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First Quarterly Progress Report

DEVELOPMENT OF A GLOBAL 3-D MAGNETOHYDRODYNAMIC COMPUTATIONAL MODEL FOR SOLAR WIND/COMETARY AND PLANETARY STUDIES

Contract NASW-4011

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DEVELOPMENT OF A GLOBAL 3-D MAGNETOHYDRODYNAMIC
COMPUTATIONAL MODEL FOR SOLAR WIND/COMETARY
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1. INTRODUCTION

This is the first Quarterly Progress Report under Contract NASW-4011. The work under this contract involves the development of a global, 3-D magnetohydrodynamic computational model to quantitatively describe the detailed continuum field and plasma interaction process of the solar wind with cometary and planetary magneto/ionopause shapes. The specific objectives of this first phase of the proposed three-phase investigation is to extend the present highly-successful solar wind/terrestrial planet interaction (Level 1) model (which is based on an axisymmetric gas dynamic plus frozen field approximation to the full MHD equations) to a full 3-D gas dynamic (Level 2) approximation, and also to develop and implement a mass loading capability in the Level 1 interaction model.

During this reporting period the technical tasks worked on included development and implementation of several enhancements to the present Level 1 model, preliminary development of the 3-D gas dynamic flow field solvers for the Level 2 model, and development of the 3-D frozen magnetic field solver for the Level 2 model. The work accomplished on each of these tasks is described in detail in the following sections.

2. ENHANCEMENTS OF LEVEL 1 MODEL

A number of important enhancements were developed and implemented in the Level 1 solar wind/terrestrial planet interaction model. First, the basic version of the Level 1 code that was developed on the NASA/Ames Research Center CDC 7600 computer facility was appropriately modified, brought up, and, through a series of case studies, verified on the RMA PRIME superminicomputer. A separate double-precision version of that code was then also developed and archived. This was done to enable exact comparisons to be made of results obtained from the Level 1 model when employing the RMA superminicomputer against corresponding model results obtained when using certain mainframe supercomputer facilities, such as the CRAY XM-P. For comparative calculations, a double-precision version is necessary due to the difference in significant digits carried for single precision arithmetic on CDC and CRAY supercomputers (14-16 digits), and those on IBM and IBM derived operating systems (7-8 digits) such as the PRIME superminicomputer. Both single and double-precision versions of the Level 1 model are now fully active and, in fact, copies have been requested and distributed to several interested space scientists. Finally, an extended graphics capability was developed for the Level 1 model. This was done to provide a complete graphical output on the RMA Printronix printer of all the detailed plasma and field parameters calculated by the model throughout the interactive magnetosheath region. This task required an entire rewrite of the originally developed graphics. The output package now includes: maps of the plasma streamlines, velocity, temperature, and density contours; magnetic field contours and field line patterns; spacecraft trajectory diagrams (ecliptic and polar plane views); time histories of plasma density, temperature, velocity magnitude, three velocity components; magnetic field magnitude, and three magnetic field components. This feature of having a complete graphics output package for use on a high-density dot matrix printer, has never been available before with the model. The output is essentially report quality, and the capability provides in effect the means for instantaneous viewing of the model results at almost no cost. This is ideal for comparative studies with other theories and, particularly, observational results. Figures 1-3 provide some examples of an abbreviated subset of the complete graphical output. Finally, the graphics package developed was intentionally based on CALCOMP routines which is a widely available industry standard. This enables the entire package to be easily transferable to other facilities.

3. PRELIMINARY DEVELOPMENT OF LEVEL 2 FLOW FIELD MODEL

For reasons that were described in detail in the proposal, the general procedure for the development of the model under this contract is such that in its final form the model will embody a hierarchy of three different levels of accuracy and associated computational algorithms. These levels are:

Level	Model
1	Axisymmetric gas dynamic + frozen $\underset{\sim}{B}$ field
2	3-D gas dynamic + 3-D frozen $\underset{\sim}{B}$ field
3	3-D MHD

A major objective of the first phase of the present study is to develop the Level 2 3-D gas dynamic plus 3-D frozen $\underset{\sim}{B}$ field model. For reasons also described in detail in the proposal, all 3 levels of the model will contain two separate flow field solvers coupled together to determine the entire steady state flow field. This feature of our model, which is unique among all currently existing global interaction models, allows very high resolution of the entire flow field, particularly in the tail region. As illustrated in Figure 4, where a typical flow field grid density of the combined Level 1 axisymmetric flow solvers is shown, the region from the subsolar point to the terminator plane is solved via a time marching solver (NOSE code) to the steady state; whereas the region downstream of the terminator is solved via a spatially marching solver (TAIL code) which advances the solution downstream as far as required. The development of the corresponding 3-D versions of the NOSE and TAIL codes (NOSE3D, TAIL3D) is described below.

