Dec. 5, 1967

(Addendum April 30, 1968)

# A Steerable 300-foot Telescope for 2 cm Wavelength

S. von Hoerner

## Summary

A fully steerable alt-azimuth telescope of 300 feet diameter has been developed. The influence of gravitation is omitted by homologous deformations. In winds up to 22 mph (3/4 of all time), the shortest wavelength is 2 cm; the structure is stable up to 110 mph (or 50 mph plus 20 $lb/ft^2$ snow). The telescope can be built from off-the-shelf pieces, and observation at 2 cm is possible in sunshine and changing air temperature. The weight on the elevation axis is 750 tons.

An optical positioning system is suggested, mounted at the apex and "locked in" to six light beacons at the ground. This omits all thermal deformations (and 3/4 of all wind deformations) between apex and ground. No high accuracy is needed for rails and foundations, and normal railroad is used. The weight on the azimuth rails is about 1600 tons.

The cost amounts to 3.3 M$ for the complete telescope with towers, foundations, drives and on-line computer. If engineering, service tower, building and other items are included, the total price is 3.8 M$. (For a diameter of 400 ft, and $\lambda$ = 3 cm, the total price is 6.7 M$).

## I. Homology Program

This program was developed for the LFST study[1]. The first and main part is a linearized and iterative procedure which yields a set of bar areas A such that $\Delta H = o$, where $\Delta H$ is the rms deviation between N points of the deformed surface and a best-fit paraboloid of revolution, in zenith and horizon position.

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1) LFST Report No. 4; Nov. 1965.

Each iteration decreases $\Delta H$ by a factor of 3-10, and the calculating accuracy soon is reached, with about $\Delta H = 10^{-5}$ inch.

The second part calculates the maximum stress $S_m$ in two survival conditions:

1. Wind of 110 mph, in stow position;
2. Wind of 50 mph, plus 20 $lb/ft^2$ of snow or ice, in any position.

It also calculates the slenderness of each bar, the resulting maximum allowed stress $S_o$, and the stress ratio $Q = S_m/S_o$. The structure is stable against survival conditions if all $Q \leq 1$.

The third part calculates the rms surface deformation $\Delta\zeta$ for a face-on wind of 22 mph (3/4 of all time at Green Bank[2] the wind is below this value). No best-fit is used here.

The fourth part, called "Sensitivity", calculates the deviations from homology resulting from manufacturing inaccuracies.

Our results of the first three parts ($\Delta H$, survival stress, wind deformation) have been checked by Simpson, Gumpertz and Heger in Cambridge, Mass. Complete agreement within 4 decimals was obtained in this check.

## II. Wind Deformation and Wavelength

From the program we obtain $\Delta\zeta$. A first part of this deformation is just a parallel translation which does not matter; a second part is a rigid-body rotation resulting in pointing errors; the remaining third part is a non-parabolic surface deformation. In addition, the towers will deform, which contributes to the first two parts only.

If the pointing is measured as suggested in Section IV, then only those pointing errors will remain which change faster than the time constant $\tau_o$ of the servo system. This constant is defined by the lowest dynamical frequency $\nu$ of

2) LFST Report No. 16; Dec. 1966.

the structure. I think the lowest mode will be an azimuth oscillation of the whole dish with the towers as springs, where an estimate gave $\nu$ = 2.0 cps; but in order to be on the safe side we will adopt $\tau_o$ = 1 sec.

From some preliminary wind measurements on a tower in the Greenbrier valley, we obtain $u(\tau)$, the rms velocity difference between neighboring time averages of duration $\tau$. We find u(1 sec) = 11.4 per cent of the average velocity v, which means an rms pressure difference $\Delta p$ = 24 per cent of p. In winds of 22 mph, the towers (slightly stronger than survival) deform by 0.18 cm, but only 24 per cent = 0.043 cm will be faster than the pointing correction. If the elevation drive is fixed at the ground, we obtain a pointing error of 2.0 arcsec in elevation, and of 1.4 arcsec in azimuth. For the rigid-body deformation of the dish, we need the velocity difference at a distance of $\ell$ = 150 feet; and with $\ell = \tau v$ we obtain from our measurements u(150 ft) = 26 per cent of v, or $\Delta p$ = 59 per cent of p. For 22 mph, our dish structure 2e/18 yields $\Delta\zeta$ = 0.212 cm, and 59 per cent = 0.124 cm. Then 24 per cent = 0.030 cm will be faster than the pointing corrections, resulting in 1.0 arcsec pointing errors for both elevation and azimuth. From towers plus dish, we thus obtain pointing errors of 3.0 arcsec; demanding that this be 1/16 of a beamwidth, we obtain a shortest wavelength of $\lambda$ = 1.78 cm.

For the non-parabolic deformation of the dish, we must divide the diameter into at least 3 parts, and from our measurements we obtain u(100 ft) = 21 per cent of v, or $\Delta p$ = 48 per cent of p. With $\Delta\zeta$ = 0.212 cm, we have 48 per cent = 0.102 cm; demanding that this be $\lambda/16$, we obtain a shortest wavelength of $\lambda$ = 1.63 cm.

Since our wind measurements and the dynamical analysis of the structure both are of a preliminary nature, we will adopt $\lambda$ = 2.0 cm for Structure 2e/18. If generalized, this means $\underline{\lambda = 9.4\ \Delta\zeta}$. (Before making the wind measurements and the dynamical analysis, I used a rough guess of $\lambda = 10\ \Delta\zeta$.)

## III. Choice of $\lambda$

After gravity has been omitted by homology for N equally spaced surface points, the shortest wavelength of observation then is limited by several other criteria:

1. Thermal deformations of the structure, resulting from sunshine and from sudden changes of ambient air temperature. Experiments at Green Bank[3] showed that $\Delta T = 5^{\circ}C$ should be used on sunny, calm days. This gives a shortest wavelength $\lambda_{th}$ which can be passed by a factor 2 - 5 during nights, or winds above 5 mph.

2. If off-the-shelf structural pieces are used, the rms deviations of the bar areas from the computer output are 10 per cent. The "Sensitivity" then gives a shortest wavelength $\lambda_{sy}$ which can be passed by a factor 1.5 - 2 by carefully combining different sizes.

3. The gravitational deformations of surface panels in between the N homologous points yield a limit $\lambda_N$ which can be arbitrarily decreased by going to higher N. Our present program is badly memory-limited and allows only N = 13; but a new version is almost finished which should yield up to N = 80.

