Laser Distance Measurements To The Elevation Bearing Support Weldments

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Abstract

The GBT laser rangefinder system has the potential to provide accurate measurements of azimuth and vertical tilt of the telescope's elevation shaft. Distance measurements can be made from ranging stations around the telescope base, to reflecting optical targets located beneath the elevation bearing support weldments located at each end of the alidade structure. For any alidade azimuth, at least two ranging lines of sight are available on the right side of the alidade and two or more on the left side, to the bottom surface of each weldment. Retroreflectors located beneath the weldments, on a line parallel to the elevation shaft, could supply excellent position fiducial reference points on the weldments, if two right side and two left side range measurements can be made to each target. At best, the horizontal angle of the line between the target fiducial points could be measured within 1 arc-second, and the vertical tilt of this line to 2 arc-second. Position determination of these reference points would give good quality information on orientation and position of the telescope's elevation shaft.

Ball retroreflectors, which have the widest angular response of any available reflector, would have to be viewed near the limits of their response range to return signal to both right and left side rangefinders, if they were simply mounted statically beneath the weldments. More complex reflector arrangements could be used, to obtain adequate rangefinder return signal. Tradeoffs between quality of shaft location and reflector target configuration are discussed in this memo.

1 Introduction.

The mission of the GBT laser rangefinder system is to make measurements giving information about main reflector shape, telescope pointing and structural deformation and displacement. Ranging measurements of the positions of fiducial reference points rigidly attached to the telescope's alidade structure, near each of the elevation shaft bearings, could provide accurate information on the orientation and position of the elevation shaft.

Twelve rangefinders are spaced at 30° intervals around the telescope base, at 120 m distance from the pintle bearing. For any alidade azimuth, four or more ranging lines of sight are available to the bottom surface of each elevation bearing support weldment, at least two from each side of the telescope's plane of symmetry. If fiducial reference points can be fixed to the bottom surface of each weldment and ranged with four lines of sight, two from the right and two from the left, the coordinates of each fiducial point can be determined with sub-millimeter accuracy. The horizontal bearing angle of the line joining these points would be determined within one arc-second, and the vertical tilt of this line would be determined within two arc-seconds. The horizontal bearing offset angle and the vertical tilt offset angle of this line relative to the elevation axis of the telescope (which is the line between elevation bearing centers) should each remain nearly constant during telescope operation. It is proposed here that the offset of the line between weldment fiducial points and the elevation axis is sufficiently constant that this line between may be used to measure the elevation axis' spatial orientation, once the initial offset has been measured by surveying at some initial telescope elevation (e.g near the telescope rigging angle).

The two support weldments are massive platforms which support the elevation bearings of the telescope. The bottom surface of each weldment is a large horizontal plane area, designed to be 137.00 inches below the elevation axis (as measured perpendicular to the alidade track plane). Under varying loading of the telescope, when tipping structure elevation, wind loading, and temperature change, the change of orientation from the horizontal of the bottom surface of either weldment is expected to be less than 150 arc-seconds [1]. It can be demonstrated that changes of weldment surface orientation to the horizontal of this magnitude will not significantly degrade the measurement suggested above.

2 Range Distance Survey Models

In order to locate the center of a target retroreflector mounted beneath a bearing support weldment it will be necessary to range this target from stations both to the right and to the left of the telescope's plane of symmetry. For each target ball two stations to the left and two other stations to the right have direct lines of sight to the ball at any alidade azimuth. Figure 1 shows one of these lines of sight.

Typically, three target sight lines are not available to targets at both ends of the elevation shaft from stations on one side of the symmetry plane. One or both sub-weldment targets will have to be viewed from 2 stations right together with 2 stations left of that plane. However, the view angles of the stations from the subweldment retroreflectors, with respect to the downwards gravity vertical direction, are large. They are given in Table 1. The expected power return to a ranging station from a ball reflector at 100 to 150 meter range, for incidence angle of 72° to the normal to the reflector aperture plane, is near one percent [2]. This level of return may be marginal for ranging measurements.

Actual ranging tests will have to be performed to determine whether power return is adequate for ranging at 72° incidence at 150 meter range. If the tests are positive, then two ball targets can be mounted for ranging under the weldments, each with its aperture plane horizontal. The laser ranging lines of sight for this 2-ball configuration are shown schematically as configuration 1 in Figure 3. This ranging configuration is statically determinate. Survey modeling of this measurement arrangement (cf. Appendix II) indicates that the horizontal bearing of the line of ball centers should be measurable to 0.7" rms, vertical tilt of this line should be measurable to 2".

If the view angle is too large to get adequate laser power return the situation becomes more complicated. A target must be viewed at large angles from both the right and left halves of the telescope, with respect to the telescope's plane of symmetry. A single ball retroreflector aimed to look between 65° and 75° to the right has no responsivity to a laser beam incident from 65° to 75° left. A ball reflector aimed midway between right and left has inadequate response on both sides.

One possible solution would be to mount each of the retroreflector target balls in a mechanical latching toggle mount, which could allow the target to look alternately to the right and to the left. The ball would rotate its glance to either side. The axis of rotation would pass through the optical center of the target, which is the ball center of curvature; in that case, the stations on either side would still range to a fixed target point.

The price of this active reflector solution, compared to use of a fixed ball, is the need to design a moving mount and to supply power lines and position control signals to the targets.

Another possible solution might be to replace the single ball target under each weldment with a pair of closely spaced targets. The targets would be mounted in a common housing at an accurately known separation and orientation relative to the bottom surface of the weldment. One reflector of the pair would be aimed approximately 70° to the right, the other 70° left, with appropriate baffling so the right-looking ball is ranged only by stations to the right and the left-looking ball is ranged only by stations to the left. The pairs of targets at the opposite ends of the elevation shaft could be aligned either perpendicular or parallel to the elevation axis of the telescope (Fig. 3).

This is a passive solution, and does not require power lines or control signals. However the ranging configuration now beomes statically indeterminate. Two stations ranging accurately on a target only restrain that target to lie on a circle. They do not fix the position of that target. Each ball center of a ball target pair at fixed separation is free to move on an arc of its circle, constrained only by the condition that a line segment of length equal to the ball center separation can be found connecting the circle arcs of the two ball centers. (The constraint geometry is discussed in more detail in Appendix I). Also, four ball targets are required instead of two.

Since a statically determinate trilateration is not generally available in here, it might appear that the separated ball pairs do not define unique target positions, so the employment of separated targets appears useless. This appearance is deceptive. Strong additional restraints on ball center positions are available in fact.

The weldment bottom surfaces will remain quite close to horizontal, for all operating conditions of the GBT. This means that the line of centers of the ball reflector pair at each end of the elevation axle will lie at a zenith angle (with respect to the direction of vertical at the pintle bearing) which is close to 90°. The line of centers of two balls at opposite ends of the elevation shaft will also lie at a zenith angle near 90°. By bounding the deviation from 90° of the zenith angle of the line of centers of any two sub-weldment ball reflectors, one obtains a strong restraint on the Z-coordinate (which is defined to be $\perp$ to the alidade track) of each ball center. We note that zenith angles are not assumed to be 90°. We do however assume that their deviation from 90° is known a-priori with a given standard deviation, in the model ranging surveys. We choose this a-priori standard deviation to be 300 arc-seconds. The structural tilts of the weldments are expected to be below 150 arc-seconds, in service. The ball centers can be mounted initially so that their Z-coordinates are the same within 1 mm. A 300 arc-second tilt in zenith angle between the centers of balls at opposite ends of the elevation axle would correspond to a 7.5 cm difference in elevation of the centers, which is a loose constraint in terms of directly restricting the ball heights.

Measurement model simulations were made using the Star*Net least squares survey adjustment program (Starplus Software Inc., Oakland, CA). The configurations 1-3 of Fig.3 were modeled, with spacing of 52 meters between balls on opposite sides of the elevation axle. (This is not a critical spacing, simulations between 45 and 52 meters give similar results). Range station levelling was assumed to have standard error of 0.2mm. The standard error of laser ranging distances was assumed to be 0.15mm. The measurement configuration and lines of sight are shown in Fig. 4. Model adjustment files are given in Appendix II. The modeling results are summarized in Table 2.

Standard error of the horizontal bearing angle between opposite balls at the two ends of the elevation axle was 0.7 arc-second for the two ball configuration, 0.84 arc-second for the two ball pair configuration with each pair perpendicular to the elevation axis, and 1.3 arc-second for the four ball in-line configuration along a line paraxial to the elevation axis. Standard error of the vertical tilt angle between opposite axle end target centers was 2 arc-seconds for the first two configurations, and 3 arc-seconds for the in-line 4-target configuration.

Configuration 1 was the strongest. Configuration 2 was slightly weaker, and configuration 3 was significantly weaker. If power return turns out to be too low for employment of configuration 1, then configuration 2 appears to be an acceptable alternative.

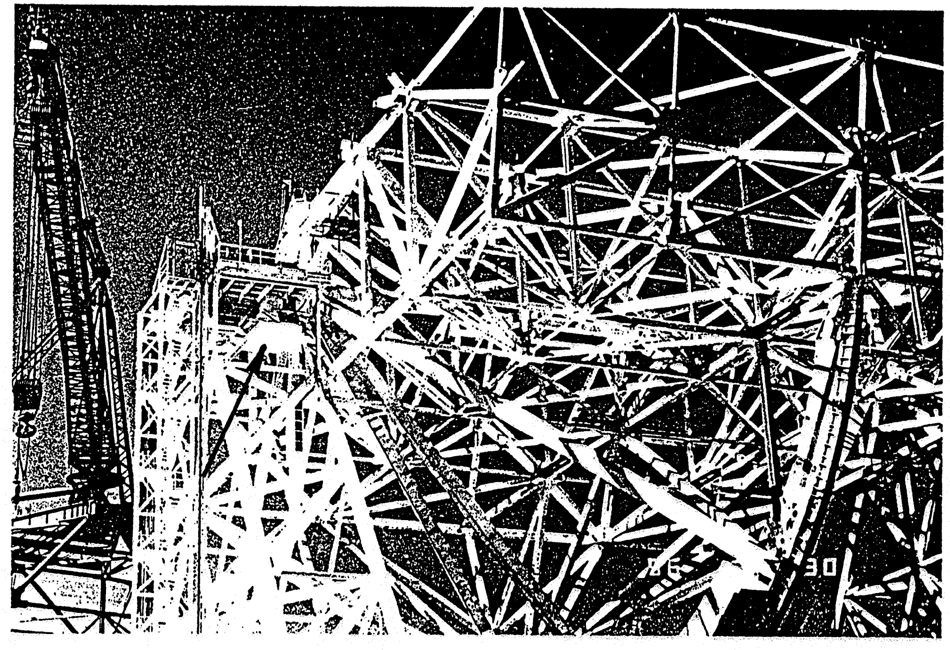

Figure 1. Bottom Surface Of An Elevation Bearing Support Weldment Viewed From A Rangefinder Station.

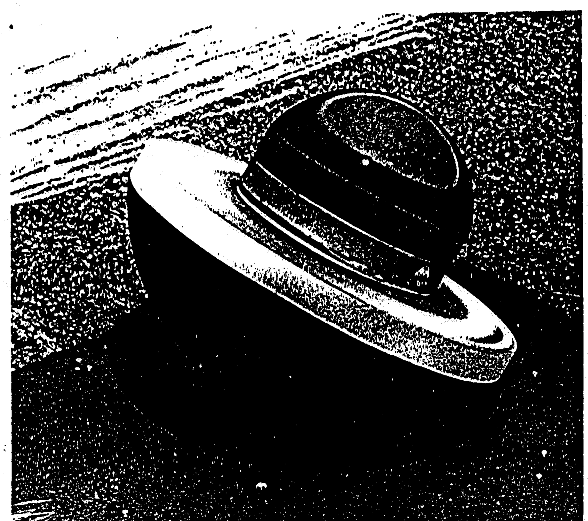

Figure 2. A Ball Retroreflector

TABLE 1. View Angles Of Ranging Stations From The Ball Reflectors.

