General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

EFFECTS OF CORONAL DISTURBANCES ON THE IONIZATION STATE OF THE SOLAR WIND

Grant NAG 5-367

Final Report

For the period 15 August 1983 through 14 December 1984

Principal Investigator

George L. Withbroe

July 1985

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory is a member of the Harvard-Smithsonian Center for Astrophysics

The NASA Technical Officer for this grant is Mr. R. O. Wales, Code 602, Orbiting Satellites Project/Science, Sciences Directorate, Goddard Space Flight Center, Greenbelt, Maryland 20771.

EFFECTS OF CORONAL DISTURBANCES ON THE IONIZATION STATE OF THE SOLAR WIND

Grant NAG 5-367

Final Report

For the period 15 August 1983 through 14 December 1984

Principal Investigator

George L. Withbroe

July 1985

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics

The NASA Technical Officer for this grant is Mr. R. O. Wales, Code 602, Orbiting Satellites Project/Science, Sciences Directorate, Goddard Space Flight Center, Greenbelt, Maryland 20771.

1. INTRODUCTION

The purpose of the current study is the theoretical investigation of the relationship between physical conditions in coronal disturbances and the ionization states of the resulting perturbed solar wind. Available measurements of active solar wind associated with solar flares often show an enhanced degree of ionization (e.g. Fe^{+17}), implying that the measured solar wind material is flare-heated at its coronal source. In contrast, other active solar wind flows sometimes show anomalously low degrees of ionization (e.g. He^{+}), implying that some solar material is expelled from the corona without ever reaching coronal temperatures. In order that such qualitative inferences can be developed into quantitative constraints on coronal conditions that give rise to solar wind disturbances, it is necessary to conduct systematic investigations of the effects of impulsive heat and/or momentum addition in the corona on the hydrodynamics and ionization state of the corona and solar wind. The results of such studies should facilitate the interpretation of interplanetary spacecraft data (e.g. the O^{+6}/O^{+7} ratio measured by ISEE-3), because it would allow an improved association of the local physical state of the solar wind with conditions of the coronal source material.

2. SOFTWARE DEVELOPMENT

One of the primary objectives of the current grant was the development of a software package suitable for (1) generating models for the effects of impulsive heat and/or momentum deposition on plasma temperatures, densities and flow velocities and (2) calculating the

ionization state of the solar wind as a function of the location, duration and magnitude of heat and/or momentum deposition. In order to accomplish this goal it was necessary to modify an existing time-dependent isothermal solar wind code to allow temperature variations and interface the results with a solar wind ionization code developed by S. Owocki. The first code had been used to study the development of stationary shocks in solar wind flows with multiple critical points (cf. Habbal and Tsinganos 1983, Habbal et al. 1983, Habbal and Rosner 1984). The original version assumed an isothermal corona. The revised code can calculate time-dependent polytropic models in which the temperature, density and flow speed of the plasma can vary in time (Habbal 1985). Heat addition by, for example, an impulsive energy release in the corona, can be simulated in the new code by the introduction of a time-varying temperature increase over a specified range of heights. The resulting effects on the temperature, density and flow speed of the solar wind can then be followed as a function of time and space.

The second computer code was developed by S. Owocki for calculating the ionizations state of the solar wind in a steady-state or time-varying flowing plasma (Owocki 1982, 1983). This code, which was developed for use on a computer system at another institution, was adapted for use on the Solar Stellar Division computer system by S. Owocki and a research assistant. In addition, an interface routine was developed which enables this ionization state code to calculate as a function of time and space the ionization state for the time-varying solar wind models calculated from Habbal's solar wind code. In the

latter stages of the development of the combined software package (solar wind, interface and ionization codes) we encountered several tough problems in getting the entire software package to perform smoothly as a unit. Solving these software probems required significantly more time and effort than anticipated, particularly since S. Owocki, who developed the original ionization code used in the project, had moved to another institution when the software problems surfaced. The problems were successfully solved and we now have a sophisticated software package that can perform calculations needed to address scientific questions concerning the effects of coronal disturbances on the physical conditions in the corona and the ionization state of the solar wind.

