N64-18104
Code 1

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Monthly Progress Report for December 1963

BRAYTON CYCLE SOLAR COLLECTOR DESIGN STUDY

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland 35, Ohio
Attn: Mr. Ralph Slavik

Contract NAS 3-2782

XEROX $ 2.60
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EOS Report 4150-M-6 15 January 1964

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Prepared by

D. E. Stewart

Approved by

Charles W. Stephens

Charles W. Stephens, Manager
OPTICS DIVISION

Approved by

D. H. McClelland

D. H. McClelland, Chief Engineer
OPTICS DIVISION

ELECTRO-OPTICAL SYSTEMS, INC. - PASADENA, CALIFORNIA

ABSTRACT

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This progress report covers the month of 1 December through 31 December 1963 and is submitted in accordance with the terms in the subject contract.

The objectives of this program include: parametric analysis of 20- and 30-foot diameter one-piece electroformed mirrors, the establishment of suitable conceptual designs and manufacturing methods for 20- and 30-foot diameter electroformed concentrators, prediction of concentrator performance, and experimental grinding and polishing studies of materials for large masters.

This report summarizes reflectivity tests of samples prior to micrometeorite degradation tests, time averaged orientation efficiency assumptions, blade grinding and polishing, structural and thermal analysis. A bar chart schedule, a work progress estimate, and plans for the remainder of the contract are also included.

Design recommendations were also submitted in a letter to NASA-Lewis during the reporting period.

Author

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1. INTRODUCTION

The feasibility of a practical solar Brayton cycle space electric power system is dependent on the development of a suitable solar concentrator. Highly accurate concentrator mirrors, which are necessary to maximize system efficiency and reduce orientation requirements, have been fabricated up to five feet in diameter by one-piece electroforming construction methods.

Presently the Saturn S-4B and S-2 stages permit maximum mirror diameters of 20 feet and 30 feet respectively. Since one-piece electroformed mirrors of this size have not been fabricated to date, some design and manufacturing problems must be studied in more detail. Therefore, the objectives of this program are to:

1. Conduct parametric analysis of specified variables that influence the performance and efficiency of 20- to 30-foot one-piece, fixed solar concentrators.
2. Establish a conceptional design of a concentrator utilizing electrofromed nickel construction suitable for use with the specified Brayton cycle power system.
3. Accurately predict the concentrator performance, both under ground test conditions and for orbital applications, in space up to one year duration.
4. Perform experimental master grinding and polishing studies, including the construction of two sample electroformed mirrors, to demonstrate large master fabrication techniques.

The previous reports summarize the initial work on design configuration definitions, preliminary designs, surface coating investigations, computer programs and calculations of optical errors, thermal

effects, structural analysis approach and calculations, manufacturing details, and experimental polishing.

This report summarizes progress and data on reflectivity samples for micrometeorite tests, time averaged orientation efficiency computation assumptions, blade grinding and polishing, structural and thermal analysis.

Design recommendations were submitted for approval during the reporting period in a separate letter.

