25 Meter Millimeter Wave Telescope
Memo # 109

NATIONAL RADIO ASTRONOMY OBSERVATORY

Charlottesville, Virginia

September 19, 1978

MEMORANDUM

TO: 25-m Design Group

FROM: W-Y. Wong

SUBJECT: A lattice structure design replacing the intermediate structure

In order to achieve an acceptable backup structure design, the stiffness of the intermediate structure must be represented properly in the backup structure model during the homologous optimization. The method of approximation is no longer applied for this short wave-length telescope design. Hence the stiffness, the center of gravity and the weight of the intermediate structure has to be incorporated to the backup structure either analytically in the form of a stiffness matrix, or by analyzing the backup structure and the intermediate structure together as one single model. The former approach requires analytical efforts, whereas the latter requires programming efforts.

The present approach is to expand the homology program to accommodate a larger structure.

Since the intermediate structure, backup structure combination is still too large for the IBM 360/65, some modification of the intermediate structure is needed to reduce the number of joints and connections. After few attempts but without success. So a new design is proposed here to replace the intermediate structure. This report is to present the design of the lattice structure. The number of joints and members of this lattice structure are greatly reduced. The surface error due to various loading conditions is comparable to the previous design. This lattice structure is ready to couple to the backup structure for a new homologous solution.

Once the program is ready, and the homologous solution achieved, the structure will be analyzed again for its non-homologous effects and the temperature effects. Modifications of the structure is to be done wherever needed. It is hoped that the telescope structure analyses will be finished by the end of 1978.

# LATTICE STRUCTURE

## SUMMARY

This lattice structure design will replace the intermediate panel design as mentioned in both of the 25-m mm-wave telescope proposals. This new design is more optimum in weight and in geometry. The deflection under the influence of its own weight, the weight of the surface plate plus the homologous deformation of the back up structure is 0.019 mm rms, larger than the value of .013 mm rms quoted from memo no. 5 ("Design and performance of Panel B" by S. von Hoerner and K. Kern, 10/15/74). This value, however, is still small compared with the balanced error budget of $.075/\sqrt{5} = .038$ mm, hence the design is considered acceptable.

The main reason to simplify the geometry is the need to include the lattice structure to the backup structure in the homologous optimization, so that the stiffness and the weight of the lattice structure is properly represented.

Reduction of the number of joints and members also means a possible reduction of cost. Table I listed some parameters of these two designs for comparison. A quadrant of these two geometries are illustrated in figure 1.

The lattice structure design does not alter the arrangement of the surface plates. There are nine concentrate rings, formed by the surface bars. The center line of these bars is 33 cm below the theoretical surface, so that rooms are provided for the plate, adjustment screws and the brackets.

TABLE I. Comparison of the intermediate panel structure and the lattice structure

| | Intermediate panels | Lattice str. |
|---|---|---|
| Joint no. | 1,136 | 396 |
| Member | 3,028 | 1,604 |
| No. of member type | 7 | 3 |
| Weight (kg) | 17,667 | 12,738 |
| <u>Error</u> (rms, mm) | | |
| Sag of surface bars | .009 | .002 |
| Dead wt. and plate | .008 | .008 |
| Homologous def. of the backup str. | .005 | .017 |
| RSS | .013 | .019 |

## Geometry

The basic geometry of the lattice structure is composed of 68 inverted pyramidal modules. Figure 2 shows one module for illustration.

In Figure 2, the surface points are identified as 108, 109, 116, 253, 255 and 256. Surface bars are 116-225, 116-256 and 108-109. These surface bars, as these modules are connected together, will form nine concentrate rings to provide supports to the surface plates. The tip of the pryramid is point 133.

It is difficult to fulfill the equal softness of the surface points if the pyramid is supported directly at joints 253, 255 and 256. But the equal softness of these points can be achieved more readily if the pyramid is supported at its mid-span (108, 109 and 116) and at its tip (133). The pyramid is connected to the strong supports (15, 21, and 22) with nine connections (22-116, 22-109, 22-133, for example). These strong supports are the homologous points of the backup structure.

One module was analyzed a few times to determine its basic geometry and the sizes of the connections. The entire lattice structure, modelled in one quadrant as shown in figure 3 and 4, was analyzed to determine the effects on surface accuracy at the various loading conditions described in the later part of this report.

## Surface Bars

Each surface bar provides support to the surface plates, relying mainly on its bending stiffness. The arrangement of these bars is shown in figure 3 in heavy lines. These bars are steel tubing of identical size. Except the specially designed connection 239-240, which is a rigid ring and serves as a reference platform for surface measurement.

The sizing of the surface bars is determined by the amount of deflection along the unsupported span. Two factors attributed to the deflection: the bars own weight and the weight of the surface plates.

With the present design concept of cast aluminum machined plates, the unit weight is about 20 $kg/m^2$. Table II shows the relevant surface plate properties needed in the design of the surface bars as well as the lattice structure.