3. APPLICATIONS

In order to demonstrate the capabilities of the software package discussed above, we calculated the effects of impulsive momentum deposition in a coronal region in which there was a standing shock. As shown by Habbal and collaborators (Habbal and Tsinganos 1983, Habbal et al. 1983, Habbal and Rosner 1984, Habbal 1985) standing shocks can develop in regions with multiple critical points such as coronal holes with rapidly diverging geometries. Figure 1 shows the radial variation of the density in the model as a function of time. The inital state is the lowest curve. Density curves for later times are displaced upward. The time interval between curves is 2000 sec. By comparing the different curves one sees how the addition of momentum causes the shock which was initially stationary to move outward so that approximately

120,000 sec (~30 hr) later the corona within 7 solar radii of the sun has evolved to a steady-state with no standing shock. Figures 2 and 3 show the corresponding evolution of the flow velocity and temperature.

The effects of the changing coronal conditions on the ionization state of the two most abundant stages of oxygen (O^{+6} and O^{+7}) was calculated. Some of the results are plotted in Figures 4-7. The upper panel in Figure 4 gives the ionization "temperature" determined from the ratio of the number densities of O^{+6}/O^{+7}. Curve (a) traces the variation of the ionization temperature for a fluid parcel starting out at the solar surface at time "0" and which passes the shock located at about 1.5 solar radii and continues outward in the solar wind. For comparison curve (b) gives the corresponding variation of the electron temperature. We see that the ionization temperature "freezes in" at 1.77×10^6 K, a value much larger than the approximately 10^6 K electron temperature near the upper boundary of the model at 8 solar radii. Curve (a) in the bottom panel of Figure 4 shows the radial variation of the number density of O^{+6} as a fraction of the total number of oxygen ions summed over all stages. For comparison curve (b) illustrates the radial variation that would be obtained if the ionization states did not freeze in (as would be the case in a static atmosphere) and depended only on the electron temperature.

Figure 5 shows the same parameters plotted for a fluid parcel starting out from the surface 13.9 hours later and passes the shock when it is slightly farther from the solar surface (at ~ 1.6 solar radii). We see that the resulting "freezing in" temperature is 1.8×10^6 K and

thus has changed very little from that illustrated in Figure 4. During this time interval, 13.9 hr after the deposition of momentum the shock is propagating outward at a very small velocity, hence there is little difference in the physical conditions in the region where the oxygen ion states freeze in. Figure 6 shows the situation 5.5 hr later (19.4 hr after the momentum deposition). Now the shock is beginning to propagate outward at a higher velocity and has moved to approximately 2.5 solar radii. The freezing in temperature is now significantly higher, 1.93 x 10^6 K. Figure 7 shows the situation when the shock has moved to nearly 4 solar radii (at a time 21.7 hr after the momentum deposition) when the freezing-in temperature has risen to 1.99 x 10^6 K. The difference (~2 x 10^5 K) between the freezing-in temperatures for parcels starting out at time 0 (Figure 4) to those starting out much later (Figure 7) is that the flow velocities within several solar radii of the surface where the region where the oxygen ionization states freeze-in are much larger after the shock has moved out beyond this region. This causes the oxygen ion states to freeze in closer to the surface where the temperature is higher.

Future work will be devoted to exploring the effects of impulsive heat, pressure and momentum deposition in a variety of scenarios which may represent different types of coronal disturbances.

4. SUMMARY

A sophisticated computer code has been developed for modeling the effects of impulsive heat, pressure and/or momentum deposition on coronal plasma temperatures, densities and flow velocities and

calculating the ionization state of the solar wind as a function of the location, duration and magnitude of heat/pressure/momentum deposition. Some of the capabilities of the code have been demonstrated by calculations of the effects of momentum deposition in a coronal region in which there was a stationary shock. Future applications will be concerned with detailed investigations of relationships between physical conditions in coronal disturbances and the ionization states of the resulting solar wind disturbances.

REFERENCES

Habbal, S. R. 1985, "Formation of a Standing Shock in a Polytropic Solar Wind Model Within 1-10 R_s", 1984 Chapman Conference on Collisionless Shocks in the Heliosphere, Napa Valley, California. J. Geophys. Res., 90, 199.

Habbal, S. R. and Rosner, R. 1984, "Temporal Evolution of the Solar Wind and the Formation of a Standing Shock", J. Geophys. Res., 89, 10645.

