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Mr. Philip Blanch,
General Manager,
A. Goninan & Co. Ltd.,,
Broadmeadows. N.S.W. 2292

13 October, 1997

Dear Mr. Blanch,

Information on the 'Big Dish' Solar Concentrating Collectors

I have assembled information on the SG 3 Collector (the unit actually installed near our laboratory at Sullivan's Creek). This information comprises:

- A set of drawings on A3 size paper;
- An overall assembly arrangement annotated to indicate how the various components fit together;
- Details of the structure and of the structural members; special nodes and their arrangement;
- A paper, with diagrams, on the mirror panels and their economical production. This paper was written in June 1997 and represents latest thinking on the subject. The preferred method of construction is that indicated in relation to Figure 7 of this paper. There are many options which could be used but the approach favoured has considerable advantage, especially with respect to materials, configuration and cost.

It should be stressed that what we are calling the 'Power Dish' is simpler than SG 3 and is more cost-effective. I would prefer very soon to discuss practical 'Power Dishes' with Goninan's to identify the most favourable practicable path for the immediate future, rather than dwelling too long on SG 3.

If the information forwarded is insufficient to your needs, please feel free to ask for more.

With best wishes,

Yours sincerely,

S. Kaneff

SG 3 Configuration and Components

- The following two drawings portray the various components of SG 3 and their location.

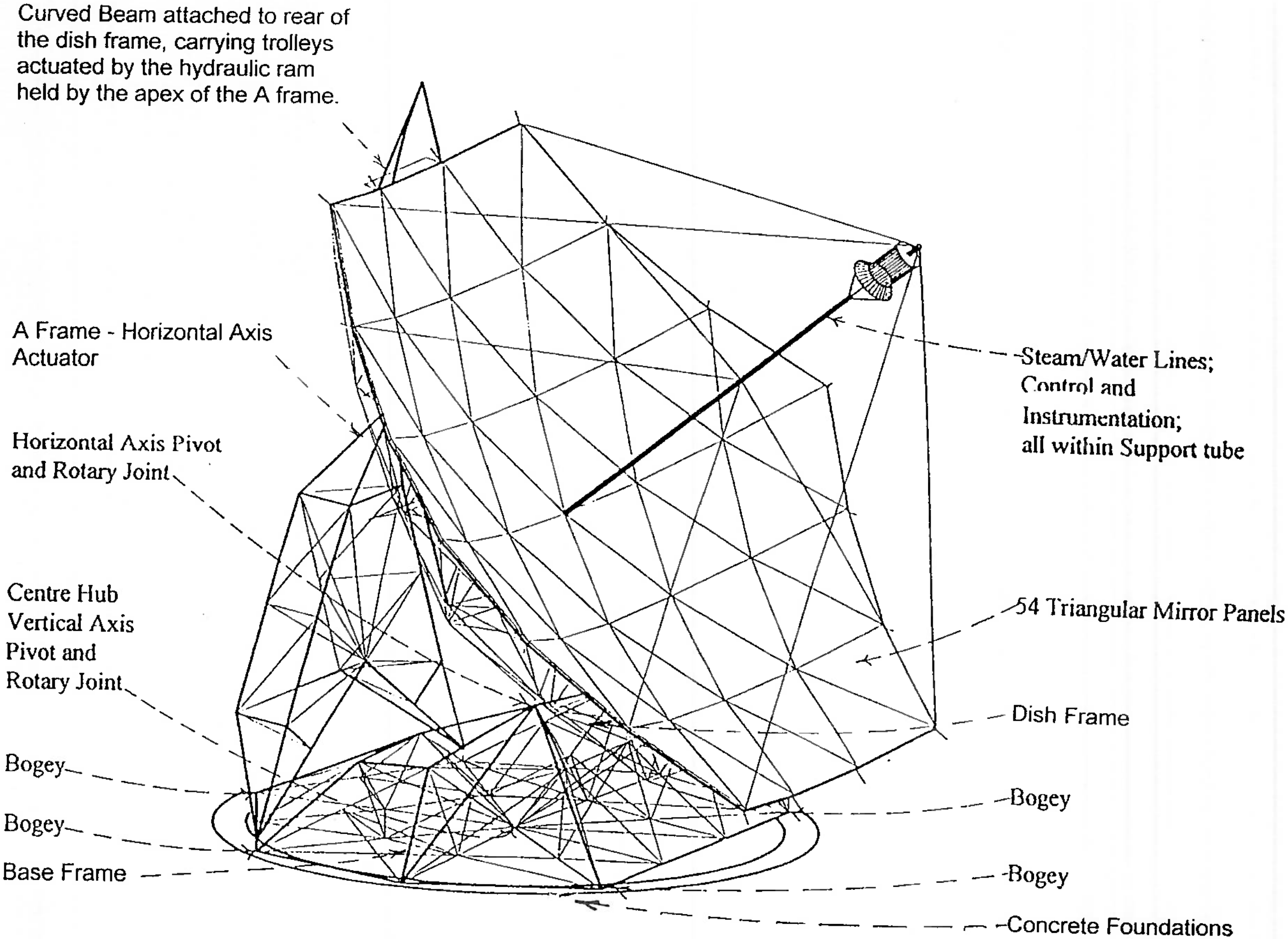
- The A3 size drawings provide details of components which are the elements making up the structure, except that the rotary joints are not detailed apart from external views, since these latter are in the process of being substantially modified to reduce costs and to form the substance of patent application.

- Structural members and nodes are detailed separately as:

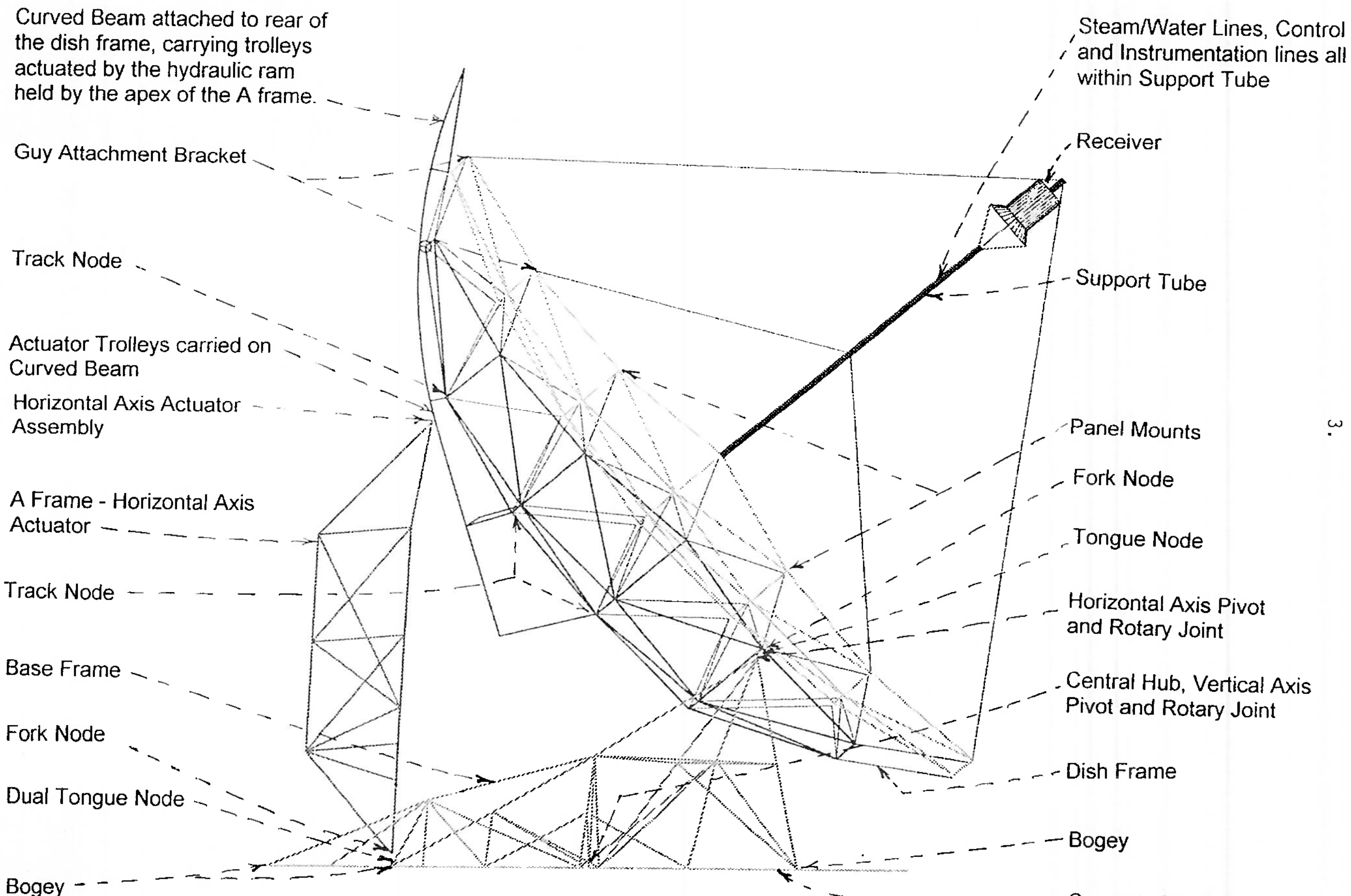
  Main frame support base
  Dish main frame
  Horizontal axis actuator frame

  In each case, the network of members is portrayed, together with recording of member length, diameter, metal thickness, node size etc.
  Diagrammatic representation of the Oktalok joints is included together with working tolerances.

- An accompanying paper, titled "The Mirror Panels", outlines details of the mirror panels which do not follow the SG 3 details, mainly because we do not recommend this approach, having developed a better arrangement for the Israeli Dish - which may be considered a Mark 2 version of SG 3.

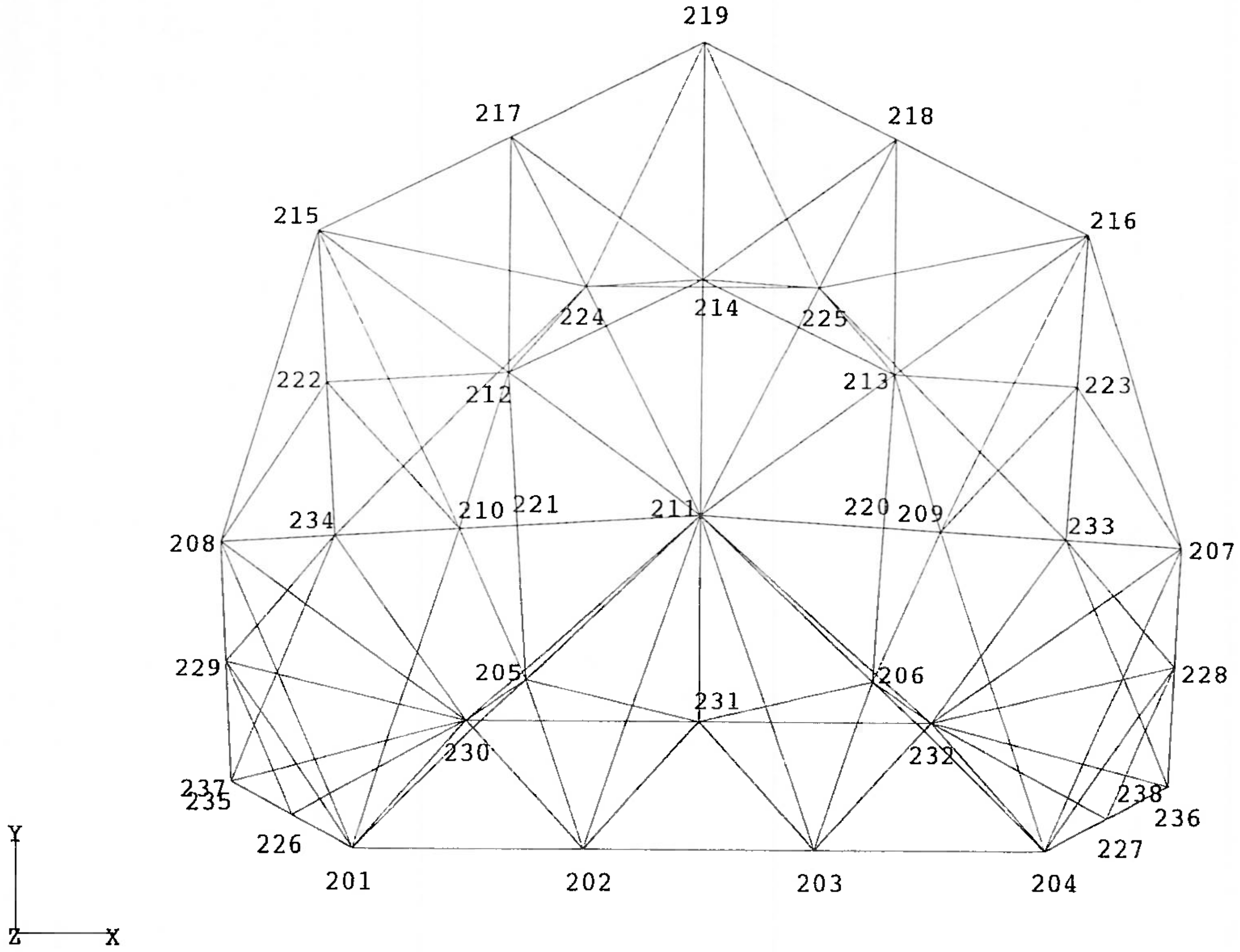


400m^2 Aperture Dish (SG3)



400m² Aperture Dish - Side View

MICROSTRAN



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| MAIN FRAME SUPPORT BASE                                             |
|                                                                     |
| ENERGY RESEARCH CENTRE, RsPhysSE, Australian National University    |
| oktaSTRAN :                            12 MAR 92   11:46:34   V1.60 |
+=====================================================================+
| SUMMARY OF QUANTITIES OF   1. MEMBERS                               |
|                            2. CONES                                 |
|                            3. BOLTS                                 |
|                            4. NODES                                 |
+=====================================================================+
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MEMBER	TYPE	COUNT
42.3*2.0	M10	0
48.3*2.3	M10	0
60.3*2.3	M10	0
42.3*2.0	M12	0
48.3*2.3	M12	8
60.3*2.3	M12	24
76.1*2.3	M12	0
88.9*2.6	M12	0
48.3*2.3	M16	0
60.3*2.3	M16	0
76.1*2.3	M16	22
88.9*2.6	M16	26
101.6*3.2	M16	0
76.1*2.3	M20	0
88.9*2.6	M20	0
101.6*3.2	M20	22
114.3*3.6	M20	0
101.6*3.2	1"UNC	0
114.3*3.6	1"UNC	9
114.3*6.0	1"UNC	4
139.7*4.9	1"UNC	4
165.1*4.9	1"UNC	4

