GRID PATTERN EFFECTS ON AERODYNAMIC CHARACTERISTICS OF GRID FINS

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Abstract

The effects of grid pattern on aerodynamic characteristics of grid fins have been investigated experimentally. The fins are designed to have the same area for each and total grid cell, and mounted on four individual fin-balances near the aft end of a body. Test parameters are grid patterns of the fin (square, triangle and hexagon), angle of attack (-5 to 30 degrees), angle of roll (0 to 180 degrees), fin deflection angle (0 and 10 degrees) and Mach number (0.5 to 2.0). Test results show that the effects of grid pattern on grid fin aerodynamic characteristics are smaller than expected in subsonic and supersonic flow.

1 Introduction

The grid fin, also known as a lattice control surface or a wing with internal framework, can provide a missile with stability and control as well as a planar fin. It also can be used as drag stabilizing devices to decelerate incoming missiles. Advantages of the grid fin over the conventional planar fins are higher strength-to-weight ratio and lower hinge moment. Therefore it can contribute to mitigate the requirements for a control actuator of the fin. On the other hand, its higher drag is a significant disadvantage [1,2,3].

Most grid fins, which have ever been investigated, have a square grid pattern. However there was no clear reason to choose this pattern.

To investigate the effect of grid pattern on aerodynamic characteristics of grid fins, three types of grid patterns are proposed in this paper. The most common grid fin has a square grid pattern. However, a grid fin with a triangle grid pattern is supposed to have higher structural strength than a grid fin with a square grid. On the other hand, in terms of the aerodynamic drag, a round grid pattern is considered to be the best, although a hexagon grid pattern is a realistic option.

This paper focuses on the effects of those grid patterns on the aerodynamic characteristics.

2 Wind Tunnel Test Program

The wind tunnel tests were performed in a blowdown tri-sonic wind tunnel at Mitsubishi Electric Corporation (MELCO) Kamakura Works. The wind tunnel model consists of an ogive-cylinder body with four planar fins mounted near the fore part and four grid fins near the aft section of the model. It has three types of the grid fins; their grid patterns are square, triangle and hexagon. They have the same area for each and total grid cell. Four fin-balances were used for instrumentation to measure three components of force and moments. Test parameters include grid pattern shape, angle of attack, angle of roll, fin deflection angle, and Mach number. The primary objectives of the tests were to investigate the effects of grid pattern.

2.1 Model Geometry

A dimensioned sketch of the wind tunnel model used for the tests is shown Figure 1. The model is a 20.32 mm diameter cylindrical body with a

2 caliber ogive nose. Geometric data of the body are listed in Table 1.

Table 1. Geometric Data of the Body.

Body length	366.0 mm
Body diameter (Ref. Length)	20.32 mm
Body cross-sectional area (Ref. Area)	324.3 mm^2

Figure 2 and 3 show three types of grid fin configurations; square, triangle and hexagon. They were designed to have the same area for each and total grid cell. With these design conditions, however, they do not have the same area of lifting surface (projected area on the vertical plane of the fin normal force direction). Geometric data for the grid fins are listed in Table 2. Figure 4 shows the cross section of the grid fins. The three types of fins have the same cross section, having double wedge shape, the chord length of 5 mm and the web thickness of 0.2 mm.

Table 2. Geometric Data of the Fin.

Area of each cell (Standard)		25.0 mm^2
Area of total grid cell (15 cells)		375.0 mm^2
Chord length		5.0 mm
Web thickness		0.2 mm
Area of lifting surface	A: square	778.8 mm^2
	B: triangle	723.8 mm^2
	C: hexagon	604.6 mm^2

2.2 Test Facility

The test was conducted in MELCO's wind tunnel. The tunnel is a blowdown, tri-sonic (subsonic, transonic and supersonic) facility, with a Mach range from 0.1 to 3.5. It has a 400 x 300 mm rectangular test section with viewing windows through which pictures are taken. Model blockage for this test is less than 0.3%.

2.3 Instrumentation

Each of the grid fins was mounted on a three-component strain gage balance. The fin-balances were manufactured by MELCO to measure each fin's normal force, hinge moment and bending moment, having full scale (FS) of 400 N, 1.5 N-m and 15.0 N-m respectively. The absolute accuracy of the fin data has been estimated to be within 1% FS.

