U.S. Weather Bureau.
Analysis of Tiros picture rectification errors
[by] E.G. Albert and R.W. White.

FOR OFFICIAL DISTRIBUTION. This paper has been printed as manuscript in limited quantity for preliminary use. As this reproduction does not constitute formal scientific publication, any reference to the paper in published articles and scientific literature should identify it as a manuscript of the U. S. Weather Bureau.

UNITED STATES DEPARTMENT OF COMMERCE

U.S. WEATHER BUREAU

Washington, D. C.

October 1962

ANALYSIS OF TIROS PICTURE RECTIFICATION ERRORS

E.G. Albert and R.W. White

National Weather Satellite Center, Suitland, Md.

ABSTRACT

Graphical analyses of the distribution of errors in the rectified location of TIROS picture elements were performed for selected attitude and time uncertainties. Two groups of examples, representative of the "low" and "medium" nadir angle ranges, were considered. The analyses (plus reasonable estimates of operational time and attitude errors) indicate that operational nephanalyses should seldom contain location errors as large as 120 nautical miles except near the horizon edge of the area.

INTRODUCTION

Prior to this study, no quantitative investigation of operational TIROS picture rectification errors has been conducted. The examples shown in Bristor, et. al.* deal only with the geometrical displacement of the principal point and other points on the picture principal line due to attitude error.

A need exists for quantitative information regarding the effect of time and attitude uncertainties on the location of rectified TIROS picture elements and regarding the distribution of the resulting errors over the picture format. If operational nephanalyses are to be distributed with estimated accuracy included in their legends, analysts must have some basis for making such estimates. Also, users of operational nephanalyses should have some general understanding of the location accuracy to be expected in different parts of nephanalyses.

*Bristor, C. L., Albert, E. G. & Jones, J. B., Problems in Mapping Data From Meteorological Satellites, Space Research II, Proceedings of the Second International Space Science Symposium, Florence, April 10-14, 1961, North-Holland Publishing Company - Amsterdam.

National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

The more important variables which affect rectification accuracy are time, attitude, nadir angle, camera and height.* The first three of these were determined to be significant variables for this study. All the examples are based on the TIROS IV camera one which carried an Elgeet lens. Errors discovered using this camera will be larger than, or equal to, those caused by the same variables using other TIROS cameras. Tegea and "Narrow-Angle" lenses have smaller fields of view and less distortion than the Elgeet. The other Elgeet lens cameras have comparable asymmetries. A circular orbit 800 km above a spherical earth is assumed for all examples. Height errors due to time errors and the interaction between time or attitude errors and height, make only small differences in constant altitude location error patterns for TIROS I through IV height ranges. The interaction effect for the more eccentric TIROS V orbit and for the contemplated "highly eccentric" orbit should be investigated.

Operational use is made of TIROS pictures having nadir angles between 0° and about 65°. The pattern and magnitude of location errors due to time and attitude uncertainties vary continuously with nadir angle. However, certain characteristics of the location errors are associated with certain ranges of nadir angle.

When the picture nadir angle is large enough to allow a useable segment of the horizon to be imaged, the position of the principal line is easily determined. In horizonless pictures, the rotary position of the principal line is more difficult to establish. In addition, simple geometry shows that the smaller the picture nadir angle is, the greater the azimuthal portion of location errors becomes.

This reasoning indicates that a minimum of two nadir angle cases - one too small to allow horizon images, the other too large to miss them - should be studied. Other considerations, particularly range of minimum nadir angle, suggest that more examples would be useful. But, for the sake of simplicity in this first study, only two nadir angle cases are included. The low nadir angle case illustrates errors in a nominal 11° nadir angle picture. The medium nadir angle case is based on a 46° picture.

Examination of the scatter among individual attitude determinations, from various sources through the operational lifetimes of TIROS III and IV,

---

*In this context, the terms mentioned have the following meanings:

Time: Instant of picture exposure - uniquely determines satellite position.
Attitude: Spin axis point coordinates. Changes are expressed as degrees of great circle arc.
Camera: A particular combination of lens and electronics (two per TIROS).
Nadir angle and height maintain their usual meanings.

indicate that attitude was known for operational purposes within about 2° most of the time. The uncertainty seems to have rarely been greater than 3°.

Preliminary analyses showed that location error patterns for 1° and even 2° attitude errors were less well-marked and reliable than those for 3° errors. This is partly due to crudities in the method used. Only analyses of location errors due to 3° attitude errors are shown in this paper.

Experience with the various techniques of TIROS picture time determination indicates that errors of a few seconds, up to possibly 10 seconds, may go undetected. In rare, extremely unfavorable circumstances, it is conceivable that 30 second uncertainties may exist. For reasons similar to those in the preceding paragraph, examples of 30 second errors in time were chosen for analysis.

One 10-second error case is presented to illustrate the following point. Geometric reasoning shows that due to the earth's curvature, the nadir angle portion of picture element location error is not linearly related to the attitude or time error causing it. If a 30-second error in time produces a picture element location error with a component of 90 nautical miles in the nadir angle direction, a 10-second error will not produce exactly a 30 nautical mile error in that direction. If the errors are towards the horizon, the result of the 10-second error will be less than 30 miles location error. If the error is away from the horizon, the result will be more than 30 miles. (The azimuthal portion of location error is considered to be linearly related to the attitude or time error for the small variations considered here.)

DESCRIPTION OF ANALYSES

The distortion-free grid, DFG, for the TIROS IV camera one; the oblique equidistant cylindrical projection map, OEC; the 800 km height grid and the nadir grid set used in the hand analysis method described by Fujita* were used to perform these analyses.

The DFG was treated as a picture, thereby eliminating the complicating effects of distortion. (Some measure of the effect of distortion is contained in the last two analyses described below which compare the DFG and the latitude/longitude grids prepared by computer.) Figures 1 and 2 illustrate the concept of a DFG as a picture. The horizon as seen from 800 km with an 11° camera nadir angle in Figure 1 and a 46° nadir angle in Figure 2 is shown. The area between a 55° object nadir angle and the horizon is crosshatched. The horizon direction of the principal line was chosen to be along the longest semidiagonal.

*Fujita, T., Outline of a Technique for Precise Rectification of Satellite Cloud Photographs, Mesometeorology Project, Dept. of the Geophysical Sciences, The University of Chicago, Research Paper #3, November 1961.

In each analysis, the DFG was rectified onto an OEC using the nadir grid appropriate to the assumed picture nadir angle. Figure 3 shows the results of such rectifications. The grid lines and intersections shown are the "data points" used for the location error analyses.

ATTITUDE ERROR ANALYSES

Attitude changes may be resolved into two components. For the purposes of these analyses one component was chosen to be along the principal line of the picture, changing nadir angle only. The orthogonal component is then a change of the direction of the principal line, a change in azimuth only. The results of such changes are independent of attitude. That is, for a particular camera nadir angle, a change in attitude which causes a 1° error in that nadir angle will produce the same error pattern in the rectification regardless of the original spin axis coordinates. Conversely, the 1° nadir angle error must be reflected in a spin axis coordinate change of precisely 1° along the principal line.

The error patterns appearing in Figures 4 through 12 are the results of comparisons between DFG rectifications for different camera nadir angles or azimuths. The specific comparisons are detailed in the discussion of each figure.

Figure 4 displays the location error field for a 3° deviation in nadir angle for the low nadir angle case. The analysis was performed by overlaying DFG rectifications for 8° and 11° camera nadir angles. The distances between corresponding grid intersections were measured, and isopleths of equal deviation were drawn. Figure 5 is the result of a similar analysis using a 43° and a 46° nadir angle DFG rectification. Comparing the error fields shown in Figures 4 and 5, it is evident that the error pattern within the 55° object nadir angle position is changed only slightly by a large change in base nadir angle. Qualitative interpolation between the low and medium nadir angle cases and extrapolation to higher or lower nadir angle cases should be relatively easy.

Figure 6 shows the location error pattern for a 3° change of attitude having no nadir angle component for an 11° camera nadir angle. Two 11° nadir angle DFG rectifications were set with a common subpoint and with their principal lines separated by an angular distance appropriate to a spin axis point separation of 3°. This resulted in approximately 16° azimuth change.

Figure 7 shows the error pattern resulting from a similar comparison of 46° DFG rectifications. The actual azimuth difference for the 3° attitude deviation in this case was 4°.

