GBT Memo No. 7

Telescope Consultation

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REMARKS ABOUT SCALING AND SURFACE

Summary

The dependence of price on diameter and wavelength frequently is assumed as $P \sim D^{\alpha}/\lambda^{\beta}$, which is misleading: α increases with D and the survival loads; and the λ-dependence is a stepfunction with very low slopes, $\beta \approx 0$, between large steps.

For the new Green Bank Telesope, I derive about $\alpha = 2.5$ if the diameter is D = (100 ± 15) m, and if the price is the total of dish, surface, azimuth-tower, drives, cabins, and foundations. But for the grand total, including building, computer, engineering and site preparation, it is only about $\alpha = 2.1$.

If surface plates for λ= 3 mm (plus thermal blinds if wanted) can be obtained for, say, 1/5 of the total cost or less, we should get them, for the whole surface from center to rim, not to be scaled. Then we just do the best we can about pointing. Only later and experimentally can we determine: whether the whole surface, or how large a central part, can be used for observations at 3 mm, and when and how long are the times of "good seeing".

Especially if later on a method would come for measuring the surface (and pointing) during observation, a large good surface should be available.

If we would choose λ= 6 cm instead (factor 20 up!), as some observers had suggested, the cost would decrease not more than 26%. Or for equal cost, the diameter would be at most 12 % larger.

For 3 mm wavelength, rough estimates are given for: the maximum surface panel length of 105 inch, manufacturing tolerance of 71 μm rms, and the number of about 3000 panels. It is suggested to ask soon for bids about panels, to learn whether 3 mm is reasonable.

Some data about our previous NRAO designs are given, for comparison with the new one.

I. PREVIOUS NRAO DESIGNS

1. Numbers, Types and Weights

Table 1. Surface Plates.
λ = 16*total rms at night; mf = rms of manufactured plates

year	name	λ[mm]	type of surface plates	number	mf[mm]
1969	300-ft	10.0	triangel, flat sheet off shelf	18,000	0.36
1972	65-m	3.3	trapezoid, internal adjustments	2,912	0.076
1975	25-m	1.2	trapezoid, cast and milled	528	0.040

Table 2. Dish and Tower: Numbers

name	interm. panel structures			backup structure		azimuth tower	
	struct.	joints	members	joints	members	joints	members
300-ft	88	350	1253	149	646	12	28
65-m	44	19	180	172	581	10	22
25-m	44	19	180	174	849	10	22

Table 3. Weights, in US-tons (1 ton = 2000 lb = 908 kg)

name	dish, single items			total dish	tower + drives	total all
	surface	backup	counterweight			
300-ft	100	1311	(small)	1411	750	2161
65-m	56	644	80	780	408	1188
25-m	11	56	15	82	48	130

2. Basic Principles

Homologous deformations, for up to 60 backup surface points, and for the intermediate structures, too. The 25-m in astrodome.

Surface plates have limited size: sag and thermal deformations, see Memo 5, May 1988, equations (5) to (8). Thus very large numbers are needed for large telescopes.

"Intermediate panel structures" bridge the distance between the backup surface points, and support each a large number of surface plates. These structures are individually erected on the ground, supplied with their plates, and then lifted onto the backup structure. Probably advisable also for the future telescope.

At the time of the 300-ft design accurate curved surface plates would have been ridiculously expensive. Thus the very large number of flat plates, just aluminum sheet off the shelf, riveted ribs.

II. PRICE AND WAVELENGTH

If we agree that the telescope will be at its best only during favourable conditions (calm nights), then the price of all the structures and foundations will almost entirely be defined by the survival stability, and not by demands on accuracy. The latter can define only the cost of the surface (plus blinds maybe, Memo 63).

For the 65-m design, in 1972 and for λ = 3.5 mm, the cost of the surface was 0.22 of the total. Since steel and labour go up with inflation, whereas techniques improve, I think that a 3 mm surface would now be a much smaller fraction, and even plus blinds would be at most 20% of the total. If so, then a change from, say, λ =3 mm to 6 mm cannot make much difference for the total cost.

This is only different if we are forced to change the design. The 25-m design was to be shielded by an astrodome, which was just as expensive as the telescope itself. The cost for accuracy: dome, surface and location (Mauna Kea), then was 0.75 of the total!

For the other extreme, if our 100-m telescope would change from 3 mm to 6 cm (factor 20!), the structure would stay the same, the surface is negligible, and the cost would go down by at most 20 %. Also, we need no active surface, which saves another 6 % (Memo 51, Table 2). Together, the cost decreases by not more than 26 %. Or, for equal cost, the size would be at most 113 m.

