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INVESTIGATION OF TERRESTRIAL PHOTOVOLTAIC POWER SYSTEMS WITH SUNLIGHT CONCENTRATION

Arizona State University

and

Spectrolab, Inc.

This joint program was started January 15, 1974. The first year was mostly analytical effort looking at the component and system characteristics expected for concentration configurations. Those studies resulted in the conclusions given in Table I and indicated very encouraging prospects if the assumptions made could be verified. The program being pursued in the second year is to experimentally verify the first year's conclusion. (See Table II).

The analytical model of the silicon solar cells for high illumination is being used to design cells for different concentration factors. Figure 1 shows that a cell design using one centimeter length grid fingers (w=1 cm) can be made that would have an efficiency at 100 suns that is 90% of the efficiency of a typical cell at one sun. This may require about 30 fingers per centimeter and thus the deposition of the grid should be achievable with conventional techniques. These results were obtained by keeping the internal voltage drop constant by varying the internal resistance. The decrease in efficiency comes from the greater coverage of the surface with grids as the concentration increases. Figure 2 shows the importance of base material resistivity on cell design for high concentration.

One of the important parameters indicated on the first year's program was the dependence of the system cost for passively cooled arrays on the thermal conductance between cell and ambient air. Therefore a wind tunnel was constructed (See Figure 3) to measure these values in a controlled environment.

Tab.e III gives the description of the heat rejection geometries being investigated in this tunnel. Figures 4 and 5 give typical results for the configurations tested to date.

Calculations on additional concentration configurations are continuing and also the dependence o. their characteristics on various design parameters. As a typical example Figure 6 shows how mirror surface inaccuracies affect the energy distribution incident at the cells. System cost studies are continuing as shown in Figures 7 and 8.

Four concentrator system desi[illegible] been made and will be built during the next six months. The[illegible] are:

1) A non-tracting system (co[illegible]tration ratio 7.5) See Figure 9
2) A circular Fresnel system (concentration ratio 16) See Figure 10
3) A fixed mirror system (concentration ratio 40) See Figure 11
4) A 5 foot diameter, parabolic reflector system with concentration ratios up to about 100 or more.

TABLE I

CONCLUSIONS FROM FIRST YEAR'S PROGRAM (ANALYTICAL)

- CONCENTRATION SYSTEMS CAN BE CHEAPER THAN FLAT ARRAYS EVEN AT PROJECTED COSTS FOR CELLS (50 ¢/PEAK WATT)

- CONVENTIONALLY PROCESSED SILICON CELLS CAN OPERATE AT LIGHT INTENSITIES UP TO 200 SUNS AT EFFICIENCIES COMPARABLE TO CURRENT PRODUCTION SPACE CELLS

- PASSIVE COOLING TECHNIQUES CAN BE ADEQUATE FOR RELATIVELY HIGH CONCENTRATION RATIOS (~50)

TABLE II

PROPOSED SECOND YEAR PROGRAM

DURATION: JANUARY 1, 1975 - DECEMBER 31, 1975

REQUESTED FUNDING: $249,274

TEAM: ARIZONA STATE UNIVERSITY (PRIME)
SPECTROLAB DIVISION, TEXTRON, INC. ($118,175 SUBCONTRACT)

OBJECTIVE: TO VERIFY THE ENCOURAGING ANALYTICAL STUDIES BY EXPERIMENTS

PROPOSED TASKS:

I. EXPERIMENTAL DEVELOPMENT OF CONCENTRATION CELLS
(GRID CONTACTS, INCREASE VOLTAGE, FABRICATE ASSEMBLIES)

II. THERMAL ANALYSIS AND TESTING
(WIND DEPENDENCE FOR PASSIVE, ACTIVE COOLING FOR HIGH CR > 100)

III. CONCENTRATED SOLAR CELL SYSTEM TESTING
(5 SYSTEMS - FLAT ARRAY AND CR OF ABOUT 3, 10, 40 AND 100)

IV. SYSTEM PERFORMANCE AND COST ANALYSIS
(COMPLETE COST ANALYSIS AND ESTABLISH CONFIDENCE LEVEL)

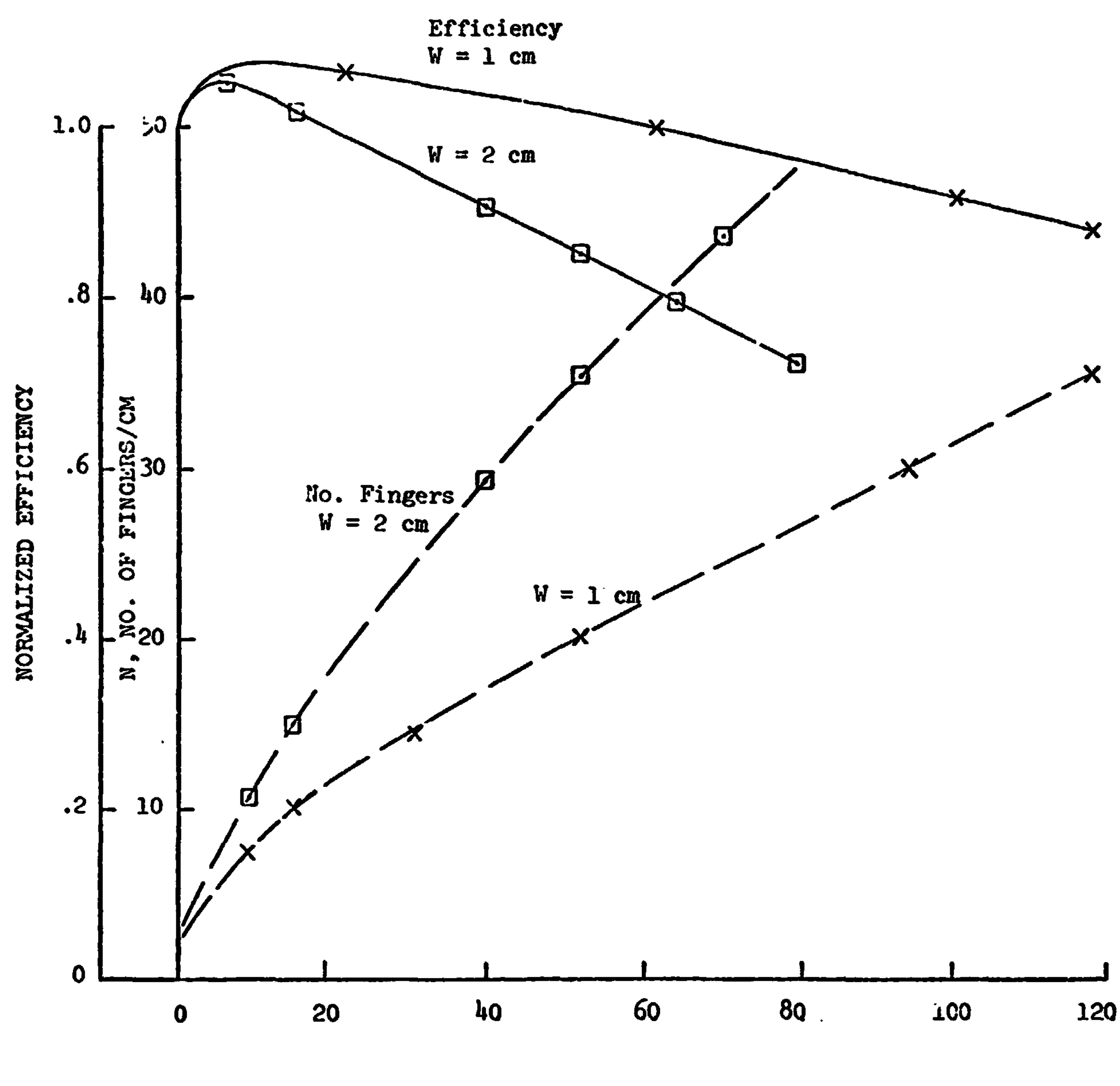


FIGURE 1

NORMALIZED EFFICIENCY & NO. OF FINGERS/CM

vs.

CONCENTRATION LEVEL

Finger Width = .009 cm
Diffused Layer Sheet Resistance = 50 Ω/square
Base Material Resistivity = 0.1 ohm-cm
Cell Thickness = .025 cm
Sheet Resistance of Metalization = .004 Ω/square

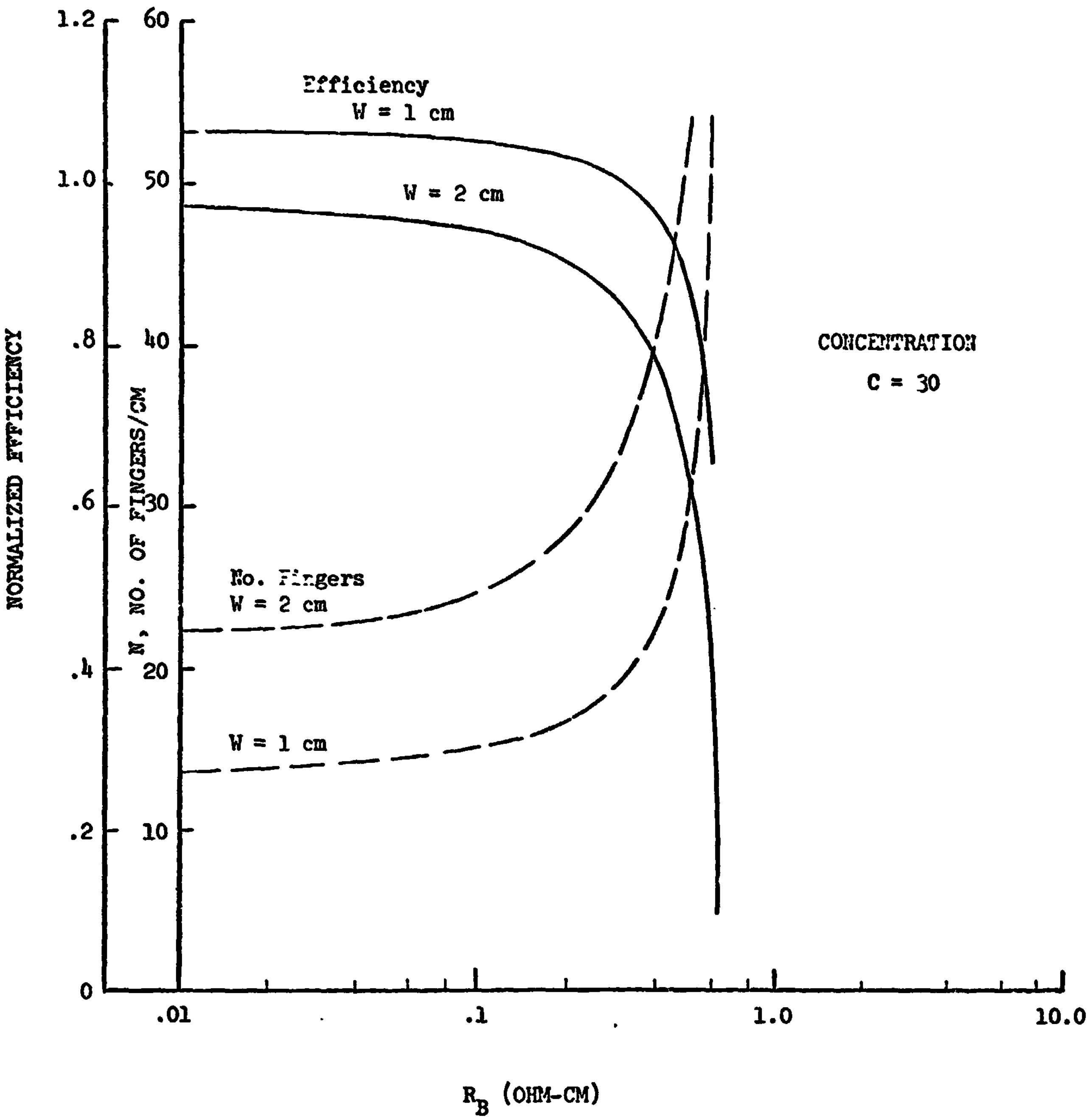


FIGURE 2

NORMALIZED EFFICIENCY & NO. OF FINGERS/CM

vs.