Comparison of Figure 6 and Figure 7 indicates that for a given azimuthal attitude error component the resulting location error decreases sharply with increasing nadir angle. In addition, comparisons among Figures 4 through 7 show that the net location error at object nadir angles less than 55° can be expected to decrease as picture nadir angle increases.

TIME ERROR ANALYSES

Picture element location error patterns caused by time errors are not independent of attitude. Unlike the attitude error case discussed above, if nadir angle, azimuth and time changes are specified, the spin axis point is essentially determined. (There is also a slight dependence on orbital inclination and "heading".) For this reason, the time error illustrations to be presented are less general than those for attitude errors. However, careful consideration of the relationships among the significant variables will allow some useful generalizations.

In order to simulate time errors it is necessary to assume a nodal period and an attitude in addition to the assumptions made earlier. Figure 9 illustrates the 30 second time error effects for the medium nadir angle range. A 45° and a 46.5° DFG were rectified with their subpoints separated by 1.7° of arc. These values correspond to a nodal period of 100.0 minutes and a minimum nadir angle of 10.7 degrees. Figure 10 illustrates the comparable 10-second error case using a 46° DFG and the 46.5° grid.

Figure 8 presents the error pattern produced by a 30-second time error for the low nadir angle range. In this case, 11° and 10° DFGrids were rectified under the same conditions as in the previous 30-second case, except that an 8.5° minimum nadir angle was assumed.

ERROR COMPENSATION BY HORIZON FITTING

A method for the partial compensation of time and attitude errors that may be used in routine operations consists of matching image horizon and prepared grid horizon. The preceding analyses are based on principal point coincidence. That procedure, which is a mechanically straightforward assembly of picture and grid, allows horizon mismatch to occur in direct proportion to nadir angle component error.

Figures 11 and 12 represent the same attitude and time errors as Figures 5 and 9 respectively, but horizons rather than principal points have been matched. The method used is most simply envisioned as "reversed rectification." That is, OEC latitude, longitude points are transferred to a DFG by the Fujita method for each subpoint, spin axis point configuration studied. Then, a pair of DFGs are matched with coincident horizons and latitude, longitude differences at corresponding points are noted.

The location error pattern shown in Figure 11 represents a remarkable improvement over that of Figure 5. It is evident that this method effectively compensates for the nadir angle component portion of location errors produced by attitude error. Of course, there will be no change in the azimuthal components.

The differences between Figures 9 and 12 probably indicate that horizon fitting is beneficial for time errors also, but there is no great improvement. The reduction of extremes and the more even distribution of errors should contribute to a better match between adjacent frames.

EFFECT OF DISTORTION

Since the DFG is not used in routine nephanalysis operations, an investigation of the effect of distortion was also carried out. The crucial factor is not the total distortion; it is the difference between the true distortion and the compensating distortion assumed to exist for the construction of operational picture grids. Figures 13 and 14 show location error patterns due to this difference for the low and medium nadir angle cases respectively. The analyses were prepared by comparing rectifications of the prelaunch system calibration picture of a target with rectifications of a distortion-free representation of that target.

It should be noted that only radially symmetrical distortion is compensated for in operational grids. TIROS pictures contain large asymmetrical distortion components. Therefore, the patterns shown in Figures 13 and 14 could be changed considerably by rotation of the principal line.

CONCLUSIONS

The values of time and attitude error for which analyses have been presented are greater than those normally encountered operationally, and areas photographed at object nadir angles above 55° are seldom included in operational nephanalyses. On this basis, the analyses demonstrate that location errors in operational TIROS nephanalyses should rarely equal or exceed 120 nautical miles. The analyses also indicate that the operational nephanalyst should insure that image and grid horizons coincide and that he should avoid analysis beyond the 55° object nadir angle when pictures fail to match their grids and adjacent pictures quite well.

Interpolation or extrapolation based on these examples should allow at least qualitative judgments to be made regarding location error patterns at other nadir angles or for other time or attitude errors. However, such judgments are quite difficult to make for very low nadir angles and for time errors when attitude is considerably different from that employed in this manuscript.

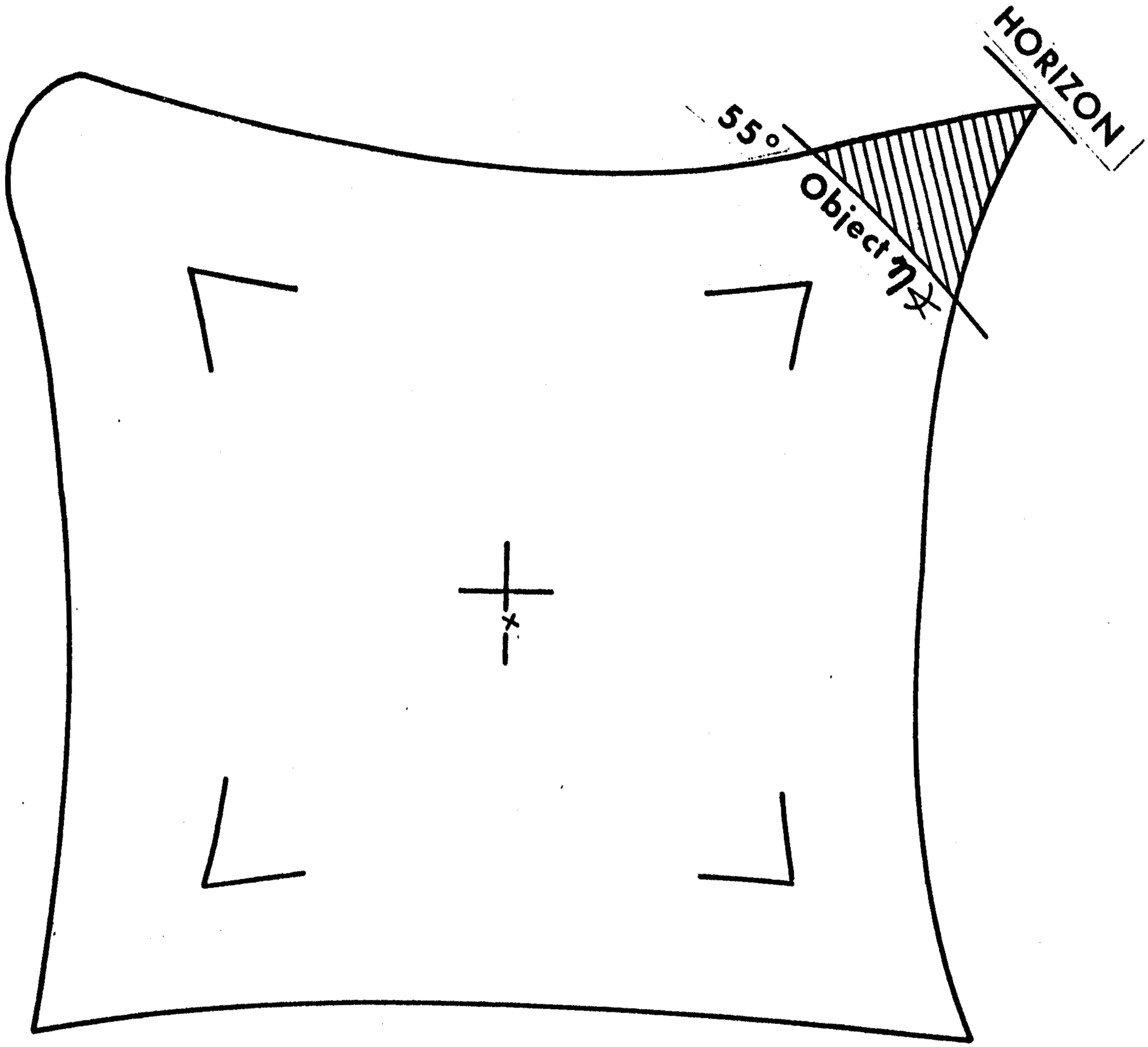


Figure 1

Unrectified, distortion-free picture (low nadir angle case).

