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A Numerical Study of Magnetohydrodynamic Flows with Respect to the Hall Effect

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With a view to the utilization of magnetic fields in hypersonic flow control an extension of the Navier-Stokes equations by magnetohydrodynamic source terms is described. The DLR TAU Code is employed as numerical tool and enhanced to simulate magnetohydrodynamic effects. As axisymmetric numerical setup a hemisphere-cylinder in a Mach 9 flow in air with an onboard 3-D dipole is chosen. The wall of the blunt body is assumed to be electrically conducting. The induced electric current density is determined by the generalized Ohm's Law. Different simulations with application of the magnetic field and with respectively without Hall effect are presented. The results are compared to a reference simulation without magnetic field. The impact of the magnetohydrodynamic source terms results in an increment of the shock distance compared to simulations without magnetic field. Thereby the effect depends on the treatment of the Hall parameter. In particular it turns out that the enhancement is reduced signifcantly if the Hall parameter is calculated as a local variable.

Nomenclature

$\bar{\bar{\tau}}$	Total stress tensor
E_t	Total energy
q	Heat flux term
$\vec{j}$	Electric current density
$\vec{B}$	Magnetic induction vector
$\vec{E}$	Electric field vector
σ	Electrical conductivity
$\vec{m}$	Dipole moment
$\vec{r}$	Position vector
e	Elementary charge
N_e	Electron number density
ϕ	Electric potential
μ_0	Magnetic permeability

I. Introduction

A body moving at hypersonic speed is surrounded by highly ionized plasma, resulting from the temperature jump the freestream gas is exposed to when passing through the bow shock. In 1958 Resler and Sears suggested to incorporate onboard electromagnets for application in reentry flight control.[1] The field of the electromagnet interacts with the ionized plasma around the vehicle. The resulting body force can influence the flow in a significant way. The theory applicable to describe the interaction between ionized flow and a magnetic field is called magnetohydrodynamics (MHD). In Ref.1 Resler and Sears mentioned several problems to utilize electromagnetic forces in hypersonic flights, especially the difficulty of developing a magnet powerful enough to provide the required field. Nowadays, superconductors can be imployed to construct a strong electromagnet at relatively small weight. Consequently, the technological development since the 1950's has lead to a growing interest in applying magnets in aerodynamics (for an overview see Shang[2,3]).

In the present study the DLR TAU Code modified for hypersonic flows is used.[4,5] The code is a well

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