Essco

12 METER MILLIMETER WAVE TELESCOPE
MEMO No. 42A

This memo #42 does not include Appendices describing program listings.

DOCUMENT D81-15

SURFACE MEASUREMENT OF 12 METER DIAMETER REFLECTOR PANELS

Prepared For

National Radio Astronomy Observatory

Green Bank, West Virginia 24944

ESSCO No. E-5817

ELECTRONIC SPACE SYSTEMS CORPORATION
Old Powder Mill Road
Concord, MA 01742
Tel: 617-369-7200 Telex: 92-3480

REV. ☐
DATE:

Essco

INITIAL RELEASE
Prepared by: Michael J Brennan Date: 5/13/81
Approved by: JE Rhoades Date: 5/13/81

REVISION STATUS OF SHEETS

REV																						
	REV.																					
	SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	REV																					
	SHEET	22	23	24	25	26	27	28	29	30	31	32	33									

	REVISION DESCRIPTION	PAGE	APPROVED/DATE

Essco

TABLE OF CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION AND SUMMARY

This report describes the surface accuracy measurements on 72 panels designed for the 12-meter diameter reflector to be installed at the Kitt Peak Radio Astronomy Observatory.

The measurements were made on a large Coordinate Measuring Machine (CMM) with digital readouts connected to an automatic Data Acquisition System (DAS).

A description of the coordinate systems is presented in Section 2.0 and the details of the associated coordinate transformations are given in Section 3.0.

Section 4.0 presents the details of the panel measurement procedure including the measurement grids used and the computer programs for the DAS and data reductions.

The formulas used to combine the individual panel data into an aggregate rms for the set are also presented along with the computer program which was used to make this final computation. (See Appendix E).

2.0 COORDINATE SYSTEMS

Two basic coordinate systems are used in the evaluation of the panel surface accuray. The primary coordinate system is that of the reflector as shown in Figure 1. The secondary coordinate system (Fig. 2) is associated with the Coordinate Measuring Machine (CMM). This is the coordinate system in which surface of the panels and molds are mapped. The origin of the CMM coordinate system can be translated along, transverse or normal to the CMM bed with simple offsets which are built into the readout system.

A reflector panel is shown oriented on the CMM bed in Figure 3. The panel is symmetrical about the X axis. In the next section, the coordinate transformations are derived.

3.0 COORDINATE TRANSFORMATION

The object of the transformation of coordinate system is to obtain the vertical or Z_2' coordinates for the panels in terms of the X_2', Y_2' coordinates of the CMM.

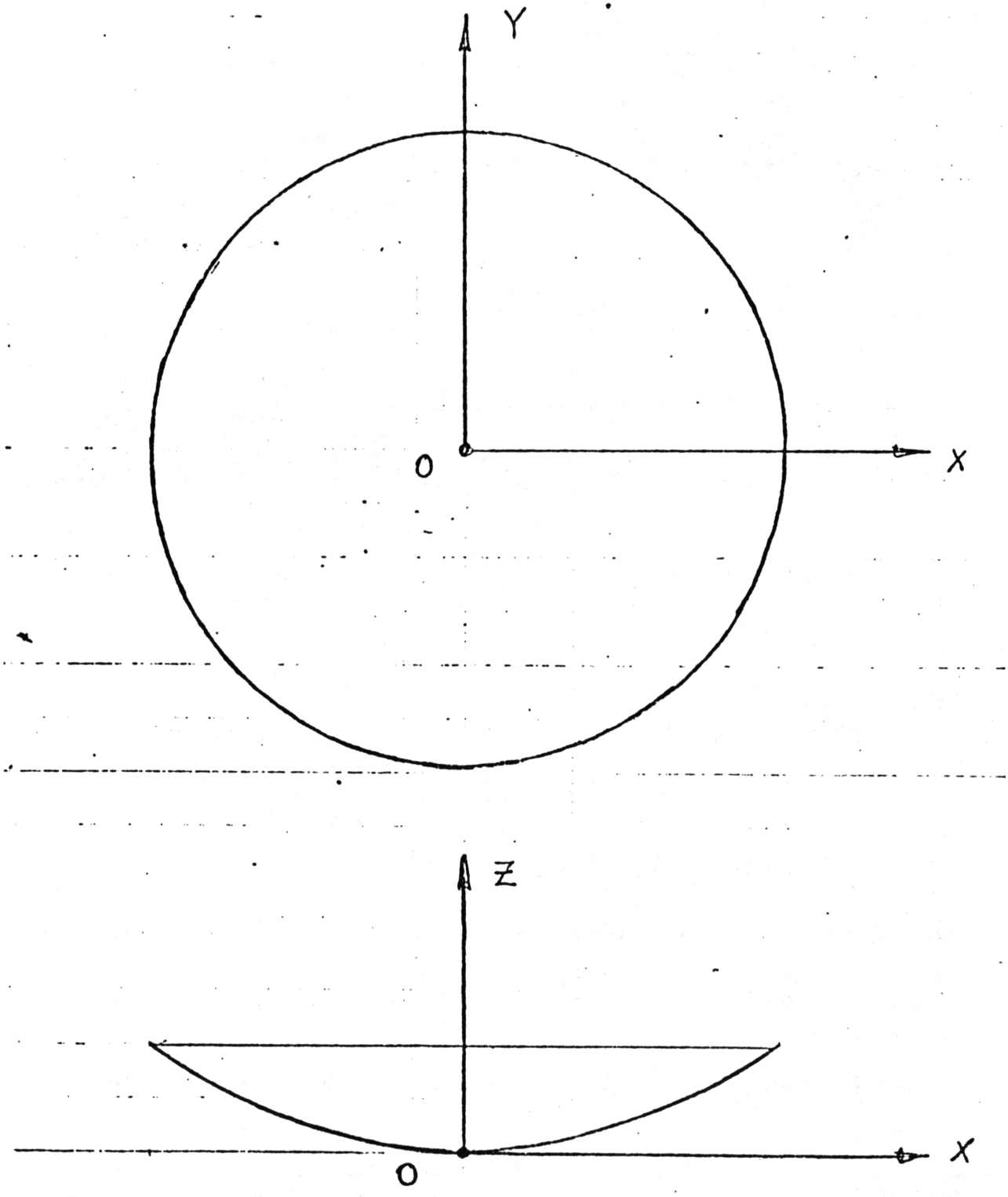
Referring to Figure 4, the transformation can be written as:

$$\begin{aligned} X &= X_2\text{Cos}\theta - Z_2\text{Sin}\theta + X_0 \\ Z &= X_2\text{Sin}\theta + Z_2\text{Cos}\theta + Z_0 \end{aligned} \qquad (1)$$

