Report 29
June 18, 1969

Simplification of Built-up Members

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Summary

The present design uses 12 segments for all members, and the cost of manufacturing these members is about 1/2 of the total cost for heavy members, and about 2/3 for light members. This cost can be reduced by decreasing the number of segments.

Of the dish structure, 23 members in each quadrant (43.0 % of the total weight of the dish) may be replaced by a single pipe. The lowest dynamical frequency of any of these pipes is 2.4 cps; wind-induced vibrations require that 4 of these pipes are made from high-stress steel. If a member is replaced by a pipe of equal stiffness, its weight decreases by 21 % , and its manufacturing cost is eliminated.

A number of 32 members (19.3 % of the total dish weight) may be designed with 4 segments instead of 12, having only 51 single pieces instead of 219. Of the tower structure, 13 out of the 28 members (60.2 % of the total tower weight) may be of a simple design.

All remaining members of dish and towers may have 10 segments instead of 12, which will reduce the manufacturing labour by 20 %.

1. Single Pipes

Many members of the dish structure carry only small loads and have small slenderness ratios. These members may be replaced by a single heavy pipe. The slenderness ratio then increases by a factor 4.77 (see Table 2); the maximum allowed stress decreases by a factor depending on the slenderness, and the stress ratio (maximum prevailing stress / maximum allowed stress) increases by the same factor.

The dish structure has 178 members in one quadrant. Subtracting the surface bars which actually are panels, and the rim of the elevation wheel which must provide a circle for the gear, we have 134 remaining members which are entered in Fig.1 with their slenderness ratio Λ_o and stress ratio Q_o, both values for built-up members of the present design with 12 segments. We call Λ_s and Q_s the values for a single pipe of same stiffness and same load. The borderline between Fields 1 and 2 in Fig.1 then is calculated for the two conditions:

$$Q_s \leq 1.00, \tag{1}$$

$$\Lambda_s \leq 200. \tag{2}$$

All members in Field 1 may be replaced by a single pipe. They are listed in Table 1, and their weight makes up 43.0 % of the total weight of the dish (including panels, but excluding the aluminum plates). Replacing a member by a pipe completely eliminates its manufacturing cost. In addition, the weight decreases by 21 %, since ρ_{eq} = 0.358 for the built-up member, compared to o.283 lb/inch^3 for steel.

Some of these members have very large bar areas, and rectangular combination shapes might be used instead of pipes. For the suspension bars, see Report 22.

Table 1. Listing of 23 members which may be replaced by a single pipe.

1 - 56	22 - 41	38 - 41	51 - 53
5 - 26	25 - 30	43 - 44	51 - 54
6 - 26	26 - 44	44 - 45	51 - 55
8 - 25	27 - 47	45 - 46	51 - 57
11 - 27	34 - 46	45 - 58	57 - 58
19 - 56	38 - 40	46 - 47	

2. Lowest Dynamical Frequency

The lowest dynamical frequency of any single member should be considerably higher than the one of the total telescope (1.05 cps). It must be checked whether the single pipes of Table 1 fulfil this condition.

From equation (3) of Report 20 we derive, for the lowest lateral vibration of a pin-ended pipe of length L, in inch,

$$\nu = 3.12 \times 10^5 \, (L\Lambda)^{-1} \text{ cps.} \tag{3}$$

Or, with $\Lambda = 4.77 \Lambda_o$,

$$\nu = 0.653 \times 10^5 \, (L\Lambda_o)^{-1} \text{ cps.} \tag{4}$$

Fig.2 gives Λ_o and L of all 23 members of Table 1. The straight lines show the lowest frequency ν, if the member is replaced by a single pipe. The lowest value is 2.4 cps, for member 40 - 43. All other members have $\nu \geq 2.8$ cps. It thus seems that vibrations do not impose a problem for the dynamical behaviour.

Wind-induced vibrations could be more serious. But if they are treated as in Report 24, the problem can be solved if 4 of the 23 pipes are made from high-stress steel of 60 ksi yield.

3. Built-up Members with n Segments

One should try to cut down the labour cost by decreasing the number of segments for those members which are not contained in Table 1. But there should not be too many groups with different n. It is suggested to have a total of three groups: (1) single pipes of Table 1; (2) simple members with $n = 4$; (3) all remaining normal members with $n = 10$.

