COMPUTATION OF FLOW REGIMES IN PARAMETER SPACE FOR THE AGCE

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ABSTRACT

This report describes the results of a small study program in support of the design studies for NASA's proposed Atmospheric General Circulation Experiment (AGCE). The proposed experiment will model the atmosphere using a hemispherical layer of a dielectric fluid such as silicone oil, heated at the equator, and with a large radial AC electric field producing a temperature-dependent radial body force similar to radial gravity. The effect of terrestrial gravity on the experiment can be eliminated by doing the experiment in space flight.

Under other NASA programs, the author developed a series of three computer models to support these design studies. The first two calculate axisymmetric solutions and their stability to small non-axisymmetric perturbations. The third computes three-dimensional solutions. These codes allow the option of solving problems in a cylindrical geometry as well as a rather generally defined spherical layer.

The present program had two components. The first was to support a parallel effort at Drake University in obtaining a regime stability diagram to correspond to a series of experiments done at Marshall Space Flight Center. The second was to attempt to improve the stability eigenvalue algorithm's convergence rate for difficult cases, either by improved choices of the method parameters or by a fundamental change in the algorithms.

The studies at Drake are proceeding well. Some of the results are presented here. We provided extensive support in a number of significant aspects of this program.

The algorithm studies were less successful. However, we still believe that improvements are possible. And it should be pointed out that the present algorithm is already proding results on a production basis.

CHAPTER 1

INTRODUCTION

The microgravity environment of Spacelab or of a Space Station presents the opportunity for experimental modeling of planetary and stellar atmospheres and other geophysical fluid flows in a true spherical geometry. In recent years a considerable amount of geophysical fluid flow modeling has been carried out in earthbound laboratories, but this work has suffered from the limitation that the radial body force of planetary gravity could not be simulated. A radial body force can be achieved in a spherical layer of dielectric liquid by the application of an electric field, but this force is small compared with terrestrial gravity. However, in an orbiting vehicle this force becomes dominant.

A spherical apparatus for modeling deep solar convection and the Jovian atmospheric circulation was flown on Spacelab 3. In this Gephysical Fluid Flow Cell (GFFC), a dielectric liquid is held between two concentric spheres, and is subjected to a large alternating-current voltage difference, together with rotation and a radially unstable temperature difference.

A model experiment simulating the large-scale circulation earth's atmosphere has been proposed for later Spacelab flights. In this Atmospheric General Circulation Experiment (AGCE), the liquid is again contained between concentric spheres and subjected to an AC voltage difference and to rotation, but the thermal driving consists of a stable radial temperature gradient together with latitudinal temperature gradients which lead to baroclinic instability. This is directly analogous to the earth's atmosphere, with its wave-cyclone storms and its frontal systems at mid-latitudes.

Extensive design studies have been undertaken in connection with AGCE planning, and this report is a part of these continuing studies (Fowlis and Roberts, 1982).

INTRODUCTION

In prior NASA-sponsored programs, the present author developed a series of computer programs for AGCE-related simulations in spherical and cylindrical geometries. The first code computes steady or time-dependent axisymmetric soluions. The second analyzes the stability of steady axisymmetric basic states to small non-axisymmetric perturbations (Roberts et al., 1984). The third computes three-dimensional steady-state or time-dependent solutions (Roberts, 1984).

An important application of the first two codes is to determine for what ranges of parameter choices the axisymmetric geometries lead to non-axisymmetric flows like those observed in the atmosphere. Diagrams of the appropriate parameter ranges are referred to as regime diagrams. The codes are now being routinely used to obtain such diagrams.

CHAPTER 2

REGIME DIAGRAM FOR THE CYLINDRICAL SAPPHIRE EXPERIMENTS

Figure 1 shows a cylindrical apparatus developed for AGCE studies. Hathaway and Fowlis (1985) describe experimental regime diagram results recently obtained using this apparatus. These results are summarized in Figures 2, 3 and 4. The sapphire discs are heated and cooled externally to maintain the vertical and horizontal temperature differences indicated in the figures. With five different rotation rates, three different vertical temperature differences, and four different horizontal differences, there are sixty distinct cases. The figures show the experimentally observed flow patterns, visualized using kalliroscope material in the fluid.

Professor Kenneth J. Kopecky of Drake University, under a separate contract from NASA, has been using our codes to study these sixty cases, and one of our tasks under the present contract has been to support these studies.

Steady axisymmetric solutions have been obtained for all the cases. One case is illustrated in Figures 5 through 9, which are contour plots for the indicated variables.

The stability studies are continuing. As the observations displayed in Figures 2 through 4 suggest, there is a wide range of phenomena, with steady and unsteady three-dimensional flow patterns and a wide range of apparent zonal wave numbers. Also, certain axisymmetric solutions are apparently stable, showing no visible sign of three-dimensional disturbances.

We hope that the stability results will show full agreement with the observations. This would require consistency not only with the observed zonal wave numbers, but also with the observed structures (spirals, cells, etc.) and with our physical interpretations of these structures.

To date, however, the cases analyzed have agreed with the observatios only for the cases unstable to small wave numbers, with baroclinic type modes. We have yet to find unstable modes which we can relate to the spoke-like spiral structures, which we attribute to convection in the thermal inversions near the upper boundary. The reason why we are not finding such modes remains obscure, and further study is required. It should always be remembered that the unstable disturbances grow to amplitudes where nonlinear effects are important. For baroclinic eddies, the wave number is not changed, but for other types of instability mode, there may be a cascade to higher wave numbers.

The three dimensional code may be required to resolve these issues.

Our part in these studies has been to set up the original parameters for the cases, and to assist in solving problems as they appeared. In addition, we were forced to make a large number of changes in the control language files (DCL - DIGITAL Control Language), when Drake upgraded their VAX system to VMS 4.

We changed the format of the diract access files used to save the axisymmetric basic states and the small disturbances. This resulted in a savings of disk space (in short supply at Drake, as elsewhere) by a factor of four.

We used the Drake computer remotely from our PC and modem in order to monitor the runs and the problems which developed.