Alidade Bearing:	0°	10°	20°	30°
Maximum Slant Range To Reflector (meter):	127.3	142.8	145.8	148.4
Minimum Slant Range To Reflector (meter):	110.9	108.2	106.1	110.9
Maximum View Angle From Reflector:	69.0°	71.4°	71.8°	72.1°
Minimum View Angle From Reflector:	65.8°	65.1°	64.6°	65.8°

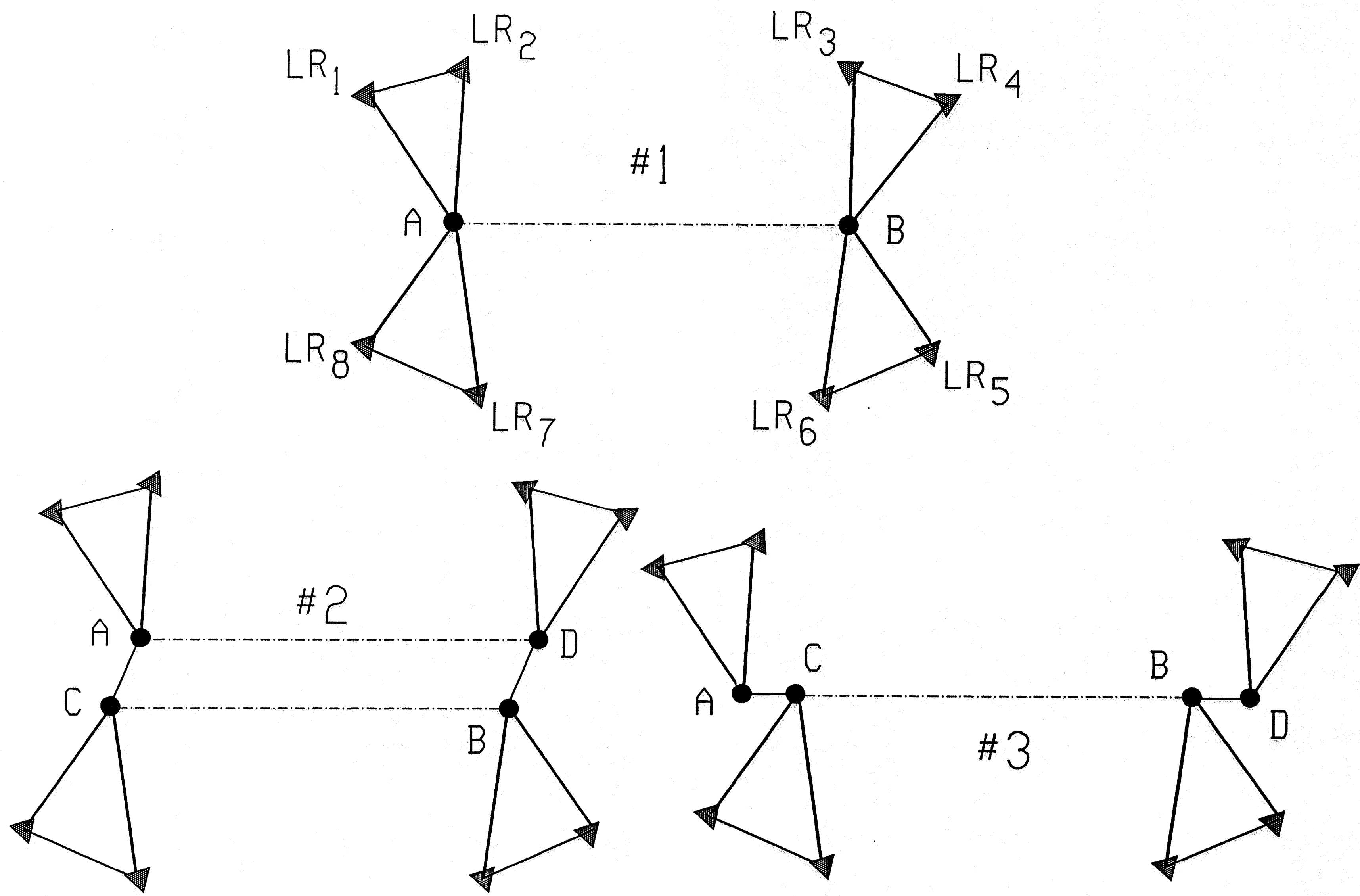

Figure 3. Bilateral Ranging Configurations Of Ball Retroreflectors.

TABLE 2. Measurement Model Adjustment Standard Errors.

Alidade Azimuth Angle:	Configuration #1 One reflector ball at each end of elevation axle.	Configuration #2 Two ball pairs, one at each end of elevation axle, line of each pair $\perp$ to axle.	Configuration #3 Four balls in-line, two at each end of elevation axle.
0°	$\sigma_{Bearing} = 0.68''$ $\sigma_{Tilt} = 1.69''$ $\sigma_{Z\_Ball} = 0.33, .29$ mm $\sigma_{Hor\_Dist} = 0.1\text{-}0.2$ mm	$\sigma_{Bearing} = 0.84''$ $\sigma_{Tilt} = 1.94''$ $\sigma_{Z\_Ball} = 0.38, .33$ mm $\sigma_{Hor\_Dist} = 0.2$ mm	$\sigma_{Bearing} = 1.31''$ $\sigma_{Tilt} = 2.96''$ $\sigma_{Z\_Ball} = 0.55, .54$ mm $\sigma_{Hor\_Dist} = 0.2\text{-}0.3$ mm
10°	$\sigma_{Bearing} = 0.63''$ $\sigma_{Tilt} =1.77''$ $\sigma_{Z\_Ball} = 0.35, .30$ mm $\sigma_{Hor\_Dist} = 0.1\text{-}0.2$ mm	$\sigma_{Bearing} = 0.84''$ $\sigma_{Tilt} = 2.0''$ $\sigma_{Z\_Ball} = 0.40, .33$ mm $\sigma_{Hor\_Dist} = 0.2$ mm	$\sigma_{Bearing} = 1.30''$ $\sigma_{Tilt} = 3.13''$ $\sigma_{Z\_Ball} = 0.61, .54$ mm $\sigma_{Hor\_Dist} = 0.2\text{-}0.3$ mm
20°	$\sigma_{Bearing} = 0.66''$ $\sigma_{Tilt} =1.74''$ $\sigma_{Z\_Ball} = 0.34,.30$ mm $\sigma_{Hor\_Dist} = 0.1\text{-}0.2$ mm	$\sigma_{Bearing} = 0.84''$ $\sigma_{Tilt} = 2.07''$ $\sigma_{Z\_Ball} = 0.40, .36$ mm $\sigma_{Hor\_Dist} = 0.2$ mm	$\sigma_{Bearing} = 1.28''$ $\sigma_{Tilt} = 2.82''$ $\sigma_{Z\_Ball} = 0.57, .46$ mm $\sigma_{Hor\_Dist} = 0.2\text{-}0.3$ mm
30°	$\sigma_{Bearing} = 0.63''$ $\sigma_{Tilt} = 1.91''$ $\sigma_{Z\_Ball} = 0.41, .28$ mm $\sigma_{Hor\_Dist} = 0.1\text{-}0.2$ mm	$\sigma_{Bearing} = 0.84''$ $\sigma_{Tilt} = 1.94''$ $\sigma_{Z\_Ball} =0.38, .33$ mm $\sigma_{Hor\_Dist} = 0.2$ mm	$\sigma_{Bearing} = 1.26''$ $\sigma_{Tilt} = 3.09''$ $\sigma_{Z\_Ball} = 0.63, .50$ mm $\sigma_{Hor\_Dist} = 0.2\text{-}0.3$ mm

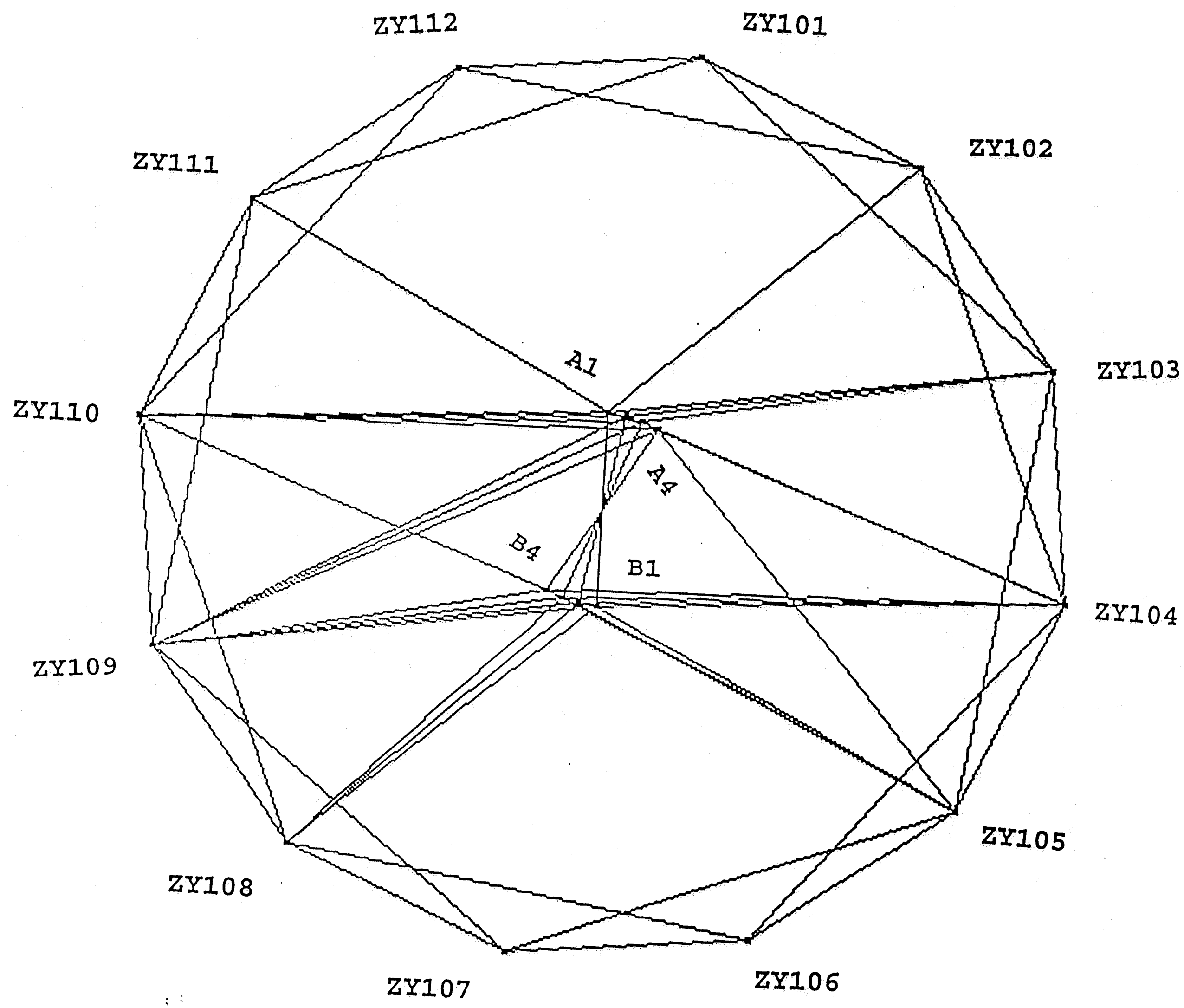

Figure 4. Ranging Measurement Sight Lines.

3 Possible Application To Telescope Pointing

GBT pointing will ultimately be done by observing a field of celestial radio sources, for calibration reference. Known source declinations and right ascensions will be converted to telescope horizon system azimuth and elevation local coordinates at time of observation. The corresponding telescope angle encoder azimuth and elevation readings at time of observation will then be fitted to a mathematical pointing model of the telescope. This model is a transformation which converts telescope horizon coordinates of an object to be observed to encoder setpoint values required to orient the telescope for observation of this object. The model contains a set of parameters, the pointing coefficients, which are obtained by some least squares procedure fitting the calibration source horizon coordinates to the encoder readouts at time of observation. After the pointing coefficients have been fitted, the observation measurement residuals are examined. If the residuals are acceptably low, the model is adopted as an algorithm to command the encoder output setpoints for driving the telescope to look at a celestial radio source. If the residuals are unacceptably large the model is modified and refitted, until the residuals are acceptable.

The pointing model is fitted initially and used subsequently for under telecope operating conditions which can be significantly different from those encountered during pointing model determination. The accepted model might not include all of the important variables encountered during telescope operations, for example thermal expansion gradients. In such a case the model might need correction.

Laser ranging is not ordinarily needed for telescope pointing, after a pointing model has been chosen, pointing coefficients fitted to a suitable field of celestial radio source objects have been obtained, and the model has been refined to the degree that the model's residuals are acceptably small.

However, in the early stages of telescope commisioning the telescope must acquire and track calibration sources before a pointing model has been fitted. During this time, the laser metrology system may be of aid in pointing the telescope. The horizontal bearing and vertical tilt angles of the mean axial line of ball target centers will likely be at small constant offset from the elevation axis defined by the line through elevation bearing centers. Shifts of the target mean line of centers are expected to be close to those of the elevation axis. The mean line of target centers can be an effective estimator for determination of elevation axis spatial orientation.

Certain motions of the antenna tipping structure and alidade, due to temperature gradients, and wind and gravity loading, can occur during telescope operation, which do not change the rotation of the antenna azimuth and elevation encoders, and are not sensed by these devices. These motions affect telescope pointing and they can be observed by laser ranging. Information about those motions, generated by laser ranging, and which supplements the angle encoder readout information, can be incorporated into the pointing command structure of the telescope.

4 Discussion

Survey modeling indicates that laser ranging of ball retroreflector targets under the GBT elevation bearing weldments could provide useful information to assist with pointing of the GBT. A structure weighing about forty to seventy pounds would have to be fastened rigidly beneath each weldment, and oriented precisely with respect to the bearing axis, upon installation. Installation mounts and procedures would have to be developed to do this. After installation of the targets, their initial positions would have to be surveyed, to determine the mean axial line of target centers relative to the bearing center defined elevation axis.

If the targets could be in place by early summer 1997, laser rangefinders could monitor structural deformations of the alidade and motions of the elevation axis during lifting of the heavy main reflector backup sections onto the box structure. The monitor information might be used to flag occurrence of possible hazard situations during the lifting.

Over a longer term, information on elevation axis orientation obtained by laser ranging can be collected and data based to allow the option of later analysis of elevation axis motions during telescope operation, for the purpose of improving the telescope pointing model and also for possible trend analysis to indicate long term changes in the telescope geometry and behavior.

Bibliography

[1] Lee King. Private Note to D. Parker, February 27, 1997. Re: Elevation Bearing Measurements.

[2] M.A. Goldman. *Ball Retroreflector Optics.* GBT Memo 148. March 23, 1996.

Appendix I. Concerning Static Determinism Of 4-Target Reflector Configurations.

Assume that laser ranging stations LR_1 and LR_2 are ranging ball retroreflector A and stations LR_3 and LR_4 are ranging ball retroreflector C, which are mounted at the same end of the elevation axle. Assume that the true range of A from LR_1 is r_1 and from LR_2 is r_2, and the true range of C from LR_3 is r_3 and from LR_4 is r_4. Let D_{12} be the distance between the scan points of stations LR_1 and LR_2, and D_{34} be the distance between the scan points of stations LR_3 and $LR4$. The scan centers of the four ranging stations lie close to a horizontal plane, to within a millimeter. The relevant geometry is shown in Fig. 5.

