DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150665

INDOOR TEST FOR THERMAL PERFORMANCE EVALUATION ON LIFE SCIENCES ENGINEERING (AIR) SOLAR COLLECTOR

Prepared by

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Under subcontract with IBM Federal Systems Division, Huntsville, Alabama

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George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

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This work was done under the technical management of Mr. Charles N. Thomas of the Marshall Space Flight Center, Alabama.

16. ABSTRACT

This report describes the test procedure used and the results obtained from an evaluation test program, conducted to obtain thermal performance data on a Life Sciences double-glazed air solar collector under simulated conditions. These tests were made using the Marshall Space Flight Center's solar simulator. A time constant test and incident angle modifier test were also conducted to determine the transient effect and the incident angle effect on the collector. These results and the results of the collector load test are also discussed.

The Life Sciences collector, Model Solar II, is an air type, double-glazed (Tedlar for outside glazing and tempered glass for inner glazing) flat plate. The gross collector area is 32 square feet (4 feet by 8 feet) with an aperture area of 30.9 square feet. The absorber plate is coated with 3M Nextel Black.

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1.0 PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during an evaluation test program. The test program was conducted to obtain thermal performance data on a Life Sciences double glazed air solar collector under simulated conditions. The tests were conducted utilizing the Marshall Space Flight Center Solar Simulator in accordance with the test requirements specified in Reference 2.1 and the procedures contained in Reference 2.2.

2.0 REFERENCES

2.1	ASHRAE-93-77	Method of Testing to Determine the Thermal Performance of Solar Collectors
2.2	MTCP-DC-SHAC-419	Test Procedure for the Performance Evaluation of Air Collectors under Simulated Conditions
2.3	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility

3.0 MANUFACTURER

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3.1 DESCRIPTION OF TEST SPECIMEN

The Life Sciences collector, Model Solar II, is an air type, double glazed (Tedlar for outside glazing and tempered glass for inner glazing), flat plate. The gross collector area is 32 square feet (4' x 8') with an aperture area of 30.9 square feet (46.75" x 95.125"). The absorber plate is coated with 3M Nextel Black.

4.0 SUMMARY

This test program was conducted to evaluate the thermal performance of a Life Sciences air collector under simulated conditions. The test conditions and the data obtained during the tests conducted on the Simulator are listed in Table II for stagnation test and Tables III and IV for thermal performance test. A graphic presentation of the data obtained is also presented in Figure 2. In addition, a time constant test and incident angle modifier test were conducted to determine the transient effect and the incident angle effect on the collector. The results of these tests are presented in Figures 4 through 6 and Table V. Results of the collector load test are listed in Table VI.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Unless otherwise specified herein, all tests will be performed at ambient conditions existing in Building 4619 at the time of the tests and listed in Tables II through V.

5.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with the requirements of MSFC-MMI-5300.4C, Metrology and Calibration. Table I contains instrumentation identification and data acquisition connection data. Instrumentation locations on the test loop and collector are depicted in Figure 1. A listing of the equipment used in each test follows.

Apparatus	Manufacturer/Model	Range/Accuracy
Platinum Resistance Thermometer	Supplied by Collector Manufacturer	0-300°F ± 0.5°F
Pyranometer	Eppley - PSP	0-800 BTU/Ft^2·Hr ± 3%
Air Loop	MSFC Supplied	N/A
Thermopile	Medtherm	0-20°F/± .05°F
Directional Anemometer	MSFC Supplied	0 - 30 MPH
Flow Measurement Nozzle	Air Filter Testing Labs, 1.59" dia.	35 - 130 CFM
Platinum Resistance Thermometer	Hy-Cal	0-300°F ± 0.5°F
Strip Chart Recorder	Mosley 680	5-500 MV ± 2%
Floor Fan	MSFC Supplied	N/A
Solar Simulator	MSFC Supplied	See SHC 3006
Inclined Manometer	MSFC Supplied	0-4" H_2O ± .01"
Differential Pressure Transducer	AMETEK/52D0010AML	0-10 in. H_2O ± 0.5%

5.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

5.3 Data Systems

Test data obtained during simulator tests will be transmitted from MSFC Building 4619 (test site) through primary data acquisition system #3 to the real time data link and the DDP-224 computer located in Building 4646. A separate data link between Building 4646 and 4619 provides for printout of real time data at the test site. A listing of all instrumentation by function, type and corresponding data recording system is indicated in Table I.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS

6.1 Collector Preconditioning and Stagnation Test

6.1.1 Test Requirement

The collector shall be mounted on an outdoor passive test stand at an angle of 45° from the horizontal and facing south. The inlet and outlet ports to the collector shall be capped to prevent flow. The lower cap shall contain a small vent hole. The preconditioning shall consist of at least three days exposure during which the mean incident solar radiation measured in the plane of the collector shall be 1500 BTU/Ft^2·day. During this preconditioning, the following data shall be recorded within two hours of solar noon when the insolation is constant and above a minimum of 200 BTU/Hr·Ft^2 in the plane of the collector. Data recorded shall be the average for at least a 20 minute period at quasi-steady state conditions.

1. Insolation rate.
2. Ambient temperature.
3. Wind velocity and direction.
4. Absorber surface temperature at either 4 or 5 locations.

6.1.2 Test Procedure

1. Mount test specimen as described above.
2. Connect instrumentation.
3. Record data as described above.

6.1.3 Results

The results obtained during these tests are contained in Table II.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.2 Collector Thermal Efficiency Test

6.2.1 Test Requirements

Thermal performance evaluation data shall be obtained at inlet temperatures of 0, 25, 50, and 100°F above ambient temperature at air flow rates of 66 and 120 SCFM at insolation rates of 260 and 300 BTU/Hr·Ft^2 and a wind speed of 7.5 mph. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet air temperature.
3. Collector outlet air temperature.
4. Collector differential temperature.
5. Differential pressure across collector.
6. Air flow rate.
7. Insolation rate.
8. Wind speed.