For standard steel pipes, $r = 0.702\ A^{2/3}$; with radius of gyration r, and bar area A. Calling α = (area of main chord) / (equivalent area of member), the slenderness ratio of a chord then is

$$\Lambda_n = \frac{L/n}{0.702\ (\alpha\ A_{eq})^{2/3}} \quad . \tag{5}$$

Table 2. Slenderness ratio Λ, and number of single pieces m, for members with n segments.

n	α	Λ_n/Λ_{12}	m	m/219
12	.250	1.000	219	1.000
10	.253	1.194	177	.808
4	.270	2.860	51	.233
single pipe	1	4.77	1	.005

Some values are given in Table 2, with α from our member program. Using these numbers, the borderlines in Fig.1 then are calculated under conditions (1) and (2). We arrive at the following results:

First, all members may be designed with $n = 10$ segments instead of 12. For two members (19 - 21 and 22 - 26), A must be increased, by less than 10%, for moving them from Field 4 into Field 3. The reduction from 12 to 10 segments decreases the number of pieces, cuttings and weldings by 19.2 % , see Table 2. The manufacturing cost will decrease by a comparable amount.

Second. We have 32 members in Field 2. Their weight is 19.3 % of the total weight of the dish (including panels, excluding aluminum plates). These members may be designed with only 4 segments, which means 2 end-pyramids and only 2 segments with battens, diagonals and triangles. This simple design has only 51 single pieces, instead of 219 for $n = 12$ or 177 for $n = 10$. All members of Field 2 are listed in Table 3.

Table 3. Listing of 32 members with 4 segments.

1 - 21	11 - 36	30 - 31	40 - 43
2 - 56	21 - 38	30 - 43	41 - 45
3 - 56	21 - 40	32 - 33	41 - 47
4 - 25	22 - 23	33 - 34	43 - 51
7 - 27	22 - 38	36 - 46	45 - 57
9 - 25	25 - 45	36 - 47	47 - 57
9 - 30	27 - 28	38 - 57	51 - 52
9 - 32	27 - 36	38 - 58	56 - 22

Field 1 (single pipes) and Field 2 ($n=4$) together make up 62.3 % of the total dish weight, leaving only 37.7 % for the normal members with $n = 10$.

4. Tower Members

All heavy or shorter tower members may be designed in a simple way; either with 4 segments, or from rectangular combination shapes with bracing plates. They are listed in Table 4, and their weight is 60.2 % of the total tower weight. The remaining tower members may also be designed with only 10 segments.

Table 4. Listing of 8 tower members of simple design.