CONE	TYPE	COUNT	
42.3	M10	0	
48.3	M10	0	
60.3	M10	0	
42.3	M12	0	
48.3	M12	16	
60.3	M12	46	
60.3	HFLANGE	2	
76.1	M12	0	
88.9	M12	0	
48.3	M16	0	
60.3	M16	0	
76.1	M16	44	
88.9	M16	44	
88.9	HFLANGE	8	
101.6	M16	0	
76.1	M20	0	
88.9	M20	0	
101.6	M20	40	
101.6	HFLANGE	4	
114.3	M20	0	
101.6	1"UNC	0	
114.3	1"UNC	16	
114.3	HFLANGE	2	
114.3	1"UNC	8	(114.3*6 1"UNC)
139.7	1"UNC	8	
165.1	1"UNC	8	

BOLT	COUNT
M10*30	0
M12*30	52
M12*65	10
M12*35	0
M16*35	0
M16*40	78
M16*50	0
M16*80	10
M20*45	0
M20*55	22
M20*100	18
1"*2.5"	32
1"*2.75"	0
1"*3.0"	10
1"*4.5"	2

NODE TYPE	COUNT
68/60	2
87/78	0
107/96	4
127/118	14
70/62	0
89/80	0
109/98	0
130/120	0
154/146	8
200/194	7

CENTRAL HUB 1

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MAIN FRAME SUPPORT BASE

ENERGY RESEARCH CENTRE, RsPhysSE, Australian National University
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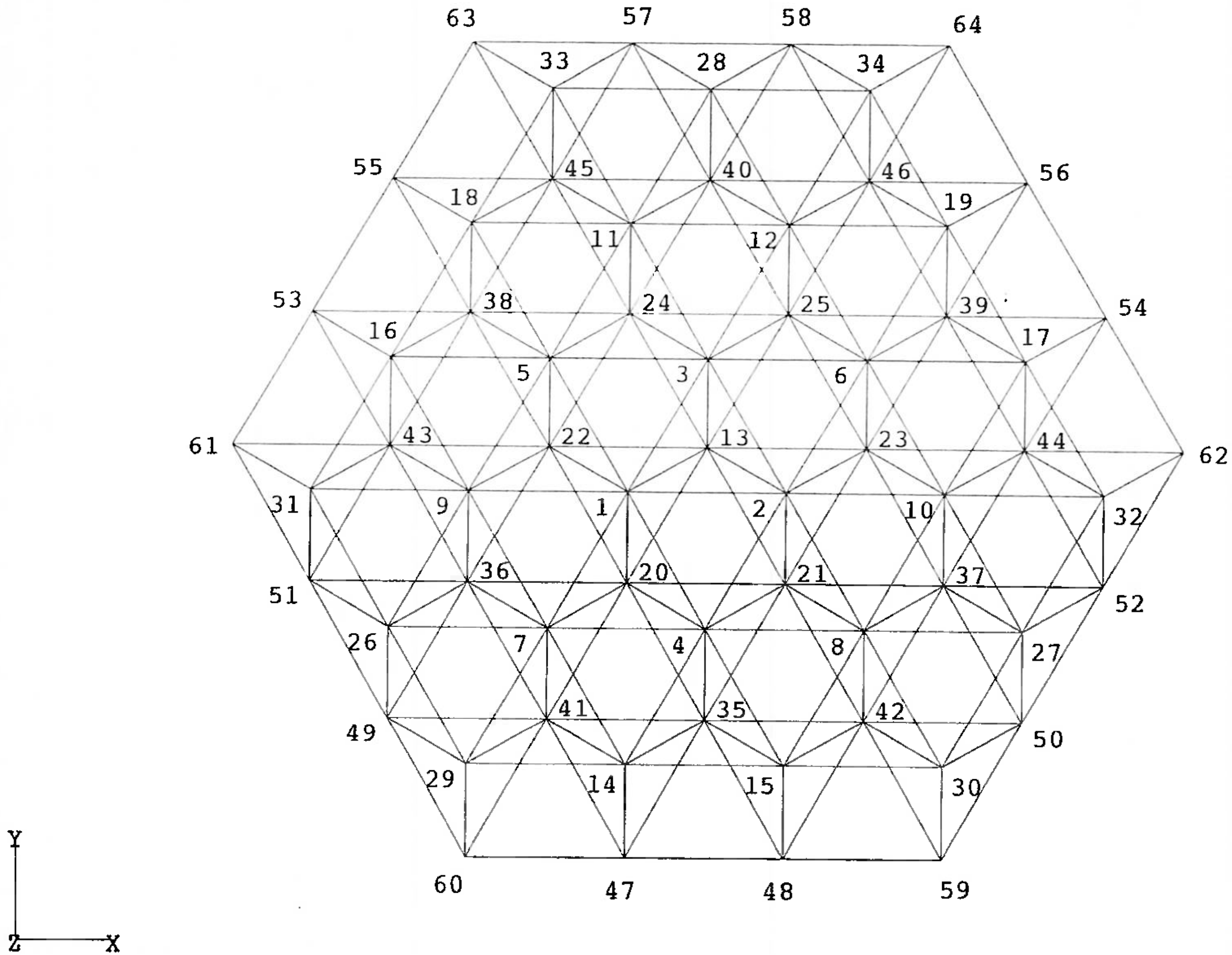
SUMMARY OF MEMBER LENGTHS : Machined nodes
Galvanised and painted struts
Chrome plated nodes

MEMBER TYPE	C/C NODES	FAB LENGTH	TUBE LENGTH	QUANTITY
48.3*2.3 M12				
A	1810.6	1707.0	1623.0	2
B	2736.5	2628.9	2544.9	2
C	2736.5	2628.9	2544.9	2
D	3501.9	3394.3	3310.3	2
60.3*2.3 M12				
A	2936.0	2782.4	2716.4	2 + S
B	2936.0	2803.4	2737.4	2
BK	2936.0	2768.4	2702.4	2 + S
C	3121.3	2967.7	2901.7	2 + S
D	3137.1	3047.5	2981.5	2
BL	3137.1	3012.5	2946.5	2 + S
E	3171.0	3038.4	2972.4	2
F	3502.8	3335.2	3269.2	2 + S
G	3566.7	3463.1	3397.1	2
H	3566.7	3459.1	3393.1	2
I	3566.7	3251.0	3179.1	2 (*)
J	3621.3	3474.7	3408.7	2
76.1*2.3 M16				
A	2962.2	2789.6	2689.6	2 + S
B	3733.1	3546.5	3446.5	2 + S
C	3735.7	3574.1	3474.1	2 + S
D	3801.3	3682.7	3582.7	2
BI	3801.3	3644.7	3544.7	4
E	3844.2	3682.6	3582.6	2 + S
F	4250.0	4131.4	4031.4	4
G	4281.6	4163.0	4063.0	2
H	4405.3	4272.7	4172.7	2
88.9*2.6 M16				
A	4057.9	3911.3	3800.3	2
B	4100.0	3967.4	3856.4	2
C	4113.2	4016.6	3905.6	1
D	4172.5	4053.9	3942.9	2
E	4182.7	4050.1	3939.1	2
F	4250.0	3923.6	3827.1	2 (*)
G	4250.0	3923.6	3827.1	3 (*)
BM	4250.0	4093.4	3982.4	3
H	4250.0	4093.4	3982.4	2
I	4701.1	4356.3	4259.8	1 (*)
J	4938.4	4604.6	4508.1	2 (*)
K	5168.5	5022.9	4911.9	2
L	5168.5	4982.9	4871.9	2 + S
101.6*3.2 M20				
A	4162.4	3991.8	3853.8	2
B	4250.0	3909.8	3799.8	2 (*)
BJ	4250.0	4103.4	3965.4	2
C	4865.3	4663.7	4525.7	2 + S
D	5871.9	5656.3	5518.3	2 + S
E	5871.9	5701.3	5563.3	2
F	5941.6	5726.0	5588.0	2 + S
G	5941.6	5681.0	5543.0	2 +2S

H	6140.5	5903.9	5765.9	2 +2S
I	6242.6	5916.4	5806.4	2 (*)
L	3540.7	3339.1	3201.1	2 +2S
114.3*3.6 1"UNC				
E	3540.7	3408.1	3239.1	2
F	4079.2	3922.6	3753.6	2
G	4079.2	3960.6	3791.6	1
J	6237.8	5880.6	5757.1	2 (*)
K	6418.2	6296.6	6127.6	2
114.3*6.0 1"UNC				
C	3137.1	3015.5	2846.5	2
BB	3137.1	2979.0	2810.0	2 + S
139.7*4.9 1"UNC				
H	5116.7	4946.1	4758.1	2
I	5432.2	5216.6	5028.6	2 + S(45mm)
165.1*4.9 1"UNC				
A	3079.6	2923.0	2657.0	2 +2S(19mm)
B	3079.6	2923.0	2657.0	2 +2S(19mm)

NOTE : (*) one end of the member uses hub flange

M I C R O S T R A N



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| DISH MAIN FRAME                                                      |
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| SUMMARY OF QUANTITIES OF  1. MEMBERS                                 |
|                           2. CONES                                   |
|                           3. BOLTS                                   |
|                           4. NODES                                   |
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MEMBER TYPE		COUNT
42.3*2.0	M10	0
48.3*2.3	M10	0
60.3*2.3	M10	0
42.3*2.0	M12	0
48.3*2.3	M12	14
60.3*2.3	M12	37
76.1*2.3	M12	0
88.9*2.6	M12	0
48.3*2.3	M16	0
60.3*2.3	M16	0
76.1*2.3	M16	130
88.9*2.6	M16	28
101.6*3.2	M16	0
76.1*2.3	M20	0
88.9*2.6	M20	0
101.6*3.2	M20	17
114.3*3.6	M20	0
101.6*3.2	1"UNC	0
114.3*3.6	1"UNC	8

CONE TYPE		COUNT
42.3	M10	0
48.3	M10	0
60.3	M10	0
42.3	M12	0
48.3	M12	28
60.3	M12	74
76.1	M12	0
88.9	M12	0
48.3	M16	0
60.3	M16	0
76.1	M16	260
88.9	M16	56
101.6	M16	0
76.1	M20	0
88.9	M20	0
101.6	M20	34
114.3	M20	0
101.6	1"UNC	0
114.3	1"UNC	16

BOLT	COUNT
M10*30	0
M12*30	84
M12*35	0
M12*65	18
M16*35	0
M16*40	257
M16*50	0
M16*80	59
M20*45	0
M20*55	28
M20*100	6
1"*2.5"	12
1"*4.0"	4

NODE TYPE	COUNT
68/60	0
87/78	0
107/96	0
127/118	58
70/62	0
89/80	0
109/98	0
130/120	0
150/142	4
200/194	2

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DISH MAIN FRAME

ENERGY RESEARCH CENTRE, RsPhysSE, Australian National University
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SUMMARY OF MEMBER LENGTHS : Machined nodes
Galvanised and painted struts
Chrome plated nodes

MEMBER TYPE	C/C NODES	FAB LENGTH	TUBE LENGTH	QUANTITY
48.3*2.3 M12				
A	2438.5	2319.9	2235.9	2
B	2524.2	2405.6	2321.6	6
C	2647.0	2498.4	2414.4	6 + S
60.3*2.3 M12				
A	2802.0	2648.5	2582.5	2 + S
B	3158.9	3040.4	2974.4	2
F	3158.9	3026.3	2960.3	4
C	3189.2	3070.7	3004.7	4
G	3189.2	3035.6	2969.6	8 + S
D	3379.9	3261.4	3195.4	9
E	3616.5	3497.9	3431.9	6
H	3616.5	3448.9	3382.9	2 + S
76.1*2.3 M16				
A	2438.5	2319.9	2219.9	1
M	2438.5	2239.9	2139.9	4 +2S
B	2802.0	2643.4	2543.4	4 + S
C	3616.5	3457.9	3357.9	2 + S
N	3616.5	3443.9	3343.9	2 + S
D	3865.7	3707.1	3607.1	5 + S
O	3865.7	3693.1	3593.1	4 + S
E	4136.0	4017.5	3917.5	14
F	4148.7	4030.1	3930.1	26
G	4186.5	4067.9	3967.9	24
P	4186.5	4053.9	3953.9	2
H	4248.7	4130.1	4030.1	12
R	4248.7	4090.1	3990.1	2 + S
I	4334.3	4215.7	4115.7	6
S	4334.3	4175.7	4075.7	2 + S
T	4334.3	4135.7	4035.7	4 +2S
J	4441.9	4323.3	4223.3	2
U	4441.9	4283.3	4183.3	4 + S
K	4550.7	4432.1	4332.1	2
V	4550.7	4418.1	4318.1	2
L	4695.1	4536.5	4436.5	6 + S
88.9*2.6 M16				
A	2984.3	2825.7	2714.7	2 + S
B	4136.0	4017.5	3906.5	4
C	4148.7	4030.1	3919.1	2
D	4186.5	4067.9	3956.9	6
J	4186.5	4053.9	3942.9	2
E	4248.7	4090.1	3979.1	4 + S
F	4550.7	4418.1	4307.1	2
G	4695.1	4498.5	4387.5	2 + S
H	4856.8	4684.2	4573.2	4 + S
101.6*3.2 M20				
A	2438.5	2281.9	2143.9	2
B	2984.3	2782.7	2644.7	4 + S
C	4136.0	4003.4	3865.4	3
D	4148.7	4016.1	3878.1	4
E	4186.5	4067.9	3929.9	2

F	4856.8	4693.2	4555.2	2 + S
114.3*3.6 1"UNC				
A	4148.7	3992.1	3823.1	4
B	4695.1	4522.5	4353.5	2 + S(40mm)
C	4695.1	4484.5	4315.5	2 + S(40mm)