6.2.2 Test Procedure

1. Mount test specimen on test table at a 45° angle with respect to the floor.
2. Assure that simulator lamp array is adjusted to an angle of 45° with respect to the floor.
3. Align the test table so that the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the top of the test specimen to the lens plane of the lamp array is 9 feet.
4. Insulate all ducts.
5. Assure that data acquisition system is operational.
6. Start air flow loop and establish a flow rate of 66 SCFM.
7. Establish the wind speed of 7.5 mph.
8. Power up simulator and establish a solar flux level of 260 BTU/Ft^2·Hr.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.2 Collector Thermal Efficiency Test (Continued)

6.2.2 Test Procedure (Continued)

9. Determine the ambient air temperature.

10. Adjust the inlet temperature of the collector to the ambient air temperature value.

11. After steady state conditions have been established, record data for a minimum of five minutes.

12. Repeat steps 8, 9, 10, and 11, changing the flux level and air inlet temperature as necessary until data has been obtained for each test condition specified in Paragraph 6.2.1.

13. Repeat steps 7, 8, 9, 10, 11, and 12 with flow rate of 120 SCFM.

14. Upon completion of testing, power down simulator and liquid loop.

15. Inform data control group that simulator operation has terminated.

6.2.3 Test Results

The results obtained during these tests are contained in Figure 2 and Tables III and IV for thermal performance data and Figure 3 for pressure drop data.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.3 Collector Time Constant Test

6.3.1 Test Requirements

In accordance with ASHRAE 93-77, the time constant test shall be conducted by abruptly reducing the flux level to zero. Inlet temperature shall be kept to within ± 2°F of ambient, with an air flow rate of 120 SCFM. The differential temperature across the collector shall be recorded to determine the time required to reach the condition of

$$\frac{Te - Ti}{Te_{ini} - Ti} = .368$$

where

Te = Outlet temperature

Te_{ini} = Initial outlet temperature

Ti = Inlet temperature

The following data shall be recorded during the test:

1. Absorber surface temperature - 4 locations.
2. Ambient temperature.
3. Collector inlet temperature.
4. Collector outlet temperature.
5. Collector differential temperature.
6. Differential pressure across collector.
7. Air flow rate.
8. Insolation rate.

6.3.2 Test Procedure

1. Mount the collector on test table at 45° from the horizontal and assure that solar simulator surface is parallel to the collector surface.
2. Assure that data acquisition system is operational.
3. Adjust the air flow rate to 120 SCFM.
4. Adjust the air inlet temperature to within ± 2°F of ambient.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.3.2 Test Procedure (Continued)

5. Adjust the flux level to 260 BTU/$Ft^2 \cdot Hr$.

6. Monitor the differential temperature across the collector.

7. Allow the system to stabilize at above conditions for at least 5 minutes.

8. Turn off the solar simulator.

9. Monitor the differential temperature until the ratio

   of $\frac{Te - Ti}{Te_{ini} - Ti}$ is less than .30.

10. Upon completion of testing, power down simulator and air loop.

11. Inform data control group that simulator operation has terminated.

6.3.3 Test Results

The results obtained during this test are shown in Figure 4.

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6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.4 Collector Incident Angle Modifier Test

6.4.1 Test Requirement

The collector incident angle modifier test shall be conducted at north-south radiation incident angle of 45 degrees. The east-west radiation incident angles shall be 30, 40, 50 and 60 degrees. The air flow rate shall be 38 SCFM with inlet temperature controlled to within ± 2°F of ambient at the insolation rate of 260 BTU/Ft^2·Hr and 0 mph wind. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet air temperature.
3. Collector outlet air temperature.
4. Collector differential temperature.
5. Air flow rate.
6. Insolation rate.

6.4.2 Test Procedure

1. Mount the collector on the test table at incident angle of 30°.
2. Adjust the air flow rate to 66 SCFM.
3. Adjust the solar simulator flux level to 260 BTU/Hr·Ft^2.
4. Adjust the inlet temperature to ambient ± 2°F.
5. Measure the flux level at 9 locations on the test plane.
6. Record data for 5 minute stabilized period.
7. Repeat above steps for incident angles of 40°, 50° and 60°
8. Upon completion of testing, power down simulator and liquid loop.
9. Inform data control group that simulator operation has terminated.

6.4.3 Test Results

Data obtained from this test program were analyzed according to ASHRAE 93-77 and reported in Table V and graphic format in Figures 5 and 6.

6.0 TEST REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.5 Collector Load Test

6.5.1 Test Requirements

One solar collector shall be subjected to load testing. The specified load requirements are listed in Table VI. The collector shall be mounted as indicated in Figure 7 but oriented such that the glazing is horizontal. Uniform loads shall be applied by means of a transparent flexible diaphragm which can be covered with a uniform layer of transparent liquid of varying depths to obtain the desired load variations.

6.5.2 Test Procedure

1. Mount the collector in the horizontal plane.

2. Place the load frame with liner over the collector.

3. Fill the load frame liner with water to a level corresponding to the Step 1 load of Table VI and let stand for five minutes.

4. Drain and remove the load frame.

5. Flush the collector exposed surface with water and inspect for leaks.

6. If the collector leaked or was damaged due to the load, record and indicate what the load level is.

7. If the collector does not leak and is not damaged, record the load level and repeat steps 3 through 5 for the next load level.

6.5.3 Test Results

The results of this test are tabulated in Table VI.

7.0 ANALYSIS

7.1 Thermal Performance Test

The analysis of data contained in this report is in accordance with the National Bureau of Standards recommended approach. This approach is outlined below.

The efficiency of a collector is stated as:

$$\eta = \frac{q_u/A}{I} = \frac{\dot{m}\, C_{tf} \left(T_{f,e} - T_{f,i}\right)}{I} \qquad (1)$$

where:

q_u = rate of useful energy extracted from the Solar Collector (BTU/Hr)

A = Gross collector area (Ft^2)

I = Total solar energy incident upon the plant of the solar collector per unit time per unit area ($BTU/Hr \cdot Ft^2$)

$\dot{m}$ = Mass flow rate of the transfer fluid through the collector per unit area of the collector ($Lbm/Ft^2 \cdot Hr$)

C_{tf} = Specific heat of the transfer fluid ($BTU/Lb \cdot °F$)

$T_{f,e}$ = Temperature of the transfer fluid leaving the collector (°F)

$T_{f,i}$ = Temperature of the transfer fluid entering the collector (°F)

Rewriting Equation (1) in terms of the total collector area yield:

$$\eta = \frac{(\dot{m}A)\, C_{tf} \left(T_{f,e} - T_{f,i}\right)}{(IA)} = \frac{\dot{M}\, C_{tf} \left(T_{f,e} - T_{f,i}\right)}{P_i} \qquad (2)$$

Notice that:

P_i = IA = Total Power Incident on the Collector.