The center of ball A is constrained to be one vertex of a triangle whose sides are r_1, r_2 and D_{12}, and whose other vertices are the scan centers of LR_1 and LR_2. The locus of all such points in space is a circle, C_A, lying in a plane $\perp$ to the line of scan centers of LR_1 and LR_2. The center point, O_{12}, of this circle lies on the line of scan centers LR_1-LR_2. Call h_{12} the radius of this circle. Similarly the locus of possible positions of the center of ball reflector C lies on a circle, C_C, of radius h_{34}, whose center, O_{34}, lies on the line of scan centers LR_3-LR_4, and whose plane is $\perp$ to the line LR_3-LR_4.

The centers of ball reflectors A and C are mounted at an accurately known distance D_{AC} from one another. This constrains the line segment $\overline{AC}$ joining the centers of reflectors A and C to have its ends on the circles C_A and C_C. The constraint that the reflector centers are at fixed distance D_{AC} from one another constrains them to lie on bounded arcs of C_A and C_C but does not spatially fix the line segment $\overline{AC}$, which is free to slide within a developable surface patch joining the bounded arcs.

The bounded arcs mentioned above are defined in the following manner. The locus of end points of line segments of length D_{AC} , whose nearer end lies at distance h_{12} from O_{12} is a closed hollow ball, HB_A , centered at O_{12}, whose inner radius is h_{12} and whose outer radius is $h_{12} + D_{AC}$. The ball reflector center point C must lie in the interior of or on the boundary spheres of HB_A. The point C must also lie on the circle C_C , and also lie at positive elevation. The point C is then constrained to lie on the arc which is the positive elevation intersection of circle C_C with hollow ball HB_A . Similarly, the ball reflector center point A must lie both on circle C_A and within or on a hollow ball HB_C whose inner radius is h_{34} and outer radius is $h_{34} + D_{AC}$ and is centered at O_{34} .

The laser ranges r_1 to r_4 only constrain the reflector centers to lie on the arcs defined above. It does not fix them. If, however, a new geometric constraint is introduced independent of laser ranging, that line segment $\overline{AC}$ is horizontal, then there is a unique *horizontal* segment $\overline{AC}$ of length D_{AC} , at positive elevation, which joins circles C_A and C_C . This additional constraint is sufficient to fix points A and C . The constraint is obtained physically by the fact that the bottom weldment surfaces are nearly horizontal and the ball centers of nearby reflectors will mount at the same distance below their common weldment surface.

Similar considerations hold for balls B and D, which mount at the other end of the elevation axle.

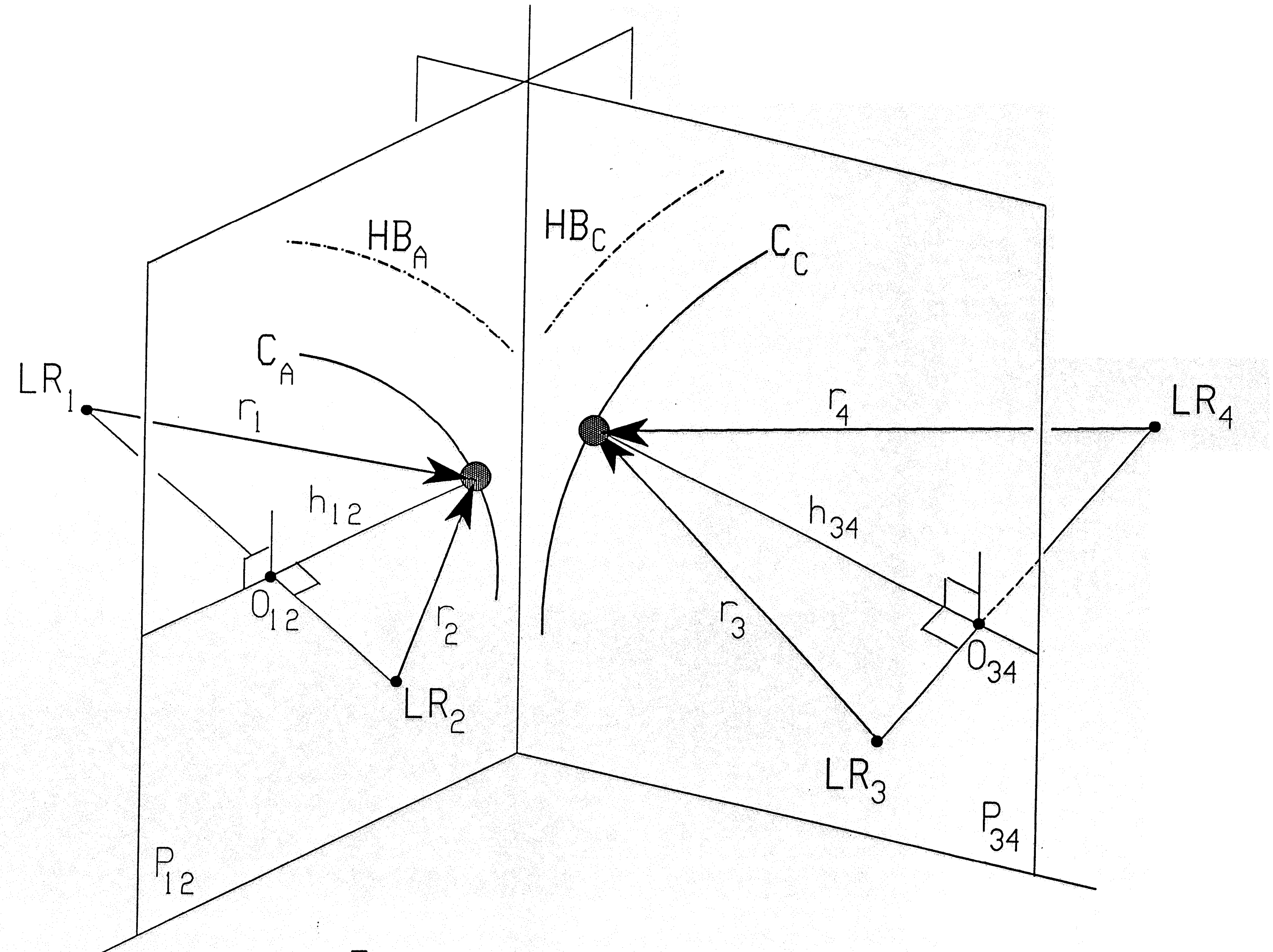

Figure 5. Ball Center Loci.

Appendix II. Models Of Adjusted Laser Ranging Surveys.

Two models of laser ranging measurement of sub-weldment ball retroreflector positions are presented. One model is that of two reflectors, one under each weldment; the balls look directly downwards vertically; each reflector is ranged by four stations (configuration 1). This is a statically determinate model. The incidence angles to the balls, from the stations, lie between 65.8° and 71.8°. If adequate laser return signal can be obtained, this will be an optimal measurement configuration.

The other model is that of two pair of balls under each weldment (configuration 2); the line of centers of the two balls on each end of the elevation axle is oriented perpendicular to the elevation axle, and is horizontal to 300 arc-seconds standard error. Input data for this model is laser range information supplemented by additional directional and angle restraints derived from the assumption that the reflectors are mounted on essentially horizontal weldment surfaces at nearly fixed position and orientation to one another. The ball centers are assumed to be precisely 0.25 meters apart. This distance is near to the smallest ball center spacing which allows the balls to be fixed rigidly in a common housing, with one ball facing right and the other facing left, and allows the housing to be mounted on a weldment so the line of ball centers is $\perp$ to the elevation axis.

File: ELBEBALL.DAT STAR*NET Project: ELBEBALL

M.A. Goldman March 04, 1997 Version 5.3

This is a data file for preanalysis simulating a set of measurements
from ground laser ranging stations to TWO cat's eye ball retroreflectors
mounted approximately 101 inches below the upper weldment deck, one ball
at each end of the elevation bearing. The pair of reflector balls will be
represented by ball pairs at 10 degree azimuth increments clockwise (ABALL
moves Eastward), to simulate rotation of the alidade.

Ranging station scan point horizontal coordinates will be assumed known
a-priori to a standard error of 1mm. We use a free adjustment, assuming
that no ground station scan points are fixed, but that the ground
station distances to first and second nearest neighbor scan points are
ranged on one another to 0.15 mm. THIS IS A FREE ADJUSTMENT, WITH NO
FIXED RANGING STATION SCAN POINTS.

The Z-coordinate of each station scan point is assumed to be known
a-priori to 0.20 mm standard error. (This is found by a levelling
survey, with a small correction for earth curvature).

Reflector ball point X and Y coordinates are assumed to be known only
to 1 meter, a-priori, and are to be calculated from this survey model
preanalysis. The ball Z-coordinate is assumed known, a-priori, to 0.30 m.

Each ball center Z coordinate is assumed, a-priori, to be
1900" - 46" - 91" -10" = 1754" (44.526 meter) with 0.30 meter
standard error.

The 2 ball centers are assumed, a-priori, to be 52 meter apart.

Ranges to ball centers are assumed measured to 0.15mm standard
error (0.006").

Each horizontal coordinate of ranging stations is assumed
to have 1 mm std error, before station-to-station ranging.

EACH BALL IS ASSUMED TO SEE TWO RANGING STATIONS TO ITS RIGHT AND
TWO STATIONS TO ITS LEFT.

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#  ENTER LASER RANGING GROUND-STATION SCAN POINT COORDINATES   (METERS)

#    POINT       X           Y           Z          Standard Error
#             (EAST)     (NORTH)                   s(X)     s(Y)       s(Z)

C    ZY101     018.4894    118.5670     0.0       0.001    0.001      0.0002
C    ZY102     075.2958    093.4370     0.0       0.001    0.001      0.0002
C    ZY103     111.9268    043.2712     0.0       0.001    0.001      0.0002
C    ZY104     118.5670   -018.4894     0.0       0.001    0.001      0.0002
C    ZY105     093.4374   -075.2958     0.0       0.001    0.001      0.0002
C    ZY106     043.2712   -111.9268     0.0       0.001    0.001      0.0002
C    ZY107    -018.4894   -118.5670     0.0       0.001    0.001      0.0002
C    ZY108    -075.2958   -093.4374     0.0       0.001    0.001      0.0002
C    ZY109    -111.9268   -043.2712     0.0       0.001    0.001      0.0002
C    ZY110    -118.5670    018.4894     0.0       0.001    0.001      0.0002
C    ZY111    -093.4374    075.2958     0.0       0.001    0.001      0.0002
C    ZY112    -043.2712    111.9268     0.0       0.001    0.001      0.0002

#  ENTER ELEVATION BEARING BALL REFLECTOR  COORDINATES  (METERS)

C   ABALL1      00.0000     26.0000      45.7          1.0       1.0        0.3
C   BBALL1      00.0000    -26.0000      45.7          1.0       1.0        0.3
C   ABALL2      04.5149     25.6050      45.7          1.0       1.0        0.3
C   BBALL2     -04.5149    -25.6050      45.7          1.0       1.0        0.3
C   ABALL3      08.8925     24.4320      45.7          1.0       1.0        0.3
C   BBALL3     -08.8925    -24.4320      45.7          1.0       1.0        0.3
C   ABALL4      13.0000     22.5167      45.7          1.0       1.0        0.3
C   BBALL4     -13.0000    -22.5167      45.7          1.0       1.0        0.3

#  ENTER LASER RANGE TO BALL CENTER STD ERRORS   (METERS)

D       ZY102-ABALL1      0.00015
D       ZY103-ABALL1      0.00015
D       ZY111-ABALL1      0.00015
D       ZY110-ABALL1      0.00015
D       ZY104-BBALL1      0.00015
D       ZY105-BBALL1      0.00015
D       ZY108-BBALL1      0.00015
D       ZY109-BBALL1      0.00015


D       ZY103-ABALL2      0.00015
D       ZY104-ABALL2      0.00015
D       ZY110-ABALL2      0.00015
D       ZY109-ABALL2      0.00015
D       ZY105-BBALL2      0.00015
D       ZY104-BBALL2      0.00015
D       ZY108-BBALL2      0.00015
D       ZY109-BBALL2      0.00015
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D        ZY103-ABALL3       0.00015
D        ZY104-ABALL3       0.00015
D        ZY110-ABALL3       0.00015
D        ZY109-ABALL3       0.00015
D        ZY105-BBALL3       0.00015
D        ZY104-BBALL3       0.00015
D        ZY108-BBALL3       0.00015
D        ZY109-BBALL3       0.00015

D        ZY104-ABALL4       0.00015
D        ZY105-ABALL4       0.00015
D        ZY109-ABALL4       0.00015
D        ZY110-ABALL4       0.00015
D        ZY104-BBALL4       0.00015
D        ZY105-BBALL4       0.00015
D        ZY109-BBALL4       0.00015
D        ZY110-BBALL4       0.00015