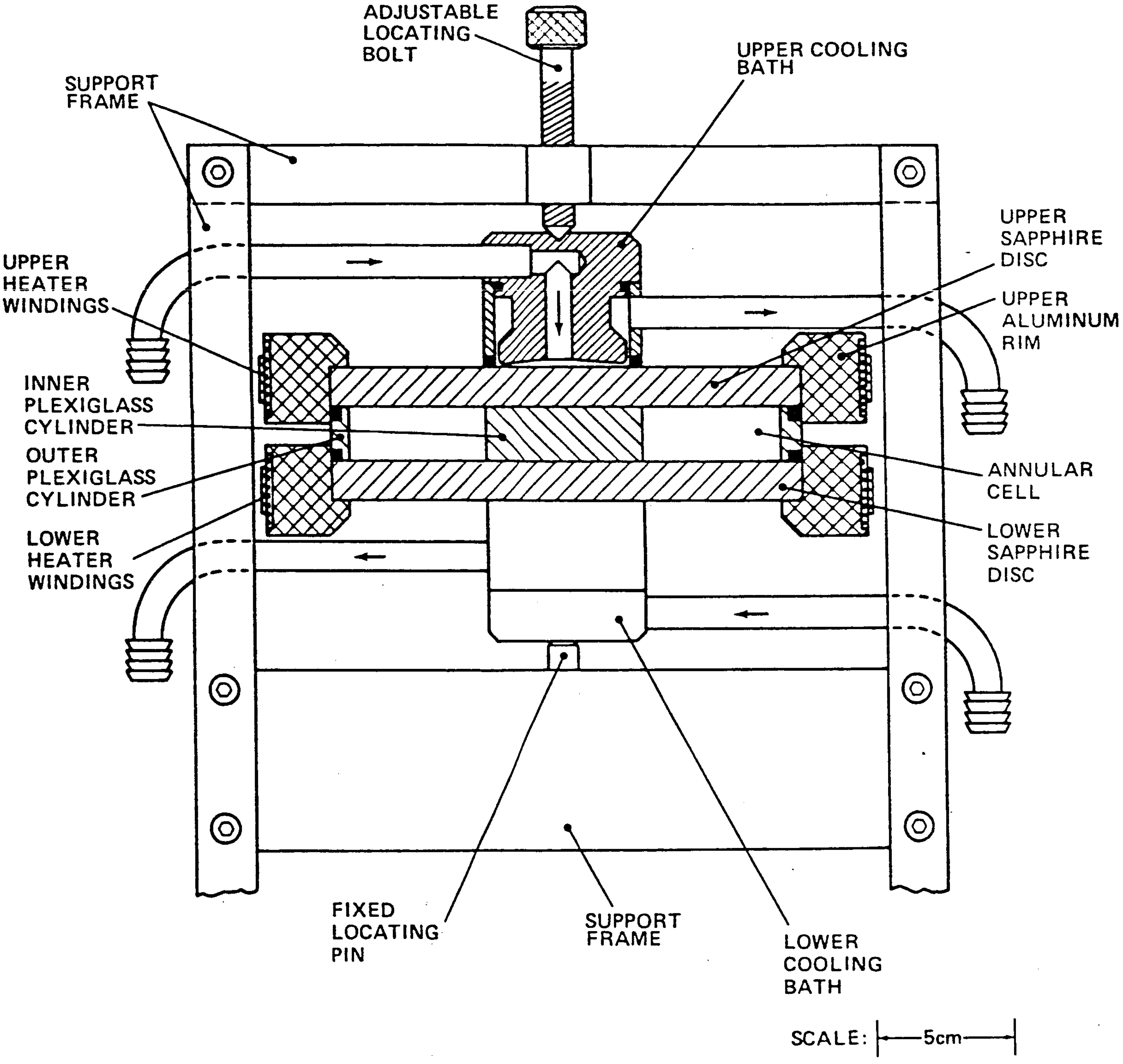

Figure 1. The Sapphire Disk Apparatus for AGCE Design Studies

REGIME DIAGRAM FOR THE CYLINDRICAL SAPPHIRE EXPERIMENTS

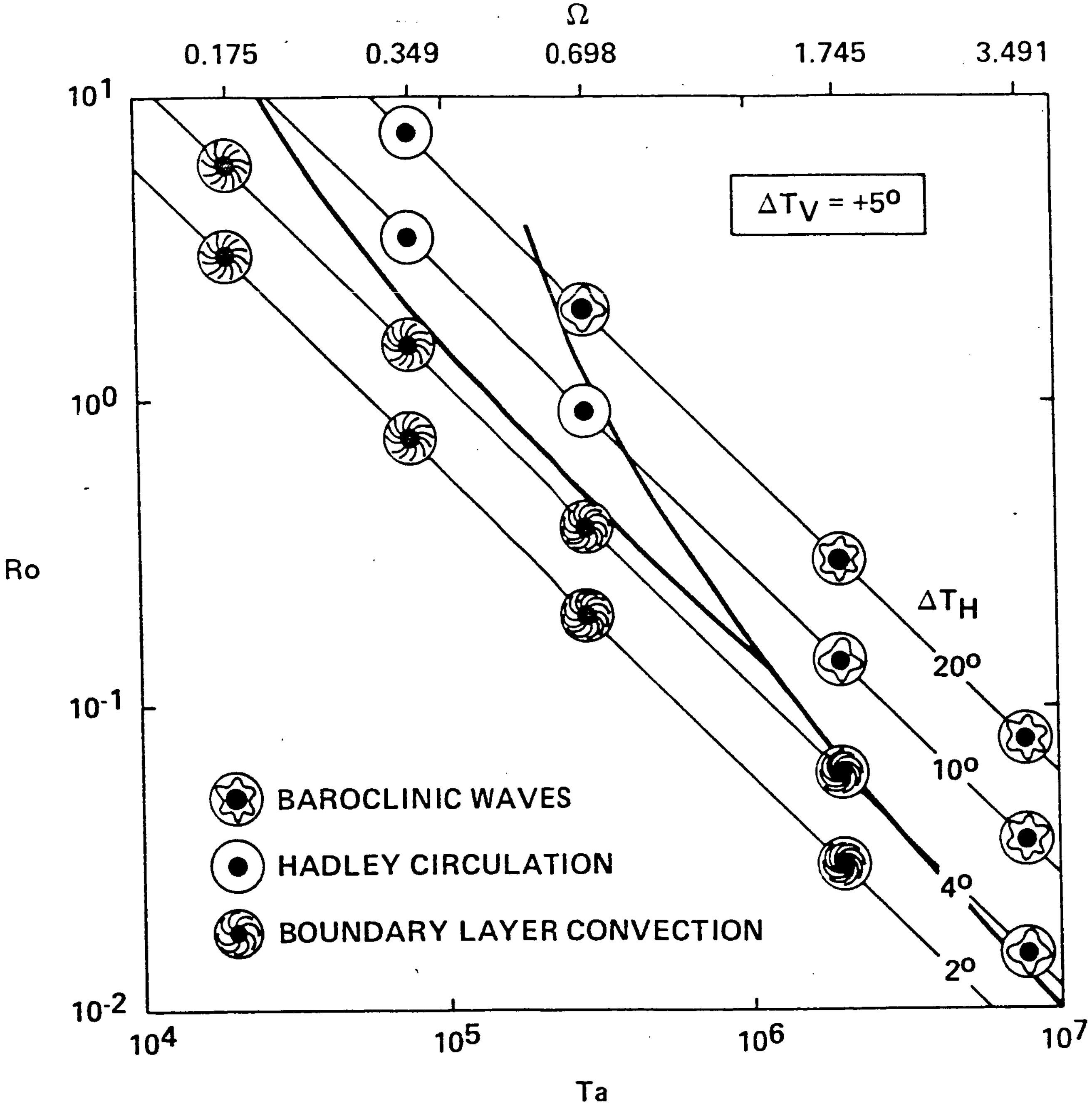

Figure 2. Results for a Stable Vertical