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Telescope Surface Plates with Internal Adjustment

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Summary

A new type of accurate surface plates is suggested for the 65-m telescope. There are 3072 plates, arranged in 17 concentric rings of equal distance. All plates have the same length of 72 inch. In each ring, there are in the average 180 identical plates; their width varies between 17 and 38 inch from ring to ring. In the average, one plate has 15 ft^2 and weighs 48 lb.

Each plate consists of a skin, an upper rib system riveted to the skin, and a lower rib system some inches underneath (all from aluminum, standard pieces). Both ribs are connected by 36 adjustment screws. The plate fabrication may have rather large tolerances, while the accuracy is achieved by adjusting the screws, on a jig with 36 dial indicators. This internal adjustment is to be done by the manufacturer. Later, the four corners of each plate are adjusted on the telescope as usual.

Three plates made at Green Bank workshop gave an rms accuracy, even after walking on them for some minutes, of .0025 inch = .063 mm.

For gravitational deformations, the contribution of the plates to the whole telescope is only .0014 inch = .035 mm. Thermal deformations are .0018 inch = .046 mm for 10 hours at night, and .0083 inch = .211 mm in full sunshine. Wind deformations are .0006 inch = .015 mm for 18 mph.

I. Introduction

The cost of large radio telescopes should mainly be defined by the stability against survival loads, whereas the accuracy should be achieved with only small extra cost. For the 65-m design, this demand is fulfilled for the disch structure (accuracy from homologous deformations) and ~~by~~ for the towers and foundations (optical pointing reference). If possible, the same demand should be applied to the surface, too.

For a wavelength of $\lambda = 3$ mm, the total surface rms error must be $\Delta z \leq \lambda/16 =$ .0074 inch = .188 mm. If n equal independent contributions add up, then each single one must be $\Delta z \leq \lambda/16\sqrt{n}$. In our case $n = 6$ (telescope gravity; panels and plates gravity; telescope thermal; panels and plates thermal; surface plate accuracy; measure and adjust plates on telescope). Thus the manufacturing accuracy of the surface plates must be

$$\Delta z \leq \lambda/16\sqrt{n} = \lambda/40 = .077 \text{ mm} = .0030 \text{ inch.} \qquad (1)$$

The telescope itself will be erected with a rather large tolerance of $\pm$ 1/2 inch, while the accuracy is achieved later on by measuring and adjusting the surface on it. This same idea is now tried for the single surface plates, too. A design is suggested where the accuracy is not specified for the fabrication process, but is achieved later by an internal adjustment. Each plate consists of a skin, a system of upper ribs riveted to the skin, and a system of lower ribs some inch below the upper ribs (skin and all ribs from aluminum). Both ribs are connected by 36 adjustment screws; turning these screws (on a jig with 36 dial indicators) then forms the surface into any shape wanted. This internal adjustment is to be done by the manufacturer before delivery, while the four corners of each plate then later are adjusted on the telescope in the usual way. Both skin and ribs should be taken just as they come from the shelf, which means with some internal "waviness" or bendings. Measurments at Green Bank showed that the accuracy of (1) can be met with a density of at least

$$2 \text{ adjustments / ft}^2 . \qquad (2)$$

II. Dimensions and Specifications

The dish structure of the 65-m telescope provides 60 homologous points. These points support 48 surface panels in a radial pattern, see Fig. 1. Each panel is a space-frame structure of over 200 steel pipes, deforming again in a homologous way, and giving support to 64 surface plates. Each plate is adjusted at its four corners, and thermal expansion is permitted.

Table 1. The 17 groups of surface plates. All plates have the same length $\ell = 72$ inch. In each group, there are n identical plates of lower width b_1 and upper width b_2 (both in inch).

No.	n	b_1	b_2
1	64	13.1	20.0
2	64	20.0	27.0
3	64	27.0	34.0
4	64	34.0	40.8
5	128	20.4	23.9
6	128	23.9	27.2
7	128	27.2	31.5
8	128	31.5	34.0

No.	n	b_1	b_2
9	256	17.0	18.7
10	256	18.7	20.3
11	256	20.3	22.0
12	256	22.0	23.6
13	256	23.6	25.2
14	256	25.2	26.8
15	256	26.8	28.3
16	256	28.3	29.9
17	256	29.9	31.4

The total number of plates is

$$N = 3072. \tag{3}$$

They are arranged in 17 rings of equal distance; thus all plates have the same length of $\ell = 72$ inch, but their width comes in 17 groups as given in Table 1. All plates in one group are identical, in the average there are

$$180 \text{ plates/group.} \tag{4}$$

A typical plate is roughly sketched in Fig. 2, and Fig. 3 shows a small copy of a technical drawing made by J. Ralston. Manufacturing tolerances are:

1. Skin size (ℓ, b_1, b_2)	$\pm$ .01 inch max.	
2. Central rib separation (h)	$\pm$ 1/4 inch max.	(5)
3. All others	$\pm$ 1/16 inch max.	

