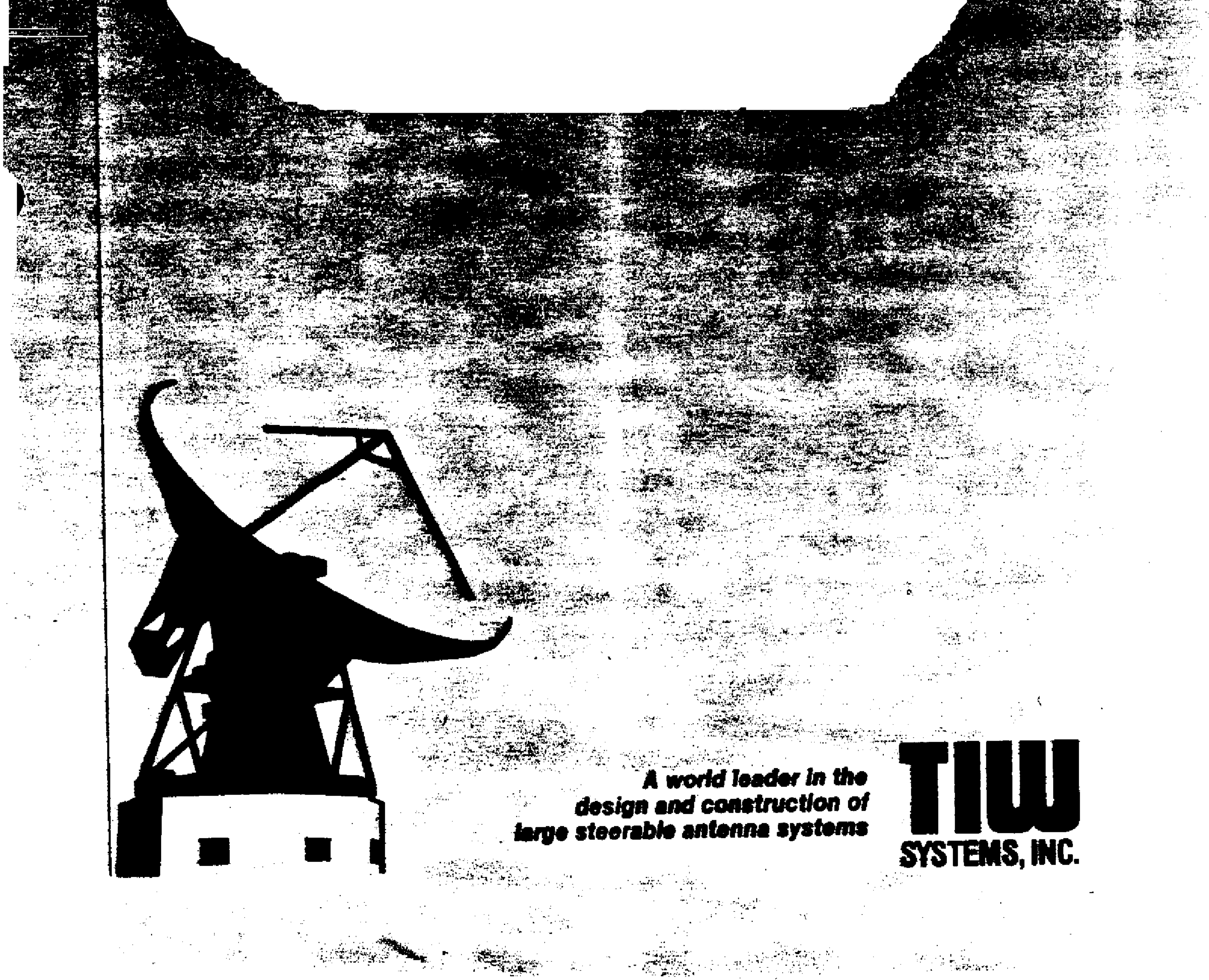
MEMO #10

6-METER ANTENNA STUDY

FOR

SMITHSONIAN ASTROPHYSICAL
OBSERVATORY

P.O. #SAO-21901



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FOR

SMITHSONIAN ASTROPHYSICAL
OBSERVATORY

P.O. #SAO-21901

SUBMITTED TO:

HARVARD SMITHSONIAN
ASTROPHYSICAL OBSERVATORY
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SUBMITTED BY:

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1.0 INTRODUCTION

TIW Systems has completed the study to evaluate structural concepts for the Smithsonian Astrophysical Observatory (SAO) 6-meter Antenna. The specific tasks accomplished in this study were:

- Preparation of a trade study investigating the use of various materials in the back-up structure.
- Examination of limitations of back-up structures to support surfaces of varying weights to the accuracies imposed by SAO. The options were based on the Hat Creek Design.
- Determination of an error budget for a representative back-up structure in an array of conditions for weights, wind loading and thermal gradients.
- Estimate of relative costs.

The SAO preliminary specification establishes several requirements that will strongly impact the antenna configuration. These requirements are:

- Altitude - Azimuth axis configuration
- Transportability
- Instrument Housing - Two-meter cube at Cassegrain focus (environmentally controlled).
- Weight less than 30,000 Kg.

- Axis Travel:

Altitude Axis:	-2 to +95 Degrees
Azimuth Axis:	±270 Degrees

- Pointing and tracking accuracies

- Reflector surface accuracy

The requirements for the SAO antenna are summarized in the preliminary specification included in Appendix A.

As a basis for conducting this study for HSAO, TIW decided to use an existing design for a 20-foot antenna now being built for the University of California site at Hat Creek. This was selected as a starting point for several reasons. The Hat Creek antennas are designed to work at 300 GHz so this design could probably be modified to work at SAO frequencies. TIW developed a finite element model of the design which could be iterated for the SAO application. The design allows for a large equipment housing at the cassegrain focus. The existing design is also cost effective and it was expected that there would be cost advantages to SAO by modifying an existing design rather than developing a completely new design.

Thus, using the Hat Creek configuration as a starting point, TIW carried out an optimization program to see if this design could be modified to meet SAO's technical requirements.

A general assembly drawing of the antenna is shown in Figure 1-1. As shown in the figure, the antenna consists of the following major assemblies: the pedestal, the elevation wheel, the reflector back-up structure, and the reflector panels.