Temperature Difference of 5 Degrees

REGIME DIAGRAM FOR THE CYLINDRICAL SAPPHIRE EXPERIMENTS

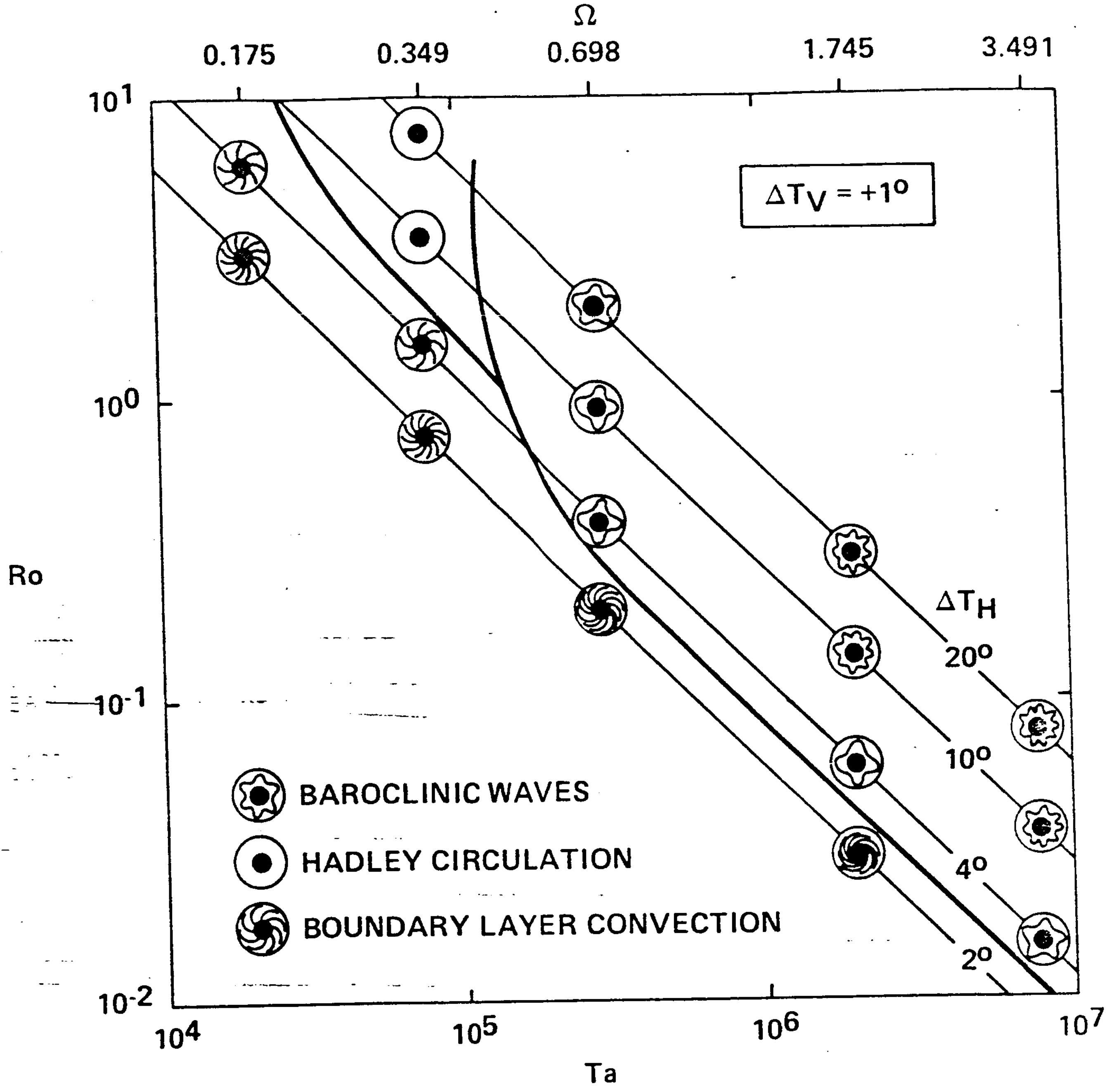

Figure 3. Results for a Stable Vertical Temperature Difference of 1 Degree

REGIME DIAGRAM FOR THE CYLINDRICAL SAPPHIRE EXPERIMENTS

