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Measurements of North-South Focal Point  
Motion and Astigmatism of the 300-foot Telescope

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Summary

The 300-foot telescope aperture efficiency as a function of declination was measured at 4.75 GHz ( $\lambda 6.3$  cm) with an offset feed system to determine whether there is a significant north-south displacement of the focal point as the antenna moves away from the zenith position. The optimum feed position was found to move relative to the feed house by 0.75 cm/degree (0.29 inches/degree) of zenith angle in the sense that as the antenna is pointed south the optimum feed position moves north. Considerable improvement in the aperture efficiency at moderate zenith angles could be obtained if provision were made to move the receiver boxes north-south in the feed house. See Fig. 5. An offset of about 36 cm (14.2 inches) would be required to track the focal point to a zenith angle of  $57^\circ$  (Declination =  $-19^\circ$ ). An explanation of the gravitational effect which produces this focal point motion has been given by Sebastian von Hoerner in a paper cited in the acknowledgements of this report.

Paraboloid astigmatism was measured at zenith angles greater than  $30^\circ$  (Dec  $< +8^\circ$ ) by independently measuring the axial positions which produce minimum beamwidths in the north-south and east-west directions. The results in Fig. 10 show that the focal points of the cross sectional parabolas in the two planes separate rapidly at zenith distances beyond about  $35^\circ$ . At a zenith distance of  $47^\circ$  (Dec =  $-9^\circ$ ) the focal points are

about 12 cm (4.7 inches) apart in the sense that the north-south focal length becomes shorter than the east-west focal length. The sharp fall-off of the optimum-feed-position vs aperture efficiency curve (dotted line in Fig. 5) is primarily due to astigmatism. This could be partially corrected with an astigmatic lens.

#### Measurement Apparatus

A special offset feed arrangement was constructed for the dual-channel, 6 cm, cooled GaAsFET receiver which has a bandwidth of 580 MHz centered on 4.74 GHz ( $\lambda 6.32$  cm). Two sectoral horns were mounted so that their phase centers were 11.4 cm ( $1.8 \lambda$ ) apart which produced two beams in the sky separated by about 8.7 arcminutes (3 HPBW). The feeds were mounted so that the line through their centers struck an angle of  $37^\circ$  to the radial line from the box center. By rotating the receiver box, this feed orientation produced four, nearly equally spaced, north-south displacements where the two beams were offset north-south by about one half-power beam width (HPBW) as shown in Fig. 1. The two feeds allowed beam switching to cancel atmospheric radiation and allowed the pointing offset at a particular declination to be determined with one drift scan.

The sectoral horns produced a nearly circularly symmetric illumination of the reflector with an edge taper of between 14 and 18 dB over the 4.5 to 5 GHz receiver band. The phase front produced by each feed was spherical to within  $\pm 5^\circ$  of phase over the full angle subtended by the reflector. The line between the phase centers of the two feeds coincided with the H-plane of both feeds, hence, the E-vector of the illuminating fields were oriented  $+20^\circ$  or  $-20^\circ$  to the north-south plane of the telescope for all measurements.

Any rotation angles given in the diagrams refer to the receiver box rotation as measured at the telescope, the values in parentheses in Fig. 1.