2.4 Test Conditions

Data was taken in the pitch plane at angles of attack from –5 to +30 degrees. Fin deflection angles were set at 0 or 10 degrees. The angle of roll was fixed for each test, and was changed by 15 degrees from 0 to 180 degrees. Figure 5 shows the definition of the model angles, and the setting ranges of these test parameters are listed in Table 3. Typical tunnel operating conditions for each Mach number are listed in Table 4.

Table 3. Test Parameters.

Mach Number	0.5, 0.8, 1.2, 2.0
Angle of attack	-5 to 30 deg.
Angle of roll	0 to 180 deg. (every 15 deg.)
Fin deflection angle	0, 10 deg.

Table 4. Tunnel Operating Conditions.

Mach Number	Total Press. (MPa)	Static Press. (MPa)	Dynamic Press. (MPa)	Static Temp. (K)	RN/L x 10^7 (per m)
0.5	0.222	0.187	0.032	274.4	2.30
0.8	0.192	0.127	0.057	255.5	2.71
1.2	0.192	0.079	0.079	223.7	3.04
2.0	0.256	0.032	0.091	160.1	3.31

2.5 Data Reduction

Body cross-sectional area and diameter is used as reference area and reference length for all fin-balance data. The moment reference center is at the root of the fin in the center of its chord. The coordinates used for the fin-balance force and moment coefficients are shown in Figure 6.

3 Results and Discussion

3.1 Effect of Grid Pattern on Normal Force

It is well known that the normal force derivative ($C_{N\alpha}$) of a grid fin tend to be lower at transonic flow than that of subsonic and supersonic flow [1,4]. This trend is caused by the choked flow in each cell of the grid fin [1]. While the cells are choked, part of the flow spills around the grid fin, which causes a reduction in the normal force. Figure 7 presents the $C_{N\alpha}$ as a function of Mach number for three types of grid fin at 90 degrees roll angle. It is observed that the $C_{N\alpha}$ of the hexagonal pattern fin is smaller at Mach 0.8 when compared to the square and triangle pattern fins. From the data presented here, it is impossible to know how the flow field inside the cells is different among the three types of grid fins. However, it is assumed that the boundary layer on the lifting surface becomes thicker as a number of the vortices from the intersection points at the leading edges of the lifting surface increases. The square fin has 4 intersection points per cell, the triangle fin has 3 and the hexagonal fin has 6. For this reason, it is reasonable to consider that the flow in the cell of the hexagonal fin is choked at Mach 0.8, though that of the square and triangle fins are not.

The normal force of the grid fin with square pattern exhibits nonlinear characteristics against the angle of attack at transonic flow [1]. Figure 8 presents the normal force coefficient (C_N) for Mach numbers of 0.5, 0.8, 1.2 and 2.0 at 90 degrees roll angle. In both cases of square and triangle pattern fins, the C_N curves change rapidly at angle of attack around 5 degrees at Mach 0.8. On the other hand, the C_N of the hexagonal pattern fin have linear characteristics against the angle of attack when compared to other fins. These trends are due to the choked flow in each cell of the grid fin. The cells of the square and triangle grid fins are choked at the angle of attack approximately over 5 degrees, while the cells of the hexagonal fin is always choked at Mach 0.8.

Referring back to Table 2, three fins have the same area of grid cells, but have the different area of lifting surface. It is interesting that the C_N of the hexagonal fin is almost as large as that of the square fin at Mach 0.5, 0.8, 1.2 and 2.0, though the hexagonal fin has about 78% lifting surface area of the square one. This indicates that the C_N of grid fin depends much more on the area of each and total grid cell than that of lifting surface.

In the case of some common planar fin, there is always some interference with the forward planar fins, however Figure 8 shows that there is no effect in the case of the grid fins, indicating that the grid fin could have smaller interference than the common planar fin.

Figure 11, 12 and 13 present the C_N data versus angle of roll for Mach numbers of 0.5, 0.8, 1.2 and 2.0. These Figures show that the body has influence on the normal force of grid fins, though the influence had no remarkable difference among three types of the grid fins.

3.2 Effect of Grid Pattern on Hinge and Bending Moments

Grid fin hinge moment coefficient (C_m) and bending moment coefficient (C_l) data for the three grid fin configurations are presented in Figures 9 and 10, respectively. Data are plotted as a function of angle of attack for Mach numbers of 0.5, 0.8, 1.2 and 2.0.

