DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-161164

CERTIFICATION AND VERIFICATION FOR NORTHRUP MODEL NSC-01-0732 FRESNEL LENS CONCENTRATING SOLAR COLLECTOR

Prepared by

Northrup, Inc.
Hutchins, Texas

Under Contract NAS8-32251 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Departm... nt of Energy

U.S. Department of Energy

Solar Energy

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16. ABSTRACT

This document constitutes the certification and verification of the Northrup Model NSC-01-0732 fresnel lens tracking solar collector. A certification statement is included with signatures and a separate report on the structural analysis of the collector system. System verification against the Interim Performance Criteria are indicated by matrices with verification discussion, analysis, and enclosed test results.

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WILLIAM A. BROOKSBANK, JR.
Mgr, Solar Heating and Cooling Project Office

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I. INTRODUCTION

This document constitutes the certification and verification of the Model NSC-01-0732 fresnel lens tracking solar collector. Section II represents the certification portion of this report. It consists of a certification statement with signatures from four independent professional engineers and a separate report on the structural analysis of the collector system. Section III presents the system verification against the Interim Performance Criteria's for commercial (Document No. 98M10001) and residential installations. Applicable paragraphs of the IPC's are indicated by matrices which immediately preceed the verification discussion, analysis, and test results. All test results are included in this report rather than a separate section.

II. CERTIFICATION

INTRODUCTION

This document constitutes the certification of the Northrup ML Series Collector, Model NSC-01-0732.

CERTIFICATION STATEMENT

The ML Series concentrating Collector complies with the following national codes where applicable:

National Standard Plumbing Code, National Association of Plumbing-Heating-Cooling Contractors 1971.

Professional Engineer

National Electrical Code 1975

Professional Engineer

Building Code ANSI A58.1-1972
Applied to the Dallas/Ft.Worth Region
For Installations less than 30 ft. above ground

Professional Engineer

I have reviewed the performance requirements, testing procedures, test facility, and data for the ML Series Concentrating Collector, Model NSC-01-732 under Contract No. NAS8-32251. I am able to certify that the collector satisfies those requirements.

Professional Engineer

3005 Hanover
Dallas, Texas 75223
May 28, 1978

Mr. Carl L. Jacobs
Northrup, Incorporated
302 Nichols Drive
Hutchins, Texas 75141

Dear Mr. Jacobs:

As you requested in your letter of April 20, 1978, and in our discussion on May 2, 1978, at the Northrup plant, I have examined the structural design of the supporting system for the Northrup ML Series Collectors, Model NSC-01-0732. My observations and evaluation of this system are enclosed.

It was a pleasure to work on this project. Please let me know if you have questions or need additional information.

Sincerely,

Bijan Mohraz, Ph.D., P.E.

EVALUATION OF THE STRUCTURAL DESIGN OF THE
NORTHRUP ML SERIES COLLECTORS
MODEL NSC-01-0732

Analysis of the Supporting System

Several analyses of the supporting system were carried out using the ACES (Analysis of Civil Engineering Structures) computer program. The supporting structure was idealized as a combination of frame amd truss system since it is believed that the connections at the upper ends of the south brace assembly and the north column assembly are not completely rigid.

Four separate solutions were obtained for the following load conditions:

a. Dead load The analysis for this loading condition was carried out using the loads provided by Northrup which are based on the actual weights of the components.

b. Live load The anlysis for this loading condition was carried out based on a live load of 16 pounds per square foot (psf) which is the minimum roof live load specified by ANSI (Table 3 ANSI A58.1-1972). It is believed that this load is more appropriate than a live load of 4.67 psf (based on 1" thick ice) used by Northrup.

c. Wind load Since it is conceivable that this system may be marketed in locations other than the Dallas-Ft. Worth area, the analysis for wind load was based on a wind speed of 110 miles per hour (mph) which is specified by ANSI for the coastal areas of the Gulf of Mexico, (Figure 2 ANSI A58.1-1972), rather than a wind speed of 70 mph used by Northrup. Using a wind speed of 110 mph, Exposure C which is specified by ANSI for flat open country, open flat coastal belts, and grasslands, and a height of less than 30 feet, a wind pressure of 46 psf (Table 6 ANSI 58.1-1972) was used in the analysis.

Two independent wind directions were considered in the solutions--one in the plane of the frame and perpendicular to the plane of the collector, and the other in the plane of the frame and in the horizontal direction. The side wind loading is discussed separately.

The analyses indicate that the design of the various members of the supporting frame is adequate. The stresses in the members were computed using the loading combinations specified on p. 10 of ANSI. For each member the wind loading which resulted in the larger stress in that member was used in the combination. A summary of stresses in the members is given in Table 1. The allowable width to thickness ratios were computed using Section 2.3.1.1 of the Cold Form Specification, 1968 edition. The stresses are well below the allowable limits.

Side Wind Loads

The design of the wind bracing system for the horizontal side wind loads is based on a wind speed of 70 mph for heights less than 30 feet. Although the design is adequate for this wind speed, it will not be adequate for higher wind speeds encountered in other locations. If the system is to be used in other locations, the wind bracing needs to be increased by additional bracing in other side panels, increasing the size of the bracing, or a combination of both.

Deflections

The solutions for different loading conditions indicate that the deflections and rotations in the members and joints of the supporting structures are extremely small.

Connections

Examination of the forces in the south brace and the north column assemblies indicate that the design of the connections is adequate. Proper anchoring of the supporting system to the foundation is necessary in order to avoid pull-out caused by the wind loading. In addition the assembly of connections should be properly carried out.

Collector Truss Assembly

The relatively small loads on each collector truss assembly result in extremely small stresses and deflections in the truss element which are well below the allowable.

Conclusion

Based on the analysis for different loading conditions and the examination of the structural design of the supporting system for the Northrup ML Series Collectors, Model NSC-01-0732, the following conclusions can be made:

1. The design of the supporting system is adequate for a live load of 16psf and a wind load based on a wind speed of 70 mph for heights of less than 30 feet above the ground. Since no seismic analysis has been carried out, the system should not be used in locations with a history of seismic activity.

2. With additional wind bracing, either by bracing more panels or using larger diameter rods, the design would be adequate for locations with a wind speed of up to 110 mph (such as the coastal belts), for heights of less than 30 feet above the ground and no seismic activity.

3. Proper tie-down of the supporting system to the foundation is necessary in order to avoid pull-out caused by the wind loading. No analysis of the foundation was carried out since it depends on the specific location where the system is to be installed.

4. The system can be certified for locations with no history of seismic activity and a wind speed of up to 70 mph and heights of less than 30 feet above the ground.

May 28, 1978

Bijan Mohraz

Bijan Mohraz, Ph.D., P.E.

Table 1 Summary of Stresses

Member	Axial[a] stress psi	Bending stress psi	Loading Combination[c]	w/t allowable	w/t actual
South brace	3374 C	433	D+L+W (horiz.)	93	85
Manifold Support[b]	2159 C	811	D+L+W (perp.)	116	81
Manifold Strut	1179 C	809	D+L+W (horiz.)	157	83
Inclined Strut	1513 T	861	D+L+W (perp.)		
North Column	3529 C	415	D+L+W (perp.)	91	79

(a) C = compression; T = tension

(b) Design of north manifold support governs

(c) D = Dead load; L = Live load; W = Wind load

III. VERIFICATION

ITEM (NAME & PART NO.)

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE			REMARKS
	DEVELOPMENT	QUALIFICATION	ACCEPTANCE	
Residential Interim Performance Criteria				
1.2.4	1	3	3	
1.3.1	1,2,4	4	4	
2.1.1	1	3	3	
2.1.2	1	3	3	
2.1.3	1,4	3	3	
2.1.4	1	3	3	
2.1.5	1	3	3	
2.1.6	1	3	3	
2.1.7	2	4	3	
2.1.8	3	3	3	
2.2.1	1	3	3	
2.2.2	1	3	3	
2.2.5	1	2	4	
2.3.1	1	4	4	
2.3.2	1	4	3	
2.4.1	1	4	3	
2.4.2	2	2	3	
2.7.1	1	1	3	
2.8.1	1	4	3	
3.1.1	1	1	3	
3.1.2	1	2	3	

ITEM (NAME & PART NO.)

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE			REMARKS
	DEVELOPMENT	QUALIFICATION	ACCEPTANCE	
3.2.1	1	2	3	
3.2.2	1	2	3	
3.2.3	3	3	3	
3.2.4	1	3	3	
3.3.1	1	3	3	
3.3.2	1	2	3	
3.4.1	1	3	3	
3.7.1	1	2	3	
3.8.1	1	3	3	
3.9.1	1	3	3	
4.1.1	1	3	3	
4.1.2	1	1	3	
4.2.1	1,4	4	3	
4.2.2	1	4	3	
4.3.1	1	3	3	
4.5.2	1	3	3	
4.6.1	1	3	3	
4.6.4	1	3	3	
4.7.1	1	3	3	
5.1.1	1	3	3	
5.1.3	1	3	3	
5.1.4	1	3	3	
5.1.5	1	3	3	
5.1.6	1	4	3	

ITEM (NAME & PART NO.)

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE			REMARKS
	DEVELOPMENT	QUALIFICATION	ACCEPTANCE	
5.2.1	4	3	3	
5.2.2	1	3	3	
5.2.3	1	3	3	
5.2.4	1	4	3	
5.2.5	1	4	3	
5.2.6	1	3	3	
5.3.1	1	3	3	
5.3.2	1	3	3	
5.3.3	1	3	3	
5.3.4	1	3	3	
5.4.1	1	3	3	
6.1.1	2	3	3	
6.1.2	1	3	3	
6.1.3	1	3	3	
6.1.4	1	3	3	
6.2.1	3	3	3	
6.2.2	3	3	3	
6.2.3	3	3	3	
6.2.4	3	3	3	
6.3.1	3	3	3	
6.3.2	3	3	3	
11.2.1	1	3	3	
11.2.2	1	3	3	
11.3.1	1	3	3	

ITEM (NAME & PART NO.)	VERIFICATION CROSS REFERENCE MATRIX			
VERIFICATION METHOD:	1. SIMILARITY 2. ANALYSIS	3. INSPECTION 4. TEST	N/A NOT APPLICABLE	
PERFORMANCE REQUIREMENT	VERIFICATION PHASE			REMARKS
	DEVELOPMENT	QUALIFICATION	ACCEPTANCE	
Commercial Interim Performance Criteria				
1.3.1	1,2,4	4	4	
2.1.1	1	3	3	
2.1.2	1	3	3	
2.1.3	1,4	3	3	
2.1.4	1	3	3	
2.1.5	1	3	3	
2.1.6	1	3	3	
2.1.7	2	4	3	
2.1.8	3	3	3	
2.2.1	1	3	3	
2.2.2	1	3	3	
2.2.4	1,2,4	4	3	
2.2.6	4	3	3	
2.3.1	1	4	4	
2.3.2	1	4	3	
2.4.1	1	4	3	
2.4.2	2	2	3	
2.7.1	1	1	3	
3.1.1	1	1	3	

ITEM (NAME & PART NO.)

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PERFORMANCE REQUIREMENT	VERIFICATION PHASE			REMARKS
	DEVELOPMENT	QUALIFICATION	ACCEPTANCE	
3.2.1	1	2	3	
3.2.2	1	2	3	
3.2.3	3	3	3	
3.2.4	1	3	3	
3.3.1	1	3	3	
3.4.1	1	3	3	
3.7.1	1	2	3	
3.9.1	1	3	3	
4.1.1	1	3	3	
4.1.2	1	1	3	
4.2.1	1,4	4	3	
4.2.2	1	4	3	
4.3.1	1	3	3	
4.5.2	1	3	3	
4.6.1	1	3	3	
4.6.4	1	3	3	
4.7.1	1	3	3	
5.1.1	1	3	3	
5.1.3	1	3	3	
5.1.4	1	3	3	
5.1.5	1	3	3	
5.1.6	1	4	3	
5.2.1	4	3	3	
5.2.2	1	3	3	

ITEM (NAME & PART NO.)

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PERFORMANCE REQUIREMENT	VERIFICATION PHASE			REMARKS
	DEVELOPMENT	QUALIFICATION	ACCEPTANCE	
5.2.3	1	3	3	
5.2.4	1	4	3	
5.2.5	1	3	3	
5.2.6	1	3	3	
5.3.1	1	3	3	
5.3.2	1	3	3	
5.3.3	1	3	3	
5.4.1	1	3	3	
6.1.1	2	3	3	
6.1.2	1	3	3	
6.1.3	1	3	3	
6.1.4	1	3	3	
6.2.1	3	3	3	
6.2.2	3	3	3	
6.2.3	3	3	3	
6.2.4	3	3	3	
6.3.1	3	3	3	
6.3.2	3	3	3	
11.2.1	1	3	3	
11.2.2	1	3	3	
11.3.1	1	3	3	

1.2.4 OPERATION IMPAIRMENT

When domestic water is used as the heat transfer fluid, Codes for potable water do not require heat exchangers for proper operation. Other than the tracking module, all outside auxiliary energy subsystems are complimentary and are not to be considered as an integral part of this system. The manifold system and absorbers are constructed of type M hard copper tubing with a limited number of brass fittings, which are standards for domestic water systems. The tracking module can be easily serviced, and any defective component therein may be conveniently replaced should any failure occur. A failure in either the manifold system or tracking module will not impair the functional capabilities of the solar powered portions of the hot water system for time periods longer than those expected for conventional hot water equipment.

1.3.1. COLLECTOR EFFICIENCY

The 1977 Northrup production concentrating collector consists of three main parts. They are the Fresnel lens, the sheet metal collector housing, and the flattened absorber tube. Results of an independent efficiency test for the collector are shown on the following pages. On the basis of these performance curves, it is evident that the efficiency criteria specified by this contract can be met by a flattened absorber tube approach. Furthermore, the Fresnel lens has been improved and now provides better concentration of sunlight. By virtue of the above discussion, it was decided to incorporate a flattened tube receiver (without an additional glass convection suppressor) into the design of the new collector.

TESTING OF SOLAR COLLECTORS ACCORDING TO ASHRAE STANDARD 93-77

James E. Hill, Senior Mechanical Engineer
John P. Jenkins, Mechanical Engineer
Dennis E. Jones, Mechanical Engineer

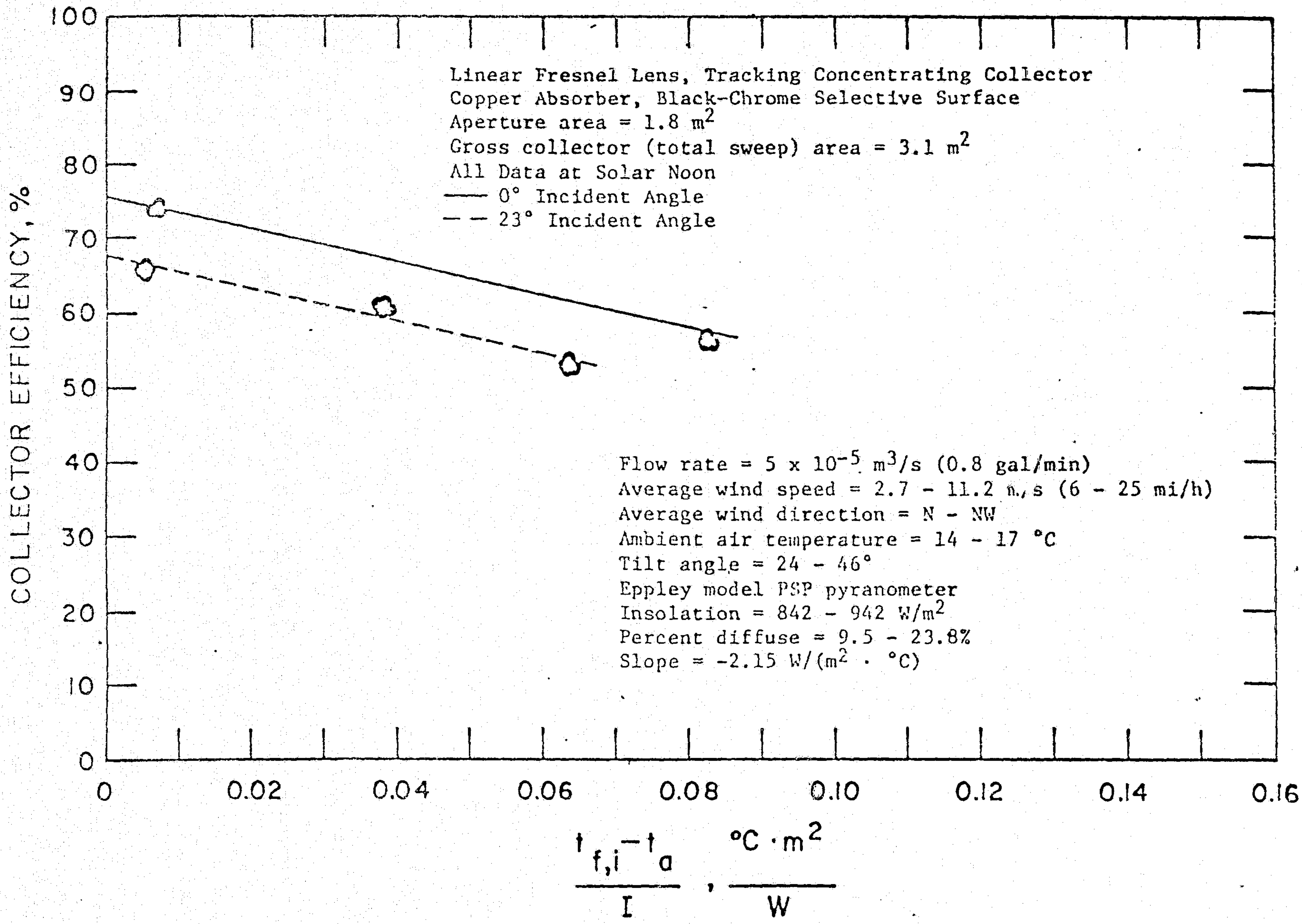
Thermal Engineering Section
National Bureau of Standards
Washington. D.C. 20234

ABSTRACT

A proposed procedure for testing and rating solar collectors was published by the National Bureau of Standards (NBS) in 1974. In early 1977, the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) adopted ASHRAE Standard 93-77 which is a modified version of the NBS procedure. A test facility for water-cooled collectors and air heaters has been built at NBS in accordance with this Standard. The purpose of this paper is to briefly explain the recently adopted test procedure, describe the NBS test facility, and to give typical test results for commercially available collectors.

NOMENCLATURE

A	= cross-sectional area of the collector, m^2
C_A	= effective heat capacity of the collector, its components, and the transfer fluid in the collector, J/°C
c_p	= specific heat of the transfer fluid, J/(kg.s)
F'	= collector efficiency factor
F_R	= collector heat removal factor
I	= total solar energy incident upon the plane of the collector per unit time per unit area, W/m^2
I_h	= total solar energy incident upon a horizontal surface, W/m^2
$K_{\alpha\tau}$	= incident angle modifier
$\dot{m}$	= mass flow rate of the transfer fluid through the collector, $kg/(s.m^2)$
q_u	= rate of useful energy extracted from the collector, W
R	= ratio of total solar energy incident upon a tilted surface to that upon a horizontal surface
t_a	= ambient air temperature, °C
t_f	= average temperature of the transfer fluid in the collecter, °C
$t_{f,e}$	= temperature of the transfer fluid leaving the collector, °C
$t_{f,i}$	= temperature of the transfer fluid entering the collector, °C
U_L	= heat transfer loss coefficient for the collector, $W/(m^2.°C)$


Linear Fresnel Lens, Tracking Concentrating Collector
Copper Absorber, Black-Chrome Selective Surface
Aperture area = 1.8 m^2
Gross collector (total sweep) area = 3.1 m^2
All Data at Solar Noon
0° Incident Angle
23° Incident Angle
Flow rate = 5 x 10^{-5} m^3/s (0.8 gal/min)
Average wind speed = 2.7 - 11.2 m/s (6 - 25 mi/h)
Average wind direction = N - NW
Ambient air temperature = 14 - 17 °C
Tilt angle = 24 - 46°
Eppley model PSP pyranometer
Insolation = 842 - 942 W/m^2
Percent diffuse = 9.5 - 23.8%
Slope = -2.15 W/(m^2 · °C)
COLLECTOR EFFICIENCY, %
100
90
80
70
60
50
40
30
20
10
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
$\frac{t_{f,i} - t_a}{I}$, $\frac{°C \cdot m^2}{W}$

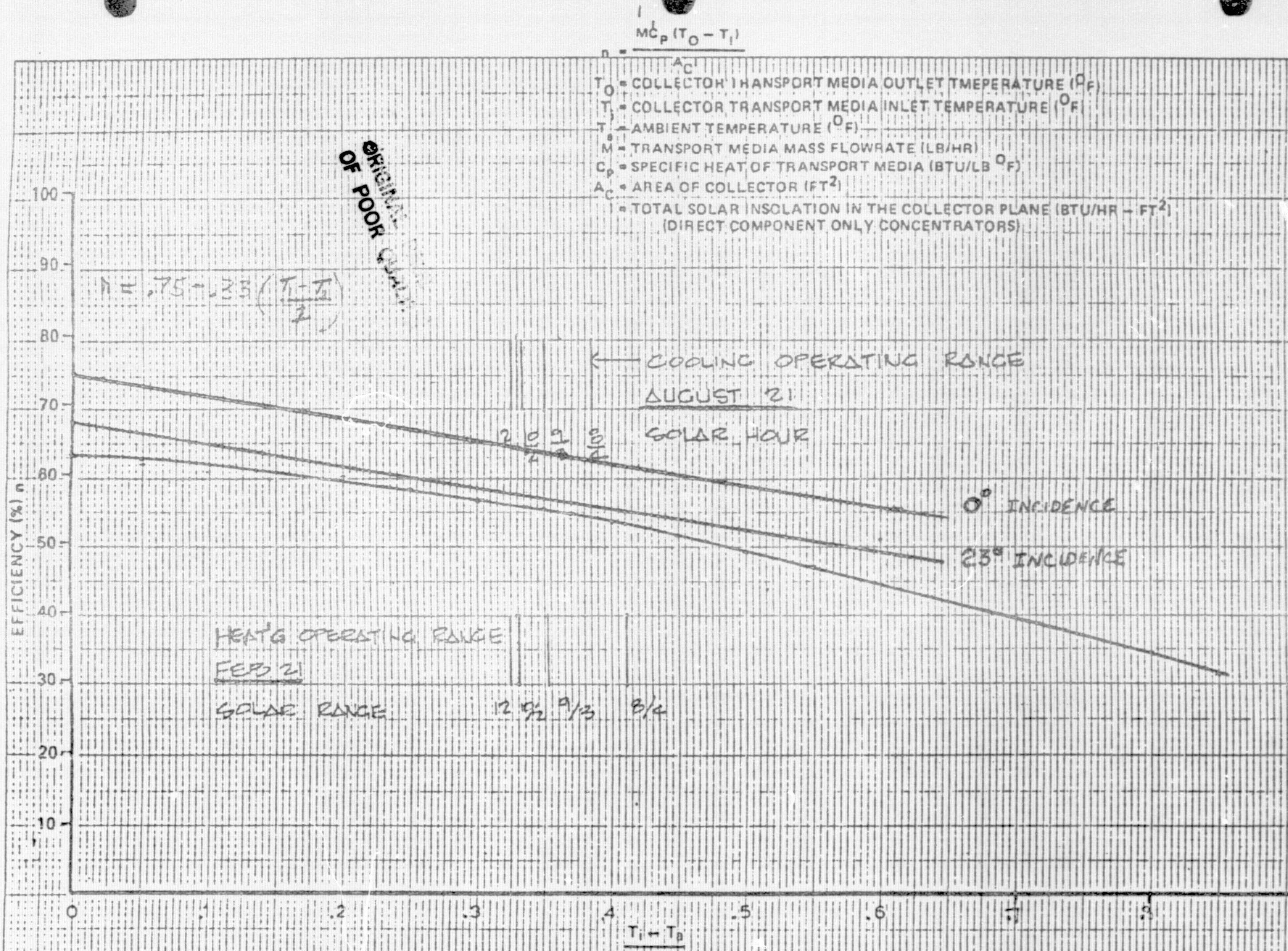


FIGURE 1 EFFICIENCY AS A FUNCTION OF OPERATING CONDITIONS
PERFORMANCE MUST BE ABOVE LINE

TECHNICAL PERFORMANCE REQUIREMENTS

SPECIFICATION NO.
REVISION
DATE

TOLERANCE - ABSORBER TUBES

A single lens concentrating collector module was tested on 3/4/78. It employed the lens and absorber tube that had been proposed for use in the 4-lens collector. Due to availability, the absorber coating was 3M Nextel paint which has an absorpitivity of .98 as compared to about .95 for black chrome.

The resulting efficiency curve is shown on the next page. For black chrome coating the efficiency intercept is expected to be

$$\eta = (.95/.98) \quad (80\%) = 77.5\%$$

while the slope of the curve should remain the same. Regarding the 4-lens design, there are extra tolerances to take into account. These tolerances are listed in Table 1. The safe design approach would be to increase the width of the absorber so that at least as much light would be gathered should the tolerance limits be reached. That width turns out to be 1.72" (see table 1). A 1-1/4" nominal diameter copper tube flattened to 1.78" has been pressure tested up to 150 psig in anticipation of the new absorber design. See Pressure Test: Flattened Tube 3/23/78 for the conclusions.