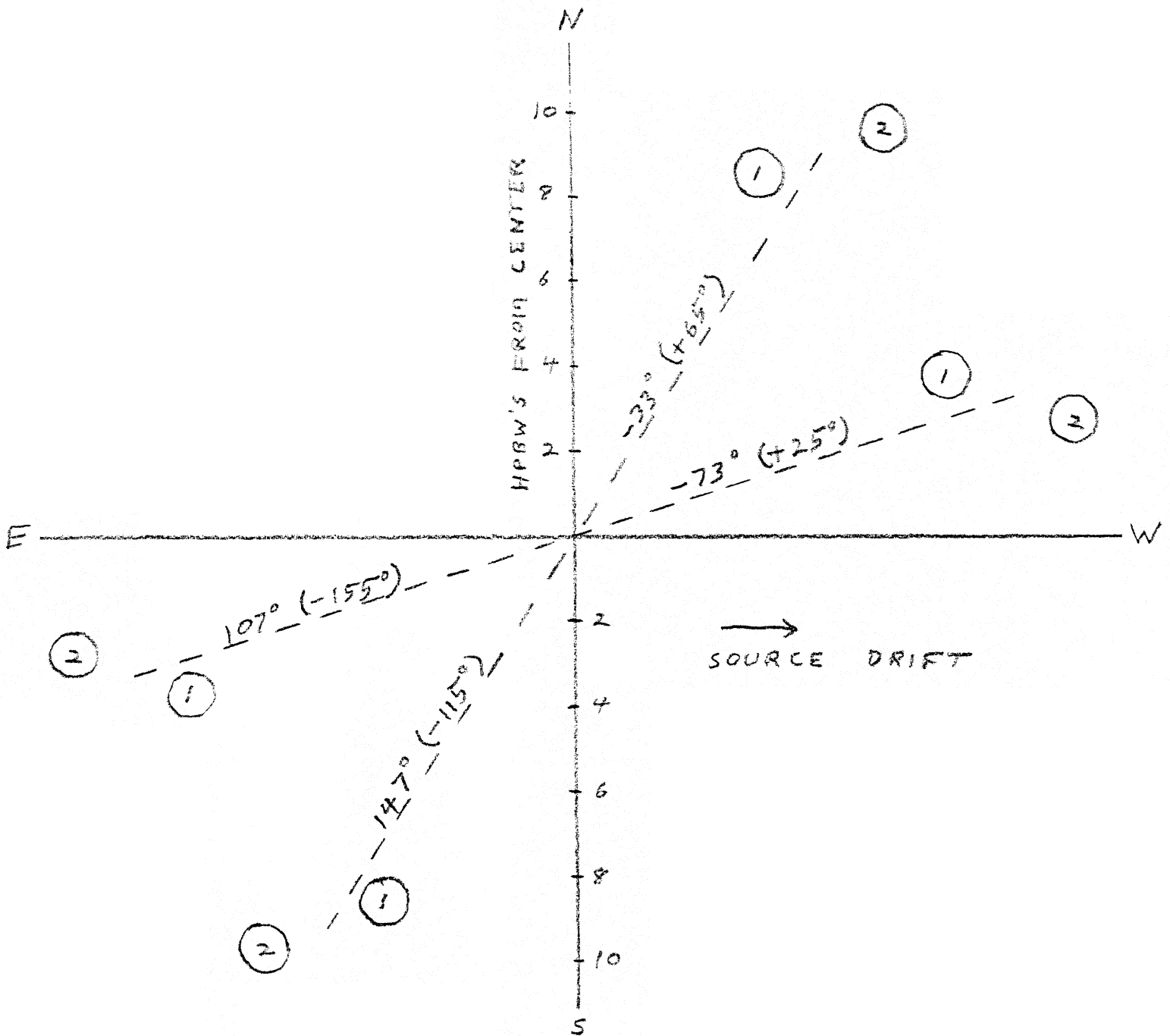


FIG. 1. BEAM ORIENTATIONS FOR 4 RECEIVER ROTATION ANGLES GIVING 1 HPBW N-S BEAM SEPARATION. NUMBERS IN ( ) ARE BOX ROTATION ANGLES AND OTHERS ARE THE POSITION ANGLES OF THE 2-BEAM MIDPOINT.

However, the important parameter here is the north-south feed displacement. Beam 1 in Fig. 1 was used for all of the aperture efficiency and astigmatism measurements, and its displacements were 13.8 cm (5"44) south for Rot. = +25°, 13.8 cm (5"44) north for Rot. = -155° and 32.2 cm (12"7) north for Rot. = -115°. The midpoint between the feeds or the center of feed 1 were placed on the east-west center line for the pointing or efficiency and astigmatism measurements, respectively, by offsetting the receiver box with the east-west tracking mount.

Before any efficiency or astigmatism measurements were made, the pointing offsets and optimum axial focus positions were determined for each of the three feed offsets. Pointing offsets were found by measuring the relative strength of a source in the two beams in a drift scan. A single pointing offset was sufficient to obtain a declination pointing accuracy of about  $\pm 20$  arcseconds ( $2\sigma$ ) over the range where each feed position produced a usable efficiency. The remaining pointing errors should have a negligible effect on the efficiency measurements.

The best axial focus positions for the feeds were determined by measuring the north-south and east-west beamwidths at three focus positions separated by 4 cm with sources covering a wide range of declinations. With the exception of astigmatic effects at low declinations, the optimum axial focus position did not change with the telescope zenith angle, and the minimum beamwidths in the two directions through the beam occurred at feed axial positions which were separated by less than 2 cm.

Aperture efficiencies were measured at each of the three north-south feed positions with a full 24-hour set of small diameter radio sources spread over the entire declination range of the telescope. The results are shown

in Figs. 2-4 with an eye-estimated average curve drawn through each set of points. The average curves are redrawn as solid lines on a single graph in Fig. 5. Also drawn in Fig. 5 as a dashed line is the efficiency curve taken from the 300-foot user's manual measured with a feed at the normal position (zero N-S offset). The dotted envelope in this figure is an estimate of the aperture efficiency that could be attained at each declination if provisions were made for north-south motion of the feed. The aperture efficiency could be increased by factors of 1.3 to 2 in the  $-10^\circ$  to  $+20^\circ$  and  $+60^\circ$  to  $+90^\circ$  declination ranges.

Since the same sources were measured at three different feed positions, the optimum N-S feed position could be determined for each declination at which a source was measured by solving for the vertex position,  $x_0$ , of a quadratic curve  $[y = a + b(x-x_0)^2]$  through the feed-position/log(efficiency) coordinates of the three measurements. These optimum feed position solutions are plotted as points in Fig. 6. Since the optimum feed positions are beyond the positions measured for declinations above about  $55^\circ$  and below  $0^\circ$ , the quadratic solutions were of little use beyond these points. Also plotted in Fig. 6 is a line through the two declinations of maximum efficiency with feed offsets of  $\pm 13.8$  cm ( $5''44$ ). This line agrees well with the plotted points and has a slope of 0.75 cm ( $0''29$ ) per degree of zenith angle or declination. Presumably this line is part of a sine curve with a period of  $360^\circ$  in declination, but over the measured range the curve is nearly straight.