The C_m data presented in Figure 9 indicate that there is not significant difference among the three grid fins. And the C_l data in Figure 10 and the C_N data in Figure 8 change the same way as a function of angle of attack, indicating that a span-wise center of pressure location moves little. The geometry of grid pattern is observed to have no significant effect on grid fin hinge and bending moment characteristics.

4 Conclusions

To investigate the effect of grid pattern on aerodynamic characteristics of grid fins, three types of grid fins were designed to have the same area for each and total grid cell, and tested in the wind tunnel to measure fin normal force, hinge moment and root bending moment. The three grid patterns are square, triangle and hexagonal respectively.

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

1. The effects of a grid pattern on the grid fin aerodynamic characteristics are smaller than expected in subsonic and supersonic flow.

2. However, in transonic flow of Mach 0.8, the normal force derivative of the hexagonal pattern grid fin is smaller when compared to the square and triangle pattern fins. It is assumed that the flow in the cell of the hexagonal fin was choked at Mach 0.8.

3. The fin normal force curve of the square- and triangle-pattern grid fins changes rapidly at angle of attack around 5 degrees at Mach 0.8. It is reasonable to consider that the cells of the fins are choked at the angle of attack approximately over 5 degrees.

The results of the wind tunnel test indicate that the aerodynamic characteristics of grid fin depend much more on the area of each and total grid cell than that of lifting surface. In other words, the triangle pattern could be better choice for the grid fin because of higher structural strength compared to a square and a hexagonal pattern. That makes it possible to have a thinner web, which reduces the drag of the grid fin.

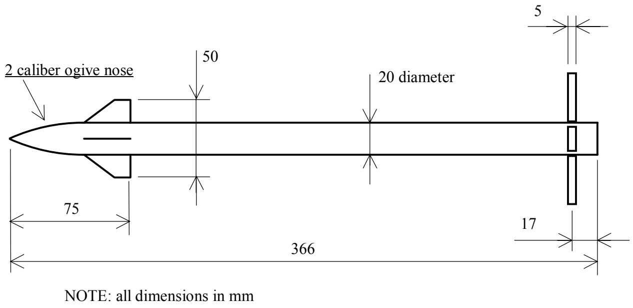

Fig. 1. Wind Tunnel Model.

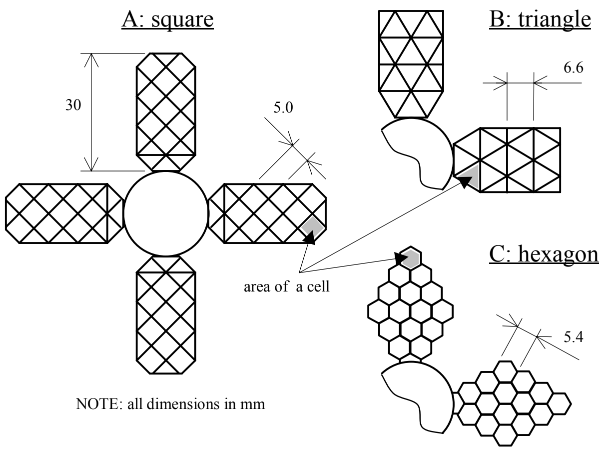

Fig. 2. Three Types of Grid Fin Configurations.

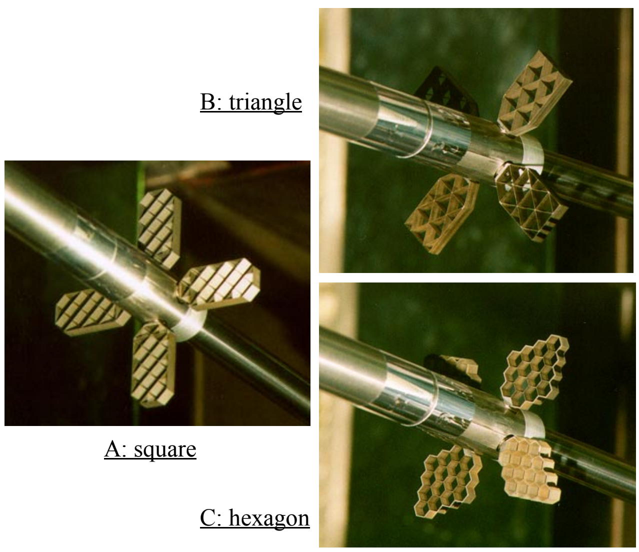

Fig. 3. Three Types of Grid Fins.