TABLE II. Properties of cast al. machined plates

| Ring | Radii m | No. of Plates | Surface area $m^2$ | Wt./plate kg |
|---|---|---|---|---|
| 1 | 1.32 | 24 | 18 | 14.9 |
| 2 | 2.57 | 24 | 32 | 26.8 |
| 3 | 3.80 | 48 | 47 | 20.0 |
| 4 | 5.26 | 48 | 60 | 24.5 |
| 5 | 6.64 | 96 | 74 | 14.7 |
| 6 | 8.10 | 96 | 86 | 17.0 |
| 7 | 9.52 | 96 | 102 | 19.1 |
| 8 | 11.05 | 96 | 123 | 20.9 |
| | 12.50 | 528 | 542 | Total Wt: 10,062 kg |

It is assumed the weight of each plate is equally distributed to the four adjustment screws, inspite of the telescopes' position. This assumption is considered close to the real life situation and the results derived from the subsequent analyses are considered reliable.

The thermal behavior of the lattice structure is not included in these analyses. Some consideration has been given to this, however, during the sizing of the structural bars. Presently all bars have an identical wall thickness. Hence the lattice itself is not affected by the change of ambient temperatures. The length of all connections does not vary a great deal, so it is safe to assume the effect of thermal gradient is negligible.

The design criteria of the surface bars is stated as follow: the sag of a surface bar, treated as a simple beam, along its unsupported span, under the influence of its own weight and the external load such as surface plates, adjustment screws and brackets should not exceed an average value of .005 mm rms. The simple beam is supported by a hinge at one end and a rigid support on the other. An external load is applied at its mid span, and a uniformly distributed load along the entire span. The max. deflections $d_m$ are expressed as follow:

$$\text{Dead Wt.} \quad d_m = \frac{q\ell^4}{185\ EI} = 1.1343\ \ell^4 \times 10^{-11}$$

$$\text{Plate load} \quad d_m = \frac{P\ell^3}{48\sqrt{5}\ EI} = 1.5299 \times 10^{-11}\ P\ell^3 \tag{1}$$

where $\ell$ = length of the span

$E$ = modulus of elasticity

$I$ = cross-sectional moment of inertia

$q$ = uniform load

$P$ = point load

Table III shows the results of the analysis with the telescope pointing to the zenith. It showed the error contribution from the sagging of the surface bars:

$$\sigma(sag) = rms(d_m - \bar{d}) = .003 \text{ mm rms} \tag{2}$$

TABLE III. Sagging of the Surface Bars

| Connection | $\ell$ (m) | P (kg) | w | $d_m(q)$ (μm) | $d_m(P)$ (μm) | $\Sigma d_m$ (μm) | $\Sigma d_m - \bar{d}$ (μm) |
|---|---|---|---|---|---|---|---|
| 68-69 | 1.58 | 41.7 | 3 | 4.3 | 8.6 | 13.0 | 1.3 |
| 72-238 | 1.58 | 48.8 | 4 | 4.3 | 10.2 | 14.5 | 2.8 |
| 74-75 | 1.36 | 43.9 | 6 | 2.3 | 5.8 | 8.1 | -3.6 |
| 81-237 | 1.36 | 40.5 | 8 | 2.3 | 5.3 | 7.6 | -4.1 |
| 85-86 | 1.53 | 42.3 | 9 | 3.6 | 7.9 | 11.4 | -0.3 |
| 95-236 | 1.53 | 43.3 | 10 | 3.6 | 8.1 | 11.7 | 0.0 |
| 100-101 | 1.69 | 43.7 | 11 | 5.6 | 11.2 | 16.8 | 5.1 |
| 112-235 | 1.68 | 20.5 | 12 | 5.6 | 5.1 | 10.7 | -1.0 |

averaged sag: $\bar{d}$ = 11.7

As the telescope points to the horizon, only the bars at the central diametric position of the aperture sag, the corresponding error can be expressed as:

$$\sigma_h(sag) = \sigma_z(sag) \times \tan\frac{\theta}{2} = .001 \text{ mm rms} \qquad (3)$$

where $\theta$ = 28° is the slope of the parabolic surface at the rim of the aperture. The averaged error due to the sagging of the surface bars is

$$\sigma(sag) = \sqrt{\frac{\sigma_z(sag)^2 + \sigma_h(sag)^2}{2}} = .002 \text{ mm rms} \qquad (4)$$

## Gravity effects on the lattice structure

The structure was analyzed twice, with the telescope points to the zenith and horizon. The bending stiffness of each member is taken into account in the analyses. The lattice structure is held rigidly at 23 supporting points. These 23 points are to be connected to the backup structures. The coordinates of these points are identical to those of homologous points. Relevant quantities are listed in Table IV for reference.