MATERIAL BASE RESISTIVITY

Finger Width = .009 cm
Diffused Layer Sheet Resistance = 50 Ω/square
Cell Thickness = .025 cm
Sheet Resistance of Metalization = .004 Ω/square

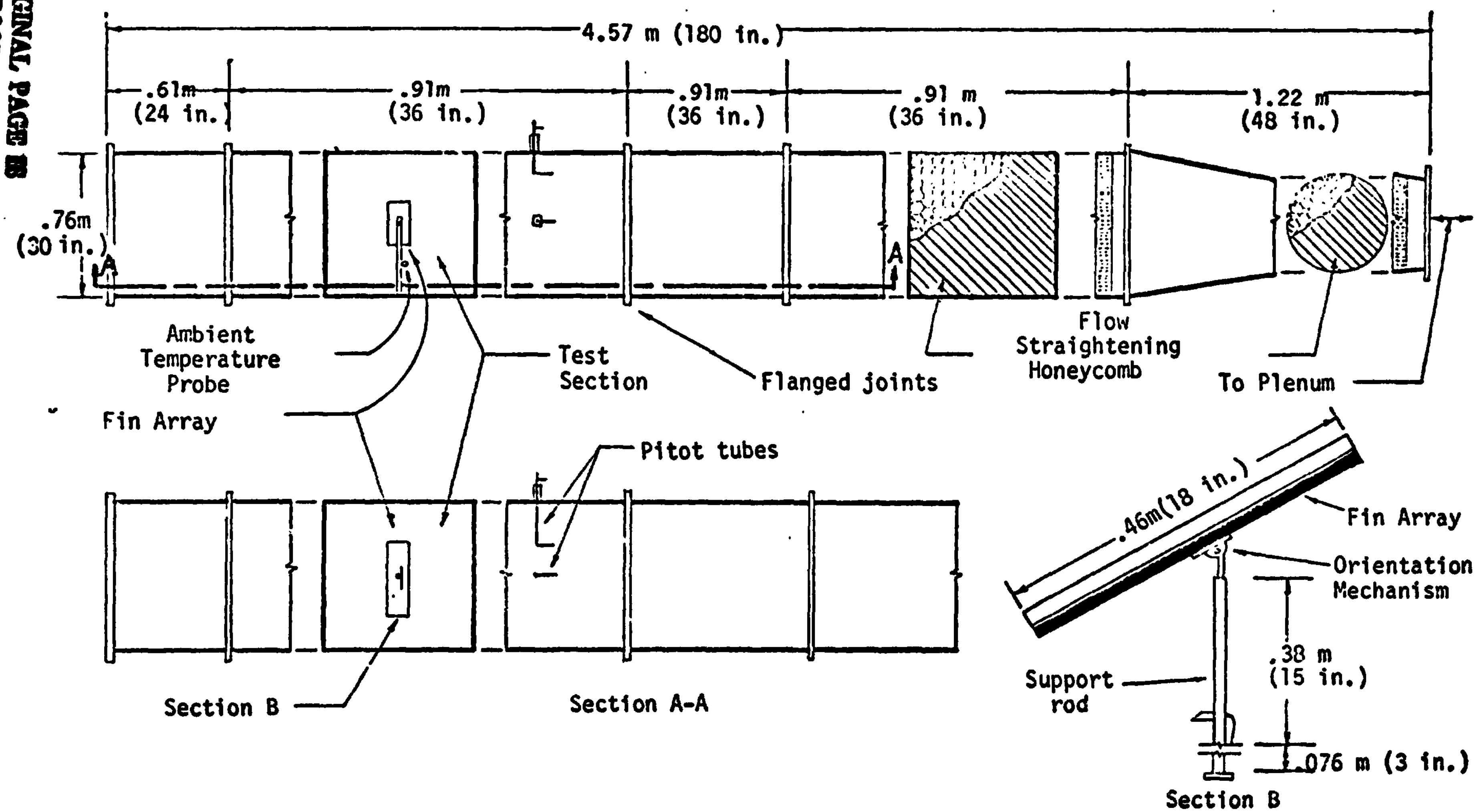


FIGURE 3

LOW SPEED WIND TUNNEL AND TEST MOUNT FOR MEASUREMENT OF COOLING RATES FROM FINNED HEAT SINKS AS A FUNCTION OF AIR FLOW SPEED AND DIRECTION