#    ENTER ASSUMED RANGE STATION TO STATION DISTANCE STANDARD ERROR (METER)

D        ZY111-ZY101        0.00015
D        ZY112-ZY101        0.00015
D        ZY112-ZY102        0.00015
D        ZY101-ZY102        0.00015
D        ZY101-ZY103        0.00015
D        ZY102-ZY103        0.00015
D        ZY102-ZY104        0.00015
D        ZY103-ZY104        0.00015
D        ZY103-ZY105        0.00015
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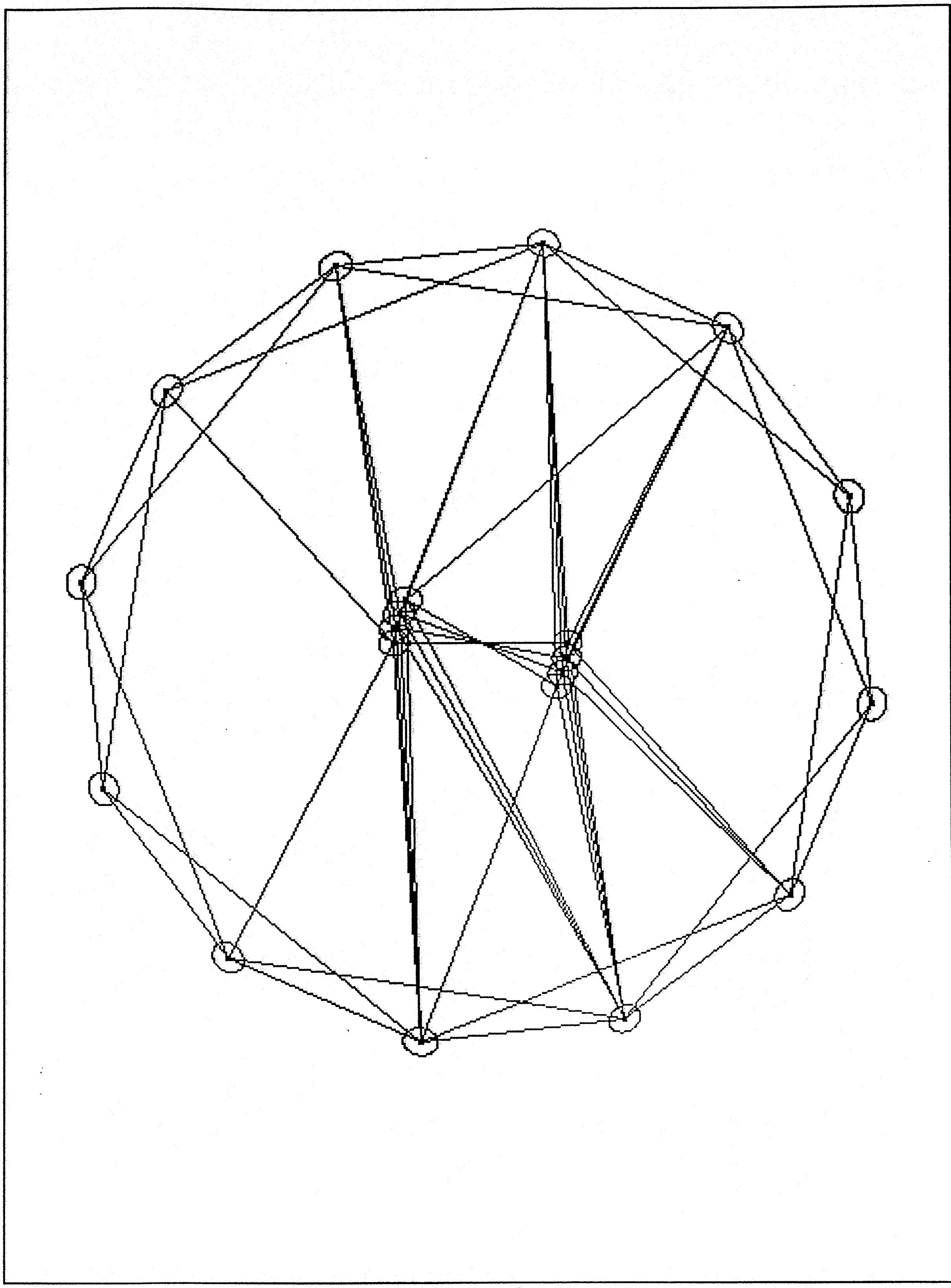
D        ZY110-ZY111        0.00015
D        ZY110-ZY112        0.00015
D        ZY111-ZY112        0.00015

#     ENTER  DUMMY ASSUMED BALL TO BALL DISTANCE STANDARD ERROR OF 1 METER
#      TO GET RELATIVE BEARING OUTPUT INFORMATION.

D       ABALL1-BBALL1       1.0
D       ABALL2-BBALL2       1.0
D       ABALL3-BBALL3       1.0
D       ABALL4-BBALL4       1.0
```



STAR*NET Adjustment Program
Version 5.0444

Licensed for Use by National Radio Astronomy Observatory
Serial Number 20649
Run Date : Tue Mar 04 1997 10:14:30

Summary of Files Used

```
Project Directory             C:\STAR
Input Data File               ELBEBRL.DAT
Output Listing (This File)    ELBEBRL.LST  (Version 5.3)
Coordinates                   ELBEBRL.PTS
Project Parameters            ELBEBRL.PRJ
Error Log                     ELBEBRL.ERR
Plot File                     ELBEBRL.SPL
```

Adjustment Options

```
STAR*NET Run Mode                      : Preanalysis
Type of Adjustment                     : 3D
Input Order for Coordinates            : X,Y,Z
Coordinate System                      : LOCAL
Project Scale Factor                   : 1.00000000
Linear Units; Angular Units            : Meters; DMS
Input Order for Angle Stations         : At-From-To
Max Iterations; Convergence Limit      : 50; 0.0001

Correct Zeniths for Curve & Refract    : No
Adjust 3D Obs for Vert Divergence      : No
3D Data Input Mode                     : Slope/Zenith
Earth Radius                           : 6372161.544 Meters
Coefficient of Refraction              : 0.070
```

Default Instrument Standard Error Settings

```
Distances ( Constant )                 :     0.0001000 Meters
Distances ( PPM )                      :     0.0000010
Angles                                 :     1.4140000 Seconds
Directions                             :     1.0000000 Seconds
Azimuth / Bearings                     :     2.0000000 Seconds
Zeniths                                :     2.0000000 Seconds
Elevation Differences ( Constant )     :     0.0001000 Meters
Elevation Differences ( PPM )          :     0.0000010
Centering Error Instrument             :     0.0000100 Meters
Centering Error Target                 :     0.0000100 Meters
```

Summary of Unadjusted Input Observations

Number of Stations (Meters) = 20

Partially Fixed	X SE-X	Y SE-Y	Z SE-Z	Description
ZY101	18.4894	118.5670	0.0000	
	0.0010	0.0010	0.0002	
ZY102	75.2958	93.4370	0.0000	
	0.0010	0.0010	0.0002	
ZY103	111.9268	43.2712	0.0000	
	0.0010	0.0010	0.0002	
ZY104	118.5670	-18.4894	0.0000	
	0.0010	0.0010	0.0002	
ZY105	93.4374	-75.2958	0.0000	
	0.0010	0.0010	0.0002	
ZY106	43.2712	-111.9268	0.0000	
	0.0010	0.0010	0.0002	
ZY107	-18.4894	-118.5670	0.0000	
	0.0010	0.0010	0.0002	
ZY108	-75.2958	-93.4374	0.0000	
	0.0010	0.0010	0.0002	
ZY109	-111.9268	-43.2712	0.0000	
	0.0010	0.0010	0.0002	
ZY110	-118.5670	18.4894	0.0000	
	0.0010	0.0010	0.0002	
ZY111	-93.4374	75.2958	0.0000	
	0.0010	0.0010	0.0002	
ZY112	-43.2712	111.9268	0.0000	
	0.0010	0.0010	0.0002	
ABALL1	0.0000	26.0000	45.7000	
	1.0000	1.0000	0.3000	
BBALL1	0.0000	-26.0000	45.7000	
	1.0000	1.0000	0.3000	
ABALL2	4.5149	25.6050	45.7000	
	1.0000	1.0000	0.3000	
BBALL2	-4.5149	-25.6050	45.7000	
	1.0000	1.0000	0.3000	
ABALL3	8.8925	24.4320	45.7000	
	1.0000	1.0000	0.3000	
BBALL3	-8.8925	-24.4320	45.7000	
	1.0000	1.0000	0.3000	
ABALL4	13.0000	22.5167	45.7000	
	1.0000	1.0000	0.3000	
BBALL4	-13.0000	-22.5167	45.7000	
	1.0000	1.0000	0.3000	

Number of Distance Observations (Meters) = 60

From	To	Obs Dist	StdErr	HI	HT	Flags
ZY102	ABALL1	110.9310	0.0001	0.000	0.000	S
ZY103	ABALL1	122.1245	0.0001	0.000	0.000	S
ZY111	ABALL1	115.1048	0.0001	0.000	0.000	S
ZY110	ABALL1	127.2911	0.0001	0.000	0.000	S
ZY104	BBALL1	127.2911	0.0001	0.000	0.000	S
ZY105	BBALL1	115.1048	0.0001	0.000	0.000	S

ZY108	BBALL1	110.9313	0.0001	0.000	0.000	S
ZY109	BBALL1	122.1245	0.0001	0.000	0.000	S
ZY103	ABALL2	118.0589	0.0001	0.000	0.000	S
ZY104	ABALL2	130.5400	0.0001	0.000	0.000	S
ZY110	ABALL2	131.4849	0.0001	0.000	0.000	S
ZY109	ABALL2	142.7974	0.0001	0.000	0.000	S
ZY105	BBALL2	118.9635	0.0001	0.000	0.000	S
ZY104	BBALL2	131.4849	0.0001	0.000	0.000	S
ZY108	BBALL2	108.1650	0.0001	0.000	0.000	S
ZY109	BBALL2	118.0589	0.0001	0.000	0.000	S
ZY103	ABALL3	114.2780	0.0001	0.000	0.000	S
ZY104	ABALL3	126.3299	0.0001	0.000	0.000	S
ZY110	ABALL3	135.5350	0.0001	0.000	0.000	S
ZY109	ABALL3	145.8407	0.0001	0.000	0.000	S
ZY105	BBALL3	123.0732	0.0001	0.000	0.000	S
ZY104	BBALL3	135.5350	0.0001	0.000	0.000	S
ZY108	BBALL3	106.1114	0.0001	0.000	0.000	S
ZY109	BBALL3	114.2780	0.0001	0.000	0.000	S
ZY104	ABALL4	122.1245	0.0001	0.000	0.000	S
ZY105	ABALL4	134.6327	0.0001	0.000	0.000	S
ZY109	ABALL4	148.4023	0.0001	0.000	0.000	S
ZY110	ABALL4	139.3362	0.0001	0.000	0.000	S
ZY104	BBALL4	139.3362	0.0001	0.000	0.000	S
ZY105	BBALL4	127.2912	0.0001	0.000	0.000	S
ZY109	BBALL4	110.9313	0.0001	0.000	0.000	S
ZY110	BBALL4	122.1245	0.0001	0.000	0.000	S
ZY111	ZY101	120.0000	0.0001	0.000	0.000	S
ZY112	ZY101	62.1165	0.0001	0.000	0.000	S
ZY112	ZY102	120.0000	0.0001	0.000	0.000	S
ZY101	ZY102	62.1167	0.0001	0.000	0.000	S
ZY101	ZY103	120.0000	0.0001	0.000	0.000	S
ZY102	ZY103	62.1163	0.0001	0.000	0.000	S
ZY102	ZY104	119.9996	0.0001	0.000	0.000	S
ZY103	ZY104	62.1165	0.0001	0.000	0.000	S
ZY103	ZY105	120.0000	0.0001	0.000	0.000	S
ZY104	ZY105	62.1165	0.0001	0.000	0.000	S
ZY104	ZY106	120.0000	0.0001	0.000	0.000	S
ZY105	ZY106	62.1166	0.0001	0.000	0.000	S
ZY105	ZY107	120.0000	0.0001	0.000	0.000	S
ZY106	ZY107	62.1165	0.0001	0.000	0.000	S
ZY106	ZY108	120.0000	0.0001	0.000	0.000	S
ZY107	ZY108	62.1165	0.0001	0.000	0.000	S
ZY107	ZY109	120.0000	0.0001	0.000	0.000	S
ZY108	ZY109	62.1166	0.0001	0.000	0.000	S
ZY108	ZY110	120.0000	0.0001	0.000	0.000	S
ZY109	ZY110	62.1165	0.0001	0.000	0.000	S
ZY109	ZY111	120.0000	0.0001	0.000	0.000	S
ZY110	ZY111	62.1165	0.0001	0.000	0.000	S
ZY110	ZY112	120.0000	0.0001	0.000	0.000	S
ZY111	ZY112	62.1166	0.0001	0.000	0.000	S
ABALL1	BBALL1	52.0000	0.0001	0.000	0.000	S
ABALL2	BBALL2	52.0000	0.0001	0.000	0.000	S
ABALL3	BBALL3	52.0000	0.0001	0.000	0.000	S
ABALL4	BBALL4	52.0001	0.0001	0.000	0.000	S

Adjusted Bearings and Horizontal Distances (Meters)

From	To	Bearing	Distance	Relative BgErr	Relative DisErr	DistPrec (PPM)
ZY102	ABALL1	S48-09-05.39W	101.0802	0.64	0.0002	1
ZY103	ABALL1	S81-13-40.76W	113.2515	0.65	0.0002	1
ZY111	ABALL1	S62-11-05.00E	105.6439	0.63	0.0002	1
ZY110	ABALL1	N86-22-31.64E	118.8046	0.63	0.0002	1
ZY104	BBALL1	S86-22-31.64W	118.8046	0.63	0.0001	1
ZY105	BBALL1	N62-11-05.00W	105.6439	0.63	0.0002	1
ZY108	BBALL1	N48-09-04.78E	101.0805	0.64	0.0002	1
ZY109	BBALL1	N81-13-40.76E	113.2515	0.64	0.0001	1
ZY103	ABALL2	S80-39-36.34W	108.8550	0.67	0.0002	1
ZY104	ABALL2	N68-51-45.67W	122.2792	0.62	0.0002	1
ZY110	ABALL2	N86-41-28.70E	123.2874	0.64	0.0001	1
ZY109	ABALL2	N59-23-43.24E	135.2871	0.60	0.0002	1
ZY105	BBALL2	N63-06-05.42W	109.8355	0.62	0.0002	1
ZY104	BBALL2	S86-41-28.70W	123.2874	0.63	0.0001	1
ZY108	BBALL2	N46-13-06.88E	98.0366	0.65	0.0002	1
ZY109	BBALL2	N80-39-36.34E	108.8550	0.67	0.0001	1
ZY103	ABALL3	S79-38-17.78W	104.7425	0.68	0.0002	1
ZY104	ABALL3	N68-37-37.13W	117.7741	0.63	0.0002	1
ZY110	ABALL3	N87-19-50.18E	127.5980	0.63	0.0001	1
ZY109	ABALL3	N60-44-06.54E	138.4956	0.60	0.0001	1
ZY105	BBALL3	N63-34-12.01W	114.2739	0.61	0.0002	1
ZY104	BBALL3	S87-19-50.18W	127.5980	0.62	0.0001	1
ZY108	BBALL3	N43-53-56.77E	95.7661	0.66	0.0002	1
ZY109	BBALL3	N79-38-17.78E	104.7425	0.68	0.0001	1
ZY104	ABALL4	N68-46-19.21W	113.2515	0.67	0.0002	1
ZY105	ABALL4	N39-25-57.44W	126.6391	0.60	0.0002	1
ZY109	ABALL4	N62-13-41.48E	141.1905	0.60	0.0002	1
ZY110	ABALL4	N88-14-48.15E	131.6286	0.64	0.0001	1
ZY104	BBALL4	S88-14-48.15W	131.6286	0.64	0.0001	0
ZY105	BBALL4	N63-37-28.46W	118.8047	0.64	0.0001	1
ZY109	BBALL4	N78-09-04.99E	101.0805	0.70	0.0002	1
ZY110	BBALL4	S68-46-19.21E	113.2515	0.69	0.0001	1
ZY111	ZY101	N68-51-48.11E	120.0000	0.68	0.0001	0
ZY112	ZY101	N83-51-48.27E	62.1165	0.88	0.0001	1
ZY112	ZY102	S81-08-11.26E	120.0000	0.68	0.0001	0
ZY101	ZY102	S66-08-10.94E	62.1167	1.04	0.0001	1
ZY101	ZY103	S51-08-12.00E	120.0000	0.68	0.0001	0
ZY102	ZY103	S36-08-12.73E	62.1163	0.72	0.0001	1
ZY102	ZY104	S21-08-12.13E	119.9996	0.59	0.0001	0
ZY103	ZY104	S06-08-11.73E	62.1165	0.73	0.0001	1
ZY103	ZY105	S08-51-48.06W	120.0000	0.59	0.0001	0
ZY104	ZY105	S23-51-47.84W	62.1165	0.65	0.0001	1
ZY104	ZY106	S38-51-48.00W	120.0000	0.65	0.0001	0
ZY105	ZY106	S53-51-48.06W	62.1166	1.02	0.0001	1
ZY105	ZY107	S68-51-48.11W	120.0000	0.66	0.0001	0
ZY106	ZY107	S83-51-48.27W	62.1165	0.85	0.0001	1
ZY106	ZY108	N81-08-11.94W	120.0000	0.66	0.0001	0
ZY107	ZY108	N66-08-12.16W	62.1165	1.01	0.0001	1
ZY107	ZY109	N51-08-12.00W	120.0000	0.65	0.0001	0
ZY108	ZY109	N36-08-11.94W	62.1166	0.67	0.0001	1
ZY108	ZY110	N21-08-11.89W	120.0000	0.59	0.0001	0
ZY109	ZY110	N06-08-11.73W	62.1165	0.69	0.0001	1
ZY109	ZY111	N08-51-48.06E	120.0000	0.58	0.0001	0

ZY110	ZY111	N23-51-47.84E	62.1165	0.71	0.0001	1
ZY110	ZY112	N38-51-48.00E	120.0000	0.68	0.0001	0
ZY111	ZY112	N53-51-48.06E	62.1166	1.03	0.0001	1
ABALL1	BBALL1	S00-00-00.00E	52.0000	0.68	0.0001	1
ABALL2	BBALL2	S10-00-00.37W	52.0000	0.63	0.0001	1
ABALL3	BBALL3	S19-59-59.85W	52.0000	0.66	0.0001	1
ABALL4	BBALL4	S29-59-59.84W	52.0001	0.63	0.0001	1

Error Propagation

Station Coordinate Standard Deviations

Station	X	Y	Z
ZY101	0.00041	0.00036	0.00020
ZY102	0.00039	0.00036	0.00020
ZY103	0.00034	0.00040	0.00019
ZY104	0.00032	0.00041	0.00019
ZY105	0.00036	0.00038	0.00020
ZY106	0.00040	0.00036	0.00020
ZY107	0.00041	0.00035	0.00020
ZY108	0.00038	0.00036	0.00020
ZY109	0.00033	0.00040	0.00019
ZY110	0.00033	0.00041	0.00019
ZY111	0.00037	0.00038	0.00020
ZY112	0.00040	0.00037	0.00020
ABALL1	0.00031	0.00036	0.00033
BBALL1	0.00031	0.00036	0.00029
ABALL2	0.00031	0.00038	0.00035
BBALL2	0.00031	0.00037	0.00030
ABALL3	0.00031	0.00038	0.00034
BBALL3	0.00031	0.00037	0.00030
ABALL4	0.00031	0.00039	0.00041
BBALL4	0.00031	0.00039	0.00028

Station Coordinate Error Ellipses
Confidence Region = 95%

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis
ZY101	0.00101	0.00087	102-29
ZY102	0.00102	0.00080	125-55
ZY103	0.00101	0.00080	157-04
ZY104	0.00101	0.00077	10-05
ZY105	0.00101	0.00078	41-15
ZY106	0.00101	0.00086	65-57
ZY107	0.00101	0.00086	101-45
ZY108	0.00101	0.00079	126-25
ZY109	0.00101	0.00077	157-20
ZY110	0.00101	0.00079	10-55
ZY111	0.00102	0.00079	41-34
ZY112	0.00101	0.00088	65-32
ABALL1	0.00090	0.00075	172-18
BBALL1	0.00089	0.00075	172-56
ABALL2	0.00092	0.00074	171-09
BBALL2	0.00092	0.00075	170-58
ABALL3	0.00093	0.00074	169-55
BBALL3	0.00092	0.00075	169-51
ABALL4	0.00096	0.00075	178-52
BBALL4	0.00095	0.00075	0-18

Elapsed Time = 00:00:01

File: ELBEBRL.DAT STAR*NET Project: ELBEBRL

M.A. Goldman March 04, 1997 Version 4.8