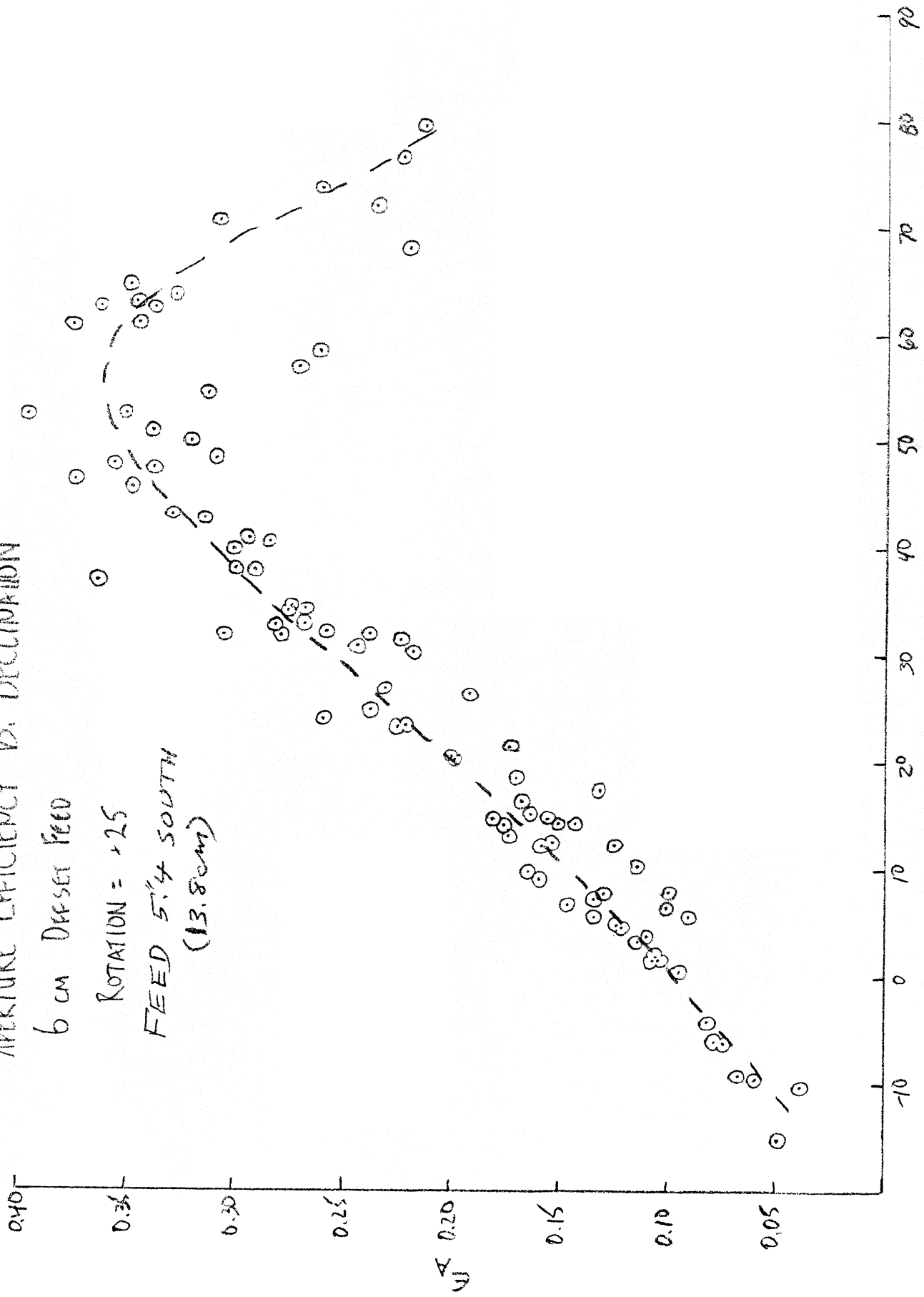
If we extrapolate the sine curve whose zero-phase slope is given in Fig. 6 to the declination limits of the telescope, the required north-south feed offsets would be 36 cm ( $14''2$ ) north for a declination of  $-19^\circ$  and 34 cm ( $13''3$ ) south for  $+90^\circ$  declination. This sine wave extrapolation

# APERTURE EFFICIENCY VS. DECLINATION

6 cm OFFSET FEED

ROTATION = +25

FEED 5.4 SOUTH  
(13.8cm)



DECLINATION

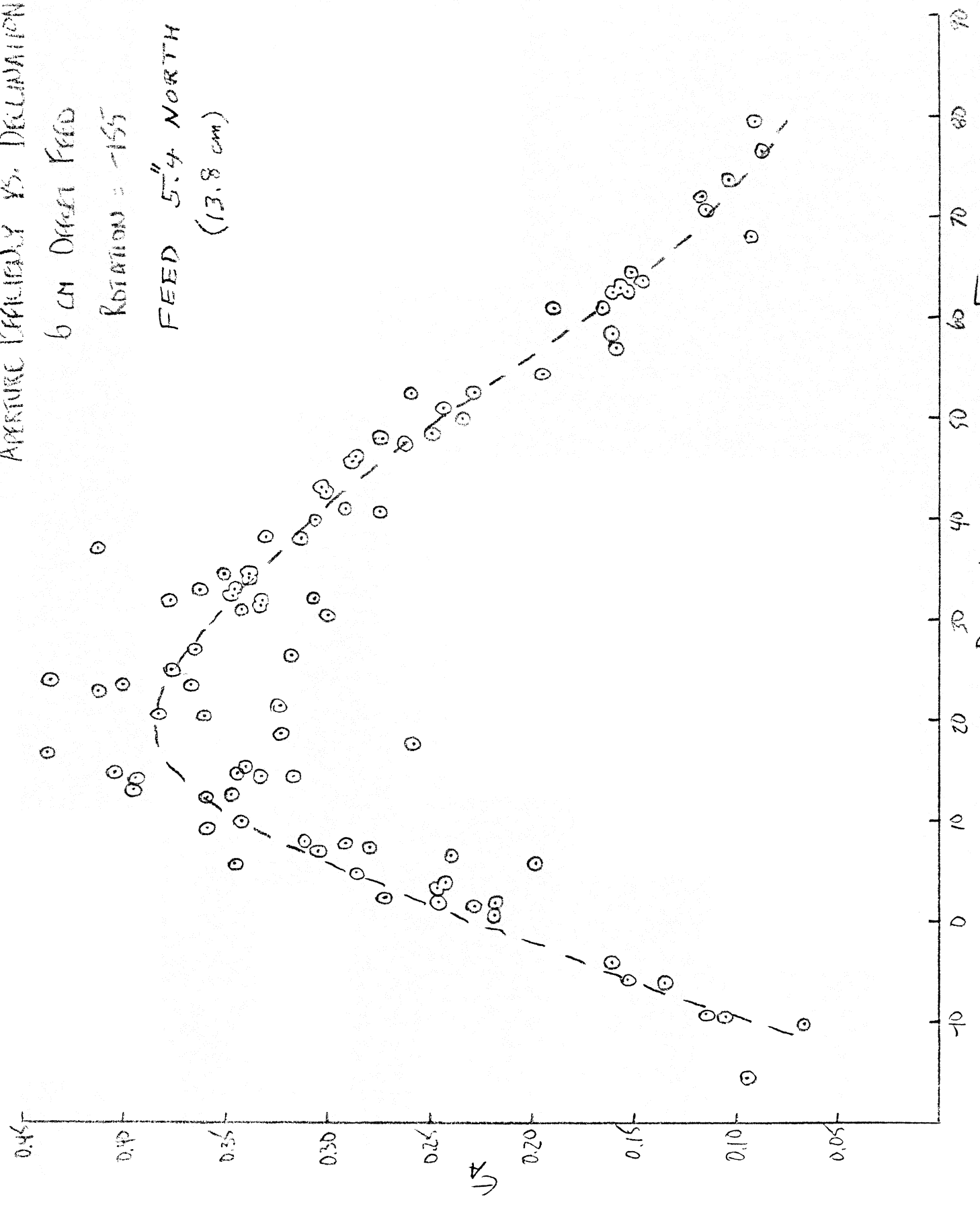
FIG. 2

APERTURE EFFICIENCY VS. DECLINATION

6 CM ORBITAL FEED

ROTATION = -155

FEED 5.4" NORTH  
(13.8 cm)