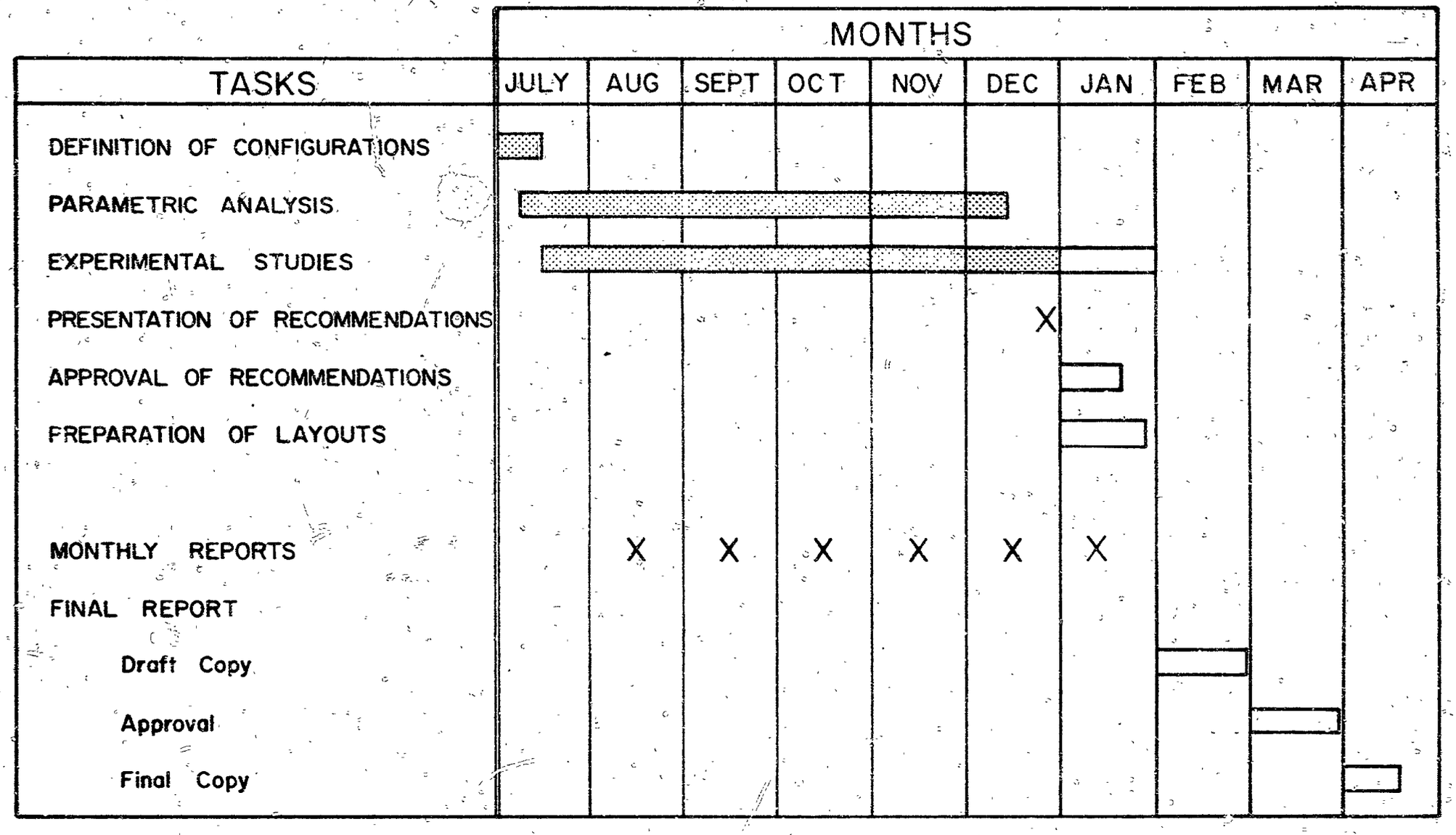

FIG. 2-1 PROGRAM SCHEDULE

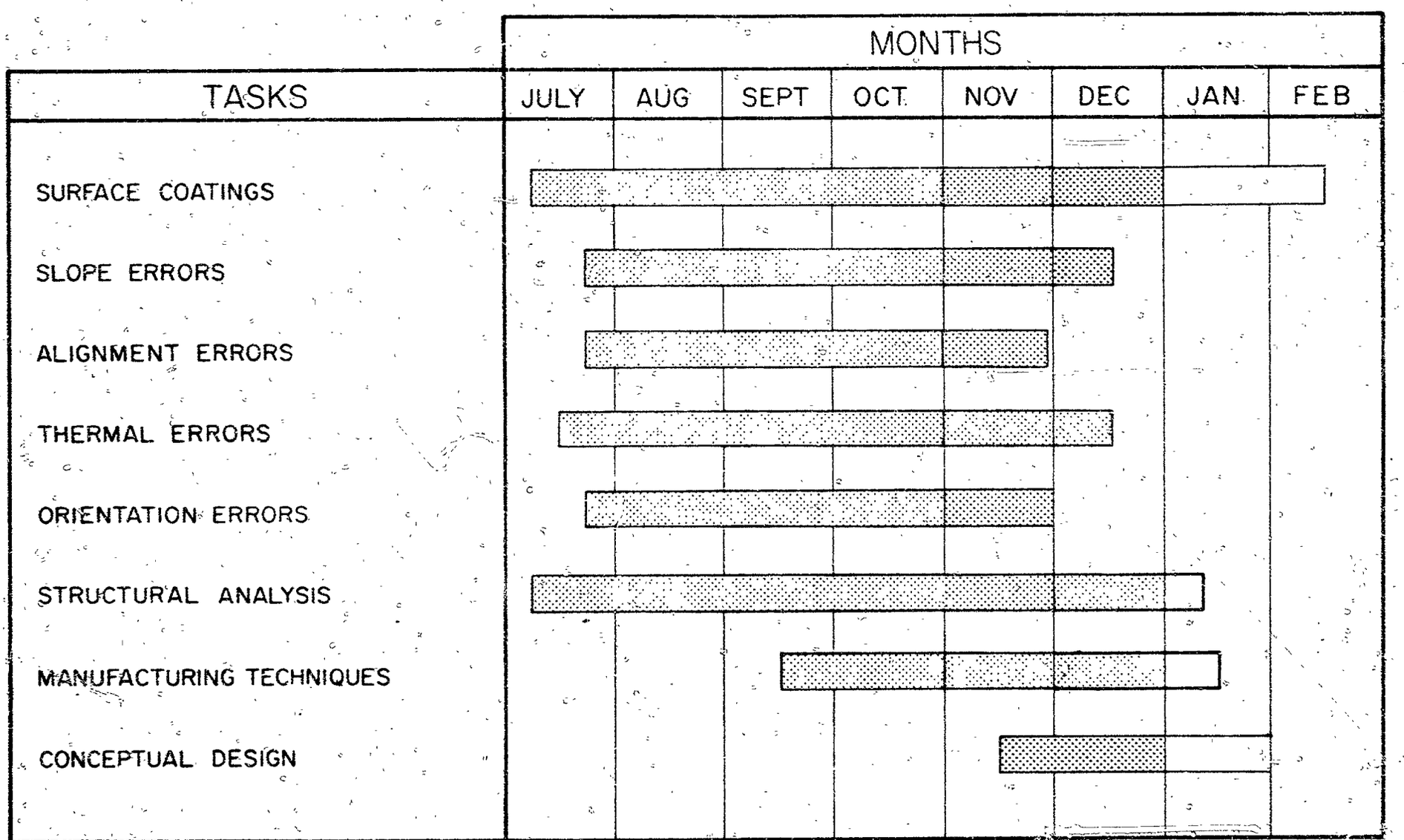

FIG. 2-2 PROGRAM SCHEDULE, PARAMETER ANALYSIS DETAILS

2. ESTIMATED WORK PERFORMANCE AND BAR CHART CALENDAR SCHEDULES

A numerical percentage estimate of work performance is given by Table 2-1 along with cross references between the Task Summary sections in Section 3 of this report and the correlative sections of the contract work statement. The calendar bar chart schedules are shown in Figs. 2-1 and 2-2.

TABLE 2-1 ESTIMATED PERCENTAGE COMPLETION BY TASK

Work Statement Section Ref.	Task Summary Section Ref.	Task	ESTIMATED PERCENT COMPLETION							
			JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB
II-1	3.1	Configuration Definition	95	95	95	100	100	100		
II-1	3.2	Preliminary Design	15	30	50	65	95	100		
II-2(a)	3.3	Surface Coatings	10	25	90	95	80*	90		
II-2(b)	3.4	Slope Errors	5	30	60	80	95	100		
II-2(c)	3.4	Alignment Errors	5	30	60	95	99	100		
II-2(d)	3.4	Thermal Errors	15	30	50	65	70	95		
II-4(e)	3.4	Orientation Errors	20	45	60	80	95	100		
II-2(f)	3.5	Structural Analysis	15	35	50	70	85	90		
II-2(g)	3.6	Manufacturing Details	0	15	35	40	50	60		
II-2(h)	3.7	Conceptual Design	0	0	10	20	30	35		
II-3	3.8	Experimental	15	35	45	60	70	85		

*Percentage completion revised due to addendum to work statement.

3. PROGRAM SUMMARY

3.1 Design Configurations

This phase of the program is complete.

3.2 Preliminary Design

Recommendations for the final design of one-piece electroformed Brayton cycle collectors were submitted to NASA/Lewis for approval.

3.3 Surface Coatings

The reflectance measurements of samples submitted to NASA/Lewis for micrometeorite testing plus those control samples retained by EOS are listed in Table 3-1. The samples were measured at 0.625, 0.7, and 1.0 microns with a Beckman DU spectrophotometer. Each sample was measured a minimum of three times. The reflectivity measurement given is an average of these three readings. Reflectance measurements were made by the goniometer method. The 100 percent reflectance