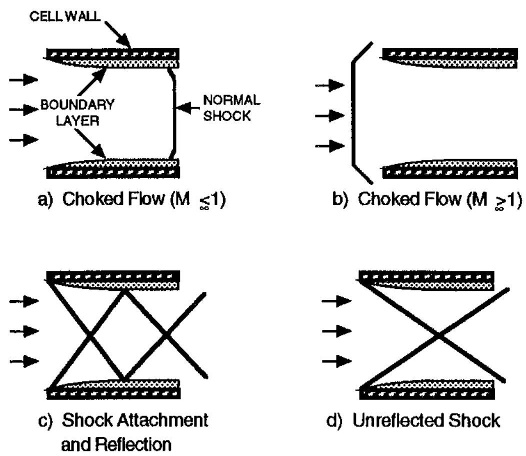

Figure 7. Grid Fin Flow Field.

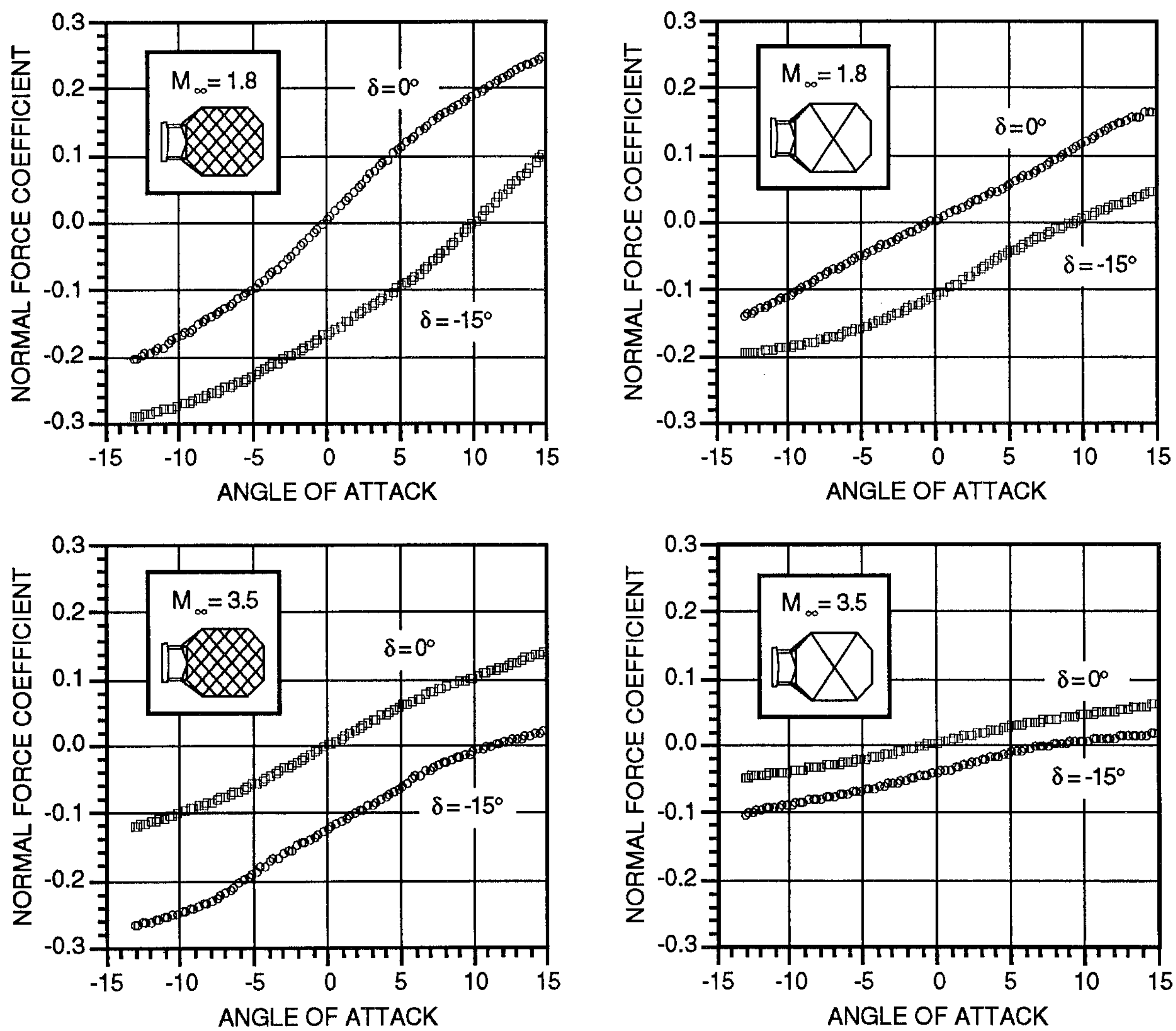

Figure 8. Grid Fin Normal Force Coefficient Versus Angle of Attack, δ = 0, -15 degrees.

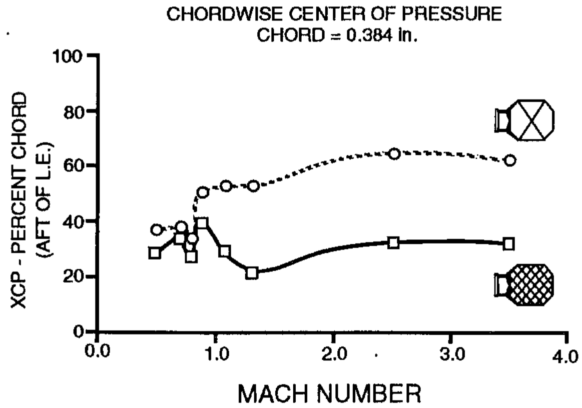