4. The limit set by wind deformations, $\lambda_{wd}$, is entirely a financial one. If all bar areas are multiplied by 2, the price is doubled but $\lambda_{wd}$ is halved.

   On the other side, if a structure just fulfills the survival conditions, it then is automatically strong enough against wind deformations to allow observation at a wavelength $\lambda_{sv}$. Considering any $\lambda \succ \lambda_{sv}$ would be uneconomical.

For a telescope with a diameter of 300 feet, and with N = 13 homologous surface points, we obtain the following values:

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3) LFST Report No. 17; Jan. 1967.

| | | |
|---|---|---|
| thermal deformations | $\lambda \geq \lambda_{th}$ | = 2.2 cm |
| off-the-shelf pieces | $\lambda \geq \lambda_{sy}$ | = 1.4 cm |
| N = 13 hom. points | $\lambda \geq \lambda_N$ | = 1.5 cm |
| survival strength | $\lambda \leq \lambda_{sv}$ | = 4.3 cm |

These values show that we should choose $2 \text{ cm} \leq \lambda \leq 4 \text{ cm}$. Two designs have been worked out, yielding $\lambda = 2.0$ cm and $\lambda = 4.2$ cm. The first one, Structure 2e/18, has a weight of 748 tons on the elevation axis; it is defined by wind deformations, and for survival conditions it is overdesigned by 21 per cent. The second one, Str. 2e/21, has 476 tons; it is defined by survival conditions, overdesigned by a margin of 10 per cent.

For comparison: our NRAO 300-foot at Green Bank has 450 tons (plus 50 tons counterweight) on the elevation axis, and its structure (with a better surface) would allow $\lambda = 15$ cm; Str. 2e/21 has exactly the same weight, but beats the wavelength by a factor 3.6, which clearly shows that $\lambda > \lambda_{sv}$ is uneconomical. Comparing Str. 2e/18 with Str. 2e/21, we find a weight ratio of 748/476 = 1.57, but a performance ratio of 4.2/2.0 = 2.10, which shows that the best economy does not start right at $\lambda = \lambda_{sv}$ but somewhat below it. In conclusion, after all these considerations, we have chosen Str. 2e/18 with $\underline{\lambda = 2 \text{ cm.}}$

## IV. Optical Pointing Method

In most radio telescopes the pointing is measured at the axes or drive rings (too far away from the telescope surface), and with respect to some structural elements or rails (stressed by heavy loads). The most logical way seems to be: measuring the pointing where it matters (right at the apex), and with respect to something unstressed and unmovable (fixed points on the ground). This can be done by optical means.

Some satellites, rockets and balloon telescopes use already optical pointing devices "locked-in" to the bright rim of earth or sun, or to some brighter stars. With the help of J. Findlay we have started an investigation into the availability, accuracy and cost of such devices. The basic idea of their application is described in Figure 1. In principle, we need three beacons, and only two if the direction of gravity is measured independently by some pendulum. Actually we should have about twice as many, because the light paths will occasionally be blocked by structural parts. This method does not work in heavy fog or cloudburst, but then we cannot observe at short wavelengths anyway; and since no high accuracy is needed for long wavelengths, the telescope might have an additional pointing system of conventional type for those cases.

The method has two major advantages. First, it keeps the pointing accuracy completely independent of the accuracy of elevation rings and azimuth rails. As far as pointing is concerned, one could as well drive the telescope on a dirt road. Actually, one would use standard railroad equipment[4)] for the azimuth ring, with 100,000 dollars per mile for material and erection, 400 dollars per mile and year for maintenance, and an accuracy of 1/4 to 1/2 inch vertical and lateral. The maximum lateral load is 5 per cent, and the maximum longitudinal load 10 per cent, of the downward load.

Second, with respect to thermal deformations, constant wind loads and all gusts slower than the servo loops, we omit completely all deformations occurring between apex and ground (in telescope suspension, bearings, elevation ring, towers, rails and foundations). The pointing errors from wind deformations thereby are cut down by a factor of 4.2, and those from thermal deformations by a factor of 3.1 (both values from our present design of dish and towers). At the same time,

4) LFST Report No. 14; Sept. 1966.

the price of foundations and rails is cut down by a factor of about 7 (from an estimate by Sidney Smith).

## V. Structure 2e/18 and Towers

The dish structure is shown in Figure 2. On top of two towers, we hold two elevation bearings (points 25 and 26), from which two suspensions of three bars each hold an octahedron, thus including the feed supports in the basic structure. The horizontal square of the octahedron then is used for obtaining an octagon. From the octagon and its center, 9 points, we reach the 13 surface points with a layer of 45 bars. The surface structure is represented by 28 surface bars, and the surface itself by an additional load of 15,000 pounds per surface point. The focus is at point 23 (going from zenith to horizon, a focal adjustment of only 0.48 inch is needed). Each bar of the structure, actually, is a built-up member as shown and explained in Figure 3. Because of the present memory limit, we could not attach an elevation ring to the telescope.

The design of the towers is shown in Figure 4. Each tower is a tetrahedron; two legs of each tower sit on wheels on the azimuth ring, the third legs of both towers meet at a strong central pintle bearing. The third legs are slightly bent at point 5 (and braced against points 2 and 3) for allowing more clearance for the dish structure. The elevation drive sits at point 6. The central pintle bearing takes up all lateral forces from the wind, thus leaving none for the rails. The weight of towers and dish turned out to be sufficient for preventing uplifting forces. The towers are designed just for survival; no extra strength for wind deformations is needed if the optical pointing is used. Both towers (including points 6, 7 and 8) have a total weight of 583 tons.

Since no accuracy is needed for the rails, and since only downward forces remain (except some longitudinal forces from asymmetric wind gusts and for acceleration), we use normal railroad, with double tracks for a better distribution of the weight. The force of each tower leg is distributed by a leg support (heavy beam or truss) on three gondolas (heavy freight cars), stripped of springs, walls and other things.