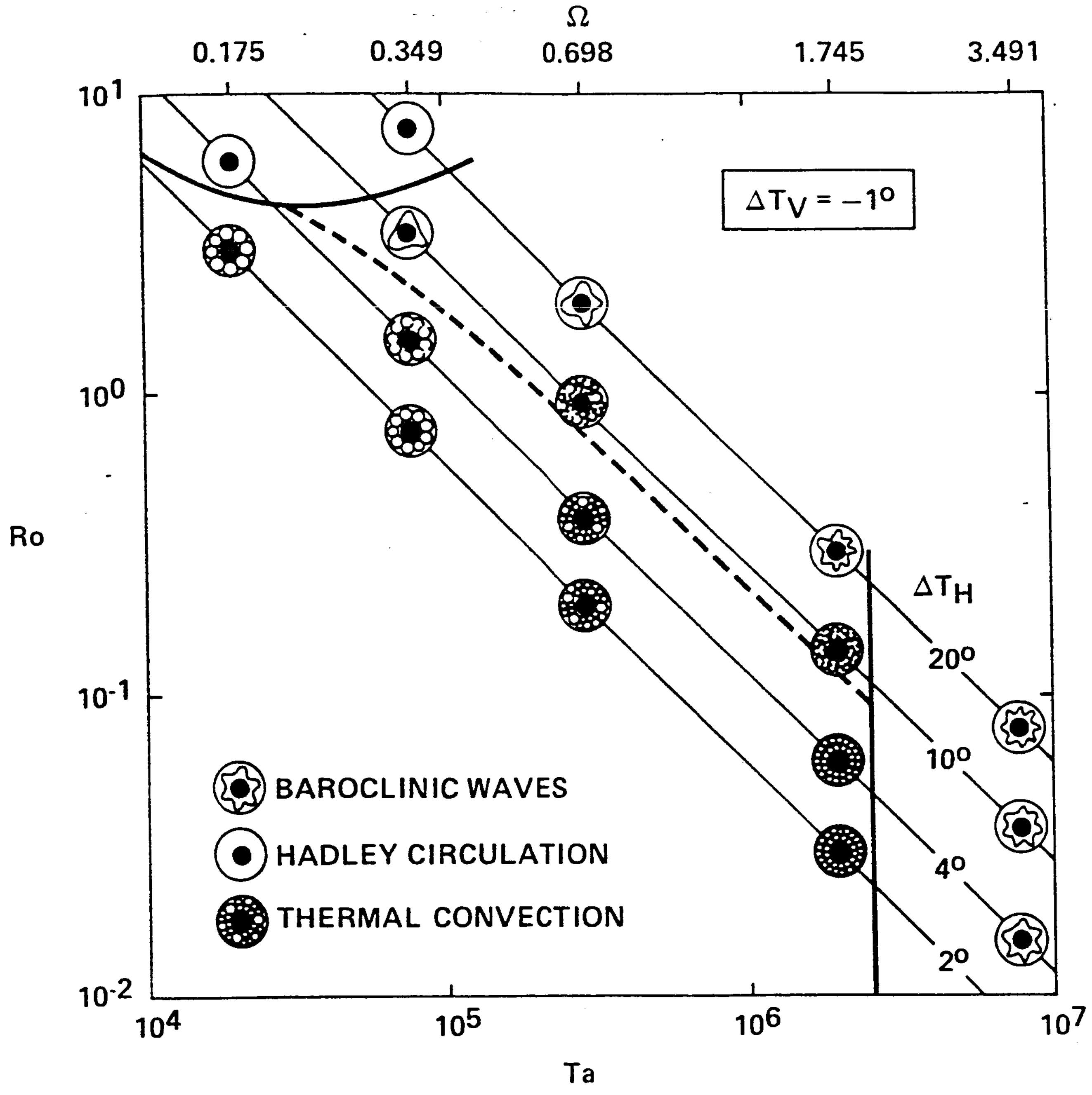

Figure 4. Results for an Unstable Vertical Temperature Difference of 1 Degree

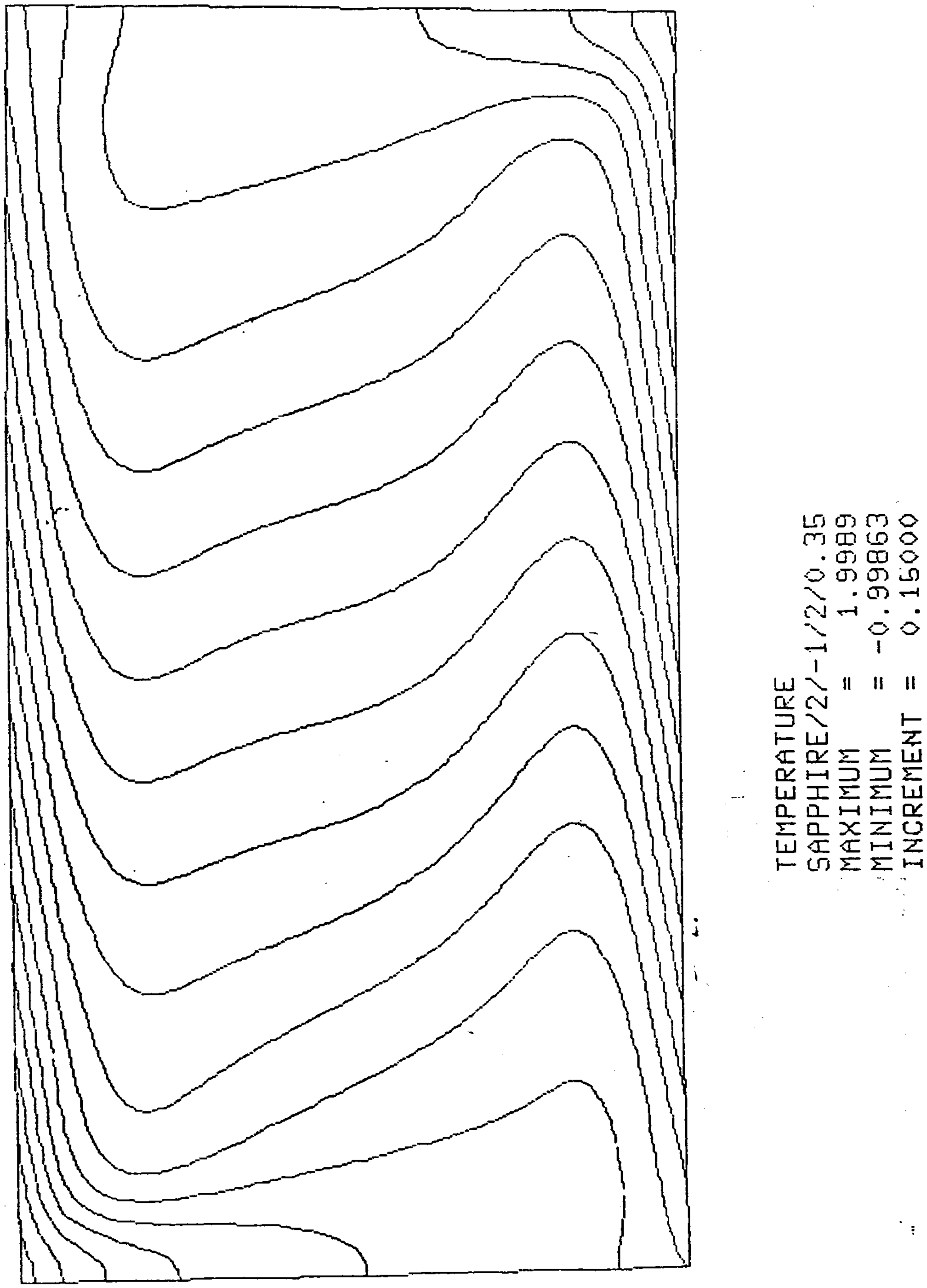

Figure 5. Temperature Contours with Temperature