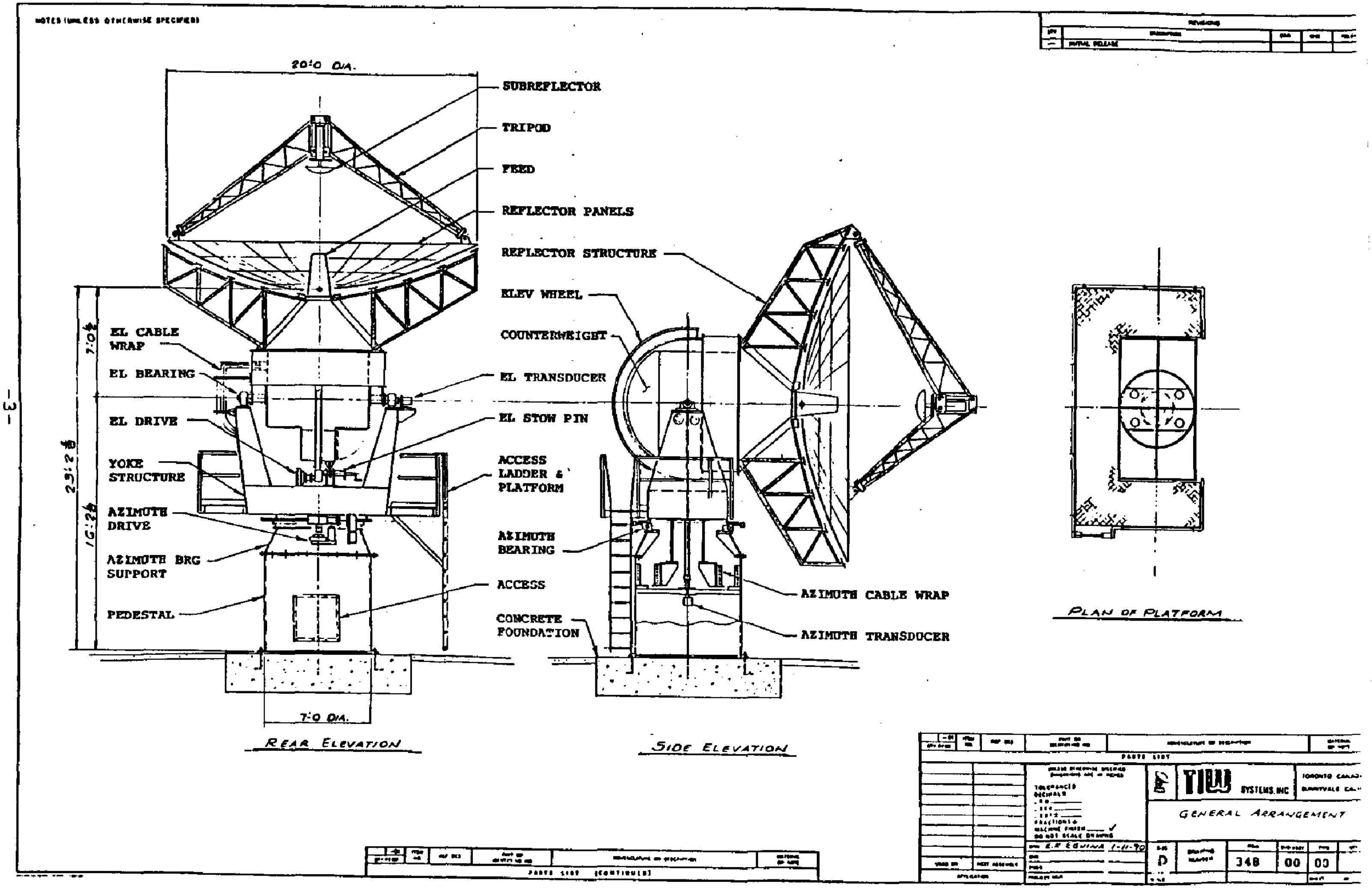
NOTES (UNLESS OTHERWISE SPECIFIED)
20'-0 DIA.
SUBREFLECTOR
TRIPOD
FEED
REFLECTOR PANELS
REFLECTOR STRUCTURE
ELEV WHEEL
COUNTERWEIGHT
EL CABLE WRAP
EL BEARING
EL TRANSDUCER
EL DRIVE
EL STOW PIN
YOKE STRUCTURE
ACCESS LADDER & PLATFORM
AZIMUTH DRIVE
AZIMUTH BEARING
AZIMUTH BRG SUPPORT
ACCESS
PEDESTAL
CONCRETE FOUNDATION
AZIMUTH CABLE WRAP
AZIMUTH TRANSDUCER
7'-0 DIA.
REAR ELEVATION
SIDE ELEVATION
PLAN OF PLATFORM
PARTS LIST
TIW SYSTEMS, INC
GENERAL ARRANGEMENT
E.R EGUINA 1-11-90
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FIGURE 1-1

The rotating structure (elevation wheel and reflector) is shown in Figures 1-2 through 1-4. The reflector is a radial truss design with circumferential trussed hoops and a large welded center hub. The center hub bolts to the welded plate elevation wheel, which consists of a box ring girder and a curved plate weldment to support the elevation drive ring (either friction or gear). The main benefit of the proposed elevation wheel design is that it allows for a two-meter cube enclosed area directly behind the Cassegrain feed. This area is easily accessible by a door in the back side of the enclosure. The area inside the enclosure is large enough to allow a normal-sized man to enter and work on equipment in an upright position. The elevation wheel also provides adequate room for counterweight to fully balance the reflector about the elevation axis.

The tilting structure was analyzed using a finite element program. The reflector back-up structure was modeled as hinged truss members, and the elevation wheel as plate elements. The deflections of the panel support points were then best-fit to a parabolic surface to determine the best-fit half-path-length error. In all cases, the reflector back-up and the elevation wheel were analyzed as a complete structure to insure that all contributing factors were included.

NOTES (UNLESS OTHERWISE SPECIFIED)

1. ALL MATERIAL TO BE A36 OR EQUAL

2. FINISH:
   SHOP
   A. CLEAN BY SANDBLASTING TO NEAR WHITE METAL EXCEPT FOR MACHINED SURFACES.
   B. PRIME WITH ONE (1) COAT OF SENTREX ZINC 17 CR METAL PRIMER.
   FIELD
   A. CLEAN DAMAGED AREA AND APPLY ONE (1) COAT OF PRIMER.
   B. FINISH WITH TWO (2) COATS OF SENTREX WHITE HIGH BUILD CHLORINATED RUBBER.

3. ALL BOLTS TO BE HIGH STRENGTH ASTM A-325 OR EQUAL. HOT DIPPED GALVANIZED PER ASTM 153 AND THREADS TO BE CHASED TO INSURE PROPER FIT OF NUTS.

4. ALL WELDS TO BE CONTINUOUS FULL PENETRATION OR DOUBLE FILLET WELD TO DEVELOPE FULL STRENGTH OF MEMBERS UNLESS NOTED.

5. STRESS RELIEVE AFTER WELDING.

6. EVERY MEMBER THAT CAN ENCLOSE WATER SHALL HAVE ADEQUATE DRAINAGE OR TUBULAR MEMBERS SHALL HAVE ONE ¼" DIA. HOLE ON EACH END LOCATED ON THE LOWER SIDE, TYPICAL AS SHOWN.