3.1 Level 2 Nose Region Flow Solver: NOSE3D Code

After an extensive review, the selection of the basic method to be employed in the NOSE3D code has now been made. The methodology will be based upon the AIR3D code developed at NASA/Ames Research Center (Ref. 1). The solution algorithm employed is the Beam and Warming implicit approximate factorization algorithm used in delta form described in Ref. 2. The original basic algorithm is first-order accurate in time, noniterative, second-order accurate in spatial derivatives with central difference operators. This methodology is capable of solving both the inviscid gas dynamic Euler equations as well as, if required, a certain form of the viscous gas dynamic equations known as the thin-layer Navier-Stokes equations. These equations include certain additional terms over and above the Euler equation level which represent viscous effects in the body-normal direction. This capability is important to our study for future planned applications in order to study certain viscous effects near magneto/ionopause boundaries. The mesh employed in this method is one which incorporates a fitted shock outer boundary which exactly satisfies the unsteady, 3-D Rankine-Hugoniot relations and moves with the shock during the convergence process. The inner boundary is implemented as a fitted stationary surface. A mesh clustering capability for high density clustering in the body-normal direction has been implemented specifically to enable accuracy to be maintained for viscous calculations. The NOSE3D code is currently being modified for implementation on the RMA PRIME computer. Additionally, comparative computations are underway using the Level 1 NOSE code on certain simple magneto/ionopause shapes. These are being archived for use in future benchmark comparisons with the Level 2 NOSE3D code.

3.2 Level 2 Tail Region Flow Solver: TAIL3D Code

The gas dynamic solver to be employed for the Level 2 solution of the 3-D tail region of the flow field will be based on the 3-D gas dynamic marching code reported in Ref. 3. The solution algorithm is a shock capturing, fully conservative form that employs second-order noncentered spatial derivatives to solve the steady, inviscid, gas dynamic Euler equations. As with the NOSE3D code, the mesh to be used with the TAIL3D code will employ a fitted outer boundary for the bow shock, at which location the steady 3-D Rankine-Hugoniot relations are exactly satisfied. The inner boundary of the mesh will also be fitted but to an impenetrable surface. Currently, the necessary geometry routines required to apply the TAIL3D solver to nonaxisymmetric magneto/ionopause surfaces typical of those in the solar system (Earth, Jupiter, Saturn) are being developed.

3.3 Development of Level 2 3-D Frozen $\underset{\sim}{B}$ Field: MAG3D Code

A method has also now been chosen to determine the frozen $\underset{\sim}{B}$ field for a general 3-D gas dynamic flow field. The implementation involves the 3-D generalization of the kinematic procedure used in the present

Level 1 model to determine the perpendicular component of the magnetosheath B field via the Alksne and Webster (Ref. 4) decomposition method. That simpler decomposition method is valid only for axisymmetric flow fields and no longer applies to 3-D flows. The generalized 3-D kinematic B field procedure has now been derived. The coding of a preliminary version of the method is almost complete.

4. TASKS PLANNED FOR NEXT REPORTING PERIOD

During the next reporting period, work will be concentrated on completion of the 3-D frozen field (MAG3D) code. Comparative computations of that generalized procedure will be made with the decomposition method in the present Level 1 model. Modifications will be completed on the 3-D nose region flow solver (NOSE3D) to enable the code to be brought up on the RMA PRIME computer. The code will then be activated and initial verification calculations carried out as far as possible. Separate benchmark computations of the NOSE3D code will be also carried out on the NASA/ARC CRAY XM-P for future comparative studies. Finally, the special geometry routines needed to describe nonaxisymmetric magneto/ionopause shapes will be developed for the TAIL3D code. If time permits, the TAIL3D code will be brought up on the RMA PRIME computer.