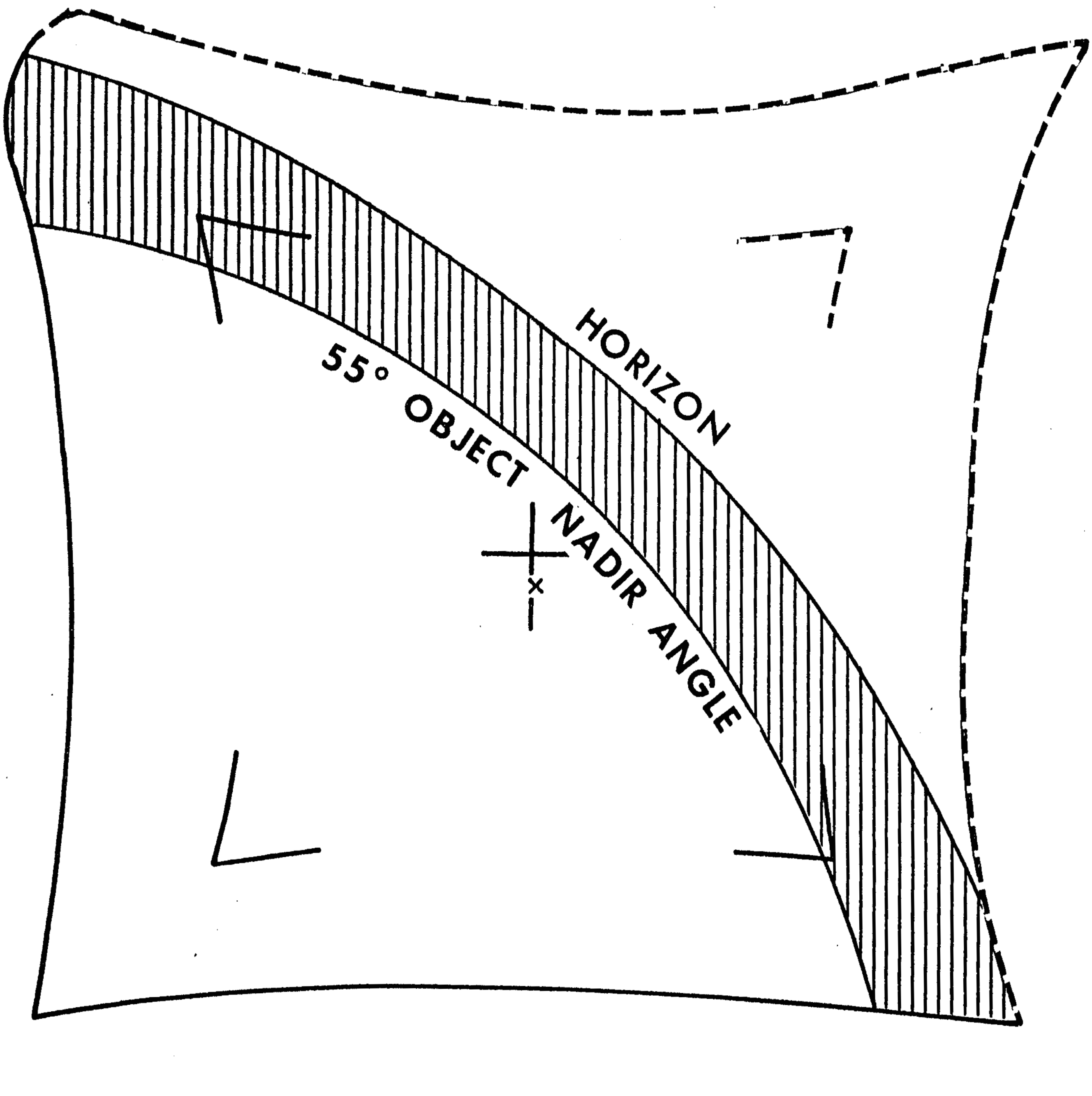
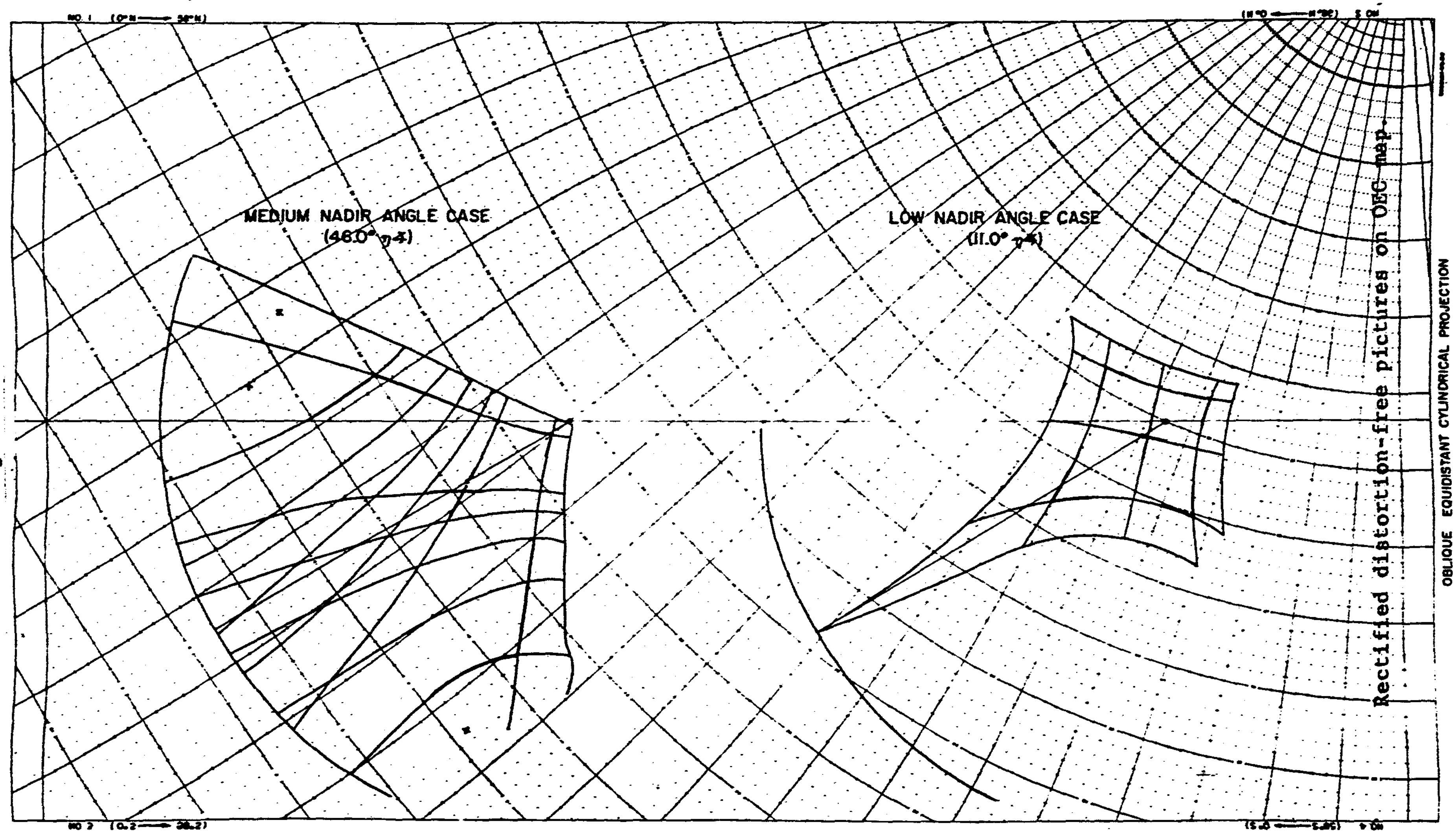


Figure 2

Unrectified, distortion-free picture (medium nadir angle case).

Figure 3



Rectified distortion-free pictures on OEC map.