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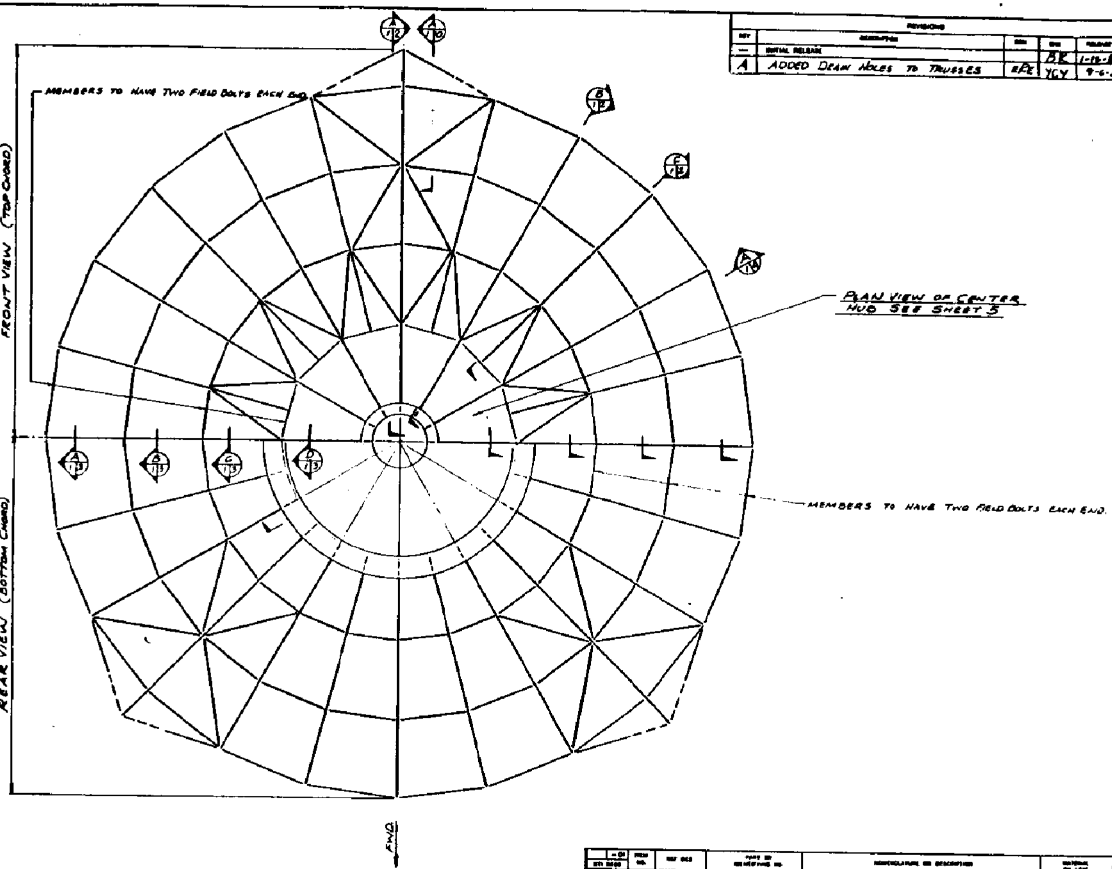
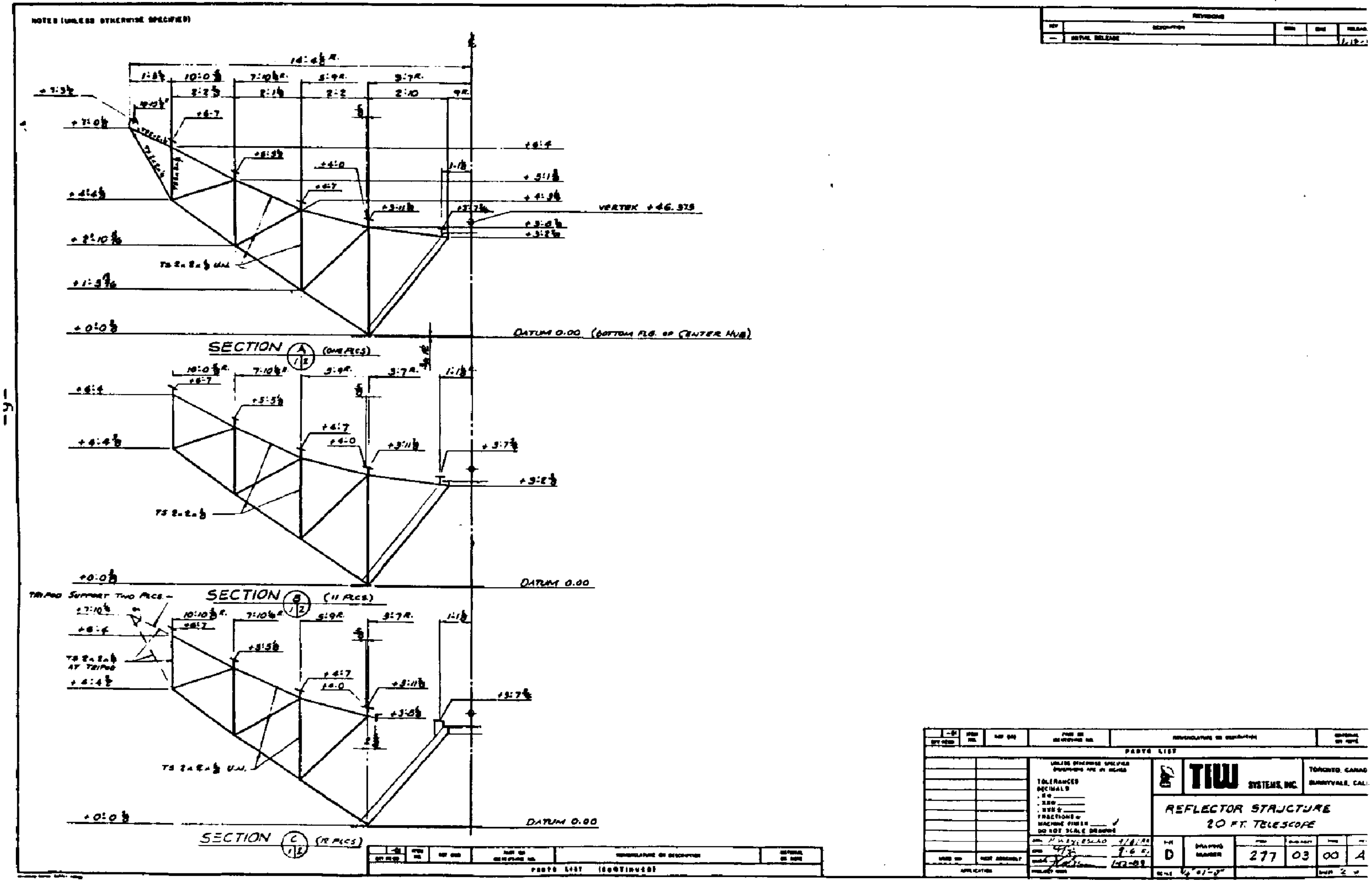


PLAN OF REFLECTOR STRUCTURE

PARTS LIST (CONTINUED)