$\dot{m}A = \dot{M}$ = Total Mass Flow Rate through the Collector.

Therefore $\dot{M}\, C_{tf}(T_{f,e} - T_{f,i})$ = Total Power Collected by the Collector.

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{Pabs}{Pinc} \qquad (3)$$

where:

Pabs = Total collected power

Pinc = Total incident power

This value of efficiency is expressed as a percentage by multiphying by 100. This expression for percent efficiency is:

$$\text{Collector Efficiency} = \frac{Pabs}{Pinc} \times 100 \qquad (4)$$

or from Equation (2), collector efficiency is defined by the equation:

$$\%\ \text{Eff.} = \frac{\dot{M}\ C_{tf}\ (T_{f,e} - T_{f,i})}{Pi} \times 100 \qquad (5)$$

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at sixty-second intervals. The mean value of efficiency was determined over a five-minute period during which the test conditions remained in a quasi-steady state. Each five-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus

$$\left((T_i - T_a)/I \right)$$

where:

T_i = Air inlet temperature (°F)

T_a = Ambient temperature (°F)

I = Incident flux per unit area ($BTU/Hr \cdot Ft^2$)

The abscissa term $\left((T_i - T_a)/I\right)$ was used to normalize the effect of operating at different values of I, T_i and T_a. The results are found in Figure 2.

The result of second order polynomial analysis is shown in Figure 2. The second order polynomial to best describe the test results is:

$$\text{Efficiency} = a_0 + a_1\mathcal{J} + a_2\mathcal{J}^2$$

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7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

where:

$$\tau = (T_i - T_a)\ I$$

and the coefficients are determined to be:

Flow Rate (SCFM)	66	120
a_0	0.491	0.625
a_1	-0.863	-1.097
a_2	-0.245	-0.080

7.0 ANALYSIS (Continued)

7.2 Time Constant Test

Two methods are proposed by ASHRAE 93-77 for conducting a time constant test. However, due to facility limitations, only the first method could be used. This method consisted of shutting down the simulator and maintaining a constant flow rate and inlet temperature while obtaining data.

According to the definition of time constant given in 93-77, it is the time required for the ratio of the differential temperature at time τ to the initial differential temperature to reach .368. It can be expressed as:

$$\frac{T_{f,e,\tau} - T_{f,i}}{T_{f,e,ini} - T_{f,i}} = .368 \qquad (1)$$

If the inlet air temperature cannot be controlled to equal the ambient air temperature, then the following equation must be used

$$\frac{F_R U_L \ (T_{f,i} - T_a) + \frac{\dot{m}C_p}{A} \ (T_{f,e,\tau} - T_{f,i})}{F_R U_L \ (T_{f,i} - T_a) + \frac{\dot{m}C_p}{A} \ (T_{f,e,ini} - T_{f,i})} = .368 \qquad (2)$$

where:

$T_{f,e,\tau}$ = Exit air temperature at time, τ

$T_{f,i}$ = Inlet air temperature

$T_{f,e,ini}$ = Initial exit air temperature

$\dot{m}$ = Air mass flow rate = 540 Lb/Hr

C_p = Specific heat of air = .24 BTU/Lb·°F

A = Collector area = 32 Ft^2

$F_R U_L$ = Negative of the slope determined from the thermal efficiency curve

During the time constant test, the inlet air temperature cannot be controlled to within ± 2°F of ambient air temperature; hence equation (2) must be used for evaluation. From the performance curve, it is found that $F_R U_L$ = .86. Equation (2) becomes

$$\frac{.86(73.8-66.2) + 4.05 \ (T_{f,e,\tau} - 73.8)}{.86 \ (73.8-66.2) + 4.05 \ (39)} = .368$$

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7.0 ANALYSIS (Continued)

7.2 Time Constant Test (Continued)

or

$$\frac{T_{f,e,\tau} - T_{f,i}}{T_{f,e\,ini} - T_{f,i}} = .342$$

From Figure 4 the time constant was determined to be 6 minutes and 52 seconds.

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7.0 ANALYSIS (Continued)

7.3 Incident Angle Modifier Test

Two methods are proposed by ASHRAE 93-77 for incident angle modifier tests. For the MSFC Solar Simulator Facility, only method 1 (tilting the collector) is applicable. The collector was adjusted so that the incident radiation angles were 30°, 40°, 50° and 60° to the normal of the collector surface.

According to 93-77, the incident angle modifier is defined as

$$K\alpha\tau = \frac{\eta}{F_R(\tau\alpha)n} \qquad (1)$$

where η = efficiency at tilted angle.

$F_R(\alpha\tau)\ n$ = Intercept of efficiency curve at normal incident angle = .46

For equation (1) to be applicable, the inlet air temperature must be controlled to within ± 2°F of the ambient air temperature. In cases where the inlet air temperature cannot be controlled to within ± 2°F, the following equation must be used to evaluate the incident angle modifier.

$$K\alpha\tau = \frac{\eta + F_R U_L \frac{T_{f,i} - T_a}{I}}{F_R(\alpha\tau)n} \qquad (2)$$

where:

$F_R U_L$ is the negative of the slope determined from the thermal efficiency curve.

Table V shows that the inlet air temperatures were not all within ± 2°F of ambient air temperature. Hence, equation (2) was used for evaluation.

$$K\alpha\tau = \frac{\eta + .86\ \frac{T_{f,i} - T_a}{I}}{.491}$$

The results of this computation are shown on Table V and plotted against incident angle in Figure 5 and plotted against $\frac{1}{\cos \theta i} - 1$ in Figure 6.