1 - 5	1 - 7	3 - 4	5 - 6
1 - 6	2 - 4	4 - 5	6 - 7

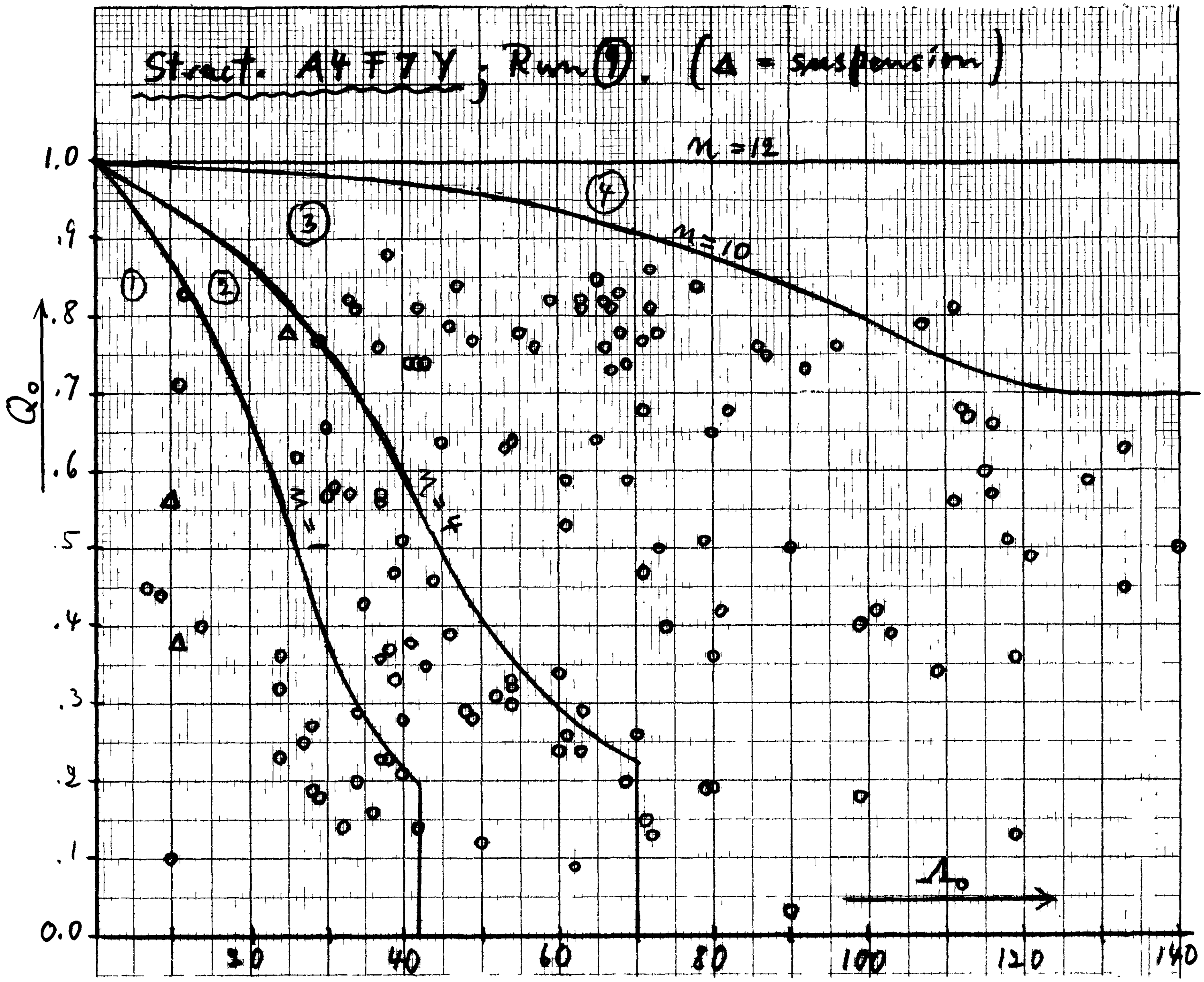

Fig. 1. All members of the dish structure (except surface and elevation wheel).

Λ_o = slenderness ratio, Q_o = stress ratio } present design, 12 segments.

Field	members	
(1)	23	single pipe
(2)	32	4 segments
(3)	77	10 segments
(4)	2	increase A by 10%