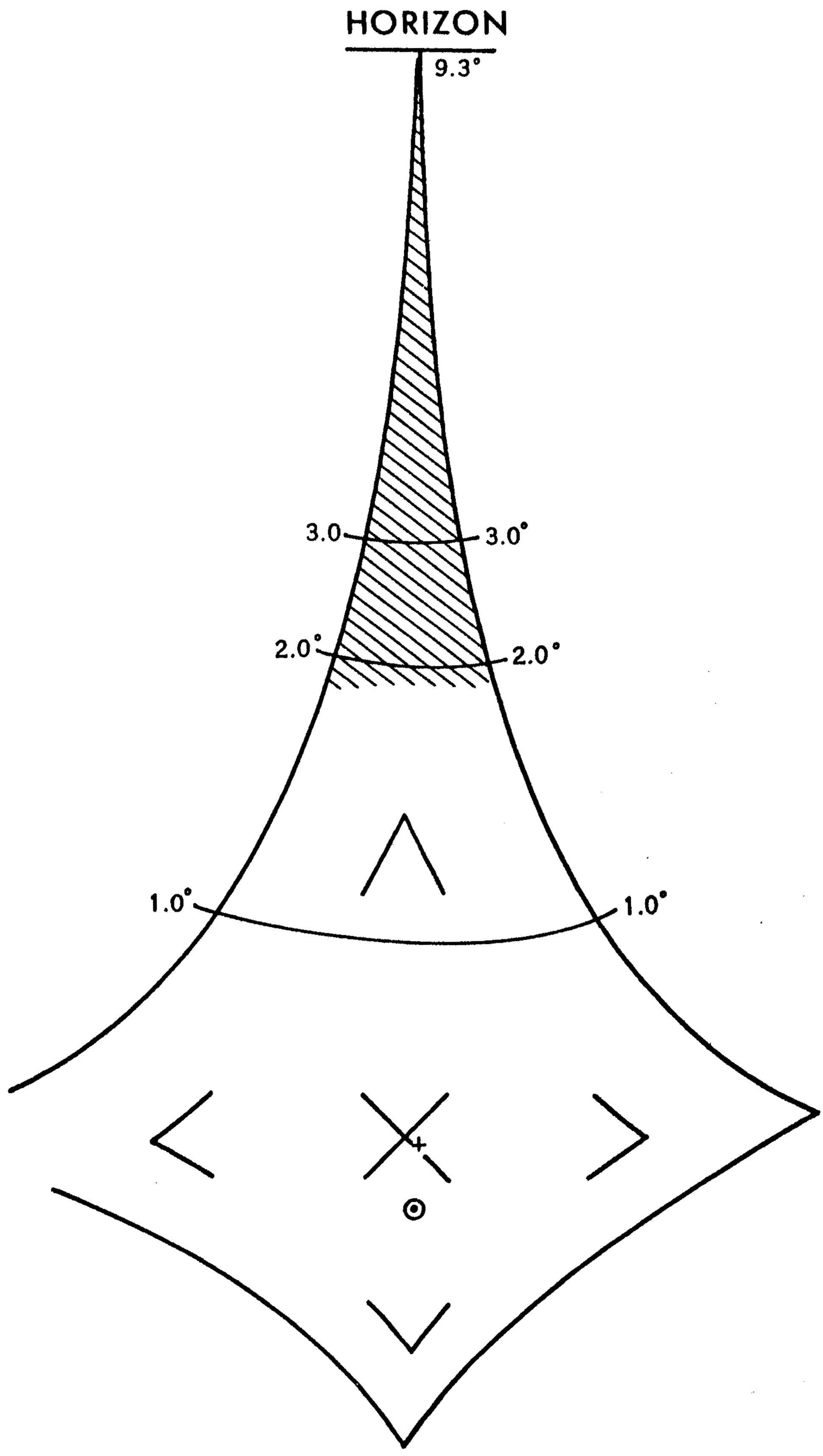
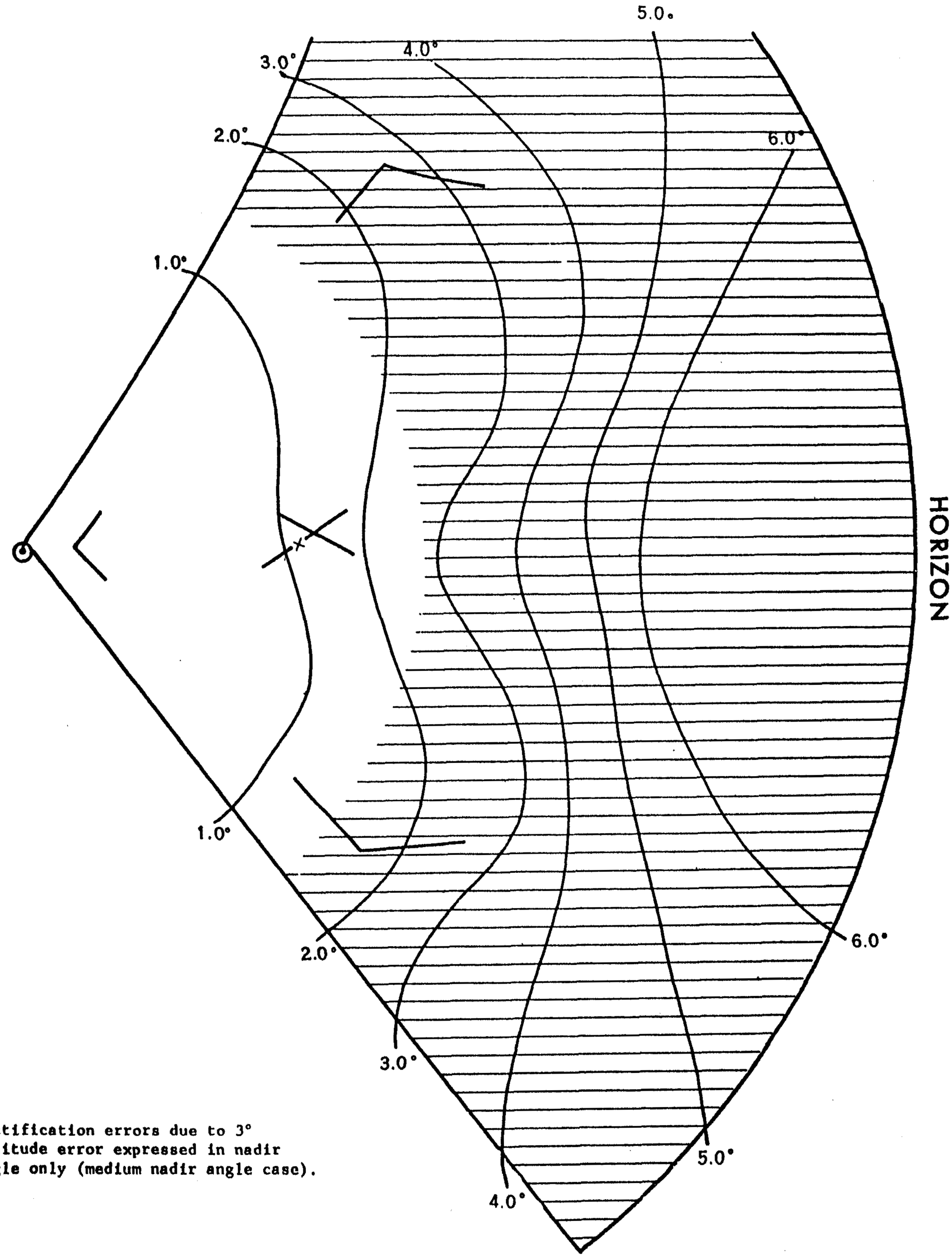