Differences of -1 and 2 Degrees and Rotation Rate 0.35 Radians per Second

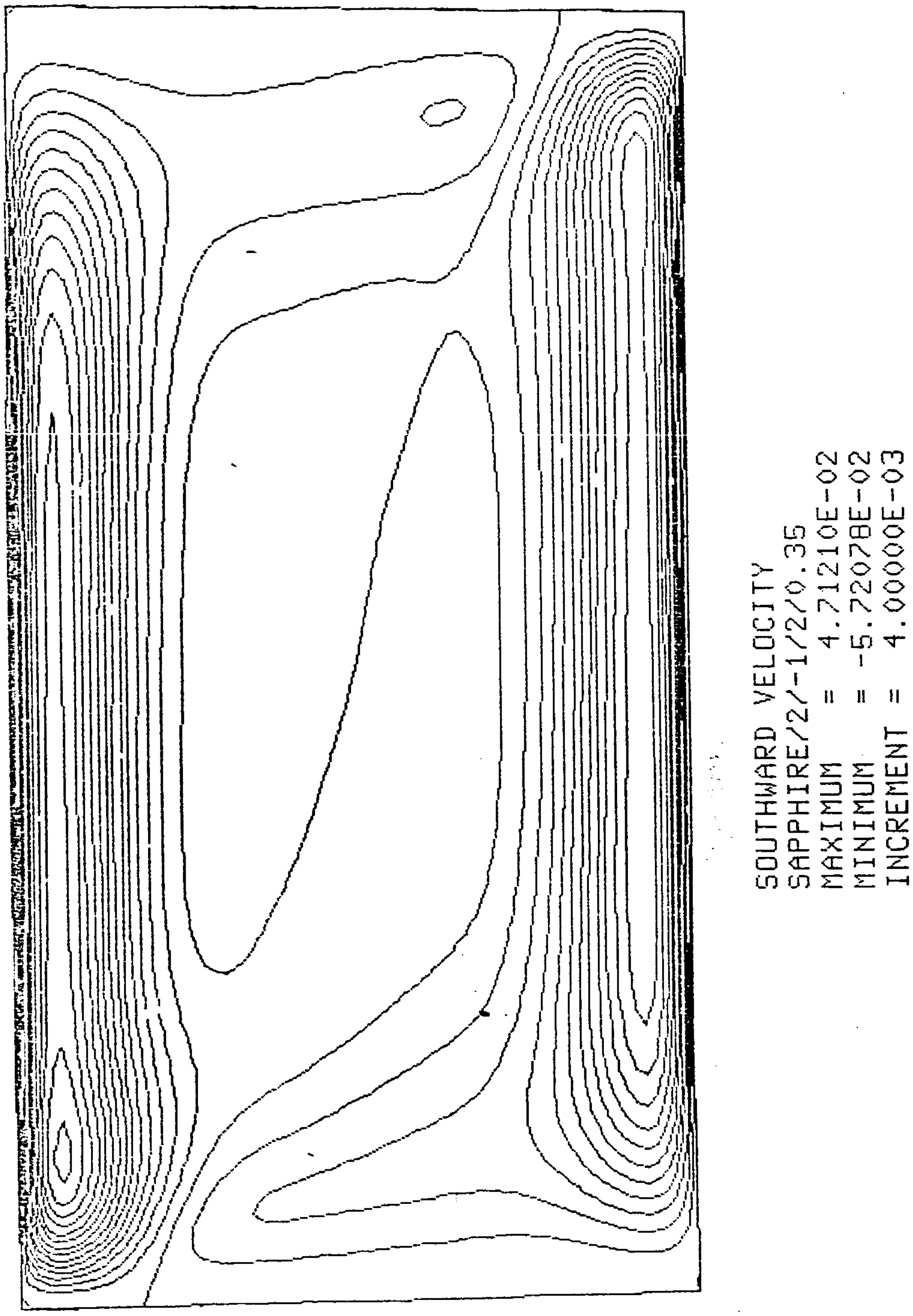

Figure 6. Southward Velocity Contours with Temperature Differences of -1 and 2 Degrees and Rotation Rate 0.35 Radians per Second