DECLINATION

FIG. 3

APERTURE EFFICIENCY VS. DECLINATION

6 cm Drift feed

ROTATION = -115

FEED 12" NORTH

(32.2 cm)

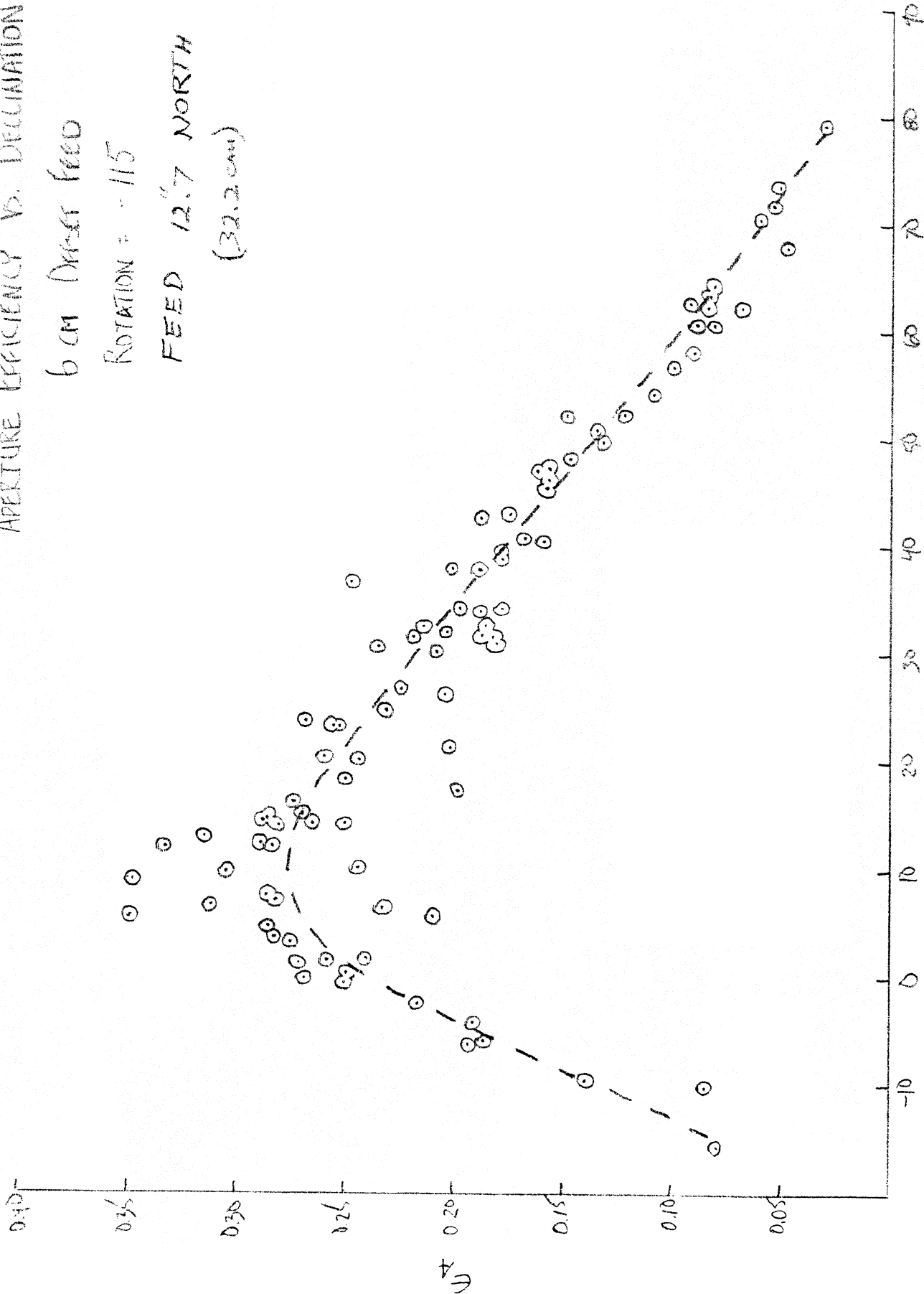
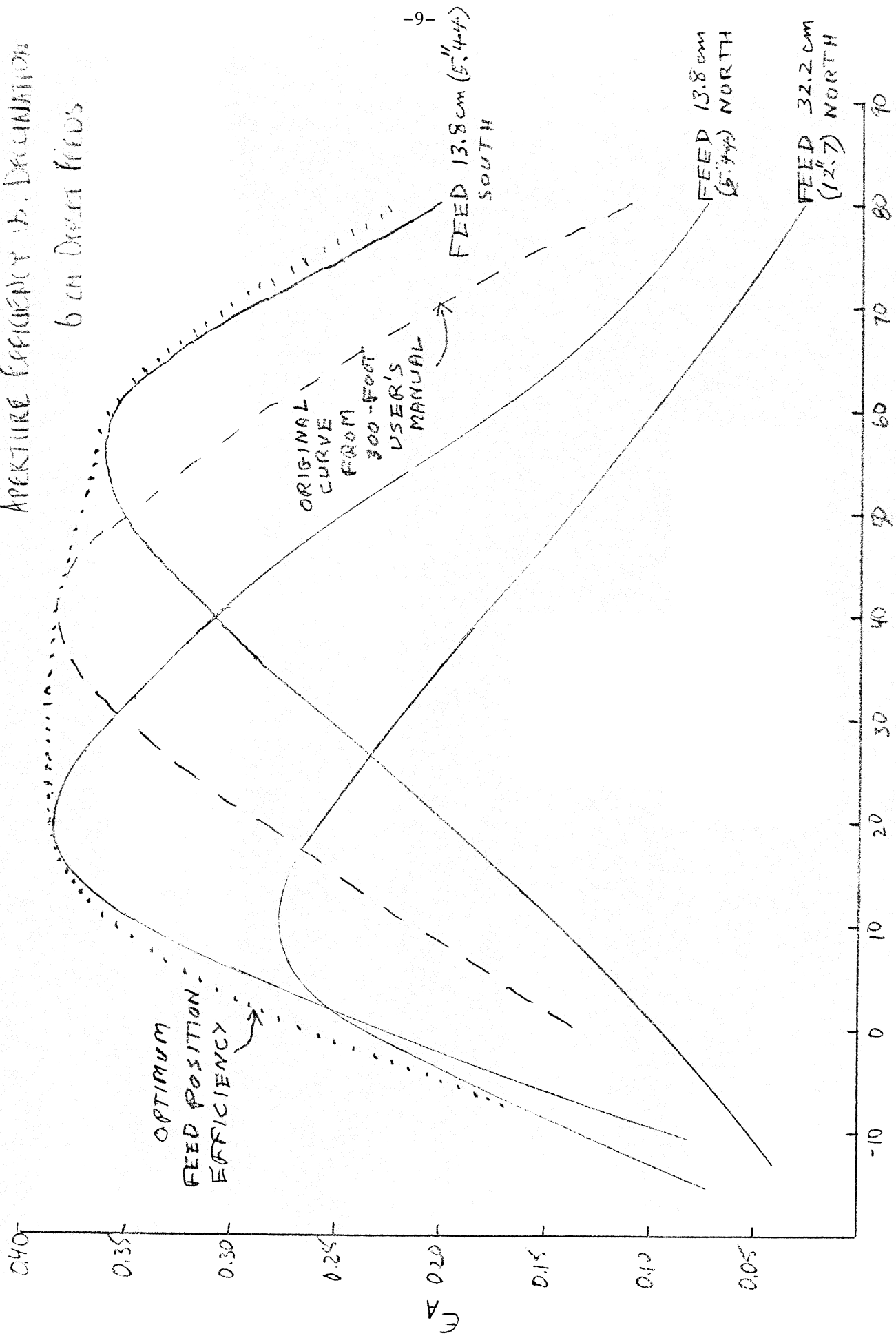


