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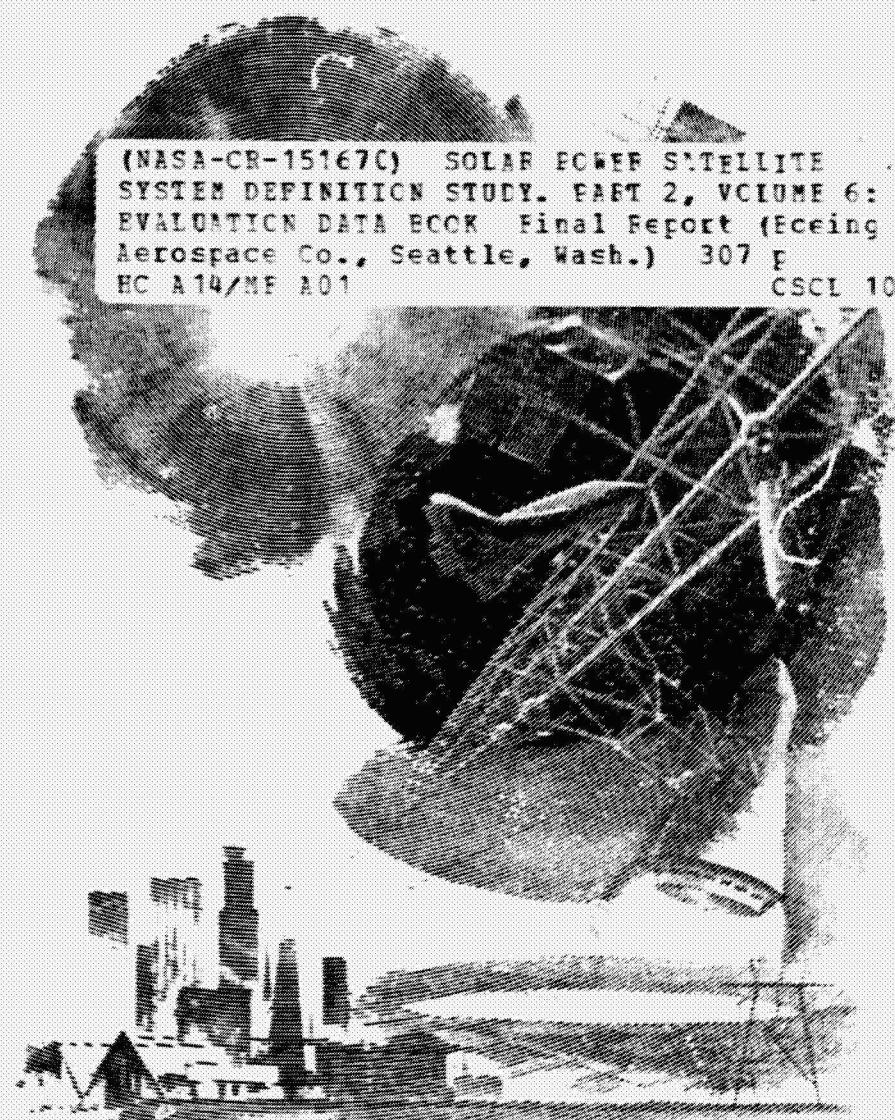
NAS9-15196
DRL T-1346
DRD MA-664T
LINE ITEM 3

Volume VI

Evaluation Data Book

(NASA-CR-15167C) SOLAR POWER SATELLITE
SYSTEM DEFINITION STUDY. PART 2, VOLUME 6:
EVALUATION DATA BOOK Final Report (Receiving
Aerospace Co., Seattle, Wash.) 307 P
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Solar Power Satellite

SYSTEM DEFINITION STUDY PART II

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CONTRACT NAS9-15196
DRL T-1346
DRD MA-664T
LINE ITEM 3

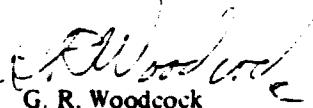
Solar Power Satellite

SYSTEM DEFINITION STUDY PART II

VOLUME VI
EVALUATION DATA BOOK
D180-22876-6
DECEMBER 1977

Submitted To
The National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
in Fulfillment of the Requirements
of Contract NAS9-15196

Approved:



G. R. Woodcock
Study Manager

BOEING AEROSPACE COMPANY
MISSILES AND SPACE GROUP—SPACE DIVISION
P.O. BOX 3999
SEATTLE, WASHINGTON

D180-22876-6

FOREWORD

The SPS system definition study was initiated in December 1976. Part I was completed on May 1, 1977. Part II technical work was completed October 31, 1977.

The study was managed by the Lyndon B. Johnson Space Center (JSC) of the National Aeronautics and Space Administration (NASA). The Contracting Officer's Representative (COR) was Clarke Covington of JSC. JSC study management team members included:

Dickey Arndt	Microwave System Analysis	Andrei Konradi	Space Radiation Environment
Harold Benson	Cost Analysis	Jim Kelley	Microwave Antenna
Bob Bond	Man-Machine Interface	Don Kessler	Collision Probability
Jim Cioni	Photovoltaic Systems	Lou Leopold	Microwave Generators
Hu Davis	Transportation Systems	Lou Livingston	System Engineering and
R. H. Dietz	Microwave Transmitter and Rectenna	Jim Meany	MPTS Computer Program
Bill Dusenbury	Energy Conversion	Stu Nachtwey	Microwave Biological Effects
Bob Gundersen	Man-Machine Interface	Sam Nassiff	Construction Base
Alva Hardy	Radiation Shielding	Bob Ried	Structure and Thermal
Buddy Heineman	Mass Properties	Jack Seyl	Analysis
Lyle Jenkins	Space Construction	Bill Simon	Phase Control
Jim Jones	Design	Fred Stebbins	Thermal Cycle Systems
Dick Kennedy	Power Distribution		Structural Analysis

The study was performed by the Boeing Aerospace Company. The Boeing study manager was Gordon Woodcock. Boeing Commercial Airplane Company assisted in the analysis of launch vehicle noise and overpressures. Boeing technical leaders were:

Ottis Bullock	Structural Design	Don Grim	Electrical Propulsion
Vince Caluori	Photovoltaic SPS's	Henry Hillbrath	Propulsion
Bob Conrad	Mass Properties	Dr. Ted Kramer	Thermal Analysis and Optics
Eldon Davis	Construction and Orbit-to-Orbit Transportation	Frank Kilburg	Alternate Antenna Concepts
Rod Darrow	Operations	Walt Lund	Microwave Antenna
Owen Denman	Microwave Design Integration	Keith Miller	Human Factors and Construction Operations
Hal DiRamio	Earth-to-Orbit Transportation	Dr. Ervin Nalos	Microwave Subsystem
Bill Emsley	Flight Control	Jack Olson	Configuration Design
Dr. Joe Gauger	Cost	Dr. Henry Oman	Photovoltaics
Jack Gewin	Power Distribution	John Perry	Structures
Dan Gregory	Thermal Engine SPS's	Scott Rathjen	MPTS Computer Program Development

The General Electric Company Space Division was the major subcontractor for the study. Their contributions included Rankine cycle power generation, power processing and switchgear, microwave transmitter phase control and alternative transmitter configurations, remote manipulators, and thin-film silicon photovoltaics.

Other subcontractors were Hughes Research Center-gallium arsenide photovoltaics; Varian-klystrons and klystron production; SPIRE-silicon solar cell directed energy annealing.

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This report was prepared in 8 volumes as follows:

- | | |
|--|--|
| I - Executive Summary | V - Space Operations |
| II - Technical Summary | VI - Evaluation Data Book |
| III - SPS Satellite Systems | VII - Study Part II Final Briefing Book |
| IV - Microwave Power Transmission
Systems | VIII - SPS Launch Vehicle Ascent and Entry
Sonic Overpressure and Noise Effects |

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**SPS SYSTEMS DEFINITION STUDY
Part II Final Report
Volume 6
Evaluation Data Book**

1.0 INTRODUCTION

This volume has been prepared to provide a permanent record of the actual calculations of mass properties, costs, and uncertainties for the Part II final reference designs. The data are presented with only the necessary amount of exploratory text. The analysts' original notes have been used whenever adequately legible in order to preserve authenticity.

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2.0 MASS PROPERTIES

2.1 SILICON PHOTOVOLTAIC REFERENCE SYSTEM

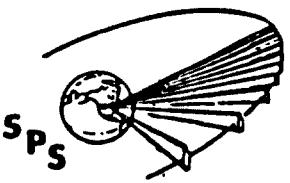
This weight definition and uncertainty notebook for the photovoltaic reference configuration is a supplement to the formal documentation provided in support of the Part II final review.

The weight definition part of this notebook provides weight data to a lower level of detail than was presented at the final review. Included in the weight definition are semi-detailed weight summaries, weight calculations, drawings and sketches, and results of weight analysis studies. A preliminary loads and stress analysis for the critical beams in the basic structural frame is also provided.

The weight uncertainty part of this notebook provides the base data pertinent to the establishment of the satellite weight/size tolerance ellipses. Subjects addressed are 1) the variation of satellite weight with array planform area, and 2) the effect of tolerances on the weight of the reference configuration.

Analyst: Bob Conrad

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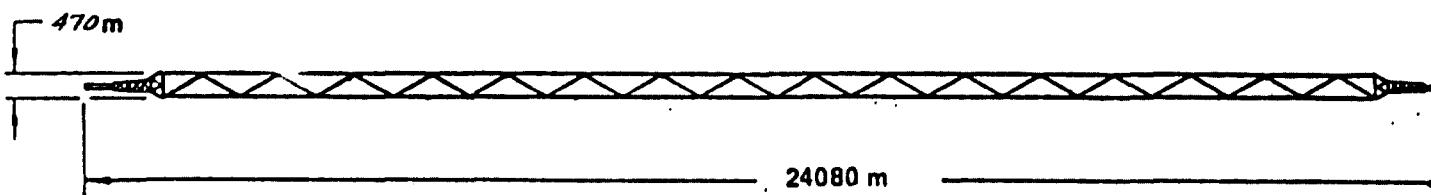
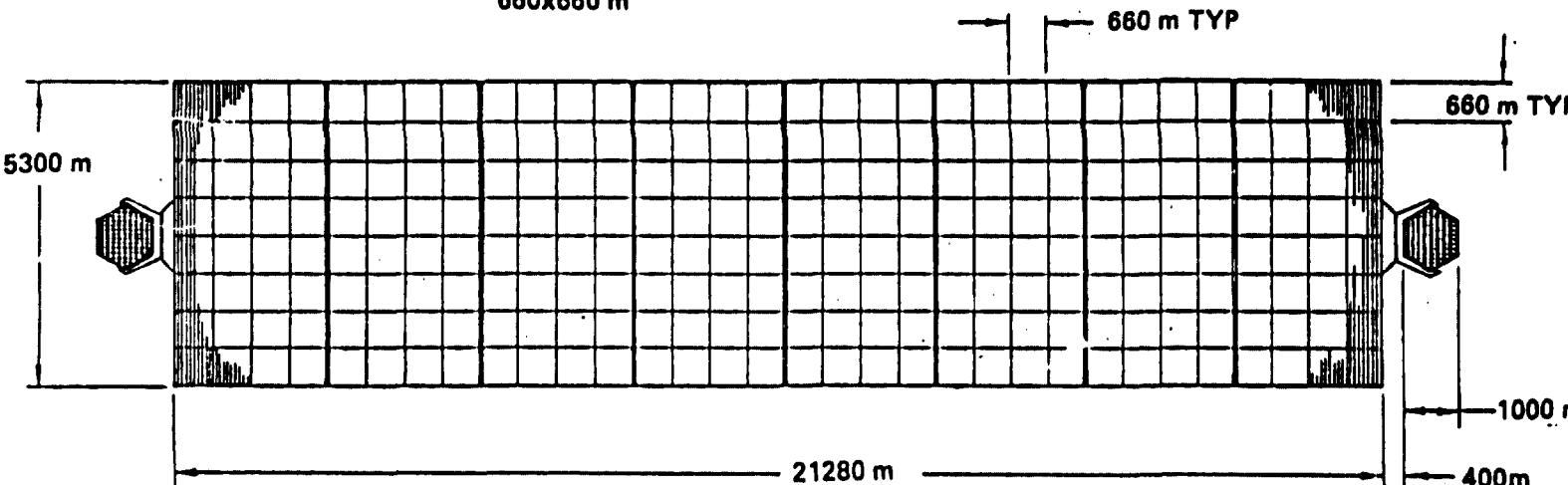


SPS-1004

Photovoltaic Reference Configuration

BOEING

256 BAYS
660x660 m



TOTAL SOLAR CELL AREA: 97.34 Km²
TOTAL ARRAY AREA: 102.51 Km²
TOTAL SATELLITE AREA: 112.78 Km²
OUTPUT: 16.43 GW MINIMUM TO SLIPRINGS

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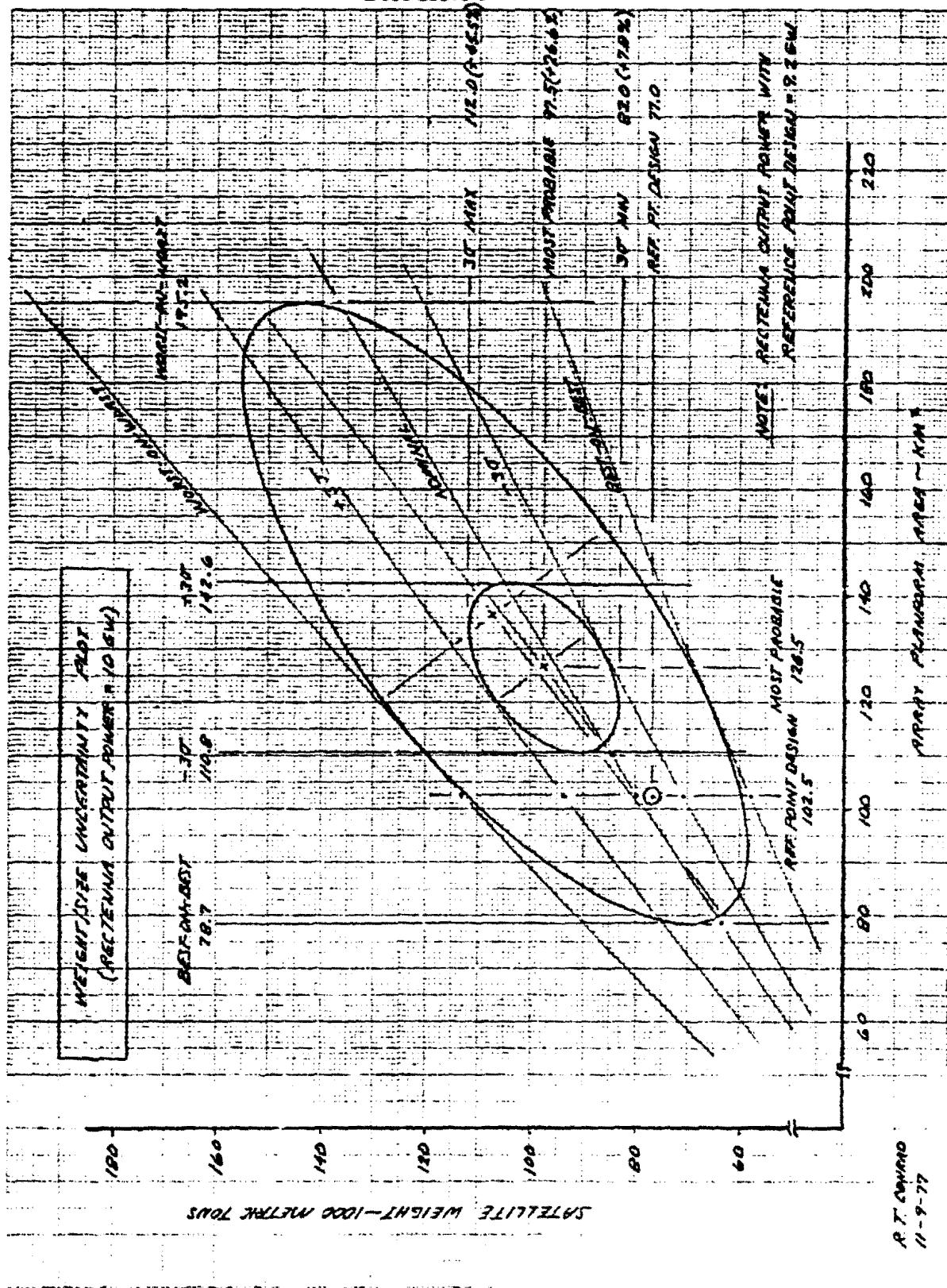
2.1.1 SUMMARY WEIGHT STATEMENT
(WEIGHT IN KILOGRAMS)

2.1.1-1.0 SOLAR ENERGY COLLECTION SYSTEM	51,782,300
2.1.1-1.1 PRIMARY STRUCTURE	5,385,000
2.1.1-1.2 SECONDARY STRUCTURE	▷
2.1.1-1.3 MECHANICAL ROTARY JOINT	66,800
2.1.1-1.4 MAINTENANCE STATION	—
2.1.1-1.5 CONTROL	178,100
2.1.1-1.6 INSTRUMENTATION/COMMUNICATIONS	4,000
2.1.1-1.7 SOLAR CELL BLANKETS	43,750,000
2.1.1-1.8 SOLAR CONCENTRATORS	—
2.1.1-1.9 POWER DISTRIBUTION	2,398,400
2.1.1-2.0 MICROWAVE POWER TRANSMISSION SYSTEM	25,212,200
(TOTAL - LESS GROWTH)	(76,994,500)
2.1.1-3.0 WEIGHT GROWTH ALLOWANCE ~ 26.6%	20,505,500
(TOTAL - WITH GROWTH)	(97,500,000)

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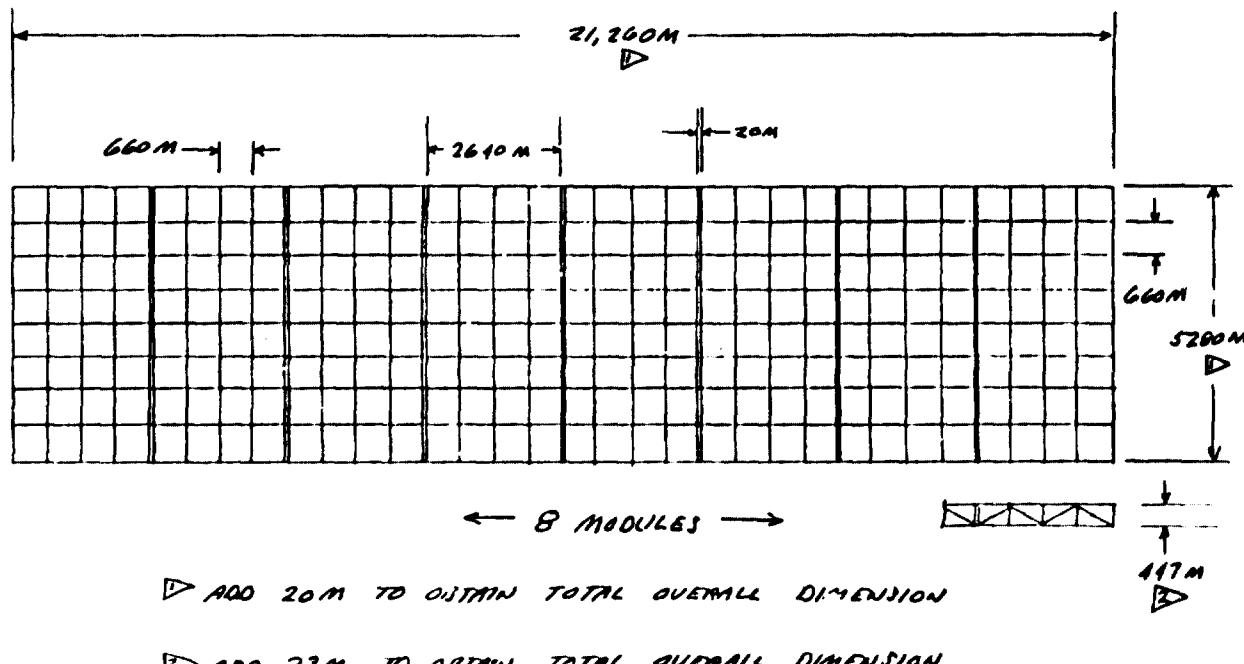
2.1.1-1.1 PRIMARY STRUCTURE

5,385,000 kg

MODULE NO. 1	755,400
BASIC FRAME	636,700
ZOM BEAMS	604,730
TENSION CABLES	1,600
ASSEMBLY ALLOWANCE ~5%	30,290
DOCKING PROVISIONS (18 PLACES)	1,500
ANTENNA SUPPORT STRUCTURE	53,000
EXTERNAL FRAME	43,000
ZOM BEAMS	10,900
ASSEMBLY ALLOWANCE ~5% - 2,100	
ADDITIONS TO MODULE FRAME	10,000
ROTARY JOINT	▷
ANTENNA YORE STRUCTURE	41,200
FRAME	36,200
SM BEAMS	34,500
ASSEMBLY ALLOWANCE ~5% - 1,700	
ROTATION JOINTS/PITCH CONTROLS	5,000
ANTENNA SUPPORT STRUCTURE (LEO-TO-GEO)	20,000
MODULE NO. 2	645,700
BASIC FRAME	636,700
ZOM BEAMS	604,730
TENSION CABLES	1,600
ASSEMBLY ALLOWANCE ~5%	30,290
DOCKING PROVISIONS (26 PLACES)	9,000
MODULE NO. 3	645,700
MODULE NO. 4	645,700
MODULE NO. 5	645,700
MODULE NO. 6	645,700
MODULE NO. 7	645,700
MODULE NO. 8	755,400

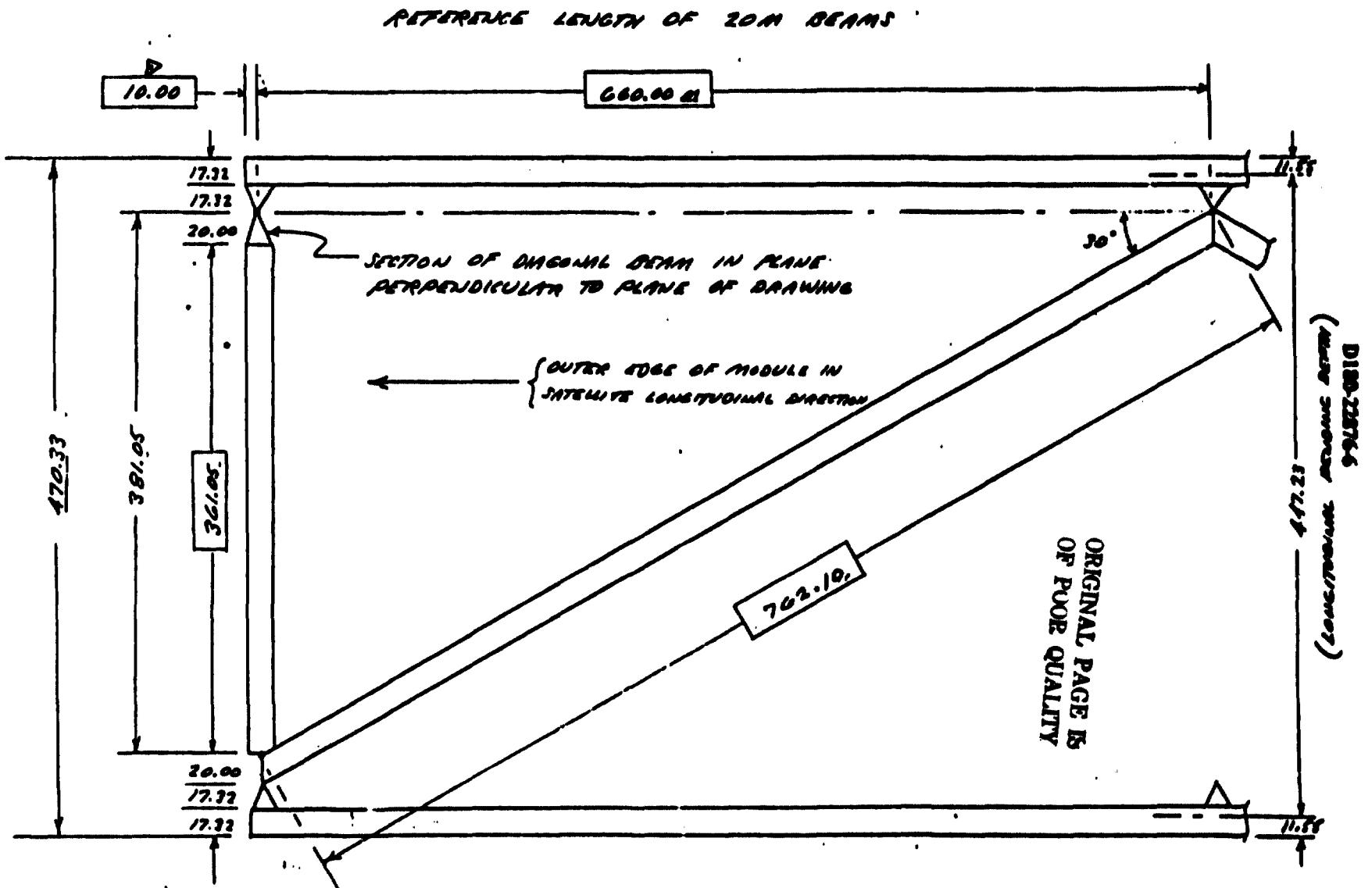
▷ INCLUDED ELSEWHERE IN WEIGHT STATEMENT UNDER
"MECHANICAL ROTARY JOINT" AND "ELECTRICAL ROTARY JOINT."

REFERENCE CONFIGURATION
(ALL DIMENSIONS ARE BEAM G TO BEAM G)



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STRUCTURAL PLANFORM AREA = 112.25 km²



▷ DEPTH LENGTH AT EDGE. (20 PLACES/SURFACE/MODULE, INCLUDING 2 PLACES/CORNER/SURFACE)

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20M BEAMS (PER MODULE)

604,730 L.

LOCATION/BEAMS	LENGTH OF BEAM PER MODULE (M)	UNIT WT. OF BEAM (kg/m)	WT. OF BEAM PER MODULE (kg)
UPR. SURFACE / LONGITUDINALS	$(9 \times 4) \times 660 = 23,760$	4.24	100,742
" " / LATERALS	$(5 \times 8) \times 660 = 26,400$	"	111,736
" " / EDGE DELTAS	$(20) \times 10 = 200$ $(50,440)$	"	1,187 (213,865)
LLR. SURFACE / LONGITUDINALS	$(9 \times 4) \times 660 = 23,760$	3.34	79,358
" " / LATERALS	$(5 \times 8) \times 660 = 26,400$	"	88,176
" " / EDGE DELTAS	$(20) \times 10 = 200$	"	935
INTRA SURF./LONG DIAGONALS	$(9 \times 4) \times 762.1 = 27,436$	"	91,636
" " / LATERAL DIAGONALS	$(5 \times 8) \times 762.1 = 30,488$	"	101,816
" " / VERTICALS B	$(20) \times 361.1 = 8660$ $(117,026)$	"	28,944 (390,865)
TOTAL - PER MODULE	167,466	—	604,730

▷ SEE SKETCH(PREVIOUS PAGE) FOR REFERENCE BEAM LENGTHS.

▷ SEE 20M BEAM WEIGHT ANALYSIS FOR DETAILS.(APPENDIX D)

▷ LOCATED AROUND ATRIUMS OF MODULE ONLY.

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KEVLAR TENSION CABLES (PER MODULE)

1680 kg

"X" CABLES IN LOWER SURFACE PERIPHERAL BAYS.

DATA PER CABLE:

$$L = (660-2d) \sin 45^\circ = 905 \text{ m}$$

$$D = 6.3 \text{ mm} = 0.0063 \text{ m}$$

$$\begin{aligned} V_{\text{KEVLAR}} &= \frac{\pi}{4} D^2 L \\ &= \frac{\pi}{4} (0.0063)^2 (905) = 0.028 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} W_{\text{KEVLAR}} &= \rho V \\ &= (1400 \text{ kg/m}^3)(0.028 \text{ m}^3) \end{aligned}$$

$$\begin{aligned} W_{\text{END FITTINGS,}} \\ \text{MANIFOLDS,} \\ \text{COURTAIN FORCE} \\ \text{JEWELS, ETC.} \\ &= 3 \text{ kg} \quad \left. \right\} 12 \text{ kg/CABLE} \end{aligned}$$

$$\begin{aligned} \text{CABLE WT. PER MODULE} &= (12 \text{ kg/cable})(2 \text{ cables/bay})(20 \text{ bays}) \\ &= 1680 \text{ kg} \end{aligned}$$

DOCKING PROVISIONS (PER LONGITUDINAL BEAM END)

250 kg

DOCKING PROVISIONS REQUIRED AT EACH BREAK IN EACH LONGITUDINAL BEAM (UPPER AND LOWER SURFACE).
18 PLACES PER END MODULE.
36 PLACES PER INTERMEDIATE MODULE.
ESTIMATE 250 kg OF DOCKING PROVISIONS ON EACH SIDE OF A BREAK IN A LONGITUDINAL BEAM.

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ANTENNA SUPPORT STRUCTURE (PER ANTENNA) 53,000 kg

REF: SRS-60-98 AND ISOMETRIC SKETCH ON NEXT PAGE

ALL BEAMS ARE 20M BEAMS @ 9.24 kg/m □

TOTAL LENGTH OF BEAM = $14.62 \times 660\text{m} = 9649\text{ m}$ □

EXTERNAL SUPPORT FRAME 43,000

20M BEAMS 40,900

ASSEMBLY ALLOWANCE~5% 2,100

ADDITIONS/CHANGES TO MIDDLE STRUCTURE 10,000 (EST)

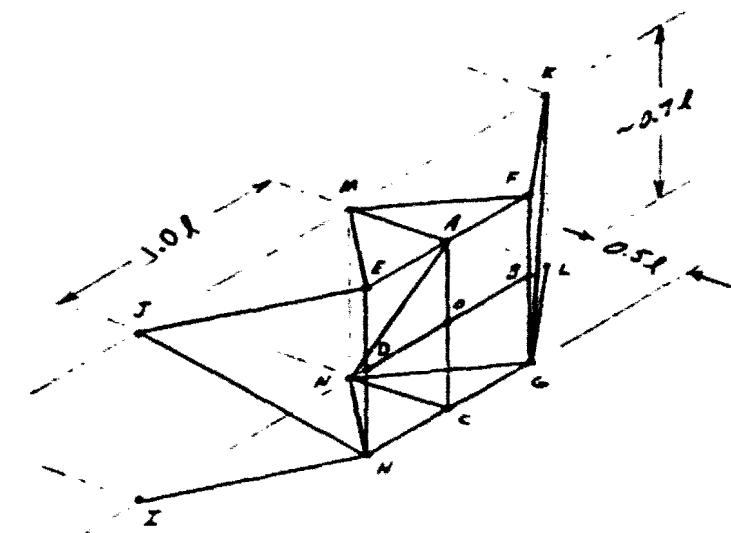
TOTAL - PER ANTENNA 53,000 kg

▷ SAME 20M BEAM AS USED ON UPPER SURFACE OF TRUSS STRUCTURE.

▷ SEE TABLE ON NEXT PAGE.

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ANTENNA SUPPORT STRUCTURE
(EXTERNAL SUPPORT FRAME)



NOTE: CIRCULAR BEAM SHOWN ON
SFS-LO-60 IS CONSIDERED
PART OF "MECHANICAL ROTARY
JOINT".

BEAM	LENGTH
EAF	1.00L
DOB	"
HCG	"
EDH	0.70L
FBG	"
AO	0.35L
OC	"
EJ	0.71L
EM	"
FM	"
FR	"
HJ	"
NN	"
CN	"
GL	"
MA	0.50L
NC	"
JH	0.99L
KG	"
AN	0.86L

TOTAL LENGTH OF BEAM = 14.62L

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ANTENNA YOKE STRUCTURE (PER ANTENNA)

41,200 kg

REF: SPS-LO-98 AND ATTACHED DRAWING AND ISOMETRIC SKETCHES

ALL BEAMS ARE 5M BEAMS @ 1.61 kg/m ▷

FRAME:

CENTER SECTION (5774 M)	9296	36,200
SIDE SECTION - RH (2772 M)	1398	
SIDE SECTION - LH (2732 M)	1398	
ARM SECTION - RH (5085 M)	8187	
ARM SECTION - LH (5085 M)	8187	
ASSEMBLY ALLOWANCE ~ 5%	1734	

ROTATION JOINTS (2):

5000 (EST.)

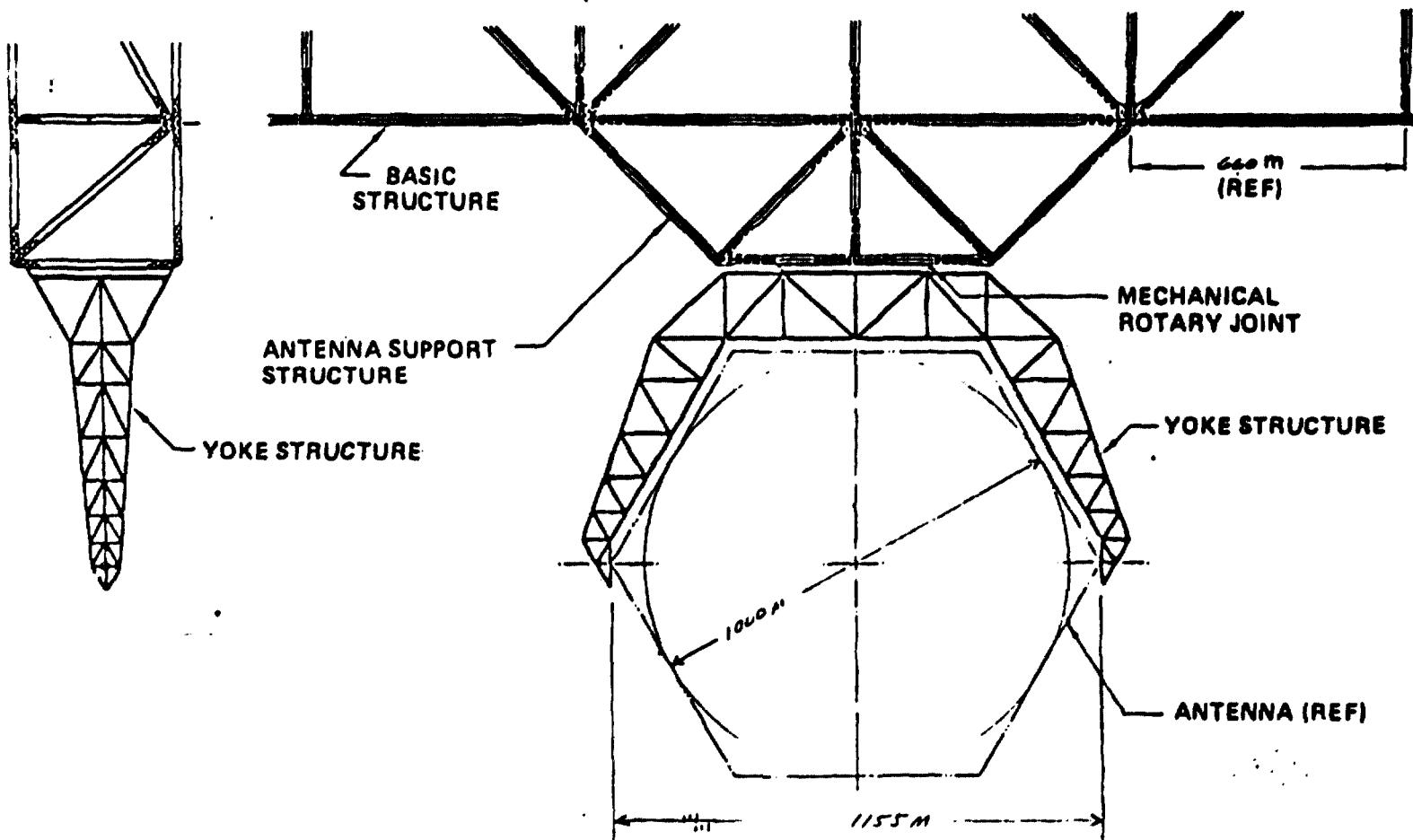
TOTAL - PER ANTENNA

41,200 kg

▷ SEE 5M BEAM WEIGHT ANALYSIS (APPENDIX D) FOR DETAILS.

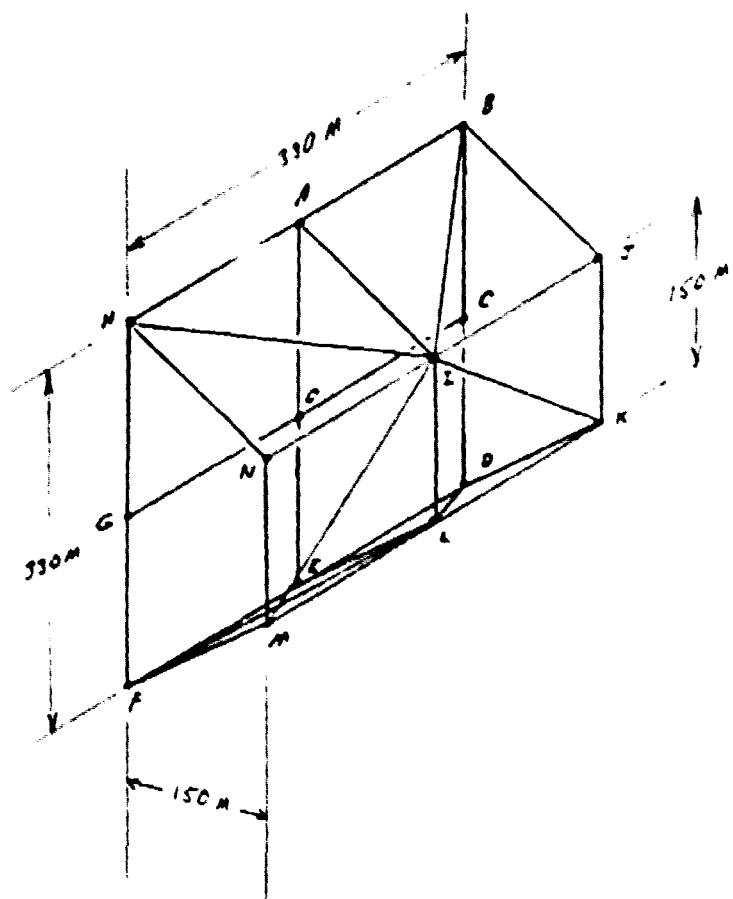
▷ DETAILS ON FOLLOWING PAGES.

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ANTENNA YOKE STRUCTURE
(CENTER SECTION)



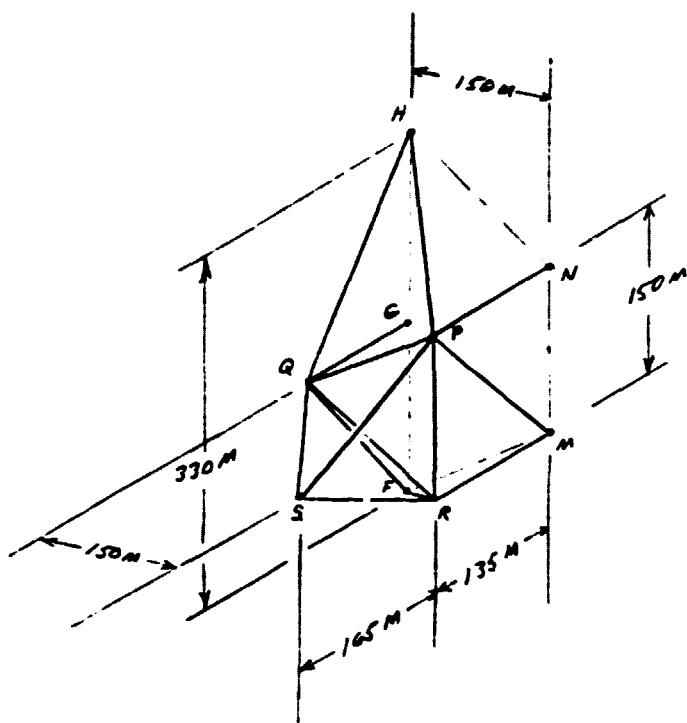
JOINTS IN REAR PLANE: DABCOEGFA

JOINTS IN FRONT PLANE: EJKLHM

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ANTENNA YOKE STRUCTURE
(SIDE SECTION-RH)

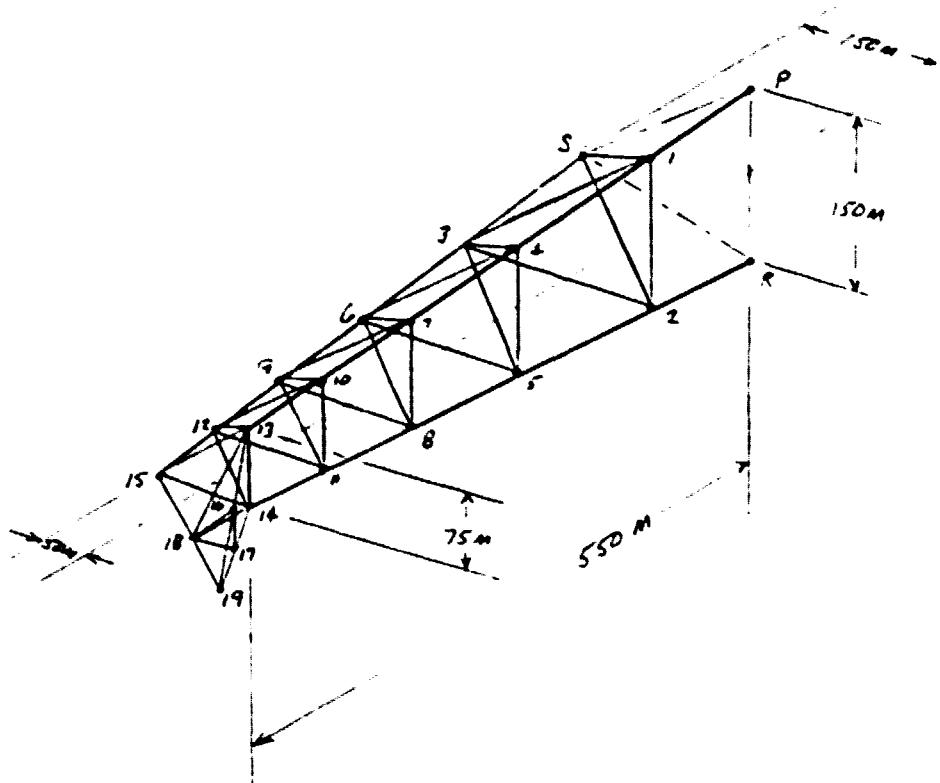


JOINTS IN REAR PLANE: HGFO

JOINTS IN FRONT PLANE: MNPRS

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ANTENNA YONE STRUCTURE
(TRAN SECTION-RH)



JOINTS IN REAR PLANE: 5, 9, 6, 7, 12, 15

JOINTS IN FRONT PLANE: 19, 1, 2, 4, 5, 7, 8, 9, 11, 13, 16, 18

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ANTENNA TOWER STRUCTURE (CONT'D)

LOCATION/BEAM	LENGTH OF BEAM (m)
<u>CENTER SECTION:</u>	
BEAM HAB	730
GOC	"
FEO	"
HGF	"
BGO	"
AO	165
DE	"
NIS	730
MLK	"
NM	150
SL	"
JK	"
ME	223
KI	"
NN	175
AZ	"
BJ	"
FN	"
EL	"
DK	"
HI	277
BI	"
FL	"
DL	"
(5774 m)	

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ANTENNA YOKE STRUCTURE (CONT'D)

LOCATION / BEAM	LENGTH OF BEAM (m)
<u>SIDE SECTION - RH: *</u>	
BEAM GO	135
HG	213
FQ	"
NP	135
MR	"
PR	150
MP	202
PS	181
RS	"
PQ	168
RQ	"
SO	223
PN	314
RF	"
(2732 m)	

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ANTENNA YORE STRUCTURE (CONT'D)

LOCATION / BEAM	LENGTH OF BEAM (m)
<u>ARM SECTION - RH:</u> *	
BEAM P-1-4-7-10-13	550
R-2-5-8-11-14	"
1-2	130
4-5	110
7-8	95
10-11	85
13-14	75
13-10	70
14-18	"
S-2-6-7-12-15	500
S-1	163
S-2	"
1-3	163
2-3	"
3-4	160
3-5	"
4-6	132
5-6	"
6-7	129
6-8	"
7-9	111
8-9	"
9-10	109
9-11	"
10-12	86
11-12	"
12-13	84
12-14	"
13-15	79
14-15	"
13-16-15	107
14-17-19	"
16-17	38
16-18	40
17-18	"
(5085 m)	

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2 1.1-1.2 SECONDARY STRUCTURE

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2.1.1-1.3 MECHANICAL ROTARY JOINT A)

33,400 kg

CIRCULAR RING BEAMS (2)	9640
PIPE BEAMS (2)	8790
TENSION CABLES (24)	250
DRIVE INSTALLATION ADJUSTMENTS	600
DRIVE RING	18,380
ROLLER ASSEMBLIES (40)	670
ASSEMBLY FITTINGS (40)	550
GUIDE WHEEL INSTALLATIONS (12)	120
ROLLER/DRIVE ASSEMBLIES (12)	950
ASSEMBLY FITTINGS (12)	550
GUIDE WHEEL INSTALLATIONS (24)	60
DRIVE WHEEL INSTALLATIONS (24)	40
D.C. DRIVE MOTORS, MOUNTS (12)	240
SPRING INSTALLATIONS-DRIVE WHEELS (12)	60
SUPPORT FITTINGS (120)	600
DRIVE RING SUPPORT FTG (60)	300
ROLLER ASSEMBLY SUPPORT FTG (40)	240
ROLLER/DRIVE ASSY SUPPORT FTG (12)	60
ASSEMBLY S' INSTALLATION HARDWARE	160
CONTINGENCY ~ 10 %	3000

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CIRCULAR RING BEAM (PER RING)

4395 kg

REF: ATTACHED SKETCH

USE A BEAM WITH A WEIGHT OF 4.0 kg/METER.

$$\begin{aligned}W_{\text{RING BEAM}} &= (\pi \cdot D_{\text{mean}}) \times 4.0 \text{ kg/m} \\&= (\pi \times 350 \text{ mm}) \times 4.0 \text{ kg/m} \\&= 4395 \text{ kg}\end{aligned}$$

TENSION CABLE (PER CABLE)

10.5 kg

REF: ATTACHED SKETCH

DATA PER CABLE:

$$L = 170 \text{ m}$$

$$D = 6.3 \text{ mm} = 0.0063 \text{ m}$$

$$\begin{aligned}V_{\text{VOLUME}} &= \frac{\pi}{4} D^2 L \\&= \frac{\pi}{4} (0.0063)^2 (170) = 0.0053 \text{ m}^3\end{aligned}$$

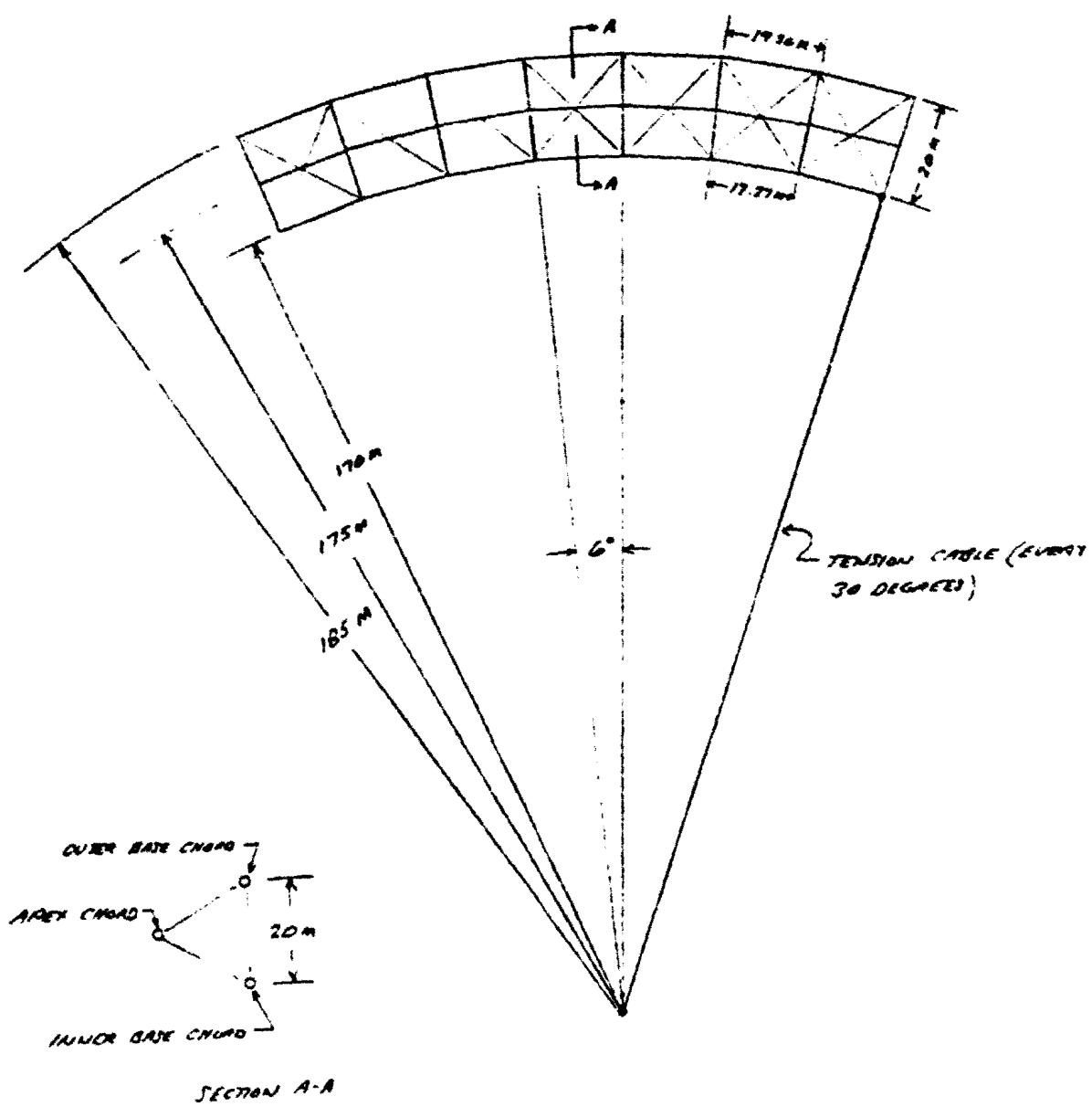
$$W_{\text{VOLUME}} = \rho V$$

$$\cdot (1400 \text{ kg/m}^3) / (0.0053 \text{ m}^3) = 7.5 \text{ kg} \quad \left. \right\} 10.5 \text{ kg}$$

W_{END FITTINGS, TURNBUCKLE, CONSTANT FORCE SPRING, INSTALLATION PROVISIONS}

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CIRCULAR RING BEAM GEOMETRY



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DRIVE RING

16,380 kg

REF: ATTACHED SKETCHES

USE SEGMENTED RING OF GRANITE/ETC

$$\text{RING X-AREA} = 16.2 \text{ IN}^2 = 0.01045 \text{ m}^2$$

$$\begin{aligned} W_{\text{RING}} &= \pi D A \rho \times k_{\text{SCOUNTS}} \\ &= \pi (350 \text{ mm})(0.01045 \text{ m}^2)/(1600 \text{ kg/m}^3) \times 1.05 \\ &= 18,380 \text{ kg} \end{aligned}$$

ROLLER ASSEMBLY (PER ASSEMBLY)

14 kg

REF: ATTACHED SKETCH

a. ASSEMBLY FITTING

USE ALUMINUM FITTING

$$X\text{-AREA} = 20 \text{ IN}^2 = 0.01806 \text{ m}^2$$

$$\text{LENGTH} = 9" - 0.23 \text{ m}$$

$$\begin{aligned} W_{\text{FITTING}} &= AL\rho \\ &= (0.01806 \text{ m}^2)(0.23 \text{ m})/(2770 \text{ kg/m}^3) = 11.5 \text{ kg} \end{aligned}$$

b. GUIDE WHEELS

USE STEEL WHEELS/SHAFTS/BETRINGS ETC

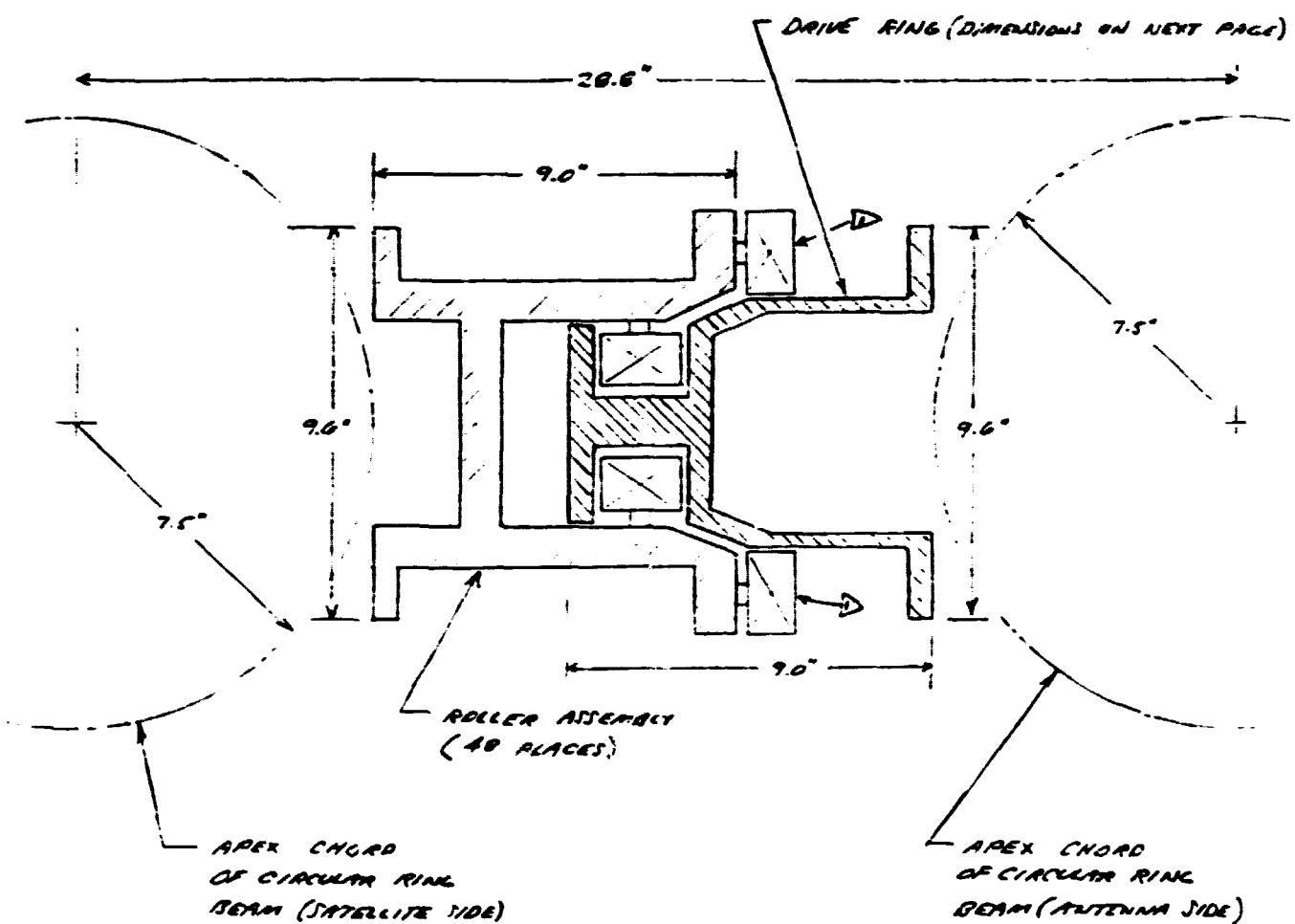
$$\left. \begin{array}{l} \text{WHEEL DIA} = 2 \text{ IN} = 5.1 \text{ CM} \\ \text{WHEEL WIDTH} = 1.25 \text{ IN} = 3.2 \text{ CM} \\ \text{SHAFT DIA} = 0.5 \text{ IN} = 1.3 \text{ CM} \\ \text{SHAFT LENGTH} = 2.0 \text{ IN} = 7.6 \text{ CM} \end{array} \right\} \text{VOL} = 1.5 \text{ IN}^3 = 0.000072 \text{ m}^3$$

$$\begin{aligned} W_{\text{GUIDE WHEELS}} &= \rho V \times 4 \text{ PER FTG} \\ &= (8000 \text{ kg/m}^3)(0.000072 \text{ m}^3) \times 4 \\ &= 0.6 \times 4 \approx 2.5 \text{ kg} \end{aligned}$$

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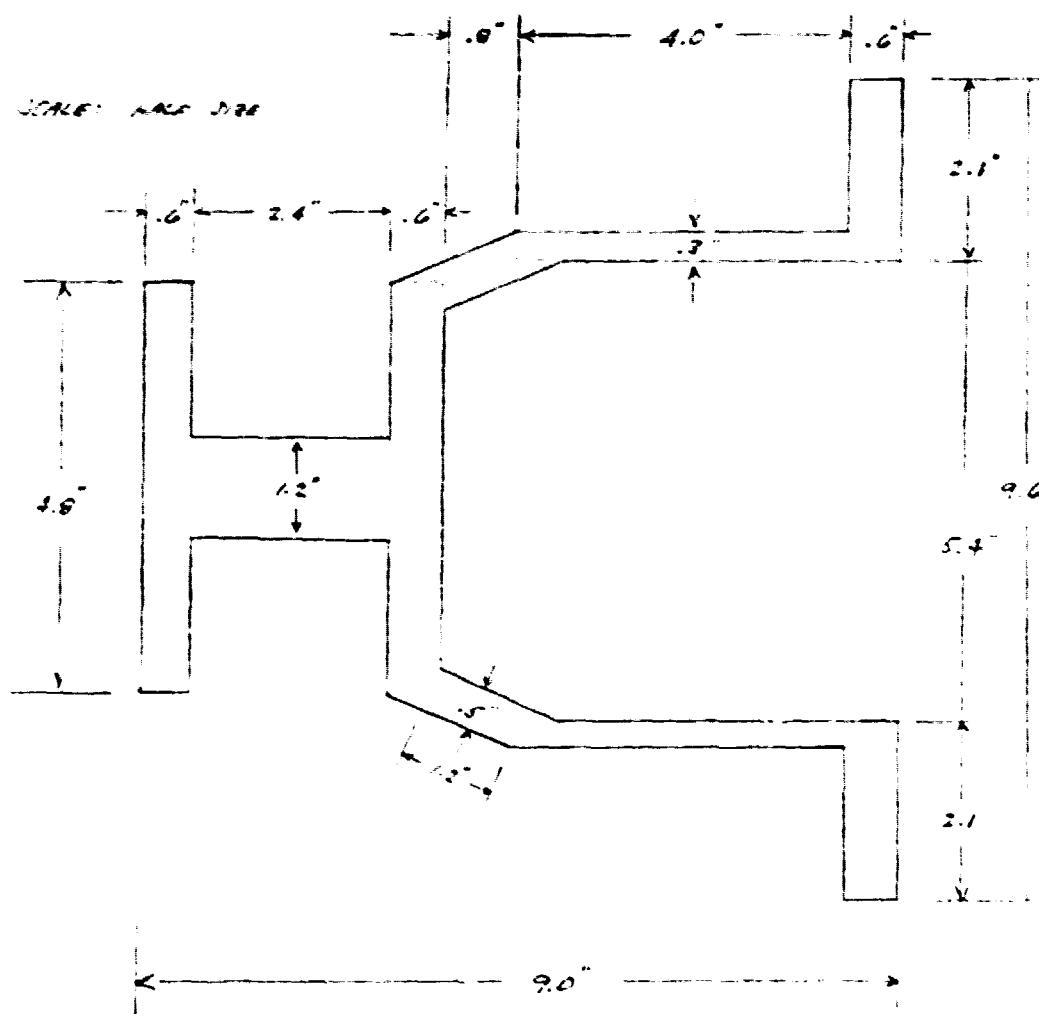
DRIVE RING AND ROLLER ASSEMBLY
LOCATION RELATIVE TO OUTER BASE
CHORDS OF CIRCULAR RING BEAMS



- ▷ A ROLLER/DRIVE ASSEMBLY IS LOCATED AT 12 PLACES (EVERY TENSION CABLE) AROUND THE PERIMETER OF THE CIRCULAR BEAM (SATELLITE SIDE). THIS ASSEMBLY IS SIMILAR TO THAT SHOWN EXCEPT THAT THE WHEELS INDICATED BY FLAG ▷ ARE MOTOR DRIVEN FRICTION WHEELS WHICH ARE SPRING LOADED ACROSS THE ASSEMBLY.