TABLE IV. Date on the Lattice Structure

| | | |
|---|---|---|
| Weight: | | 12,738 kg |
| Inertia (Z-axis) | | $10.7 \times 10^6$ N-m$^2$ |
| Inertia (X-axis) | | $6.1 \times 10^6$ N-m$^2$ |
| No. of joints | | 396 (113 in one quadrant) |
| No. of member | | 1,604 (417 in one quadrant) |
| Surface bars: | Diameter: | 6.625 in (16.83 cm) |
| | Area: | 2.450 in$^2$ (15.8 cm$^2$) |
| | Inertia: | 13.454 in$^4$ (559.7 cm$^4$) |
| | Wall: | 0.12 in (3.05 mm) |
| | Unit Wt: | 0.694 #/in (.124 kg/cm) |
| Type 1: | Diameter: | 1.563 in (3.97 cm) |
| | Area: | 0.544 in$^2$ (3.5 cm$^2$) |
| | Inertia: | 0.166 in$^4$ (6.9 cm$^4$) |
| | Wall: | 0.12 in (3.05 mm) |
| | Unit Wt: | 0.154 #/in (.0275 kg/cm) |
| Type 2: | Diameter: | 2.500 in (6.35 cm) |
| | Area: | 1.1488 in$^2$ (7.4 cm$^2$) |
| | Inertia: | 0.8975 in$^4$ (37.3 cm$^4$) |
| | Wall: | 0.12 in (3.05 mm) |
| | Unit Wt: | 0.325 #/in (.0580 kg/cm) |

The deflections of the surface points are computed and the deviations from a best-fit paraboloid are summarized in Table V.

TABLE V. Deviation from the best-fit paraboloid due to gravity effects in zenith and horizontal positions. All dimensions are in mm and radians x $10^{-5}$

| Gravity | Best fit rms Surface Error | $\Delta X$ | $\Delta Y$ | $\Delta Z$ | $\theta X$ | $\theta Y$ | $\Delta f$ |
|---|---|---|---|---|---|---|---|
| -Z | .005 | 0.0 | 0.0 | -.03 | 0.0 | 0.0 | +0.10 |
| Y | .003 | 0.0 | -0.23 | 0.0 | -1.3 | 0.0 | 0.0 |

If the surface is adjusted at elevation angle of 45°, the averaged error of the surface due to gravity alone is

$$\sigma(g) = .004 \text{ mm rms} \tag{5}$$

Deflection due to the weight of the surface plates

The cast aluminum, machined plates weigh 20 kg/$m^2$. The total weight of the surface plates is 10,062 kg (Memo. 101). Each plate is supported at the four corners, connected to the surface bars by the adjustment screws and bracket combinations. The thickness of the plate is approximately 10.2 cm (4 inches) at the edge.

Again the structure was analyzed in two positions. There are two assumptions in these computations: first it is assumed that the weight of each plate is equally distributed to the four adjustment screws in all telescope positions; and second, the weight of the plates are lumped to the nearest joints. These assumptions are considered to have negligible effects on the results of the analyses. Table VI shows the summarized results of this analyses.

TABLE VI. Deviation from the best-fit paraboloid due to the weight of surface plate alone. All discussions are in mm or x $10^{-5}$ rad.

| Gravity | Best fit rms Surface Error | $\Delta X$ | $\Delta Y$ | $\Delta Z$ | $\theta X$ | $\theta Y$ | $\Delta f$ |
|---|---|---|---|---|---|---|---|
| -Z | .007 | 0.0 | 0.0 | -0.05 | 0.0 | 0.0 | +0.01 |
| Y | .005 | 0.0 | -0.04 | 0.0 | -0.4 | 0.0 | 0.0 |

In the average sense, the deflection of the lattice structure under the weight of the surface plates is given in (6)

$$\sigma(\text{plate}) = .006 \text{ mm rms} \tag{6}$$

Effects on support displacements

The lattice structure and the back up structure are rigidly connected through 72 homologous points. The optimum design of the backup structure is based on the homologous solution achieved for these 72 points. When these 72 points deform from one paraboloid into another as the telescope tilts, the surface points of the lattice structure will also deform likewise, but with a degradation. Presently the analyses on the backup structure and the lattice structure are performed separately. Then good homologous solutions from the backup structure are applied to the lattice structure as support displacements to serve as an indication as how closely the surface follows the homologous solutions. These results will eventually be verified by analyses with the lattice structure and the backup structure combined as one model.

The homologous solutions used in these analyses are listed in Table VII.