Habbal, S. R. and Tsinganos, K. 1983, "Multiple Transonic Solutions and a New Class of Shock Transitions in Steady Isothermal Solar and Stellar Winds", J. Geophys. Res., 88, 1965.

Habbal, S. R., Tsinganos, K. and Rosner, R. 1983,"Multiple Transonic Solutions and a New Class of Shock Transitions in Solar and Stellar Winds", in Solar Wind V, NASA Conference Publication 2280, ed. M. Neugebauer, p213.

Owocki, S. 1982, "The Ionization State of the Solar Wind", NCAR/CT-66, National Center for Atmospheric Research, Boulder, CO.

Owocki, S. P. 1983, "Intepreting the Solar Wind Ionization State", in Solar Wind V, NASA Conference Publication 2280, ed. M. Neugebauer, p623.

FIGURE CAPTIONS

Figure 1. Radial variation of the coronal density as a function of time. The densities in the initial model are given by the lowest curve. Density curves for later times are displaced upward. The time interval between curves is 2000 sec.

Figure 2. Radial variation of the flow velocity as a function of time. Same format as Figure 1.

Figure 3. Radial variation of the coronal temperature as a function of time. Same format as Figure 1.

Figure 4. Upper panel. Radial variation of the ionization temperature determined from the calculated ratios O^{+6}/O^{+7}. Curve (a) traces the variation of temperature for a fluid parcel starting out at the solar surface at time "0" and which passes the shock located at about 1.5 solar radii and continues outward into the solar wind. For comparison curve (b) gives the corresponding electron temperatures.

Lower panel. Radial variation of the number density of O^{+6} as a fraction of the total number of oxygen ions summed over all stages. Curve (a) shows the variation calculated from the model. For comparison curve (b) shows the variation that would be obtained if the ionization temperature remained equal to the electron temperature instead of freezing-in.

Figure 5. Same as Figure 4, but for a fluid parcel leaving the solar surface 13.9 hr later.

Figure 6. Same as Figure 4, but for a fluid parcel leaving the solar surface 19.4 hr later.

Figure 7. Same as Figure 4, but for a fluid parcel leaving the solar surface 21.7 hr later.