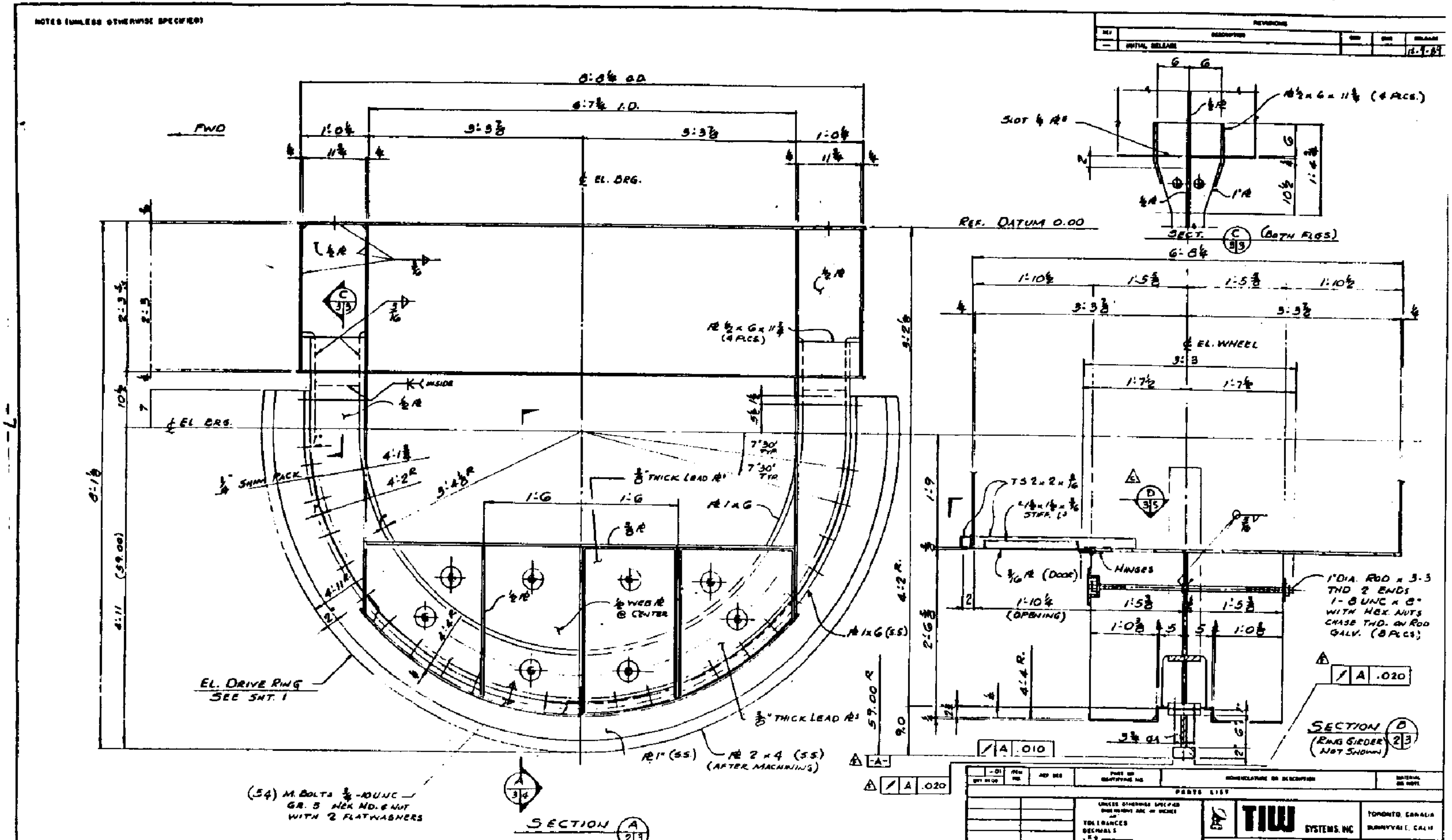
TIW SYSTEMS, INC	TORONTO, CANADA / SUNNYVALE, CALIF
REFLECTOR STRUCTURE 20 FT TELESCOPE	
SIZE D	DRAWING NUMBER 277 03 00 A

FIGURE 1-2



SECTION A
SECTION B
SECTION C
VERTEX +46.375
DATUM 0.00 (BOTTOM FLG. OF CENTER HUB)
DATUM 0.00
DATUM 0.00
PARTS LIST
TIW SYSTEMS, INC.
REFLECTOR STRUCTURE
20 FT. TELESCOPE
D
277
03
00
A

FIGURE 1-3



ELEVATION WHEEL
20 FT TELESCOPE

TIW SYSTEMS, INC — TORONTO, CANADA — SUNNYVALE, CALIF

SIZE	DRAWING NUMBER			
D	277	02	01	F

PARTS LIST (CONTINUED)

2.0 STUDY RESULTS

In order to meet SAO's overall surface accuracy specification, TIW needed to determine the magnitude of each of the individual errors which would contribute to the total error. The individual erros included: panel manufacturing, panel alignment, gravity deformation of the panels, gravity deformation of the back-up structure, thermal error in the panels, thermal error in the back-up structure, long-term creep, wind deformation of the panels, and wind deformation of the back-up strucutre. To understand the magnitude of the individual errors, TIW began with a parametric study of the backstrucutre. Several materials were analyzed as candidates for the backstructure. These materials were then looked at in combination with various possible materials for the surface panels.

This section describes work that was done on the backstructure comparing gravity, thermal, wind, and panel loadings for various materials. Section 3.0 describes the total error budget in more detail for combinations of backstructure and panel materials.

2.1 Investigation of Various Materials

TIW investigated the use of various materials for the reflector back-up. The materials evaluated were:

- Steel
- Aluminum
- High Nickel Steel (Invar)
- Carbon (Composite)

As discussed above, the finite element model which TIW used included the elevation wheel structure. In looking at different materials for the back-up structure, the elevation wheel was always modeled of steel because it was not considered practical to make the wheel out of either aluminum or carbon composite. The possibility of making the elevation wheel out of invar is discussed in Section 3.0 of this report.

A comparison of the materials considered in the study is shown in Table 2-1. This table identifies the material properties used in the model and shows the relative weightrs and material costs for each one.

The tilting structure was analyzed for each material. The member sizes were based on the design accomplished for the University of California 20-foot reflectors. The analysis included gravity, thermals, and wind. The panel weight was allowed to vary from 0 to 5 psf.

2.1.1 Gravity

The gravity deflections determined from the analysis are shown in Table 2-2.

This data is plotted in Figure 2-1. The results show that the reflector rms error due to gravity would stay nearly constant for aluminum or carbon (composite) and increase linearly for steel or invar. The reason for this difference is the interaction that takes place between the reflector back-up and the wheel when a load is applied. These results indicate that the reflector was reasonably well proportioned for aluminum or carbon (composite), but not for steel or invar.

TABLE 2-1

MATERIAL COMPARISON

	STEEL	ALUMINUM	INVAR	COMPOSITE
WEIGHT DENSITY (#/IN³)	0.283	0.097	0.291	0.061
MODULUS (E,PSI)	30×10^6	10×10^6	21.5×10^6	17×10^6
C.T.E. (STR/°F)	6.5×10^{-6}	12.8×10^{-6}	0.9×10^{-6}	$.101 \times 10^{-6}$
YIELD STRENGTH (KSI)	36	20	40	160
MATERIAL COST PER #	$.40/#	$2.00/#	$8/#	$93.3/#
20 FT REFLECTOR WEIGHT	7500#	2800#	7500#	1600#
MATERIAL COST ONLY FOR 20-FOOT REFLECTOR	$3000	$5600	$60,000	$149,280

TABLE 2-2

INITIAL EVALUATION OF BACK-UP STRUCTURE -

GRAVITY LOADING

WEIGHT (#/FT²)	SURFACE ACCURACY DUE TO GRAVITY FOR REFLECTOR BACK-UP STRUCTURE (STEEL ELEVATION WHEEL)			
	STEEL	ALUMINUM	INVAR	CARBON
0	0.00086	0.0018	0.00102	0.00108
1	0.00090	0.0018	0.00106	0.00107
2	0.00094	0.0018	0.00110	0.00105
3	0.00098	0.0017	0.00114	0.00105
4	0.00103	0.0017	0.00119	0.00104
5	0.00107	0.0017	0.00123	0.00104

