Axisymmetric Implicit Blunt-Body Computation of Solar Wind Flows Past Planets

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Abstract

IN recent years, plasma and magnetic field data acquired in the vicinity of the Earth, Mars, and Venus have disclosed two essentially different types of interactions with the solar wind, depending upon whether the planet has a magnetic field or not. The primary emphasis of this paper is on the application of a recently developed axisymmetric implicit unsteady Euler equation solver[1,2] to the calculation of the flowfield properties of steady, axisymmetric, supersonic/hypersonic flows past blunt-nosed shapes characteristic of the interplanetary solar wind flows past both magnetic and nonmagnetic planets. The purpose is to demonstrate both the accuracy and flexibility of this new technique, as well as to present a novel application of such supersonic blunt-body procedures.

Contents

For a magnetic planet, a magnetosphere is established which acts as an obstacle in the supersonic flow of the solar wind. No solar wind flow crosses the boundary of the magnetosphere, termed the magnetopause, and a bow wave is established some distance upstream. For nonmagnetic planets such as Venus or Mars, the electrical conductivity and density of the upper ionosphere are sufficiently great that the solar wind is deflected around the ionosphere, with a corresponding bow wave standing off from the ionosphere boundary or ionopause. Aside from the evident differences in the underlying physical processes occurring at the two boundaries (i.e., the magnetopause and the ionopause), the principal difference between the two flows is the size of the cavity formed in the solar wind. The ionopause is wrapped much closer around Venus or Mars than the magnetopause is around Earth, the nose being at an altitude of about 500 km for Venus and probably about 175 km for Mars, compared with about 60,000 km for Earth. However, as far as the gasdynamic flow is concerned, the basic patterns are similar, with the only significant difference being the particular boundary shapes.

Although somewhat surprising at first, it has been amply demonstrated[3,4] that the magnetohydrodynamic equations governing solar wind flows simplify in such a fashion that the average bulk properties of the flow can be determined adequately by the inviscid continuum equations for a perfect gas (Euler equations). The corresponding magnetic and electric fields then can be found by a separate subsequent calculation using the previously determined flowfield properties. Only results for the flowfield will be presented here.

The blunt-body computational procedure employed consists of an axisymmetric implicit unsteady Euler equation solver[1,2] and proceeds by mapping the physical domain bounded by the bow shock, body surface, symmetry plane, and outflow boundary into a rectangular computational domain. Flow properties at interior points are determined by advancing an implicit finite-difference algorithm[1,2] in time until a converged steady-state solution is obtained. The outermost shock separating the freestream from the nonuniform flow surrounding the body is treated as a sharp discontinuity, while the flowfield between body and outermost shock is computed in a shock-capturing fashion to allow for the automatic formation of secondary internal shocks.

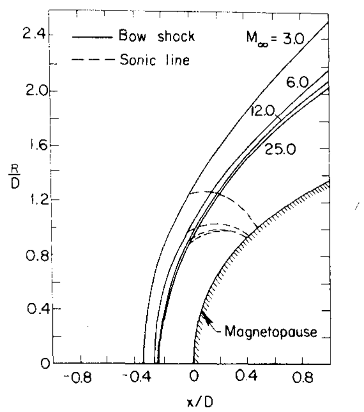

Fig. 1 Bow wave and sonic line locations for various supersonic flows past the equatorial trace of the magnetopause with $\gamma = 5/3$.

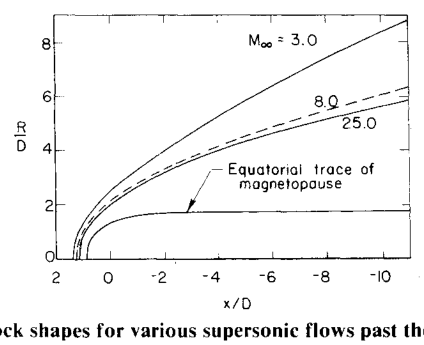

Fig. 2 Shock shapes for various supersonic flows past the equatorial trace of the magnetopause; combined near (blunt-body) and far (marching) solutions.

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Index categories: Computational Methods; Supersonic and Hypersonic Flow; Atmospheric and Space Sciences.