TITLE SINGLE LENS ALUMINUM CONC COLLECTOR 1 7/16" ABSORBER - NEXTEL COATING
JAN 1978 - LENS

PERSONNEL: CARL L JACOBS

DATE: 3/4/78

TEST No: 02

CONDITIONS: APERTURE AREA = 9.7 ft²

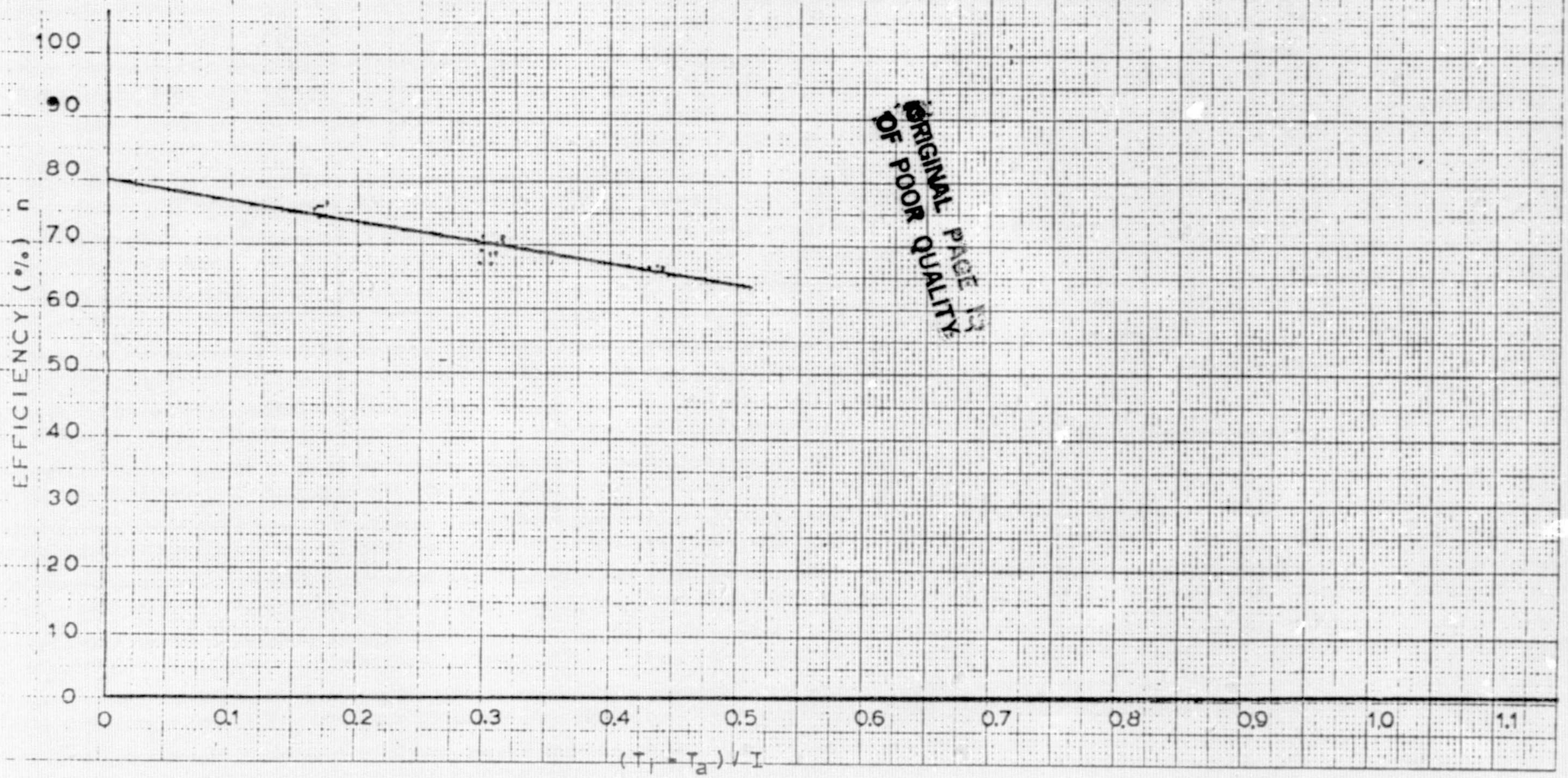
EXTREMELY CLEAR DAY - VERY HIGH DIRECT

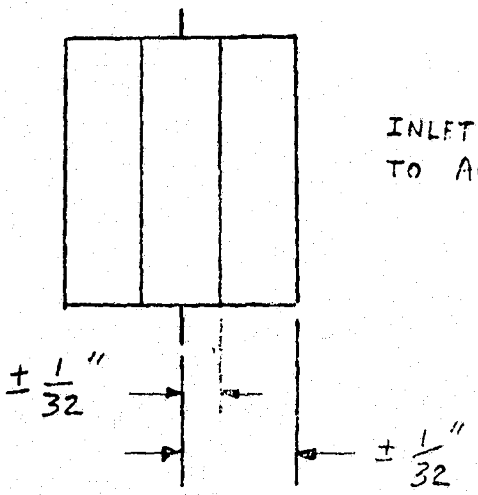
INSOLATION RATES, 32° TILT ANGLE

ACRYLIC τ = .92 ; NEXTEL α = .98, ε = .89

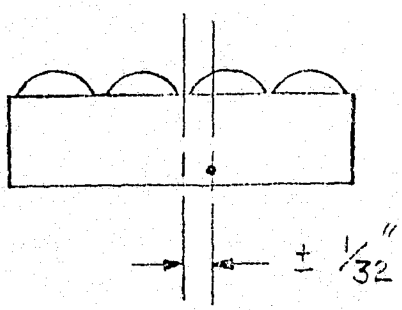
CHANNELS 14 & 15 COLL. HOUSING W/ WHITE FINISH

$$\eta = \frac{M C_p (T_o - T_i)}{A_c I}$$

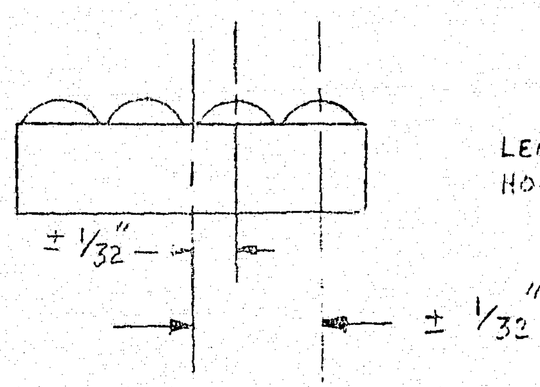




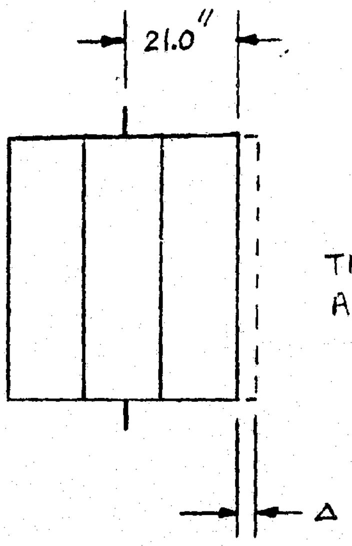
INLET (OR OUTLET) TO ABSORBER ALIGNMENT



INLET (OR OUTLET) TO CENTER OF HOUSING ALIGNMENT



LENS CENTER TO CENTER OF HOUSING ALIGNMENT

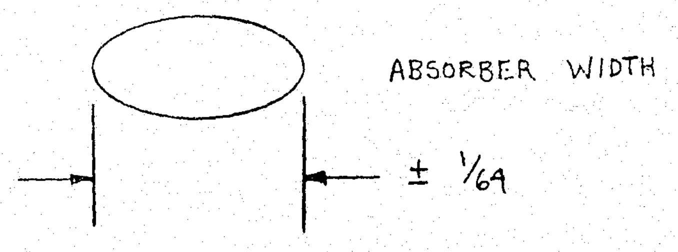


THERMAL EXPANSION
ABSORBER POSITION

$$\Delta = \alpha_{cu} \, l \, \Delta T = (9.2 \times 10^{-6} \text{ IN/IN-}^\circ\text{F})(21.0 \text{ IN})(220^\circ\text{F} - 65^\circ\text{F})$$

APPROXIMATE DESIGN TEMP. — ASSEMBLY TEMP

$$\Delta = .03 \text{ IN}$$



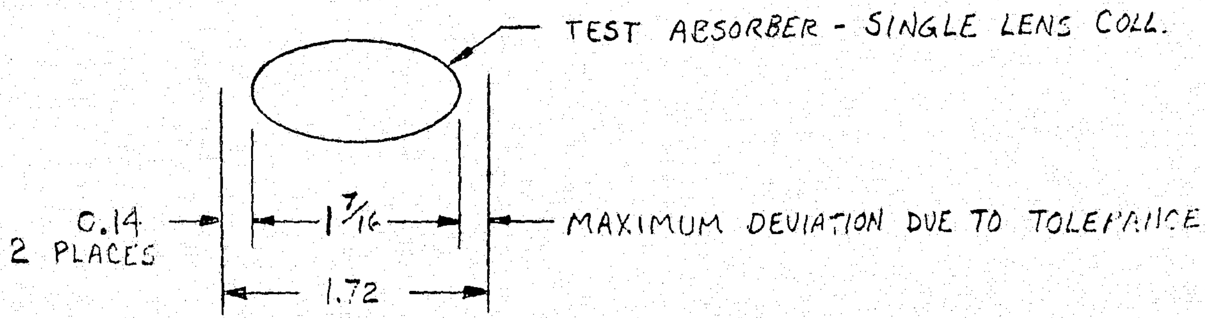


TABLE 1 TOLERANCE

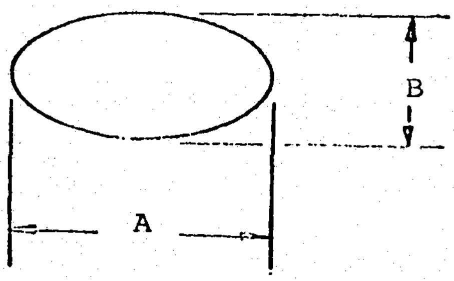
RELATIVE ALIGNMENT	
1. Inlet (or outlet) to absorber	± 1/32
2. Inlet (or outlet) to housing center	± 1/32
3. Lens center to housing center	± 1/32
Absorber Width	± 1/64
Thermal Expansion	± .03
MAX. DEVIATION	0.14 in

Test absorber - Single Lens Collector = 1-7/16

Conservative Tube Size needed for the 4-Lens Collector

= 1-7/16 + 2 X 0.14 = 1.72 in

PRESSURE TEST: FLATTENED TUBE
3/23/78



INTRODUCTION

A 1" nominal copper tube flattened to a width of about 1-1/2" had originally been planned for use as the receiver in the 4-Lens collector. However, when tolerances were taken into consideration it became clear that an absorber width of about 1.7" was needed. This required stepping up to a 1-1/4" nominal tube. Since the exposed convective area of the tube is set, it is advantageous to flatten it as much as possible in order to "pick up" stray light from the lens. The limiting factor is internal pressure. The purpose of this test is to determine if a 1-1/4" nominal tube flattened to 1.78" can withstand working pressures of 100 psi (gauge).

TEST PROCEDURE AND RESULTS

Pressure levels were maintained by filling the tube with nitrogen gas. A Bourdon tube gauge with an accuracy of at least ±5 psi was used. The tube tested was 10 feet long. The results are tabulated below.

Type M Copper Tube, 1-1/4" Nominal Diameter Pre-Flattened

PRESSURE (psig)	DIM. A	DIM. B
0	1.78	.88
50	1.78	.88
70	1.75	.89
90	1.75	.91
110	1.75	.94
130	1.73	.95
150	1.72	.97

The highest test value, 150 psi, is 50% higher than the normal working pressure which verifies the practicality of using a tube such as this in relatively high pressure situations. The recommended width for the 4-Lens absorber tube is 1.75".

1.3.1 THERMAL PERFORMANCE (EFFICIENCY)

INTRODUCTION

Efficiency curves for a 4-lens collector panel were determined for 0° and 12° incidence. The test procedure used was similar to ASHRAE Standard 93-77, although somewhat abbreviated.

EQUIPMENT

Two stainless steel sheathed Type T thermocouples to measure the collector inlet and outlet temperatures; a variable area flow meter to measure the flow rate through the collector; an Eppley standard pyrheliometer (with a clock drive) for direct insolation measurement; an Eppley pyranometer for total insolation measurement; an anemometer for wind velocity measurement; a Type 2240-A Fluke Datalogger to record instantaneous signals from the thermocouples, pyrheliometer, pyranometer, and anemometer, a thermocouple housed in a well ventilated instrumentation shelter painted white on the outside to be used in measuring ambient temperature.

CALIBRATION PROCEDURE:

1. Before the beginning of the efficiency tests, the thermocouple used for the ambient temperature measurement was checked against an Erco precision mercury-in-glass thermometer. They were compared in ice water, and then in ambient air. In either case, the thermocouple agreed to within $\pm.5^\circ F$ of the thermometer.
2. Prior to the efficiency tests, two stainless steel sheathed thermocouples were tested by placing them and the Erco precision mercury-in-glass thermometer in silicone heat transfer

fluid that was heated to about 320°F. The fluid was allowed to cool to about 60°F during which time the responses of the three temperature measuring devices were periodically monitored. In all cases, the thermocouples agreed to within at least 0.2°F of each other and to 0.5°F of the thermometer which was occasionally checked.

3. The flow meter was calibrated by running water through it at about 1.7gpm which corresponds to the proposed test flow rate through one collector panel. The actual flow rate was determined by running the water through the flow meter into a weigh tank while timing it, afterwards adjusting the flow-meter scale correspondingly. The procedure was repeated until the flow rate was calibrated to better than ±1.0%. 40 lbs. of water was used on the final calibration run.

4. The anemometer was calibrated by the manufacturer prior to procurement about two years ago. Since wind velocity is not a part of the efficiency calculation, and, because the readouts from this instrument have agreed with local weather services, no attempt will be made to calibrate it.

5. The Datalogger was calibrated by the manufacturer March 28, 1978. Between calibration dates, which occur every six months, the Datalogger should be accurate to within ± 1%.

LIST OF SYMBOLS

A - collector aperture area

C - specific heat of the transfer fluid

I_d - direct normal insolation

I_t - total insolation

$\dot{m}$ - mass flow rate of the transfer fluid

η - collector efficiency %

T_a - ambient temperature

T_i - collector inlet temperature

T_o - collector outlet temperature

TEST PROCEDURE THERMAL EFFICIENCY

1 The collector tilt angle was adjusted so that the lenses were approximately normal to the sun during the hours of data accumulation which were two hours before solar noon through two hours afterwards.

2. The water-flow rate through the collector panel was set at about 1.7gpm and recorded. During the progress of the test, the flow meter was checked every five minutes to ensure that the volume rate of flow did not change.

3. The pyranometer (total insolation measurement) was placed on a tracking mount that maintained near normal incidence to the sun. The pyrheliometer (direct insolation measurement) was mounted on a clock drive which was aligned to the sun during the test. Each instrument as well as the collector aperture was wiped clean before the tests on each day.

4. Four different values of inlet fluid temperature were used to obtain the values of $(To-Ti)/I_d$, which is the abscissa value in the efficiency plot. Fifteen "data points" were used in the determination of the normal incidence efficiency curve. A data point encompassed a five-minute time span in which the total and direct insolation, the collector inlet and outlet temperatures, and wind velocity were recorded at one-minute intervals. The efficiency data point was then calculated as:

$$\eta = \frac{\sum_{n=1}^{5} \left[\dot{m}\, C(To - Ti) \right]_n}{\sum_{n=1}^{5} (AI_d)_n}$$

which is essentially a numerical integration over the five-minute time span. The collector was allowed to stablized before each test. During the five-minute intervals, the inlet temperature did not change by more than 0.6^{o}F and the average wind velocity was lower than 10mph for all tests. The instantaneous efficiency curve was obtained using the technique of a linear least-squares fit.

5. In order to determine the efficiency at 12^{o} incidence, another efficiency value was determined in general accordance with the methods previously described. The collector panel was oriented so that the average incident angle between it and the solar radiation for the test was 12 degrees.

RESULTS

The individual data points from the normal incidence test are shown plotted on the first of the two efficiency graphs that follow. Note that there is very little deviation of the points from the fitted curve, indicating that test conditions had stablized. The equation for efficiency

$$\eta = .80 - .4986 \left(\frac{Ti - Ta}{I}\right)$$

which is based on direct insolation only, was derived through the use of a linear least-squares fit.

One of the performance requirements of this contract states that the collector efficiency on February 21 and August 21 be the same or better than that of a performance specification which is shown on the second graph. The collector orientation on these two dates corresponds to a seasonal tilt angle of 12 degrees. The efficiency curve for 12 degrees (based on insolation normal to the plane of the collector) is

$$\eta = .79 - .4986 \left(\frac{Ti - Ta}{I}\right)$$

which is nearly the same as the performance at normal incidence. Calculation of the 12^{o} efficiency is included later in this report. The two curves are shown on the second efficiency graph relative to the performance specification. It can be easily seen that the performance specification is exceeded.

The second performance requirement of this contract is stated below.

For Dallas Texas, the single solar collector will collect a minimum of 1144 $BTU/Ft^2/day$ of energy at an inlet fluid temperature of $190^{o}F$ (water). The tilt angle at this performance basis will be equal to the latitude angle, azimuth of 0 degrees, average ambient dry bulb 100°F, wind velocity zero, August 21 date, direct normal noon solar flux of 283* BTU/Hr Ft^2, longitude of 97° degrees and 32° latitude.

When used primarily for heating a single collector will provide 1242 BTU/Ft^2/day at an inlet fluid temperature of 150°F (water). The tilt angle at this performance basis is equal to the latitude angle, azimuth of 0 degrees, average ambient 50°F, wind velocity zero, February 21 date, direct normal noon solar flux of 316* BTU/Hr-Ft^2, longitude of 97° and 32° degrees latitude.

For the two dates mentioned above, a seasonal incidence angle of 12° will be maintained throughout the day. Therefore, the equation

$$\eta = .79 - .4986 \left(\frac{Ti - Ta}{I}\right)$$

is used in the calculation of the all day energy gain. The values of direct normal irradiation are taken from the 1972 ASHRAE Handbook of Fundamentals. The final calculations, based on eight hours of sun tracking, are tabulated in the following pages. In either case, the calculated energy gain is greater than the performance requirements.

In conclusion, the 4-lens concentrating collector was tested according to the previously described procedures. Test data and calculations are included in the following pages as verification. The test results indicate that this collector exceeds the performance requirements of Contract No. NAS8-32251.

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*ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 345 East 47th Street, New York, NY, 1972.

Table 3 . . . . Solar Position and Intensity; Solar Heat Gain Factors[a] for 32 Deg North Latitude

Date	Solar Time A.M.	Solar Position Alt.	Solar Position Azimuth	Direct Normal Irradiation, Btuh, sq ft	N	NE	E	SE	S	SW	W	NW	Hor.	Solar Time P.M.
					Solar Heat Gain Factors, Btuh/sq ft									
Jan 21	7	1.4	65.2	1	0	0	1	1	0	0	0	0	0	5
	8	12.5	56.5	202	9	29	160	180	103	9	8	8	32	4
	9	22.5	46.0	269	15	16	175	246	109	16	15	15	88	3
	10	30.6	33.1	295	19	20	135	249	212	45	19	19	136	2
	11	36.1	17.5	306	22	22	67	221	238	110	22	22	166	1
	12	38.0	0.0	309	23	23	25	174	246	174	25	23	176	12
			Half Day Totals		75	91	523	974	834	262	75	75	509	
Feb 21	7	6.7	72.8	111	4	47	102	95	26	4	4	4	9	5
	8	18.5	63.8	244	12	64	205	217	95	12	12	12	63	4
	9	29.3	52.8	287	19	32	199	248	149	19	19	19	127	3
	10	38.5	38.9	305	23	24	151	241	189	31	23	23	176	2
	11	44.9	21.0	314	26	26	76	208	213	87	26	26	207	1
	12	47.2	0.0	316	27	27	29	155	221	155	29	27	217	12
			Half Day Totals		97	207	749	1091	780	227	98	97	689	
Mar 21	7	12.7	81.9	183	9	105	176	142	19	9	9	9	31	5
	8	25.1	73.0	260	17	107	227	209	62	17	17	17	99	4
	9	36.8	62.1	289	23	64	210	227	107	23	23	23	163	3
	10	47.3	47.5	304	27	30	158	215	144	29	27	27	211	2
	11	55.0	26.8	310	30	31	82	179	168	58	30	30	242	1
	12	58.0	0.0	312	31	31	33	122	176	122	33	31	252	12
			Half Day Totals		122	308	891	1054	588	191	123	122	872	
Apr 21	6	6.1	99.9	66	9	54	65	37	3	3	3	3	7	6
	7	18.8	92.2	206	17	147	201	136	15	14	14	14	61	5
	8	31.5	84.0	256	23	144	228	178	30	22	22	22	130	4
	9	43.9	74.2	278	28	103	206	188	58	27	27	27	189	3
	10	55.7	60.3	290	32	52	156	173	87	33	32	32	234	2
	11	65.4	37.5	296	34	36	83	135	108	40	34	34	263	1
	12	69.6	0.0	298	35	35	38	82	115	82	38	35	272	12
			Half Day Totals		159	559	965	898	359	174	150	149	1022	
May 21	6	10.4	107.2	113	32	108	116	55	8	8	8	8	21	6
	7	22.8	100.1	211	35	170	204	118	18	18	18	18	81	5
	8	35.4	92.9	249	29	165	220	149	27	25	25	25	146	4
	9	48.1	84.7	269	32	128	198	155	37	30	30	30	201	3
	10	60.6	73.3	279	36	76	150	138	54	35	35	35	243	2
	11	72.0	51.9	285	38	41	82	102	68	39	37	37	269	1
	12	78.0	0.0	286	39	39	41	59	74	59	41	39	277	12
			Half Day Totals		[illegible]	697	953	747	248	181	172	171	1100	
June 21	6	12.2	110.2	130	41	123	127	55	10	10	10	10	28	6
	7	24.3	103.4	209	46	176	201	108	19	19	19	19	88	5
	8	36.9	96.8	244	36	171	214	135	28	26	26	26	151	4
	9	49.6	89.4	263	34	136	193	139	35	32	32	32	203	3
	10	62.2	73.7	273	38	86	146	122	45	36	36	36	244	2
	11	74.2	60.5	278	40	46	81	88	56	40	38	38	238	1
	12	81.5	0.0	280	40	41	42	52	60	52	42	41	276	12
			Half Day Totals		252	744	972	672	222	186	180	180	1119	
July 21	6	10.7	107.7	113	[illegible]	105	112	53	8	8	8	8	22	6
	7	23.1	100.6	203	37	167	198	114	19	18	18	18	81	5
	8	35.7	93.6	241	31	163	216	145	29	26	26	26	145	4
	9	48.4	85.5	261	34	123	195	150	37	31	31	31	199	3
	10	60.9	74.3	271	37	78	149	134	53	35	35	35	240	2
	11	72.1	53.3	277	39	43	82	99	66	40	38	38	265	1
	12	78.6	0.0	278	40	40	42	58	71	58	42	40	271	12
			Half Day Totals		227	694	964	724	245	[illegible]	176	175	1089	
Aug 21	6	6.5	100.5	59	9	50	59	34	3	3	3	3	7	6
	7	19.1	92.8	189	18	140	189	127	16	15	15	15	61	5
	8	31.8	81.7	239	25	111	219	170	30	23	23	23	127	4
	9	44.3	75.0	263	29	104	200	180	50	29	29	29	185	3
	10	56.1	61.3	275	35	55	152	167	84	34	33	33	229	2
	11	66.0	38.4	281	36	38	83	131	104	41	36	36	256	1
	12	70.3	0.0	[illegible]	37	37	40	80	111	80	40	37	265	12
			Half Day Totals		169	552	923	858	349	180	159	158	999	
Sep 21	7	12.7	81.9	163	10	95	153	158	19	9	9	9	30	5
	8	25.1	73.0	240	13	163	215	199	60	18	18	18	96	4
	9	36.8	62.1	272	24	64	202	218	105	24	24	24	158	3
	10	47.3	47.5	287	29	32	154	208	141	30	29	29	204	2
	11	55.0	26.8	294	31	32	81	174	164	59	31	31	234	1
	12	58.0	0.0	296	[illegible]	32	34	120	171	120	34	32	244	12
			Half Day Totals		[illegible]	375	846	1004	575	194	128	127	844	
Oct 21	7	6.8	73.1	98	4	43	92	85	23	4	4	4	9	5
	8	18.7	64.0	229	13	63	195	205	90	13	13	13	62	4
	9	29.5	53.0	273	19	33	193	239	144	20	19	19	125	3
	10	38.7	39.1	292	24	25	147	234	183	32	24	24	173	2
	11	45.1	21.1	301	27	27	75	202	206	85	27	27	203	1
	12	47.5	0.0	304	28	28	30	151	214	151	30	28	213	12
			Half Day Totals		109	255	718	1044	750	225	101	100	677	
Nov 21	7	1.5	65.4	1	0	0	1	1	0	0	0	0	0	5
	8	12.7	56.6	196	9	29	156	183	100	9	9	9	32	4
	9	22.6	46.1	262	15	17	172	241	166	16	15	15	87	3
	10	30.8	33.2	288	20	20	134	244	209	45	20	20	135	2
	11	36.2	17.6	300	22	22	67	218	234	108	22	22	165	1
	12	38.2	0.0	303	23	23	25	171	243	171	25	23	175	12
			Half Day Totals		76	92	521	955	820	258	77	76	505	
Dec 21	8	10.3	53.8	176	7	16	135	166	96	7	7	7	22	4
	9	19.8	43.6	257	13	14	162	238	171	15	13	13	72	3
	10	27.6	31.2	257	16	18	127	216	217	52	18	18	119	2
	11	32.7	16.4	300	20	20	63	222	243	116	20	20	148	1
	12	34.6	0.0	304	21	21	23	177	252	177	23	21	158	12
			Half Day Totals		67	76	482	947	844	273	68	67	440	
					N	NW	W	SW	S	SE	E	NE	HOR.	←P.M.