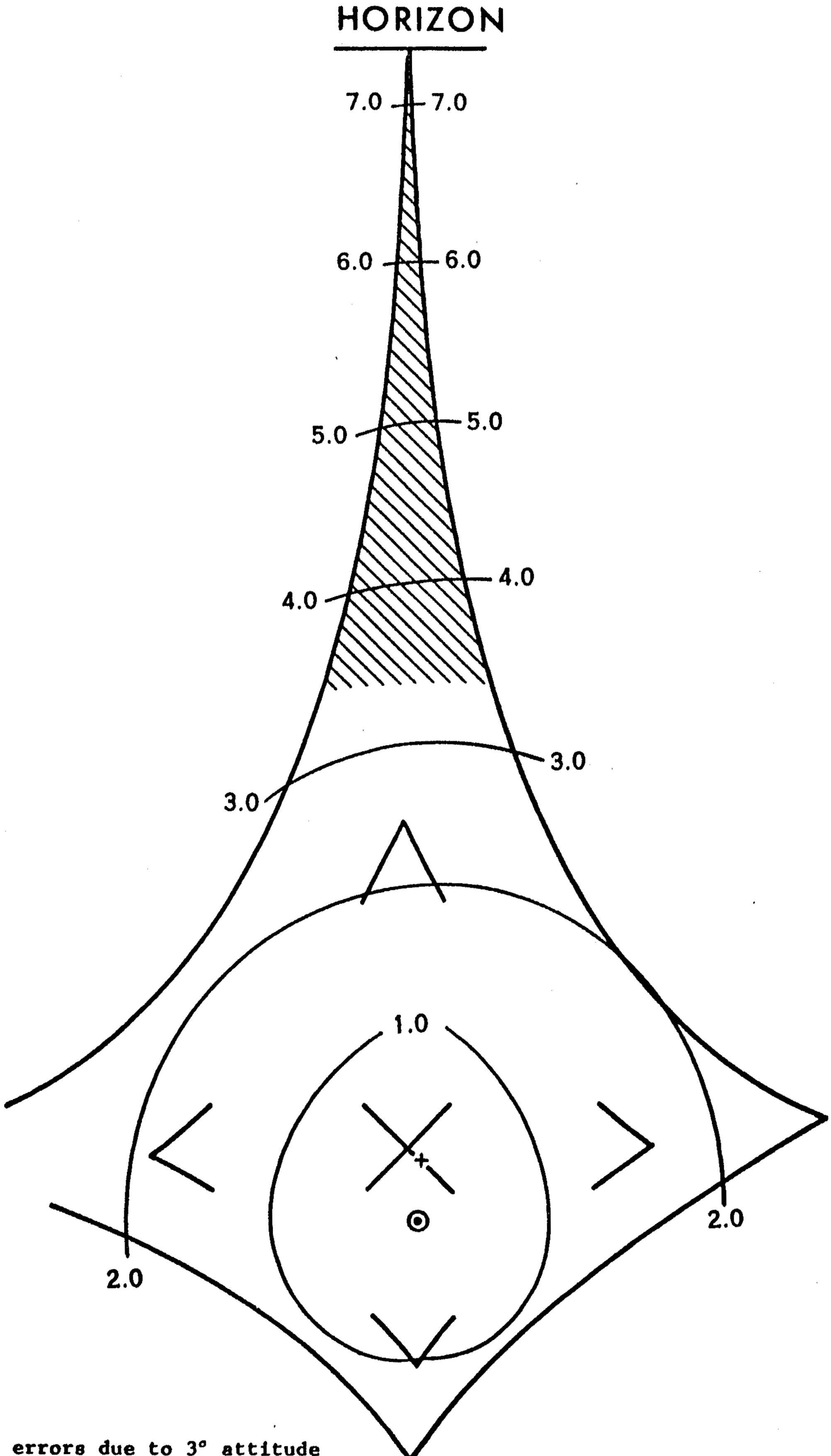
Figure 4

Rectification errors due to 3° attitude error expressed in nadir angle only (low nadir angle case).



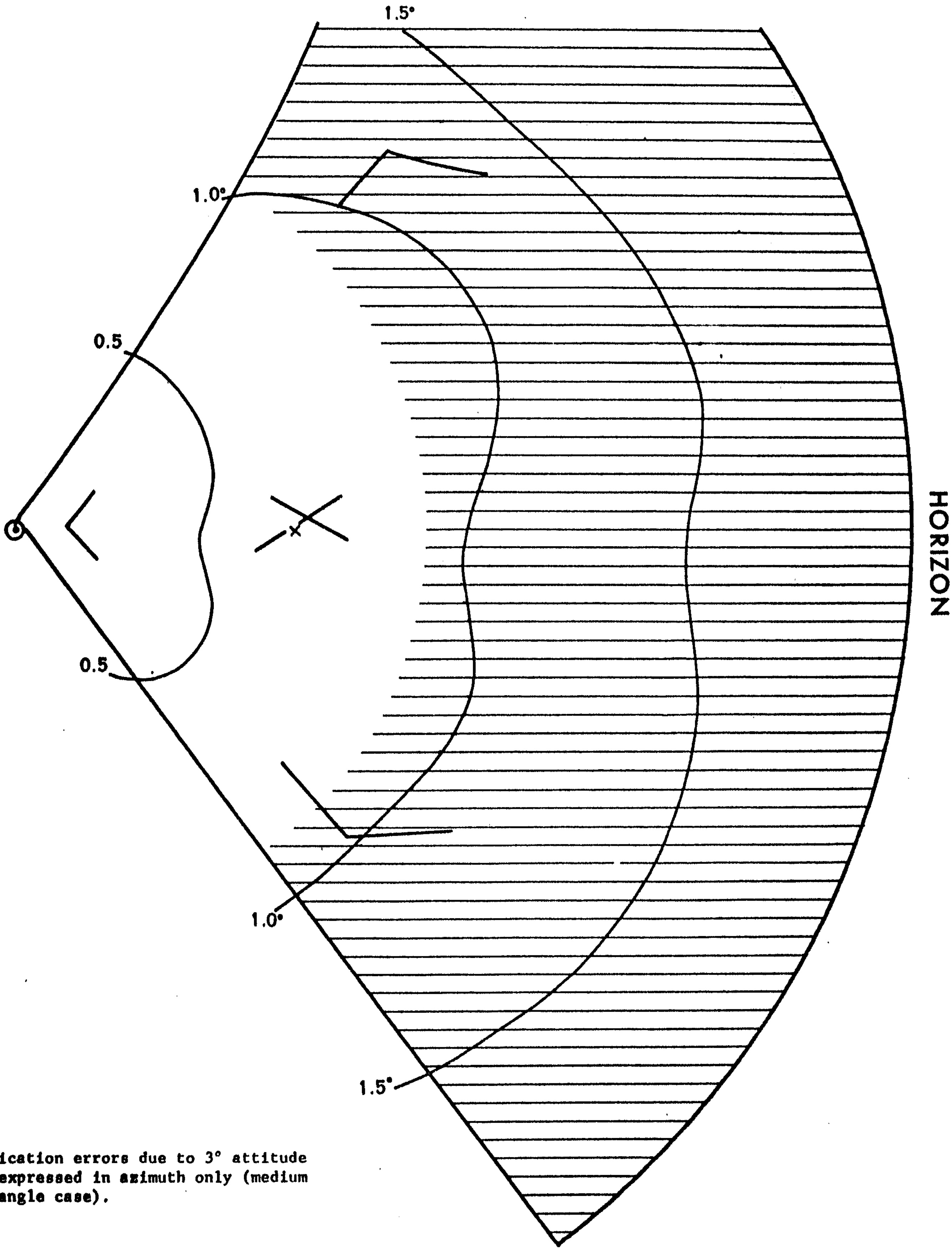
Rectification errors due to 3° attitude error expressed in nadir angle only (medium nadir angle case).

Figure 5



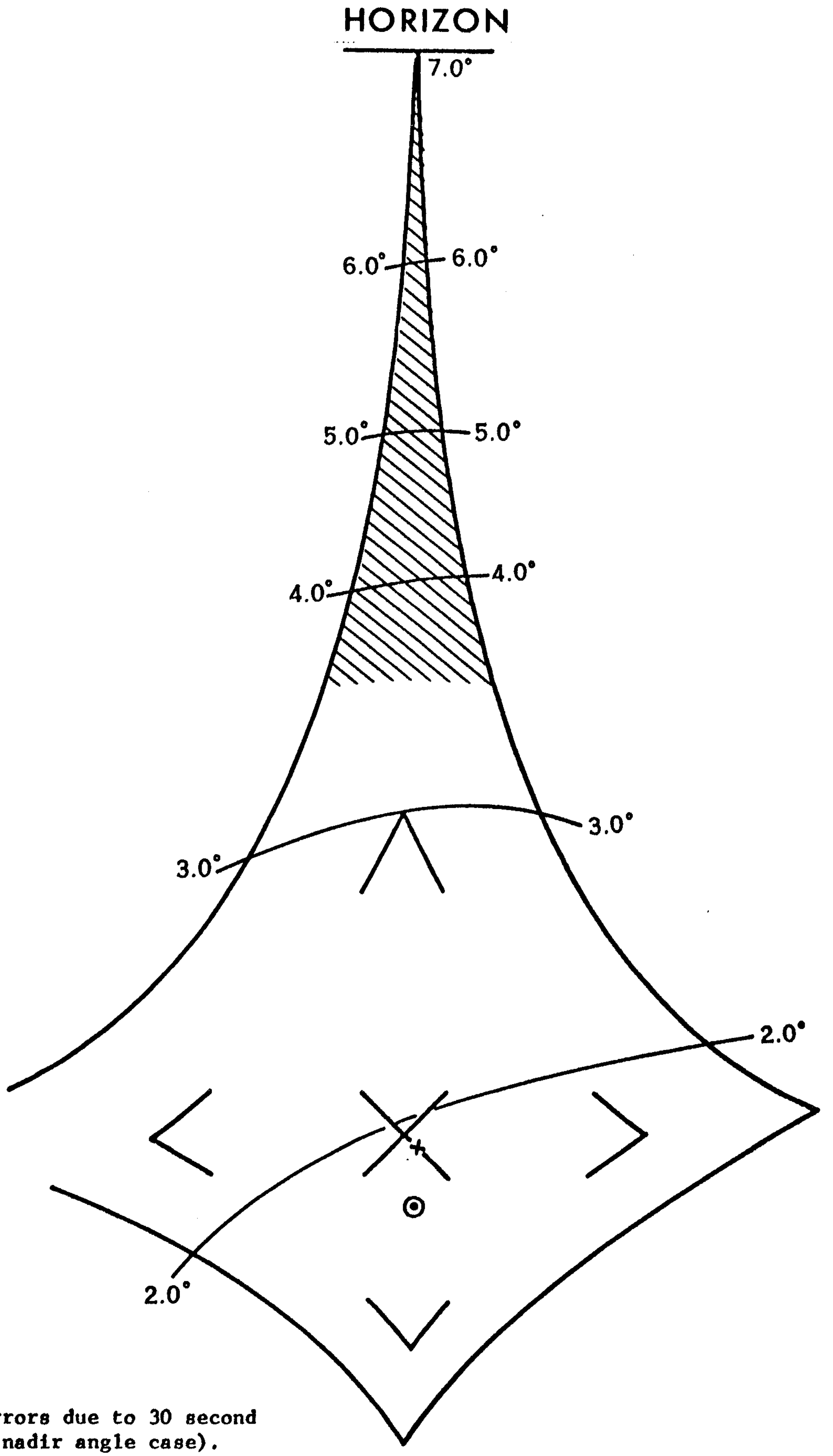
Rectification errors due to 3° attitude error expressed in azimuth only (low angle case).