Figure 1

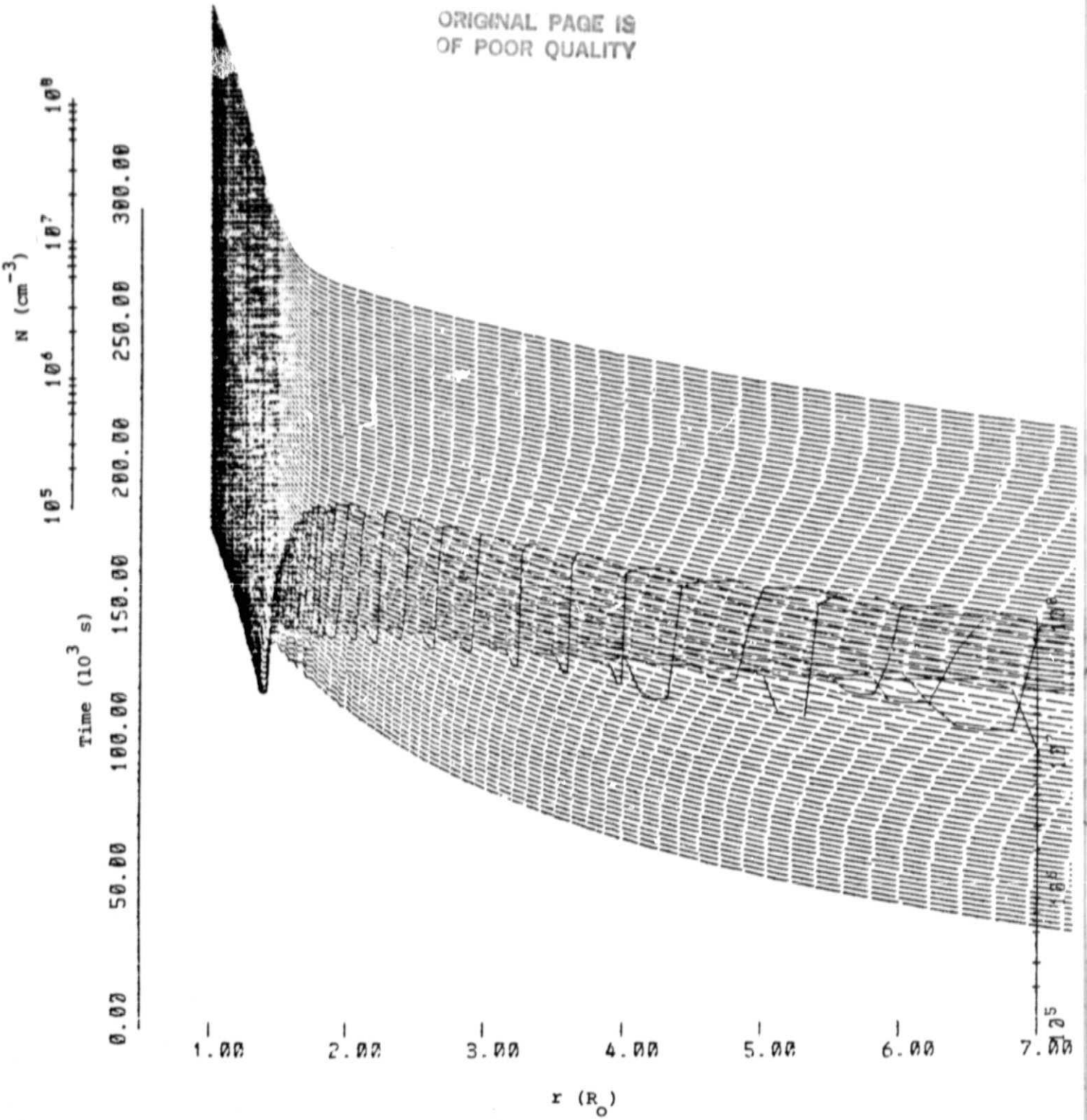

Figure 2