TABLE VII. Homologous solutions. All dimensions are in mm or $10^{-5}$ rad.

| Gravity | Best fit rms Surface Error | $\Delta X$ | $\Delta Y$ | $\Delta Z$ | $\theta X$ | $\theta Y$ | $\Delta f$ |
|---|---|---|---|---|---|---|---|
| -Z | .003 | 0.0 | 0.0 | -4.48 | 0.0 | 0.0 | -1.19 |
| Y | .004 | 0.0 | +4.86 | 0.0 | -34.8 | 0.0 | 0.0 |

Ref. G0009 (4/26/78)

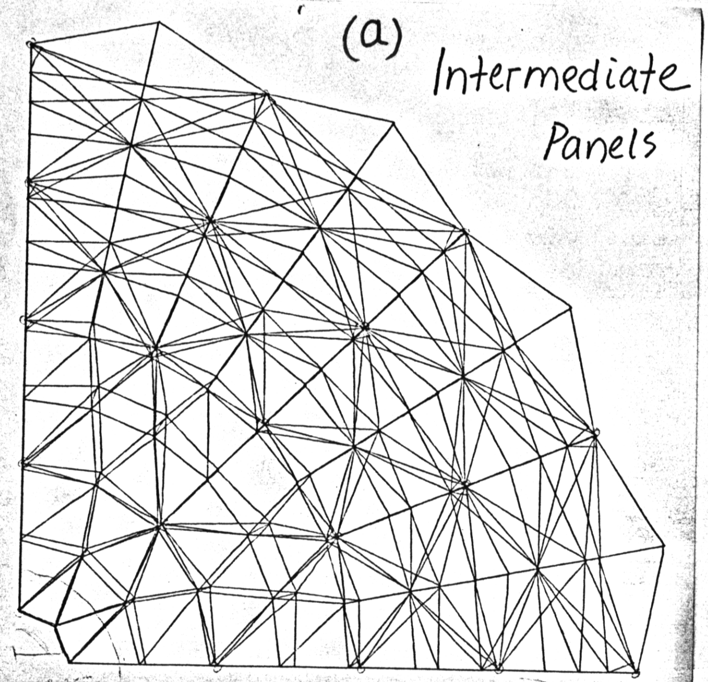
The degradation of the surface accuracy is illustrated in figure 5 as the telescope points to the zenith, and figure 6 as the telescope points to the horizon. The details of the deviations from the best fit paraboloid is listed in table VIII.

TABLE VIII. Degradation of surface of the lattice structure due to the movements of supports. All dimensions are in mm and $10^{-5}$ rad.

| Gravity | Best fit rms Surface Error | $\Delta X$ | $\Delta Y$ | $\Delta Z$ | $\theta X$ | $\theta Y$ | $\Delta f$ |
|---|---|---|---|---|---|---|---|
| -Z | .013 | 0.0 | 0.0 | -4.42 | 0.0 | 0.0 | -1.30 |
| Y | .020 | 0.0 | +5.29 | 0.0 | -33.0 | 0.0 | 0.0 |

The averaged degradation is

$$\sigma(\text{displacement}) = .017 \text{ mm rms} \tag{7}$$



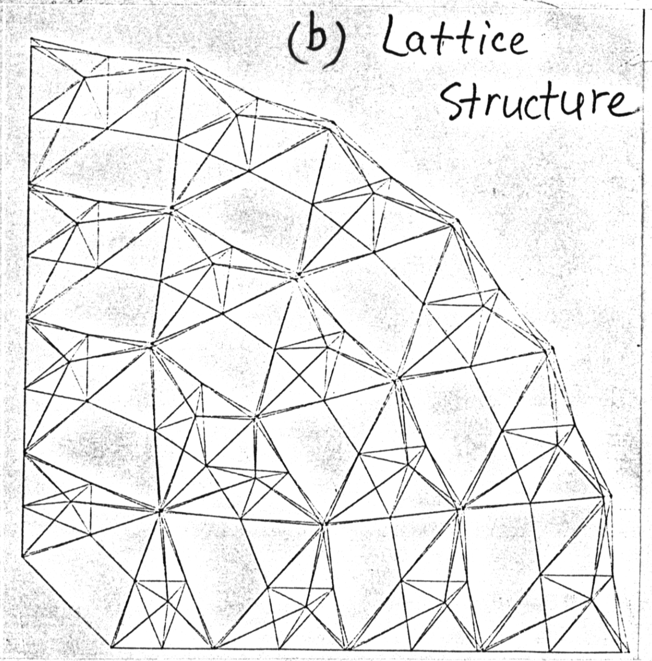




Figure 1 A comparison of geometries between (a) the intermediate structure and (b) the lattice structure. Shown in one quadrant only due to symmetry.