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DRIVE RING GEOMETRY



$$\begin{aligned} \text{CROSS SECTION AREA} = & [(4.0 \times .6) + (2.4 \times .6) + (4.0 \times .6) + 2(2.1 \times .6)] \\ & + 2(4.0 \times .2) + 2(2.4 \times .6) \} .110 = 16.2 \text{ in}^2 \\ \text{TOLERANCES / FILTERS} = & \end{aligned}$$

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2.1.1- 1.4. MAINTENANCE STATION

NOT APPLICABLE

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2.1.1-1.5 CONTROL

178,100 kg

THRUST PRODUCTION EQUIPMENT	23,300	}
POWER PROCESSORS	90,000	
INSTALLATION HARDWARE	16,800	
(TOTAL DRY WEIGHT)	(130,100)	*
ANNUAL PROPELLANT (ARGON)	48,000	
(1-YEAR TOTAL)	(178,100)	

* ESTIMATES PER G. WOODCOCK

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2.1.1-1.6 INSTRUMENTATION/COMMUNICATIONS 4000 kg

USE THE JSC "GREENBOOK" VALUE OF 4000 kg

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OF PAGE A

D180-22876-6

2.1.1-1.7 SOLAR CELL BLANKETS

13,750,000 kg

SOLAR CELL PANELS	43,191,350
COVER GLASS - FUSED SILICA	16,987,940
CELLS - SILICON	11,670,850
INTERCONNECTS - COPPER	1,150,160
SUBSTRATE - FUSED SILICA	11,325,290
TOLERANCES ALLOWANCE(5%)	2,057,110
JOINT/SUPPORT TAPES	300,360
CATENARY SYSTEM	258,290

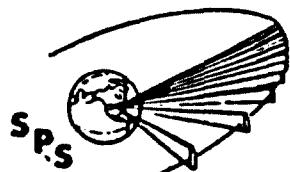
PHOTOVOLTAIC BLANKET WEIGHT BUILDUP

ITEM (S.G.)	DENSITY (g/m ³ /mil)	THICKNESS (MILS)	AREA FACTOR	WEIGHT (g/m ²)
COVERS - FUSED SILICA	2.20	55.88	1.0	167.64
CELLS - SILICON	2.36	57.74	2.0	115.17
INTERCONNECTS-COPPER	8.94	227.08	0.100	11.75
SUBSTRATE-FUSED SILICA	2.20	55.88	1.0	111.76

THEORETICAL PANEL WEIGHT	405.92
TOLERANCES ALLOWANCE (5%)	20.30
ESTIMATED PANEL WEIGHT	426.22
PANEL AREA FACTOR (.9913)	422.51
SEGMENTS AREA FACTOR (.9972)	421.33
JOINT/SUPPORT TAPES	2.93
CATENARY SYSTEM	2.52
ESTIMATED ARRAY WEIGHT	426.78

CELL AREA = 380,264 m²/BAT
 PANEL AREA = 395,843 m²/BAT
 ARRAY AREA = 400,474 m²/BAT
 NO. OF BAYS = 256

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Photovoltaic Reference Configuration Solar Array Fundamental Element “Blanket Panel”

SPS-1390

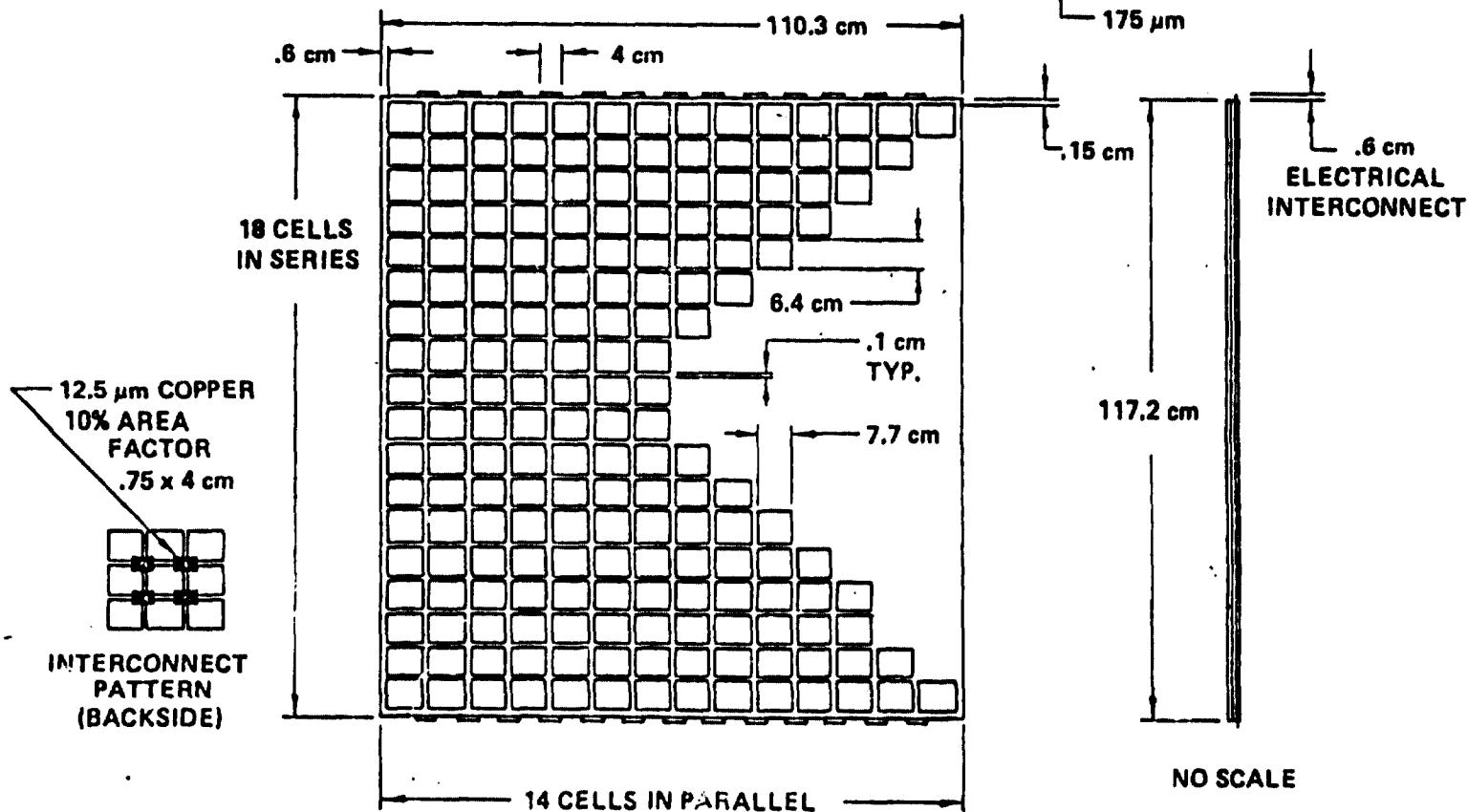
- 14 CELLS IN PARALLEL WILL TOLERATE
4 CELL FAILURES IN ANY ROW

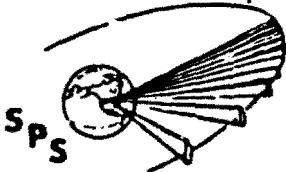
BOEING

# CELLS/PANEL	: 252
WGT/PANEL	: 426 GRAMS
PANELS/BAY	: 306,206
PANELS/SATELLITE	: 78,388,736

34

D180-22876-6

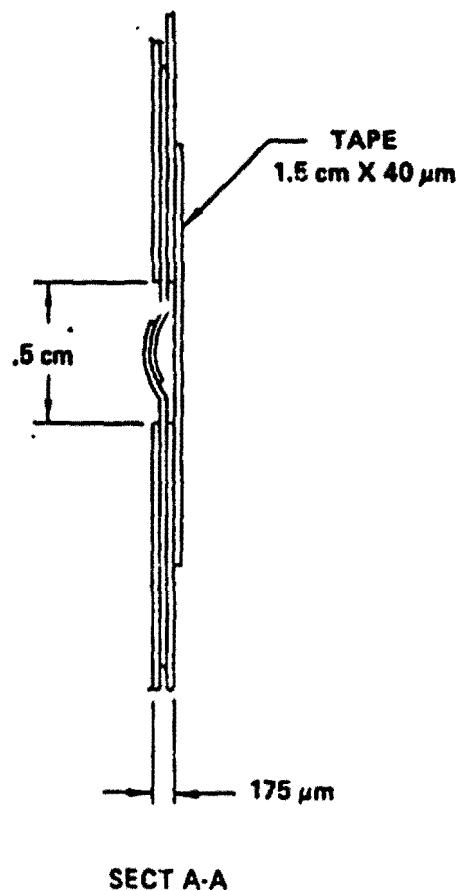
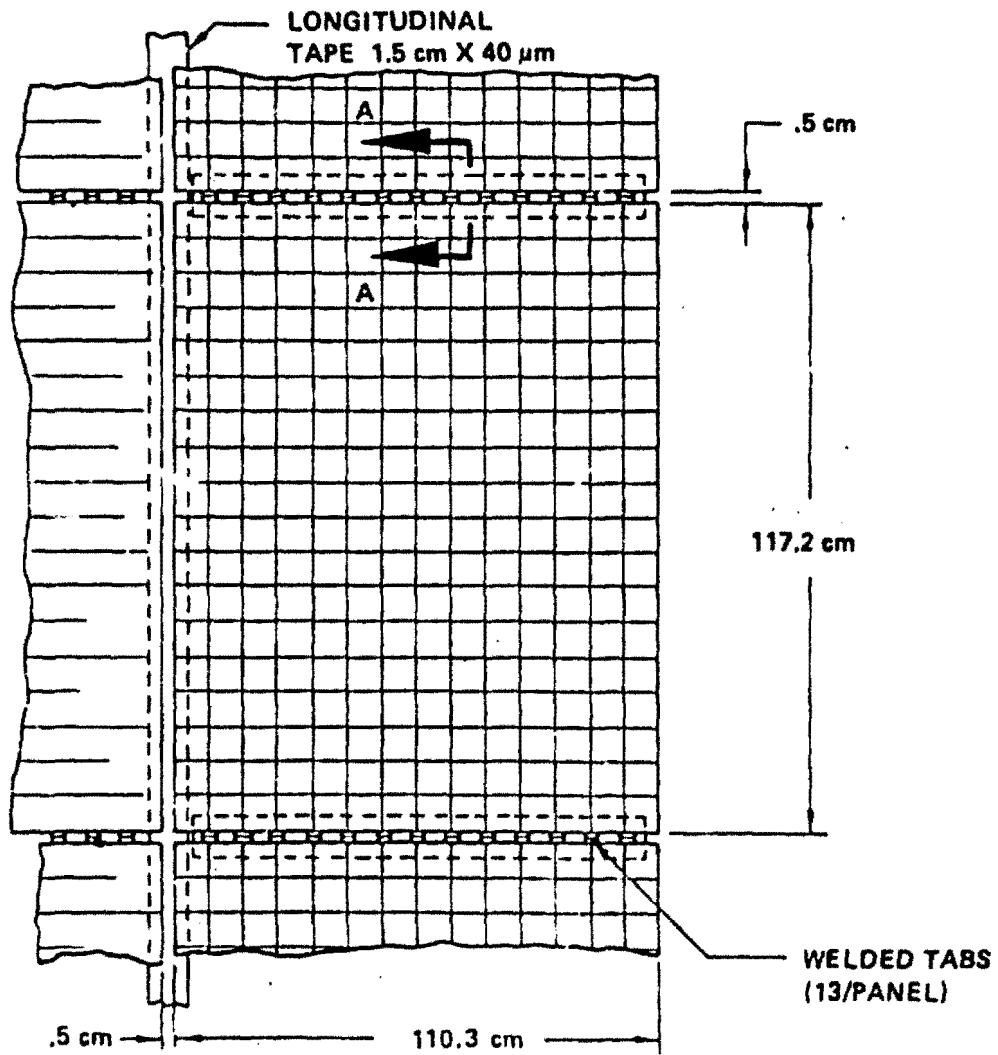




Photovoltaic Reference Panel to Array Assembly

BOEING

SPS-1391

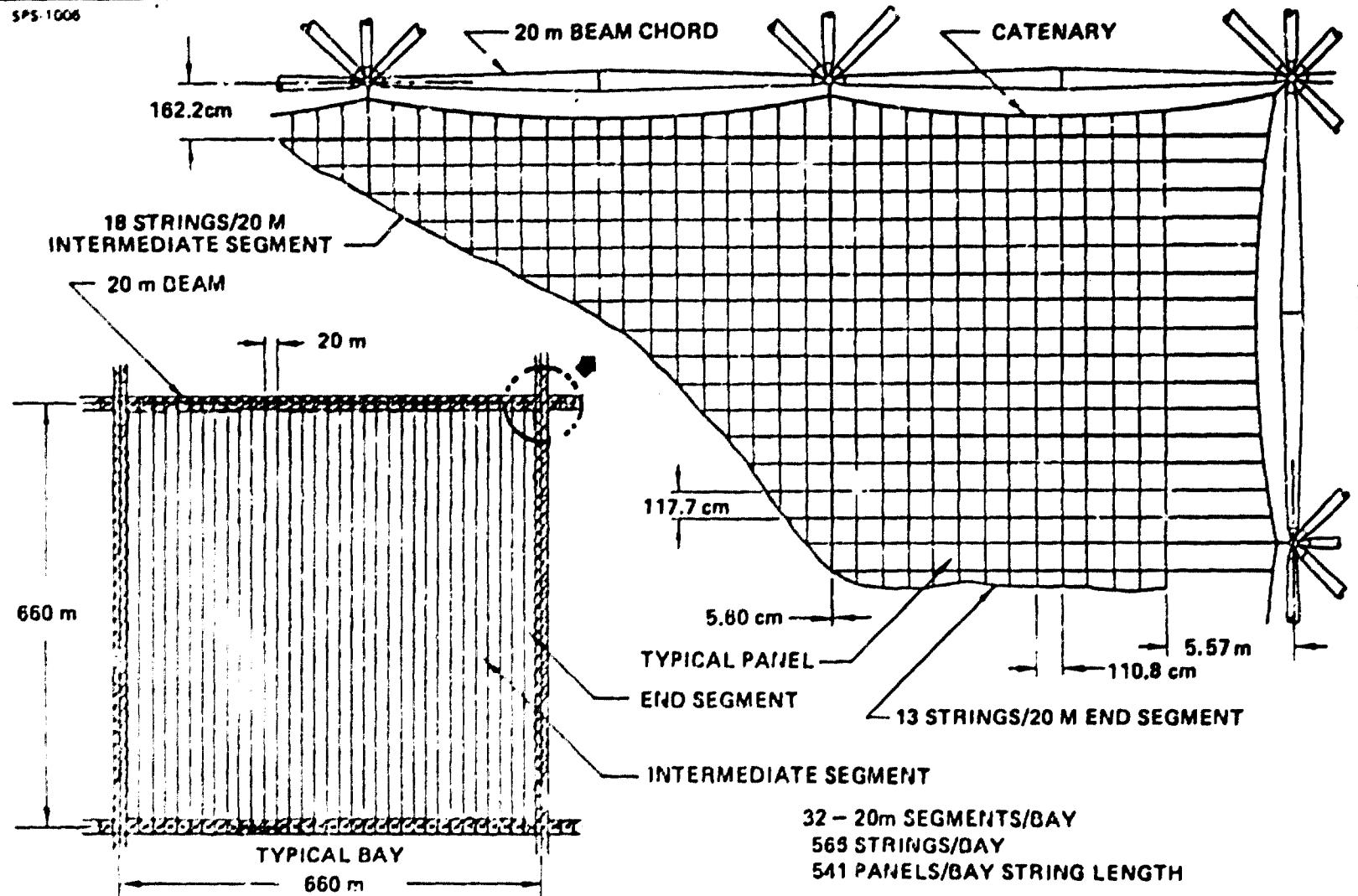


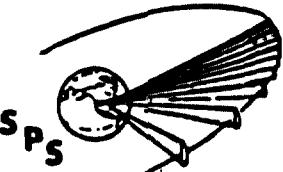
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Photovoltaic Reference Solar Array Arrangement and Attachment

SPS 1006

BOEING



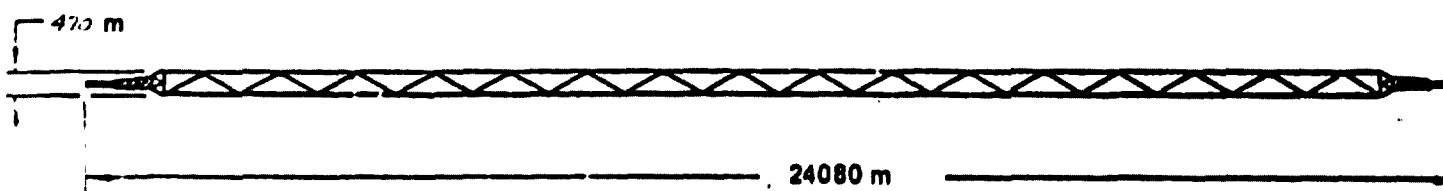
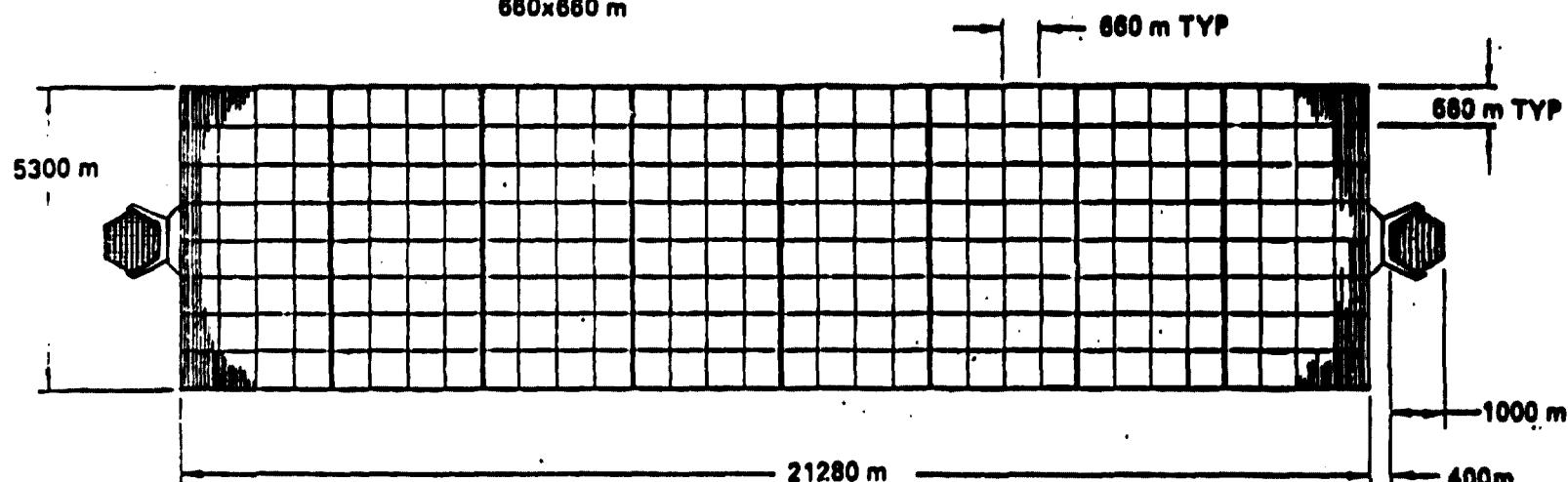


SPS-1004

Photovoltaic Reference Configuration

BOEING

256 BAYS
660x660 m



TOTAL SOLAR CELL AREA: 97.34 Km²
TOTAL ARRAY AREA: 102.51 Km²
TOTAL SATELLITE AREA: 112.78 Km²
OUTPUT: 18.43 GW MINIMUM TO SLIPRINGS

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AREA FACTORS

$$\begin{aligned} \text{SOLAR CELL} &= \frac{\text{AREA OF 252 SOLAR CELLS}}{\text{AREA OF 1 PANEL(LESS INTERCONNECTS)}} \\ \text{AREA FACTOR} &= \frac{252 (6.40 \text{ cm} \times 7.70 \text{ cm})}{117.2 \text{ cm} \times 110.3 \text{ cm}} = 0.96066 \\ (\text{PER PANEL}) & \end{aligned}$$

$$\begin{aligned} \text{PANEL AREA} &= \frac{\text{AREA OF 1 PANEL(LESS INTERCONNECTS)}}{\text{AREA OF 1 PANEL(INSTALLED)}} \\ \text{FACTOR} &= \frac{117.2 \text{ cm} \times 110.3 \text{ cm}}{117.7 \text{ cm} \times 110.8 \text{ cm}} = 0.99126 \end{aligned}$$

$$\begin{aligned} \text{ZOM SEGMENT} &= \frac{\text{AREA OF 9738 PANELS(INSTALLED)}}{\text{AREA OF ZOM SEGMENT}} \\ \text{AREA FACTOR} &= \frac{9738 (117.7 \text{ cm} \times 110.8 \text{ cm})}{2000 \text{ cm} \times 67,675.7 \text{ cm}} = 0.99720 \end{aligned}$$

$$\begin{aligned} \text{END SEGMENT} &= \frac{\text{AREA OF 7073 PANELS(INSTALLED)}}{\text{AREA OF END SEGMENT}} \\ \text{AREA FACTOR} &= \frac{7073 (117.7 \text{ cm} \times 110.8 \text{ cm})}{1447.2 \text{ cm} \times 67,675.7 \text{ cm}} = 0.99806 \end{aligned}$$

$$\text{SEGMENT AREA} = \frac{(30 \times 0.99720) + (2 \times 0.99806)}{32} = 0.99725$$

$$\begin{aligned} \text{ARRAY AREA} &= \frac{\text{AREA OF 30 ZOM + 2 END SEGMENTS}}{\text{AREA OF 650M BAY}} \\ \text{FACTOR} &= \frac{62,886.4 \text{ cm} \times 67,675.7 \text{ cm}}{66,000 \text{ cm} \times 66,000 \text{ cm}} = 0.91927 \\ (\text{PER BAY}) & \end{aligned}$$

(CONT'D)

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AREA FACTORS (CONT'D)

$$\begin{aligned} \text{SOLAR CELL AREA FACTOR} &= \frac{\text{AREA OF } 77,163,912 \text{ SOLAR CELLS}}{\text{AREA OF } 660 \text{ m DAY}} \\ &= \frac{77,163,912 (6.40 \text{ cm} \times 7.70 \text{ cm})}{66,000 \text{ cm} \times 66,010 \text{ cm}} \\ &= 0.87297 \Delta \end{aligned}$$

$$\begin{aligned} \text{SOLAR CELL AREA FACTOR} &= \frac{\text{AREA OF } 19,753,961,472 \text{ SOLAR CELLS}}{\text{AREA OF SATELLITE}} \\ &= \frac{19,753,961,472 (.064 \text{ m} \times .077 \text{ m})}{21,280 \text{ m} \times 5700 \text{ m}} = 0.86713 \end{aligned}$$

$$\begin{aligned} \text{ARRAY AREA FACTOR (PER SATELLITE)} &= \frac{\text{AREA OF } 256 \text{ DAY ARRAYS}}{\text{AREA OF SATELLITE}} \\ &= \frac{256 (628.864 \text{ m} \times 636.757 \text{ m})}{21,280 \text{ m} \times 5700 \text{ m}} = 0.90891 \end{aligned}$$

$$\begin{aligned} \Delta \text{ OR, SOLAR CELL AREA FACTOR} &= (\text{SOLAR CELL AREA FACTOR}) \times (\text{PANEL AREA FACTOR}) \times (\text{SEGMENT AREA FACTOR}) \times (\text{ARRAY AREA FACTOR}) \\ &= 0.96066 \times 0.97126 \times 0.99125 \times 0.91927 \\ &= 0.87297 \end{aligned}$$

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WEIGHT FACTOR FOR JOINT/SUPPORT TAPE
(FIBERGLASS TYPE TAPE PLUS ADHESIVE)

REF: SEE JOINT TAPE CONFIGURATIONS ON FOLLOWING PAGE

$$\begin{aligned} \text{LENGTH OF 1.5 CM WIDE} &= (578 \times 636.8 \text{m}) + (542 \times 628.9 \text{m}) \\ \text{TAPE PER DAY} &= 721,670 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{LENGTH OF 5.1 CM WIDE} &= (71 \times 636.8 \text{m}) = 19,741 \text{ m} \\ \text{TAPE PER DAY} & \end{aligned}$$

$$\begin{aligned} \text{TOTAL AREA OF TAPE} &= (721,670 \times .015) + (19,741 \times .051) \\ \text{PER DAY} &= 11,832 \text{ m}^2 \end{aligned}$$

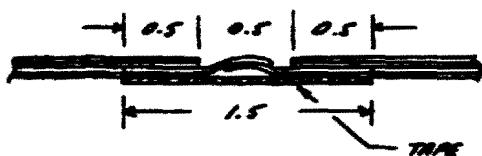
$$\begin{aligned} \text{WEIGHT OF TAPE (PLUS} &= (11,832 \text{ m}^2 \times 1.6 \text{ MIL} \times 50.8 \text{ g/m}^2/\text{MIL})_{\text{TAPE}} \\ \text{ADHESIVE) PER DAY} &+ (11,832 \text{ m}^2 \times 0.5 \text{ MIL} \times 35.56 \text{ g/m}^2/\text{MIL})_{\text{ADHESIVE}} \\ &= 1,172,078 \text{ g} \end{aligned}$$

$$\begin{aligned} \text{TAPE (PLUS ADHESIVE)} &= \frac{\text{WEIGHT OF TAPE(PLUS ADHESIVE) PER DAY}}{\text{ARRAY AREA PER DAY}} \\ \text{WEIGHT FACTOR} &= \frac{1,172,078 \text{ g}}{636.8 \text{ m} \times 628.9 \text{ m}} \\ &= 2.927 \text{ g/m}^2 \end{aligned}$$

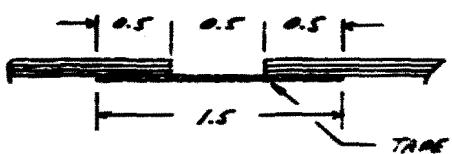
D180-22876-6
 JOINT TAPE CONFIGURATIONS
 (ALL DIMENSIONS IN CENTIMETERS)

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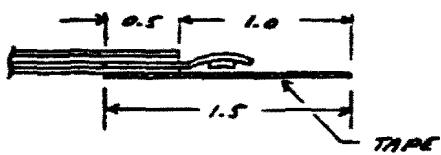
a) PANEL-TO-PANEL (WITH INTERCONNECTS)



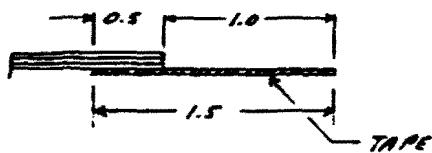
b) PANEL-TO-PANEL (NO INTERCONNECTS)



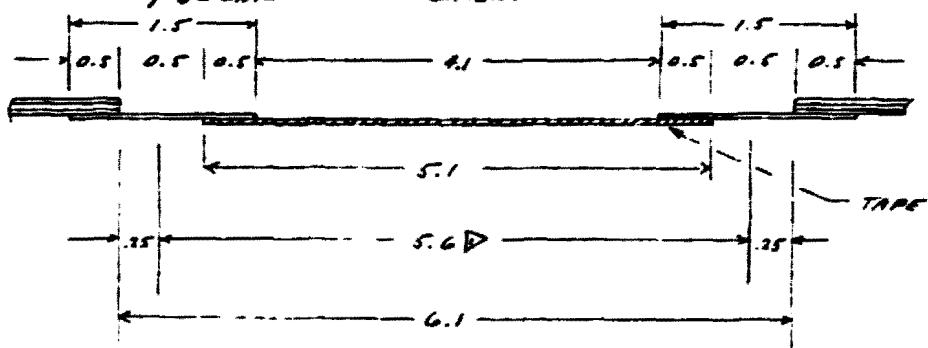
c) SEGMENT OUTER EDGE (WITH INTERCONNECTS AND CABLE)



d) SEGMENT OUTER EDGE (NO INTERCONNECTS)



e) SEGMENT-TO-SEGMENT



> REFERENCE SEGMENT-TO-SEGMENT SPACING.

D190-22876-6

WEIGHT FACTOR FOR CATERINARY SYSTEM

$$\text{NO. OF CATERINARIES} = 4 \left(\frac{660}{20} - 1 \right) = 128$$

$$\text{WEIGHT PER CATERINARY} = \frac{17.5 \text{ kg}}{\text{EST. INSTALLATION}} = 7900 \text{ g}$$

$$\begin{aligned}\text{CATERINARY WEIGHT FACTOR} &= \frac{\text{WEIGHT OF CATERINARIES PER DAY}}{\text{ARRAY AREA PER DAY}} \\ &= \frac{128 \times 7900 \text{ g}}{636.8 \text{ m} \times 628.9 \text{ m}} \\ &= 2.525 \text{ g/m}^2\end{aligned}$$

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2.1.1-1.8 SOLAR CONCENTRATORS

NOT APPLICABLE

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D180-22876-6

2.1.1-1.9 POWER DISTRIBUTION

2,398,400 kg

POWER BUSES	2,030,000
CCELL STRAYING FEEDERS	38,800
DISCONNECTS (384)	70,000
IN-LINE SWITCH GEAR (192)	70,000
DC-DC CONVERTERS	200
ENERGY STORAGE	20,000
ELECTRICAL ROTARY JOINT(2)	39,200
SUPPORT STRUCTURES - 5%	114,200

- * USED MASS ESTIMATES DEVELOPED BY JACK GEWIN OF THE ELECTRICAL POWER STAFF.
- ** ELECTRICAL ROTARY JOINT WEIGHT BASED ON MASS CALCULATIONS OF CONCEPTUAL DESIGN. (DETAILS ON FOLLOWING PAGES).

D180-22876-6

ELECTRICAL POTTERY JOINT (1)

19,600 kg.

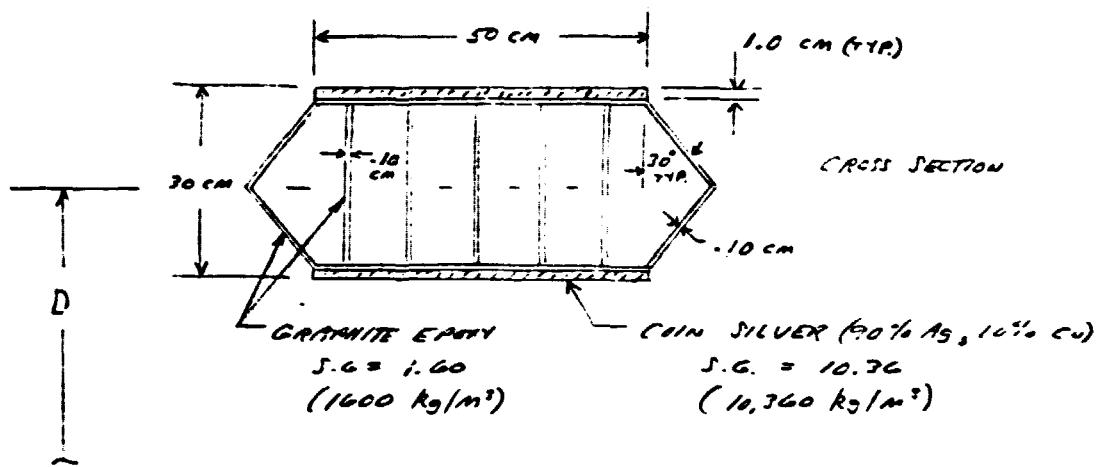
SLIP RINGS	11,810
INNER RING	2510
MIDDLE RING	3940
OUTER RING	5360
BRUSHES (B32)	540
BRUSH WIRE (16G4)	270
BRUSH HOLDERS	1160
1G-BRUSH HOLDER (8)	216
20-BRUSH HOLDER (16)	448
24-BRUSH HOLDER (16)	496
FEEDERS (2 SIDES)	3840
INNER FEEDERS (16)	896
MIDDLE FEEDERS(16)	1536
OUTER FEEDERS(16)	1408
STRUCTURAL SUPPORT FRAME ~ 5%	900
ASSEMBLY & INSTALLATION HARDWARE ~ 1%	180
CONTINGENCY ~ 5%	900

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SLIP RINGS (3)

11,810 kg



$$X\text{-AREA OF COIN SILVER} = 2(50 \times 0.5) = 50 \text{ cm}^2 = 0.0050 \text{ m}^2$$

$$X\text{-AREA OF GRANITE EPOXY} = 2(50 \times .1) + 5(26.6 \times .1)$$

$$+ 4(17.9 \times .1) \approx 31 \text{ cm}^2 \approx 0.0031 \text{ m}^2$$

RING	DIA. (cm)	VOL. OF Ag (m ³)	VOL OF G/E (m ³)	WT OF Ag (kg)	WT OF G/E (kg)
INNER	7	0.220	0.068	2280	110
MIDDLE	11	0.346	0.107	3580	170
OUTER	15	0.472	0.146	4880	230
				10,740	510

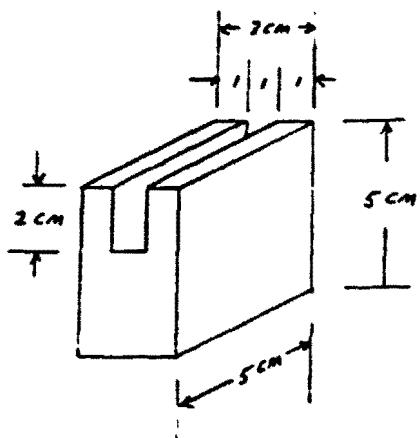
$$\begin{aligned}
 W_{\text{SLIP RINGS}} &= 1.05 (W_{\text{inner}} + W_{\text{G/E}}) \\
 &= 1.05 (10,740 + 510) \\
 &= 11,810 \text{ kg}
 \end{aligned}$$

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BRUSH (1)

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0.65 kg



85% Ag, 3% C, 12% Ni-S
S.G = 9.57
(9570 kg/m³)

$$\text{VOLUME} = (5 \times 5 \times 3) - (5 \times 2 \times 1) = 65 \text{ cm}^3 = 0.000,065 \text{ m}^3$$

$$\begin{aligned}\text{WEIGHT} &= 1.05(9570 \text{ kg/m}^3)(0.000,065 \text{ m}^3) \\ &= 0.65 \text{ kg/brush}\end{aligned}$$

BRUSH WIRE (1)

0.10 kg

2 WIRES/BRUSH

L = 0.2 M

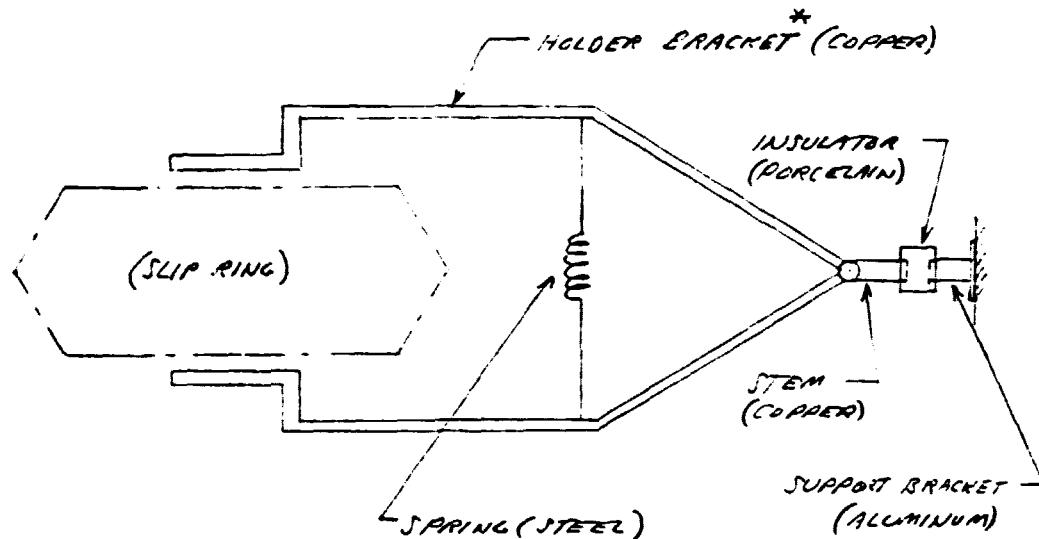
#000 COPPER BRAID WIRE @ 578 lb/1000 ft (0.77 kg/m)

$$\begin{aligned}\text{WEIGHT} &= 1.05(0.77 \text{ kg/m})(0.2 \text{ m}) \\ &= 0.10 \text{ kg/wire}\end{aligned}$$

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BRUSH HOLDER, 16-BRUSH/20-BRUSH/24-BRUSH(1 EA.) 27 kg / 28 kg / 31 kg



* GEOMETRY ON NEXT PAGE

ITEM	ITEM VOLUME (m ³)	DENSITY kg/m ³	WEIGHT (kg)
UPR HOLDER ARM, 16-BRUSH	0.00122	8980	11.0
LWR " " "	"	"	11.0
UPR HOLDER ARM, 20-BRUSH	0.00127	"	11.5
LWR " " "	"	"	11.5
UPR HOLDER ARM, 24-BRUSH	0.00143	"	13.0
LWR " " "	"	"	13.0
STEM	0.00008	"	1.0
SPRING	—	8030	2.1
INSULATOR	0.00010	2960	0.5
SUPPORT BRACKET	—	2770	1.5

$$W_{16\text{-}BRUSH\text{ HOLDER}} = (2 \times 11.0) + 1.0 + 2.0 + 0.5 + 1.5 = 27 \text{ kg}$$

$$W_{20\text{-}BRUSH\text{ HOLDER}} = (2 \times 11.5) + 1.0 + 2.0 + 0.5 + 1.5 = 28 \text{ kg}$$

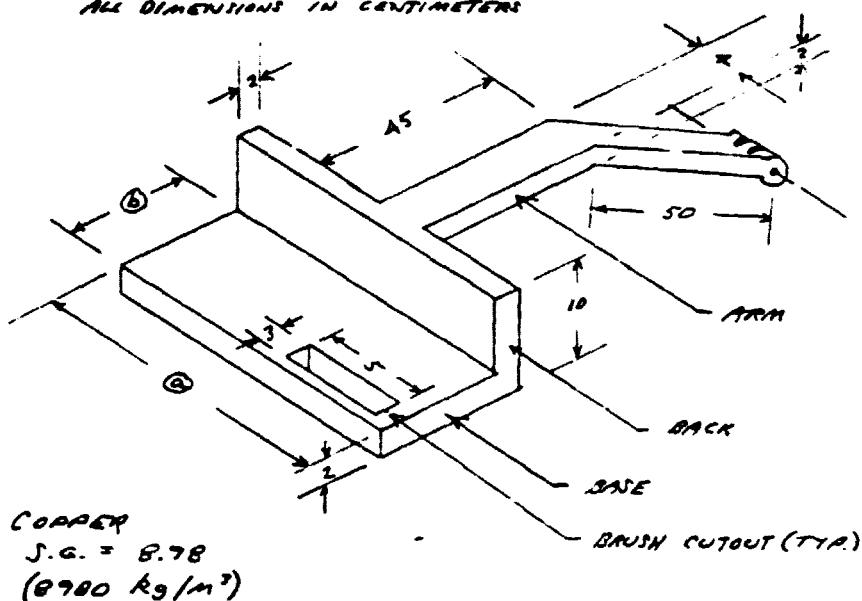
$$W_{24\text{-}BRUSH\text{ HOLDER}} = (2 \times 13.0) + 1.0 + 2.0 + 0.5 + 1.5 = 31 \text{ kg}$$

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HÖLDER BRACKET GEOMETRY

ALL DIMENSIONS IN CENTIMETERS



$$\text{VOL. OF } \text{Pb} = 95 \times 4 \times 2 = 760 \text{ cm}^3$$

$$\text{VOL. OF DACK} = @ \times 10 \times 2 = 20 @ \text{ CM}^3$$

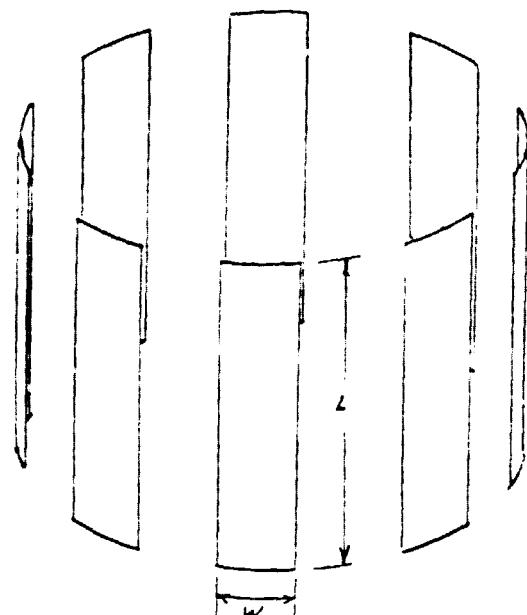
$$\text{VOL. OF BASE} = [\textcircled{1} = \textcircled{2} \times 2] - [(5 \times 3 \times 2) \text{ NO. OF BRUSHES }] \\ = 2 \textcircled{2} \textcircled{3} - 30 \text{ NO. OF BRUSHES}$$

TYPE	HOLDER	BRUSH CONFIG.	(2) (cm)	(3) (cm)	N _{BRUSHES}	V _{AIR} (cm ³)	V _{GASK} (cm ³)	V _{PAGE} (cm ³)	V _{TOTAL} (cm ³)
16-BRUSH		4x2	19	17	8	760	260	202	1222
20-BRUSH		5x2	13	21	10	760	260	246	1226
24-BRUSH		4x3	19	17	12	760	380	286	1426

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FEEDERS (PER SIDE)

1920 kg



8 FEEDERS/RING

ALUMINUM
S.G = 2.70
(2700 kg/m³)

LOCATION	L (m)	W (m)	T (cm)	PER FEEDER			
				Vol (m ³)	DENSITY (kg/m ³)	WT (kg)	WT FEEDERS (kg)
INNER RING	1.1	0.92	0.20	0.0202	2700	56	448
MIDDLE RING	8	1.44	0.30	0.0346	"	96	768
OUTER RING	5	1.96	0.32	0.0316	"	88	704

TOTAL: 1920 kg

D180-228766

2.1.1-2.0 MICROWAVE POWER TRANSMISSION SYSTEM (1)

12,606,100 \$

PRIMARY STRUCTURE	52,500
SECONDARY STRUCTURE	197,500
ANTENNA CONTROL SYSTEMS	(780)
POWER DISTRIBUTION SYSTEM - EXCL. SUBARRAYS	2,933,100
POWER BLADES	380,700
ROTARY JOINT TO PLUR SECTOR CONTROL	270,000
SECTOR CONTROL TO SUBARRAYS	109,700
SWITCH GEAR / DISCONNECTS	136,000
DC-DC CONVERTERS	1,241,000
THERMAL CONTROL (ACTIVE)	736,000
ENERGY STORAGE	299,300
SUPPORT STRUCTURES ~ 5%	139,700
ANTENNA COMMUNICATIONS/DATA SYSTEM	(780)
ANTENNA SUBARRAYS	9,423,000
TYPE 1 (272)	637,000
TYPE 2 (580)	1,506,000
TYPE 3 (612)	1,305,000
TYPE 4 (612)	1,122,000
TYPE 5 (756)	1,156,000
TYPE 6 (864)	1,043,000
TYPE 7 (628)	614,000
TYPE 8 (576)	508,000
TYPE 9. (1032)	760,000
TYPE 10 (1000)	581,000

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PRIMARY STRUCTURE

52,500 kg.

USED MASS ESTIMATE DEVELOPED BY
STRUCTURES RESEARCH STAFF GROUP.

SECONDARY STRUCTURE

197,500 kg.

USED MASS ESTIMATE DEVELOPED BY
STRUCTURES RESEARCH STAFF GROUP.

ANTENNA CONTROL SYSTEMS

(700)

POWER DISTRIBUTION SYSTEM - EXCL. SUBARRAYS

2,519,000 kg.

USED MASS ESTIMATE DEVELOPED BY
JACK GELNN OF ELECTRICAL POWER STAFF

OF THE TOTAL MASS, THE HEAVIEST
ITEMS ARE THE DC-DC CONVERTERS
AND ASSOCIATED THERMAL CONTROL, WHICH
COMPOSE 47.3% AND 29.2%, RESPECTIVELY.

(CONT'D)

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POWER DISTRIBUTION SYSTEM (CONT'D)

THE RATIONALE FOR THE MASS OF THE DC-DC CONVERTERS AND ASSOCIATED THERMAL CONTROL ARE GIVEN BELOW:

a) DC-DC CONVERTERS

- 220 CONVERTERS PER ANTENNA.
- EACH CONVERTER SUPPLIES POWER TO APPROXIMATELY 425 KLYSTRONS.
- POWER OUTPUT OF EACH CONVERTER IS 5443 KW.
- ESTIMATED SPECIFIC MASS IS 1.0 kg / KW
- ESTIMATED TOTAL MASS = $220 \times 5443 \times 1.0 = 1,261,000 \text{ kg}$.

b) THERMAL CONTROL

- DC-DC CONVERTER EFFICIENCY IS 96.0% □
- ESTIMATED RADIATOR AREA = $323 \text{ m}^2/\text{CONVERTER}$
- ESTIMATED SPECIFIC MASS OF ACTIVE THERMAL CONTROL SYSTEM = $10 \text{ kg}/\text{m}^2$ OR MOUNTING AREA
- ESTIMATED TOTAL MASS = $220 \times 323 \times 10 = 736,000 \text{ kg}$

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(780)

ANTENNA COMMUNICATIONS/ARM SYSTEM

ANTENNA SUBARRAYS

9,423,000 kg

OF THE TOTAL MASS, THE HEAVIEST ITEMS ARE THE KLYSTRONS, THERMAL CONTROLS AND RADIATING WAVEGUIDES, WHICH COMprise 49.5%, 22.1%, AND 15.8%, RESPECTIVELY. (SEE ATTACHED TABLES). THE UNIT MASS DATA FOR INDIVIDUAL ITEMS ARE: KLYSTRON, 48 kg EACH; THERMAL CONTROL, 21.6 kg/KLYSTRON; RADIATING WAVE GUIDE, 214 kg/SUBARRAY.

THE RATIONALE FOR THE UNIT MASS DATA ARE GIVEN BELOW:

a) KLYSTRON

- PERFORMED A MASS ANALYSIS OF A CONCEPTUAL DESIGN OF A 70KW KLYSTRON. (SEE APPENDIX E)

b) THERMAL CONTROL

- KLYSTRON EFFICIENCY IS 85%.
- COLLECTOR SECTION HEAT PIPE/RADIATOR DISSIPATES 8.0 KW AT 500°C. RF SECTION HEAT PIPE/RADIATOR DISSIPATES 5.2 KW AT 300°C.
- MERCURY WORKING FLUID
- ESTIMATED MASS-OPTIMIZED HEAT PIPE/RADIATOR MASS AT 6.2 kg FOR COLLECTOR SECTION AND 12.7 kg FOR RF SECTION. ADDED MULTI-LAYER INSULATION AT 2.7 kg.

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ANTENNA SUBMURALS (CONT'D)

c) ROTATING WAVE GUIDE

- PERFORMED A MASS ANALYSIS OF A CONCEPTUAL DESIGN. (SKETCH AND CALCULATIONS ATTACHED).

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SUBARRAY MASS MATRIX BASED ON MASS DATA
OF EACH GROUP OF IDENTICAL SUBARRAYS

SUBARRAYS	KLYSTRONS PER SUBARRAY	SUBARRAYS PER ANTENNA	KLYSTRON MASS (kg)	DISTRIBUTION WAVEGUIDE MAN (kg)	RADIATING WAVEGUIDE MAN (kg)	SOLID STATE CONTROL MAN (kg)	PWM. DISTR. CARLING MASS (kg)	Thermal control mass (kg)	SUBARRAY STRUCTURE MASS (kg)	TOTAL (MT)
TYPE 1	36	272	470,016	16,864	58,208	18,960	3536	216,394	24,208	833
TYPE 2	30	580	895,200	30,160	124,180	87,000	5800	375,260	48,720	1506
TYPE 3	24	612	705,024	25,704	130,968	73,140	5508	317,016	47,736	1305
TYPE 4	20	612	587,520	32,436	130,968	61,200	4896	267,772	44,004	1122
TYPE 5	16	756	580,608	31,752	161,704	60,980	4536	260,880	50,652	1151
TYPE 6	12	864	497,664	27,648	104,896	51,040	3456	223,776	53,568	1013
TYPE 7	9	628	271,296	20,096	134,392	28,260	1804	121,832	35,796	614
TYPE 8	8	576	221,184	12,096	123,264	23,040	1728	93,000	32,832	508
TYPE 9	6	1032	297,216	21,672	220,048	30,960	3096	193,128	58,632	760
TYPE 10	4	1008	192,000	21,000	214,000	20,000	2000	86,000	46,000	581
TOTAL (MT)		4658	239	1485	485	36	2087	433	9423	
% GROSS TOTAL		19.5%	3.5%	15.8%	5.1%	0.4%	22.1%	4.0%	100.0%	

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SUBARRAY MASS MATRIX BASED ON MASS DATA
OF INDIVIDUAL SUBARRAYS

SUBARRAY	KLYSTRON PER SUBARRAY	KLYSTRON MASS (kg)	DISTRIBUTION WAVEGUIDE MASS (kg)	RADIATING WAVEGUIDE MASS (kg)	SOLID STATE CONTROL MASS (kg)	PWR. DISTR. CABLING MASS (kg)	THERMAL CONTROL MASS (kg)	SUBARRAY STRUCTURE MASS (kg)	SUBTOTAL (kg)	SUBARRAYS PER ANTENNA	TOTAL (MT)
TYPE 1	36	1720	62	214	180	18	777	89	3069	272	833
TYPE 2	30	1440	52	214	150	10	697	84	2597	580	1506
TYPE 3	24	1152	42	214	120	9	578	70	2133	612	1305
TYPE 4	20	960	53	214	100	8	431	67	1838	612	1122
TYPE 5	16	768	42	214	80	6	345	67	1522	756	1151
TYPE 6	12	576	32	214	60	4	259	62	1207	864	1043
TYPE 7	9	432	32	214	45	3	194	57	977	620	614
TYPE 8	8	384	21	214	40	3	163	57	982	576	508
TYPE 9	6	268	21	214	30	3	129	51	736	1032	760
TYPE 10	4	192	21	214	20	2	86	46	581	1000	581
									6932	9423	

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PERTINENT UNIT MASS DATA:

KLYSTRON (70 KW)	48 kg EACH
RADIATING WAVE GUIDE	214 kg / SUBARRAY
THERMAL CONTROL	21.6 kg / KLYSTRON
SOLID STATE CONTROL	5.0 kg / KLYSTRON

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RADIATING WAVE GUIDE (PER SUBARRY)

214.0 k.

a. GRAPHITE EPOXY STRUCTURE

SEE ATTACHED SKETCH

$$\begin{aligned}
 V_{GIE} &= (S_{\text{upper curved surfaces}} + S_{\text{flats}} + S_{\text{end crossouts}}) \times \\
 &\quad \times [(11.964 \times 7.728) z + (7.728 \times 0.06) / 121 \\
 &\quad + (0.09325 \times 0.06) (120) z] 0.00041 \\
 &= (227.63 + 72.08 + 1.34) 0.00041 \\
 &= 0.1234 \text{ m}^3
 \end{aligned}$$

b. TEGUMINUM CERTUS

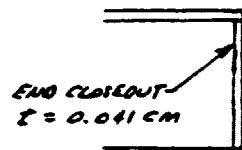
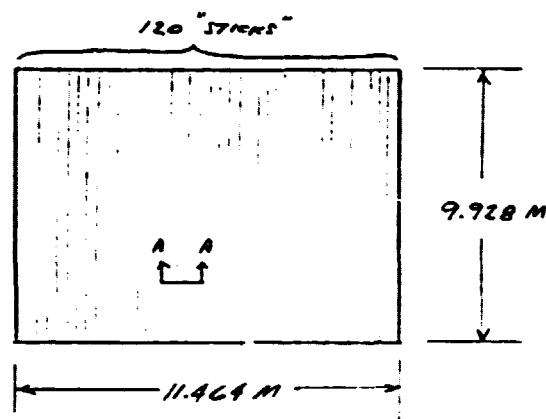
SEE ATTACHED SKETCH

$$\begin{aligned}
 V_{\text{Actual}} &= (S_{\text{INTERNAL, TOP, BOTTOM + SIDES}} + S_{\text{INTERNAL, ENDOS}} + S_{\text{EXTERNAL, LUMPSUM}})t \\
 &= [(0.09325 + 0.09325 + 0.06 + 0.06)(9.728)/120 \\
 &\quad + (0.09325 \times 0.06)(1/120)(2) + (11.464 \times 9.728)]0.000,006,67 \\
 &= (3 - 5.15 + 1.34 + 112.8)0.000,006,67 \\
 &= 0.00320 \text{ m}^3 \\
 W_{\text{Actual}} &= 1.05 \rho V \\
 &= 1.05(2770 \text{ kg/m}^3)(0.00320 \text{ m}^3)
 \end{aligned}$$

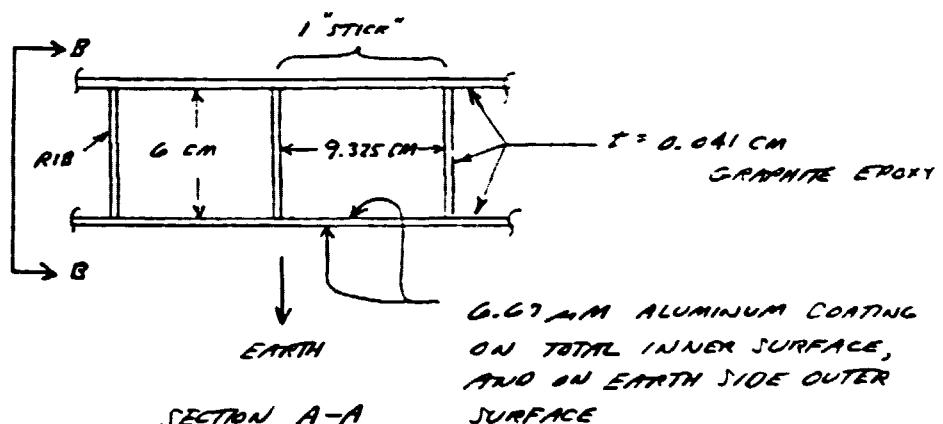
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RADIATING WAVE GUIDE



SECTION B-B



SECTION A-A

NOTE: INTERNAL CLOSEOUTS ARE KEVLAR SHEET. (WEIGHT IS NEGIGIBLE)

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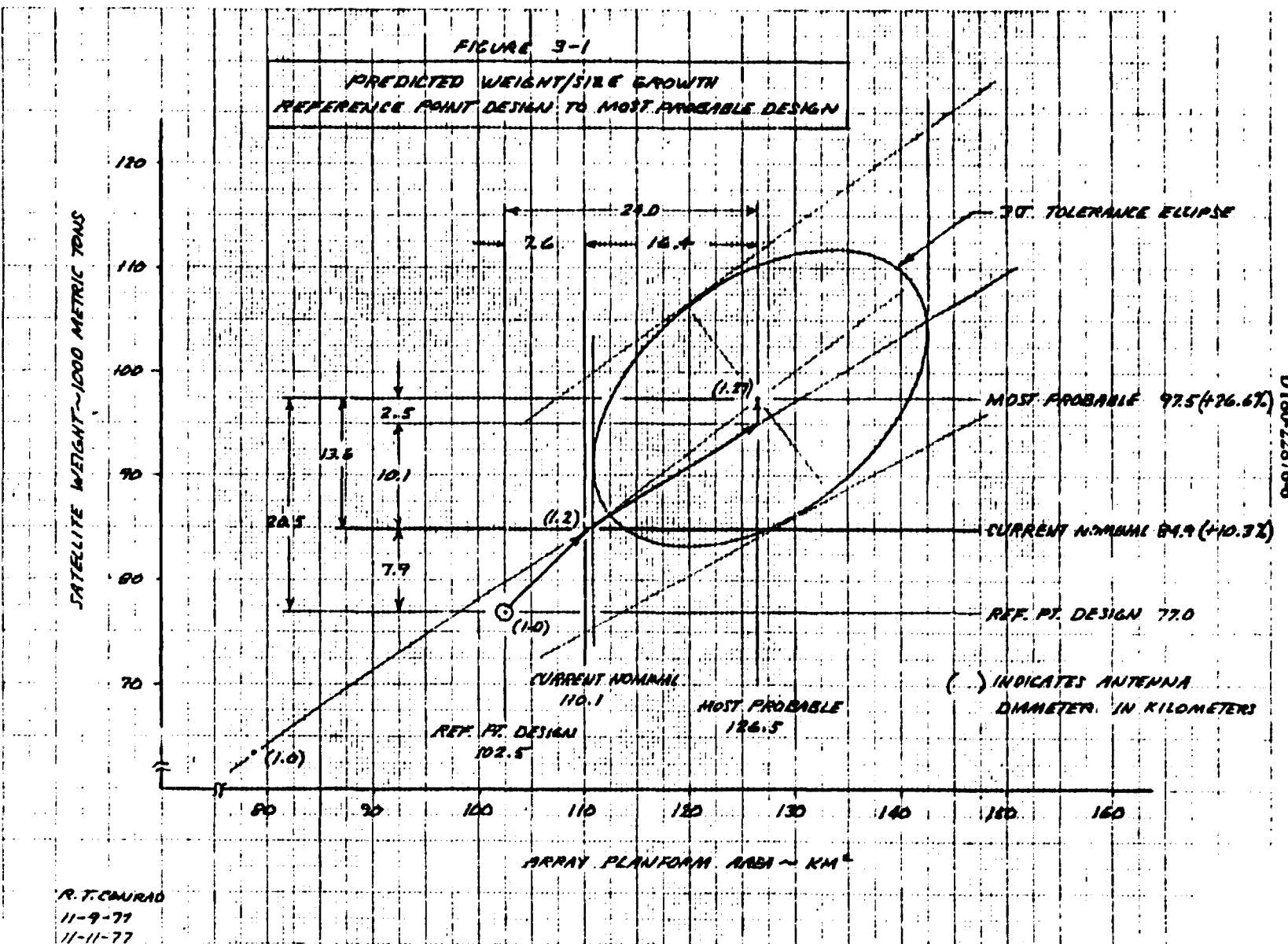
2.1.1-3.0 WEIGHT GROWTH ALLOWANCE

20,505,500 kg

THE RESULTS OF THE WEIGHT/SIZE UNCERTAINTY ANALYSIS ARE PRESENTED ON PAGE VI. AS INDICATED, THE REFERENCE POINT DESIGN WEIGHS 77.0×10^3 METRIC TONS AND HAS AN ARRAY AREA OF 102.5 km^2 . ALSO, AS NOTED, THE RECTENNA OUTPUT POWER WITH THE REFERENCE POINT DESIGN IS 9.2 GW. THE MOST PROBABLE DESIGN HAS A PREDICTED WEIGHT OF 97.5×10^3 METRIC TONS AND A PREDICTED ARRAY AREA OF 126.5 km^2 . THE RECTENNA OUTPUT POWER WITH THE MOST PROBABLE DESIGN IS PREDICTED AT 10.0 GW. THE WEIGHT AND SIZE GROWTH IN GOING FROM THE REFERENCE POINT DESIGN TO THE MOST PROBABLE DESIGN ARE 20.5×10^3 METRIC TONS AND 24.0 km^2 , RESPECTIVELY.

FIGURE 3-1 PROVIDES SOME DETAILS ON THE PREDICTED WEIGHT/SIZE GROWTH IN GOING FROM THE REFERENCE POINT DESIGN TO THE MOST PROBABLE DESIGN. THE FIRST STEP IS TO GO FROM THE REFERENCE POINT DESIGN TO THE CURRENT NOMINAL CONFIGURATION. THE CHANGES ($+7.9 \times 10^3$ METRIC TONS, $+7.6 \text{ km}^2$) REFLECT THE IMPACT OF NORMALIZING THE REFERENCE POINT DESIGN TO A RECTENNA OUTPUT POWER OF 10.0 GW, USING AN UPDATED POWER EFFICIENCY STRING (A MAJOR IMPACT OF THE UPDATED POWER EFFICIENCY STRING IS AN INCREASE IN ANTENNA DIAMETER FROM 1.0 KM TO 1.2 KM) AND NOMINAL UNIT WEIGHTS. THE SECOND STEP IS TO GO FROM THE CURRENT NOMINAL CONFIGURATION TO THE MOST PROBABLE CONFIGURATION. THE CHANGES ($+13.6 \times 10^3$ METRIC TONS, $+16.4 \text{ km}^2$) REFLECT ANTICIPATED OVERALL DEGRADATION IN THE POWER EFFICIENCY STRING AND IN THE NOMINAL UNIT WEIGHTS. AS INDICATED, OF THE 13.6×10^3 METRIC TON WEIGHT INCREASE, 10.1×10^3 METRIC TON IS PREDICTED TO OCCUR DUE TO CHANGES IN POWER EFFICIENCIES, AND ONLY 2.5×10^3 METRIC TON IS PREDICTED TO OCCUR DUE TO CHANGES IN NOMINAL UNIT WEIGHTS.

IN CONCLUSION, THE POWER EFFICIENCY STRING, BECAUSE ITS CONTROLS ARRAY SIZE AND ANTENNA SIZE, WILL BE THE MAJOR WEIGHT DRIVER. DEGRADATION OF NOMINAL UNIT WEIGHTS WILL BE A SECONDARY WEIGHT DRIVER.



R. T. CAURAD
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2.1.1
APPENDIX A

**SIZING DATA FOR A 20 METER LONG
TAPERED TUBE OF GRAPHITE/EPOXY**

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SIZING DATA FOR A 20 METER LONG
TAPERED TUBE OF GRAPHITE/EPOXY

2. PHYSICAL CHARACTERISTICS/PROPERTIES OF TUBE

AS A COMPRISE BET. JEUN FAILURE MODES OF LONG
COLUMN BUCKLING AND LOCAL CRIPLING, THE
FOLLOWING GRAPHITE/EPOXY TUBE DEFINITION HAS
BEEN SELECTED.

3 LAYER TUBE OF GY-70/904 $\begin{cases} \text{OUTER LAYER IS } 0.2t @ 90^\circ \\ \text{MIDDLE LAYER IS } 0.6t @ 0^\circ \\ \text{INNER LAYER IS } 0.2t @ 90^\circ \end{cases}$

THE PHYSICAL CHARACTERISTICS/PROPERTIES OF THE TUBE
ARE

$$E_x = 25.57 \times 10^6 \text{ PSI}$$

$$E_y = 17.34 \times 10^6 \text{ PSI}$$

$$G_{xy} = 0.60 \times 10^6 \text{ PSI}$$

$$\nu_{xy} = 0.0124$$

$$\nu_{yx} = 0.0084$$

$$\rho = 0.061 \text{ lb/in}^3$$

$$\alpha = -0.2486 \times 10^{-6} \text{ in/in/}^\circ\text{F}$$

6. CRIPLING COEFFICIENT

FROM DM 84-A2, SECTION 311.5.7.B, CRIPLING STRESS
FOR A FILAMENTARY COMPOSITE TUBE IS GIVEN AS

$$F_{cr} = K \phi \alpha \frac{\varepsilon}{R} \quad (1)$$

WHERE $K = 1 - 0.901 \left(1 - e^{-\frac{R}{10} \sqrt{\frac{E}{\varepsilon}}} \right) \quad (2)$

$$\phi \left\{ \begin{array}{l} = 1.0 \\ = \left[\frac{2 G_{xy} (1 + \sqrt{\nu_{xy} \nu_{yx}})}{\sqrt{E_x E_y}} \right]^{1/2} \end{array} \right\} \text{ WHICHEVER IS LESS} \quad (3a)$$
$$(3b)$$

$$\alpha = \left[\frac{E_x E_y}{3(1 - \nu_{xy} \nu_{yx})} \right]^{1/2} \quad (4)$$

b. CRIPPLING COEFFICIENT (CONT'D)

THE CLASSIC EXPRESSION FOR CRIPPLING STRESS IN TERMS OF A CRIPPLING COEFFICIENT IS

$$F_{cr} = C E_x \frac{\epsilon}{R} \quad (5)$$

EQUATING EQUATIONS (1) AND (5) AND SOLVING FOR THE CRIPPLING COEFFICIENT YIELDS

$$C = \frac{K \phi \alpha}{E_x} \quad (6)$$

SOLVING FOR K FROM EDTN (2) :

R/ϵ	K
10	0.878
100	0.583
250	0.434
500	0.321
750	0.262
1000	0.223

} (7)

SOLVING FOR ϕ FROM EDTN'S (3a) AND (3b) :

EDTN (3b) GOVERNS,

$$\phi = 0.240 \quad (8)$$

SOLVING FOR α FROM EDTN (4) :

$$\alpha = 12.16 \times 10^6 \quad (9)$$

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b. CRIMPING COEFFICIENT (Cont'd)

SUBSTITUTING EOTIN'S (π_1, π_2, m_1, m_2) AND
EOTIN BY YIELD

R/L	C	
10	0.096	
100	0.067	
250	0.050	
500	0.037	
750	0.030	
1000	0.025	

SEE FIG. A-1

{ AN APPROPRIATE EQUATION FOR C FOR
 R/L VALUES BETWEEN 150 AND 1500 IS

$$C = \frac{0.8}{(R/L)^{0.50}} \quad (11)$$

c. OPTIMUM TUBE DEFINITION FOR 20M PINCHED STRUT

* LONG COLUMN BUCKLING

FOR LOW STRESS LEVELS, SHEAR DEFLECTION
EFFECTS ARE NEGLECTABLE, AND THE EULER
EQUATION APPLIES:

$$F_{cr} = \frac{\pi^2 m E_p}{(L/a)^2} \quad (12)$$

SUBSTITUTING

$L = 1$ FOR PINNED ENDS

$m = 2.75$ FOR $R_1/R_2 = 1/3$

$E_p = 25.57 \times 10^6$ MN

$L = 787.4$ IN

$P = 0.707 R_2$ FOR THIN WALLED TUBE

Y10205

$$F_{cr} = 77.30 R_2^2 \quad (13)$$

2. OPTIMUM TUBE DEFINITION FOR 20M TRAMPED STUT (CONT'D)

• LONG COLUMN BUCKLING (CONT'D)

$$\begin{aligned}
 P_{cr} &= 2\pi R_2 t F_{cr} \\
 &= 2\pi R_2 t (77.30 R_2^2) \\
 &= 485.4 R_2^3 t
 \end{aligned} \tag{14}$$

FROM WHICH

$$t = \frac{P_{cr}}{485.4 R_2^3} \tag{15}$$

• CRIPPLING AT MIDSPAN - NOMINAL CRIPPLING COEFFICIENT

$$F_{cr} = C E_x \left(\frac{t}{R_2}\right) \tag{16}$$

WHERE, FOR THE SDS COMPOSITE TUBE, THE NOMINAL CRIPPLING COEFFICIENT CAN BE APPROXIMATED AS

$$C = \frac{0.8}{\left(\frac{R_2}{t}\right)^{0.50}} ; 150 \leq \frac{R_2}{t} \leq 1500 \tag{17}$$

THUS

$$F_{cr} = 0.8 E_x \left(\frac{t}{R_2}\right)^{1.5} \tag{18}$$

SUBSTITUTING

$$E_x = 25.57 \times 10^6 \text{ MN}$$

YIELDING

$$F_{cr} = 20.46 \times 10^6 \left(\frac{t}{R_2}\right)^{1.5} \tag{19}$$

THUS

$$\begin{aligned}
 P_{cr} &= 2\pi R_2 t F_{cr} \\
 &= 2\pi R_2 t \left[20.46 \times 10^6 \left(\frac{t}{R_2}\right)^{1.5} \right] \\
 &= 128.5 \times 10^6 \frac{t^{2.5}}{R_2^{0.5}}
 \end{aligned} \tag{20}$$

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C. OPTIMUM TUBE DEFINITION FOR 20M UNSTRESSED STRUT (CONT'D)

* CRIPPLING AT MODULUS - NORMAL CRIPPLING COEFFICIENT (CONT'D)

FROM WHICH

$$t = \frac{P_{cr}^{0.4} R_2^{0.2}}{1752} \quad (19)$$

* LONG COLUMN BUCKLING AND LOCAL CRIPPLING

LETTING EQUN (15) EQUAL EQUN (19) AND
SOLVING FOR $R_2 = 7162.08$

$$R_2 = 1.49 P_{cr}^{-0.1075} \quad (20)$$

SEE PG. A-2

P_{cr}	$R_2 D$	$t D$	R_2/t
(lb/in.)	(in.)	(in.)	(in/in)
500	4.78	.0074	509
1000	5.14	.0127	428
1500	5.87	.0152	386
2000	6.20	.0172	360
2500	6.46	.0190	340
3000	6.69	.0205	326
3500	6.88	.0220	313
4000	7.06	.0233	303
4500	7.21	.0245	294
5000	7.36	.0257	286

(21)

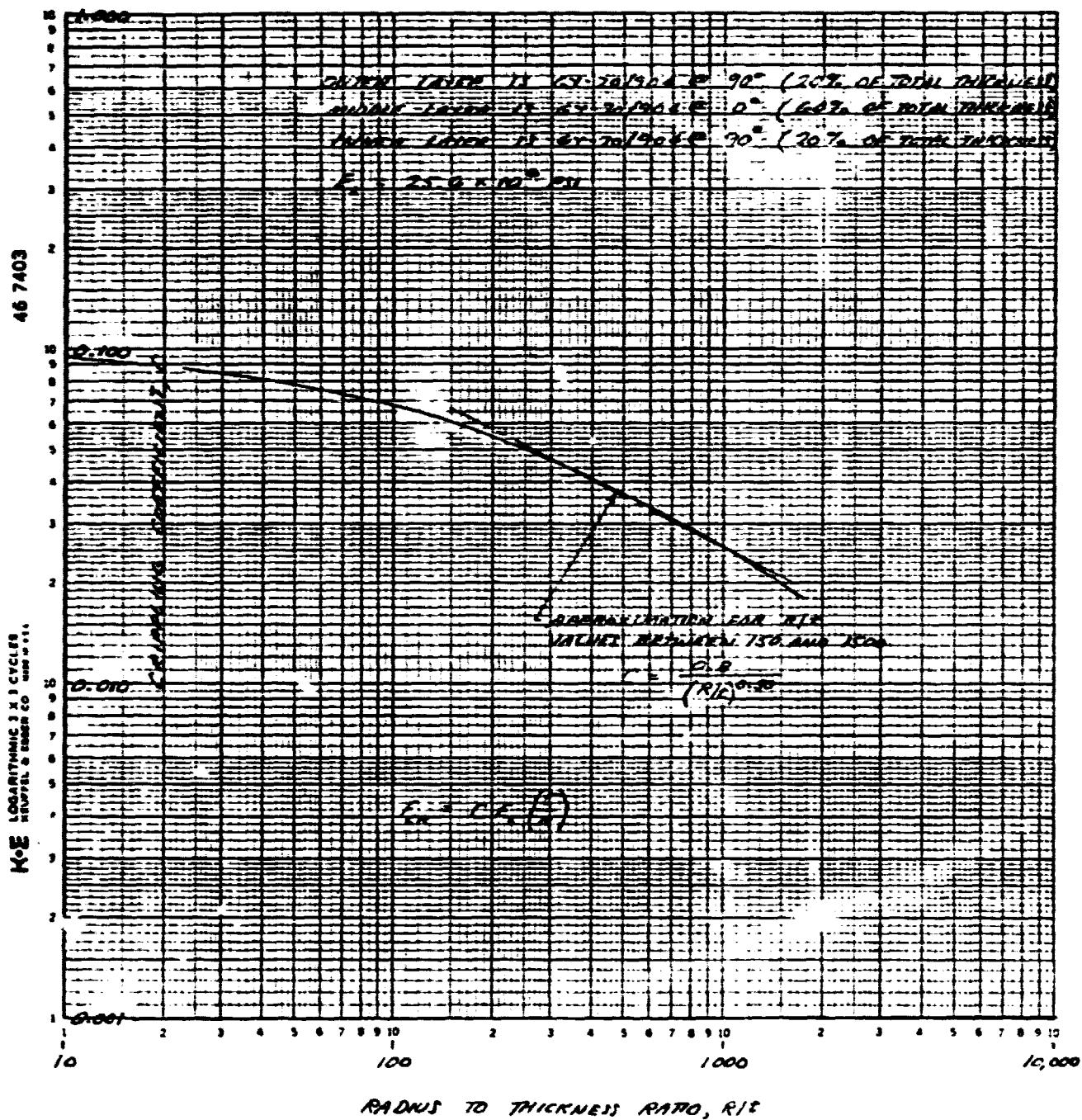
> FROM EQUN (20)

▷ FROM EITHER EQUN (15) OR (19)

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FIGURE A-1

CRIMPING COEFFICIENT FOR TYPICAL
COMPOSITE TUBE OF GRAPHITE/EPOXY

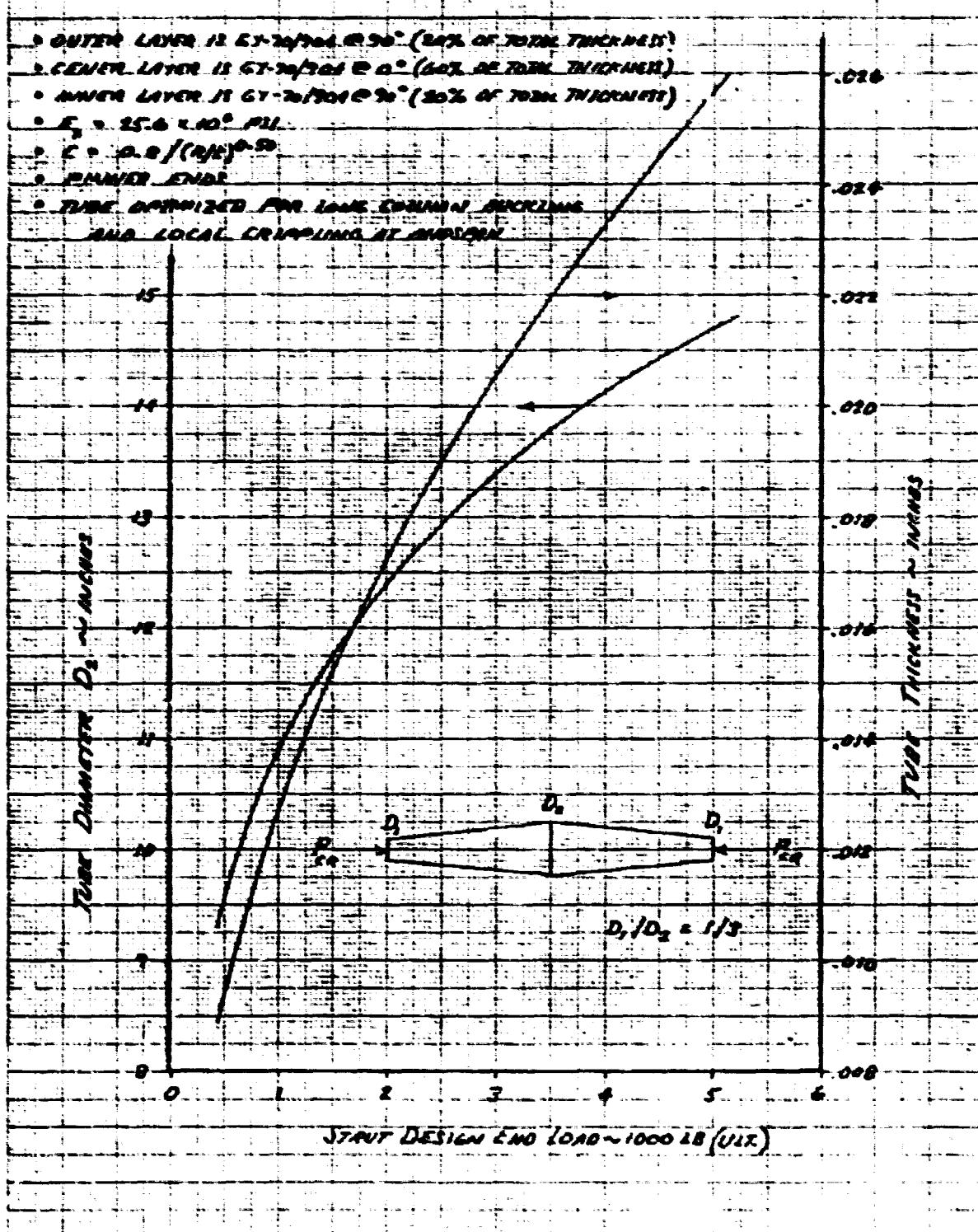


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FIGURE A-2

SIZING DATA FOR A 20 METER LONG
TAPERED TUBE OF GRANITE EPOXY

- OUTER LAYER IS GY-20/70@ 0.90° (20% OF TOTAL THICKNESS)
- CENTER LAYER IS GY-20/70@ 0.0° (0% OF TOTAL THICKNESS)
- INNER LAYER IS GY-20/70@ 2.0° (20% OF TOTAL THICKNESS)
- $E_g = 25.0 \times 10^6$ PSI
- $E_c = 10.0 \times 10^6$ PSI
- PLUNGE END
- TUBE OPTIMIZED FOR LOAD SPANNING OVERHANG
AND LOCAL CRIMPING AT MIDSPAN



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2.1.1
APPENDIX B

ARRAY EDGE LOADING ANALYSIS

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ARRAY EDGE LOADING ANALYSIS

STIFFNESS COMPARISONS FOR STRUCTURAL CONCEPTS FOR SPS ARE SUMMARIZED IN FIGURE B-1. CONCEPT #2 IS THE STRUCTURAL CONCEPT "MOST-LIKE" THE CURRENT REFERENCE CONFIGURATION. FOR CONCEPT #2, THE FIRST MODE FREQUENCY OF THE TRUSS WITH SOLAR CELLS AND ANTENNAS IS 0.0012 Hz.

TO PREVENT COUPLING OF THE SOLAR ARRAYS AND TRUSS, THE FIRST MODE FREQUENCY OF EACH ARRAY INSTALLATION SHOULD BE HIGHER THAN THE FIRST MODE FREQUENCY OF THE TRUSS BY A FACTOR OF AT LEAST 2 TO 3. THE RESULTANT FIRST MODE FREQUENCY RANGE OF 0.0024 Hz TO 0.0036 Hz CORRESPONDS TO AN HOURLY CYCLE RATE RANGE OF 8.6 TO 13.0.

FOR THE PURPOSE OF ESTABLISHING EDGE LOADING ON EACH ARRAY, AN ARRAY FIRST MODE FREQUENCY OF 12 CYCLES PER HOUR (0.0033 Hz) HAS BEEN SELECTED.

THE EQUATION FOR THE FIRST MODE FREQUENCY OF VIBRATION FOR A SQUARE MEMBRANE IS

$$\omega = \frac{\pi}{L} \sqrt{\frac{2T}{w}} \quad \text{~RADIAN/SECOND}$$

OR

$$f = \frac{3600}{2\pi} \frac{\pi}{L} \sqrt{\frac{2T}{w}} \quad \text{~CYCLES/HOUR}$$

FROM WHICH

$$T = \frac{2f^2 L^2 w}{(3600)^2}$$

WHERE

T = TENSION LOADING ALONG EDGE
OF MEMBRANE IN NEWTONS/METER
f = FIRST MODE FREQUENCY IN CYCLES/HOUR
L = LENGTH OF SIDE OF SQUARE MEMBRANE
IN METERS
w = UNIT WEIGHT OF MEMBRANE IN
KILOGRAMS/METER²

FIGURE B-2 PRESENTS ARRAY EDGE LOADING DATA FOR SPS.