The total covered telescope surface is

$$\text{surface} = 38{,}300 \text{ ft}^2, \tag{6}$$

and in the average there is

$$12.5 \text{ ft}^2 / \text{plate}. \tag{7}$$

For the sizing of the plates, length ℓ and depth h are defined by keeping thermal deformations ($\sim \ell^2/h$) and gravitational deformations ($\sim \ell^4/h^2$) both small enough. The width b is defined by a maximum of two inner screws and by their density (2). Skin, ribs and screws are sized for a man of 200 lb standing on any place, and a distributed load of 20 lb/ft^2, without giving permanent deformations. The screws have 32 threads/inch, which means an adjustment angle of

$$12 \text{ degrees} / .001 \text{ inch}. \tag{8}$$

The weight is

$$3.8 \text{ lb/ft}^2 = 48 \text{ lb/plate}. \tag{9}$$

The adjustment to parabolic shape is considerably eased if the screws are put in and set while the plate is bent over a central rod on a flat table. The manufacturing procedure then is:

1. Assemble whole plate except adjustment screws;
2. Bend over rod (1/16 inch thick) along long center line; insert all interior screws and tighten nuts;
3. Bend over rod (1/4 inch thick) along short center line; insert all long-side

screws and tighten nuts;

4. Weld counter-nuts to srews;

5. Adjust on jig for parabolic shape, first long-side screws, then interior.

6. Seal all screws with a bit of epoxy.

III. Test Plates Made at Green Bank

Various designs were tried at Green Bank workshop, until the design of Fig.3 emerged. Of this type, 3 plates were made. Plate 1 did not have any weldings and showed too much permanent deformation (.005 inch) after walking on it. Plates 2 and 3 have the weldings of Fig. 3 and are the final design.

1. Measuring Procedure

Measuring (and adjusting) was done with the plate put on a jig with 4 adjustment screws for leveling its 4 corners. A parabolic shape was calculated for a position of 2/3 distance from the telescope center. A vertical precision scale was placed on the point to be measured, reading it with a very accurate level from 5 ft distance. The measuring accuracy (repeatability) was

$$\text{rms error} = .0006 \text{ inch} = .015 \text{ mm.} \qquad (10)$$

Adjusting a plate took 3 hours for two men, but this would be considerably reduced if the manufacturer uses a jig with 36 dial indicaters.

The 36 adjustment screws plus 4 corners give 40 adjusted points. In addition, 48 intermediate (unadjusted) points are measured. Since all points are equally spaced, shorter surface waves are neglected. An estimate showed that this neglection can be corrected by giving the intermediate points a higher weight (1.2). For all averages and rms values, the weights of Table 2 are used.

Table 2. Number n and weight w for averaging 88 measured points.

		n	w	nw
adjusted points	corner	4	.25	1
	side	14	.5	7
	inner	22	1.0	22
	all	40		30
intermediate pts.	side	12	.6	7.2
	inner	36	1.2	43.2
	all	48		50.4
total		88		80.4

2. Surface Accuracy

Rough Setting. Right after bending over central rods and setting the screws, all 88 points were measured and gave the following rms deviation from the true parabolic shape:

plate	rms(Δz)
1	21
2	27
3	37
theory	18

10^{-3} inch, (11)

The last line is the deviation from a parabola, of a beam supported at both ends with a central point load. After a few more trials for finding a better thickness of the rods, one should have about

$$\mathrm{rms}(\Delta z) = .025 \text{ inch} = .64 \text{ mm}. \qquad (12)$$

After Adjustment of the 36 screws, all 88 points were measured again, giving the following deviations from the true shape:

plate	40 adjusted points max(Δz)	40 adjusted points rms(Δz)	48 intermediate points max(Δz)	48 intermediate points rms(Δz)	total rms(Δz)	
1	2.0	.90	5.9	2.40	2.00	10^{-3} inch (13)
2	2.4	1.02	6.7	2.26	1.89	
3	2.4	.94	7.9	3.00	2.43	