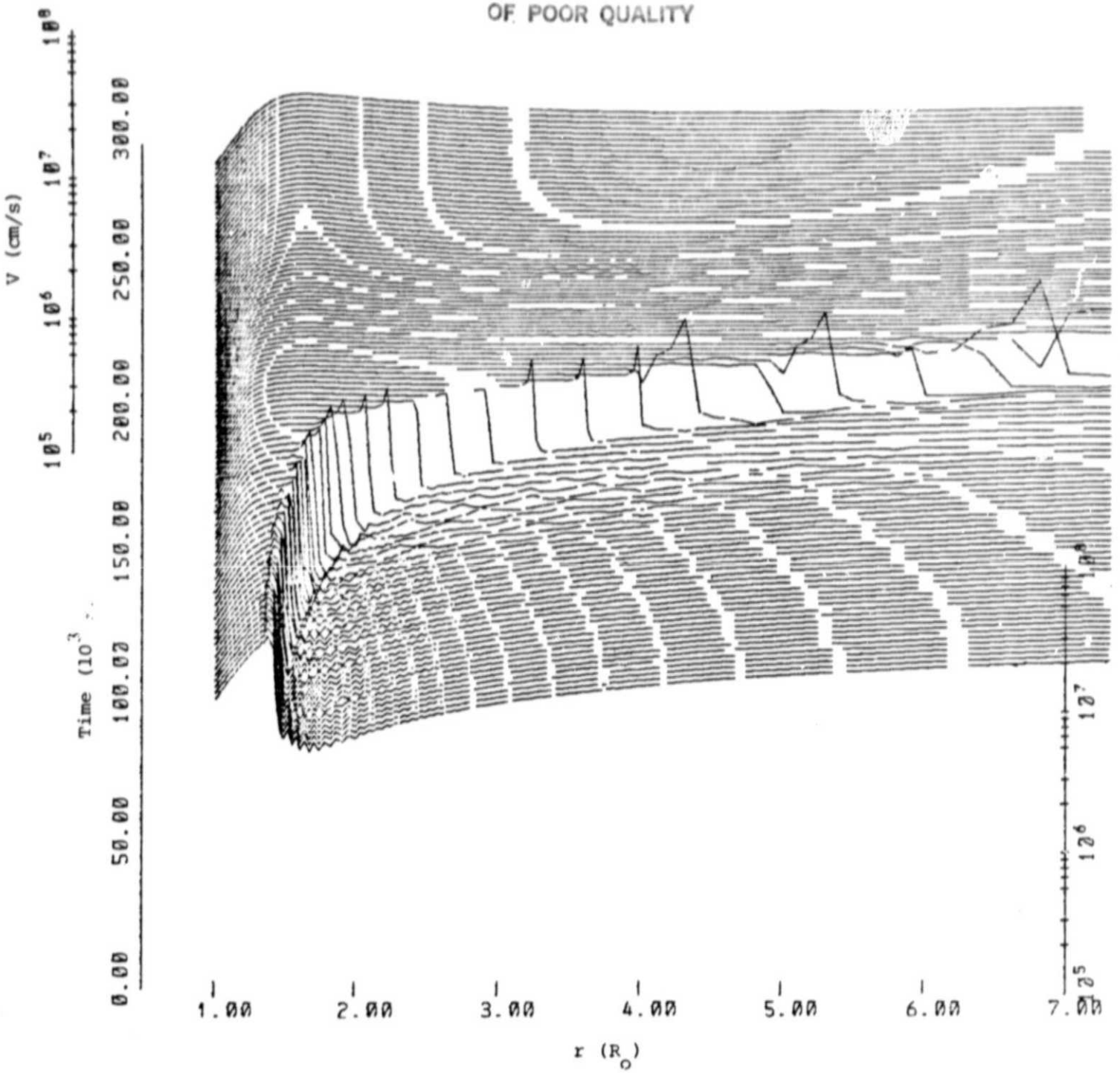

Figure 3

