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Second Quarterly Progress Report

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

Contract NASW-4011

Resource Management Associates, Inc.
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DEVELOPMENT OF A GLOBAL 3-D MAGNETOHYDRODYNAMIC COMPUTATIONAL MODEL FOR SOLAR WIND/COMETARY AND PLANETARY STUDIES

1. INTRODUCTION

This is the second 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, detailed development of the 3-D gas dynamic flow field solvers for the Level 2 model, and continued 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

Several important enhancements were developed and implemented into the current updated version of the Level 1 solar wind/terrestrial planet interaction model. The first involved development of a detailed diagnostic graphics package to enable direct viewing of all plasma and field quantities along arbitrary computational mesh surfaces. This was developed for output on the RMA Printronix high-density dot matrix printer, and provides an extremely efficient means for examining the solution behavior at critical regions of the interactive magnetosheath region. The output package includes: map of the entire computational grid; plots displaying the variation of the magnitude of total velocity and velocity components, density, and pressure along arbitrary segments of the computational mesh; similar plots showing the variation of the magnitude and vector angle of the three magnetic field components; vector plots of the velocity and magnetic field vectors along arbitrary segments of the computational mesh. This plot capability is ideal for comparative studies, and was developed specifically to enable comparisons of the axisymmetric Level 1 model with the 3-D Level 2 model. As with the existing Level 1 graphics package, these new routines were developed employing the widely available CALCOMP routines to enable portability to other computational facilities. A sample of the output package is provided in Figrues 1 to 3 which show the graphic output of the computational mesh and vector plots of the velocity and perpendicular unit magnetic field components along certain computational lines.

Additionally, preliminary work was done on developing the appropriate methodology to enalbe, at user option, an improved satisfaction of the pressure balance boundary condition at the magneto/ionopause. The present Level 1 model employs a specified magneto/ionspause shape which is previously determined using a Newtonian surface pressure to approximate the pressure on the magnetosheath side of the magneto/ionopause. We plan to iteratively alter the magneto/ionopause shape so as to more accurately satisfy the true pressure balance required by replacing the Newtonian pressure initially with the exact plasma pressure, and later by the sum of the plasma and magnetic field pressures.

3. DEVELOPMENT OF LEVEL 2 FLOW FIELD MODEL

Significant development work was accomplished on the Level 2 3-D flow field solvers for treating the complete magnetosheath flow field. These include the unsteady time marching solver NOSE3D for determing the region from the subsolar point to the termination plane, and the spacially marching solver TAIL3D to carry the solution from the termination plane downstream as far a needed. These results are discussed in the following two subsections.

3.1 Level 2 Nose Region Flow Solver: NOSE3D Code

The NOSE3D code was modified, debugged, and brought up on the RMA PRIME superminicomputer. It was then verified by comparisons with a number of benchmark results. The first of these check cases was axisymmetric flow past a sphere at $M_\infty = 5.94$ and $\gamma = 7/5$. Both the CRAY run and the RMA PRIME run with the code in double precision, were advanced 600 time steps. Both intermediate and final results from the CRAY and RMA PRIME were identical. Next, an axisymmetric benchmark calculation was made at $M_\infty = 8.0$ and $\gamma = 5/3$ and the results from the NOSE3D run compared with the corresponding results from the Level 1 model NOSE code (NOSEAX). The results for the plasma properties (velocity, density, pressure, temperature) between the two different model calculations agreed quite satisfactorily. Finally, the full three-dimensional capability of the NOSE3D code was checked and verified. This was done for the sample case of flow at $M_\infty = 5.94$ and $\gamma = 7/5$ past a sphere/cylinder at angle of attack of 10° . Comparative calcuations were performed on the NASA/ARC CRAY and on the RMA PRIME computers, and the results were identical. Also, preliminary work was initiated on developing the geometry routines to describe 3-D magneto/ionopauses which have elliptical cross sections and have blunt-nosed parabolic profiles in the meridian and ecliptic planes. Such general classes of shapes will form an essential geometric family of obstacle shapes for 3-D magnetosheath studies about Earth, Jupiter, and Saturn. Finally, the mating of the NOSE3D code with the TAIL3D has been initiated, and is described in more detail in the following subsection.