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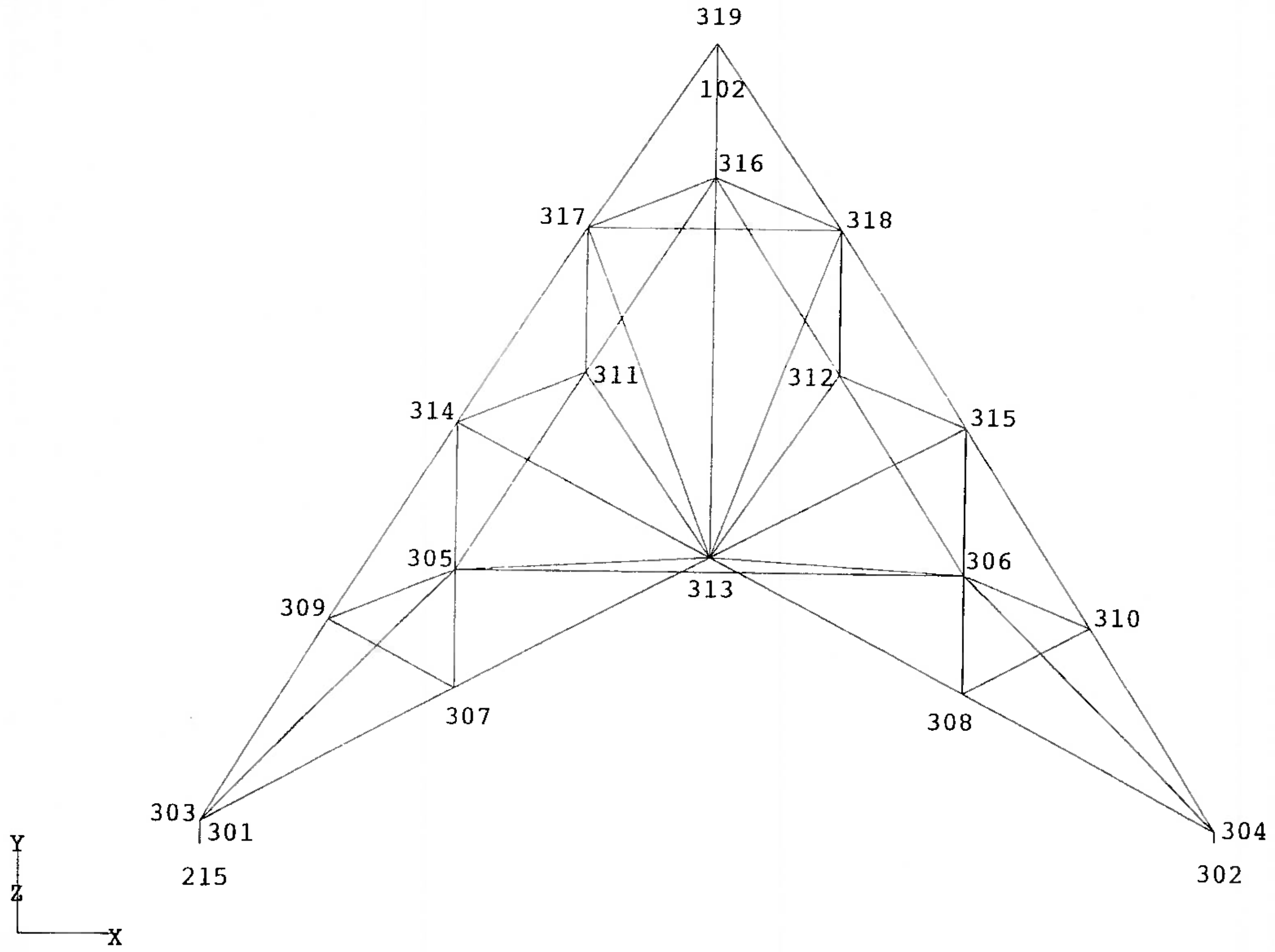
MICROSTRAN



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HORIZONTAL AXIS ACTUATOR FRAME

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SUMMARY OF QUANTITIES OF 1. MEMBERS
2. CONES
3. BOLTS
4. NODES

MEMBER	TYPE	COUNT
42.3*2.0	M10	0
48.3*2.3	M10	0
60.3*2.3	M10	0
42.3*2.0	M12	0
48.3*2.3	M12	4
60.3*2.3	M12	11
76.1*2.3	M12	0
88.9*2.6	M12	0
48.3*2.3	M16	0
60.3*2.3	M16	0
76.1*2.3	M16	16
88.9*2.6	M16	6
101.6*3.2	M16	0
76.1*2.3	M20	0
88.9*2.6	M20	0
101.6*3.2	M20	0
114.3*3.6	M20	0
101.6*3.2	1"UNC	0
114.3*3.6	1"UNC	1
114.3*6.0	1"UNC	6
139.7*4.9	1"UNC	2

CONE	TYPE	COUNT	
42.3	M10	0	
48.3	M10	0	
60.3	M10	0	
42.3	M12	0	
48.3	M12	8	
60.3	M12	22	
76.1	M12	0	
88.9	M12	0	
48.3	M16	0	
60.3	M16	0	
76.1	M16	32	
88.9	M16	12	
101.6	M16	0	
76.1	M20	0	
88.9	M20	0	
101.6	M20	0	
114.3	M20	0	
101.6	1"UNC	0	
114.3	1"UNC	2	
114.3	1"UNC	12	(114.3*6.0 1"UNC)
139.7	1"UNC	4	

BOLT	COUNT
M10*30	0
M12*30	30
M12*35	0
M16*35	0
M16*40	36
M16*80	8
M16*50	0
M20*45	0
M20*55	0
1"*2.5"	14
1"*2.75"	4

NODE TYPE	COUNT
68/60	0
87/78	2
107/96	4
127/118	5
70/62	0
89/80	0
109/98	0
130/120	0
200/194	6

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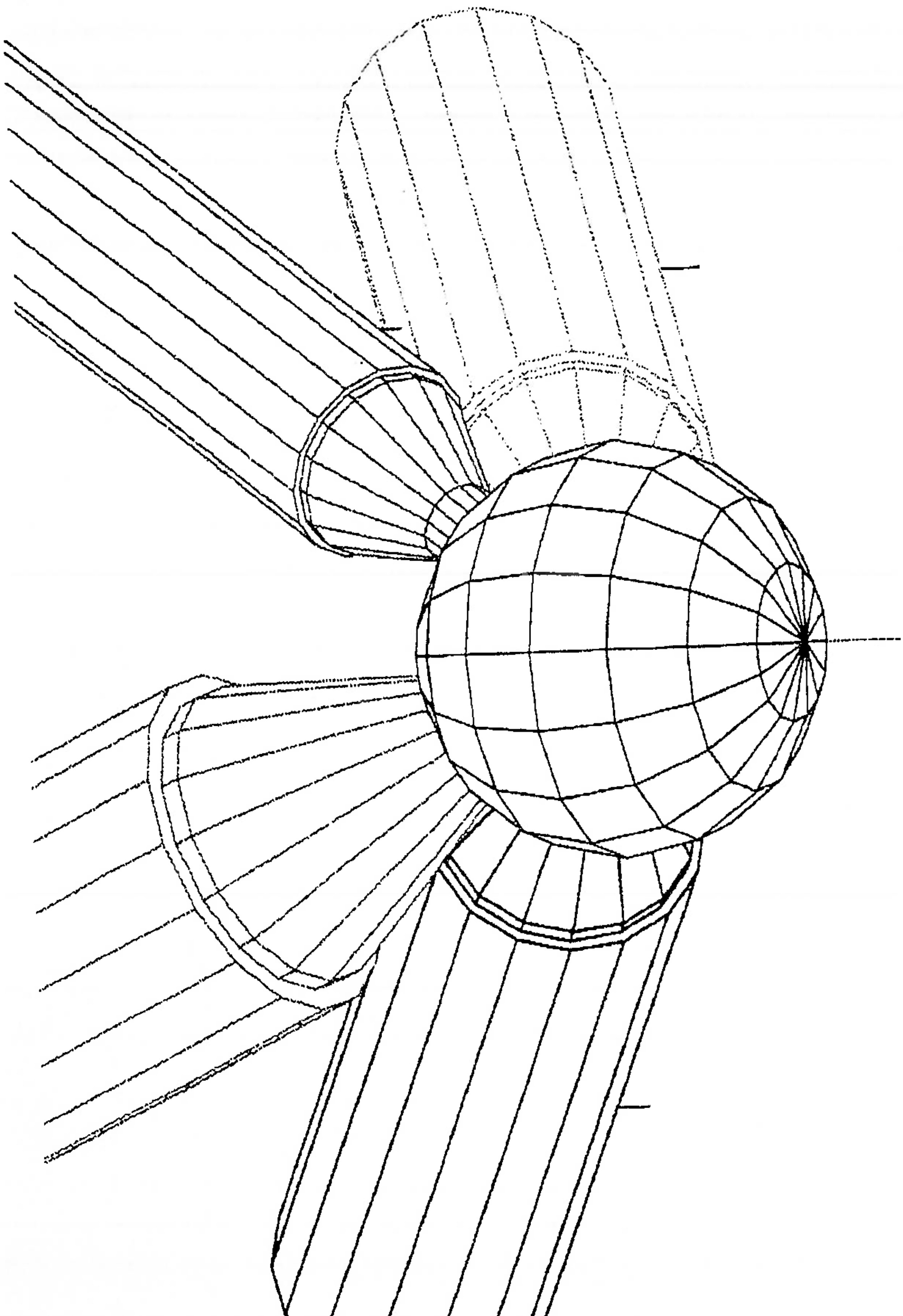
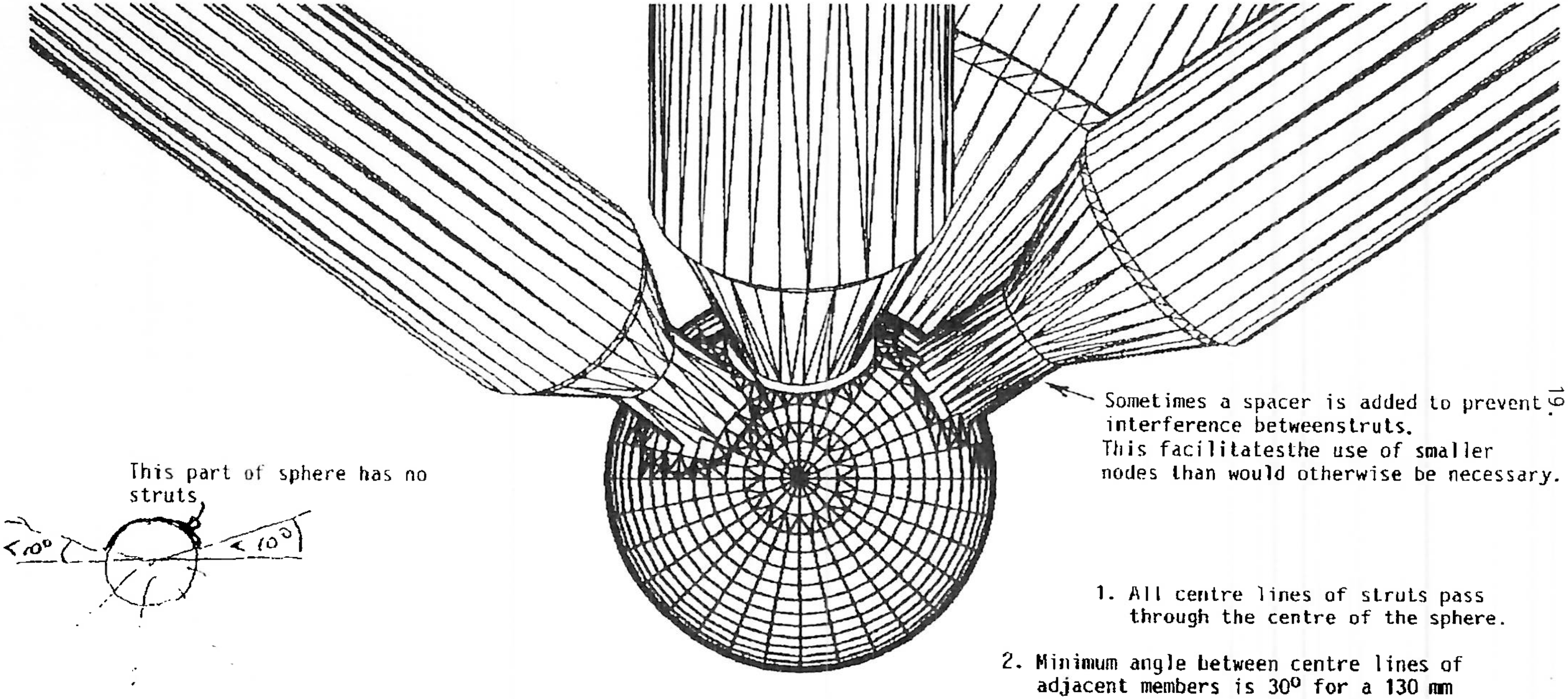
HORIZONTAL AXIS ACTUATOR FRAME

ENERGY RESEARCH CENTRE, RsPhysSE, Australian National University
oktaSTRAN : 12 MAR 92 11:46:34 V1.60

SUMMARY OF MEMBER LENGTHS : Machined nodes
Galvanised and painted struts
Chrome plated nodes

MEMBER TYPE	C/C NODES	FAB LENGTH	TUBE LENGTH	QUANTITY
48.3*2.3 M12				
A	1963.0	1875.4	1791.4	2
B	2576.9	2478.3	2394.3	2
60.3*2.3 M12				
A	3044.2	2936.6	2870.6	2
AE	3044.2	2898.6	2832.6	2
B	3400.0	3281.4	3215.4	1
C	3400.0	3292.4	3226.4	4
D	3423.4	3277.8	3211.8	2
76.1*2.3 M16				
A	3044.2	2925.6	2825.6	2
B	3926.0	3731.4	3631.4	2
C	3926.0	3789.4	3689.4	2
AG	3926.0	3749.4	3649.4	4 + S
D	4141.1	3984.5	3884.5	2
E	4141.1	3993.5	3893.5	2 + S
F	4427.3	4230.7	4130.7	2 + S
88.9*2.6 M16				
A	4364.9	4208.3	4097.3	1
B	4950.3	4793.7	4682.7	2
C	5192.1	5035.5	4924.5	1
D	5193.6	5037.0	4926.0	2
114.3*3.6 1"UNC				
C	6800.0	6681.5	6512.5	1
114.3*6.0 1"UNC				
A	3400.0	3243.4	3074.4	2
B	3400.0	3254.4	3085.4	4
139.7*4.9 1"UNC				
AA	3400.0	3243.4	3055.4	2





Sometimes a spacer is added to prevent interference betweenstruts. This facilitatesthe use of smaller nodes than would otherwise be necessary.

This part of sphere has no struts

1. All centre lines of struts pass through the centre of the sphere.

2. Minimum angle between centre lines of adjacent members is 30° for a 130 mm diameter sphere and 60 mm diameter member (strut).