Figure 9. Chordwise Center of Pressure Location Versus Mach Number.

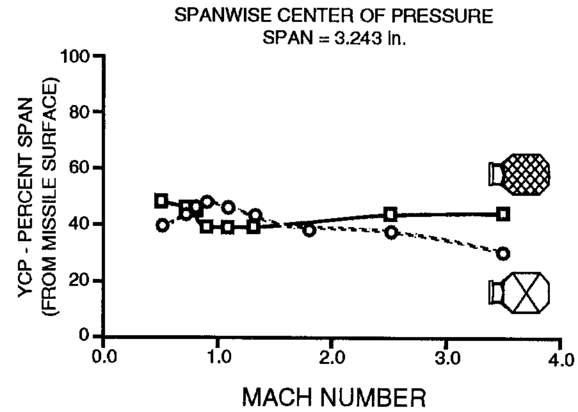

Figure 11. Spanwise Center of Pressure Location Versus Mach Number.

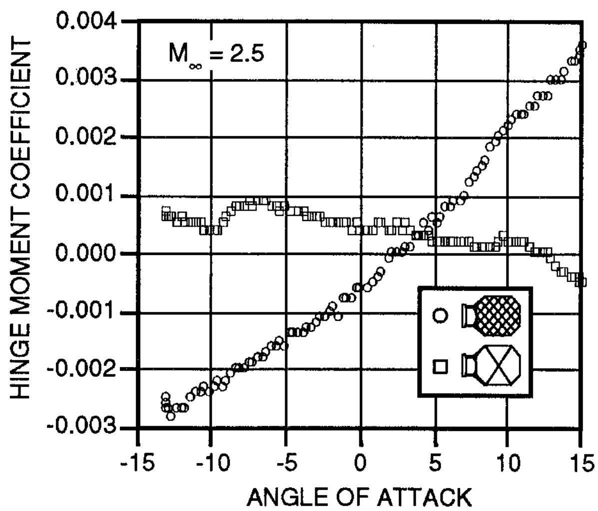

Figure 10. Hinge Moment Coefficient Versus Mach Number.