[a] Total solar heat gains for DS (1/8 in.) sheet glass. Based on a ground reflectance of 0.20 and values in Tables 1 and 9.

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February 21 ALL DAY ENERGY GAIN

$$n = .79 - .4986 \left(\frac{Ti - Ta}{I}\right)$$

$T_i = 150^oF$

$T_a = 50^oF$

E_T must be larger than 1242 $BTU/Ft^2/Day$.

Solar Time	8:00		9:00		10:00		11:00		12:00
I_{DN}	244		287		305		314		316
$\frac{In+In+1}{2}$		265.5		296		309.5		315	
$\frac{Ti-Ta}{I}$		.377		.338		.322		.317	
n		.602		.621		.629		.632	

$$E_T = 2 \cos (12^o) \left[(.602)\ (265.5) + (.621)\ (296) + (.6\ 29)\ (309.5) + (.632)\ (315)\right]$$

$= 1442.6$ BTU/Ft2/Day 1242 $BTU/Ft^2/Day$

August 21 ALL DAY ENERGY GAIN

$\eta_{12^\circ} = .79 - .4986 \frac{(Ti - Ta)}{(I)}$

$T_i = 190^\circ F$

$T_a = 100^\circ F$

E_T must be larger than 1144 BTU/Ft^2/Day

Solar Time	8:00		9:00		10:00		11:00		12:00
I_{DN}	239		263		275		281		283
$\frac{In+In+1}{2}$		251		269		278		282	
$\frac{Ti-Ta}{I}$		.359		.335		.324		.319	
η		.611		.623		.628		.631	

$E_T = 2 \cos (12^\circ) \left[(.611)(251) + (.623)(269) + (.628)(278) + (.631)(282)\right]$

$E_T = 1317.5$ BTU/Ft^2/Day > 1144 BTU/Ft^2/Day

Efficiency at 12° Incidence Angle Based on Direct Insolation Normal to the Plane of the Collector

At 0° Incidence:

$$\eta = .80 - .4986 \left(\frac{Ti - Ta}{I}\right)$$

At 12° Incidence:

$$\eta = .739 \quad @ \quad \frac{Ti - Ta}{I} = .104$$

The intercept of the 12° incidence curve will be different than the 0° curve if the amount of incident energy on the absorbers has changed. However, the slope will remain the same since the convective and radiative area did not change.

$$-.4986 = \frac{\text{Intercept} - .739}{0 - .104}$$

Intercept = .79

$$\therefore \eta_{12^\circ} = .79 - .4986 \left(\frac{Ti - Ta}{I}\right)$$

This is virtually the same as the 0° incidence curve.

TITLE A LENS CONC COLL "ML" MODEL NSC-01-0732

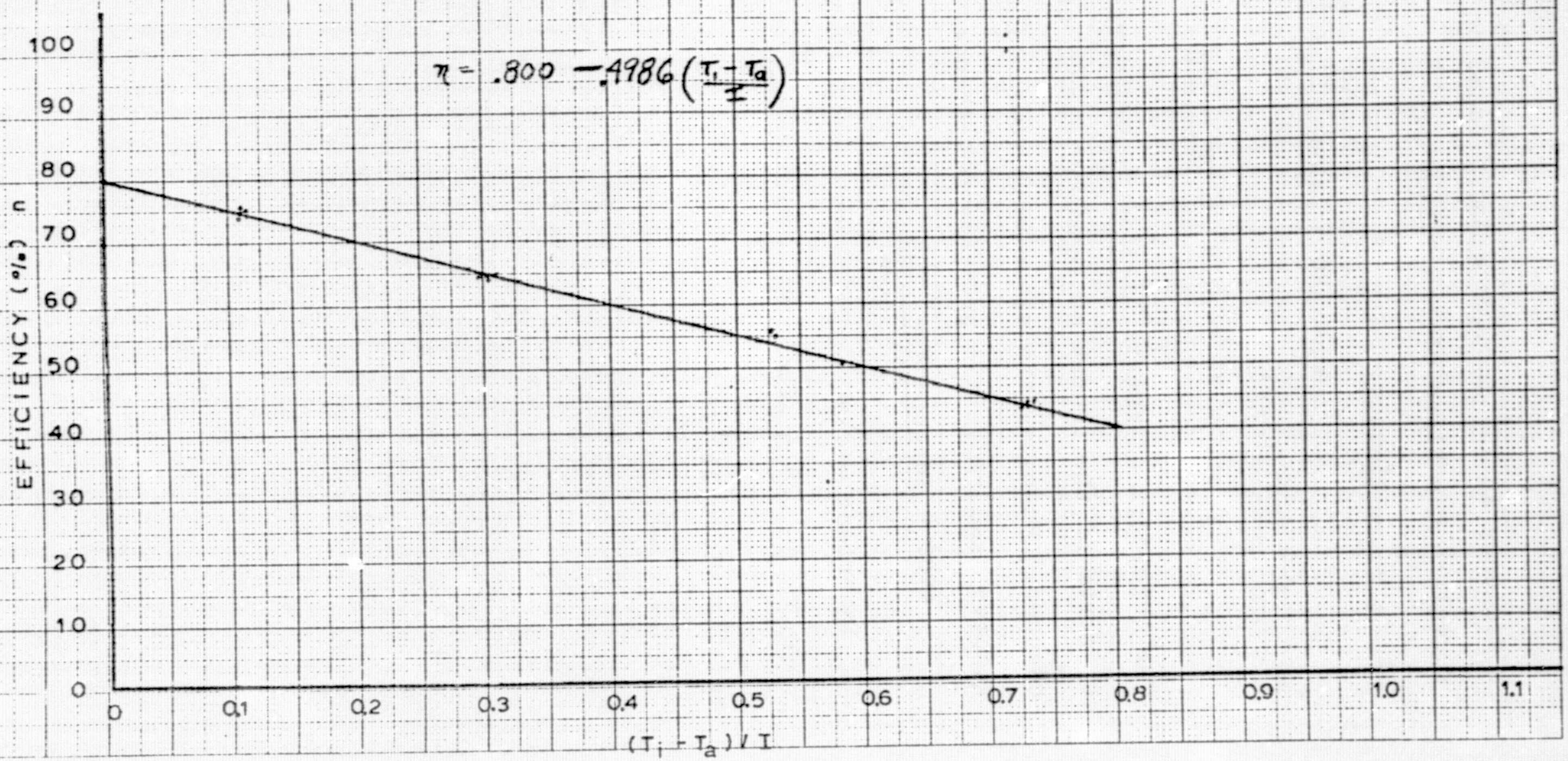
PERSONNEL: C. JAMES
D. SEIFER

DATE: APRIL 25 & 26, 1973

TEST No.: 1 & 2

CONDITIONS: CLEAR, 0° INCIDENCE ANGLE, LIGHT WINDS, COLLECTOR TRACKING NORMALLY

$$n = \frac{M C_p (T_o - T_i)}{A_c I}$$



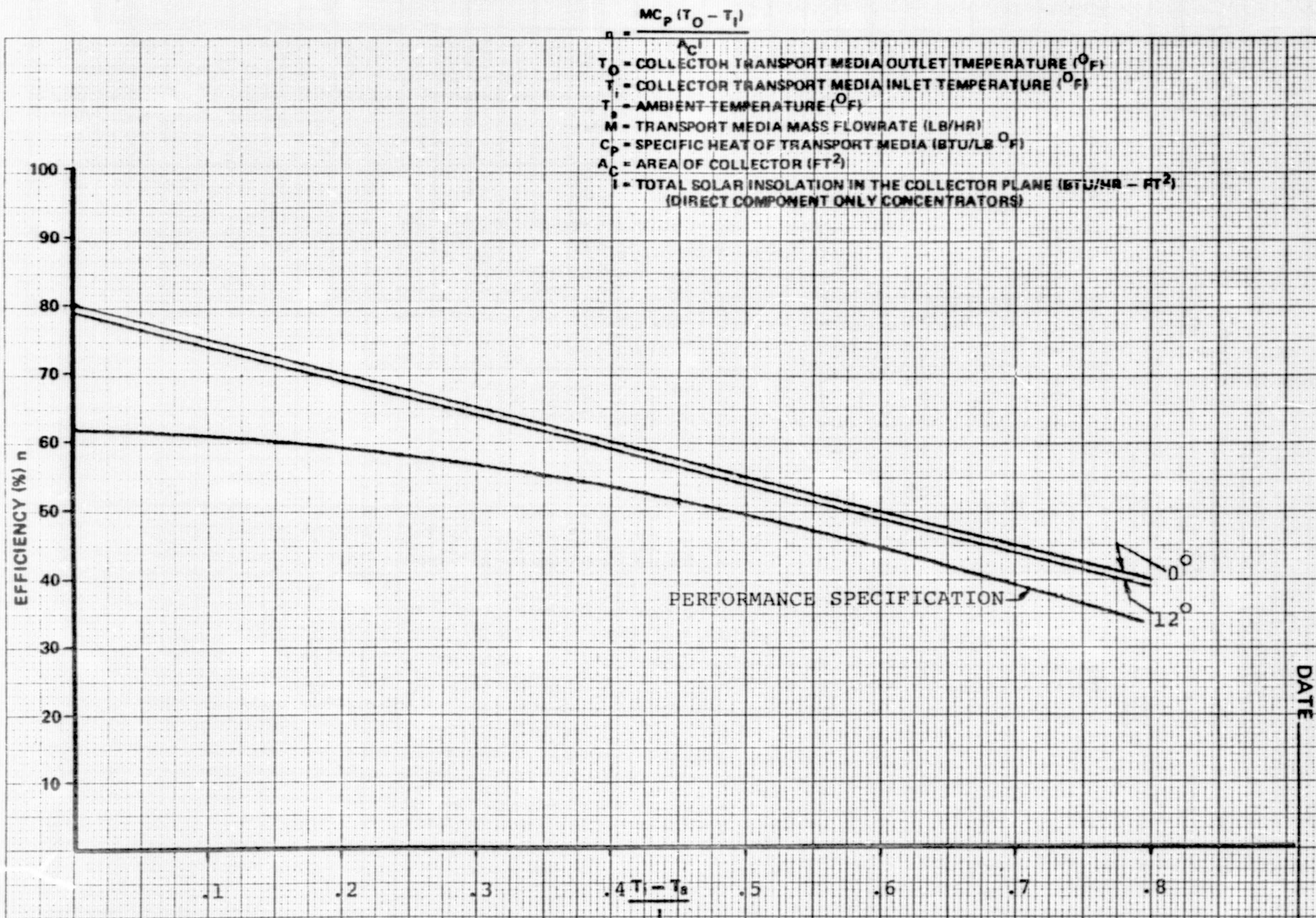


FIGURE 1 EFFICIENCY AS A FUNCTION OF OPERATING CONDITIONS
PERFORMANCE MUST BE ABOVE LINE

TITLE: 4 LENS CONC. COLL.
"ML" MODEL NSC-01-0732
PERSONNEL: C. JACOBS / D. SEITER
TEST No.: 1
COLLECTOR APERTURE: 43.0 ft²

DATE: 4/25/78
WIND SPEED: 1.0 — 7.4
WIND DIRECTION: S.E.
CONDITIONS: VERY CLEAR DAY, 0° INCIDENCE ANGLE

$$EFF = \frac{m \cdot C_p (T_{out} - T_{in})}{A_c \cdot I'^*} \; ; \; \frac{\Delta T'}{I'^*} = \frac{(T_{in} - T_a)}{I'^*}$$

TIME	T_a	T_{in}	T_{out}	WIND VEL.	FLOW	I	$\Sigma \dot{m} C \Delta T$	m	I'^*	ΔT	$\Sigma A I'$	EFF	$\Delta T'/I'$	AVG $\Delta T'/I'$
11:50	71.5	102.8	113.8	3.4	1.71	321.9		849.0	289.0	11.0			.1083	
11:51	71.5	102.7	114.0	2.4	1.71	321.2		849.0	288.7	11.3			.1081	
11:52	71.3	102.9	113.9	2.4	1.71	320.6		849.0	287.9	11.0			.1098	
11:53	71.1	102.8	113.9	4.3	1.71	321.8		849.0	289.4	11.1			.1095	
11:54	71.1	102.8	113.7	2.4	1.71	322.7	46,977	849.0	291.0	11.1	62,178	.755	.1093	.109
11:55	71.0	103.0	114.1	2.7	1.71	322.3		849.0	287.8	11.1			.1104	
11:56	70.8	102.9	114.0	3.0	1.71	321.5		849.0	288.1	11.1			.1114	
11:57	71.5	102.9	113.9	2.7	1.71	320.0		849.0	287.3	11.0			.1093	
11:58	71.6	103.0	113.9	2.8	1.71	320.1		849.0	286.7	10.9			.1095	
11:59	71.7	102.9	113.6	1.7	1.71	319.8	46,384	849.0	286.5	10.7	61,851.2	.750	.1090	.110
12:00	71.1	102.9	113.9	7.4	1.71	319.7		849.0	285.7	11.0			.1113	
12:01	71.4	102.9	114.0	3.2	1.71	319.8		849.0	286.7	11.1			.1099	
12:02	70.8	103.0	114.2	6.0	1.71	320.5		849.0	287.0	11.2			.1122	
12:03	70.8	103.1	113.8	2.6	1.71	321.1		849.0	288.0	10.7			.1122	
12:04	71.3	103.1	114.1	1.0	1.71	323.0	46,554	849.0	290.3	11.0	61,821.1	.753	.1095	.111
12:05	71.8	103.2	113.9	3.1	1.71	323.2		849.0	291.2	10.7			.1078	
12:06	71.8	103.1	114.2	3.3	1.71	321.9		849.0	289.6	11.1			.1081	
12:07	72.1	103.2	114.1	3.1	1.71	322.2		849.0	288.5	10.9			.1074	
12:08	71.7	103.1	114.1	2.3	1.71	322.1		849.0	287.3	11.0			.1085	
12:09	72.2	103.1	113.9	3.6	1.71	321.5	46,130	849.0	289.8	10.8	62,324.2	.740	.1066	.108

@ 108°F ρ_{H_2O} = 61.9 lb/ft³
@ 108°F c_p = .997

TITLE: 4 LENS CONC. COLL. "ML" MODEL NSC-01-0732

PERSONNEL: C JACOBS, D SEITER

TEST No.: 1

COLLECTOR APERTURE: 430 ft²

DATE: 4/25/78

WIND SPEED: 1.5 — 9.8

WIND DIRECTION: SE.

CONDITIONS: VERY CLEAR DAY, 0° INCIDENCE ANGLE

$$EFF = \frac{m \cdot C_p (T_{out} - T_{in})}{A_c \cdot I'^{+}} \; ; \; \frac{\Delta T'}{I'^{+}} = \frac{(T_{in} - T_a)}{I'^{+}}$$

TIME	T_a	T_{in}	T_{out}	WIND VEL	FLOW	I	$\Sigma \dot{m} C \Delta T$	m	I'^{+}	ΔT	$\Sigma A I'^{+}$	EFF	ΔT'/I'	AVG ΔT'/I'
12:31	71.8	159.1	169.0	4.5	1.70	322.9		830.3	289.4	9.9			.3017	
12:32	71.7	159.3	169.1	9.8	1.70	325.5		830.3	293.2	9.8			.2988	
12:33	71.2	159.4	169.1	5.1	1.70	322.2		830.3	290.5	9.7			.3036	
12:34	71.9	159.5	169.2	5.0	1.70	322.6		830.3	290.5	9.7			.3015	
12:35	72.2	159.5	169.2	3.5	1.70	323.2	40,518	830.3	291.1	9.7	62,552.1	.648	.3005	.301
12:36	72.4	159.6	169.3	2.2	1.70	322.2		830.3	290.1	9.7			.3006	
12:37	72.6	159.7	169.4	5.0	1.70	322.3		830.3	291.0	9.7			.2993	
12:38	72.6	159.7	169.4	5.5	1.70	322.7		830.3	291.2	9.7			.2991	
12:39	73.1	159.9	169.6	3.3	1.70	324.0		830.3	292.5	9.7			.2968	
12:40	72.4	159.7	169.5	3.3	1.70	323.8	40,351	830.3	292.6	9.8	62,668.2	.644	.2984	.299
12:41	73.2	160.1	169.9	2.5	1.70	322.1		830.3	290.6	9.8			.2990	
12:42	73.1	160.2	169.7	2.4	1.70	322.0		830.3	290.7	9.5			.2996	
12:43	72.9	160.3	170.0	4.7	1.70	324.1		830.3	293.5	9.7			.2978	
12:44	73.0	160.6	170.3	1.5	1.70	322.5		830.3	292.2	9.7			.2998	
12:45	73.2	160.5	170.3	3.6	1.70	321.5	40,268	830.3	291.2	9.8	62,702.6	.642	.2998	.299
12:46	72.7	160.7	170.3	3.5	1.70	321.5		830.3	290.0	9.6			.3034	
12:47	72.5	160.8	170.4	3.2	1.70	322.6		830.3	290.8	9.6			.3036	
12:48	72.4	161.0	170.6	5.2	1.70	322.4		830.3	291.1	9.6			.3044	
12:49	71.9	161.0	170.7	4.9	1.70	323.6		830.3	292.3	9.7			.3048	
12:50	71.4	160.9	170.8	4.7	1.70	321.6	40,102	830.3	289.8	9.8	62,522	.642	.3088	.305

@165°F C_{H_2O} = 60.9 lb/ft³

@165°F C_p = 1.0005

TITLE: 4 LENS CONC. COLL.
"ML" MODEL NSC-01-0732

PERSONNEL: C JACOBS / D SEMER

TEST No.: 2

COLLECTOR APERTURE: 43.0 ft²

DATE: 4/26/78

WIND SPEED: 0-6 mph

WIND DIRECTION: W — NW

CONDITIONS: MOSTLY CLEAR, SOME LIGHT HAZE DURING 2nd "DATA PT", 0° INCIDENCE ANGLE

$$EFF = \frac{m \cdot Cp (T_{out} - T_{in})}{A_c \cdot I'^{+}} ; \quad \frac{\Delta T'}{I'^{+}} = \frac{(T_{in} - T_a)}{I'^{+}}$$

TIME	T_a	T_{in}	T_{out}	WIND VEL.	FLOW	I	ΣṁCΔT	m	I'⁺	ΔT	ΣAI's	EFF	ΔT'/I'	AVG. ΔT'/I'
13:14	71.0	211.1	218.0	2.2	1.72	318.9		823.6	252.8	6.9			.5542	
13:15	71.8	211.1	217.9	1.4	1.72	319.5		823.6	254.3	6.8			.5478	
13:16	72.2	211.2	218.2	5.3	1.72	319.3		823.6	255.0	7.0			.5451	
13:17	71.0	211.1	218.2	4.6	1.72	319.5		823.6	253.3	7.1			.5531	
13:18	72.2	211.2	218.3	2.5	1.72	318.2	28,916	823.6	250.6	7.1	54,435	.531	.5547	.551
13:19	71.5	211.2	218.2	2.7	1.72	315.2		823.6	246.4	7.0			.5670	
13:20	71.4	211.5	218.4	2.1	1.72	316.9		823.6	246.8	6.9			.5677	
13:21	73.0	211.7	218.2	0.0	1.72	299.1		823.6	228.3	6.5			.6075	
13:22	72.1	211.7	217.8	1.1	1.72	283.0		823.6	214.1	6.1			.6520	
13:23	72.3	211.8	217.6	0.3	1.72	286.4	26,763	823.6	217.0	5.8	49,561.8	~~.539~~	.6429	~~.607~~
13:24	72.4	212.0	217.7	2.0	1.72	305.3		823.6	237.5	5.7			.5876	
13:25	73.3	212.1	218.2	2.6	1.72	305.1		823.6	237.7	6.1			.5839	
13:26	71.9	212.1	218.6	0.2	1.72	306.5		823.6	239.8	6.5			.5847	
13:27	71.4	212.1	218.6	2.3	1.72	306.3		823.6	240.8	6.5			.5843	
13:28	71.2	212.1	218.7	1.4	1.72	309.9	26,016	823.6	244.9	6.6	51630.1	.504	.5753	.583
13:29	71.2	212.2	218.9	3.2	1.72	311.2		823.6	248.0	6.7			.5685	
13:30	72.1	212.4	219.1	4.1	1.72	312.6		823.6	251.9	6.7			.5570	
13:31	70.9	212.3	219.3	5.1	1.72	312.8		823.6	253.1	7.0			.5537	
13:32	71.7	212.3	219.4	4.0	1.72	312.1		823.6	252.6	7.1			.5566	
13:33	[illegible]	212.3	219.3	4.8	1.72	314.6	28,585	823.6	255.3	7.0	54240.2	.527	.5503	.553

THE "DATA POINT" CORRESPONDING TO THE TIME INTERVAL 13:18–13:23 WAS NOT USED IN THE EFFICIENCY CALCULATION BECAUSE THE INSOLATION RATE CHANGED SIGNIFICANTLY DURING THIS PERIOD.