Figure 6



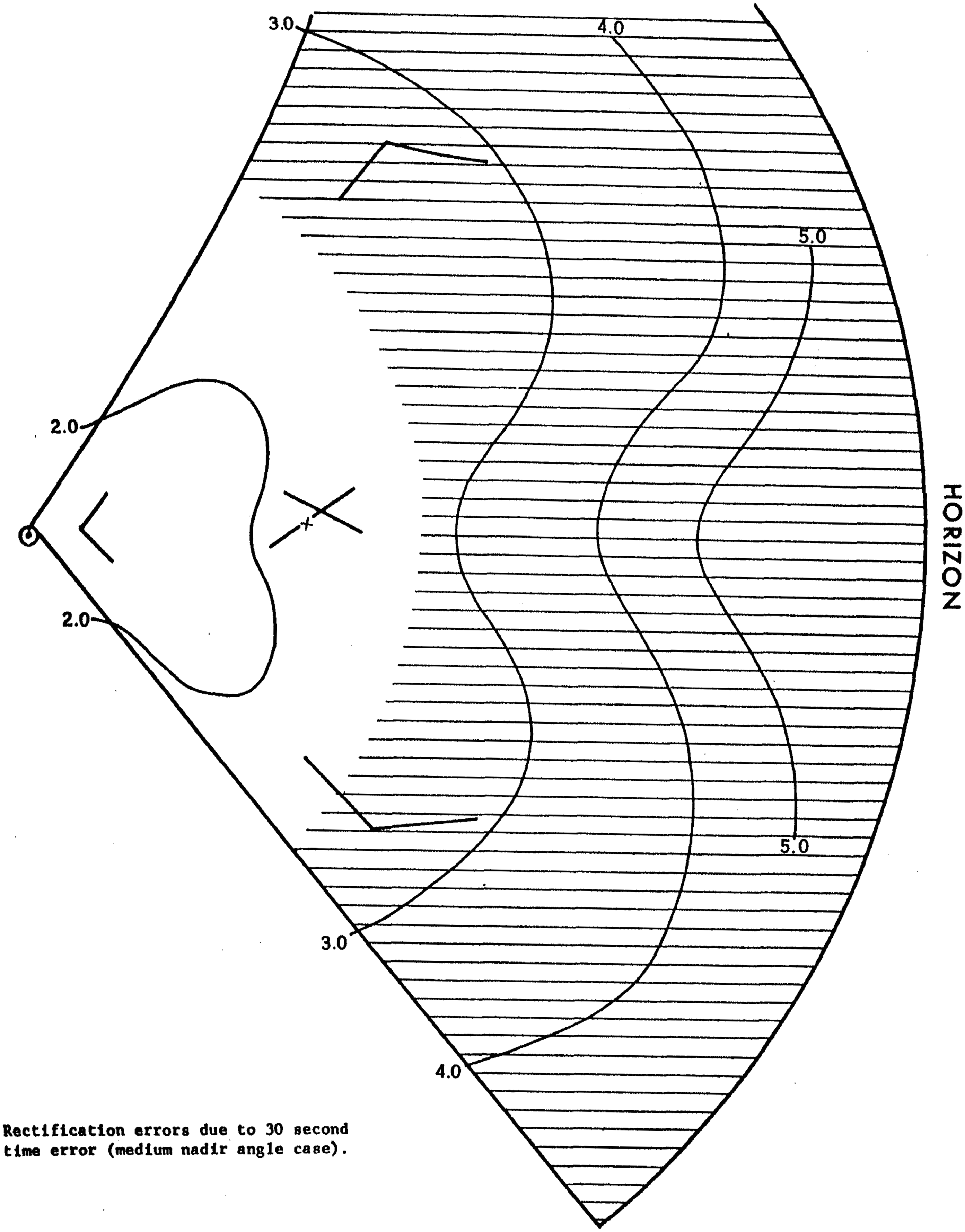
Rectification errors due to 3° attitude error expressed in azimuth only (medium nadir angle case).

Figure 7



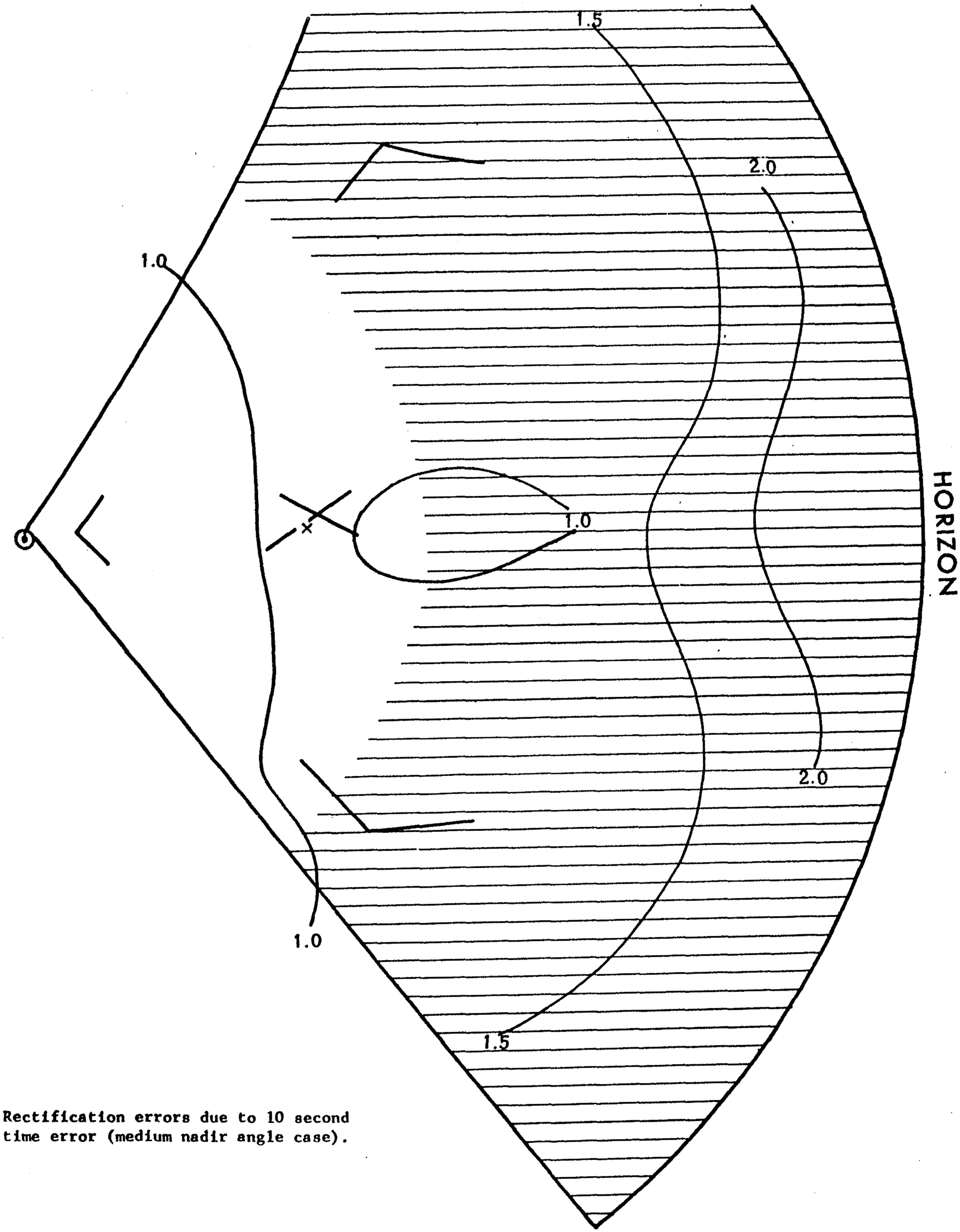
Rectification errors due to 30 second
time error (low nadir angle case).