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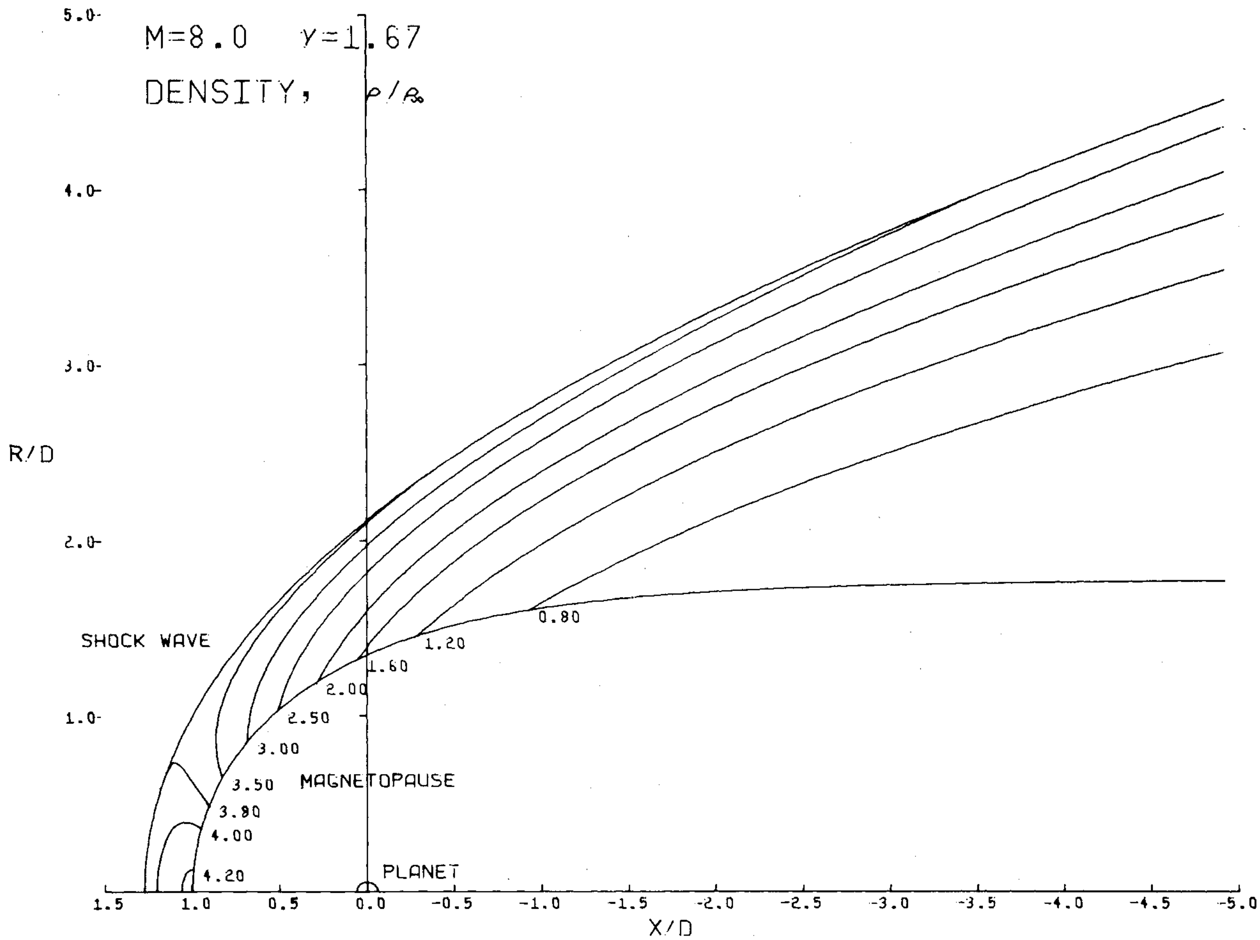

Fig. 3 Density map for $M_\infty = 8.0$, $\gamma = 5/3$ flow past the equatorial trace of the magnetopause; combined blunt-body and marching flowfield.

Several hydromagnetic flows around the equatorial trace of the magnetosphere are shown in Fig. 1 for $\gamma = 5/3$ and freestream Mach number $M_\infty = 3$, 6, 12, and 25. The dashed line indicated on the plots represents the sonic line. In some cases of solar wind flows, it is of interest to proceed far downstream of the planetary object. Figure 2 displays such a calculation for the location of the bow wave at three different Mach numbers, $M = 3$, 8, and 25, as the flow continues downstream past the equatorial trace of the magnetopause. The far-field portion of the flow was determined by using the marching technique developed by Kutler et al.[5] This example demonstrates the current capability[6] of solving the complete (near and far) flowfield for solar wind flows past terrestrial planets. In Fig. 3, the computer-generated contour map of density ρ/ρ_∞ is shown for the complete near- and far-field flow about the equatorial trace of the magnetosphere for $M_\infty = 8$ and $\gamma = 5/3$.

Acknowledgment

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