FIG. 4



# APERTURE EFFICIENCY vs. DECLINATION

6 cm Direct Feeds



DECLINATION

FIG. 5

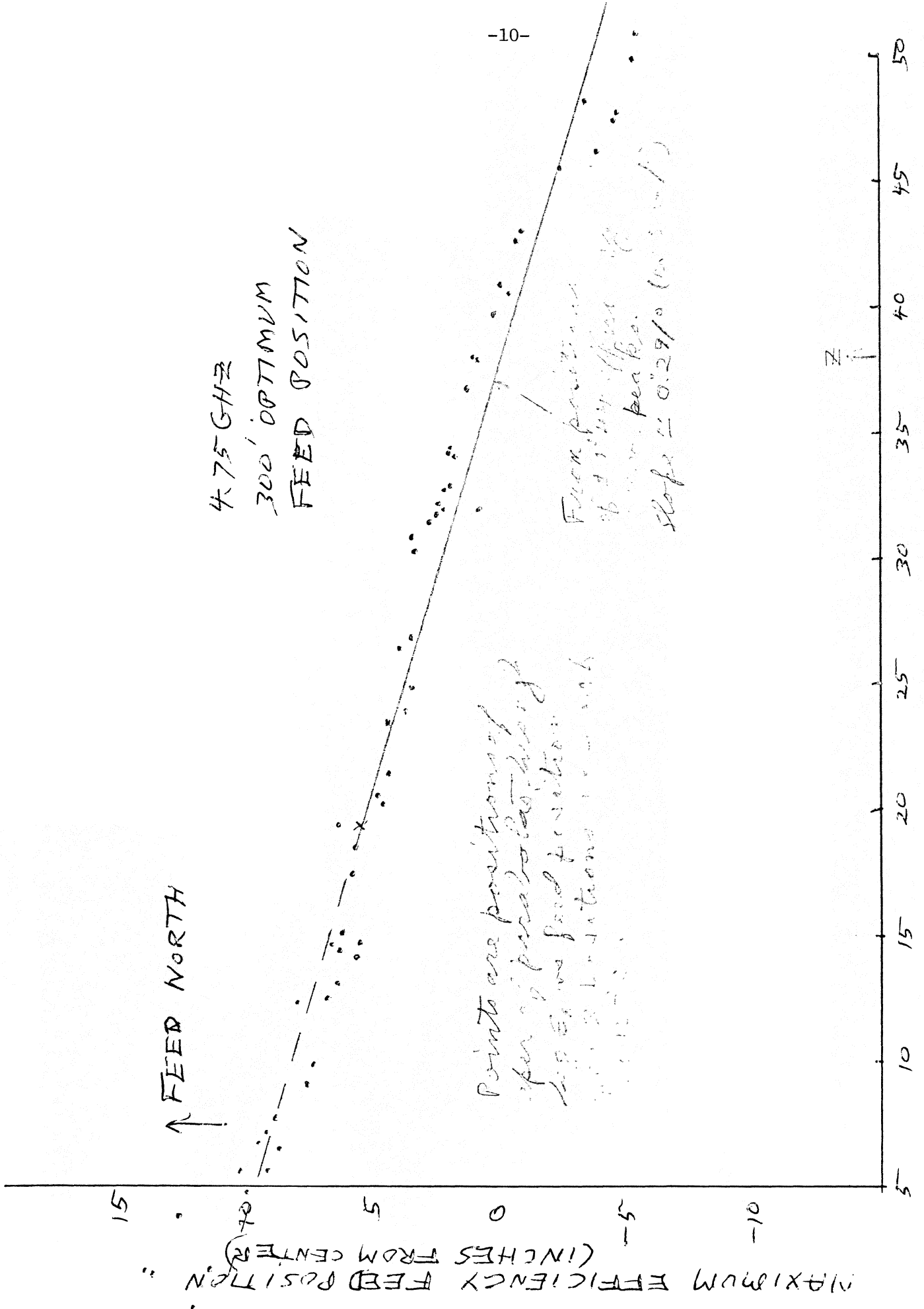


FIG. 1

may be in error for large zenith angles because of nonlinearities associated with strongly distorted paraboloids, but this error should not cause too much trouble here.