3.2 Level 2 Tail Region Flow Solver: TAIL3D Code

The 3-D gas dynamic solver for the Level 2 solution of the 3-D tail region has now been appropriately modified for use on the RMA PRIME superminicomputer, debugged, and brought up. A number of benchmark runs have been made to verify the code. These have involved several standard test cases for supersonic flow about a 20 $^{\circ}$ half-angle cone at 15° angle of attack and free-stream Mach number of 7. Comparative calculations on the RMA PRIME using a double-precision version of the code have agreed exactly with previously determined results. In addition to this three-dimensional test case, several test cases have been run for axisymmetric flow about a cone cylinder, to check for flow symmetry, and these have now also been verified. Finally, the TAIL3D has been preliminarily joined with NOSE3D code and a single check case run to verify that the correct starting plane information is being passed to the TAIL3D code. This was for axisymmetric flow past a sphere/cylinder. Results indicated satisfactory initial condition transfer. A 3-D flow check case is currently underway involving a sphere/cylinder at angle of attack to verify that the 3-D information from NOSE3D is correctly passed to the TAIL3D code.

4. DEVELOPMENT OF LEVEL 2 3-D MAGNETIC FIELD SOLVER

Significant development of the MAG3D code which will determine the frozen $\bar{B}$ field for a general 3-D gas dynamic flow field was also accomplished during this reporting period. The preliminary coding of the method was completed. Comparative calculations were initiated of the MAG3D code with the Alksne/Webster decomposition method. The initial comparisons were generally favorable, but some discrepancies were observed. More detailed and systematic comparisons are required and are planned.

5. TASKS PLANNED FOR NEXT REPORTING PERIOD

During the next reporting period, work will continue on the final development and verification of the joined NOSE3D/TAIL3D flow code. Benchmark calculations will be made to verify the combined code. Next, the verified code will be applied to 3-D shapes having elliptic cross section. The verified code will then be brought up on the CRAY-XMP and a limited matrix of 3-D flow solutions determined for these shapes. These solutions will be archived for use in testing and application of the MAG3D code to 3-D magnetospheres. Comparative MAG3D computations will also be carried out and the MAG3D code systematically tested as far as possible.