Figure 8



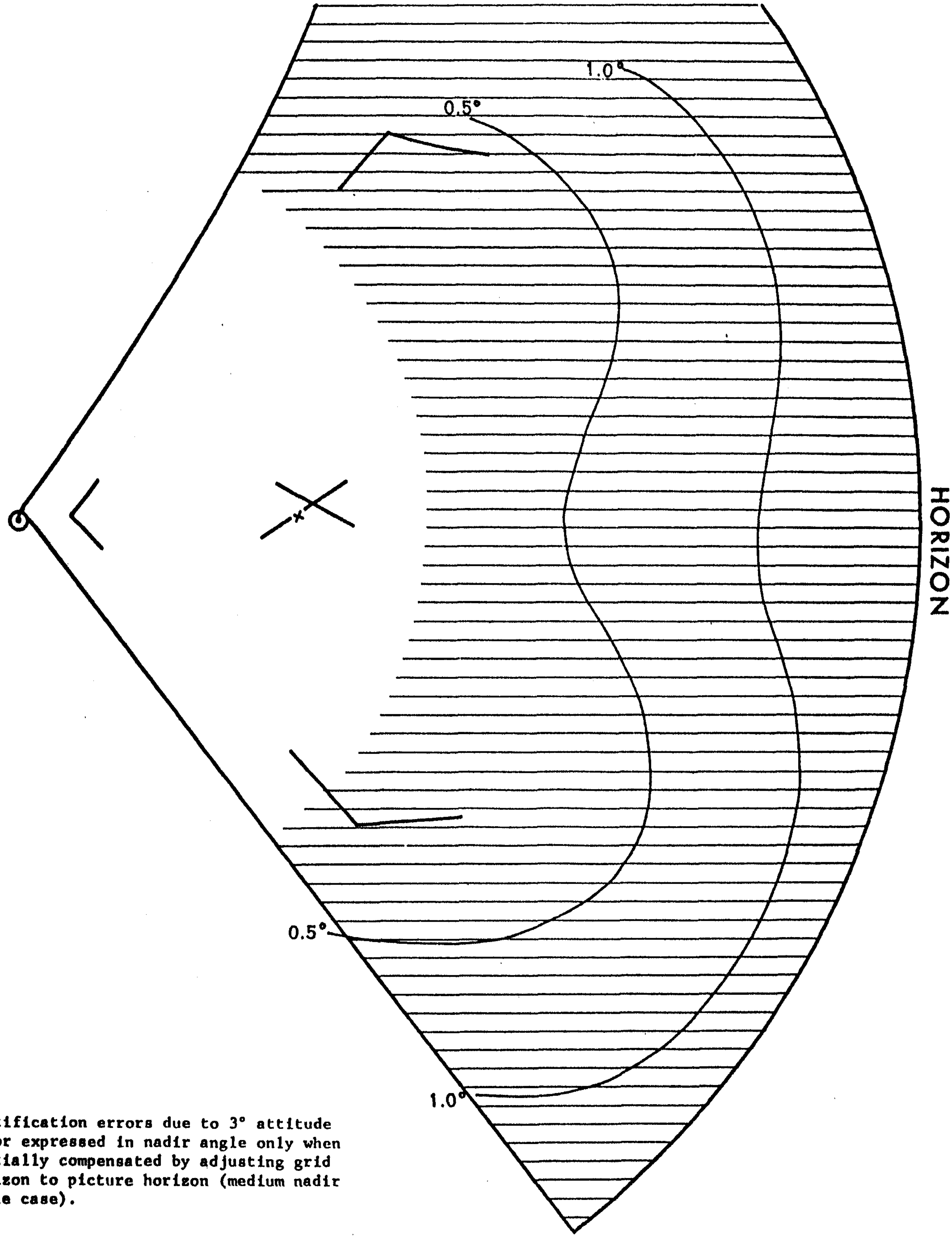
Rectification errors due to 30 second time error (medium nadir angle case).

Figure 9



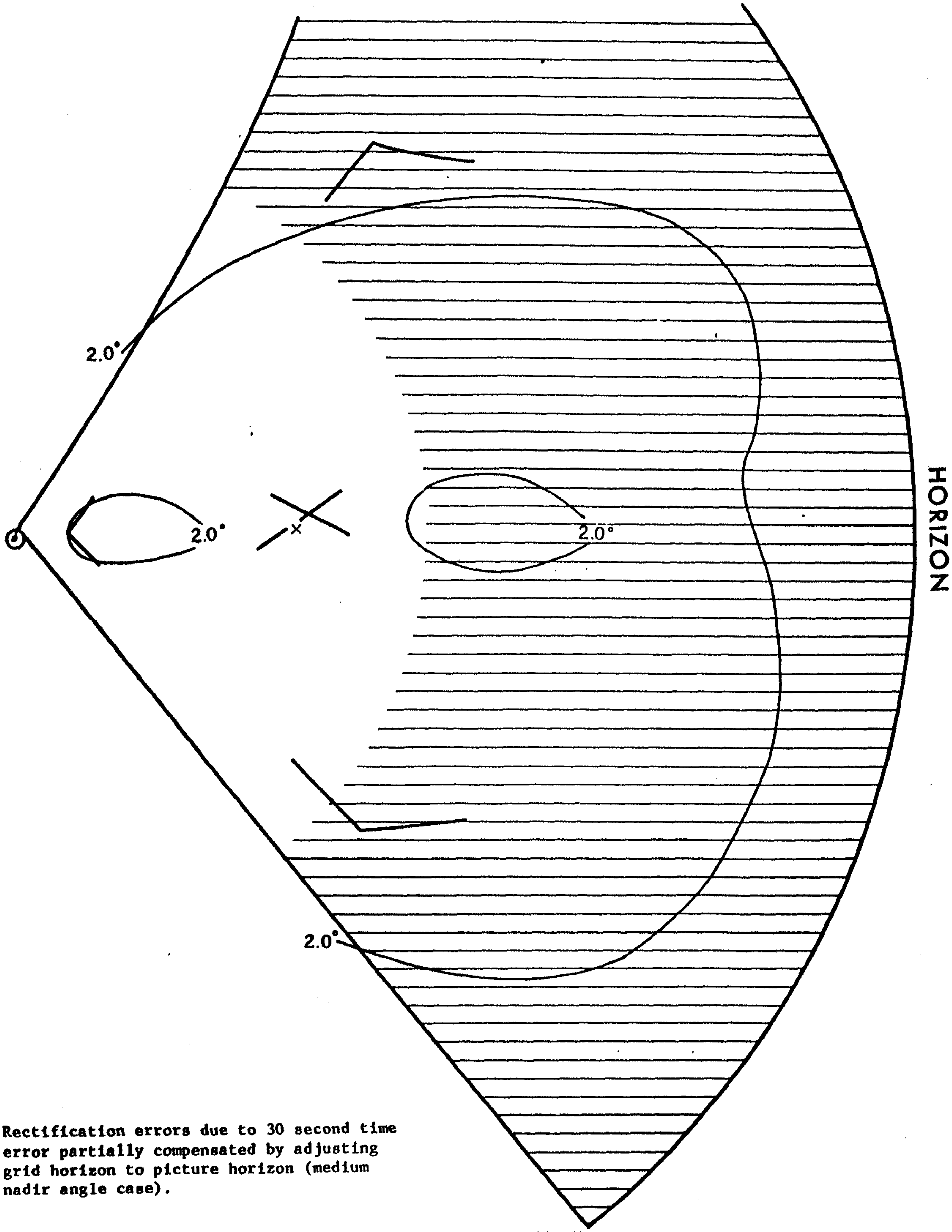
Rectification errors due to 10 second time error (medium nadir angle case).