```
#      This is a data file for preanalysis simulating a set of measurements
#  from certain ground laser ranging stations to TWO PAIRS of ball retro-
#  reflectors, each pair mounted approximately 101 inches below the alidade
#  structure upper weldment deck at each end of the elevation bearing.
#    The pairs of elevation bearing balls will be represented by quadruples
#  of balls at 10 degree azimuth increments clockwise (ABALL and CBALL move
#  Eastward), to simulate rotation of the alidade.
#
#    The pair of balls mounted on a common fixture on each end of the
#  elevation shaft is assumed to be fixtured so that the line of ball
#  of ball centers will be oriented perpendicular to the shaft, to 1/12
#  degree standard error (300 arc seconds).
#
#      A balls and C balls are at one end of the elevation shaft.  B and D
#  balls are at the other end of the shaft. The A and D balls are viewed
#  from one side of the elevation shaft (the left side as seen from the A
#  ball, looking along the elevation shaft).  The B and C balls are viewed
#  by stations on the other side of the elevation shaft.
#
#
#  Ranging station scan point horizontal coordinates will be assumed known
#  a-priori to a standard error of 1mm. We use a free adjustment, assuming
#  that no ground station scan points are fixed, but that the ground station
#  distances to first and second nearest neighbor scan points are ranged on
#  one another to 0.15 mm.  THIS IS A FREE ADJUSTMENT, WITH NO FIXED RANGING
#  STATION SCAN POINTS.

#  The Z-coordinate of each station scan point is assumed to be known
#  a-priori to 0.20 mm standard error.  (This is found by a levelling
#  survey, with a small correction for earth curvature).

#  Each ball center  Z  coordinate is assumed, a-priori, to be
#  1900" - 46" - 91" -10"  =  1754"   (44.526 meter), with 0.30
#  meter standard error.


#   A and B Balls are assumed a-priori to be 52 meter apart.
#   C and D Balls are assumed a-priori to be 52 meter apart.

#   The distance between the A and C balls is assumed to be 0.25
#   meters and measured accurately in the laboratory to 50 um. This is
#   a distance fixed by their mounting on a common fixture for
#   installation under the weldment. The distance is also 0.25 meter
#   between the B and D balls, measured to 50 um.
```

```
#   The quadruplet of balls corresponding to a particular alidade
#   azimuth will be called  ABALL(n), BBALL(n), CBALL(n), DBALL(n).


#   Version 4.4.  THIS MODEL ASSUMES A STANDARD ERROR OF 0.20 MM ON
#   THE Z-COORDINATE OF EACH RANGING STATION.


#   Ball ranges are assumed measured to 150 um  standard error (0.006").


#   In this model we use the fact that the balls almost lie in a horizontal
#   plane, and can assume that their zenith angles (viewed from one another)
#   to vertical are nearly 90 degrees. (We assume 1/12 degree Standard Error)

#       We assume that we can orient the ball mounting fixtures during
#   installation on the alidade so the angles B-A-C and A-B-D are known
#   (by proper orientational setting during installation and subsequent
#   measurement) to a standard error of 1/12 degree.
#      These angles should be each be set to 90 degrees on installation.
#   That is, the ball lines AB and AC, and AB and BD should cross at
#   90 degrees.


#  ENTER LASER RANGING GROUND-STATION SCAN POINT COORDINATES   (METERS)

#    POINT       X          Y           Z           Standard Error
#              (EAST)    (NORTH)                  s(X)      s(Y)       s(Z)

C    ZY101    018.4894   118.5670     0.0      0.001     0.001      0.0002
C    ZY102    075.2958   093.4370     0.0      0.001     0.001      0.0002
C    ZY103    111.9268   043.2712     0.0      0.001     0.001      0.0002
C    ZY104    118.5670  -018.4894     0.0      0.001     0.001      0.0002
C    ZY105    093.4374  -075.2958     0.0      0.001     0.001      0.0002
C    ZY106    043.2712  -111.9268     0.0      0.001     0.001      0.0002
C    ZY107   -018.4894  -118.5670     0.0      0.001     0.001        !
C    ZY108   -075.2958  -093.4374     0.0      0.001     0.001      0.0002
C    ZY109   -111.9268  -043.2712     0.0      0.001     0.001      0.0002
C    ZY110   -118.5670   018.4894     0.0      0.001     0.001      0.0002
C    ZY111   -093.4374   075.2958     0.0      0.001     0.001      0.0002
C    ZY112   -043.2712   111.9268     0.0      0.001     0.001      0.0002


#  ENTER ELEVATION BEARING BALL REFLECTOR  COORDINATES   (METERS)


C   ABALL1     00.1250    26.0000      44.526       1.0       1.0       1.0
C   CBALL1    -00.1250    26.0000      44.526       1.0       1.0       1.0
C   BBALL1    -00.1250   -26.0000      44.526       1.0       1.0       1.0
C   DBALL1     00.1250   -26.0000      44.526       1.0       1.0       1.0

C   ABALL2     04.63795   25.58330     44.526       1.0       1.0       1.0
C   CBALL2     04.39175   25.62671     44.526       1.0       1.0       1.0
C   BBALL2    -04.63795  -25.58330     44.526       1.0       1.0       1.0
C   DBALL2    -04.39175  -25.62671     44.526       1.0       1.0       1.0
```

C	ABALL3	09.00999	24.38926	44.526	1.0	1.0	1.0
C	CBALL3	08.77506	24.47476	44.526	1.0	1.0	1.0
C	BBALL3	-09.00999	-24.38926	44.526	1.0	1.0	1.0
C	DBALL3	-08.77506	-24.47476	44.526	1.0	1.0	1.0
C	ABALL4	13.10825	22.45416	44.526	1.0	1.0	1.0
C	CBALL4	12.89175	22.57916	44.526	1.0	1.0	1.0
C	BBALL4	-13.10825	-22.45416	44.526	1.0	1.0	1.0
C	DBALL4	-12.89175	-22.57916	44.526	1.0	1.0	1.0

ENTER LASER RANGE TO BALL CENTER STD ERRORS (METERS)

D	ZY102-ABALL1	0.00015
D	ZY103-ABALL1	0.00015
D	ZY111-CBALL1	0.00015
D	ZY110-CBALL1	0.00015
D	ZY104-BBALL1	0.00015
D	ZY105-BBALL1	0.00015
D	ZY108-DBALL1	0.00015
D	ZY109-DBALL1	0.00015
D	ZY103-ABALL2	0.00015
D	ZY104-ABALL2	0.00015
D	ZY110-CBALL2	0.00015
D	ZY109-CBALL2	0.00015
D	ZY106-BBALL2	0.00015
D	ZY105-BBALL2	0.00015
D	ZY109-DBALL2	0.00015
D	ZY108-DBALL2	0.00015
D	ZY109-BBALL2	0.00015
D	ZY103-ABALL3	0.00015
D	ZY104-ABALL3	0.00015
D	ZY110-CBALL3	0.00015
D	ZY109-CBALL3	0.00015
D	ZY106-BBALL3	0.00015
D	ZY105-BBALL3	0.00015
D	ZY104-BBALL3	0.00015
D	ZY108-DBALL3	0.00015
D	ZY109-DBALL3	0.00015
D	ZY103-ABALL4	0.00015
D	ZY104-ABALL4	0.00015
D	ZY105-ABALL4	0.00015
D	ZY109-CBALL4	0.00015
D	ZY110-CBALL4	0.00015
D	ZY104-BBALL4	0.00015
D	ZY105-BBALL4	0.00015
D	ZY109-DBALL4	0.00015
D	ZY110-DBALL4	0.00015
D	ZY111-DBALL4	0.00015