@ 215°F ρ_{H_2O} = 59.7 lb/ft³
@ 215°F C_p = 1.006

TITLE: 4 LENS CONIC. COLL.
"ML" MODEL NSC-01-0732
PERSONNEL: C. JACOBS / D. SEITER
TEST No.: 2
COLLECTOR APERTURE: 43.0 ft^2

DATE: 4/26/78
WIND SPEED: 0 - 5.3 mph
WIND DIRECTION: W - SW
CONDITIONS: CLEAR, 0° INCIDENCE ANGLE

$$EFF = \frac{\dot{m} \cdot C_p (T_{out} - T_{in})}{A_c \cdot I'^{+}} \; ; \; \frac{\Delta T'}{I'^{+}} = \frac{(T_{in} - T_a)}{I'^{+}}$$

TIME	T_a	T_{in}	T_{out}	WIND VEL	FLOW	I	$\Sigma \dot{m} C \Delta T$	m	I'^{+}	ΔT	$\Sigma A I'^{+}$	EFF	ΔT'/I'	AVG ΔT'/I'
14:12	73.1	257.2	263.3	4.3	1.72	309.0		807	254.1	6.1			.7245	
14:13	72.8	257.3	263.0	0.4	1.72	308.5		807	254.0	5.7			.7264	
14:14	74.7	257.4	263.0	0.1	1.72	307.3		807	253.2	5.6			.7216	
14:15	74.0	257.4	263.0	1.1	1.72	306.3		807	252.7	5.6			.7258	
14:16	73.8	257.3	263.1	1.0	1.72	306.0	23,591	807	252.8	5.8	54,472.4	.434	.7259	.725
14:17	72.9	257.1	263.0	3.4	1.72	306.0		807	252.5	5.9			.7295	
14:18	73.1	257.1	263.0	1.3	1.72	305.4		807	251.5	5.9			.7316	
14:19	74.1	257.1	262.7	0.0	1.72	304.9		807	252.5	5.6			.7248	
14:20	74.7	257.1	262.9	1.5	1.72	304.4		807	250.6	5.8			.7279	
14:21	72.8	257.1	262.8	5.3	1.72	304.1	23,673	807	250.8	5.7	54,087.7	.437	.7348	.730
14:22	73.2	257.1	262.9	3.1	1.72	304.0		807	250.7	5.8			.7335	
14:23	72.7	257.0	262.8	2.6	1.72	304.0		807	250.0	5.8			.7372	
14:24	73.7	256.8	262.7	4.2	1.72	303.5		807	249.7	5.9			.7333	
14:25	72.8	256.8	262.6	2.8	1.72	303.0		807	249.5	5.8			.7375	
14:26	72.2	256.7	262.5	2.9	1.72	302.2	23,836	807	248.6	5.8	53,685.5	.444	.7422	.737
14:27	72.8	256.7	262.4	2.5	1.72	301.8		807	249.1	5.7			.7383	
14:28	73.5	256.7	262.4	2.0	1.72	302.5		807	249.5	5.7			.7343	
14:29	74.5	256.6	262.4	2.9	1.72	303.1		807	249.9	5.8			.7287	
14:30	74.1	256.4	262.3	2.9	1.72	303.1		807	249.3	5.9			.7312	
14:31	74.2	257.2	262.3	2.8	1.72	302.3	23,099	807	248.9	5.1	53,608.1	.431	.7352	.734

@260°F ρ_{H_2O} = 58.5 lb/ft^3
@260°F C_p = 1.015

TITLE: EFFICIENCY @ 12° INCIDENCE ANGLE
4 LENS CONC. COLL. "ML" MODEL NSC-01-0732

DATE: 4/27/78

PERSONNEL: C. JACOBS, D. SEITER

WIND SPEED: 1.2 — 9.4 mph

TEST No.: 3

WIND DIRECTION: W – NW

COLLECTOR APERTURE: 43.0 ft²

CONDITIONS: CLEAR, 12° INCIDENCE ANGLE

$$EFF = \frac{m \cdot Cp \cdot (T_{out} - T_{in})}{A_c \cdot I'^*} \; ; \; \frac{\Delta T'}{I'^*} = \frac{(T_{in} - T_a)}{I'^*}$$

$$\eta = \Sigma \dot{m} C \Delta T / \Sigma A I'^* [\cos(12°)]$$

TIME	T_a	T_{in}	T_{out}	WIND VEL	FLOW	I	$\Sigma \dot{m} C \Delta T$	m	I'^*	ΔT	$\Sigma A I'^*$	EFF	ΔT'/I'	AVG ΔT'/I' cos(12°)
9:40	70.2	96.3	105.3	4.1	1.76	298.6		875.2	253.6	9.0			.1029	
9:41	70.5	96.2	105.6	2.7	1.76	298.6		875.2	254.3	9.4			.1011	
9:42	70.0	96.2	105.4	3.2	1.76	298.0		875.2	254.7	9.2			.1029	
9:43	70.9	96.2	105.2	1.2	1.76	298.1		875.2	255.5	9.0			.0990	
9:44	70.5	96.4	105.6	6.6	1.76	297.5	39,966	875.2	256.2	9.2	54,794.9	.746	.1011	.103
9:45	70.0	96.3	105.2	3.6	1.76	297.4		875.2	256.5	8.9			.1025	
9:46	69.7	96.4	105.2	6.4	1.76	298.1		875.2	255.6	8.8			.1045	
9:47	70.5	96.4	105.6	6.3	1.76	297.6		875.2	256.2	9.2			.1011	
9:48	70.5	96.4	105.4	6.1	1.76	297.7		875.2	256.9	9.0			.1008	
9:49	70.1	96.4	105.7	9.0	1.76	297.1	39,442	875.2	256.7	9.3	55,121.7	.732	.1025	.104
9:50	69.5	96.4	105.6	5.3	1.76	297.2		875.2	256.8	9.2			.1048	
9:51	69.9	96.4	105.4	4.7	1.76	296.8		875.2	256.0	9.0			.1035	
9:52	70.1	96.5	105.7	4.2	1.76	296.0		875.2	256.2	9.2			.1030	
9:53	70.4	96.4	105.7	2.9	1.76	296.1		875.2	257.3	9.3			.1010	
9:54	70.3	96.4	105.6	4.7	1.76	295.8	40,053	875.2	258.0	9.2	55,224.7	.741	.1012	.105
9:55	71.0	96.5	105.3	3.2	1.76	295.4		875.2	258.1	8.8			.1013	
9:56	70.8	96.7	106.0	3.8	1.76	295.3		875.2	258.5	9.3			.1002	
9:57	70.4	96.5	105.7	3.6	1.76	294.9		875.2	259.3	9.2			.1007	
9:58	70.9	96.6	105.9	3.6	1.76	294.6		875.2	259.8	9.3			.0989	
9:59	70.2	96.6	106.0	9.4	1.76	294.4	40,140	875.2	257.2	9.4	55,594.7	.738	.1026	.103
												AVG EFF		AVG ΔT'/I' cos(12°)
												.739		.104
			@101°F	ρ_{H_2O}	= 62.0									
			@101°F	Cp =	.997									

Flow Meter Calibration

Run 1 Flow Meter Reading = 1.68 GPM

Measured Flow

Amount	Time
40 lb	169 sec

$$\text{Actual Flow} = \frac{(40\ \text{lb})\ (60\ \text{sec/min})}{(8.34\ \text{lb/gal})\ (169\ \text{sec})} = 1.70\ \text{GPM}$$

Run 2 Meter Scale Adjusted Before Run 2

Flow Meter Reading = 1.67 GPM

Measured Flow

Amount	Time
40 lb	172 sec

$$\text{Actual Flow} = \frac{(40\ \text{lb})\ (60\ \text{sec/min})}{(8.34\ \text{lb/gal})\ (169\ \text{sec})} = 1.673\ \text{GPM}$$

FLUKE

FLUKE SOUTHWESTERN TECHNICAL CENTER

CERTIFICATE OF CALIBRATION

MODEL 2240A SERIAL NO. 510012 DATE 3-28-78

The Fluke Southwestern Technical Center does hereby certify the above listed instrument meets or exceeds all published specifications and has been calibrated using standards whose accuracies are traceable to the National Bureau of Standards within the limitations of the Bureau's Calibration services, or have been derived from accepted values of natural physical constants, or have been derived by the ratio type of self-calibration techniques.

Applicable NBS Test Report Numbers: DC Voltage – 207627
AC Voltage – 807675
Resistance – 207693

JOHN FLUKE MFG CO INC.
FLUKE
METROLOGY SYSTEMS
SEAL OF CERTIFIED CALIBRATION
SEATTLE WASHINGTON

SERVICE MANAGER

2.1.1 EQUIPMENT CAPABILITIES

The pumps required to circulate the heat transfer fluid through the collector are not to be supplied as part of this contract. However, proper attention has been given to pump size and pressure drops in the manifold-collector system. Proper pump sizing can be determined for the design flow rate using the information given in the applications manual.

2.1.2 NOISE OR EROSION - CORROSION

From previous noise or erosion - corrosion tests, a maximum velocity of 4 fps is an accepted flow for piping with working temperatures above 150°F for copper tubing.* A 1.72 gpm flow rate per collector panel as the upper design limit is equivalent to less than 2.6 fps flow in the 5/8" O.D. copper tubing at the inlet and outlet of each collector. The flow rate in the absorber tubes is below one fps. Fluid velocities for the manifold are listed below. As can be seen, all velocities are well below the maximum of 4 fps.

SUPPLY MANIFOLD FLUID VELOCITIES

Supplying Collector Panel	Manifold Size	GPM (Max)	Velocity (Max)
2	1 1/4"	10.32	2.7
3	1 1/4"	8.6	2.2
4	1"	6.88	2.8
5	1"	5.16	2.1
6	3/4"	3.44	2.5
7	3/4"	1.72	1.2

Northrup has many isntallations which have been in use for years utilizing a similar design for the manifold and fluid handling system. No failures have occurred during this period which have been attributed to noise or erosion - corrosion in these systems.

*National Standard Plumbing Code, National Association of Plumbing-Heating-Cooling Contractors, Appendix B, pp. 10-11, Washington,

2.1.3 OPERATING CONDITIONS

All of the components of the design are capable of operating over their respective temperature and pressure range without breakage, rupture, binding, galling, or significant loss in pressure. The fluid loop is capable of operating at pressures above 125 psi while the design operating pressure is 100 psi. Each of the components in the fluid loop is outlined below with its maximum pressure and temperature.

Automatic Air Vent

The recommended air vent is a Maid O' Mist No. 74 and has a rated maximum pressure of 150 psi. The valve seat material is made of Neoprene and is rated at 300°F. See paragraph 2.3.1 for the results of a pressure test.

Pressure Relief Valve

The automatic relief valve is located on the bottom manifold of the system. The automatic relief valve is specified to open at 125 psi which is 25% greater than the working pressure of 100 psi. This pressure relief valves have provided more than adequate safety measures when properly installed on similar Northrup concentrating collectors. See paragraph 2.3.1 for the results of a pressure test.

Swivel Seal

The swivel joints used in this design are manufactured by GRA-TEC. This swivel assembly is constructed of silicone hose, and brass and utilizes an ethylene propylene rubber o-ring.

The recommended working pressure in this application is 0-125 psig using water with a temperature up to 300°F with or without an ethylene glycol additive. See ver. par. 5.2.5 for the results of an accelerated swivel life test.

Selective Coating

The selective coating on the absorber tube is capable of withstanding temperatures in excess of 550°F without sub- sustaining permanent damage or increase in emissivity or a decrease in absorbtivity. The absorber should be capable of withstanding stagnation temperatures without being permanently affected.

2.1.4 FLUID FLOW IN COLLECTORS

To insure constant flow rate to the collector panels, a reversed supply and return header with parallel arrays of collectors is employed. Graduated manifold sizes are also utilized to comply with the changes in flow rate within the supply and return lines.

Additionally, all absorber tubes within the collector panel have the same cross-sectional area. This will allow the same fluid velocity per absorber tube.

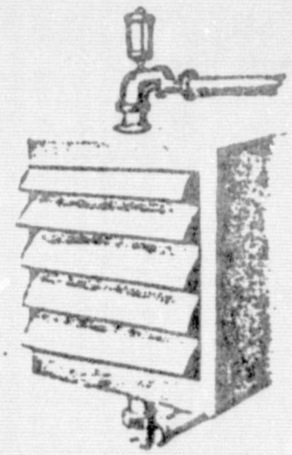
2.1.5 ENTRAPPED AIR

A suitable means of air removal from the fluid lines has been provided by an automatic air valve. The automatic air valve which has been selected for this application is a Maid-O-Mist No. 74 and is rated at 150 psi. Heat losses from the manifold lines will be minimized by the proper installation of insulation around the air vent, and sufficient heat conduction from the copper manifold to the brass auto-vent will provide antifreeze protection in the insulated environment so that the proper operation of the automatic air vent will not be impeded. The particular auto-vent which has been selected is also capable of withstanding the fluid temperatures without damaging the seal components. Drawing number 01-04-062 shows how insulation should be installed around the air vent.

This page was copyrighted. For information on Auto-vent Air Eliminators (Float type) contact MAID-O'-MIST, Chicago, Illinois 60641.

INSTRUCTIONS
FOR
INSTALLING

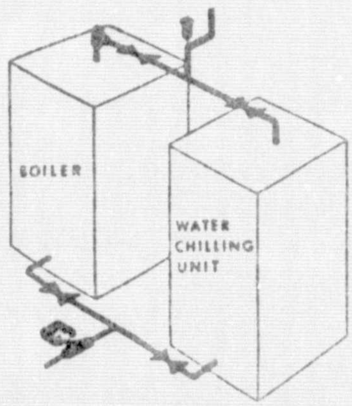
VENTING HIGH POINTS



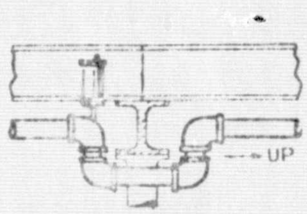
VENTING UNIT TYPE
HOT WATER RADIATORS

1. To attach, always use a *very short* I.P. nipple.
2. Always install at the highest point of a pipe line, never on the side of a fitting.
3. Never install on the exhaust line of a plunger type pump unless you use an air chamber at least 3 ft. long of 1½" pipe and take opening out of the side of air chamber near bottom.
4. Always vent an indirect radiator out of the top of the radiator manifold.
5. The vent cap should be screwed down tight when refilling system with water. After system is filled, loosen vent cap and allow air to release slowly. If air is released too fast it may draw scale or dirt up into valve seat, causing it to leak. If this occurs, push valve core in, allowing water to flush out seat and then pull out slightly on valve stem which should dislodge this scale. For normal venting, cap should be open at least one full turn. To shut off valve, screw vent cap down tight.
6. For maximum pressures—see other side.
7. Valve cores or entire bonnet assembly may be ordered for replacement. Order No. 7XP for No. 71, No. 74 or No. 75 Auto-Vents—No. 7X for No. 78 Auto-Vent.
8. Special valves can be supplied when specified to be used to vent oil tanks or gasoline lines.
9. Special No. 7-A connectors for ¼" copper tubing are recommended in place of regular cap, when installed where leakage could cause damage.
10. No air chamber is necessary.

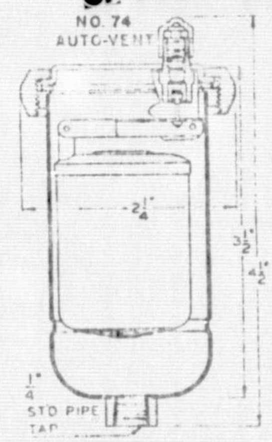
Write for Bulletin No. 713 describing complete line of Auto-Vent Air Eliminators.



VENTING BOILER OR CHILLING UNIT



VENTING TRAPPED MAINS
AND CIRCULATING LINES



CONNECT WITH CLOSE NIPPLE
SECTIONAL VIEW

AIR STRANGLES CIRCULATION, REDUCES EFFICIENCY

2.1.6 THERMAL EXPANSION OF FLUIDS

Thermal expansion of the heat transfer fluid can be accommodated by the use of a conventional expansion tank or compensator which is the responsibility of the user (see Applications Manual). The pressure relief valve, preset at 125 psi will limit excessive pressures for safety.

2.1.7

PRESSURE DROPS

Design criteria is as stated in 2.1.4 which are standards recommended by ASHRAE. Pressure drop across the entire array of 7 collectors is as tabulated below, with manifold of size tabulated. The calculated pressure drop is not considered excessive. Flow rate is based on 0.43 GPM per collector with values of P.D. obtained from ASHRAE.

Supply Manifold P.D. To And Through Last Collector:

Supplying Collector Numbers	Manifold Size	GPM	Equivalent Foot Length	PD Ft H_2O
1	1¼"	12.04	7.2	.22
2	1¼"	10.32	17	.47
3	1¼"	8.6	16.8	.32
4	1"	6.88	15.4	.53
5	1"	5.16	15	.29
6	3/4"	3.44	14	.58
7	3/4"	1.72	26.2	.89
			Sub Total	3.3

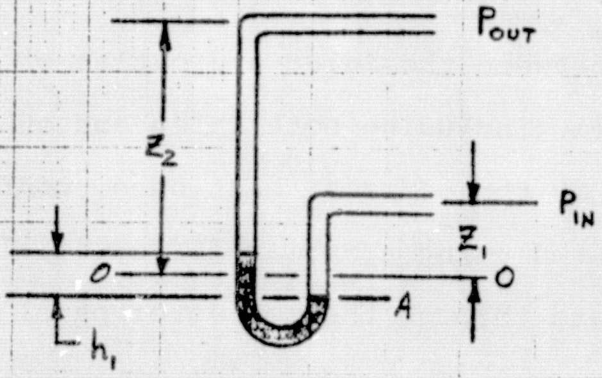
Measured P.D. across a Collector Plus the Inlet and Outlet Swivel Joint Connectors 2.9

Total P.D. For Array 6.2 ft H_2O

2.1.7 COLLECTOR PRESSURE DROP

The pressure drop between the inlet and outlet of a 4-lens collector panel (including both inlet and outlet swivel arrangement in the correct, bent tube, configuration) will be measured using a Meriam differential manometer. The flow rate through the collector panel will be at least 1.7gpm.

4-LENS COLLECTOR PRESSURE DROP TEST 5/20/78
W/ INLET & OUTLET
SWIVEL JOINT CONNECTORS



$$P_{IN} = P_A - \gamma_{H_2O}\left(Z_1 + \tfrac{1}{2}h_1\right)$$

$$P_{OUT} = P_A - \gamma_{Hg} h_1 - \gamma_{H_2O}\left(Z_2 - \tfrac{1}{2}h_1\right)$$

(1) $$P_{IN} - P_{OUT} = h_1\left(\gamma_{Hg} - \gamma_{H_2O}\right) + \left(Z_2 - Z_1\right)\gamma_{H_2O}$$

$$P_{IN} = P_{OUT} + D.L. + \left(Z_2 - Z_1\right)\gamma_{H_2O}$$

D.L. ≡ DYNAMIC LOSS

(2) $$D.L. = P_{IN} - P_{OUT} - \left(Z_2 - Z_1\right)\gamma_{H_2O}$$

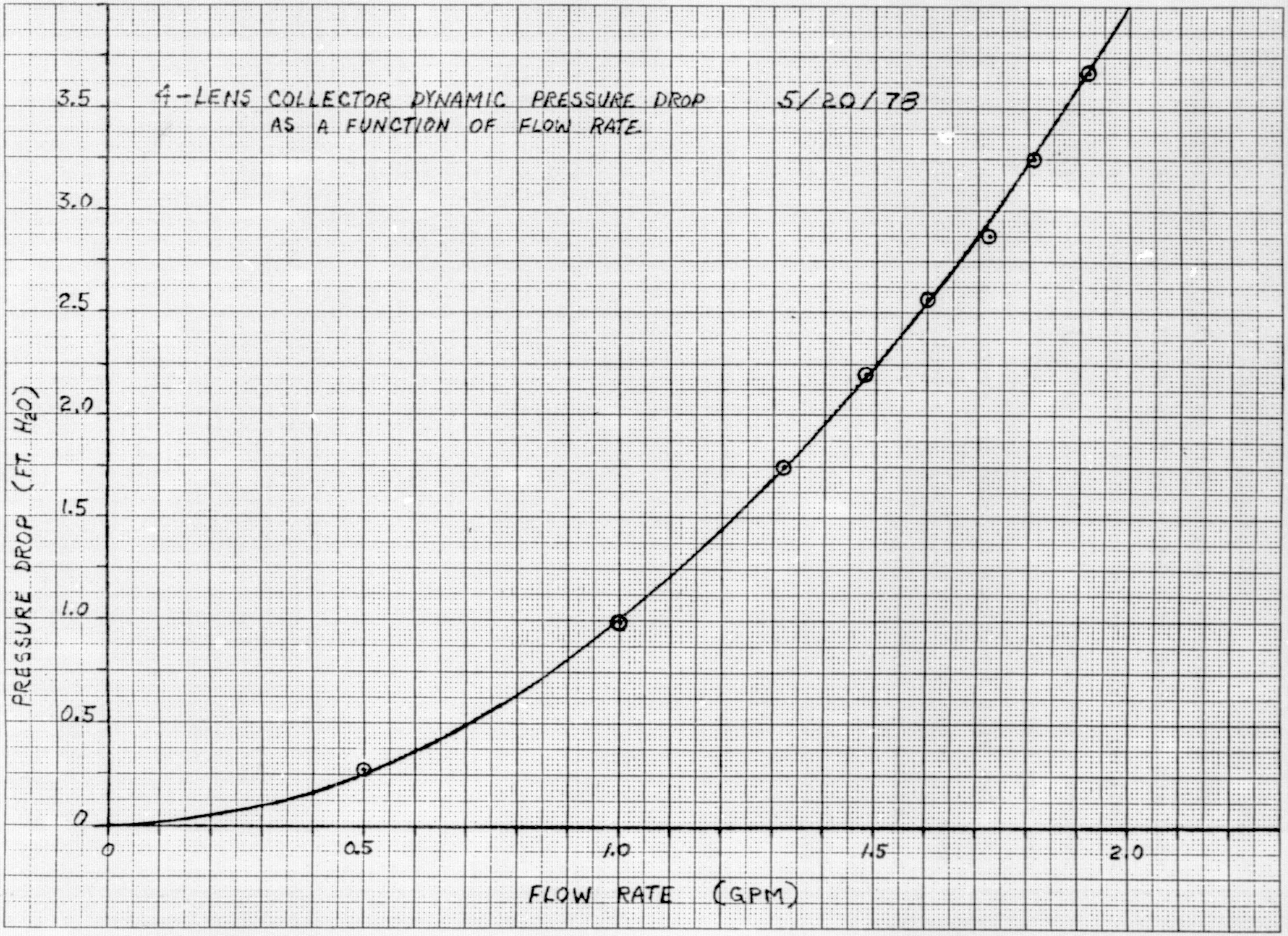
(1) & (2) ⇒ $$D.L. = h_1\left(\gamma_{Hg} - \gamma_{H_2O}\right)$$

$\gamma_{H_2O} = 62.4\ lb/ft^3$

$\gamma_{Hg} = 845.3\ lb/ft^3$

FLOW RATE (GPM)	h_1 (INCHES)	D.L. (PSI)	D.L. (FT. H_2O)
0	0	0	0
0.5	.25	.113	.261
1.0	.95	.430	.993
1.32	1.65	.748	1.724
1.48	2.1	.951	2.194
1.6	2.45	1.11	2.560
1.72	2.75	1.246	2.873
1.81	3.1	1.404	3.239
1.92	3.5	1.586	3.657

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1510



2.1.8 CONDENSATE REMOVAL

This requirement states that means shall be provided for adequate disposal of condensate from cooling equipment. However, no cooling equipment is included with this system. Any such equipment installed in conjunction with this system will be the responsibility of the user.

Dew will sometimes form on the system as it normally does on other structures. But, this represents no threat to the system or surroundings.

2.2.1 VIBRATION STRESS LEVELS

The operating system to be supplied under the conditions of this contract include only one device which could cause vibrations in the system. This device is the tracking motor for the attitude controls. However, since the rotational rate of this fractional horsepower motor (20 rpm) is so low, this device does not constitute a serious vibration source.

Vibrations in the fluid handling system due to pulsating flows should be minimized by the manifold support system. The manifolding is contained within the manifold support system and surrounded by insulation which will damp the vibrations of the fluid line. The manifold support, which functions as part of the support structure provides rigidity to the piping and connection equipment. Wind pulsations do not effect the support structure as is evidenced by the performance of structures similiarly designed and currently employed at various job sites of Northrup, Inc.

Furthermore, vibration due to any cause has not presented itself as a problem in current Northrup systems which are similar to the new design.

2.2.2 VIBRATION FROM MOVING PARTS

The operating system to be supplied as partial fulfillment of this contract does not include the pumps and other circulating devices. A single device which is to be supplied as part of the contract is the tracking motor for the attitude controls. This device, however, is only a small fractional horsepower motor which operates at extremely low rotational rates (20 rpm). Adequate structural support has been provided for the motor, so no vibrational stresses or problems are anticipated.

2.2.4 VACUUM RELIEF PROTECTION

The fluid handling system that is included in this design as partial fulfillment of this contract includes the manifolding and absorber tubes, swivel joints, a pressure relief valve, and automatic air vent. The largest fluid handling component in the manifold system is 1 1/4" (1 3/8" O.D.) copper tubing with a wall thickness of 0.042 inches. Analysis shows that the collapsing pressure is well above that which occurs should an internal vacuum be created.* The other components of the fluid handling system will be tested by using a high vacuum pump.

* $E = 16 \times 10^6 \text{ lb/in}^2$

$u = .33$

$t = .042 \text{ in}$

$d = 1.375 \text{ in}$

$$P_{cr} = \frac{2E}{1 - u^2}\left(\frac{t}{d}\right)^3 = \frac{2\,(16 \times 10^6 \text{ lb/in}^2)}{1 - (.33)^2}\left(\frac{.042 \text{ in}}{1.375 \text{ in}}\right)^3$$

$$P_{cr} = 1023.5 \text{ lb/in}^2$$

$$\sigma_{cr} = \frac{E}{1 - u^2}\left(\frac{t}{d}\right)^2 = \frac{(16 \times 10^6 \text{ lb/in}^2)}{1 - (.33)^2}\left(\frac{.042 \text{ in}}{1.375 \text{ in}}\right)^2$$

$$\sigma_{cr} = 16{,}753 \text{ lb/in}^2$$

2.2.4 VACUUM RELIEF PROTECTION (continued)

This fluid handling system is similar to those employed on other Northrup systems in which failure due to internal vacuum has not presented itself as a problem. See Paragraph 2.1.5 for a description of the automatic air vent.

2.2.4 INTERNAL VACUUM TEST

INTRODUCTION

This test will ensure there is no danger that fluid handling components can be damaged due to an internal vacuum. The flattened absorber tubes, relief valves, and swivels will be individually tested. The copper pipe used in the manifold will not be tested since it is designed to withstand an internal vacuum, and since analysis indicates it can easily withstand the pressure created by an internal vacuum.

PROCEDURE

The absorber tubes, swivels, and relief valves will be tested separately by connecting the components in series with a 2-stage high-vacuum pump and a Stokes-McLeod mercury gauge with a scale range of 5000 to 0 microns. Each component will be subjected to an internal pressure of 1000 microns or less or will be shown to have vacuum relief protection. In either case, the component must not be damaged.

RESULTS

On May 29, 1978, the air vent was vacuum tested according to the above procedure. The air vent acted like a vacuum release valve by venting in air. This in itself should verify the system for vacuum relief protection since the system should not see an internal vacuum by virtue of the air vent.

In addition a swivel joint connector, pressure relief valve, and a flattened copper tube (ten feet long and with the same cross sectional area as an absorber tube) were vacuum tested. They were subjected to absolutely no damage. Also, a cap was screwed onto the air vent to prevent its operation. It was then vacuum tested without damage.

2.2.5 THERMAL CHANGES

Thermal contraction and expansion will occur in both the manifold and collector absorbers. Their lengths will be subjected to sizeable variations which will be accommodated by appropriate clearance between the absorber and collector casing, and between the manifold and manifold assembly. There is also ample clearance in the collector and manifold assemblies to allow for any flexing that may occur.

In addition to allowing sufficient room for expansion and contraction, a flexible connection between the absorber tubes and manifold is employed to account for any relative dimensional changes between the two (see Drawing 01-03-023).