From these figures we adopt

$$\mathrm{rms}(\Delta z) = .0024 \text{ inch} = .061 \text{ mm.} \qquad (14)$$

Walking Test. The plate was taken down, supported (skin up) at its four corners, and a man walked on it some minutes; the palte then was put back on the jig, levelled, and measured (= z_u). Then the plate was turned over (skin down) and walked upon, put back on the jig and measured again (= z_d). This was repeated, up and down, five times. The resulting peak-to-peak difference, $Z_d - z_u$, was for the two final plates averaged over five ups and downs:

plate	max(z_d-z_u)	rms(z_d-z_u)	
2	1.73	.87	10^{-3} inch (15)
3	1.50	.95	

From which we adopt

$$\mathrm{rms}(\Delta z) = \mathrm{rms}(z_d - z_u)/\sqrt{2} = .95/\sqrt{2} = .00067 \text{ inch} = .017 \text{ mm.} \qquad (16)$$

Final Accuracy. We add (14) and (16) quadratically and obtain for the adopted final surface accuracy of this type of surface plate:

$$\underline{\underline{\mathrm{rms}(\Delta z) = .0025 \text{ inch} = .063 \text{ mm.}}} \qquad (17)$$

This is even better than demanded in (1). It should be emphasized that a good surface accuracy is more crucial than anything else: gravitational deformations are small for a part of the sky, wind and thermal deformations are small for a part of the time, and a better measuring technique for the telescope may be developed in the future; but the surface accuracy is always the same, all sky and all time.

IV. Various Deformations

1. Gravitational Deformation

The plate was levelled on the jig and measured (z_1). Then a lot of heavy nuts, of the same total weight as the plate, was distributed over the surface; the plate was levelled and measured again (z_2). Finally the nuts were removed and the plate levelled and measured (z_3). The gravitational deformation, $\Delta z = z_2 - (z_1 + z_3)/2$, was for all measured points:

$$\left.\begin{aligned} \max(\Delta z) &= 4.17 \\ \text{average } \overline{\Delta z} &= 2.79 \\ \text{rms}(\Delta z) &= 3.02 \\ \text{rms}(\Delta z - \overline{\Delta z}) &= 1.38 \end{aligned}\right\} 10^{-3} \text{ inch} \qquad (18)$$

In principle, the plates could be adjusted to any shape wanted, for example including a "gravitational offset". But since the gravitational deformation of the whole telescope is larger in zenith position than it is in horizon position, it is best to let the plates do the opposite, which means <u>no</u> offset, if we neglect the curvature of the telescope surface. Titlting the telescope then means, first, a parallel shift in proportion to $\overline{\Delta z}$ which is homologous and does not matter, and, second, a deviation from it in prportion to $\text{rms}(\Delta z - \overline{\Delta z})$. As for the whole telescope, we call ΔH_1 the deviation in zenith position, and ΔH_2 for horizon position, and we have from the plates

$$\begin{aligned} \Delta H_1 &= 0 \\ \Delta H_2 &= .0014 \text{ inch} = .035 \text{ mm} \end{aligned} \qquad (19)$$

which must be added quadratically to the ΔH values of the telescope. Regarding now the actual curvature of the telescope surface is best done by adding a correction to the surface accuracy of (17). But an estimate showed that this correction is so small that it can be neglected.

2. Thermal Deformations

Thermal deformations of the plates are described in detail in Report 36 (Jan. 20, 1971). The result is

$$\left.\begin{aligned} \max(\Delta z) &= 2.58 \\ \text{average } \overline{\Delta z} &= 1.76 \\ \text{rms}(\Delta z) &= 1.87 \\ \text{rms}(\Delta z - \overline{\Delta z}) &= .67 \end{aligned}\right\} \begin{array}{l} 10^{-3} \text{ inch, per } {}^{\circ}\text{F} \\ \text{difference between} \\ \text{skin and rib} \end{array} \tag{20}$$

or

$$\Delta z = \begin{cases} .0018 \text{ inch} = .046 \text{ mm}, & 10 \text{ hours at night;} \\ .0083 \text{ inch} = .211 \text{ mm}, & \text{full sunshine.} \end{cases} \tag{21}$$

3. Wind Deformations

Report 36 also mentions wind deformations, but unfortunately there is a mistake; the plate used was what is called now plate 1, without weldings at the corners, and the wind deformations measured where much too large (factor 2). The following data are from the final plates 2 and 3.