REFERENCES

1. Pulliam, T. H. and Steger, J. L.: On Implicit Finite-Difference Simulations of Three-Dimensional Flow. AIAA Paper 78-10, January 1978.

2. Beam, R. and Warming, R. F.: An Implicit Factored Scheme for the Compressible Navier-Stokes Equations. AIAA Paper 77-645, June 1977.

3. Kutler, P., Warming, R. F. and Lomax, H.: Computation of Space Shutle Flow Fields Using Noncentered Finite-Difference Schemes. AIAA Journal, Vol. 11, No. 2, February 1973, pp. 196-204.

4. Alksne, A. Y. and Webster, D. L.: Magnetic and Electric Fields in the Magnetosheath. Plan. and Space Sci., Vol. 18, pp. 1203-1212, 1970.

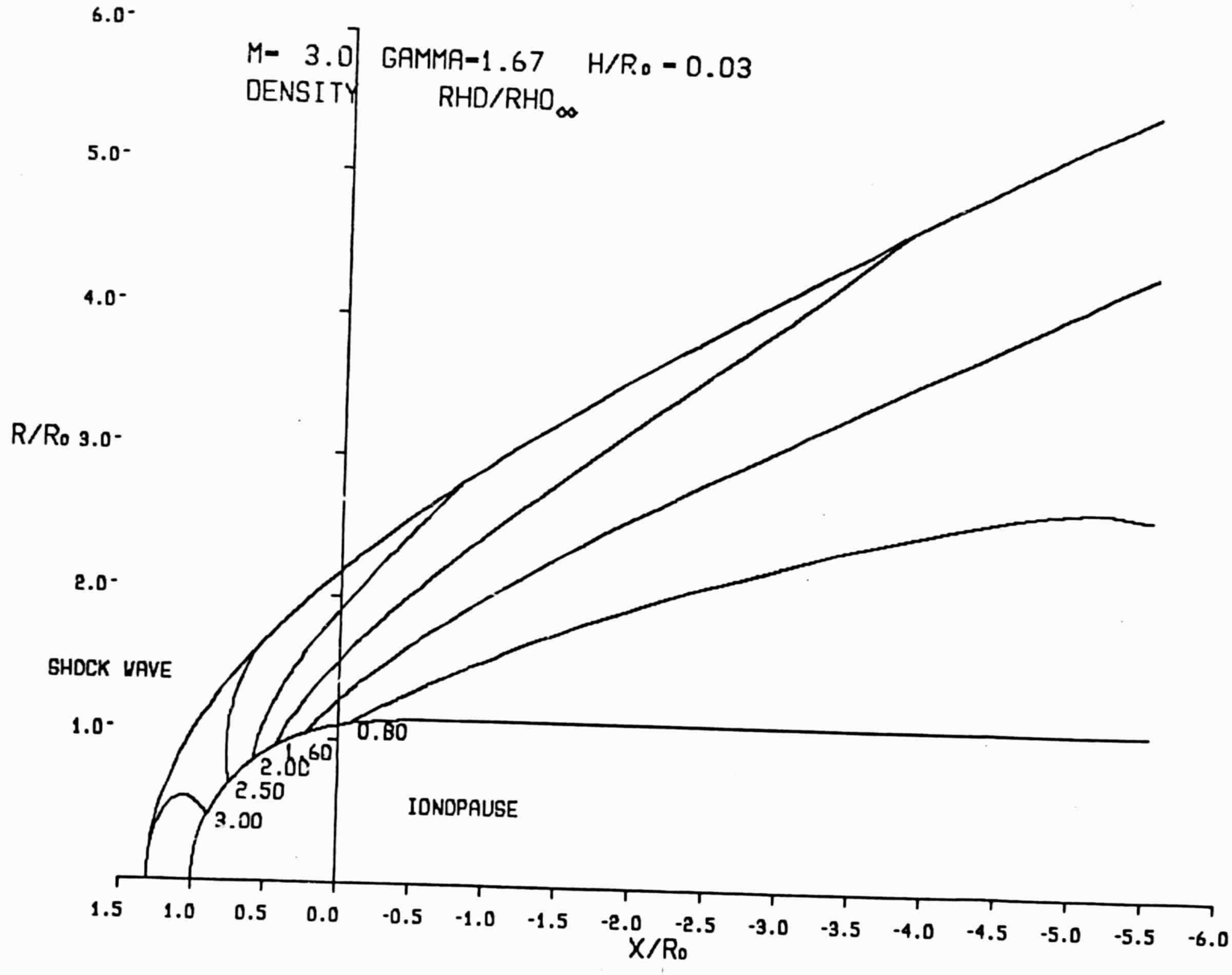

Figure 1. Sample flow field output from Level 1 model graphical output package: density contours for $M_\infty = 3.0$, $\gamma = 5/3$ flow past an ionopause shape with $H/R_0 = 0.03$