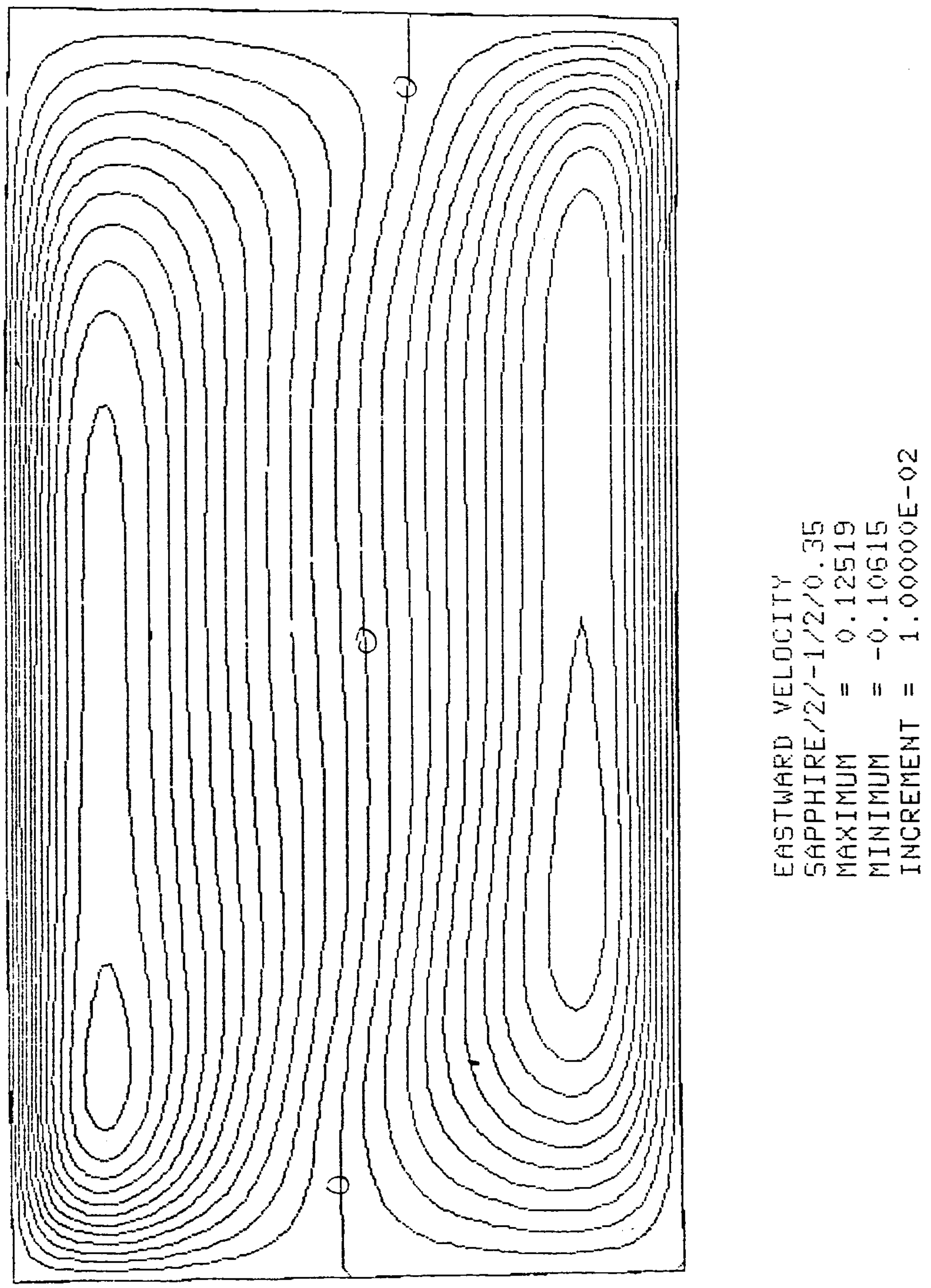

Figure 7. Eastward Velocity Contours with Temperature Differences of -1 and 2 Degrees and Rotation Rate 0.35 Radians per Second