## VI. Price Estimate for D = 300 ft and $\lambda$ = 2 cm

| | Amount | Price | M $ | Sum |
|---|---|---|---|---|
| 1. Dish | | | | |
| back structure, steel | 590 tons | 1300 $/ton | 0.767 | |
| surf. structure, steel | 100 | 2000 | .200 | |
| surf. skin, 1/8 inch alum. | 58 | 5000 | .290 | |
| | 750 tons | | 1.257 M$ | 1.257 M$ |
| 2. Towers | | | | |
| 2 towers proper, steel | 382 tons | 1100 $/ton | .421 | |
| bars for points 6, 7, 8 | 201 | 1100 | .221 | |
| | 583 tons | | .642 | 1.899 |
| 3. Azimuth Ring | | | | |
| gondolas (stripped) | 12 | 30 K$ | .360 | |
| leg supports | 4 | (1/4 of gond.) | .090 | |
| double railway | 1/2 mile | 200 K$/mile | .100 | |
| pintle + stow foundation | | | .200 | |
| | | | .750 | 2.649 |
| 4. Drive System | | | | |
| pointing device + servos | | | .150 | |
| pintle + elev. bearings | | | .120 | |
| drive motors + gearboxes | | | .200 | |
| control panels | | | .060 | |
| on-line computer | | | .100 | |
| | | | .630 | 3.279 M$ |
| 5. Engineering | | | | |
| outside contracts | | | .100 | |
| AUI management | | | .075 | |
| | | | .175 | 3.454 |
| 6. Additionals | | | | |
| service tower | | | .100 | |
| building (5000 ft$^2$) | | | .175 | |
| power line + transformer | | | .050 | |
| water + sewer | | | .010 | |
| road improvement | | | .030 | |
| | | | .365 | 3.819 M$ |

This price estimate is supposed to be realistic. All structural items are based on computer output. Prices for railway and freight cars result from discussions with several railway engineers of the New York Central System. Prices for bearings and drive systems are based on discussions with engineers of the LFST group, and T. Riffe provided estimates for engineering and additionals.

The complete telescope and drive system amounts to 3.3 M$. Including engineering, site development, building and service tower, we arrive at a total of 3.8 M$. The fact that this price seems extremely low as compared to other telescope projects, is mainly explained by four reasons:

1. Homologous deformations can be achieved without paying any price (see the comparison of Structure 2e/21 with the NRAO 300-foot, Section III).

2. We have developed a nice, fast and flexible computer program for structural analysis, and we do not pay for computer time. This allows trying many improvements until a minimum weight is obtained.

3. A very cheap azimuth ring is made possible by the optical pointing system.

4. The pointing error from wind deformations is reduced by the optical pointing system, without which much heavier towers and a somewhat heavier dish structure would have been needed.

## VII. Location

A very good location for a large future telescope was found in the Greenbrier valley. The best point is on State property, separated from the NRAO site only by a single farm which NRAO is buying anyway for avoiding public traffic through our present site. (Not much money is needed for land acquisition).

Seen from the ground at the best point, no point of the horizon is higher than $12^{\circ}$ and no point is lower than $6^{\circ}$, which provides nice shielding against interference and wind without blocking too much sky. The site is about 150 yards from a dirt road which needs some improvement. There is no public traffic in this valley, except for a railway beyond the river, which runs only twice a week. If a temporary bridge is built, all heavy equipment, structural parts and railroad material can be brought per railway right to the site, which eases the erection considerably.

Observation at 2 cm might be troublesome at Green Bank and is better in Arizona; erection and operation is easier here. For a final conclusion, the time lost by bad weather at Green Bank must be compared with the time lost by delayed receiver repair in Arizona.

## VIII. Other Choices of D and $\lambda$

There is nothing magical about a diameter of 300 feet. In our homology study, this value was chosen just for comparison with our present NRAO 300-foot. If the financial situation would allow, one certainly would like to build something bigger and better.

The international situation is shown in Figure 5. Jodrell Bank plans and probably builds a 450-foot telescope, probably for 15 cm wavelength. The construction for the Bonn telescope begins right now; it has 100 m (330 ft) diameter for $\lambda$ = 5 cm, but a diameter of 90 m (295 ft) is claimed to be usable for $\lambda$ = 2.6 cm.

Can we build a larger telescope, for achieving a leading position instead of just a catch-up? For all items in the price estimate we have decided with which power of D and $\lambda$ the price should be scaled; and $\lambda$ is chosen according to the procedure of Section III. This leads to the following values (entered also in Figure 5):

| Type | D feet | λ cm | P M$ |
|---|---|---|---|
| mm-telescope | 85 | 0.1 | 2 - 3 |
| Medium size | 300 | 2.0 | 3.82 |
| | 350 | 2.5 | 5.10 |
| | 400 | 3.0 | 6.69 |
| LFST | 500 | 4.0 | 11.10 |
| | 600 | 5.0 | 17.07 |

Up to now, our design studies have been made in a more general way, where the results can be scaled up or down in diameter. But after a while, we must settle on one or two given diameters for working out the details. We would appreciate opinions as to which diameter is the most desirable one and still financially feasible.