It is evident from the 32.2 cm offset curve in Fig. 5 that the efficiency loss at large zenith distances cannot be corrected with just a feed offset. The paraboloid must be distorting. The effect of changing telescope position with respect to gravity will be to introduce a first order astigmatism into the surface. This astigmatism can be thought of as different focal lengths for the two parabolas fitted to the north-south and east-west surface cross sections. The relative focal lengths of these cross sections can be measured by determining the feed positions which produce minimum beam widths in the two directions.

Since astigmatism is strongest at large zenith distances, only sources below  $+15^\circ$  declination and the 32.2 cm north feed offset were used to measure beam widths at three axial focal positions of  $-4.7$ ,  $-8.7$ , and  $-12.7$  cm on the telescope focus readout. The best focus at higher declinations was about  $-8.7$  cm.

Figure 7 shows a beamwidth versus declination curve for one of the axial focus positions. The scatter in the points at the right hand end of the plot is fairly typical of all of the measurements. Since different sources were measured at each focus position, a line was hand drawn through each set of points as in Fig. 7 so that beam widths at common declinations could be interpolated for each focus. The results are plotted in Figs. 8 and 9 as beam width versus axial focus position. Unfortunately, no north-south beam width measurements were available at declinations below  $-9^\circ$  at two of the three focus positions with the exception of one anomalous, but well determined, beam width of  $3.06$  at  $-17^\circ$ , and  $-12.7$  cm.

NORTH-SOUTH (FOCUS = -87mm)

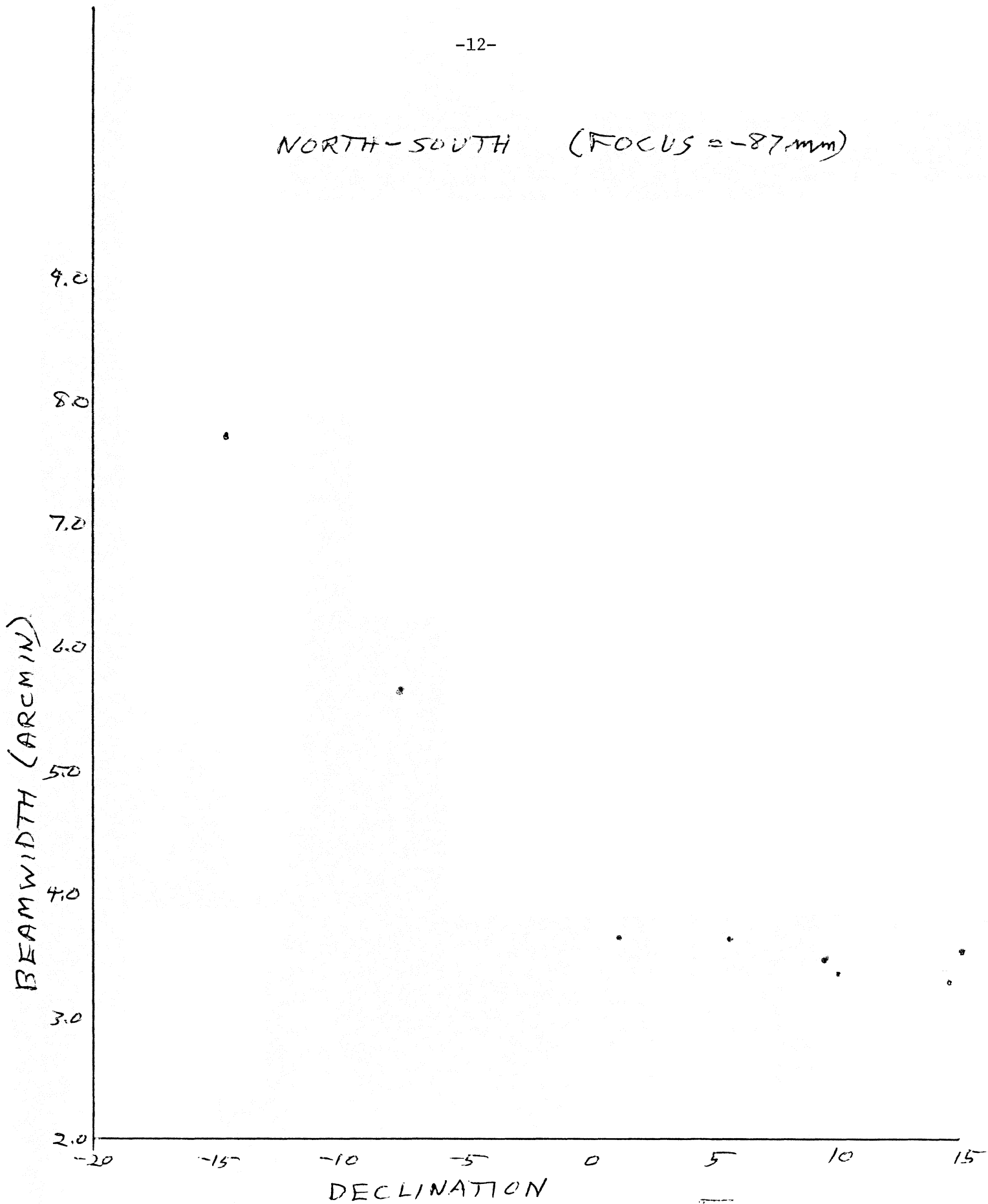
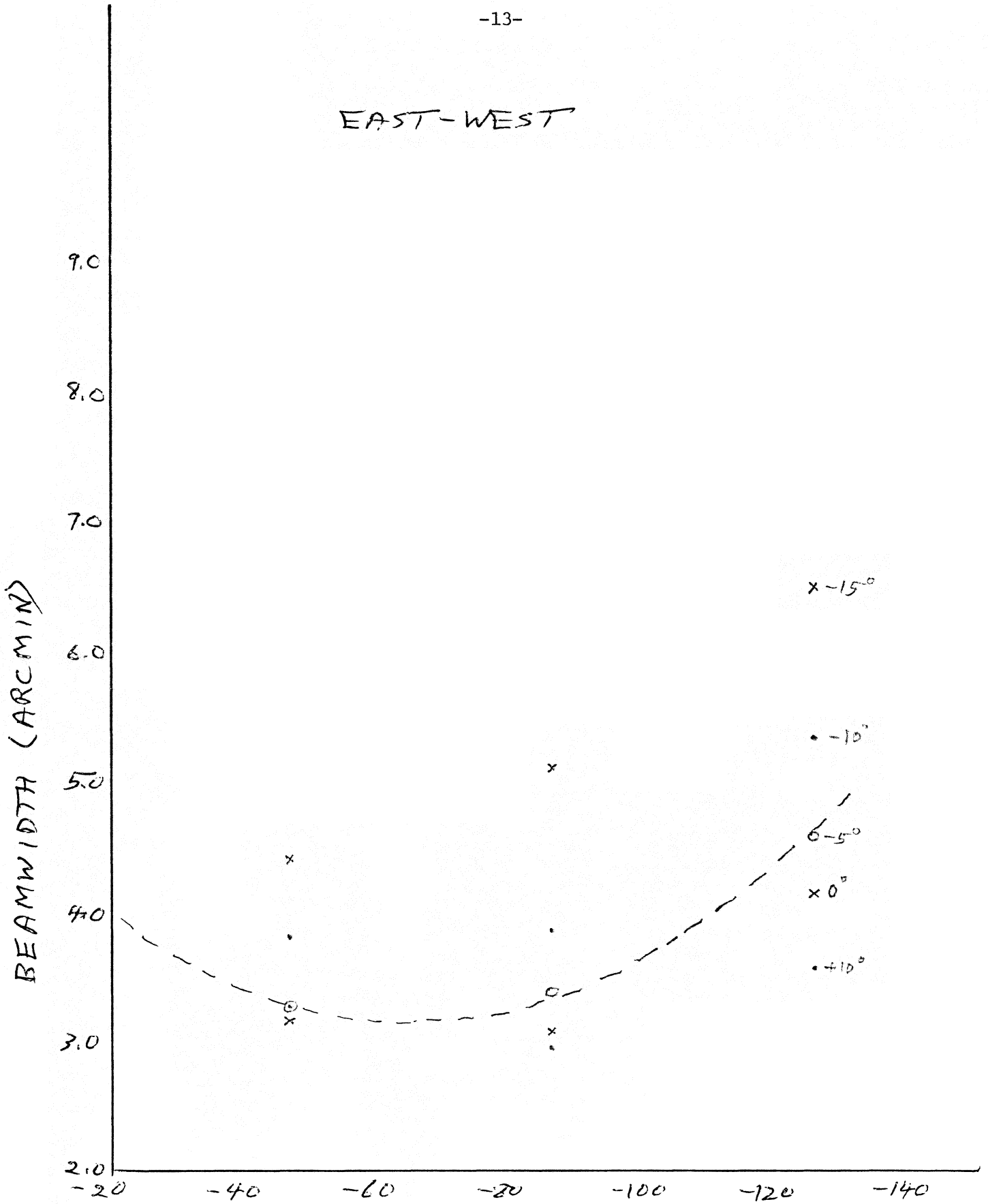