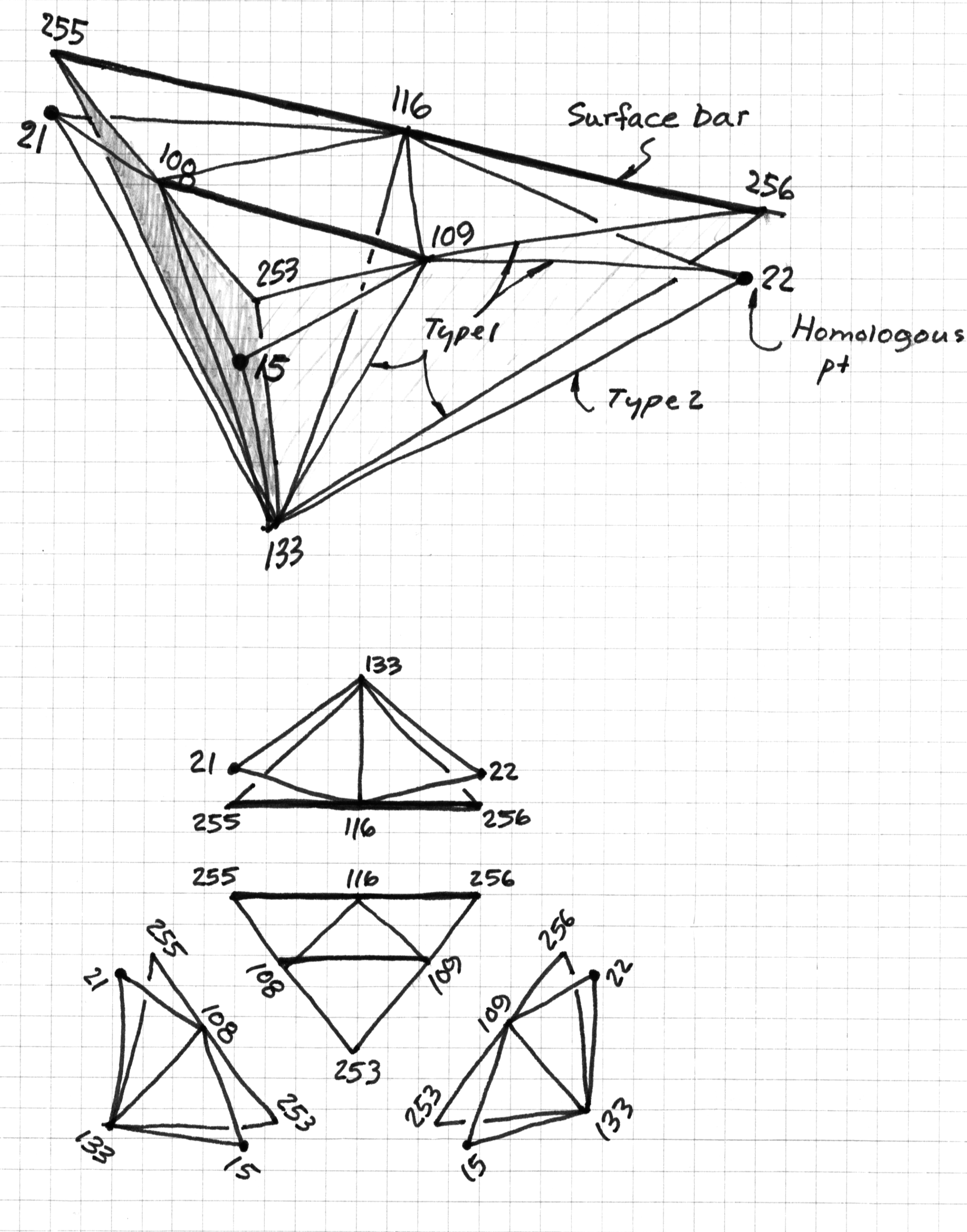
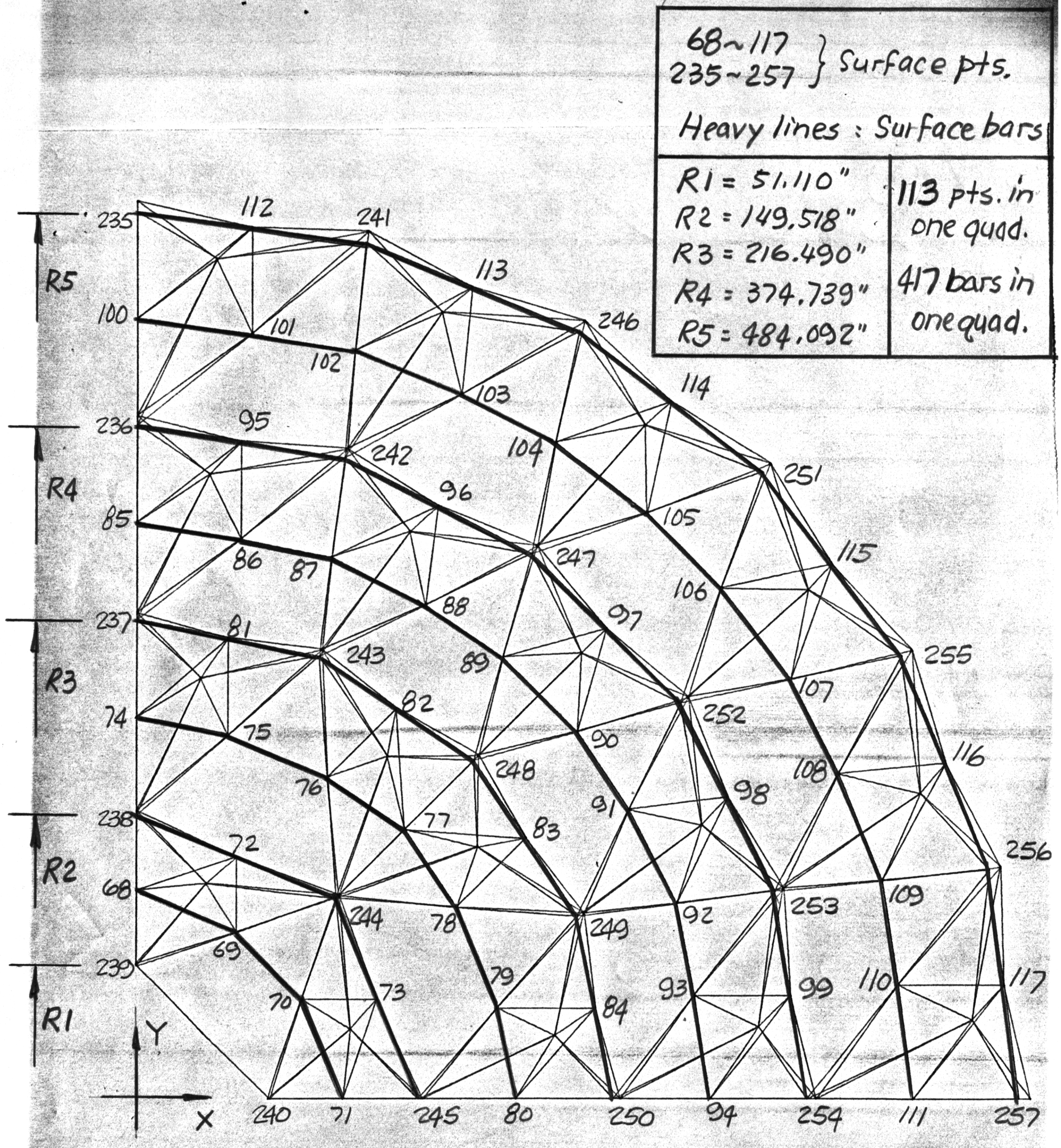