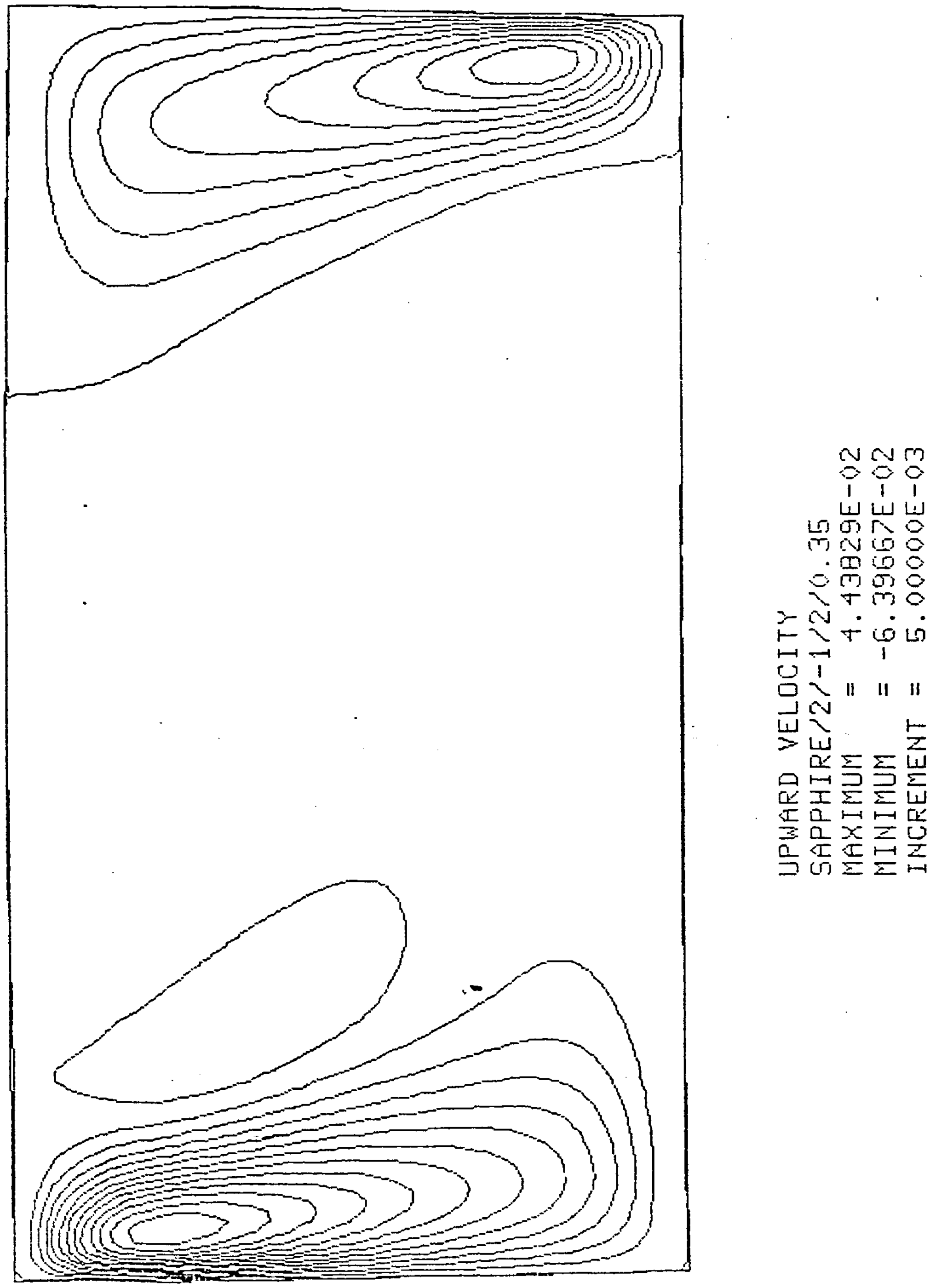

Figure 3. Upward Velocity Contours with Temperature Differences of -1 and 2 Degrees and Rotation Rate 0.35 Radians per Second

REGIME DIAGRAM FOR THE CYLINDRICAL SAPPHIRE EXPERIMENTS

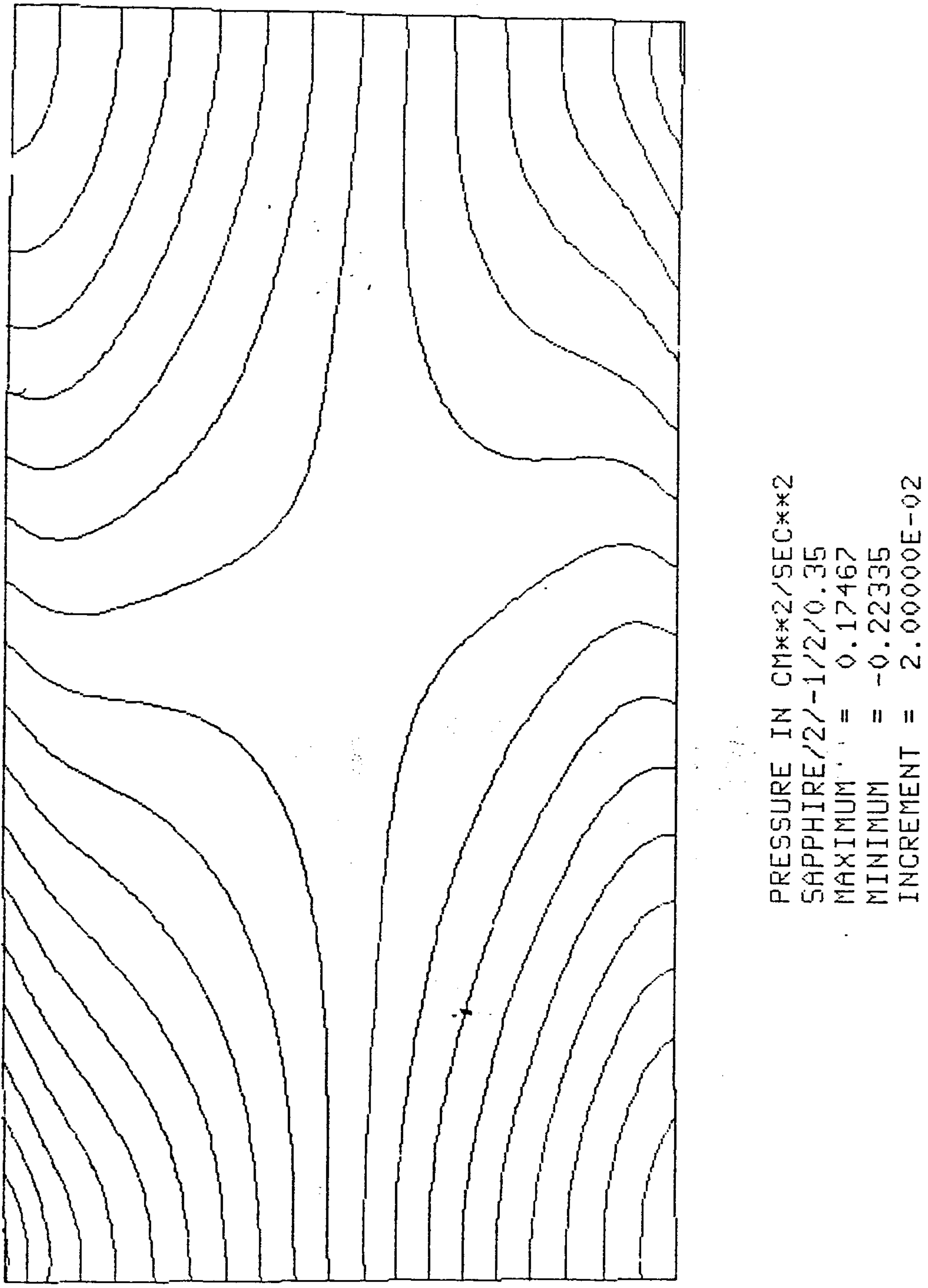

Figure 9. Pressure Contours with Temperature Differences of -1 and 2 Degrees and Rotation Rate 0.35 Radians per Second