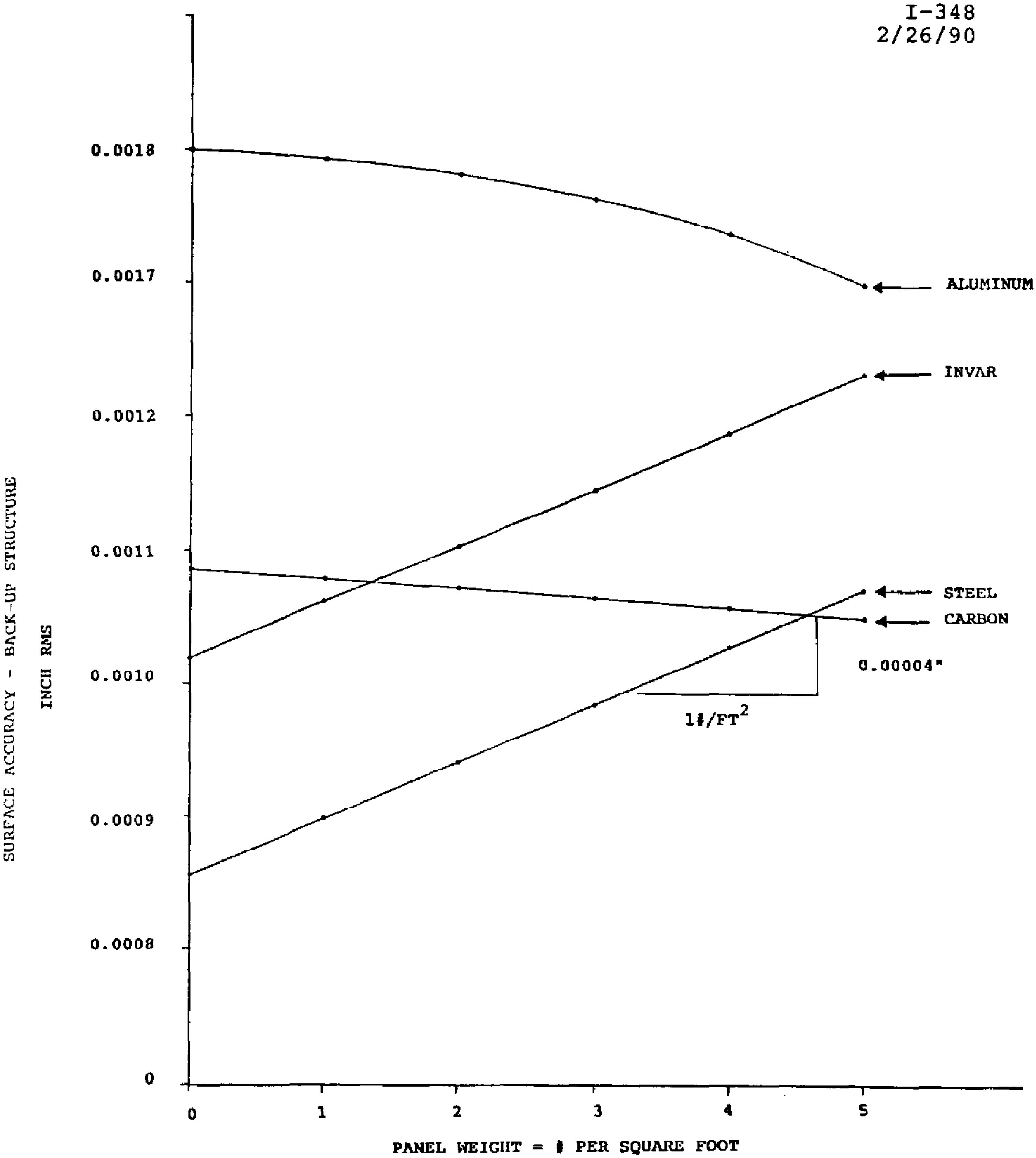


FIGURE 2-1

REFLECTOR GRAVITY DEFORMATION

A first level optimization effort was then conducted for steel and invar. The results are indicated in Figure 2-2, which shows that a steel or invar reflector can be proportioned so that it is basically insensitive to the panel weight. The first level optimization produced a design that has a slope of 0.00001 inch rms per pound/ft² of panel weight compared to a slope of 0.00004 inch rms per pound/ft² of panel weight shown in Figure 2-1.

2.1.2 Thermal

In evaluating the materials for varying thermal conditions, both gradient and an overall temperature change were considered. A unit gradient of 1°F was applied across the diameter of the reflector as shown in Figure 2-3. Also a unit gradient of 1°F was applied across the depth of the reflector as shown in Figure 2-4.

As expected, the thermal deformations are related to the coefficient of thermal expansion of the materials under consideration. The composite and invar are the least sensitive to thermal gradients. Steel and aluminum show larger deflections with aluminum being twice that of steel. Even though there are measurable thermally induced errors, the magnitude of these errors is small.

The biggest thermal problem in the structure comes from large temperature changes. For example, if the antenna is in a desert climate where temperatures during the day might be 80°F and then fall to 30°F at night. Table 2-3 quantizes the effect of a 50° absolute temperature change on the structure. The numbers in Table 2-3 represent the error induced by having a steel pedestal and elevation wheel mounted to a reflector of a different material. The use of different materials in the elevation wheel and the reflector back-up structure results in a significant error. Although the design has not been