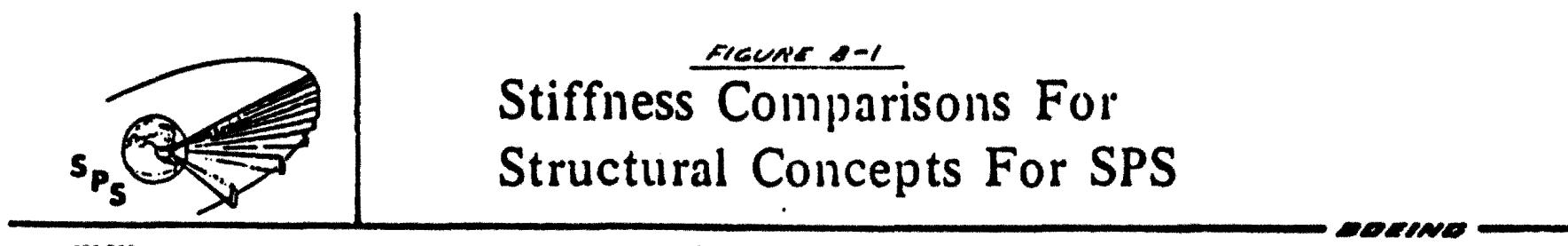
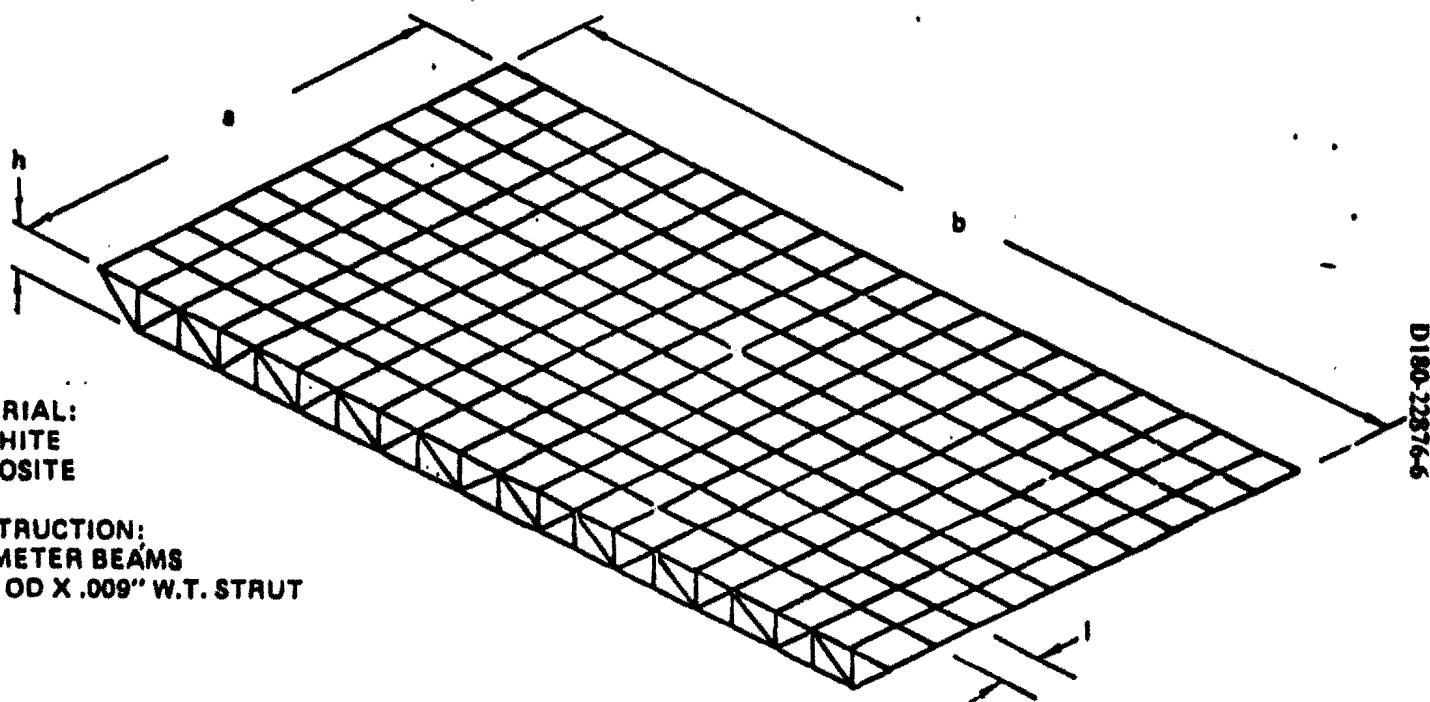


FIGURE 8-1
Stiffness Comparisons For
Structural Concepts For SPS

GIVEN:

- (1) MATERIAL:
GRAPHITE
COMPOSITE
- (2) CONSTRUCTION:
. 20 METER BEAMS
. 12" OD X .009" W.T. STRUT



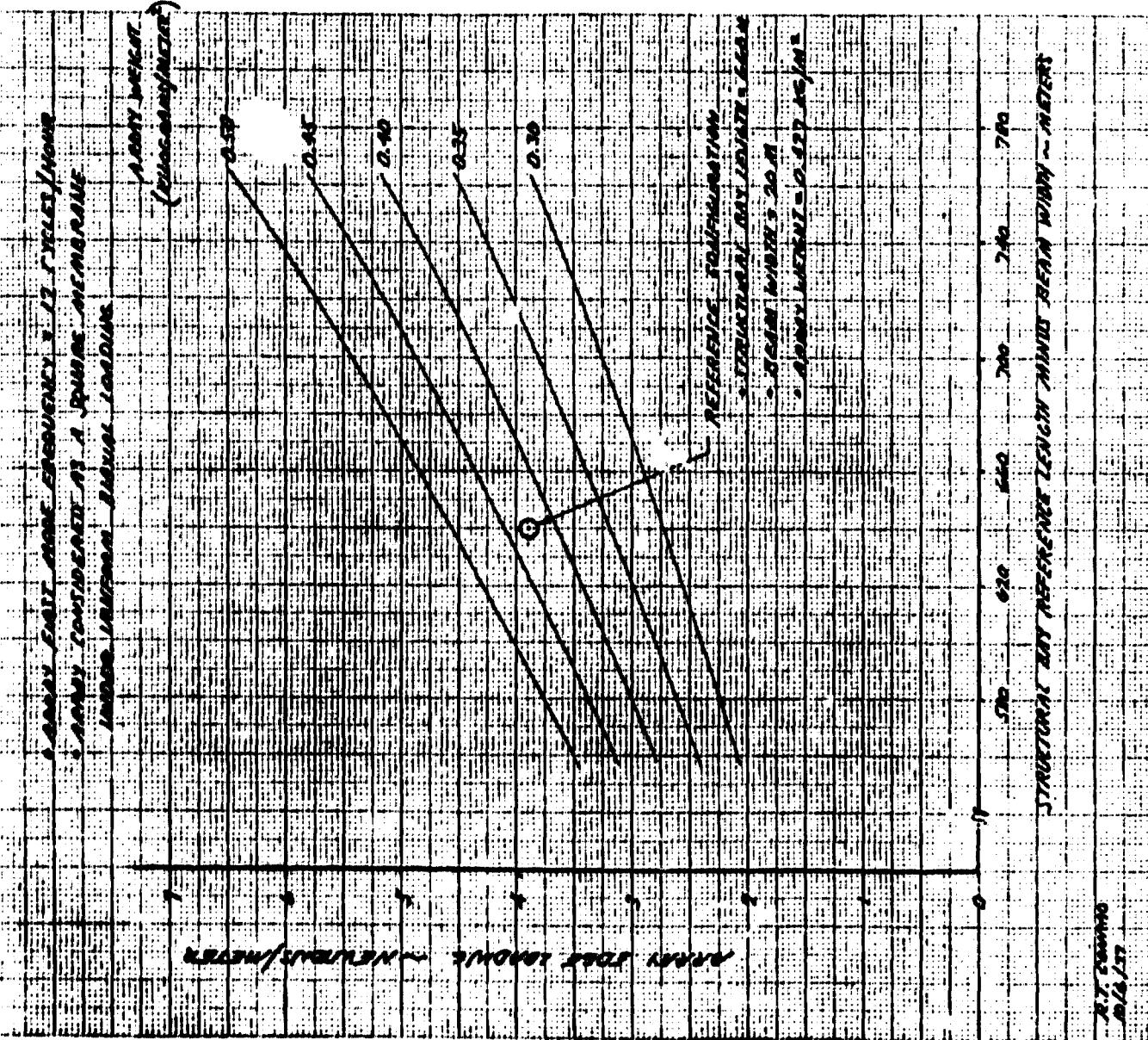
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TRUSS ANGLE θ	CONCEPT NO.	a IN METERS	b IN METERS	l IN METERS	h IN METERS	MASS (Kg)	AREA IN M ²	TRUSS f ₁ (Hz) ONLY	WITH SOLAR CELLS f ₁ (Hz)	WITH SOLAR CELLS AND ANTENNAS f ₁ (Hz)
30°	1	10240	10240	640	406	4.16×10^6	1.05×10^8	.0130	.0035	.0032
30°	2	5120	20480	640	406	4.19×10^6	1.05×10^8	.0052	.0014	.0012
45°	3	6240	16640	520	566	5.81×10^6	1.04×10^8	.0100	.0032	(NOT DETERMINED)
90°	4	6080	18240	380	683	10.30×10^6	1.11×10^8	.0094	.0037	(NOT DETERMINED)

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Figure 8-2. RARRY EDGE PRACTICING



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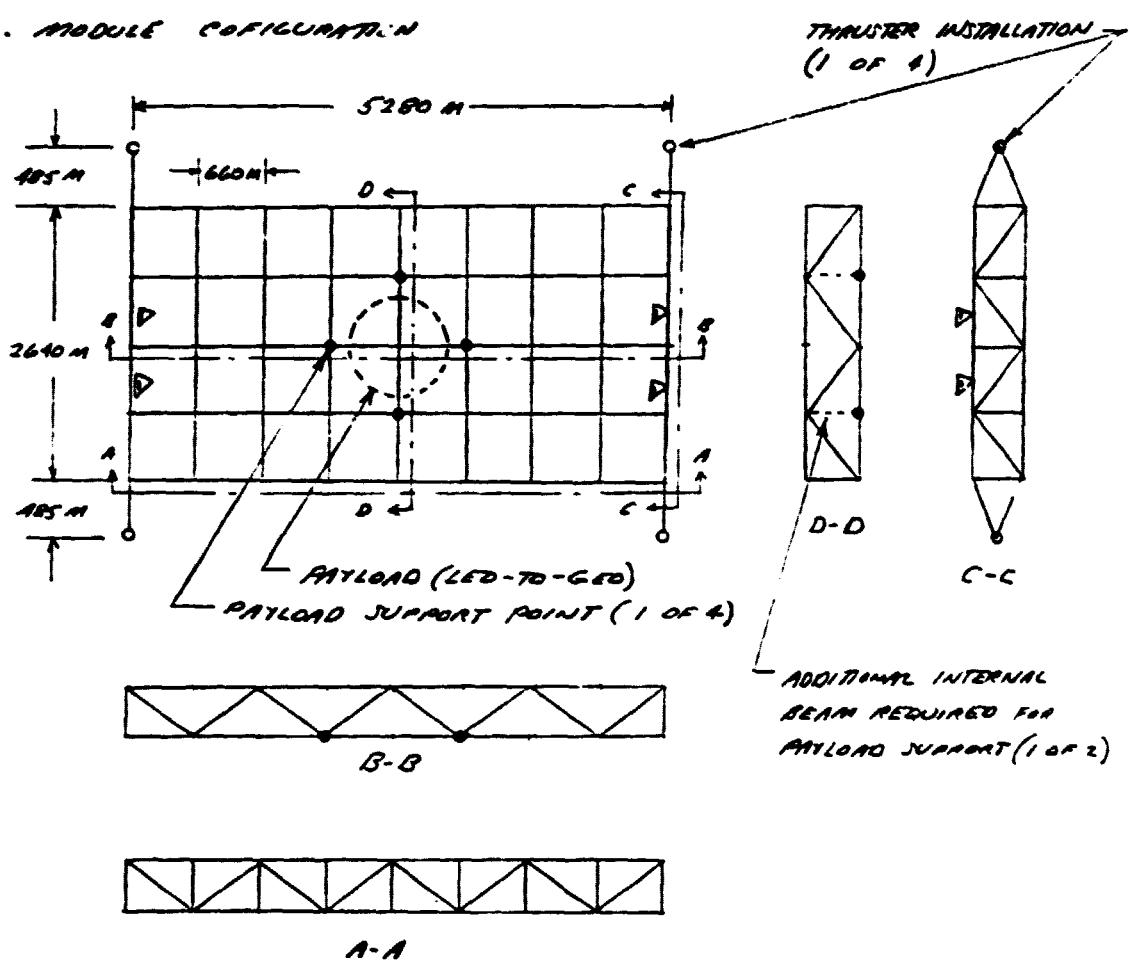
2.1.1
APPENDIX C

**LOAD ANALYSIS AND LOADS/SIZING SUMMARY
FOR
CRITICAL BEAM IN UPPER SURFACE**

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LOADS ANALYSIS AND LOADS/SIZING SUMMARY
FOR
CRITICAL BEAM IN UPPER SURFACE

a. MODULE CONFIGURATION

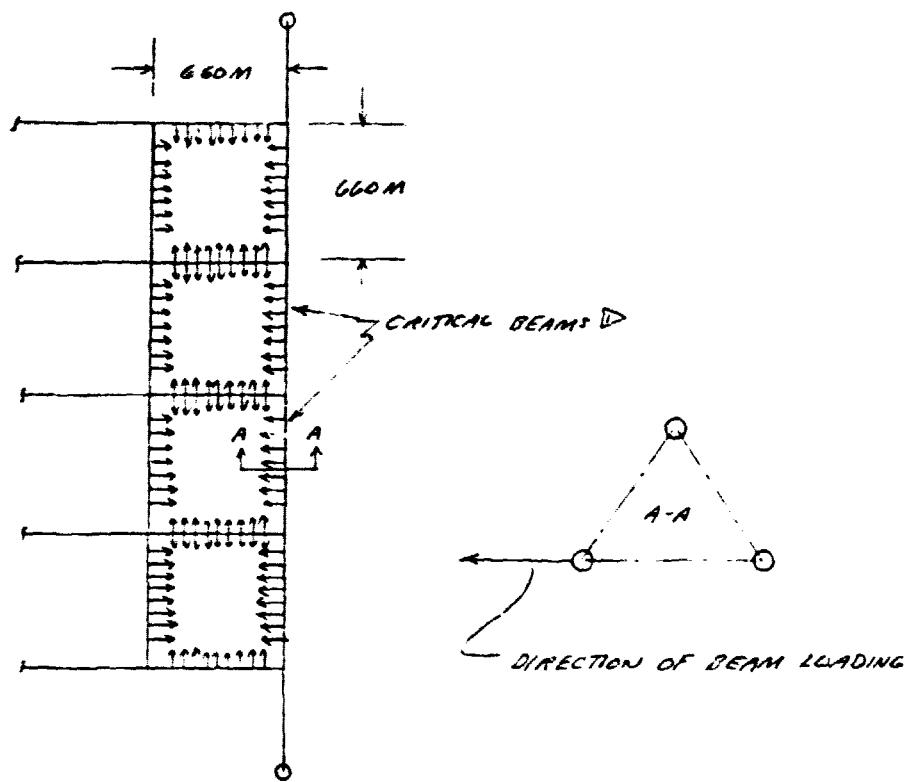


► CRITICAL BEAM (FOR CASE OF UPPPER SURFACE IN COMPRESSION)

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b. LOADS ON CRITICAL BEAM DUE TO PRETENSION IN ARRAY



- ARRAY PRETENSION LOADING ALONG EDGE = 3.9 N/. D }
• LOADS IN CRITICAL BEAM
BEAM LOADING = 3.9 N/M = .5223 LBS/IN }
COLUMN LOAD = -(3.9 N/m)($\frac{1}{2} \times 660\text{ m}$) } D
= -1287 N = -289 LB }
}

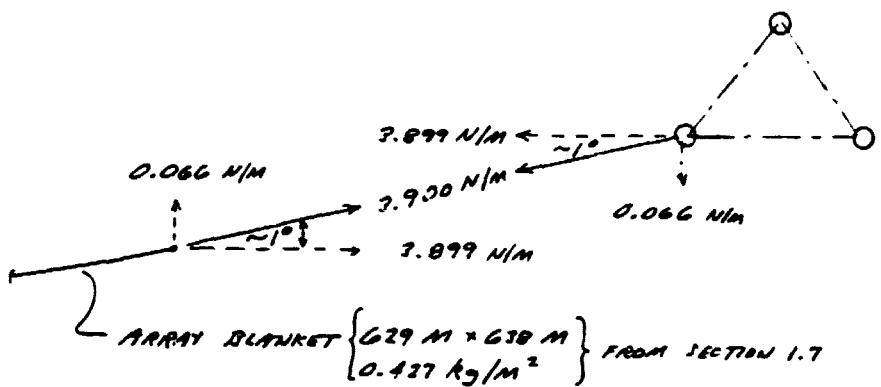
D PART OF SATELLITE LONGITUDINAL BEAM SYSTEM / MODULE LATERAL BEAM SYSTEM.

D FROM APPENDIX A, FIGURE A-2.

D APPLIED (LIMIT) LOADS.

C. LOADS ON CRITICAL BEAM DUE TO PRETENSION IN
ARRAY DURING LTO TO GEO TRANSFER

- ASSUME THAT THE ARRAY CATERPILLAR SUPPORT SYSTEM ATTACHES TO THE BEAM (AT 20M INTERVALS) BY MEANS OF CONSTANT FORCE SPRINGS. THE LOAD IN A SPRING IS 78 N (3.9 N/m \times 20 m).
- THEN, SHOULD THE T/W DURING LTO TO GEO REACH THE MAXIMUM CAPABILITY OF 0.0001, THE VERTICAL AND HORIZONTAL COMPONENTS OF THE ARRAY PRETENSION LOADING (AND THE ARRAY BLANKET SAG ANGLE AT OUTER EDGE), ARE AS SHOWN BELOW



- THE CORRESPONDING LOADS IN THE CRITICAL BEAM ARE

$$\left. \begin{aligned} \text{BEAM LOADING (HORIZ.)} &= 3.899 \text{ N/w} = 0.0223 \text{ lb/in} \\ \text{BEAM LOADING (VERT.)} &= 0.066 \text{ N/w} = 0.0004 \text{ lb/in} \\ \text{COLUMN LOAD} &= -(3.899 \text{ N/m})(\frac{l}{2} = 660 \text{ m}) \\ &= -1287 \text{ N} = -287 \text{ lb} \end{aligned} \right\} \triangleright$$

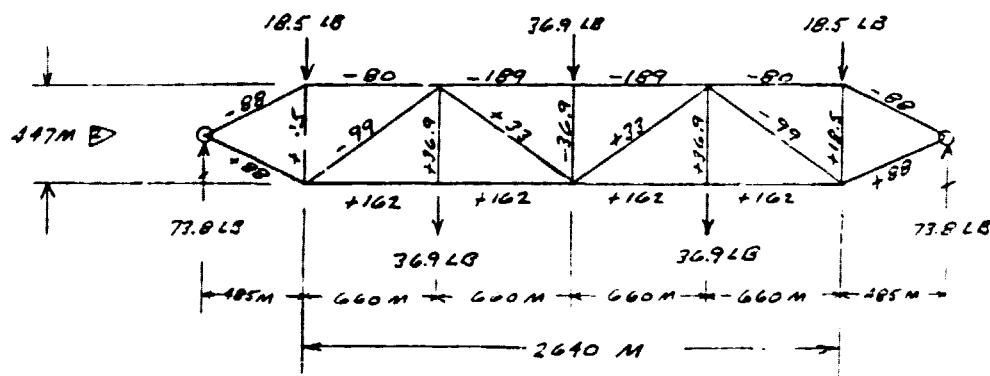
▷ APPLIED (LIMIT) LOADS

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d. DELTA LOAD ON CRITICAL BEAM DUE TO MODULE SELF
TRANSPORT FROM LEO TO GEO, NO PAYLOAD CASE

- TYPICAL MODULE WEIGHT = 6,500,000 kg ▷
- APPLIED THRUST AT EACH OF FOUR THRUSTER
INSTALLATIONS (BASED ON MAX THW CAPABILITY
= 0.0001) $\approx 162.5 \text{ kg}_f \approx 73.8 \text{ lb}_f$
- WORST CASE LOADS ACTING ON SECTION CC TRUSS:



- ▷ COLUMN LOAD ON CRITICAL BEAM = -189 LB ▷

▷ SOLAR ENERGY COLLECTION SYSTEM WT = $\frac{\sim 52,000,000 \text{ kg}}{8} = 6,500,000 \text{ kg}$

▷ $470.33 - 2\left(\frac{2}{3} \times 17.32\right) = 447.24 \text{ N}$

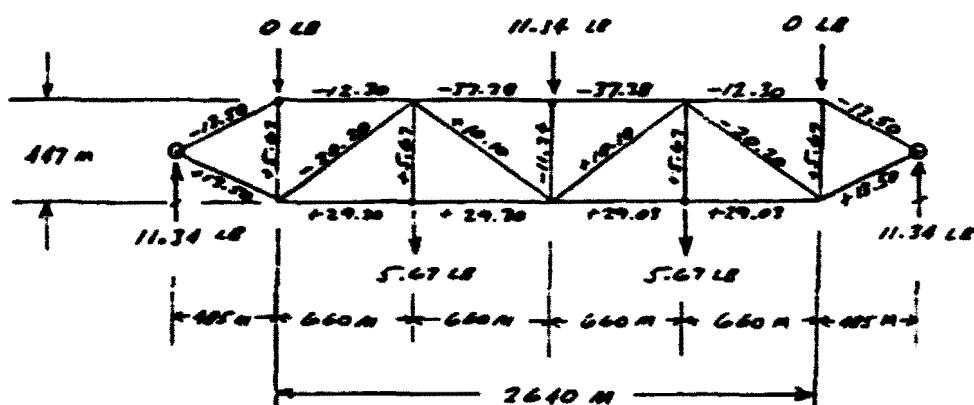
▷ APPLIED (LIMIT) LOAD

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c. DEPTH LOAD ON CRITICAL BEAM PER 1,000,000 kg OF PAYLOAD TRANSPORTED FROM LEO TO GEO

- DEPTH APPLIED THRUST AT EACH OF FOUR THRUSTER INSTALLATIONS (BASED ON MAX THW CAPABILITY = 0.0001) = $25 \text{ kg}_f = 11.34 \text{ lb}_f$
- WORST CASE LOADS ACTING ON SECTION C-C TRUSS:

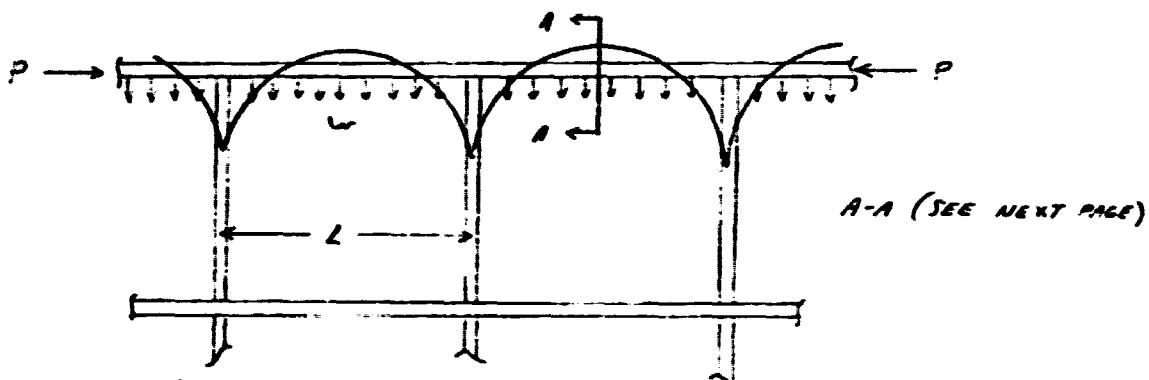


• ΔCOLUMN LOAD ON CRITICAL BEAM = $-37.38 \text{ lb} / 1,000,000 \text{ kg P/L}$ □

▷ APPLIED (UNIT) LOAD

F. EQUATION FOR COLUMN LOAD ON CRITICAL STRUT IN CRITICAL BEAM

TREATING THE CRITICAL BEAMS AS BEING CONTINUOUSLY SUPPORTED, IT FOLLOWS THAT THE MOMENT DIAGRAM IS AS SHOWN BELOW:



WHERE

$$M_{\text{maximum}} = \frac{w L^2}{24}$$

AND

$$M_{\text{beam intersect}} = -\frac{w L^2}{12}$$

} ASSUMES BEAM-COLUMN IMPACT ON M. MOMENTS IS NEGIGIBLE. D

THUS, THE MAXIMUM MOMENT IN THE CRITICAL BEAM OCCURS AT A BEAM INTERSECT LOCATION.

(CONT'D)

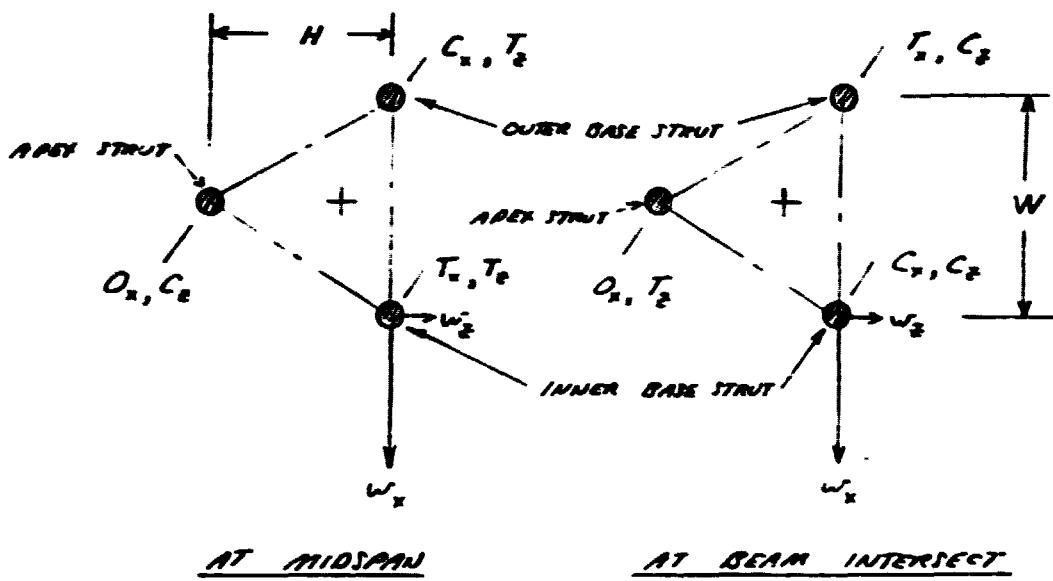
- ▷ THIS ASSUMPTION IS VALID SO LONG AS $P/P_{\text{euler}} \approx 1$, WHERE P IS THE APPLIED COMPRESSIVE LOAD ON THE BEAM AND P_{euler} IS THE EULER LOAD, $C \pi^2 EI/L^2$, CAPABILITY OF THE BEAM. BEAM-COLUMN EFFECTS HAVE BEEN FOUND TO BE NEGIGIBLE IN ALL BEAM CONFIGURATIONS CONSIDERED TO DATE.

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F. (CONT'D)

SECTION A-A IS SHOWN BELOW WITH THE LOAD IN
THE STRUTS INDICATED AS COMPRESSION(C), TENSION(T),
OR NO LOAD(O).



AS INDICATED, THE CRITICAL STRUT IS THE INNER
BASE STRUT AT THE BEAM INTERSECT LOCATION.

THE EQUATION FOR THE DESIGN (ULTIMATE) COLUMN
LOAD ON THIS STRUT IS

$$P = \left[\left(\frac{w_x l^2}{12 W} + \frac{l}{2} \left(\frac{w_x l^2}{12 H} \right) + \frac{P}{3} \right) \times U.F.S. \right]_{\text{AT BEAM INTERSECT}}$$

WHERE THE $\frac{l}{2}$ FACTOR ACCOUNTS FOR THE COMPRESSION
LOAD IN THE BEAM DUE TO THE w_x LOADING
BEING CARRIED EQUALLY IN THE TWO BASE STRUTS.

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f. LOADS/SIZING SUMMARY

A LOAD/SIZING SUMMARY FOR THE CRITICAL BEAM IN THE
UPPER SURFACE IS PRESENTED IN FIGURE C-1. THE SIZING
DATA FOR THE CRITICAL STRUT (D_m , AND t) ARE PER
APPENDIX A.

NOTICE, FOR THE FOUR DESIGN CONDITIONS CONSIDERED, THAT
THE DESIGN(ULTIMATE) COLUMN LC US ON THE CRITICAL
STRUT ALL FALL WITHIN A FAIRLY NARROW RANGE.
THIS SITUATION INDICATES THAT THE ARRAY PRETENSION
IS THE MAJOR DRIVER WITH RESPECT TO LOADS.

THE BASELINE DESIGN CONDITION IS: ARRAY PRETENSION,
MODULE SELF TRANSPORT, P/L = ANTENNA.

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FIGURE C-1
 LOADS/SIZING SUMMARY
 FUR
 CRITICAL BEAM IN UPPER SURFACE

DESIGN CONDITION	APPLIED(LIMIT) LOADS ON CRITICAL BEAM			DESIGN(FURTHMATH) COLUMN LOAD ON CRITICAL STRUT P_D (kN)	SIZING DATA FOR 20 METER LONG THICKED TUBE D ₀		
	UNIFORM LOADING ALONG BEAM		COLUMN LOAD ON BEAM		D _{min} (m)	E (N)	A _{ave.} (m ²)
	W _x (kN/m)	W _y (kN/m)	P (kN)		D _{max} (m)	L (m)	A _{ave.} (m ²)
• ARRAY PRETENSION	.0223	—	289	2536	12.96	.0191	.510
• ARRAY PRETENSION, MODULE SELF TRANSPORT, NO PAYLOAD	.0223	.0004	478	2655	13.07	.0195	.534
• ARRAY PRETENSION, MODULE SELF TRANSPORT, PIL = 1/4 ANTENNA	.0223	.0004	592	7712	13.12	.0197	.541
• ARRAY PRETENSION, MODULE SELF TRANSPORT, PIL = ANTENNA	.0223	.0004	934	2083	13.27	.0202	.561

ARRAY PRETENSION = 3.9 NEWTONS/METER
 MAX T/W CAPACITY DURING SELF TRANSPORT = 0.0001
 MODULE WEIGHT ≈ 6,500,000 kg
 ANTENNA WEIGHT ≈ 12,300,000 kg

$$\Delta P = \left[\frac{W_x L^2}{12 W} + \frac{1}{2} \left(\frac{W_y L^2}{12 H} \right) + \frac{P}{3} \right] \times U.F.S.$$

WHERE

$$\begin{aligned} L &= 660 \text{ m} = 25,984 \text{ in.} \\ W &= 20 \text{ m} = 707 \text{ in.} \\ H &= 17.3 \text{ m} = 682 \text{ in.} \\ U.F.S. &= 1.5 \end{aligned}$$

$$\Delta D_{\min} / D_{\max} = 1/3$$

→ ← INDICATES BASELINE DESIGN CONDITION

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2.1.1
APPENDIX D

WEIGHT ANALYSIS OF 20M BEAM AND 5M BEAM

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WEIGHT ANALYSIS OF 20M BEAM AND 5M BEAMS

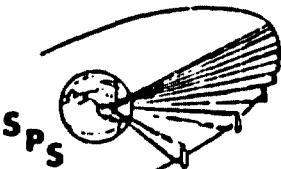
THE GEOMETRY AND COMPONENT NOMENCLATURE FOR THE 20M BEAMS ARE PRESENTED IN FIGURE D-1. THE DATA ALSO APPLIES TO THE 5M BEAMS USED IN THE ANTENNA YOKE ASSEMBLY.

THE WEIGHT DEFINITION FOR A SECTION OF UPPER SURFACE 20M BEAM IS GIVEN IN FIGURE D-2. THE CHORD DIAMETER AND THICKNESS VALUES ($D/4/r = 13.3/4.4/1.020$ in.) ARE PER APPENDIX C. THE DESIGN CONDITION FOR THE CHORDS IS: ARRAY PRETENSION, MODULE SELF TRANSPORT, $P/L = \text{ANTENNA}$. ALL OTHER TUBE MEMBERS HAVE BEEN SELECTED AS HAVING THE SAME MAXIMUM AND MINIMUM DIAMETERS AS THE CHORDS, BUT A MINIMUM THICKNESS OF .010 in. THE BEAM UNIT WEIGHT OF 4.24 kg/m CORRESPONDS TO A CHORD STRUT DESIGN END LOAD OF 2003 lb(UL). FOR THE LOWER SURFACE AND INTRA SURFACE BEAMS, THE CHORD STRUT THICKNESS IS REDUCED TO THE MINIMUM GAGE OF 0.010 in. THE CORRESPONDING BEAM UNIT WEIGHT IS 3.24 kg/m.

THE VARIATION OF 20M BEAM UNIT WEIGHT WITH CHORD STRUT DESIGN COLUMN LOAD IS PRESENTED IN FIGURE D-3.

THE WEIGHT DEFINITION FOR A SECTION OF 5M BEAM IS GIVEN IN FIGURE D-4. THE 5M BEAM IS THE BASIC ELEMENT OF THE ANTENNA YOKE ASSEMBLY. TUBE SIZING IS A GUESSESTIMATE.

GEOMETRY AND VOLUME DATA FOR THE COMPONENTS OF THE 20M BEAM AND 5M BEAM ARE PRESENTED ON PAGES D-7 thru D-17.



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FIGURE D-1

Photovoltaic Reference 20 Meter Beam Structure

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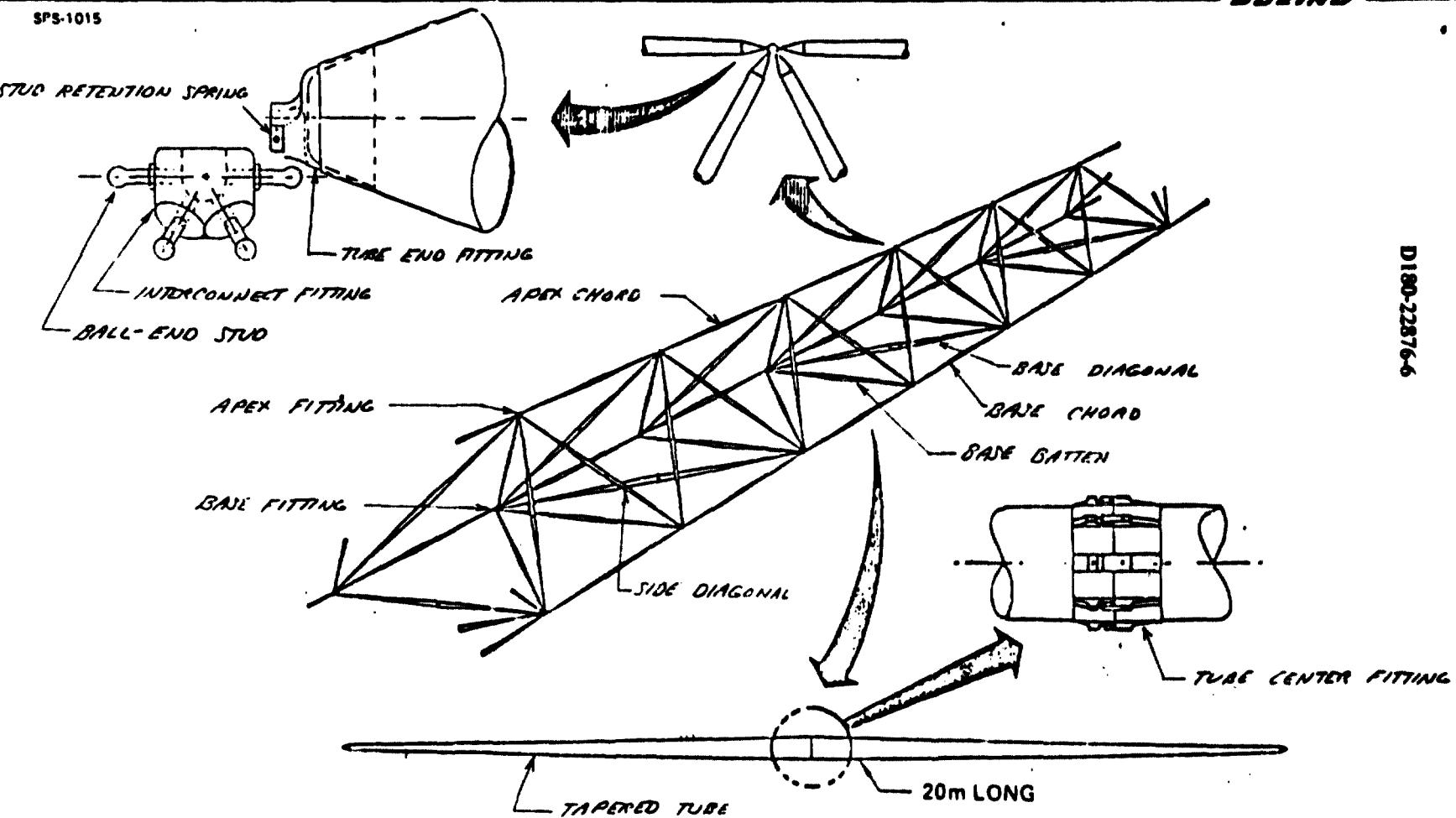


FIGURE "D-2"
 WEIGHT DEFINITION FOR 20M BEAM SECTION
 (UPPER SURFACE BEAMS)

CHORD STRUT DESIGN END LOAD = 2803 LB(ULT.)

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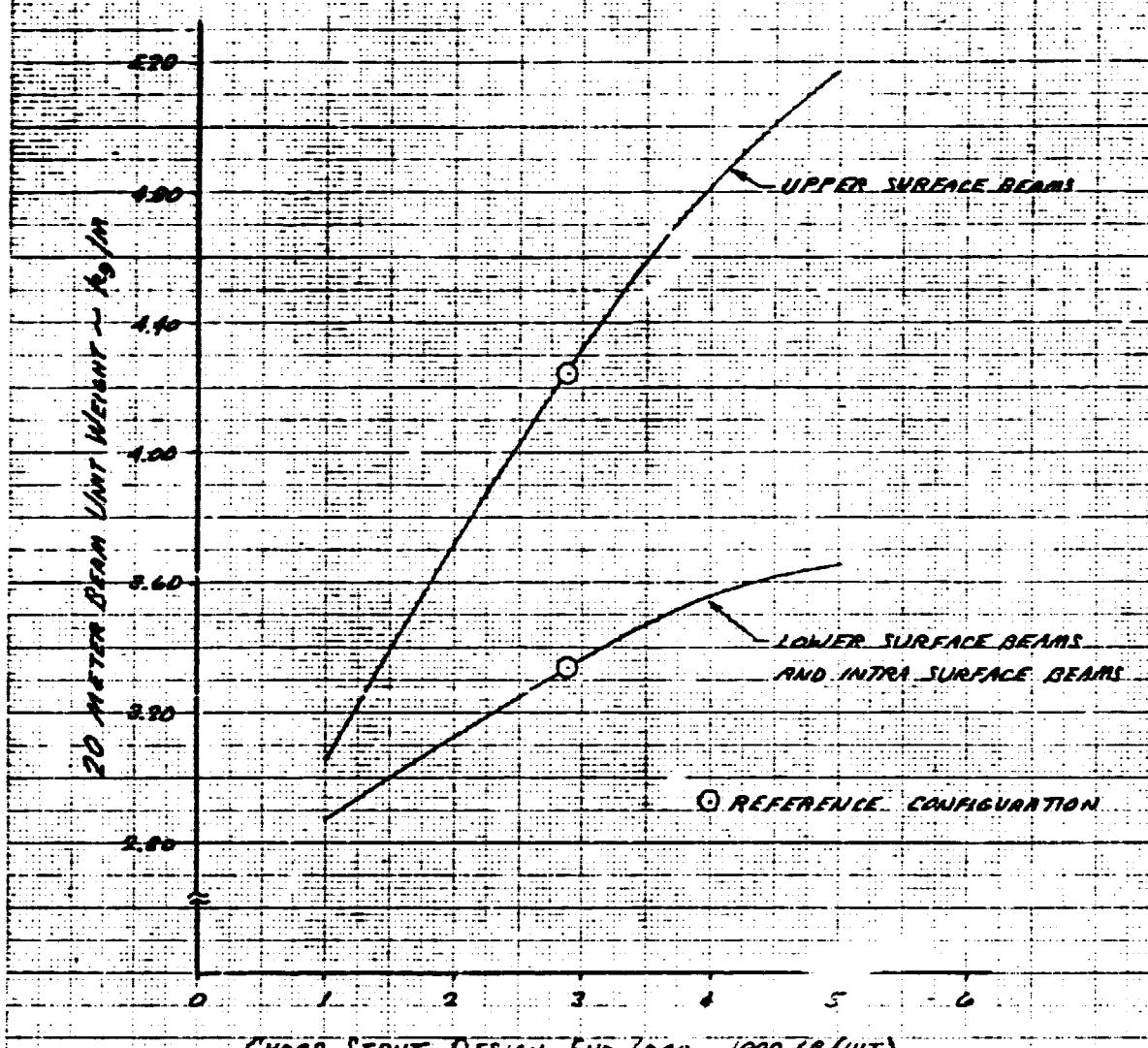
ITEM	MATERIAL	PRINCIPAL DIMENSIONS (IN.)	WT/ITEM (LB)	NO. OF ITEMS	TOTAL WT (LB)
TAPERED TUBE:					
CHORD HALF SECTION	G/E	D=13.3, d=4.4, L=386.9, t=.020	13.12	6	(169.20)
SIDE DIAGONAL HALF SECTION	"	" " 432.4 t=.010	7.34	8	.78.72
BASE DIAGONAL HALF SECTION	"	" " 519.7 "	7.32	1	7.32
BASE BATTEN HALF SECTION	"	" " 386.9 "	6.56	2	13.12
TUBE CENTER JOINTS					
CHORD CTR. JOINT HALF SECTION	ALUM	FITS TUBE END WITH D=13.3	0.61	6	(10.98)
DIAG./BATTEN CTR. JT. HALF SECTION	"	" " " " "	"	12	3.60
TUBE END FITTINGS					
CHORD END FITTING	ALUM	FITS TUBE END WITH d=4.4	0.28	6	1.68
BASE/BATTEN END FITTING	"	" " " " "	"	12	3.36
STUD ATTENTION SPRING	INCONEL		0.002	36	0.07
SPRING INSTALLATION BOLT	STEEL		0.0009	72	0.06
SPRING INSTALLATION NUT	"		0.0003	36	0.01
STRUT INTERCONNECT FITTINGS					
APEX FITTING	ALUM	L=2.25, W=2.25, H=1.65	0.35	1	0.35
BASE FITTING	"	" W=1.65 "	0.30	2	0.60
STELL-END STUD	STEEL	D _{OUT} =0.375, L=1.35	0.025	18	0.45
				219	186.76 LB (4.24 kg/m)

NOTE: FOR LOWER SURFACE BEAMS AND INTR SURFACE BEAMS, USE 197.40 LB
(3.36 kg/m) BASED ON CHORD THICKNESS = 0.010 IN.

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FIGURE D-3. VARIATION OF 20 METER PEARL UNIT
WEIGHT WITH CHORD STRUT DESIGN
END LOAD.



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10/10/77

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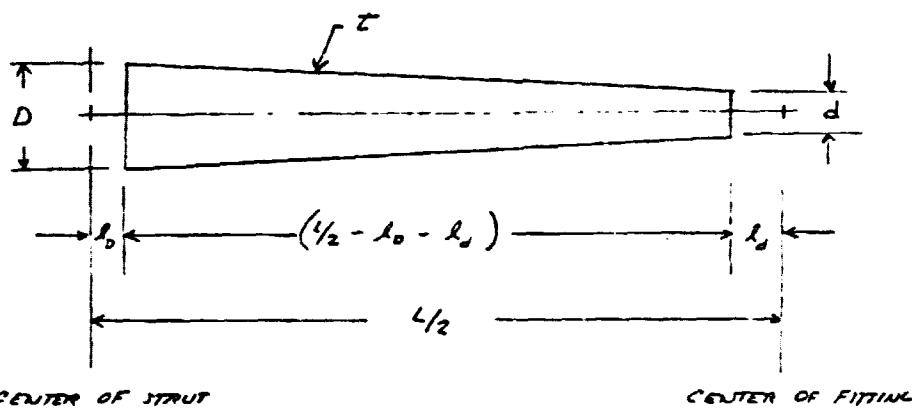
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FIGURE "D-3"

WEIGHT DEFINITION FOR 5M BEAM SECTION
(BEAMS FOR ANTENNA YOKE ASSEMBLY)

ITEM	MATERIAL	PRINCIPAL DIMENSIONS (IN.)	WT/ITEM (LB)	NO. OF ITEMS	TOTAL WT (LB)
TAPERED TUBES					
CHORD HALF SECTION	G/E	$D = 5.0, d = 1.7, L = 95, t = .008$	0.51	6	(10.10)
SIDE DIAGONAL HALF SECTION	"	" " $L = 107$ "	0.57	8	4.56
BASE DIAGONAL HALF SECTION	"	" " $L = 136$ "	0.73	2	1.46
BASE BATTEN HALF SECTION	"	" " $L = 95$ "	0.51	2	1.02
TUBE CENTER JOINTS					
CHORD CTR. JOINT HALF SECTION	ALUM	FITS TUBE END WITH $D = 5.0$	0.23	6	(4.14)
DIAG./BATTEN CTR. JT. HALF SECTION	"	" " " "	"	12	1.38
DIAG./BATTEN CTR. JT. HALF SECTION	"	" " " "	"	12	2.76
TUBE END FITTINGS					
CHORD END FITTING	ALUM	FITS TUBE END WITH $d = 1.7$	0.11	6	(2.12)
DIAG./BATTEN END FITTING	"	" " " "	"	12	0.66
STUD RETENTION SPRING	INCONEL		0.002	36	1.32
SPRING INSTALLATION BOLT	STEEL		0.0009	72	0.07
SPRING INSTALLATION NUT	"		0.0003	36	0.01
STRUT INTERCONNECT FITTINGS					
APEX FITTING	ALUM	$L = 2.25, W = 2.25, H = 1.65$	0.35	1	(1.40)
BASE FITTING	"	" $W = 1.05$ "	0.30	2	0.35
BALL-END STUD	STEEL	$D_{BALL} = 0.375, L = 1.35$	0.025	18	0.45
				219	17.76 LB
					(1.61 kg/m)

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$$\text{MATERIAL VOLUME} = \pi \left(\frac{D+d}{2} \right) \left(\frac{L}{2} - l_o - l_d \right) t$$

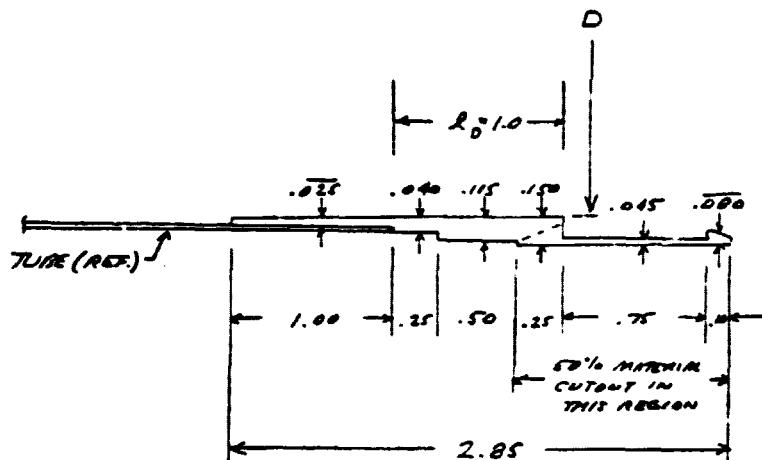
	TUBE	D (in)	d (in)	L (in)	l_o (in)	l_d (in)	$(\frac{L}{2} - l_o - l_d)$ (in)	I (in)	V (in³)
20 M BEAM	CHOKO*	13.3	4.4	20.00	787.4	1.0	5.8	386.9	.020 215.0
	CHOKO	13.3	4.4	20.00	787.4	1.0	5.8	386.9	.010 107.5
	SIDE DIAGONAL	13.3	4.4	22.76	880.2	1.0	5.8	433.4	.010 120.4
	BASE DIAGONAL	13.3	4.4	28.28	1113.4	1.0	5.8	549.9	.010 152.8
	BASE BATTEN	13.3	4.4	20.00	787.4	1.0	5.8	386.9	.010 107.5
5M BEAM	CHOKO	5	1.7	5.00	196.9	1.0	2.5	95.0	.008 8.79
	SIDE DIAGONAL	5	1.7	5.59	220.1	1.0	2.5	106.6	.008 9.87
	BASE DIAGONAL	5	1.7	7.07	278.3	1.0	2.5	135.7	.008 12.56
	BASE BATTEN	5	1.7	5.00	196.9	1.0	2.5	95.0	.008 8.79

* UPPER SURFACE ONLY.

▷ SIZING FOR APPENDIX C. ▷ SIZING ESTIMATED.

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GEOMETRY OF TUBE CENTER JOINT HALF SECTION



* SAME CROSS SECTION AS USED ON 4.00 DIA (REF) SNAP LOCK
DEMONSTRATION FITTING (SEE ATTACHED DRAWINGS)

VOLUME OF THE CENTER JOINT HALF SECTION

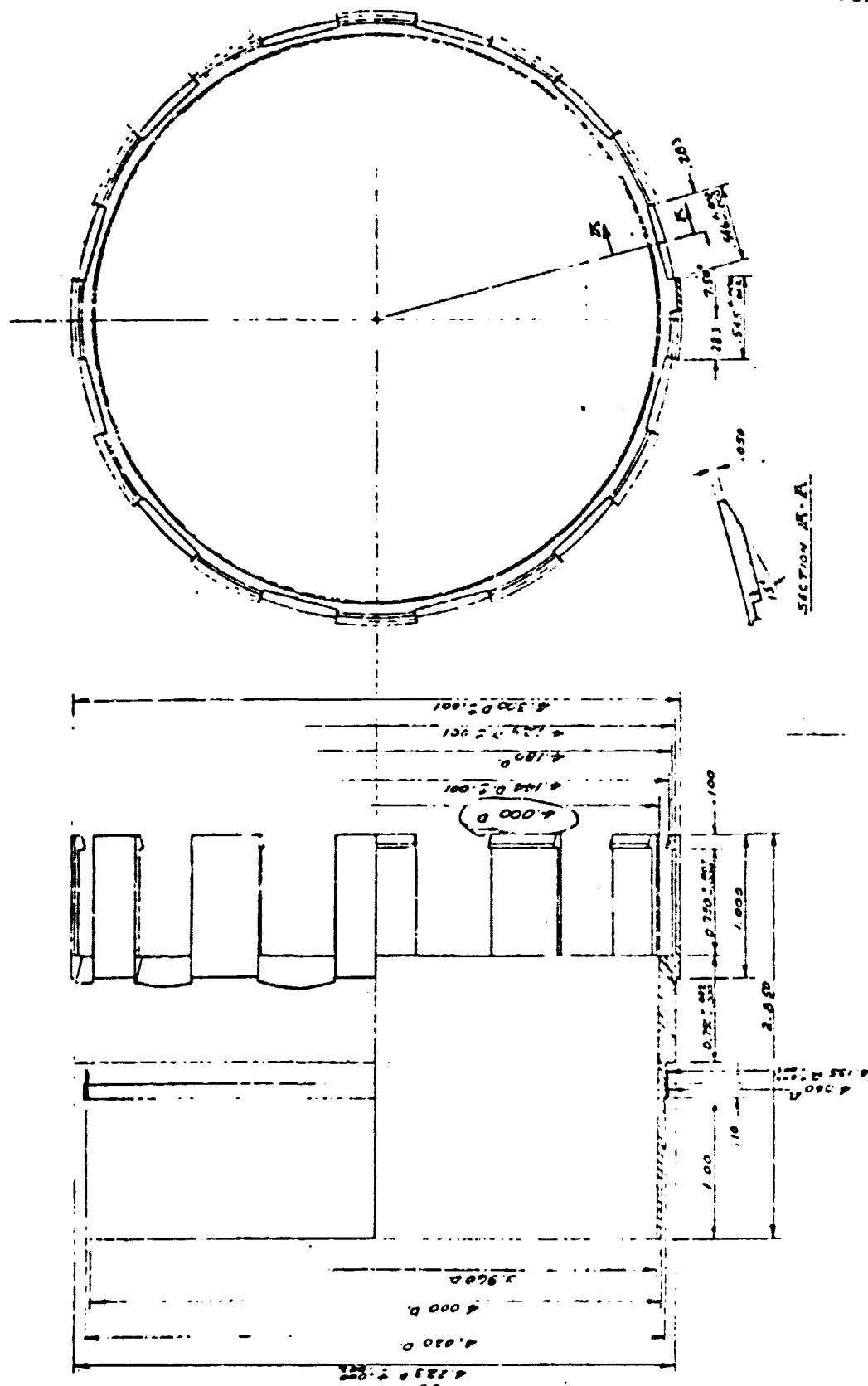
$$\begin{aligned}
 \text{Ave. Cross Section Area} &= (1.00 \times .025) + (.25 \times .040) + (.50 \times .115) \\
 &\quad + \frac{1}{2} (.25 \times .150) + \frac{1}{2} (.75 \times .045) + \frac{1}{2} (.10 \times .080) \\
 &= .0250 + .0100 + .0575 + .0125 + .0169 + .0040 \\
 &= 0.1322 \text{ in}^2
 \end{aligned}$$

$$\text{PART VOLUME} = \pi D A \times k_{\text{TOLERANCES}}$$

$$\approx \pi / 0.1322 \times 1.10 \approx 0.460$$

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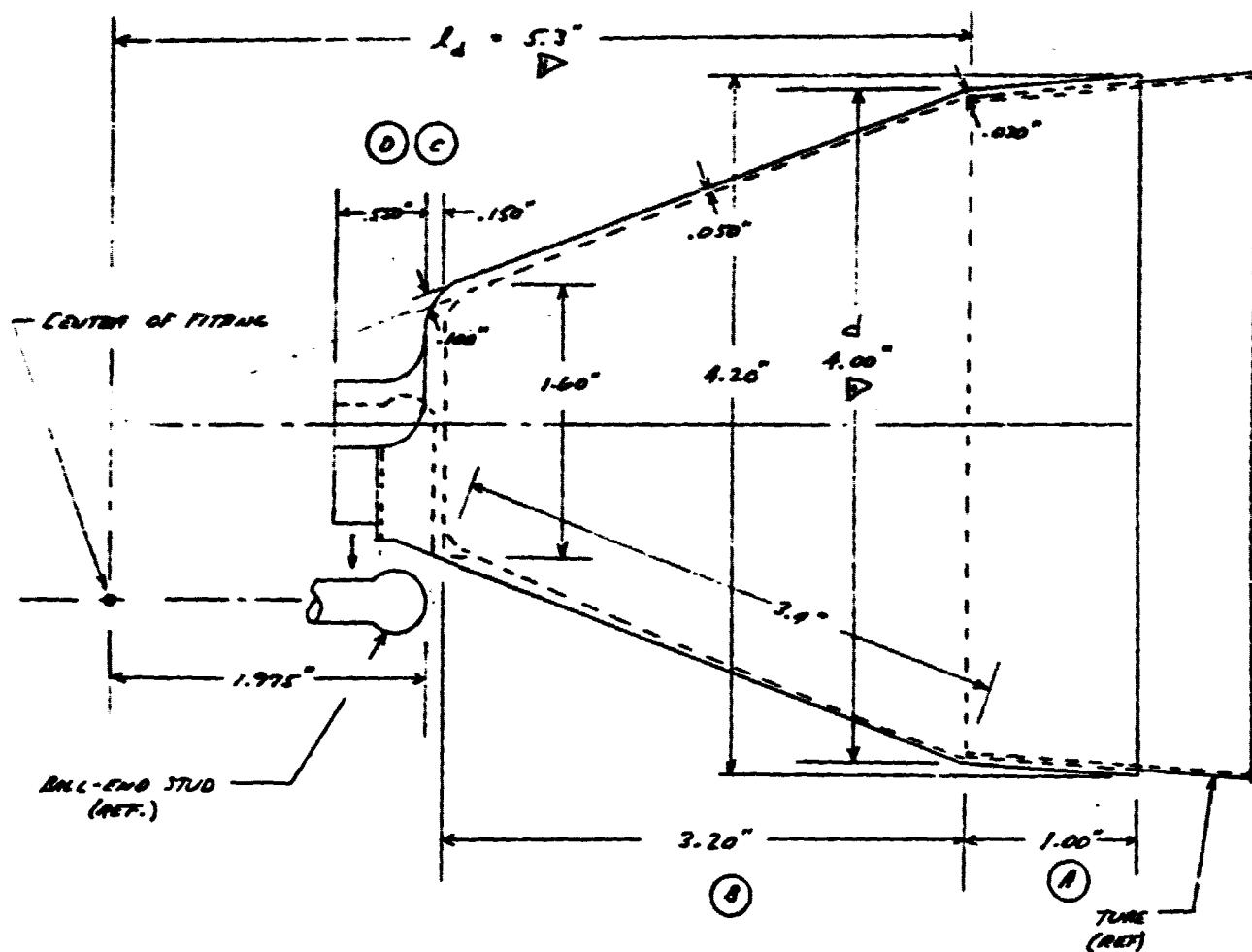
TUBE CENTER STANT HALF SECTION

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GEOMETRY OF TUBE END FITTING (4")

SCALE: FULL SIZE



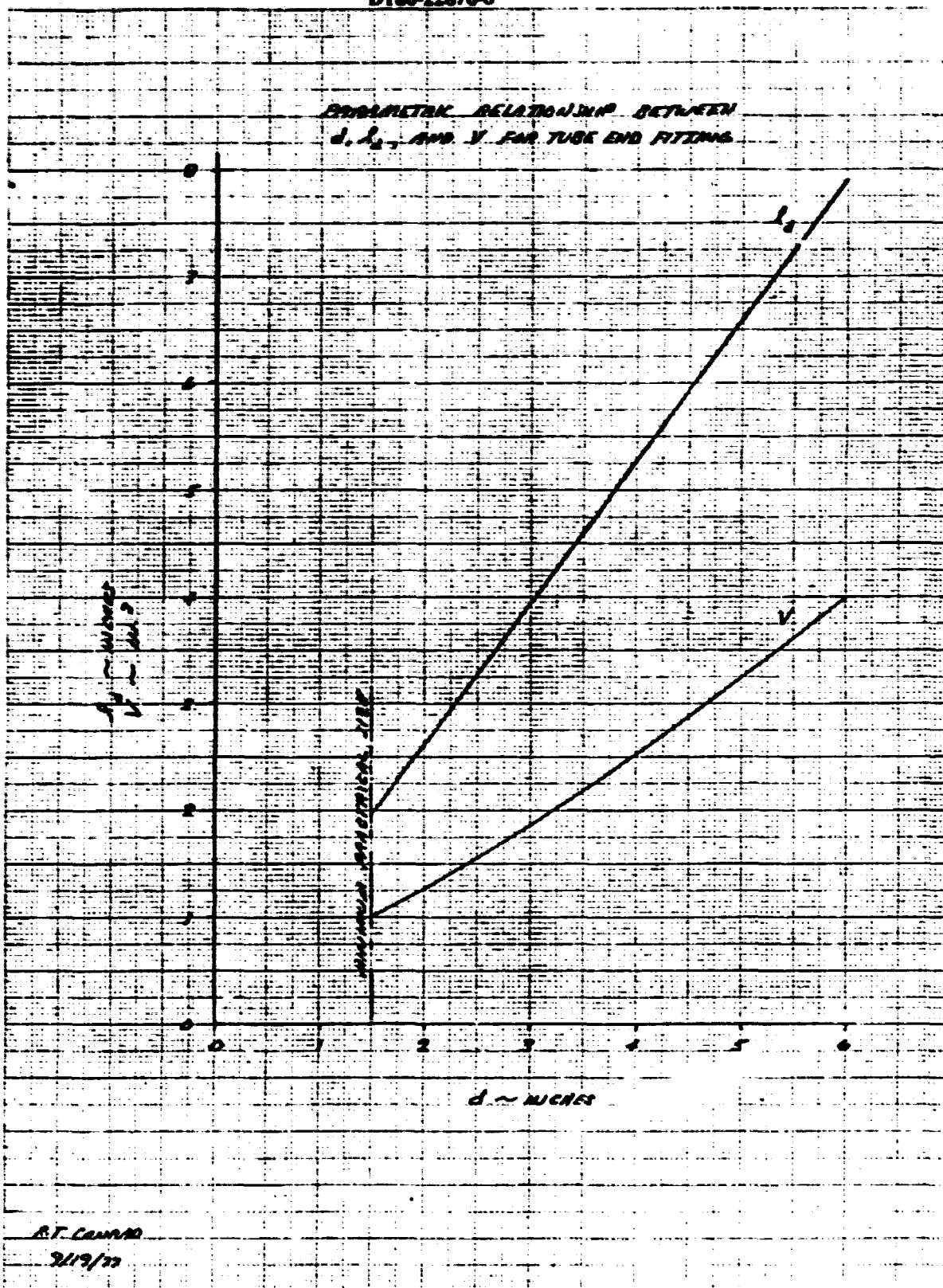
VOLUME OF TUBE END FITTING (4")

$$\begin{aligned}
 V &= (V_{\text{C}} + V_{\text{D}} + V_{\text{H}} + V_{\text{S}}) \times \text{tolerances, } \text{allowances}^{\text{use } 1.10} \\
 &= \left\{ (\pi \times 0.7 \times 0.020)(1.00) + \frac{\pi}{4} \left[(4 \times 0.05) + (2.8 \times 0.05) + (1.6 \times 0.05) \right] (2.1) \right. \\
 &\quad \left. + \frac{\pi}{4} (1.6)^2 (0.150) + 0.30_{\text{err.}} \right\} 1.10 \\
 &= (0.79 + 1.49 + 0.70 + 0.30) 1.10 = 2.59 \text{ in}^3 \Delta
 \end{aligned}$$

PARAMETRIC RELATIONSHIP BETWEEN d , L_d , AND V
GIVEN ON NEXT PAGE.

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GEOMETRIC RELATIONSHIP BETWEEN
 d , l_1 , AND V FOR TUBE END FITTING

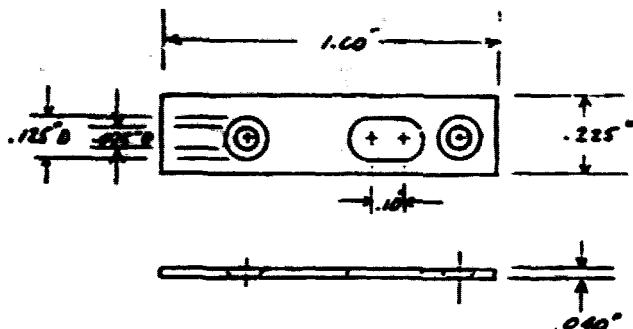


R.T. CARRETT
2/19/77

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GEOMETRY OF STUD RETENTION SAWINGS

SCALE: TWICE SIZE, FLAT PATTERN



VOLUME OF STUD RETENTION SAWING

$$V = V_{\text{enclosed}} - V_{\text{BOLT INSTALLATION HOLE}} - V_{\text{COUNTERSUNK HOLES}}$$

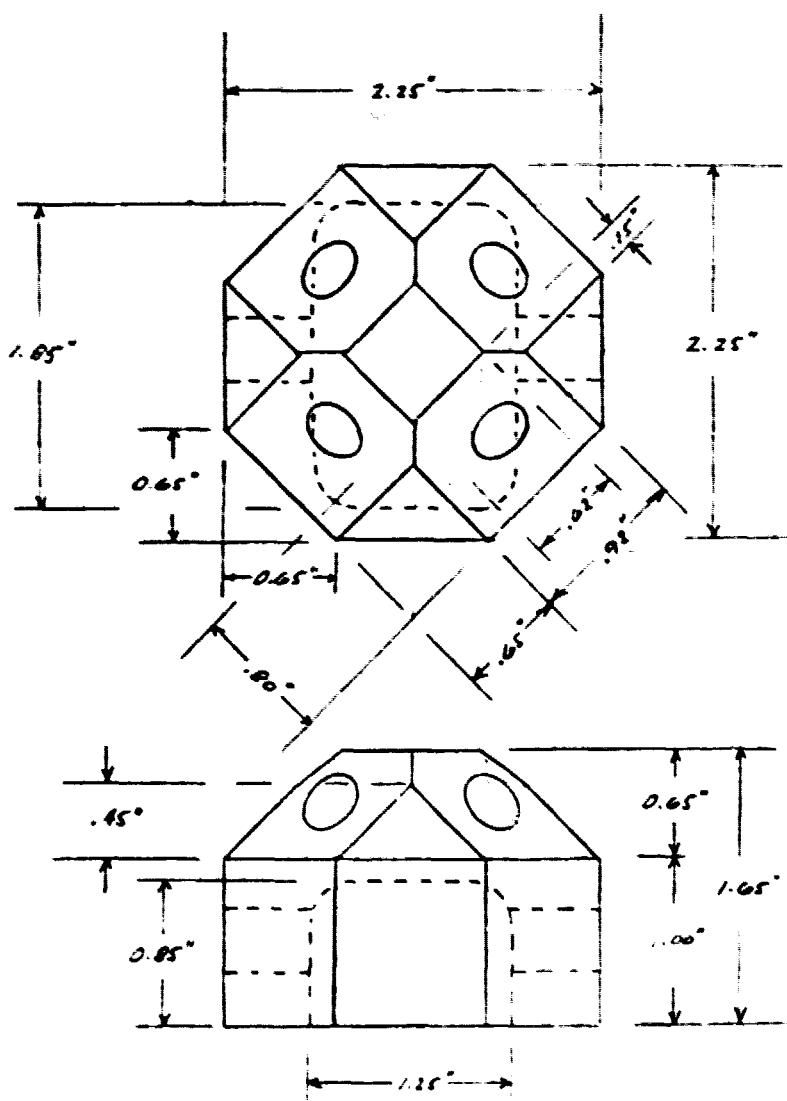
$$\begin{aligned} &= (1.00 \times 0.225)(0.040) \\ &- \left(\frac{\pi}{4} (0.125)^2 + (0.225 \times 0.10) \right) (0.040) \\ &- \left(\frac{\pi}{4} (0.10)^2 \times 2 \right) (0.040) \end{aligned}$$

$$\begin{aligned} &= 0.0090 - 0.0014 - 0.0006 \\ &= 0.0070 \text{ IN}^3 \end{aligned}$$

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GEOMETRY OF APEX CHORD FITTING

SCALE: FULL SIZE



INSIDE FILLET RADIUS = 0.25"

HOLE DIAMETER = 0.250"

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VOLUME OF APEX CHORD FITTING

$$\begin{aligned}V_{\text{lower section}} &= \left[(2.25 \times 2.25 \times 1.00) - 4 \left(\frac{1}{2} \times .65 \times .65 \times 1.00 \right) \right]_{\text{ENCLOSED VOLUME}} \\&- \left[(1.05 \times 1.25 \times .05) - 2 \left((1.05 \times 1.25) + (1.25 \times .05) \right) \left(1 - \frac{\pi}{4} \right) (.25)^2 \right]_{\text{CUTOUT}} \\&- \left[\left(\frac{\pi}{4} (.250)^2 \times .50 \right) \times 2 \right]_{\text{TWO HOLES}} \\&= 4.22 - 1.90 - 0.05 \\&= 2.27 \text{ IN}^3\end{aligned}$$

$$\begin{aligned}V_{\text{upper section}} &= \left[(.02 \times .62 \times .05) \right. \\&+ 4 \left(\frac{1}{2} \times .80 \times .65 \times .72 \right) - 4 \left(\frac{1}{2} \times .15 \times .15 \times .60 \right) \\&+ 4 \left(\frac{1}{4} \times .65 \times .65 \times .40 \right) \left. \right]_{\text{ENCLOSED VOLUME}} \\&- \left[\frac{\pi}{4} (.250)^2 \times .50 \right) \times 4 \right]_{\text{TWO HOLES}} \\&= 1.37 - 0.10 \\&= 1.27 \text{ IN}^3\end{aligned}$$

$$\begin{aligned}V_{\text{total}} &= V_{\text{lower section}} + V_{\text{upper section}} \\&= 2.27 + 1.27 \\&= 3.54 \text{ IN}^3\end{aligned}$$

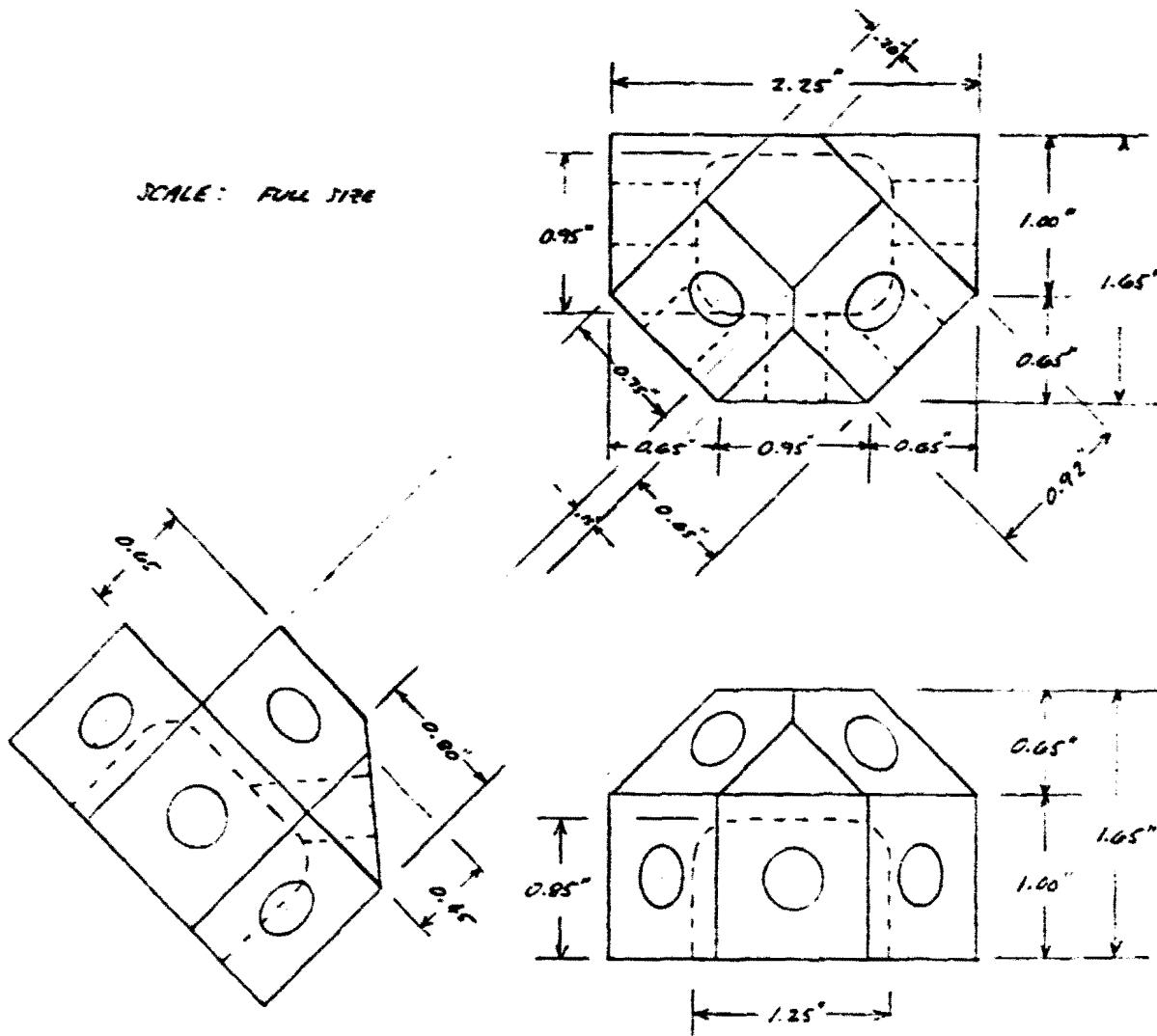
$$\frac{V_{\text{internal}}}{V_{\text{envelope}}} = \frac{3.54}{2.25 \times 2.25 \times 1.05} = \frac{3.54}{8.35} = 42\%$$

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GEOMETRY OF BASE CHORD FITTING

SCALE: FULL SIZE



INSIDE FILLET RADIUS = 0.25"

HOLE DIAMETER = 0.250"

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2
3
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9

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VOLUME OF BASE CHORD FITTING

$$\begin{aligned} V_{\text{lower section}} &= \left[(2.25 \times 1.65 \times 1.00) - 2\left(\frac{1}{2} \times .65 \times .65 \times 1.00\right) \right]_{\substack{\text{ENCLOSED} \\ \text{VOLUME}}} \\ &- \left[(1.25 \times 0.95 \times 0.05) - (1 \times (1.25 - .25) \times (1 - \frac{5}{8})(.25)^2) \right]_{\substack{\text{CUTOUT}}} \\ &- \left[\left(\frac{\pi}{4} (.250)^2 \times .40 \right) \times 5 \right]_{\substack{\text{STUD} \\ \text{HOLES}}} \\ &= 3.29 - 0.96 - 0.10 \\ &= 2.23 \text{ IN}^3 \end{aligned}$$

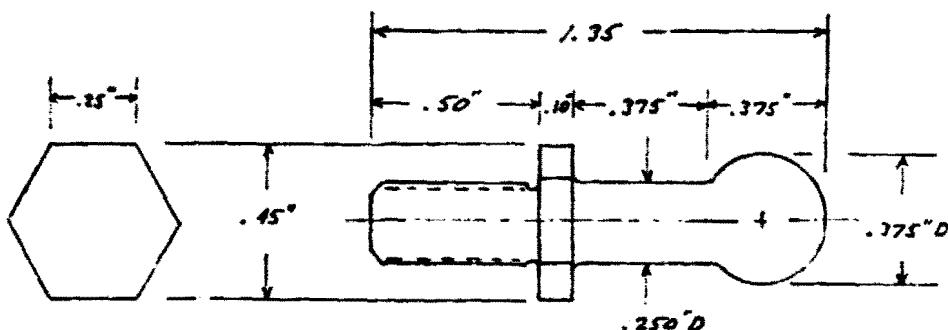
$$\begin{aligned} V_{\text{upper section}} &= \left[(.75 \times .75 \times 0.65) - \left(\frac{1}{2} \times .20 \times .20 \times .65 \right) \right. \\ &\quad + 2\left(\frac{1}{2} \times .80 \times .65 \times .92 \right) - 2\left(\frac{1}{2} \times .15 \times .15 \times .60 \right) \\ &\quad \left. + \left(\frac{1}{4} \times .65 \times .65 \times .45 \right) \right]_{\substack{\text{ENCLOSED} \\ \text{VOLUME}}} \\ &- \left[\left(\frac{\pi}{4} (.250)^2 \times .50 \right) \times 2 \right]_{\substack{\text{STUD} \\ \text{HOLES}}} \\ &= 0.87 - 0.05 \\ &= 0.82 \text{ IN}^3 \end{aligned}$$

$$\begin{aligned} V_{\text{TOTAL}} &= V_{\text{lower section}} + V_{\text{upper section}} \\ &= 2.23 + 0.82 \\ &= 3.05 \text{ IN}^3 \end{aligned}$$

$$\frac{V_{\text{MATERIAL}}}{V_{\text{ENVIRONMENT}}} = \frac{3.05}{2.25 \times 1.65 \times 1.65} = \frac{3.05}{6.13} = 50\%$$

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GEOMETRY OF BALL-END STUD



VOLUME OF BALL-END STUD

$$\begin{aligned} V &= V_{\text{THREADED SECTION}} + V_{\text{HEX NUT SECTION}} \\ &\quad + V_{\text{NECK SECTION}} + V_{\text{BALL SECTION}} \\ &= 0.7 \left(\frac{\pi}{4} \right) (.25)^2 (.50) + 6 \left(\frac{1}{2} \times .25 \times .225 \right) (.10) \\ &\quad + \frac{\pi}{4} (.25)^2 (.375) + \frac{\pi}{6} (.375)^3 \\ &= 0.022 + 0.017 + 0.018 + 0.021 \\ &= 0.085 \text{ IN}^3 \end{aligned}$$

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2.1.1
APPENDIX E

WEIGHT ANALYSIS OF ZONED KRYPTON

CONFIDENTIAL

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WEIGHT ANALYSIS OF 70KW KLYSTRON

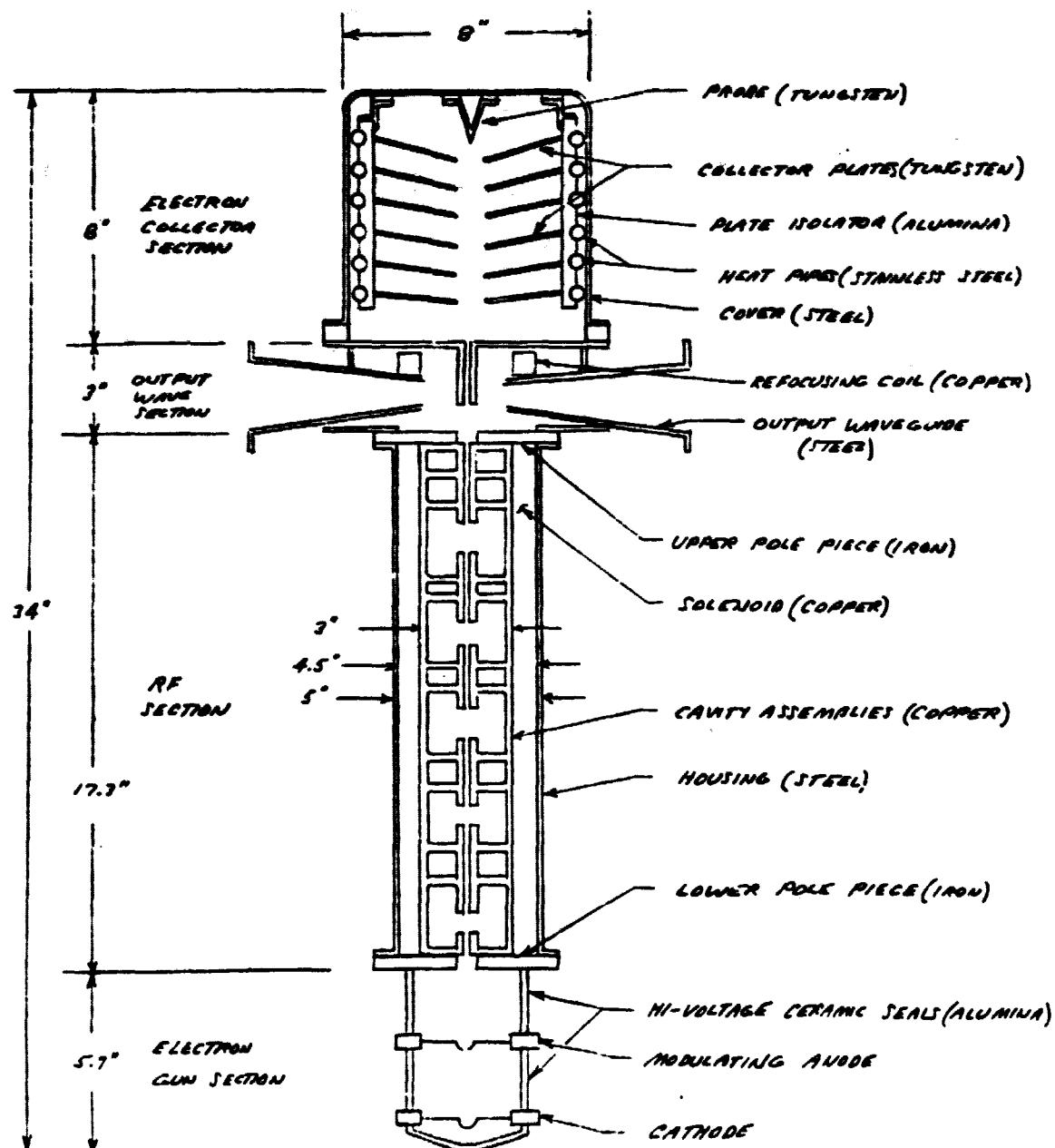
THE GEOMETRY AND COMPONENT NOMENCLATURE FOR A CONCEPTUAL VERSION OF A 70KW KLYSTRON ARE PRESENTED IN FIGURE E-1. A WEIGHT DEFINITION FOR THE TUBE IS GIVEN IN FIGURE E-2. SUPPORTING DETAILS ARE PROVIDED ON PAGE E.5 THRU E.11.