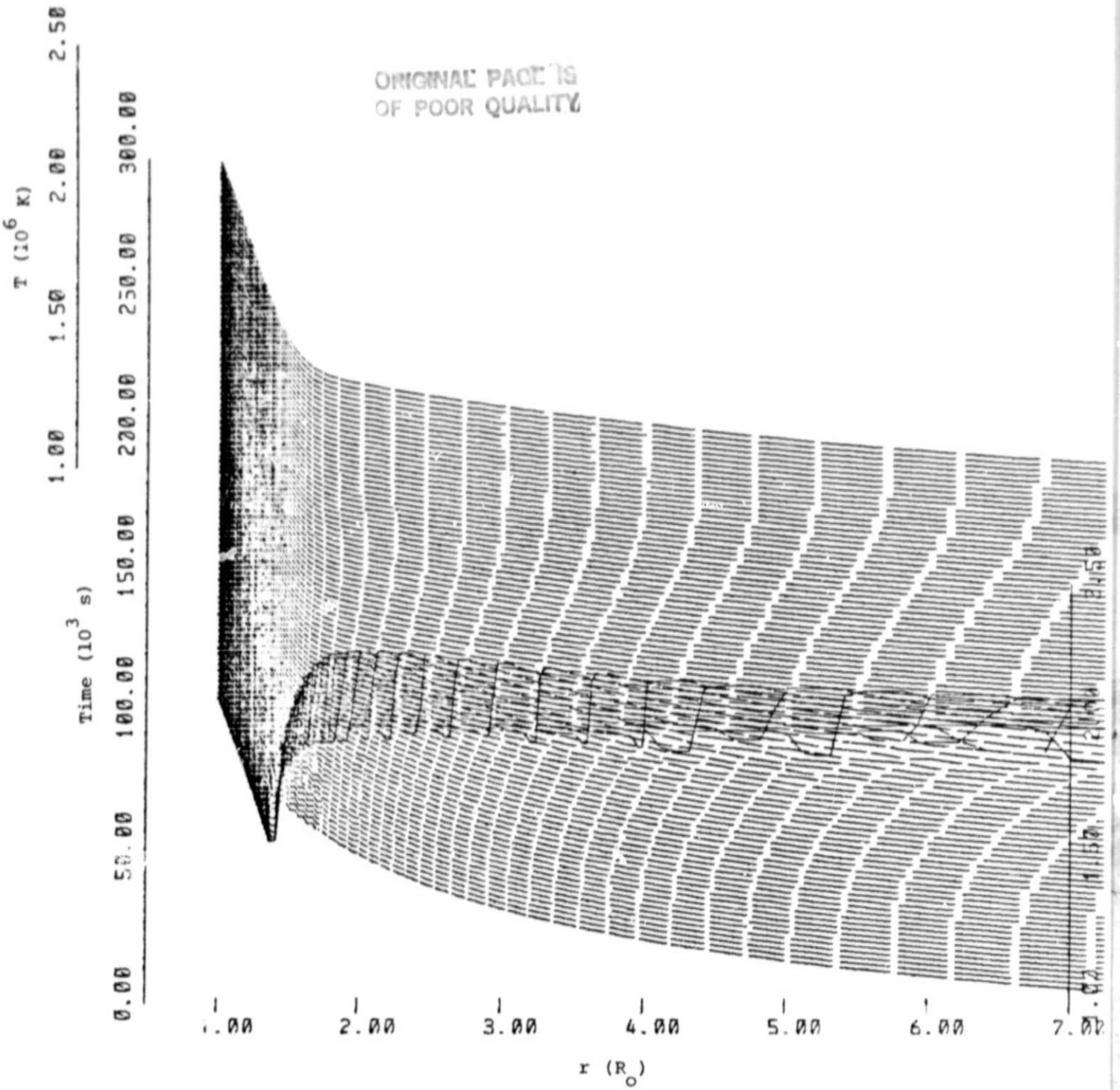

Figure 4

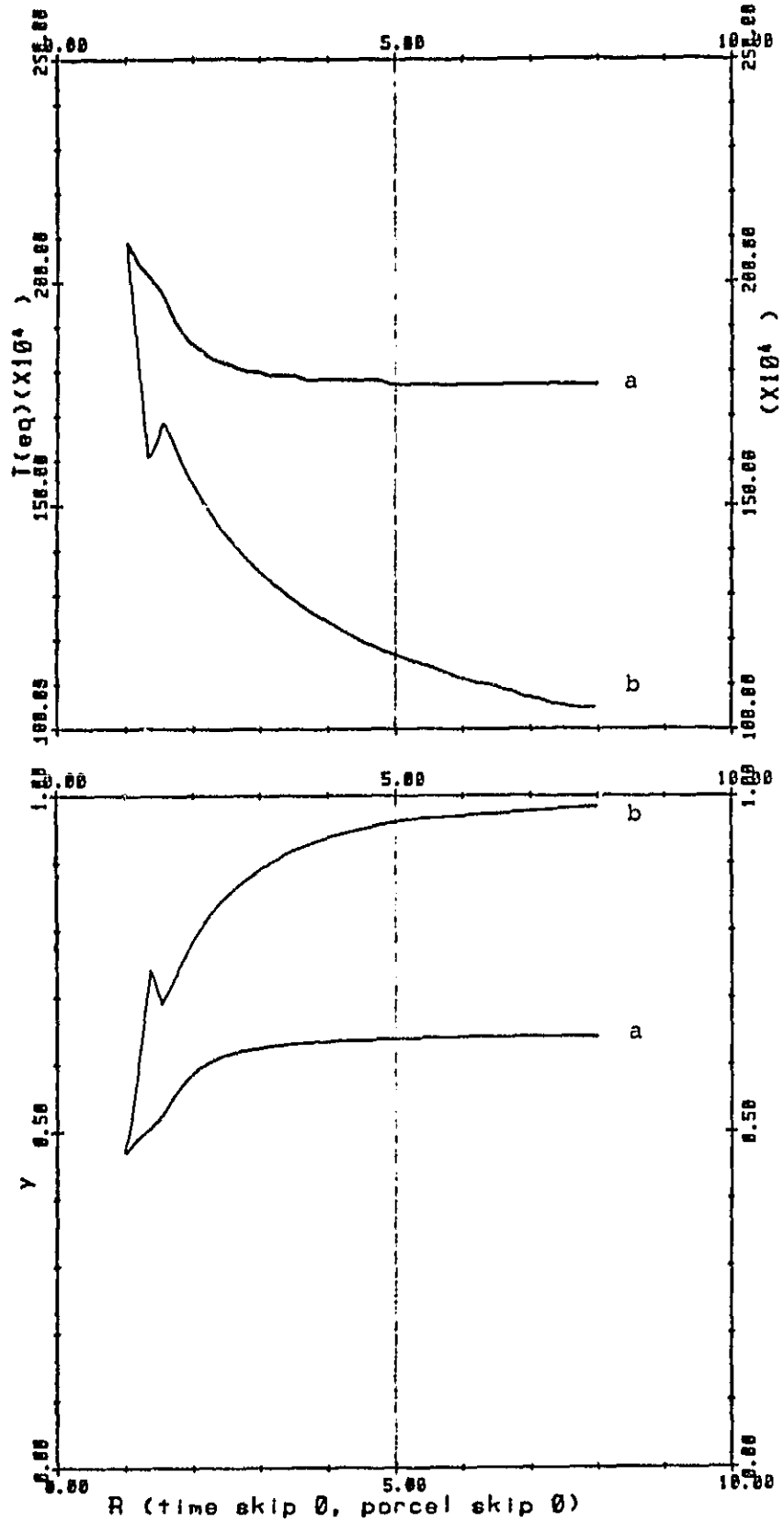

