SOUTHWEST RESEARCH INSTITUTE
ANNUAL PROGRESS REPORT
NASA GRANT NO. NAGW-2621

AN MHD STUDY OF THE INTERACTION BETWEEN THE SOLAR WIND AND THE INTERSTELLAR MEDIUM

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Period covered by report:
Second year of above grant

(NASA-CR-192353) AN MHD STUDY OF THE INTERACTION BETWEEN THE SOLAR WIND AND THE INTERSTELLAR MEDIUM Annual Progress Report (Southwest Research Inst.) 4 p

N93-23067

Unclas

G3/92 0150577

SUMMARY

The overall objective of this research program is to obtain a better understanding of the interaction between the solar wind and the interstellar medium through the use of numerical solutions of the time-dependent magnetohydrodynamic (MHD) equations. The simulated results will be compared with observations where possible and with the results from previous analytic and numerical studies. The primary progress during the first two years has been to develop codes for 2-D models in both spherical and cylindrical coordinates and to apply them to the solar wind-interstellar medium interaction. Computations have been carried out for both a relatively simple gas-dynamic interaction and a flow-aligned interstellar magnetic field. The results have been shown to compare favorably with models that use more approximations and to modify and extend the previous results as would be expected. Work has also been initiated on the development of a 3-D MHD code in spherical coordinates.

I. SCOPE OF THE INVESTIGATION

The interaction of the solar wind with the interstellar medium has received increased interest recently due to improved observations of the local interstellar medium and to the fact that a deep space probe may soon intersect the shock terminating the supersonic solar wind flow. Previous theoretical and computational efforts at studying the interaction have been hampered by a lack of observational guidance and have not been developed to the level necessary to determine the quantitative effects of some of the important known physical processes on the global interaction. When used in conjuction with present and forthcoming observations, the present models may assist in determining the effects of the relevant physical processes. In addition, they may also indirectly be able to place bounds on the currently unknown or speculative values of physical quantities in the local interstellar medium as well as the location of the termination shock and the heliopause.

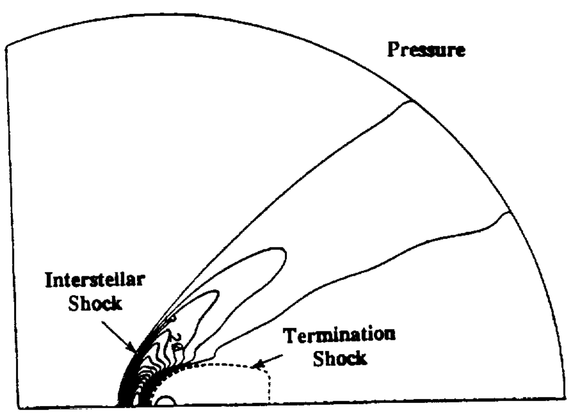
Time-dependent, multi-dimensional, gas dynamic and MHD codes will be used to study this interaction through the use of a relaxation technique in which an assumed non-equilibrium initial state approaches a final steady-state equilibrium. Although the codes incorporate numerous physical mechanisms, they can optionally be included in individual studies. The approach is to begin with simple cases, to compare with applicable earlier work and build on the previous results, and to separately include effects, such as the interstellar and interplanetary magnetic fields, thereby providing a consistent basis from which to quantify the effects of a particular mechanism.

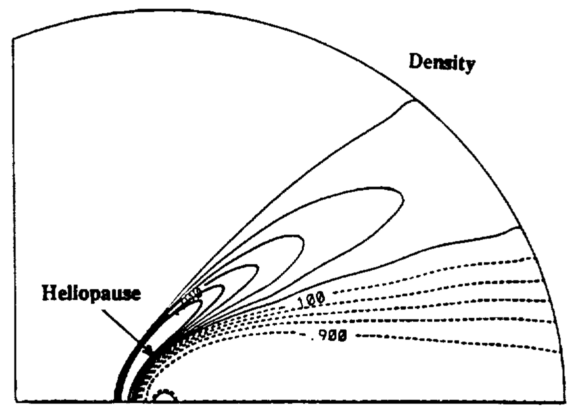
The overall objective is to achieve a better understanding of the processes involved in the interaction. Some of the more specific issues that this study will address are (a) the influence of various thermodynamic, dynamic, and magnetic conditions in the interplanetary and interstellar mediums on the location of the terminal shock and the heliopause, (b) the differences between two-dimensional and three-dimensional models, (c) the complete self-consistent global interaction including the tail region, and (d) the effect of both temporal and spatial gradients in solar wind parameters. Model predictions will be compared with observations whenever possible, and the available observations will be used to provide guidlines on model input values for the solar wind and interstellar medium.

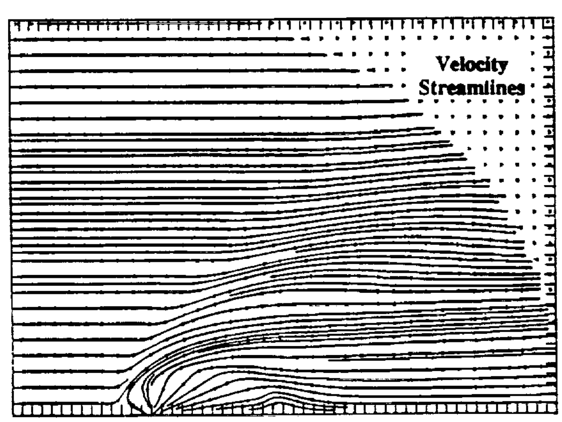
II. PROGRESS TO DATE

As mentioned previously, the MHD simulations will ultimately be performed using a three-dimensional model. However, due to the large memory and computation time requirements for the 3-D simulations, the initial computations have been carried out using a 2-D model. These preliminary 2-D simulations serve several purposes in addition to providing useful physical insight. They will be used to determine some of the numerical parameters required in the 3-D studies, such as the grid spacing needed in order to resolve particular features and the damping that must be including to remove highfrequency oscillations. Furthermore, the first computations neglect the magnetic field so the results can be compared directly with those from more approximate analyses.