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FIGURE E-1

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CROSS SECTION VIEW OF CONCEPTUAL
VERSION OF 70KW KLYSTRON



R.T. Conner
7/20/77

FIGURE E-2
WEIGHT DEFINITION FOR 70 KW KLYSTRON

ITEM	MAT'L	PRINCIPAL DIMENSIONS (IN.)	WEIGHT (LB)
SOLENOID WIRE INSULATION	COPPER ALUMINA	$OD = 4.5, ID = 3.0, L = 16.5$ (75% OF SOLENOID VOLUME) (5% OF SOLENOID VOLUME)	36.1 35.3 0.8
CAVITIES ASSEMBLY	COPPER	$D = 7.0, L = 16.5, \bar{E} = 0.375$	16.4
POLE PIECES (2)	IRON	$D = 6.0, d = 1.0, \bar{E} = 0.40$	6.2
SOLENOID SHELL	STEEL	$D = 5.0, L = 16.5, \bar{E} = 0.125$	9.3
COLLECTOR PLATES, PROBE PLATE NO. 1 (LWR)	TUNGSTEN	$D = 6.0, d = 2.0, H = 0.3, t = 0.210$	10.2 3.7
PLATE NO. 2	"	" $H = 0.4, t = 0.120$	2.1
PLATE NO. 3	"	" $H = 0.5, t = 0.060$	1.1
PLATE NO. 4	"	" $H = 0.6, t = 0.030$	0.5
PLATE NO. 5	"	" $H = 0.7, t = 0.030$	0.6
PLATE NO. 6 (UPR)	"	" $H = 0.8, t = 0.110$	2.1
PROBE	"	$D = 1.0, d = 0, H = 1.5, t = 0.060$	0.1
COLLECTOR PLATE ISOLATOR	ALUMINA	$OD = 7.2, ID = 6.0, H = 6.1, \bar{E} = 0.48$	6.4
COLLECTOR SECTION COVER	STEEL	$D = 8.0, H = 7.5, t = 0.050$	4.4
OTHER COMPONENTS:			17.0
REFOCUSING COIL, HEAT PIPES, HI-VOLTAGE CERAMIC SEALS, MODULATING ANODE/CONNECTOR, CATHODE/CONNECTOR, HEATER, OUTPUT WAVEGUIDES (2), VAC. ION CONNECTOR, CAVITY TUNING PROVISIONS, INTERNAL CABLEING, ETC., AND ASSEMBLY AND INSTALLATION HARDWARE.			(106.18)

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PRELIMINARY WEIGHT ESTIMATE
FOR 70KW KLYSTRON

SOLENOID (COPPER WIRE + ALUMINA INSULATION)

36.1 lb

$$OD = 4.5", ID = 3.0", L = 16.5"$$

VOLUME DISTRIBUTION IS 75% COPPER,
5% ALUMINA INSULATION, 20% EMPTY SPACE.

$$\begin{aligned} \text{vol} &= \frac{\pi}{4} (D^2 - d^2) L \\ &= \frac{\pi}{4} (4.5^2 - 3.0^2) 16.5 \\ &= 146 \text{ in}^3 \end{aligned}$$

$$W_{\text{COPPER}} = (0.322 \text{ lb/in}^3)(0.75 \times 146 \text{ in}^3) = 35.3 \text{ lb}$$

$$W_{\text{ALUMINA}} = (0.107 \text{ lb/in}^3)(0.05 \times 146 \text{ in}^3) = 0.8 \text{ lb}$$

CAVITIES ASSEMBLY (COPPER)

16.4 lb

$$OD = 3.0", L = 16.5", \bar{d} = 0.375$$

$$\begin{aligned} \text{vol} &= \frac{\pi}{4} (D^2 - d^2) L \\ &= \frac{\pi}{4} (3.0^2 - 2.25^2) 16.5 \\ &= 51 \text{ in}^3 \end{aligned}$$

$$W = (0.322 \text{ lb/in}^3)(51 \text{ in}^3) = 16.4 \text{ lb}$$

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POLE PIECES (IRON)

6.2 lb

$$OD = 6", ID = 1", t = 0.4"$$

$$\begin{aligned} VOL &= \frac{\pi}{4} (D^2 - d^2) t \\ &= \frac{\pi}{4} (6^2 - 1^2) 0.4 \\ &= 11 \text{ in}^3 / \text{pole piece} \end{aligned}$$

$$WT = (0.282 \text{ lb/in}^3 \times 11 \text{ in}^3) \times 2 = 6.2 \text{ lb}$$

SOLENOID SECTION OUTER SHELL (STEEL)

9.3 lb

$$OD = 5.0", L = 16.5", t = 0.125"$$

$$\begin{aligned} VOL &= \frac{\pi}{4} (D^2 - d^2) L \\ &= \frac{\pi}{4} (5.00^2 - 4.75^2) 16.5 \\ &= 32 \text{ in}^3 \end{aligned}$$

$$WT = (0.296 \text{ lb/in}^3 \times 32 \text{ in}^3) = 9.3 \text{ lb}$$

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COLLECTOR PLATES/PROBE (TUNGSTEN)

10.2 LB

PLATE SHAPE IS FRUSTUM OF CIRCULAR CONE
PROBE SHAPE IS CIRCULAR CONE

$$\text{SURFACE AREA OF PLATE/PROBE} = \pi \left(\frac{D+d}{2} \right) \sqrt{H^2 + \left(\frac{D-d}{2} \right)^2}$$

TUNGSTEN DENSITY IS 0.697 LB/in³

ITEM	D (in)	d (in)	H (in)	S (in ²)	T (in)	WT (lb)
(bottom)	PLATE 1	6	2	0.3	25.4	0.210
	PLATE 2	-	1	0.4	25.6	0.120
	PLATE 3	-	1	0.5	25.7	0.060
	PLATE 4	-	1	0.6	26.2	0.030
	PLATE 5	-	1	0.7	26.6	0.030
(top)	PLATE 6	-	1	0.8	27.1	0.110
	PROBE	1	0	1.5	2.5	0.060

TOTAL = 10.2 LB

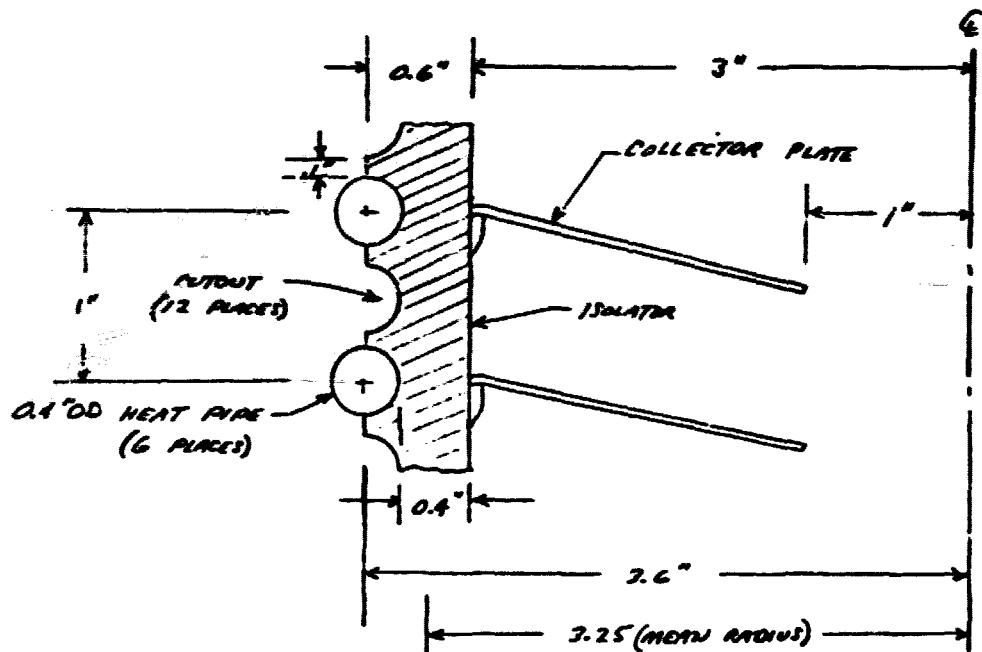
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COLLECTOR PLATE ISOLATOR (ALUMINUM)

6.4 LB

ASSUME CROSS SECTION GEOMETRY AS SHOWN BELOW



$$\begin{aligned} \text{CROSS SECTION AREA} &= (\text{HEIGHT} \times \text{WIDTH}) - (\text{SCALLOPING}) \\ \text{THRU ISOLATOR} &= (6.1 \times 0.6) - \left[\frac{\pi}{8} (0.4)^2 \times 12 \right] \\ &= 3.66 - 0.75 \\ &= 2.91 \text{ IN}^2 \end{aligned}$$
$$\bar{\varepsilon} = \frac{2.91}{3.66} = .60 = .48$$

$$\begin{aligned} WT &= \rho A (\text{MEAN CIRCUMFERENCE}) \\ &= (0.107 \text{ LB/IN}^2)(2.91 \text{ IN}^2)(2\pi \times 3.25 \text{ IN.}) = 6.4 \text{ LB} \end{aligned}$$

$$\Delta H = (1/2 \times .4) + (12 \times .1) = 6.1^\circ$$

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COLLECTOR SECTION AREA (STEEL)

4.148

OD = 8", L = 7.5", ATTACH FLANGE WIDTH = .75"

USE 0.050 STAINLESS STEEL

$$\begin{aligned} S &= S_{top} + S_{bottom} + S_{inner flange} \\ &= \frac{\pi}{4}(8)^2 + \pi(8)(7.5) + \frac{\pi}{4}(7.5^2 - 8^2) \\ &= 50 + 100 + 21 \\ &\approx 259 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} WT &= \rho \cdot E \cdot S \\ &= .15(0.290)(.050)(259) \\ &= 4.4 \text{ lb} \end{aligned}$$

REFOCUSING COIL (COPPER WIRE + ALUMINUM INSULATION)

2.248

OD = 4.5", ID = 3.0", L = 1"

VOLUME DISTRIBUTION IS 75% COPPER,
5% ALUMINUM INSULATION, 20% EMPTY SPACE.

$$\begin{aligned} VOL &= \frac{\pi}{4}(4.5^2 - 3.0^2)1.0 \\ &\approx 8.8 \text{ in}^3 \end{aligned}$$

$$W_{copper} = (0.222)(.75 \times 8.8) = 2.2$$

$$W_{aluminum} = (0.107)(.05 \times 8.8) = .066$$

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COLLECTOR SECTION HEAT PIPES (STAINLESS STEEL/MERCURY)

2.6 10

a. STRUCTURE

USE 316 STAINLESS STEEL (ANNEALED CONDITION) TUBING
WITH 0.40" O.D. AND 0.036" I.D.

$$\begin{aligned} W &= k \rho A L \times G \\ &= 1.33 (0.290) \frac{\pi}{4} (.40^2 - .36^2) / \underbrace{[\frac{\pi}{4} \times 7.2] + 10 }_{32.6} \times G \\ &= 1.0 \text{ lb} \end{aligned}$$

b. WIRES

USE STAINLESS STEEL WIRE MESH (20 MESH) WITH
12 MIL THICKNESS AND 80% POROSITY.

$$\begin{aligned} W &= k \rho S L (1 - F_{porosity}) \times G \\ &= 1.0 (0.290) \underbrace{ \frac{\pi}{4} \times 0.35 \times 32.6 }_{35.0} (0.012)(1 - 0.80) \times G \\ &= 0.15 \text{ lb} \end{aligned}$$

c. MERCURY

MERCURY IN WIRES. WIRES ARE 12 MIL THICK AND
80% POROUS. ASSUME 60% OF THIS VOLUME IS
ILLED WITH MERCURY

$$\begin{aligned} W &= k \rho S L (F_{porosity})(F_{mercury}) \times G \\ &= 1.0 (0.290) (35.0) (0.012) (0.8) (0.6) \times G \\ &= 0.6 \text{ lb} \end{aligned}$$

Δ LENGTH OF PIPE SECTION EXTRUDED FROM HOUSING.

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OUTPUT GAP AND BODY MONT RIBES (STAINLESS STEEL/MERCURY)

1.740

USE 4 PIPES SIMILAR TO COLLECTOR SECTION PIPES

STRUCTURE	4 x 0.3	= 1.2
WATER	4 x 0.025	= 0.1
MERCURY	4 x 0.1	= 0.4

HI-VOLTAGE CERAMIC SEALS (ALUMINA)

0.548

$$O.D. = 3.5, I.D. = 2.3, L = 2.0"$$

$$Vol = \frac{\pi}{4} (3.5^2 - 2.3^2) 2.0 = 2.1 \text{ in}^3/\text{seal}$$

$$WT = (0.107)(2.1) \times 2 \text{ seals} = 0.548$$

OTHER COMPONENTS

10.048

- MODULATING ANODE/CONNECTOR
- CATHODE/ CONNECTOR
- HEATER/ CONNECTOR
- OUTPUT WAVEGUIDES (2)
- HAC. ION CONNECTOR
- CAVITY TUNING PROVISIONS
- ELECTRICAL CABLEING - INTERNAL
ASSEMBLY AND INSTALLATION HARDWARE

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2.1.1
APPENDIX F

SCALING RELATIONSHIPS FOR COLUMN
LOAD ON CRITICAL SPAN IN CRITICAL BEAM

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SCALING RELATIONSHIPS FOR COLUMN
LOAD ON CRITICAL STRUT IN CRITICAL BEAM

FROM APPENDIX C, THE DESIGN(ULTIMATE) COLUMN LOAD
ON THE CRITICAL STRUT IN THE CRITICAL BEAM CAN BE
EXPRESSED AS

$$P = \left(\frac{w_x L_s^2}{12 w_b} + \frac{w_z L_s^2}{24 H_s} + \frac{P}{3} + \frac{\Delta P_1}{3} + \frac{\Delta P_2}{3} \right) \times UFS$$

WHERE

w_x = APPLIED LOADING ALONG BEAM
DUE TO STRUT PRETENSION

w_z = APPLIED LOADING ALONG BEAM
DUE TO MODULE SELF-TRANSPORT

P = APPLIED COLUMN LOAD ON BEAM
DUE TO STRUT PRETENSION, NO P/L

ΔP_1 = DELTA APPLIED COLUMN LOAD ON
BEAM DUE TO SELF TRANSPORT
FROM LED TO GED, NO P/L

ΔP_2 = DELTA APPLIED COLUMN LOAD ON BEAM
DUE TO STRUT TRANSPORT

L_s, w_b, H_s = BEAM LENGTH, WIDTH, HEIGHT

UFS = ULTIMATE FACTOR OF SAFETY

FOR A FIXED FREQUENCY OF VIBRATION FOR THE STRUT,
IT FOLLOWS THAT (FROM APPENDIX B).

$$w_x \propto (L_A)^2 (w_n) \propto (L_s - w_b)^2 (w_n)$$

WHERE

L_A = LENGTH OF SIDE OF SQUARE ARRAY $\approx (L_s - w_b)$

w_n = ARRAY WEIGHT PER UNIT AREA

FOR A FIXED MAX T/W CAPABILITY DURING LED-TO-GED
SELF TRANSPORT, IT FOLLOWS THAT (FROM APPENDIX C)

$$w_z \propto (L_A)(w_n) \propto (L_s - w_b)(w_n)$$

(CONT'D)

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THE RELATIONSHIP FOR THE COLUMN LOAD ON THE BEAM DUE TO ARRAY PRETENSION IS (FROM APPENDIX C)

$$P \propto (w_x)(L_a) \propto (L_a - w_a)^2 (w_a)(L_a)$$

FOR A FIXED MAX TOW CAPABILITY DURING LED-TO-GEO SELF TRANSPORT, AND FOR A FIXED RELATIVE LOCATION FOR THE THRUSTERS, IT FOLLOWS THAT (FROM APPENDIX C)

$$\Delta P \propto \frac{(w_m)(L_m)}{(H_m)} \propto \frac{(w_m)(L_m)(w_m)}{(H_m)}$$

AND

$$\Delta P_2 \propto \frac{(w_{m,2})(L_m)}{(H_m)}$$

WHERE

w_m = MODULE WEIGHT

w_m = MODULE WEIGHT PER UNIT AREA

L_m = MODULE LENGTH

w_m = MODULE WIDTH

H_m = MODULE HEIGHT

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2.2 RANKINE THERMAL ENGINE REFERENCE SYSTEM

This section provides a record of mass estimation calculations for the thermal engine SPS. Calculations for the thermal engine SPS. Calculations were made by Dan Gregory and Jim Jenkins. Assumptions, methodology, and key results were reviewed by Bob Conrad.

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Mass Summary - Potassium Rankine SPS
Power generation system

Structure

	10^6 kg
facet support	5.370
edge beams	0.309
cavity support arms	0.517
cavity to cavity struts	0.192
antenna supports	0.074
ACS supports	0.050
steel trip frames	<u>0.450</u>
	<u>6.976</u>

facets

radiators (without potassium but with heat pipe sodium) 10.768

power distribution 4.760

switch gear

generators, accessories 2.508

generator radiators 1.140

turbines

pumps and their radiators 13.755

0.984

boilers and manifolds (feeders) 3.296

1.000

cavity assembly (with cpc frame) 0.299

Compound parabolic concentrators (cpc) skrs

light filters (cpc apertures) 0.025

monitor, command & control 0.100

ACS (attitude control system) 1.200

Turbine Start Loops & Controls 0.250

Antenna Support (springs, turntables) 0.286

potassium inventory radiators 4.634

0.402

boilers

1.015

feeders

0.006

turbines, misc.

6.058

misc., including energy storage 0.200

Power generation 55.660

Antennas 24.384

80.044

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SYNOPSIS "FINNE" CONFIGURATION MASS ESTIMATION

TURBINES: ORIGINAL GE MASS WAS 12.91×10^6 FOR 344 turbines
FOR 576 turbines 13.755×10^6 $+20\%$
(G.E.
estimates) -40%

FACETS ACTUAL TOTAL DISH AREA ON CURVE = $1.221 \times 10^8 \text{ m}^2$
THE "GAP FACTOR" IS 0.95, HENCE $1.16 \times 10^8 \text{ m}^2$ FACET:
ACTUAL AREA IS $1000 \text{ m}^2/\text{facet}$, HENCE 116,000 FACETS

FACETS & ASSOCIATED ROCKER ARMS 15.84 kg EACH

$1.837 \times 10^6 \text{ kg}$

FACET SUPPORT FRAMEWORK (24/77) 46.3 kg/facet
 $5.370 \times 10^6 \text{ kg}$.

EDGE BEAMS OF SUPP. FRAMEWORK

1.75 kg/m OF EDGE, EDGE IS $2763 \text{ m} \times 64 = 1.764 \times 10^5 \text{ m}$,
 $0.309 \times 10^5 \text{ kg}$

GRAPHITE SUPPORT ARMS (204) 2760 EACH, $\times 64 = 1.766 \times 10^6 \text{ m}$
 2.93 kg/m
 $0.517 \times 10^5 \text{ kg}$

RADIATORS, PRIMARY

INLET MANIFOLD	1240
THICKNESS	790
VALVES (1 KG EACH)	710
REF. CAN	216
BUMPS IN	481
OUT	298 P
REFAT PIPE	<u>13,299</u>
	<u>$18,694$</u>
	<u>$\times 576$</u>

(RAD. POTENTIAL/IN IS 804 kg/in , $= 4.63 \times 10^6 \text{ kg/l}$)
(FOR $3.21 \times 10^6 \text{ m}^2$ radiating, spread over
 1.84×10^6 projected.

10.768×10^6

GENERATOR RADIATORS

on fractional area basis, rel.
to primary

1.80×10^6

GENERATORS

(0.227 kg/kWe)

4.066×10^6

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POWER DISTRIBUTION

from J. Gavrin

main buses	4.600×10^6
switchgear	0.218×10^6
cavity buses	0.160×10^6
	-4978×10^6

BOILER AND FEEDERS

BOILER:	INLET MANIFOLD	39.1
	OUTLET MANIFOLD	1063
	TUBES	$\frac{1210}{2312}$
		1332×10^6

FEEDERS		
	INLET	123
	RETURN	$\frac{3288}{3411}$
		1.964×10^6
		3.296×10^6
		0.984×10^6

PUMPS & PUMP RADIATORS

POTASSIUM

RADIATOR	8046
BOILER	698
FEEDERS	1763
TURBINE	$\frac{10}{10517}$
	6059×10^6

CAVITY

ABSORPTION	0.937×10^6
FRAMES	0.055×10^6
	0.972×10^6
	1×10^6

ADDITIONAL STRUCTURES

CAVITY - 70 - CAVITY STRUTS	0.192×10^6
ANTENNA SUPPORTS	0.091×10^6
ACS SUPPORTS	0.050×10^6
STEEL TOP FRAMES	0.450×10^6
	0.720×10^6

GPC

0.3×10^6

LIGHT - 50K, 125A, 25x11 A/m
 $\pm 20\%$

0.024×10^6

ACS (extrapolation/modification to
self power thruster concept -
prop leakage for one year)

1.20×10^6

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RADIATORS (PRIMARY)

- 1) POWER REJECTED = $96.115 \times 10^6 - 18.166 \times 10^6 = 77.947 \times 10^6 \text{ kW}$.
- 2) ALLOWING FOR REJECTION BY VAPOR MANIFOLD, USE $77 \times 10^6 \text{ kW}$.
- 3) REJECTION TEMPERATURE = $932 - 4 = 928 \text{ K}$.
- 4) CONCENTRATOR BLOCKAGE IS INSIGNIFICANT.
- 5) RADIATOR MANIFOLDS ON 10M CENTERS →
- 6) SURFACE $\epsilon \approx 0.90$

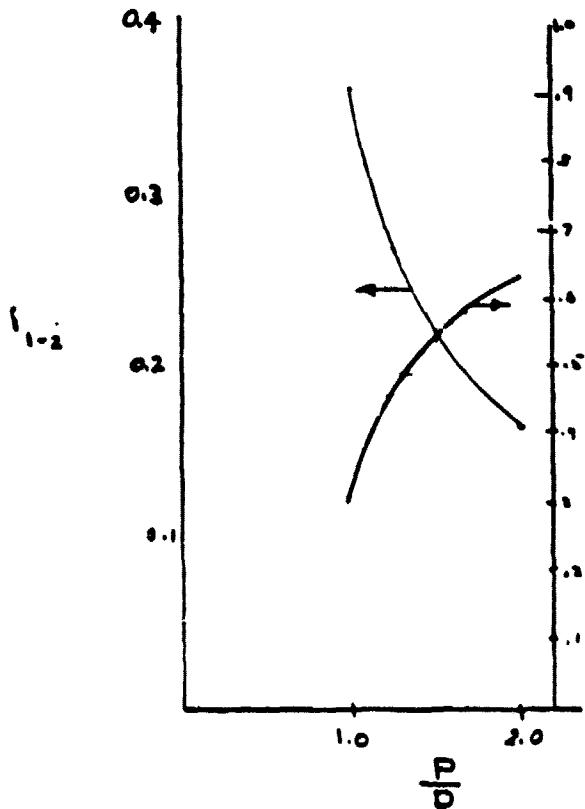
- 7) HEAT PIPE SPACING EFFECT: SPACE = P, DIA = D

$$F_{1-2} = \frac{2}{\pi} \left\{ 2 \left[\left(\frac{\alpha}{3600} \right) \pi + \frac{P \cos \alpha}{2D} \right] - \frac{P}{D} \right\}$$

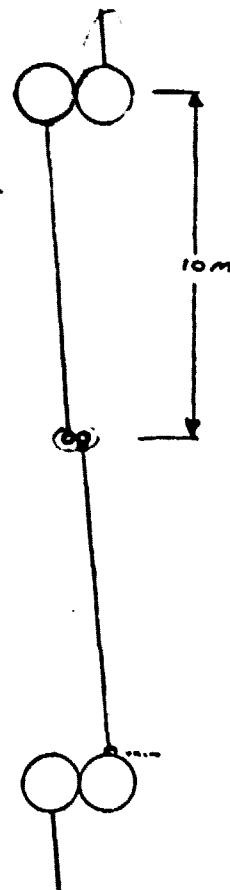
$$\text{WHERE } \alpha = \sin^{-1} \frac{D}{P}$$

$$F_{1-\text{SPACE}} = 1 - 2 F_{1-2}$$

$$\text{EMISSION IS } \Delta \epsilon \sigma T^4 (1 - 2 F_{1-2} \epsilon)$$



← "NET EMISSIVITY" = $\epsilon (1 - 2 F_{1-2} \epsilon)$



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8) HEAT PIPE SPACING SET AT $\frac{D}{d} = 1.6$.9) NET $\epsilon = 0.57$, $Q/A = 24.0 \text{ kW/m}^2$.10) RADIATING AREA = $\frac{77 \times 10^6 \text{ kW}}{24.0 \text{ kW/m}^2} = 3.21 \times 10^6 \text{ m}^2$ 11) THE PROJECTED AREA IS $\frac{3.21 \times 10^6 \text{ m}^2}{\pi} = 1.02 \times 10^6 \text{ m}^2$ ORIGINAL PAGE IS OF POOR QUALITY12) ALLOW 10% OVERAGE FOR HEAT PIPE PENETRATIONS, 3% FOR THRU PIPES,
TOTAL PROJECTED AREA = $1.15 \times 10^6 \text{ m}^2$.13) BASELINE H.P. HAS $D = 0.006 \text{ m}$, $L_{wrap} = 0.5 \text{ m}$, PROJECTED
AREA = $3 \times 10^{-3} \text{ m}^2$,

$$\# \text{ TOTAL PIPES} = \frac{1.15 \times 10^6 \text{ m}^2}{3 \times 10^{-3} \text{ m}^2} = 3.83 \times 10^8$$

$$\# \text{ FUNCTIONAL PIPES} = \frac{3.83 \times 10^8}{613} = 3.39 \times 10^8$$

10% HITS

FACTOR FOR FLYING RADIATOR
EDGE-ON TO METEOR "STREAM"

$$\frac{3.83 \times 10^8 \times 0.399}{1.15 \times 10^6 \times 25 \times 10^8 \text{ sec}} = 1.4 \times 10^{-8} \text{ HITS/m}^2/\text{sec}$$

$$\text{PARTICLE MASS} = 2.6 \times 10^{-7} \text{ gm} = 2.6 \times 10^{-10} \text{ kg}$$

$$r = \left(\frac{3 \times 2.6 \times 10^{-10}}{2000 \pi} \right)^{\frac{1}{3}} = 4.99 \times 10^{-5} \text{ m}$$

$$t = 1.97 d = 1.97 \times 10^{-6} \text{ m} \quad (\text{SCREEN THICKNESS}) \quad \approx 0.000$$

14) LET $L_{wrap} = 0.12 \text{ m}$ (TO MAKE $\frac{1}{2}$ WRAP ON 8CM THRUPIPE)

$$\frac{L_{wrap}}{L_{H.P.}} = 0.5 \text{ m}$$

$$L_{H.P.} = 0.62 \text{ m}$$

15) HEAT PIPE SHELL MASS:

$$0.62 \text{ m} \times 0.006 \text{ m} \times \pi \times 1.97 \times 10^{-6} \times 7800 \text{ kg/m}^3 = 0.0163 \text{ kg}$$

16) SCREEN MASS (SEE 8/3/77), $t = 1 \times 10^{-4} \text{ m}$, POROSITY = 0.7

$$0.62 \text{ m} \times 0.0056 \text{ m} \times \pi \times 1 \times 10^{-4} \times 0.3 \times 7800 = 0.0026 \text{ kg}$$

17) SODIUM, MAXIMUM ALLOWS FILL OF 80% OF SCREEN VOID

$$0.62 \text{ m} \times 0.0056 \text{ m} \times \pi \times 1 \times 10^{-4} \times 0.7 \times 0.8 \times 780 = 0.00049 \text{ kg}$$

18) INDIVIDUAL HEAT PIPE MASS = $1.73 \times 10^{-6} \text{ kg} = 0.019 \text{ kg}$ —

ROUND-UP TO 0.02 kg /PIPE

$$120 \times 3.83 \times 10^8 = 7.66 \times 10^6 \text{ kg /SPS}$$

Project ch.6 - 355 X 8 M = 27400 m
Heat pipe D = 0.006 m $\rho = 1.6 \times 0.0076$, $L_{H.P.} = \frac{2.74 \times 10^6}{0.006} = 456666.67$

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3

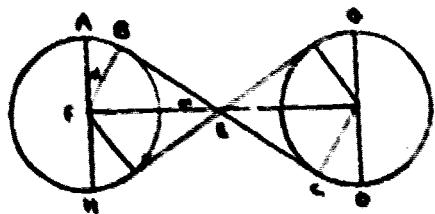
- 19) DUE TO THE SPACING ($\frac{P}{D} = 1.6$) THE ACTUAL PROJECTED AREA OF THE RADIATOR = $1.15 \times 10^6 \times 61 = 1.89 \times 10^6 \text{ m}^2$
- 20) WITH 876 ENGINES, THIS IS $3194 \text{ m}^2/\text{ENG}$ -
- 21) PER 5), THE THRUPIPE L ≈ 9m, OR A "PANEL" IS 9x1 M, HENCE 355 THRUPIPES, ACTIVE MANIFOLD LENGTH = 355M.

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VIEW FACTOR - PARALLEL TUBES



$$\begin{aligned} \bar{H} &= D \\ \bar{G} &= P \\ A_1 F_{1-2} &= \frac{(\bar{H}D + \bar{H}P) - (\bar{G}\bar{H} + \bar{D}\bar{H})}{2} = \frac{(4\bar{H}E) - 2P}{2} = 2\bar{H}E - P \end{aligned}$$

$$\alpha = \sin^{-1} \frac{P_E}{F_E} = \sin^{-1} \frac{D_L}{P_L} = \sin^{-1} \frac{D}{P}$$

$$\bar{H}E = \left(\frac{\alpha}{360^\circ} \right) \pi D$$

$$\bar{E}P = EP \cos \alpha = \frac{P}{2} \cos \alpha$$

$$A_1 F_{1-2} = 2\bar{H}E - P = 2(\bar{H}E + \bar{E}P) - P = 2 \left[\left(\frac{\alpha}{360^\circ} \right) \pi D + \frac{P}{2} \cos \alpha \right] - P$$

LET $P = XD$ ($X = \text{PITCH / DIAMETER}$)

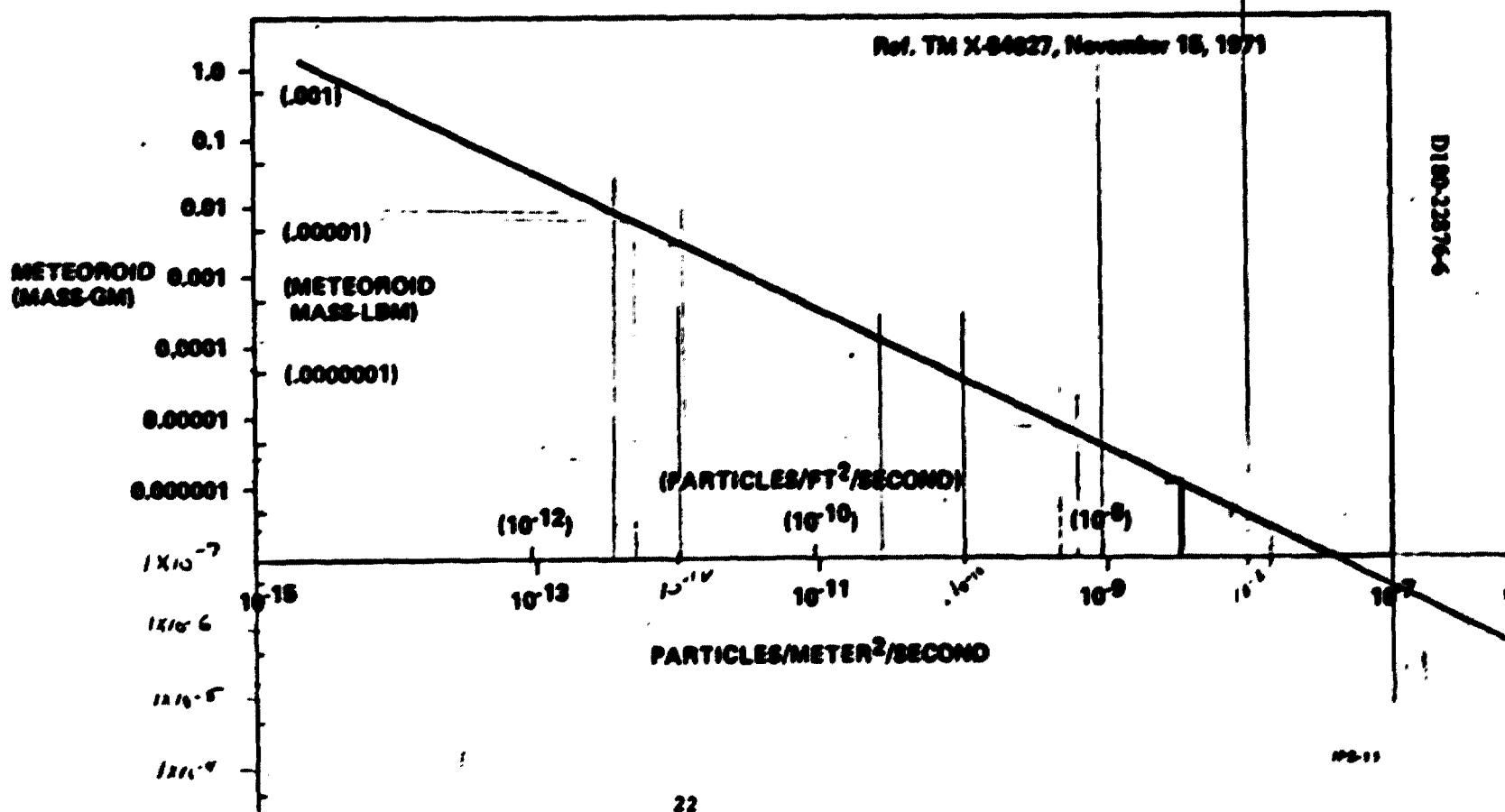
$$\begin{aligned} \text{THEN } A_1 F_{1-2} &= 2 \left[\left(\frac{\alpha}{360^\circ} \right) \pi D + \frac{XD}{2} \cos \alpha \right] - XD \\ &= D \left\{ 2 \left[\left(\frac{\alpha}{360^\circ} \right) \pi + \frac{X}{2} \cos \alpha \right] - X \right\} \end{aligned}$$

$$\text{BUT } A_1 = \frac{\pi D^2}{2}$$

$$\begin{aligned} \text{thus } F_{1-2} &= \frac{D}{\frac{\pi D^2}{2}} \left\{ 2 \left[\left(\frac{\alpha}{360^\circ} \right) \pi + \frac{X}{2} \cos \alpha \right] - X \right\} \\ &= \frac{2}{\pi} \left\{ 2 \left[\left(\frac{\alpha}{360^\circ} \right) \pi + \frac{X}{2} \cos \alpha \right] - X \right\} \end{aligned}$$



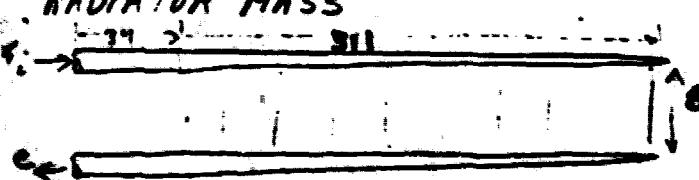
Sporadic & Stream Average Total Meteoroid Environment (Omnidirectional)



RADIATOR MASS

D180-228766

9/12/77



$$m = .87 \times 83.9 \text{ kg/sec} = 74.67 \text{ kg/sec}$$

$$T_0 = 933^\circ K \quad x_0 = .786 \quad P_0 = 5.504 \text{ PSIA}$$

at. figures

$$P_0 = 688 \text{ kg/m}^3 \quad \rho_{av} = .202 \text{ kg/m}^3 \quad \mu_L = 130 \times 10^{-6} \text{ at sec/m}^2$$

$$\mu_S = 18.8 \times 10^{-6} \text{ at sec/m}^2$$

$$\rho_i = \left(\frac{1}{\rho_{av}} + \frac{(1-x)}{\rho_L} \right)^{-1} = .257 \text{ kg/m}^3$$

$$\mu_i = 4.26 \times 10^{-5} \text{ at sec/m}^2$$

inlet header & manifold 34 mm header 311 mm manifold

Outlet = 1.60 m cont $\frac{\Delta P}{\rho L}$ manifold

$$N_{Re} = \frac{4 \pi \bar{v}}{\eta \mu D_i} = 1.39 \times 10^6 \quad f = .011$$

$$\Delta P = \frac{8 f L \bar{v}^2}{D^5 \pi^2 \rho} = 6421 \text{ at/m}^2, .9312 \text{ PSIA}$$

THROUGH PIPE

$m/\text{pipe} = .276 \text{ kg/sec}$ 311 through pipes 87% ing rate

$$D = .08 \text{ m} \quad L = 8 \text{ m} \quad \bar{v} = 8.63 \times 10^5 \text{ at sec/m}^2 \quad \rho = .514 \text{ kg/m}^3$$

$$\text{Press. recovery} \quad \Delta P_r = \rho_2 v_2^2 - \rho_1 v_1^2 = \frac{m^2}{A^2} \left(\frac{1}{\rho_2} - \frac{1}{\rho_{0.786}} \right)$$

$$\Delta P_r = -11,727 \text{ at/m}^2, -1.701 \text{ PSIA pressure increase}$$

Press drop

$$N_R = 50,900 \quad f = .022$$

$$\Delta P = 6452 \text{ at/m}^2, .936 \text{ PSIA}$$

assume get $\frac{1}{2}$ press. recovery

$$\text{net } \Delta P = .936 - .851 = .086$$

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RETURN HEADER & MANIFOLD

$$D_{ext} = .278 \text{ m} \quad \text{constant } \frac{\Delta P}{\Delta L} \text{ manifold}$$

$$\rho = 680 \text{ kg/m}^3 \quad \mu = 130 \times 10^{-6} \text{ Nt sec/m}^2$$

$$N_{Re} = 2.631 \times 10^6 \quad f = .0099$$

$$\Delta P = 13516 \text{ nt/m}^2, 1.960 \text{ PSIA}$$

Total pressure drop

$$.9312 + .086 + 1.960 = 2.977 \text{ PSIA}$$

$$5.404 \text{ PSIA} - 2.977 \text{ PSIA} = 2.427 \text{ PSIA} \quad \text{need 1.5 PSIA MFSH at v}$$

MASSESINLET HEADER & MAN. in gage all pipe $1.27 \times 10^{-4} \text{ m}$

$$M = [34 \times \pi \times 1.6 + 311 \times \pi \times 1.131] \times 1.27 \times 10^{-4} \times 7750 = \boxed{1256 \text{ kg}} \checkmark$$

THROUGH PIPE

$$M = 311 \times \pi \times .08 \times 8 \times 1.27 \times 10^{-4} \times 7750 = \boxed{615 \text{ kg}}$$

RETURN HEADER & MAN

$$M = [34 \times \pi \times .278 + 311 \times \pi \times .197] \times 1.27 \times 10^{-4} \times 7750 = \boxed{218 \text{ kg}} \checkmark$$

POTASSIUM MASSES

$$\text{INLET} \quad M = [34 \times \pi \times (\frac{1.6}{2})^2 + 311 \times \pi \times (\frac{1.131}{2})^2] \times .257 = \boxed{98 \text{ kg}} \checkmark$$

$$\text{THROUGH PIPES} \quad M = 311 \times \pi \times (\frac{.08}{2})^2 \times 8 \times .514 = \boxed{6 \text{ kg}} \checkmark$$

$$\text{RETURN} \quad M = [34 \times \pi \times (\frac{.278}{2})^2 + 311 \times \pi \times (\frac{.197}{2})^2] \times 688 = \boxed{7742 \text{ kg}} \checkmark$$

PUMPERSINLET $.0004 \text{ thick}$ 890 kg/m^3 

$$M = \left[34 \cdot \left(\frac{\pi D}{4} + D + .16\pi \right) + 311 \cdot \left(\frac{.707 \pi D}{4} + .707 D + .16\pi \right) \right] \times .0004 \times 890 \\ = \boxed{434 \text{ kg}} \checkmark$$

RETURN $.08 \text{ m spacing}$ $3 \times .0028 \text{ - thick}$

$$M = \boxed{2004 \text{ kg}} \checkmark$$

$$\text{TOTAL RADIATOR MASS, 1 ENGINE} = \boxed{12573 \text{ kg}}$$

(less heat pipes, 16,195 kg)

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Manifolds & Throughpipes

7/20/77

Revised Radiator

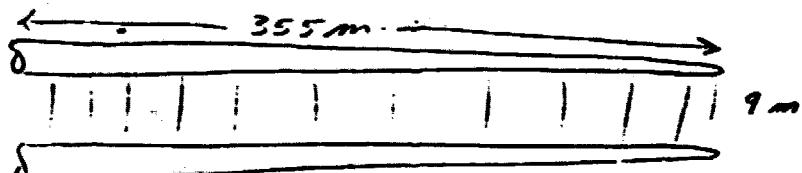
355. Throughpipes

-

$$\dot{m} = 74.67 \text{ kg/sec} \quad T_e = 930^\circ K \quad \lambda_i = .786 \quad P_i = 5.504 \text{ psia}$$

$$P_e = 680 \text{ kg/m}^3 \quad \rho_{\infty} = .202 \text{ kg/m}^3 \quad M_e = 130 \times 10^{-6} \text{ slug/sec} \\ N_{e\infty} = 18.8 \times 10^{-6} \text{ slug/sec}$$

$$\rho_i = .257 \text{ kg/m}^3 \quad \mu_i = 4.26 \times 10^{-5} \text{ nt sec/m}^2$$



$$\text{intlet man. } N_{Re} = \frac{4 \cdot 9}{\pi \mu D_i} = 1.39 \times 10^6 \quad f = .011 \quad D = 1.6 \text{ m}$$

$$\Delta P = \frac{8 \times .011 \times 355 \times 74.67^2}{(1.6)^5 \pi^2 .257} = 6,602 \text{ nt/m}^2, .958 \text{ psia}$$

$$\text{Through pipe } \dot{m}/\text{pipe} = .210 \text{ kg/sec}$$

$$D = .08 \quad L = 9 \text{ m} \quad \bar{\mu} = 8.63 \times 10^{-5} \text{ nt sec/m}^2 \quad \bar{\rho} = .514 \text{ kg/m}^3$$

$$\text{Press recovery } \Delta P_r = \frac{\dot{m}^2}{A^2} \left(\frac{1}{P_e} - \frac{1}{\rho(\lambda=.786)} \right)$$

$$\Delta P_r = -6,811 \text{ nt/m}^2; -.988 \text{ psia}$$

Press drop

$$\Delta P = \frac{8 \times .022 \times 9 \times .210^2}{(.08)^5 \times \pi^2 \times .514} = 4202 \text{ nt/m}^2; .609 \text{ psia}$$

$$\text{assume } \frac{1}{2} \Delta P_r \text{ available net } .609 - .494 = .115 \text{ psia}$$

Return man.

$$D_{ex} = .278 \text{ m} \quad \rho = 682 \text{ kg/m}^3 \quad \mu = 130 \times 10^{-6} \text{ slug/sec}$$

$$N_{Re} = 2.63 \times 10^6 \quad f = .0099 \quad L = 355 \text{ m}$$

$$\Delta P = 13,908 \text{ nt/m}^2 \quad 2.017 \text{ psia}$$

$$\text{Total } \Delta P = .958 + .115 + 2.017 = 3.090 \text{ psia}$$

$$\text{MPSH available } 5.404 - 3.090 = 2.314 \text{ psia}$$

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Masses

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INLET MAN $\text{air gage } 1.37 \times 10^{-4} \text{ m}$ $D = 1.13 \text{ m}$

$$M = [355 \times \pi \times 1.13 \times 1.37 \times 10^{-4} \times 7750] = 1240 \text{ kg}$$

Thru pipes

$$M = 355 \times \pi \times .08 \times 9 \times 1.37 \times 10^{-4} \times 7750 = 790 \text{ kg}$$

return man

$$M = 355 \times \pi \times .197 \times 1.37 \times 10^{-4} \times 7750 = 216 \text{ kg}$$

K masses

$$\text{INLET } M = 355 \times \pi \left(\frac{1.13}{2}\right)^2 \times .257 = 91 \text{ kg}$$

$$\text{THROUGH PIPES } M = 355 \times \pi \times \left(\frac{.08}{2}\right)^2 \times 9 \times .514 = 8 \text{ kg}$$

$$\text{return } M = 355 \times \pi \left(\frac{.197}{2}\right)^2 \times 6.88 = 744 \text{ kg}$$

Bumpers

$$\text{INLET } M = 355 \times \left(\frac{.707\pi 660 + .707\pi 660 + .16\pi}{2}\right) \times .0004 \times 890 = 93 \text{ kg}$$

$$\text{return } M = 355 \times \left(\frac{.707\pi 278 + .707\pi 278 + .08\pi}{2}\right) \times 3 \times .0027 \times 890 = \\ = 2008 \text{ kg}$$

TOTAL MASS

PIPING : 2246 kg

PER SPS
 $1.294 \times 10^6 \text{ kg}$

K : 7543 kg

$4.345 \times 10^6 \text{ kg}$

BUMPERS : 2439 kg

$1.405 \times 10^6 \text{ kg}$

TOTAL 12,228 kg ←

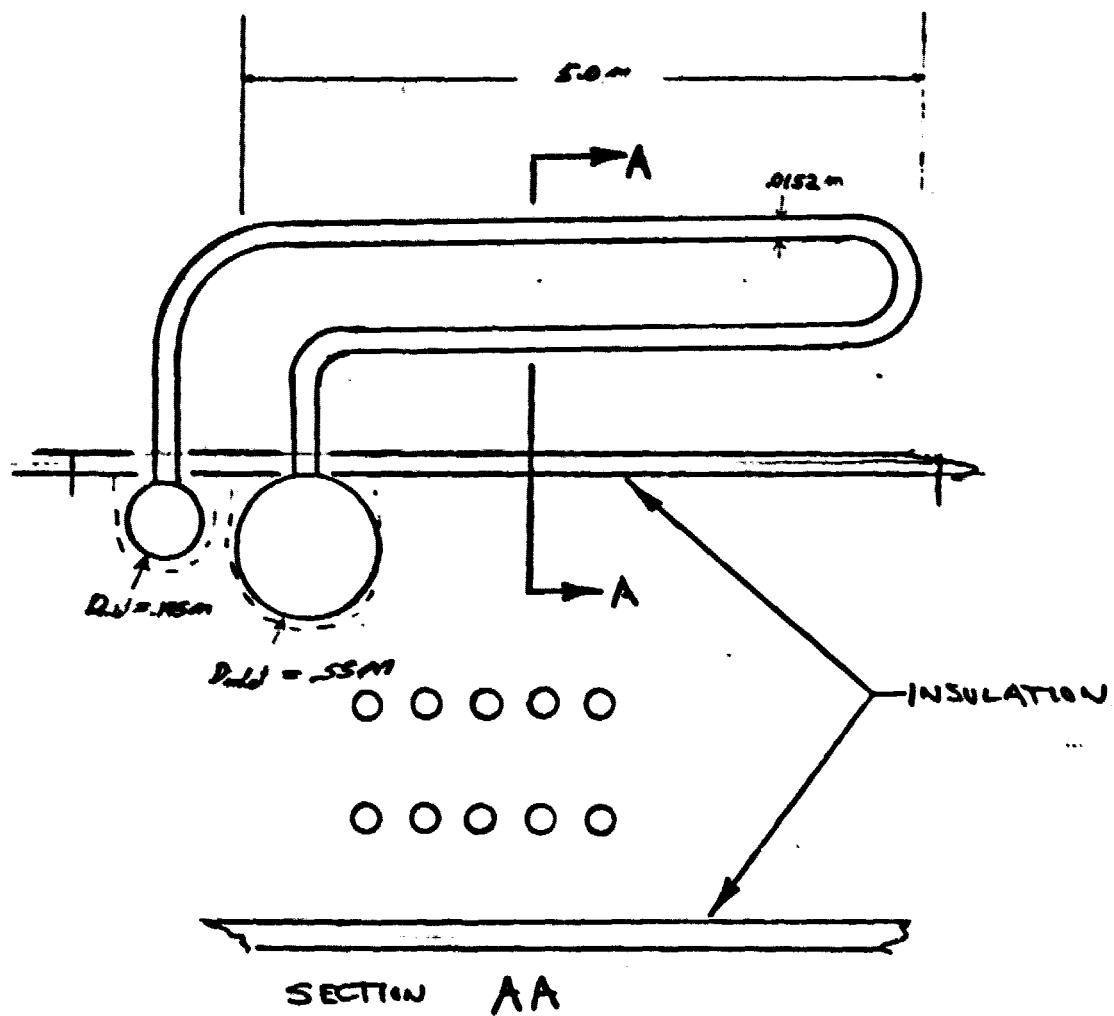
$7.043 \times 10^6 \text{ kg}$ ←

PER ENGINE

less heat pipes

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BOILER TUBES



3 panels/engine: 20m long x 6m wide

ENGINE TO BOILER EXTENSION PIPES 70m ave

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Liquid: .145m DIA ft².009

$$\Delta P = \frac{8 \times .009 \times 70 \times 81.5^2}{\pi^2 \times 688 (.145)^5} = 7.672 \times 10^7 \text{ N/m}^2 = 11.16 \text{ PSIA}$$

or high
water

$$\Delta P = \frac{8 \times .010 \times 70 \times 81.5^2}{\pi^2 \times 688 (.175)^5} = \frac{10.247}{D^5} \quad \text{above} = 4 \text{ PSIA; } 1.000 \text{ m}$$

$$D^5 = \frac{10.247}{6.283 \times 10^{-4}} \quad D = .175 \text{ m}$$

Vapour: $\Delta P = \frac{8 \times .010 \times 130.96 \times 81.5^2}{\pi^2 \times 3.263 \times D^5} = \frac{3.116 \times 10^3}{D^5} \quad \text{and } 4 \text{ PSIA; } 3.758 \text{ m}$

$$D^5 = \frac{3.116 \times 10^3}{2.758 \times 10^{-4}} = .647 \quad \text{use } .65 \text{ m}$$

Masses

Liquid: $m_m = (70 \times \pi \times .175 + 60.96 \times \pi \times .124) 2.2 \times 10^{-4} \times 9810 = 123 \text{ kg}$

$$m_A = (70 \times \pi \left(\frac{.175}{2}\right)^2 + 60.96 \times \pi \left(\frac{.124}{2}\right)^2) \times 688 = 1,665 \text{ kg}$$

Vapour $m_m = (70 \times \pi \times .65 + 60.96 \times \pi \times .460) \times 1.58 \times 10^{-3} \times 9810 = 32.88 \text{ kg}$

Liq: $m_A = (70 \times \pi \left(\frac{.65}{2}\right)^2 + 60.96 \times \pi \left(\frac{.460}{2}\right)^2) \times 2.263 = 98 \text{ kg}$

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CAVITY ANALYSIS

$$\dot{q}_I : \text{flux on tubes} = \dot{q}_I / A_T$$
$$A_T = \frac{\pi}{4} A_C$$

\dot{q}_I : net input to working fluid

A_T : tube area

A_C : cavity wall area

$$\dot{q}_S = \frac{.93 \text{ loss factor} (I_0 C_{EFF}) - \sigma T_T^4 \text{ re-radiation}}{\pi/4 A_C / A_A}$$

I_0 : insolation

C_{EFF} : effective conc. ratio to cavity aperture

A_A : aperture area

loss factor accounts for reflection from cavity and wall losses.

$$\dot{Q}_I = m (C_P \Delta T_f + h_f g)$$

THERMAL BALANCE

POWER TO APERTURE : $7.050 \times 10^6 \text{ KW}$

RE-RAD LOSS : - $.551 \times 10^6 \text{ KW}$ 7.8%

WALL & REFLECTION LOSS : - $.493 \times 10^6 \text{ KW}$ 7.0%

NET POWER TO ENGINES : $6.006 \times 10^6 \text{ KW}$ 85.2%

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BOILER & CAVITY ANALYSIS

9/19/77 (1)

$$\dot{m} = 83.9 \text{ kg/sec}, 185 \text{ lb/sec}$$

$$T_e = 1242^\circ K, 2236^\circ R$$

$$P_{SAT} = 75.5 \text{ psia}$$

$$T_i = 932^\circ K, 1678^\circ R$$

(open region $2236^\circ R$)

$$c_p = .2755 \text{ BTU/lbm } ^\circ R$$

$$\mu = .0522 \text{ lbm/lbm ft}$$

$$k = \mu (c_p + 2.48) = .144 \text{ BTU/lbm } ^\circ R$$

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$$P_v = .1413 \text{ lb/ft}^3$$

$$N_{Re} = \frac{\rho v D}{\mu} = \frac{.1413}{.0522} vD = 2.707 vD$$

$$N_{Pr} = \frac{\mu c_p}{k} = \frac{.0522 \times .2755}{.144} = .0999$$

$$h_w = \frac{k}{D} \cdot 0.22 N_{Pr}^{-0.6} N_{Re}^{-0.8} = \frac{.144}{D} \times 0.22 \times (.0999)^{-0.6} \times (2.707 vD)^{-0.8}$$

$$= 1.764 \times 10^{-3} \frac{vD^{-0.8}}{D}$$

$$vD^2 = \frac{4 \dot{m} \times 3600}{\rho \pi N_T}; vD = \frac{4 \times 185 \times 3600}{\pi \times .1413 N_T \times D} = \frac{6.001 \times 10^6}{D N_T}$$

$$h_w = \frac{1.764 \times 10^{-3}}{D} \times \left(\frac{6.001 \times 10^6}{D N_T} \right)^{-0.8} = \frac{466.76}{D^{1.8} N_T^{-0.8}}$$

Subcooled region $T = 1678^\circ R$

$$h_c = 23.13 \text{ BTU/lbm ft}$$

$$\rho_c = 42.95 \text{ lb./ft}^3$$

$$\mu = .347 \text{ lbm/lbm ft} \quad N_{Pr} \approx .0019$$

$$h_s = \frac{23.13}{D} \left(6.3 + .003 \left(\frac{vD + 42.95}{.347} \right) (.0019) \right) = \frac{23.13}{D} (6.3 + 7.055 \times 10^{-4} vD)$$

$$vD = \frac{4 (185) 3600}{42.95 \times \pi N_T D} = \frac{1.974 \times 10^4}{D N_T}$$

$$h_s = \frac{23.13}{D} \left(6.3 + \frac{15.93}{D N_T} \right) = \frac{14.57}{D} + \frac{382.3}{D^2 N_T}$$

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$$t_{2236^{\circ}R} h_{fg} = 774.9 \text{ BTU/lbm}$$

$$c_{pL}(2236^{\circ}F) = .1981$$

$$c_{pL}(1678^{\circ}R) = .1836$$

$$\bar{c}_{pL} = .1908$$

(2)

$$\text{Total heat flux required } \dot{Q}_I = m(c_{pL}\Delta T + m h_{fg})$$

$$\dot{Q}_I = 185 (.1908 \times 558 + 774.9) = 1631 \times 10^5 \text{ BTU/sec} ; 5.870 \times 10^8 \frac{\text{BTU}}{\text{hr}}$$

$$\dot{Q}_s = m c_{pL} \Delta T = 7.091 \times 10^7 \text{ BTU/lbm}$$

$$\dot{Q}_e = .6 m h_{fg} = 3.097 \times 10^8 \text{ BTU/lbm}$$

$$\dot{Q}_{nr} = .4 m h_{fg} = 2.064 \times 10^8 \text{ BTU/lbm}$$

$$\dot{Q}_I = \dot{Q}_h - A_A \sigma T_w^4 \quad \dot{Q}_h = I_s C_{h,eff} \times A_A$$

$$\dot{g}_I = \frac{\dot{Q}_c}{A_T} \quad A_T, \text{ tube area} = \frac{\pi}{8} A_c, \text{ cavity area}$$

$$\dot{g}_I = \frac{I_s C_{h,eff} A_A - A_A \sigma T_w^4}{\frac{\pi}{8} A_c}$$

$$\dot{g}_I = \frac{I_s C_{h,eff} - \sigma T_w^4}{\frac{\pi}{8} A_c / h_a}$$

$$\dot{g}_I = h_s (T_{w_1} - \bar{T}_f) \quad \dot{g}_I = h_B (T_{w_0} - T_B) \quad \dot{g}_I = h_w (T_{w_w} - T_w)$$

$$\bar{T}_f = 1957^{\circ}R \quad T_B = T_v = T_{SAT} = 2236^{\circ}R$$

$$A_T = \frac{\dot{Q}_I}{\dot{g}_I} = \frac{5.870 \times 10^8}{\dot{g}_I}$$

$$A_s = .1208 A_T \quad A_B = .5276 A_T \quad A_v = .3516 A_T$$

$$\Delta P = \frac{153.62}{A_T^{1.320} D^{4.220}} \times \frac{L_s}{\pi D N_T} \quad L_s = \frac{A_s}{\pi D N_T}$$

$$\Delta P = \frac{1 \times \frac{3.674 \times 10^9}{N_T^{2.82} D^{5.82}}}{\pi} \frac{16/\mu^2}{}$$

$$\Delta P_r = \frac{.7638}{N_T^2 (1.3048 D)^4}$$

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<u>D(H)</u>	<u>N_T</u>	<u>h_s</u>	<u>h_c</u>	<u>T_w-T_f</u>	<u>T_w-T_a</u>	<u>T_w-T_c</u>
.05	100	4,203	2,576	12.72	4	21
	500	3,172	711	16.85		75
	1000	3,043	408	17.57		131
	2000	2,979	234	17.94		228
.10	100	1,777	740	30.05		72
	500	1,522	204	35.12		262
	1000	1,489	117	35.90		457
	2000	1,473	67.3	36.27		794
.20	100	809	212	66.07		252
	500	745	58.6	71.75		912
	1000	737	33.7	72.52		1586
	2000	733	19.3	72.92		2767
.40	100	384	61.0	139.17		876
	500	368	16.8	145.25		3182
	1000	366	9.7	146.04		5510
	2000	365	5.6	146.44	V	9545

$$A_c/A_a = 6.5$$

$$C_{fc} = 1441$$

$$\text{Diss. agent} = 67 \text{ mm}$$

$$\text{try } T_w = 2350^{\circ}\text{R}$$

$$\dot{q}_f = \frac{415 \times 1441 - 1.714 \times 10^{-9} (2350)^4}{\pi \times 6.5} = 53,450 \text{ BTU/ft}^2 \text{ hr}^2$$

<u>D</u>	<u>N_T</u>	<u>ΔP</u>	<u>P_n</u>	<u>H_v</u>	<u>H_K</u>
.05	100	40,815	1416	2.534 × 10 ⁵	731
	500	436	56.6	3,697	
	1000	61.8	14.2	1,073	
	2000	8.7	3.5	720	↓
.10	100	722	88.5	11,480	1461
	500	7.7	3.5	1,501	
	1000	1.1	.7		
	2000	.2	.2		↓
.20	100	12.8	5.5		2923
	500	.1	.2		
	1000	—	.1		
	2000	—	—		↓
.40	100	.2	.3		5846
	500	—	—		
	1000	—	—		
	2000	—	—		↓

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Revised Potassium Boiler 9/20/77
Boiler Dia: .05' N: 2000 tubes

$$(\text{out}) \dot{m} = 179.6 \text{ kg/sec} \quad \dot{Q}_T = 179.6 (1.165 \times 55.5 + 224.9) \xrightarrow[200^{\circ}\text{C}]{\text{out}} = 5.697 \times 10^6 \frac{\text{Btu}}{\text{hr}}$$

$$\dot{q}_t = \frac{.93 (415 \times 1491) - 1.714 \times 10^{-7} (2285)^2}{\eta_t \times 6.5} = 49,894 \frac{\text{Btu}}{\text{lb} \cdot \text{ft}^2}$$

$$A_T = 5.697 \times 10^6 / 49,894 = 11,418 \text{ ft}^2$$

$$L_T = \frac{A_T}{\eta_T D_T} = \frac{11,418}{2000 \pi \times .05} = 36.39 \text{ ft}$$

Manifolds $L_m = 2 \times .05 \times 2000 = 200 \text{ ft}, 60.96 \text{ m}$

Temps. $T_{ws} = \frac{\dot{q}_t}{h_s} + 1957^{\circ}\text{R} = 1974^{\circ}\text{R}$

$T_{wg} = 2240^{\circ}\text{R}$ $T_{wir} = \frac{\dot{q}_t}{h_{ir}} + 2236^{\circ}\text{R} = 2447^{\circ}\text{R}$

Pressure drops.