The gravitational deformations (18) apply to a dead load of 3.8 lb/ft^2 according to (9). For the wind load we use a pressure of

$$p = .00256 \text{ lb/ft}^2 \, C_s \, (v/\text{mph})^2. \tag{22}$$

With a shape factor of $C_s = 1.56$ for flat plates in a curved telescope and face-on wind, this is

$$p = 1.29 \text{ lb/ft}^2, \quad \text{for } 18 \text{ mph.} \tag{23}$$

We thus reduce (18) by a factor $1.29/3.8 = .339$, and obtain

$$\begin{aligned} \text{rms}(\Delta z) &= .00103 \text{ inch} \\ \text{rms}(\Delta z - \overline{\Delta z}) &= .00047 \text{ inch} \end{aligned} \tag{24}$$

For a steady wind of 18 mph we should use .00047 inch; for 18 mph on half the telescope and nothing on the other half, we would have $.00103/\sqrt{2} = .00073$ inch, and from an estimate with various wind gusts we adopt

$$\Delta z = .0006 \text{ inch} = .015 \text{ mm}, \quad \text{for } 18 \text{ mph.} \tag{25}$$

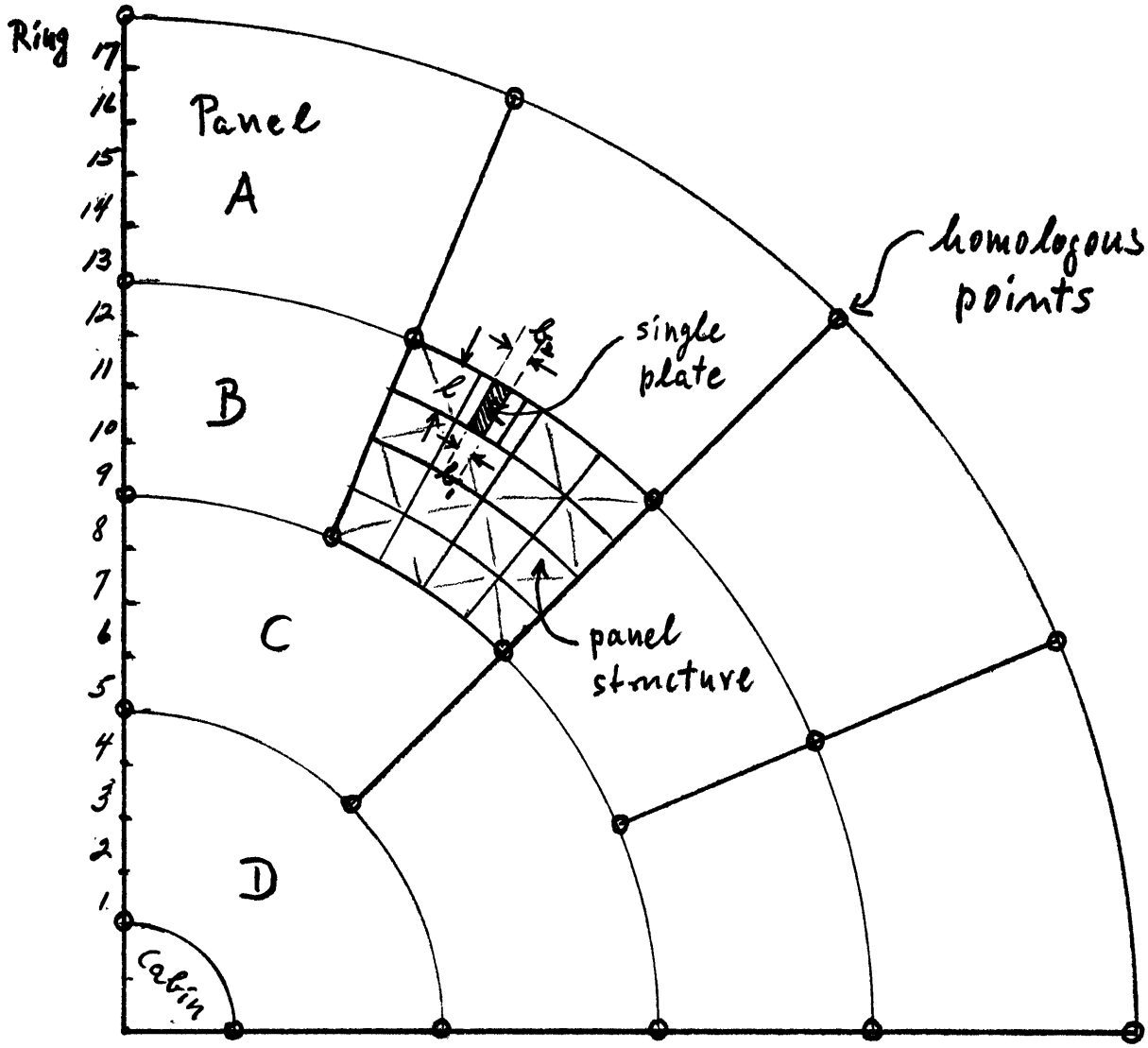

Fig. 1. One quarter of the telescope surface, with panels and one plate.