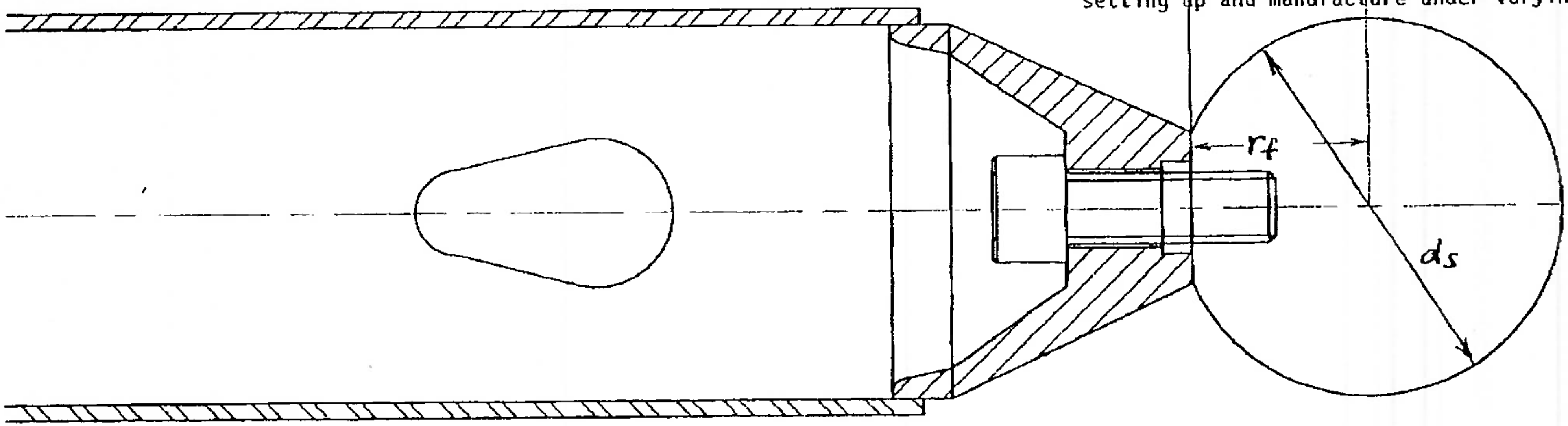
3. Tolerance on distance between centre of the sphere and the 'flat' machined to accept the end of a strut is 0.1 mm.

4. In all cases struts occupy only a one half hemisphere, Except for the inside dish nodes, where intrusion into the other half hemisphere is less than 10°. *See diagram*

Member Tolerance ± 0.3 mm

Tolerance ± 0.1 mm

These are setting-up tolerances; that is, were the manufacturing plant and the steel tubes to be maintained at a near constant temperature, the lengths of members should turn out to be within 0.3 mm of the designed length. In practice the combination of varing temperatures in the factory and of the materials still allows coping with the structural needs for accuracy without other special measures; i.e. setting up and manufacture under varying temps.



d_s = diameter of spherical node

r_f = distance from sphere centre to the flat machined to accommodate the cone.

Recorded usually as d_s/r_f (in mm)

eg. 154 mm node 154/146

130 mm node 130/119

200 mm node ..... 200/194 etc.

The Mirror Panels

There are many ways in which the front face of the dish can be subdivided into geometric shapes, based on the 54 triangles which constitute the main frame. Figure 1 shows the front face of the dish; and Figure 2 illustrates how these triangles can form the basis of mirror panels sectioned in two different ways - comprising respectively 54 separate panels of which there are 9 slightly different shapes (each being replicated 6 times for the whole dish); or the triangles being combined into 3 trapezia (each formed from 3 triangles), again each trapezium being slightly different but each replicated 6 times for the whole dish. There are clearly other combinations possible.

To make handling easier at the manufacturing and assembly stages, it is felt that the separate triangles (each of about 4 m side) represent a good size. However, if there is need to transport them some distance, then it seems prudent to separate each 4 m triangle into 4 smaller triangles each of about 2 m a side; this is what we have done for the Israeli dish. On the other hand, if the panels were manufactured on site, the 4 m size might be preferable - as we did for our present collector in Canberra; this seems more economical in both manufacture, handling and assembly; but mass production might change this picture.

The options suggested below can be employed to make both sizes of panel - 2m or 4m - the actual size being chosen on the basis of overall considerations, including the location of manufacture in relation to the location of the solar site. If the 4 m triangles are sub-divided into 4 panels, then the centres of the front-face members of the dish need bracing and supports to carry the 2 metre panels, or a separate frame needs to be provided - See Figure 3. In comparing the relative benefits of 2m or 4m panels, it is consequently necessary to include any additional structural elements necessary in each case.

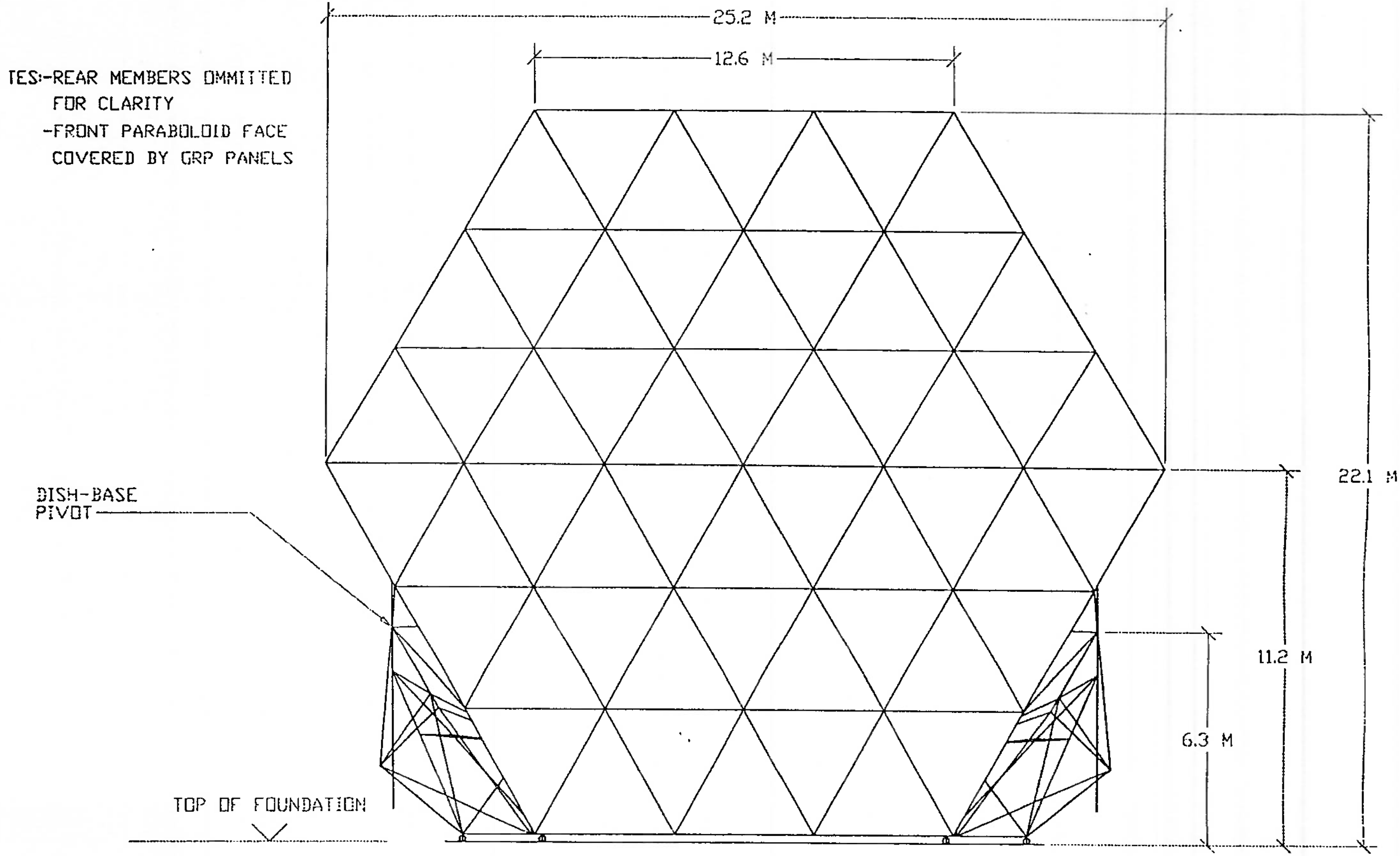


Figure 1 – Mark 2 Collector - Front Elevation.

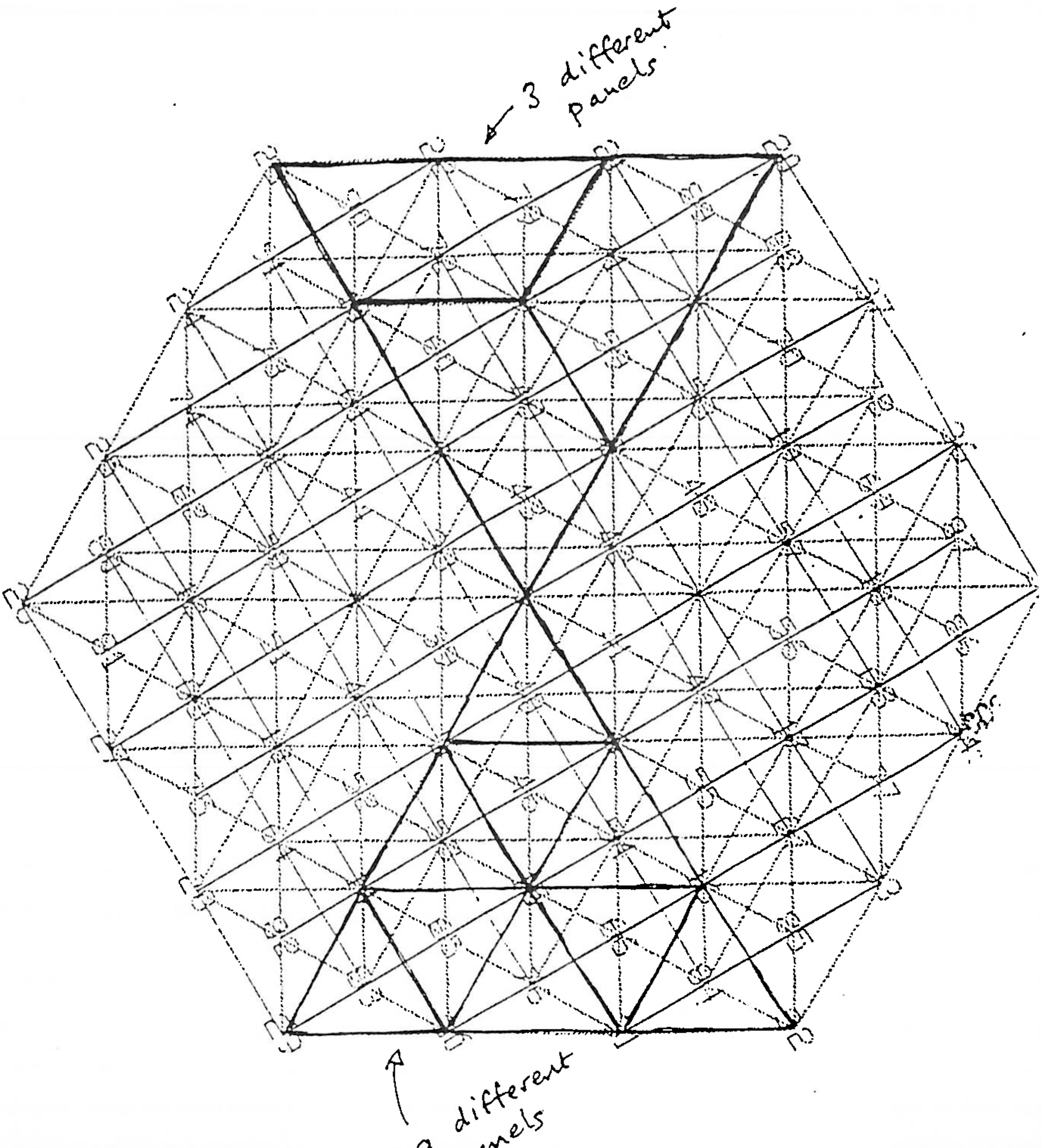
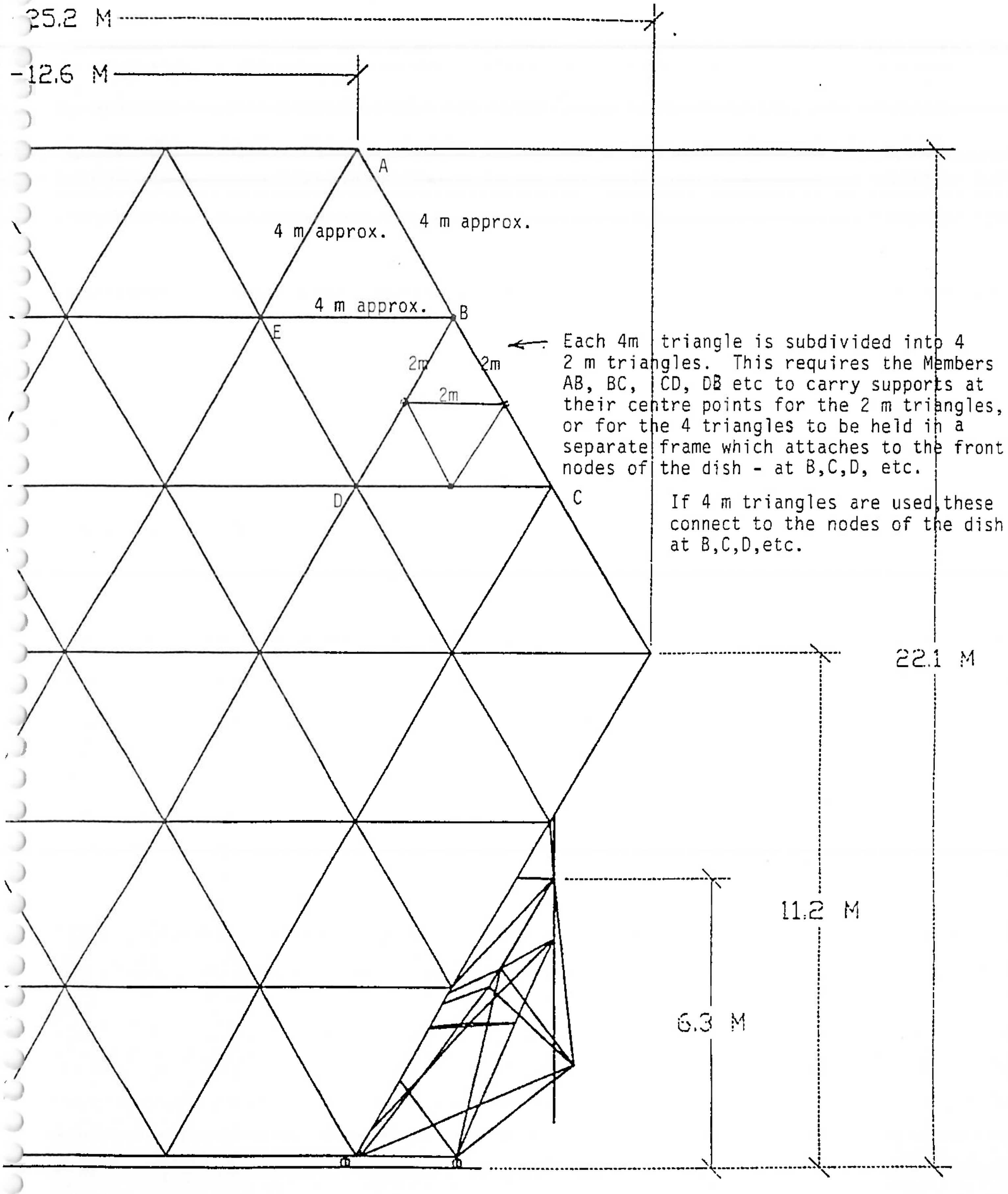


Figure 2 - The 54 Triangles at the face of the Dish can be Separated or Combined in many ways.
Each triangle is approx. 4 m a side.



rk 2 Collector - Front Elevation.