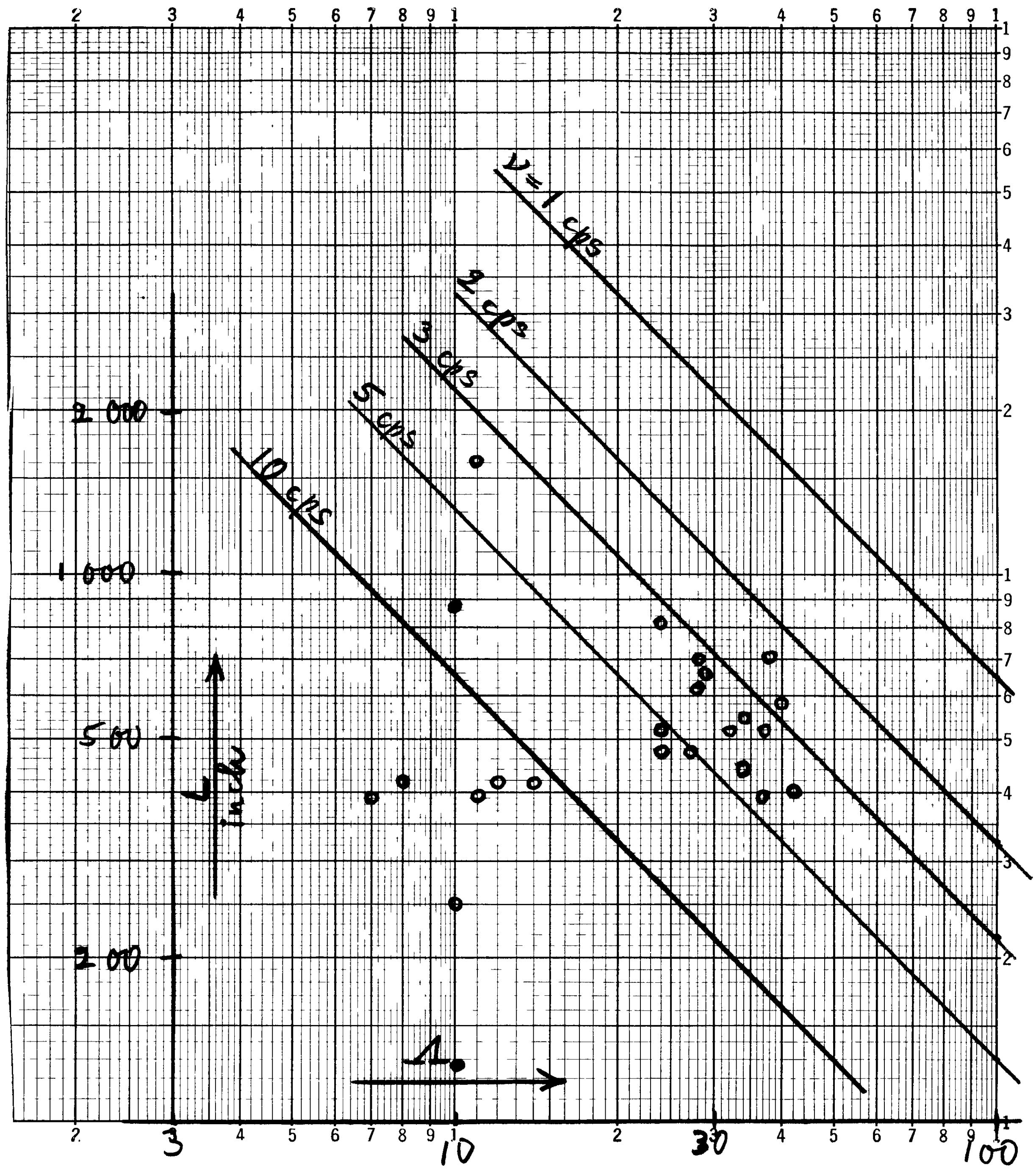

Fig. 2. Lowest dynamical frequency ν (lateral vibration), of all members of Table 1, if replaced by a single pipe.

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DEAR SEBASTIAN:

APRIL 24, 1969

THANK YOU FOR YOUR LETTER OF APRIL 20 REGARDING THE UNIT COST SCALING FOR THE STRUCTURAL WORK OF THE HOMOLOGY TELESCOPE.

I HAVE REVIEWED YOUR DERIVATIONS AND THINK YOUR SCALING FOR WELD LENGTHS IS CORRECT.

HOWEVER, WELDING COST IS ALSO DEPENDING UPON WELD SIZE WHICH IN THIS CASE SHOULD BE EXPRESSED AS FUNCTION OF WALL THICKNESS, SO THAT ANOTHER SCALING FACTOR SHOULD BE INTRODUCED.

I HAVE PLOTTED AVERAGE WELDING DEPOSITION RATES VS. PLATE THICKNESSES FROM INFORMATION CONTAINED IN "WELDING ENGINEERING" BY ROSSI. AS YOU CAN SEE THIS CAN ALSO BE EXPRESSED AS AN EXPONENTIAL FUNCTION.

BUT WE MUST ALSO REMEMBER NOT TO USE SMALLER THAN SAY .10 IN AVERAGE WALLS, THUS THE SMALLER DIA. INSTRUMENTS WILL HAVE THIS ADDITIONAL LIMITATION.

I HAVE PREPARED A COST ANALYSIS (ENCLOSED) CONSIDERING EACH REFLECTOR SIZE AND HAVE COMPUTED WELDING, FITTING, MATERIAL & ERECTION COSTS STEP BY STEP SO AS TO BE ABLE TO SEE WHETHER THOSE FIGURES ARE REASONABLE IN EACH CASE AND TO REFLECT THE ABOVE LIMITATIONS.