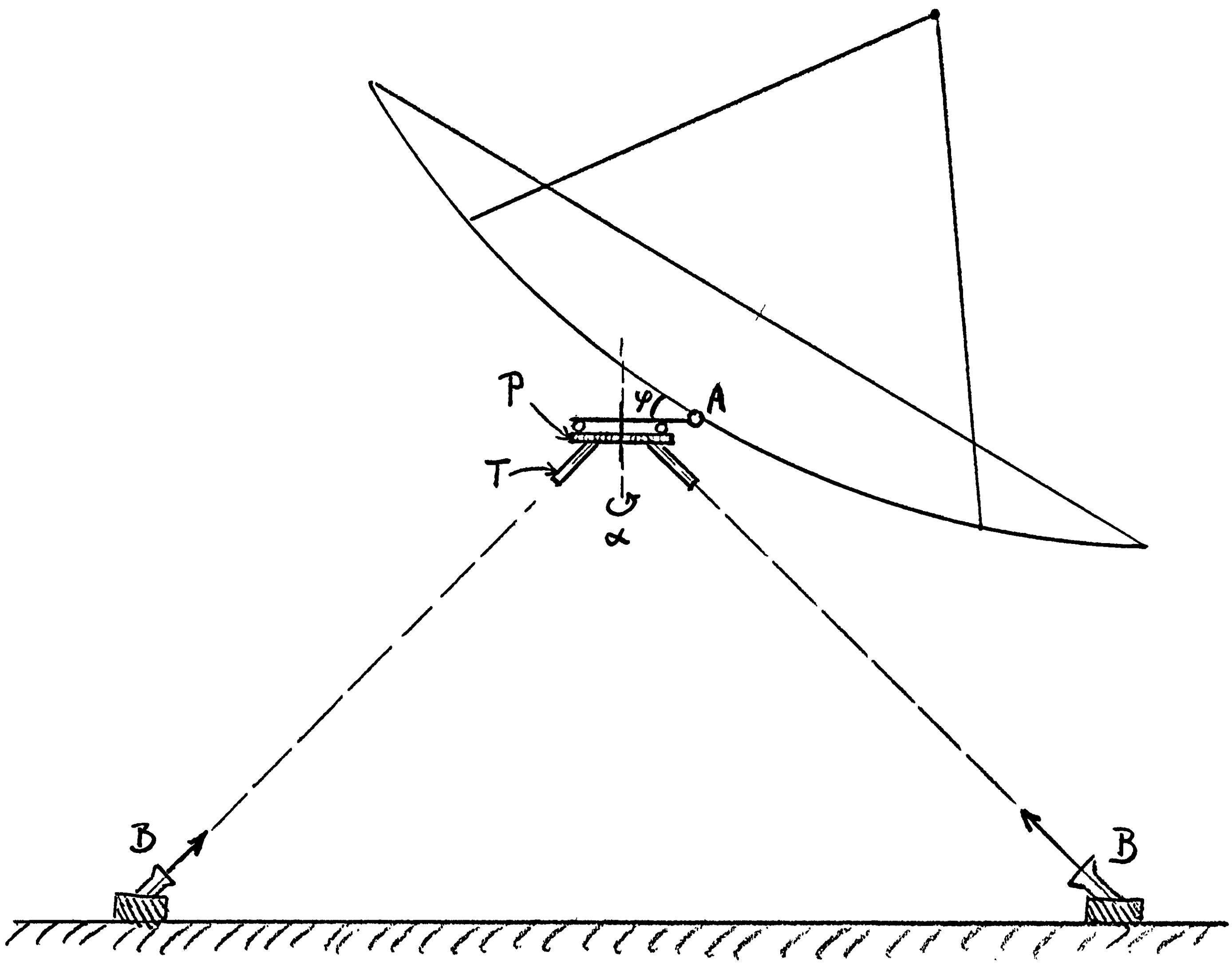
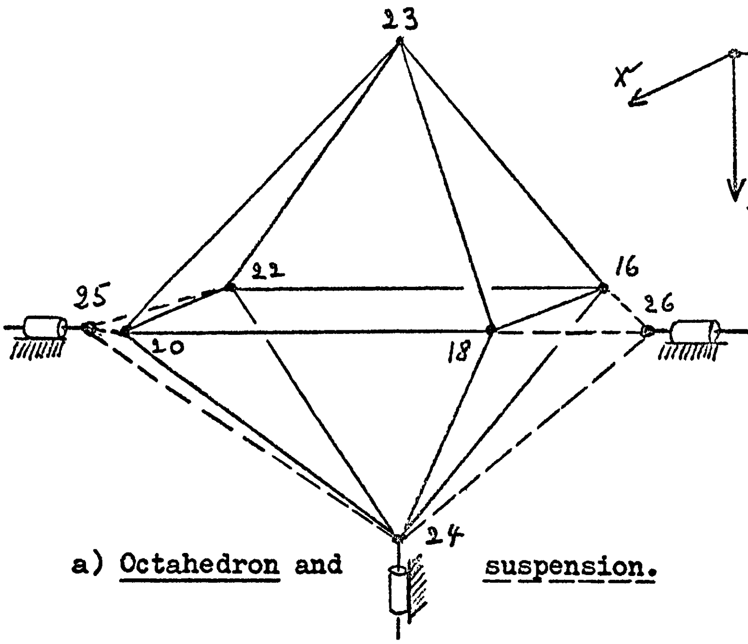
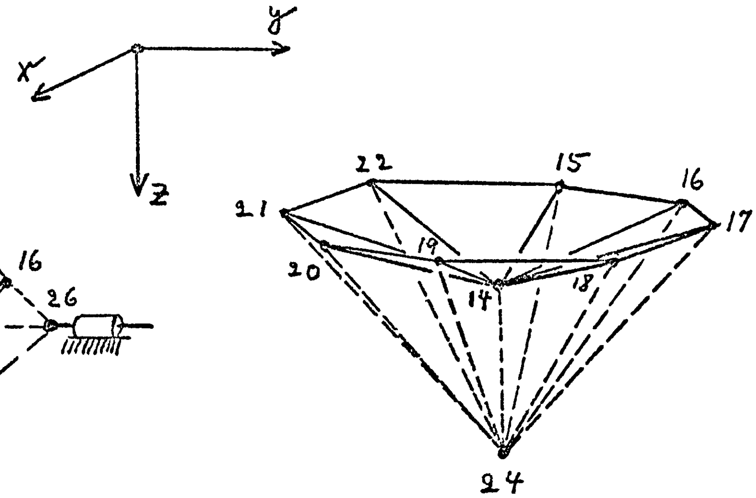



Figure 1. Position measurments by optical means.

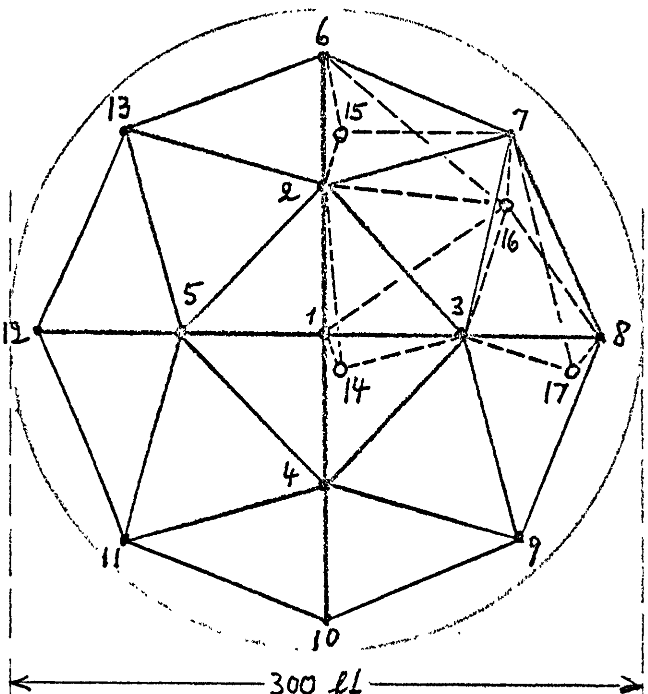
A small tiltable and rotatable platform P is mounted behind the apex A and looks with about six theodolites T to as many optical beacons B fixed at the ground. Three servo motors keep the platform "locked-in" to the beacons; elevation φ and azimuth α then are measured between structure and platform. In this way, the position is measured where it matters and with respect to something unstressed and unmovable. No high accuracy is required for foundations, azimuth rails and elevation ring; also, all deformations between apex and ground are omitted.