FIGURE 3. Showing how each 4 m trinagle may be subdivided into 2 m triangles

Spherical/Paraboloidal Geometry

The options suggested below can also use spherical or paraboloidal geometry or a combination. If high focal region density is required, it is necessary to have the mirror reflectors of paraboloidal form, but a compromise is possible for lower focal densities, for which spherical form of the panels can be employed. The advantage in doing this is that only one mould is strictly necessary, with a curvature for the 400 m2 collectors as presently designed, of 26.2 m radius. This could reduce costs of manufacture. We have found that this is not quite adequate for power system application because the focal region is too corrupted.

However, if the dish structure places the nodes on the front face of the dish on a paraboloidal shell while the mirror panels themselves are each formed to a spherical contour, the overall difference from a purely paraboloidal surface is quite small and more than tolerable. Moreover, only one shape mould (spherical) is required. This can be used if the consequent costs are less than for paraboloidal moulds. In a mass production situation the difference may not be great, since it seems inevitable that many moulds would be needed in order to speed up manufacture, but logistic aspects could be eased.

The panels change dimension (if not shape) from the centre of the dish outwards whatever curvature (paraboloidal or spherical) is employed, so that there is no apparent neat solution to the making of all panels exactly identical, which they might otherwise be with spherical curvature. **It may be concluded that if there is cost benefit in using spherical reflective surfaces for the mirror panels, then it would also be beneficial and cost-effective to use a paraboloidal location of the front-face nodes of the dish; this would be very satisfactory for dishes employed to generate steam to run turbines.**

Shape Precision and Tolerable Deflection of Mirror Panels

The perturbations which apply to distort the reflective surface arise due to

1. Construction errors in the support frame and in the mirror panels;
2. Gravity forces acting at different dish orientations;
3. Wind forces acting while the dish is tracking - up to a maximum velocity of 80 km/h, deflecting the frame and mirror panels;
4. Some combination of 1,2,3.

The accuracy, or lack of it, is expressed normally in terms of the "Slope Error" which is defined as in Figure 4.

For Power Dishes (that is, dishes to power steam turbines), the average slope error for practical purposes need not be extremely small; we have found by theory and practical experience that a slope error of 6 milliradians is satisfactory for the efficient, economical production of steam of more than adequate quality. Indeed to achieve too accurate a focal region introduces problems of material integrity and lifetime, increases absorber costs substantially, as well as requiring more-accurate tracking to keep the

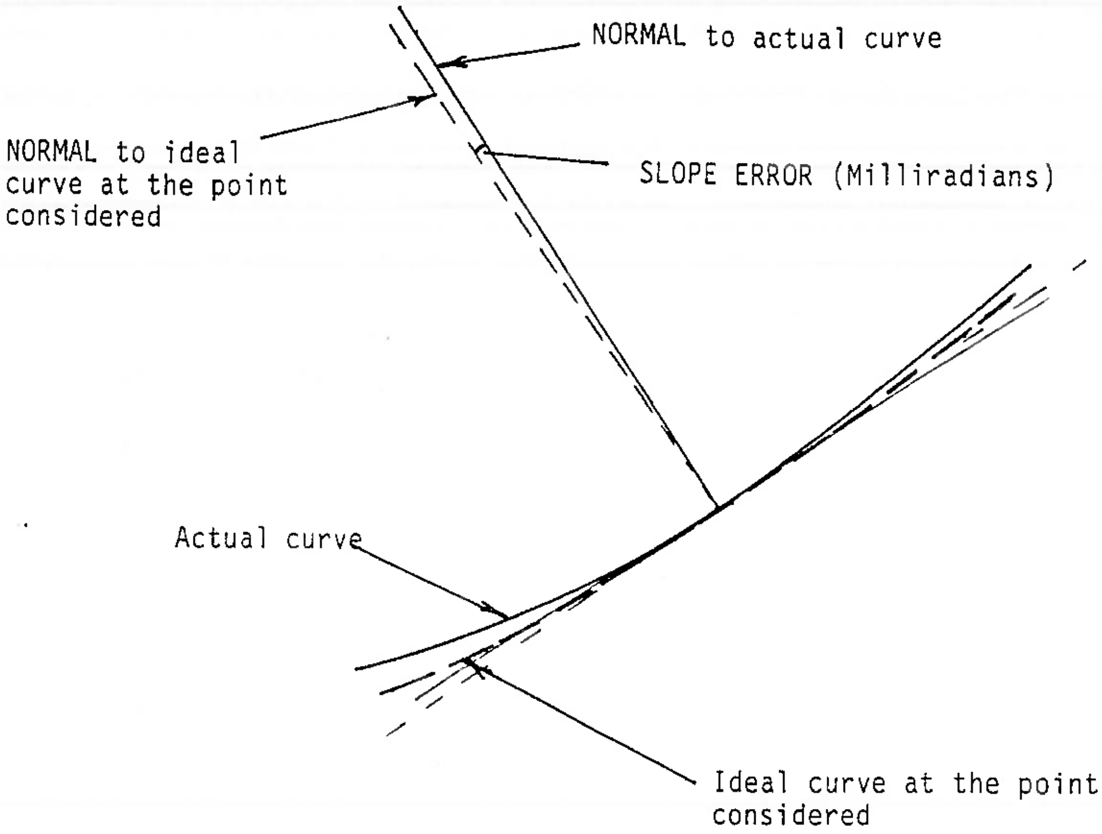


FIGURE 4. Illustrating the concept of 'Slope Error'. There should not of course be any steep transitions in slope error over the surface of the mirror panel, or any large digressions from the 'average slope error' designed for. In the case of a 'Power Dish', this average slope error can be taken as 6 milliradians as a satisfactory working accuracy requirement.

The 'average slope error' is an integrated average of all the errors resulting from: manufacture of frame and mirror panels, gravitational forces and their effects at different dish orientations, and wind forces on the dish while tracking. Some errors can act to reduce the total integrated average under certain conditions.

As a design consideration, it may be noted that even though the dish is able to track at wind velocities of up to 80km/h, solar resources at this wind velocity are rarely adequate for useful power outputs. Accordingly, with little loss of effectiveness, the value of 6 milliradian average slope error could be taken at a lower wind velocity, for example at 60 km/h when wind forces are little more than one half their values at 80 km/h. It is common for dish designs to take 50 km/h as a limiting tracking velocity.

absorbing device (receiver) in the right relationship to the smaller focal region. The SG 3 collector at Canberra realised a designed 6 milliradian slope error closely, giving a solar concentration of 1800 suns, with the reflected solar flux from the mirror being contained well within a receiver skirt of 1.5 m diameter, most of the energy (over 85%) being directed into the receiver cavity of less than 0.7 m diameter, giving high conversion and absorption efficiency (90% and higher, depending on steam temperature required); and low losses, over the normal insolation range. See Figure 4a.

Mirror reflectivity plays an important role in the achievement of high concentration ratio; if the SG 3 mirror had been 1 mm thick low iron mirrored glass of reflectivity 96% instead of 2 mm thick 'green glass' of reflectivity 86%, the concentrataion ratio would have been more than 2000 suns. The cost penalty in using the best mirrors of highest reflectivity, is relatively trivial compared with the gains arising from employing fewer collectors (since the mirrored glass represents only a small fraction - about 4% or so - of the total collector costs).

Although perturbations which distort the optical system overall depend on a number of factors, as already indicated, the major distortions can come from the mirror panels themselves and especially from the effect of wind loading on their shape. So long as no sudden jumps in slope error occur, however, that is so long as the digressions in slope error over the whole dish do not significantly exceed the average slope error - a property which is retained by smooth mirror panels which are formed from a smooth accurate mould - then the deflection of the mirror panels due to wind are likely to be significant only at the upper end of the wind velocities for which sun following and useful power output are practicable. Moreover, the change in panel shape due to wind loading is constrained to cause movement very nearly normal to the panel, an effect which moves the focus of the dish in or out relative to the ideal focus, as well as broadening slightly the focal cone of rays - this causes little if any spillage of solar flux from the receiver, so long as the receiver skirt is well designed. As a result, the limited deflection of the mirror panels is not a problem for power dishes.

(The Israeli dish, on the other hand, requires high solar concentration ratios and better imaging - accordingly, the focal region needs to remain intact; in turn this requires that mirror deflection due to wind forces and dish orientation should be severely limited. The small degree of required panel deflection communicated to you previously, referred to the Israeli dish and needs to be modified considerably for a Power Dish).

Consequently, we recommend the following for 'Power Dishes':

- **Design the dish and base frames to withstand tracking wind velocities of up to 80 km/h and**

- **Design the overall system to have an integrated slope error of 6 milliradians at 60 km/h. This will ensure that almost all of the solar energy can be gathered with high efficiency up to this wind velocity, and the rest of the energy for wind velocities of 60-80 km/h can be gathered with only slightly less effectiveness (noting that the total such energy is a very small fraction of the annual energy available, and**

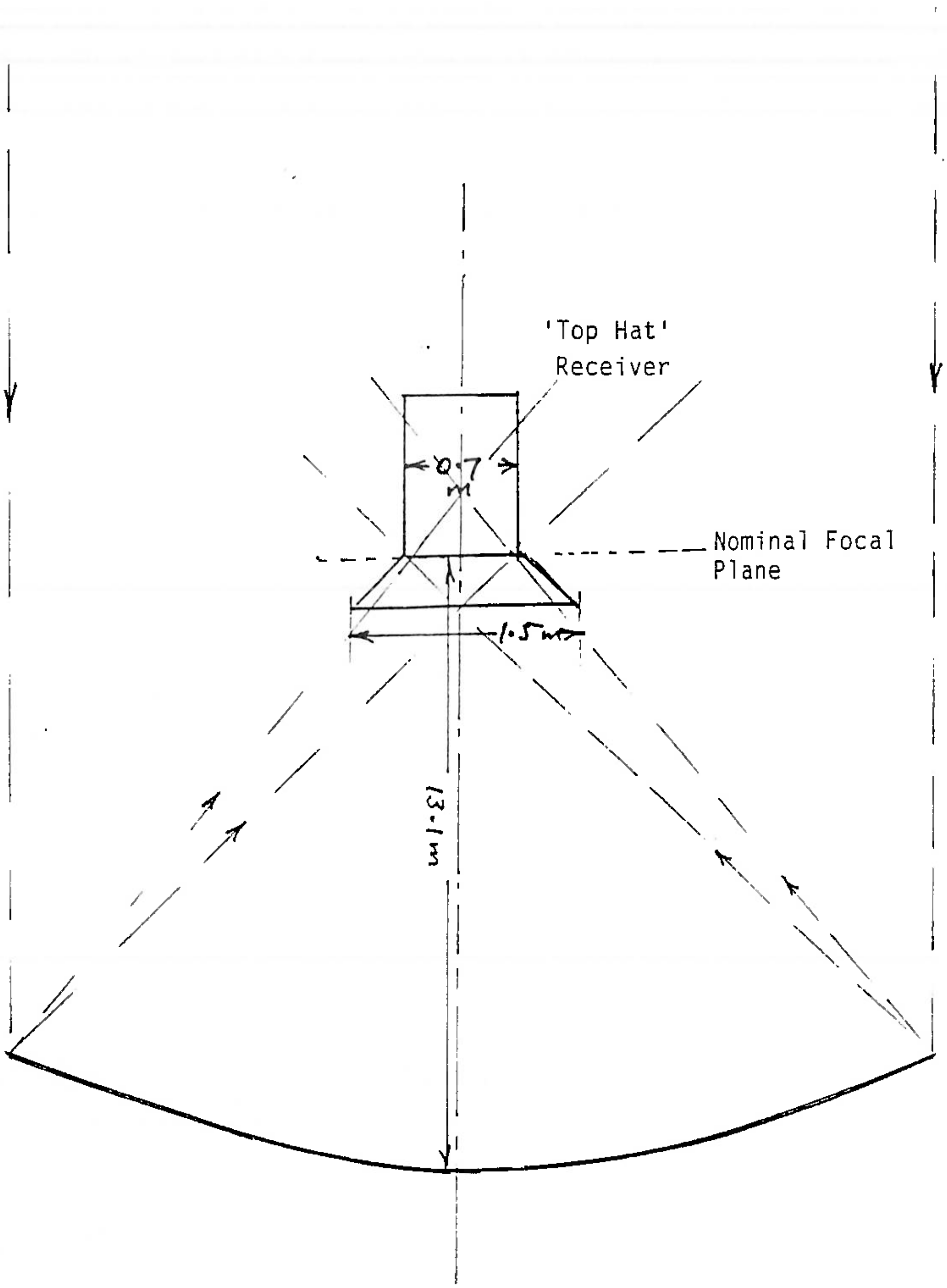


FIGURE 4 a - Dish Optical Arrangement with 'Top Hat' Receiver.

that in any case, little if any 'spillage' of energy will occur from the receiver if some defocussing occurs at the higher wind velocities).

This means in practice that the mirror panels themselves can have a slope error due to wind loading alone at 80 km/h of 6 milliradians, the load normal to the panels at this velocity being 200 kg per 4m. triangular panel or 50 kg per 2m. panel, due to wind.