TABLE I

LIFE SCIENCES COLLECTOR AT
SIMULATOR

Meas. No.	Test	Location		Elect. Range	Full Scale	Meas. Range	S/N	Mfg. M/N
T101	Simulator	Coll. Internal	1	0 - 20	20 MV	-50 - 400°	Mfg.	RTS-4175-100
T102	"	" "	2	"	"	"	"	"
T103	"	" "	3	"	"	"	"	"
T104	"	" "	4	"	"	"	"	"
T105	"	" "	5	"	"	"	"	"
T106	"	Coll. Inlet		"	"	60 - 250	35	RTS-4135-100
T107	"	Coll. Outlet		"	"	60 - 250	85	RTS-4135-100
T009	"	Amb		0 - 20	20 MV	40 - 100	100	RTS-4135-100
F001	"	Coll. Inlet		0 - 5	5 VDC	35 - 130 ACFM		Air Filter
I00_	"	Solar Flux		0 - 20	20 MV	0 - 743 BTU/Hr.	14134F3	PSP
T008	"	Nozzle Temp.		0 - 20	20 MV	60 - 250°	50	RTS-4135-100
TD100	"	Across Collector		TO BE RECORDED ON STRIP CHART				

TABLE II

STAGNATION TEST DATA
LIFE SCIENCES SOLAR COLLECTOR

Solar Flux BTU/Hr·Ft^2	161	314	320
Ambient Temp. °F	28.6	28.2	21.5
Absorber Temp. North °F	225	273	279
Absorber Temp. Center °F	229	283	288
Absorber Temp. South °F	219	259	273
Absorber Temp. West °F	220	265	256
Average Absorber Temp. °F	223	270	274

TABLE III

THERMAL PERFORMANCE TEST DATA
66 SCFM

Ambient °F	61.8	65.2	64.2	70.6	65.6	66.0	66.7	66.8	65.4	66.5
T_{in} °F	67.8	69.6	86.1	95.8	115.3	117.3	138.2	142.5	166.7	166.0
T_{out} °F	122.8	133.6	137.1	153.9	155.3	164.3	167.0	181.1	183.2	191.8
ΔT °F	55.0	64.0	51.0	58.1	40.0	47.0	28.8	38.6	16.5	25.8
Solar Flux BTU/Hr·Ft^2	263.3	304.5	263.3	304.5	263.3	304.5	263.3	304.5	263.3	304.5
Flow Rate SCFM	67	66.4	65.5	64.9	63.9	62.9	62.9	61.5	61.4	61.4
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Efficiency %	47.2	47.1	42.9	49.9	31.5	32.8	23.3	26.3	13.0	17.6
(Ti-Ta) /I °F·Hr·Ft^2/BTU	0.023	0.015	0.083	0.083	0.189	0.169	0.272	0.249	0.384	0.327

TABLE IV

THERMAL PERFORMANCE TEST DATA
120 SCFM

Ambient	°F	62.3	66.7	63.5	68.9	66.6	67.1	66.8	66.8	66.2	66.5
T_{in}	°F	69.0	73.2	86.9	93.3	117.0	118.3	140.1	144.7	166.8	166.0
T_{out}	°F	108.0	116.2	123.5	133.4	145.1	152.3	161.9	171.7	181.8	184.9
ΔT	°F	39.0	43.0	36.6	40.1	28.1	34.0	21.8	27.0	15.0	18.9
Solar Flux	$BTU/Hr \cdot Ft^2$	263.3	304.5	263.3	304.5	263.3	304.5	268.3	304.5	263.3	304.5
Flow Rate	SCFM	122.0	120.6	120.5	117.8	114.0	116.0	111.5	113.8	110.8	110.4
Wind Speed	MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Efficiency	%	61.0	57.5	56.5	52.4	41.0	43.7	31.2	34.1	21.3	23.1
$(T_i-T_a)/I$	$°F \cdot Hr \cdot Ft^2/BTU$	0.025	0.021	0.089	0.080	0.191	0.168	0.278	0.256	0.382	0.327

TABLE V

INCIDENT ANGLE MODIFIER TEST DATA

Incident Angle Degree		30	40	50	60
Ambient	°F	72.6	73.1	68.3	67.5
T_{in}	°F	77.8	78.5	75.4	75.6
T_{out}	°F	126.9	120.6	109.0	99.8
ΔT	°F	49.1	42.0	33.3	23.5
Solar Flux	BTU/Hr·Ft^2	227.8	194.6	172.0	128.3
Flow Rate	SCFM	64.7	64.5	65.6	64.9
Wind Speed	MPH	0	0	0	0
Efficiency	%	47.1	46.9	42.9	40.1
Incident Angle Modifier $K\alpha\tau$		1.00	1.00	0.945	0.927

TABLE VI

SERVICE LOAD STEPS AND TEST RESULTS

Step No.	Load (Lb/Ft^2)	Pass/Fail	Comments
1	10	Pass	
2	20	Fail	See Note 1.
3	30	Fail	
4	50	Fail	
5	80	Fail	
6	120	Fail	

Tested By B. Henderson Date 2/10/78

Note 1. The outside Tedlar film pulled out of the edge mounting for about one and one half feet in two places at 20 PSF allowing leakage between the film and the glass. Test loading continued up to 120 PSF without additional structural damage or leakage around the glass seal into the main body of the collector.

