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# PARAMETRIC STUDY OF A GRID FIN WITH DIFFERENT SHAPES FOR AERODYNAMIC PERFORMANCE AT SUPERSONIC REGIME

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## ABSTRACT

*In a modern military, high maneuver capability for a missile is highly demanded by wide variety of nations. Missile aerodynamic performance highly depends on the control surfaces like wing, tail, etc. Designers chose an unconventional fin model to survive under critical and challenging conditions on their flight scenario. Grid fin is one of the examples for unconventional type of control surfaces that has paneled shaped with rectangular box and small intersection planar surfaces. The main advantage of the grid fins is that they have small planform area against the flow direction which leads to smaller hinge moments, requiring smaller servo mechanism. In addition, grid fins have high control effectiveness in high angle of attack due to smaller chord length. In this paper, MICOM Grid fin [Miller, 1994] wind tunnel model is used to perform computational fluid dynamic analysis to validate the methodology. Six different grid fin configurations are created by changing its chord length, thickness and span. The numerical analysis is done under supersonic conditions, 2.5 Mach number with different angle of attacks. The effects of geometrical parameters on aerodynamics performance are discussed in detailed with figures and contour plots.*

## INTRODUCTION

Today's modern tactical missiles have higher capability of control systems thanks to advance in technology. A missile flight control is characterized by its own flight dynamics that allows missile to meet system performance requirements. Missile control surfaces define the aerodynamic characteristics of a system. Grid fin is one of the unconventional type control surfaces used for missiles especially in supersonic regime. The reason for choosing grid fins is mainly due to lower hinge moments. Also, the smaller chord also gives them less likely to stall at high angle of attacks. The shapes of grid fins are extremely different than typical control surfaces so that generating different scaled model at the beginning of experimental setup is not cost-efficient. The purpose of this paper is to perform how aerodynamic performance changes with different span, thickness and chord length. To understand the aerodynamic behavior for different shapes of grid fin, normal force coefficient (CN), axial force coefficient (CA), Bending Moment Coefficient (CBM) and Hinge Moment coefficient (CHM) are calculated by numerical solver with 2nd Order k-$\varepsilon$ turbulence model. The comparison for experimental and numerical solver data was done and it was used for parametric study.

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## METHOD

### Governing Equations

The fundamental governing equations of fluid dynamic consist of continuity, momentum and energy equation. They are also a coupled system of non-linear partial differential equations and it is very difficult to have analytical solution currently. The system of solution has six conservative variables. The perfect gas assumption is required for compressible flow to close system. Compressible Navier-Stokes equations are given as Gibbs notation below.

$$\frac{D\rho}{Dt} + \rho\nabla \cdot v = 0 \tag{1}$$

$$\rho\frac{Dv}{Dt} = \rho f - \nabla \mathrm{p} + \nabla\big(\lambda(\nabla \cdot v)\big) + 2\nabla \cdot (\mu E) \tag{2}$$

$$\rho\frac{De}{Dt} = -p\nabla \cdot v + \lambda(\nabla \cdot v)^2 + 2\,\mu E{:}E + \nabla \cdot (k\nabla \mathrm{T}) \tag{3}$$

$k$: $Thermal\ conductivity$

$\mu$: $Viscosity\ coefficients$

### Geometrical Acquisition

MICOM Grid Fin geometry [Miller, 1994] is detailed in Figure 1. In addition, model is mounted on the ogive-nose missile with 5-inch diameter shown in Figure 2.