level is measured by placing the photocell in line with the spectrophotometer beam and an aluminum standard is referenced in the testing of each sample. During reflectance measurements and checks with the aluminum reference standard, the spectrophotometer beam made an angle of incidence of 34° with the reflective surfaces.

The reflectance measurements of samples 1 to 3, groups 1 through 4, correlate closely with each other and with published reflectance data. The maximum variation between samples within a group is 1.3 percent which indicates the reproducibility between measurements and coating samples.

Reflectance variations among samples within groups 5 and 6 are caused by the thickness variations of the silicon monoxide overcoating. The silicon monoxide overcoating acts as a selective spectral

TABLE 3-1
(continued)

0.700μ TEST WAVELENGTH

Group	Sample	Reflectance Before	After	Loss
1	1	69.9		
	2	69.9		
	3	69.5		
2	1	99.3		
	2	99.8		
	3	100.1*		
3	1	91.1		
	2	91.1		
	3	90.2		
4	1	89.0		
	2	89.7		
	3	88.8		
5	1	79.5		
	2	89.2		
	3	82.4		
	4	81.6		
6	1	83.0		
	2	72.6		
	3	65.5		
	4	82.9		

TABLE 3-1
(continued)

1.0μ TEST WAVELENGTH

Group	Sample	Reflectance Before	After	Loss
1	1	74.6		
	2	74.7		
	3	7[illegible].9		
2	1	98.5		
	2	98.3		
	3	98.6		
3	1	94.6		
	2	94.3		
	3	94.0		
4	1	94.2		
	2	94.3		
	3	93.2		
5	1	93.1		
	2	91.7		
	3	91.5		
	4	92.5		
6	1	92.6		
	2	83.9		
	3	92.1		
	4	85.0		

NOTES ON TABLE 3-1

1. Group:

   1. Bare electroformed nickel
   2. Chemically deposited silver, 600 to 1000 Å thick
   3. Vacuum deposited: chromium 100 Å, aluminum 1000 Å
   4. Vacuum deposited: chromium 100 Å, silicon monoxide 2500 Å aluminum 1000 Å
   5. Vacuum deposited: chromium 100 Å, silicon monoxide 2500 Å aluminum 1000 Å, silicon monoxide 2500 Å
   6. Vacuum deposited: chromium 100 Å, silicon monoxide 2500 Å aluminum 1000 Å, silicon monoxide 20,000 Å

2. Before:

   Refers to sample reflectance before micrometeorite tests

3. Samples:

   Samples 1 and 2 were sent to NASA/Lewis. Sample 3 was retained by EOS as a control sample.