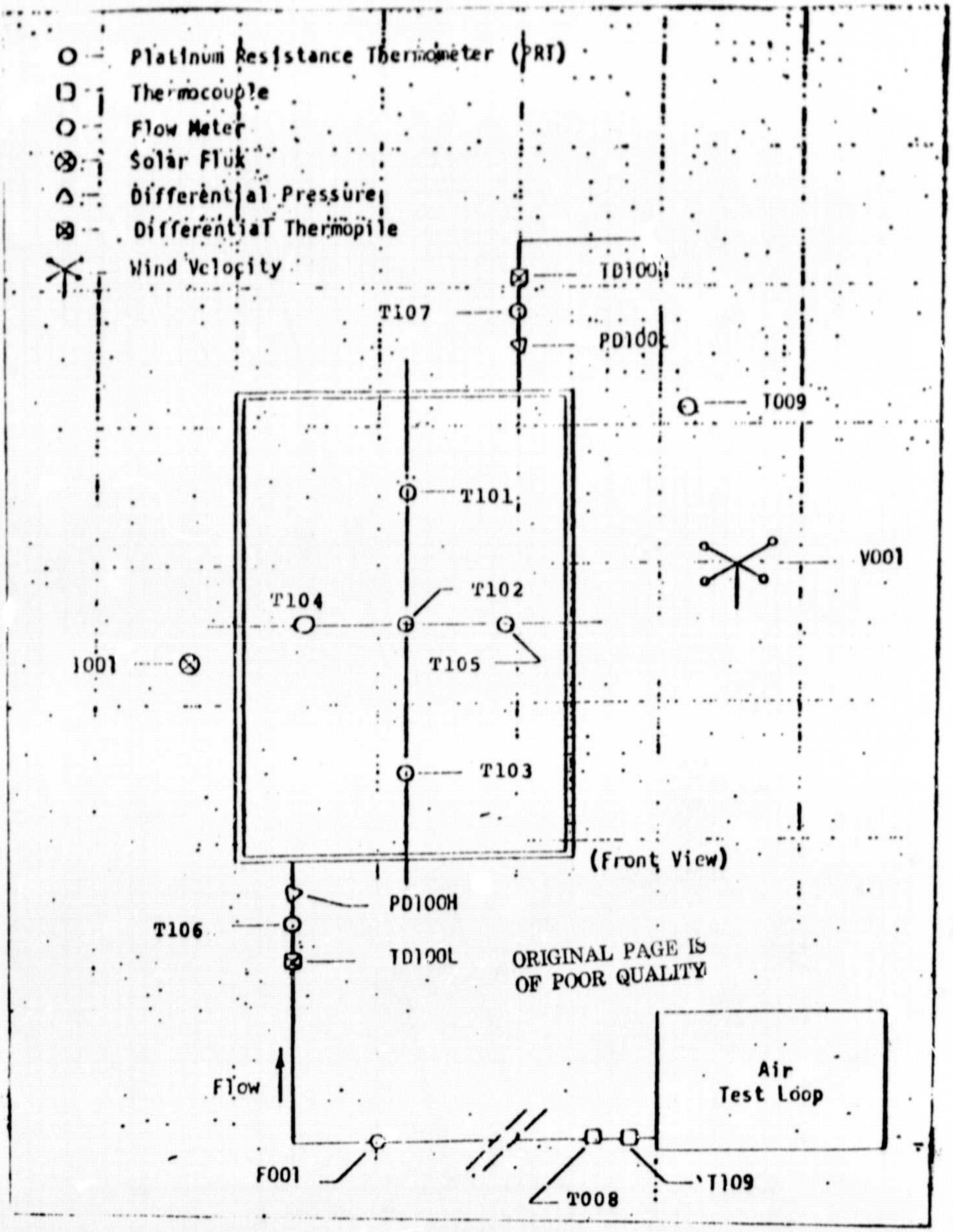

Figure 1. Instrumentation Locations for Life Sciences Air Collector Test

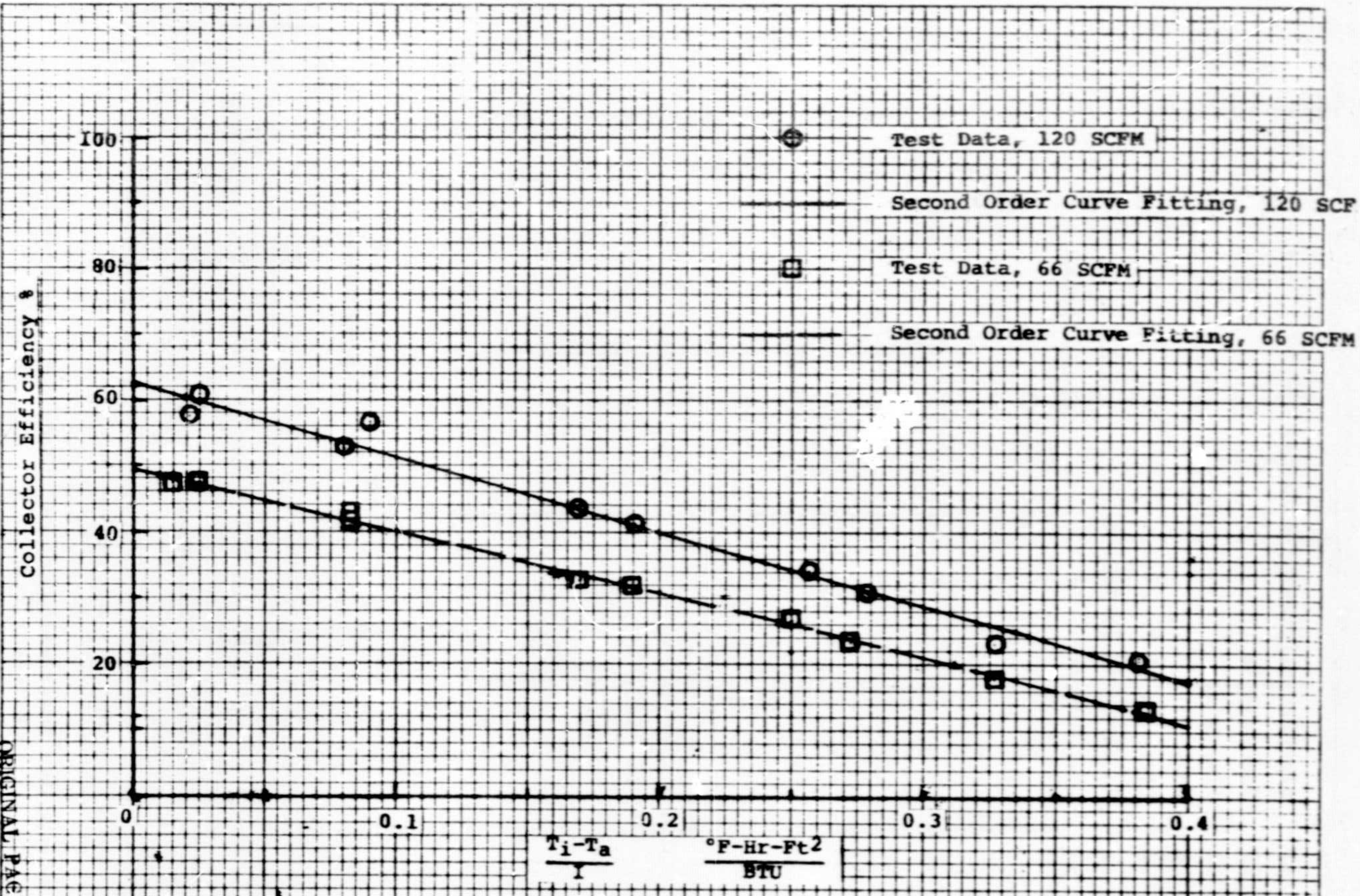

Figure 2. Life Sciences Collector Indoor Thermal Performance Test Data