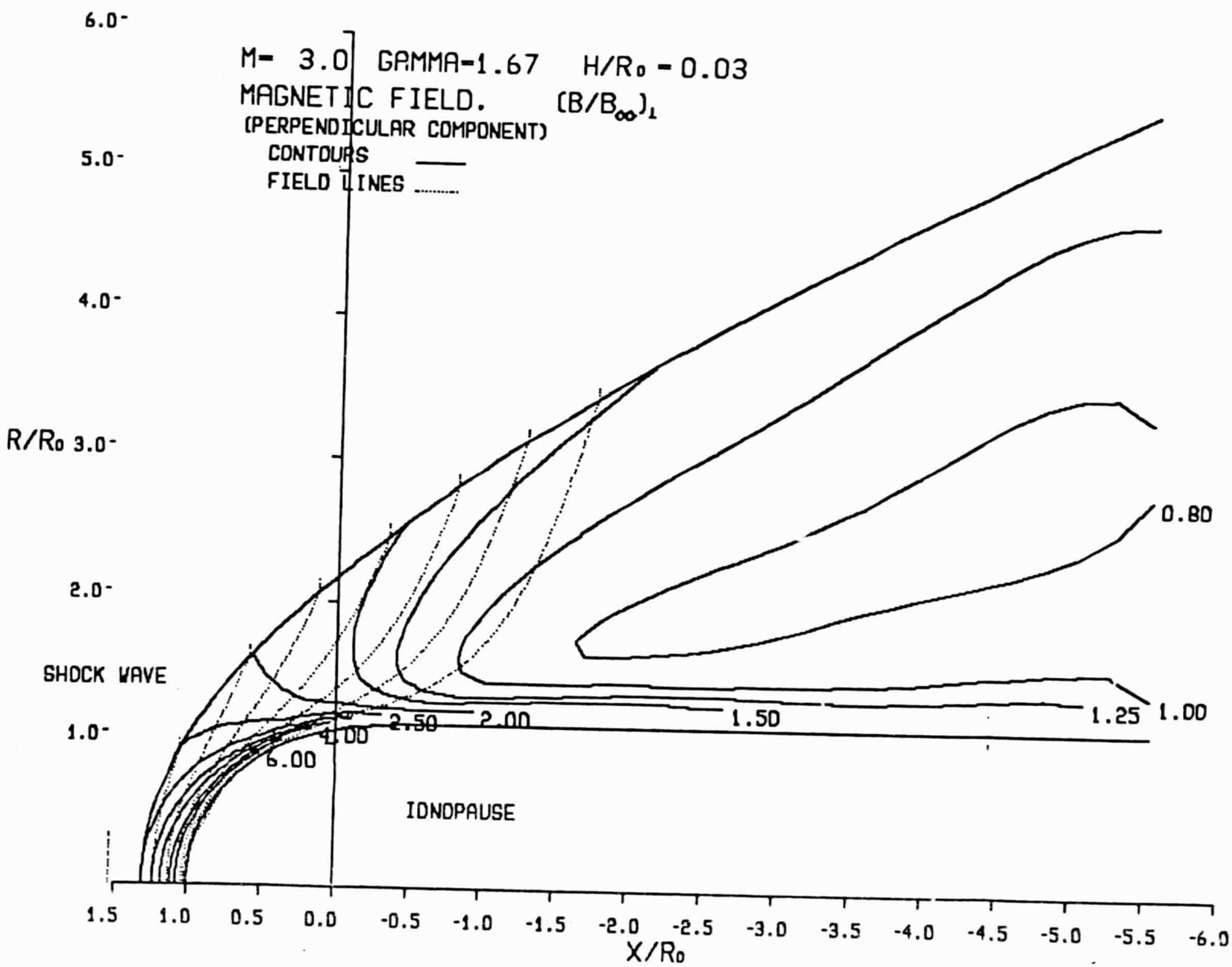

Figure 2. Sample magnetic field output from Level 1 model graphical output package: magnetic field lines and contours for perpendicular field component for $M_\infty = 3.0$, $\gamma = 5/3$, $H/R_0 = 0.03$ ionopause obstacle flow