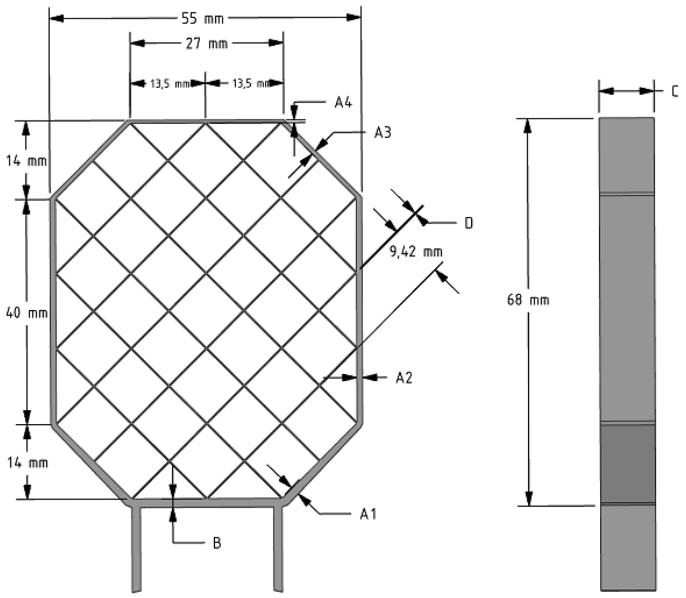



Figure 1 : MICOM Grid Fin Geometry Properties in inch (Front and Side view)

**Table 1** Grid Fin Thicknesses in millimeters

| | | | | | | |
|---|---|---|---|---|---|---|
| A1 | A2 | A3 | A4 | B | C | D |
| 1.5 to 1.0 | 1.0 | 0.76 | 0.5 | 1.5 | 9.75 | 0.2 |

Grid fin is mounted on the ogive-nose, its fineness ratio equals to 3, with tail control model. The model is 1.3-meter-long with 0.127-millimeter diameter. The reference area and length are set to body cross sectional area and body diameter respectively.

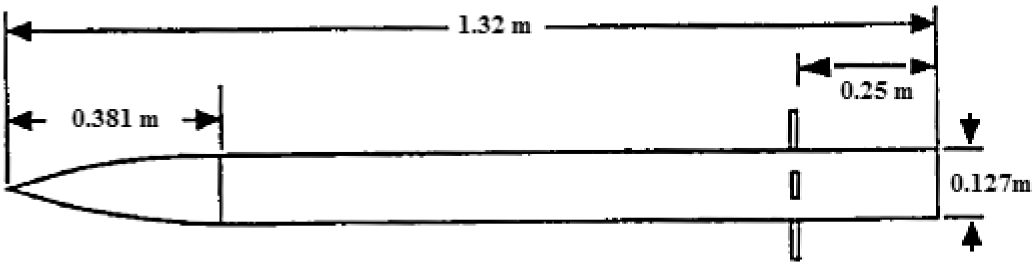



Figure 2: Missile with Grid Fin Geometry in inch

## DISCUSSION AND RESULTS

### Validation

CFD analysis are compared with experimental data from the Figure 3,4 and 5. Normal Force Coefficient, Hinge Moment Coefficients and Bending Moments error are less than 5%. In addition, there is 10-12% error in axial coefficient with experimental data. Aerodynamic coefficients are measured at the panel-4(located at the middle left with appropriate sign convention)