FIGURE 4

MEASURED THERMAL CONDUCTANCES FOR FRONT SURFACE OF BASELINE FLAT PLATE AS A FUNCTION OF AIR FLOW SPEED AND DIRECTION

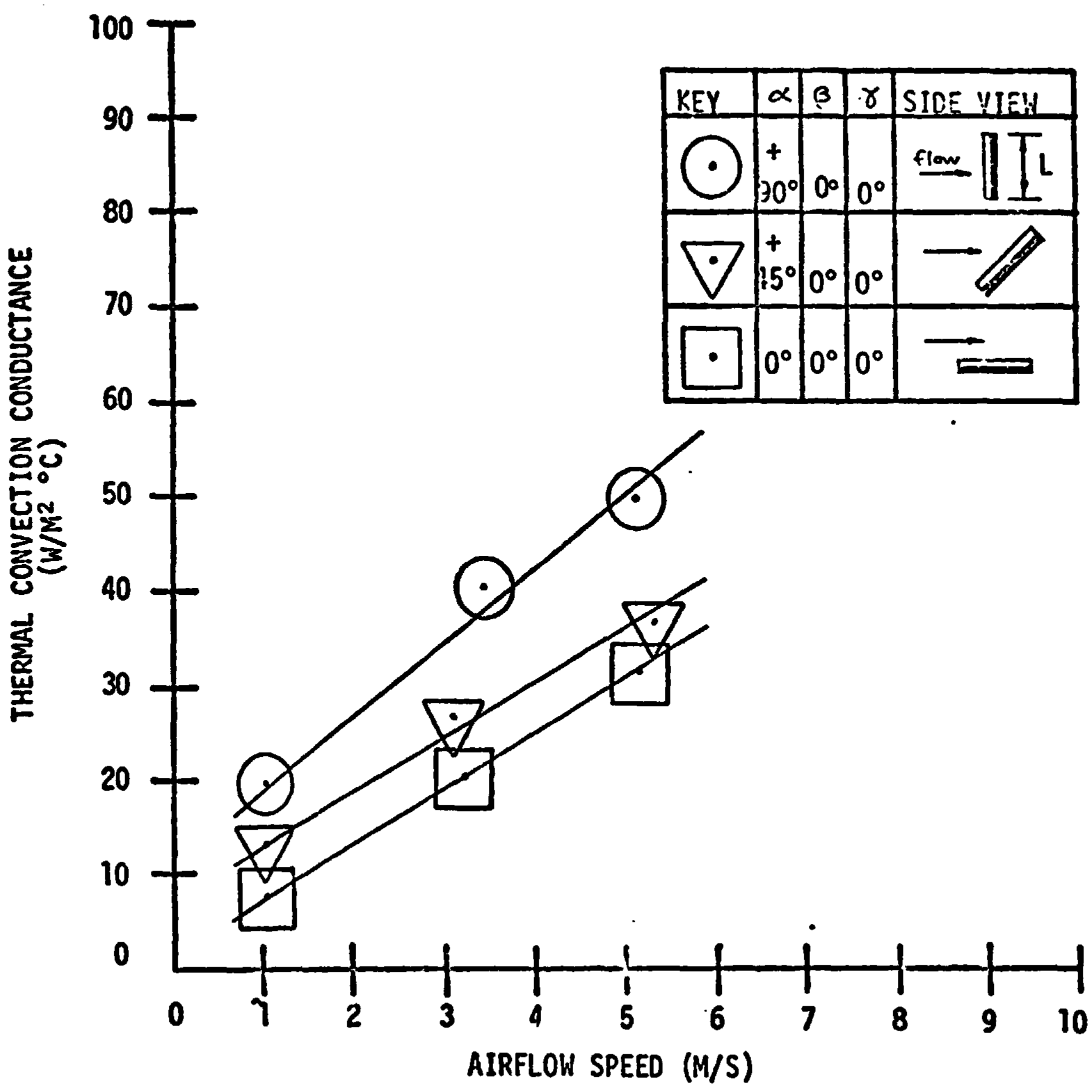
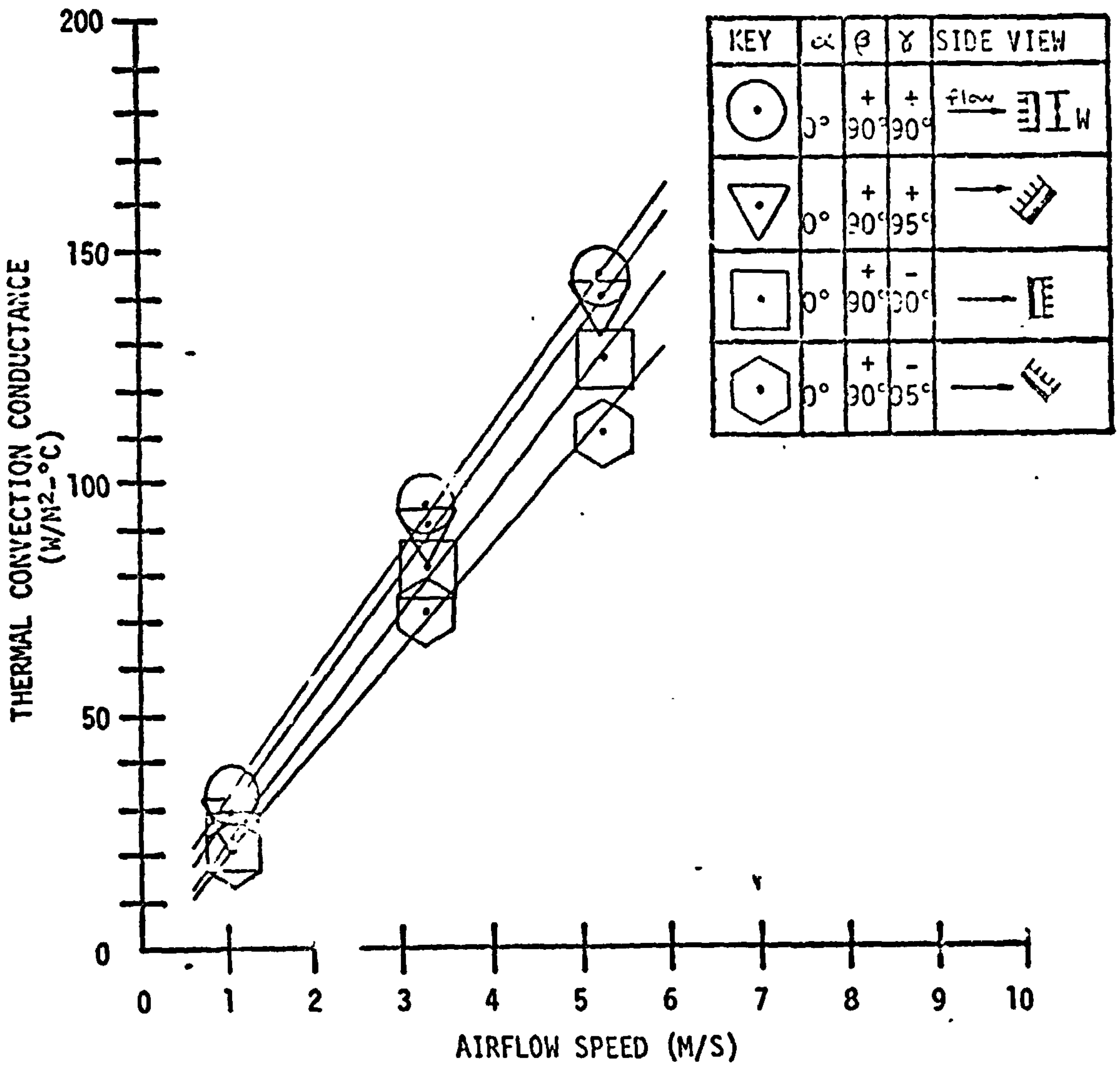


FIGURE 5

MEASURED THERMAL CONVECTION CONDUCTANCES PER UNIT BASE AREA FOR STUBBY TRAPEZOIDAL LONGITUDINAL FINNED SURFACE AS A FUNCTION OF AIR FLOW SPEED AND DIRECTION (SEE TABLE III FOR DIMENSIONS)



ARRAY DESCRIPTION		ARRAY DIMENSIONS								
		N_f	A_t/A_b	L	W	B_1	B_2	H_f	S_1	Z
FLAT PLATE		0	1	.459m (18.0")	.076m (3.00")	-	-	-	-	.0030m (.12")
FINNED PLATE WITH STUBBY TRAPEZOIDAL FINS	LONGITUDINAL	21	4.59	.459m (18.0")	.093m (3.66")	.00038m (.015")	.00076m (.030")	.0081m (.32")	.0046m (.18")	.0020m (.08")
	TRANSVERSE	101	4.47	.462m (18.2")	.089m (3.50")					
FINNED PLATE WITH LONG TRAPEZOIDAL FINS	LONGITUDINAL	12	7.86	.462m (18.2")	.103m (4.06")	.00051m (.02")	.0025m (.10")	.305m (1.20")	.0091m (.36")	.0046m (.18")
	TRANSVERSE	49	7.25	.459m (18.0")	.102m (4.00")					