Now the equation of the parabolic surface is:

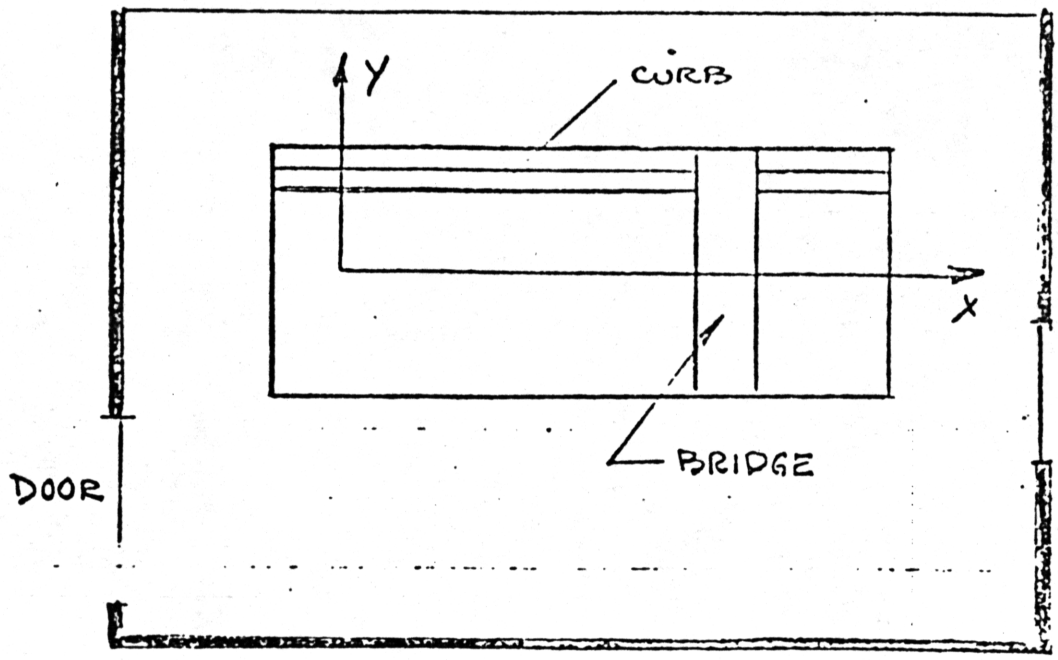
$$X^2 + Y^2 = 4FZ \qquad (2)$$

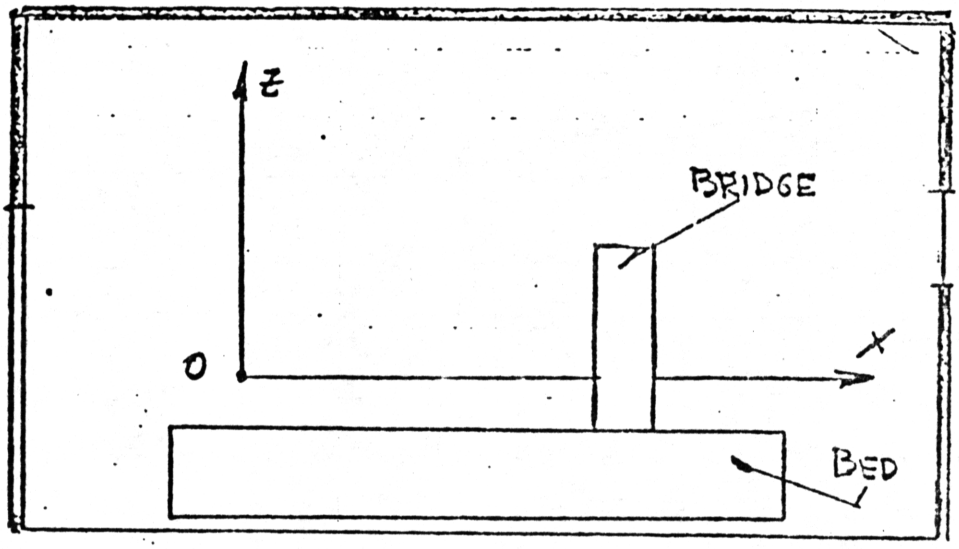
where F is the focal length of the parabola.