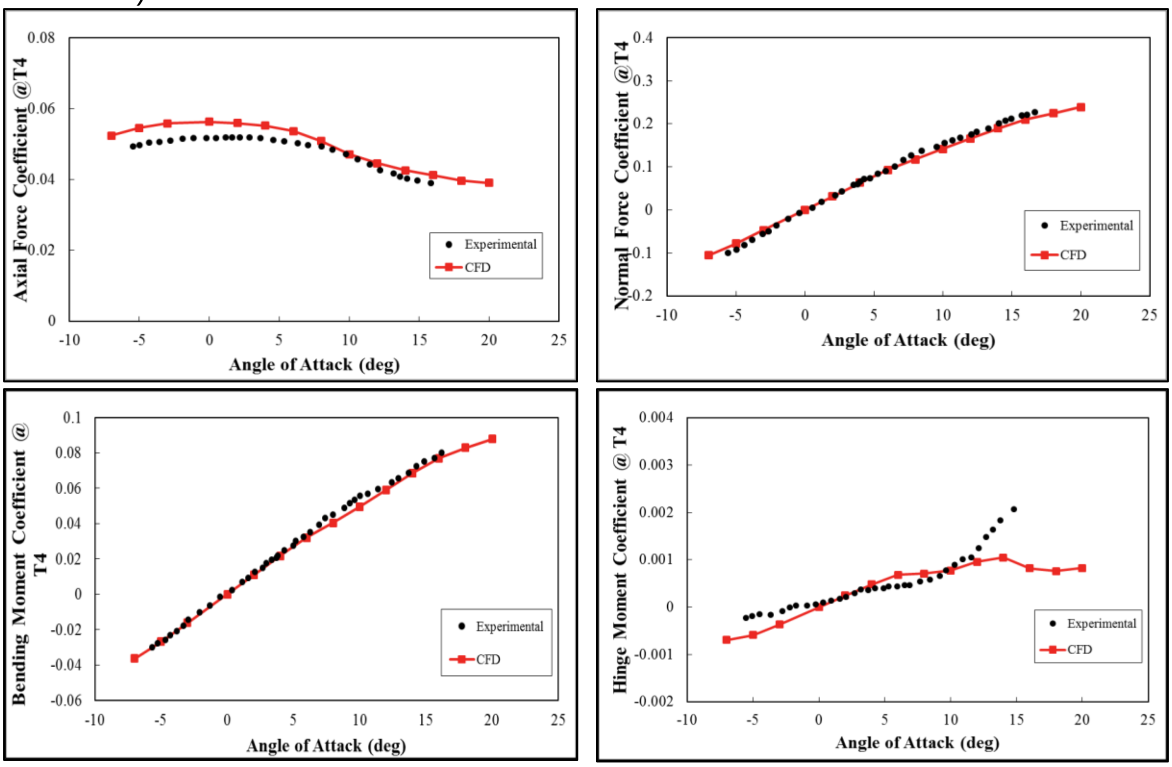



Figure 3: Comparisons for Axial Force (CA), Normal Force (CN), Bending Moment (CBM) and Hinge Moment (CHM) Coefficients vs Angle of Attack @ Mach = 2.5

From the Figure 3, numerical results for Normal Force Coefficient and Bending Moments Coefficients matching perfectly with experimental values. However, there are considerable errors for Hinge Moment Coefficients at higher angle of attack. Indeed, two possible contributions to those errors come from the lack of measurement instruments 'precision and numerical model incapability to capture the turbulent accurately.

### Parametric Study

In this part, how geometrical properties of lattice fin influence the aerodynamics performances are investigated. Span, chord and thickness are parameters to be changed for numerical analysis. Flow analysis was done when flow angle equals to 10.