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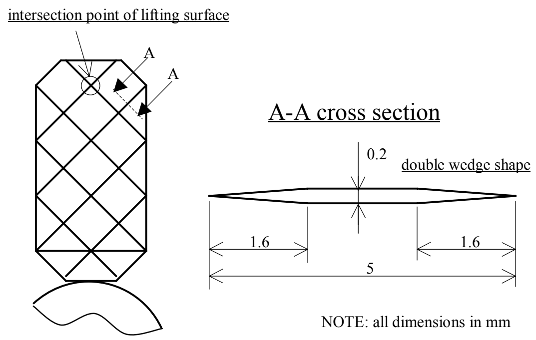

Fig. 4. Grid Fin Cross Section.

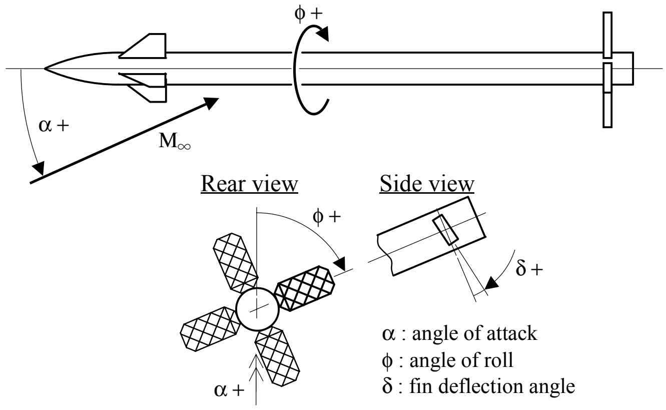

Fig. 5. Definition of the Model Angles.

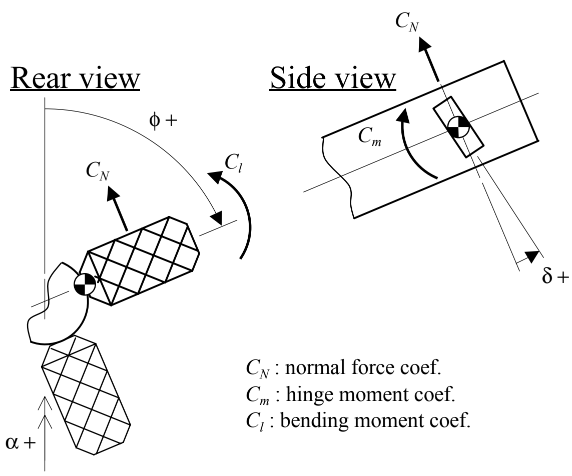

Fig. 6. Balance Coordinates.

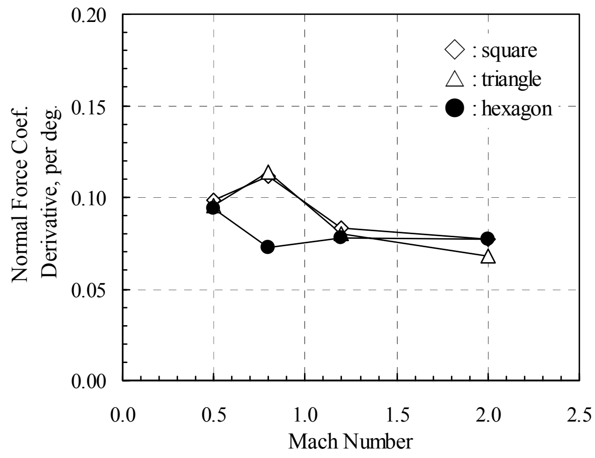

Fig. 7. Normal Force Coefficient Derivative versus Mach Number; Angle of Roll is 90 Degrees.