Fictional $\alpha_f = \frac{144.8 L_s}{N_r^{1.82} D^{4.82}}$ $L_s = .1208 \times L_T = 4.39'$
 $\Delta P_f = 1.165 \times 10^3 \text{ lb/ft}^2 = 8.09 \text{ psia}$

Momentum $\Delta P_m = \frac{7199}{N_r^2 (3048 D)^4} = 3.34 \text{ psia}$

MANIFOLDS

Liquid $\dot{m} = 81.5 \text{ kg/sec}$ $D = .145 \text{ m}$

$$NRe = \frac{4 \dot{m}}{\pi \mu D} = 5.505 \times 10^6 \quad f = .009$$

$$\Delta P = \frac{P_f f L \dot{m}^2}{\pi^2 \rho D^5} = \frac{8 \times .009 \times 60.96 \times 81.5^2}{\pi^2 \times 688 \times (.145)^5} = 6.698 \times 10^4 \text{ N/m}^2; 9.71 \text{ ps}$$

Vapor $L = 200 \text{ ft}, 60.96 \text{ m}$ $D = .55 \text{ m}$

$$NRe = 8.576 \times 10^6 \quad f = .008$$

$$\Delta P = 2.305 \times 10^4 \text{ N/m}^2 \quad 3.34 \text{ psia}$$

$$\text{Total Press} = \frac{\text{Total engine mass}}{75.4 + 3.34 + 3.34 + 8.09 + 7.71} = 79.88 \text{ PSIA}$$

INLET man. $T = 1218^{\circ}\text{F}$ $\bar{d} = 2.02 \text{ in}$

$$G_{Cp} = 35,000 \quad \bar{e} = \frac{99.88 \times 2.02}{.667 \times 35000} = .0086 \text{ in}, 2.20 \times 10^{-4} \text{ in}$$

$$\rightarrow m_a = 60.96 \times \pi \times 103 \times 2.2 \times 10^{-4} \times 9,010 = 39.1 \text{ kg}$$

$$\rightarrow m_k = 60.96 \pi (103)^2 \times 688 = 397.96 \text{ kg}$$

$$\text{Total } M_{in} = [389 \text{ kg}]$$

outlet man. $T = 1776^{\circ}\text{F}$ $\bar{d} = .39 \text{ in}$

$$G_{Cp} = 14,500 \text{ PSIA} \quad \bar{e} = \frac{78.7 \times 15.31}{27.667 \times 14,500} = .062 \text{ in}, 1.58 \times 10^{-3} \text{ in}$$

$$\rightarrow m_a = 60.96 \times \pi \times .39 \times 1.58 \times 10^{-3} \times 9,010 = 1,063 \text{ kg}$$

$$\rightarrow m_k = 60.96 \times \pi \times \frac{39^2}{4} \times 2.263 = 16.41 \text{ kg}$$

$$\text{total } M_{out} = [1079 \text{ kg}]$$

Tubes:

$$\text{subcooled } L_s = 4.39' \quad \text{saturation } L_g = 19.17' \quad \text{super } L_g = 12.78'$$

$$P = 90 \text{ PSIA} \quad D = .05 \text{ ft} \quad t = .005" \text{ min gage, } 1.27 \times 10^{-3} \text{ in}$$

$$\rightarrow m_a = 4 \times 11.08 \text{ m} \times \pi \times .0152 \times 1.27 \times 10^{-4} \times 2000 \times 9010 = 1210 \text{ kg}$$

$$\rightarrow m_k = 11.08 \times \pi \times \frac{.0152^2}{4} \times 82.37 \times 2000 = 331 \text{ kg}$$

$$\text{total } M_{tub} = [1541 \text{ kg}]$$

$$\text{Total Boiler Mass : } \frac{m_{man}}{\text{per engine}} + \frac{m_{tubes}}{\text{per engine}} + \frac{m_{outlet}}{\text{per engine}} = [3009 \text{ kg}]$$

$$\text{Sub. mass of boiler } K = 697 \text{ kg}$$

$$\text{mass of metal} : 2312 \text{ kg}$$

$$\text{Total for one SPS } 16 \times 36 = 576 \text{ engines} \quad 1.733 \times 10^6 \text{ kg}$$

$$\begin{aligned} \text{mass } K &: .401 \times 10^6 \text{ kg} \\ \text{mass metal} &: 1.332 \times 10^6 \text{ kg} \end{aligned}$$

"FIXED" PALET - MASS: D180-22876

FILM 3 μ M Kapton, $\rho = 1.42 \times 10^{-3} \text{ kg/m}^3$

$A = 1000 \text{ m}^2$, mass = 4.26 kg

+ spoms, foobles, etc.

4.07 kg

ALUMINIZATION, 1000 Å = 0.7 μm, $\rho = 2.7 \times 10^{-3} \text{ kg/m}^3$ $\frac{0.37 \text{ kg}}{4.74 \text{ kg}}$

TENSION TO 1000 PSI ALONG EDGE MEMBER

= $6.9 \times 10^6 \text{ N/m}^2$ - PER LINEAR M; 20.7N (4.65 lbf)

EDGE MEMBER LENGTH = 19.81 M, $F = 410 \text{ N}$ (92.1 lbf)



EDGE IS CHAMFER, $L = 19.81 \text{ m}$, $t = 2 \times 10^{-4} \text{ m}$ (8 mil)
 $D = 0.1 \text{ m}$, $\rho = 1750 \text{ kg/m}^3$

MASS = 2.17 kg, EA, + LOCAL THICKNESS,
 BRIOLE PINS, ETC 2.29 kg, EA.

BRIOLES, $L = 10 \text{ m}$, $T = 205 \text{ N} \times 8 = 1640 \text{ N}$, ULTRIOM

KEVAR TAPE, 100,000 PSI, $O = 1.45 \times 10^{-3} \text{ m}^2$,

$V = 6.45 \times 10^{-6}$, $K = 1900 \text{ kg/m}^3$ $m = 0.0026 \text{ kg}$
 USE 0.01 kg,

INCLUDES LOWER TENDON CABLES

SPRINGS, $T = 820 \text{ N}$ for $L = 0.1 \text{ m}$

ASSUME WIRE OF STEEL WIRE, $D = 0.7 \text{ cm}$, IN COIL 5CM DIAM,
 $L = 10 \text{ cm}$ COILED, .25 CM MAX EXTENSI



$$L = (0.05)(\pi) \times \frac{0.10}{0.007} = 2.24 \text{ m}$$

$$A = \frac{(0.05)^2}{4} \pi$$

$$V = 8.6 \times 10^{-5} \text{ m}^3 \text{ mm} = 0.7 \text{ kg}$$

in coil, 0.84 kg

TENDON SPRING

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FACET, 9/14/77

ALUMINIZED FILM, ADHESIVES, ETC.	4.74 kg
EDGE MEMBERS 3X2.29	6.87
BRIOLLES, HOOKS	0.03
SPRINGS IN CANISTERS 3X0.8	2.40
ROCKER ARMS 3X0.4	1.20
MOUNT POINTS, 3X0.2 (ON STRUTS)	<u>0.60</u>
	15.84

PRELIM QUANTITY OF PACKS = 11232 m^2 , less 5% in gross \times SLS correc
 $\div 1020 \text{ m}^2 = 112,000$ facets

$$= 1.25 \times 10^6 \text{ kg}$$

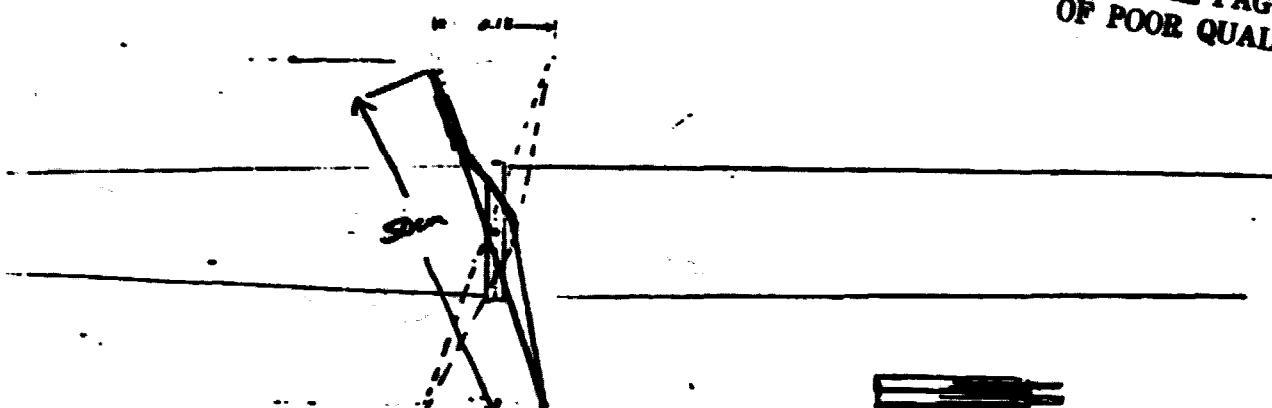
SUPPORT FRAMINGK WWS 463 kg/PACKET, X 112,000	$5.47 \times 10^6 \text{ kg}$
EDGE BEAMS, 1.75 kg/m	0.306×10^6
SUPPORT ARMS, L=3000 m	0.562×10^6

9/14/77

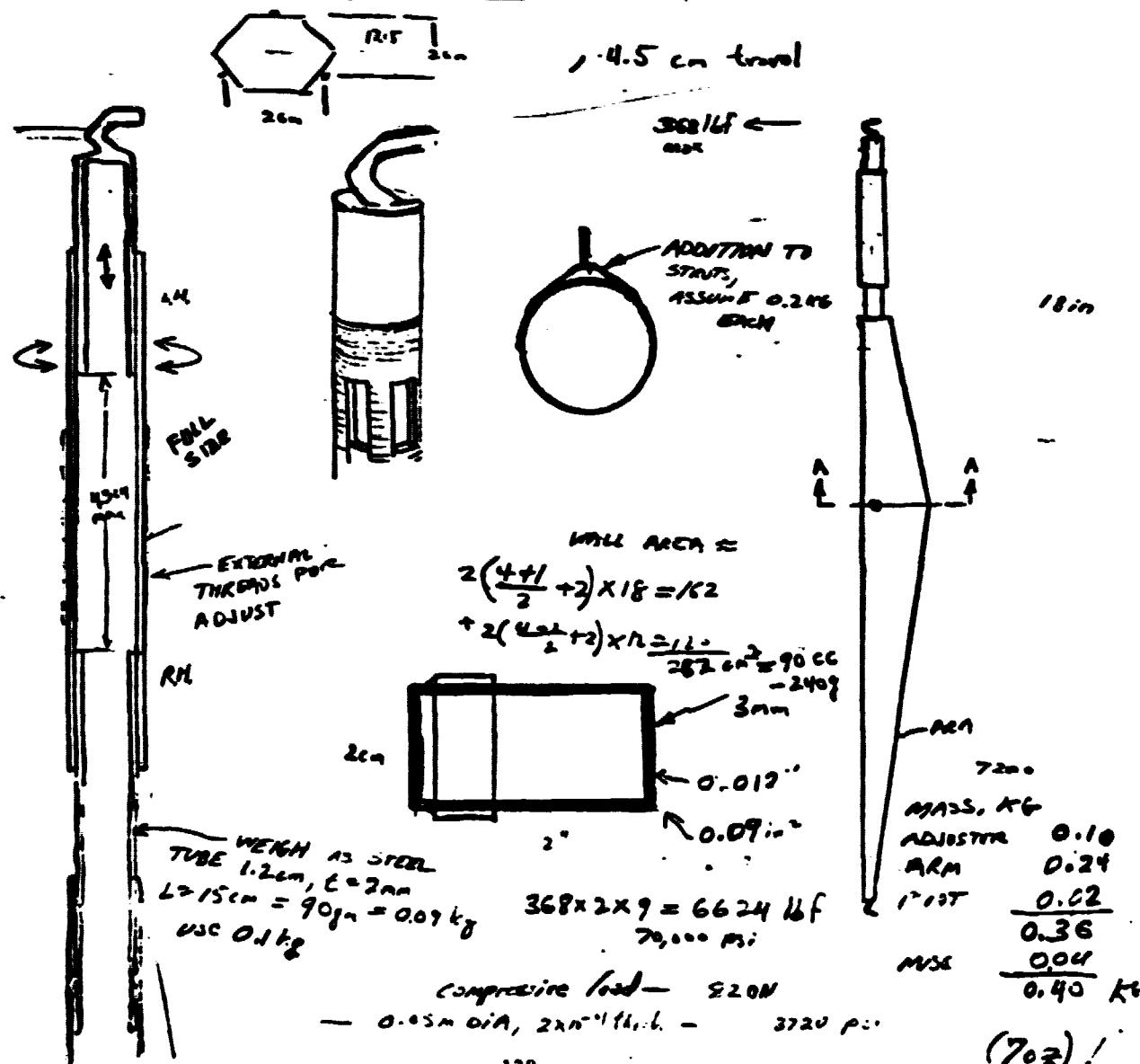
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ROCKER ARMS, OPERATIONAL : ARC = 0.18m

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Provide angular adjustment capability of 0.1° - two rockers



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8/29/67

Generator Radiators

Shaft Power 18.166×10^6 kw
Gas Output 12.857×10^6 kw
Dissipation 0.307×10^6 kw

Copper temp = 478K

Oil temp \approx 460K

Radiator surface \approx 455K, net $\epsilon = 0.57$ (tube view factor)

$1.38 \text{ kw}/\text{m}^2$ radiated

$$\text{Rd surface (tubes) area} = \frac{0.307 \times 10^6}{1.38} = 2.23 \times 10^5 \text{ m}^2$$

$$\text{Projected area} = 0.712 \times 10^5 \text{ m}^2$$

$$+ 13\% \text{ for metasid oversize} = 0.8 \times 10^5 \text{ m}^2$$

$$\div 16 = 5 \times 10^3 \text{ m}^2/\text{cavity} = 71 \times 71 \text{ m}$$

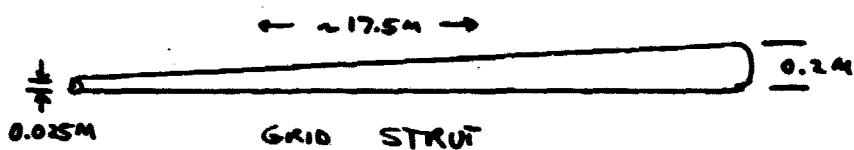
Area = 0.07 of primary

$$\frac{0.75 \times 10^6}{0.39 \times 10^6} \frac{k_1}{k_2} = \text{pumps, manifolds, pumps}$$
$$\frac{1.14 \times 10^6}{k_2}$$

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Support Structure for Facets

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$$Wall \ t = 0.2mm (0.008 \text{ in})$$

$$\begin{aligned} \text{Area} &= \pi(R+r)[h^2 + (R-r)^2]^{\frac{1}{2}} \\ &= \pi(0.1 + 0.0125)[125^2 + (0.1 - 0.0125)^2]^{\frac{1}{2}} \\ &= 6.185 \text{ m}^2 \end{aligned}$$

$$\text{Vol} = 1.237 \times 10^{-3} \text{ m}^3$$

$$\rho = 1750 \text{ kg/m}^3$$

$$\text{mass} = 2.165 \text{ kg.}$$

Each facet has 18 of these "GRID STRUTS" or 38.97 kg

"Thickening" and center GRID-TO-GRID JOINTS



$$\begin{aligned} \text{q of } 0.25 \text{ kg,} \\ = 2.25 \text{ kg} \end{aligned}$$

$$\text{Ball end fittings, 18 @ } 0.20 \text{ kg each } = 3.60 \text{ kg}$$

Sockets (Receive ball end fittings)

$$2 \text{ per facet, } 0.75 \text{ kg each}$$

per facet	38.97
	2.25
	3.60
	1.50
	<u>46.30 kg</u>

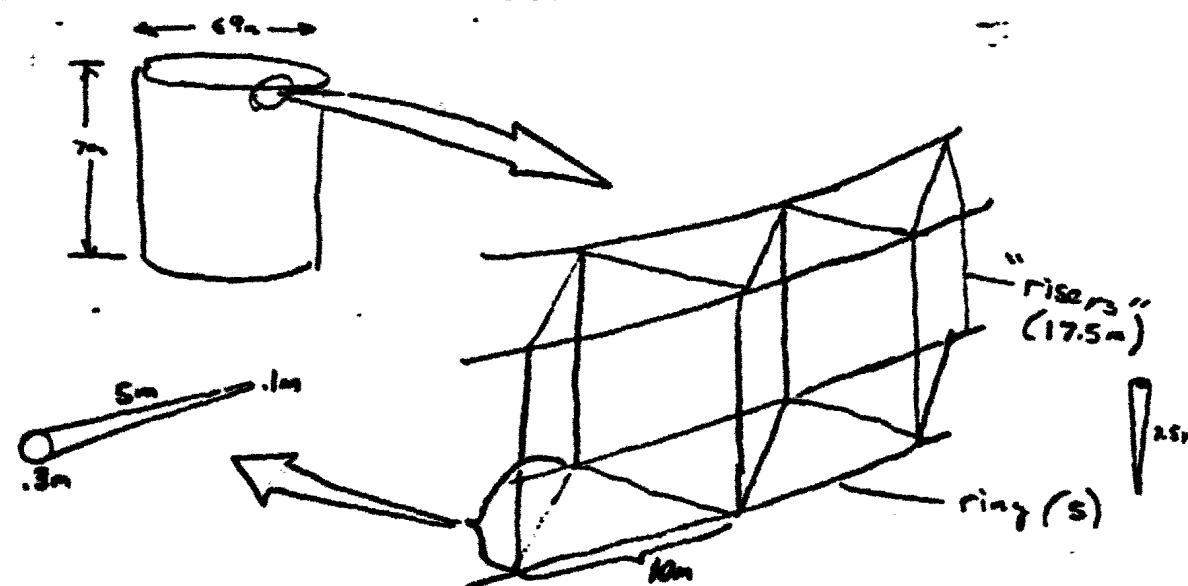
This is the mass of the support disk associated with a single facet

Stress analysis by O. Bullock using 10^{-4} g acceleration from thrusters gave factor of safety > 2 with 260e minimum gage.

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CAVITY FRAME

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Steel (31C) struts, 5m, $t = 1 \times 10^{-4} m$

6 pcs per 10 m length, or 1.47 kg/m^2

5 "rings" each 216 m circumference

18 risers = 2340 m -

$0.120 \times 10^6 \text{ kg}$
with fittings

Special engine bearing 10cm dia steel tubes, 180 m long
2mm wall (cylindrical)

$0.363 \times 10^6 \text{ kg}$

CAVITY INSULATION

Multifoil - M6 into Thorite separators

$$\text{Area} = (16) \times (\pi)(6.9) \times (70) + 16 \frac{(6.9)^2}{4} \pi = 3.03 \times 10^5 \text{ m}^2$$

$$5 \text{ layers of foil } @ 1.65 \text{ kg/m}^2 = 5.00 \times 10^5 \text{ kg}$$

CPC SKIN Geo. Conv. Ratios. = 3.05

$$\text{Area} = 1.2 \pi \left(\frac{6.9 + 12.0}{2} \right) \left[145^2 + (6.0 - 3.5) \right]^{\frac{1}{2}} = 5.17 \times 10^4 \text{ m}^2$$

$$\times 16 = 8.272 \times 10^5 \text{ m}^2$$

M6 foil
Rhodium
frame, foil supports $\frac{25.4 \text{ M}}{1000 \text{ A}} \cdot \frac{0.209 \times 10^6 \text{ kg}}{0.001} \cdot \frac{0.001}{0.001} \cdot \frac{0.255 \times 10^6}{0.255 \times 10^6}$

use $3 \times 10^6 \text{ kg}$



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3.0 COST DATA PACKAGE

3.1 INTRODUCTION

The final Part II cost estimates utilized the Boeing parametric cost model and the mature industry costing methodologies developed during the study. The procedure used was as follows:

The first step was to make cost estimates for DDT&E and first unit costs using the parametric cost model.

The parametric cost model predicts costs for typical aerospace products at typical aerospace production rates on the order of 100 units per year or less. Many of the items in these SPS's must be produced at relatively high production rates to meet any reasonable SPS deployment scenario. Hardware produced at high rates employs different tooling concepts and different production methods, more similar to mass production than typical aerospace techniques. Correlations developed for a wide variety of products indicate a production rate, cost improvement slope of approximately 70%. Adjustments to the PCM results for high production items were made as follows:

First, a standard hours estimate of typical aerospace costs was developed utilizing a typical aerospace cost improvement slope for 1,000 units.

(Experience of jetliner production indicates that approximately 1,000 units production are required to reach the standard hours predictable by tasks/timeline/headcount analyses.) A production rate improvement factor is then calculated based on the ratio of required annual production rate to a typical aerospace product value of 100 units per year. A production rate improvement slope of 70% was used.

In certain instances detailed estimates were available for manufacturing costs. These were used as available.

Total SPS system costs include also costs for space transportation, costs for space construction operations, and costs for ground receiving stations. Details of the launch vehicle cost per flight estimating procedure were reported in Volume V of the Part I Final Report. Launch vehicle cost per flight is dependent on launch rate.

Total transportation costs included transportation of propellants and orbit transfer hardware to low Earth orbit, and in addition the cost of orbit transfer hardware (either chemical orbit transfer vehicles or self-power electric orbit transfer system installations depending on construction location).

Construction costs included the transportation costs for crew rotation and resupply, the crew operations support costs and the amortization of construction base costs using typical capital facilities amortization procedures. Construction base habitats and basic structure were amortized over a 25

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year period with the construction equipment amortized over an 8 year period. Crew transportation costs presumed for the 1 SPS per year rate, the use of a modified shuttle vehicle at \$12 million per flight and for the 4 SPS per year rate, the use of an advanced fully reusable shuttle at \$5 million per flight. Delivery of propellants to low Earth orbit for the crew rotation and resupply orbit transfer vehicles is assumed to occur with the heavy lift launch vehicle at the appropriate cost per flight figure. Costs for orbit transfer installations for the self-power case, were derived using the parametric cost model with production rate adjustments for high production items as previously discussed.

3.2 COST ESTIMATING DETAILS

Table 1 in the cost data package is a capital cost summary for the photovoltaic SPS. It summarizes total costs in accordance with the work breakdown structure generally used and indicates source data and references further backup tables that provide additional detail. Interest during construction is added to the total costs based on an estimated construction period. Growth is added to provide a cost equivalent of the mass growth projections developed and the mass uncertainty analyses.

Table 2 summarizes the mature industry estimate. **Table 2** goes to a level of work breakdown structure below that of **Table 1**. (Note that the "other" category from the first part of **Table 2** is included in the multiple-common item in **Table 1**.) The cost calculations for **Table 2** support the SPS (satellite) cost values for GEO construction. The SPS values for solar cells and multiple-common use equipment have been adjusted for the LEO construction case to allow for the increase in SPS size from the reference configuration that was costed. The columns in **Table 2** reflect the calculation steps in applying the mature industry approach and some of the columns are not directly related to the final cost estimates. At the left (with the titles), the mass of each costed element is indicated and the number of such elements required carried under the number column. For example, the costed unit for primary structure was estimated to weigh 7250 lb. 1,824 of these units are required to make up an SPS structure. "Slope" indicates the learning slope used to develop the aerospace fully learned unit cost. Cost figures are in thousands. For example, the first unit cost for one 7250 lb element of primary structure as estimated by the PCM method was 2.375 million dollars. The PCM program predicted a first unit cost including the learning for 1824 of these units of 971 million dollars. The fully learned unit (down the 85% curve to 1,000 units) would be \$470,000. This figure compares with the column called "PCM unit cost" which is for the first such unit. The next total is simply the product of the fully learned unit times the number of units required. In the case of the primary structure, the mature industry estimates are taken from the detailed manufacturing estimate discussed under enclosure 1, which follows **Table 4**. The mature industry cost for primary structure was believed to have reached a materials cost plateau such that increasing production rate would not decrease cost. Therefore, the costs for 4 SPS's per year are not less than for one per year. In several of the other elements, however, the cost is production rate sensitive. For example, in processors (under attitude control), 12 of these units are required. Notice that at this low production rate, the estimated mature industry cost is greater than the fully learned aerospace cost since the latter would apply to 1,000 units.

The mature industry estimates were developed from parametric cost model runs that used traditional aerospace estimating methods. The PCM runs are included as **Table 3** for the photovoltaic system. **Table 4** summarizes the solar cell and blanket estimates that were made. Enclosure 1 describes the detailed manufacturing cost estimate that was made for graphite main structure hardware. **Table 5** presents a reference photovoltaic SPS summary weight statement. **Table 6** provides the rectenna cost estimate. **Tables 7 thru 11** provide construction base cost and mass data. **Table 12** provides an estimate for crew support costs (those in addition to crew transportation). The

space construction crew represents two crews to account for time off duty (90 days in space and 90 days off), with a 10% margin, and provides a crew support staff of ten people for each crew man working in space. Table 13 summarizes transportation costs estimated. Table 14 provides the mature industry cost estimate for the self-powered orbit transfer system. In this case the system costed included mass growth and the mass growth was deleted and the values carried in Table 13. Table 15 is the parametric cost model run that provides the raw data from which Table 14 was prepared. Table 16 summarizes crew rotation and resupply requirements. Table 17 summarizes the calculations of cost growth equivalent to the mass growth determined from the uncertainty analyses. Table 18 summarizes LEO versus GEO cost differences. Tables 19 thru 27 provide a similar cost package for the thermal engine system.

TABLE 1
CAPITAL COST SUMMARY - PHOTOVOLTAIC SPS (SILICON CR=1)

WBS #	ITEM	SOURCES & REFERENCES	1 SPS/YR		4 SPS/YR	
			LEO CON- STRUCTION	GEO CON- STRUCTION	LEO CON- STRUCTION	GEO CON- STRUCTION
1.01	Solar Power Satellite		(7442)	(7190)	(5587)	(5378)
1.01.00	Multiple/Common	<ul style="list-style-type: none"> . Mature Industry Estimate, Table 2 . Mature Industry Discussion . Parametric Cost Model Run, Table 3 	897	793	760	661
1.01.01	Energy Collection	<ul style="list-style-type: none"> . Solar Cell Costs, Table 4 	0	0	0	0
1.01.02	Energy Conversion	<ul style="list-style-type: none"> . Solar Cell Cost Discussion, Volume II 	3731	3588	2793	2686
1.01.03	Power Distribution	<ul style="list-style-type: none"> . Structural Mfg Estimate, Encl. 1 . Varian Analysis of Klystron Production 	138	133	82	79
1.01.04	Microwave Power Transmission	<ul style="list-style-type: none"> . MPTS Error Analysis . SPS Mass Estimate, Table 5 & Backup . LEO Figures Reflect 5% Oversize 	2676	2676	1952	1952
1.02	Ground Receiving Station	<ul style="list-style-type: none"> . Rectenna Cost Estimate, Table 6 . Bovay Studies (JSC Contract) . Raytheon Studies (Various Contracts) . Rectenna Optimal Sizing Analysis 	(4446)	(4446)	(4000)	(4000)
2.0	Construction/ Space Support		(1109)	(1126)	(1109)	(1126)
2.01	Construction Base (Facility Writedown)	<ul style="list-style-type: none"> . Writedown Summary, Table 7 . Facility Mass & Cost Estimates, Tables 8 & 9 . Construction Analyses & Base Definitions (See Volume V) 	596	620	596	620
2.02	Space Support					
2.02.01	Staging Base	<ul style="list-style-type: none"> . Staging Base Mass & Cost Estimates, Tables 10 & 11 	N/A		N/A	
2.02.02	Crew Support	<ul style="list-style-type: none"> . Crew Support ROM Estimate, Table 12 . Crew Reqts from Construction Analysis (Parts I & II Documentation) 	497	506	597	506
2.02.03	Other OPS Support		16		16	

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TABLE 1
CAPITAL COST SUMMARY - PHOTOVOLTAIC SPS (SILICON CR=1) (CONT)

WBS #	ITEM	SOURCES & REFERENCES	1 SPS/YR	4 SPS/YR		
			LEO CON- STRUCTION	GEO CON- STRUCTION	LEO CON- STRUCTION	GEO CON- STRUCTION
3.00	Space Transportation		(6445)	(9780)	(4188)	(6522)
3.01	Earth - LEO	. Numbers of Flights & Costs Summary, Table 13				
3.01.01	Freight	. Cost Per Flight Analyses (Parts I & II Documentation)	3139	2415	2155	1658
3.01.02	Crew	. Cost Per Flight Discussion, Volume II	336	336	140	140
3.02	LEO-GEO	. HLLV Operations Studies, Contract NAS				
3.02.01	Freight	. OTV Performance (Volume V) . OTS Performance (Part I) . OTS Mature Industry Estimate, Table 14 . OTS PCM Run, Table 15 . FSTSA Reports (Contract NAS9-14323) . Crew Rotation & Resupply Summary, Table 16 . Crew Duty Cycle Studies (Part I) . Advanced Earth Orbit Transportation Systems Technology Requirements (Contract NAS1-13944)	2816 154	6670 359	1790 103	4482 242
Interest During Construction		Construction/Transportation Timelines	(700 days) (1864)	(450 days) (1388)	(566 days) (1154)	(366 days) (851)
Growth		. Table 17 . Uncertainty Analyses; . FSTSA Mass/Cost Growth Correlation	(3450)	(4034)	(938)	(1094)
Total			24,756	27,964	16,976	18,971

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TABLE 2
MATURE INDUSTRY ESTIMATE, PHOTOVOLTAIC SPS AND MPTS

<u>ITEM & MASS (LB)</u>	<u>NUMBER</u>	<u>SLOPE</u>	<u>PCM UNIT COST</u>	<u>PCM TFU</u>	<u>FULLY LEARNED UNIT</u>	<u>TOTAL</u>	<u>MATURE INDUSTRY '81 SPS/YR</u>	<u>MATURE INDUSTRY '84 SPS/YR</u>	<u>DOLLAR/KG</u>
<u>P/V SPS</u>							<u>4,745,750</u>	<u>3,495,900</u>	
<u>OTHER</u>							<u>225,988</u>	<u>166,971</u>	
<u>MULT/COM</u>							<u>637,278</u>	<u>564,266</u>	
PRIM STRUC 7250#	1,824	.85	2,375	971,550	470	857,615	.360,000	.360,000	50 (From Mfr, Est)
<u>ATT. CONT</u>							<u>152,891</u>	<u>79,879</u>	
THRUSTERS 110 Lb.	640	.85	1,328	243,150	262	168,260	66,510	33,255	2,082
PROCESSORS 12,000 Lb.	12	.85	6,248	51,550	1,236	14,843	42,848	21,424	655
STRUCTURE 10,000 Lb.	4	.85	7,505	25,140	1,485	5,943	25,140	14,860	1,637
TANKS 1,130 Lb.	8	.85	1,040	6,178	206	1,647	5,823	2,912	1,420
INSTRUM. 1,000 Lb.	4	.85	3,752	12,570	742	2,971	12,570	7,428	8,188
CENTRAL COMPUTER 500 Lb	3	1.0	7,385	28,157	9,385	<u>28,157</u>	<u>28,157</u>	<u>28,157</u>	
COMMUNIC 2,000 Lb.	3	1.0	24,576	73,729	24,576	<u>73,729</u>	<u>73,729</u>	<u>73,729</u>	
ANTI-YOKE 13,800 Lb.	2	.85	12,145	22,501			<u>22,501</u>	<u>22,501</u>	

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TABLE 2 (Continued)

<u>ITEM & MASS (LB)</u>	<u>NUMBER</u>	<u>SLOPE</u>	<u>PCM UNIT COST</u>	<u>PCM TFU</u>	<u>FULLY LEARNED UNIT</u>	<u>TOTAL</u>	<u>MATURE INDUSTRY '01 SPS/YR</u>	<u>MATURE INDUSTRY '04 SPS/Y</u>	<u>DOLLAR/KG</u>
POWER GENERATOR							<u>3,749,628</u>	<u>2,686,207</u>	
SOLAR BLANKETS		.8	15,056	9,945,165					
ARRAY PANELS 1 LB.	78,387,000	.8	17		3,365	2,633	3,588,000	2,563,000	\$35/M ² & \$25/M ²
JUMPERS 0.01 Lb.	78,387,000	.85	0.123		.024	2,537,800	16,000	16,000	\$45/KG
NETWORK	6,124	.85	444		87	538,300	68,786	68,786	\$25/KG
CATERNARIES	6,124	.85	496		98	601,341	76,842	38,421	\$30/KG
POWER DISTRIBUTION							<u>132,856</u>	<u>78,956</u>	
SWITCHGEAR 1,320 Lb.	208	.85	3,787	292,000	750	156,000	108,000	54,100	868
BUSSES 15,000 Lbs.	32	.85	626	11,276	124	3,966	7,000	7,000	\$32
ROTARY JOINT 38,000 Lb.	2	.85	9,639	17,856			17,856	17,856	\$560

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TABLE 2 (Continued)

<u>ITEM & MASS (LB)</u>	<u>NUMBER</u>	<u>SLOPE</u>	<u>PCM UNIT COST</u>	<u>PCM Tfu (1 MPTS)</u>	<u>FULLY LEARNED UNIT</u>	<u>TOTAL</u>	<u>MATURE INDUSTRY #1 SPS/YR (2 MPTS)</u>	<u>MATURE INDUSTRY #4 SPS/YR (2 MPTS)</u>	<u>DOLLAR/KG</u>
MPTS TOTAL (2 Ant)							<u>2,675,542</u>	<u>1,951,823</u>	
CHECKOUT & PKG'G							<u>54,000</u>	<u>54,000</u>	
<u>MULT/COM</u>				<u>318,033</u>			<u>469,976</u>	<u>347,517</u>	
PRIMARY STRUC (965 Lb.)	240	.85	431	21,760	85	20,478	13,218	6,609	125
SEC STRUC (7,137 Lb)	122	.85	2,344	69,857	464	56,613	51,256	25,627	129
ATT CONTROL (1,000 Lb)	24	90	13,278	124,529	4,646	111,515	201,736	111,515	21,000
ISI CENTRAL COMPUTE (500 Lb)	6	1	9,385	28,157	9,385	56,310	56,310	56,310	41,000
COMMUNIC (2,000 Lb)	6	1	24,576	73,729	24,576	147,456	147,456	147,456	27,000
<u>POWER DISTRIBUTION</u>				<u>1,188,068</u>			<u>632,497</u>	<u>446,907</u>	
PWR PROC (12,000 Lb)	456	90	3,497	410,414	1,223	558,000	261,317	261,317	105
SWITCHGEAR (660 Lb)	912	85	2,120	299,137	420	382,767	126,746	63,373	464
THERMAL CONTROL (3,600 Lb.)	456	85	3,476	287,699	688	313,800	146,948	73,474	197

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TABLE 2 (Continued)

<u>ITEM & MASS (LB)</u>	<u>NUMBER</u>	<u>SLOPE</u>	<u>PCM UNIT COST</u>	<u>PCM TFU</u>	<u>FULLY LEARNED UNIT</u>	<u>TOTAL</u>	<u>MATURE INDUSTRY '81 SPS/YR</u>	<u>MATURE INDUSTRY '84 SPS/YR</u>	<u>DOLLAR/KG</u>
POWER DISTRIBUTION (7,000 Lbs.)	456	85	2,306	190,818	457	208,175	97,486	48,743	67
<u>SUBARRAYS</u>									
STRUCTURE AND WAVEGUIDES (685 Lb.)	13,864	85	323	368,651	64	886,534	258,439	258,439	60
KLYSTRONS (70 KW _{RF})	194,112	90	53	687,240	18	3,600,136	524,102	339,696	Varian Estimates
THERMAL CONTROL	194,112	85	157	1,762,474	31	6,033,318	274,000	274,000	45
CONTROL CKTS (11 Lb.)	194,112	90	300	3,889,287	105	20,378,131	462,528	231,264	477

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Table 3A Parametric Cost Model Output for Photovoltaic SPS

NO	NAME	SUB TO	ELEMENT METHOD	SOUR- CES	BLEND FACTORS	SUPT FROM X	OTS X	MOD CMPLX	MOD X	NUMBER LRN X	COST (000)
1	TOTAL PROGRAM	0	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0.0		1,980,938
		0	UNIT SUBS OPCODE= 0	0	0.00	0				0 0	13,710,942
2	PROG INTEG & MGMT.	0	DDT&E FACTOR OPCODE= 2	3	0.06	0	0	0	0.0		83,654
		0	UNIT FACTOR OPCODE= 2	3	0.06	0				0 0	738,356
3	PHOTOV SPS	0	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0.0		1,817,276
		0	UNIT SUBS OPCODE= 0	0	0.00	0				0 0	12,972,589
4	FLT SYS D&D	0	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0.0		136,536
153		0	UNIT SUBS OPCODE= 0	0	0.00	0				0 0	11,261,891
5	SUSTAINING	0	DDT&E FAC UN OPCODE= 3	4	0.05	0	0	0	0.0		393,262
		0	UNIT N/A OPCODE= 8	0	0.00	0				0 0	0
6	SE & I	0	DDT&E CER= 32 OPCODE= 12	4	0.00	0	0	0	0.0		27,669
		0	UNIT N/A OPCODE= 8	0	0.00	0				0 0	0

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Table 3A (continued)

NO	NAME	SUB ELEMENT TO	METHOD SOUR- CES	BLEND FACTORS FROM	SUPT OTS X	MOD X	MOD CMPLX X	NUMBER LRN X	COST (000)
7	FLT SYS DD&T	0	0 DDT&E FACTOR OPCODE= 2 6 9 UNIT N/A OPCODE= 8	4 1.00 1.00 1.00 0 0.00	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0
8	SYSTEM TEST	0	3 DDT&E SUBS OPCODE= 0 UNIT N/A OPCODE= 8	0 0 0 0	0.00 0.00 0.00 0	0 0 0 0	0 0 0 0	0 0 0 0	716,921
9	SYS TEST LDR	0	8 DDT&E CERN OPCODE= 12 34 UNIT N/A OPCODE= 8	4 0.00 0.00 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	263,645
10	GR TEST HDWE	0	8 DDT&E FAC UN OPCODE= 3 UNIT N/A OPCODE= 8	4 0 0	0.02 0.00 0.00 0	0 0 0 0	0 0 0 0	0 0 0 0	223,637
11	FLT TEST HDWE	0	8 DDT&E FAC UN OPCODE= 3 UNIT N/A OPCODE= 8	4 0 0	0.02 0.00 0.00 0	0 0 0 0	0 0 0 0	0 0 0 0	223,637
12	SOFTWARE ENGR	0	3 DDT&E CERN OPCODE= 12 37 UNIT N/A OPCODE= 8	7 0 0	0.00 0.00 0.00 0	0 0 0 0	0 0 0 0	0 0 0 0	130,478

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Table 3A (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	X	X	X	X	X	(000)
13	GSE	3 DDT&E FACTOR OPCODE= 2 UNIT FACTOR OPCODE= 2		4	0.10	0	0	0	0.0			42,298
	0			4	0.10	0				1 100		644,561
14	TOOLING	3 DDT&E FACTOR OPCODE= 2 UNIT H/A OPCODE= 8		4	0.25	0	0	0	0.0			150,200
	0			0	0.00	0				0	0	0
15	ASSY & C/O	3 DDT&E H/A OPCODE= 8 UNIT FAC UN OPCODE= 3		0	0.00	0	0	0	0.0			0
	0			4	0.07	0				0	0	846,141
16	MULT/COM	4 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0		0	0.00	0	0	0	0.0			220,960
	0			0	0.00	0				0	0	1,412,034
17	PRIM STRUCT 7250 LBS	16 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1		1	1.00	30	0	0	0.0			6,354
				46	1.00	45				1824 84		2,379
										AGGREGATED VALUES		971,958
18	ATT CONTROL	16 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0		0	0.00	0	0	0	0.0			101,453
	0			0	0.00	0				0	0	338,589

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Table 3A (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OVS	MOD	MOD	NUMBER	LRH	COST
		TO		CES	FACTORS	FROM	%	%	%	CHPLX	%	(000)
19	THRUSTERS	18	DDT&E CER	21	1.00	31	0	0	0.0	-	-	8,321
110	LBS		OPCODE= 1									
			UNIT CER	66	1.00	45				640	84	1,328
			OPCODE= 1									
										AGGREGATED VALUES		243,150
20	PROCESSOPS	18	DDT&E CER	14	1.00	31	0	1	9.0	-	-	43,226
12000	LBS		OPCODE= 1									
			UNIT CER	99	0.20	45				12	84	6,248
			OPCODE= 1									
										AGGREGATED VALUES		51,550
21	STRUCTURE	13	DDT&E CER	2	1.00	30	0	0	9.0	-	-	30,939
10000	LBS		OPCODE= 1									
			UNIT CER	47	1.00	45				4	84	7,505
			OPCODE= 1									
										AGGREGATED VALUES		25,140
156	22 TANKS	18	DDT&E CER	2	1.00	30	0	0	9.0	-	-	4,967
1130	LBS		OPCODE= 1									
			UNIT CER	47	1.00	45				8	84	1,040
			OPCODE= 1									
										AGGREGATED VALUES		6,178
23	INSTRUM	18	DDT&E CER	15	1.00	31	0	0	0.0	-	-	13,999
1000	LBS		OPCODE= 1									
			UNIT CER	60	1.00	45				4	84	3,752
			OPCODE= 1									
										AGGREGATED VALUES		12,570
24	CENTRAL COMPUTE	16	DDT&E CER	19	1.00	31	0	90	9.0	-	-	43,523
500	LBS		OPCODE= 1									
			UNIT CER	64	1.00	45				3	160	9,385
			OPCODE= 1									
										AGGREGATED VALUES		28,197

D108-225760

Table 3A (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	X	X	X	X	X	(000)
25	COMMUNIC 2000	LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	16	1.00	31	0	90	5.0		69,629
										3 100		24,876
										AGGREGATED VALUES		73,729
26	PWR GEN 0		4	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0	0.00	0	0	0	0.0		3,953
										0 0		9,826,210
27	SOLAR BLANKETS 0		26	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0	0.00	0	0	0	0.0		876
										6124 79		15,710
										AGGREGATED VALUES		8,551,862
28	ARRAY PANELS 10.75 SQ FT		27	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	26	1.00	30	0	0	0.0		375
										12800 79		17
										AGGREGATED VALUES		15,486
29	JUMPERS 0.01	LBS	27	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	13	1.00	30	0	0	0.0		0
										12800 84		0
										AGGREGATED VALUES		224
30	NETWORK 1000	LBS	26	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1	1.00	30	0	0	0.0		1,065
										6124 84		444
										AGGREGATED VALUES		460,436

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Table 3A (continued)

NO	NAME	SUB ELEMENT TO	METHOD	SOUR- CES	BLEND FACTORS	SUPT FROM	OTS %	MOD X	MOD CMPLX	NUMBER LRN X	COST (000)
31	CATERNARIES 500 LBS	26	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	2 47	1.00 30 1.00 45	0 0	0 0	0 0	0 0	2,511 6124 84 AGGREGATED VALUES	2,511 696 \$13,915
32	PWR DISTR 0	4	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0 0.00 0	0 0	0 0	0 0	0 0	96,840 0 0 AGGREGATED VALUES	96,840 321,148
33	SWITCHGEAR 1320 LBS	32	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	14 59	1.00 30 1.00 45	0 0	50 0	5.0 0	0 0	4,624 208 84 AGGREGATED VALUES	4,624 3,787 \$22,014
34	BUSES 15000 LBS	32	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1 46	0.10 29 0.10 45	0 0	0 0	0 0	0 0	1,459 32 84 AGGREGATED VALUES	1,459 626 \$11,276
35	ROTARY JOINT 38000 LBS	32	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	2 46	1.00 29 1.00 45	0 0	0 0	0 0	0 0	90,756 2 84 AGGREGATED VALUES	90,756 9,639 \$17,857
36	ANTENNA YOKE 13800 LBS	4	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	4 5 47 50	0.90 29 0.10 0.90 45 0.10	0 0	50 0	5.0 0	0 0	14,781 2 84 AGGREGATED VALUES	14,781 12,145 \$22,501

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Table 3B Parametric Cost Model Output for Transmitter

NO	NAME	SUB ELEMENT TO	METHOD	SCUR- CES	BLEND FACTORS	SUPT X	OTS X	MOD CMPLX	MOD NUMBER	LRN X	COST (000)
1	TOTAL PROGRAM		0	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0.0	3,237.735
			0	UNIT SUBS OPCODE= 0	0	0.00	0			0	9,765.689
2	PROG INTEG & MGMT		1	DDT&E FACTOR OPCODE= 2	3	0.06	0	0	0	0.0	63.081
			0	UNIT FACTOR OPCODE= 2	3	0.06	0			0	526.290
3	MICPDHAWE PTS		2	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0.0	1,174.653
			0	UNIT SUBS OPCODE= 0	0	0.00	0			0	9,239.322
4	FILT SVS D&D		3	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0.0	288.791
			0	UNIT SUBS OPCODE= 0	0	0.00	0			0	8,213.757
5	MULT/COMMON		4	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0.0	213.815
			0	UNIT SUBS OPCODE= 0	0	0.00	0			0	316.033
6	PRIMARY STRUC 965 LBS		5	DDT&E CER OPCODE= 1	1	1.00	30	0	0	0.0	1,032
				UNIT CER OPCODE= 1	46	1.00	45			120 84	431
										AGGREGATED VALUES	21,768

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Table 38 (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOR	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	%		CHPLX	X		(000)
7	SECONDARY STRUC	5	DDT&E CER	'	1	1.00	30	0	0	0.0		6,264
	7137 LBS		OPCODE= 1									
			UNIT CER	46	1.00	45				61 84		2,344
			OPCODE= 1									
										AGGREGATED VALUES		69,857
8	ATTITUDE CONTROL	5	DDT&E CER	25	1.00	31	0	0	0	0.0		17,206
	1000 LBS		OPCODE= 1									
			UNIT CER	67	1.00	45				12 89		13,278
			OPCODE= 1									
										AGGREGATED VALUES		124,529
9	CENTRAL COMPUTE	5	DDT&E CER	19	1.00	31	0	1	5.0			72,756
	500 LBS		OPCODE= 1									
			UNIT CER	64	1.00	45				3 100		9,385
			OPCODE= 1									
										AGGREGATED VALUES		28,157
10	COMMUNIC	5	DDT&E CER	16	1.00	31	0	0	5.0			116,556
	2000 LBS		OPCODE= 1									
			UNIT CER	61	1.00	45				3 100		24,576
			OPCODE= 1									
										AGGREGATED VALUES		73,729
11	PWR DISTR	4	DDT&E SUDS	0	0.00	0	0	0	0	0.0		56,480
	0		OPCODE= 0									
			UNIT SUBS	0	0.00	0				0 0		1,168,070
			OPCODE= 0									
12	PWR PROC	11	DDT&E CER	14	1.00	30	0	0	0	0.0		35,235
	12000 LBS		OPCODE= 1									
			UNIT CER	59	0.10	45				228 89		3,497
			OPCODE= 1									
										AGGREGATED VALUES		410,414

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Table 3B (continued)

NO	NAME	SUB TO	ELEMENT CES	METHOD FACTORS	SOUR- FROM	BLEND X	SUPT X	OTS X	MOD CMPLX	MOD X	NUMBER X	LBN X	COST (000)
13	SWITCHGEAR 650 LBS	11	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	14 59	1.00 1.00	29 45	0 0	0 0	0.0 0.0				3,235 2,120
												AGGREGATED VALUES	299,137
14	THERMAL CONTROL 3600 LBS	11	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	9 54	1.00 1.00	30 45	0 0	0 0	0.0 0.0				12,156 3,476
												AGGREGATED VALUES	287,699
15	PWR DISTR 7000 LBS	11	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1 46	1.00 1.00	29 45	0 0	0 0	0.0 0.0				5,852 2,306
												AGGREGATED VALUES	190,818
16	SUBARRAYS 0	4	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0.00	0 0	0 0	0 0	0.0 0.0				10,495 5,895
												AGGREGATED VALUES	6,707,654
17	STRUCTURE 685 LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1 46	1.00 1.00	30 45	0 0	0 0	0.0 0.0				758 323
												1 100	
18	KLYSTRONS 70 KWRF	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	21 67	2.00 2.00	30 45	20 0	0 0	0.0 0.0				6,860 53
												AGGREGATED VALUES	603

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Table 3B (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	%	%	%	CMPLX	%	(000)
19	THERM CONT	16	DDT&E CER	9	1.00	31	0	0	0.0			629
70	LBS		OPCODE= 1									
			UNIT CER	54	1.00	45				15	84	157
			OPCODE= 1									
										AGGREGATED VALUES		1,549
20	CONTROL CKTS	16	DDT&E CER	23	1.00	31	0	0	0.0			2,247
11	LBS		OPCODE= 1									
			UNIT CER	68	1.00	45				15	89	300
			OPCODE= 1									
										AGGREGATED VALUES		3,418
21	ASSY & C/O	3	DDT&E N/A	0	0.00	0	0	0	0.0			0
0			OPCODE= 8									
			UNIT FAC UN	4	0.05	0				0	0	410.687
			OPCODE= 3									
162	22 TOOLING	3	DDT&E FACTOR	4	0.10	0	0	0	0.0			49,363
0			OPCODE= 2									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
23	SYSTEM TEST	3	DDT&E SUBS	0	0.00	0	0	0	0.0			359,085
0			OPCODE= 0									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
24	SYS TEST LABOR	2	DDT&E CERN	4	0.00	0	0	0	0.0			194,811
0			OPCODE= 12	34	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									

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Table 3B (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LBN	COST
		TO		CF%	FACTORS	FROM	X	X	X	CMPLEX	X	(000)
25	GR TEST HOME	23 DDT&E FAC UN OPCODE= 3 UNIT N/A OPCODE= 8	4	0.01	0	0	0	0.0				82,137
				0	0.00	0			0	0		0
26	FLT TEST HOME	23 DDT&E FAC UN OPCODE= 3 UNIT N/A OPCODE= 8	4	0.01	0	0	0	0.0				82,137
				0	0.00	0			0	0		0
27	SE & I	3 DDT&E CERN OPCODE= 12 UNIT N/A OPCODE= 8	4	0.06	0	6	0	0.0				22,420
				32	0.70				0	0		0
				0	0.00	0			0	0		0
28	SUSTAINING	3 DDT&E FAC UN OPCODE= 3 UNIT N/A OPCODE= 8	4	0.05	0	0	0	0.0				286,313
				0	0.00	0			0	0		0
29	FLT SYS DDT	0 DDT&E FACTOR OPCODE= 2 UNIT N/A OPCODE= 8	4	1.00	0	0	0	0.0				0
				24	1.00				0	0		0
				27	1.00				0	0		0
				0	0.00	0			0	0		0
30	SOFTWARE ENGR	3 DDT&E CERN OPCODE= 12 UNIT N/A OPCODE= 8	29	0.00	0	0	0	0.0				120,581
				37	0.00				0	0		0
				0	0.00	0			0	0		0

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Table 38 (continued)

ID	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OIS	MOD	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	X	X	CMPLX	X	X	(000)
31 GSE	0	3 DDT&E CERS	4		0.00	0	0	0	0.0			56,097
		OPCODE= 12	38		0.00							
		UNIT FACTOR	4		0.10	0				1 100		614,880
		OPCODE= 2										

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TABLE 4
SOLAR CELL/BLANKET COSTS

1) J. Gauger's Mature Industry Correlation

8¢ to 17¢/Watt = 13.60 to 28.90/M² (Cells Only)
= 22.00 to \$37/M² (Array Panels)

2) Manufacturers Estimates

10¢ to 25¢/Watt (Cells Only)
= 17.00 to 42.50/M² (Cells Only)
= \$25.00 to \$50/M² (Array Panels)

3) Production Rate

Today \$10,000/M² for 50 kw

Then $(17\text{¢}/50)^{-1/2} = .0017 \times 10,000$ (70% Curve)
= \$17.00/M²

Energy Cost = \$17/M² for \$34/M² @ 1 SPS/YR

4) Denman's Estimate = \$40/M² (Median)

Average of these values is \$35/M² @ 1 SPS/YR;
use \$25/M² for 4 SPS/YR

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ENCLOSURE I

Manufacturing Analysis—Terrestrial Fabrication of Primary Structure Strut Assemblies

Our reference structure fabrication concept has proposed use of 10M tapered strut segments (20M strut assemblies) as the basic beam construction building block. In this approach, a highly automated terrestrial factory which produce strut segments on a mass production basis and package in high density magazines for transport to the LEO construction base.

During this period we expanded our analysis to include a brief look at factory manufacturing processes and non-recurring facility and tooling needs to sustain a "thruput" of one SPS/year. Specific objectives were to: a) gain a better understanding of rate processing requirements and to review producibility of the proposed tapered strut design; b) identify production rate "short fall" high risk areas; and c) test our mature industry estimate for primary/secondary structure.

Machine Process Center Concept

We subjected the strut design, and a slightly modified derivative, to step by step manufacturing process plan analysis. With a reasonably detailed processing plan in-hand we then established the "process flow limiters" for each operation or process step (i.e., feed and speed achievable for that process using that material) which gave us a reasonable feel for the effective yield of each process step. By applying the annual strut segment rate to produce one SPS per year (1.4×10^6 strut halves) we were then able to size the machine tools, special tooling, material consumption facility needs, etc.

Two mass production manufacturing concepts were evaluated. The first, generally referred to as the "Machine Process Center Concept," assumes design of special purpose machine tools (process centers) that essentially fabricate a completed part from raw materials, i.e., beam builder or automotive block processing type centers. In this case, complete injection molded end fittings and finish machined center fittings are loaded into the processing center and tension winding, curing, NDT inspection, etc., steps are all completed within the center with center operation sequenced by N.C. program. The second process evaluated was a typical "Process Station Flow-thru Concept" whereby each successive process step is accomplished by special purpose in-line (assembly line) machine tools. Each machine tool (station) is connected by appropriate transfer equipment with buffer storage between stations and multiple stations added at "process flow limiter" (bottleneck) positions. Specific features of each of these concepts are presented in Tables E-1 and E-2. Figure E-1 illustrates the process flow for the assembly line concept.

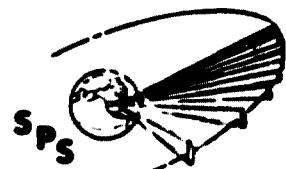
Table E-1
Primary Structure Production Concept
Opt 1: Machine Process Center

- STRUT END FITTING: (Gr/THERMOPLASTIC) INJECTION MOLDED NET IN MULTI CAVITY MOLDS
- CENTER JOINT: (7075 ALUM) CLOSE TOL DIE FORGING WITH FINAL SIZING ACCOMPLISHED ON SPECIALIZED NC TURNING MACHINE STATIONS
- STRUT TUBE ASSEMBLY
 - LARGE 8 TURRET TURNING CENTER SEQUENCES PARTS IN 4 PROCESS STAGES
 - STAGE 1 COOL DOWN, LOAD FITTINGS, APPLY FILM ADHESIVE & PARTING FILMS
 - STAGE 2 CIRC WINDING
 - STAGE 3 DEBULK & CURE
 - STAGE 4 NDT, PART REMOVAL, TOOL CHANGEOUT/REPAIR
 - 2 MIL TAPE (13MM WIDE BY CONTINUOUS) TENSION WOULD $\theta \approx 180$ RPM
 - 8 SPOOL (4 PAIRS) TAPE LAYING WITH 4.7M/MIN YIELD/LAYER (STRUT CGMP. 3.6 MIN)
 - TAPE WILL BE "B" STAGED Gr/E TO SHORTEN CURE (MICROWAVE)
 - COCURRED OF END FITTING & STRUT TUBE
- PROCESS CENTER YIELD 30 PARTS/HR (THRUPUT 16 MIN/PART) (NEED 10 CENTERS)
- AUTOMATED NON-DESTRUCTIVE INSPECTION (NDT)--INCLUDES LIMIT LOAD STATIC TESTS
- PLANT AREA NEEDS 80-100K SQ/FT INCLUDING REFRIG STORES, MATER STAGING MACHINE CENTERS, RMK CENTER
- TOOLING--APPROX 600 TOOLS INCL NC MASTERS FOR TURNING MANDREL FABRICATION
- ONE 750-1000 TON PRESS WITH 8-10 CAVITY MOLD--COOL DOWN & SCARF REMOVAL STATIONS IN PROCESS LINE
- STATIONS WILL ACCEPT DIE PRE-FORMS VIA CENTER FEED TRANSFER SYSTEM--CARBINE MULTI-SPINDLE CUTTING STATIONS FOR TURNING, & GANG MILL FINGER CUTS--MACHINE YIELD 16-20/HR--19 STATIONS REQUIRED.
PROCESS STATION IN LINE FOR NDT, HEAT TREAT, ANODIZE, ETC.

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Table E-2
Primary Structure Production Concept
Opt 2: Process Station Flow-Thru

- STRUT END FITTING & CENTER JOINT: (BOTH Gr/THERMOPLASTIC)--INJECTION MOLDED NET IN MULTI CAVITY MOLDS--SAME AS OPT 1
- STRUT TUBE ASSEMBLY
 - SPECIAL PURPOSE MACHINE STATIONS WITH FLOW THRU TRANSFER SYSTEM--BUFFER STORAGE BETWEEN STATIONS & PARTS CROSS TRANSFER AT MULTI POSITION STATIONS
 - 2 MIL TAPE (13MM WIDE BY CONTINUOUS--TENSION WOULD $\theta = 180$ RPM)
 - KEY WINDING STATIONS INCLUDE
 - 4 STATIONS CIRC WINDING POSITIONING FABRIC & INNER KEVLAR
 - 4 STATIONS LAYING 0° Gr/E GORES (PRECUT & FORMED)
 - 4 STATIONS CIRC WINDING 90° KEVLAR OVER-WRAPPS
- PRODUCTION LINE YIELD 90-92 PARTS/HR (3 LINES REQUIRED)
- AUTOMATED NON-DESTRUCTIVE TESTING (NDT)--SAME AS OPT 1
- PLANT AREA NEEDS 60-70K SQ/FT TOTAL
- TOOLING: APPROX 400 TOOLS--MORE MANDRELS THAN OPT 1 BY ELIMINATE TURNING TOOLING



SPS-1367

**WORK STATION
TASK DESCRIPT.**

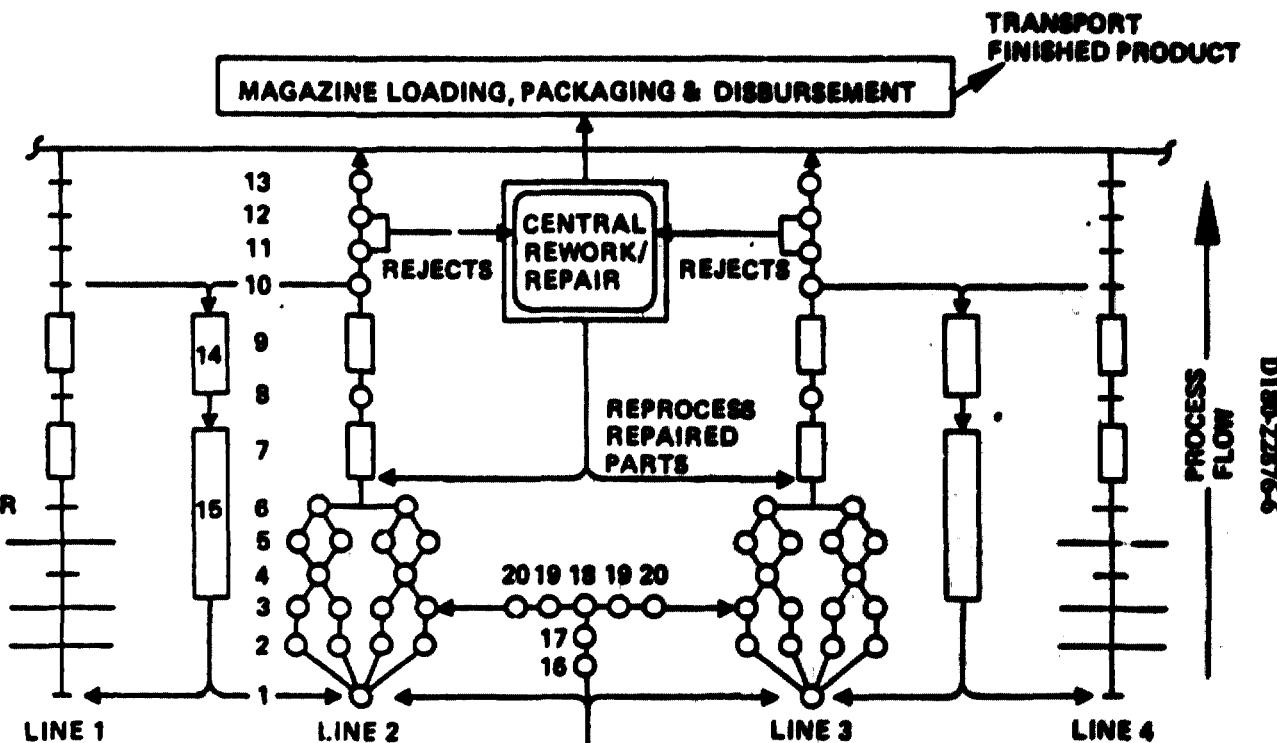
- 1 LOAD FITTINGS
- 2 INNER CIRC WIND
- 3 CENTER GORE LAY
- 4 VACUUM DEBULK
- 5 OUTER CIRC WIND
- 6 VACUUM DEBULK
- 7 MICROWAVE CURE
- 8 REM DEBULK TOOL
- 9 POSTCURE
- 10 MANDREL REMOVAL
- 11 NDT-ANALYZER
- 12 NDT-STATIC LOAD
- 13 FINAL ASSY
- 14 TOOL COOLDOWN
- 15 TOOL CHANGE/REPAIR
- 16 GORE TAPE PREP
- 17 GORE LASER TRIM
- 18 REAPPLY CARRIER
- 19 INDUCTION HEAT
- 20 CONTOUR ROLL

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Figure E-1
Strut Tube Process Flow-Through
Facility Concept

BOEING

MAGAZINE LOADING, PACKAGING & DISBURSEMENT

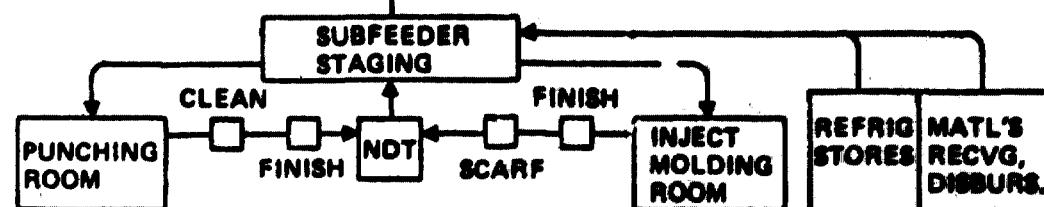


SIZING DATA:

92 PARTS/HR/LINE

19 MINUTES TO CYRUPUT (STA. 1-13)

2.6 MINUTES MAX STATION



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The results of our studies clearly show that production rates of 300 strut segments per hour (3 shift/5 day week basis) are easily believable with modest non-recurring investment using current available aerospace processing technique. No high risk or long lead process development tasks were identified. Table E-3 provides summary costing data on the strut segment alternate design/process-ing approaches reviewed. Our detail manufacturing plan analysis has confirmed that the mature industry cost estimate of \$55/kg (now year dollars) for terrestrial fabrication of primary/secondary structure is credible. We do, in fact, believe further design/process producibility efforts will yield even lower primary structure costs.

Table E-3
Cost Analysis Summary
(77S)

• MACHINE PROCESS CENTER (ORIGINAL STRUT DESIGN)

NON-RECURRING: $(\$60 \times 10^6$ FACILITY, 2.6×10^6 TOOLING) $\$62.6 \times 10^6$

RECURRING:

MATL	617.20	(96%)	=	\$640/20M STRUT
LABOR	22.90	(4%)	=	

AVERAGE COST--OPT 1 PLAN [R + (NR/8 YRS)] = \$57.87/kg

• PROCESS STATION FLOW THRU (MODIFIED DESIGN)

NON-RECURRING: $(\$55 \times 10^6$ FACILITY, 2×10^6 TOOLING) $\$57 \times 10^6$

RECURRING:

MATL	506.20	(96%)	=	\$527/20M STRUT
LABOR	20.10	(4%)	=	

AVERAGE COST--OPT 2 PLAN [R + (NR/8 YRS)] = \$47.58/kg

• PRIMARY STRUT MATURE INDUSTRY ESTIMATE = \$55/kg

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TABLE 5
REFERENCE PHOTOVOLTAIC'S
SUMMARY WEIGHT STATEMENT
(Weight in Kilograms)

1.0	SOLAR ENERGY COLLECTION SYSTEM	51,782,300
1.1	Primary Structure	5,385,000
1.2	Secondary Structure	1
1.3	Mechanical Rotary Joint	66,800
1.4	Maintenance Station	<u> </u>
1.5	Control	178,100
1.6	Instrumentation/Communications	4,000
1.7	Solar Cell Blanket	43,750,000
1.8	Solar Concentrators	<u> </u>
1.9	Power Distribution	2,398,400
2.0	MICROWAVE POWER TRANSMISSION SYSTEM	25,212,200
	(TOTAL - LESS GROWTH)	(76,994,500)
3.0	WEIGHT GROWTH ALLOWANCE - 26.6%	20,505,500
	(TOTAL - WITH GROWTH)	(97,500,000)

1 Distributed to other WBS items.

TABLE 6
RECTENNA NOMINAL COST ESTIMATE @ 1 SPS/yr

BEAM DIAMETER 13 KM
 RECTENNA INTERCEPT DIAMETER 9.36 KM @ 95% EFFICIENCY
 RECTENNA GROUND AREA = $1.535 \times \pi/4 \times 9.75^2 = 105 \text{ KM}^2$
 RECTENNA PANEL AREA = 68.8 KM^2
 TOTAL CONTROLLED AREA (LAND AQUIS) = $204\text{KM}^2 = 50,400 \text{ ACRES}$

<u>WBS</u>	<u>ITEM</u>	<u>ESTIMATING FACTOR</u>	<u>NUMBER</u>	<u>COST, MILLIONS</u>	<u>D180-228766</u>
1.02					
1.02.00	Mult/Common				
1.02.00.01	Land	\$5,000/Acre Acquis & Prep	50,400 Acres	252	
1.02.00.02	Prim Structure	\$10/M ²	68.8 KM ²	688	
1.02.00.03	Control	\$1,000/Subunit	500 Subunits	0.5	
1.02.00.04	Commun			50	
1.02.01	Energy Coll/Conv				
1.02.01.00	Support Str/Gnd Plane	\$3/M ²	68.8 KM ²	206	
1.02.01.01	Dipole/Diode/Filter Units	0.08 Ea @ 70 CM ² /Element	0.983 x 10 ¹⁰	787	
1.02.02	Power Distr. Sys.				
1.02.02.01	Busses	Satellite Value		7	
1.02.02.02	Processors	\$50/KWe	$4.65 \times 10^6 \text{ KWe}$	<u>233</u>	
				<u>2,223</u>	

= 4,446 for 2
Rectennas

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TABLE 7

CONSTRUCTION BASE WRITE DOWN SUMMARY
PHOTOVOLTAIC SPS
LEO CONSTRUCTION

<u>Item</u>	<u>Cost (Millions)</u>	<u>Amortized Over</u>	<u>Cost/SPS (Millions)</u>
<u>LEO Base</u>			
Facility	3465	25 years	139
Facility O/H	1629	25 years	65
Constr. Equip.	1310	8 years	164
C.E. O/H	616	8 years	77
<u>GEO Base</u>			
Facility	380	25 years	15
Facility O/H	179	25 years	7
Constr. Equip.	425	8 years	53
C.E. O/H	201	8 years	25
<u>LEO Base Transport</u>	625	15 years	42
<u>GEO Base Transport</u>	137.5	15 years	<u>9</u>
			<u>596</u>

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TABLE 7(Cont'd)

<u>ITEM</u>	<u>Cost (Millions)</u>	<u>Amortized Over</u>	<u>Cost/SPS (Millions)</u>
<u>LEO</u>			
<u>Staging Base</u>			
Facility	650	25 years	26
Facility Wrap	304	25 years	12
Equipment	135	8 years	5
Equipment Wrap	61	8 years	2
<u>GEO Construction</u>			
<u>Base</u>			
Facility	3610	25 years	144
Facility Wrap	1690	25 years	68
Equipment	1555	8 years	194
Equipment Wrap	730	8 years	91
<u>LEO S/B</u>			
<u>Transportation</u>	37.5	15 years	3
<u>GEO C/B</u>			
<u>Transportation</u>	1125	15 years	75
			<hr/>
			620

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TABLE 8

**P/V CONST BASE COST SUMM
(FIRST SET) \$M**

LEO Base	(7020)
Facility	3465
Const Equip	1310
Overhead	2245
GEO Base	(1185)
Facility	380
Const. Equip	425
Overhead	380

\$8205



 This has 90% learning within the first set but does not include those units used for testing.

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TABLE 8 (Cont'd)

Facility		(3465)
Foundation	250	
Crew Modules	2870	
Cargo Handling	330	
Base Subsys	15	
Maint. Provisions	-	
Const. & Support Equip.		(1310)
Struct Assy.	356	
Energy Collection Conversion	165	
Power Distrib.	75	
Subarray Install.	80	
Cranes/Manip	560	
Indexers	80	
		Basic HRW
		4775
Spares		715
Install, Assy, C/O		765
SE&I		335
Proj. Mgt.		95
Sys. Test		145
GSE		190
		\$7020 M

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TABLE 9
P/V CONST BASE MASS SUMMARY

	(10^3 kg)
LEO CONST BASE	(5870)
Facility	5200
Const & Supp Equip	400
Consumables	270
GEO CONST BASE	(770)
Facility	565
Const & Supp Equip	175
Consumables	30

	6640

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TABLE 9 (Cont)

LEO CONST. BASE	<u>10³ kg</u>
FACILITY	(5200)
Foundation	2500
Crew Modules	2000
Cargo Handling/Distribution	400
Base Subsystems	200
Maintenance Provisions	100
CONST & SUPPLY EQUIPMENT	(400)
Struct. Assy.	80
Solar Array Inst.	60
Power Dist. Inst.	20
Subarray Inst. (Incl. sec str)	30
Cranes/Manipulators	180
Indexers	<u>30</u>
TOTAL DRY	5600
CONSUMABLES (90 Days)	270

 Includes 33% growth allow. No other item does.

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TABLE 9 (Continued)

GEO FINAL ASSY BASE

Facility	<u>10^3 kg</u>	(565)
Foundation	280	
Crew Module	220	
Cargo Handling/Dist	55	
Base Subsystems	10	
 Const & Support Equipment		(175)
Solar Array Inst.	50	
Crane/Manipul.	15	
Indexers	6	
Docking Cranes	104	
		<hr/> <hr/> <hr/> <hr/> <hr/>
		740

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TABLE 10
COST SUMMARY
P/V GEO CONST CONCEPT

	<u>\$10⁶M</u>
LEO Staging Depot	(\$1130)
GEO Const Base	(7585)
Facility	3610
Const Equip	1555
Wraparound	2420
	<u>\$8735 M</u>

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TABLE 10 (Continued)

<u>LEO STAGING DEPOT</u>	($\$10^6$)
Foundation	1
Crew Modules	645
Base Subsystems	4
Vehicle and Payload Handling	120
Propellant Storage and Distribution	<u>15</u>
Basic Hardware	\$785
Spares (15%)	115
Install, Assy, C/O (16)	125
SE&I (7)	55
Proj. Mgt. (2)	15
Sys. Test (3)	25
GSE (4%)	<u>30</u>
Total	\$1150

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TABLE 10 (Continued)

GEO CONST BASE

Facility	(3610)
Foundation	250
Crew Modules	3020
Cargo Handling	330
Base Subsystems	10
Maintenance Prov	-
Construction Equip	(1555)
Struct Assy	350
Energy Collection & Conversion	165
Power Dist.	75
Subarray Inst.	80
Cranes/Manip	760
Indexers	<u>125</u>
	Basic Hardware
	5165
 Spares	 775
Install, Assy, C/O	825
SE&I	360
Proj. Mgt.	100
Sys. Test	155
GSE	<u>205</u>
	2420
 Total	 7585

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TABLE 11
MASS SUMMARY
P/V SAT
GEO CONST CONCEPT

	<u>10³ kg</u>
GEO STAGING DEPOT	(750)
Facility & Equip.	730
Consumables	20
GEO Const Base	(6535)
Facility	5730
Const. Equip.	515
Consumables	270
	7285

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TABLE 11 (Cont.)