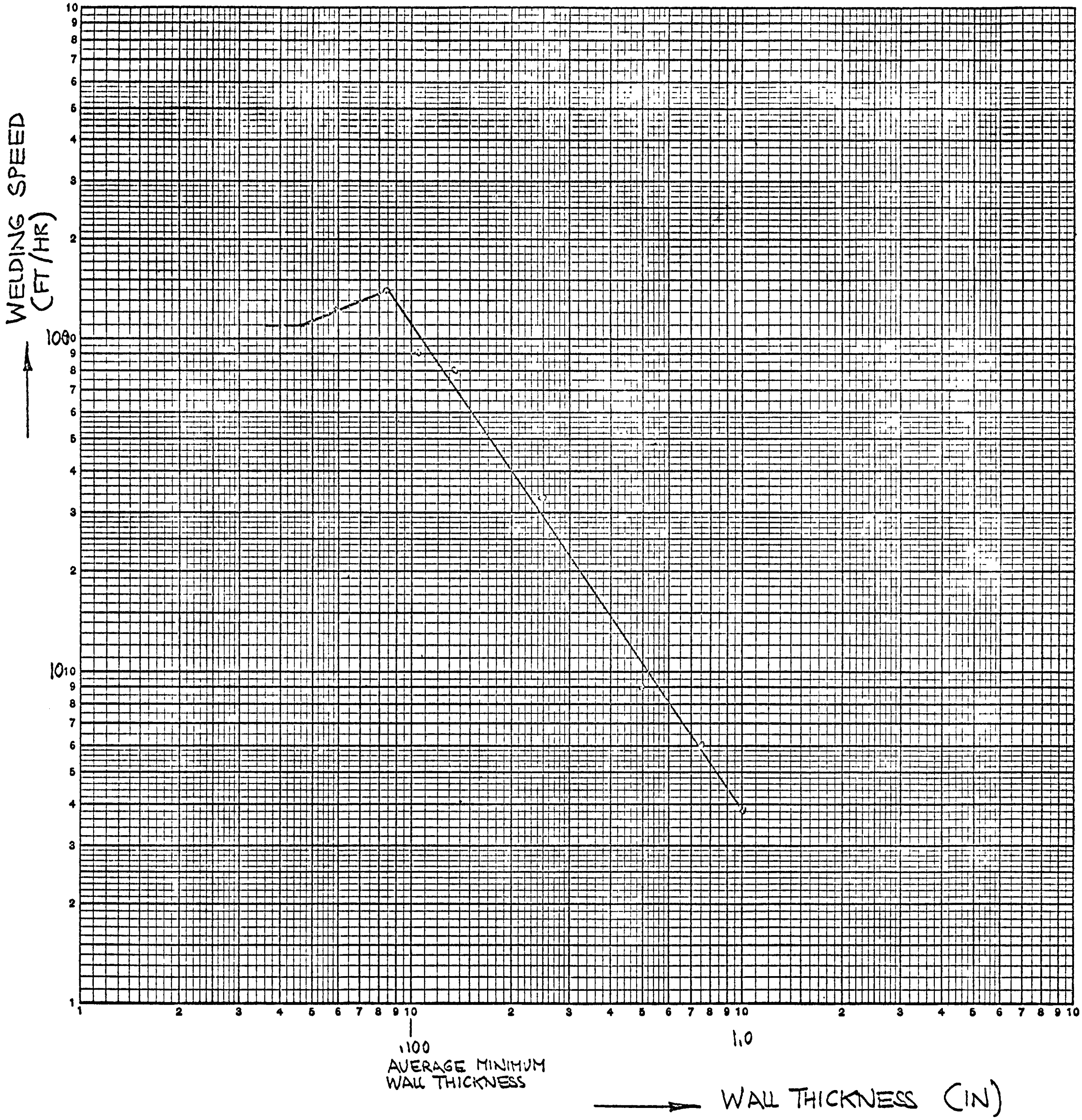
AS YOU CAN SEE I HAVE USED THE EXPONENTS WORKED OUT BY YOU AND HAVE ASSUMED THAT THE FABRICATION COST INCLUDES WELDING COST AT 50% AND FITTING & ASSEMBLY AT ANOTHER 50%. THE WELDING COST PORTION IS THAN VARYING WITH LENGTH AND WALL THICKNESS, WHILE THE FITTING- AND ASS'Y COST PORTION CHANGES ONLY LINEARLY (PIECES BECOME HEAVIER OR LIGHTER RESPECTIVELY).