The centroids of the respective triangular panels can move in or out as much as indicated below, while still remaining within the 6 milliradian tolerance:

Triangular Mirror Panel	4 metre sides	2 metre sides
Distributed wind load on mirror panel	200 kg	50 k
Deflection of Centroid of triangle at 80 km/h wind velocity - for 6 milliradian slope error (normal to panel surface)	14 mm	7 mm

NOTE: The above is conservative; deflections can be relaxed further if economic benefit warrants this. However, as panels become slimmer and consequently more flexible, in principle, it is prudent to maintain as much rigidity as practicable to prevent flutter or vibration from occurring when using such thin mirror-substrate combinations.

Preferred Means for Substrate Realisation

In a telephone discussion on Tuesday 10 June, Dr. Piccioli thought it may not be practicable to produce 4 m triangular panels using structural foam core material because there would need to be more than one layer of such material since thick (greater than 50 mm) foam is hard to conform to the curvature; it would be problematic to use slabs glued together. Cast foam seems unsuitable, as it does not have the right structural properties.

Nevertheless, because of the intrinsic simplicity of employing 4m panels which attach to the nodes of the dish front face, were it practicable to make 4m triangular substrates with a structural foam clad in fibreglass or similar, this could be a competitive solution overall.

It has to be stressed that if a wire or other rigid frame is not used to keep the substrate panel in shape, then the material, once configured into a panel, needs to keep its correct shape without warping or otherwise distorting over the lifetime of the structure. If a frame is used to hold the substrate, then it is a practicable requirement to expect that the frame will keep the substrate in shape. In this latter case, the substrate need be no more than a quite thin support for the mirror: for example, say a 2-3 mm coremat or similar, to which the mirror is attached, or a specially corrugated very thin metal sheet (mild steel for economy) of thickness 0.3 mm or less. We have used this kind of construction ourselves; it would need specially stamped thin sheets for best effect, as for example as illustrated in Figure 5.

Figures 6,7 illustrate the kind of wire frame support which can be used for the 2m and 4m panels respectively. The wire is generally 6mm diameter galvanised steel which can be readily spot welded into the configurations by automated machinery, and represents a particularly economical means for construction - with steel and labour costs being low.

We have had 2m mirror substrates and wire frames constructed by local industry in Canberra (Sunset Pty., Ltd.,) and have quotes for the mirror panels for a complete dish as follows (not produced by automation):

216 substrates employing a 20mm thick non-structural foam covered by 2.5 mm fibreglass cloth and resin on each side (total thickness of 25 mm.) Quoted $160 each. ie. 216 x $160 = $34,560 for a whole dish. (Foam 18 kg/ m3)

216 wire frames as in Figure 6, quoted $80/panel, or $17,280 for all 216 wire frames (fully assembled) for a dish. (Sunset quote).

This quote has been bettered by Wiredex Pty., Ltd., of Clayton Vic. who have quoted recently $6400 for the wire frames for the Israeli dish (these frames are somewhat disassembled for transport and need some extra labour for on-site assembly - See Figures 6a,b,c).

Deflection Tests on the Sunset Miror Substrate Panels

The above 2m triangular panels of 25 mm total thickness, without wire frame supports, were tested for deflection in accordance with the above table (50 kg distributed load corresponding to 80 km/h wind velocity normal to the surface).

Deflection at the centroid of the triangle was 8 mm. This is considered satisfactory and would be reduced were structural foam to be used.

Summary of Options

It is assumed that in providing cost details etc, the more economical structure - paraboloidal or spherical, as appropriate - would be used.

1. 2 m triangular substrate formed by a coremat, marine plywood (or other) 2-3 mm thick, to be supported by a wire frame as in Figure 6.

2. 2 m triangular substrate formed by a very thin corrugated steel sheet (less than 0.3 mm thick), for support by a wire frame as in Figure 6.

3. 2 m triangular panel from a 20 or 25mm structural foam core with fibeglass cover with no frame support.

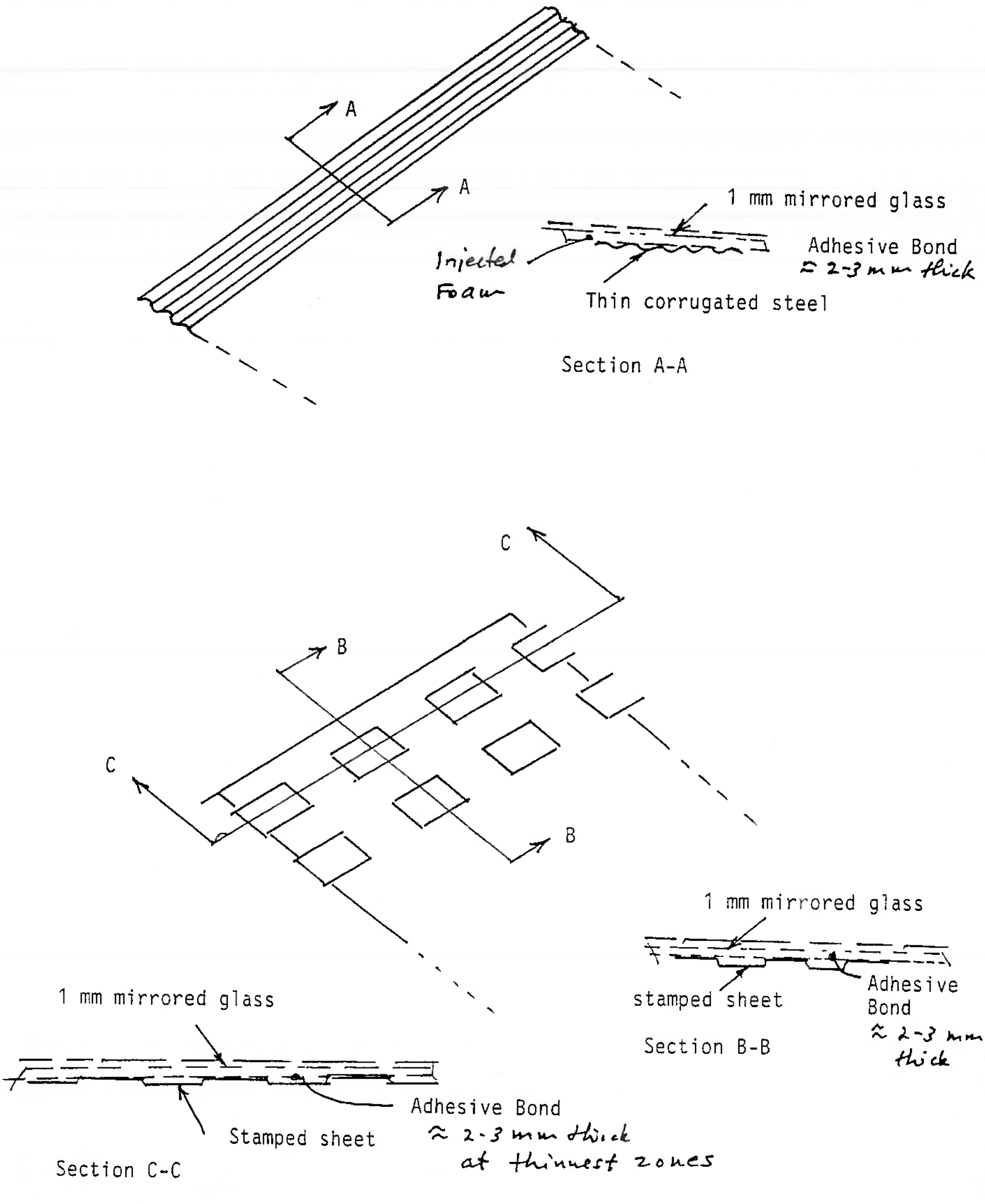


Figure 5. Two different steel mirror substrated (using mild steel of less than 0.3 mm thick. Mirrors bonded to the steel by silicone or similar : eg. polyurethane

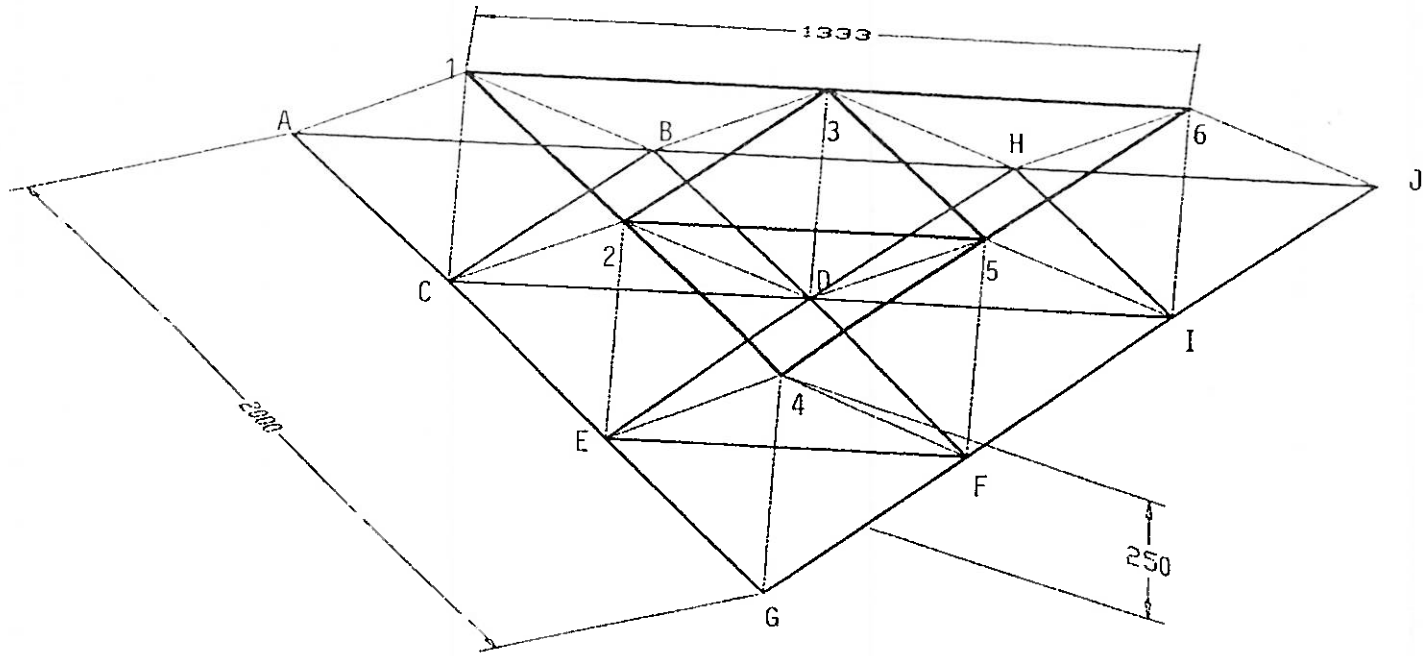


FIGURE 6 - Wire frame support for 2 m panels (facing downwards)