4. *The 100.1 percent silver reflectance measurement indicates that the experimental error was in the order of ±0.6 percent.

filter. Visual observation of these samples indicated a range of colors, i.e., the samples within a group did not have maximum absorption at the same wavelength. This observation correlated with the reflectance measurements.

3.4 Optical Error Analysis

3.4.1 Time Averaged Misorientation

The time averaged misorientation values for cavity emissivities of 0.3, 0.6, and 0.9, referred to on page 19 of the November Monthly Report were derived from efficiency curves calculated from Eq. 3.3 of the October Monthly Report:

$$\eta_{m-a,g} = \frac{\eta_m r_m \epsilon_1}{1 - (1 - \theta)(1 - \epsilon_1)} - \frac{A_1}{A_2}\left[\frac{\epsilon_1 \theta}{1 - (1 - \theta)(1 - \epsilon_1)}\right]\frac{\sigma T_1^4}{CH_s}$$

These calculated efficiencies for "gray" body cavity absorbers, assumed the following:

A_1	- aperture area	πr^2
A_2	- cavity area, constant for all cases	705 inches^2
β	- cavity length to aperture radius ratio	$\frac{21.2}{r}$
C	- concentration ratio	$\left[\frac{2r}{D}\right]^2$
D	- collector diameter	360 inches
ϵ_1	- cavity emissivity = absorptivity	0.3, 0.6, 0.7
H_s	- solar constant	442.7 BTU/hr-ft^2
η_m	- intercepted percent of reflected energy, varies with r	
r	- cavit perture radius	$\geq$ 2.12 inches (the minimum computed by the optical program for a 60° collector)
T_1	- cavity temperature	2110°R (assumed constant)
θ	- form factor. See Fig. A-3, Ref. 1, varies with A_1/A_2, β, and cavity shape	

The increase of θ and A, and the decrease in C with increasing r decreases the overall mirror-cavity absorber efficiency appreciably, compared to a blackbody cavity absorber, for gray body absorbers.

More sophisticated analyses now being generated by Dr. Shrenk, consultant to Allison, and A. Lowi of Aerospace confirms this type of efficiency drop for gray body absorbers. Even higher efficiency losses could be encountered for many mirror error and cavity temperature distributions.

3.4.2 Thermal Mapping

Transient temperature profiles have now been calculated for seven different collector points, see Fig. 3-1 to 3-5:

Point 1	- central collector shall	
2	- collector shell edge	$\psi = 0^{\circ}$
3	- torus	$\psi = 0^{\circ}$
4	- collector shell edge	$\psi = 90^{\circ}$
5	- torus	$\psi = 90^{\circ}$
6	- collector shell edge	$\psi = 180^{\circ}$
7	- torus	$\psi = 180^{\circ}$

Figure 3-1 explains the location terminology. These cases use the same equations and assumptions discussed in the November Monthly Report. Cases 1 and 2, described therein have been redesignated as Point 1 - 36 inches (36-inch radiator height) and Point 1 - 60 inches (60-inch radiator height). Figure 3-2 shows the revisions. Cases 2 through 7 used a 60-inch radiator. Point 1 had a thickness of 0.009 inch, points 2, 4 and 6 a 0.0128 inch thickness (this variation depicts the tapered shell) and points 3, 5 and 7 a 0.095 inch thickness, representing the mass of a 0.030 inch thick 4-inch diameter torus spread over a flat 4-inch span.

These points will now be used to depict a thermal map for specific orbit times or positions.