THE RESULTS OF THIS ANALYSIS ARE SHOWN ON A PLOT OF UNIT COST ($/LB) OF REFLECTOR AND TOWER STRUCTURES V.S. SIZE AND INDICATES A HIGHEST UNIT COST OF $ 1.74 FOR THE 210 FT. UNIT OR A LOWEST OF $.77/LB FOR THE 600 FT. UNIT.

BEST REGARDS,

4/23/69

WELDING DEPOSITION RATES
V.S. WALL THICKNESS



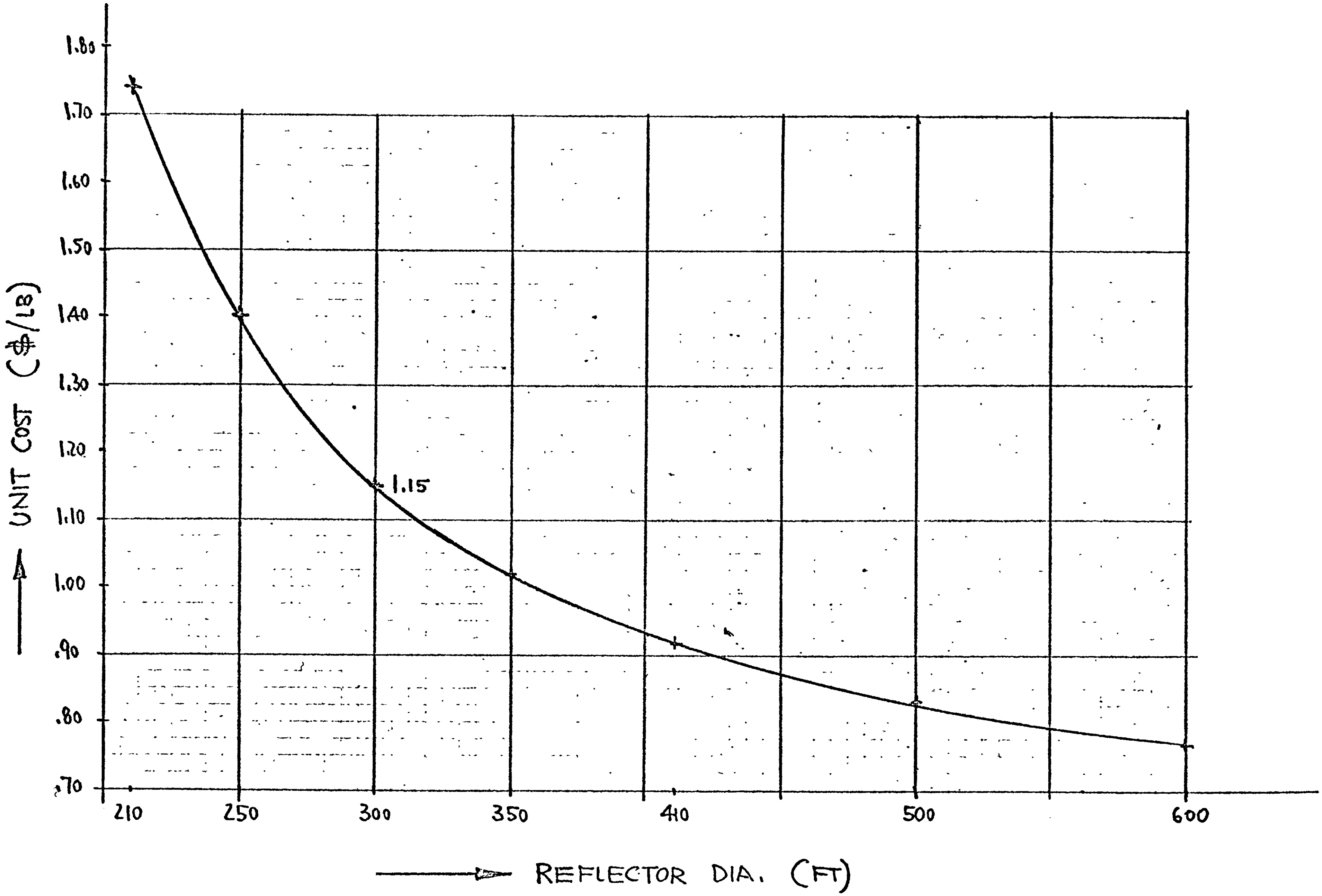
RE: "WELDING ENGINEERING"