2.2.5 THERMAL CHANGES

During operating conditions the collector, swivel joints, lenses, housing, framework, etc. will be visually inspected to ensure there is no failure of the system due to excessive thermal contraction or expansion. The fluid inlet temperature will be raised to at least 250°F for this test.

2.2.5 THERMAL CHANGES 5/20/78

During operating conditions a collector, swivel joints, lenses, housing, framework and the manifold (which were set up to handle one collector) were visually inspected to ensure there was no failure of the system due to excessive thermal expansion. The fluid inlet temperature was raised to 270°F for this test which is considered to be well above normal operating temperatures. During this test there were no failures nor any sign of a problem resulting from thermal changes.

2.2.6 FLEXIBLE JOINTS

Flexing of the manifold subsystem is adequately compensated for with the clearances inside the manifold structure. Linear expansion of the absorber is accommodated by the adequate room in the manifold structure. Relative expansion of the absorber to the manifold and _visa versa_ is allowed for by a flexible connection. See 2.2.5. See ver: par. 5.2.5 for the results of an accelerated swivel and flexible joint life test.

2.3.2, 2.8.1,
4.2.2, 5.2.4

2.3.1 PRESSURE TEST: NON-POTABLE FLUIDS

The portions of the system containing heat transfer fluid that would not necessarily be connected directly to the potable water supply are the manifold, absorber tubes, swivel connections, air valve, and pressure relief valve. The suggested working pressure for the system is 100 psi. The pressure relief valve is preset to open at 125 psi.

The aforementioned components, except the manifold are pressure tested before they go into operation. The test is performed by submersing the desired subsystem in water and filling it with nitrogen gas to the desired pressure level. If there is a leak, it will manifest itself in the appearance of bubbles. The pressure relief valve is tested up to its rated release pressure to ensure proper function. The other components are tested at 150 psi. None of these tests have resulted in leaks or damage to components when the subsystem was assembled correctly. Therefore, a working pressure of 100 psi should be acceptable.

Any connecting pipe from the collector array to and including a heat exchanger is not part of this contract and is considered the responsibility of the user.

2.3.1, 2.3.2, 2.8.1,
4.2.2, 5.2.4

PRESSURE TEST

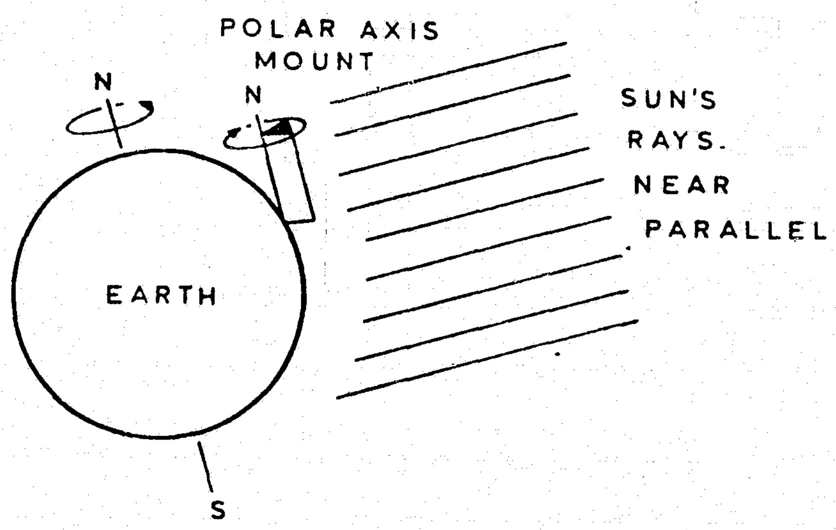
All the absorber tubes were pressure tested to 150 psig on April 7, 1978, according to the procedure described on the preceding page. The air vent and one of the swivel joint connectors were pressure tested to 150 psig on May 29, 1978 according to the previously described test procedure. In all of the above tests there were no failures of any kind. The pressure relief valve was also tested on May 29, 1978. This valve opened at 125 psi as specified by the manufacturer.

2.3.2 PRESSURE TEST: POTABLE WATER

The pressure tests performed to satisfy paragraph 2.3.1 will also satisfy 2.3.2.

2.4.1 ORIENTATION AND TILT

Detailed discussions concerning the selection of a rotating polar axis mounted system are contained in the first monthly report. The principle of the rotating polar axis mounted system is illustrated in Figure .



Figure

Rotating Polar Axis Mount

The rotation of the collector proceeds at the same rate as the earth's rotation so that the collector is normal to the sun. The collector does experience a change of sun altitude due to the earth's orbit about the sun. This movement results in a change in the sun's attitude of $\pm$ 23.5^{o} either side of normal line which occurs on September 21 and March 21.

2.4.1 (Continued)

The structure is fabricated so that the collectors will be aligned with the polar axis and this dictates the design collector tilt. Orientation is maintained with the Northrup attitude controls which typically updates the collector position ever 45 seconds. This corresponds to a tracking precision of .19 degrees which is well within the required design tracking precision.

2.4.1 TRACKING TEST

Procedure

The entire collector array consisting of seven panels will be tested for alignment accuracy. The collector panels will be tracked without fluid flow during this test. All seven collector panels will be aligned to the sun by focusing the concentrated light from the lenses onto the absorbers. The panels will then be allowed to track the sun as they would in normal operation. The collector panels will be periodically checked visually for alignment accuracy.

Results

The array was allowed to track for eight days (6/22/78 through 6/29/78). During this period of time the collectors remained aligned to the sun during clear weather.

2.7.1 Applicable Plumbing Standards

All piping and fittings in the array are of brass or copper which conform to a vast majority of local codes that may be encountered. All fittings and joints will be made with brazing that is 6% silver. This brazing will withstand temperatures in excess of 800°F before melting. And in using it in the present Northrup Concentrating Collector, there has never been an incident where it melted.

Insulation around the copper pipe in the manifold-frame is glass wool. Minimum thickness is 1 3/4" at tangent points of tubing to sides, top and bottom of steel housing, and varies from 3" to 4" between these points. The insulation has a "k" factor of 0.28 @ 200°F, thus giving an average R factor of 10 plus. In past Northrup installations that have similar design characteristics there is no evidence to indicate there has been excessive heat conduction to the environment.

2.8.1 RELIEF VALVES AND VENTS

The automatic pressure relief valve is located on the bottom manifold of the system. The automatic relief valve is specified to open at 125 psi, which is 25% greater than the working pressure of 100 psi. Located on the top of the manifold system is an air relief vent rated at 150 psi. These relief valves have provided more than adequate safety measures when used on similar Northrup concentrating collectors. See ver. par. 2.3.1 for pressure test results on the relief valves.

3.1.1 Applicable Standards (Structural Design)

Structural design has been based on the applicable provision of MPS and references standards therein. It has been treated as "conventional elements" which a review of structural analysis should confirm, and which are on the conservative side. Analysis is based on working stresses rather than ultimate stress provisions. All steel used in fabrication of structural elements has a minimum yield point of 33,000 lbs./sq.in. All connecting bolts conform to ASTM 307. Allowable working stesses are in accordance with above referred standards for these materials. Service loads are as stipulated in paragraphs 3.1.2. See paragraph 3.2.2 which refers to paragraph 3.2.1 for compliance to load combinations.

Structural calculations follow paragraph 3.2.2.

3.1.2 Service Loads

Dead loads have been determined almost totally by weighing components rather than by calculation. One inch thick ice on all surfaces is used for live loads which is very conservative. The wind loads used are also conservative.

For ease of calculation, axial loads are assumed to be applied at an end point. On certain members the weight is assumed to act through the center which is slightly off the true center of gravity. This is true of the manifold supports, but will have negligible effect on the outcome. Also, for simplicity, the wind loading on the south brace and the manifold supports is based on an angle of attach of 90°. This results in a slightly larger load.

The collector tilt angle used in all calculations is 32°. The collector alignment corresponds to solar noon with the wind blowing from the south. All analysis of forces is done graphically.

The following loads are used for design analysis:

Dead Loads

Collector	- 425 lb.
Manifold Strut	- 62 lb.
Manifold Support	- 25 lb.
South Brace	- 6 lb.
South Col. Base Angle	- 4 lb.
Inclined Strut	- 33 lb.
North Wind Street	- 28 lb.
North Column	- 20 lb.

Live Loads Based on Ice (1" Thick - 4.67 lbs/ft^2

Collector	- 700 lb.
Manifold Strut	- 75 lb.
Manifold Support	- 30 lb.
South Brace	- 15 lb.
South Col.Base Angle	- 10 lb.
North Wind Strut	- 65 lb.
North Column	- 45 lb.
Inclined Strut	- 80 lb.

3.1.2 Service Loads (cont'd)

Wind Loads Based on 70 m.p.h. wind velocity at 30 ft. above ground level per Table 6, ANS A58.1-1972.

Collector	- 885 lb.
Manifold Strut	- 105 lb.
Manifold Support	- 24 lb.
South Brace	- 18 lb.
South Col. Base Angle	- 0 lb.
Inclined Strut	- 55 lb.
North Wind Strut	- 63 lb.
North Column	- 46 lb.

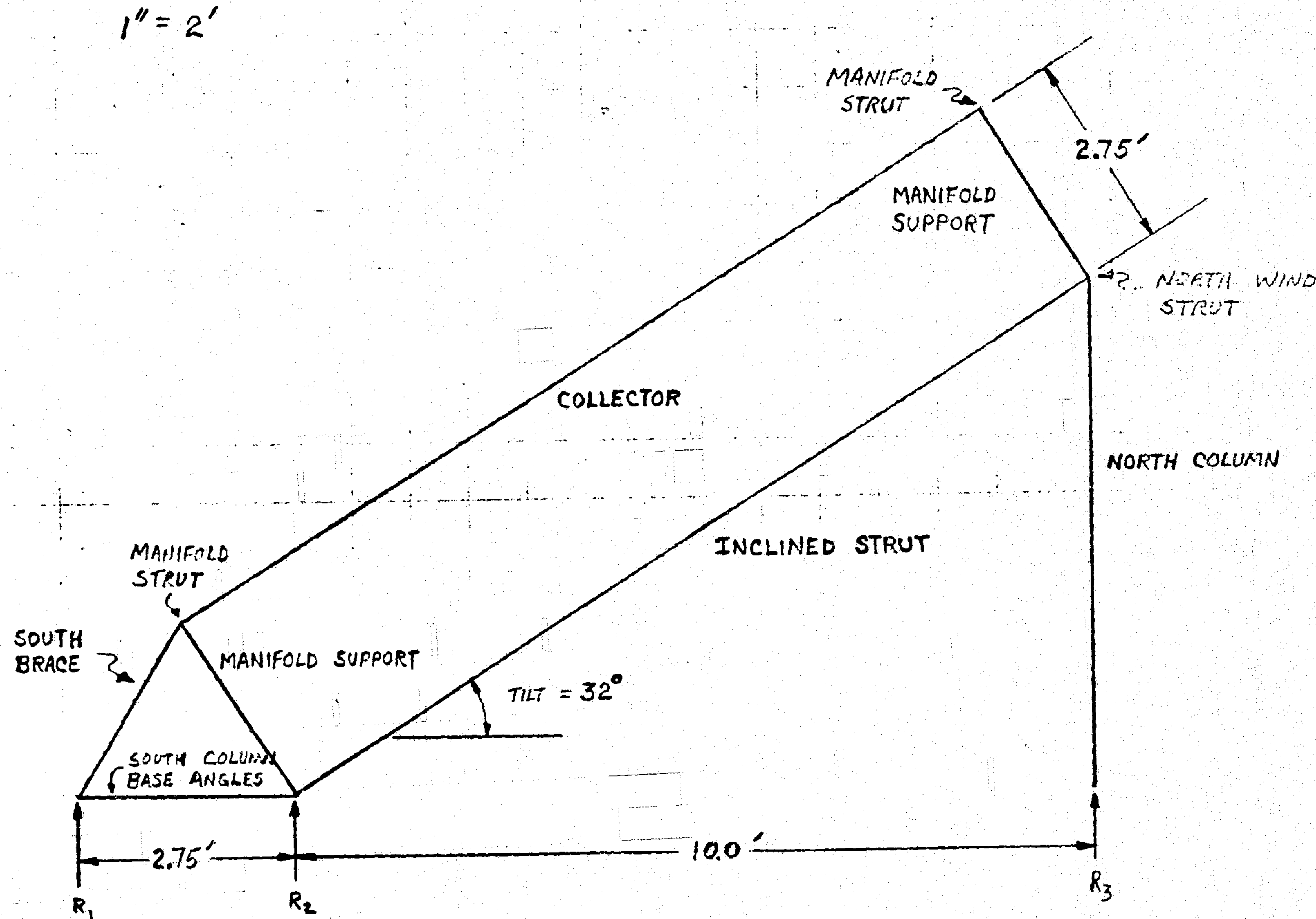
Structural calculations follow paragraph 3.2.2.

3.2.1&3.2.2 ULTIMATE LOAD COMBINATIONS-ICE LOADS

One-inch thick ice is used in the calculation of ice loads. Since the system is considered made of conventional elements only, load combinations (1)* and (4)* will be used in which the load factors* are taken as 1.0.

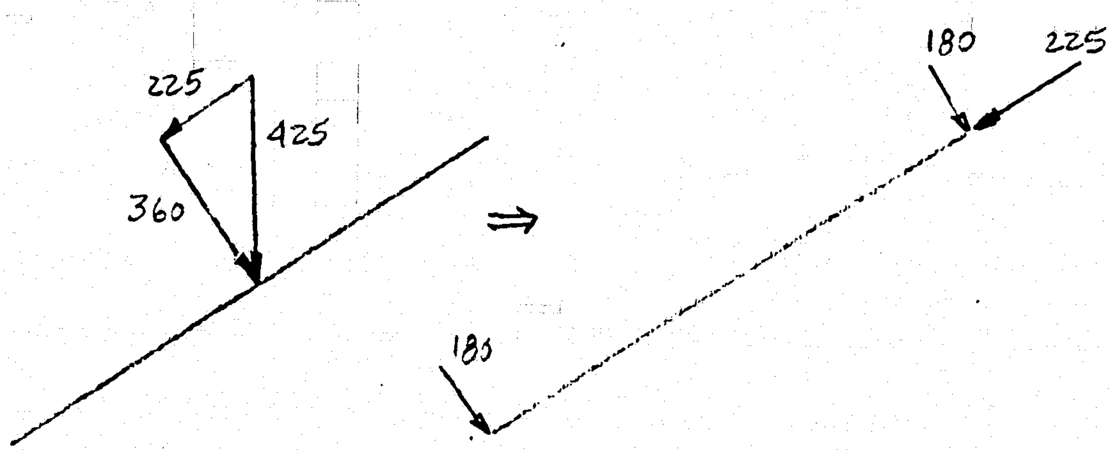
Structural analysis follows in the subsequent pages.

*Load factors and load combinations are explained in Paragraphs 3.2.1 and 3.2.2 of the IPC Manuals.

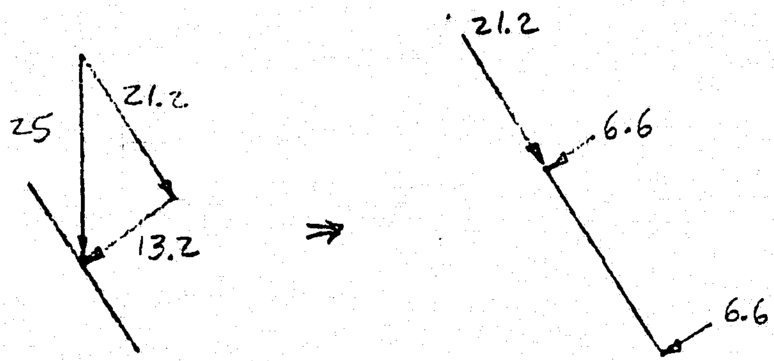

1" = 2'
MANIFOLD STRUT
2.75'
MANIFOLD SUPPORT
NORTH WIND STRUT
COLLECTOR
NORTH COLUMN
INCLINED STRUT
MANIFOLD STRUT
SOUTH BRACE
MANIFOLD SUPPORT
TILT = 32°
SOUTH COLUMN
BASE ANGLES
2.75'
10.0'
R1
R2
R3