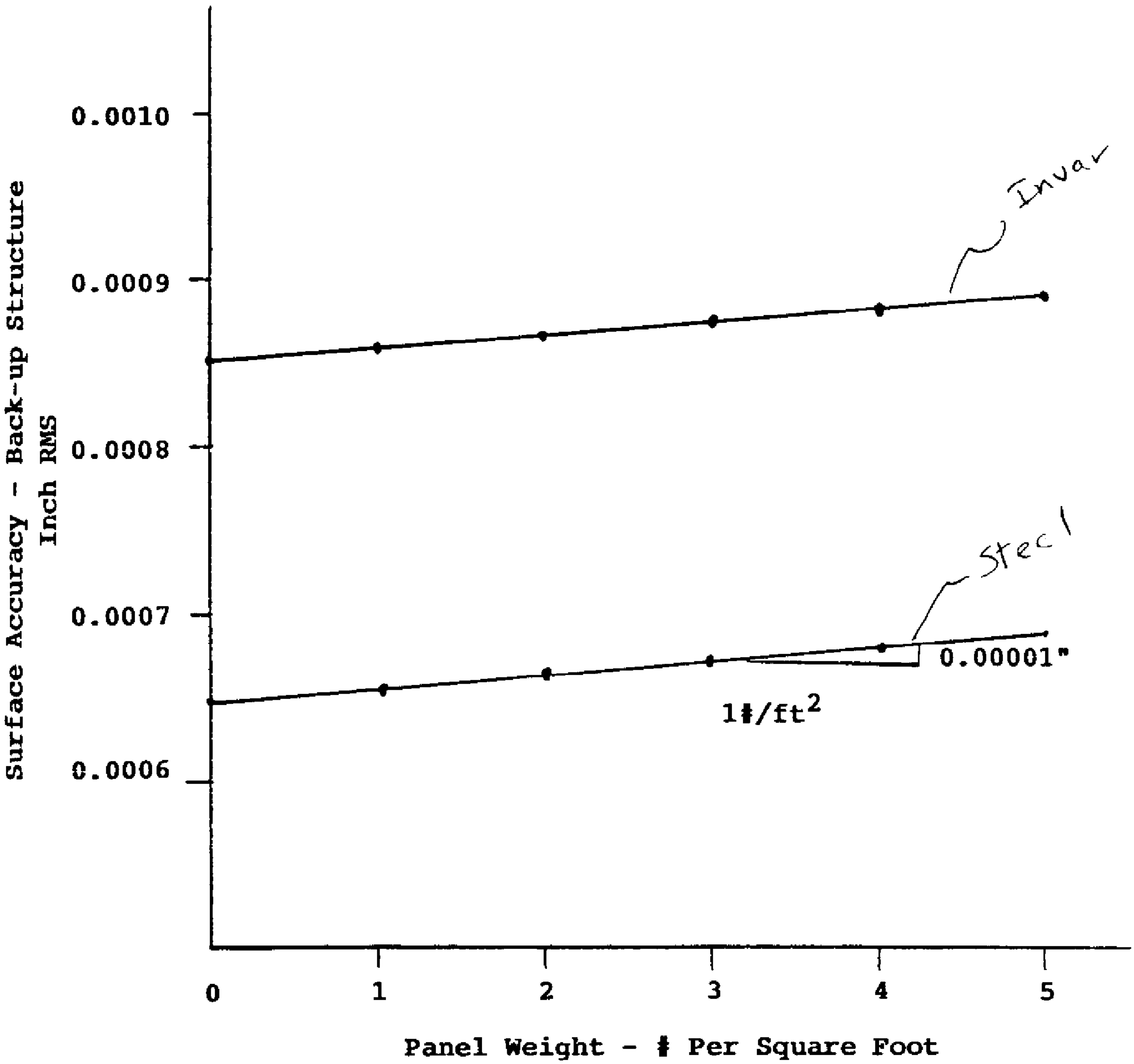


FIGURE 2-2

REFLECTOR GRAVITY DEFORMATION

FIRST LEVEL OPTIMIZATION - STEEL & INVAR

FIGURE 2-3

1 DEGREE THERMAL GRADIENT ACROSS REFLECTOR DIAMETER

MATERIAL	SURFACE ACCURACY RMS (BEST-FIT) (INCH)
STEEL CONSTRUCTION	0.000054
ALUMINUM	0.000103
HIGH NICKEL STEEL (INVAR)	0.000008
CARBON FIBER	0.000003

FIGURE 2-4

1 DEGREE THERMAL GRADIENT ACROSS REFLECTOR DEPTH

MATERIAL	SURFACE ACCURACY RMS (BEST-FIT) (INCH)
STEEL CONSTRUCTION	0.000107
ALUMINUM	0.000202
HIGH NICKEL STEEL (INVAR)	0.000018
CARBON FIBER	0.000007

TABLE 2-3

OVERALL 50 DEGREE TEMPERATURE CHANGE

MATERIAL	Surface Accuracy RMS (Best-Fit) (INCH)
Carbon Fiber	0.0025
High Nickel Steel (Invar)	0.0022
Steel Construction	0.0000
Aluminum	0.0025

Note: Steel Back-up Elevation Wheel

optimized to preclude this effect, and it would be possible to improve the thermal response of the structure, these results are indicative of the magnitude of the problem. The thermal gradient issue is important not only to surface accuracy assessments, but is a factor in the pointing error of the telescope. Clearly, thermals will be a critical aspect of the design for the SAO 6-meter telescope; thermal effects must be carefully modeled and budgeted for.

2.1.3 Wind

The critical wind condition was found to be when the reflector is at 0° elevation and the wind blowing perpendicular to the elevation axis. This loading was applied to the reflector considering all four materials. The surface accuracy results are shown in Table 2-4. As shown in the table, the steel structure is the least sensitive to wind, while the aluminum structure is most effected.

As can be seen from these results, the deformation due to a 20 mph wind is not critical.

2.2 Limitations on Support of Panels of Varying Weight

The reflector was analyzed for each material in regards to a varying weight (0 psf to 5 psf) for the reflector panels. For reference, aluminum panels would be about 5 psf, and carbon panels would be 1-1.5 psf. A first level of optimization was achieved for each material. Final optimization is not considered part of the scope of work for this study. The goal of this study was to determine if the design could be configured to be relatively insensitive to the uniform weight per unit area of the reflector panels, thus making panel material selection independent of backstructure material from a structural point of view.

TABLE 2-4

20 MPH FRONT WIND LOAD

MATERIAL	SURFACE ACCURACY RMS (BEST-FIT) (INCH)
STEEL CONSTRUCTION	0.000027
ALUMINUM	0.000043
HIGH NICKEL STEEL (INVAR)	0.000031
CARBON FIBER	0.000034

It was found that with some optimization, this could be achieved. The results of this phase of the study are presented in Figure 2-5.

2.3 Determination of Error Budget

The overall error budget for the reflector must consider all factors contributing to the surface distortion. These factors are:

- Panel Manufacturing Tolerance
- Panel Alignment on the Reflector
- Gravity Deformation of Panels
- Gravity Deformation of Back-up Structure
- Thermal Gradient in Panels
- Thermal Distortion in Back-up Structure
- Allowance for Long-term Creep
- Wind on Reflector Panels
- Wind on Reflector Back-up Structure

Each of these error sources is discussed briefly below.

2.3.1 Panel Manufacturing

TIW Systems believes there are two practical solutions to making the panels. These two solutions are:

- Machined Aluminum Castings
- Carbon (Composite) Lay-up

Both types of panels can be manufactured to tight tolerances, and both can be designed to meet the allowable stress and deflection requirement.