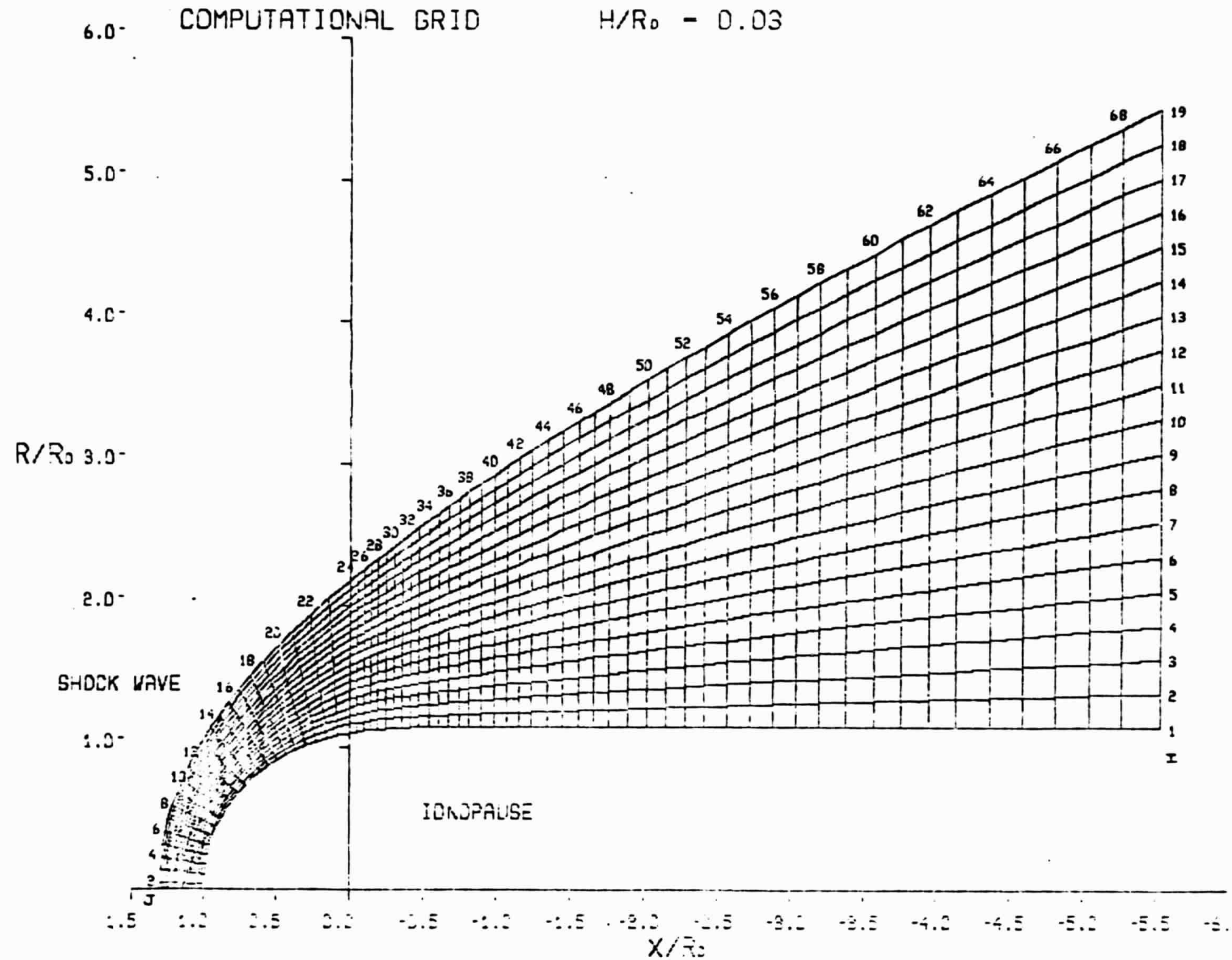

Figure 1. Sample plot from Level 1 model extended diagnostic graphic output package: computational grid for M_∞ = 3.0, γ = 5/3 flow past an ionopause shape with H/R_o = 0.03

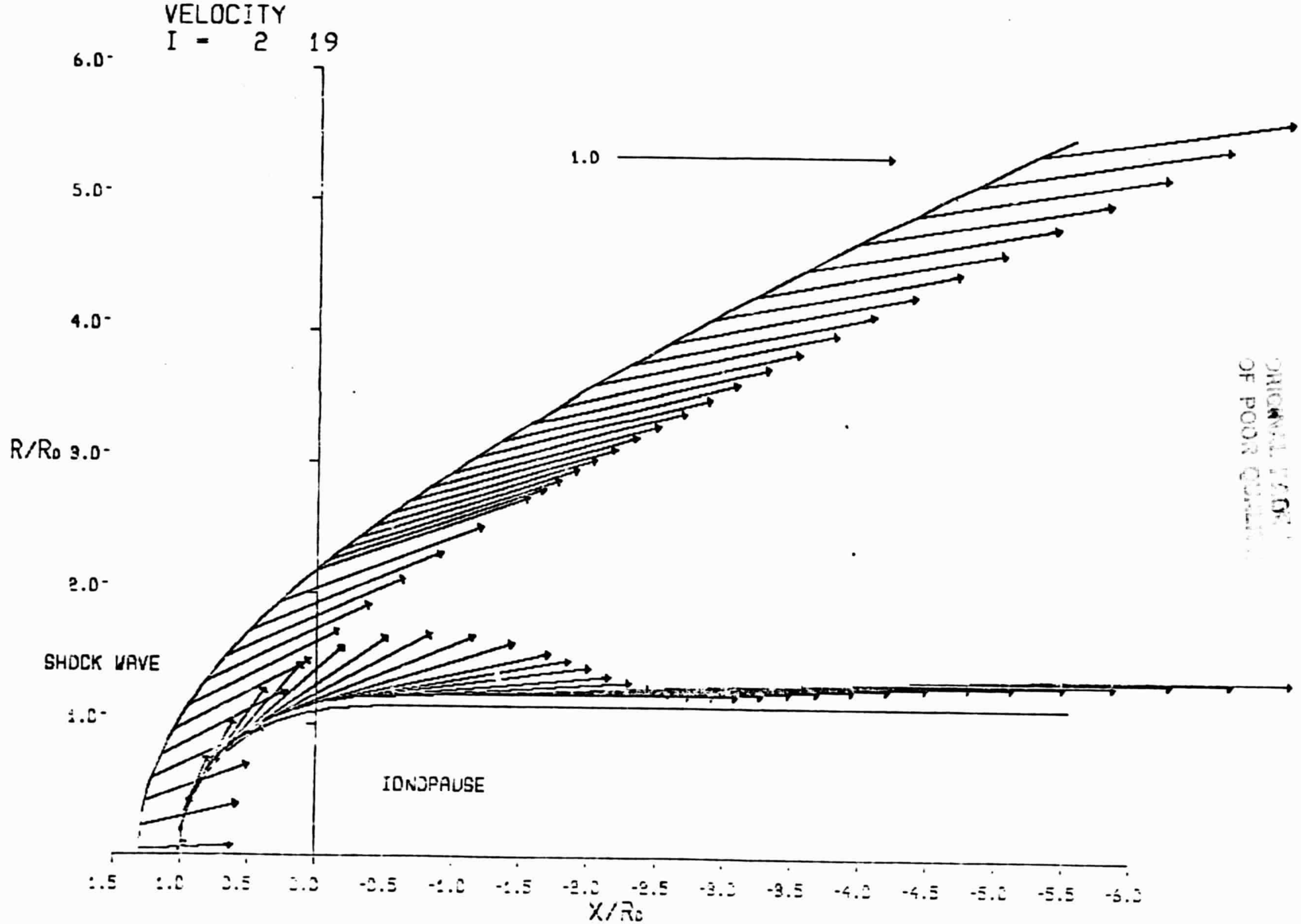

Figure 2. Sample plasma property output from Level 1 model extended diagnostic graphic output package: velocity vector plots along constant radial mech locations at one mesh spacing away from the obstacle surface (I=2) and along bow shock (I=19)