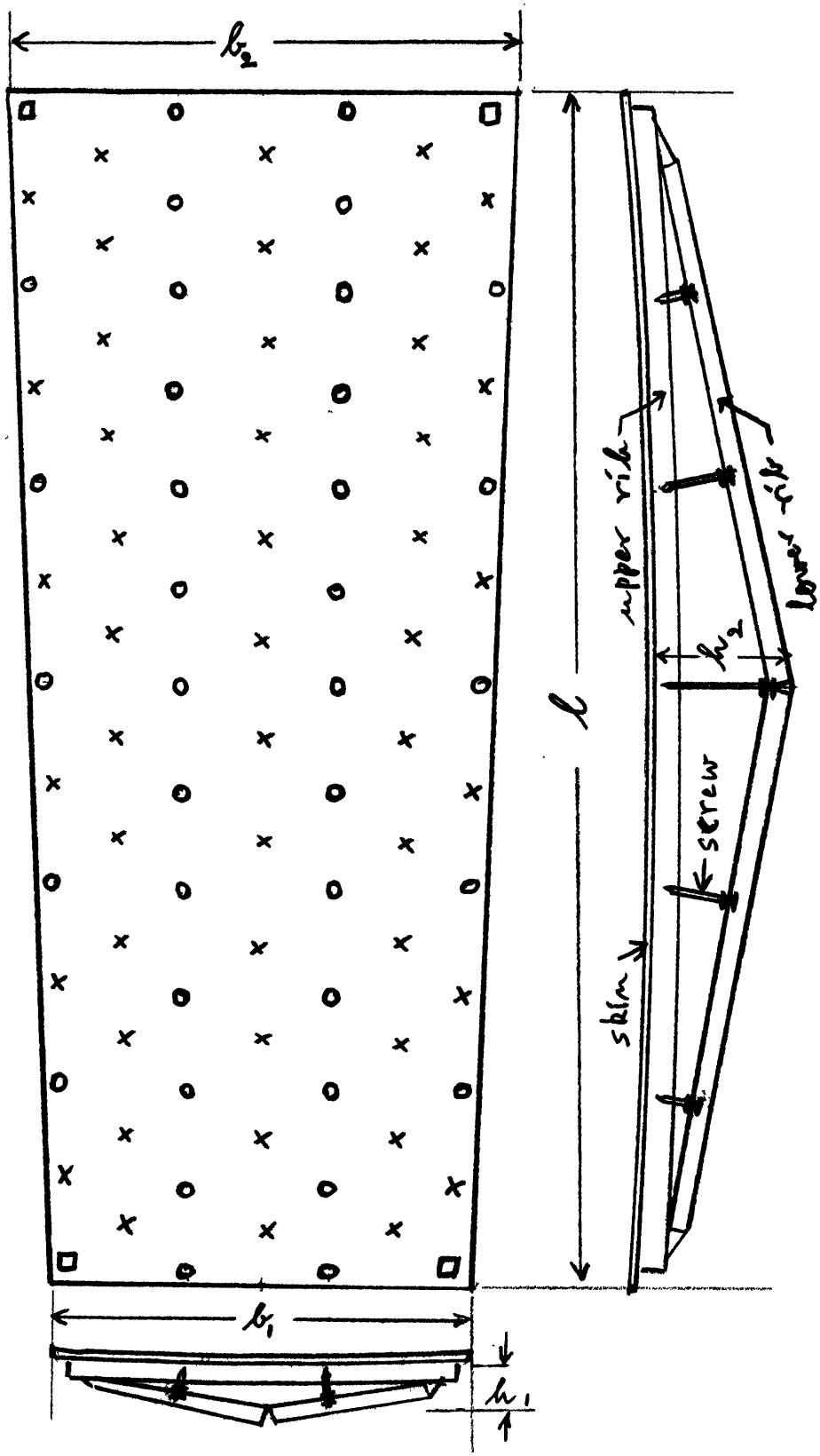

Fig. 2. Typical surface plate (l = 72 inch, b_1 = 27 inch, b_2 = 30 inch, h
h_1 = 2 inch, h_2 = 5 inch).