III. ROUGH SURFACE ESTIMATES

If the last statements make sense, then we should try to have a surface for **λ = 3.0 mm wavelength.** Thus the total surface rms is 3mm/16 = 188 µm. Let us assume the following 7 contributions are independent and, for a well balanced error budget, of equal size:

1. Panel manufacturing
2. Panel internal deformations
3. Computer backup model, gravity
4. Surface actuator setting, gravity
5. Backup thermal deformation
6. Backup wind deformation

n = 7. Gain loss, pointing error

Then each single contribution should be $1/\sqrt{n}$ of the total, or 71 µm. Thus we should try to ask for

$$\sigma = 71\ \mu m = \text{manufact.tolerance} = \text{max. rms deformation.} \qquad (1)$$

If there is not much difference between λ = 3 mm and 6 mm for the total cost, then a 3 mm surface of (1) should cover the **whole** telescope up to the rim. We can <u>only</u> experimentally find out which central part of the whole is good for 3 mm under which external conditions. And mainly: if after some years a good method would be available, to measure the surface (or the pointing) during observation, we would be very glad to have already the proper surface.

We now use equations (5) to (8) of Memo 5 (May 1988). Since 71 μm > 46 μm, **gravity** will give the maximum panel deformation and thus will define also the maximum panel length, L. With H = panel height (or thickness), and using L/H = 18, as it was for the 65-m panels, we find from equation (6) a length of 2.66 m = 105 inch. If the panel width is about 0.4 L = 42 inch, then a symmetric telescop of D = 100 m will need almost 3000 such panels, and an offset one about 12 % more. The panels will be in about 20 concentric rings on the symmetric telescope, and on 40 rings if offset.

If all this sounds agreeable, I suggest to ask several firms soon for bids, for the following specifications:

a. 3000 trapezoidal surface panels,
   A) in 20 groups of equal shape
   B) in 40 groups
b. Length = 105 inch, average width = 42 inch, central height 6 inch (or slightly more, if needed for d.)
c. Surface = paraboloid, with 71 μm rms tolerance
d. If supported horizontally at the four corners, the dead load deformation δz should be

$$\mathrm{rms}(\delta z - \overline{\delta z}) \leq 71\ \mu\mathrm{m}. \qquad (2)$$

The answers of the bids then will tell us whether our estimates and the resulting reasoning (3 mm, whole surface) can be used for designing the new telescope.

IV. PRICE AND DIAMETER

If a structure is enlarged but unchanged otherwise, then the length of all members scale in proportion with D, but their diameter and wallthickness are defined by different criteria (loads, slenderness ratio, welding ability) and thus will scale with different exponents of D. Since small exponents will dominate at small D, and large exponents at large D, the log/log plot of P(D) will not be a straight line, but its slope must increase with D. Also, for larger changes of D, optimum structures will be changed.

For changes within, say, ± 15 %, we may neglect the curvature; and if so, we have an overall exponent α, for $P \sim D^{\alpha}$, which is for all items the average of α, weighted with the cost of the items. This was done in detail in connection with the 300-ft design, see Table 4.

If we assume similar cost relations for the 100-m telescope, we obtain from Table 4:

$\alpha = 2.47$, using the total of structures, surface, adjustment, cabins, erection, foundation. (3)

$\alpha = 2.06$, for the grand total, including computer, site preparation, buildings, engineering. (4)

Table 4. Scaling of Price with Diameter, single items, assuming $P \sim D^{\alpha}$.

This table is copied from page 7-4 of "A 300 FOOT HIGH PRECISION RADIO TELESCOPE" NRAO, 1969

Item	300-ft price M$	Subtotals M$	α
Aluminum surface, studs	0.70		2.0
Dish structure	2.62		2.8
Tower structure	1.52		3.0
Track assemblies	0.30		2.9
Foundations + tracks	0.12		1.0
Elevation bearings	0.10		2.8
Pintle bearing	0.06		2.0
Elevation gear	0.03		2.8
Azimuth gear	0.16		2.9
Feed mount	0.05		0
Surface adjustment	0.15		0
		5.81	
Optical pointing (7 beacons, platform, encoders, servo)	0.35	6.16	0
Drive system (amplifiers, console)	0.30		0
Computer	0.10		0
		0.75	
Cabling, catwalks, small items	0.10		1.0
Service tower	0.11		1.0
		0.21	
Building (3000 ft^2)	0.12		0
Power + transformer	0.08		1
Water, sewer, road	0.03		0
Site preparation	0.03		0
Engineering	0.50		0
		0.76	
Total		7.53	
Add 10% contingency		8.28	