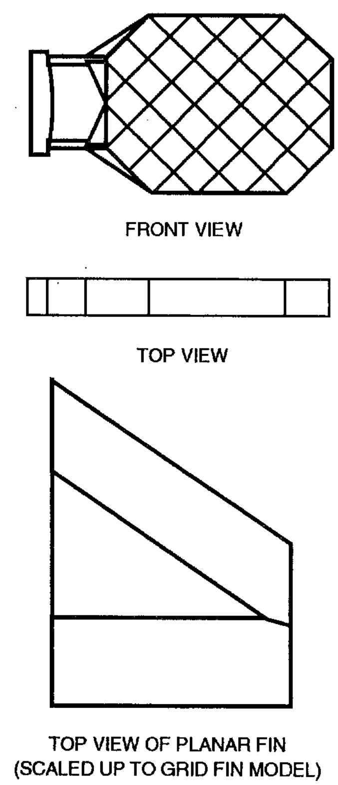

Figure 12. Scaled Comparison Between Grid Fin and Planar Fin.

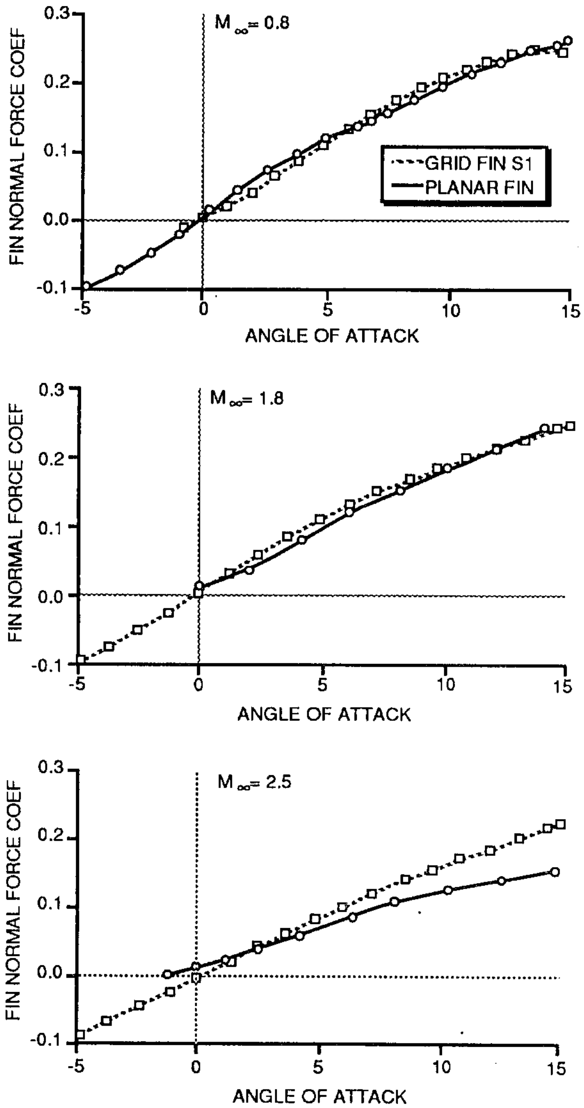

Figure 13. Grid Fin - Planar Fin Normal Force Comparison.

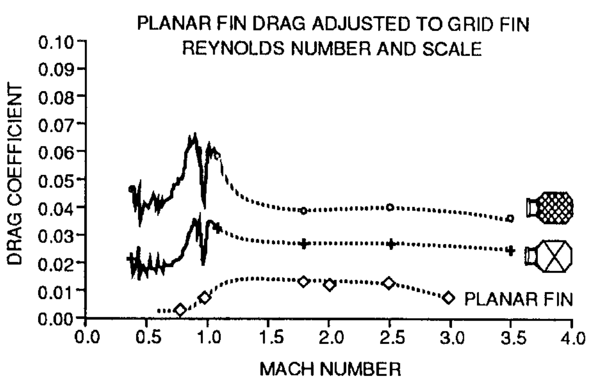

Figure 14. Grid Fin - Planar Fin Drag Comparison, $\alpha = 0^{o}$.