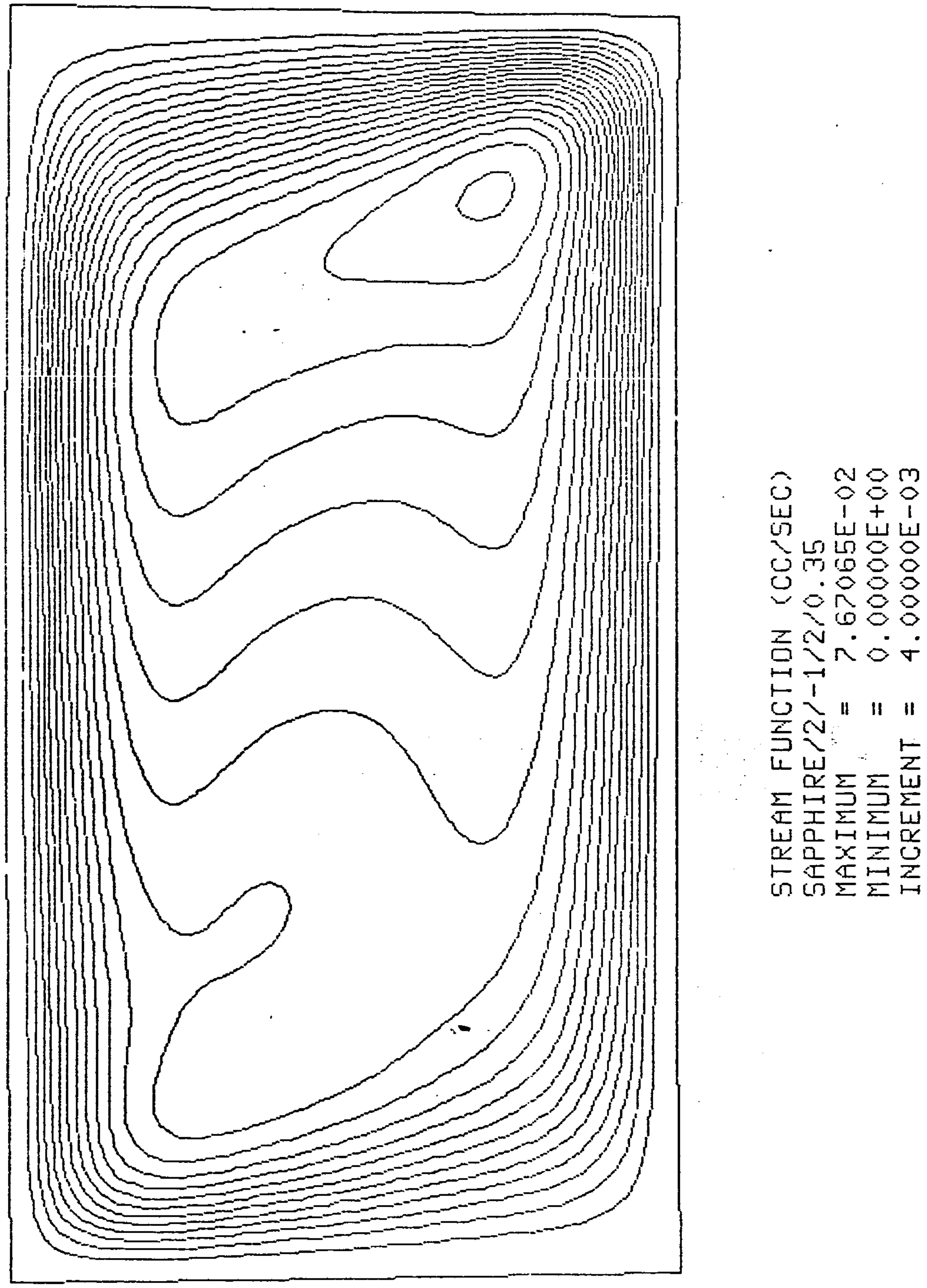

Figure 10 Stream Function Contours with Temperature Differences of -1 and 2 Degrees and Rotation Rate 0.35 Radians per Second

CHAPTER 3

EIGENVALUE ALGORITHM STUDIES

our eigenvalue algorithm is closely related to time stepping the equations for small linearized disturbances to the basic axisymmetric state. In theory, such time stepping cannot fail to converge to the fastest growing or slowest decaying eigenmode. Since stability imposes unreasonable time step limits on an explicit time stepping method, we use implicit methods, with successive tridiagonal inversions in the two coordinate directions. We can then take large steps, and separate modes with similar growth rates in relatively few iterations.

For some cylindrical and spherical cases, this algorithm has been very successful, with convergence to three or four significant figures in fifty or a hundred iterations. In other cases, we have only been able to obtain convergence by reducing the time step to very small values and using an unreasonably large number of iterations.

One task of the present contract was to attempt to understand this problem and to discover a remedy. We have not succeeded in this task. There are a large number of method parameters which can be modified to obtain slight improvements in the convergence rate. But we have not been able to find an algorithm modification which reliably gives fast convergece in all cases.

CHAPTER 4

REFERENCES

W.W. Fowlis and G.O. Roberts, 1982, "The Numerical Design of a Spherical Baroclinic Experiment for Spacelab Flights", NASA Report MSFC-SSL-82-1105, -and- Proceedings of the International Conference on Computational Methods and Experimental Measurements (Springer-Verlag, Berlin).

D.R. Hathaway and W.W. Fowlis, 1985, To appear.

G.O. Roberts, 1984, "Three-Dimensional Computer Model for the Atmospheric General Circulation Experiment", Report SAI-84/1142, Science Applications International Corp., McLean, VA.

G.O. Roberts, W.W. Fowlis, and T.L. Miller, 1984, "Finite-Difference Fluid Dynamics Computer Mathematical Models for the Design and Interpretation of Experiments for Space Flight", NASA Technical Paper 2323, 12pp..