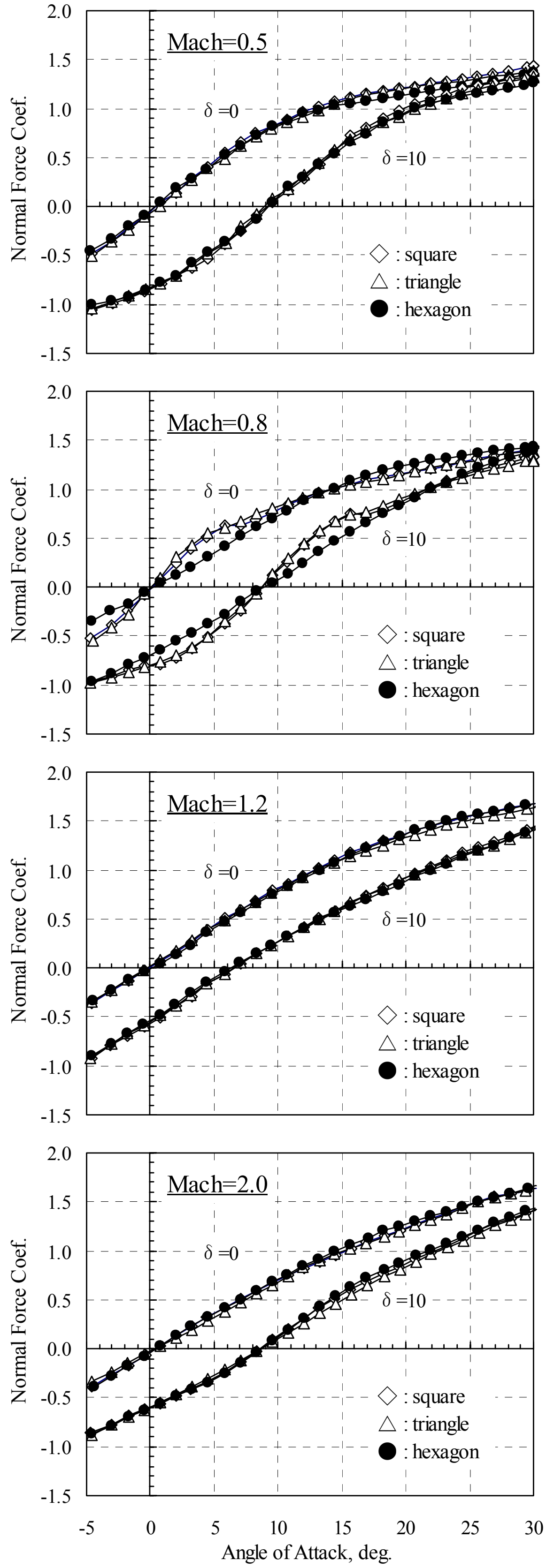

Fig. 8. Normal Force Coefficient Comparisons for Grid Patterns; Angle of Roll is 90 Degrees.