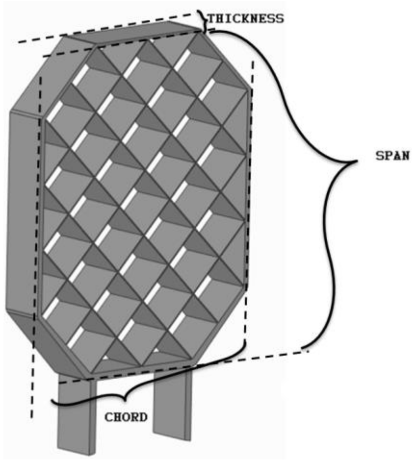



Figure 4: Lattice Fin Geometry Parameters

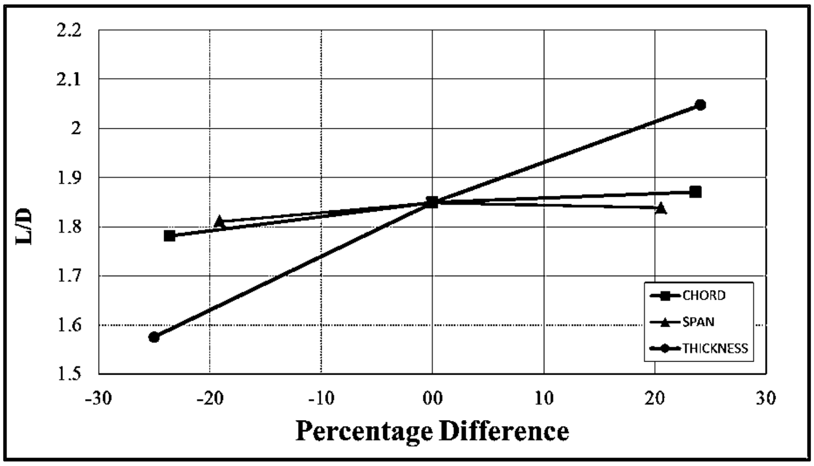



Figure 5: L/D vs Parameter Percentage Difference

Lift to drag ratio is highly sensible to chance in thickness focusing on the numerical data mention in Figure 5. It has positive relation with other parameters as well. To increase a percent in the values of lift to drag ratio, thickness, span and chord should be increased by 0.22 mm, 17.7 mm and 10.8 mm respectively.

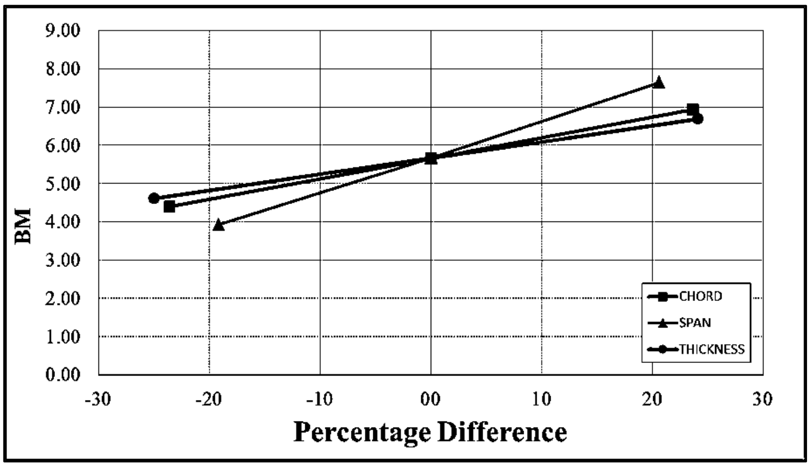



Figure 6: Bending Moment vs Parameter Percentage Difference

Changing in all three parameters perform nearly equal for Bending Moment. In addition, span has a little more affect than others, giving 2.5 percent increase in Bending Moment when 1mm added to its length. The expectation for bending moment relation with span can also be seen in the Figure 6 .

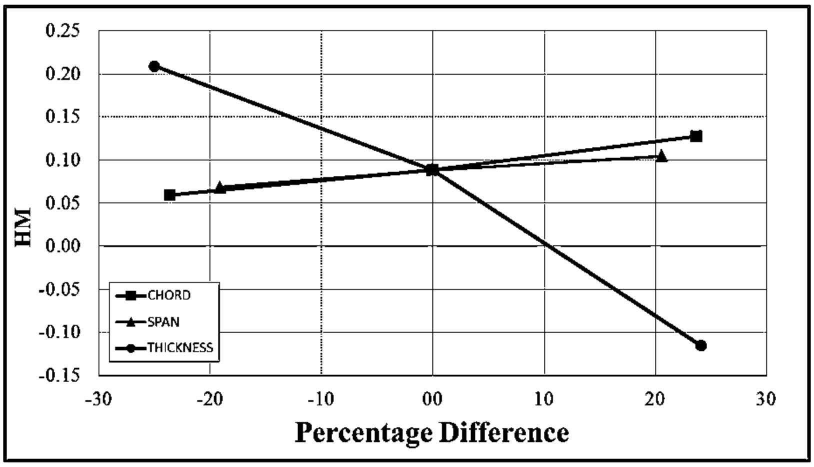



Figure 7: Hinge Moment vs Parameter Percentage Difference

Hinge Moments limitation defines the fin model geometrical details. The less hinge moments are, the better for servo mechanism selection with respect to mechanical packaging is. Span and chord perform nearly equal trend. However, changing of thickness values makes the hinge moment direction reverse for tail number 4.