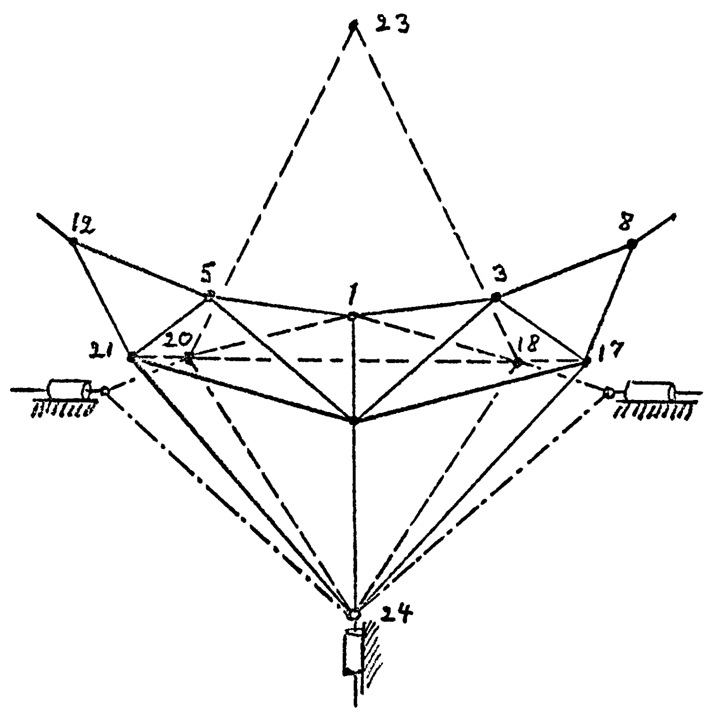

a) Octahedron and suspension.




b) Octagon and layer 1.




c) Surface and layer 2 (one quadrant).
Circle = rim of surface pannels.




d) Side view of plane 12-8-24, octahedron and suspension.

Figure 2. Geometry of Structures 2e/4 to 2e/21. The basic structure is an octahedron, held by a suspension from two elevation bearings mounted on top of two towers. This structure has 13 homologous surface points, a total of 26 points (pin joints) and 112 members.

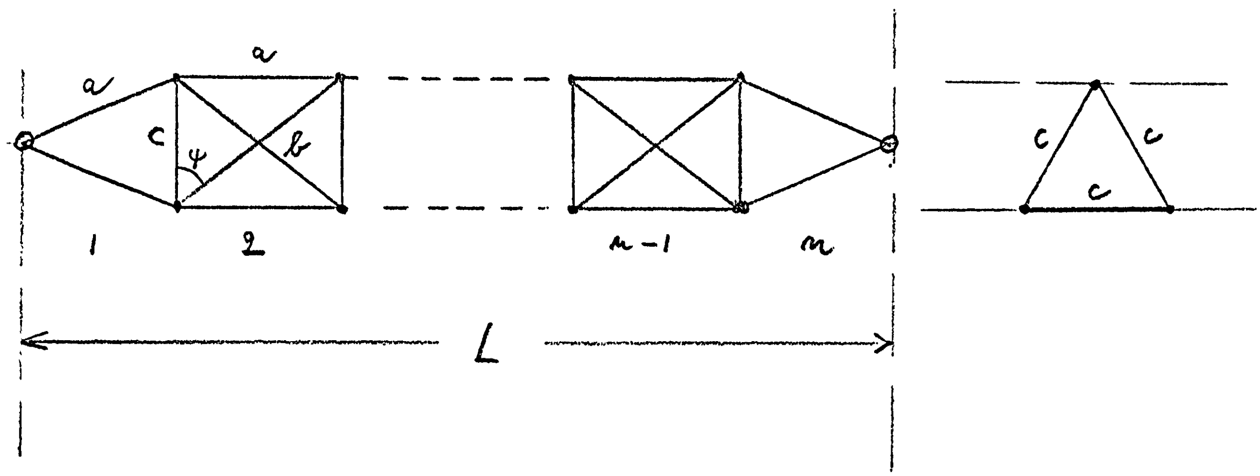
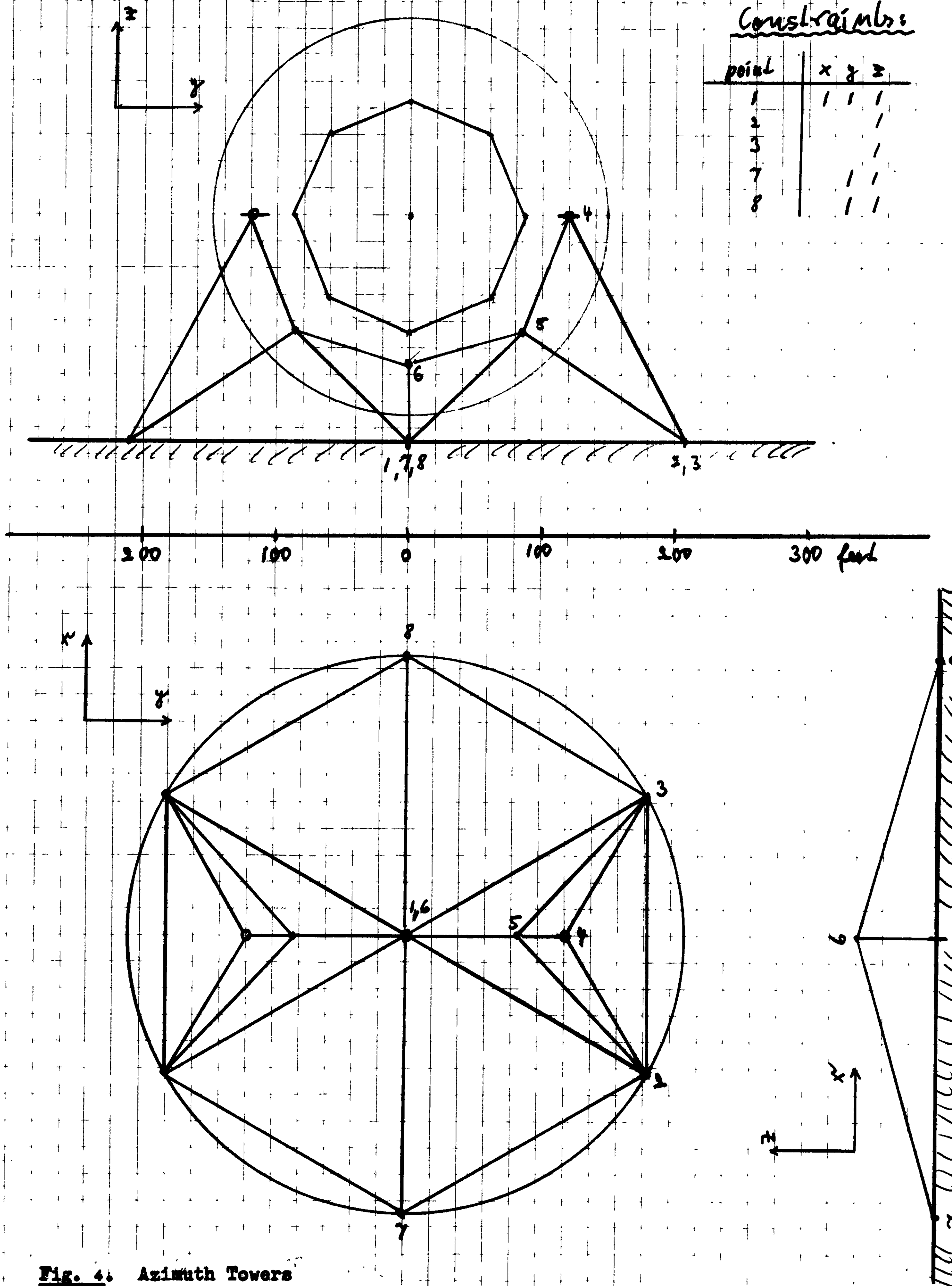