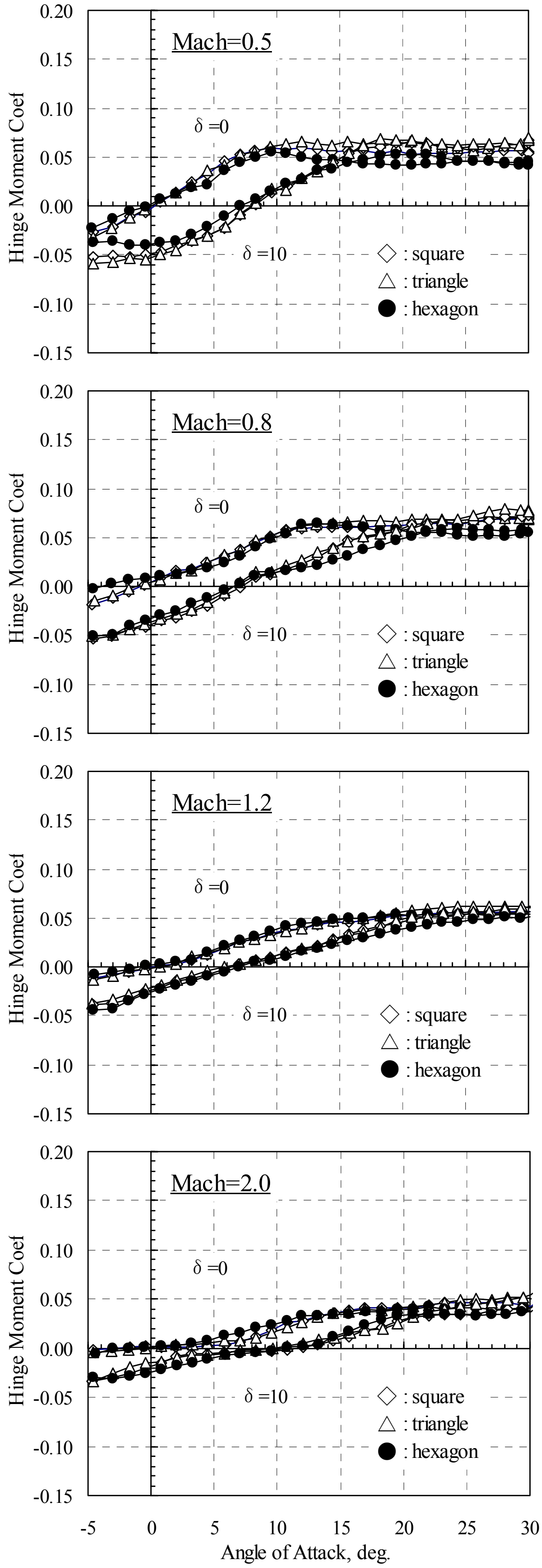

Fig. 9. Hinge Moment Coefficient Comparisons for Grid Patterns; Angle of Roll is 90 Degrees.

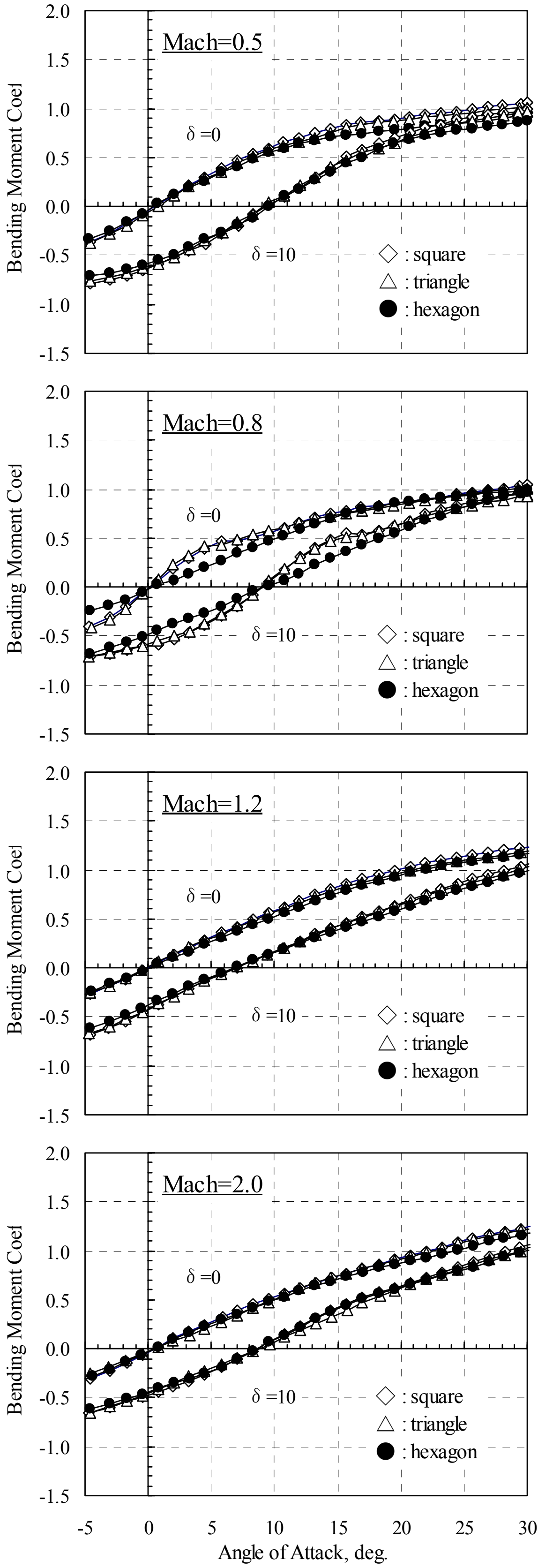

Fig. 10. Bending Moment Coefficient Comparisons for Grid Patterns; Angle of Roll is 90 Degrees.