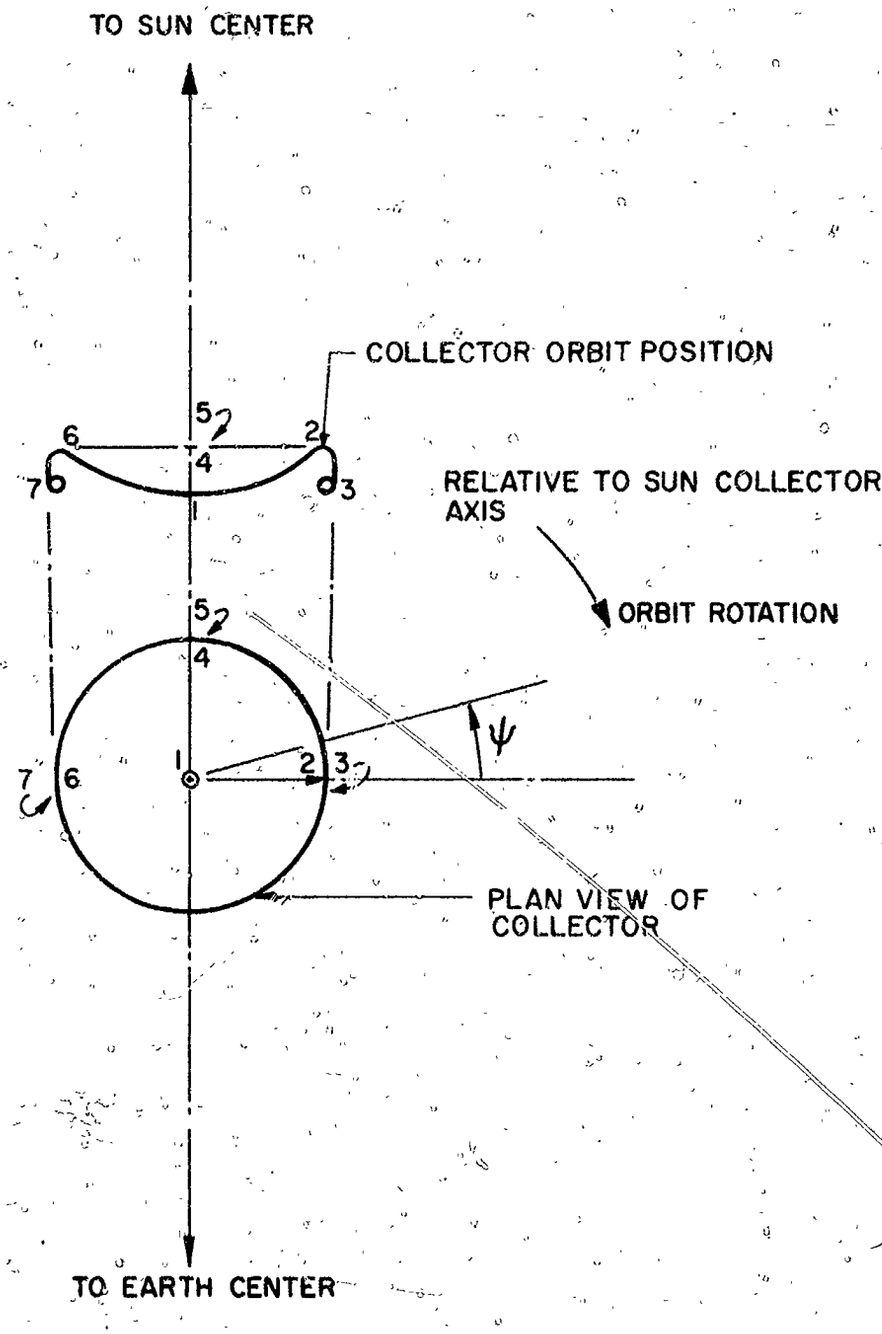

FIG. 3-1 LOCATION OF COLLECTOR POINTS WITH RESPECT TO THE ORBIT ROTATION AND SUN-EARTH AXIS

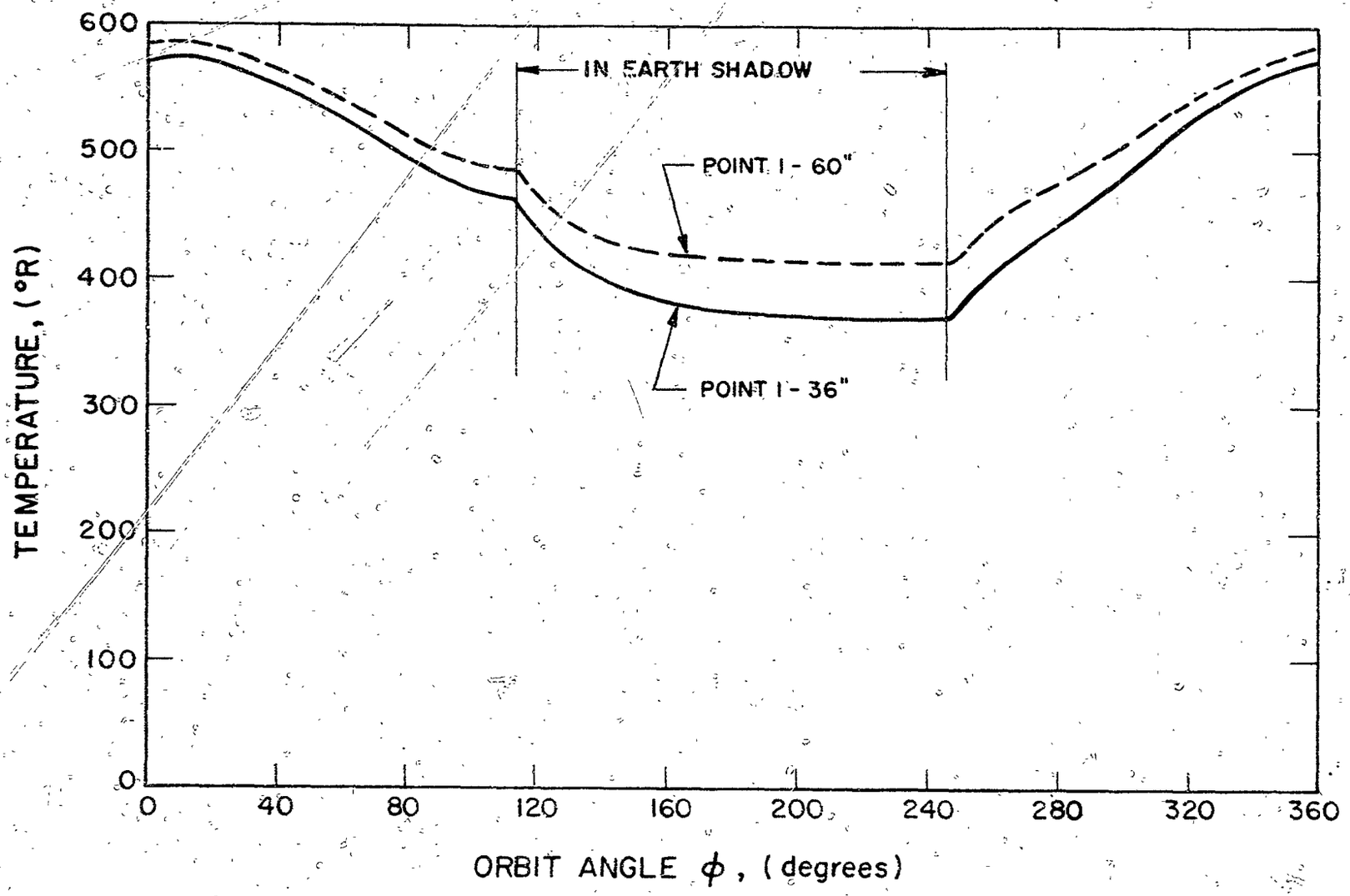

FIG. 3-2 CENTRAL COLLECTOR SURFACE TEMPERATURES FOR A 300-NAUTICAL-MILE ORBIT

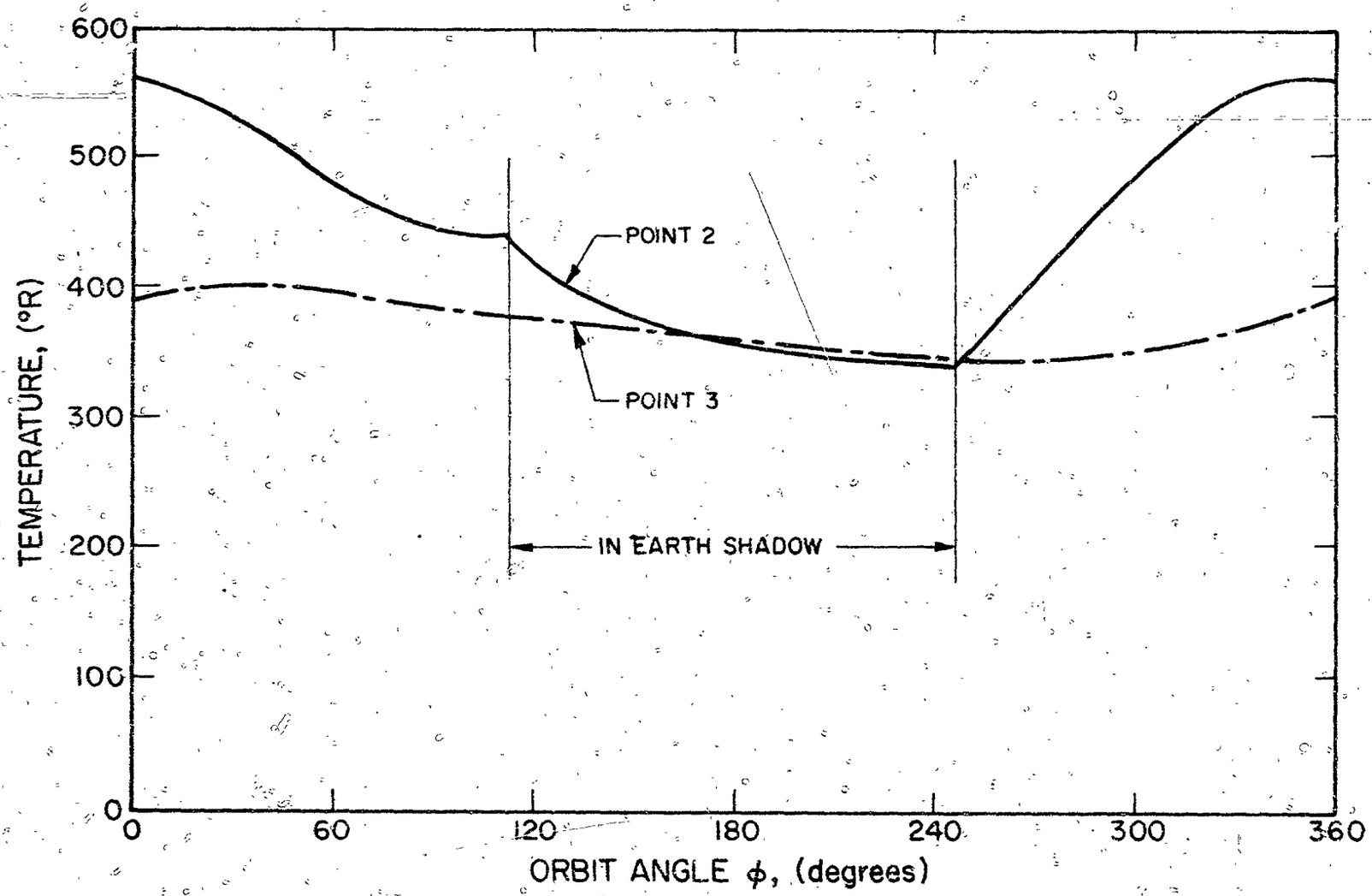

FIG. 3-3 COLLECTOR SURFACE TEMPERATURES, $\zeta = 0^{\circ}$, FOR A 300-NAUTICAL- MILE ORBIT

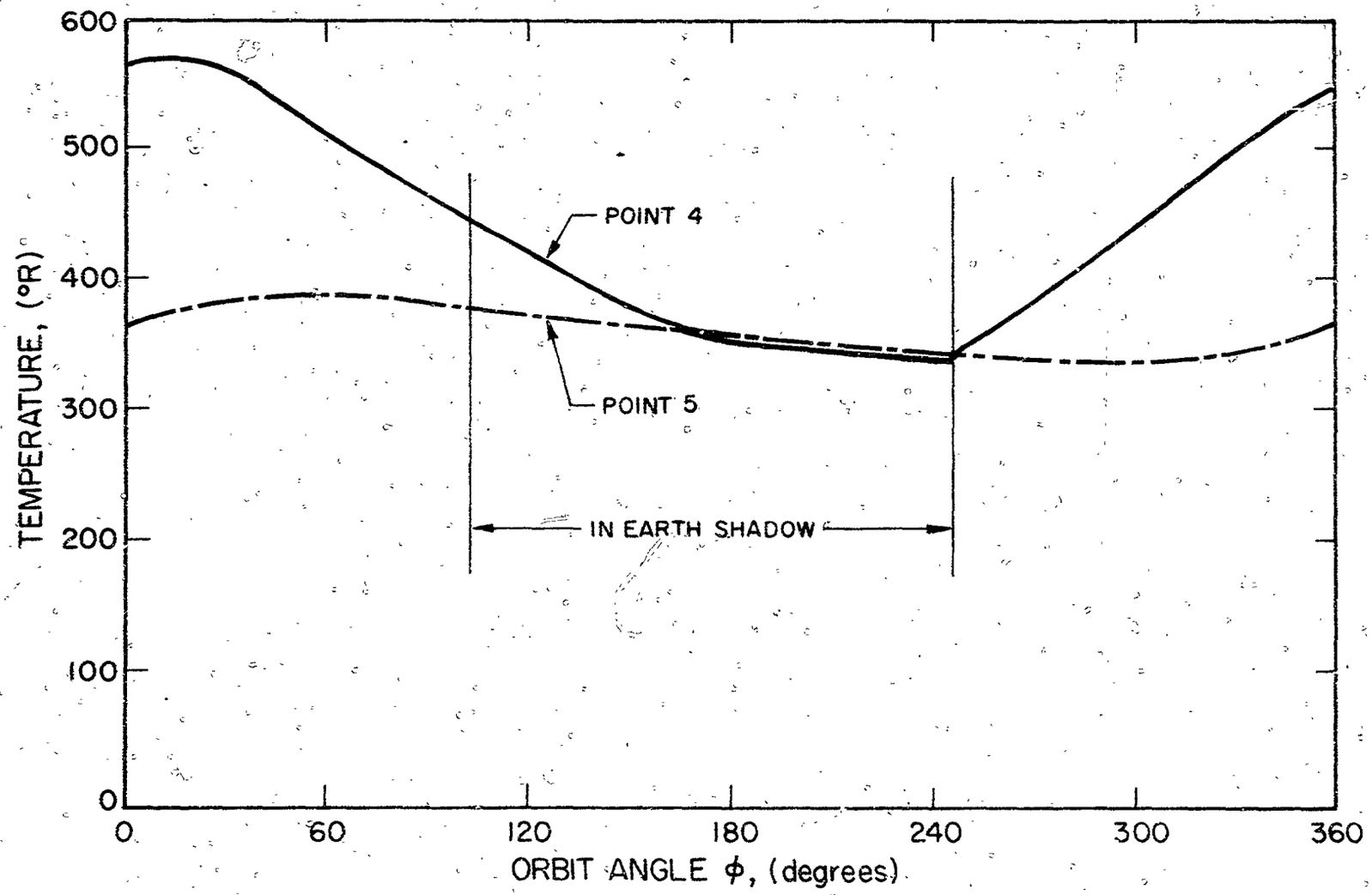

FIG. 3-4 COLLECTOR SURFACE TEMPERATURES, ψ = 90°, FOR A 300-NAUTICAL-MILE ORBIT

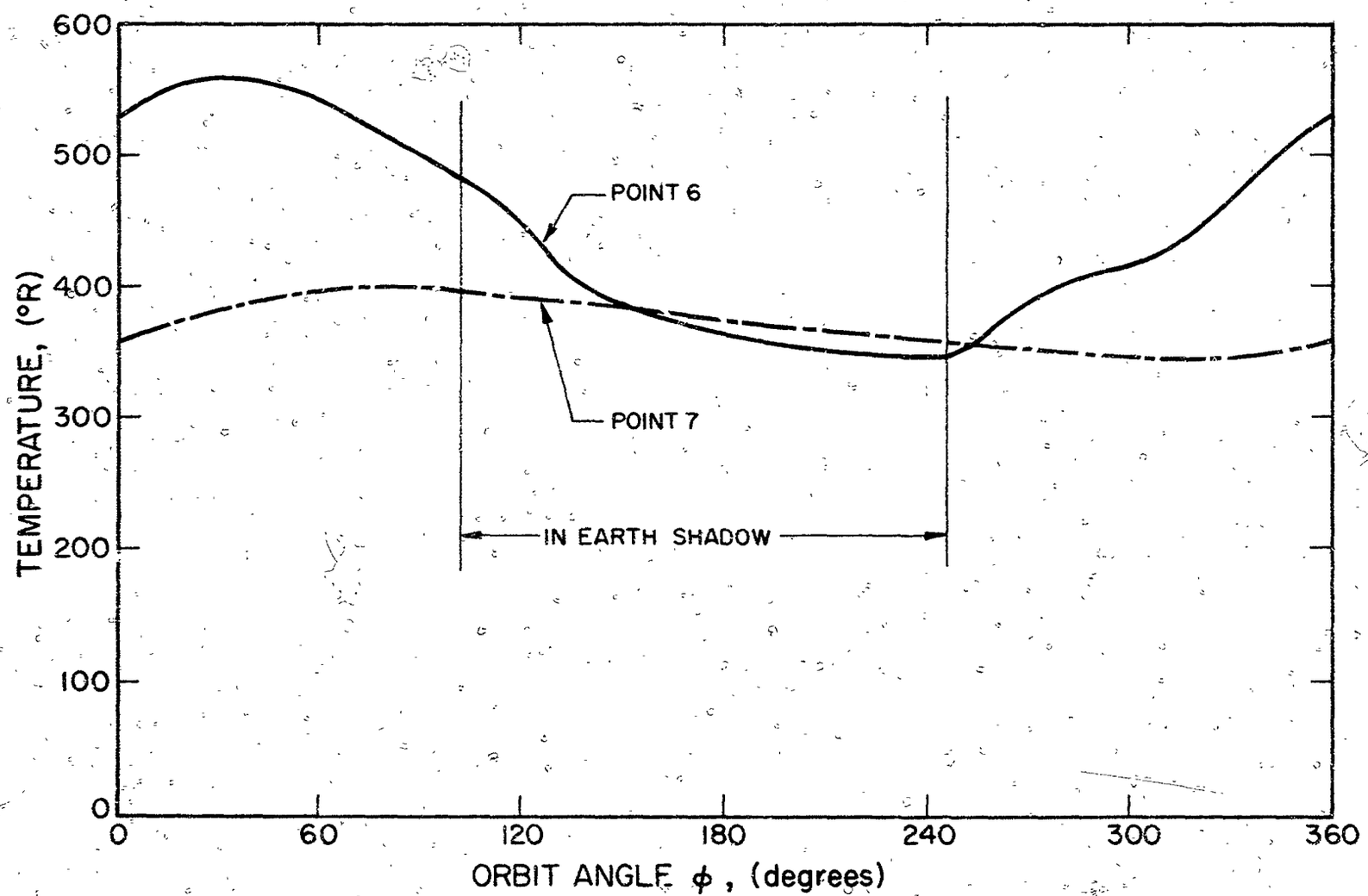

FIG. 3-5 COLLECTOR SURFACE TEMPERATURES, = 180°, FOR A 300-NAUTICAL-MILE ORBIT

3.5 Structural Analysis