Figure 2   Pyramidal module of the lattice structure. It has 10 nodes and 24 members.




LATTICE 5 & 6

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Figure 3. Surface pts. of the lattice structure. It has 73 surface pts. in one quad., 256 in total

1~23 : Homologous pts

118~134 : Tip of pyramidal modules

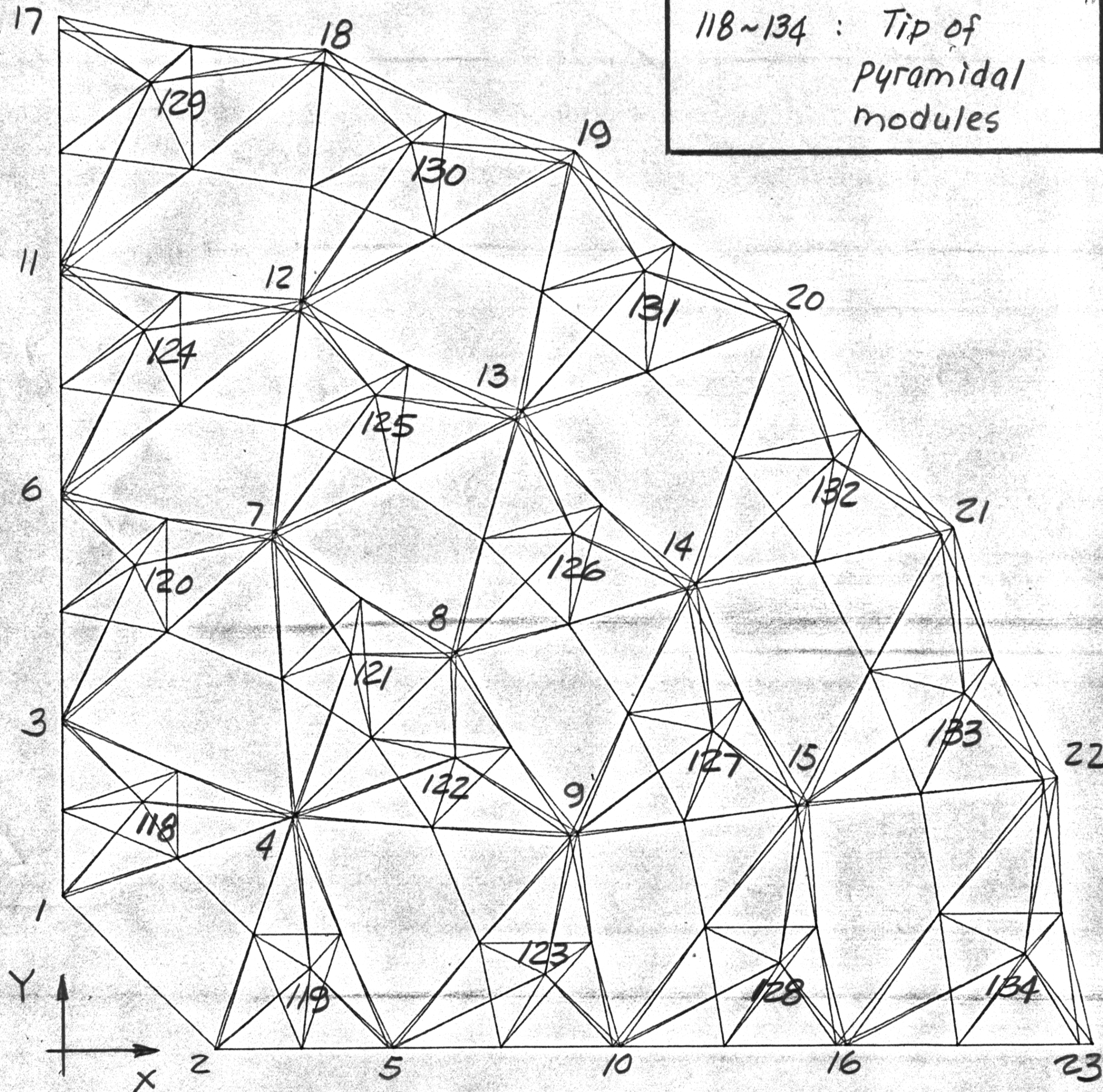


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Figure 4. Non-Surface pts. of the lattice structure