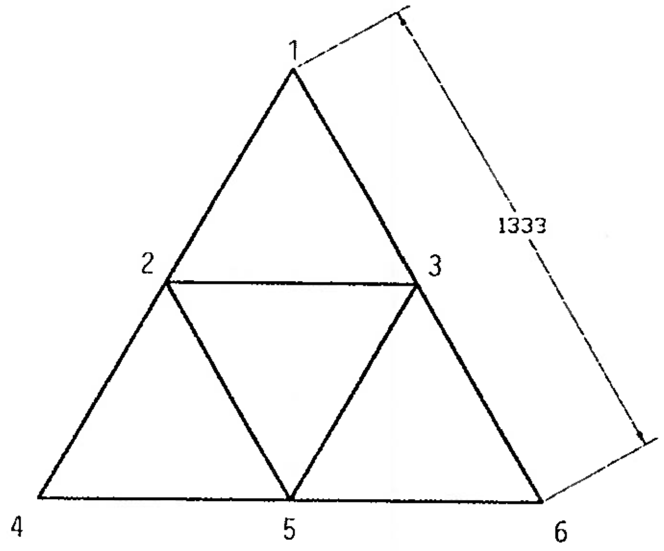


Figure 6a. Rear Frame

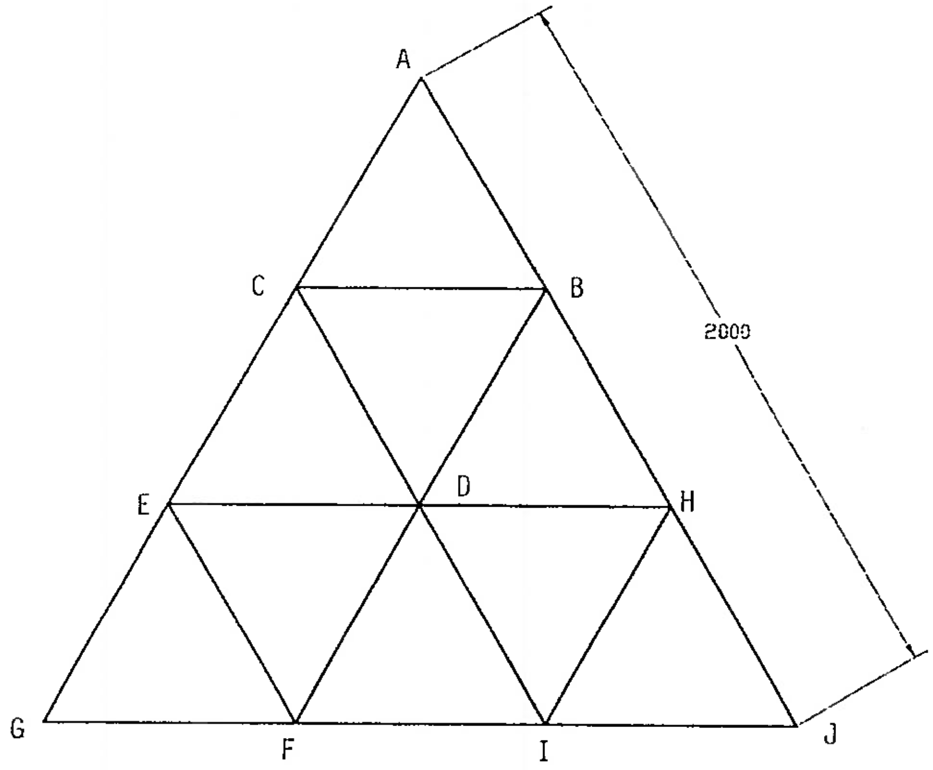
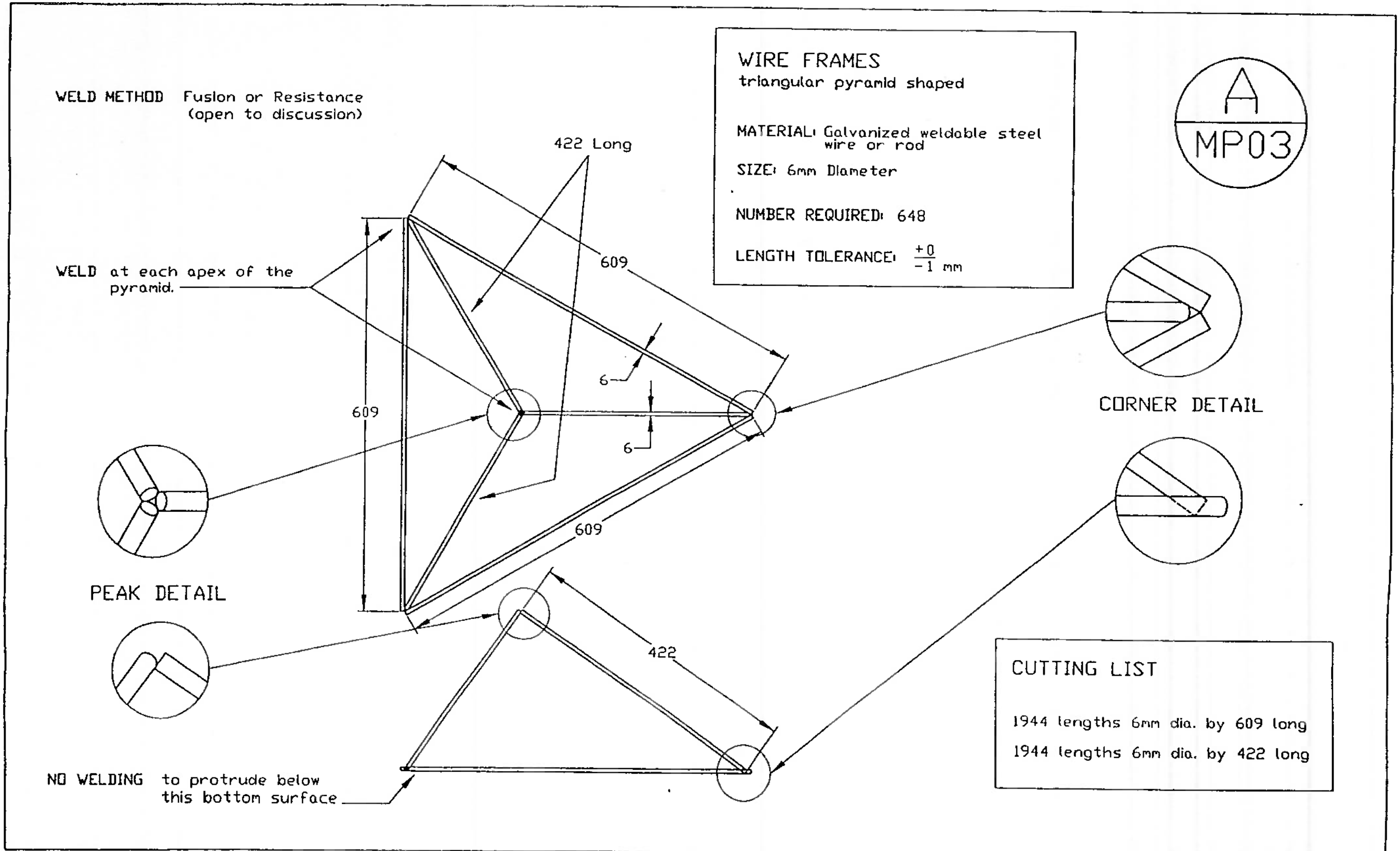


Figure 6b. - Front Frame, produced when the tetrahedra ABC1, BDH3 etc., are joined.



35.

ANUTECH Pty Ltd Technology Marketing Physical Sciences Division ENERGY RESEARCH CENTRE GPO Box 4 CANBERRA ACT 2601 AUSTRALIA Tel: 61 6 249 3811 Fax: 61 6 257 1433	FIGURE 6 c	Date 29/5/97 · Scale NTS Designed R D · Drawn G H Checked · Job No.	400 m² DISH COLLECTOR SYSTEM DRAWING TITLE : MIRROR PANEL, BACK FRAME PYRAMIDS
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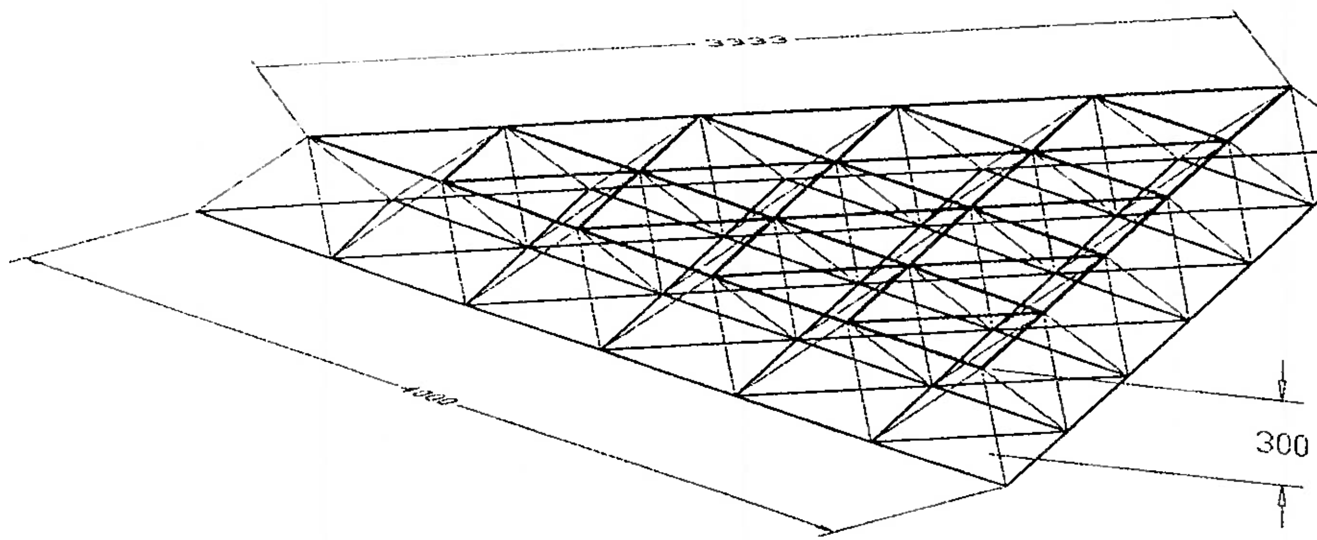

FIGURE 7 - Wire frame for 4 m panel (facing downwards)

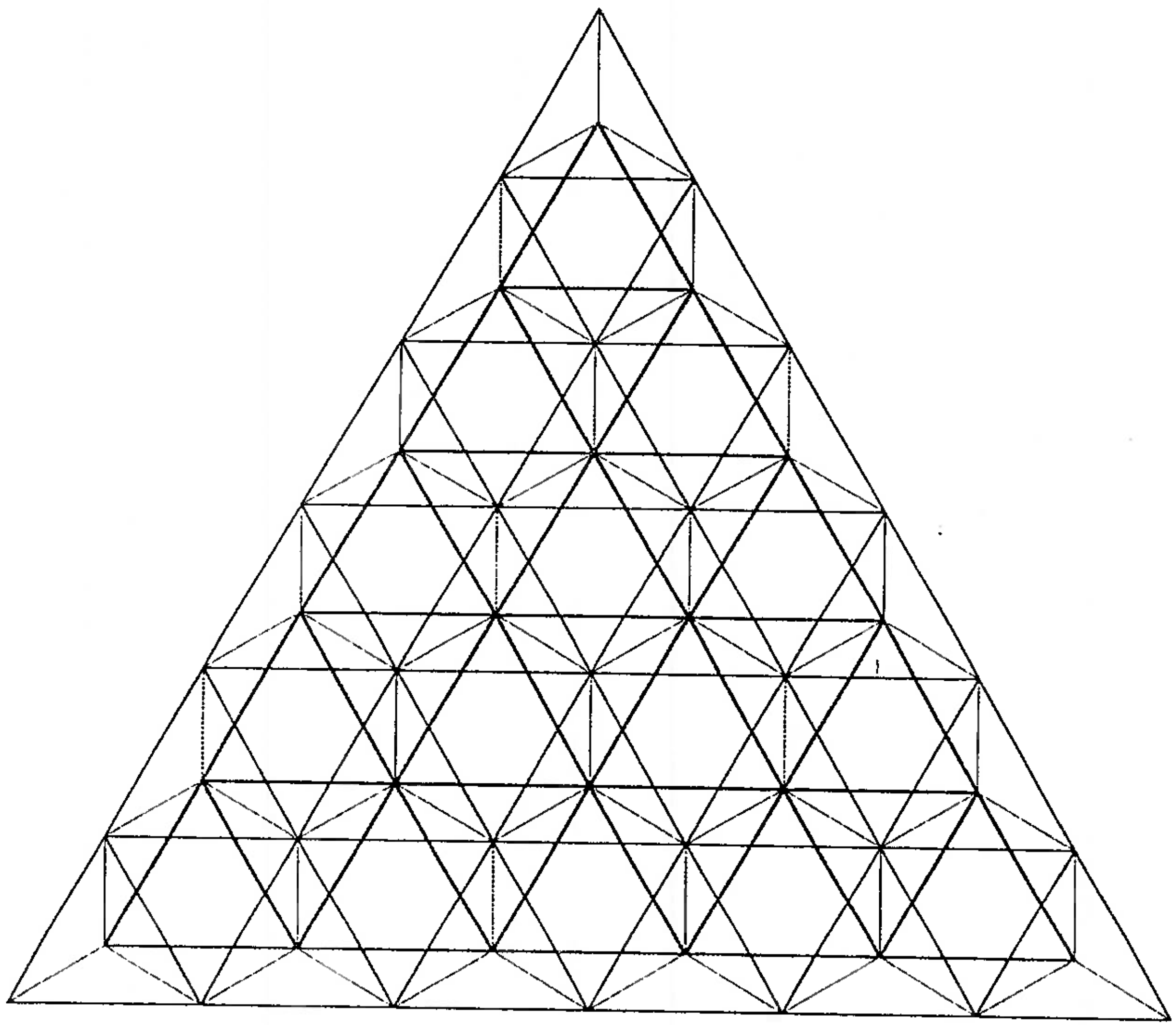

Figure 7a - Wire frame for 4 m panel (plan view)

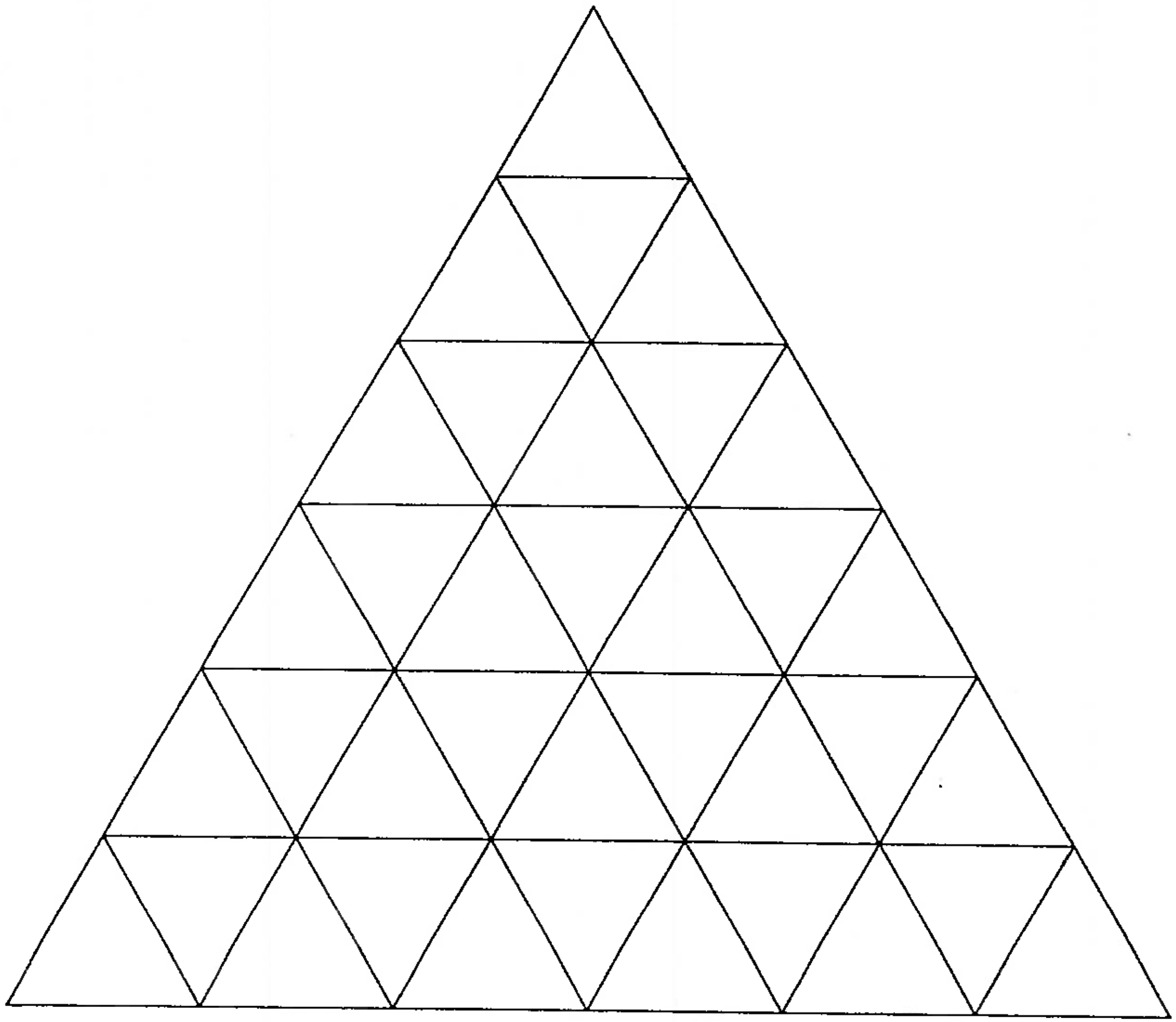

Figure 7b - Front face for 4 m panel.