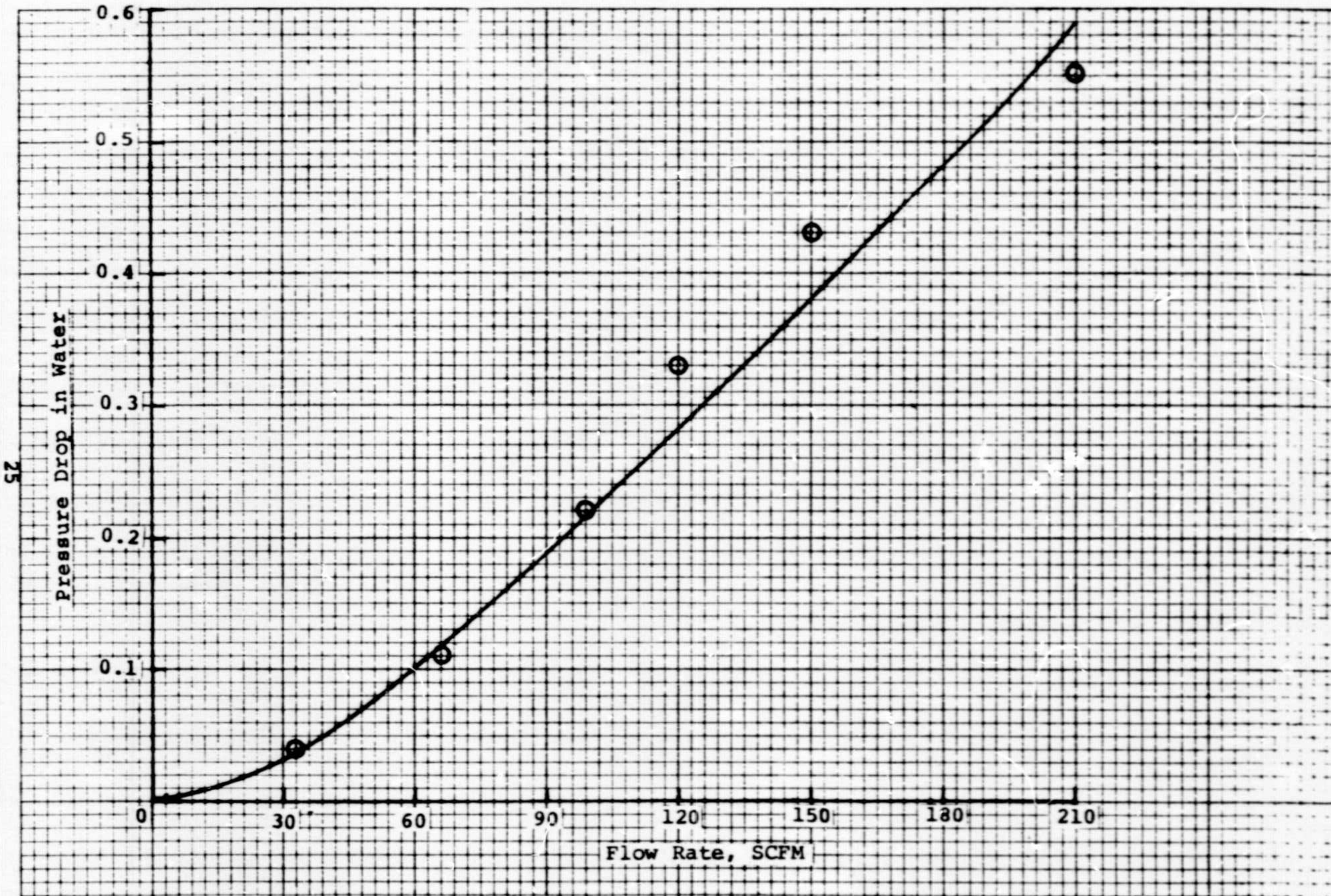

Figure 3. Life Sciences Collector Pressure Drop Test Data

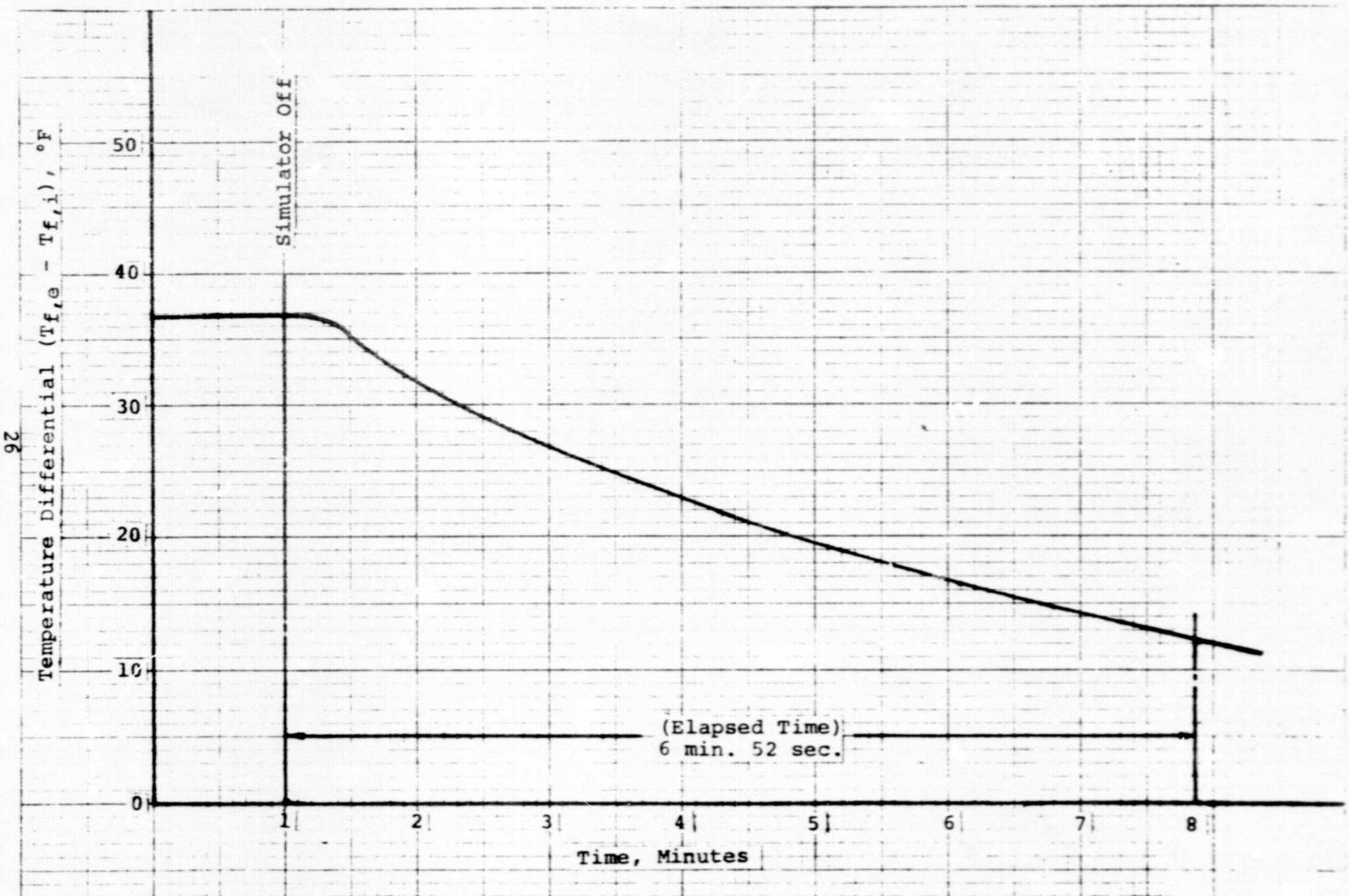

Figure 4. Life Sciences (Air) Collector Time Constant Test (120 SCFM)