REFLECTOR COORDINATE SYSTEM

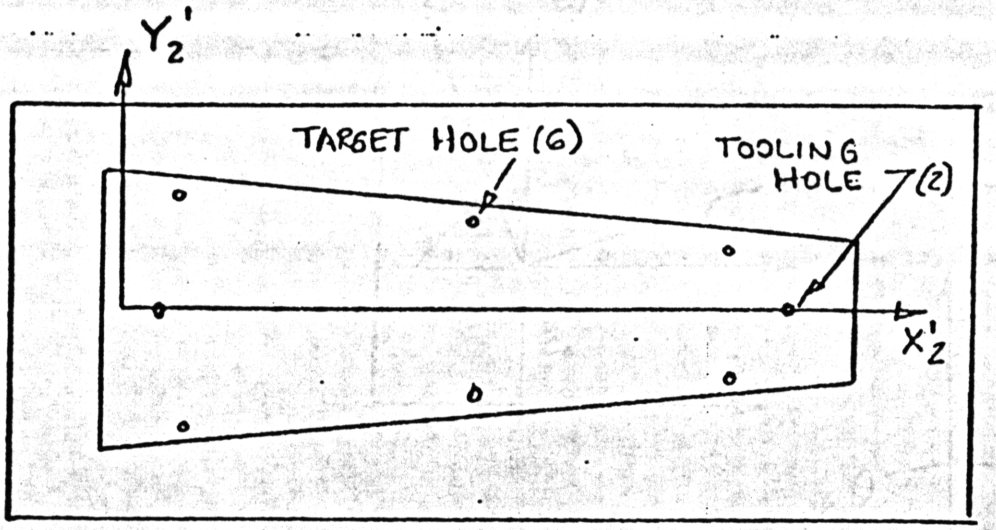
FIGURE 1

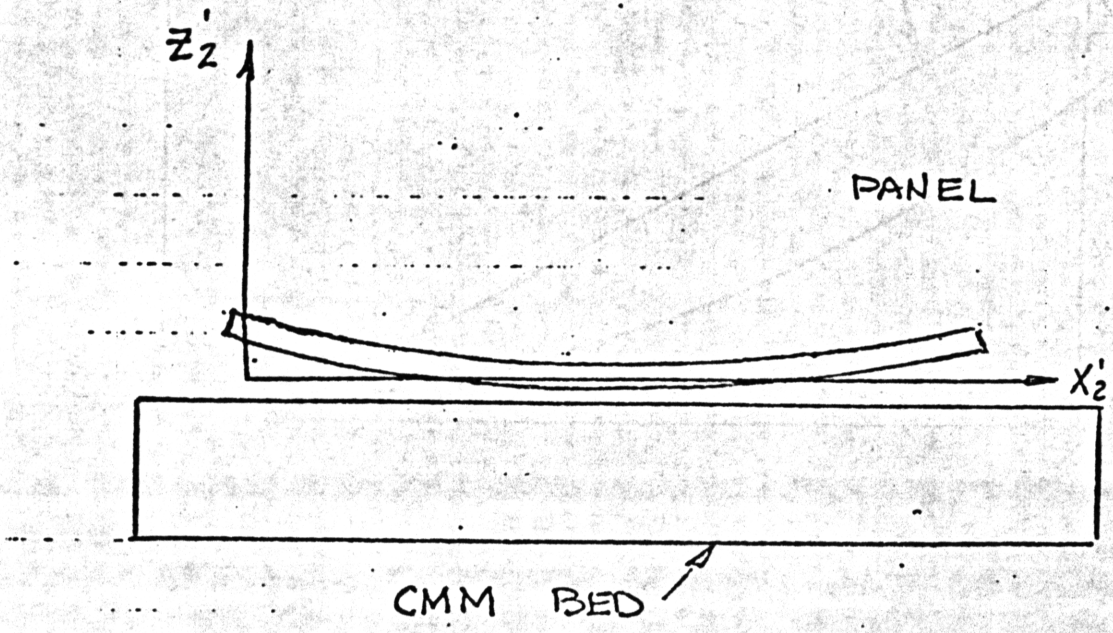




COORDINATE SYSTEM FOR CMM

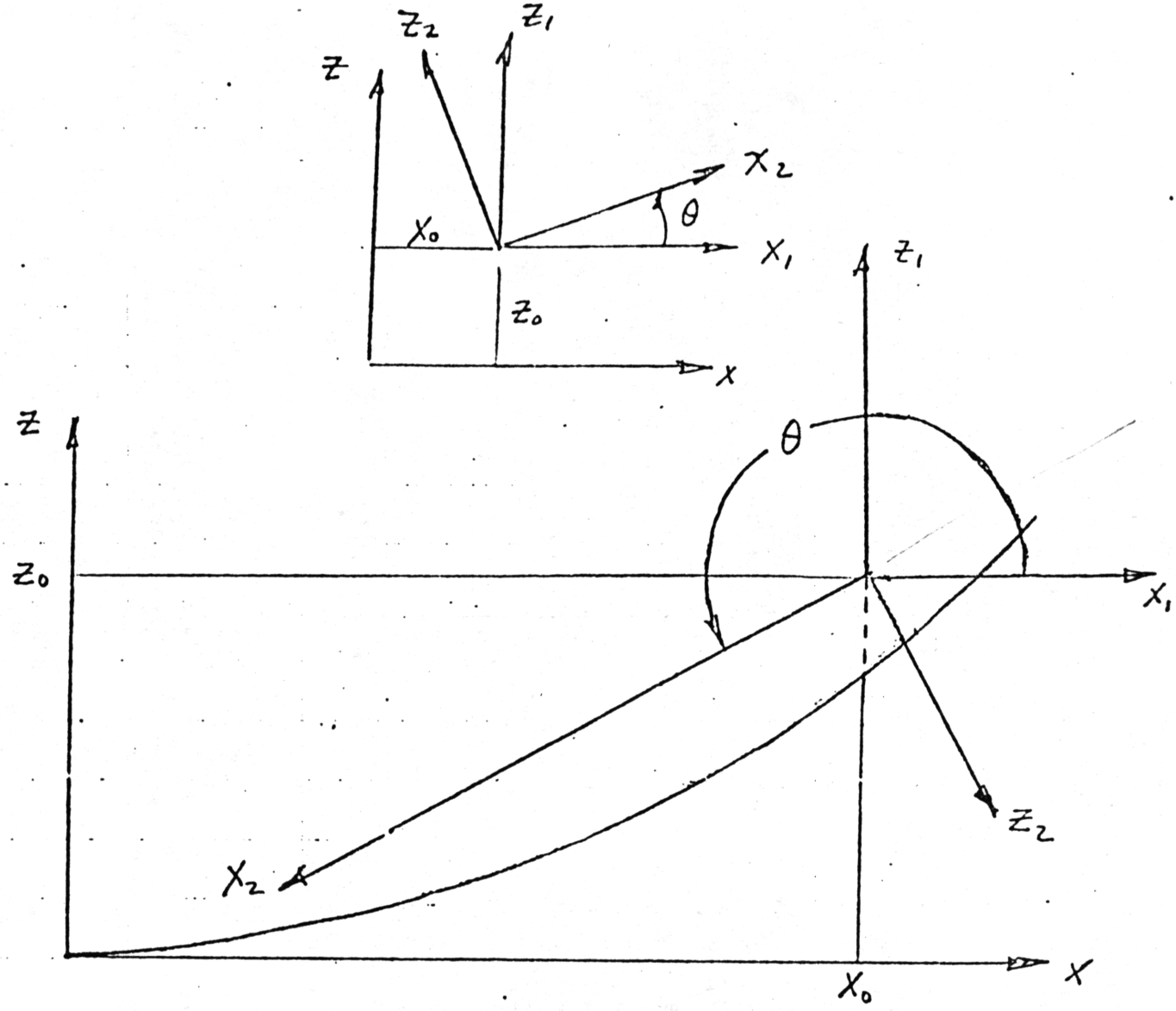
FIGURE 2





PANEL COORDINATE SYSTEM

FIGURE 3.



TRANSFORMATION OF COORDINATES

FIGURE 4

Substituting equation (1) into equation (2), there is obtained:

$$(X_2\text{Cos}\theta - Z_2\text{Sin}\theta + X_0)^2 + Y_2^2 = 4F(X_2\text{Sin}\theta + Z_2\text{Cos}\theta + Z_0) \quad (3)$$

Expanding and combining equation (3), there is obtained:

$$AZ_2^2 + BZ_2 + C = \theta \quad (4)$$

where

$$\left.\begin{aligned} A &= \text{Sin}^2\theta \\ B &= -2X_2\text{Cos}\theta\text{Sin}\theta - 2X_0\text{Sin}\theta - 4F\text{Cos}\theta \\ C &= X_2^2\text{Cos}^2\theta + X_0^2 + 2X_2X_0\text{Cos}\theta + Y_2^2 - 4FX_2\text{Sin}\theta - 4FZ_0 \end{aligned}\right\} \quad (5)$$

and

$$Z_2 = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (6)$$

Thus, with equations (5) and (6), Z_2 may be obtained in terms of X_2, Y_2 the CMM coordinates. Table 1 provides the specific values of X_0, Z_0 and θ for each of the two panel types of the 12-meter reflector.