| Position | Best Fit rms Surface error (mm) | — mm — dx | dY | dz | — rad. — $\phi x$ | $\phi Y$ | mm $\Delta F$ |
|---|---|---|---|---|---|---|---|
| Zenith | .013 | 0.0 | 0.0 | -4.417 | 0.0 | 0.0 | +1.30 |

Ref: LAT7 8/14/78

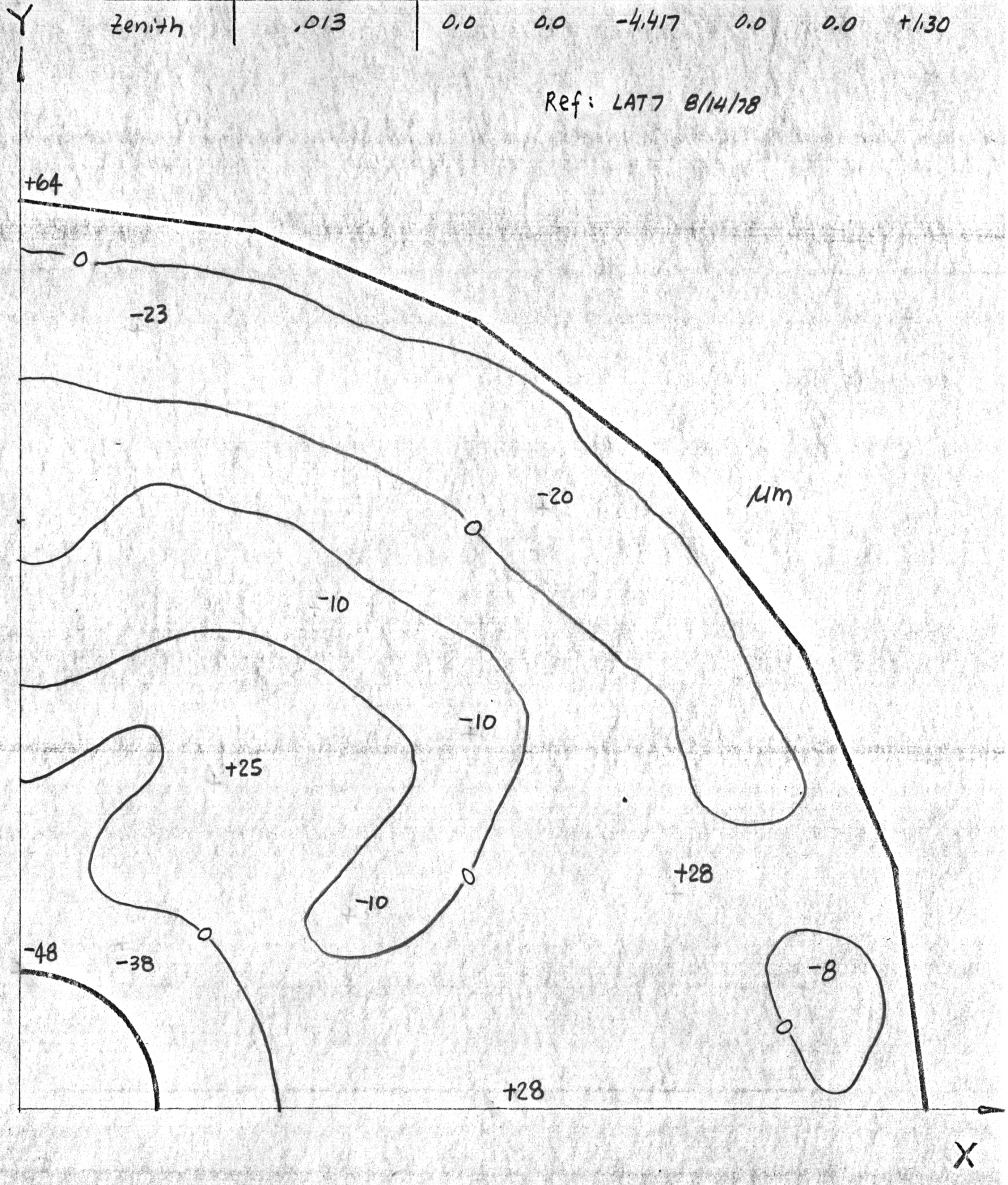


Figure 5. Surface error due to dead wt. deflection of homologous pts. at zenith position.