□ 4 corner points for external adjustment on telescope;

O 36 screws for internal adjustment in factory;

× 48 intermediate points for additional measurments.

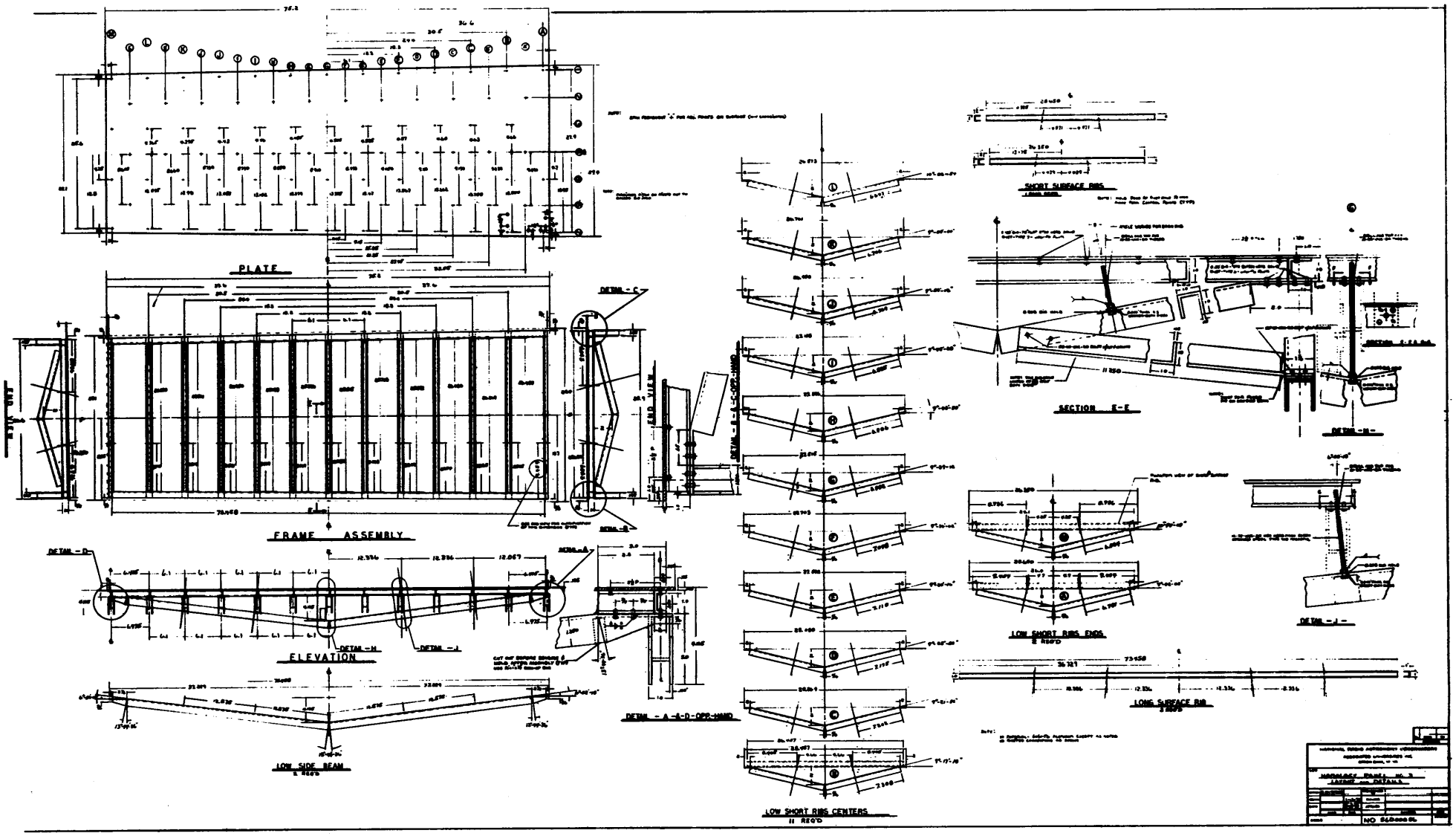

Fig. 3. Reduced copy of technical drawing, for test plates made at Green Bank workshop.