In terms of the coordinate Z_2, the panel coordinate, Z_2', can be written as:

$$Z_2' = K_2 - Z_2$$

where K_2 is an arbitrary constant. This constant has been chosen so that all Z_2' values are positive. The values of K_2 for each of the two panel types are given in Table 1.

Figure 5 presents the target and tooling hole designations for each of the two panels. Table 2 presents the nominal target and hole locations in both the CMM and reflector coordinate systems. Table 3 presents supplementary locations used for adjusting the panel to its correct position in the CMM coordinate system.

4.0 PANEL MEASUREMENT

The overall dimensions of the two panels are shown in Figures 6 and 7. Included on these figures are the location of the coordinate axes.

A Data Acquisition System (DAS) Operating Tape has been prepared for panel measurement. A description of the panel measurement programs is given in Table 3, and program listings are included in Appendix A.

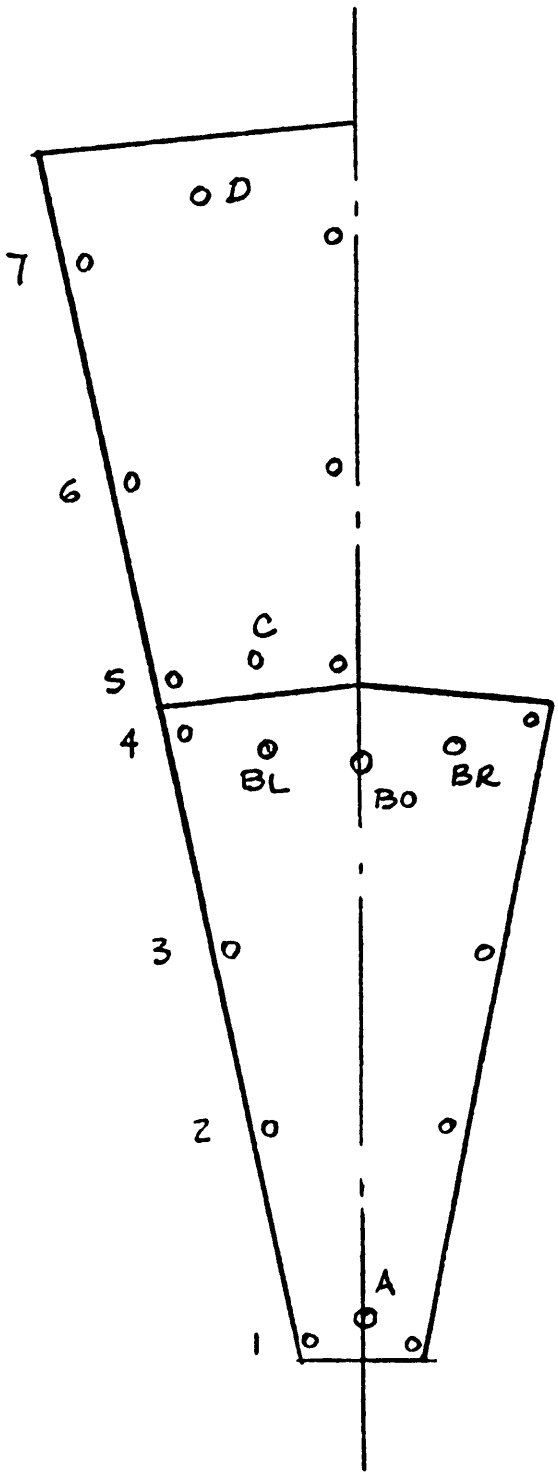
The two programs used for panel measurement are identical except for certain data peculiar to the individual panels.