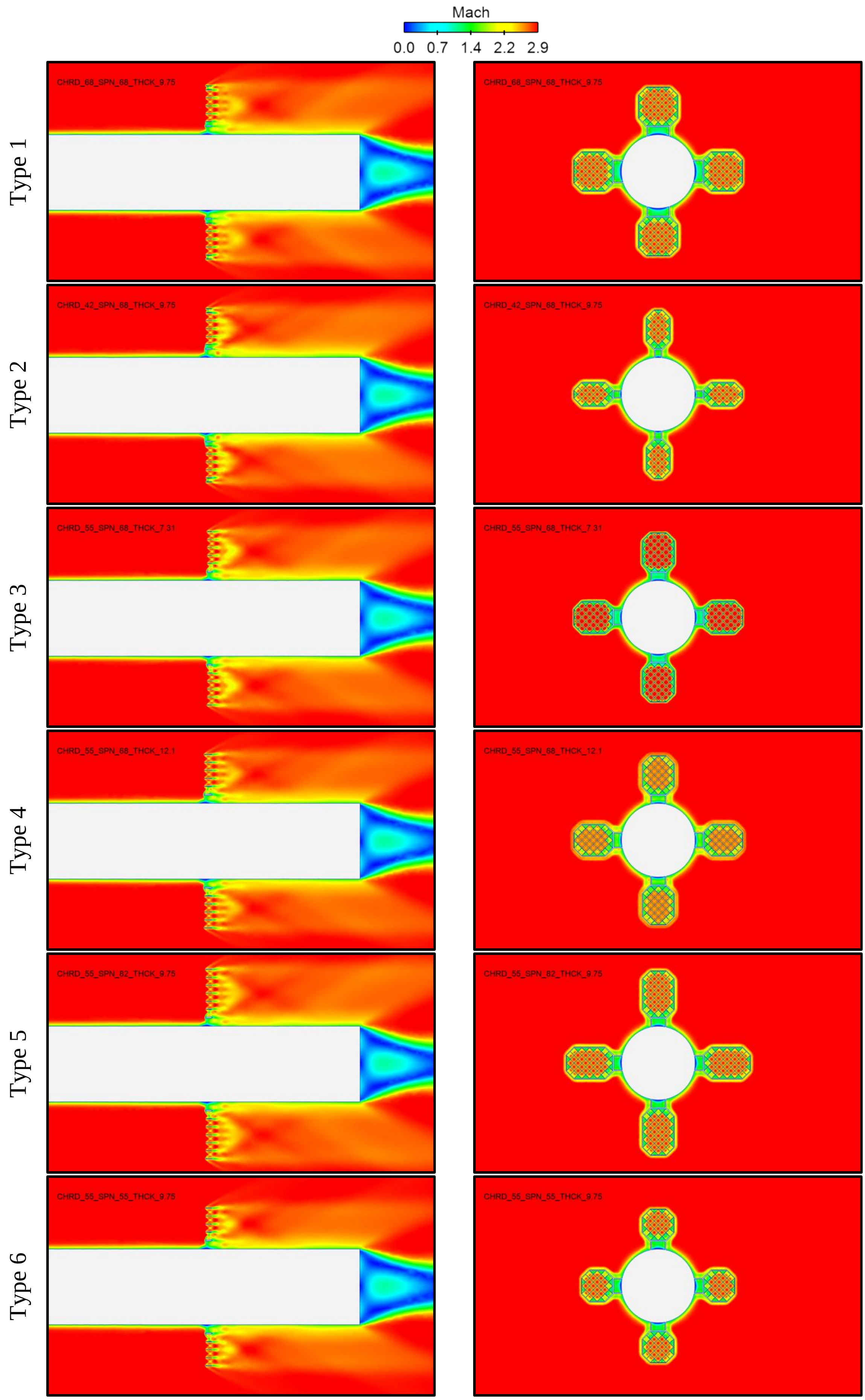
## CONCLUSION

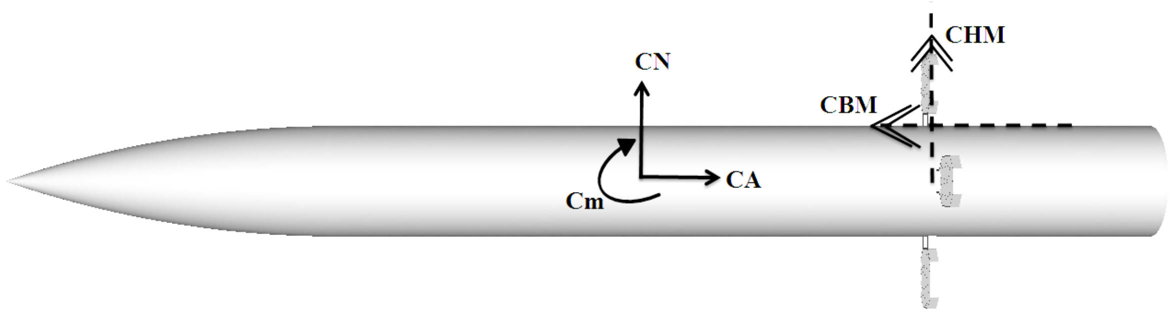
In this paper, lattice fin geometry parameters were investigated by changing their lengths to find aerodynamic performances. MICOM Grid fin was taken for validation case. The difference between numerical results and experimental data for Axial Force, Normal Force, Bending Moments and Hinge Moments Coefficients were very close. The parametric study was done by creating fin models with different span, chord and thickness at 2.5 Mach number. For L/D values for single panel, thickness has more effects than others, a percent change leading 0.45 percent change in L/D. Also, those three parameters have same behavior on Bending Moment values; a percent change in all leading nearly 0.75-1 percent change in BM. Lastly, hinge moment center direction can be turned opposite with different values for thickness. When same operation was applied (a percent change in all), a percent increase for span and 0.5 percent increased for chord was obtained. However, thickness has -0.1 