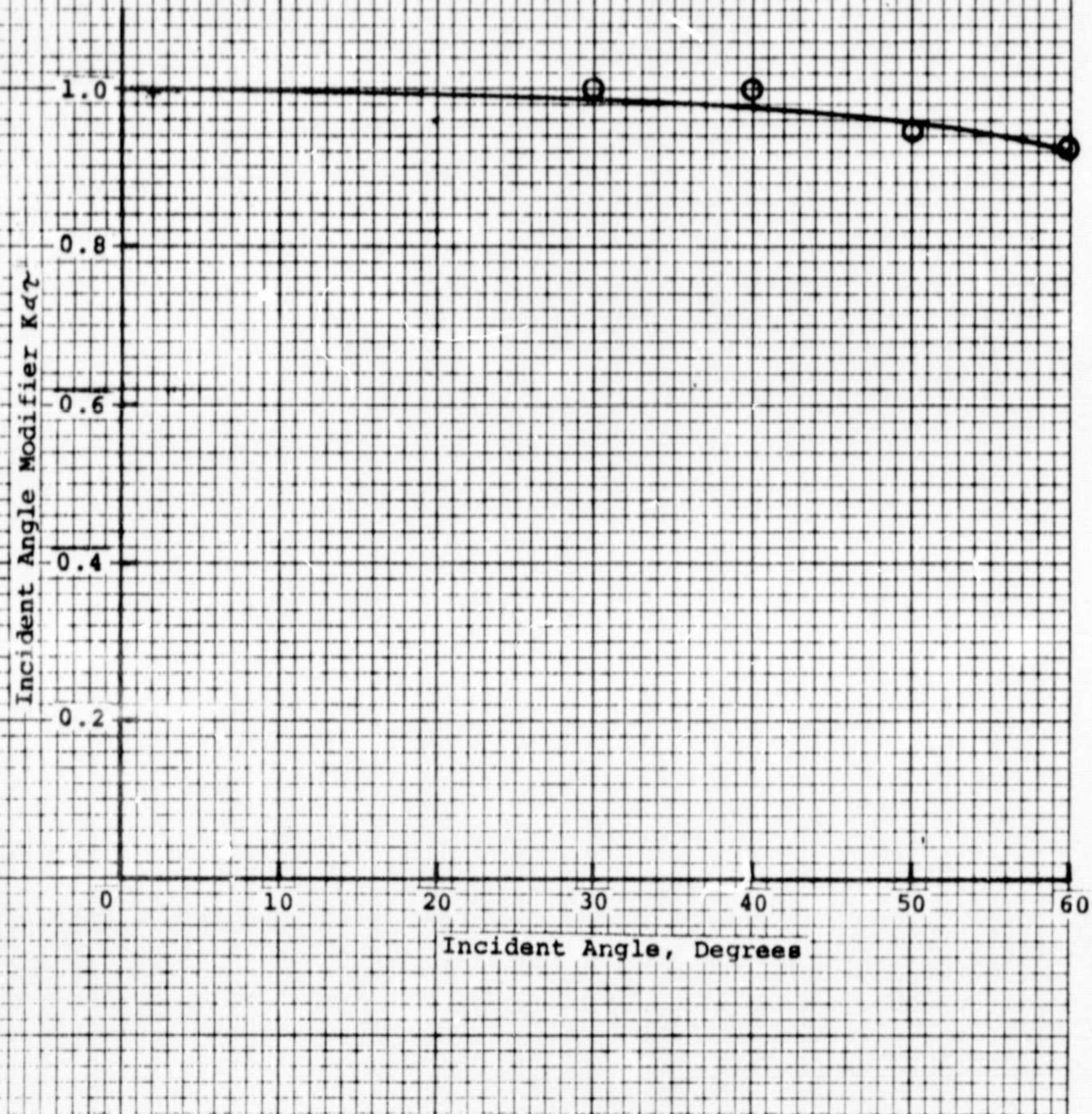

Figure 5. Incident Angle Modifier for Life Sciences Collector

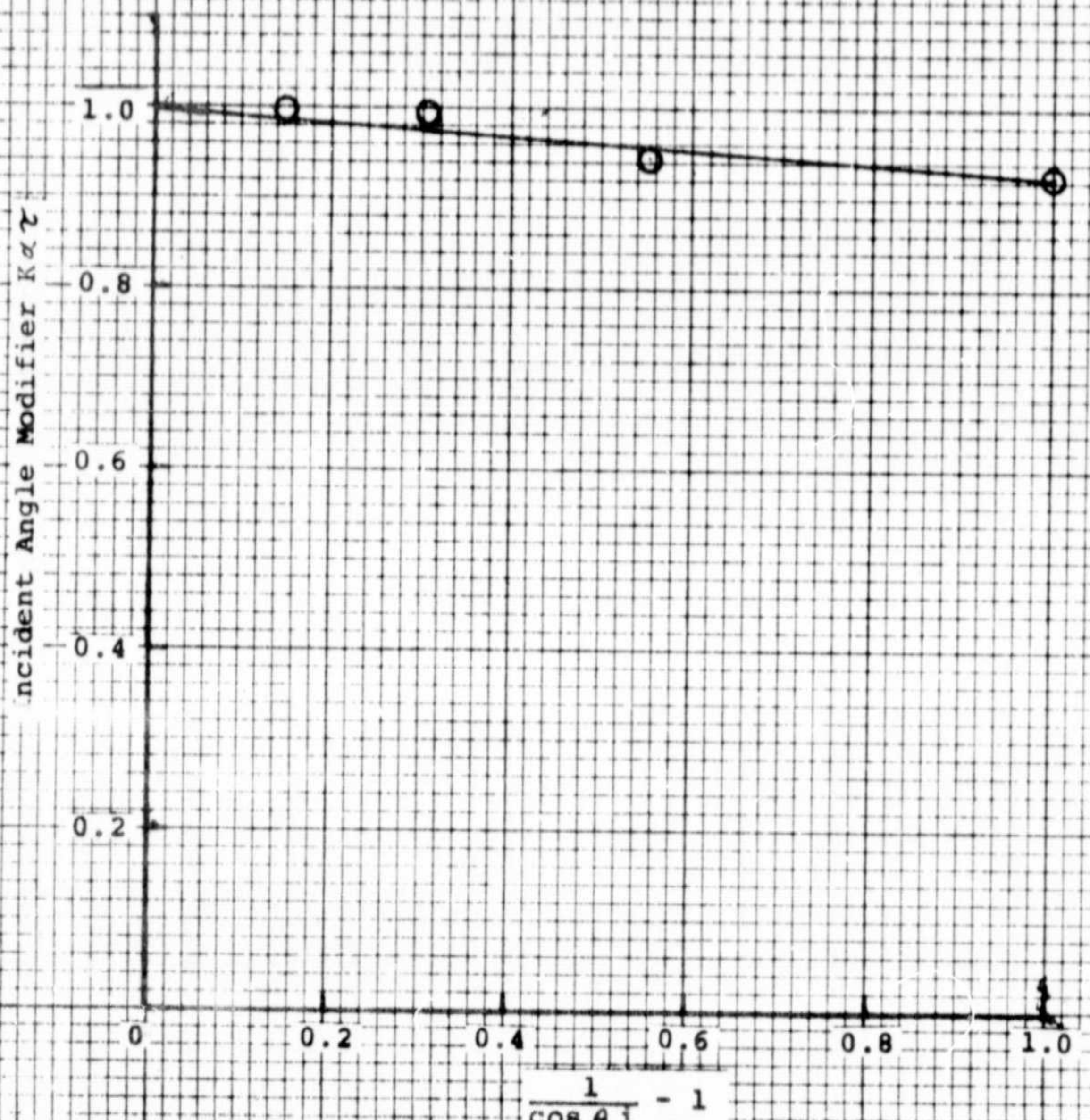

Figure 6. Incident Angle Modifier for Life Sciences Collector