TABLE 1

COORDINATE TRANSFORMATION PARAMETERS

	X_o (in)	Z_o (in)	θ (degrees	K_2 (in.)
Inner (A) Panel	155.000	35.000	192.4749	12.000
Outer (B) Panel	270.000	95.000	207.6801	12.000

F = 200 inches



TOOLING AND TARGET HOLE DESIGNATIONS

Figure 5

Essco

TABLE 2

TARGET AND TOOLING HOLE LOCATION

(Nominal)

	Target No.	X_2	Y_2	Z_2	R	Z
PANEL A	1	135.081	± 1.375	6.793	24.272	0.736
	2	88.972	± 7.432	2.224	70.632	6.236
	3	47.022	±12.814	2.576	111.860	15.641
	4	6.058	±17.960	6.793	151.280	28.607
PANEL B	5	132.451	± 8.326	8.019	154.781	29.946
	6	79.395	±11.505	4.758	203.382	51.705
	7	58.625	±12.578	7.337	219.787	60.383

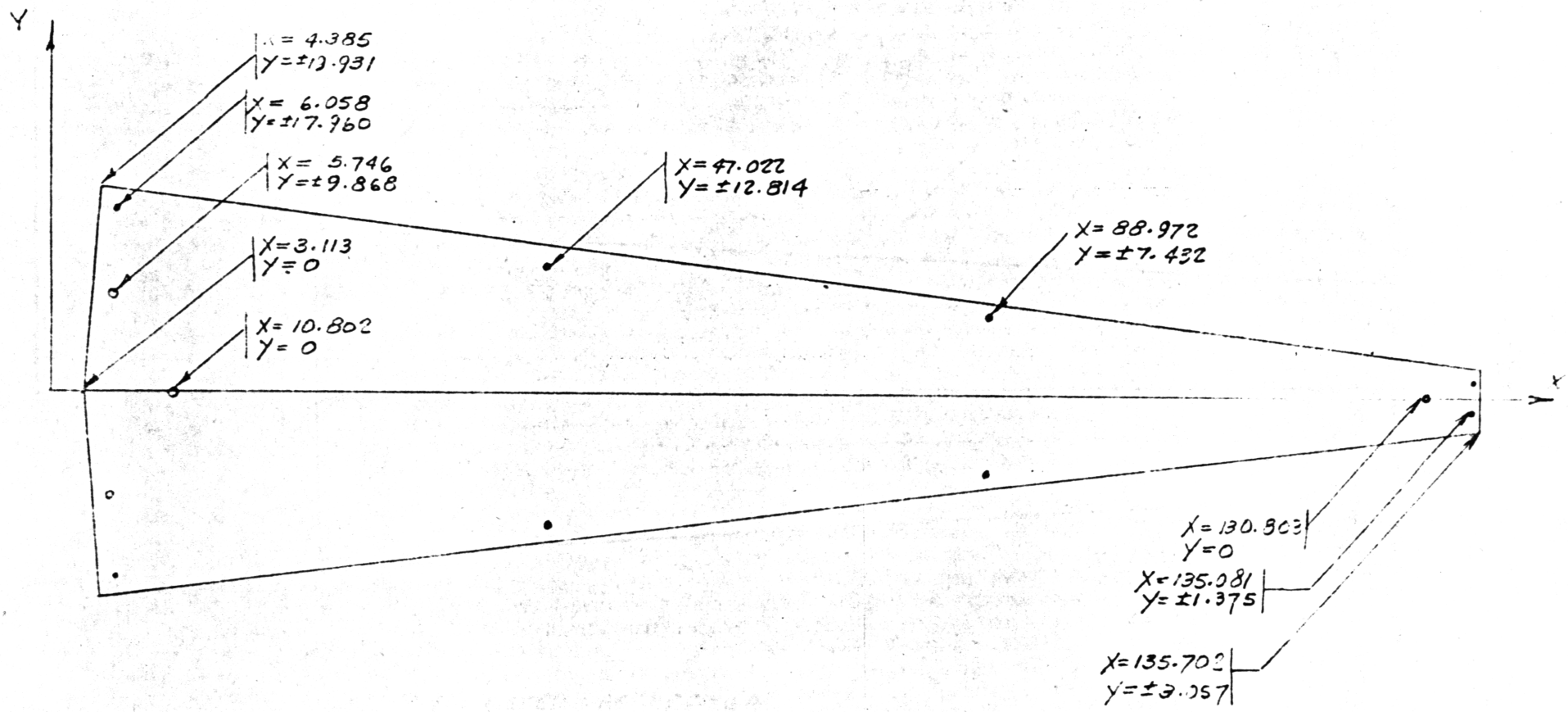
	Tooling Hole	X_2	Y_2	Z_2	R	Z
PANEL A	A	130.803	0	6.136	28.552	1.019
	BL	5.746	-9.868	6.571	150.885	28.458
	BO	10.802	0	5.758	145.801	26.572
	BR	5.746	9.868	6.571	150.885	28.458
PANEL B	C	130.008	0	7.663	156.885	30.766
	D	43.521	0	6.760	234.600	68.796