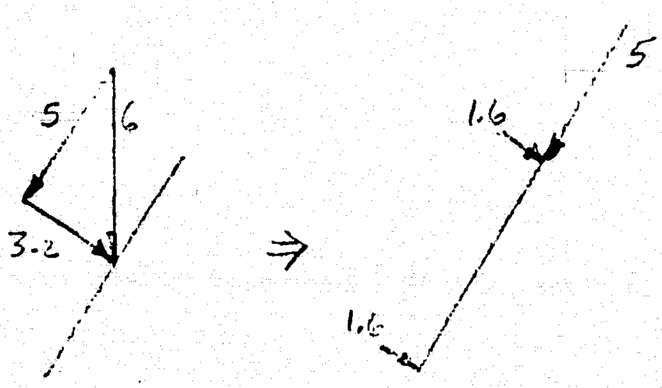
DEAD LOADS

COLLECTOR



MANIFOLD SUPPORT

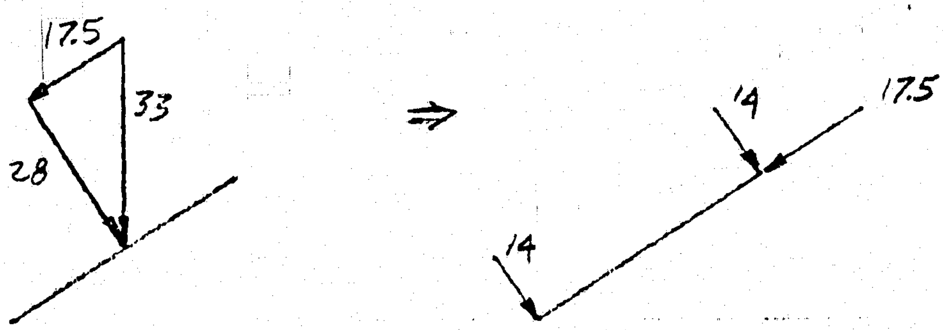


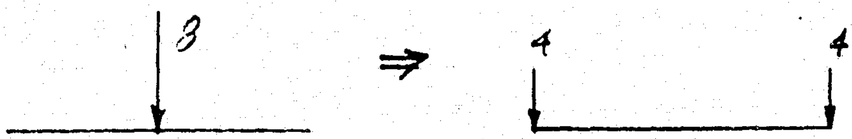


SOUTH BRACE

DEAD LOADS

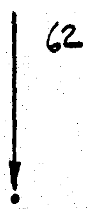
INCLINED STRUT



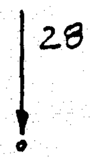


2 SOUTH COL.
BASE ANGLES

MANIFOLD STRUT

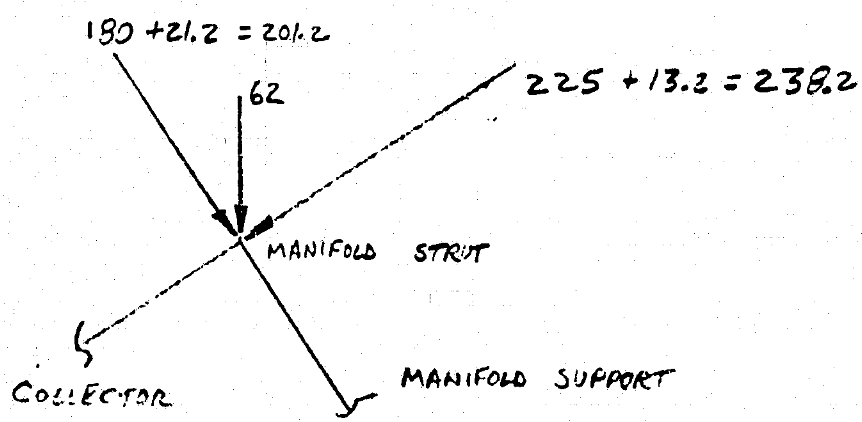


NORTH COLUMN

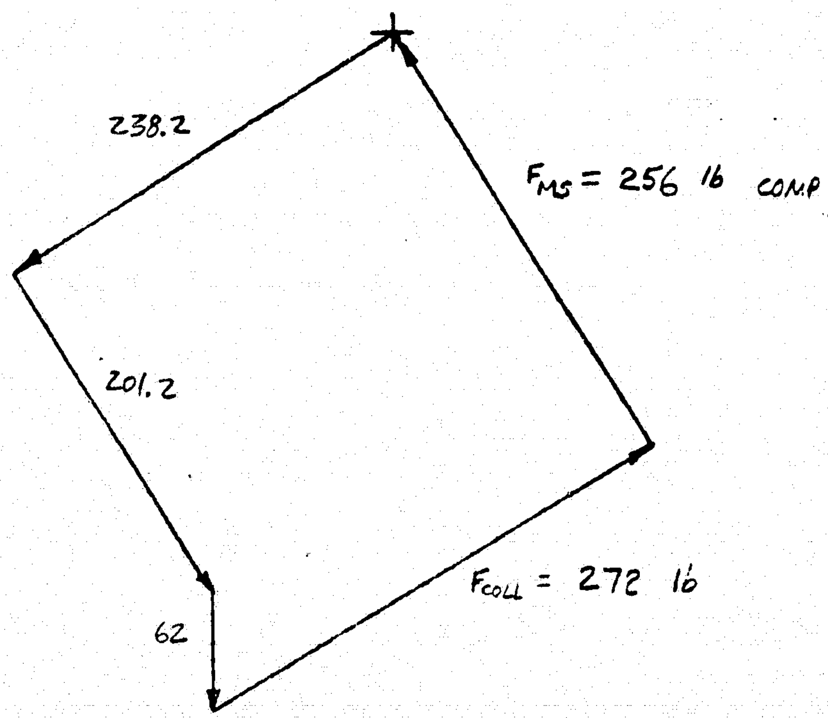


NORTH WIND STRUT

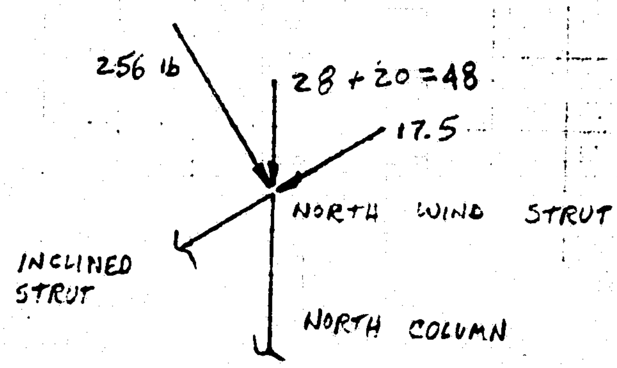
DEAD LOADS



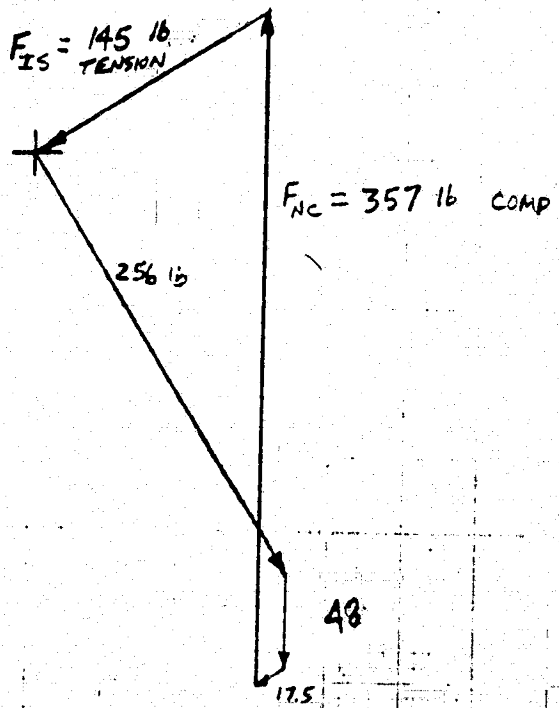
1" = 100 lb



DEAD LOADS

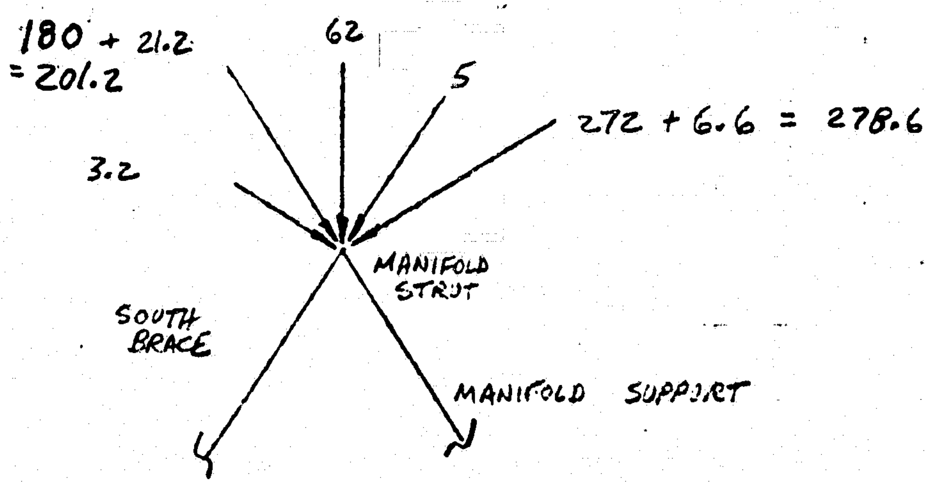


1" = 100 lb

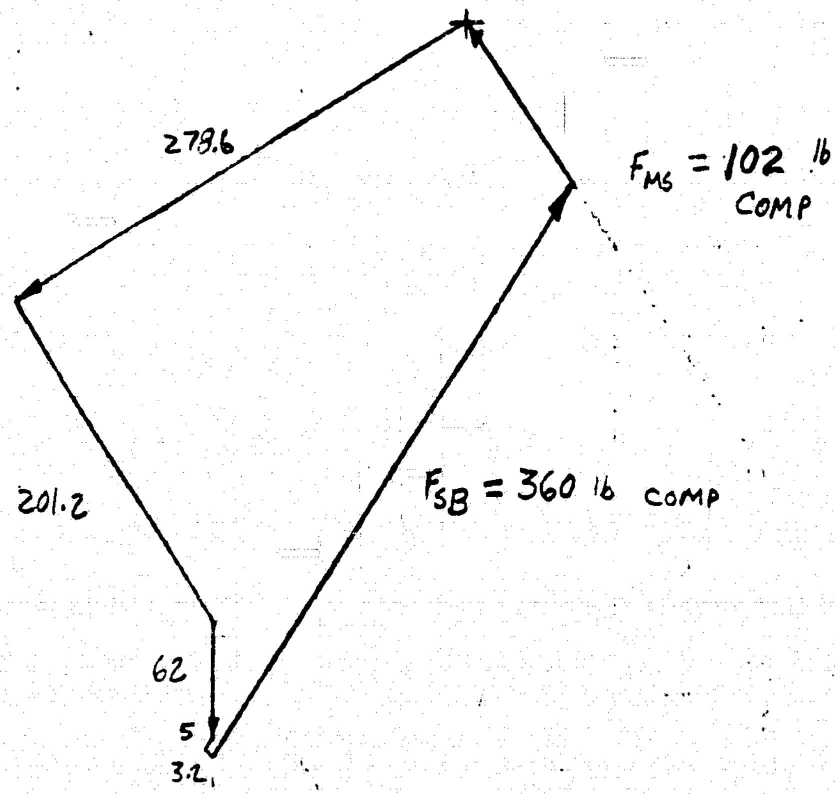


R_3 = 357 lb DEAD LOAD

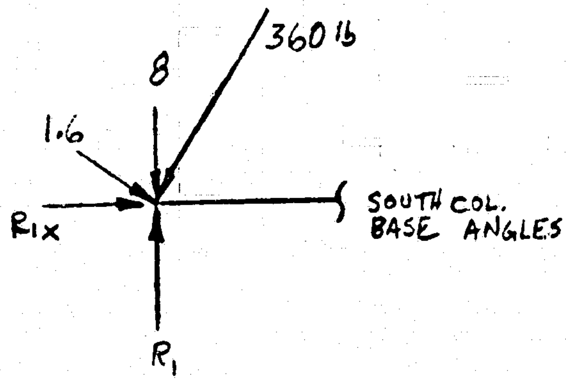
DEAD LOADS



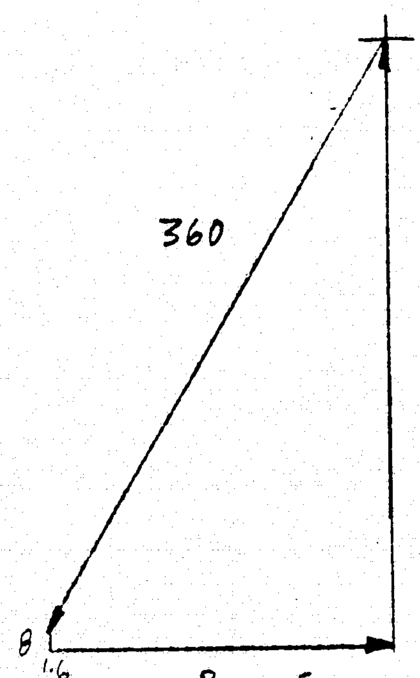
1" = 100 lb



DEAD LOADS



1" = 100 lb

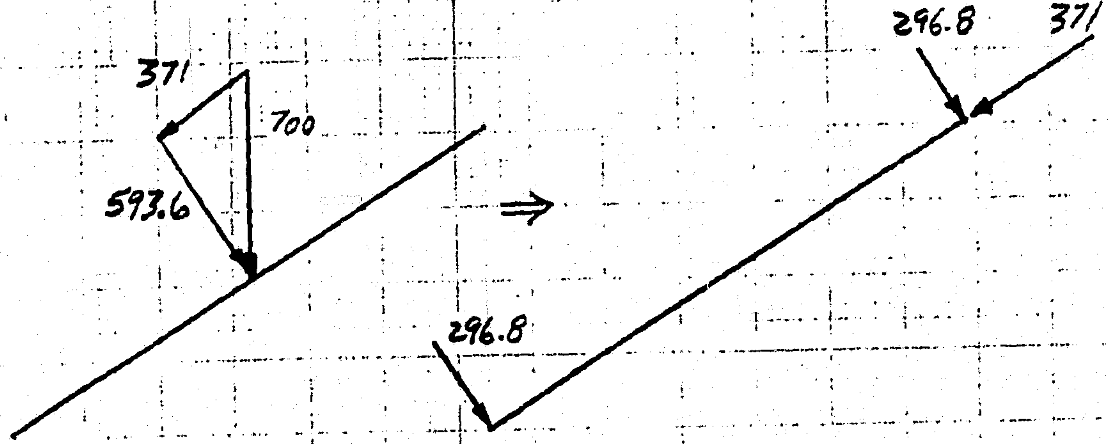


$+\uparrow \; \Sigma F_x = 0 = 319 + 357 + R_z - 425 - 2(25) - 6 - 33 - 8 - 2(62) - 20 - 28$

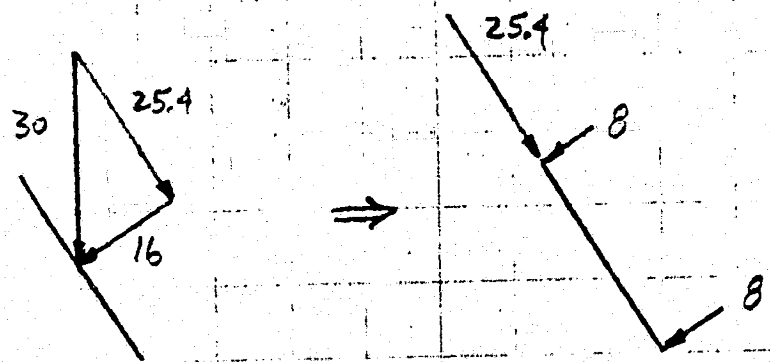
$R_z = 18$ lb DEAD LOAD

LIVE LOADS

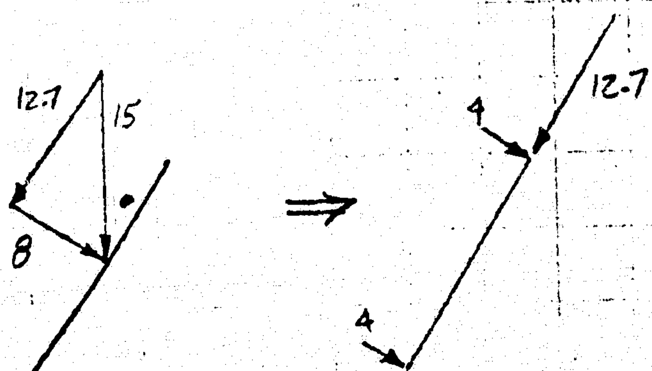
COLLECTOR



MANIFOLD SUPPORT

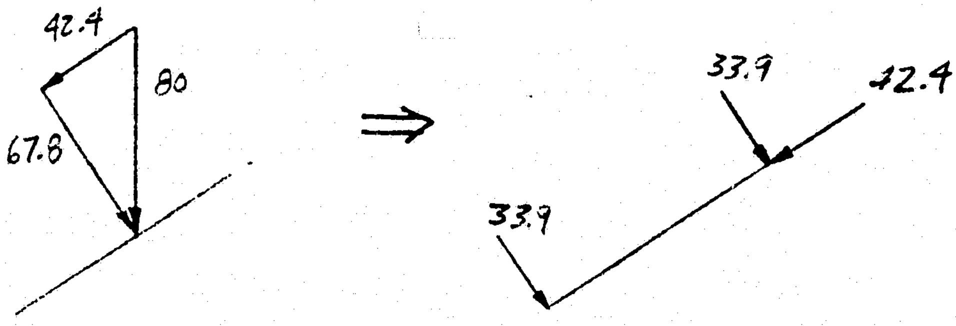


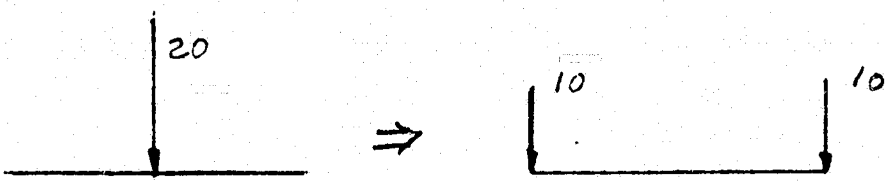
SOUTH BRACE



LIVE LOADS

INCLINED STRUT

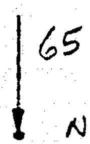




2 SOUTH COL.
BASE ANGLES

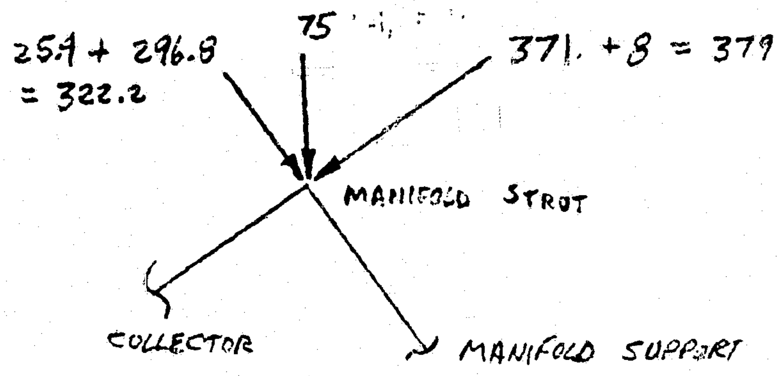
MANIFOLD STRUT

NORTH COLUMN

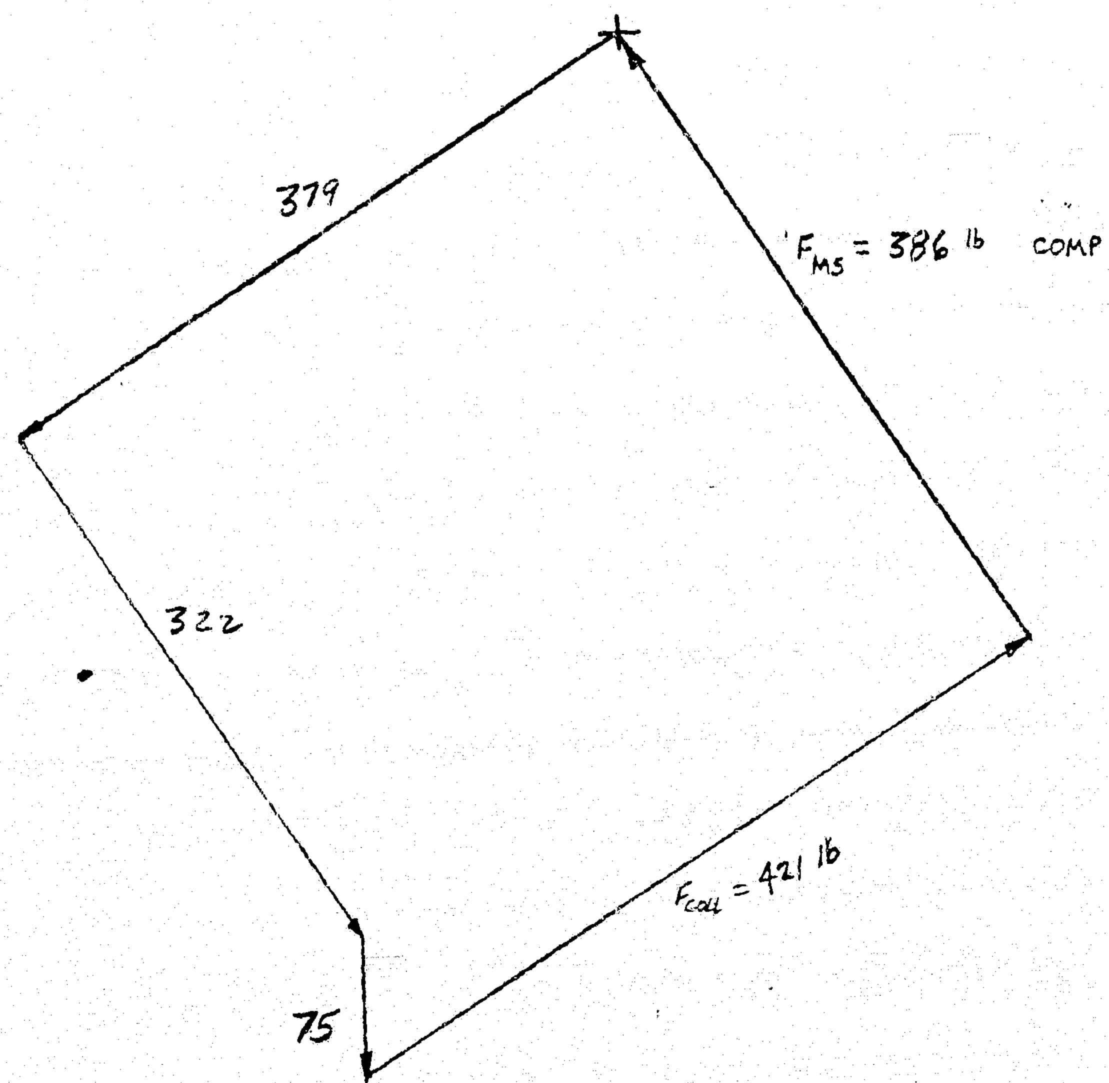


NORTH WIND STRUT

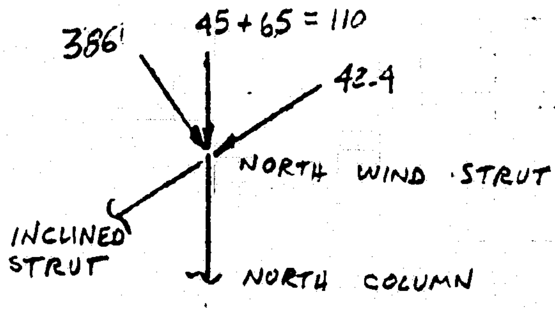
LIVE LOADS

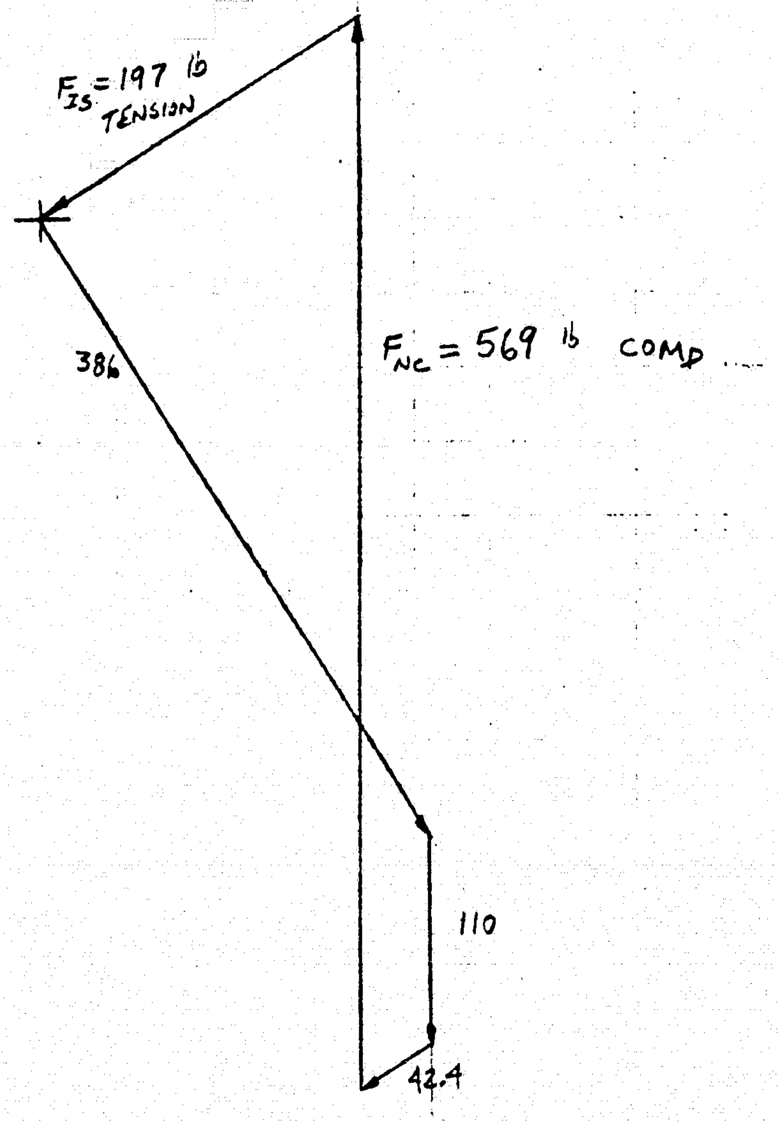


1" = 100 lb



LIVE LOADS

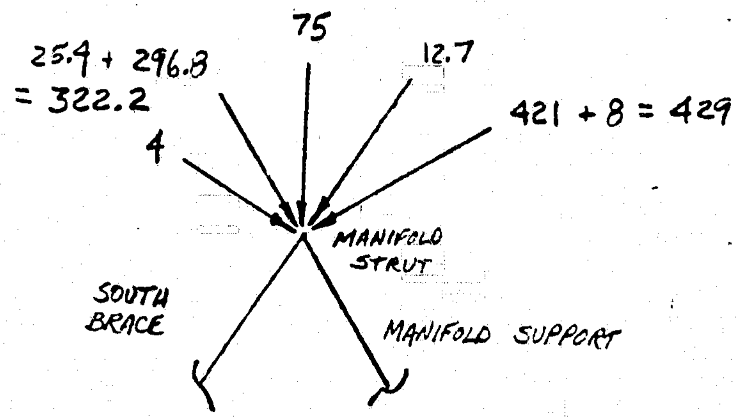




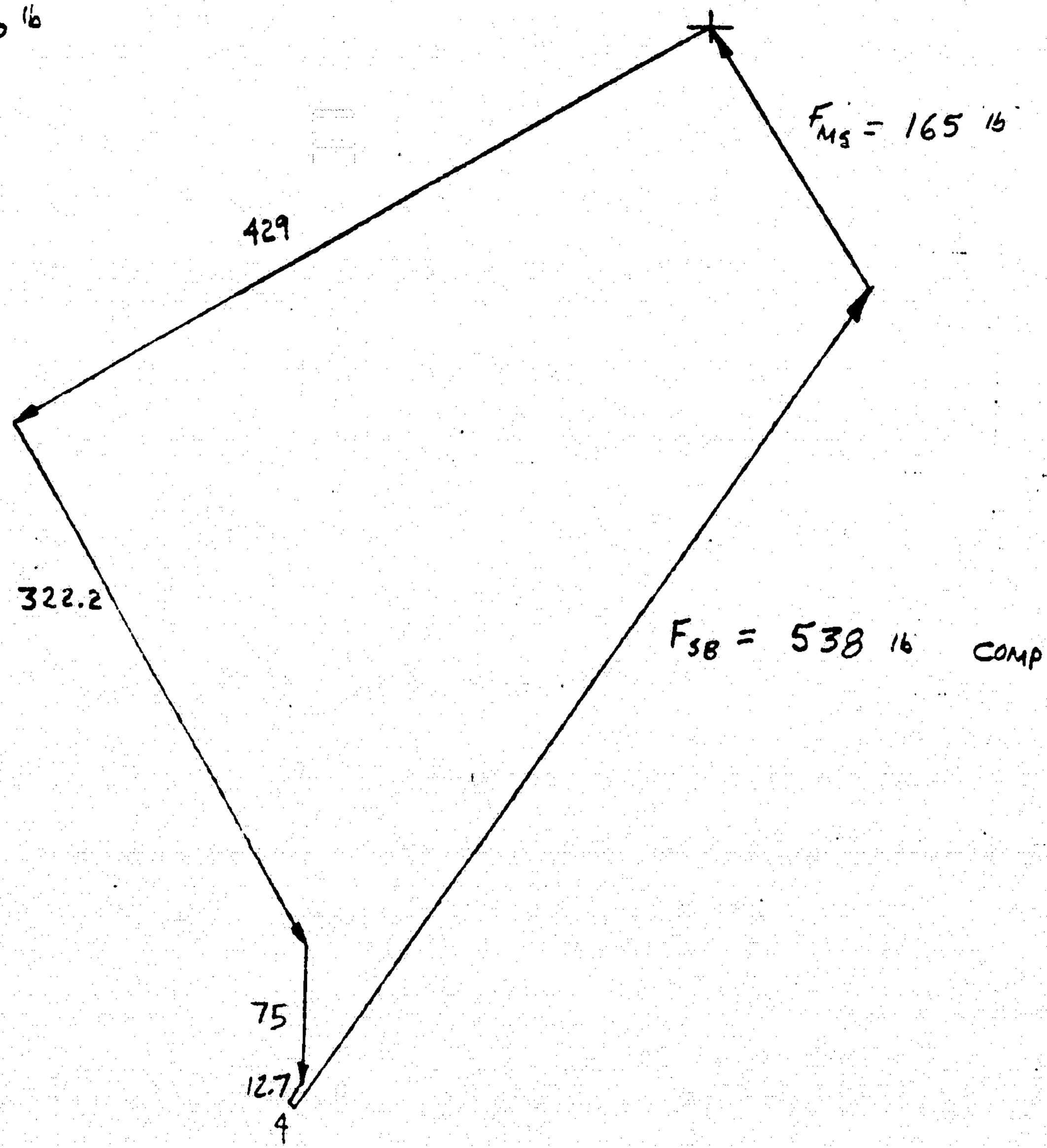
R_3 = 569 lb

C-2

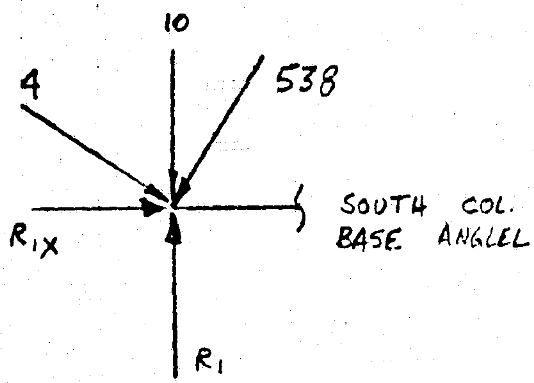
LIVE LOADS



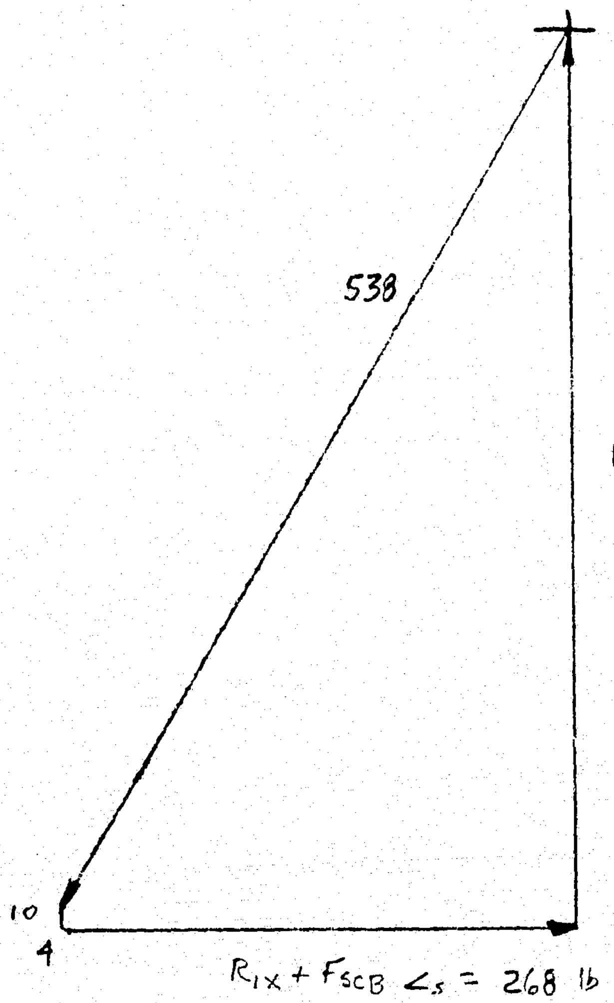
1" = 100 lb



LIVE LOADS



1" = 100 lb



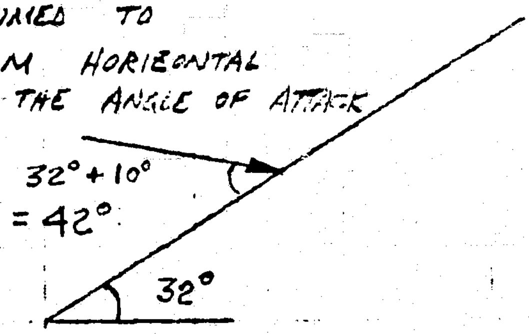
$R_1 = 472$ lb LIVE LOAD

$$+\uparrow \Sigma F_x = 0 = 472 + 569 + R_2 - 700 - 2(30) - 15 - 80 - 20 - 2(75) - 45 - 65$$