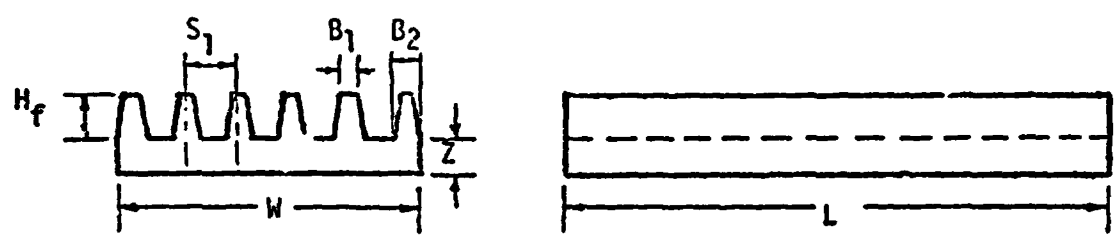


TABLE III

SUMMARY OF DIMENSIONS OF ALUMINUM FINNED PLATE TEST MODELS

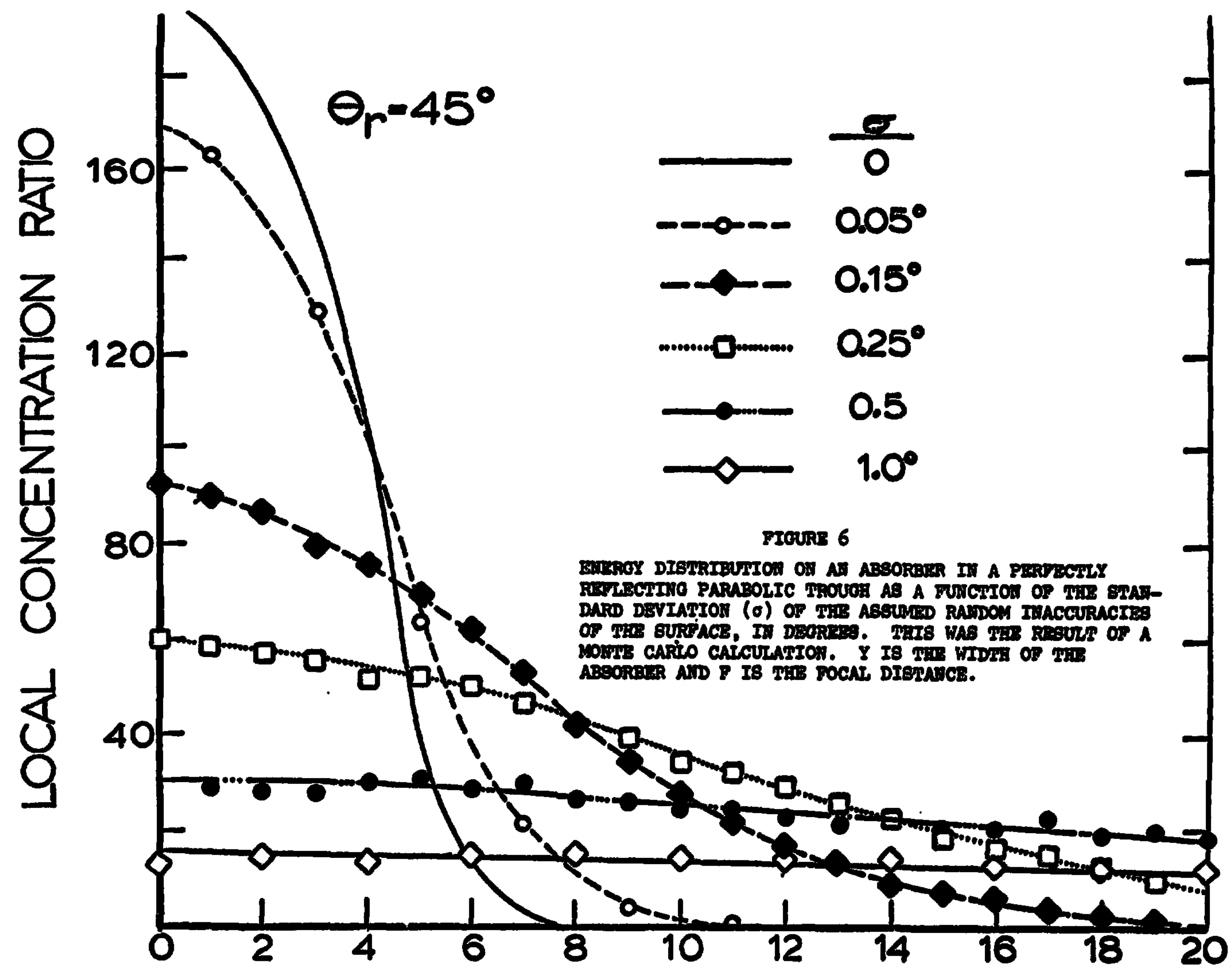


FIGURE 6

ENERGY DISTRIBUTION ON AN ABSORBER IN A PERFECTLY REFLECTING PARABOLIC TROUGH AS A FUNCTION OF THE STANDARD DEVIATION (σ) OF THE ASSUMED RANDOM INACCURACIES OF THE SURFACE, IN DEGREES. THIS WAS THE RESULT OF A MONTE CARLO CALCULATION. Y IS THE WIDTH OF THE ABSORBER AND F IS THE FOCAL DISTANCE.