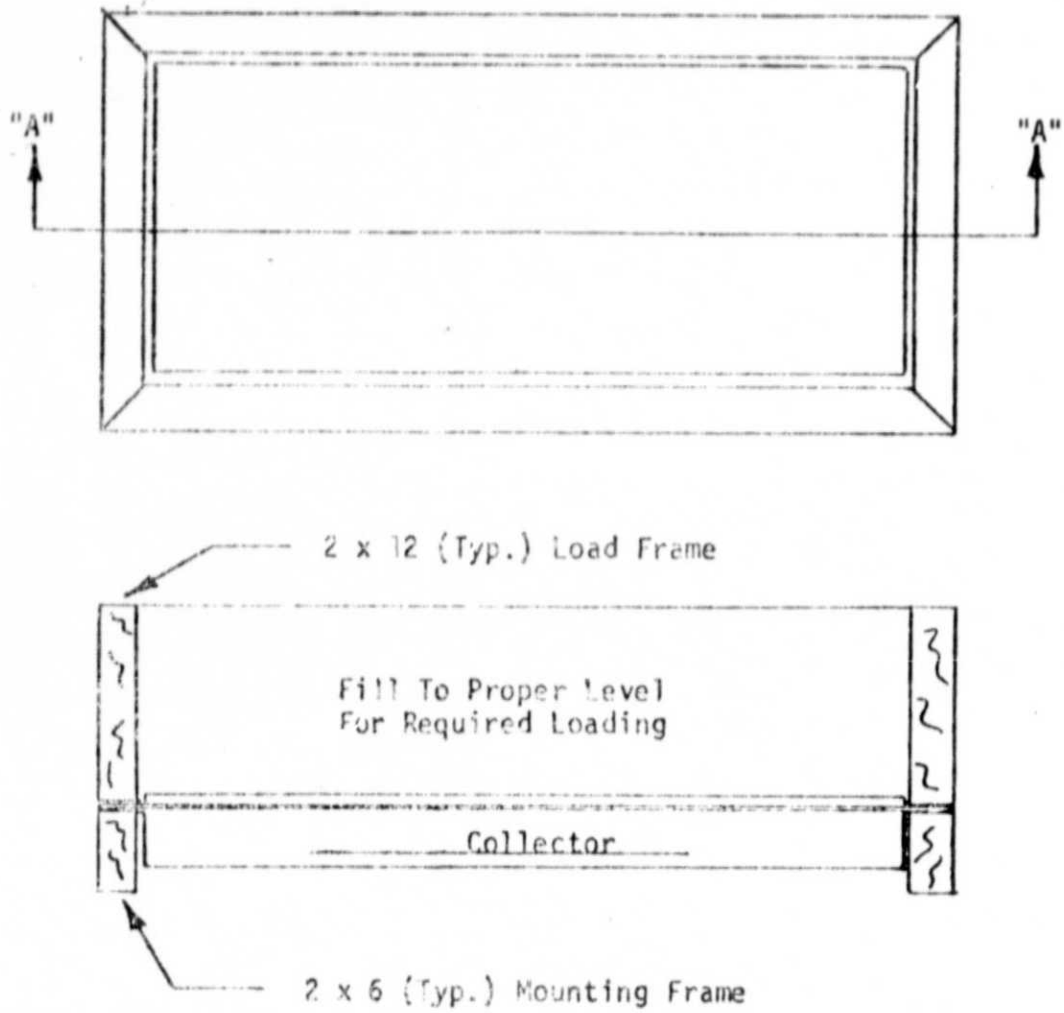

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FIGURE 7. Test Setup for Static Loads.

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