$R_2 = 94$ lb LIVE LOAD

COLLECTOR

THE WIND IS ASSUMED TO DEVIATE BY ± 10° FROM HORIZONTAL SO 42° IS USED AS THE ANGLE OF ATTACK



$W = q C_F A$

$A = (4.8)(11) \sin(42°) = 35.3 \ ft^2$

$q = 19 \ lb/ft^2$ - TABLE 6 ANSI A58.1-1972

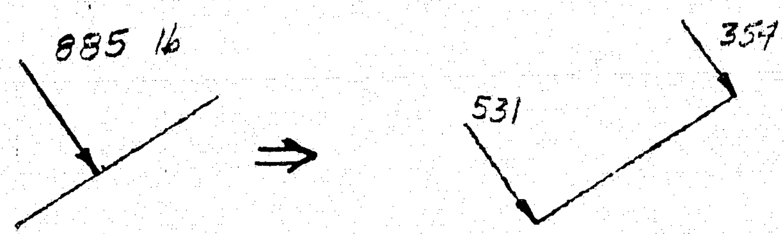
$\lambda = \dfrac{4.8}{11(\sin 42°)} = .65$

$C_F = 1.32$ - TABLE 13 ANSI A58.1-1972

$\dfrac{X}{C} = .4$ - TABLE 14 " "

$X = 4.4 \ ft$ CENTER OF PRESSURE

$W_{COLL} = (19)(1.32)(35.3) = 885 \ lb$



INCLINED STRUT

42° IS USED AS THE ANGLE OF ATTACK

$W = q C_F A$

$A = (.43)(11) \sin 42° = 3.2 \text{ ft}^2$

$q = 19 \text{ lb/ft}^2$ TABLE 6 ANSI A58.1-1972

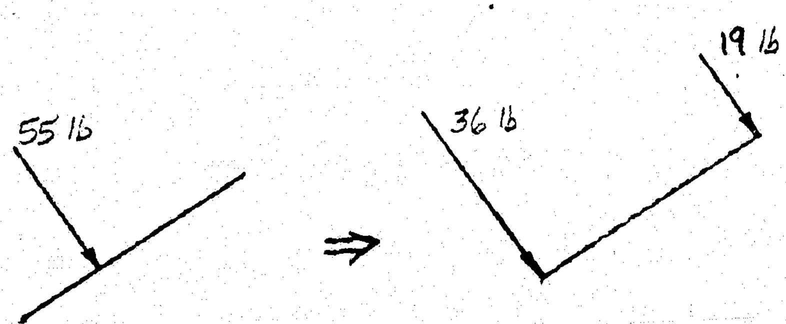
$\lambda = \frac{.43}{(11)(\sin 42°)} = .06$

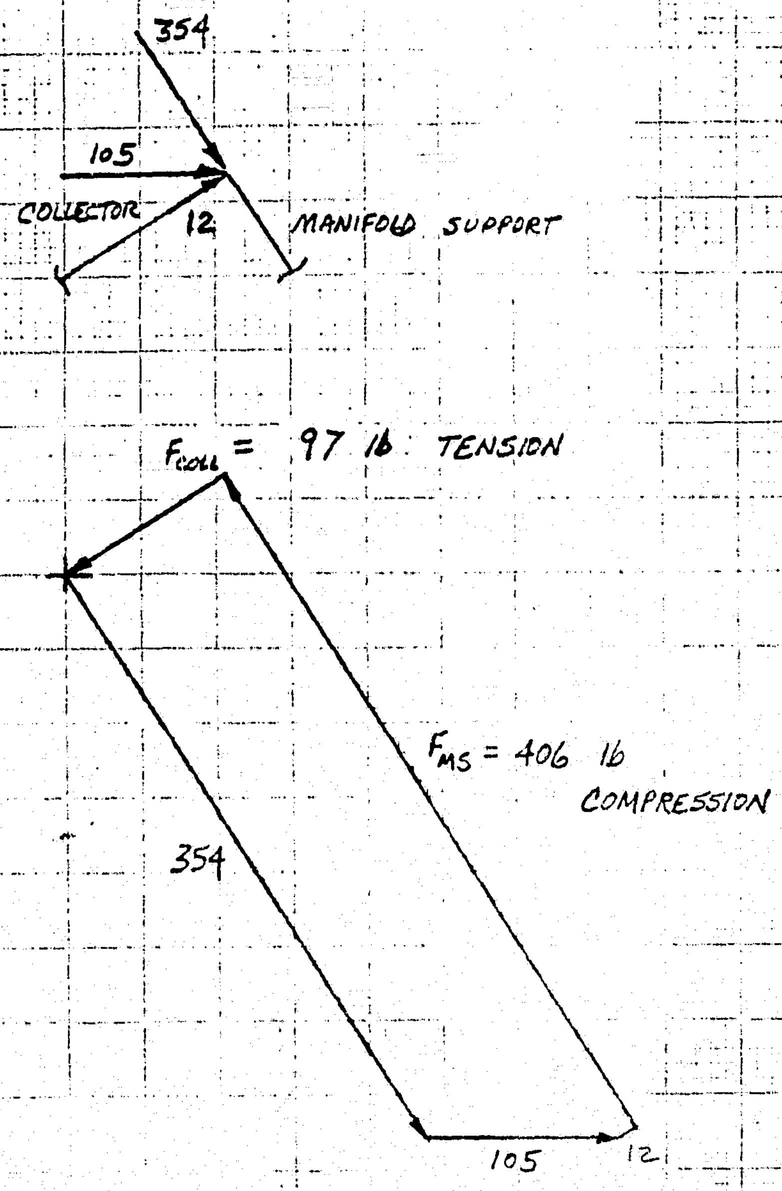
$C_F = .9$ TABLE 13 ANSI A58.1-1972

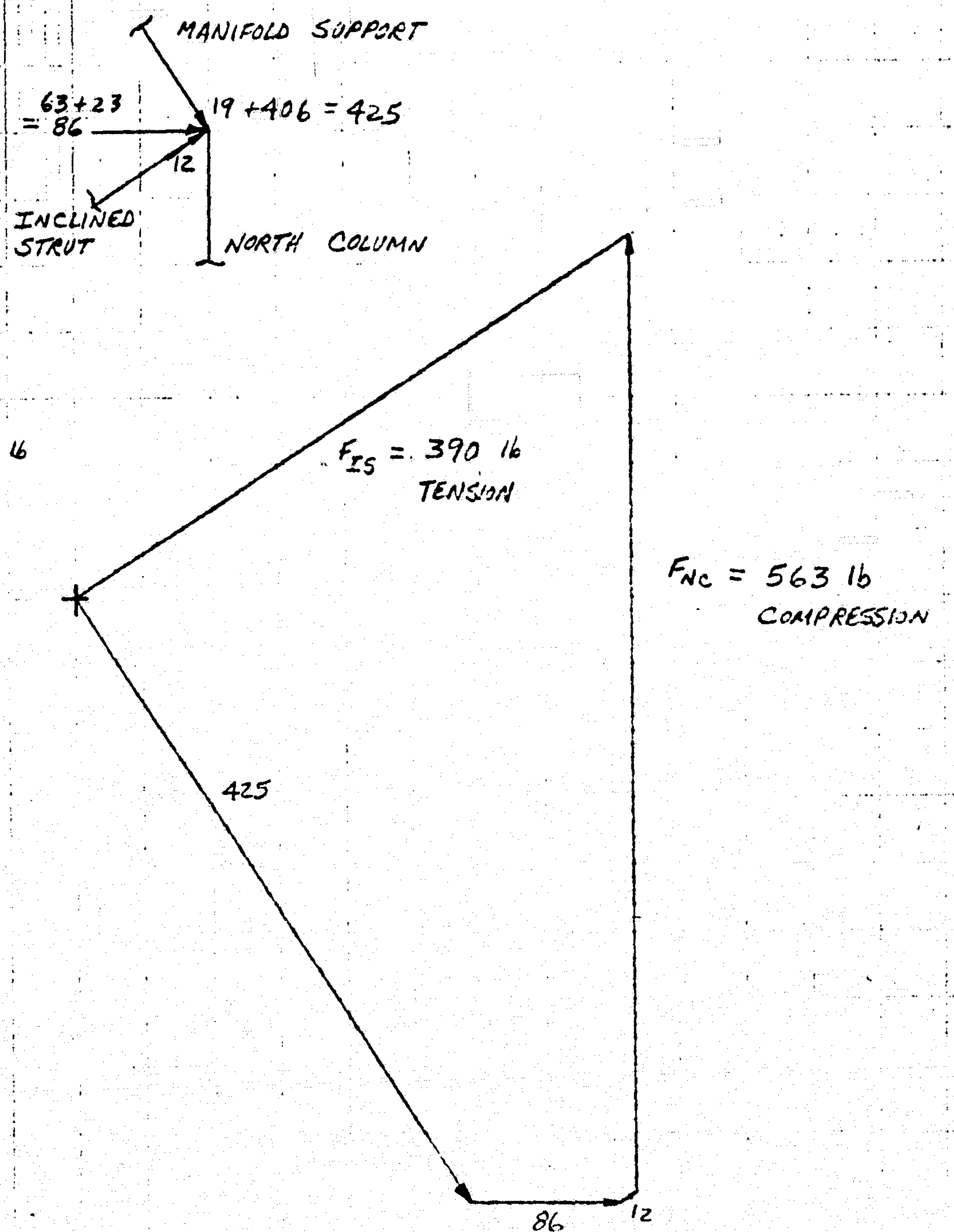
$\frac{X}{C} = .35$ TABLE 14 " "

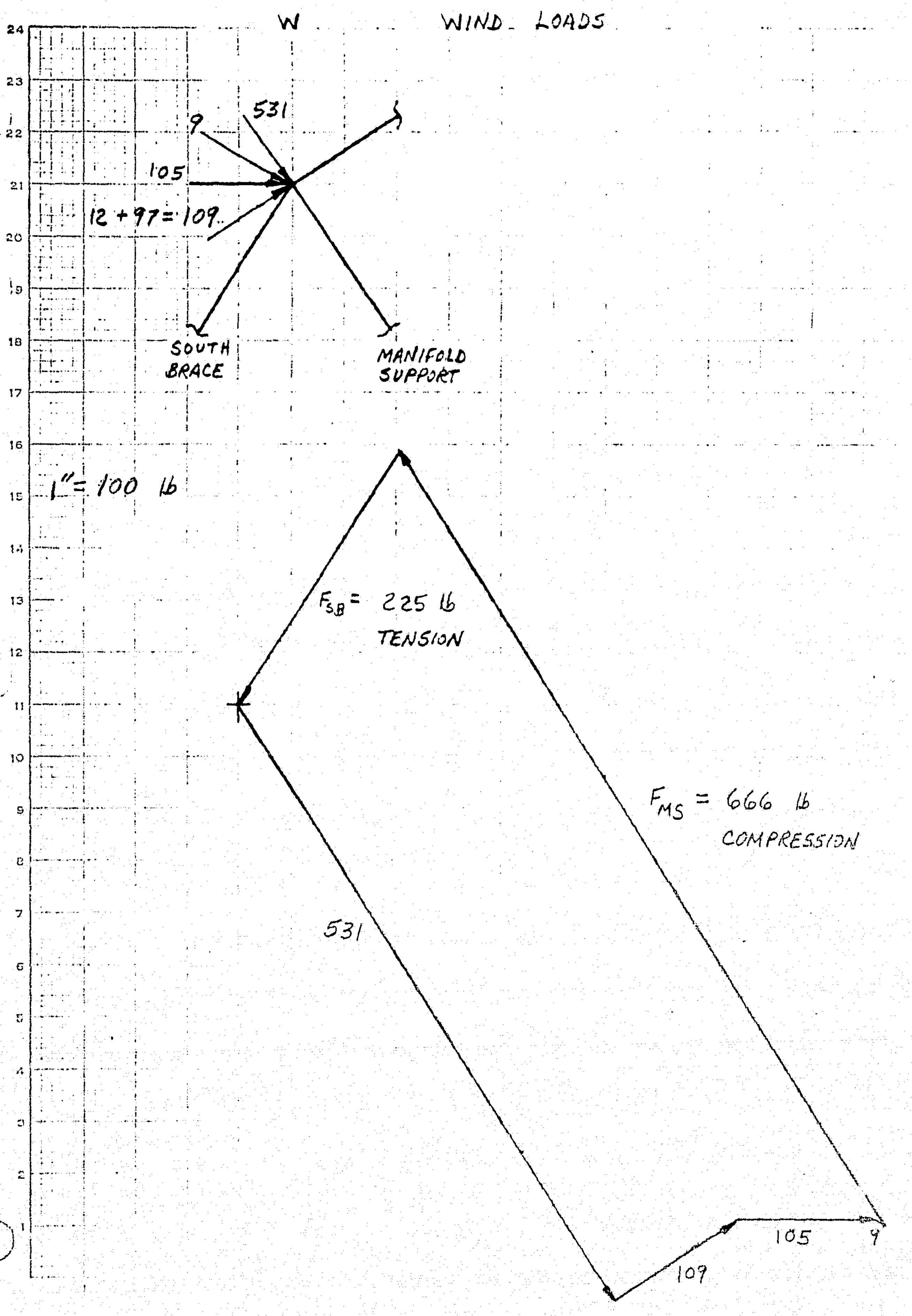
$X = 3.85 \text{ ft}$ CENTER OF PRESSURE

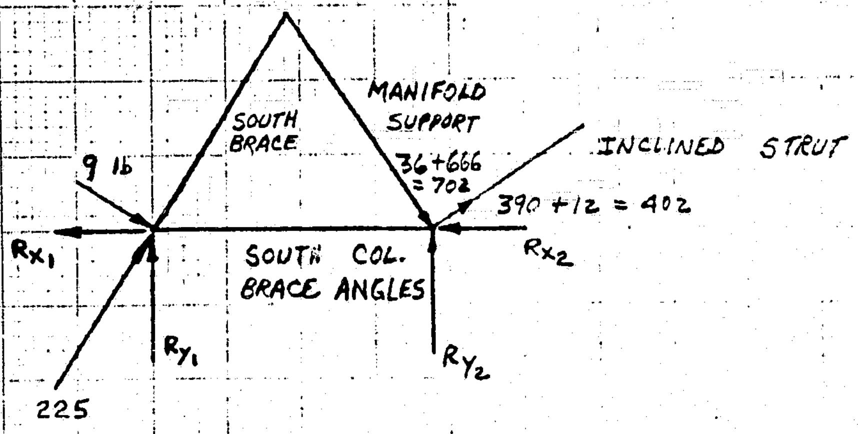
$W_{IS} = (19)(.9)(3.2) = 55 \text{ lb}$



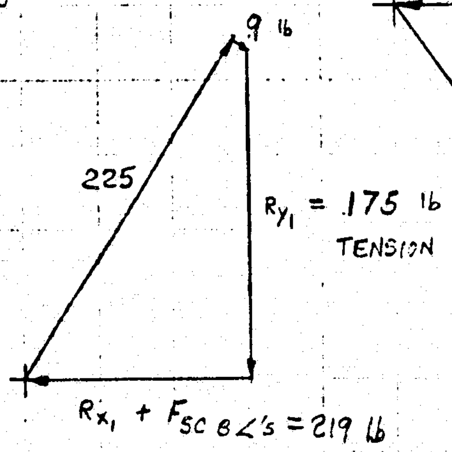

354
105
COLLECTOR
12
MANIFOLD SUPPORT
1" = 100 lb
F_COLL = 97 lb TENSION
F_MS = 406 lb
COMPRESSION
354
105
12


MANIFOLD SUPPORT
63+23
= 86
19 + 406 = 425
12
INCLINED
STRUT
NORTH COLUMN
1" = 100 lb
F_{IS} = 390 lb
TENSION
F_{NC} = 563 lb
COMPRESSION
425
86
12

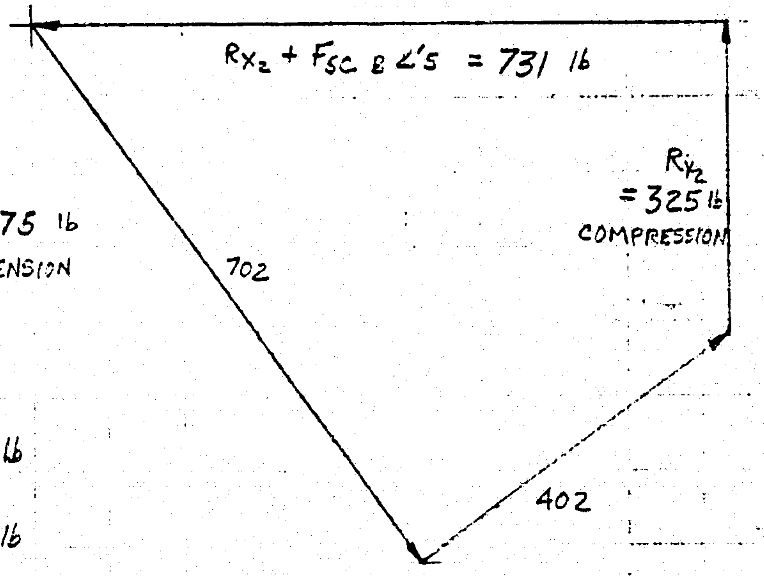

W
WIND LOADS
531
9
105
12 + 97 = 109
SOUTH BRACE
MANIFOLD SUPPORT
1" = 100 lb
F_{SB} = 225 lb
TENSION
F_{MS} = 666 lb
COMPRESSION
531
109
105
9



1" = 100 lb



1" = 200 lb

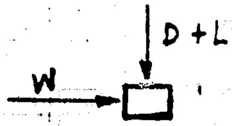


$R_{x_2} - R_{x_1} = 731 - 219 = 512$ lb

$R_{x_1} + R_{x_2} = \Sigma W_x$

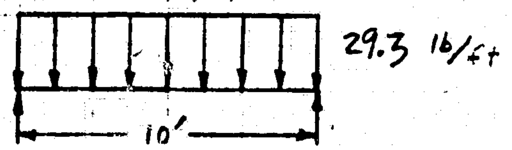
MAX. POSSIBLE $F_{SC\,B\angle's} = 219$ lb TENSION

MANIFOLD STRUT

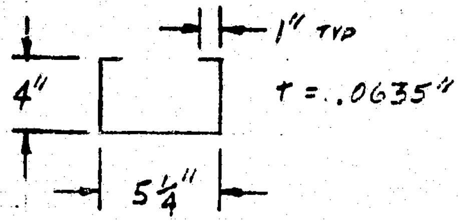


$D + L = 2(62 + 75) = 274$

$D + L + W = \sqrt{274^2 + 105^2} = 293$ lb



$\sigma_{MAX} \approx \frac{M_{MAX}\, C}{I}$ $\qquad M_{MAX} = \frac{\omega L^2}{8} = \frac{29.3 \text{ lb/ft} (10 \text{ ft})^2}{8} = 366$ ft-lb $= 4392$ in-lb



SECTION	A	Y	YA
BOTTOM	.0635 x 5.25 = .3334	.03175	.0106
WEBS	2 x 3.873 x .0635 = .4919	2	.9838
FLANGES	2 x 1 x .0635 = .127	3.9683	.5040
	Σ .9523		Σ 1.4984

$\bar{Y} = \frac{1.4984}{.9523} = 1.57''$

SECTION	I_o	Ah^2
BOTTOM	$\frac{1}{12} \times 5.25 \times .0635^3 = .000$ IN⁴	$5.25 \times .0635 \times 1.54^2 = .791$ IN⁴
WEBS	$2 \times \frac{1}{12} \times .0635 \times 3.873^3 = .615$ IN⁴	$2 \times .0635 \times 3.873 \times .43^2 = .091$ IN⁴
FLANGES	$2 \times \frac{1}{12} \times 1 \times .0635^3 = .000$ IN⁴	$2 \times .0635 \times 1 \times 2.4^2 = .731$ IN⁴
	Σ .615 IN⁴	1.613 IN⁴

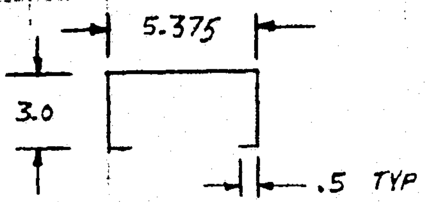
$I_{xx} = .615 + 1.613 = 2.228$ in⁴

$\sigma_{MAX} \approx \frac{(4392 \text{ in-lb})(2.43 \text{ in})}{2.228 \text{ in}^4} = 4790 \text{ psi} \ll 33{,}000 \text{ psi}$

SOUTH BRACE

$D+L = 360 + 538 = 898\ lb$ COMP

$D+L+W = 898\ lb - 225\ lb = 673\ lb$ COMP



SECTION	A	Y	YA
TOP	$.0635 \times 5.375 = .3413$	2.9683	1.0131
WEBS	$2 \times .0635 \times 2.873 = .3649$	1.5	.5473
FLANGES	$2 \times .0635 \times .5 = .0635$	.03175	.0020
	$\Sigma\ .7697$		$\Sigma\ 1.5624$

$$\bar{Y} = \frac{1.5624}{.7697} = 2.03''$$

SECTION	I_o	Ah^2
TOP	$\frac{1}{12} \times 5.375 \times .0635^3 = .000$	$.3413 \times .94^2 = .302$
WEBS	$2 \times \frac{1}{12} \times .0635 \times 2.873^3 = .251$	$.3649 \times .53^2 = .103$
FLANGES	$2 \times \frac{1}{12} \times .5 \times .0635^3 = .000$	$.0635 \times 2.0^2 = .254$
	$\Sigma\ .251$	$\Sigma\ .659$

$$I_x = .251 + .659 = .91\ in^4$$

$$P_{cr} = \frac{\pi^2 E I}{L^2} = \frac{\pi^2 \times 30 \times 10^6 \times .91}{24.2^2} = 460{,}000\ lb$$

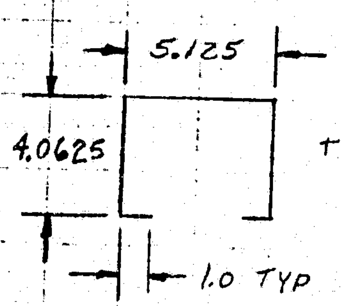
∴ BUCKLING NEED NOT BE CONSIDERED EXCEPT FOR MUCH LONGER MEMBERS

$$\sigma = \frac{P}{A} = \frac{898}{.7697} = 1167\ psi \ll 33{,}000\ psi$$

MANIFOLD SUPPORT

D+L = 256 + 386 = 642 lb COMP

D+L+W = 642 + 406 = 1048 lb COMP



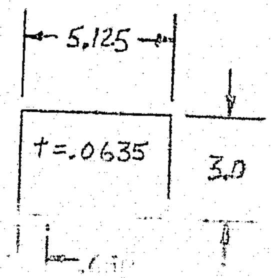
SECTION	A
TOP	5.125 X .0635 = .3254
WEBS	2 X .0635 X 3.9355 = .4998
FLANGES	2 X 1 X .0635 = .127
	Σ .9522