Figure 3. Built-up structural members.

In principle all members could be different; but at present the same values are adopted for all members: $n = 10$, $\psi = 55^{\circ}$, $A_b = A_c = 0.3\ A_a$. This built-up member then is represented in our program by a single shape or pipe of area $A = 3.84\ A_a$, density $\rho = 1.19\ \rho_o$, and unchanged elasticity E. With respect to stability, we call $\Lambda$ the $\ell/r$ ratio of the single chord, use standard pipes of the Steel Construction Manual, and obtain $\Lambda = L\ /\ (2.88\ A^{2/3})$.




Constraints:

| point | x | y | z |
|---|---|---|---|
| 1 | / | / | / |
| 2 | | | / |
| 3 | | | / |
| 7 | | / | / |
| 8 | | / | / |

**Fig. 4.** Azimuth Towers

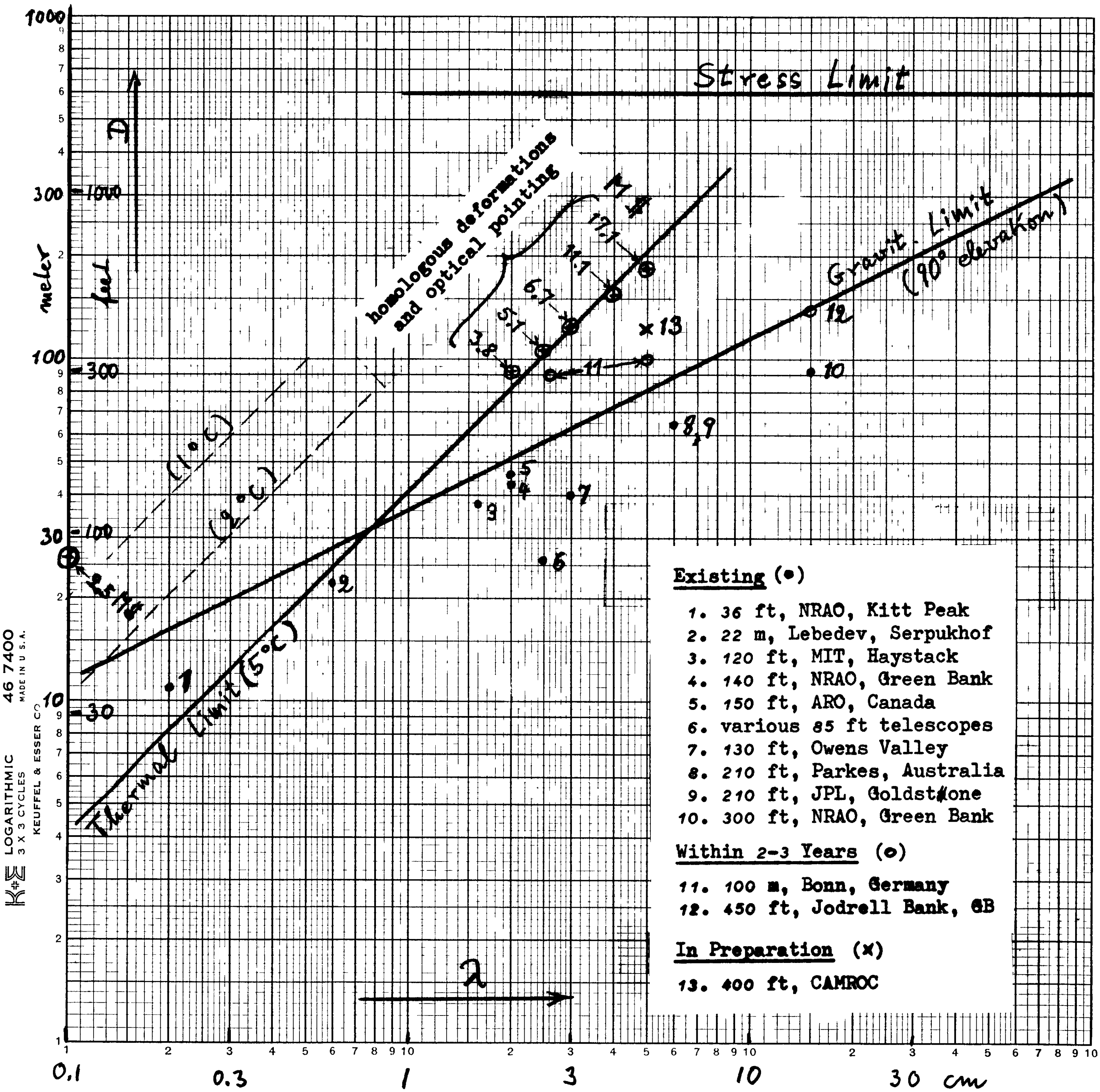



**Fig. 5.** Diameter D and shortest wavelength λ.
Three natural limits for tiltable, conventional telescopes.
⊕ = suggestions from present design study

## Addendum of April 30, 1968

### 1. Homology Program

The new version of the program has been finished by Woon-Yin Wong. It assumes a symmetrical structure and calculates only one quadrant, thus allowing more complicated structures. The old version was memory-limited to N = 13 homologous surface points, the new one should allow up to N = 80. The calculation time is cut down by a factor 4 at present, and some planned minor changes will give a further cut of about a factor 3.