FIG. 7

EAST-WEST



AXIAL FOCUS POSITION OF FEED (mm)

FIG. 8

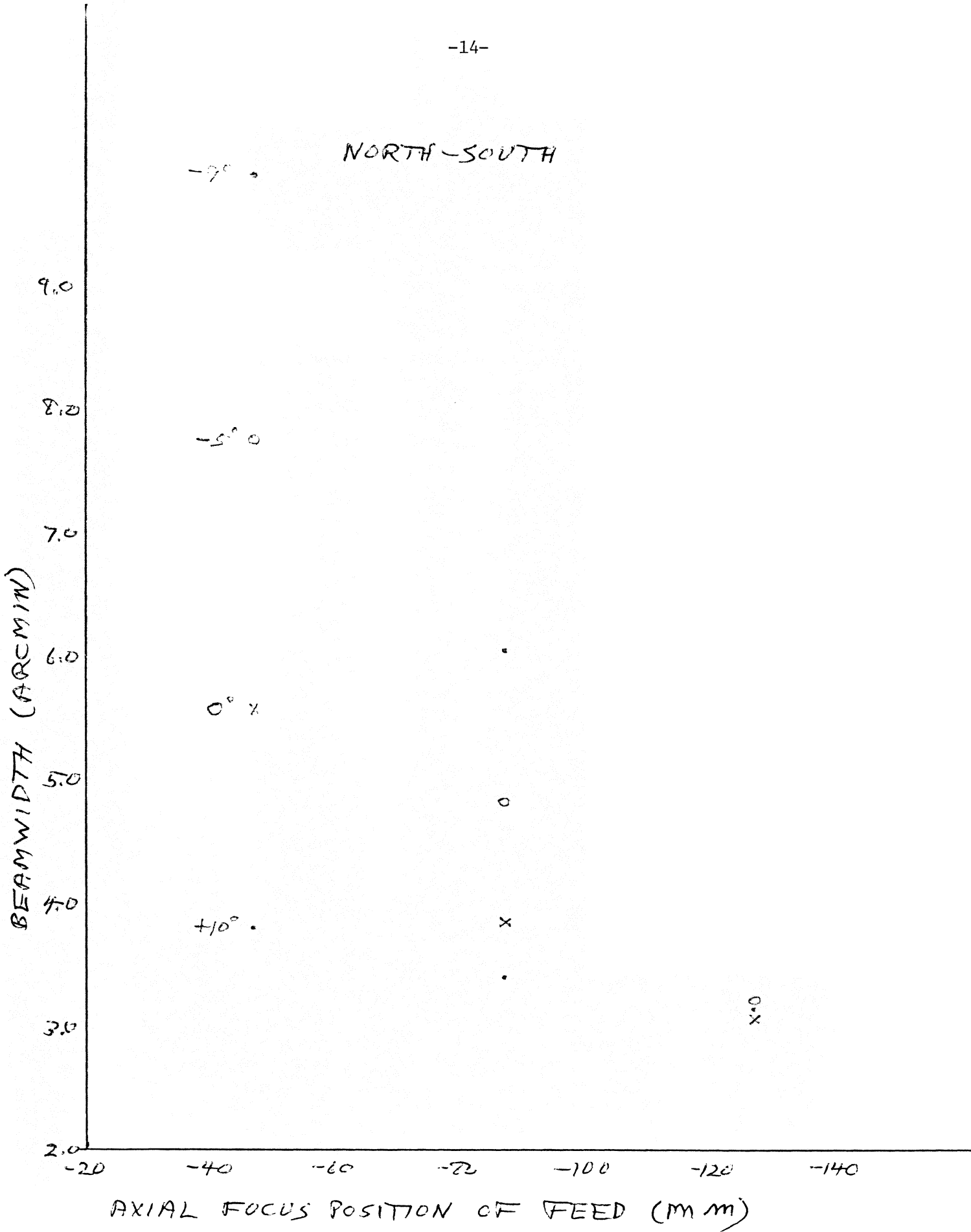


FIG. 9

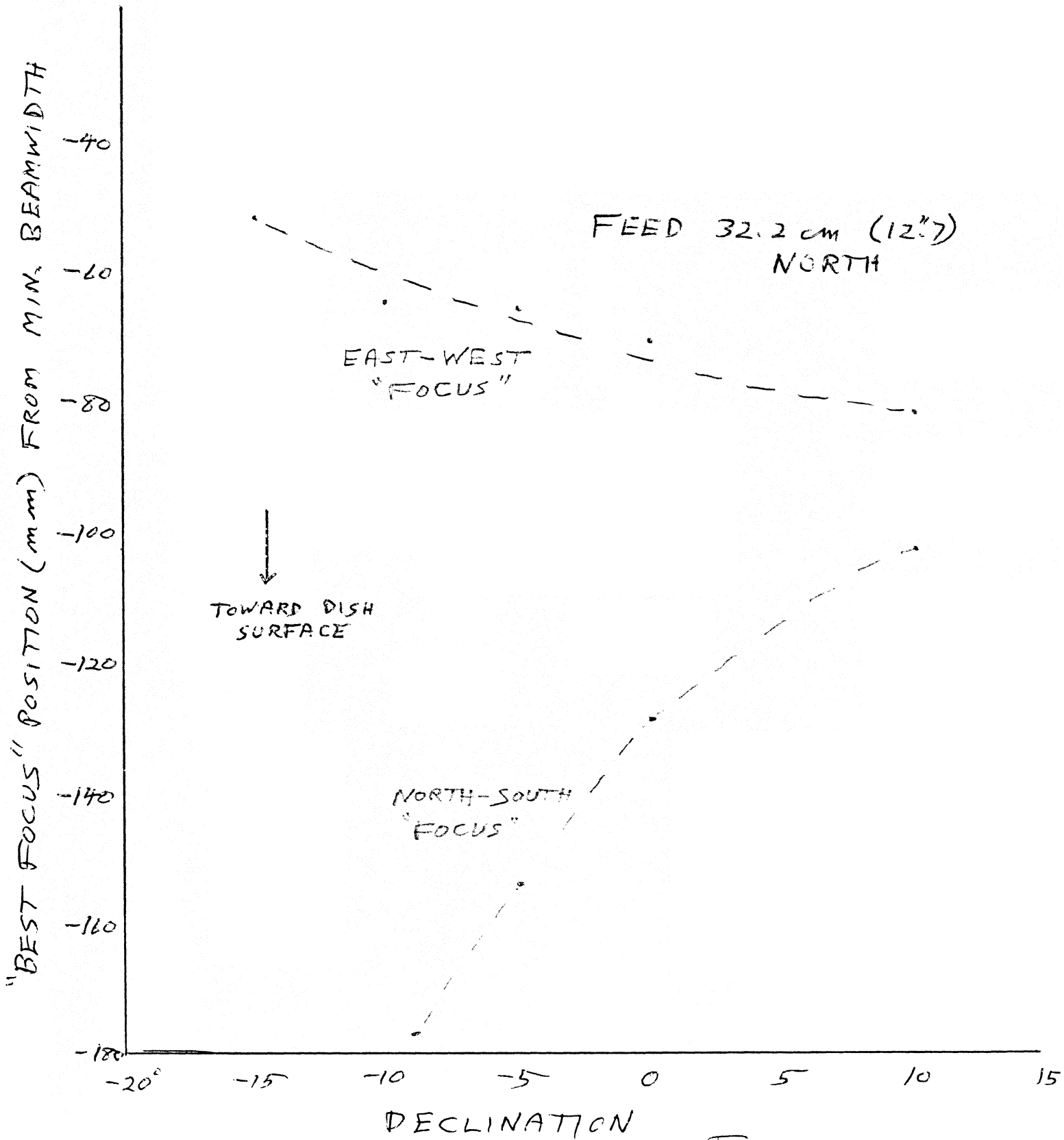


FIG. 10

The optimum focus position in each direction and at each declination was determined by visually estimating the position of best fit of a quadratic focus curve  $[y = a + b(x-x_0)^2$  with  $b$  fixed] as shown for declination  $-5^\circ$  in Fig. 8. The optimum focus positions are plotted in Fig. 10.

Two things are evident from Figs. 8-10. First, the north-south focal length changes most rapidly, probably because the antenna is least stiff in this direction and because the gravity effect is changing in this plane. Second, the beam width at optimum focus increases below about  $-5^\circ$  declination, at least for the east-west direction, which leads us to believe that the dish cross sectional profile begins deviating significantly from a parabola at this declination. Even with this distortion from a parabola, the efficiency at very low declinations could probably be improved with a first order astigmatic lens or feed. The dotted efficiency envelope in Fig. 5 might be broadened by another  $10^\circ$  or  $15^\circ$  at high and low declinations with this correction.

#### Acknowledgements

We thank Wendell Monk for constructing the feed system necessary for these measurements, Jim Coe, Bill Shank and Jim Oliver for preparation of the receiver, and Jim Lyons for help with the observations and data reduction. The original impetus for this work was provided by Lee King some years ago from a structural analysis of the telescope. Considerable help in planning the measurements was derived from a related study of the 140-foot telescope by Sebastian von Hoerner, "Strong Coma Lobes from Small Gravitational Deformations," IEEE Transactions, AP-28, p. 652.