| Position | Best Fit rms Surface error (mm) | — mm — | | | - rad — | | mm. |
|---|---|---|---|---|---|---|---|
| | | dx | dY | dz | $\phi x$ | $\phi Y$ | $\Delta F$ |
| Horizon | .020 | 0.0 | 5.29 | 0.0 | $-33\times10^{-5}$ | 0.0 | 0.0 |

Ref: BESTFIT6 8/21/78

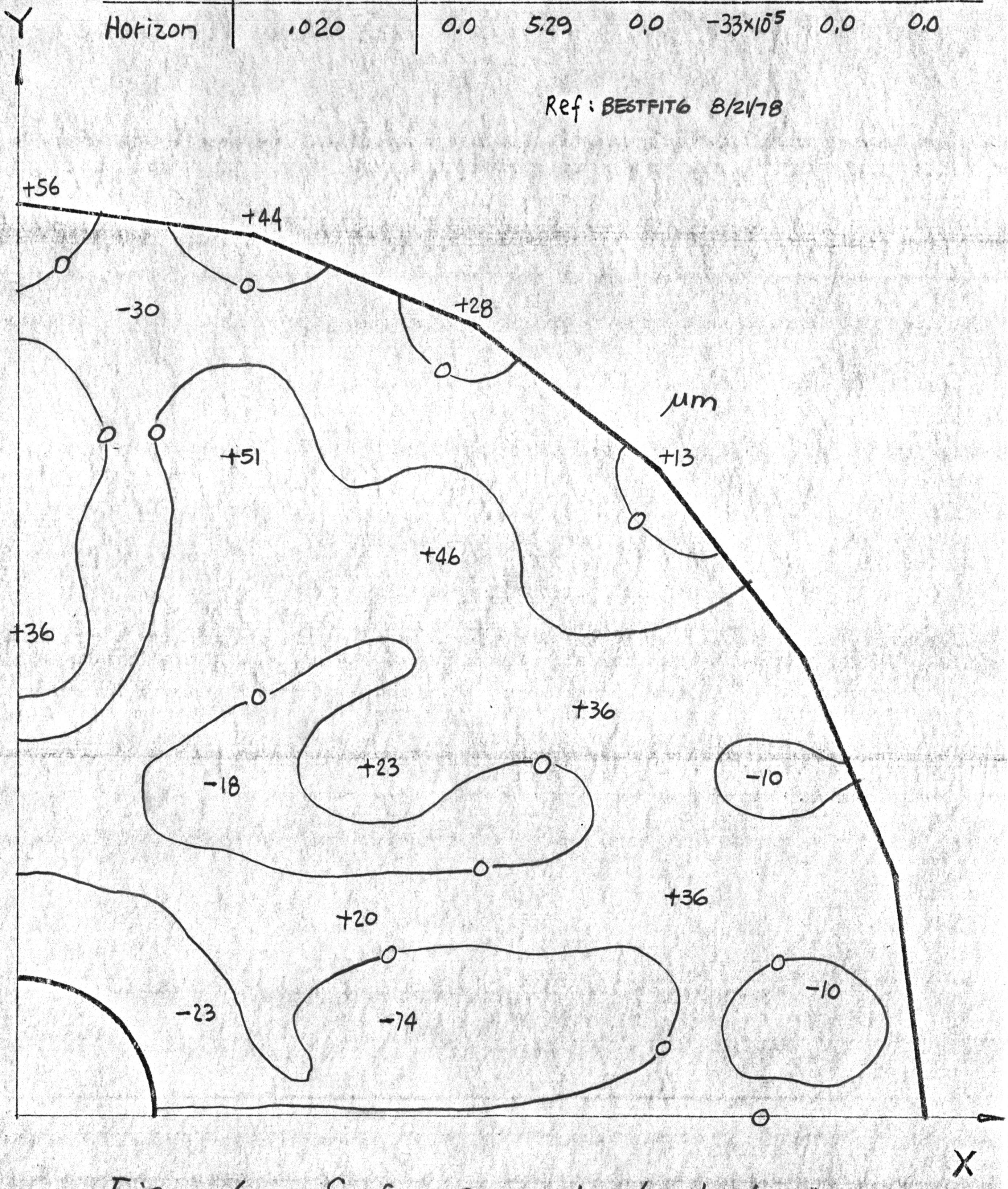


Figure 6. Surface error due to dead wt. deflection of homologous pts. at horizontal position.