Furthermore, the new program checks the buckling stability of each member and develops only such homology solutions where all stability criteria are fulfilled. This cuts down considerably the number of tries needed until a practical solution is reached.

This program is very flexible and can be run in a variety of modes, depending on 8 decision parameters given with the input data. Except for the reduction of calculation time, no further change is planned.

### 2. Built-up Members

A separate program for investigating and optimizing the single built-up members of the telescope (see Fig. 3) is made by A. Rahim; it is finished except for some minor improvements and additions.

The homology program considers each member as a single pipe with an "equivalent bar area" and "equivalent density", and the buckling stability is estimated by a special formula developed for this purpose. All of this then is checked in detail by the built-up member program. It receives as input the length and equivalent bar area of any member, as resulting from the homology program, and 4 parameters defining the way in which to build up this member (number of segments, angles, area ratios). The program then calculates the actual weight and stiffness of this member, and the buckling stability for all its individual parts under given external loads plus dead load and survival wind force. The results then are compared with the equivalent values as used in the homology program, and any changes needed are calculated.

In some preliminary tries, not much change was needed. Final results should be available within a few weeks, but no drastic surprises are expected. It seems that we have already used quite reasonable estimates for the behavior of the built-up members. The most to be expected is a change of, say, $\pm$ 10 per cent for the total weight of the telescope.

In preparation is an additional part of this program, which replaces each computed bar area by the one most similar to it as offered in the steel manual (off-the-shelf pipes). Again, the changes needed for the homology program then are calculated.

3. <u>New Structures</u>

In order to reach finally about N = 80 homologous surface points, we decided first to develop a good structure with about N = 20, and then to try whether we can get N = 80 by a single additional layer.

At present we have finished <u>Structure 4</u> with N = 20, having a total of p = 37 pin joints and m = 127 members. It has the same weight, wind deformation and survival strength as the old Structure 2e/18 (see page 5) with N = 13. A second one, <u>Structure 5</u>, is almost finished, with N = 24, p = 53, and m = 199. The distribution of its surface points is shown in Fig. 6 and was chosen in such a way that the design of the additional layer should be most easy. We are still working at it, and the final version should be at least as good as 2e/18 or slightly better.

As soon as Structure 5 is satisfactory, we will add one layer for N = 80. When this is finished, each member goes through the built-up member program to be analyzed and optimized, and the computed areas are replaced by off-the-shelf pipes. The resulting equivalent values then go back to the homology program which then tells whether this structure is good enough, or whether it needs improvement. Maybe we have to go back and forth between the two programs a few times until a final solution is reached. For comparison, we show the number and size of surface panels:

| Structure | N | surface panels | |
|---|---|---|---|
| | | number | size (feet) |
| 2e/18 | 13 | 16 | 96 |
| 5 | 24 | 21 | 64 |
| final | ≈80 | ≈40 | ≈30 |

## 4. Optical Pointing System

With John Findlay's help we have asked 10 firms whether they have something to offer. Positive replies came from two, Autonetics and Kollsman. Whereas the "Auto-collimator" from Autonetics would need quite some change and development, the "Beacon Tracker" from Kollsman seems to fit exactly our purpose. They suggested a demonstration, and maybe we should go and see it. The price is, with 200 K$, only a little higher than my old wild estimate of 150 K$, but the servos would now be in addition, see page 8. (All details will be worked out by O. Heine, Los Angeles.)

### Beacon Trackers from Kollsman

| | | |
|---|---|---|
| 5 beacons: | pulsed arsenide diode, 5000 Hz, 80 microwatt output; | |
| 5 sensors: | quadrupel silikon cell, analog output $\leq$ 40 microwatt;<br>signal/noise $\geq$ 40,000, in full sun shine; | |
| optics: | 1 inch diameter, 10 inch long | |
| accuracy: | electronics $\pm$ 3.0 arcsec<br>structural (temperature) $\pm$ 3.5 arcsec | total $\pm$ 4.8 arcsec; |
| field of view: | $\pm$ 2 arcmin; | |
| delivery time: | 9 months | |
| price: | 195 K$. | |

## 5. Several Possibilities

Some Telescopes with Homologous Deformations.

| D feet | $\lambda$ cm | $\beta$ arcsec | N | $\Delta T$ $^oC$ | $\Delta A/A$ per cent | n | $\ell$ m | W (exposed) tons | Price (total) M$ |
|---|---|---|---|---|---|---|---|---|---|
| 85 | .1 | 10 | 17 | .8 | 9 | 165 | .11 | 100 | 2 - 3 |
| 300 | 2.0 | 54 | 10 | 4.5 | 18 | 60 | .96 | 755 | 3.82 |
| 350 | 2.5 | 58 | 11 | 4.8 | 17 | 58 | 1.20 | 1250 | 5.10 |
| 400 | 3.0 | 61 | 12 | 5.1 | 16 | 56 | 1.35 | 1600 | 6.69 |
| 450 | 3.5 | 63 | 13 | 5.2 | 13 | 53 | 1.50 | 1900 | 8.70 |
| 500 | 4.0 | 65 | 14 | 5.4 | 13 | 50 | 1.80 | 2400 | 11.10 |
| 600 | 5.0 | 67 | 16 | 5.6 | 13 | 47 | 2.10 | 4200 | 17.07 |

Free Choice:

$$\left.\begin{array}{l} D = \text{telescope diameter} \\ \lambda = \text{shortest wavelength} \end{array}\right\} \quad \beta = 1.2\ \lambda/D = \text{half-power beam width}$$

Requirements:

N = minimum number of homologous surface points (at present we have N = 24; the planned structure should have N = 80).

$\Delta T$ = maximum tolerated temperature differences in the structure (good protective paint gives about 5$^o$C in sunshine)

$\Delta A/A$ = maximum tolerated rms deviation of bar areas from computed values (off-the-shelf structural pipes give 10 per cent).