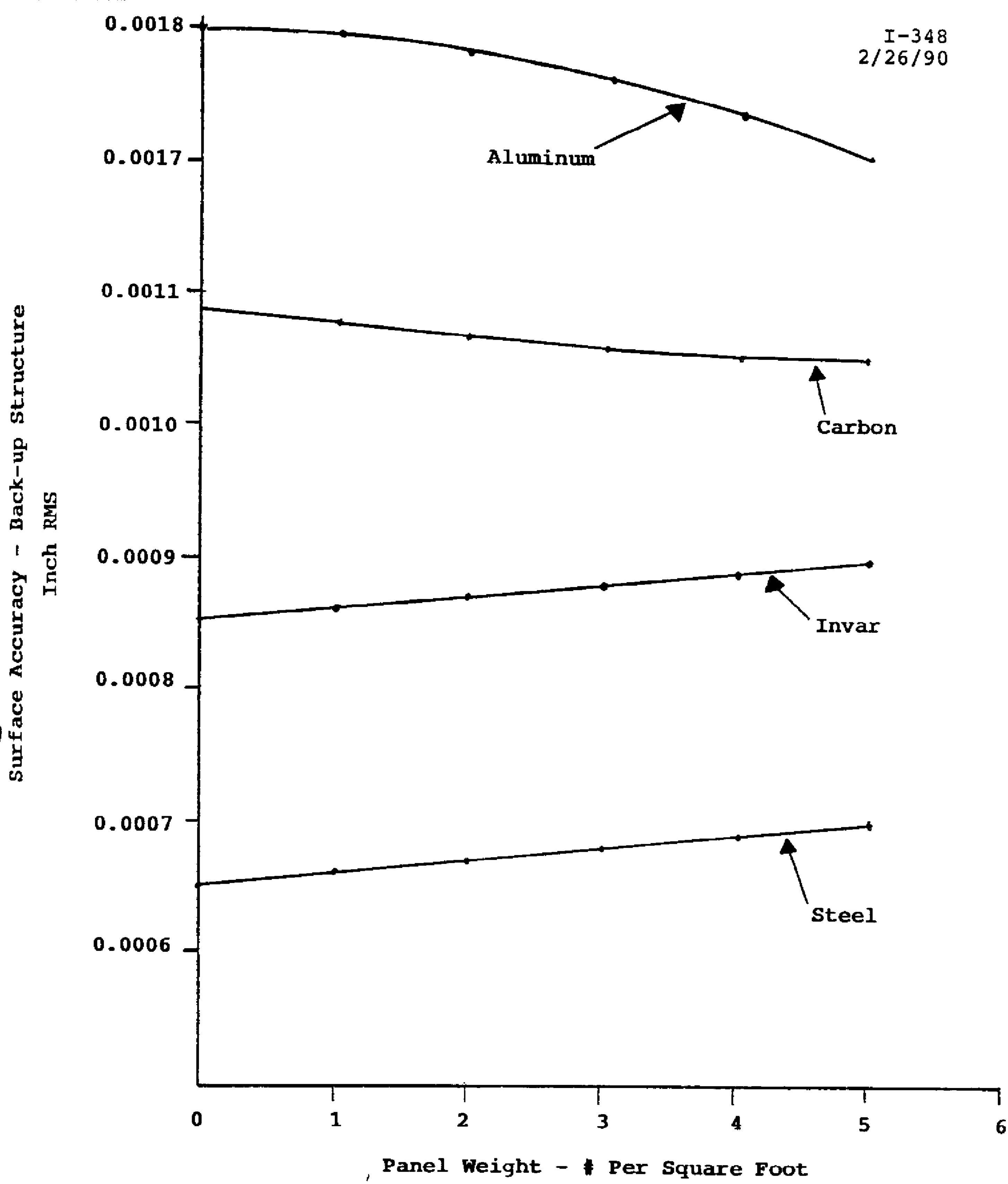


FIGURE 2-5

Reflector Deformation - Uniform Panel Weight

Based on input from Hexcel, the carbon (composite) panels can be manufactured to within 0.0003 inch rms. After discussions with precision surface finishing sources, TIW Systems believes that a tolerance of 0.0003 inch rms can also be achieved on machined cast aluminum panels. TIW Systems has had extensive experience in machining large diameter aluminum castings. With proper selection of the alloy and a careful independent surface checking procedure, it is possible to have a great deal of confidence in the machined cast aluminum approach.

2.3.2 Panel Alignment

The panels would have to be rough aligned when installed. This could easily be done to within 0.005 inch rms. Final alignment would then need to be done by microwave holography. Experience on the University of California 20-foot reflectors indicates that with care, an alignment accuracy of 0.0003 inch rms should be possible.

2.3.3 Gravity Deformation of Panels

Bases on the panel construction used for the University of California 20-foot reflectors, TIW has determined that a panel gravity deflection of 0.00008 inch rms can be achieved for a weight of approximately 5.0 psf.

2.3.4 Gravity Deformation of Back-up Structure

TIW Systems completed a preliminary analysis of the tilting structure (reflector back-up and elevation wheel). Based on a first level optimization effort for a configuration with machined cast aluminum panels on a steel reflector back-up and steel elevation wheel, it was determined that the back-up gravity deformation would be within 0.0007 inch rms. With further optimization, TIW is optimistic that this can be reduced to about 0.00035 inch rms.

2.3.5 Thermal Error in Panels (1°F Gradient)

Tests conducted by the University of California on machined aluminum panels determined that the maximum thermal gradient was 1-2°F, with a minimum effort. A 1°F gradient results in a surface error of 0.00010 inch rms. TIW believes that 1°F is possible with some design improvements in the thermal control system.

2.3.6 Thermal Error in Back-Up

Based on previous experience and a preliminary analysis, it was determined that if an insulated back-skin is provided over the back of the reflector structure, and if sufficient ambient air is circulated through the enclosed area, the thermal gradient across the reflector can be kept to within 1°F. This results in a surface error of 0.00011 inch rms.

2.3.7 Long-Term Creep

TIW Systems does not have any data on long-term creep for an all welded back-up structure. However, it would be very conservative to allow for a value of approximately 10% of the projected optimized gravity deformation. An allowance will therefore be made for 0.00003 inch rms.

2.3.8 Wind on Reflector Panels

The panels were analyzed for a wind loading of 10 meters/sec. This loading results in a surface distortion of 0.00002 inch rms.

2.3.9 Wind Loading on Back-up Structure

The reflector back-up structure and elevation wheel were modeled and analyzed for a 10 meter/sec wind. The calculated error for this loading is 0.00008 inch rms.

2.3.10 Resulting Error

Based on the results obtained from the preliminary analysis and actual field data, TIW Systems predicts the overall surface accuracy to be within 15 µm as shown in Table 2-5. The values established in this table can be used as the basis for an overall error budget for the surface accuracy performance of the SAO 6-meter antenna.

2.4 Estimate of Relative Costs

In making an engineering cost estimate, it is first necessary to establish the type of panels that will be used. Table 2-6 compares the cost of carbon (composite) to machined aluminum. As can be seen, the machined aluminum approach is more cost effective. Machined aluminum panels are therefore used for further analysis to determine the most cost effective approach.

Table 2-7 summarizes the cost for each of the materials considered for the reflector, elevation wheel, and pedestal. Table 2-8 summarizes the projected overall performance for each of the options considered. It should be noted that the back-up structure deflections are projected values that TIW believes can be achieved for the University of California 20-foot configuration. Further optimization work will be required to verify the achievement of these values.

TABLE 2-5

PREDICTED SURFACE ACCURACY/ERROR BUDGET

6-Meter Antenna

Precision Operation
(Aluminum Panels, Steel Back-up,
Steel Elevation Wheel and Steel Pedestal)

Error Source	σ(IN)	σ(IN²)
Panel Manufacturing	0.00030	0.000000090
Panel Alignment	0.00030	0.000000090
Gravity Deformation of Panels	0.00008	0.0000000064
Gravity Deformation * of Back-up	0.00035	0.000000122
Thermal Error in Panels	0.00010	0.000000010
Thermal Error in Back-up	0.00011	0.000000012
Long-Term Creep	0.00003	0.0000000009
Wind Deformation of Panels	0.00002	0.0000000004
Wind Deformation of Back-up	0.00008	0.0000000064
Resulting Error	0.0006	0.0000003381
SAO Specification	15 μm	

* Projected on fully optimized structure -- current first level optimization has achieved 0.0007 inch rms.

TABLE 2-6

PANEL COST TRADE STUDY SUMMARY

Panel Type	Non-Recurring Cost Divided by Six (6)	Material	Labor	Packaging	Total Cost Per Reflector
Carbon * (Composite)	$30,000	$50,000	$98,000	$6,000	$184,000
Machined Aluminum Castings	$15,000	$50,000	$65,000	$7,000	$137,000

* Costs are based on preliminary material estimates from Hexcel combined with TIW's estimate of the manufactured cost.