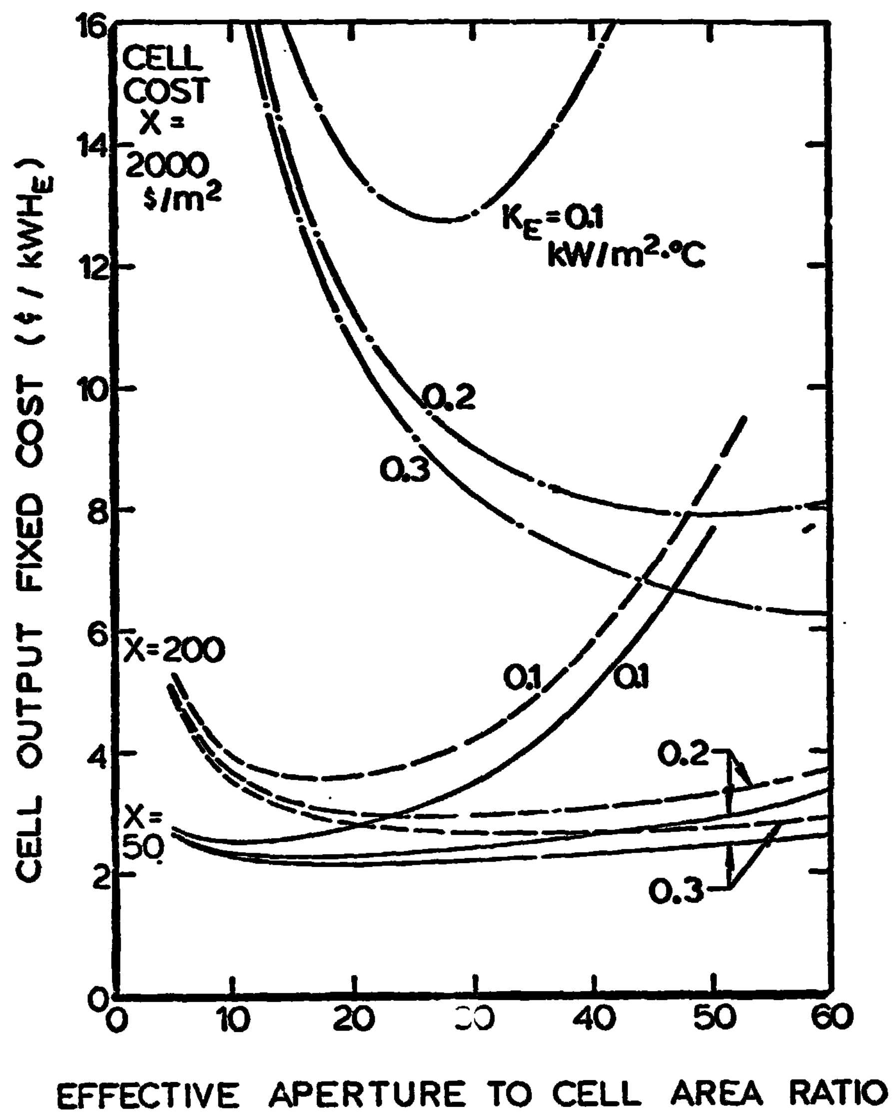


FIGURE 7

ELECTRICAL OUTPUT COST AVERAGED OVER A YEAR IN ALBUQUERQUE FOR A FIXED MIRROR CONCENTRATOR WITH AN ASSUMED COST OF 20$/m^2 FOR THE REFLECTOR AND A PACKING FACTOR OF 0.35. SILICON SOLAR CELLS, PASSIVELY COOLED WERE ASSUMED WITH THE THERMAL CONDUCTANCES OF K_E=0.1, 0.2 and 0.3 AS A PARAMETER. THE INCLUDED ANGLE FOR THE MIRROR WAS 120° WITH A 15° TILT AND A 15° INCLINATION USED.

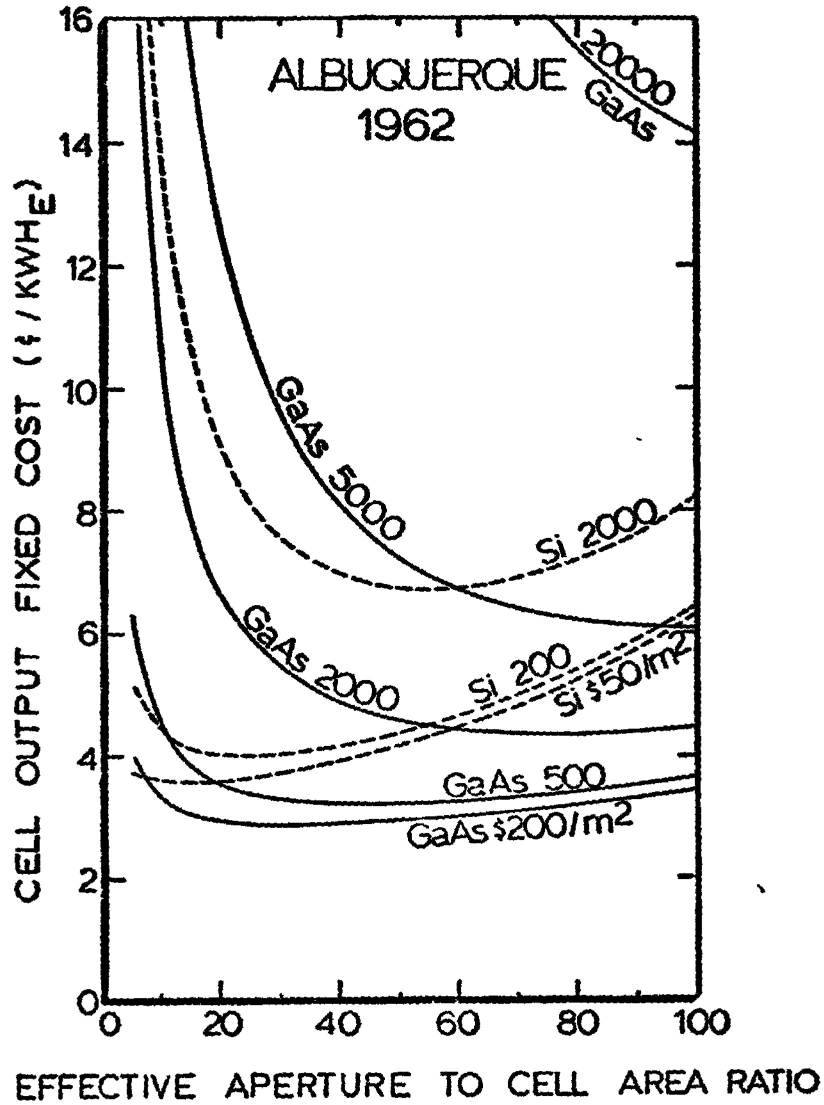


FIGURE 8

A COMPARISON OF S_i AND GaAs SYSTEMS FOR VARIOUS ASSUMED COSTS FOR THE CELLS IN $/$m^2$, PASSIVELY COOLED, K_e=0.4 KW/M^2-°C, REFLECTIVITY OF 0.85 AND CELL ABSORPTIVITY OF 0.8, Si CELLS WERE 15% EFFICIENT AT 25°C GOING LINEAR TO 0 AT 270°C. GaAs WAS 20% AT 25°C GOING TO 0 AT 400°C