```
#    ENTER ASSUMED RANGE STATION TO STATION DISTANCE STANDARD ERROR (METER)

D         ZY111-ZY101         0.00015
D         ZY112-ZY101         0.00015
D         ZY112-ZY102         0.00015
D         ZY101-ZY102         0.00015
D         ZY101-ZY103         0.00015
D         ZY102-ZY103         0.00015
D         ZY102-ZY104         0.00015
D         ZY103-ZY104         0.00015
D         ZY103-ZY105         0.00015
D         ZY104-ZY105         0.00015
D         ZY104-ZY106         0.00015
D         ZY105-ZY106         0.00015
D         ZY105-ZY107         0.00015
D         ZY106-ZY107         0.00015
D         ZY106-ZY108         0.00015
D         ZY107-ZY108         0.00015
D         ZY107-ZY109         0.00015
D         ZY108-ZY109         0.00015
D         ZY108-ZY110         0.00015
D         ZY109-ZY110         0.00015
D         ZY109-ZY111         0.00015
D         ZY110-ZY111         0.00015
D         ZY110-ZY112         0.00015
D         ZY111-ZY112         0.00015


#     ENTER  ASSUMED BALL-TO-BALL DISTANCE STANDARD ERROR

D        ABALL1-BBALL1       1.0           #  Centers of balls at opposite ends
D        CBALL1-DBALL1       1.0           #  of the elevation shaft are assumed
D        ABALL1-CBALL1       0.00005       #  not to be known accurately a-priori
D        BBALL1-DBALL1       0.00005

D        ABALL2-BBALL2       1.0
D        CBALL2-DBALL2       1.0
D        ABALL2-CBALL2       0.00005
D        BBALL2-DBALL2       0.00005

D        ABALL3-BBALL3       1.0
D        CBALL3-DBALL3       1.0
D        ABALL3-CBALL3       0.00005
D        BBALL3-DBALL3       0.00005

D        ABALL4-BBALL4       1.0
D        CBALL4-DBALL4       1.0
D        ABALL4-CBALL4       0.00005
D        BBALL4-DBALL4       0.00005
```

```
#       ENTER ASSUMED INSTALLATION BALL (HORIZ.) ORIENTION ANGLE & STD. ERROR

DB      ABALL1                              #  Ref. station.  Begin direction set.
DN      BBALL1    00-00-00      0.01        #  Direction (D-M-S) and S.E. (Sec).
DN      CBALL1   270-00-00      300.0       #  Assume 1/12 degree S.E.
DE                                          #  End direction data set entry.

DB      BBALL1
DN      ABALL1    00-00-00      0.01
DN      DBALL1    90-00-00      300.0
DE

DB      CBALL1
DN      DBALL1    00-00-00      0.01
DN      ABALL1    90-00-00      300.0
DE

DB      DBALL1
DN      CBALL1    00-00-00      0.01
DN      BBALL1   270-00-00      300.0
DE


DB      ABALL2
DN      BBALL2    00-00-00      0.01
DN      CBALL2   270-00-00      300.0
DE

DB      BBALL2
DN      ABALL2    00-00-00      0.01
DN      DBALL2    90-00-00      300.0
DE

DB      CBALL2
DN      DBALL2    00-00-00      0.01
DN      ABALL2    90-00-00      300.0
DE

DB      DBALL2
DN      CBALL2    00-00-00      0.01
DN      BBALL2   270-00-00      300.0
DE


DB      ABALL3
DN      BBALL3    00-00-00      0.01
DN      CBALL3   270-00-00      300.0
DE

DB      BBALL3
DN      ABALL3    00-00-00      0.01
DN      DBALL3    90-00-00      300.0
DE

DB      CBALL3
DN      DBALL3    00-00-00      0.01
DN      ABALL3    90-00-00      300.0
DE
```

```
DB      DBALL3
DN      CBALL3    00-00-00     0.01
DN      BBALL3   270-00-00     300.0
DE


DB      ABALL4
DN      BBALL4    00-00-00     0.01
DN      CBALL4   270-00-00     300.0
DE

DB      BBALL4
DN      ABALL4    00-00-00     0.01
DN      DBALL4    90-00-00     300.0
DE



DB      CBALL4
DN      DBALL4    00-00-00     0.01
DN      ABALL4    90-00-00     300.0
DE

DB      DBALL4
DN      CBALL4    00-00-00     0.01
DN      BBALL4   270-00-00     300.0
DE

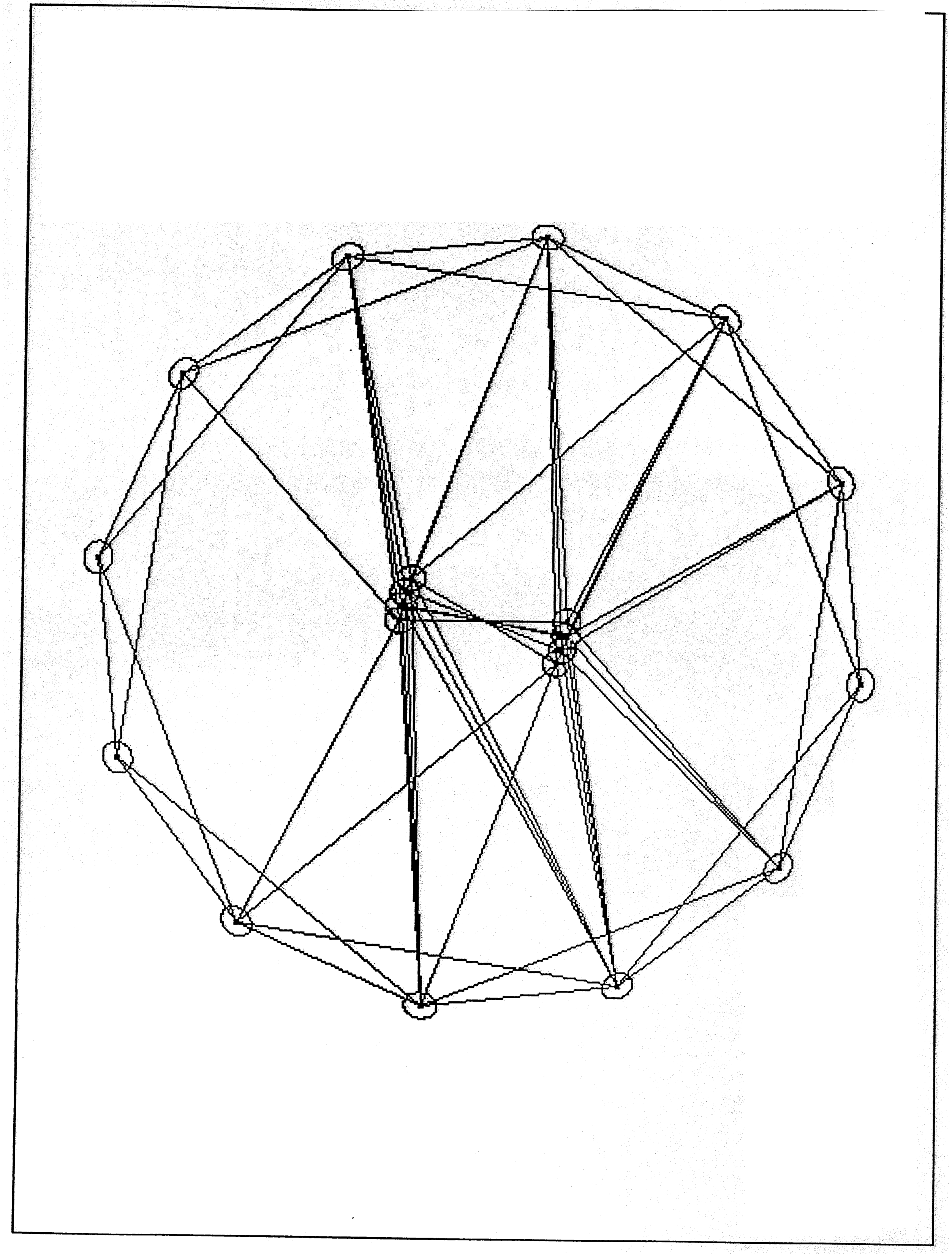

#       ENTER ASSUMED ZENITH ANGLE (D-M-S) & STD. ERROR (SEC)

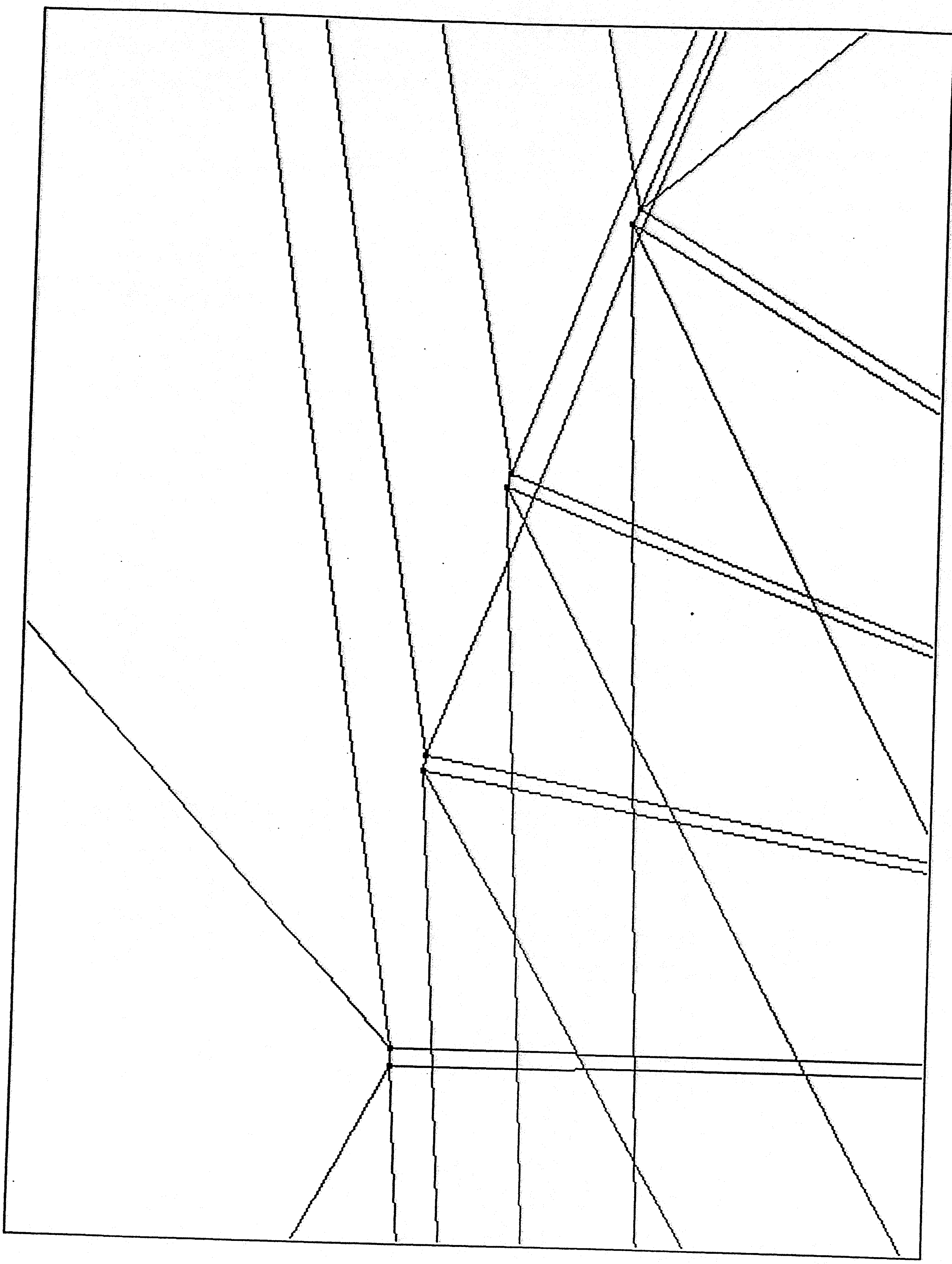
V       ABALL1-BBALL1    90-00-00     300.0
V       ABALL1-CBALL1    90-00-00     300.0
V       CBALL1-DBALL1    90-00-00     300.0
V       BBALL1-DBALL1    90-00-00     300.0