percent changes, turning opposite for direction of hinge moment center. Finally, those relations can be useful especially at preliminary design stage for control surface selection.

## APPENDICES

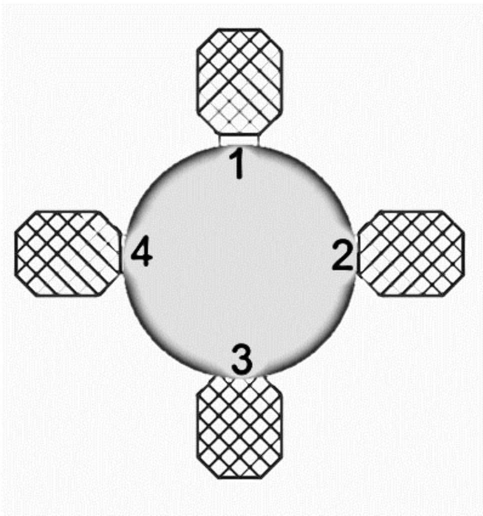
Table 2: Parametric Fin Models Geometrical Details

| | CHORD (mm) | SPAN (mm) | THICKNESS (mm) |
|---|---|---|---|
| Baseline | 55 | 68 | 9.75 |
| Type-1 | 68 | 68 | 9.75 |
| Type-2 | 42 | 68 | 7.31 |
| Type-3 | 55 | 68 | 12.1 |
| Type-4 | 55 | 68 | 9.75 |
| Type-5 | 55 | 82 | 9.75 |
| Type-6 | 55 | 55 | 9.75 |


Mach
0.0 0.7 1.4 2.2 2.9
Type 1
CHRD_68_SPN_68_THCK_9.75
CHRD_68_SPN_68_THCK_9.75
Type 2
CHRD_42_SPN_68_THCK_9.75
CHRD_42_SPN_68_THCK_9.75
Type 3
CHRD_55_SPN_68_THCK_7.31
CHRD_55_SPN_68_THCK_7.31
Type 4
CHRD_55_SPN_68_THCK_12.1
CHRD_55_SPN_68_THCK_12.1
Type 5
CHRD_55_SPN_82_THCK_9.75
CHRD_55_SPN_82_THCK_9.75
Type 6
CHRD_55_SPN_55_THCK_9.75
CHRD_55_SPN_55_THCK_9.75




**Aerodynamic Sign Convention (Side View)**




**Sketch of the Numbered Fins (Back View)**

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