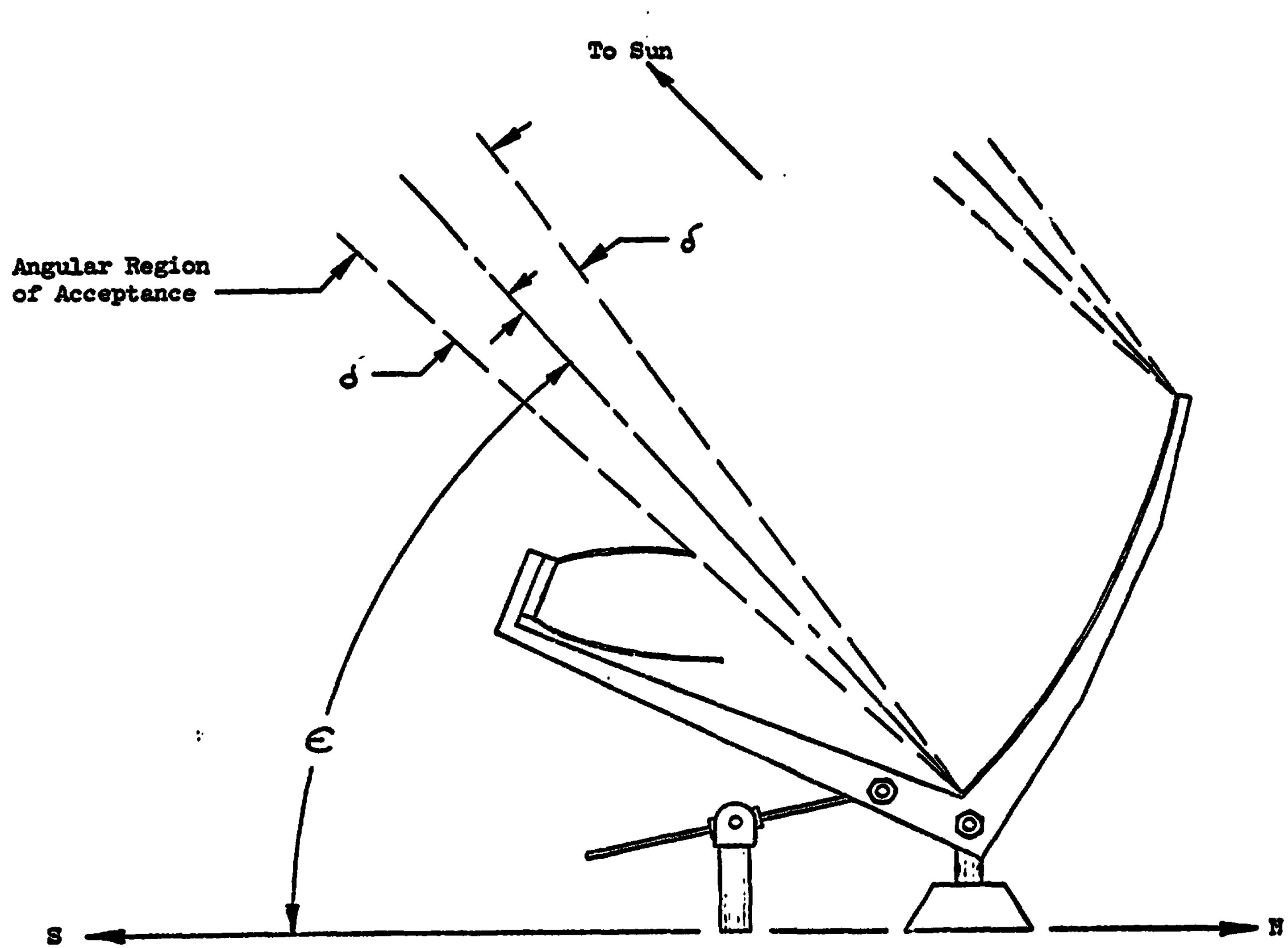


FIGURE 9
MOUNTING ORIENTATION OF PTCEC

THIS NON-TRACKING CONCENTRATOR SYSTEM USES A PARABOLIC TROUGH AND A COMPOUND ELIPTICAL CONCENTRATOR ORIENTED IN THE EW DIRECTION. GEOMETRICAL CONCENTRATION FACTOR IS 7.5