Surface:

n = minimum number of toroidal panels

$\ell$ = maximum size of flat plates

Weight (of elevation-moving structure: dish, surface, feed-legs) = W

exposed: a) wind deformation $\leq \lambda/16$ for 17 mph on ground (22 mph at 300 ft height)

b) survival = 20 lb/ft$^2$ of snow, or 4 inch solid ice, or 90 mph on ground (110 mph at 200 ft height).

comparison: the NRAO 300-ft telescope ($\lambda$ = 15 cm) has W = 450 tons.

Price includes towers, drive and pointing, foundations, engineering.

## 6. Future Work

First, we need a decision as to the actual diameter D and wavelength $\lambda$. I would suggest accepting the wavelengths as given for each diameter on page 20; they are already carefully chosen for an optimum performance/price ratio, within the limits discussed on page 4. The first telescope (85 ft) can observe at $\lambda = 1$ mm only during the night ($\Delta T = 0.8\ ^{o}C$); during the day, the limit is 2.5 mm if shadow is provided by an open dome ($\Delta T = 2\ ^{o}C$), and 6 mm in full sunshine ($\Delta T = 5^{o}C$). All other telescopes (300 - 600 ft) can observe in full sunshine at ~~a~~ the wavelength given on page 20.

The choice of the diameter is necessarily like gambling. We must guess as to how much money we can ask for after, say, one year from now. This guess then decides our choice of D. But if the actual financial situation in a year is better than anticipated, we then are left with too small a telescope; whereas if it is worse, we are left with none.

Any suggestions and comments are welcome. My own suggestion would be to decide on 400 ft, say, and to make a detailed design only for this diameter. But a less detailed one should be also made for, say, 500 ft, just for learning how the scaling of the price will work. Furthermore, I would like to work out a less detailed suggestion for the 85-ft millimeter telescope, in case that the interest in shorter wavelengths keeps increasing as it does now.

Second, once the diameter is chosen, we will work out a detailed design with complete price estimate. The structures of telescope and towers (and a preliminary design for the foundations) will be designed inhouse with Wong and Rahim. The results will be checked later on by Simpson, Gumpertz and Heger, who also can perform the dynamical analysis (acceleration, wind flutter, time constants). For the design of the pointing system, drives, bearings and other details, we have a contract with O. Heine. Our goal is to have this design finished by January 1969.

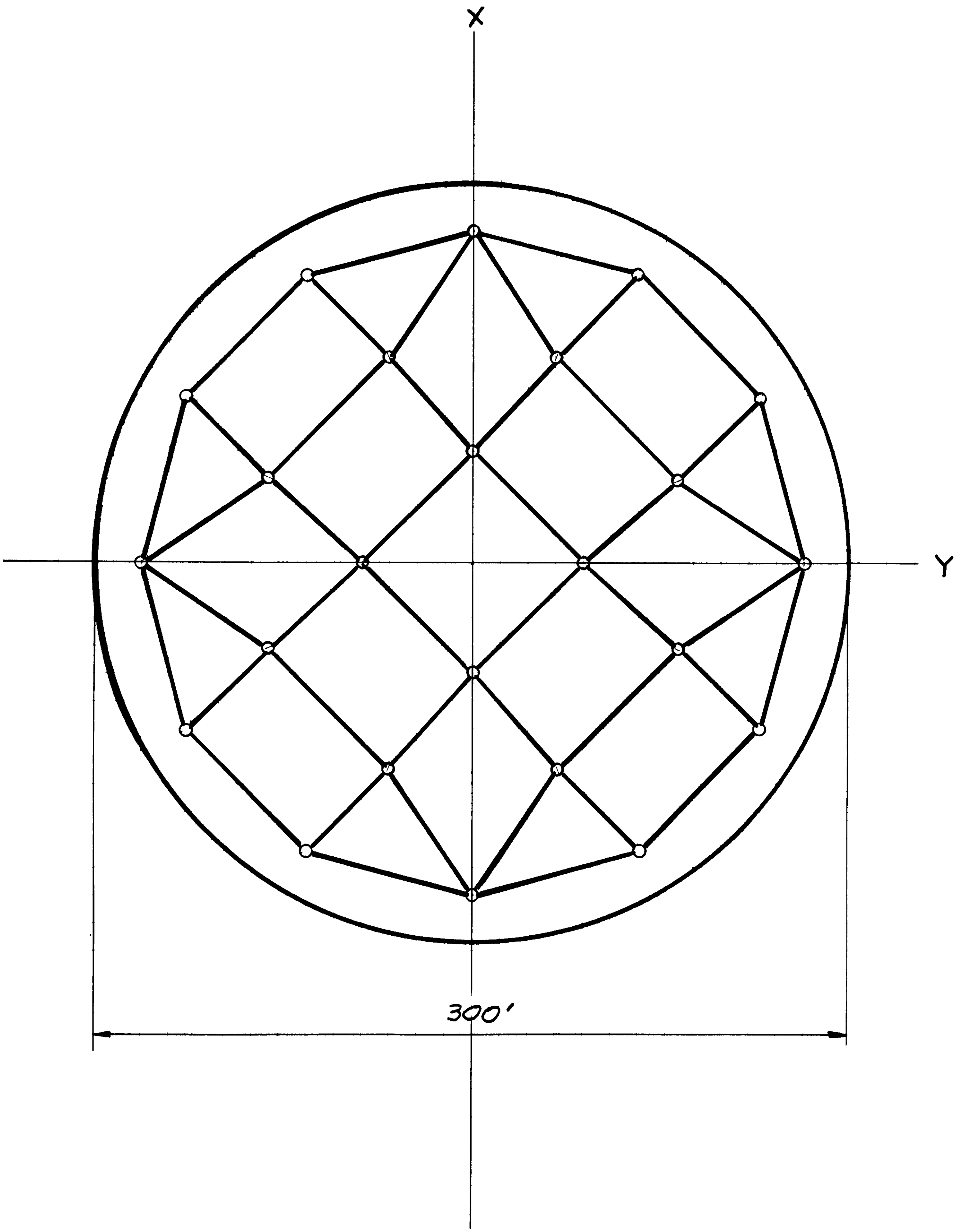



FIGURE 6: Surface of <u>Structure 5</u>, with N = 24 homologous surface points. The remainder of this structure is similar to Structure 2e, see Figure 2a, b, and d. Structure 5 has a total of 53 points and 199 members.