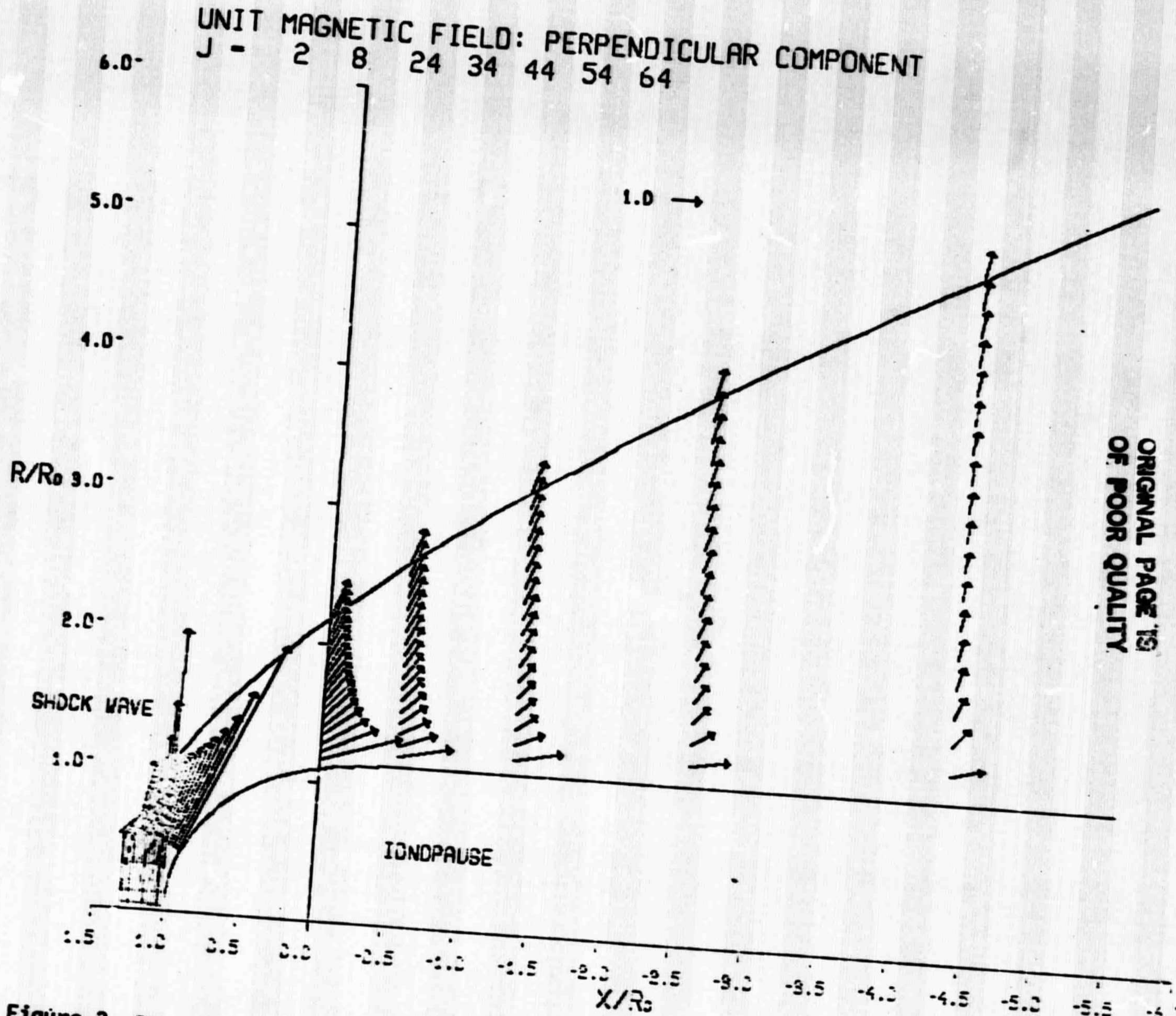

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Figure 3. Sample magnetic field output from Level 1 model extended diagnostic graphic output package: vector plots of unit magnetic field perpendicular component along various radial mech lines normal to the obstacle for M_∞ = 3.0, γ = 5/3 flow past an ionopause shape with H/R_0 = 0.03