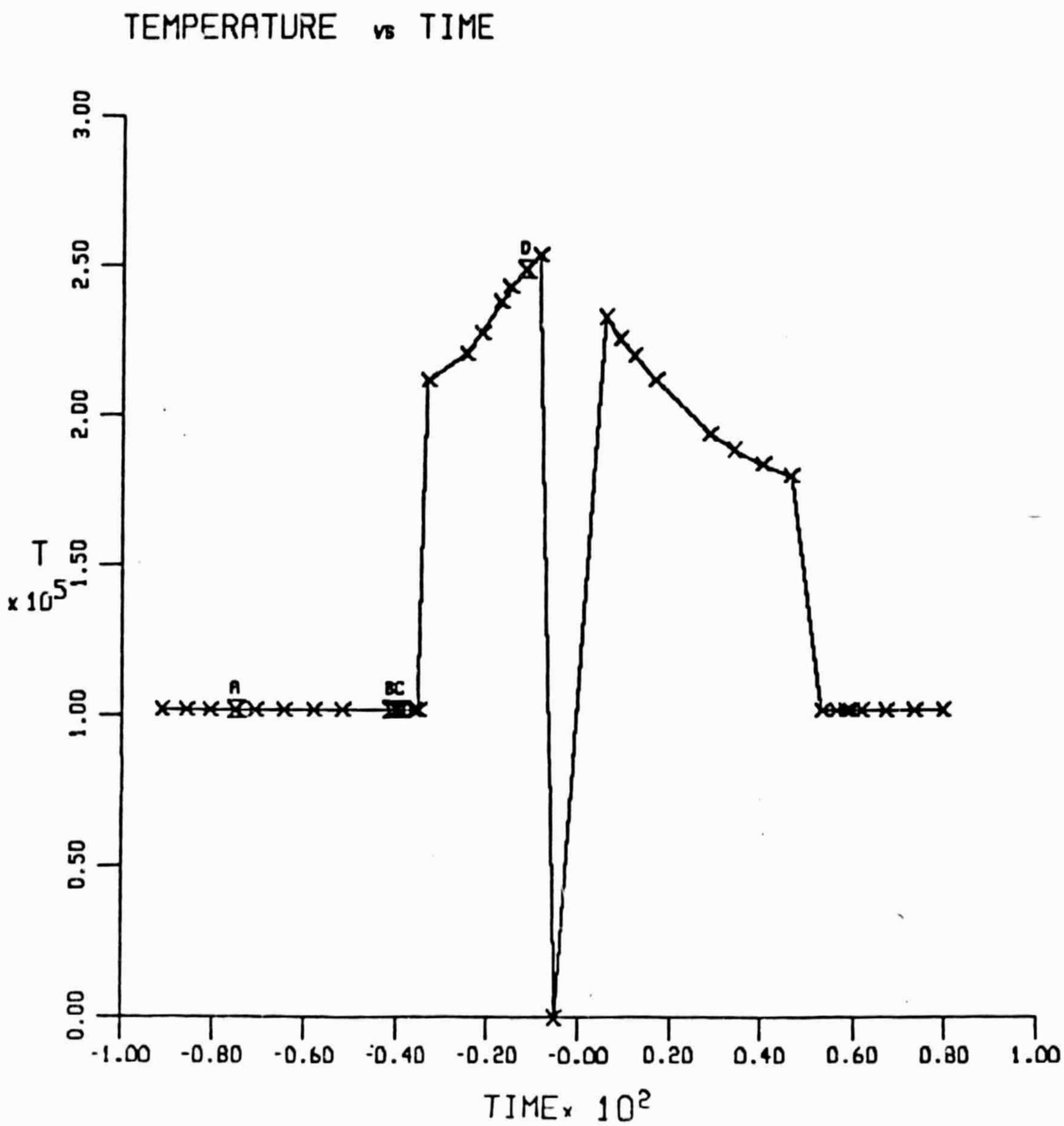

Figure 3. Sample time history output from Level 1 model graphical output package: temperature vs. time for a trajectory passing through the magnetosheath region and ionopause of the flow field shown in Figure 1