Two separate codes for the 2-D model have been developed. In one the equations are solved in the r-θ plane of a cylindrical coordinate system in which the axial (z) axis is perpendicular to the interstellar flow direction. For the second the equations are solved in a spherical coordinate system. The two coordinate systems are used in order to allow greater flexibility for the inclusion of a magnetic field within the confines of a 2-D model. A variable grid spacing is incorporated in the radial direction to provide better resolution in the solar wind portion (and near the termination shock) of the interaction. The magnetic field is neglected in these initial computations. A typical result for a supersonic interstellar flow in spherical coordinates is shown in the following figures of the pressure and density contours and the velocity streamlines. The Mach number of the interstellar flow is 2.5 for this computation, and the solution has reached a dynamic equilibrium at the time shown.

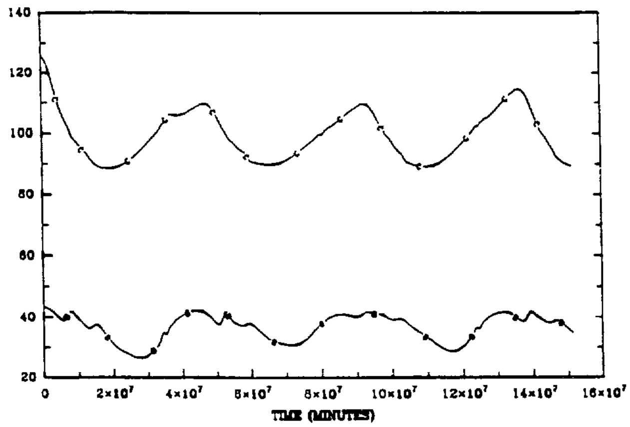






As would be expected, both a termination shock and a shock to slow the interstellar flow to subsonic speed are formed. The interstellar flow is from left to right in the figure and is responsible for noticeably distorting the termination shock in the downstream direction. The 2-D results have been analyzed and compared with results from more simplified earlier studies (e.g., the gas dynamic study of Baranov, Space Sci. Rev., 52, 89, 1990). The results of this study were presented at two international conferences and the Fall AGU meeting, and papers are currently in preparation. Abstracts have also been submitted to the Spring AGU meeting and the URSI meeting in Japan.

A completely unanticipated result is the fact that the interaction does not come to a dynamic equilibrium when the interstellar Mach number is supersonic but less than approximately 2.0. The solution oscillates radially with the termination shock and the heliopause moving in and out at a fixed, repeatable frequency. The radial motion of these discontinuities along the radius extending upstream into the interstellar flow is illustrated in the following figure (termination shock result is shown in the bottom curve). The amplitude decreases with increasing interstellar Mach number until it disappears at about 2.0.



Now that the gas dynamic interaction in our 2-D model is better understood, the next step is to include a flow-aligned interstellar magnetic field. The magnetic field has been added to the code, and preliminary simulations have been performed.

A significant part of any multi-dimensional study such as that discussed here is the development of suitable graphics to assist in the physical interpretation of the simulated results. With partial support from the present grant the pv-wave software package has been and continues to be extended to produce 2-D and 3-D displays of particular interest to the present work. For instance, the ability to generate shaded 3-D plots of a given value of a physical quantity is being developed. Spatial plots of overlays of magnetic field lines, velocity vectors, and velocity streamlines on the distribution of a thermodynamic quantity such as the particle density are also under development.

III. PRESENTATIONS AND PAPERS

R.S. Steinolfson, A numerical study of the interaction between the solar wind and the interstellar medium, **Solar Wind VII**, Goslar, Germany, 16-20 September 1991.

R.S. Steinolfson and T.E. Holzer, A numerical study of the interaction between the solar wind and the interstellar medium, **XVII General Assembly of the European Geophysical Society**, Edinburgh, Scotland, 6-10 April 1992.

R.S. Steinolfson, V. Pizzo, and T. Holzer, The interaction of the solar wind with the interstellar medium, **EOS, 73**, 445, 1992.

R.S. Steinolfson and V. Pizzo, Gas-dynamic simulations of the two-shock model of the solar wind/interstellar medium interaction, **Spring AGU Meeting**, submitted, 1993.

R.S. Steinolfson, The interaction of the solar wind with the interstellar medium, **XXIV General Assembly of the International Union of Radio Science**, Kyoto, Japan, 25 August-2 September 1993.

R.S. Steinolfson, V. Pizzo, and T. Holzer, Gas dynamic models of the solar wind/interstellar medium interaction, **Geophys. Res. Lett.**, in preparation, 1993.

R.S. Steinolfson, An MHD simulation of the solar wind-interstellar medium interaction, **Astrophys. J.**, in preparation, 1993.