

# Numerical Study on Choked Flow over Grid-Fin Configurations

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**An improved configuration, which we term a swept-back grid fin, is proposed in the present study to reduce the detrimental effects of high drag caused by the flow choking within the transonic regime. Viscous computational fluid dynamics simulations were performed to investigate flows over a missile with baseline and swept-back grid fins under supersonic and transonic conditions at zero incidence. The computed drag coefficients for the baseline missile agree well with those in the literature. Our numerical results indicate that flow choking can be reduced by using the swept-back grid fin. As a result, the drag coefficient on the fins is decreased by approximately 13% for all the Mach numbers investigated in the present study.**

## Nomenclature

$C_D$	=	drag coefficient on the whole missile
$C_{Df}$	=	drag coefficient on the grid fin only
$C_p$	=	pressure coefficient
$c$	=	chord length for a lattice grid-fin configuration
$D$	=	diameter of the cylinder
$h$	=	height for a lattice grid-fin configuration
$Ma$	=	calculated Mach number
$M_\infty$	=	freestream Mach number
$Re_D$	=	Reynolds number, $U_\infty D/\nu_\infty$
$s$	=	span for a lattice grid-fin configuration
$t$	=	thickness of the cell spar for a lattice grid-fin configuration
$U_\infty$	=	freestream velocity
$\alpha$	=	swept-back angle
$\nu$	=	kinematic viscosity

## I. Introduction

A GRID fin, also termed a lattice grid fin, is a less conventional aerodynamic control device consisting of an outer frame with an internal intersecting grid made up of cells with small chord lengths. Unlike conventional fins that are aligned parallel to the direction of the airflow, grid fins are arranged perpendicular to the flow, allowing the oncoming air to pass through the lattice grid cells.

The primary advantage of grid fins is that they have a much shorter chord length than conventional planar fins. As a result, they generate smaller hinge moments, which require smaller actuators to rotate them in a high-speed flow. The small chord length of grid fins also makes them less likely to stall at high angles of attack. This resistance to stall increases the control effectiveness of grid fins compared with conventional planar fins. Because of their unique shape and small chord length, grid fins can be conveniently folded against the body so as to make them easier to store or transport. For this reason, grid fins have attracted much attention in recent years.

The first investigation of grid-fin aerodynamics was carried out by Belotserkovskiy et al. [1] using a theoretical method that relied mainly on empirical formulas. Some analytical work has also been conducted using the vortex-lattice-type approach in the subsonic regime [2]. More recently, Theerthamalai and Nagarathinam [3] developed an aerodynamic prediction method for the estimation of the aerodynamic characteristics of grid-fin configurations at super-

sonic Mach numbers. The shock and expansion relations and the interactions between the shock and expansion waves were used to predict the pressure distribution inside each grid-fin cell.

Washington et al. [4] conducted wind-tunnel experiments to study the effects of fin curvature and leading-edge sweep back on the aerodynamic characteristics at several subsonic and supersonic Mach numbers and different angles of attack. The balance data indicated that "fin curvature has a small effect on fin normal force, hinge moment, and bending moment." Miller and Washington [5] extended the experiments to study the effects on drag of the outer frame cross-sectional shape and the cell spar thickness. Their findings indicated that a simple shaping of the frame cross section, a reduction of the cell spar thickness, or a combination of both can yield considerably lower drag levels with minimal impact on the grid-fin lift and other aerodynamic properties. Ballistic experiments conducted by Abate et al. [6] at the U.S. Air Force's Aeroballistic Research Facility (ARF) focused on the overall aerodynamic performance of missiles with grid fins in the subsonic and transonic regimes. They found a critical transonic Mach number at which normal shocks and choked flow are believed to have formed within some of the cells. At this Mach number, dynamic instabilities are visible together with rapid fluctuations in the normal force. These studies relied mainly on force and moment measurements from individual fins or from the whole missile. No attempt was made to resolve in detail the flow characteristics inside and around the lattice cells or to optimize the cross section of their walls.

Besides theoretical and experimental studies, computational fluid dynamics (CFD) analysis has been used to investigate the aerodynamic characteristics of grid-fin configurations. Chen et al. [7] conducted numerical investigations of a missile configuration with grid fins by using the NPARC code of NASA. The issue of the optimum grid-fin size, in terms of both the panel thickness and the frontal shape, was addressed. Lin et al. [8] performed computations of turbulent flows past a grid fin alone and fin-body combinations at Mach numbers of 2.5 and 0.7. The computations provided detailed flowfields, including Mach number contours, pressure contours, streamline patterns, and the integrated aerodynamic coefficients. DeSpirito and Sahu [9] and DeSpirito et al. [10] conducted CFD studies on grid fins using the commercial CFD code FLUENT, which presented the first known published viscous CFD computations of grid fins. The simulations successfully predicted the flow structures around the fin in the separated flow region at higher angles of attack. The objective was to investigate the advantages grid fins offered over conventional controls when employed on highly maneuverable missiles. DeSpirito et al. [11] also performed viscous CFD calculations to predict the aerodynamic coefficients and flowfield around a generic canard-controlled missile with planar and grid tail fins in supersonic flow. The CFD results showed the advantages of grid fins in alleviating roll control issues related to canard trailing vortex-fin interactions. Hughson et al. [12] conducted CFD studies to investigate the flowfields over the missile-grid-fin configuration tested by

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