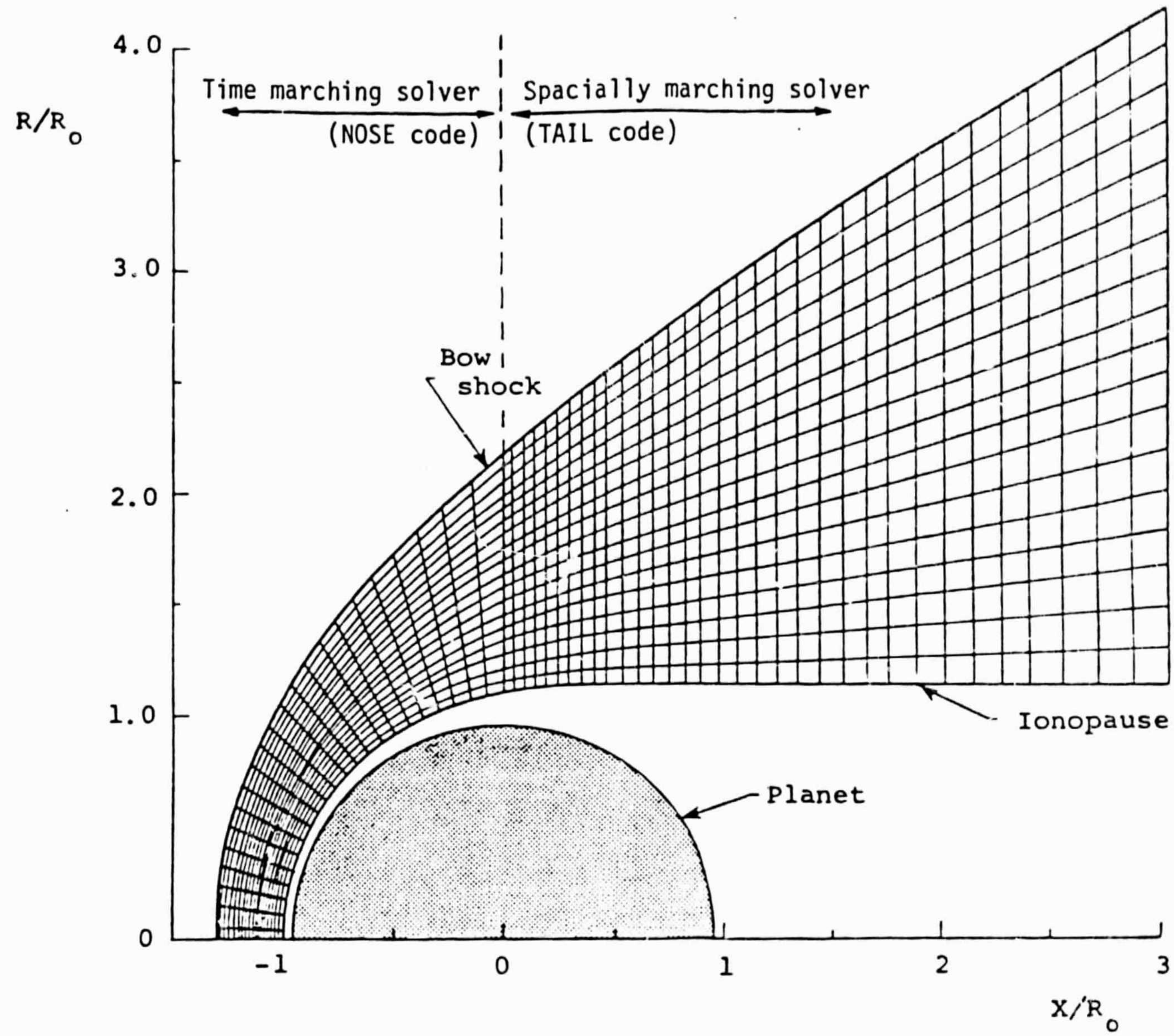

Figure 4. Illustration of typical flow-field grid density for gas dynamic solution; $M_\infty = 3.0$, $\gamma = 5/3$, $H/R_0 = 0.03$