TABLE 3

DAS PROGRAMS

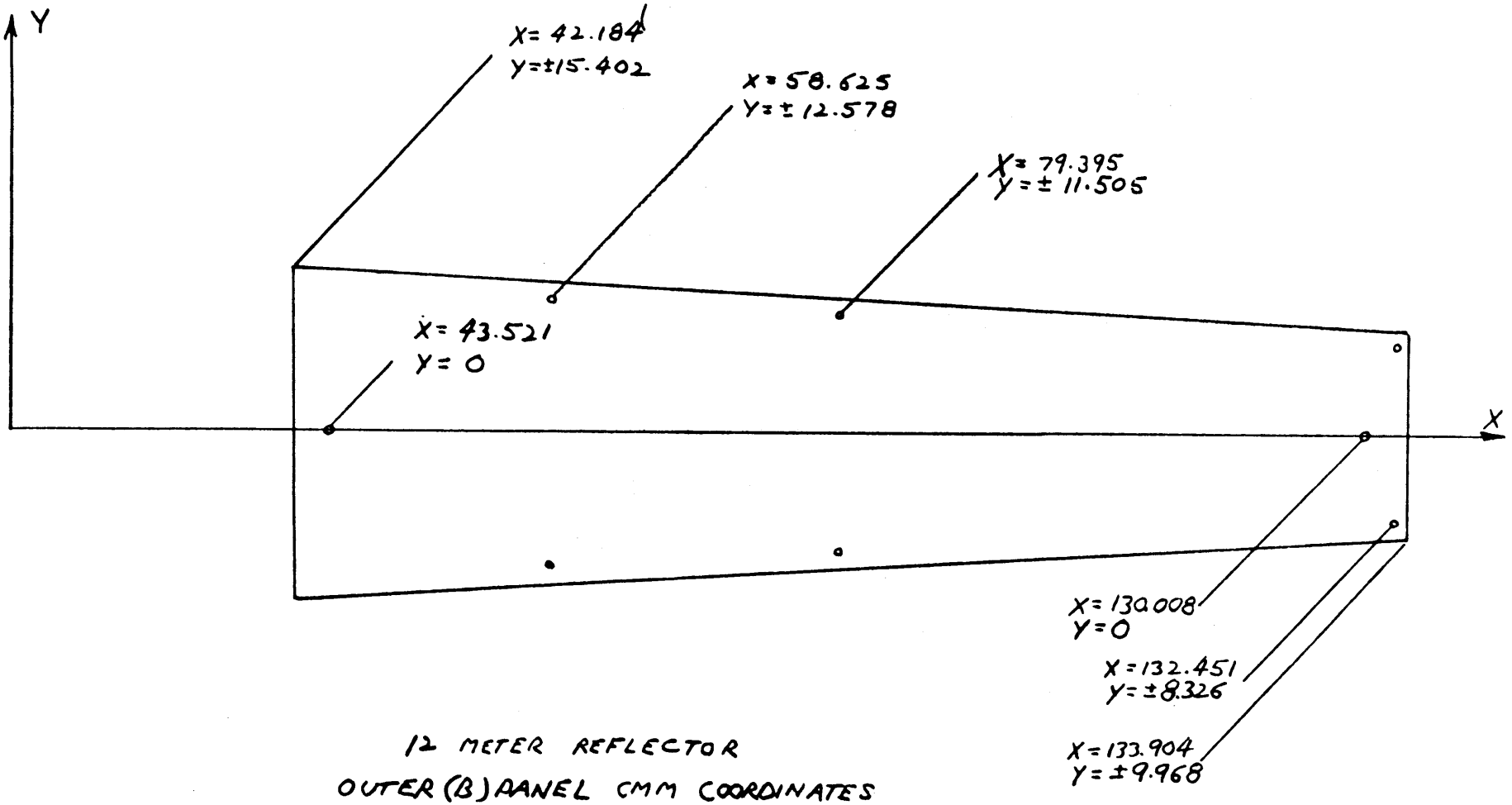
12-M REFLECTOR PANELS

Program	Description
45APDAS	This program is used to determine the deviation of the inner panel from the theoretical surface. The CMM probe is positioned sequentially over the points to be measured and the keys "M" and "RETURN" are pressed. Each measurement is displayed on CRT. When all of the points have been measured, the keys "C" and "RETURN" are pressed. The data is then stored on the data tape and the RMS, Average Deviation and Number of Data Points are recorded on the CRT.
12BPDAS	Same as 45APDAS except for outer panel.



INNER (A) PANEL CMM COORDINATES

FIGURE 6



12 METER REFLECTOR
OUTER (B) PANEL CMM COORDINATES

FIGURE 7

5/11/81

The measurement grids for the panels are shown in Figures 8 and 9. The average area per measurement represented by the inner panel grid is 21 square inches, and that of the outer panel grid is 42 square inches.

The RMS and Average Deviation for the panels are based on the following formulas:

$$RMS = \sqrt{\frac{\Sigma(Di-\bar{D}')^2\cos\theta}{N-1}} = \sqrt{\frac{\Sigma Di'^2\cos^2\theta - \frac{(\Sigma Di')^2\cos^2\theta}{N}}{N-1}}$$

$$\bar{D}' = \frac{\Sigma Di'}{N}$$

where $\bar{D}'$ = Average deviation

Di' = Deviation of measured from theoretical Z_2' for i^{th} point.

θ = Transformation angle given in Table 1.

The N-1 is used to account for the degree of freedom used in subtracting the average, $\bar{D}'$ from the individual measurements. The angle θ accounts for the fact that the path length change is twice the axial component of the deviation measured perpendicular to the surface.

In addition to the DAS programs, Data Reduction programs have been prepared to list the data for each panel. Table 4 lists the programs with a brief description of each program. Listings of the programs are given in Appendix B. These programs are used to present the data recorded on the data tapes.

The data recorded on the DAS are reduced by means of the programs 45APPLAT and 12BPPLAT. As described above, these programs produce an output in the form of an X-Y grid to allow an easier assimilation of the data. It is to be noted that the deviations are given in milli inches (mils).