Figure 5

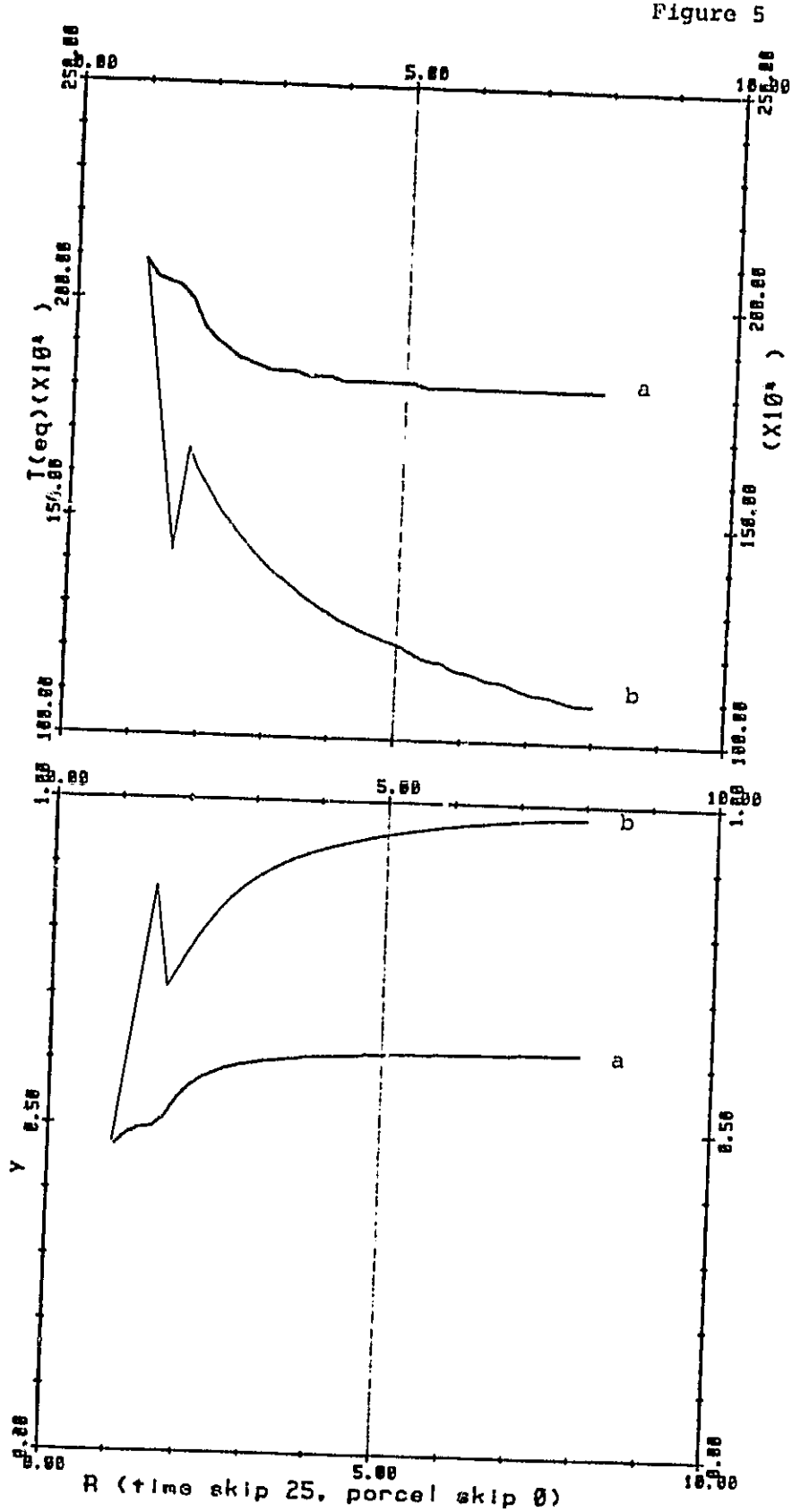