TABLE 2-7

ANTENNA COST TRADE STUDY SUMMARY
(NOTE - HARDWARE FOB POINT OF MANUFACTURER)

Component	Antenna Configuration			
	Alum. Panels Alum. Back-up Steel El. Wheel	Alum. Panels Steel Back-up Steel El. Wheel	Alum. Panels Carbon Back-up Invar El. Wheel	Alum. Panels Invar Back-up Invar El. Wheel
Reflector Panels	$137,000	$137,000	$137,000	$137,000
Reflector Back-up	59,000	39,000	350,000	143,000
Elevation Wheel	35,000	35,000	125,000	125,000
Pedestal	70,000	70,000	70,000	70,000
Mechanical Components	95,000	95,000	95,000	95,000
Counterweight	17,000	20,000	15,000	20,000
Thermal Protection	45,000	40,000	15,000	15,000
Misc. Items (Paint, Lube, Etc.)	10,000	10,000	10,000	10,000
TOTAL	$468,000	$446,000	$817,000	$615,000

COSTS DO NOT INCLUDE DESIGN ENGINEERING, ELECTRIC DRIVES, CONTROLS, READOUTS, FURNISHINGS, SHIPPING, SITE INSTALLATION, OR ANY MICROWAVE EQUIPMENT

TABLE 2-8
SURFACE ACCURACY PERFORMANCE SUMMARY

Error Source	Alum. Panels Alum. Back-up Steel El. Wheel Steel Pedestal		Alum. Panels Steel Back-up Steel El. Wheel Steel Pedestal		Alum. Panels Carbon Back-up Invar El. Wheel Steel Pedestal		Alum. Panels Invar Back-up Invar El. Wheel Steel Pedestal	
	σ(IN) x10^{-3}	σ^2(IN^2) x10^{-6}	σ(IN) x10^{-3}	σ^2(IN^2) x10^{-6}	σ(IN) x10^{-3}	σ^2(IN^2) x10^{-6}	σ(IN) x10^{-3}	σ^2(IN^2) x10^{-6}
Panel Mfg.	0.30	0.09	0.30	0.09	0.30	0.09	0.30	0.09
Panel Alignment	0.30	0.09	0.30	0.09	0.30	0.09	0.30	0.09
Gravity Deformation of Panels	0.08	0.0064	0.08	0.0064	0.08	0.0064	0.08	0.0064
* Gravity Deformation of Back-up	0.80	0.64	0.35	0.122	0.50	0.250	0.40	0.160
Thermal Error in Panels	0.10	0.010	0.10	0.010	0.10	0.010	0.10	0.010
Thermal Error in Back-up	2.7	7.29	0.11	0.012	0.01	0.0001	0.02	0.0004
Long Term Creep	0.08	0.0064	0.03	0.0009	0.05	0.0025	0.04	0.0016
Wind Deformation on Panels	0.02	0.0004	0.02	0.0004	0.02	0.0004	0.02	0.0004
Wind Deformation on Back-up	0.12	0.014	0.08	0.0064	0.10	0.010	0.10	0.010
Resulting Error	2.85	8.1472	0.58	0.3381	0.68	0.4594	0.61	0.3688
SAO Specification	15μm		15μm		15μm		15μm	

* Represents projected tolerances that TIW believes can be achieved with extensive optimization -- based on configuration shown in Figure 1-1.

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3.0 CONCLUSION

The results of this study show that the most economical approach to meeting the SAO specification for reflector accuracy is to use the following configuration:

- Machined Aluminum Cast Panels
- Steel Reflector Back-up
- Steel Elevation Wheel
- Steel Pedestal

This would not only be a cost effective solution, it would also be a very reliable approach providing good thermal protection is included. However, there is one possible complication. Should SAO apply thermal loads to the reflector hub/elevation wheel enclosure area, the surface accuracy and antenna pointing will be significantly impacted. Also, since thermals in general are always a difficult item to forecast, it is possible that for a reasonable cost increase SAO may elect to go with the invar reflector back-up and invar elevation wheel. Should that be the decision, the recommended error budget would be revised to the values shown in Table 2-8. This approach will meet the required specification at a cost increase of about $170,000 per unit. However, the availability of invar is in question. TIW is currently exploring the availability of invar in the required shapes and will advise SAO further on this possibility.

TIW does not recommend the use of aluminum. Because of its high coefficient of thermal expansion, it will always present thermal problems. The problem could be helped by making the elevation wheel out of aluminum, but this would result in other problems involving mechanical components, thermal protection, etc.

TIW is of the opinion that the carbon (composite) approach could be optimized for a different configuration than used by TIW in this study, and be made to have better performance. However, any such design needs to be analyzed in conjunction with the elevation wheel. It is TIW Systems' opinion that any resulting design using carbon (composite) will be considerably more expensive than the other approaches if the same access and functional requirements are maintained.

APPENDIX A

SAO Preliminary Specification

Preliminary Specifications for the SAO Submm Array Antennas (9/26/89)

I. Diameter: Approx. 6 m ± ?

II. Configuration: Alt-Az

III. Pointing:

A. Altitude axis -2 to +95 degrees

B. Azimuth axis ± 270 degrees

IV. Optics: Classical cassegrain, f ratio approx. f/10

V. Environment

A. General:
1. Elevation, approx. 3000-4000 meters
2. Temperature, -30 to +40 degrees C
3. Dust, occasionally heavy

B. Precision Operations:
1. Wind ≤10 m/sec
2. Relative humidity <20%
3. all sun angles

C. Degraded Operations:
1. wind ≤25 m/sec
2. relative humidity <60%
3. all sun angles

D. Instrument Survival:
1. in winds to 75 m/sec in dish-up stow position; 50 m/sec all alt-az positions
2. humidity: 0-100%;

3. snow: up to 1 meter fall in unattended status;
4. ice: up to 3 cm coverage on all surfaces;
5. instrument must drive to stow position in winds to 50m/sec

VI. Surface Accuracy, Primary

A. Precision Operations: better than 15μm RMS

B. Degraded Operations: better than 35μm RMS

VII. Surface Accuracy, Secondary: better than 5μm RMS, all operating conditions

VIII. Pointing Accuracy (as measured at the Cassegrain focus)

A. Precision Operations:
1. max error: <±1 arc sec each axis when offset from known standard within 20 degrees
2. max error: <±2 arc sec each axis for >18 hours following development of mount model

B. Degraded Operations: max error <±3 arc sec each axis

IX. Tracking accuracy (as measured at the instrument focus)

A. Precision Operations: <±1 arc sec peak to peak tracking deviations at sidereal rates

B. Degraded Operations: <±2 arc sec peak to peak tracking deviations at sidereal rates

X. Slew speeds: >1 degree/sec both axes

XI. Axis alignment

A. Orthogonality: <10 arc sec

B. Axis Wobble: <10 arc sec, repeatable to 0.5 arc sec

XII. Computer control:

A. Digital readout available both axes to <1 arc sec

B. Both axes addressable in drive rate from 0 to slew speeds

C. Closed loop drive in alt-az to selected coordinates

D. readout of the tilt of azimuth axis to $<\pm 0.2$ arc sec

XIII. Transportability:

A. Weight: <30,000 Kg

B. Time to move 1 Km to prepared location - < 2 hour

C. Possible transportation path: Unimproved roads with grade <10%

D. Realignment activities at new location - < 3 hours

XIV. Instrument Housing:

A. An environmentally controlled, approx. 2 meter cube at Cassegrain focus

B. Approximately 4 cubic meter enclosed instrument housing located elsewhere on the transportable mount

C. Cables to the cassegrain cabin equiv. to 25 cm diameter bundle

D. Mount for an auxiliary optical telescope of ≤ 12 cm aperture

XV. Surface Finish: Painted, with the exception of the reflecting surfaces and those specially wrapped or covered for thermal control

XVI. Required Operating Life: 30 years

- ☐ Satellite Communications Earth Station Systems
- ☐ Large Steerable Antenna Systems
- ☐ Major Scientific Instruments
- ☐ Digital Communications Products
- ☐ Position Control and Monopulse Tracking Equipment
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