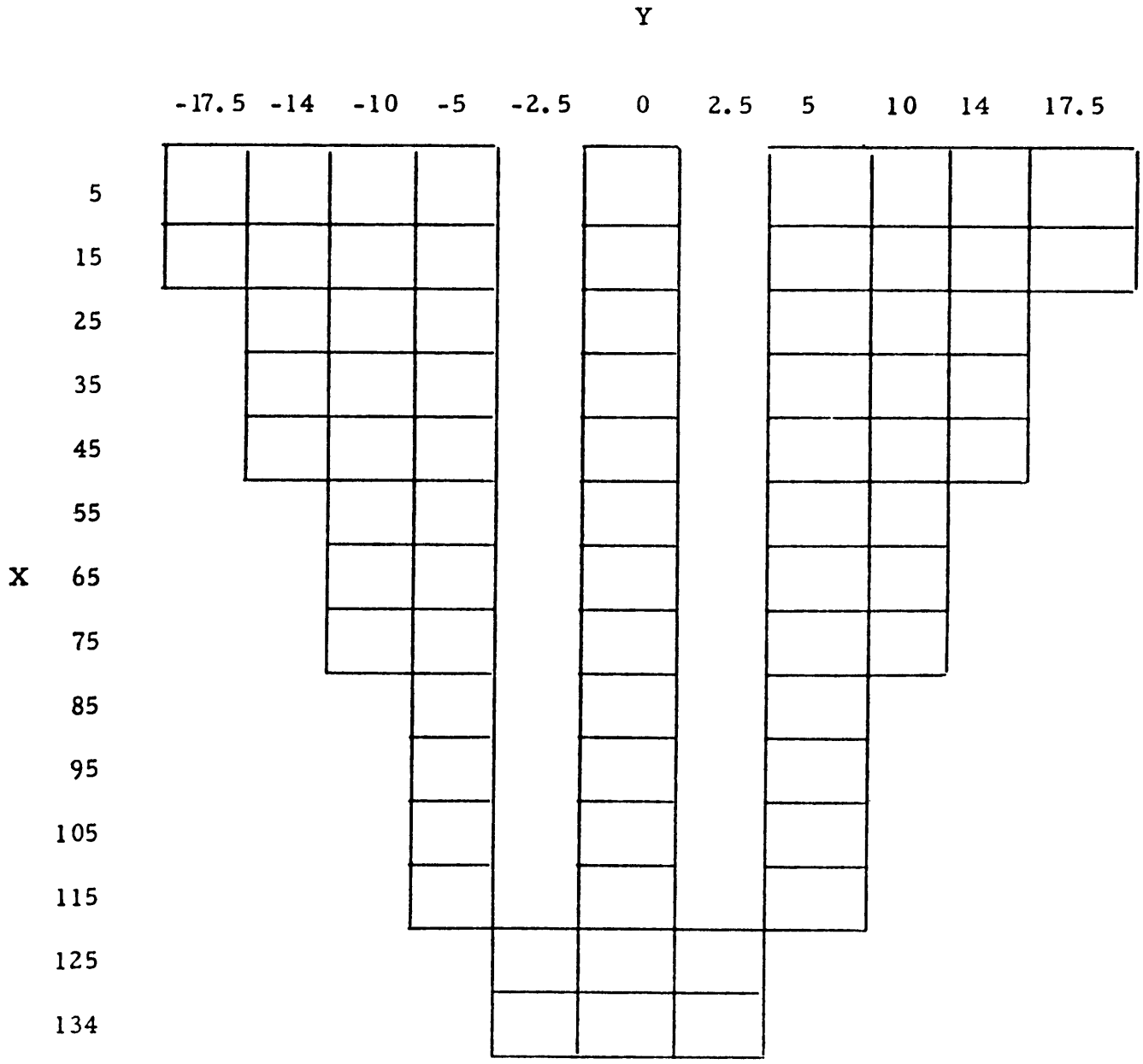
It is necessary now to combine these data to obtain an overall aggregate RMS for all of the panels. The development of the formulas to do this follows:

For any individual panel, for say the inner complement (24 total):

$$\Sigma D_i^2 = [(N_A-1)(RMS)^2 + N_A\bar{D}^2]$$

Thus, for all 24 panels:

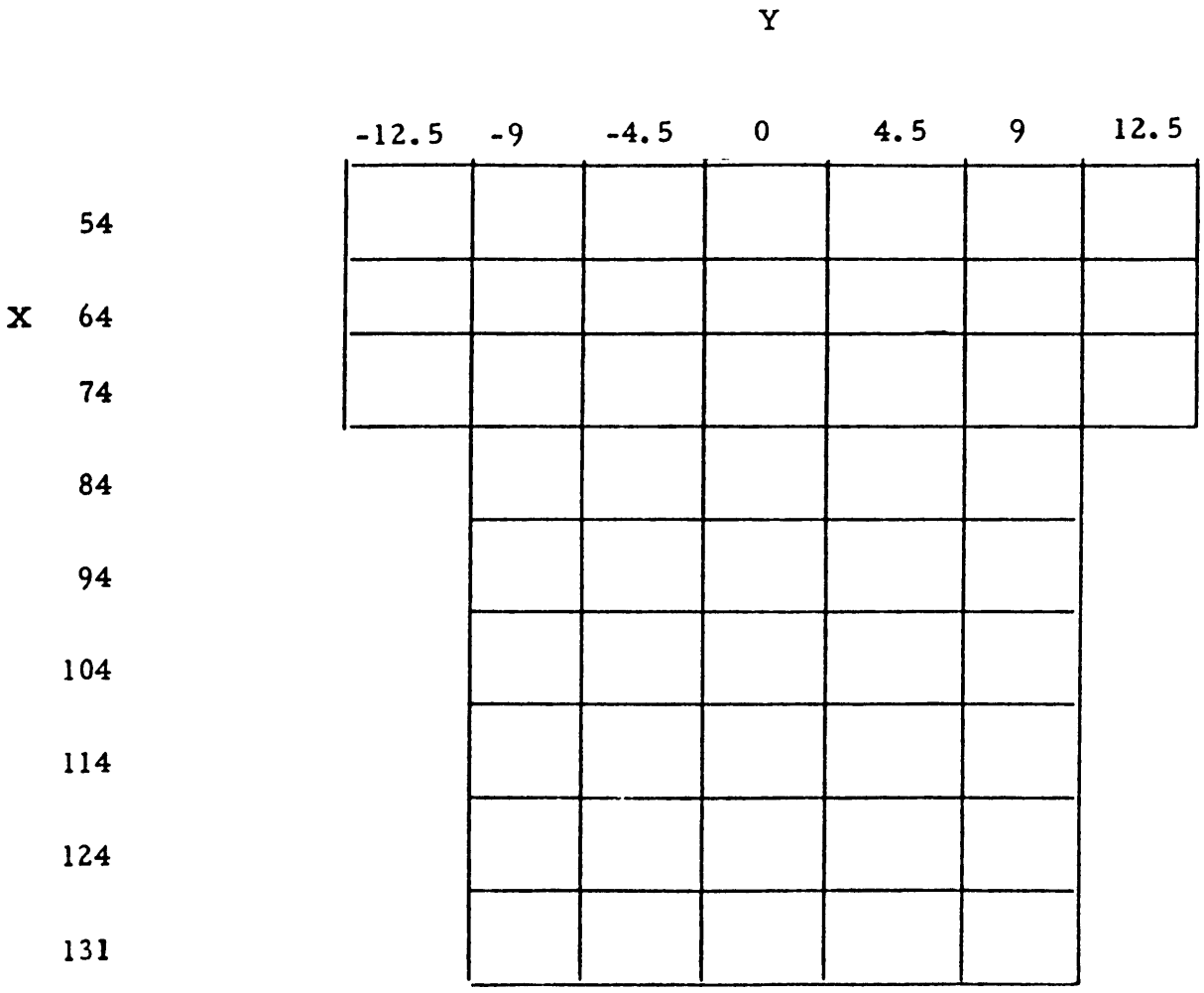
$$\sum_{J=1}^{24}(\Sigma D_i^2)_J = \sum_{J=1}^{24}[(N_A-1)(RMS_J)^2 + N_A\bar{D}_J^2]$$



CHECK-OFF TABLE FOR MEASURING GRID

PANEL A (INNER)

Figure 8



CHECK-OFF TABLE FOR MEASURING GRID

PANEL B (OUTER)

Figure 9

TABLE 4

DATA REDUCTION PROGRAMS

Program	Description
45APPLT	This program is used to present the deviations of the panel in the form of an X-Y grid to allow an easier assimilation of the data. In addition to printing out the grid, the program also prints out the RMS and average deviation of the panel.
12BPPLT	Same as 45APPLT except for outer panel.

Furthermore, the average deviation for the aggregate, $\bar{\bar{D}}_A$, will be:

$$\bar{\bar{D}}_A = \frac{N_A \sum_{J=1}^{24} \bar{D}_J}{24N_A}$$

Thus, the aggregate RMS for the inner panels can be expressed as:

$$\overline{\overline{RMS}}_A = \sqrt{\frac{\sum_{J=1}^{24} [(N_A-1)(RMS_J)^2 + N_A\bar{D}_J{}^2] - 24N_A\bar{\bar{D}}_A{}^2}{23N_A}}$$

Using the weighting factors S_A and S_B for the two panel types, the average deviation and RMS for the aggregate are given as:

$$\bar{\bar{D}}_{A_B} = \frac{S_A N_A \sum_{}^{24} \bar{D}_{A_J} + S_B N_B \sum_{}^{48} \bar{D}_{B_J}}{24S_A N_A + 48(S_B N_B)}$$

$$\overline{\overline{RMS}}_{A_B} = \sqrt{\frac{(\Sigma_A + \Sigma_B) - C\bar{\bar{D}}^2_{A_B}}{23S_A N_A + 47(S_B N_B)}}$$

where

$$\Sigma_A = S_A \sum_{}^{24} [(N_A-1)(RMS_{A_J})^2 + N_A\bar{D}_{A_J}{}^2]$$

$$\Sigma_B = S_B \sum_{}^{48} [(N_B-1)(RMS_{B_J})^2 + N_B\bar{D}_{B_J}{}^2]$$

$$C = 24S_A N_A + 48(S_B N_B)$$

The constants for the panels are:

$N_A = 72$ $\quad$ $S_A = 21$

$N_B = 51$ $\quad$ $S_B = 42$

Note that in all these formulas $D = D' \cos\theta$.

The program which accomplished the calculations outlined in the above formulas is presented for reference in Appendix C.

In cases where surface illumination taper is significant, this factor can be included in the weighting of each data point, where the weighting factor is a function of the radius of the data point in the reflector aperture.

ELECTRONIC SPACE SYSTEMS CORPORATION

EXHIBIT I

FINAL ACCEPTANCE RECORD

Customer National Radio Astronomy Observatory Contract No. _____

Model: 12-Meter Diameter Reflector Assembly Location _____

Specification Requirements	Ref. Para.	Discrepancy				No Discrepancy or Discrepancy Cleared		
		No.	Inspectors Initials		Date	Inspectors Initials		Date
Reflector Surface Accuracy Measure-	1.0							
ments.								

CONDITIONAL ACCEPTANCE

Reflector panels are accepted with the discrepancies noted.

ESSCO Rep./Title _____ Date _____ Customer Rep./Title _____ Date _____

FINAL ACCEPTANCE

Reflector panels are accepted in conformance with contractual requirement.

ESSCO Rep./Title _____ Date _____ Customer Rep./Title _____ Date _____