Figure 6

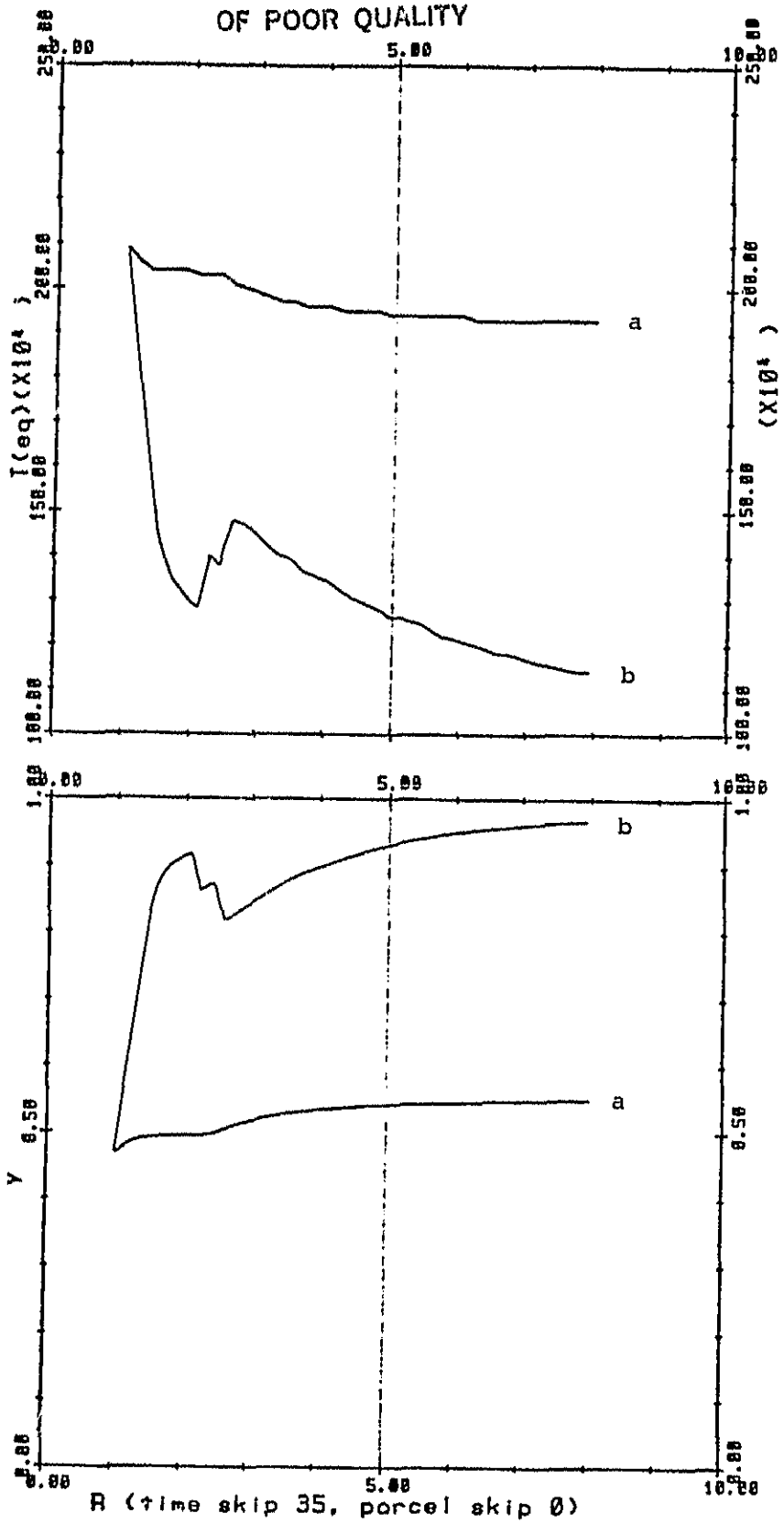

Figure 7