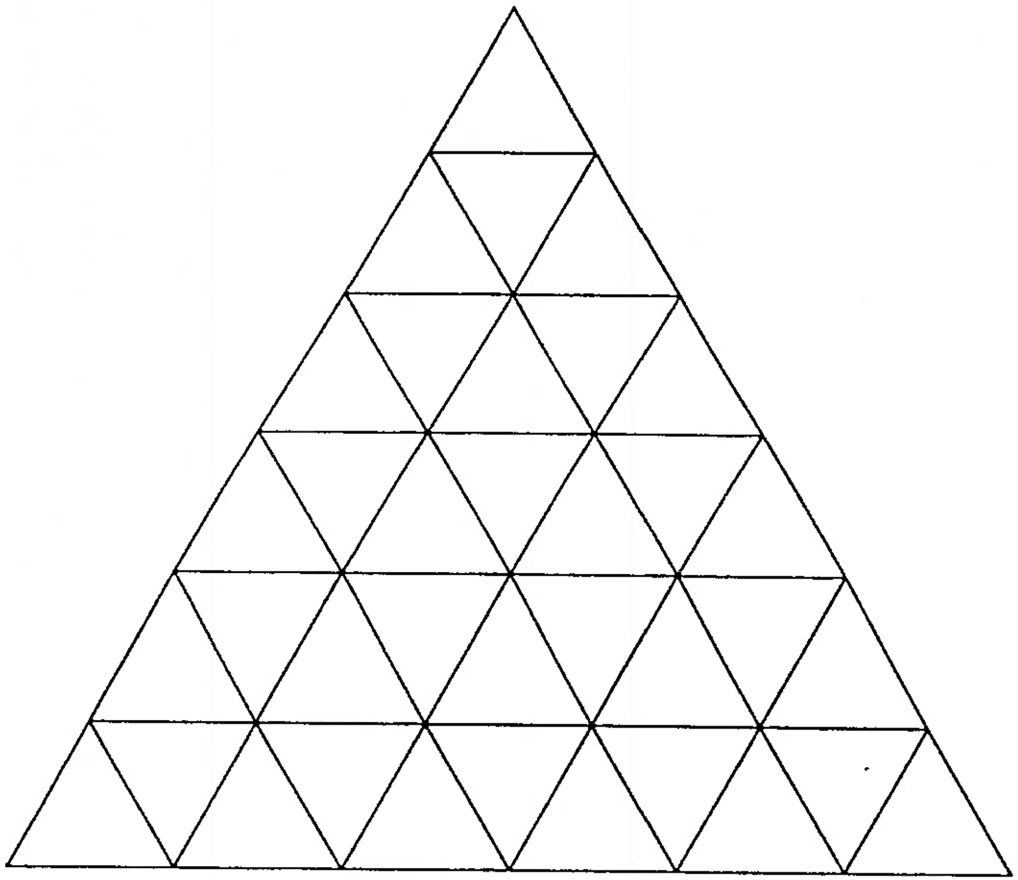

FIGure 7 c - Rear of 4 m panel

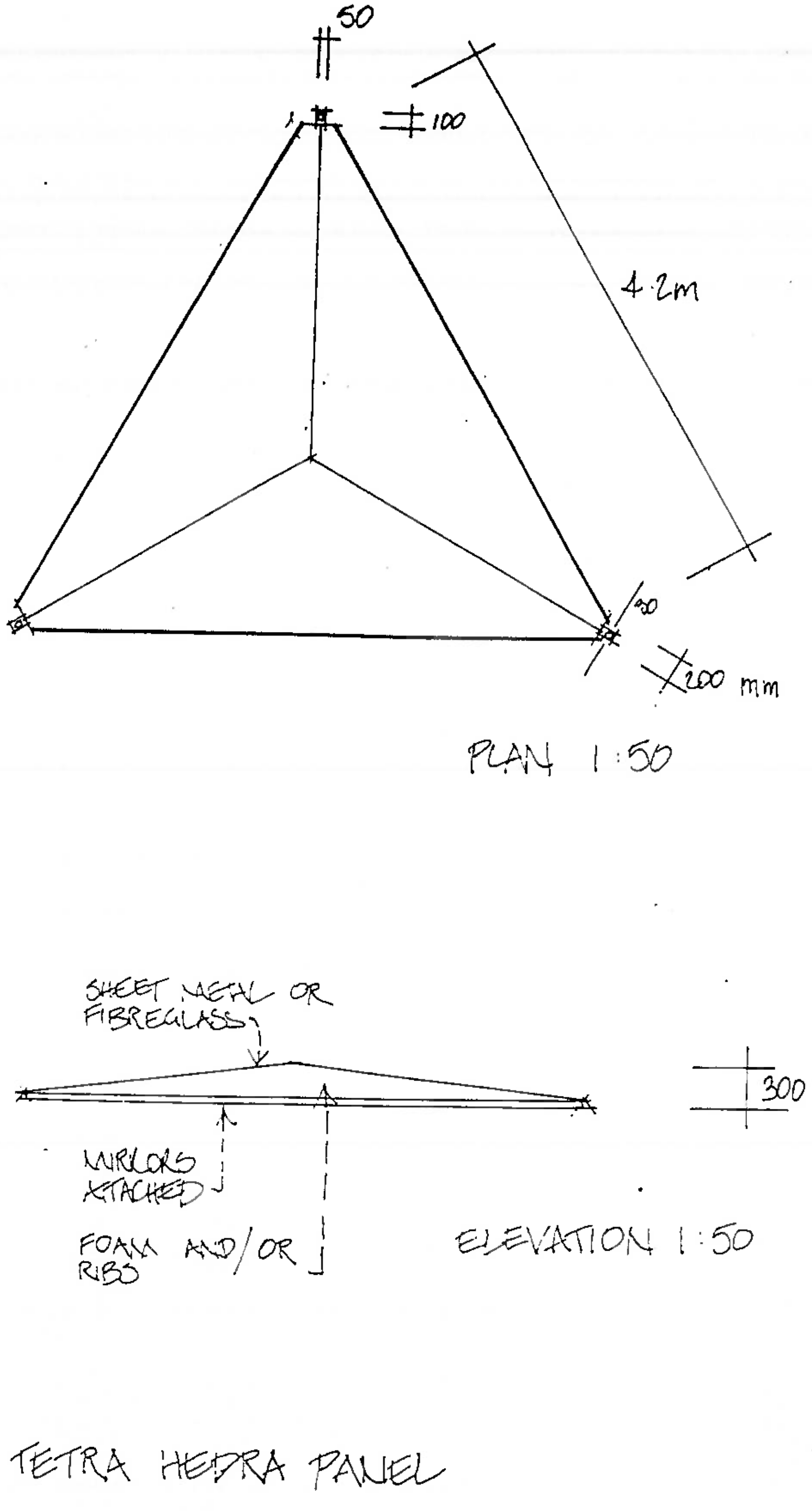

FIGURE 8 - Tetrahedral injected panel with fibreglass skin, sized for 4 m panel (2 m panel would be similar)

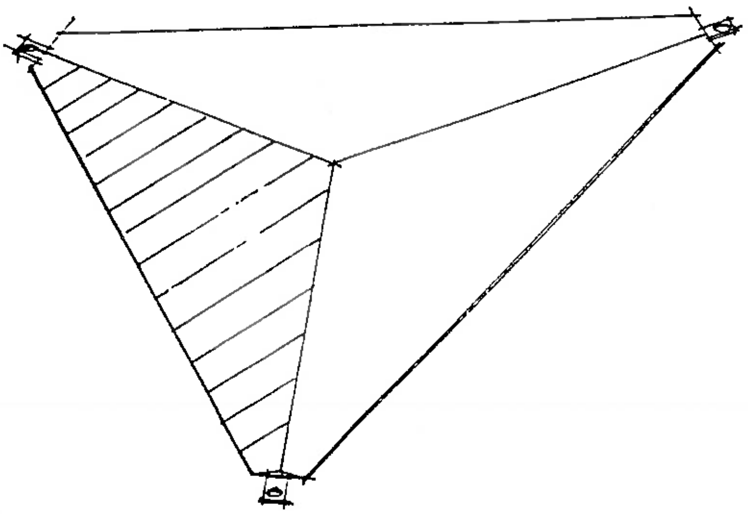

Figure 8a - Perspective view of tetrahedral panel.

4. 2 m triangular panel from paper hexagonal core with a fibreglass cover with no frame support. (The paper core is that used for house doors and sells for $2 per square metre, 25 mm deep.)

5. 2 m triangular tetrahedral form panel (maximum depth 70mm) formed by injection moulding, with a fibreglass cover - as in Figure 8.

6. 4 m triangular thin substrate as for (1) above, supported by a wire frame as in Figure 7. The substrate itself would be partitioned into 4 triangulaar sections for ease in handling.

7. 4 m triangular thin substrate as for (2) above, supported by a wire frame as in Figure 7. The substrate would be partitioned into 4 triangles.

8. 4 m triangular tetrahedral form panel (maximum depth 200 mm) formed by injection moulding, with fibreglass cover - as in Figure 8.

The preferred structures may be (6) and (7), then (3) and (4). However, since it is overall cost which is important and since each option has other implications, it would be important to have information on the economics of each panel type.

Other Considerations

Whatever the mirror support means, it is necessary to provide a mirror system with good impact absorption properties to cope with hail. Our experience has been that assumptions on how to realise good impact resistance are not always a satisfactory guide to design. Accordingly we have, over the past 2 weeks, subjected the 1 mm low iron glass to various tests in different configurations and arrangements to ascertain the most succssful economical method of mounting to provide the most durable system consistent with low cost. With the relatively fragile glass, a hard rigid support is appropriate.

Manufacturing and Assembling the Complete Mirror Panels

Little comment is needed regarding the substrate only (that is, no wire frame) panels except that they should remain undistorted during their working life.

The wire frames (as in Figures 6,7) can be produced by automated machinery in several ways, depending on the details of the machinery and on the size of production run, as well as the manufacturing location relative to the collector site. For example, one way is that based on producing 6 tetrahedra per 2 m panel, the front faces of which are respectively ABC, CDE, EFG, BDH, DIF, HIJ; and asembling them to form the front face of the mirror panel as shown in Figures 6, 6(b). The 'top' vertices of the tetrahedra (1,2, ... 6), are then joined with the mirror panel rear frame, Figure 6(a), to form the complete panel of Figure 6. The 6 tetrahedra/panel plus the rear frame can be mass produced in the factory and assembled on site, if so needed. This approach was chosen in order to facilitate transport to Israel.

In other circumstances, it would probably be more rational to build the whole panel in one process using automated machinery, as a means for reducing costs. Further reduction in cost would occur by building 4 m panels automatically. (Note the lesser number of members required by a 4 m panel compared to four 2 m panels).

In a similar manner, the components of Figure 7 can be assembled for each 4 m panel from 21 tetrahedra, joined at their rear vertices to the rear frame of Figure 7(c), to form the panel of Figure 7 (or 7a).

By other combinations of elements of the wire frames, automation can be carried out by other approaches, to the extent that the whole panel could be produced in one automated operation.

The panels should, if practicable, be manufactured and assembled on site in one operation, or at least the components - if made elsewhere - should be assembled on site to avoid handling problems; this applies particularly to the attachment of the mirrored glass.

As we envisage the operation, the mirrored glass should be placed face down on the mould and held there by vacuum; the substrate should be attached (or built up) on the back of the mirrors and any fittings attached. Any wire or other support frame should be attached also at that stage, so that before removal from the mould, a mirrored panel is complete for mounting on the dish.

Some Key Points

It has emerged that the most economical mirror panels are not going to use fibreglass reinforced plastic (FRP).

Other means are available to produce more economical panels.

Panels of 4 m triangular shape appear the most appropriate as regards cost and handling convenience (but there are other approaches possible).

A tetrahedra-based wire frame seems a good way to realise economical panels to provide appropriate stiffness to a thin substrate for mirror support.

A suitable low cost thin substrate could employ marine plywood, which is successful in aircraft as well as in boats.

If panels are constructed without wire frame bracing or similar, then the substrate itself must retain its form throughout its lifetime.

The mirror support must provide hail tolerance, as the mirror itself is relatively fragile (1 mm glass).

Prices for mirror panels obtained recently suggest that low cost mirrors systems are practicable.

It is preferable to assemble complete mirror panels on site.

Quotations Available

We have the following quotations available for the **wire frames for ONE dish:**
This is based on Figure 6 with 6 tetrahedra plus back frame/panel, of which there are 216 panels required for the Israeli Dish.

2 metre wire triangular panels:

Supplier	2 m wire frames for ONE dish	Additional cost to complete frames	Total/dish
Windex, Clayton Vic.	$6400	$2100	$8500
Loft & Co. Newpport Vic.	$10500	$2100	$12600
Sunset Industries, Queanbeyan NSW			$17280
Baxter Engineering Fyshwick ACT	$42000	$2100	$44100

Windex produce their work by automatic machines from galvanized wire in large rolls. Loft use automatic machines but employ short rods. Sunset Industries and Baxter Engineering use short rods with manual effort.

Quotation for 1 mm low iron mirrored glass:

Erie, Romont, Switzerland, mirrors for one dish + 10% $10,700
(Ordered for the Israeli Dish)

Estimate for mirror substrate to be supported by the wire frame

Pressed sheet steel (0.3 mm) 800 kg,(Figure 5) + adhesive $5000

Optional 3 mm marine ply + adhesive $5600
This figure is based on a price from Frank Grandi, Manager, Brims Distributors (NSW) Pty., Ltd. This firm could produce the panels to shape and contour were a large order to be given (a special press whould need to be provided, costing some $250,000). This could be a substantial saving as there would be no waste and the thin substrates would be ready for mirror mounting (could use spherical coutour for the substrates).

Estimate for cost of 4 m triangular wire frames for ONE dish on the basis of the Windex **quotation for the 2 m wire frames for ONE dish.**

There are fewer components for the 54 wire frames of 4 m each compared with the 216 wire frames of 2 m each triangle. Using a pro-rata estimate for a disassembled frame (as in the case of the Israeli dish) based on number of welds and members,

> Cost of 54 wire frames of 4 m triangles would be $5600 + 1900 for assembly; total $7500.

Cost reduction would be expected for a completely automatic product as well as for production for many dishes.

Summary of Costs for Mirror Panels (Part Quoted, Part Estimated)

Given for the preferred 4 m wire frame trianglular panels with marine ply thin substrates. This price would be indicative for several related alternatives.

Item	54 panels for one dish		Estimate/Dish when 200 Dishes produced	
4 m galv. wire frame (Fig, 7)	$7500	Quote	$6500	estimate
Mirrored glass	10700	Quote	7000	estimate
Ply Substrate	5600	Estimate	5000	estimate
Adhesive	1200	"	1000	"
Fittings to dish	750	"	600	"
Assembly Labour	200	"	200	"
	$26,000		$20,300	

The figures for one dish are reasonably close to reality.

I consider the 'estimates' for 200 dishes can be reduced.

I hope the above is useful.

With best wishes,

Yours sincerely,

S. Kaneff
Professor and Head,
Energy Research Centre.
20/6/97