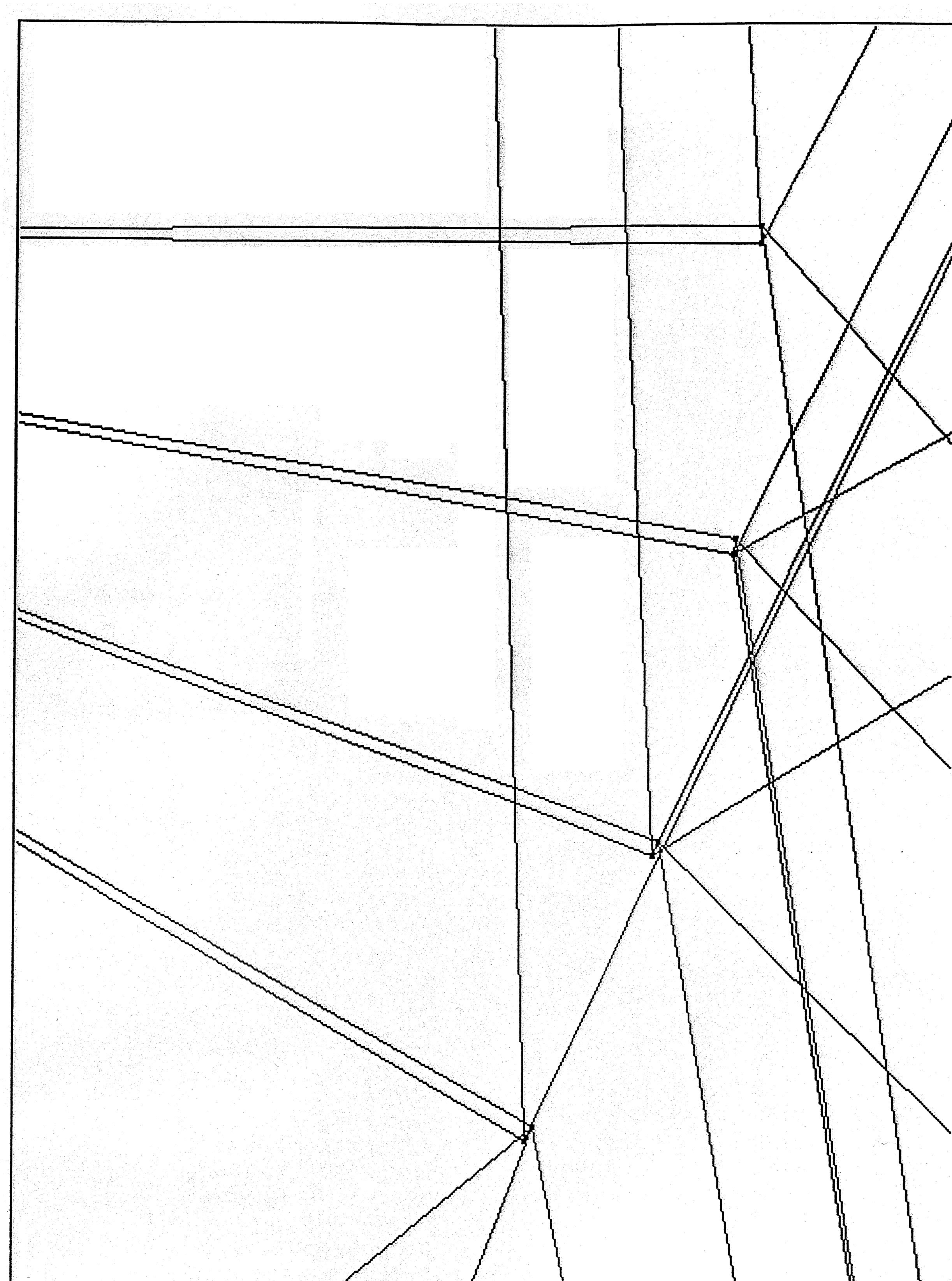
V       ABALL2-BBALL2    90-00-00     300.0
V       ABALL2-CBALL2    90-00-00     300.0
V       CBALL2-DBALL2    90-00-00     300.0
V       BBALL2-DBALL2    90-00-00     300.0


V       ABALL3-BBALL3    90-00-00     300.0
V       ABALL3-CBALL3    90-00-00     300.0
V       CBALL3-DBALL3    90-00-00     300.0
V       BBALL3-DBALL3    90-00-00     300.0