<u>GEO Const. Base</u>	(10^3 kg)
Facility	(5750)
Foundation	2500
Crew Modules	2690
Cargo Handling/Dist	400
Base Subsystems	60
Maint. Provision	100
Construction Equip.	(515)
Struct. Assy.	80
Solar Array Inst.	60
Power Dist. Inst.	20
Subarray Inst.	30
Cranes/Manipulators	255
Indexes	<u>70</u>
Total Day	6265
Consumables (90 Days)	<u>270</u>
	6535

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TABLE 11 (Cont.)

LEO Staging Depot	<u>10^3 kg</u>
Foundation	15
Crew Modules	590
Base Subsystems	30
Vehicle and Payload Handling	40
Propellant Storage and Distribution	<u>55</u>
	730
Consumables (90 days)	<u>20</u>
Total	750

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TABLE 12

CREW SUPPORT ROM ESTIMATE

LEO CONSTRUCTION

Crew Size = 541	
Total Staff = 2 (541) + 10% =	1190
Cost \$120K/Man-Year =	\$143M
Crew Support 10X Working	
Crew = 5410 (on ground)	
@ \$50K/Man-Year	\$271M
Training, etc. (20%)	<u>\$83M</u>
	497M

GEO CONSTRUCTION

Crew Size = 551
By Ratio, Cost is \$506M

THERMAL ENGINE LEO CONSTRUCTION

Crew Size = 811
By Ratio, Cost is \$745M

There is an estimated additional \$4M operations support per SPS
for LEO construction to accommodate the more complex operations.

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TABLE 13

NUMBERS OF FLIGHTS & COSTS SUMMARY

HLLV Cost/Flt = 67.56 X (Annual Rate) - .2715

	<u>Cost</u>			
	1 SPS/Yr		4 SPS/Yr	
	LEO	GEO	LEO	GEO
1. P/V Hardware				
● Mass is 77,000 Tons				
● HLLV Payload is 391 Tons				
● 10% for Packaging				
Flights = 217 (GEO)	3139	2415	2155	1658
= <u>228</u> (LEO - 5% Oversize)				
2. Orbit Transfer Sys (LEO)				
Mass is 12,236 tons				
(Total SPS)				
10% for packaging				
35 Flights (LEO)	482	--	330	--
3. OTV's				
217 trips to GEO				
wears out 4.34 vehicles	-	48	-	33
= 4.34 flights (GEO)				
4. Propellant for OTS	1074	--	737	
OTS = 3620 ton/module				
x 8 modules & 5% boiloff				
= 30408 tons ~ tanks are in OTS above				
= 78 flights (LEO)				
5. Propellant for OTV's				
● Factor = 2.075 (includes boiloff but not tanker)				
● Mass is 77,000 tons + 10% packaging				
● Allow 15% for tankers, transfer & boiloff				
<u>517 flights</u> (GEO)	--	5754	--	3950

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TABLE 13 (Continued)

6. OTV Cargo	(0)	(868)	(0)	(499)
None (LEO)	0	0		
217 Flights		868		499
(GEO)				
7. Crew Rotation & Resupply	(476)	(695)	(234)	(382)
Shuttle (\$12M/Flt, 1 SPS per yr)	336	336		
Advanced Shuttle (\$5M/Flt, 4 SPS/Yr)			140	140
28 Flights per SPS				
HLLV - Supplies				
5 Flights LEO	69	44	47	31
4 Flights GEO				
HLLV Tanker 5 (LEO)	69	267	47	183
24 (GEO)				
OTV Flights 4 (LEO)	16		9	
12 (GEO)		48		28
OTV @ \$4M/Flt 1 SPS/Yr				
& 2.3M/Flt 4 SPS/Yr				
Total HLLV Flights	351	766	1404	3064
\$/Flt	13.77	11.13	9.45	7.64
8. OTS Hardware	1260		723	
(From Table 14 with growth deleted)				

TABLE 14
SELF-POWER ORBIT TRANSFER SYSTEM MATURE INDUSTRY COST ESTIMATE

ITEM & MASS (LB)	#	SLOPE	PCM UNIT COST	PCM TFU (1 OTS)	FULLY LEARNED UNIT	TOTAL	MATURE INDUSTRY @ 1 SPS/YR (8 OTS)	MATURE INDUSTRY @ 4 SPS/YR	\$/KG
0's System							1,458,160	836,643	
							69,436	39,840	
O.S							1,388,724	796,803	
Thruster Panel (13,532,000)							790,432	440,177	
Panel Struc (1540 LB)	192	.85	641		127	24,364	17,583	8,792	\$131
Thrusters (110 LBS)	26,800	.85	409		81	2,176,490	132,752	66,376	\$ 98
Processors (18,230 LBS)	384	.85	6,151		1,217	467,607	238,624	119,312	\$ 75
Switchgear (660 LBS)	1920	.85	2,120		420	805,826	183,903	91,952	\$320
Interrupter (50 LBS)	26,880	.85	244		48	1,298,444	79,197	79,197	\$130
Interrupter (2 LBS)	26,880	.85	16		3.17	85,143	5,193	2,596	\$212
Cabling (1500 LBS)	192	.85	3,496		692	132,835	95,901	47,950	\$734
Instrum (200 LBS)	192	.85	968		192	36,794	26,554	13,277	1524
Prop Sys (1500 LBS)	192	.85	391		77	14,862	10,725	10,725	82

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TABLE 14 (Continued)

ITEM & MASS (LB)	#	SLOPE	PCM UNIT COST	PCM TFU (1 OTS)	FULLY LEARNED UNIT		MATURE INDUSTRY @ 1 SPS/YR (8 OTS)	MATURE INDUSTRY @ 4 SPS/YR	\$/KG
						TOTAL			
Thrust. Frame (6160 LBS)	32	.85	2,069		410	13,104	<u>23,170</u>	<u>11,585</u>	\$260
Gimbal Assy (6160 LBS)	32	.85	11,876		2,351	75,235	<u>133,000</u>	<u>66,500</u>	\$1487
Computer (100 LBS)	32	.85	2,448		484	15,508	<u>27,415</u>	<u>13,707</u>	18,000
Communic (100 LBS)	32	.85	1,718		340	10,883	<u>19,240</u>	<u>9,620</u>	13,000
Standoff Str (10,000 LBS)	32	.85	3,117		617	19,746	<u>34,907</u>	<u>17,454</u>	240
Argon Tks (40,000 LBS)	32	.85	6,801		1,346	43,085	<u>76,164</u>	<u>38,082</u>	131
LO ₂ Tks (16,000 LBS)	32	.85	3,106		615	19,677	<u>34,784</u>	<u>17,392</u>	149
LH ₂ Tks (16,000 LBS)	32	.85	2,078		411	13,164	<u>23,271</u>	<u>41,636</u>	160
Tank Insul.	16	.90	1,083		378	6,063	<u>15,159</u>	<u>7,580</u>	2
Prop. Sys. (10,000 LBS)	32	.85	1,443		285	9,141	<u>16,160</u>	<u>16,160</u>	111
Chem. Thr. (1000 LBS)	96	.85	74		14	1,406	<u>1,435</u>	<u>1,435</u>	
TCS/RAD (8680 LBS)	384	.85	4,027		797	306,138	<u>156,225</u>	<u>78,113</u>	103
Pwr. Distr. (41,830 LBS)	160	.85	1,492		295	47,260	<u>37,362</u>	<u>37,362</u>	12

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Table 15 Parametric Cost Model Output for Orbit Transfer System

NO	NAME	SUB ELEMENT METHOD TO	SOUR- CES	BLEND FACTORS	SUPT OTS FROM X	OTS X	MOD CMPLX	MOD NUMBER	LRN X	COST (000)
1	TOTAL PROGRAM	0	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0.00	0 0	0 0	0.0 0.0		1,430,785 1,479,087
2	PROG INTEG & MGMT	1	DDT&E FACTOR OPCODE= 2 UNIT FACTOR OPCODE= 2	3 3	0.06 0.06	0 0	0 0	0.0 0.0		40,535 79,610
3	OTS INSTL	1	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0.00	0 0	0 0	0.0 0.0		1,390,249 1,399,476
4	FLT SYS D&D	3	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0.00	0 0	0 0	0.0 0.0		211,482 1,217,131
5	SUSTAINING	3	DDT&E FAC UN OPCODE= 3 UNIT N/A OPCODE= 8	4 0	0.05 0.00	0 0	0 0	0.0 0.0		42,401 0
6	SE & I	3	DDT&E CERN OPCODE= 12 UNIT N/A OPCODE= 6	4 32 0	0.00 0.00 0.00	0 0 0	0 0 0	0.0 0.0 0.0		19,141 0

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Table 15 (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	X	X	X	CMPLX	X	(000)
7	FLT S'S DDT&T	0	DDT&E FACTOR OPCODE= 2	4 6 9	1.00 1.00 1.00	0	0	0	0	0.0		0
			UNIT N/A OPCODE= 8	0	0.00	0				0	0	0
8	SYSTEM TEST	3	DDT&E SUBS OPCODE= 0	0	0.00	0	0	0	0	0.0		905,635
			UNIT N/A OPCODE= 6	0	0.00	0				0	0	0
193	9 SYS TEST LBR	8	DDT&E CERN OPCODE= 12	4 34	0.00 0.00	0	0	0	0	0.0		154,303
			UNIT N/A OPCODE= 8	0	0.00	0				0	0	0
10	GR TEST HDWE	8	DDT&E FAC UN OPCODE= 3	4	0.30	0	0	0	0	0.0		365,139
			UNIT N/A OPCODE= 8	0	0.00	0				0	0	0
11	FLT TEST HDWE	8	DDT&E FAC UN OPCODE= 3	4	0.30	0	0	0	0	0.0		365,139
			UNIT N/A OPCODE= 8	0	0.00	0				0	0	0
12	SOFTWARE ENGR	3	DDT&E CERN OPCODE= 12	7 37	0.00 0.00	0	0	0	0	0.0		94,321
			UNIT N/A OPCODE= 8	0	0.00	0				0	0	0

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Table 15 (continued)

NO	NAME	SUB ELEMENT TO	METHOD SOUR- CES	BLEND FACTORS	SURF FROM	OTS X	MOD X	MOD CMPLX	NUMBER X	COST (000)
13	GSE		3 DDT&E FACTOR OPCODE= 2 UNIT FACTOR OPCODE= 2	4 4	0.10 0.10	0 0	0 0	0 0.0	25 100	25,724 91,061
14	TOOLING		3 DDT&E FACTOR OPCODE= 2 UNIT N/A OPCODE= 8	4 0	0.25 0.00	0 0	0 0	0 0.0	0 0	91,542 0
15	ASSY & C/O		3 DDT&E N/A OPCODE= 8 UNIT FAC UN OPCODE= 3	0 4	0.00 0.07	0 C	0 0	0 0.0	0 0	0 91,284
16	THRUSTER PANEL		4 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0.00	0 0	0 0	0 0.0	24 24	73,114 70,031
									AGGREGATED VALUES	1,003,973
17	PANEL STRUCT 1540 LBS		16 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1 46	1.00 1.00	30 45	0 0	0 0.0	1 100	1,572 641
18	THRUSTERS 110 LBS		16 DDT&E CEP OPCODE= 1 UNIT CEP OPCODE= 1	21 66	1.00 0.25	31 45	0 0	0 0.0	140 84	8,321 409
									AGGREGATED VALUES	23,226

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Table 15 (continued)

NO	NAME	SUB ELEMENT TO	METHOD CES	SOUR- FACTORS	BLEND FROM	SUPT X	OTS X	MOD X	MOD CMPLX	NUMBER X	LRN X	COST (000)
19	PROCESSORS 18230 LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	7 52	1.00 0.50	29 45	0 0	0 0	0.0 5.0			48,492 6,151 11,395
										AGGREGATED VALUES		
20	SWITCHGEAR 660 LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	14 59	1.00 1.00	30 45	0 0	50 84	5.0 10			2,648 2,120 15,097
										AGGREGATED VALUES		
195	INTERRUPTER 50 LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	14 59	1.00 1.00	30 45	0 0	0 0	0.0 5.0			428 244 13,877
										AGGREGATED VALUES		
22	INTERRUPTER 2 LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	14 59	1.00 1.00	30 45	0 0	0 0	0.0 5.0			32 16 937
										AGGREGATED VALUES		
23	CABLING 1500 LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	13 58	1.00 1.00	29 45	0 0	0 0	0.0 5.0			3,804 3,496
										AGGREGATED VALUES		
24	INSTRUM 200 LBS	16	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	15 60	1.00 1.00	30 45	0 0	0 0	0.0 5.0			3,218 968
										AGGREGATED VALUES		

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Table 15 (continued)

NO	NAME	SUB ELEMENT METHOD TO	SOUR- CES	BLEND FACTORS	SUPT FROM	OTS X	MOD X	MOD CMPLX	NUMBER LRN X	COST (000)
25	PROP SYS 1500 LBS	16 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	40 76	1.00 1.00	30 45	0 0	0 0.0			4,576
								1 100		392
26	THRUSTER FRAME 6160 LBS	4 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1 46	1.00 1.00	29 45	0 0	0 0.0			5,214
								4 84		2,069
								AGGREGATED VALUES		6,932
27	GIMBAL ASSY 6160 LBS 196	4 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	2 6 47 51	0.75 0.25 0.75 0.25	30 30 45	0 0	0 0.0			46,039
								4 84		11,876
								AGGREGATED VALUES		39,782
28	COMPUTER 100 LBS	4 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	19 64	1.00 1.00	30 45	0 0	30 5.0			12,614
								4 84		2,448
								AGGREGATED VALUES		8,200
29	COMMUNIC 100 LBS	4 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	16 61	1.00 1.00	30 45	0 0	50 5.0			7,328
								4 84		1,718
								AGGREGATED VALUES		5,754
30	STANDOFF STR 10000 LBS	4 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1 46	1.00 1.00	29 45	0 0	50 5.0			6,279
								4 84		3,117
								AGGREGATED VALUES		10,443

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Table 15 (continued)

NO	NAME	SUB ELEMENT TO	METHOD	SOUR- CES	BLEND FACTORS	SUPPLY FROM	OTS	MOD X	MOD CMPLX	NUMBER X	LRM X	COST (000)
31	ARGON TANKS 40000 LBS		8 DDT&E CER OPCODE= 1	81	1.00	29	0	0	0.0			21,053
			UNIT CER OPCODE= 1	82	1.00	45				4 84		6,801
										AGGREGATED VALUES		22,783
32	L02 TANKS 16000 LBS		6 DDT&E CER OPCODE= 1	81	1.00	29	0	0	0.0			9,184
			UNIT CER OPCODE= 1	82	1.00	45				4 84		3,106
										AGGREGATED VALUES		10,406
33	LH2 TANKS 10000 LBS		4 DDT&E CER OPCODE= 1	81	1.00	29	0	0	0.0			6,004
			UNIT CER OPCODE= 1	82	1.00	45				4 84		2,078
										AGGREGATED VALUES		6,962
34	TANK INSUL 2200 SQ FT		4 DDT&E CER OPCODE= 1	8	1.00	30	0	0	0.0			3,655
			UNIT CER OPCODE= 1	53	1.00	45				16 84		104
										AGGREGATED VALUES		1,083
35	PROPELLANT SYS 10000 LBS		4 DDT&E CER OPCODE= 1	40	1.00	30	0	0	0.0			12,521
			UNIT CER OPCODE= 1	76	1.00	45				4 84		1,443
										AGGREGATED VALUES		4,834
36	CHEM THRUST 1000 LBF		4 DDT&E CER OPCODE= 1	42	0.50	31	0	0	0.0			11,444
			UNIT CER OPCODE= 1	78	0.50	45				12 89		74

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Table 15 (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	X	X	X	CHPLX	X	(000)
37	TCS/RADIATORS 8680 LBS	4 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	9	1.00	29	0	75	3.0				12,403
				0.50	45				48	84		4,027
											AGGREGATED VALUES	99,562
38	POWER DISTR 41830 LBS	4 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1	0.10	29	0	0	0.0				3,677
				0.10	45				20	84		1,492
											AGGREGATED VALUES	18,513

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TABLE 16

CREW ROTATION/RESUPPLY

Launches Per Year

	<u>LEO Const.</u>		<u>GEO Const</u>	
	<u>P/V</u>	<u>T/E</u>	<u>P/V</u>	<u>T/E</u>
Shuttle Growth (Crew to LEO)	28	44	28	
HLLV-Supplies	4	6	4	
HLLV-Tanker	5	5	24	
OTV	4	4	12	

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TABLE 17

GROWTH CALCULATIONS

Growth is Applied to:

SPS
Construction/Space Support
Space Transportation
Pro Rata Share of Interest During Construction

	1 SPS/Yr		4 SPS/Yr	
	LEO	GEO	LEO	GEO
SPS	7442	7190	5587	5378
Constr/Space Sup	1109	1126	1109	1126
Space Trans	6445	9780	4188	6522
Pro Rata IDC	1437	1114	842	651
Subtotal	16433	19210	11726	13677
Mass Growth	26.6%	26.6%	10%	10%
Cost Growth Equiv.	21%	21%	8%	8%
Cost Growth Amount	3450	4034	938	1094

TABLE 18 LEO/GEO DIFFERENCES

RFP REF	ITEM	RATIONALE	DELTA COST IN MILLIONS PER SPS (GEO - LEO)	
			RECURRING (4 SPS/YR)	INITIAL NON- RECURRING
a)	Transportation Requirements (Includes Crew)	<ul style="list-style-type: none"> o HLLV Launch Rate, 1400/Yr VS 3064/Yr P 4 Yr o 350/Yr VS 766/Yr P 1/Yr o See Also Table 1 	Net = 2,343	-1,431 (OTS) 2,223 (Fleet Invoice)
b)	Construction Requirements	<ul style="list-style-type: none"> o See Tables 1,7,8,9,10,11 for Facility Delta Costs o Stationkeeping Propellant 800 Kg/day - 292 Tons/Yr o Crew Support o Oversizing for Radiation Degradation o Delta Structural Mass - 854 Tons for GEO (See Table 4, Sheet 2) o Satellite Mods. for OTS Included in OTS Costs o Included in SPS Design Requirements (Oversizing Compensates for Output and Mismatch Loss) o Higher Launch Rate for GEO (See (a)) 	24 -9 9 -139 -70	530
c)	SPS Design Requirements			-350 -175
d)	Degradation Potential			
e)	Launch Site Differential Effects			1,715 Launch Facility Costs
f)	Startup	<ul style="list-style-type: none"> o Orbit Transfer Hardware Elements Included in OTS Cost o Delta Interest During Construction 	-303	
g)	Operations Considerations	<ul style="list-style-type: none"> o Can't Reuse Packaging Materials and Pallets for GEO (Not Quantified) o No Difference In Numbers of Vehicles in Flight. More Complex Monitoring for OTS. o Docking Equipment Included in GEO Facility for LEO Construction o Estimated Collision Avoidance Propellant 32 Tons/Yr o Object Monitoring Cost o Other Factors Itemized in This Table o Delta Growth (Factor on Delta Cost) o Hardware/Software Costs Reflected as OTS Costs o Software Preliminary Design Incorporated In Existing Simulations 	-10 -1 -5 156 -	
i)	Cost Differentials			
j)	Orbit Transfer Complexity			
TOTAL COST DIFFERENTIALS			1,995	2,512

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3.3 REFERENCE THERMAL ENGINE

Cost Data Package

Table 19 provides a cost summary and references the backup substantiation material. Tables 20 through 27.

TABLE 19 CAPITAL COST SUMMARY-THERMAL ENGINE SPS (RANKINE)

DOLLARS IN MILLIONS

WBS NUMBER	ITEM NUMBER	SOURCES AND REFERENCES	1 SPS/YR		4 SPS/YR	
			LEO CONSTRUCTION	GEO CONSTRUCTION	LEO CONSTRUCTION	GEO CONSTRUCTION
1.01	Solar Power Satellite	o Mature Industry Estimate, Table 20	(7,987)	(7,987)	(5,284)	(5,284)
1.01.00	Multiple/Common and Pkg'g Energy Collection	o PCM Run, Table 21	1,196	1,196	846	846
		o General Electric Turbine, Generator, & Pump Cost Estimates	374	374	374	374
	Energy Conversion	o Structural Mfr. Estimate, 9th MPR	3,365	3,365	1,890	1,890
	Power Distribution	o Varian Analysis of Klystron Production	376	376	222	222
	Microwave Power Transmission	o MPTS Error Analysis	2,676	2,676	1,952	1,952
		o SPS Mass Estimate, Table 22				
1.02	Ground Receiving Station	(Same as Photovoltaic)	(4,446)	(4,446)	(4,000)	(4,000)
2.00	Construction & Space Support		(1,716)	(1,768)	(1,716)	(1,768)
..01	Construction Base (Facility Writedown)	Writedown Summary, Table 23 Facility Mass & Cost Estimates Tables 24 and 25	971	1,010	971	1,010
2.02	Space Support					
2.02.01	Staging Base	(Same as P/V)	N/A		N/A	
2.02.02	Crew Support	o Crew Support ROM Estimates, Table 12	745	758	745	758
		o Crew Requirements from Construction Analyses (Part I Vol. III and Part II Vol. IV)				
2.02.03	Other OPS Support		16		16	
3.00	Space Transportation	o Numbers of Flights and Costs Summary, Table 26	(7,425)	(11,182)	(4,678)	(7,275)
3.01	Earth - Leo					
3.01.01	Freight	o Other References Same as Photovoltaic	3,900	3,270	2,527	2,095
3.01.02	Crew		528	528	220	220
3.02	LEO - GEO		181	533	141	357
3.02.01	Freight		2,816	6,851	1,790	4,603
3.02.02	Crew					
	Interest During Construction		(700 Days) (2,068)	(450 Days) (1,563)	(566 Days) (1,215)	(366 Days) (916)
	Growth	Table 27				
			(2,946)	(3,489)	(755)	(903)
			TOTALS	26,588	30,435	17,648
						20,146

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TABLE 20
MATURE INDUSTRY ESTIMATE, THERMAL ENGINE SPS

ITEM & MASS (LB)	#	SLOPE	PCM UNIT COST	PCM TFU	FULLY LEARNED UNIT		MATURE INDUSTRY @ 1 SPS/yr	MATURE INDUSTRY @ 4 SPS/yr	\$/KG
						TOTAL			
T/E SPS							<u>5,311,168</u>	<u>3,341,927</u>	
Other							<u>252,913</u>	<u>159,139</u>	
Mult/Com							<u>942,079</u>	<u>686,546</u>	
Prim. Struc (8537 LBS)	200	.85	2,727	203,993	540	107,974	<u>76,340</u>	<u>46,744</u>	98
Att. Control							<u>451,852</u>	<u>229,925</u>	
Thrusters (110 LBS)	5120	.85	1,328	1,198,036	263	1,346,084	188,121	94,060	\$736
Processors (12,000 LBS)	96	.85	6,248	264,920	1237	118,745	121,194	60,597	231
Structure (10,000 LB)	32	.85	7,505	135,001	1485	47,545	84,048	42,024	579
Tanks (1130 LB)	64	.85	1,040	32,174	205	13,177	16,471	8,235	502
Instrum (1000 LBS)	32	.85	3,752	67,500	743	23,769	42,018	21,009	2,895
Central Compute (700 LBS)	3	1.0	12,430	37,291	--	--	<u>37,291</u>	<u>37,291</u>	
Communic (2000 LBS)	3	1.0	24,576	73,729			<u>73,729</u>	<u>73,729</u>	
Ant. Yoke (258,000 LBS)	2	.85	163,474	302,857			<u>302,857</u>	<u>302,857</u>	1,294

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TABLE 20 (Continued)

ITEM #	MASS (LB)		SLOPE	PCM UNIT COST	PCM TFU (1 MPTS)	FULLY LEARNED UNIT	TOTAL	MATURE INDUSTRY @ 1 SPS/YR (2 MPTS)	MATURE INDUSTRY @ 4 SPS/YR	\$/KG
Energy Cell								<u>374,456</u>	<u>374,456</u>	
Concent								<u>374,456</u>	<u>374,456</u>	
Structure (8537 LBS)	1600	.85	2727		119,349	540	863,792	310,000	310,000	50
Facets (35 lbs)	116,000	.85	44			8.7	1,010,450	64,456	64,456	36
Energy Conversion								<u>3,365,444</u>	<u>1,899,974</u>	
Cavity (137,779 lbs)	16				297,547			<u>297,547</u>	<u>297,547</u>	298
Boiler (12,615 lb)	576	.85	25,079			4964	2,859,808	<u>1,191,587</u>	<u>595,793</u>	361
CPC/Door (20,250 lbs)	16	.85	26,669		277,050	5279	84,475	<u>211,188</u>	<u>105,594</u>	1436
Turbines (52,646 lb)	576	.85	23,199			4592	2,645,428	<u>1,102,262</u>	<u>551,130</u>	80.1
Generators (9600 lbs)	576	.85	6,397			1266	729,463	<u>303,942</u>	<u>151,971</u>	121
Pumps (3766 lb)	576	.85	3,150			624	359,200	<u>145,667</u>	<u>74,833</u>	152
Radiator Manifold (8587 Lb)	32	.85	2,094			415	13,265	<u>109,251</u> <u>23,450</u>	<u>97,526</u> <u>1,725</u>	188

TABLE 20 (Continued)

ITEM & MASS (LB)	#	<u>SLOPE</u>	PCM UNIT COST	PCM TFU (1 MPTS)	FULLY LEARNED UNIT		MATURE INDUSTRY @ 1 SPS/YR (2 MPTS)	MATURE INDUSTRY @ 4 SPS/YR	\$/KG
						TOTAL			
H. P. Panels (98 LB)	192960	.85	59		11.7	2,253,842	85,801	85,801	10
Potassium (13.36E6LB)							25,880	25,880	4
Power Distr.							<u>376,276</u>	<u>221,812</u>	
Switchgear (1320 LB)	304	.85	3787	449,414	749	272,898	<u>143,038</u>	<u>71,519</u>	655
Busses (150,000 LB)	364	.85	4392	521,153	869	316,495	<u>165,289</u>	<u>82,944</u>	67
Rotary Joint (57,000 LB)	2	.85	36,353	67,349			<u>67,349</u>	<u>67,349</u>	1302

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Table 21 Parametric Cost Model Output for Thermal Engine SPS

NO	NAME	SUB ELEMENT METHOD SOUR- TO	BLEND CES	SUPT FACTORS	OTS FROM X	MOD X	MOD CMPLX	NUMBER X	LBN X	COST (000)
1	TOTAL PROGRAM	0 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0	0.00	0	0	0	0.0		5,277,159
			0	0.00	0			0	0	24,884,144
2	PROG INTEG & MGMT	1 DDT&E FACTOR OPCODE= 2 UNIT FACTOR OPCODE= 2	3	0.06	0	0	0	0.0		284,913
			3	0.06	0			0	0	1,292,617
207										
3	TE SPS	1 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0	0.00	0	0	0	0.0		4,992,249
			0	0.00	0			0	0	22,711,536
4	FLT SYS D&D	3 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0	0.00	0	0	0	0.0		1,159,597
			0	0.00	0			0	0	19,751,440
5	SUSTAINING	3 DDT&E FAC UN OPCODE= 3 UNIT N/A OPCODE= 8	4	0.05	0	0	0	0.0		688,434
			0	0.00	0			0	0	0
6	SE & I	3 DDT&E CERN OPCODE= 12 UNIT N/A OPCODE= 8	4	0.00	0	0	0	0.0		86,255
			32	0.00						0
			0	0.00	0			0	0	0

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TABLE 21 (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST
		TO		CFS	FACTORS	FROM	X	X	X	X	X	(000)
7	FLT SYS DDT&T	0	DDT&E FACTOR	4	1.00	0	0	0	0.0			0
			OPCODE=	2	1.00							
				9	1.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE=	8								
8	SYSTEM TEST	0	DDT&E SUBS	0	0.00	0	0	0	0.0			1,815,267
			OPCODE=	0								
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE=	8								
9	SYS TEST LBR	0	DDT&E CERN	6	0.00	0	0	0	0.0			1,420,239
208			OPCODE=	12	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE=	8								
10	GR TEST HDWE	0	DDT&E FAC UN	4	0.01	0	0	0	0.0			197,814
			OPCODE=	3								
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE=	8								
11	FLT TEST HDWE	0	DDT&E FAC UN	4	0.01	0	0	0	0.0			197,814
			OPCODE=	3								
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE=	8								
12	SOFTWARE ENGR	0	DDT&E CERN	7	0.00	0	0	0	0.0			366,471
			OPCODE=	12	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE=	8								

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TABLE 21 (continued)

NO	NAME	SUB ELEMENT METHOD TO	SOUR- CES	BLEND FACTORS	SUPT OFS	MOD X	MOD X COMPLX	MURDER LEN X	COST (000)
13 GSE		3 DOT&E FACTOR OPCODE= 2 UNIT FACTOR OPCODE= 2	4	0.10	0	0	0	0.0	148,343
			4	0.10	0			1 100	1,478,733
14 TOOLING		3 DOT&E FACTOR OPCODE= 2 UNIT N/A OPCODE= 8	4	0.25	0	0	0	0.0	527,886
			8	0.80	0			0 0	0
15 ASSY & C/O		3 DOT&E N/A OPCODE= 8 UNIT FAC UN OPCODE= 3	8	0.00	0	0	0	0.0	0
			4	0.97	0			0 0	1,481,336
16 MULT/COMMON		4 DOT&E SUBS OPCODE= 8 UNIT SUBS OPCODE= 8	8	0.00	0	0	0	0.0	311,613
			0	0.00	0			0 0	2,812,643
17 PRIM STRUC		16 DOT&E CEE OPCODE= 1 UNIT CEE OPCODE= 1	1	1.00	30	0	0	0.0	7,363
8537 LBS			46	1.00	45			200 84	2,727
								AGGREGATED VALUES	283,993
18 ATT CONTROL		16 DOT&E SUBS OPCODE= 8 UNIT SUBS OPCODE= 8	8	0.00	0	0	0	0.0	91,887
			0	0.00	0			0 0	1,697,632

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TABLE 21 (continued)

NO	NAME	SUB ELEMENT METHOD SOUR- TO	CES	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST (000)
					X	X	X	X	X	X	
19	THRUSTERS										
110	LBS	18 DDT&E CER OPCODE= 1	21	1.00	31	0	0	0.0			8,321
		UNIT CER OPCODE= 1	66	1.00	45				3120	84	1,326
									AGGREGATED VALUES		1,198,036
20	PROCESSORS										
12000	LBS	18 DDT&E CER OPCODE= 1	14	1.00	31	0	30	5.0			33,627
		UNIT CER OPCODE= 1	39	0.20	45				96	84	6,248
									AGGREGATED VALUES		264,920
210	STRUCTURE										
10000	LBS	18 DDT&E CER OPCODE= 1	2	1.00	30	0	0	0.0			30,967
		UNIT CER OPCODE= 1	47	1.00	45				32	84	7,505
									AGGREGATED VALUES		135,001
22	TANKS										
1130	LBS	18 DDT&E CER OPCODE= 1	2	1.00	30	0	0	0.0			4,971
		UNIT CER OPCODE= 1	47	1.00	45				64	84	1,040
									AGGREGATED VALUES		32,174
23	INSTRUM										
1000	LBS	18 DDT&E CER OPCODE= 1	15	1.00	31	0	0	0.0			23,999
		UNIT CER OPCODE= 1	60	1.00	45				32	84	3,752
									AGGREGATED VALUES		67,500
24	CENTRAL COMPUTE										
700	LBS	16 DDT&E CER OPCODE= 1	19	1.00	31	0	0	0.0			95,701
		UNIT CER OPCODE= 1	64	1.00	45				3 100		12,430

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TABLE 21 (continued)

NO	NAME	SUB ELEMENT METHOD TO	SOUR- CES	BLEND FACTORS	SUPT FROM	OTS X	MOD X	MOD CHPLX X	NUMBER LRN X	COST (000)
25 COMMUNIC 2000	LBS	16 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	16	1.00	31	0	0	0.0		136,668
			61	1.00	45				3 100	24,376
									AGGREGATED VALUES	73,729
26 POW GEN MOD 0		4 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0	0.00	0	0	0	0.0		462,406
			0	0.00	0				16 84	1,875,991
									AGGREGATED VALUES	26,372,154
27 CONCENTRATOR 0		26 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0	0.00	0	0	0	0.0		5,091
211			0	0.00	0				0 0	171,851
28 STRUCTURE 8537	LBS	27 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1	1.00	29	0	50	3.0		4,819
			46	1.00	45				100 84	2,727
									AGGREGATED VALUES	119,349
29 FACETS 35	LBS	27 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	2	1.00	30	0	0	0.0		272
			47	1.00	45				7250 84	44
									AGGREGATED VALUES	52,501
30 CAVITY 137779	LBS	26 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1	1.00	30	0	0	0.0		91,029
			46	1.00	45				1 100	28,642

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TABLE 21 (continued)

NO	NAME	SUB ELEMENT	METHOD	SOUR-	BLEND	SUPT	OTS	MOD	MOD	NUMBER	LRN	COST
		TO		CES	FACTORS	FROM	X	X	X	CMPLX	X	(000)
31	BOILER 12615 LBS	26	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	2 47	3.00 3.00	30 45	0 0	0 36	0 84	0 100	0 LRN	94,775 28,079 494,844
												AGGREGATED VALUES
32	CPC/DOOR 20250 LBS	26	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	2 47	2.00 2.00	30 45	0 0	0 36	0 84	0 100	0 LRN	100,336 26,669
212												
33	TURBINES 52646 LBS	26	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	7 52	1.00 1.00	29 45	0 0	0 36	0 84	0 100	0 LRN	110,526 23,199 457,744
												AGGREGATED VALUES
34	GENERATORS 9600 LBS	26	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	7 52	1.00 1.00	29 45	0 0	0 36	0 84	0 100	0 LRN	29,480 6,397 126,228
												AGGREGATED VALUES
35	PUMPS 3766 LBS	26	DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	7 52	1.00 1.00	29 45	0 0	0 36	0 84	0 100	0 LRN	14,272 3,150 62,163
												AGGREGATED VALUES
36	RADIATOR 0	26	DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0.00	0 0	0 0	0 36	0 84	0 100	0 LRN	16,894 10,534 207,047
												AGGREGATED VALUES

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TABLE 21 (continued)

NO	NAME	SUB ELEMENT METHOD TO	SOUR- CES	BLEND FACTORS	SUPT FROM X	OTS X	MOD CHPLX	MOD %	NUMBER LRN X	COST (\$000)
37	MANIFOLDS 8587 LBS	36 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	40 76	2.00 29 2.00 45	0 0	0 0	0.0 0.0	0.0 0.0	15,857 2,094	15,857 2,094
									AGGREGATED VALUES	3,880
38	H. P. PANELS 98 LBS	36 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	40 76	1.00 29 1.00 45	0 0	0 0	0.0 0.0	0.0 0.0	1,037 59	1,037 59
213									AGGREGATED VALUES	6,654
39	POWER DISTR 0	4 DDT&E SUBS OPCODE= 0 UNIT SUBS OPCODE= 0	0 0	0.00 0 0.00 0	0 0	0 0	0.0 0.0	0.0 0.0	145,334 1,037,916	145,334 1,037,916
40	SWITCHGEAR 1320 LBS	39 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	14 59	1.00 30 1.00 45	0 0	0 0	0.0 0.0	0.0 0.0	5,947 3,787	5,947 3,787
									AGGREGATED VALUES	449,614
41	BUSES 150000 LBS	39 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	1 46	0.10 29 0.10 45	0 0	0 0	0.0 0.0	0.0 0.0	11,651 4,392	11,651 4,392
									AGGREGATED VALUES	521,153
42	ROTARY JOINT 57000 LBS	39 DDT&E CER OPCODE= 1 UNIT CER OPCODE= 1	2 47	1.00 29 1.00 45	0 0	0 0	0.0 0.0	0.0 0.0	127,735 36,353	127,735 36,353

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TABLE 21 (continued)

NO	NAME	SUB ELEMENT TO	METHOD	SOUR- CES	BLEND FACTORS	SUPT FROM	OTS X	MOD X	MOD CMPLX	NUMBER	LRN X	COST (000)
43	ANT YOKE		4 DDT&E CER	1	0.90	29	0	0	0.0			240,243
258000	LBS		OPCODE= 1	5	0.10							
			UNIT CER	47	0.90	45				2	84	163,474
			OPCODE= 1	50	0.10							
											AGGREGATED VALUES	302,857
44	POTASSIUM		4 DDT&E N/A	0	0.00	0	0	0	0.0			0
13355500	LBS		OPCODE= 8									
			UNIT CER	46	0.01	0				1	100	25,880
			OPCODE= 1									

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TABLE 22
THERMAL ENGINE MASS STATEMENT

<u>Values are Thousands of Metric Tons</u>		
1.0.	SPS	<u>80,170</u>
1.01.00	Mult/Common Use Equipment	<u>2,662</u>
1.01.00.00	Primary Structure	774
1.01.00.01	Satellite Control	1,450
1.01.00.02	Com and Data	4
1.01.00.03	Mech Sys. and Other	200
1.01.00.04	Antenna Yoke	234
1.01.01	Energy Collection	<u>8,091</u>
1.01.01.00	Support Structure	6,254
1.01.01.01	Facets	1,837
1.01.02	Energy Conversion:	<u>40,084</u>
1.01.02.00	Support Str	0 (included in primary structure)
1.01.02.01	CPC and Light Doors	324
1.01.02.02	Cavity Absorber	1,000
1.01.02.03	Thermal Engines	21,933
	Boilers	3,296
	Turbines	13,755
	Generators and Coolers	3,648
	Pumps	1,234
1.01.02.04	Radiators	10,769
1.01.02.05	Fluids	6,058
1.01.03	Power Distr.	<u>4,978</u>
1.01.04	MPTS	<u>24,355</u>

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TABLE 23
CONSTRUCTION BASIC WRITEDOWN SUMMARY
THERMAL ENGINE SPS
LEO CONSTRUCTION

ITEM	COST (MILLIONS)	AMORTIZED OVER	COST/SPS (MILLIONS)
<u>LEO BASE</u>			
Facility	4,670	25 Years	187
Facility Wrap	2,185	25 Years	87
Equipment	2,930	8 Years	366
Equipment Wrap	1,370	8 Years	171
<u>GEO BASE</u>			
Facility	600	25 Years	24
Facility Wrap	280	25 Years	11
Equipment	250	8 Years	31
Equipment Wrap	115	8 Years	14
<u>LEO BASE TRANSPORT</u>	995	15 Years	66
<u>GEO BASE TRANSPORT</u>	207	15 Years	<u>14</u>
			971

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TABLE 24
T/E CONSTRUCTION BASE COST SUMMARY
FIRST SET
(Dollars in Millions)

LEO BASE	(11,155)
FACILITY	4,670
CONSTRUCTION & SUPPORT EQUIPMENT	2,930
WRAP-AROUND	3,555
GEO BASE	(1,245)
FACILITY	600
CONSTRUCTION & SUPPORT EQUIPMENT	250
WRAP-AROUND	395

	(\$12,400M)

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TABLE 24 (continued)

TFU COST SUMMARY

FACILITY	\$ <u>10⁶</u>
T/E LEO CONSTRUCTION BASE	
FOUNDATION	400
CREW MODULES	3,600
CARGO HANDLING/DISTRIBUTION	470
BASE SUBSYSTEMS	200
MAINTENANCE PROVISIONS	-
CONSTRUCTION AND SUPPORT EQUIPMENT	(2,920)
STRUCTURE ASSEMBLY	1,420
ENERGY COLLECTION	280
ENERGY CONVERSION	250
POWER DISTRIBUTION	190
SUBARRAY INSTALLATION	90
CRANES/MANIPULATORS	600
INDEXERS	90
BASIC HARDWARE	7,590
SPARES (15%)	1,135
INSTALLATION, ASSEMBLY C/O (16%)	1,210
SE&I (7%)	530
PROJECT MANAGEMENT (2%)	150
SYSTEMS TEST (3%)	225
GSE (4%)	305
TOTAL	\$11,145 M

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TABLE 25
T/E CONSTRUCTION BASE MASS SUMMARY

(10^3 Kg)

LEO CONSTRUCTION BASE		(8,960)
FACILITY	7,615	
CONSTRUCTION AND SUPPORT EQUIPMENT	945	
CONSUMABLES 	400	
GEO FINAL ASSEMBLY BASE		(850)
FACILITY	690	
CONSTRUCTION AND SUPPORT EQUIPMENT	130	
CONSUMABLES 	30	
TOTAL		<hr/> 9,810



90 Days

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Table 25 (continued)

T/E MASS SUMMARY

LEO CONSTRUCTION BASE

10^3kg

FACILITY (7,615)

FOUNDATION	4,000
CREW MODULES	2,600
CARGO HANDLING/DIOTRCK	515
BASE SUBSYSTEMS	400
MAINTENANCE PROVISION	100

CONSTRUCTION AND SUPPORT EQUIPMENT (945)

STRUCTURE ASSEMBLY	500
ENERGY COLLECTION INSTALLATION	75
POWER DISTRIBUTION INSTALLATION	70
SUBARRAY INSTALLATION	30
CRANES/MANIPULATORS	240
INDEXERS	30
TOTAL DRY	8,560

CONSUMABLES (90 Days) 400

8,960

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Table 25 (continued)
T/E MASS SUMMARY

GEO FINAL ASSEMBLY BASE

10³Kg

FACILITY	(690)
FOUNDATION	390
CREW MODULES	220
CARGO HANDLING/DISTRIBUTION	60
BASE SUBSYSTEMS	20
MAINTENANCE PROVISIONS	-
CONSTRUCTION & SUPPORT EQUIPMENT	(130)
CRANES/MANIPULATORS	35
DOCKING CRANES	60
INDEXERS	35
HARDWARE TOTAL	820

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TABLE 26
NUMBERS OF FLIGHTS AND COSTS SUMMARY
HLLV COST/FLT = 67.56 X (ANNUAL RATE) -.2715

	COST			
	1 SPS/YR		4 SPS/YR	
	LEO	GEO	LEO	GEO
1. T/E HARDWARE				
o Mass is 80,170 Tons				
o HLLV Payload is 391 Tons				
o 10% for Packaging				
225 Flights LEO & GEO	3,098	2,468	2,126	1,694
Expendable Shrouds	802	802	401	401
2. ORBIT TRANSFER SYSTEM				
Same as P/V 35 Flights (LEO)	482		330	
3. OTV'S 225 Flights				
Wears Out 4.5 Vehicles 4.5 Flights (GEO)		49		34
4. PROPELLANT FOR OTS				
Same as P/V				
78 Flights LEO	1,074		737	
5. PROPELLANT FOR OTV'S				
Same Rationale as P/V				
538 Flights (GEO)		5,902		4,051
6. OTV CARGO	(0)	(900)	(0)	(518)
(OTV Cost/Flight)				
225 Flights (GEO)	0	900	0	518
7. CREW ROTATION AND RESUPPLY				
Shuttle (\$12M/Flt, 1 SPS/Yr)	528	528		
Advanced Shuttle (\$5M/ Flight, 4 SPS/Yr)			220	220
44 Flights/SPS				

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Table 26 (continued)

	COST			
	1 SPS/YR <u>LEO</u>	4 SPS/Yr <u>GEO</u>	1 SPS/YR <u>LEO</u>	4 SPS/Yr <u>GEO</u>
7. (Continued)				
HLLV - Supplies				
7 Flights LEO	96	66	66	45
6 Flights GEO				
HLLV - Tanker				
5 (LEO)	69		47	
36 (GEO)		395		271
OTV - 18 Flights GEO		72		41
4 Flights LEO	16		28	
OTS Hardware (Refer to P/V)	(1,260)		(723)	
TOTAL HLLV FLIGHTS	350	809	1,400	3,236
DOLLAR/FLIGHT	13.77	10.97	9.45	7.53

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**TABLE 27
GROWTH CALCULATIONS**

Growth is Applied to:

**SPS
Construction/Space Support
Space Transportation
Pro Rata Share of Interest
During Construction**

	<u>1 SPS/YR</u>		<u>4 SPS/YR</u>	
	<u>LEO</u>	<u>GEO</u>	<u>LEO</u>	<u>GEO</u>
SPS	7,987	7,987	5,284	5,284
Construction/Space Support	1,716	1,768	1,716	1,768
Space Transportation	7,425	11,182	4,678	7,275
Pro Rata IDC	1,642	1,289	905	716
SUBTOTAL	18,770	22,226	12,583	15,043
Mass Growth	20%	20%	7.5%	7.5%
Cost Growth Equiv.	15.7%	15.7%	6%	5%
Cost Growth Amount	2,946	3,489	755	903

3.4 NONRECURRING COST

An estimate was made of the nonrecurring costs required to construct the first SPS. In order to accomplish this estimate, it was necessary to invoke certain programmatic assumptions. These do not represent conclusions or recommendations as to how an SPS program should be conducted. There are of course many possible program options; no systematic analysis and comparison has been conducted. The assumptions for nonrecurring cost were:

- o After a technology verification program, involving ground and flight programs but no new space vehicles, development of the 10,000 megawatt SPS, and its associated systems begins.
- o The production capacity initially developed is sized for a production rate of one SPS per year.

Table 3.4-1 presents the principal elements of the nonrecurring estimate, and the sources of data.

**Table 3.4-1
Total Costs Through #1 SPS
(Photovoltaic System)**

Item	Cost (Billions)	Source/Rationale
Technical Verification	3.0	Ground + Flight Verification Program summarized in Volume II Draft
Energy Conversion DDT&E	1.9	p. 121, this volume PCM DDT&E total
Power Transmission DDT&E	1.24	p. 127, this volume PCM DDT&E total
Power Receiver DDT&E	0.25	ROM estimate for diode/dipole/filter assemblies and field tests
SPS Freighter & Tanker Dev't.	8.0	Part I Vol. 5, pp. 31, 47, 50. Sum of DDT&E totals
Crew OTV	1.0	Part I, Vol. 5 with allowance for crew cab
SPS Orbit Transfer System	1.43	Vol. 6 Draft, p. 161, PCM DDT&E total
Construction Base	6.9	Based on JSC estimate
SPS Hardware Production Facilities	10.2	Solar Blankets 5.0 Klystrons 1.5 Structures 1.2 All Other 2.5
SPS Freighter Production	0.70	3x Boeing 747 Plant at Everett, Wash.
Launch Facilities at KSC	4.0	Extrapolation of Part I, Vol. 5, p. 149 to 500 flts/yr
#1 Construction Base	8.8	Vol. 6 Draft p. 145, plus transport cost

Table 3.4-1 (Continued)

Item	Cost (Billions)	Source/Rationale
Initial Fleet	7.4	10 boosters and 11 upper stages to support 500 flts/yr
#1 SPS	<u>28.8</u>	As follows:
Sum	83.62	(1) 1 SPS/yr without growth and interest
		19.442
		(2) Deduct following amortizations:
		Solar blanket plant .60
		Structures plant .02
		Klystron plant .12
		Rectenna factory .25
		Constr. base .596
		Transp. fleet <u>1.500</u>
		(3) Results
		16.306
		(4) Add growth
		<u>2.894</u>
		(5) Result
		19.200
		(6) Add 50% for prototype factor:
		28.800

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4.0 UNCERTAINTY ANALYSIS DATA PACKAGE

4.1 APPROACH AND SUMMARY

An important objective of the SPS systems study was to make the best possible estimates of uncertainty in size, mass and costs, for the SPS systems characterized. The methodology employed was newly developed for the study and included the principal steps indicated in Figure 4-1. The basis for the uncertainty analyses was itemized estimates in the uncertainties of component performance, masses, and cost. A typical example would be the uncertainty in solar cell efficiency and degradation. This is an example of the case where correlation exists between the two factors; i.e., more efficient cells tend to experience somewhat greater degradation because the greater efficiency tends to be associated with greater thickness and experimental data indicate thicker cells degrade more. In developing the statistics in size, mass and cost, these kinds of correlations were taken into account through use of a bivariate normal distribution probability model.

Also providing input data to the uncertainty analyses was a conventional mass property analyses for the systems with estimated uncertainties in such factors as structural crippling criteria, solar cell thickness, and turbomachinery unit masses. Additional uncertainties were developed in system costs, such as uncertainty in solar cell cost per unit area and uncertainties in machinery costs. These uncertainties were coupled with the cost analyses discussed later to prepare the cost statistics. Size statistics and mass statistics were combined to develop a joint mass/size uncertainty estimate and mass statistics and cost statistics were combined to generate combined cost/mass uncertainties. The bivariate normal distribution model was used to statistically combine the uncertainties, with recognition of correlations between component uncertainties where significant correlations were determined to exist.

The uncertainty analysis, in addition to estimating uncertainties, produced the unexpected result of predicting mass growth equivalent to that predicted by historical correlations. It had been believed that mass growth was the result of unpredictable variables, e.g., changes in program requirements. The outcome of this uncertainty analysis suggests that growth is more predictable than formerly believed and in fact results largely from the natural tendency to set point design parameters on the optimistic side of the actual uncertainty range.

Figure 4-2 compares the statistically-derived result for the photovoltaic SPS with the worst-on-worst and best-on-best results defined by combining all the most optimistic component uncertainties and all the most pessimistic component performances. As increased detail is developed in this kind of analysis, the worst-on-worst and best-on-best extremes will continue to become further apart, while the statistical uncertainties will tend to change little and will approach a representation of true uncertainties. Significantly, the reference point design was outside the projected 3 sigma range for mass and size. This resulted primarily because the efficiency chain assigned to the reference design was more optimistic than the most probable efficiency chain defined by the statistical analyses.

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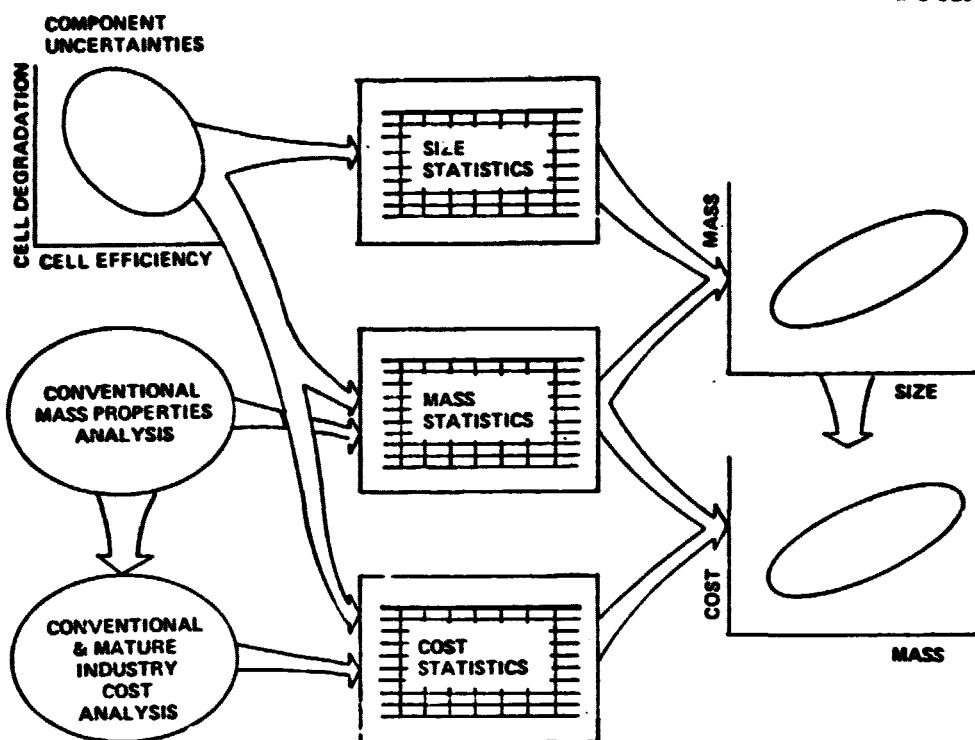
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FIGURE 4-1 UNCERTAINTY ANALYSIS METHODOLOGY

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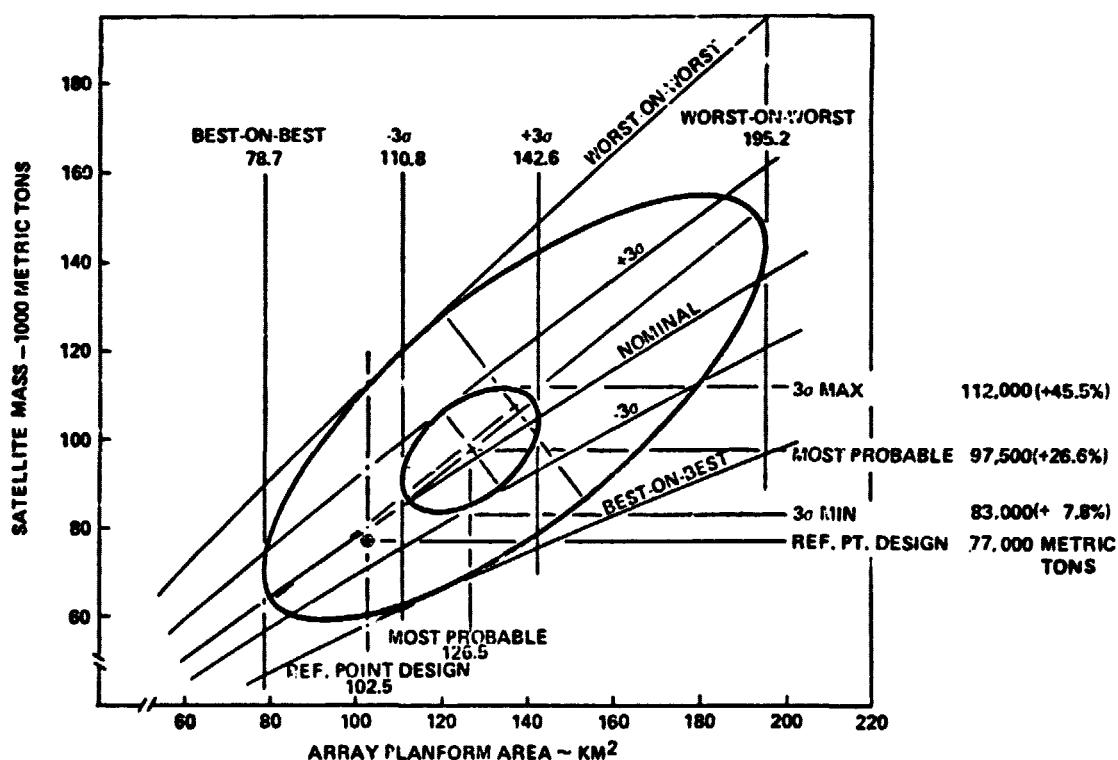


FIGURE 4-2 PHOTOVOLTAIC SPS MASS/SIZE UNCERTAINTY ANALYSIS RESULTS

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Presented in Figure 4-3 is an uncertainty estimate for the thermal engine comparable to the previous one for the photovoltaic system. Because the technology of the thermal engine system is somewhat more mature, it would be expected to estimate somewhat less mass growth and that turned out to be the case. An additional factor in the reduced mass growth projection is that a significant part of the size escalation is associated with the size of the concentrator which is a low-mass component of the thermal engine system.

With costs included in the uncertainty analyses, it is necessary to discriminate between the 1 SPS per year case and the 4 SPS per year case. As discussed under cost analyses, for the 4 SPS per year case, an estimate was made that about 60% of the predicted mass growth could be removed by product improvement. Similarly to the size and mass estimates, the reference design trended towards the optimistic side of the median of the cost uncertainties as shown in Figure 4-4. Consequently, one sees first a cost escalation at the reference design point and then a further cost growth associated with the mass growth projection. Note the very high correlation between cost and mass uncertainties. This corresponds to the historical indications that cost growth is frequently associated with mass growth, and especially with the compensation for (or removal of) mass growth in a system when performance requirements dictate that mass growth be limited to predetermined values.

The bottom line for an SPS system is its capability to produce power at an acceptable cost. The result shown in Figure 4-5 represents the final result of the costing and uncertainty analyses. Uncertainties for busbar power costs include the uncertainties in unit costs as well as uncertainties in the appropriate capital charge factor to be applied and the plant factor at which the SPS can operate. Capital charge factors from 12-18 percent were considered and the plant factor uncertainty was taken as 70%-90% at one SPS per year and 85%-95% for four SPS's per year. These uncertainties were statistically combined with the cost uncertainties derived by the cost uncertainty analyses.

4.2 COMPONENT AND ELEMENT UNCERTAINTIES

Component and element uncertainties that went into the uncertainty analysis are tabulated in Tables 4-1, 4-2 and 4-3. Cost uncertainties at this level were not completed as it was found that uncertainties in solar cell costs, ground receiver costs, and transportation costs entirely dominated the overall cost uncertainties. Of greatest significance are the size/mass uncertainty effects on costs; these are included in the overall cost uncertainty data discussed in Section 4.4.

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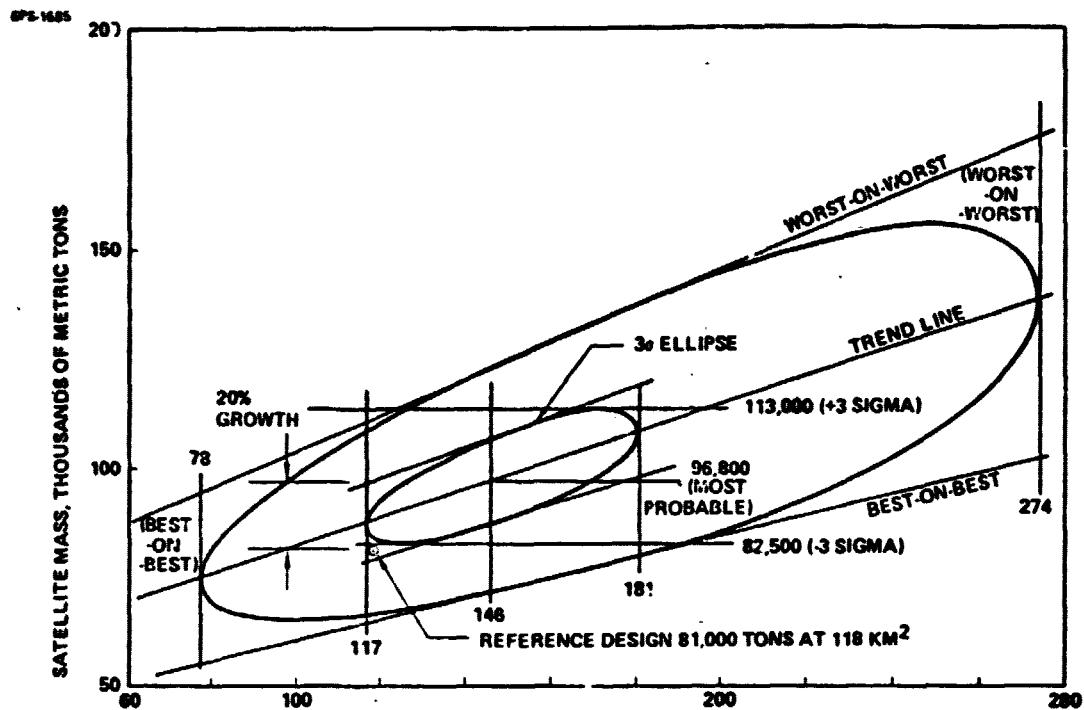


FIGURE 4-3 RANKINE THERMAL ENGINE SIZE /MASS UNCERTAINTY ANALYSIS RESULTS

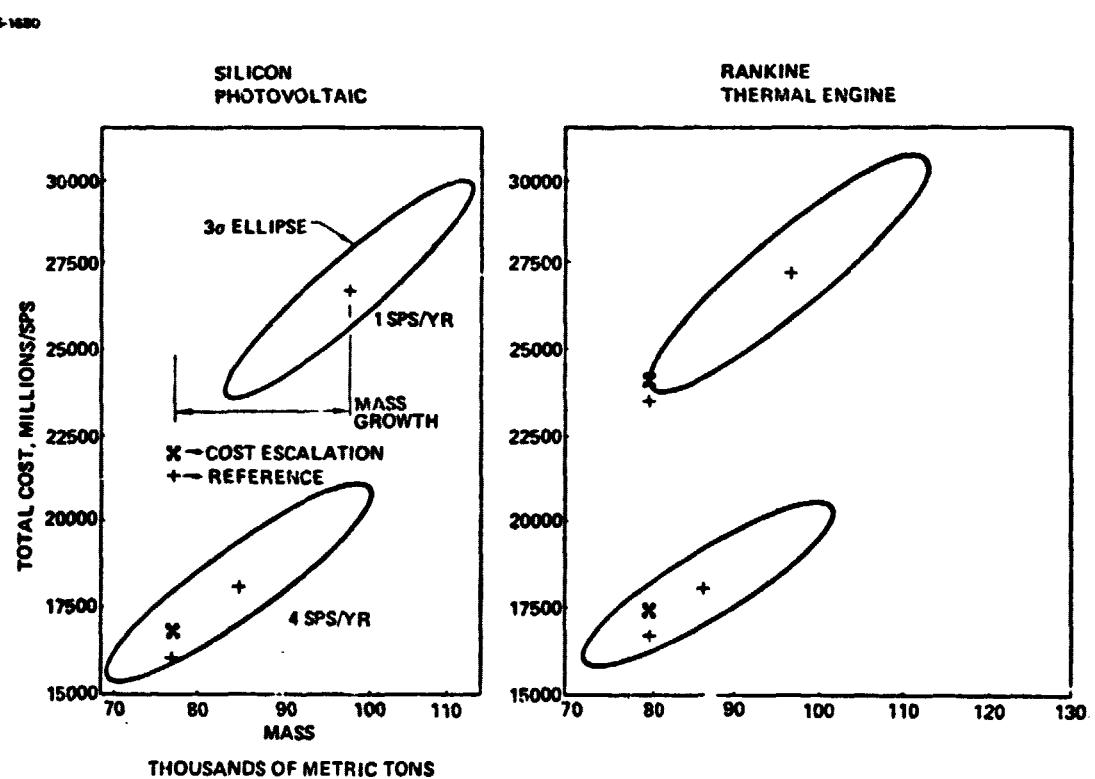


FIGURE 4-4 MASS/COST UNCERTAINTY ANALYSIS RESULTS

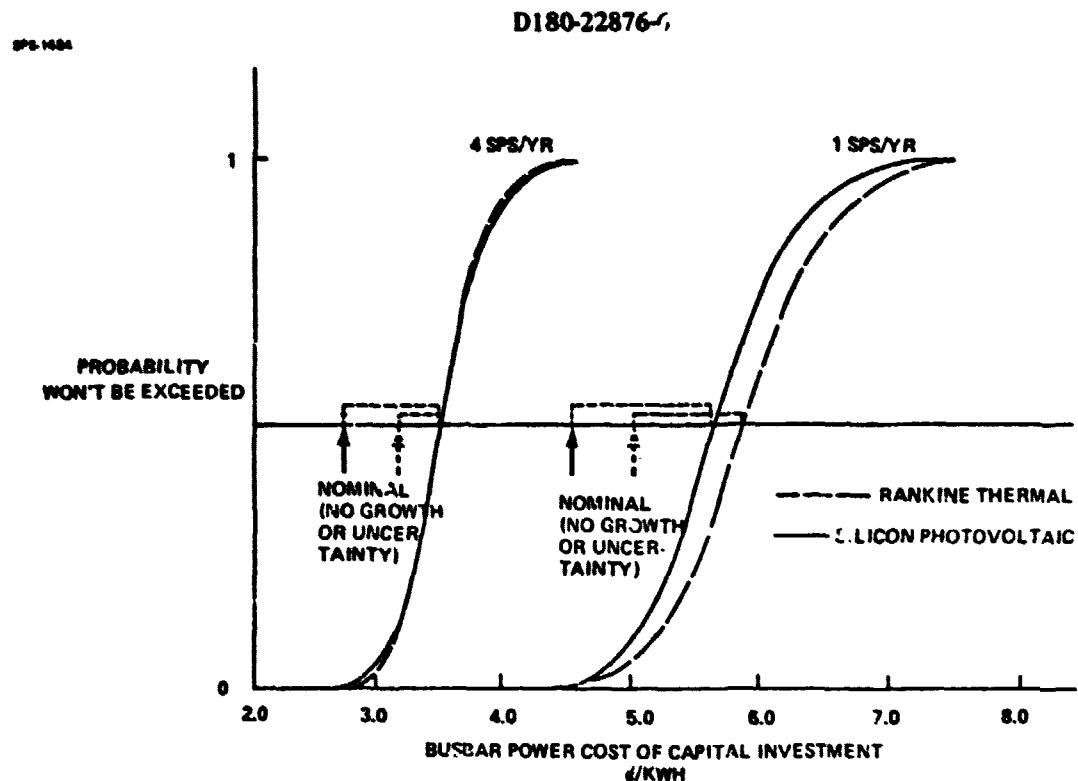


FIGURE 4-5 PREDICTED BUSSBAR POWER COST & UNCERTAINTIES

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Table 4-1 Photovoltaic Traceability/Uncertainty Worksheet

ITEM #	ITEM	VALUE FROM JSC-11568 GREEN BOOK	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (%) PER %)		CORRELATED VARIABLES
									MASS	COST	
1.	Solar cell thickness	100 um	50 um	1. Lower rad. degradation 2. Lower mass 3. Lower efficiency a. Add "Saw-tooth" cover 4. Currently manufactureable	100 um	1. Handling 2. Lower manuf. cost 3. Slightly more efficient	40 um	1. Rapid decrease in efficiency below 40 um. 2. Recognized lower limit for silicon cells. 3. Lower mass			Radiation degradation mass Efficiency(?)
2.	Solar cell Unit mass (g/m^2)	265	119.8	1. For 50 um cell	231.6	1. For 100 um cell	92.6	1. For 40 um cell			Cell thickness
3.	Solar Cell Efficiency (100-250C)	18%	17.5%	1. For 18.8% cell with 10% increase for "saw-tooth" cover. 2. Presently 16.5% cells available in lab tests	14.8%	1. For 13.8% cell with "saw-tooth" cover. 2. 13.5% - 50 um cells now available	18%	1. Recognized target for silicon solar cells with or without covers			Manuf. processes cell thickness(?)
4.	Radiation degradation factor (for 30 years)	-	0.97	1. Based on 70% annealing recovery & 50 um solar cell degradation with 75 um cover.	0.90	1. Based on no annealing recovery & a 50 um solar cell and 75 um cover.	1.00	1. Based on 100% annealing recovery on 50 um solar cell with 75 um cover			Solar cell thickness Cover thickness Substrate thickness Annealing efficiency Mass End efficiency
5.	Annealing Recovery	-	95%	1. 95% recovery demonstrated by NRL tests	95% per anneal	1. No repeated annealing has been documented.	100%	1. Theoretically possible			Type of blanket End efficiency Loss
6.	Solar cell unit cost	72 \$/m ²	40 \$/m ²	1. Mature industry projection	67 \$/m ²	1. ERDA projected 30\$/watt ^{MAX} . Space cell may cost more.	225/m ²	1. ERDA projected 10¢/watt min. 2. Approx. 20 billion solar cells/SPS will justify sophisticated sealing			Type of cell efficiency
7.	Solar cell cover Unit mass	55	167.6	1. Three mil borosilicate glass a. Plastic films not compatible b. Radiation degradation c. Annealing compatibility d. Incorporation of "saw-tooth" e. Electrostatic bonding	167.6	1. Three mil borosilicate W/O "saw-tooth" a. Manufacturability b. Radiation protection	111.7	1. Two mil borosilicate a. Low pt. in efficiency & mass bucket trade. 2. "Saw-tooth" may not be necessary for 10%			Radiation degradation efficiency Mass
8.	Cover UV degradation factor (for 30 years)	-	0.956	1. Design input	0.956	1. Possible conservative estimate	1.00	1. If no u-v degradation on borosilicate glass (possible)			End efficiency Mass
9.	Solar cell substrate unit mass (g/m^2)	91	111.0	1. Two mil borosilicate glass a. Radiation protection b. Annealing compatibility c. Electrostatic bonding	167.6	1. Three mil borosilicate glass a. More radiation protection b. Manufacturability	62.7	1. One mil kapton/one mil adhesive a. Possibly enough rad. prot. b. If no annealing or if annealing compatible			Radiation degradation Annealing End efficiency Mass

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Table 4-1 Photovoltaic Traceability/Uncertainty Worksheet (continued)

ITEM #	ITEM	VALUE FROM JSC-11568 GREEN BOOK	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (% PER %)		CORRELATED VARIABLES
									MASS	COST	
10.	Solar cell mismatch loss factor	-	0.99	1. Acceptable manufacturing tolerance for performance	0.99	1. Should not be any larger than this.	0.99	1. Acceptable penalty			End Efficiency, Mass
11.	Solar panel lost area factor	-	0.961	1. Cell area/panel area ratio	0.961	1. Conservative design	0.961	1. Acceptable penalty			End Efficiency Blanket Mass
12.	Solar cell interconnect unit mass (g/m ²)	10	11.4	1. Half mil copper a. Very low I ² R loss b. Back-connected cells need only short interconnectors	11.4	1. Conservative value	3.4	1. Half Mil Aluminum a. Still low I ² R Loss (1) Slightly more b. Lower mass			End Efficiency Mass Mfg'ability Handling
13.	Solar cell string I ² R losses	0.998		1. Calculated for ref. blanket	0.998	1. Aluminum Interconnects 2. Longer strings	0.999	1. Thicker interconnect 2. Shorter blanket			End Efficiency Mass Aspect Ratio Bus I ² R Loss
14.	Solar Blanket Unit Mass (g/m ²)	412	426.0	1. Combination of component masses							
15.	Support & attachment unit mass (g/m ²)	-	5.0	1. Design point including installation joints, tapes, & catenary sys.	7.5	1. More support (50%) 2. Higher loading	2.5	1. Use uniaxial tapes 2. Lower loading			
POWER DISTRIBUTION											
16.	Bus Mass (kg/kwe)	0.1905	0.1215	1. No lateral busbars 2. Emissivity (E_u) = 0.90	0.1600	1. Lateral & longitudinal bus bars	0.0600	1. Optimized for low aspect ratio.			Bus Efficiency (I ² R) Aspect ratio Bus Mass Bus Effici.
17.	Current Density (A/cm ²)	558	633	1. Optimized for minimum satellite mass.	569.7	1. To lower I ² R loss if E_u = 0.90	696	1. Reflects lower I ² R loss if E_u = 0.90			Emissivity Bus Mass Bus Efficiency
18.	Bus I ² R Loss	8.51	6.63	1. Reflects no lateral Bus bars.	9.05	1. Lateral and longitudinal bus bars.	3.95	1. Optimized for low aspect ratio			Efficiency Mass Aspect Ratio Bus Config.
19.	Bus Unit Cost (\$/kg)	2.2	22	1. Reflects material and manufacturing cost.							
20.	Switchgear Mass (g/kwe)	3.87	4.55	1. Based on Hughes best plasma switch gear data.							System Mass
21.	Switch gear cost (\$/kwe)	98	414	1. Small amount necessary would not support mature industry projections.							