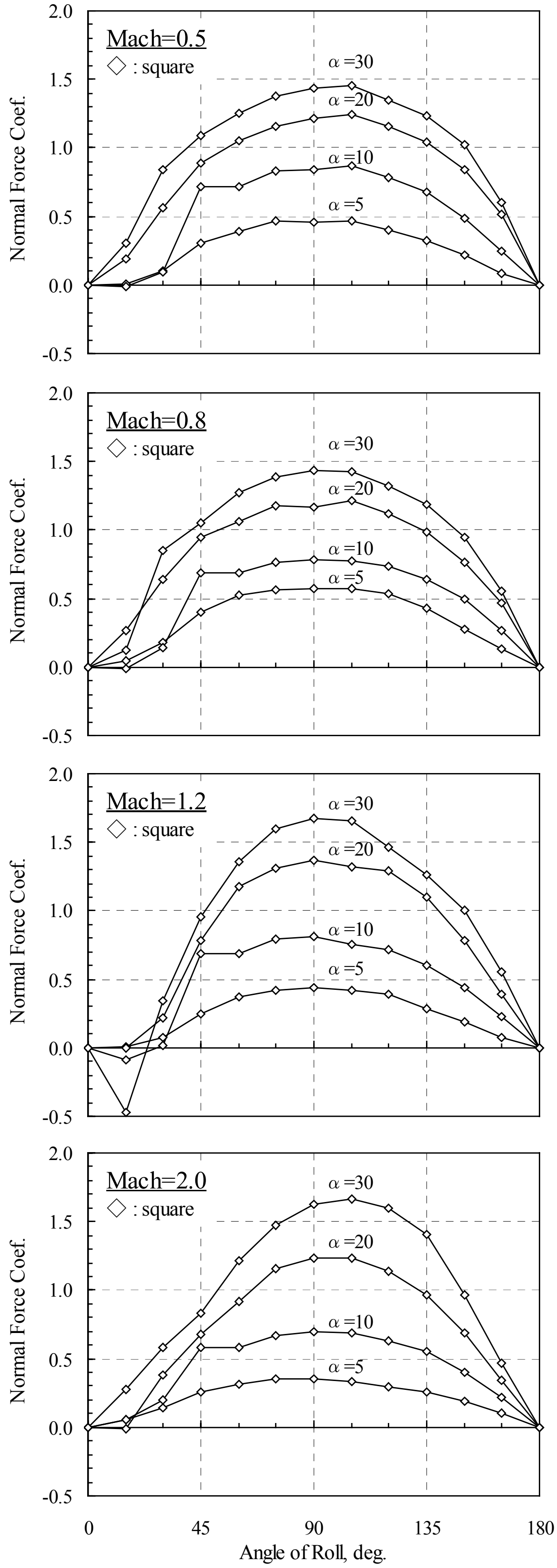

Fig. 11. Normal Force Coefficient versus Angle of Roll; Square Grid Patterns.