V       ABALL4-BBALL4    90-00-00     300.0
V       ABALL4-CBALL4    90-00-00     300.0
V       CBALL4-DBALL4    90-00-00     300.0
V       BBALL4-DBALL4    90-00-00     300.0
```







STAR*NET Adjustment Program
Version 5.0444

Licensed for Use by National Radio Astronomy Observatory
Serial Number 20649
Run Date : Tue Mar 04 1997 11:30:19

Summary of Files Used

Project Directory	C:\STAR
Input Data File	ELBEBRL.DAT
Output Listing (This File)	ELBEBRL.LST (Version 4.8)
Coordinates	ELBEBRL.PTS
Project Parameters	ELBEBRL.PRJ
Error Log	ELBEBRL.ERR
Plot File	ELBEBRL.SPL

Adjustment Options

STAR*NET Run Mode	: Preanalysis
Type of Adjustment	: 3D
Input Order for Coordinates	: X,Y,Z
Coordinate System	: LOCAL
Project Scale Factor	: 1.00000000
Linear Units; Angular Units	: Meters; DMS
Input Order for Angle Stations	: At-From-To
Max Iterations; Convergence Limit	: 50; 0.0001
Correct Zeniths for Curve & Refract	: No
Adjust 3D Obs for Vert Divergence	: No
3D Data Input Mode	: Slope/Zenith
Earth Radius	: 6372161.544 Meters
Coefficient of Refraction	: 0.070

Default Instrument Standard Error Settings

Distances (Constant)	: 0.0001000 Meters
Distances (PPM)	: 0.0000010
Angles	: 1.4140000 Seconds
Directions	: 1.0000000 Seconds
Azimuth / Bearings	: 2.0000000 Seconds
Zeniths	: 2.0000000 Seconds
Elevation Differences (Constant)	: 0.0001000 Meters
Elevation Differences (PPM)	: 0.0000010
Centering Error Instrument	: 0.0000100 Meters
Centering Error Target	: 0.0000100 Meters

Summary of Unadjusted Input Observations
==

Number of Stations (Meters) = 28

Partially Fixed	X SE-X	Y SE-Y	Z SE-Z	Description
ZY101	18.4894	118.5670	0.0000	
	0.0010	0.0010	0.0002	
ZY102	75.2958	93.4370	0.0000	
	0.0010	0.0010	0.0002	
ZY103	111.9268	43.2712	0.0000	
	0.0010	0.0010	0.0002	
ZY104	118.5670	-18.4894	0.0000	
	0.0010	0.0010	0.0002	
ZY105	93.4374	-75.2958	0.0000	
	0.0010	0.0010	0.0002	
ZY106	43.2712	111.9268	0.0000	
	0.0010	0.0010	0.0002	
ZY107	-18.4894	118.5670	0.0000	
	0.0010	0.0010	FIXED	
ZY108	-75.2958	-93.4374	0.0000	
	0.0010	0.0010	0.0002	
ZY109	-111.9268	-43.2712	0.0000	
	0.0010	0.0010	0.0002	
ZY110	-118.5670	18.4894	0.0000	
	0.0010	0.0010	0.0002	
ZY111	-93.4374	75.2958	0.0000	
	0.0010	0.0010	0.0002	
ZY112	-43.2712	111.9268	0.0000	
	0.0010	0.0010	0.0002	
ABALL1	0.1250	26.0000	44.5260	
	1.0000	1.0000	1.0000	
CBALL1	-0.1250	26.0000	44.5260	
	1.0000	1.0000	1.0000	
BBALL1	-0.1250	-26.0000	44.5260	
	1.0000	1.0000	1.0000	
DBALL1	0.1250	-26.0000	44.5260	
	1.0000	1.0000	1.0000	
ABALL2	4.6380	25.5833	44.5260	
	1.0000	1.0000	1.0000	
CBALL2	4.3918	25.6267	44.5260	
	1.0000	1.0000	1.0000	
BBALL2	-4.6380	-25.5833	44.5260	
	1.0000	1.0000	1.0000	
DBALL2	-4.3918	-25.6267	44.5260	
	1.0000	1.0000	1.0000	
ABALL3	9.0100	24.3893	44.5260	
	1.0000	1.0000	1.0000	
CBALL3	8.7751	24.4748	44.5260	
	1.0000	1.0000	1.0000	
BBALL3	-9.0100	-24.3893	44.5260	
	1.0000	1.0000	1.0000	
DBALL3	-8.7751	-24.4748	44.5260	
	1.0000	1.0000	1.0000	
ABALL4	13.1083	22.4542	44.5260	
	1.0000	1.0000	1.0000	
CBALL4	12.8918	22.5792	44.5260	

		1.0000	1.0000	1.0000
BBALL4		-13.1083	-22.4542	44.5260
		1.0000	1.0000	1.0000
DBALL4		-12.8918	-22.5792	44.5260
		1.0000	1.0000	1.0000

Number of Direction Observations = 32

From	To	Direction	StdErr
ABALL1	BBALL1	180-16-31.65	0.08
ABALL1	CBALL1	270-00-00.00	300.45
BBALL1	ABALL1	0-16-31.65	0.08
BBALL1	DBALL1	90-00-00.00	300.45
CBALL1	DBALL1	179-43-28.35	0.08
CBALL1	ABALL1	90-00-00.00	300.45
DBALL1	CBALL1	359-43-28.35	0.08
DBALL1	BBALL1	270-00-00.00	300.45
ABALL2	BBALL2	190-16-31.62	0.08
ABALL2	CBALL2	279-59-58.62	300.45
BBALL2	ABALL2	10-16-31.62	0.08
BBALL2	DBALL2	99-59-58.62	300.45
CBALL2	DBALL2	189-43-28.33	0.08
CBALL2	ABALL2	99-59-58.62	300.45
DBALL2	CBALL2	9-43-28.33	0.08
DBALL2	BBALL2	279-59-58.62	300.45
ABALL3	BBALL3	200-16-31.67	0.08
ABALL3	CBALL3	289-59-54.16	300.45
BBALL3	ABALL3	20-16-31.67	0.08
BBALL3	DBALL3	109-59-54.16	300.45
CBALL3	DBALL3	199-43-28.34	0.08
CBALL3	ABALL3	109-59-54.16	300.45
DBALL3	CBALL3	19-43-28.34	0.08
DBALL3	BBALL3	289-59-54.16	300.45
ABALL4	BBALL4	210-16-31.63	0.08
ABALL4	CBALL4	300-00-02.62	300.45
BBALL4	ABALL4	30-16-31.63	0.08
BBALL4	DBALL4	120-00-02.62	300.45
CBALL4	DBALL4	209-43-28.37	0.08
CBALL4	ABALL4	120-00-02.62	300.45
DBALL4	CBALL4	29-43-28.37	0.08
DBALL4	BBALL4	300-00-02.62	300.45

Number of Distance Observations (Meters) = 76

From	To	Obs Dist	StdErr	HI	HT	Flags
ZY102	ABALL1	110.3674	0.0001	0.000	0.000	S
ZY103	ABALL1	121.5751	0.0001	0.000	0.000	S
ZY111	CBALL1	114.5419	0.0001	0.000	0.000	S
ZY110	CBALL1	126.7576	0.0001	0.000	0.000	S
ZY104	BBALL1	126.9912	0.0001	0.000	0.000	S
ZY105	BBALL1	114.7456	0.0001	0.000	0.000	S
ZY108	DBALL1	110.5381	0.0001	0.000	0.000	S
ZY109	DBALL1	121.8050	0.0001	0.000	0.000	S
ZY103	ABALL2	117.5003	0.0001	0.000	0.000	S
ZY104	ABALL2	130.0184	0.0001	0.000	0.000	S
ZY110	CBALL2	130.9670	0.0001	0.000	0.000	S
ZY109	CBALL2	142.3358	0.0001	0.000	0.000	S
ZY106	BBALL2	108.3192	0.0001	0.000	0.000	S
ZY105	BBALL2	118.6283	0.0001	0.000	0.000	S
ZY109	DBALL2	117.7186	0.0001	0.000	0.000	S
ZY108	DBALL2	107.7415	0.0001	0.000	0.000	S
ZY109	BBALL2	117.5003	0.0001	0.000	0.000	S
ZY103	ABALL3	113.7144	0.0001	0.000	0.000	S
ZY104	ABALL3	125.7930	0.0001	0.000	0.000	S
ZY110	CBALL3	135.0348	0.0001	0.000	0.000	S
ZY109	CBALL3	145.3995	0.0001	0.000	0.000	S
ZY106	BBALL3	111.2596	0.0001	0.000	0.000	S
ZY105	BBALL3	122.7579	0.0001	0.000	0.000	S
ZY104	BBALL3	135.2526	0.0001	0.000	0.000	S
ZY108	DBALL3	105.6571	0.0001	0.000	0.000	S
ZY109	DBALL3	113.9129	0.0001	0.000	0.000	S
ZY103	ABALL4	110.3677	0.0001	0.000	0.000	S
ZY104	ABALL4	121.5750	0.0001	0.000	0.000	S
ZY105	ABALL4	134.1283	0.0001	0.000	0.000	S
ZY109	CBALL4	147.9814	0.0001	0.000	0.000	S
ZY110	CBALL4	138.8549	0.0001	0.000	0.000	S
ZY104	BBALL4	139.0563	0.0001	0.000	0.000	S
ZY105	BBALL4	126.9913	0.0001	0.000	0.000	S
ZY109	DBALL4	110.5381	0.0001	0.000	0.000	S
ZY110	DBALL4	121.8050	0.0001	0.000	0.000	S
ZY111	DBALL4	134.3491	0.0001	0.000	0.000	S
ZY111	ZY101	120.0000	0.0001	0.000	0.000	S
ZY112	ZY101	62.1165	0.0001	0.000	0.000	S
ZY112	ZY102	120.0000	0.0001	0.000	0.000	S
ZY101	ZY102	62.1167	0.0001	0.000	0.000	S
ZY101	ZY103	120.0000	0.0001	0.000	0.000	S
ZY102	ZY103	62.1163	0.0001	0.000	0.000	S
ZY102	ZY104	119.9996	0.0001	0.000	0.000	S
ZY103	ZY104	62.1165	0.0001	0.000	0.000	S
ZY103	ZY105	120.0000	0.0001	0.000	0.000	S
ZY104	ZY105	62.1165	0.0001	0.000	0.000	S
ZY104	ZY106	120.0000	0.0001	0.000	0.000	S
ZY105	ZY106	62.1166	0.0001	0.000	0.000	S
ZY105	ZY107	120.0000	0.0001	0.000	0.000	S
ZY106	ZY107	62.1165	0.0001	0.000	0.000	S
ZY106	ZY108	120.0000	0.0001	0.000	0.000	S
ZY107	ZY108	62.1165	0.0001	0.000	0.000	S
ZY107	ZY109	120.0000	0.0001	0.000	0.000	S
ZY108	ZY109	62.1166	0.0001	0.000	0.000	S
ZY108	ZY110	120.0000	0.0001	0.000	0.000	S
ZY109	ZY110	62.1165	0.0001	0.000	0.000	S
ZY109	ZY111	120.0000	0.0001	0.000	0.000	S

ZY110	ZY111	62.1165	0.0001	0.000	0.000	S
ZY110	ZY112	120.0000	0.0001	0.000	0.000	S
ZY111	ZY112	62.1166	0.0001	0.000	0.000	S
ABALL1	BBALL1	52.0006	0.0001	0.000	0.000	S
CBALL1	DBALL1	52.0006	0.0001	0.000	0.000	S
ABALL1	CBALL1	0.2500	0.0001	0.000	0.000	S
BBALL1	DBALL1	0.2500	0.0001	0.000	0.000	S
ABALL2	BBALL2	52.0006	0.0001	0.000	0.000	S
CBALL2	DBALL2	52.0006	0.0001	0.000	0.000	S
ABALL2	CBALL2	0.2500	0.0001	0.000	0.000	S
BBALL2	DBALL2	0.2500	0.0001	0.000	0.000	S
ABALL3	BBALL3	52.0006	0.0001	0.000	0.000	S
CBALL3	DBALL3	52.0006	0.0001	0.000	0.000	S
ABALL3	CBALL3	0.2500	0.0001	0.000	0.000	S
BBALL3	DBALL3	0.2500	0.0001	0.000	0.000	S
ABALL4	BBALL4	52.0006	0.0001	0.000	0.000	S
CBALL4	DBALL4	52.0006	0.0001	0.000	0.000	S
ABALL4	CBALL4	0.2500	0.0001	0.000	0.000	S
BBALL4	DBALL4	0.2500	0.0001	0.000	0.000	S

Number of Zenith Observations = 16

From	To	Obs Zenith	StdErr	HI	HT	Flags
ABALL1	BBALL1	90-00-00.00	300.00	0.000	0.000	
ABALL1	CBALL1	90-00-00.00	300.00	0.000	0.000	
CBALL1	DBALL1	90-00-00.00	300.00	0.000	0.000	
BBALL1	DBALL1	90-00-00.00	300.00	0.000	0.000	
ABALL2	BBALL2	90-00-00.00	300.00	0.000	0.000	
ABALL2	CBALL2	90-00-00.00	300.00	0.000	0.000	
CBALL2	DBALL2	90-00-00.00	300.00	0.000	0.000	
BBALL2	DBALL2	90-00-00.00	300.00	0.000	0.000	
ABALL3	BBALL3	90-00-00.00	300.00	0.000	0.000	
ABALL3	CBALL3	90-00-00.00	300.00	0.000	0.000	
CBALL3	DBALL3	90-00-00.00	300.00	0.000	0.000	
BBALL3	DBALL3	90-00-00.00	300.00	0.000	0.000	
ABALL4	BBALL4	90-00-00.00	300.00	0.000	0.000	
ABALL4	CBALL4	90-00-00.00	300.00	0.000	0.000	
CBALL4	DBALL4	90-00-00.00	300.00	0.000	0.000	
BBALL4	DBALL4	90-00-00.00	300.00	0.000	0.000	

Adjusted Bearings and Horizontal Distances (Meters)

From	To	Bearing	Distance	Relative BgErr	Relative DisErr	DistPrec (PPM)
ZY102	ABALL1	S48-06-15.05W	100.9871	0.66	0.0002	1
ZY103	ABALL1	S81-13-06.01W	113.1280	0.65	0.0002	1
ZY111	CBALL1	S62-09-10.99E	105.5333	0.64	0.0002	1
ZY110	CBALL1	N86-22-17.90E	118.6799	0.63	0.0002	1
ZY104	BBALL1	S86-22-45.34W	118.9294	0.63	0.0001	1
ZY105	BBALL1	N62-12-58.76W	105.7544	0.64	0.0002	1
ZY108	DBALL1	N48-11-54.80E	101.1736	0.64	0.0002	1
ZY109	DBALL1	N81-14-15.44E	113.3750	0.64	0.0001	1
ZY103	ABALL2	S80-38-17.84W	108.7371	0.69	0.0002	1
ZY104	ABALL2	N68-51-04.92W	122.1566	0.62	0.0002	1
ZY110	CBALL2	N86-40-40.50E	123.1657	0.64	0.0002	1
ZY109	CBALL2	N59-21-39.07E	135.1922	0.60	0.0002	1
ZY106	BBALL2	N29-01-28.00W	98.7446	0.62	0.0002	1
ZY105	BBALL2	N63-07-13.55W	109.9550	0.66	0.0001	1
ZY109	DBALL2	N80-40-54.72E	108.9730	0.65	0.0002	1
ZY108	DBALL2	N46-16-38.97E	98.1105	0.61	0.0002	2
ZY109	BBALL2	N80-38-17.84E	108.7371	0.66	0.0002	1
ZY103	ABALL3	S79-36-13.24W	104.6346	0.65	0.0002	1
ZY104	ABALL3	N68-37-31.84W	117.6491	0.59	0.0002	1
ZY110	CBALL3	N87-18-32.23E	127.4826	0.62	0.0002	1
ZY109	CBALL3	N60-41-45.40E	138.4141	0.59	0.0002	1
ZY106	BBALL3	N30-50-50.89W	101.9615	0.57	0.0002	1
ZY105	BBALL3	N63-34-37.29W	114.3982	0.58	0.0002	1
ZY104	BBALL3	S87-21-07.97W	127.7133	0.59	0.0001	1
ZY108	DBALL3	N43-58-02.77E	95.8168	0.63	0.0002	1
ZY109	DBALL3	N79-40-22.08E	104.8503	0.66	0.0002	1
ZY103	ABALL4	S78-06-14.58W	100.9874	0.63	0.0002	1
ZY104	ABALL4	N68-46-54.03W	113.1279	0.58	0.0002	1
ZY105	ABALL4	N39-24-45.89W	126.5220	0.56	0.0002	1
ZY109	CBALL4	N62-11-06.99E	141.1238	0.57	0.0001	1
ZY110	CBALL4	N88-13-05.05E	131.5224	0.59	0.0002	1
ZY104	BBALL4	S88-16-31.21W	131.7349	0.58	0.0001	1
ZY105	BBALL4	N63-37-14.69W	118.9295	0.58	0.0001	1
ZY109	DBALL4	N78-11-54.93E	101.1736	0.60	0.0002	1
ZY110	DBALL4	S68-45-44.59E	113.3750	0.61	0.0002	1
ZY111	DBALL4	S39-27-08.93E	126.7561	0.59	0.0001	1
ZY111	ZY101	N68-51-48.11E	120.0000	0.68	0.0001	0
ZY112	ZY101	N83-51-48.27E	62.1165	0.88	0.0001	1
ZY112	ZY102	S81-08-11.26E	120.0000	0.68	0.0001	0
ZY101	ZY102	S66-08-10.94E	62.1167	1.03	0.0001	1
ZY101	ZY103	S51-08-12.00E	120.0000	0.68	0.0001	0
ZY102	ZY103	S36-08-12.73E	62.1163	0.72	0.0001	1
ZY102	ZY104	S21-08-12.13E	119.9996	0.57	0.0001	0
ZY103	ZY104	S06-08-11.73E	62.1165	0.68	0.0001	1
ZY103	ZY105	S08-51-48.06W	120.0000	0.57	0.0001	0
ZY104	ZY105	S23-51-47.84W	62.1165	0.64	0.0001	1
ZY104	ZY106	S38-51-48.00W	120.0000	0.55	0.0001	0
ZY105	ZY106	S53-51-48.06W	62.1166	0.67	0.0001	1
ZY105	ZY107	S68-51-48.11W	120.0000	0.60	0.0001	0
ZY106	ZY107	S83-51-48.27W	62.1165	0.83	0.0001	1
ZY106	ZY108	N81-08-11.94W	120.0000	0.56	0.0001	0
ZY107	ZY108	N66-08-12.16W	62.1165	0.84	0.0001	1
ZY107	ZY109	N51-08-12.00W	120.0000	0.61	0.0001	0

ZY108	ZY109	N36-08-11.94W	62.1166	0.66	0.0001	1
ZY108	ZY110	N21-08-11.89W	120.0000	0.57	0.0001	0
ZY109	ZY110	N06-08-11.73W	62.1165	0.66	0.0001	1
ZY109	ZY111	N08-51-48.06E	120.0000	0.57	0.0001	0
ZY110	ZY111	N23-51-47.84E	62.1165	0.67	0.0001	1
ZY110	ZY112	N38-51-48.00E	120.0000	0.66	0.0001	0
ZY111	ZY112	N53-51-48.06E	62.1166	1.03	0.0001	1
ABALL1	BBALL1	S00-16-31.65W	52.0006	0.84	0.0001	1
CBALL1	DBALL1	S00-16-31.65E	52.0006	0.84	0.0001	1
ABALL1	CBALL1	S90-00-00.00W	0.2500	148.44	0.0001	403
BBALL1	DBALL1	S90-00-00.00E	0.2500	145.40	0.0001	403
ABALL2	BBALL2	S10-16-31.62W	52.0006	0.78	0.0001	1
CBALL2	DBALL2	S09-43-28.33W	52.0006	0.84	0.0001	1
ABALL2	CBALL2	N80-00-01.38W	0.2500	142.33	0.0001	403
BBALL2	DBALL2	S80-00-01.38E	0.2500	139.13	0.0001	370
ABALL3	BBALL3	S20-16-31.67W	52.0006	0.83	0.0001	1
CBALL3	DBALL3	S19-43-28.34W	52.0006	0.84	0.0001	1
ABALL3	CBALL3	N70-00-05.84W	0.2500	143.14	0.0001	402
BBALL3	DBALL3	S70-00-05.84E	0.2500	139.33	0.0001	400
ABALL4	BBALL4	S30-16-31.63W	52.0006	0.82	0.0001	1
CBALL4	DBALL4	S29-43-28.37W	52.0006	0.83	0.0001	1
ABALL4	CBALL4	N59-59-57.38W	0.2500	143.88	0.0001	401
BBALL4	DBALL4	S59-59-57.38E	0.2500	143.38	0.0001	402

Error Propagation

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Station Coordinate Standard Deviations

Station	X	Y	Z
ZY101	0.00041	0.00036	0.00020
ZY102	0.00039	0.00036	0.00020
ZY103	0.00034	0.00040	0.00019
ZY104	0.00031	0.00041	0.00019
ZY105	0.00035	0.00037	0.00019
ZY106	0.00040	0.00033	0.00019
ZY107	0.00041	0.00034	0.00000
ZY108	0.00038	0.00035	0.00019
ZY109	0.00032	0.00040	0.00019
ZY110	0.00032	0.00041	0.00019
ZY111	0.00037	0.00038	0.00020
ZY112	0.00040	0.00036	0.00020
ABALL1	0.00032	0.00037	0.00038
CBALL1	0.00032	0.00036	0.00039
BBALL1	0.00032	0.00037	0.00033
DBALL1	0.00032	0.00036	0.00033
ABALL2	0.00032	0.00038	0.00040
CBALL2	0.00032	0.00038	0.00041
BBALL2	0.00031	0.00038	0.00033
DBALL2	0.00032	0.00037	0.00039
ABALL3	0.00032	0.00036	0.00040
CBALL3	0.00032	0.00037	0.00041
BBALL3	0.00032	0.00035	0.00036
DBALL3	0.00032	0.00037	0.00034
ABALL4	0.00032	0.00034	0.00038
CBALL4	0.00032	0.00036	0.00039
BBALL4	0.00031	0.00035	0.00033
DBALL4	0.00032	0.00034	0.00031

Station Coordinate Error Ellipses
Confidence Region = 95%

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis
ZY101	0.00101	0.00087	101-30
ZY102	0.00101	0.00080	125-51
ZY103	0.00101	0.00079	157-13
ZY104	0.00101	0.00075	9-10
ZY105	0.00101	0.00075	39-01
ZY106	0.00101	0.00077	68-33
ZY107	0.00101	0.00083	99-27
ZY108	0.00101	0.00076	128-59
ZY109	0.00101	0.00075	157-52
ZY110	0.00101	0.00078	10-13
ZY111	0.00101	0.00079	42-26
ZY112	0.00101	0.00086	66-25
ABALL1	0.00090	0.00078	171-48
CBALL1	0.00089	0.00078	174-27
BBALL1	0.00089	0.00078	174-00
DBALL1	0.00089	0.00078	173-08
ABALL2	0.00093	0.00078	174-45

CBALL2	0.00093	0.00077	170-29
BBALL2	0.00093	0.00076	10-21
DBALL2	0.00091	0.00079	8-54
ABALL3	0.00088	0.00078	168-26
CBALL3	0.00091	0.00077	169-36
BBALL3	0.00087	0.00078	167-28
DBALL3	0.00090	0.00078	173-52
ABALL4	0.00084	0.00079	169-17
CBALL4	0.00087	0.00077	169-53
BBALL4	0.00085	0.00077	1-52
DBALL4	0.00083	0.00078	5-44

Elapsed Time = 00:00:02