Figure 10



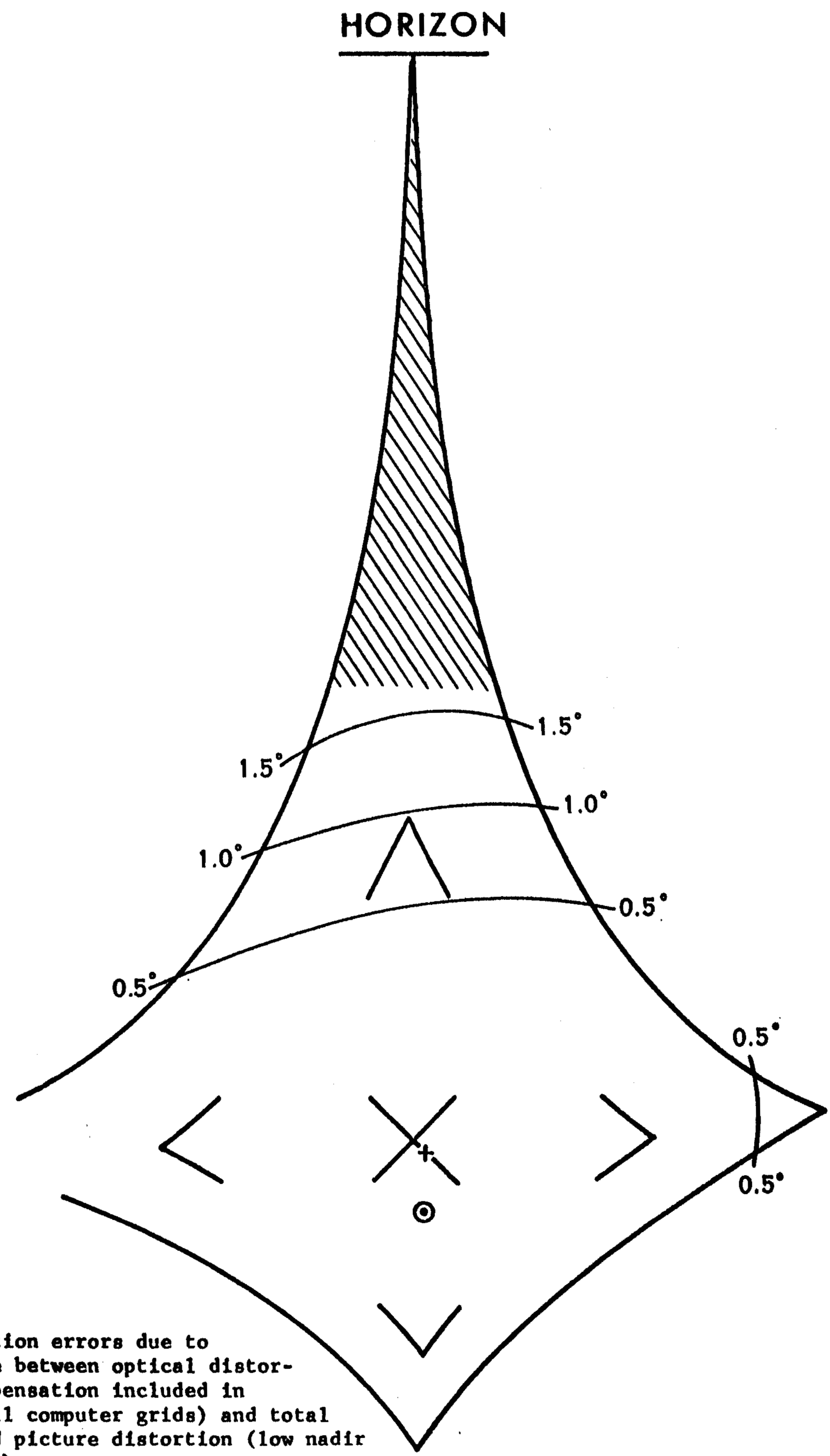
Rectification errors due to 3° attitude error expressed in nadir angle only when partially compensated by adjusting grid horizon to picture horizon (medium nadir angle case).

Figure 11



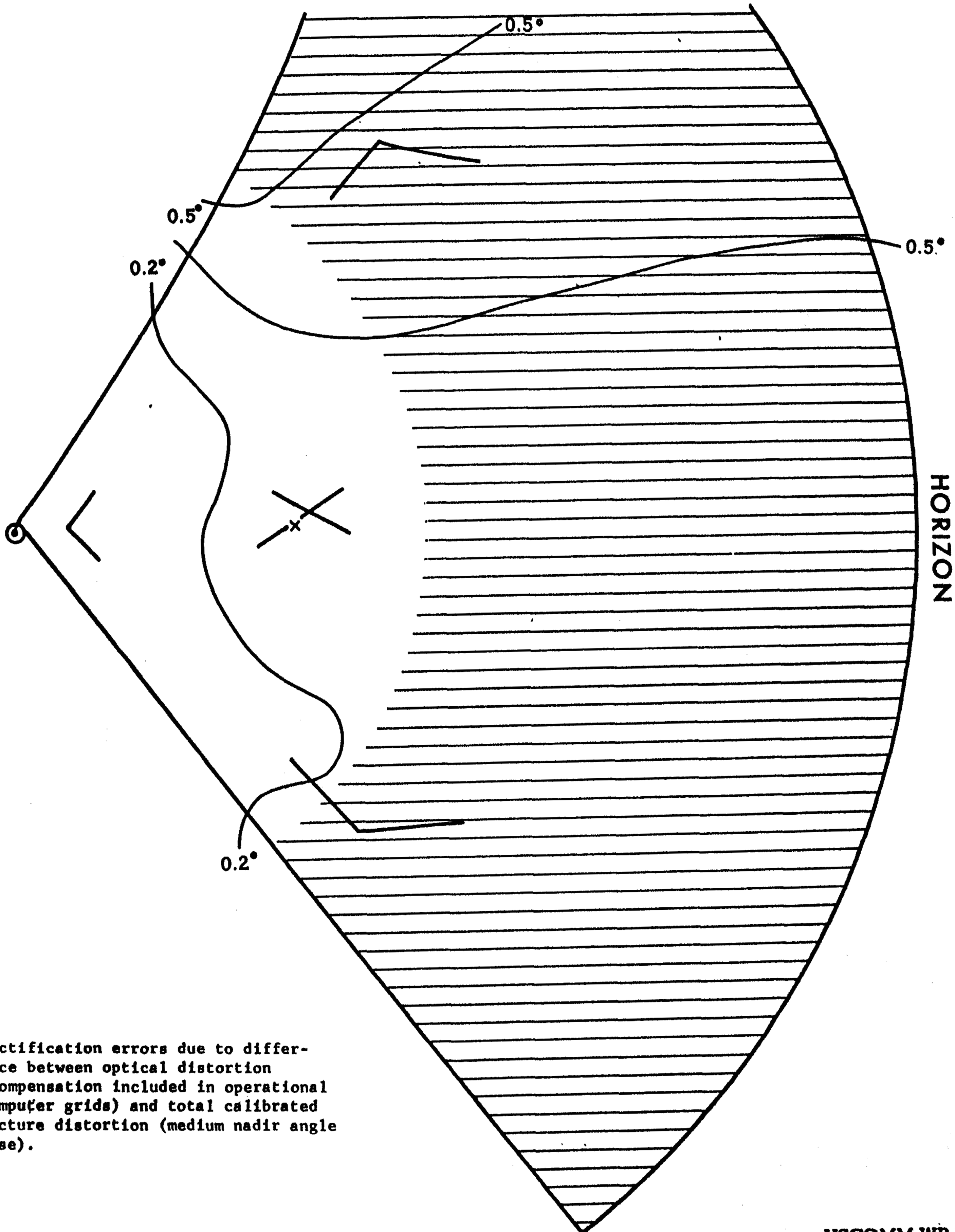
Rectification errors due to 30 second time error partially compensated by adjusting grid horizon to picture horizon (medium nadir angle case).

Figure 12



Rectification errors due to difference between optical distortion (compensation included in operational computer grids) and total calibrated picture distortion (low nadir angle case).

Figure 13



Rectification errors due to difference between optical distortion (compensation included in operational computer grids) and total calibrated picture distortion (medium nadir angle case).

Figure 14