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Table 4-1 Photovoltaic Traceability/Uncertainty Worksheet (continued)

ITEM #	ITEM	VALUE FROM JSC-11508 GREEN BOOK	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (\$ PER %)		CORRELATED VARIABLES
									MASS	COST	
22.	<u>STRUCTURE</u> Crippling Criteria										
	Minimum Gauge										
	Unit Mass (kg/m ³)										
23.	Unit Cost (\$/kg)	-	95	1. Mature industry projection	60	1. Metal instead of non-metal joints from detailed manufacturing & fabrication analysis.	40	1. Detailed mfg. & fabrication analysis (terrestrial) yielded 48 \$/kg presently at one SPS/year.			
24.	<u>CONTROL SYSTEMS</u> Flight Control System Mass (Metric Tons)	340	100	1. First detailed analysis a. Optimized I _{sp} b. Perfect control laws							
	Flight Control System Cost (\$/kg)	-	440	1. Conservative a. Small overall effect							Mass Configuration Aspect Ratio Orbit

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Table 4-2 Thermal Engine Traceability/Uncertainty Worksheet

ITEM #	ITEM	VALUE FROM MSFC SPS STUDY	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (% PER %)		CORRELATED VARIABLES
									MASS	COST	
1	Plastic Film Reflectivity, Initial	0.87	0.90	Tests by Boeing Engineering & Construction	0.87	Measured Kapton Value	0.90	With Ag overcoat	-0.110		
2	Reflectivity degradation (1 = none)	1.0	1.0		0.70	Project ADLE data	1.0	Solar sail test, indicate no degradation until rad. dose = 50 times SPS	-0.110		
3	Plastic Film thickness	0.4 μm	3 μm	Solar Sail Work, Dupont Projections	8.7 μm	Heavier gauge required for "handling"	1.6-7 μm	Solar sail work, Dupont projections	+0.002		
4	Cavity Reflectance Loss	3%	5%		5%	Bench Model Cavity Tests	~6.2%	High temperature anti-reflective coating	+0.000		
5	CPC Reflectivity	N/A	0.065	N/A	0.000	Extreme distortion in reflector surface	0.065	Calculated performance from ray trace program; rhodium reflector, C.R. = 3	-0.120		
6	Cavity Emissivity based on aperture area	0.8	1.00	Conservation	1.00	Black body limit	0.8	With low emissivity high temperature interior coatings	+0.009		
7	Boiler material allowable	100%	100%		80%	No 30 year test data on niobium	120%	No 30 year test data	-0.001		
8	Boiler Droplet Removal	N/A	No Removal System	N/A	Vertex Removal System	Once - through boilers may emit droplets	No Removal System	Temperature ratio selected tends to total vaporization	0.055 increase if required		
9	Turbine Efficiency	N/A	80%	N/A	80%	Obtained in LoRC tests	85%	Aerodynamic improvements	-0.03		
10	Turbine Mass	N/A	1.00	N/A	1.20	G.E. Estimate	0.80	G.E. Estimate	+0.17		
11	Generator Efficiency	0.984	0.984		0.984	Currently obtained	0.986	Improvements	-0.70		

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Table 4-2 Thermal Engine Traceability/Uncertainty Worksheet (continued)

ITEM #	ITEM	VALUE FROM MSFC SPS STUDY	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (\$ PER S)		CORRELATED VARIABLES
									MASS	COST	
12	Generator Temperature	400K	400K		400K	Current capability	400K	Advanced insulation	-0.055		
13	Generator specific heat	0.22	0.14 kJ/kg °C	Aerospace rather than terrestrial practice	0.22 kJ/kg °C	Current long life airborne gen.	0.08	Advanced airborne generators (short life)	+0.031		
14	Watergated Environment	"100°"	"100°"		"100°"	Current model is considered pessimistic	"60°"	Current model is considered pessimistic	+0.09		
15	West Pipe Watergated Resistance	"100°"	"100°"		"200°"	Elevated temperature steel may offer poor resistance	"80°"	Gas gun test data may be pessimistic	+0.09		

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Table 4-3 MPTS Traceability/Uncertainty Worksheet

ITEM #	ITEM	VALUE FROM JSC-11550 GREEN BOOK	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (\$ PER %)		CORRELATED VARIABLES
									MASS	COST	
1.	% of electric power that must be processed	N/A	.185	Multiple voltage requirements of high-efficiency klystron	.305	Voltage/current requirements of depressed collector are rough estimates	.105	Could go to more busses and tiered array voltages.			
2.	Power Processing & Distr. Efficiency	.985	.975	Detailed Analysis including I ² R	.985	Uncertainty in thermal environment and % power processed	.985	Some			
3.	Power Processing Mass Kg/kwe	0.02	1.0	Design Pt. N/High H ₂ Conv.	2.7	Low Hz Conv.	1.0	High Hz Conv.			
4.	PPU Thermal Control, kg/kwe ₂		14.0	Red. E _u = 0.90	15.0	Red E _u = 0.85	14.1	Red. E _u = 0.88			
5.	PPU Cost, \$/kWe ₂ of PPU		414								
6.	PPU Thermal Control Cost, \$/kg										
7.	Klystron Efficiency	.875	.855	Varian Estimate	.805	Effectiveness of Depressed Collectors with high-efficiency RF circuits remains to be demonstrated	.865	Varian Estimate (max)			
8.	Klystron Mass, kg/kwe	1.14 Incl. thermal control	0.85	Detailed Mass Statement							
9.	Klystron Cost \$/kwe	46	50	Varian Manufacturing Estimate	100	Assumes more burn-in required	40	Varian facilitization cost was high			
10.	Klystron Heat Removal (kg) / Kwt Mass	Incl. in Klystron	1.63	Heat removal system accounted separately	1.96	20% increase	1.3	20% less			
11.	Klystron Heat Removal Cost	Incl. in Klystron		Heat removal system accounted separately.							
12.	Waveguide I ² R Loss	.98	.985	Calculated Average	.985	Variance analysis not made	.985	Variance analysis not made.			
13.	Subarray structure Mass kg/m ²	1.15	.52	Design Pt. Avg. for I-Beam "Egg-Crate"	.66	20% increase	.46	20% less			
14.	Waveguide mass kg/m ²	6.1	1.88	Design Pt. (Gr-Ep) Rect. Section w/cond. coating							

NOTE: Estimates on this page incomplete.

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Table 4-3 MPTS Traceability/Uncertainty Worksheet (continued)

ITEM #	ITEM	VALUE FROM JSC-11568 GREEN BOOK	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (\$ PER %)		CORRELATED VARIABLES ^a
									MASS	COST	
15.	Waveguide & Structure Cost, \$/kg	.70	\$64	Updated Estimate							
16.	RF Control Circuitry Mass/kg/kw	.05	0.050	485.2×10^3 $8.22 \times 10^6 \text{kw}$.05		.05				
17.	RF Control Circuitry Cost, \$/kg/kw	\$56/unit	2.1 \$/kg	Using 341.5 \$/kg							
18.	Ideal Beam Efficiency	*	.965	Computer Analysis	.965	Corresponds to 10 db taper	.99	Corresponds to 17 db taper			
19.	Intra-Subarray Losses	*	.956	Computer analysis of phase & amplitude contribution (100 E_0 , 1db)	.98	20° Phase Error	.97	5° Phase Error			
20.	Intra-Subarray Losses	.98	.981	Detailed Error Analysis	.97	Inability to Hold Mechanical Tolerances	.99	Eliminate tilt errors and Improve flatness.			
21.	Atmosphere Absorption	.98	.98	No additional analysis	.98		.98				
22.	Rectenna Intercept Efficiency	* .98	.95	Optimal for Nominal Rectenna	.90	Optimal for high-cost rectenna	.98	Optimal for low-cost rectenna			
23.	RF-DC Conversion	.90	.048	Based on numerical integration for nominal JPL Efficiency vs. Intensity	.70	Assumes low range of JPL estimates.	.90	Raytheon projection for improved diodes			
24.	Grid Interfacing Efficiency	.99	.97	Includes DC-AC processing	.96	ROM Estimate	.98	ROM Estimate			
25.	Land Cost \$/Acre	2450	5000	Nominal Median	10000	Assumes some improved property acquisition	2000	Low-cost land; value is mainly site prep.			
25.	Dipole Spacing	0.5	0.5	Test results	0.5	Test results	0.8	Theory shows greater spacing possible			

^aThese three items combined into "Energy Collection".

NOTE: Estimates on this page incomplete.

Table 4-3 MPTS Traceability/Uncertainty Worksheet (continued)

ITEM #	ITEM	VALUE FROM JSC-11568 GREEN BOOK	CURRENT VALUE	REASON FOR CHANGE	WORST CASE	RATIONALE	BEST CASE	RATIONALE	SPS SENSITIVITY (\$ PER S)		CORRELATED VARIABLES
									MASS	COST	
27.	Dipole Cost		\$4	Estimated 2x Material Cost	\$4	Same	0.54	Raytheon Estimate (for cage Dipole integral with structure).			
28.	Average Diodes/Dipole	\$8/m ²	1	Standard RF Circuit Design	1	Same	3	Advanced RF Circuit			
29.	Diode/Filter Cost	\$4	Boeing Nominal Estimate	204	JSC "Worst Case"	1.44	Raytheon Estimate				
30.	Support Rigging Cost, \$/m ²	\$10/m ²	\$12.90		21.50	Boeing Results	3.50	Raytheon Estimate			
31.	Construction Cost, \$/m ²	Included in support rigging					2.30	Raytheon Estimate			
32.	SPS Cost, \$/kw _{dc}	\$400			\$100		\$25				
33.	Rectenna Area	10 km dia	10 km dia	(0.8 beam diameter = 95% cell effy)	14 km dia.	Full beam for sidelobe suppression	8 km	90% collection efficiency			

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4.3 SIZE/MASS UNCERTAINTY ANALYSIS

The size/mass uncertainty analysis was the first step. It began with analysis of uncertainties in the efficiency chain to determine size uncertainty.

4.3.1 Photovoltaic Size/Mass Uncertainty

Table 1 presents the photovoltaic system efficiency uncertainty worksheet, including the microwave power transmission system. The aggregate values for the MPTS were carried over to the thermal engine size/mass uncertainty analysis.

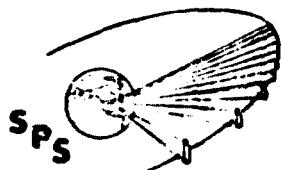


Table 1
Photovoltaic
End-To-End Efficiency Worksheet

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ITEM	NOMINAL	MINIMUM	MAXIMUM	LOG MIN	LOG MAX	LOG MEAN	σ	Correlations
Summer Solstice Factor	.9675	.9675	.9675	-.0330	-.0330	-.0330	0	
Cosine Loss (POP)	.919	.919	.919	-.0845	-.0845	-.0845	0	
Solar Cell Efficiency	.173	.148	.18	-1.9105	-1.7147	-1.8126	.0326	
Radiation Degradation	.97	.90	1.0	-.1393	0	-.06963	.0232	
Temperature Degradation	.954	.954	.954	-.0471	-.0471	0.0471	0	{ -0.6 (-.0009076)}
Cover UV Degradation	.956	.956	1.0	-.0450	0	-.0225	.00750	
Cell-to-Cell Mismatch	.99	.99	.99	-.01005	-.01005	-.01005	0	
Panel Lost Area	.961	.961	.961	-.0398	-.0398	-.0398	0	
String I^2R	.998	.995	.999	-.00501	-.001	-.00301	.00067	
Bus I^2R	.934	.91	.961	-.0943	-.0398	-.0670	.0091	
Rotary Joint	1.0	1.0	1.0	0	0	0	0	
Antenna Power Distr	.97	.95	.98	-.0513	-.0202	-.0357	.0052	
DC-RF Conversion	.85	.80	.86	-.223	-.1508	-.1870	.0121	
Waveguide I^2	.985	.985	.985	-.0151	-.0151	-.0151	0	
Ideal Beam	.965	.965	.99	-.0356	-.0100	-.0228	.0043	
Inter-Subarray Errors	.956	.88	.97	-.1278	-.0305	-.0791	.0162	{ -0.3 (-.000366)}
Intra-Subarray Errors	.981	.97	.99	-.0304	-.010	-.0203	.0034	
Atmosphere Absorp.	.98	.93	.98	-.0202	-.0202	-.0202	0	
Intercept Efficiency	.95	.90	.98	-.1054	-.0202	-.0629	.0142	{ -0.5 (-.000361)}
Rectenna RF-DC	.848	.79	.92	-.2357	-.0834	-.1596	.0254	
Grid Interfacing	.97	.96	.98	-.0408	-.0202	-.0305	.0034	
Products/Sums Sizes (Km^2)	.0679	.0383	.095			-2.822	Sums Q = .00306	
	108.8	193	77.8					

$$3\sigma_{\text{Max}} = \exp(-2.822 + 3 \times 0.042) = .0675 \text{ size} = 109.5$$

$$3\sigma_{\text{Min}} = \exp(-2.822 - 3 \times 0.042) = .0524 \text{ size} = 141.0$$

$$\eta = .0595 \text{ size} = 124.0$$

$$\text{Correlation prod sum} = -.00131$$

$$\text{Net } \sigma = \sqrt{.00306 - .00131} = .042$$

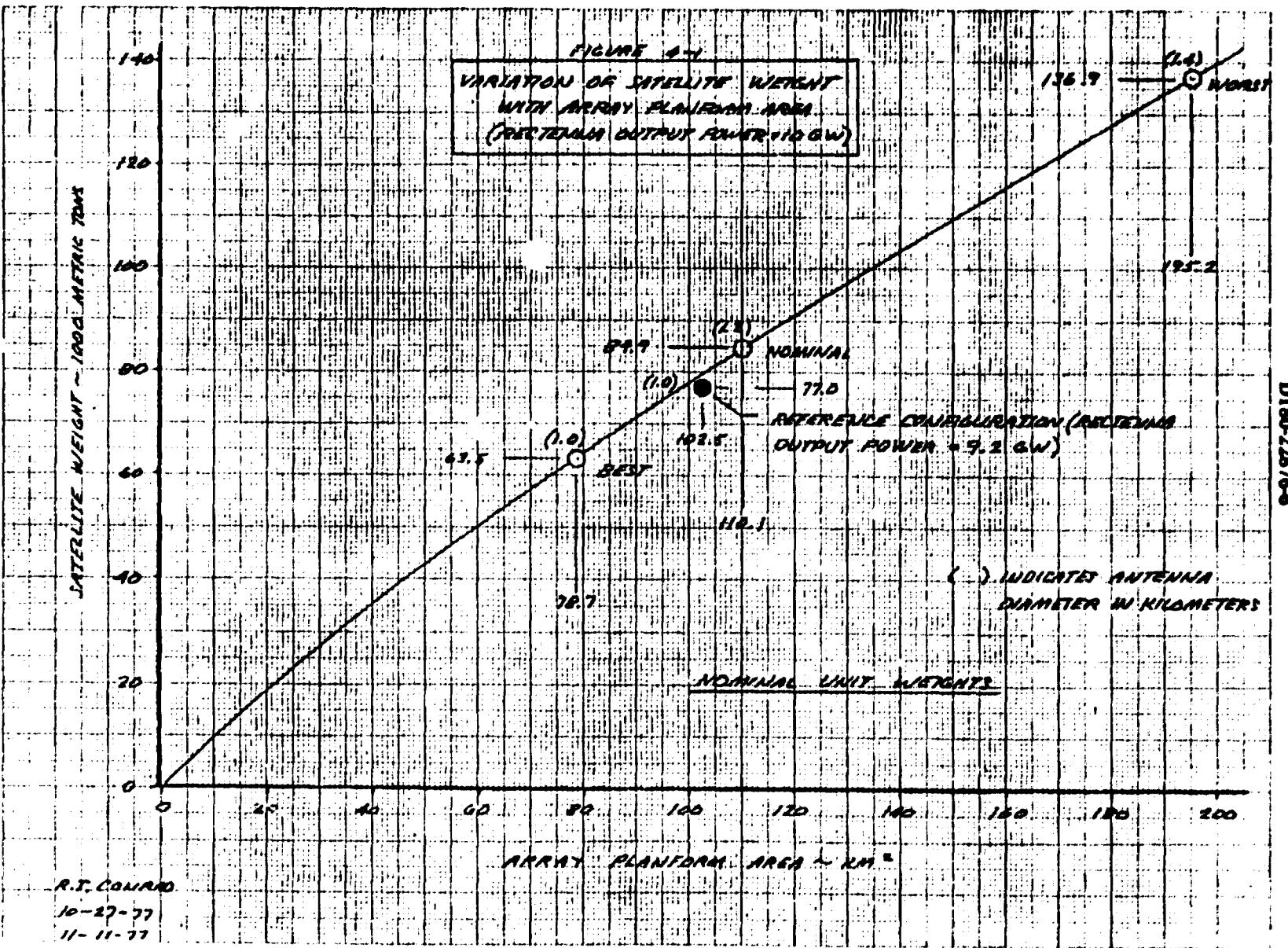
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Variation of Satellite Weight with Array Planform Area

The results of a study to determine the variation of satellite weight with array planform area are presented in Figure 4-1. Weight statements, scaling parameters, and scale factors are presented in Table 4-1 for the total satellite, with the detail data for the MPTS being presented in Table 4-2.

As indicated in Table 4-1, the satellite primary structure weight has been scaled directly proportional to structural planform area. The validity of using this scale factor has been verified by analysis. Pertinent data is included in Appendices F, G, and H.



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TABLE A-1
SATELLITE WEIGHT SUMMARY
(NOMINAL UNIT WEIGHTS)

ITEM	WEIGHT IN METRIC TONS				SCALE FACTOR
	REF.	BEST	NOM.	WORST	
1.0 SOLAR ENERGY COLLECTION SYSTEM	(51,782)	(39,960)	(55,677)	(99,460)	S □
1.1 PRIMARY STRUCTURE	5385	4270	5747	10,605	—
1.2 SECONDARY STRUCTURE	▷	▷	▷	▷	D
1.3 MECHANICAL ROTARY JOINT	67	67	80	94	—
1.4 MAINTENANCE STATION	—	—	—	—	—
1.5 CONTROL	178	115	207	617	S x W ₆
1.6 INSTRUMENTATION/COMMUNICATIONS	4	4	4	4	—
1.7 SOLAR CELL BLANKETS	43,750	33,571	46,974	83,317	A
1.8 SOLAR CONCENTRATORS	—	—	—	—	—
1.9 POWER DISTRIBUTION					
POWER BUSES	2030	1587	2265	4208	L x P
CELL STRING FEEDERS	39	35	42	74	B x P
DISCONNECTS, SWITCH GEAR, CONVERTERS	156	139	169	231	P
ENERGY STORAGE	20	18	22	30	P
ELECTRICAL ROTARY JOINTS	39	35	42	58	P
SUPPORT STRUCTURE ~5%	114	91	127	230	—
2.0 MICROWAVE POWER TRANSMISSION SYSTEM	(25,212)	(23,508)	(29,170)	(37,458)	▷
TOTAL WEIGHT - LESS GROWTH (W ₀)	76,994	63,468	84,877	136,926	

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STRUCTURAL PLANFORM AREA (S) ~ KM ²	112.3	68.8	119.1	220.4
ANTENNA DIAMETERS (D) ~ KM	1.0	1.0	1.2	1.4
ARRAY PLANFORM AREA (A) ~ KM ²	102.5	78.7	110.1	195.2
SATELLITE STRUCTURAL LENGTH (L) ~ KM	21.3	18.7	21.9	27.8
POWER TO SLIPRINGS (P) ~ GW MIN.	16.4	14.6	17.8	24.3
NO. OF INTERMEDIATE LONGITUDINAL BEAMS (B)	7	7	7	9

- ▷ DISTRIBUTED TO OTHER WBS ITEMS
- ▷ VERIFIED BY ANALYSIS (SEE APPENDICES F, G, AND H)
- ▷ DETAILS ON FOLLOWING PAGE

TABLE 4-2
MPTS WEIGHT SUMMARY
(NOMINAL UNIT WEIGHTS)

ITEM	WEIGHT IN METRIC TONS				SCALE FACTOR
	REF.	BEST	NOM.	WORST	
PRIMARY STRUCTURE	52	52	75	102	D^2
SECONDARY STRUCTURE	197	197	204	386	D^2
ANTENNA CONTROL SYSTEMS	(700)	(700)	(700)	(700)	-
POWER DISTRIBUTION SYSTEM - EXCL. SUBARRAYS					
• BUSES - ROTARY JOINT TO SECTOR CONTROL	271	271	325	379	D
• BUSES - SECTOR CONTROL TO SUBARRAYS	110	110	158	216	D^2
SWITCH GEAR/DISCONNECTS	137	125	148	187	K
DC-DC CONVERTERS	1241	1133	1345	16.95	K
THERMAL CONTROL (ACTIVE)	736	672	797	1006	K
ENERGY STORAGE	299	273	324	408	K
SUPPORT STRUCTURE ~ 5%	140	129	155	195	-
ANTENNA COMMUNICATIONS/DATA SYSTEM	(700)	(700)	(700)	(700)	-
ANTENNA SUBARRAYS					
KLYSTRONS	4658	4253	5047	6364	K
THERMAL CONTROL	2087	1906	2261	2851	K
DISTRIBUTION WAVEGUIDES	234	239	344	468	D^2
RADIATING WAVEGUIDES	1485	1485	2128	2911	D^2
POWER CONTROL	485	443	525	663	K
POWER DISTRIBUTION	36	37	39	49	K
STRUCTURE	433	433	624	847	D^2
TOTAL WEIGHT - PER ANTENNA	12,606	11,758	14,589	18,739	

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ANTENNA DIA. (D) ~ MM NO. OF KLYSTRONS (K)	1.0 97,036	1.0 88,606	1.2 105,136	1.4 132,570
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Effect of Tolerances on Weight of Reference Configuration

The results of a study to determine the effect of tolerances on the weight of the reference configuration are presented in Figure 5-1. A weight tolerances worksheet for the reference configuration is presented in Table 5-1. Note that the tolerances which are the major drivers are those associated with the solar cell blankets, the MPTS, and the primary structure.

A weight tolerances worksheet for the solar cell blankets is presented in Table 5-2.

A weight tolerances worksheet for the MPTS is presented in Table 5-3. Details of the tolerances for the combination of DC-DC converters and thermal control are given in Table 5-4.

A weight tolerances worksheet for the primary structure is presented in Table 5-5. Supporting data include the following: Figure 5-2, which gives the variation of structure weight with array unit weight; Figure 5-3, which gives the variation of structure weight with antenna weight; Figure 5-4, which presents the effect of uncertainty in crippling coefficient on the sizing of a 20 meter long tapered tube of graphite/epoxy; and Table 5-6, which presents a weight distribution for the primary structure with particular emphasis on the amount of graphite/epoxy (tubing) and hardware (tube center joints, tube end fittings, and strut interconnect fittings) comprising beam weight.

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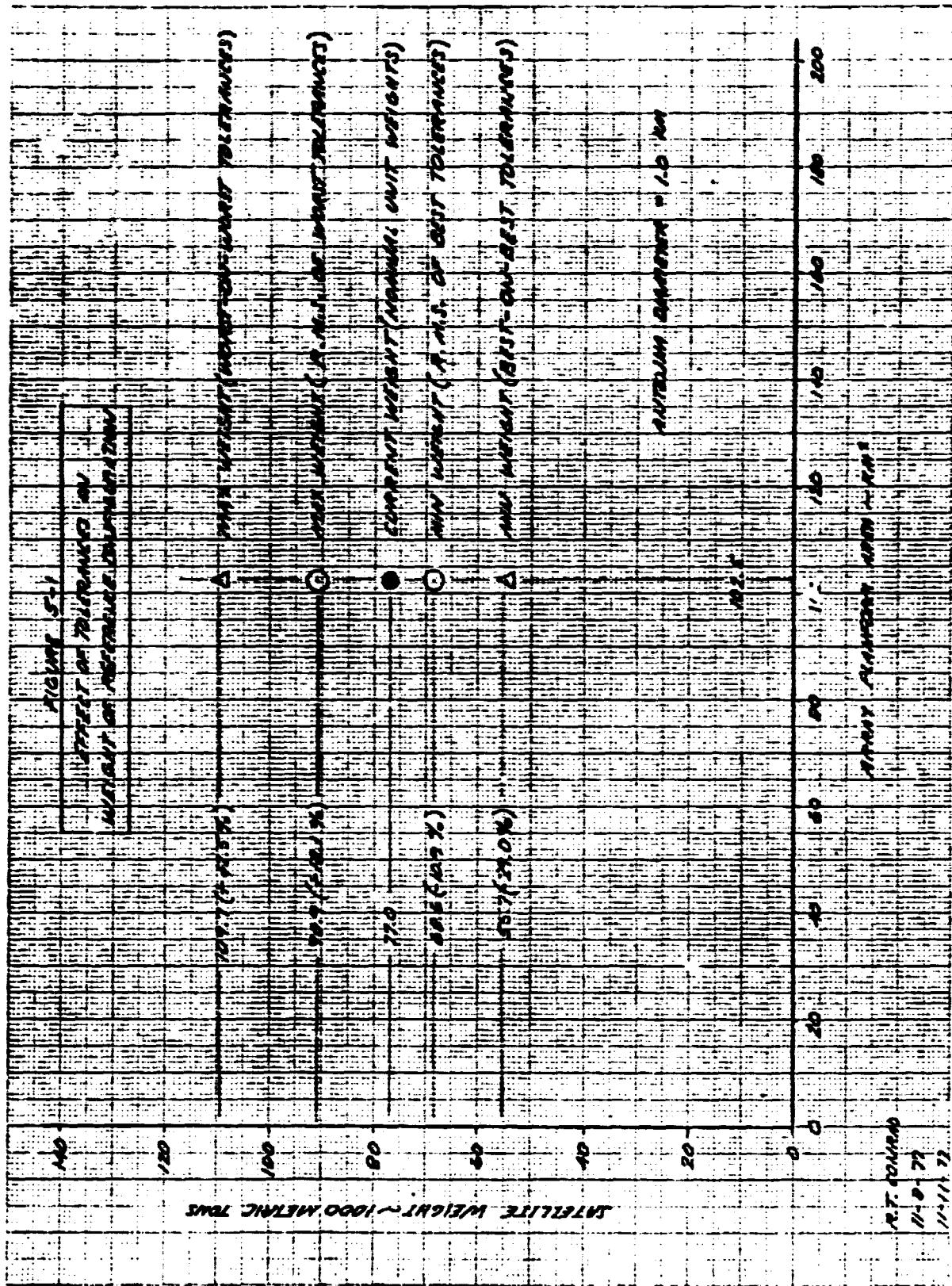


TABLE 5-1
WEIGHT TOLERANCES WORKSHEET
REFERENCE CONFIGURATION

ITEM	CURRENT WEIGHT~kg	WORST TOLERANCE		BEST TOLERANCE	
		dw~kg	%	dw~kg	%
1.0 SOLAR ENERGY COLLECTION SYSTEM	(51,702,300)	{+ 22,421,000 (AOD.) {+ 13,164,000 (RMS)	{+ 43.3 (AOD.) {+ 25.4 (RMS)	{-16,987,000 (AOD.) {-8,036,000 (RMS)	{-72.0 (AOD.) {-15.5 (RMS)
1.1 PRIMARY STRUCTURE	5,305,000	{+ 3,182,000 (AOD.) {+ 1,953,000 (RMS)	{+ 57.1 (AOD.) {+ 36.3 (RMS)	{-1,534,000 (AOD.) {-802,000 (RMS)	{-20.5 (AOD.) {-14.7 (RMS)
1.3 ROTARY JOINT	60,000	+67,000	+100.0	-12,000	-25.0
1.5 CONTROL	178,100	+87,000	+50.0	-45,000	-25.0
1.6 INSTRUMENTATION/COMMUN.	4,000	+4,000	+100.0	-1,000	-25.0
1.7 SOLAR CELL BLANKETS	43,750,000	{+18,479,000 (AOD.) {+13,004,000 (RMS)	{+42.2 (AOD.) {+29.7 (RMS)	{-14,786,000 (AOD.) {-7,973,000 (RMS)	{-39.8 (AOD.) {-18.2 (RMS)
1.9 POWER DISTRIBUTION	2,370,100	+600,000	+25.0	-600,000	-25.0
2.0 MICROWAVE POWER TRANS. SYSTEM	(25,212,200)	{+10,294,000 (AOD.) {+4,531,000 (RMS)	{+40.0 (AOD.) {+19.0 (RMS)	{-5,342,000 (AOD.) {-2,512,000 (RMS)	{-21.2 (AOD.) {-10.0 (RMS)
TOTAL	76,974,500	{+32,715,000 (AOD.) {+17,922,000 (RMS)	{+42.5 (AOD.) {+18.1 (RMS)	{-22,725,000 (AOD.) {-8,619,000 (RMS)	{-29.0 (AOD.) {-10.9 (RMS)

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TABLE 5-2
WEIGHT TOLERANCES WORKSHEET
REFERENCE CONFIGURATION
(1.7 SOLAR CELL BLANKETS)

ITEM	CURRENT	WORST	BEST
SOLAR CELLS:			
MATERIAL	SILICON		
THICKNESS ~ MILS	2.0	4.0	1.6
WEIGHT ~ kg	11,670,050	23,741,700	9,736,600
ΔWEIGHT ~ kg	0	+11,670,050	-2,334,170
SOLAR CELL COVERS:			
MATERIAL	FLUDED SILICA		
THICKNESS ~ MILS	3.0	3.0	2.0
WEIGHT ~ kg	16,982,940	16,982,940	11,725,230
ΔWEIGHT ~ kg	0	0	-5,662,650
SOLAR CELL SUBSTRATE:			
MATERIAL	FLUDED SILICA		HAPRON/ADSORB
THICKNESS ~ MILS	2.0	3.0	1.0/1.0
WEIGHT ~ kg	11,325,290	16,707,940	6,345,800
ΔWEIGHT ~ kg	0	+5,662,650	-4,979,490
SOLAR CELL INTERCONNECTS:			
MATERIAL	COPPER		ALUMINUM
THICKNESS ~ MILS	0.5	0.5	0.5
WEIGHT ~ kg	1,150,160	1,150,160	743,070
ΔWEIGHT ~ kg	0	0	-607,130
MANUFACTURING TOLERANCES ALLOWANCE			
% OF FOREGOING WEIGHTS	5	5	5
WEIGHT ~ kg	2,057,110	2,923,330	1,222,360
ΔWEIGHT ~ kg	0	+866,280	-723,730
SUPPORT / ATTACHMENT:			
DESIGN INTRUSION WEIGHT RATIO	1.0	1.5	0.5
WEIGHT ~ kg	550,650	827,975	279,725
ΔWEIGHT ~ kg	0	+279,725	-279,325
TOTAL WEIGHT ~ kg	12,750,000		
WEIGHT TOLERANCE (ADDITION) ~ kg	—	+18,479,105	-14,766,495
WEIGHT TOLERANCE (R.M.S.) ~ kg	—	+13,002,955	-7,972,610
WEIGHT TOLERANCE (ADDITION) ~ %	—	+42.2	-33.8
WEIGHT TOLERANCE (R.M.S.) ~ %	—	+29.7	-16.2

TABLE 5-3
WEIGHT TOLERANCES WORKSHEET
REFERENCE CONFIGURATION
(2.0 MMTS)

ITEM	CURRENT WEIGHT-kg	WORST TOLERANCE		BEST TOLERANCE	
		%	CWT-kg	%	BWT-kg
PRIMARY STRUCTURE	105,000	+100	+105,000	-10	0
SECONDARY STRUCTURE	395,000	+50	+198,000	-25	-98,000
ANTENNA CONTROL SYSTEMS	(780)	—	—	—	—
POWER DISTRIBUTION SYSTEM - EXCL. SUBARRAYS					
BUSES - ROTARY JOINT TO SECTOR CONTROL	511,200	+15	+81,000	-10	-54,000
BLADES - SECTOR CONTROL TO SUBARRAYS	219,400	+25	+55,000	-10	-22,000
SWITCH GATES/DISCONNECTS	273,600	+15	+41,000	-50	-137,000
DC-DC CONVERTERS	{2,492,000}	{+74}*	{+2,930,000}	{-51}*	{-2,019,000}
THERMAL CONTROL (ACTIVE)	{1,472,000}				
ENERGY STORAGE	570,600	+15	+90,000	-50	-279,000
SUPPORT STRUCTURES	279,400	+50	+140,000	-25	-70,000
ANTENNA COMMUNICATIONS/DATA SYSTEM					
ANTENNA SUBARRAYS	(780)	—	—	—	—
KLYSTRONS	9,316,000	+25	+2,329,000	-10	-932,000
DISTRIBUTION WAVEGUIDES	978,000	+50	+257,000	-10	-10,000
RADIATING WAVEGUIDES	2,974,000	+50	+738,000	-10	-297,000
SOLID STATE CONTROL	978,000	+25	+247,000	-10	-77,000
POWER DISTRIBUTION CABLING	77,000	+25	+18,000	-10	-7,000
THERMAL CONTROL	4,174,000	+25	+1,044,000	-25	-1,044,000
STRUCTURE	866,000	+50	+213,000	-25	-217,000
TOTAL WEIGHT	25,212,200	—	—	—	—
WEIGHT TOLERANCE (ADITIVE)	—	+10.8	+10,294,000	-21.2	-5,342,000
WEIGHT TOLERANCE (A.M.S.)	—	+10.0	+4,571,000	-10.0	-2,572,000

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* DETAILS ON FOLLOWING PAGE

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TABLE 5-4
 WEIGHT TOLERANCES WORKSHEET
 REFERENCE CONFIGURATION
 MPTJ
 DC-DC CONVERTERS + THERM. CONTROL

THE WEIGHT OF THE DC-DC CONVERTERS (PROCESSORS) PLUS
 ASSOCIATED THERMAL CONTROL CAN BE EXPRESSED AS

$$W = f_p [w_p + (1-\eta_p)w_r] P \quad \sim k_g$$

WHERE

f_p = FRACTION OF POWER PROCESSED

w_p = SPECIFIC WEIGHT OF PROCESSORS, k_g/kW_e

η_p = PROCESSOR EFFICIENCY FRACTION

w_r = SPECIFIC WEIGHT OF THERM. CONTROL, k_g/kW_e

P = POWER PROCESSED (~POWER OUT OF ROTARY JOINT), kW_e

THE CURRENT, WORST, AND BEST VALUES ARE GIVEN BELOW

	CURRENT	WORST	BEST
f_p	0.15	0.20	0.10
w_p	1.0	1.3	0.9
η_p	0.96	0.95	0.98
w_r	14.9	15.9	13.9
$f_p [w_p + (1-\eta_p)w_r]$	0.2394	0.2190	0.1178
P	16,430,000	—	—
$W \sim k_g$	3,954,000	6,084,000	1,975,000
$\Delta W - k_g$	—	+2,930,000 (+74%)	-2,019,000 (-51%)

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TABLE 5-5
WEIGHT TOLERANCES WORKSHEET
REFERENCE CONFIGURATION
(1.0 PRIMARY STRUCTURE)

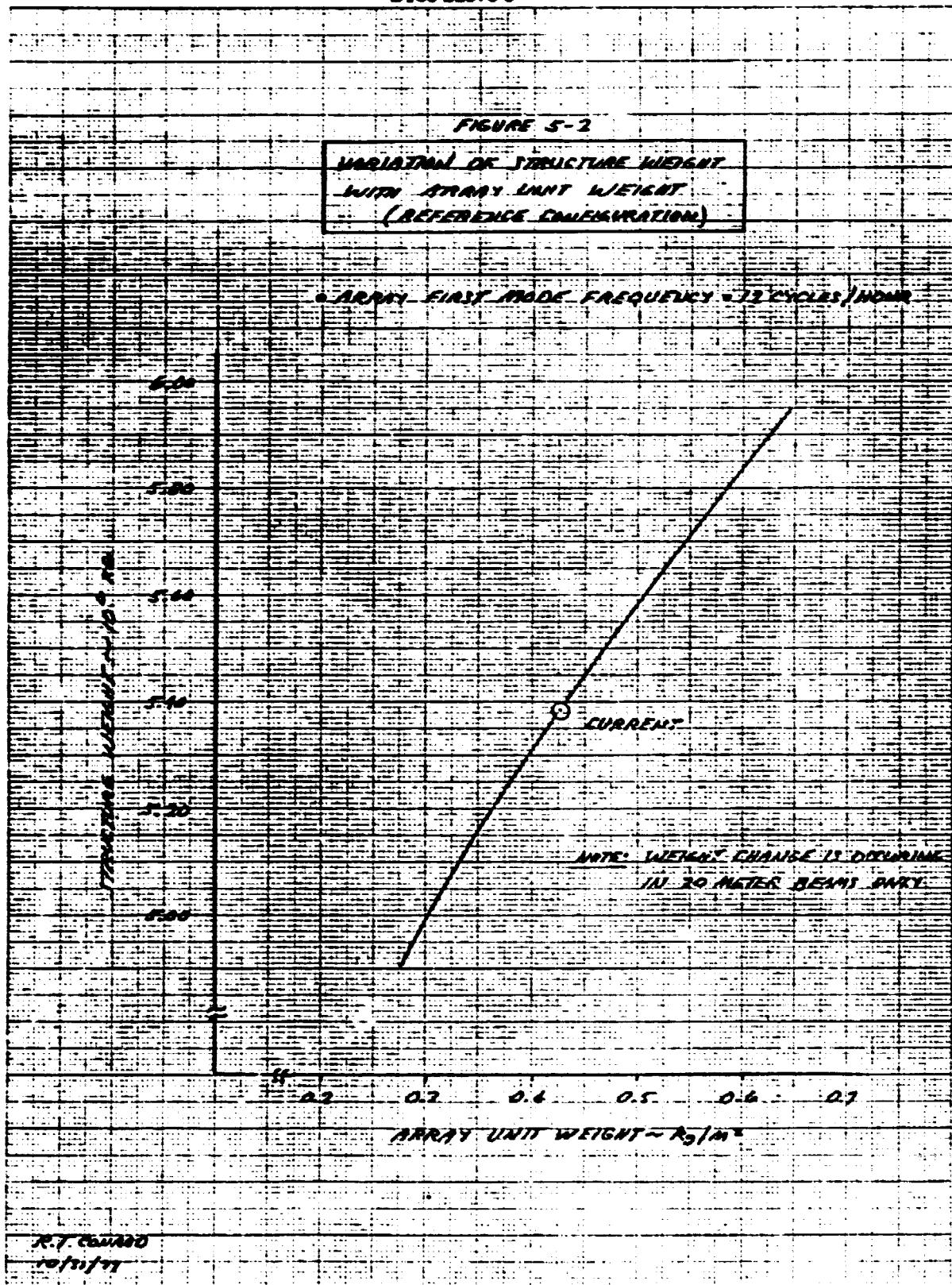
ITEM	CURRENT	WORST	BEST
TUBING MATERIAL	GRAPHITE/EPOXY		
ARRAY UNIT WEIGHT ~ kg/m ²	0.427	{ 0.607 (ADDITIONAL) 0.554 (R.M.S.)	{ 0.283 (ADDITIONAL) 0.349 (R.M.S.)
ANTENNA WEIGHT ~ 10 ⁶ kg	25.2	{ 35.5 (ADDITIONAL) 29.7 (R.M.S.)	{ 19.9 (ADDITIONAL) 22.7 (R.M.S.)
TUBE CRIMPING COEFFICIENT	0.8 / $\sqrt{R/I}$	0.4 / $\sqrt{R/I}$	1.3 / $\sqrt{R/I}$
TUBE MINIMUM WALL THICKNESS ~ mils	10	15	8
LOCATION 0° VERTICAL 20 METER BEAMS	MODULE AEROPHORE NODE POINTS ONLY	ALL NODE POINTS	MODULE PERIPHERAL NODE POINTS ONLY
DESIGN MATURITY WEIGHT RATIO FOR NON-TUBING ITEMS	1.0	1.5	0.75
• IMPACT OF ARRAY WEIGHT ON WEIGHT OF 20M BEAMS ~ kg	0	{ + 470,000 (ADDITIONAL) + 340,000 (R.M.S.)	{ - 160,000 (ADDITIONAL) - 230,000 (R.M.S.)
• IMPACT OF ANTENNA WT. ON WEIGHT OF 20M BEAMS ~ kg	0	{ + 42,000 (ADDITIONAL) + 19,000 (R.M.S.)	{ - 22,000 (ADDITIONAL) - 10,000 (R.M.S.)
• IMPACT OF CRIMPING COEFFICIENT ON WEIGHT OF TUBING IN UPPER SURFACE 20M BEAM CHORDS ~ kg	0	+ 132,000	- 86,000
• IMPACT OF MINIMUM WALL THICKNESS ON WEIGHT OF TUBING EXCLUSIVE OF UPPER SURFACE 20M BEAM CHORDS ~ kg	0	+ 1,845,000	- 724,000
• IMPACT OF LOCATION OF VERTICAL 20M BEAMS ON WEIGHT OF 20M BEAMS ~ kg	0	+ 203,000	0
• IMPACT OF DESIGN MATURITY WEIGHT RATIO ON WEIGHT OF NON-TUBING ITEMS ~ kg	0	+ 485,000	- 242,000
TOTAL WEIGHT ~ kg	5,385,000	—	—
WEIGHT TOLERANCE (ADDITIONAL) ~ kg		+ 3,102,000	- 1,574,000
WEIGHT TOLERANCE (R.M.S.) ~ kg		+ 1,953,000	- 802,000
WEIGHT TOLERANCE (ADDITIONAL) ~ %		+ 59.1	- 28.5
WEIGHT TOLERANCE (R.M.S.) ~ %		+ 36.3	- 14.9

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► MAJOR DRIVER WITH RESPECT TO LOADS.

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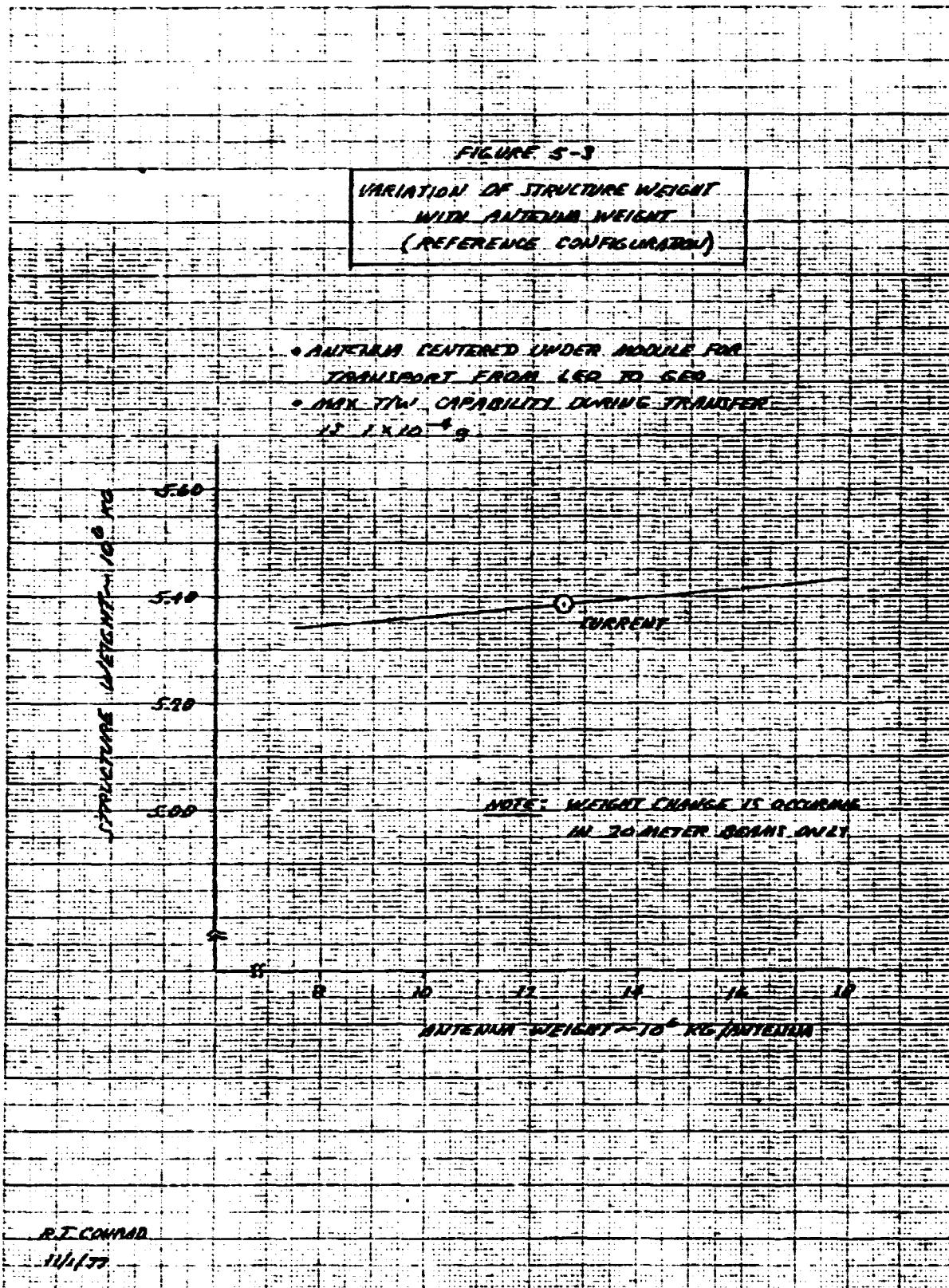


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FIGURE 5-3

VARIATION OF STRUCTURE WEIGHT
WITH ANTENNA WEIGHT
(REFERENCE CONFIGURATION)

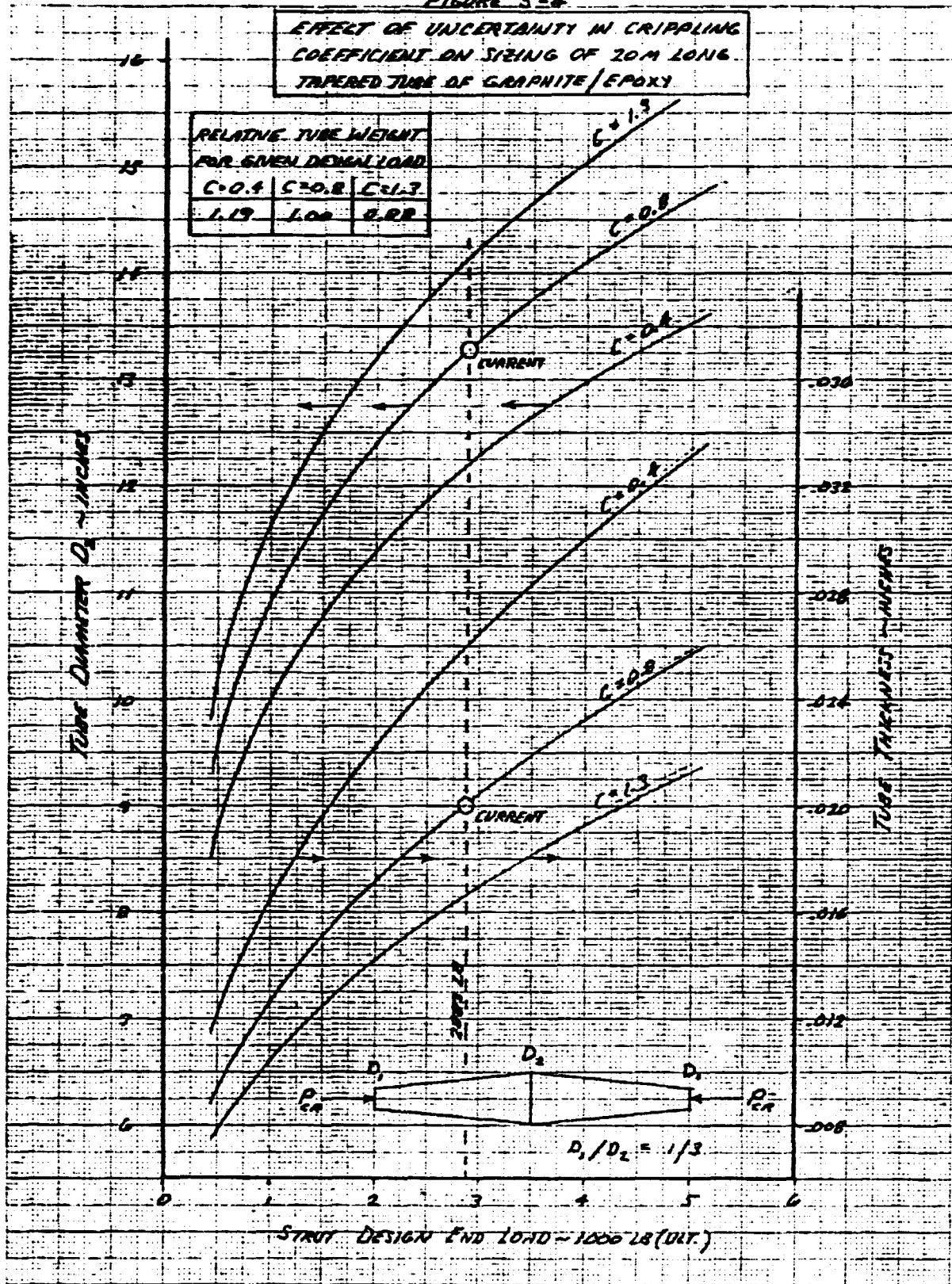
- ANTENNA CENTERED UNDER MODULE FOR
TRANSPORT FROM LEO TO GEO
- MAX TOW CAPABILITY DURING TRANSFER
 12×10^3 kg



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FIGURE 5-4



R.T. CONRAD
9/29/77

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TABLE 5-6
PRIMARY STRUCTURE WEIGHT DISTRIBUTION
(WEIGHT IN KILOGRAMS)

UPPER SURFACE 20 M BEAMS		1,710,720
G/E TUBING - CHORDS ($D_2 = 13.3"$, $t = .020"$)	720,200	
G/E TUBING - DIAG./BATTENS ($D_2 = 13.3"$, $t = .010"$)	829,200	
HARDWARE	161,440	
LOWER SURFACE 20 M BEAMS		1,347,760
G/E TUBING ($D_2 = 13.3"$, $t = .010"$)	1,106,320	
HARDWARE	161,440	
INTRA SURFACE DIAGONAL 20 M BEAMS		1,517,640
G/E TUBING ($D_2 = 13.3"$, $t = .010"$)	1,362,200	
HARDWARE	155,360	
INTRA SURFACE VERTICAL 20 M BEAMS		231,520
G/E TUBING ($D_2 = 13.3"$, $t = .010"$)	203,840	
HARDWARE	27,680	
ANTENNA SUPPORT FRAME 20 M BEAMS		61,800
G/E TUBING - CHORDS ($D_2 = 13.3"$, $t = .020"$)	34,440	
G/E TUBING - DIAG./BATTENS ($D_2 = 13.3"$, $t = .010"$)	39,640	
HARDWARE	7,720	
ANTENNA YOKE 5M BEAMS		62,000
G/E TUBING ($D_2 = 5.0"$, $t = .008"$)	39,120	
HARDWARE	29,580	
OTHER STRUCTURES		396,360
TENSION CABLES	13,440	
MODULE-TO-MODULE DOCKING PROVISIONS	63,000	
ADDITIONS TO TRUSS - ANTENNA SUPPORT FRAME BACKUP	20,000	
ANTENNA ROTATION JOINTS/PITCH CONTROLS - ON YOKE	10,000	
ANTENNA SUPPORT STRUCTURE - LEO TO GEO	40,000	
ASSEMBLY HARDWARE - MODULE FRAMES	242,320	
ASSEMBLY HARDWARE - ANTENNA SUPPORT FRAMES	4,200	
ASSEMBLY HARDWARE - YOKE FRAMES	3,400	
TOTAL WEIGHT		5,385,000 kg

D_2 = TUBE DIA. AT MIDSPAN
 D_1 = TUBE DIA. AT END = $\frac{1}{3} D_2$

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APPENDIX G

**STRUCTURAL PLANFORM SIZING, REFERENCE LENGTHS OF
20 METER BEAMS, AND DESIGN LOADS, STRUT SIZING, AND
20 METER BEAM UNIT WEIGHTS FOR NOMINAL, BEST
AND WORST CONFIGURATIONS**

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STRUCTURAL PLANFORM SIZING, REFERENCE LENGTHS FOR
20 METER BEAMS, AND DESIGN LOADS, STRUT SIZING,
AND 20 METER BEAM UNIT WEIGHTS FOR NOMINAL,
BEST, AND WORST CONFIGURATIONS

STRUCTURAL PLANFORM SIZING

THE REQUIRED TOTAL SOLAR PANEL AREAS FOR THE SUBJECT
CONFIGURATIONS ARE: NOMINAL CONFIG, 108.8 km^2 ; BEST
CONFIG, 77.0 km^2 ; WORST CONFIG, 173.0 km^2 . THESE ARE
SOLAR PANEL AREAS EXCLUSIVE OF INSTALLATION EDGE MARGINS
(SEE FIGURE 1.7-6). THE RELATIONSHIP BETWEEN THE
REQUIRED TOTAL STRUCTURAL BAY AREA AND THE REQUIRED
TOTAL SOLAR PANEL AREA CAN BE EXPRESSED AS

$$\left(\frac{\text{REQ'D TOTAL BAY AREA}}{\text{REQ'D TOTAL PANEL AREA}} \right) = \frac{1}{\text{PANEL AREA FACTOR} \times \text{SEGMENT AREA FACTOR} \times \text{ARRAY AREA FACTOR}}$$

FOR THE REFERENCE CONFIGURATION, IT FOLLOWS THAT (SEE
PAGE 1.7-7)

PANEL AREA FACTOR = 0.9713 (DESIGN)

AND

SEGMENT AREA FACTOR = 0.9972 (TYPICAL)

THE ARRAY AREA FACTOR IS DEPENDENT ON BAY SIZE, BEAM
WIDTH, AND EDGE MARGIN FOR THE CATENARY SUPPORT SYSTEM.
FOR THE CASE OF A 20 METER BEAM AND A 1.5 METER
EDGE MARGIN FOR INSTALLATION OF THE CATENARY SUPPORT SYSTEM,
IT FOLLOWS THAT

$$\text{ARRAY EDGE MARGIN} = \left(\frac{\text{BAY SIZE} - 23}{\text{BAY SIZE}} \right)^2 \quad (\text{MAX})$$

A TABULATION OF CALCULATIONS LEADING TO PLANFORM SIZING
DETERMINATION (BAY SIZE, NO. OF BAYS, AND BAY ARRANGEMENT)
IS PRESENTED IN FIGURE G-1. THE PLANFORM CONFIGURATIONS
ARE SHOWN IN FIGURES G-2, G-3, AND G-4, FOR THE
NOMINAL, BEST, AND WORST CONFIGURATIONS, RESPECTIVELY. ALL
CONFIGURATIONS HAVE AN ASPECT RATIO OF 4, THIS BEING THE
ASPECT RATIO OF THE REFERENCE CONFIGURATION AS DETERMINED
BY ELECTRICAL REQUIREMENTS.

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REFERENCE LENGTHS FOR 20 METER BEAMS

THE REFERENCE LENGTHS FOR THE 20 METER BEAMS OF THE NOMINAL, BEST, AND WORST CONFIGURATIONS ARE PRESENTED IN FIGURES G-5, G-6, AND G-7, RESPECTIVELY. ALL CONFIGURATIONS HAVE A LONGITUDINAL BENDING DEPTH EQUAL TO APPROXIMATELY 2.1% OF SATELLITE LENGTH, THIS BEING THE THICKNESS RATIO OF THE REFERENCE CONFIGURATION AS DETERMINED BY A 30° TRUSS ANGLE. THE TRUSS ANGLE OF 30° IS MAINTAINED IN THE NOMINAL AND BEST CONFIGURATIONS. HOWEVER, WORST CONFIGURATION HAS A LARGER TRUSS ANGLE (- - - FOR OPTION 1, 41.5° FOR OPTION 2) DUE TO AVOIDANCE OF AN EXCESSIVELY LARGE BAY SIZE.

DESIGN LOADS, STRUT SIZING, AND 20 METER BEAM UNIT WEIGHTS

THE SUBJECT DATA IS PRESENTED IN FIGURE G-8. DESIGN LOADS DETERMINATION IS BASED ON THE SCALING RATIONAL OF APPENDIX F. STRUT SIZING IS PER FIGURE A-2, AND 20 METER BEAM UNIT WEIGHTS ARE PER FIGURE D-3.

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FIGURE G-1 STRUCTURAL PLATFORM SIZING

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A

B

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CONFIG.	REQ'D TOTAL PANEL AREA	BAY SIZE	PANEL AREA FACTOR (DESIGN)	SEGMENT AREA FACTOR (TYPICAL)	ARRAY AREA FACTOR (MAX)	Δ $\left(\frac{\text{REQ'D TOTAL BAY AREA}}{\text{REQ'D TOTAL PANEL AREA}} \right)$	REQ'D TOTAL BAY AREA	REQ'D NO. OF BAYS	BAY ARRANGEMENT FOR MAX
		m^2	m				m^2		
REFERENCE B	101,370,000	640	.9913	.9972	.9274	1.08845	110,272,000	239.3	
		660	"	"	.9315	1.08599	110,000,000	252.6	
		680	"	"	(< MAX)		111,516,000	256.0	8 x 32
NOMINAL	100,000,000	660	.9913	.9971	.9315	1.08599	110,156,000	271.2	
		680	"	"	.9325	1.08367	117,903,000	265.0	
		680	"	"	(< MAX)		110,374,000	256.0	8 x 32
BEST	77,800,000	560	.9913	.9972	.9195	1.10017	85,573,000	272.9	
		580	"	"	.9227	1.09691	86,373,000	252.7	
		580	"	"	(< MAX)		86,110,000	256.0	8 x 32
WORST	193,000,000	720	.9913	.9972	.9371	1.07750	208,394,000	401.9	
		740	"	"	.9388	1.07755	207,967,000	379.8	
		740	"	"	(< MAX)		210,040,000	400.0	10 x 40
		620	.9913	.9972	.9248	1.09386	211,115,000	506.4	
		620	"	"	.9372	1.09103	210,569,000	517.0	
		620	"	"	(< MAX)		221,416,000	576.0	12 x 48

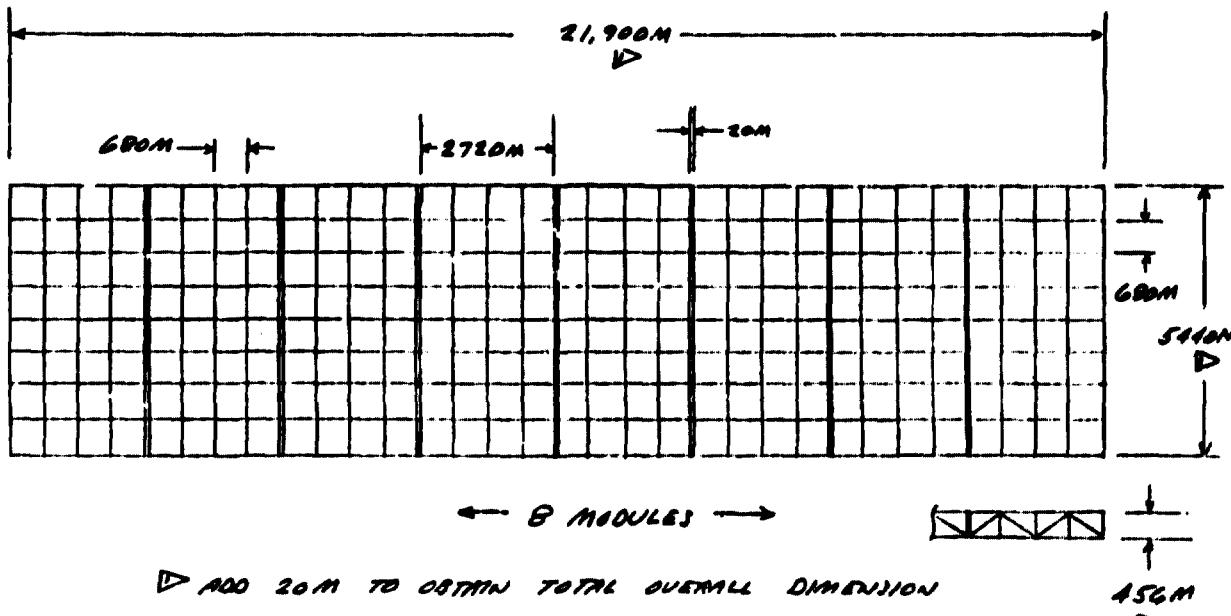
$$\Delta \left(\frac{\text{REQ'D TOTAL BAY AREA}}{\text{REQ'D TOTAL PANEL AREA}} \right) = \frac{1}{\text{PANEL AREA FACTOR} \times \text{SEGMENT AREA FACTOR} \times \text{ARRAY AREA FACTOR}}$$

Δ SHOWN FOR METHOD CHECKOUT PURPOSES.