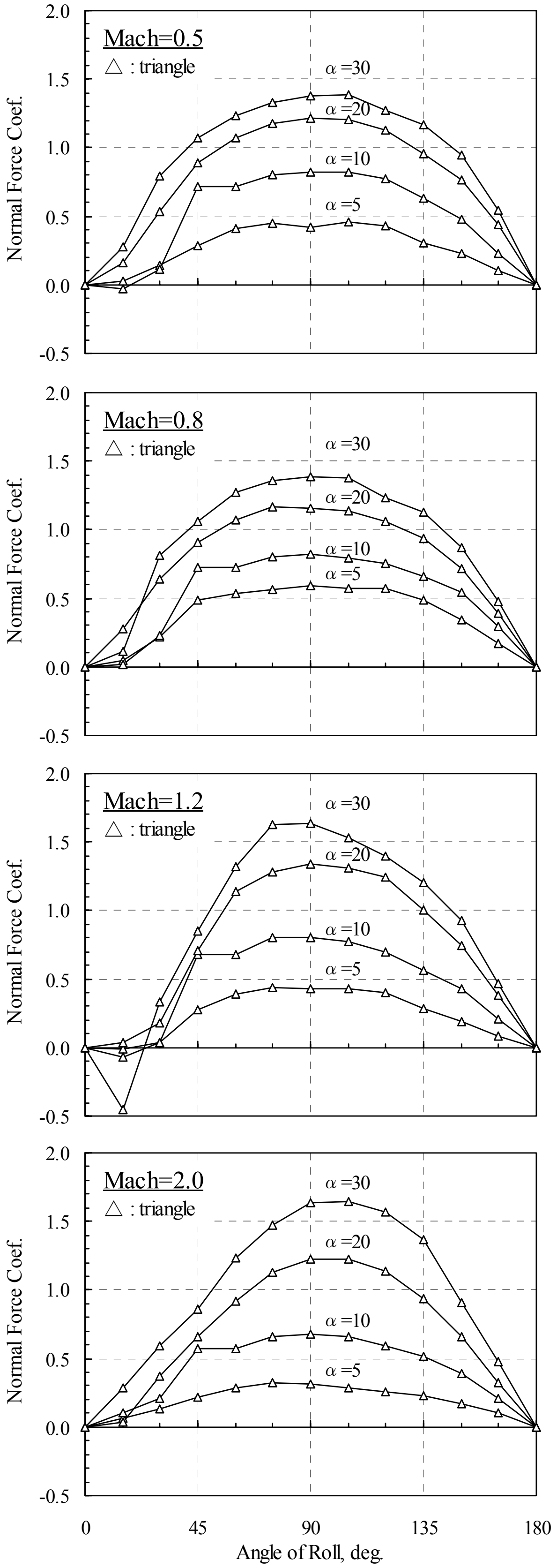

Fig. 12. Normal Force Coefficient versus Angle of Roll; Triangle Grid Patterns.

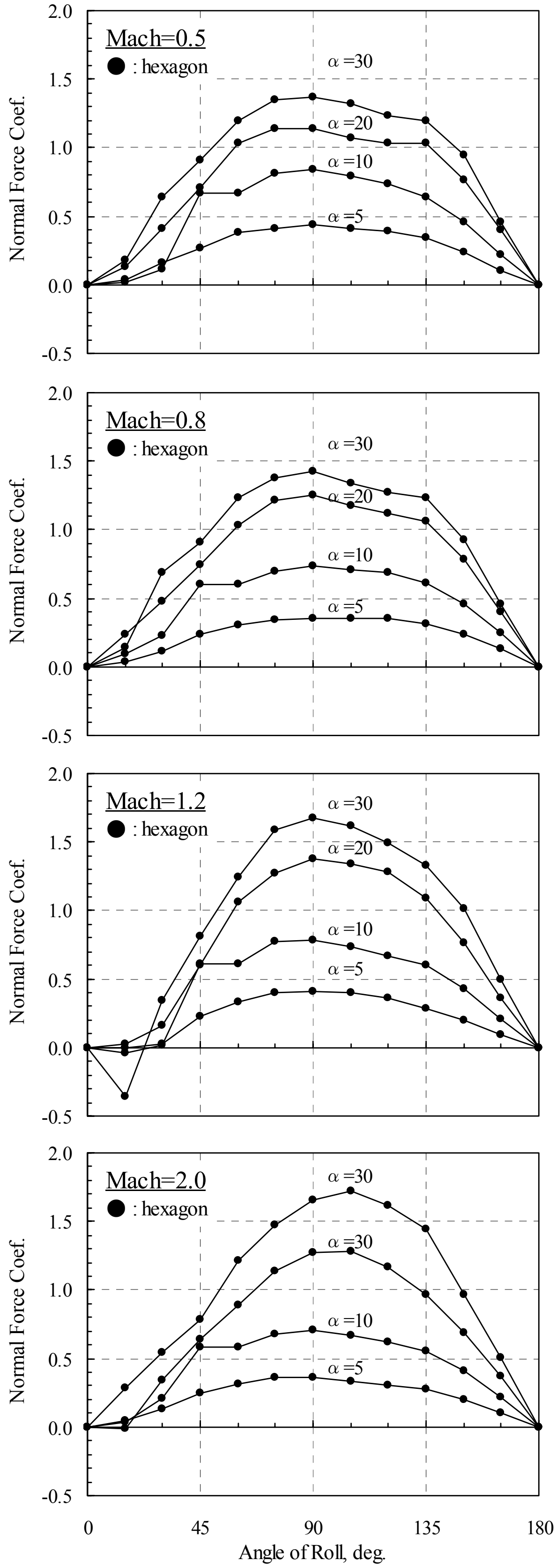

Fig. 13. Normal Force Coefficient versus Angle of Roll; Hexagonal Grid Patterns.