4/23/69

COST ANALYSIS, REF[redacted]CTOR & TOWER STRUCTURES ERECTED FOR VARIOUS SIZE HOMOLOGY TELESCOPES

↓ BASIS FOR COMPARISON (300)

REFLECTOR DIA. (FT.)	210	250	300	350	410	500	600	REMARKS
REFLECTOR WT. (LBS) 10^6	.85	1.39	2.3	3.57	5.6	9.7	16.1	VARIES WITH $D^{2.8}$
TOWER WT. (LBS) 10^6	.45	.76	1.3	2.08	3.34	6.1	10.4	VARIES WITH $D^{3.0}$
COMBINED WEIGHT (LBS) 10^6	1.30	2.15	3.6	5.65	8.94	15.8	26.5	
$D/300$ RATIO	.70	.835	1.0	1.17	1.37	1.67	2.0	
$(D/300)^{1.2}$ **	.652	.806	1.0	1.207	1.458	1.85	2.3	RELATIVE DIAS OF MEMBERS – REFLECTOR
$(D/300)^{1.33}$ *	.622	.786	1.0	1.233	1.520	1.976	2.51	RELATIVE DIAS OF MEMBER – TOWER
$(D/300)^{.60} \times .100$ *	.100*	.100*	.100*	.110	.121	.136	.156	WALL THICKNESSES – REFLECTOR (AVERAGE)
$(D/300)^{.67} \times .500$ *	.390	.440	.500	.550	.620	.700	.800	WALL THICKNESSES – TOWER (AVERAGE)
WELDING COST REFLECTOR ($) 10^6	.59	.70	.84	1.18	1.59	2.45	3.73	$W_{CR} = (.84)(D/300)^{1.2} R_F$
WELDING COST TOWER ($) 10^6	.22	.32	.48	.68	.99	1.56	2.43	$W_{CT} = (.48)(D/300)^{1.33} R_T$
COST OF ASSY, FITTING ETC. TOWER & REFLECTOR ($) 10^6	.92	1.09	1.31	1.53	1.79	2.18	2.62	VARIES WITH $D^{1.0}$
COST OF MATERIAL COMBINED ($) 10^6	.26	.43	.72	1.13	1.78	3.16	5.30	$.20/LB × COMBINED WEIGHT
ERECTION COST COMBINED ($) 10^6	−4% .27	−2% .46	.79	+1.7% 1.26	+3.7% 2.05	+6.7% 3.68	+10% 6.40	INCLUDES ESCALATION FACTOR
TOTAL COST ($) 10^6	2.26	3.00	4.14	5.78	8.20	13.03	20.48	
UNIT COST ($/LB)	1.74	1.40	1.15	1.02	.92	.83	.77	
RATIO OF WELDING DEPOSITION RATES – REFLECTOR	1.0	1.0	1.0	$110/95 = 1.16$	$110/85 = 1.30$	$110/70 = 1.58$	$110/57 = 1.93$	R_F
RATIO OF WELDING DEPOSITION RATES – TOWER	$10.5/15 = .70$	$10.5/12.5 = .84$	1.0	$10.5/9 = 1.16$	$10.5/7.8 = 1.35$	$10.5/6.4 = 1.64$	$10.5/5.2 = 2.02$	R_T
								** RE: V. HOERNER RPT #26



UNIT COST ($/LB) OF REFLECTOR- & TOWER STRUCTURES VS. TELESCOPE SIZE FOR HOMOLOGY TELESCOPE

4/23/69