During and since the reporting period additional structural analyses have been made in the areas of shock, vibration and tripod strut studies. These and previous analyses are now being summarized for the final report. No additional data will be summarized herein.

3.6 Manufacturing and Handling Considerations

This area will be summarized in the final report.

3.7 Designs

See Section 3.2.

3.8 Master Grinding and Polishing

The 2-foot diameter master was resurfaced with epoxy. Regrinding and polishing indicated the need for some patch repairs, which were easily made. The generating blade matches the paraboloidal convex master within 0.001 inch. A check of the curve of the blade prior to fine polishing indicated that the paraboloid is accurate to ± 0.002 inch from a true curve. This deviation was the maximum encountered over any 6-inch span and represents an error of one minute of arc. Since the inherent drafting errors of the layout used to check the paraboloid are probably 0.002 to 0.005 inch, it can reasonably be expected that the total error is probably less than one minute of arc. This is in the accuracy range of the WW II 60-inch blade ground glass searchlights. The master is now ready for the first replication.

4. WORK TO BE PERFORMED BEFORE THE FINAL REPORT

4.1 Surface Coatings

Upon return of the reflectance samples now being tested under simulated micrometeorite damage at NASA/Lewis, final reflectance measurements will be performed. The differences between initial and final reflectance measurements on the tested samples, in relationship to the differences on control samples, will be used to determine simulated micrometeorite damage.

4.2 Optical Error Analysis

Using the transient temperature values derived for seven selected collector points, the optical and structural effects of the collector thermal variations will be analyzed. 20,000-mile orbit thermal effects will also be estimated.

4.3 Structural Analysis

The structural analysis summary will

4.4 Experimental Blade Grinding and Polishi

The two 2-foot diameter electroformed she[illegible] completed and tested.

4.5 Design Recommendations

Final drawings will be completed on the final collector design recommendations.

REFERENCES

1. Fuller, Fredric E., "Mathematical Model of Factors Affecting Solar Energy Collector Efficiency," EOS Report 480-Final, Contract No. AF 33(616)-7316, 30 December 1960