Δ OPTION 1

Δ OPTION 2

FIGURE G-2
NOMINAL CONFIGURATION
(ALL DIMENSIONS ARE BEAM G TO BEAM G)



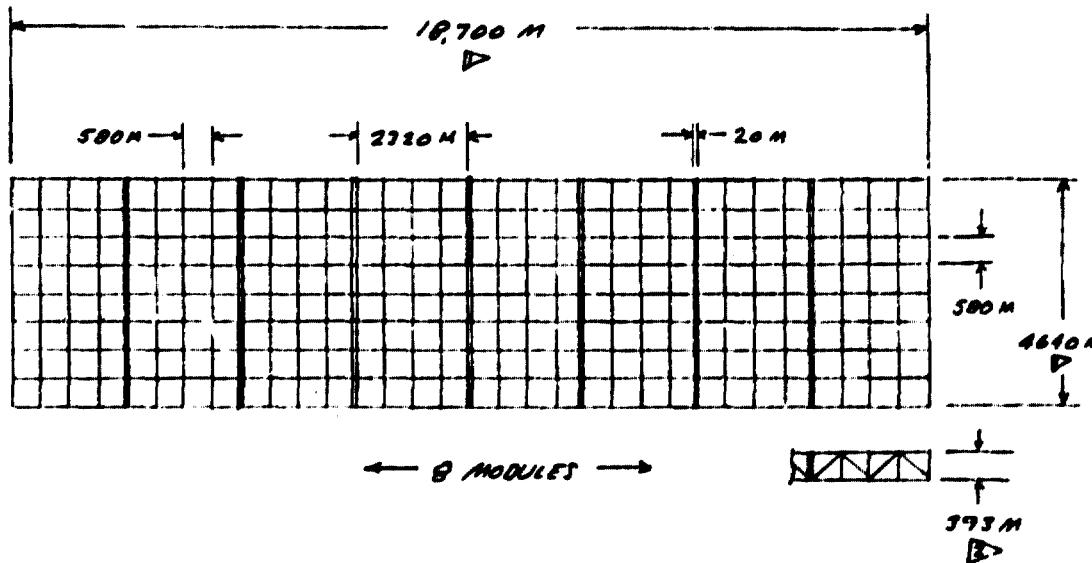
STRUCTURAL PLANFORM AREA = 119.16 KM²

DISPARITIES

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FIGURE G-3
BEST CONFIGURATION
(ALL DIMENSIONS ARE BEAM G TO BEAM G)

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▷ ADD 20M TO OBTAIN TOTAL OVERALL DIMENSION

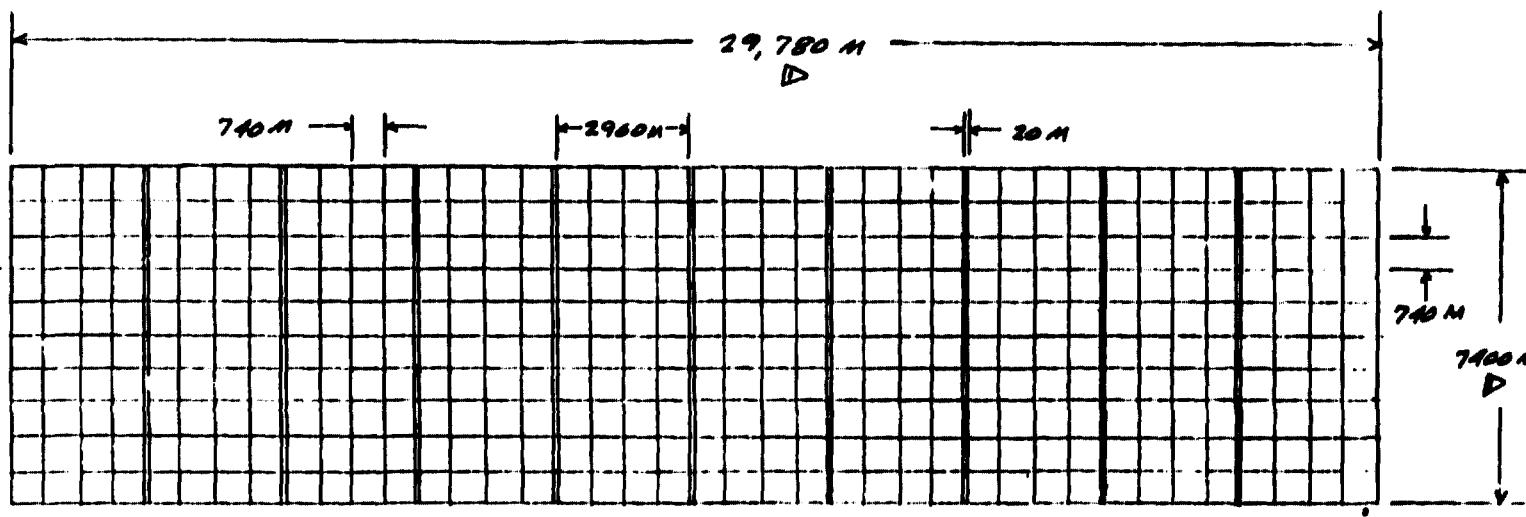
▷ ADD 23M TO OBTAIN TOTAL OVERALL DIMENSION

STRUCTURAL PLANFORM AREA = 00.77 KM²

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FIGURE G-4A
WOT CONFIGURATION-OPTION 1
(ALL DIMENSIONS ARE BEAM 8 TO BEAM 8)



← 10 MODULES →

D 100 20 m TO OBTAIN TOTAL OVERALL DIMENSION

B 100 23 m TO OBTAIN TOTAL OVERALL DIMENSION

STRUCTURAL PLATFORM AREA = 220.37 m²

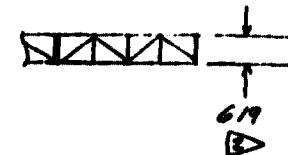
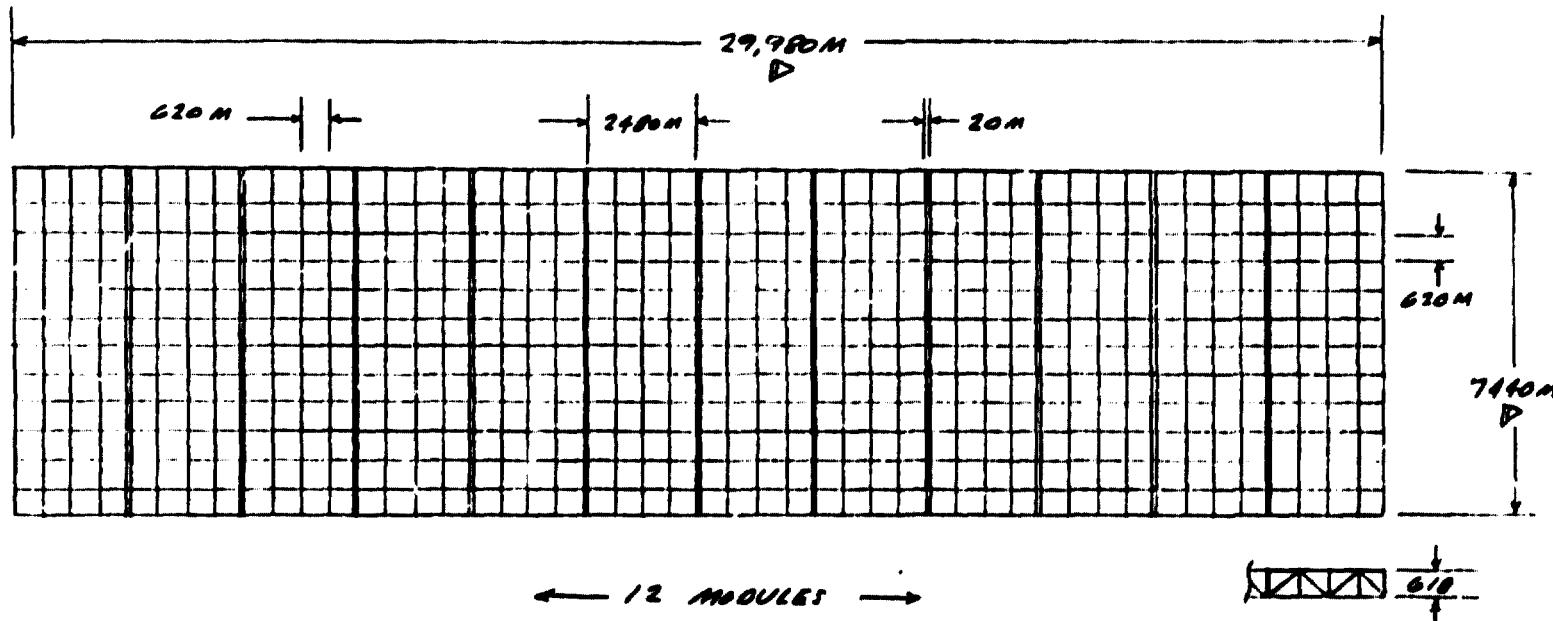


FIGURE G-1B
WORST CONFIGURATION - OPTION 2
(ALL DIMENSIONS ARE BEAM 6 TO BEAM 6)

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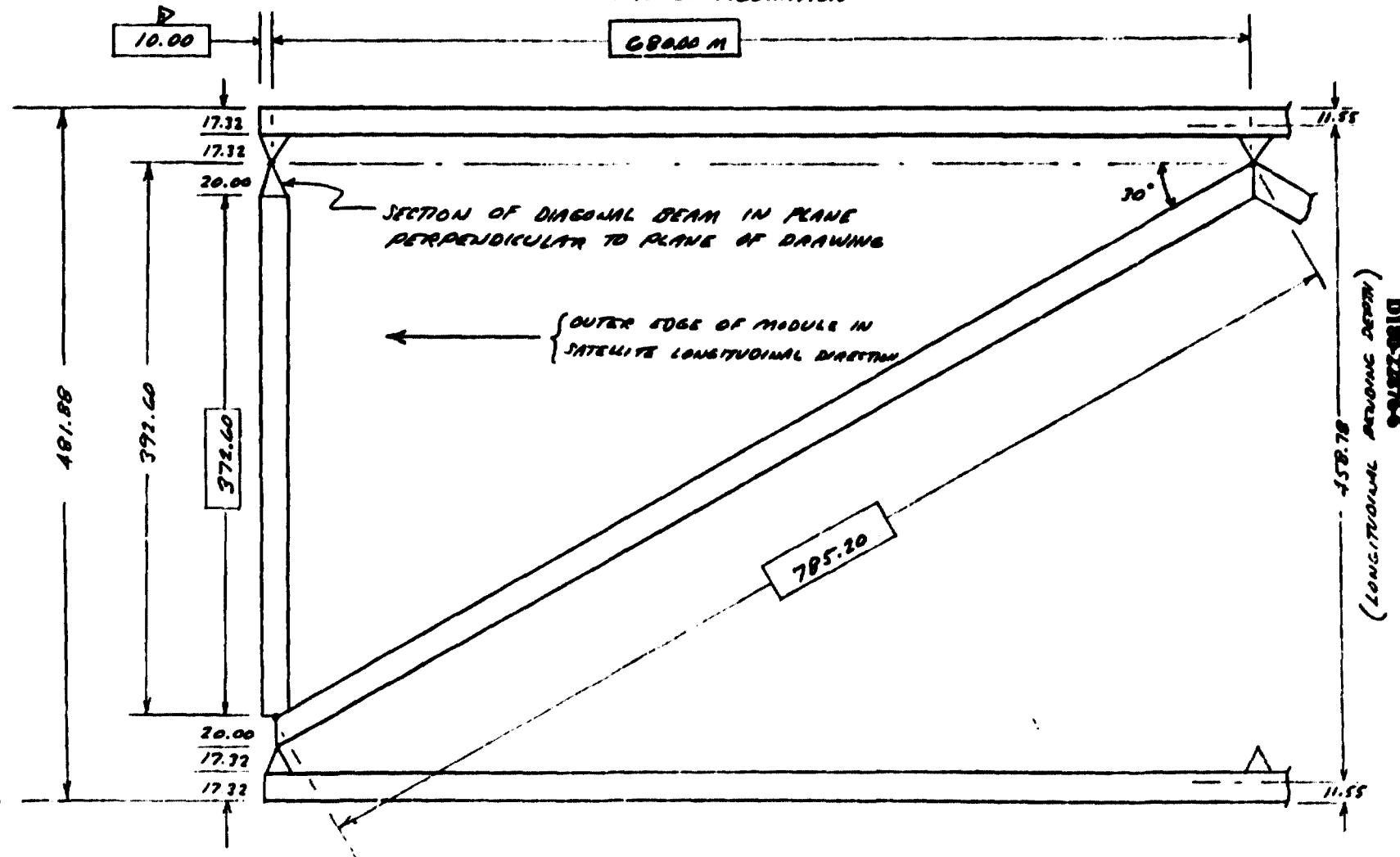
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▷ ADD 20M TO OBTAIN TOTAL OVERALL DIMENSION

▷ ADD 23M TO OBTAIN TOTAL OVERALL DIMENSION

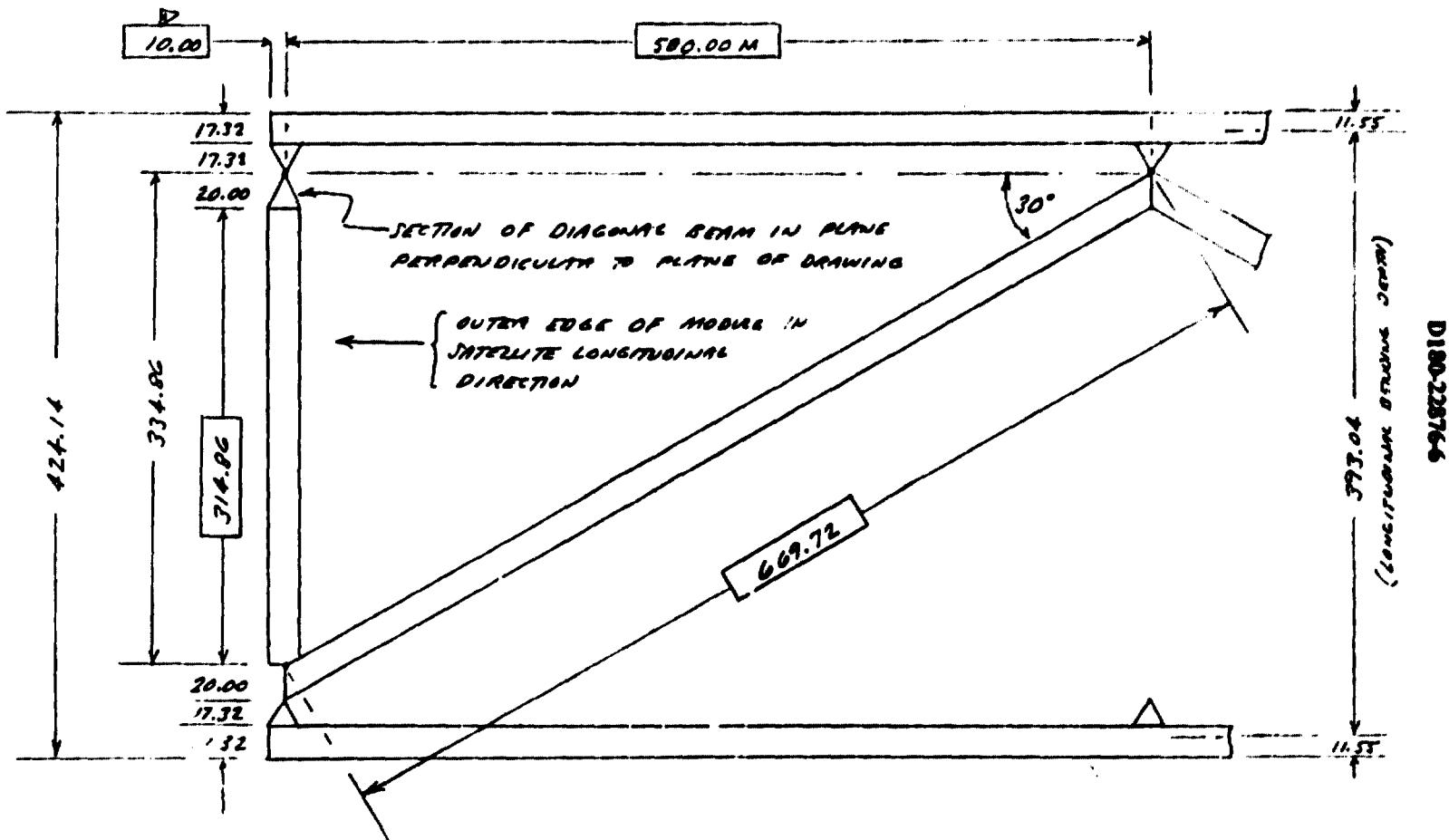
STRUCTURAL PLANFORM AREA = 227.05 KM²

FIGURE G-5
REFERENCE LENGTHS FOR 20 METER BEAMS
NOMINAL CONFIGURATION



▷ DELTA LENGTH AT EDGE. (20 PLACES/SURFACE/MODULE, INCLUDING 2 PLACES/CORNER/SURFACE)

FIGURE G-6
REFERENCE LENGTHS FOR 20 METER BEAMS
BEST CONFIGURATION



▷ DEPTH LENGTH AT EDGE. (28 PLACES/SURFACE/MODULE, INCLUDING 2 PLACES/CORNER/SURFACE)

FIGURE G-7A
REFERENCE LENGTHS FOR 20 METER BEAMS
WORST CONFIGURATION (OPTION 1)

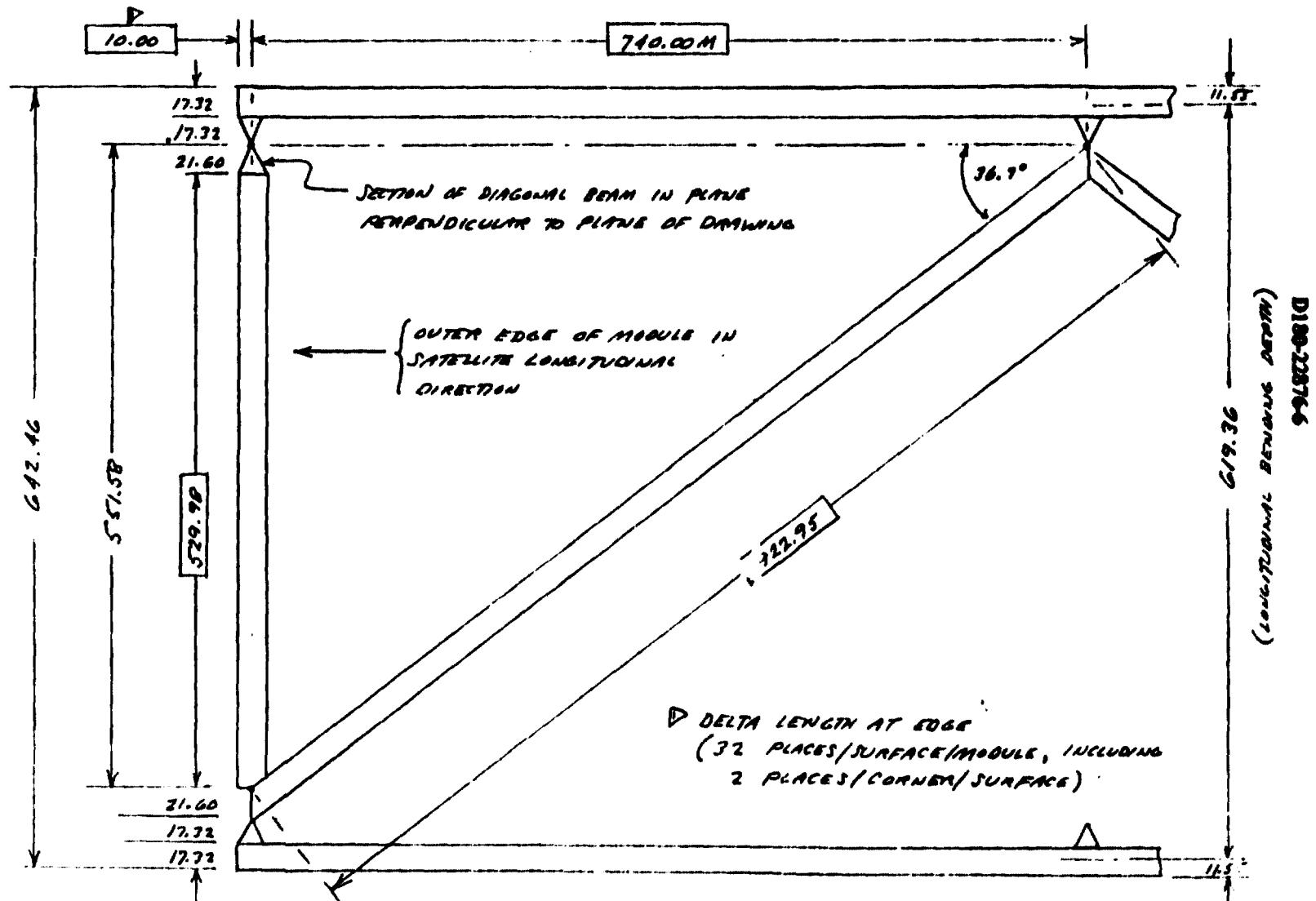
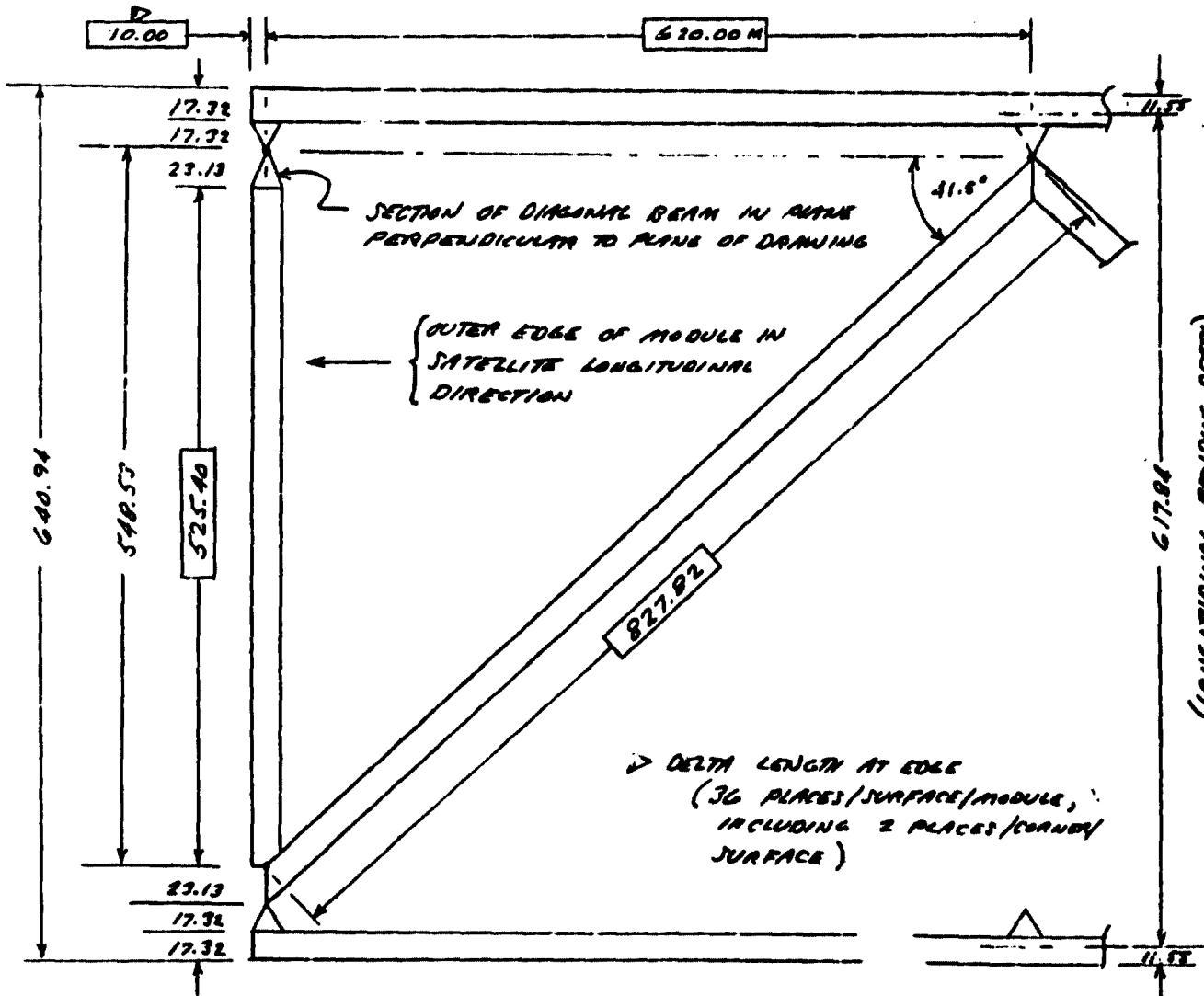


FIGURE G-7B
REFERENCE LENGTHS FOR 20 METER BEAMS
WORST CONFIGURATION (OPTION 2)



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FIGURE G-8
DESIGN LOADS, STRUT SIZING, AND 20 METER BEAM UNIT WEIGHTS

ITEM	REF.	CONFIGURATION			WORST
		NON.	BEST	OPTION 1	OPTION 2
PARAMETERS:					
$L_{beam} \sim m (m)$	660(25,784)	600(26,772)	580(22,835)	740(29,134)	620(24,409)
$w_{beam} \sim m (m)$	20 (787)				
$H_{beam} \sim m (m)$	17.3 (684)				
$w_{strut} \sim kg/m^2$	0.427				
$L_{strut} \sim m$	2640	2720	2320	2960	2480
$w_{strut} \sim m$	5280	5480	4640	7400	7440
$H_{strut} \sim m$	147	156	393	619	618
$w_{strut} \sim kg/m^2 (approx.)$	0.466				
$w_{strut} \sim kg$	12,192,000	14,130,000	11,375,000	18,161,000	18,161,000
SCALING TERMS:					
$(L_0 - w_0)^2 (w_{beam})$	175,000	186,000	134,000	221,000	154,000
$(L_0 - l_0) (w_{beam})$	273	282	239	307	256
$(L_0 - h_0)^2 (w_{beam}) (L_0)$	1.15×10^8	1.26×10^8	0.70×10^8	1.64×10^8	0.95×10^8
$(w_{beam}) (L_n) (w_n) / (H_n)$	14,530	15,120	12,760	16,490	13,910
$(w_{beam}) (L_n) (w_n) / (H_n)$	72×10^6	26×10^6	67×10^6	87×10^6	73×10^6
APPLIED '0:05 ON BEAM:					
$w_1 \sim L_0/m$	0.0223	0.0237	0.0171	0.0282	0.0196
$w_3 \sim L_0/m$	0.00040	0.00041	0.00035	0.00045	0.00038
$P \sim L_0$	209	317	196	412	239
$\Delta P_1 \sim L_0$	189	197	166	214	181
$\Delta P_2 \sim L_0$	456	532	424	551	462
STRUT COLUMN LOAD INCREMENTS:					
$w_1 L_0^2 / 12 w_0 \sim L_0$	1594	1799	944	2535	1237
$w_2 L_0^2 / 24 H_0 \sim L_0$	17	18	11	23	14
$P/3 \sim L_0$	96	106	65	137	80
$\Delta P_1/3 \sim L_0$	67	66	55	71	60
$\Delta P_2/3 \sim L_0$	152	177	141	184	154
(Σ INCREMENTS-APPLIED)	(1922)	(2160)	(1216)	(2950)	(1545)
U.F.S.	1.5				
(Σ INCREMENTS-DESIGN)	(2883)	(3249)	(1024)	(4425)	(2316)
STRUT SIZING: D					
$D_{max} \sim m$	17.3	13.6	12.2	14.4	12.8
$D_{min} \sim m$	4.4	4.5	4.1	4.8	4.3
$t \sim m$	0.020	0.021	0.017	0.024	0.018
BEAM UNIT WEIGHTS: D					
UPR. SURF. BEAMS ~ kg/m	4.24	4.47	3.60	4.99	3.92
LWR. SURF. BEAMS ~ kg/m	3.34	3.42	3.08	3.61	3.20
INT'L. SURF. BEAMS ~ kg/m	3.34	3.42	3.08	3.61	3.20

D METHODOLOGY PER APPENDIX E.

D FROM APPENDIX A, FIGURE A-2.

D FROM APPENDIX D, FIGURE D-3.

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APPENDIX H

*VARIATION OF STRUCTURE WEIGHT
WITH STRUCTURAL PLANFORM AREA*

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VARIATION OF STRUCTURE WEIGHT
WITH STRUCTURAL PLATFORM AREA

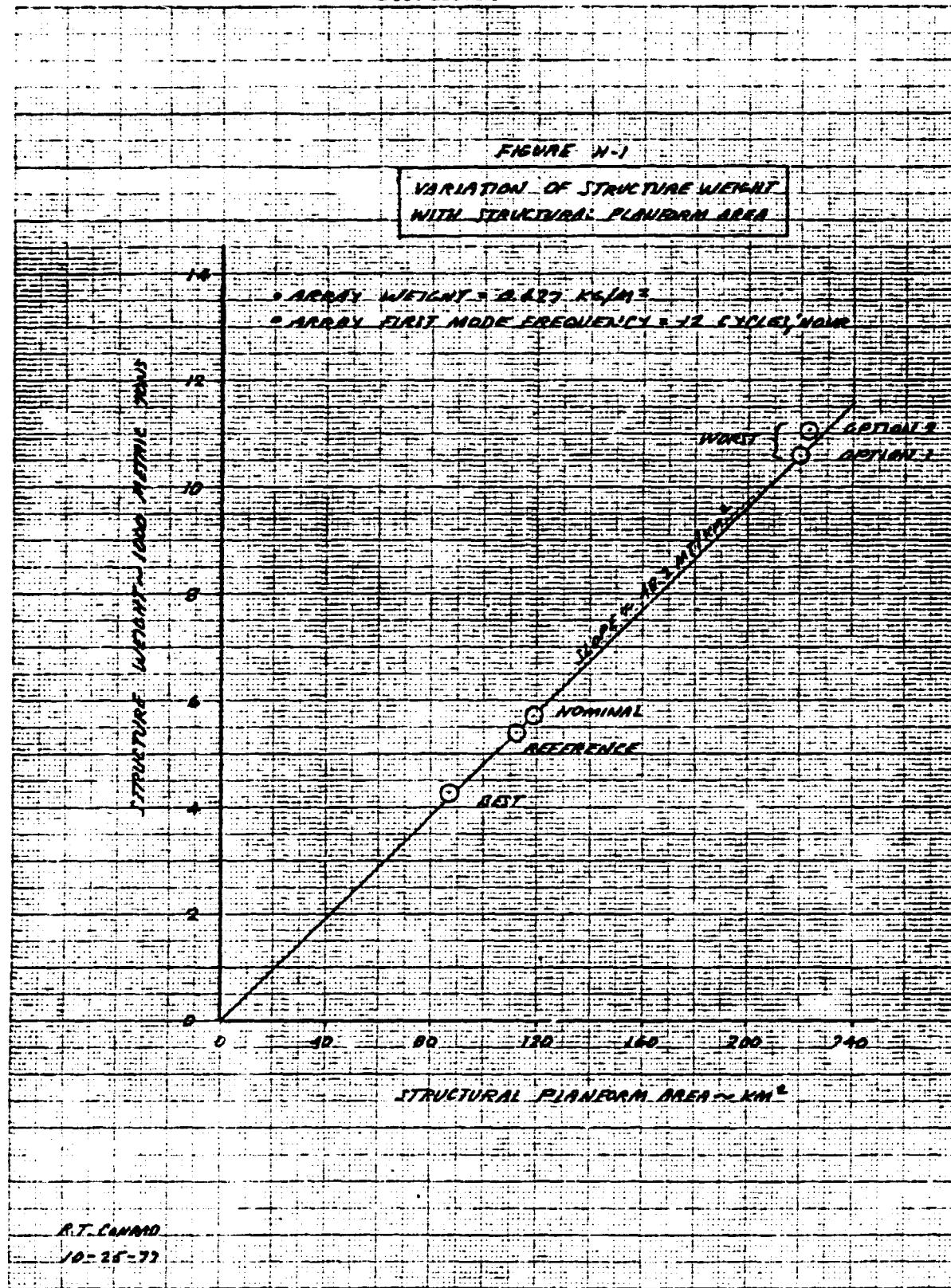
THE RESULTS OF A STUDY TO DETERMINE THE VARIATION OF STRUCTURE WEIGHT WITH STRUCTURAL PLATFORM AREA ARE PRESENTED IN FIGURE H-1. AS SHOWN, STRUCTURE WEIGHT (FOR ALL PRACTICAL PURPOSES) IS DIRECTLY PROPORTIONAL TO STRUCTURAL PLATFORM AREA.

STRUCTURE WEIGHT SUMMARIES PLUS ASSOCIATED 20 METER BEAM WEIGHT SUMMARIES ARE PRESENTED ON THE FOLLOWING PAGES FOR THE NORMAL, BEST, AND WORST CONFIGURATIONS. THE STRUCTURAL ARRANGEMENT AND 20 METER BEAM UNIT WEIGHT DATA FOR THESE CONFIGURATIONS IS DEFINED IN APPENDIX G.

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STRUCTURE WEIGHT STATEMENT
FOR "NOMINAL" CONFIGURATION

1.1 PRIMARY STRUCTURE

5,746,600 kg

MODULE NO. 1		<u>810,200</u>
BASIC FRAME		<u>678,700</u>
ZOM BEAMS	<u>644,640</u>	
TENSION CABLES	<u>17400</u>	
CONTINGENCY~5%	<u>32,700</u>	
DOCKING PROVISIONS (16 PLACES)		<u>4500</u>
ANTENNA SUPPORT STRUCTURE		<u>57,000</u>
EXTERNAL FRAME	<u>46,700</u>	
ZOM BEAMS	<u>44,440</u>	
CONTINGENCY~5%	<u>2260</u>	
ADDITIONS TO MODULE FRAME	<u>10,302</u>	
ROTARY JOINT		▷
ANTENNA Yoke STRUCTURE		<u>50,000</u>
FRAME	<u>42,500</u>	
SM BEAMS	<u>41,400</u>	
CONTINGENCY~5%	<u>2100</u>	
ROTATION JOINTS/PITCH CONTROLS	<u>4,200</u>	
ANTENNA SUPPORT STRUCTURE (LED-TO-GEO)	<u>20,000</u>	
MODULE NO. 2		<u>681,700</u>
BASIC FRAME		<u>678,700</u>
ZOM BEAMS	<u>644,640</u>	
TENSION CABLES	<u>17400</u>	
CONTINGENCY~5%	<u>32,700</u>	
DOCKING PROVISIONS (26 PLACES)	<u>9000</u>	
MODULE NO. 3		<u>687,700</u>
MODULE NO. 4		<u>687,700</u>
MODULE NO. 5		<u>687,700</u>
MODULE NO. 6		<u>687,700</u>
MODULE NO. 7		<u>687,700</u>
MODULE NO. 8		<u>810,200</u>

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▷ INCLUDED ELSEWHERE IN WEIGHT STATEMENT UNDER
"MECHANICAL ROTARY JOINT" AND "ELECT. ROTARY JOINT."

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20 METER BEAM WEIGHT SUMMARY
FOR "NOMINAL" CONFIGURATION

20M BEAMS (PER MODULE)

644,640 kg

LOCATION/BEAMS	LENGTH OF BEAM PER MODULE (m)	WT. OF BEAM (kg/kg)	WT. OF BEAM PER MODULE (kg)
CUR SURFACE/LONGITUDINALS	$(9 \times 4) \times 680 = 24,480$	4.47	107,426
" " /LATERTALS	$(5 \times 8) \times 680 = 27,200$	—	121,584
" " /EDGE DIAGONALS	$(20) \times 10 = 200$ $(57,960)$	—	1252 (232,262)
CUR SURFACE/LONGITUDINALS	$(9 \times 4) \times 680 = 24,480$	3.42	83,722
" " /LATERTALS	$(5 \times 8) \times 680 = 27,200$	—	93,024
" " /EDGE DIAGONALS	$(20) \times 10 = 200$	—	958
INTEN SURF./LONG. DIAGONALS	$(9 \times 4) \times 705.2 = 26,267$	—	96,674
" " /INTERNAL DIAGONALS	$(5 \times 8) \times 705.2 = 31,408$	—	107,415
" " /VERTICALS	$(24) \times 377.6 = 8942$ $(120,577)$	—	30,585 (412,378)
TOTAL - PER MODULE	172,537	—	644,640

▷ SEE SKETCH FIGURE G-5 FOR REFERENCE BEAM LENGTHS.

▷ FROM FIGURE G-8

▷ LOCATED AROUND PERIPHERY OF MODULE ONLY.

D180-22866
STRUCTURE WEIGHT SUMMARY
FOR "BEST" CONFIGURATION

1.1 PRIMARY STRUCTURE

4,278,100 lb

MODULE NO. 1	<u>606,800</u>
BASIC FRAME	<u>501,800</u>
ZOM BEAMS	<u>176,370</u>
TENSION CABLES	<u>1520</u>
CONTINGENCY~5%	<u>22,910</u>
DOCKING PROVISIONS (18 PLACES)	<u>4500</u>
ANTENNA SUPPORT STRUCTURE	<u>40,900</u>
EXTERNAL FRAME	<u>32,100</u>
ZOM BEAMS	<u>30,570</u>
CONTINGENCY~5%	<u>1570</u>
ADDITIONS TO MODULE FRAME	<u>8800</u>
ROTARY JOINT	<u>▷</u>
ANTENNA YORE STRUCTURE	<u>41,000</u>
FRAME	<u>36,200</u>
SM BEAMS	<u>24,500</u>
CONTINGENCY~5%	<u>4,700</u>
ROTATION JOINTS/PITCH CONTROLS	<u>1800</u>
ANTENNA SUPPORT STRUCTURE (LEO-TO-GEO)	<u>10,600</u>
MODULE NO. 2	<u>510,800</u>
BASIC FRAME	<u>501,800</u>
ZOM BEAMS	<u>176,370</u>
TENSION CABLES	<u>1520</u>
CONTINGENCY~5%	<u>22,910</u>
DOCKING PROVISIONS (26 PLACES)	<u>9000</u>
MODULE NO. 3	<u>510,800</u>
MODULE NO. 4	<u>510,800</u>
MODULE NO. 5	<u>510,800</u>
MODULE NO. 6	<u>510,800</u>
MODULE NO. 7	<u>510,800</u>
MODULE NO. 8	<u>606,800</u>

▷ INCLUDED ELSEWHERE IN WEIGHT STATEMENT UNDER
"MECHANICAL ROTARY JOINT" AND "ELECTRICAL ROTARY JOINT."

D180-228766

**20 METER BEAM WEIGHT SUMMARY
FOR "BEST" CONFIGURATION**

20M BEAMS (PER MODULE)476,370 kg

LOCATION/BEAMS	LENGTH OF BEAM PER MODULE (m)	WT. OF BEAM PER MODULE (kg)
UPR SURFACE/LONGITUDINALS	$(9 \times 4) \times 580 = 20,880$	3,60
" " /LATERTALS	$(5 \times 8) \times 580 = 23,200$	—
" " /EDGE DECTRS	$(28) \times 10 = 280$	—
		(44,360)
UPR SURFACE/CONSTRUCTIONALS	$(9 \times 4) \times 580 = 20,880$	3.08
" " /LATERTALS	$(5 \times 8) \times 580 = 23,200$	—
" " /EDGE DECTRS	$(28) \times 10 = 280$	—
INTRA SURF./LONG. DIAGONALS	$(9 \times 4) \times 669.7 = 24,109$	—
" " /LATERTAL DIAGONALS	$(5 \times 8) \times 669.7 = 26,788$	—
" " /VERTICALS Δ	$(24) \times 314.9 = 7558$	—
		(102,815)
TOTAL - PER MODULE	147,175	—
		476,370

Δ SEE SKETCH FIGURE G-G FOR REFERENCE BEAM LENGTHS.

Δ FROM FIGURE G-G

Δ LOCATED AROUND PERIPHERY OF MODULE ONLY.

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STRUCTURE WEIGHT SUMMARY FOR
"WANT" CONFIGURATION (OPTION 1)

1.1 PRIMARY STRUCTURE

10,605,200 lb

MODULE NO. 1	<u>1,184,600</u>
BASIC FRAME	<u>1,018,500</u>
ZOM BEAMS	<u>963,750</u>
TELLION CABLES	<u>2260</u>
CONTINGENCY~5%	<u>18,470</u>
DOCKING PROVISIONS (.22 PLACES)	<u>5,500</u>
ANTENNA SUPPORT STRUCTURE	<u>71,400</u>
EXTERNAL FRAME	<u>69,200</u>
ZOM BEAMS	<u>57,150</u>
CONTINGENCY~5%	<u>2,850</u>
ADDITIONS TO MODULE FRAME	<u>11,200</u>
ROTARY JOINT	▷
ANTENNA YORE STRUCTURE	<u>59,200</u>
FRAME	<u>50,700</u>
SM BEAMS	<u>48,300</u>
CONTINGENCY~5%	<u>2,400</u>
ROTATION JOINTS/PITCH CONTROLS	<u>8,500</u>
ANTENNA SUPPORT STRUCTURE (150-70-60)	<u>30,000</u>
MODULE NO. 2	<u>1,029,500</u>
BASIC FRAME	<u>1,018,500</u>
ZOM BEAMS	<u>963,750</u>
TELLION CABLES	<u>2260</u>
CONTINGENCY~5%	<u>18,470</u>
DOCKING PROVISIONS (.44 PLACES)	<u>11,000</u>
MODULE NO. 3	<u>1,029,500</u>
MODULE NO. 4	<u>1,029,500</u>
MODULE NO. 5	<u>1,029,500</u>
MODULE NO. 6	<u>1,029,500</u>
MODULE NO. 7	<u>1,029,500</u>
MODULE NO. 8	<u>1,029,500</u>
MODULE NO. 9	<u>1,029,500</u>
MODULE NO. 10	<u>1,184,600</u>

▷ INCLUDED ELSEWHERE IN WEIGHT STATEMENT UNDER
"MECHANICAL ROTARY JOINT" AND "ELECTRICAL ROTARY JOINT."

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20 METER BEAM WEIGHT SUMMARY
FOR "WORST" CONFIGURATION (OPTION 1)20M BEAMS (PER MODULE)967,750 kg

LOCATION/BEAMS	LENGTH OF BEAM PER MODULE (m)	WT. OF BEAM (kg/m)	WT. OF BEAM PER MODULE (kg)
UPR SURFACE/LONGITUDINALS	$(11 \times 4) \times 740 = 32,560$	14.99	462,474
" " /LATERTALS	$(5 \times 10) \times 740 = 37,000$	—	184,630
" " /EDGE DIAGONALS	$(32) \times 10 = 320$ (69.88)	—	1596 (348,700)
LLW SURFACE/LONGITUDINALS	$(11 \times 4) \times 740 = 32,560$	3.61	112,542
" " /LATERTALS	$(5 \times 10) \times 740 = 37,000$	—	133,570
" " /EDGE DIAGONALS	$(32) \times 10 = 320$	—	1155
INTIR SURF./LONG. DIAGONALS	$(4 \times 4) \times 923.0 = 40,912$	—	146,609
" " /LATENTL DIAGONALS	$(5 \times 4) \times 923.0 = 46,150$	—	166,602
" " /VERTICALS	$(28) \times 530.0 = 14,840$ $(171,482)$	—	53,572 619,050
TOTAL - PER MODULE	241,362	—	967,750

- ▷ SEE SKETCH FIGURE G-7A FOR REFERENCE BEAM LENGTHS.
- ▷ FROM FIGURE G-8
- ▷ LOCATED AROUND PERIPHERY OF MODULE ONLY.

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STRUCTURE WEIGHT SUMMARY FOR
"WORST" CONFIGURATION (OPTION 2)

1.1 PRIMARY STRUCTURE

11,077,600 b

MODULE NO. 1	<u>1,045,300</u>
BASIC FRAME	<u>898,200</u>
20M BEAMS	<u>817,400</u>
TENSION CABLES	<u>2,240</u>
CONTINGENCY ~5%	<u>12,500</u>
DOCKING PROVISIONS (~ PLACES)	<u>6,500</u>
ANTENNA SUPPORT STRUCTURE	<u>57,900</u>
EXTERNAL FRAME	<u>16,000</u>
20M BEAMS	<u>45,690</u>
CONTINGENCY ~5%	<u>2,210</u>
ADDITIONS TO MODULE FRAME	<u>9,100</u>
ROTARY JOINT	▷
ANTENNA YORE STRUCTURE	<u>59,200</u>
FRAME	<u>50,700</u>
5M BEAMS	<u>18,100</u>
CONTINGENCY ~5%	<u>2,400</u>
ROTATION JOINTS/PITCH CONTROLS	<u>8,500</u>
ANTENNA SUPPORT STRUCTURE (LED-R-GEO)	<u>30,000</u>
MODULE NO. 2	<u>898,700</u>
BASIC FRAME	<u>898,200</u>
20M BEAMS	<u>817,400</u>
TENSION CABLES	<u>2,240</u>
CONTINGENCY ~5%	<u>12,500</u>
DOCKING PROVISIONS (SL-LACES)	<u>12,000</u>
MODULE NO. 3	<u>898,700</u>
MODULE NO. 4	<u>898,700</u>
MODULE NO. 5	<u>898,200</u>
MODULE NO. 6	<u>898,200</u>
MODULE NO. 7	<u>898,700</u>
MODULE NO. 8	<u>898,700</u>
MODULE NO. 9	<u>898,700</u>
MODULE NO. 10	<u>898,700</u>
MODULE NO. 11	<u>8,10,700</u>
MODULE NO. 12	<u>1,045,300</u>

▷ INCLUDED ELSEWHERE IN WEIGHT STATEMENT UNDER
"MECHANICAL ROTARY JOINT" AND "ELECTRICAL ROTARY JOINT."

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~~24 METER BEAM WEIGHT SUMMARY
FOR "WORST" CONFIGURATION (OPTION 2)~~

20M BEAMS (PER MODULE)847,460 kg

LOCATION/BEAMS	LENGTH OF BEAM PER MODULE (m)	WT. OF BEAM (kg/m)	WT. OF BEAM PER MODULE (kg)
CUR SURFACE/LONGITUDINALS	(3x4) x 620 = 32,240	3.92	126,381
" " /LATERTALS	(3x12) x 620 = 37,200	-	145,824
" " /EDGE DICTAS	(36) x 10 = 360	-	1411
	(69,860)		(277,616)
CUR SURFACE/LONGITUDINALS	(3x4) x 620 = 32,240	3.20	103,168
" " /LATERTALS	(5x12) x 620 = 37,200	-	119,040
" " /EDGE DICTAS	(36) x 10 = 360	-	1152
INTRA SURF./LONG. DIAGONALS	(3x4) x 822.8 = 43,046	-	137,747
" " /LATERTAL DIAGONALS	(5x12) x 822.8 = 49,668	-	158,935
" " /VERTICALS Δ	(32) x 525.1 = 16,818	-	53,802
	(179,327)		(573,844)
TOTAL - PER MODULE	249,127	-	847,460

Δ SEE SKETCH FIGURE 2-78 FOR REFERENCE BEAM LENGTHS.

Δ FROM FIGURE G-0

Δ LOCATED AROUND PERIPHERY OF MODULE ONLY.

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APPENDIX I

**CRIPLING COEFFICIENT UNCERTAINTY
FOR SPS GRAPHITE/EPOXY TUBES**

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CRIPPLING COEFFICIENT UNCERTAINTY FOR SPS GRAPHITE/EPOXY TUBES

Figure I-1 presents a crippling coefficient comparison between the SPS composite tube and metal tubes. Curve is an empirical curve for metal tubes, per NACA TN 3783. Curves and are recommended design curves from a Boeing design manual for the Minuteman program. The positions of curves and relative to curve reflect the degradation of allowable stresses associated with high probabilities (at high confidence levels) of no structural failure. As such, the degradation is a measure of the impact of slight structural imperfections on crippling of thin walled tubes. Curve is the empirical curve for the SPS composite tube, and is reflected in the tube sizing data of Appendix A. This curve was developed using the Boeing design manual equations shown. Curve is the result of applying these equations to some typical metals. (7075 aluminum, 18-8 stainless steel, and inconel were considered. The scatter in crippling coefficient with metal type was negligible.) The close correlation between curve and curve suggests that, when sufficient test data is available, some degradation will occur in the crippling coefficient to be used for design of actual hardware.

Figure I-2 presents crippling coefficient curves for the SPS composite tube. Curve is the nominal curve (designated as curve in Figure I-1). Curve reflects the possibility (Convair position) that the shear modulus G_{xy} has an effective value twice as large as the current predicted value of 0.6×10^6 psi. Curve reflects the assumption that 'A' allowables for point design of composite tubes will have the same position relative to nominal values as do 'B' allowables for general design of metal tubes. Curve is an approximation to the nominal curve for R/t values between 150 and 1500. Curve is the recommended upper uncertainty curve. It reflects the use of a twice larger shear modulus and, in addition, allows for a more optimum tube definition. Curve is the recommended lower uncertainty curve. It allows for some margin of error in the location of the curve corresponding to 'A' allowables.

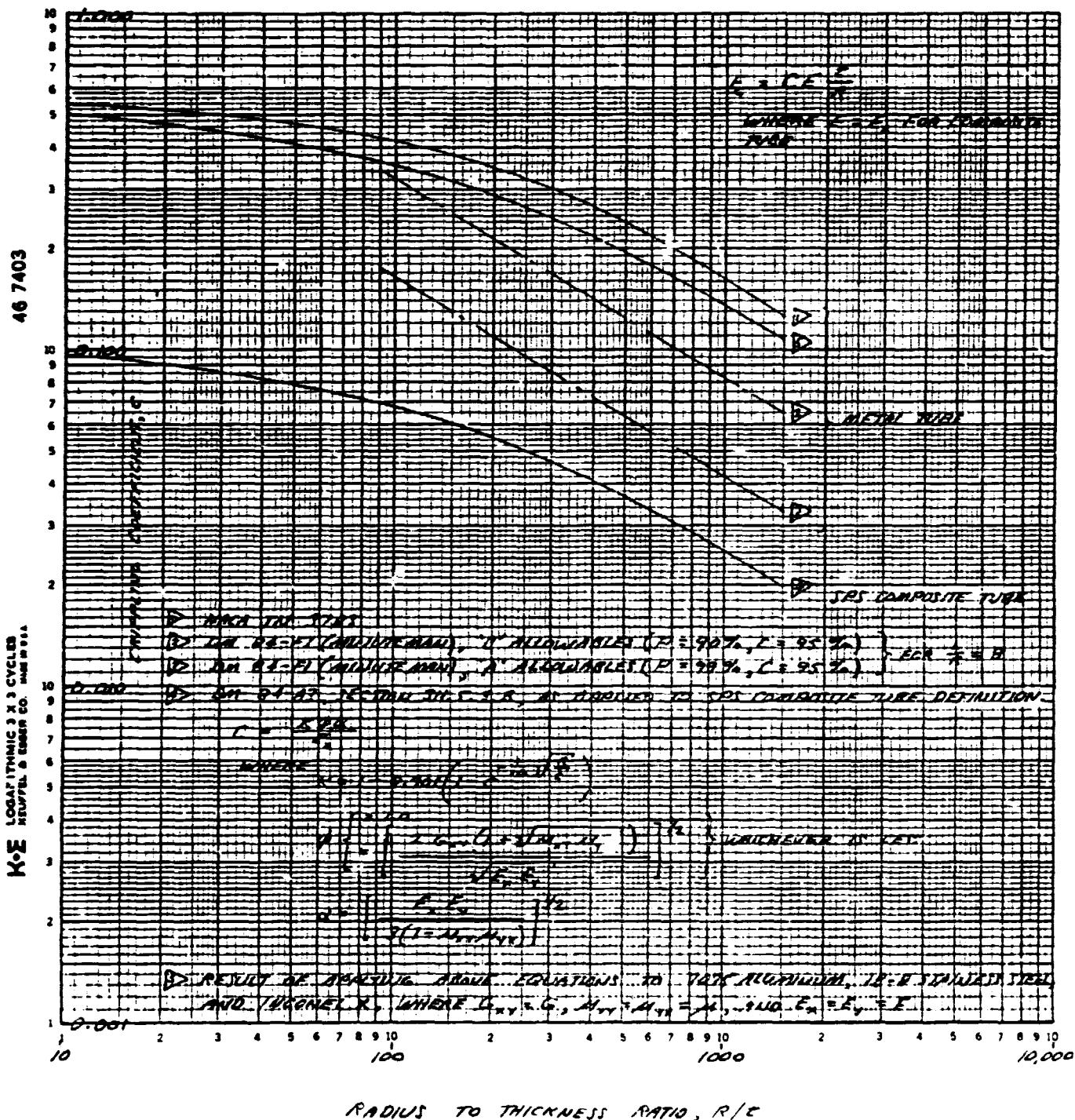
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FIGURE I-1

CRIPPLING COEFFICIENT COMPARISON

- SPS COMPOSITE TUBE VS. METAL TUBE -



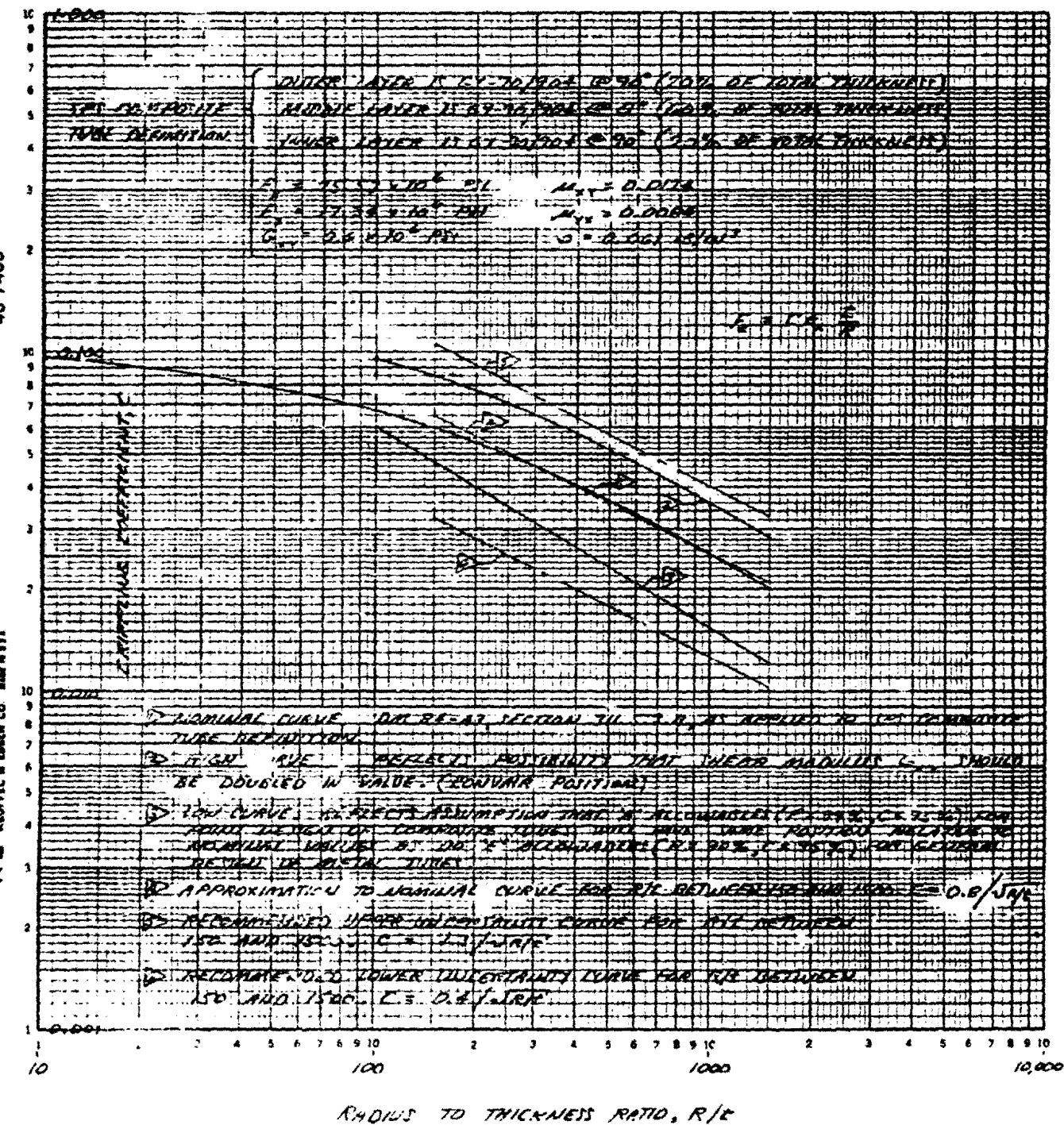
R.T. CONRAD
7/28/17

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FIGURE I-2

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FLIPPING COEFFICIENT UNCERTAINTY
- SPS COMPOSITE TUBE -



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4.3.2 Thermal Engine Size/Mass Uncertainty

The thermal engine size uncertainty analysis was conducted similarly to the photovoltaic system. The efficiency chain worksheet is shown in Table 4.3.2-1.

The thermal engine size/mass uncertainty analysis employed a parametric method. This method was also applied to the photovoltaic system and agreed with the more detailed mass estimator's result within 1%. The parametric method worksheet is shown in Table 4.3.2-2.

TABLE 4.3.2-1
THERMAL ENGINE EFFICIENCY CHAIN

ITEM	NOMINAL	MINIMUM	MAXIMUM	LOG MIN	LOG MAX	LOG MEAN	σ	Correlations
CONCENTRATOR	.877	.83	.95	-.1863	-.0513	-.1188	.0225	
REFLECT DEGR	1.0	.70	1.0	-.3567	0	-.1783	.059	
CPC	.865	.80	.865	-.2231	-.145	-.1841	.013	
CAVITY OPTICAL	.950	.95	.98	-.0513	-.0202	-.0357	.0052	
CAVITY RERADIATION	.917	.917	.934	-.0866	-.0683	-.0775	.0031	
CAVITY THERMAL	.995	.990	.998	-.010	-.003	-.0065	.0012	
CYCLE	.189	.189	.200	-1.666	-1.609	-1.6377	.0094	
GENERATOR	.984	.984	.986	-.0161	-.0141	-.0151	.0003	
PARASITIC	.962	.944	.98	-.0576	-.0202	-.0389	.0062	
POWER DISTR	.948	.93	.96	-.0753	-.0408	-.0567	.0053	
MPTS (from P/V)	.563	.412	.683	-.8853	-.3806	-.6331	.0304	
	.0628	.027	.095	-3.6143	-2.3525	-2.9834	.0726	
SIZES	118km ²	272km ²	77.8km ²			146km ²		

$$+3\sigma = 181 \text{ km}^2$$

$$-3\sigma = 117 \text{ km}^2$$

DETERMINED
NO CORRELATIONS

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WBS #	ITEM	EQUATION	AREF = 118	A = 146 m ² CONSTANT AREA (MOST PROB)					UNIT (= AREA OR POWER SLOPE, ETC)	AREA SCALING FACTOR	CORRECTED AREA SLOPE
				REF VALUE (TONS)	WORST	BEST	Avg	σ AT CONST AREA			
1.01 SPS			81027	122435	71193	96822	3097				
1.01.01 MULT/COM			8916	13297	9341	11319	477				
1.01.00	PRIMARY STRUCTURE	$M = M_{REF} \frac{A}{AREF}$	7262	10266	7704	8985	427	.0615	1	.0615	
1.01.00.01	SATELLITE CONTROL	$M = M_{REF} \frac{A}{AREF} \frac{M}{M_{REF}}$	1450	2706	1458	2082	208				.0142
1.01.00.02	SATELLITE COM AND DATA		4	6	4	5	-				-
1.01.00.03	MECH SYS & OTHER		200	319	175	247	24				.0009
1.01.01	ENERGY COLLECTION		1837	5925	1215	3570	785				.0244
1.01.01.00	SUPPORT STRUC	(INCL IN MAIN STR)	0								
1.01.01.01	FACTETS	$M = M_{REF} \frac{A}{AREF}$	1837	5925	1215	2570	785				
1.01.02	ENERGY CONV		40084	59268	29010	44147	2488				
1.01.02.00	SUPPORT STR.	(INCLUDED IN MAIN STR)	0								
1.01.02.01	CPC & LIGHT DOORS	$M = M_{REF} \frac{A}{AREF}$	324	500	300	400	35	0.0027	1	0.0027	
1.01.02.02	CAVITY ABSORBER	$M = M_{REF} (1 + \frac{A - A_{REF}}{AREF} F)$	1000	1300	900	1109	67				.00349
1.01.02.03	THERMAL ENGINE SYS										
1.01.03.01	BOILERS	$M = M_{REF} (1 + \frac{A - A_{REF}}{AREF} F)$	3296	5057	2918	3987	356				.0123
1.01.03.02	TURBINES		13755	18269	9134	13701	1522				.0422
	GENERATORS & COOLERS		3648	5765	2309	4037	576				.0124
	PUMPS		1234	1666	1066	1376	100				.004
	RADIATORS	$M = P_{th}/P_{thref} M_{ref}$	10769	17953	7645	12799	1718				.0324
	POTASSIUM INVENTORY	$M = P_{th}/P_{thref} M_{ref}$	6058	8758	4738	6748	670				.0171
1.01.03	POWER DISTR & SWG	$M = M_{REF} (1 + \frac{A - A_{REF}}{AREF} F)$	4978	7133	3839	5486	549				.0162
1.01.04	MPTS	FROM P/V ANALYSIS	25212	36812	27788	32300	1504				.095

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4.4 MASS/COST UNCERTAINTY NOTES:

CAPITAL COST UNCERTAINTIES

Preliminary analysis of cost estimates indicated five primary contributors to uncertainties: solar cells (or thermal engines), klystrons, the ground receiver, space construction operations, and space transportation. Estimates are as follows:

Item	Nominal	Range	Range Rationale
Solar Cells	3,731	2,050 to 6,870	\$20 to \$67 /m ² from various solar cell cost estimates
Klystrons	1,048	600 to 2,000	\$40 to \$100 /kWe
Ground Receiving Station	4,446	2,500 to 6,500	Part II Midterm Range
Construction	1,110	700 to 1500	Uncertainty in crew size and equipment costs
Transportation	6,445	4,834 to 8,050	Low value assures less maintenance cost. High value includes 1% attrition and certain interest costs.

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These ranges were treated as uncorrelated:

Item	Nominal	Mean (from range)	σ
Solar Cells	3,731	4,460	803
Klystrons	1,048	1300	235
Ground Receiving Station	4,446	4,500	667
Construction	1,110	1100	133
Transportation	6,445	6,445	536

The RSS is $1203 = \pm 6.2\%$ (1σ)

The RSS at the expected mass (with growth) is 1375. The cost escalation ($\sum \text{Mean} - \sum \text{Nominal}$) is 1025.

A similar procedure was followed for the thermal engine.

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POWER COST UNCERTAINTIES

The power cost equation is,

$$C = \frac{C_c r}{8766 f} \text{, in } \text{£/kwh}$$

where C_c is capital cost in £/kW

r is capital charge factor (per annum)

f is plant factor

The figure 8766 is the number
of hours in a year.

At the 1 SPS/year rate, values and
uncertainties are:

Capital 2725 ± 480

r $0.15 \pm .03$

f $0.8 \pm .1$

The equation may be linearized by:

$$\ln C = \ln C_c + \ln r - \ln 8766 - \ln f$$

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The calculation proceeds as follows:

Item	nominal value	log _e	$\sigma(\log_e)$
C _c	2725 ⁻	(+) 7.910	.0547
r	.15	(+) -1.897	.0608
f	.8	(-) -.2230	.0392
8766	8766	<u>(-) 9.079</u>	<u>0</u>
		-2.843	.0906

Power Cost Values are:

	-3σ	-2σ	-σ	Nom	+σ	+2σ	+3σ
log _e	-3.1148	-3.0242	-2.9336	-2.893	-2.7524	-2.6618	-2.5712
\$/kwh	.044	.049	.053	.058	.064	.070	.076

Similar calculations were used for the thermal engine and for the higher rates (4 sps/yr)

Note that the uncertainty in r is the largest contributor!

NOTES ON UNCERTAINTY ANALYSIS:
CORRELATED VARIABLES

The normal distribution

All variables will be assumed randomly distributed according to the normal distribution,

$$P(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where σ is the standard deviation of x and μ is the variance of x from its mean.

The bivariate normal distribution

This distribution is expressed as follows:

$$P(x, y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-r^2}} e^{-\frac{G}{2}}$$

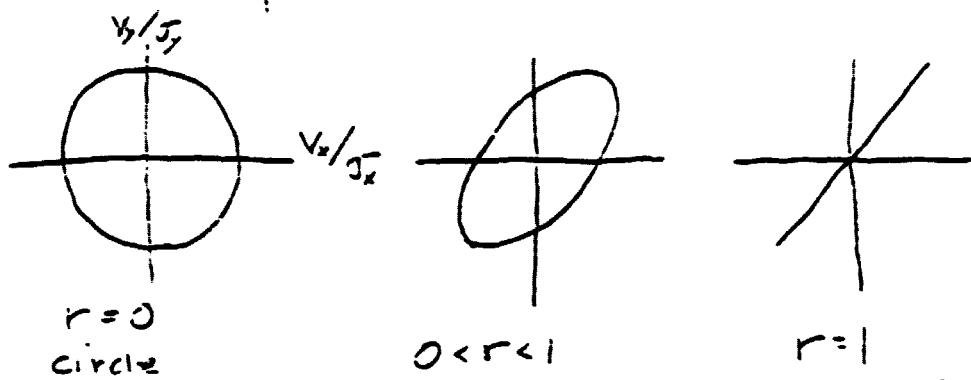
$$\text{where } G = c^2 = \frac{1}{1-r^2} \left[\frac{\nu_x^2}{\sigma_x^2} - \frac{2r\nu_x\nu_y}{\sigma_x\sigma_y} + \frac{\nu_y^2}{\sigma_y^2} \right]$$

The locus of ν_x and ν_y for a given value of c^2 is an equi-probability ellipse.

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The ellipse can be sketched as follows:



The value r is the correlation coefficient.

It is a measure of the dependency of y on x . If $r=0$ there is no dependency (no correlation). If $r=1$ they are completely dependent and the problem can be reduced to one with only one uncertain variable.

Properties of the ellipse

The equation for the ellipse may be written:

$$x^2 - 2\rho xy + y^2 = (1-\rho^2)c^2$$

where $x = v_x/\sigma_x$ and $y = v_y/\sigma_y$. Note that the correlation coefficient is independent of scaling on x and y . If a new variable

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$V_t = KV_x$ is introduced, we have

$$x = V_x / \sigma_x = V_t / K \sigma_x$$

$$\frac{V_t^2}{K^2 \sigma_x^2} - \frac{2 \rho V_t V_y}{K \sigma_x \sigma_y} + \frac{V_y^2}{\sigma_y^2} = (1 - \rho^2) c^2$$

It is evident that $\sigma_t = K \sigma_x$ and that ρ does not change.

We may also ask, what is the maximum value of x and where does it occur?

If the ellipse equation is solved for x ,

$$x = \rho y \pm \sqrt{(c^2 - y^2)(1 - \rho^2)}$$

The derivative is

$$\frac{dx}{dy} = \rho \pm \frac{1}{2} \left[(c^2 - y^2)(1 - \rho^2) \right]^{-1/2} [-2y(1 - \rho^2)]$$

Setting the derivative to zero:

$$\rho = \pm \frac{y(1 - \rho^2)}{\sqrt{(c^2 - y^2)(1 - \rho^2)}}$$

which solves to:

$$| Y = \mp \rho c |$$

This can be substituted to find x_{\max} :

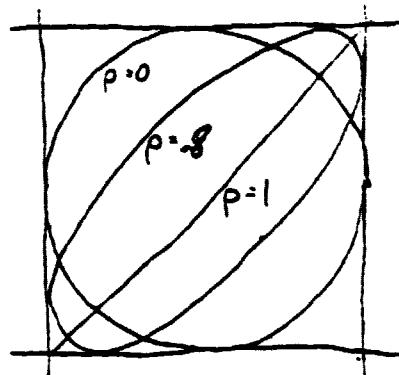
$$x_{\max} = \pm \rho^2 c \pm \sqrt{(c^2 - \rho^2 c^2)(1 - \rho^2)}$$

which simplifies to

$$\boxed{x_{\max} = \pm c} \quad \text{not dependent on } \rho$$

In the normalized ellipse equation (x and y rather than v_x and v_y), the ellipse is a circle if $\rho=0$.

If $\rho > 0$ the axis of the ellipse is tilted at 45° . If the non-normalized ellipse is considered, it can be shown* that the ellipse tilt angle is $\alpha = \frac{1}{2} \tan^{-1} \frac{2\rho \sigma_x \sigma_y}{\sigma_x^2 - \sigma_y^2}$.



It can also be shown that the major and minor axes of the ellipse are given by:

* Hald, Statistical Theory With Engineering Applications, Wiley, 1952

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$$a = \frac{1}{2} \left\{ \sqrt{\sigma_1^2 + \sigma_2^2 + 2\sigma_1\sigma_2\sqrt{1-\rho^2}} + \sqrt{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\sqrt{1-\rho^2}} \right\}$$

$$b = \frac{1}{2} \left\{ \sqrt{\sigma_1^2 + \sigma_2^2 + 2\sigma_1\sigma_2\sqrt{1-\rho^2}} - \sqrt{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\sqrt{1-\rho^2}} \right\}$$

In the normalized ellipse, these simplify to

$$a = \sqrt{1+\rho}$$

$$b = \sqrt{1-\rho}$$

Drawing the ellipse; estimating ρ .

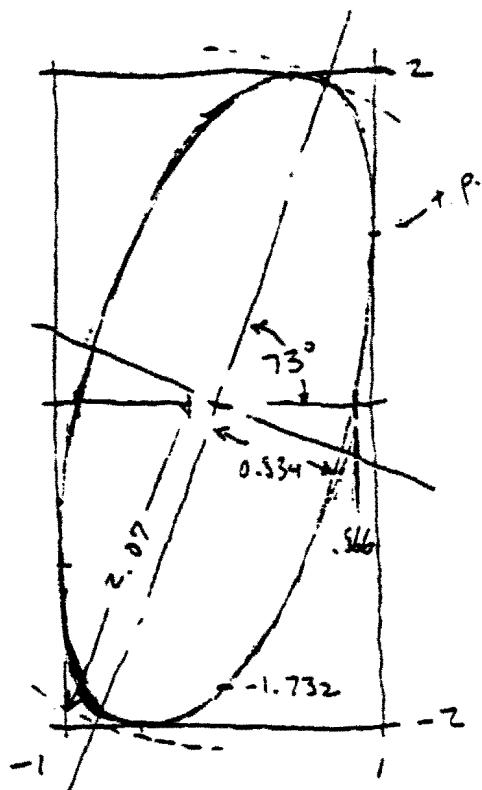
These relations can be used to sketch the ellipse: Example - suppose $\sigma_x = 1$, $\sigma_y = 2$, and $\rho = 0.5$. Draw the 1σ ellipse.

The maxima occur at v_x/σ_x and $v_y/\sigma_y = \rho c$.
(For the 1σ ellipse, $c=1$.)

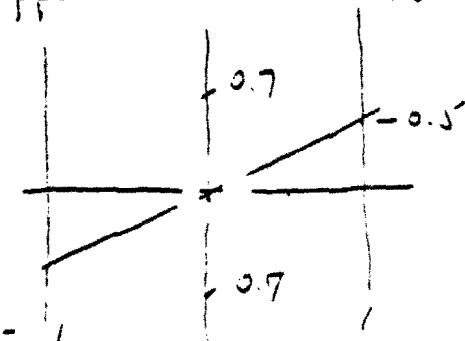
When either variable is zero, the values of the other are

$$\boxed{v_x/\sigma_x = v_y/\sigma_y = \sqrt{(1-\rho^2)c^2}}$$

The major & minor axes are 2.07 and 2.292
0.834



These values allow the ellipse to be sketched reasonably accurately as illustrated above. Similarly, if some estimates are available regarding the variances, these may be used to estimate ρ . For example, suppose that the information in the sketch is available, representing 3 σ limits. Then σ_x is 0.333.



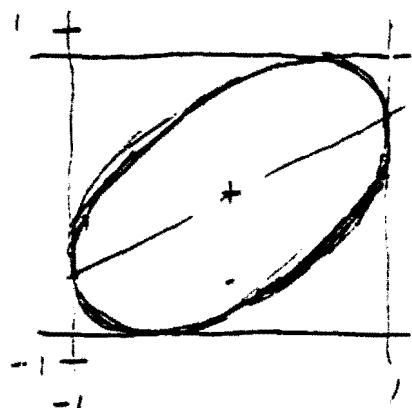
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A trend line for V_y dependence on V_x is shown, as are estimated 3σ limits on V_y when $V_x = 0$. Since these are 3σ limits, we know $C=3$.

Also, if the trend line's intercept at the V_x limits are the ellipse tangency points,

$$V_y/\sigma_y = \rho C = 3\rho.$$

The limits on V_y when $V_x = 0$ allow setting $V_y/\sigma_y = 3\sqrt{1-\rho^2}$. These may be solved to find $\rho = 0.581$ and $\sigma_y = 0.287$ ($3\sigma_y = 0.862$). The 3σ ellipse can then be sketched:



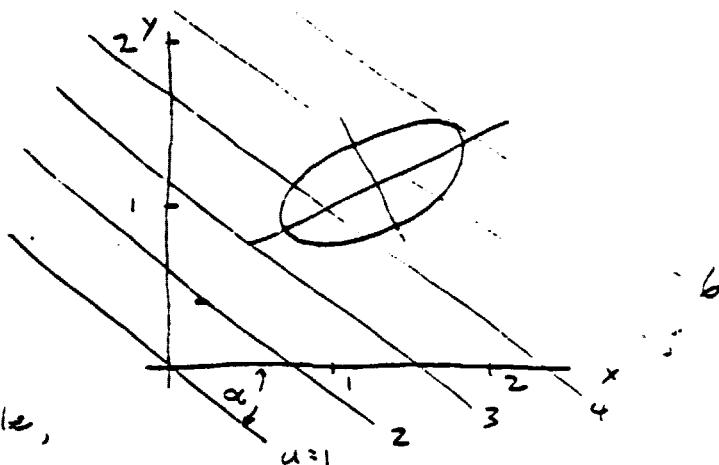
Note that the trend line is not the semimajor axis of the ellipse. The trend line is at 26.5° . The SMA is at 38° .

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Functions of correlated variables

Suppose we have a variable U that is a (definite) function of x and y . The problem may be sketched as follows:

We are interested in finding the uncertainty in U . (σ_U)



In this example,
suppose that

$\partial U / \partial x = 2.3$ and $\partial U / \partial y = 2.8$. The angle α between the lines of constant U and the x -axis is given by $\tan \alpha = -\frac{\partial U / \partial x}{\partial U / \partial y}$, about -36° in the example.

We will determine σ_U by application of a co-ordinate rotation through the angle α . Consider co-ordinates t, u with the same grid spacing as x and y .

$$\text{Then } v_t = v_t \cos \alpha - v_u \sin \alpha$$

$$v_y = v_t \sin \alpha + v_u \cos \alpha.$$

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Substituting into the ellipse equation;

$$G = \frac{1}{1-\rho^2} \left[V_t^2 \left(\frac{\cos^2\alpha}{\sigma_x^2} - \frac{\sin^2\alpha}{\sigma_y^2} - \frac{2\rho \sin\alpha \cos\alpha}{\sigma_x \sigma_y} \right) + V_u^2 \left(\frac{\sin^2\alpha}{\sigma_x^2} + \frac{\cos^2\alpha}{\sigma_y^2} + \frac{2\rho \sin\alpha \cos\alpha}{\sigma_x \sigma_y} \right) - V_t V_u \left(\frac{2\sin\alpha \cos\alpha}{\sigma_x^2} - \frac{2\sin\alpha \cos\alpha}{\sigma_y^2} + \frac{\cos^2\alpha - \sin^2\alpha}{\sigma_x \sigma_y} \right) \right]$$

We conclude that

$$\frac{1}{1-r^2} \frac{V_t^2}{\sigma_t^2} = \frac{1}{1-\rho^2} V_t^2 \left(\frac{\cos^2\alpha}{\sigma_x^2} - \frac{\sin^2\alpha}{\sigma_y^2} - \frac{2\rho \sin\alpha \cos\alpha}{\sigma_x \sigma_y} \right)$$

etc. and therefore,

$$\frac{V_t^2}{\sigma_t^2} = \frac{\frac{\cos^2\alpha}{\sigma_x^2} + \frac{\sin^2\alpha}{\sigma_y^2} - \frac{2\rho \sin\alpha \cos\alpha}{\sigma_x \sigma_y}}{\frac{\sin^2\alpha}{\sigma_x^2} - \frac{\cos^2\alpha}{\sigma_y^2} + \frac{2\rho \sin\alpha \cos\alpha}{\sigma_x \sigma_y}}$$

Rearranging,

$$\sigma_t^2 / \sigma_u^2 = \frac{\cos^2\alpha \sigma_x^2 + \sin^2\alpha \sigma_y^2 + 2\rho \sigma_x \sigma_y \sin\alpha \cos\alpha}{\sin^2\alpha \sigma_x^2 + \cos^2\alpha \sigma_y^2 - 2\rho \sigma_x \sigma_y \sin\alpha \cos\alpha}$$

We know that $\sigma_u^2 + \sigma_t^2 = \sigma_x^2 + \sigma_y^2$

$$\text{So that } \sigma_x^2 \left(1 + \frac{\sigma_t^2}{\sigma_u^2} \right) = \sigma_x^2 + \sigma_y^2$$

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The parenthesis term simplifies to

$$\frac{\sigma_x^2 + \sigma_y^2}{\sin^2 \alpha \sigma_x^2 + \cos^2 \alpha \sigma_y^2 - 2\rho \sigma_x \sigma_y \sin \alpha \cos \alpha}$$

and

$$\sigma_u^2 = \sin^2 \alpha \sigma_x^2 + \cos^2 \alpha \sigma_y^2 - 2\rho \sigma_x \sigma_y \sin \alpha \cos \alpha.$$

To get σ_v , we need to scale by

$$\sigma_v^2 = \sigma_u^2 \left(\frac{\partial u}{\partial v} \right)^2.$$

The value $\partial u / \partial v$ is the length of a unit vector along the u axis in terms of v . This length is $\sqrt{(\partial u / \partial x)^2 + (\partial u / \partial y)^2}$

Therefore,

$$\sigma_v^2 = \left(\sin^2 \alpha \sigma_x^2 + \cos^2 \alpha \sigma_y^2 - 2\rho \sigma_x \sigma_y \sin \alpha \cos \alpha \right) \left[\left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial y} \right)^2 \right]$$

We next use trigonometric identities:

$$\sin^2 \alpha = \tan^2 \alpha / (1 + \tan^2 \alpha);$$

$$\cos^2 \alpha = 1 / (1 + \tan^2 \alpha); \quad \sin \alpha \cos \alpha = \tan \alpha / (1 + \tan^2 \alpha)$$

And note that $\tan \alpha = -\partial u / \partial v / \partial u / \partial y$

$$\text{Then } \sigma_v^2 = \frac{\left(\frac{\partial u}{\partial x} \right)^2 \sigma_x^2 + \sigma_y^2 + 2\rho \sigma_x \sigma_y \frac{\partial u}{\partial x} / \frac{\partial u}{\partial y} - \frac{\left(\partial u / \partial x \right)^2 / \left(\partial u / \partial y \right)^2 - 2\rho^2 -}{\left(\frac{\partial u}{\partial x} \right)^2 / \left(\frac{\partial u}{\partial y} \right)^2 -}}$$

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which simplifies very nicely to

$$\boxed{\sigma_v^2 = \sigma_x^2 \left(\frac{\partial U}{\partial x}\right)^2 + \sigma_y^2 \left(\frac{\partial U}{\partial y}\right)^2 + 2\rho\sigma_x\sigma_y \frac{\partial U}{\partial x} \frac{\partial U}{\partial y}}$$

In the example sketched a few pages prior, assume $\sigma_x = 0.55$, $\sigma_y = 0.35$, $\rho = 0.5$

Then

$$\begin{aligned}\sigma_v^2 &= .55^2 \times 1.3^2 + .35^2 \times 1.8^2 + 2 \times .5 \times 1.3 \times 1.8 \times .55 \times .35 \\ &= 1.359\end{aligned}$$

and $\sigma_v = 1.166$