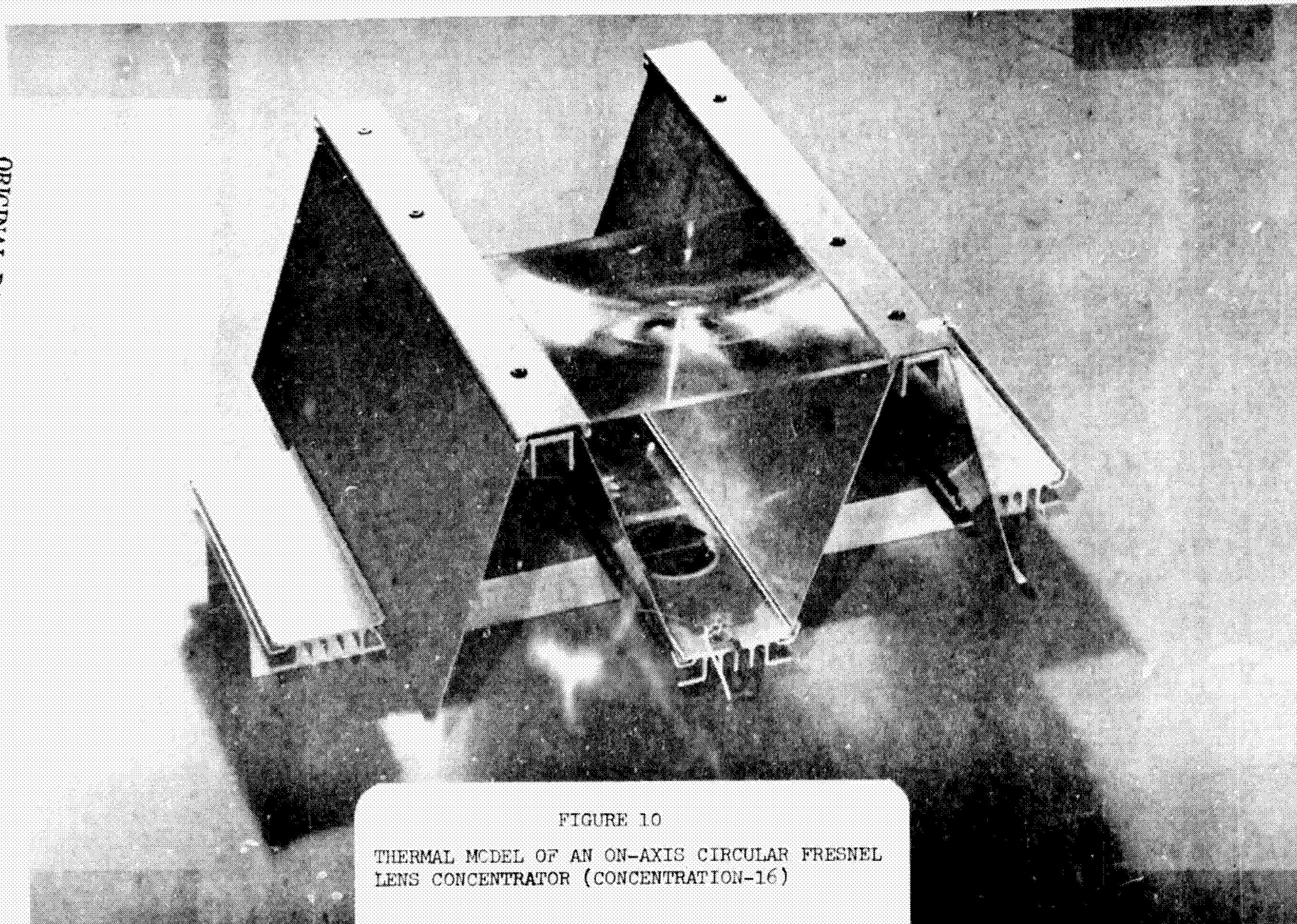


FIGURE 10

THERMAL MODEL OF AN ON-AXIS CIRCULAR FRESNEL LENS CONCENTRATOR (CONCENTRATION-16)

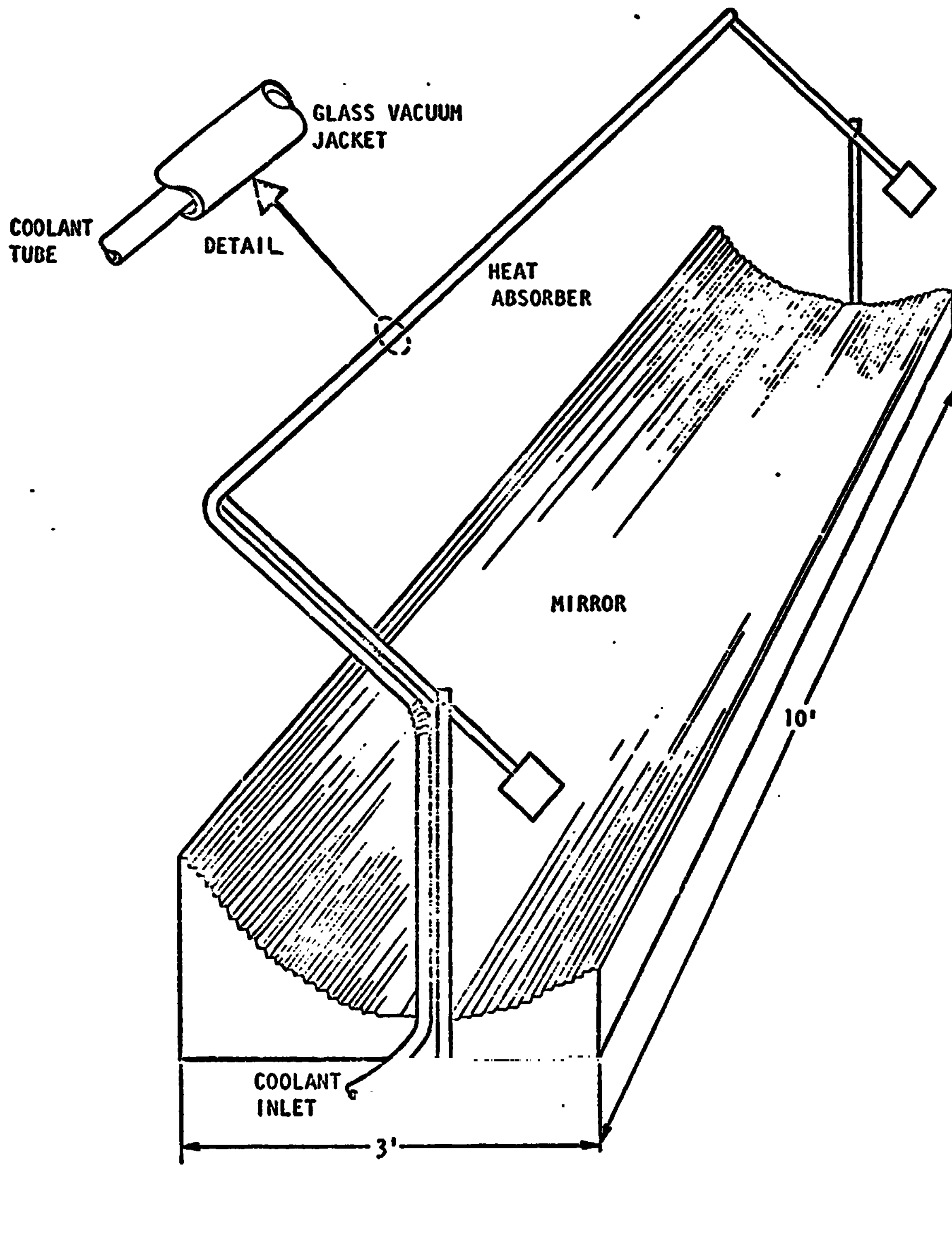


FIGURE 11
Model of fixed-mirror concentrator