$\sigma = \frac{1048}{.9522} = 1100$ psi << 33,000 psi

INCLINED STRUT

D+L = 145 + 197 = 342 lb TENSION

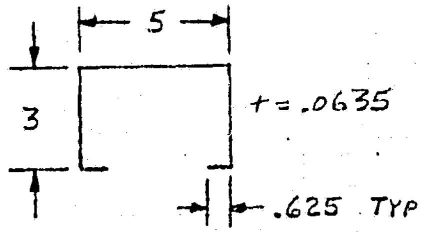
D+L+W = 342 + 390 = 732 lb TENSION



SECTION	A
TOP	.0635 X 5.125 = .3254
WEBS	2 X 2.873 X .0635 = .3649
FLANGES	2 X .658 X .0635 = .0836
	Σ .7739

$\sigma = \frac{732 \text{ lb}}{.7739 \text{ in}^2} = 946$ psi << 33,000 psi

NORTH COLUMN

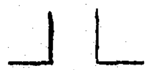


D + L = 357 + 569 = 926 lb COMP
D + L + W = 926 + 563 = 1489 lb COMP

SECTION	A
TOP	.0635 x 5 = .3175
WEBS	2 x .0635 x 2.873 = .3649
FLANGES	2 x .0635 x .625 = .0794
	Σ .7618

$$\sigma = \frac{1489}{.7618} = 1954 \text{ psi} \ll 33{,}000 \text{ psi}$$

SOUTH COLUMN BASE ANGLES

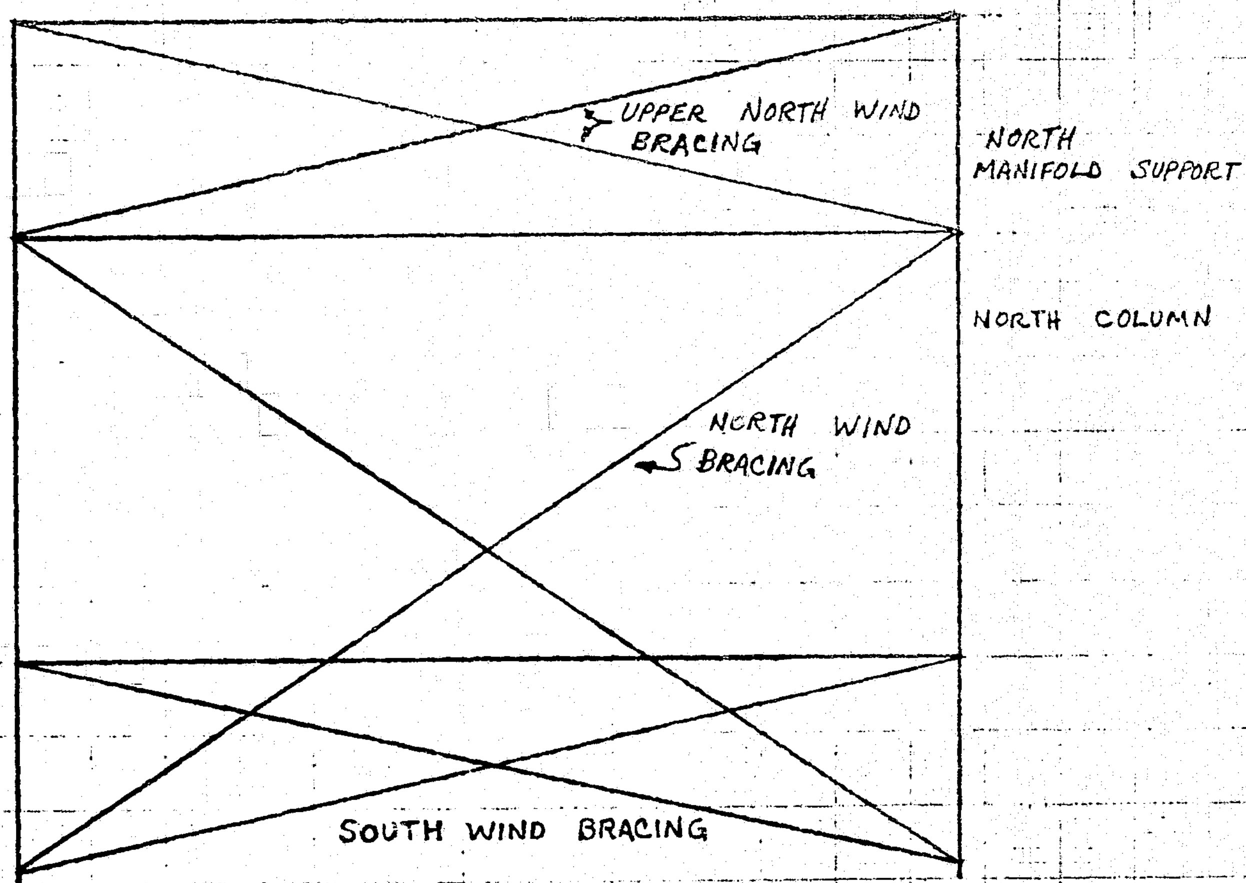


D + L ≤ 181 + 268 = 449 lb TENSION
D + L + W ≤ 449 + 219 = 668 lb TENSION

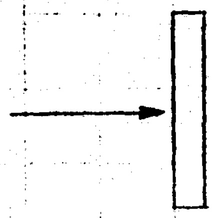
$$A = 2 \times (2.25 + 3.3) \times .25 = 2.775 \text{ IN}^2$$

$$\sigma = \frac{668}{2.775} = 241 \text{ psi} \ll 33{,}000 \text{ psi}$$

SIDE WIND LOAD



SIDE WIND LOADS



FOR ANALYSIS THE COLLECTOR IS ASSUMED TO BE PERPINDICULAR TO HORIZONTAL. THIS IS WORSE THAN WORST CASE BECAUSE THE COLLECTORS WILL NOT BE ALLOWED TO ROTATE THIS FAR.

$W = q C_F A$ $q = 19 \frac{lb}{ft^2}$ - TABLE 6 ANS A58.1-1972

$C_F = 1.32$ - WORST VALUE TABLE 14 ANS A58.1-1972

$A = 4.8' \times 11' = 52.8 \ ft^2$

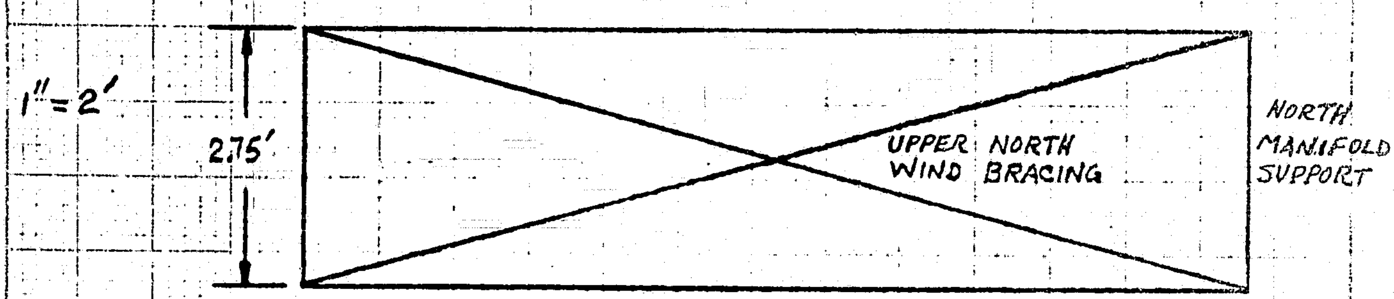
$W = \left(19 \frac{lb}{ft^2}\right)(1.32)(52.8 ft^2) = \underline{\underline{1324 \ lb}}$

SIDE WIND LOADS ON THE OTHER COMPONENTS ARE NOT CONSIDERED, BECAUSE THEY ARE SMALL WHEN COMPARED TO THE COLLECTOR LOADING, AND THE ANALYSIS IS VERY CONSERVATIVE WITHOUT THEIR USE. FURTHERMORE, SHIELDING OF THE WIND FROM ONE COLLECTOR BY THE PREVIOUS COLLECTOR IS NOT TAKEN INTO ACCOUNT. THIS WILL RESULT IN AN EXTREMELY CONSERVATIVE ANALYSIS.

3 SECTIONS WITH WIND BRACING WILL CARRY THE SIDE LOAD FROM 7 COLLECTORS. THEREFORE, THE SIDE LOAD CARRIED PER EACH WIND BRACED SECTION IS

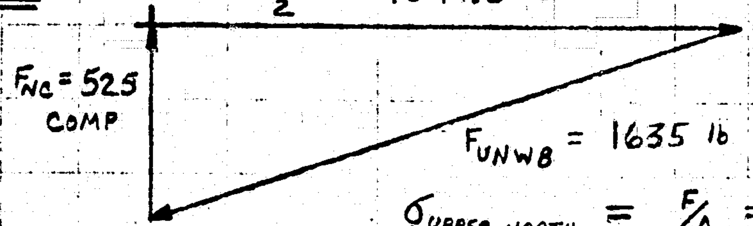
$1324 \ lb \times \frac{7}{3} = \underline{\underline{3089 \ lb}}$

SIDE WIND LOAD



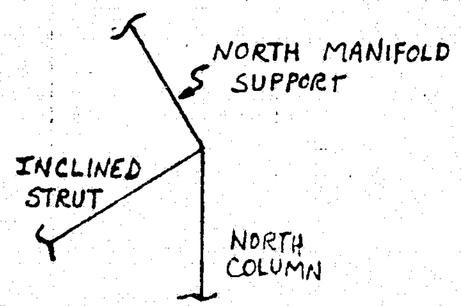
1" = 500 lb

$F_W = \frac{3089}{2} = 1544.5$ lb

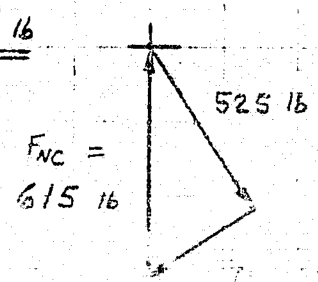


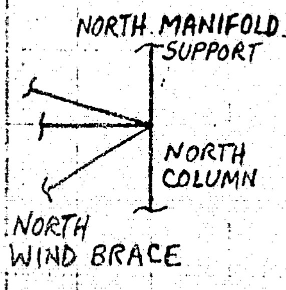
F_{UNWB} = 1635 lb TENSION

$\sigma_{\text{UPPER NORTH WIND BRACE}} = F/A = \frac{1635 \text{ lb}}{.078 \text{ in}^2} = 20{,}962$ lb/in²

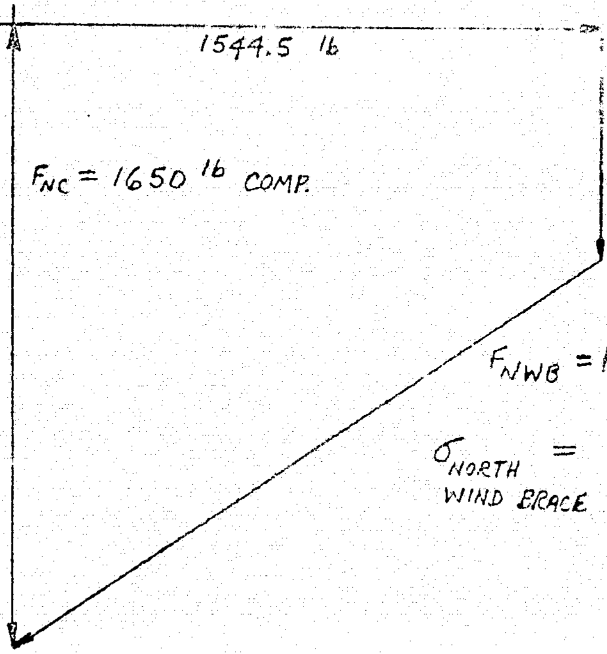


1" = 500 lb





1" = 500 lb



F_{NWB} = 1860 lb [illegible]

$\sigma_{\text{NORTH WIND BRACE}} = \frac{1860 \text{ lb}}{.078 \text{ in}^2}$ = 23,[illegible] lb/in²

THE WIND BRACING IS 3/8" ROUND THREADED STEEL ROD WITH A TENSILE STRESS AREA OF .078 IN^2 AND TENSILE STRENGTH OF 60,000 lb/in^2. FOR A SAFETY FACTOR OF $n_u = 2$, THE MAXIMUM ALLOWABLE STRESS IS

$$\sigma_{MAX} = \frac{\sigma_u}{n_u} = \frac{60,000}{2} = \underline{\underline{30,000 \ lb/in^2}} > 23,846 \ lb/in^2$$

THE ANALYSIS FOR THE UPPER NORTH WIND BRACING WILL ALSO APPLY TO THE SOUTH WIND BRACING.

3.2.3 VEHICULAR LOADS

The collector system is not intended for below grade installation and, therefore, will not be subjected to vehicular loading.

3.2.4 Load Capacity; Resistance to Damage; Deflection Limitations;
3.3.1 Foundation Settlement; Contraction and Expansion:
3.4.1
3.8.1

The system is considered to be made of conventional elements and, therefore, is deemed to satisfy these criteria.

3.3.2 GLAZING DESIGN

Glazing material is Du Pont Lucite 147 with the following physical properties:

MODULUS ELASTICITY FLEXURAL (ASTM-D638	450,000 PSI
FLEXURAL STRENGTH (ASTM-D790)	17,000 PSI
SHEAR STRENGTH (ASTM-D732)	9,400 PSI

An analysis purely as a simple beam indicates that a uniform load of 184 PSF could be applied before failure would occur. Considering the probable loads that may be encountered in use and these working loads, it appears that the acrylic lens material would satisfy such conditions.

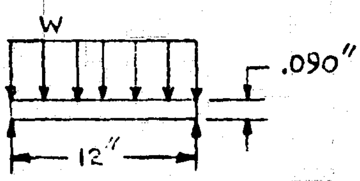
Furthermore, the above does not give credit to shape factory of lens which would increase load capacity to a degree.

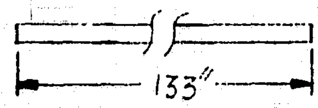
Past experience of Northrup Concentrating Collectors has proven that no detrimental damage to the lens has occured with approximately 3" of ice or 12" snow, on a lens having a greater radius than this design. This would indicate this design with smaller radius could endure greater loads than the past experience.

Also during past experience with over 6000 collectors in use, there has never been an instance that lens have failed due to effect of hail storm.

Analysis is performed on the next page,

GLAZING: ALLOWABLE DISTRIBUTED LOADS





$E = 450{,}000\ \text{lb/in}^2$

$\sigma\ MAX = 17{,}000\ \text{lb/in}^2$

$\tau\ MAX = 9{,}400\ \text{lb/in}^2$

$$I = \frac{1}{12} bh^3 = \frac{1}{12} \times (133\ \text{in})\ (.090\ \text{in})^3 = .00808\ \text{in}^4$$

$$\sigma\ MAX = \frac{M_{Max} C}{I} \qquad M_{MAX} = \frac{1}{8} WL^2 = \frac{W}{8} (12\ \text{in})^2 = 18W\ \text{in}^2$$

$$C = \frac{.090\ \text{in}}{2} = .045\ \text{in}$$

$$\sigma\ MAX = 17{,}000\ \text{lb/in}^2 = \frac{18W\ \text{in}^2 \times .045\ \text{in} \times W}{.00808\ \text{in}^4}$$

$W = 170\ \text{lb/in}$

$$W = \frac{170\ \text{lb/in} \times 12\ \text{in}}{12\ \text{in} \times 133\ \text{in}/144\ \frac{\text{in}^2}{\text{ft.}^2}} = \underline{\underline{184\ \text{lb/ft}^2}}$$

$$\tau = \frac{3}{2} \frac{VMAX}{A} \qquad V\ Max = \frac{WL}{2} = W \frac{12\text{in}}{2} = 6W\ \text{in}$$

$$A = .090\ \text{in} \times 133\text{in} = 12\ \text{in}^2$$

$$\tau MAX = 9{,}400\ \text{lb/in}^2 = \frac{3}{2} \times \frac{6W\ \text{in}}{12\ \text{in}^2}$$

$W = 12{,}533\ \text{lb/in}$ >> MAX per flexure

Therefore

$WMax = 184\ \text{lb/ft}^2$

The total load is

$$WA = 184\ \text{lb/ft}^2 \times \frac{133\ \text{in} \times 12\ \text{in}}{144\ \frac{\text{in}^2}{\text{ft}^2}} = 2039\ \text{lb.}$$

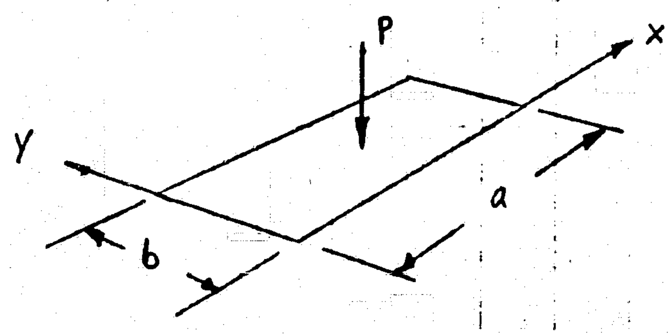
This is larger than the anticipated loading from dead, live, and wind loads combined. (see 3.1.2). Furthermore, the lens shape factor has not been taken into account which means that the glazing is more rigid than indicated.

3.7.1 HAIL LOADING

The portion of the system most susceptible to hail damage is the acrylic lens. During past experience with over 6,000 collectors in use, employing a similar lens, there has never been an instance of failure due to hail storms.

Although similarity represents the means of verification for 3.7.1, additionally, analysis is presented for a flat acrylic plate subjected to loading at the center. This model, though very approximate, is thought to be similar to the lens design to the extent that the analysis provides ample assurance that the lens will not fail on account of hail.

RECTANGULAR PLATE: SIMPLY SUPPORTED AT EDGES, CONCENTRATED LOAD AT CENTER



FROM ENERGY METHODS

$$U_b = \frac{1}{2} D \iint \left(\frac{d^2W}{dX^2} + \frac{d^2W}{dY^2} \right)^2 dX\,dY$$

U_b – STRAIN ENERGY OF BENDING

W – DEFLECTION IN THE Z-DIRECTION

$$D = \frac{Eh^3}{12(1-\mu^2)}$$

E – MODULUS OF ELASTICITY
h – PLATE THICKNESS
μ – POISSON'S RATIO

LET

$$W = c \sin\frac{\pi X}{a} \sin\frac{\pi Y}{b}$$

c – UNKNOWN COEFFICIENT

THIS SATISFIES THE BOUNDARY CONDITIONS AT THE EDGES

$$W = 0, \quad \frac{d^2W}{dX^2} = 0, \quad \frac{d^2W}{dY^2} = 0$$

$$\therefore \quad U_b = \frac{1}{8}\pi^4 abD\left(\frac{1}{a^2} + \frac{1}{b^2}\right)^2 c^2$$

THE POTENTIAL ENERGY OF THE CONCENTRATED LOAD IS

$$\Omega = -PW \qquad @ \quad X = \frac{a}{2}, \quad Y = \frac{b}{2}$$

$$\Omega = -Pc$$

$V = U_b + \Omega$ V – TOTAL POTENTIAL ENERGY

$\frac{\partial V}{\partial c} = 0$ BY THE PRINCIPAL OF STATIONARY POTENTIAL ENERGY

$$\frac{\partial V}{\partial c} = 0 = \frac{1}{4}\pi^4 abD\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2 c - P$$

$$c = \frac{4P}{\pi^4 abD\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2}$$

$$\sigma = \frac{12 M z}{h^3}$$

σ – NORMAL STRESS
M – MOMENT
z – DIMENSION ON THE z-AXIS MEASURED FROM THE CENTER OF THE PLATE THICKNESS

THE MAX. STRESS OCCURS AT

$x = \frac{a}{2}$, $y = b/2$

$$M_y = -D\frac{d^2w}{dy^2} \qquad \frac{d^2w}{dy^2} = -c\frac{\pi^2}{b^2}\sin\frac{\pi x}{a}\sin\frac{\pi y}{b}$$

@ $x = \frac{a}{2}$, $y = \frac{b}{2}$ $\qquad M_y = cD\frac{\pi^2}{b^2}$

$$\sigma_y = \frac{12\, z\, c\, \pi^2 D}{h^3 b^2} \qquad z = \frac{h}{2}$$ AT POINT OF MAX. NORMAL STRESS

$$\sigma_y = \frac{24P}{\pi^2 a b^3 h^2\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2}$$

FOR THE ACRYLIC GLAZING

$h = .090$ IN

$a = 155$ IN

$b = 12$ IN

$\sigma_{MAX} = 1.7 \times 10^4$ lb/in²

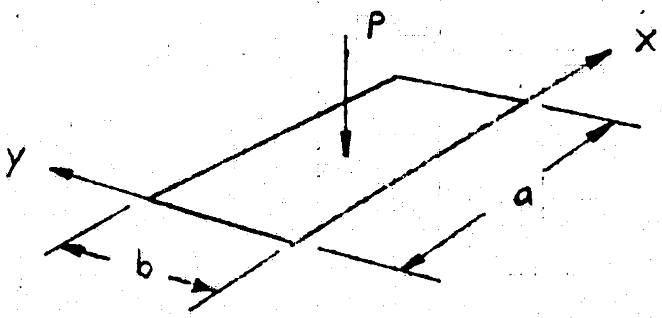
ALLOWABLE

$$P_{MAX} = \sigma_{MAX} \frac{\pi^2 a b^3 h^2 \left(\frac{1}{a^2} + \frac{1}{b^2}\right)^2}{24}$$

$$= \frac{\left(1.7 \times 10^4 \frac{lb}{IN^2}\right)}{24} \pi^2 (133\ IN)(12\ IN)^3 (.090\ IN)^2 \left[\frac{1}{(133\ IN)^2} + \frac{1}{(12\ IN)^2}\right]^2$$

$P_{MAX} = 638\ lb$ MAX. ALLOWABLE CONC. LOAD

IMPACT LOADING AT THE CENTER OF A SIMPLY SUPPORTED RECTANGULAR PLATE



$$K.E. = \frac{P\delta}{2}$$

K.E. – KINETIC ENERGY TO BE DISSIPATED BY THE PLATE

P – DYNAMIC FORCE ON THE PLATE

δ – MAXIMUM DEFLECTION AT THE CENTER OF THE PLATE

FROM THE PRECEDING ANALYSIS

$$\delta = W \quad @ \quad x = a/2 \;,\; y = b/2$$

$$\delta = \frac{4P}{\pi^4 abD\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2}$$

$$K.E. = \frac{24\, P^2(1-\mu^2)}{\pi^4 ab\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2 Eh^3} \qquad D = \frac{Eh^3}{12(1-\mu^2)}$$

$P_{MAX} = 638$ lb – PRECEDING ANALYSIS

$a = 12$ IN

$b = 133$ IN

$E = 450{,}000$ lb/IN² – ACRYLIC

$h = .090$ IN

$\mu \simeq 0$

THE MAXIMUM KINECTIC ENERGY THAT CAN BE DISSIPATED BY THE PLATE IS, THEN:

$$K.E._{\substack{MAX \\ ALLOWABLE}} = \frac{24\,(638\ lb)^2\,(1-0^2)}{\pi^4\,(12\ IN)\,(133\ IN)\left[\frac{1}{(12\ IN)^2}+\frac{1}{(133\ IN)^2}\right]^2 (450{,}000\ lb/IN^2)\,(.09?\ IN)^3}$$

$$K.E._{\substack{MAX \\ ALLOWABLE}} = 3908\ IN\text{-}lb = \underline{325.7\ ft\text{-}lb}$$

THIS VALUE OF KINETIC ENERGY IS CLEARLY LARGER THAN ANY SPECIFIED IN TABLE 3.7.1 OF THE INTERIM PERFORMANCE CRITERIA'S FOR HAIL LOADING. THEREFORE, HAIL LOADING ON THIS MODEL SHOULD NOT BE A SIGNIFICANT PROBLEM.

3.9.1 DESIGN PROVISIONS

Ponding shall not be a problem with this design due to the stiffness of the acrylic lens. There are no horizontal surfaces on which water will accumulate and all slanted or inclined surfaces are either constructed of 16 or 20 gauge galvanized steel or at least 0.090" acrylic. In prototype work no ponding of any magnitude has occurred. There have been no failures associated with structural water loading on Northrup's similarly designed systems which are currently employed in the field in the past years.

4.1.1 PLUMBING CODES ON STANDARDS

See paragraph 2.7.1.

4.1.2 ELECTRICAL CODES AND STANDARDS

All wiring in the control box meets clearance standards required by U.L. for out-door condensing units, which is the closest standard applicable to the installation. All wiring in the control box is protected from water and the elements by the water-proof box enclosure. Wire and cable entries to the box are sealed with rubber grommets. Wiring throughout is U.L. approved 2/64" insulation, stranded 105 ^{o}C, thermoplastic, moisture resistant, U.L. classification 1230, and is sized per N.E.C. The external low voltage wire from the control box to the sensor is the same type wire. The installation manual requires that the field power supply be connected and switched per N.E.C. The control box is labled "Do Not Remove This Cover When Dis-Connect Switch Is On." The above complies with referenced standards and codes.

4.2.1. SYSTEM FAILURE PREVENTION

The system is designed so that the pump should be electrically paralleled with the attitude control system. In the event of a power failure the pump and tracking system will cease operation. Assuming the collector is initially focused during the period when the power was available, the subsequent movement of the sun with respect to the collector will cause the collector to defocus. A movement of 8.4° is sufficient in order to move the focal point off the tube. This angle corresponds to 34 minutes of exposure. During the period the focus will be gradually moving across the tube so that the intensity of light hitting the tube will slowly decrease. Similar concentrators employing this electrical arrangement have had no failures reported which are attributed to power failure stagnation. As an added safety measure, a pressure relief valve has been mounted on the lower manifold.

See "Concentrator Stagnation-Defocusing Test 10/18/77", which immediately follows, for verification that a similar collector design (Standard Northrup Concentrator) will not be subjected to unreasonable temperatures during a power failure. Also see "Stagnation-Defocusing Test 5/9/78 for verification of the 4-lens collector.

CONCENTRATOR STAGNATION - DEFOCUSING TEST 10/18/77

PURPOSE: To determine the maximum absorber and swivel temperatures during a stagnation-defocusing period corresponding to a power failure.

PROCEDURE: The concentrating collector was allowed to come to steady-state operating conditions, water flowing at .3 gpm and the collector tracking normally. After an hour of operation the tracking and water flow were simultaneously turned off. This turn-off point corresponds to the time value of "0" on the data and on the plot.

CONDITIONS: Winds were out of the northwest and light, ranging from .5 mph to 11.6 mph. The sky was clear with no clouds or haze throughout the test.

DISCUSSION AND CONCLUSION:

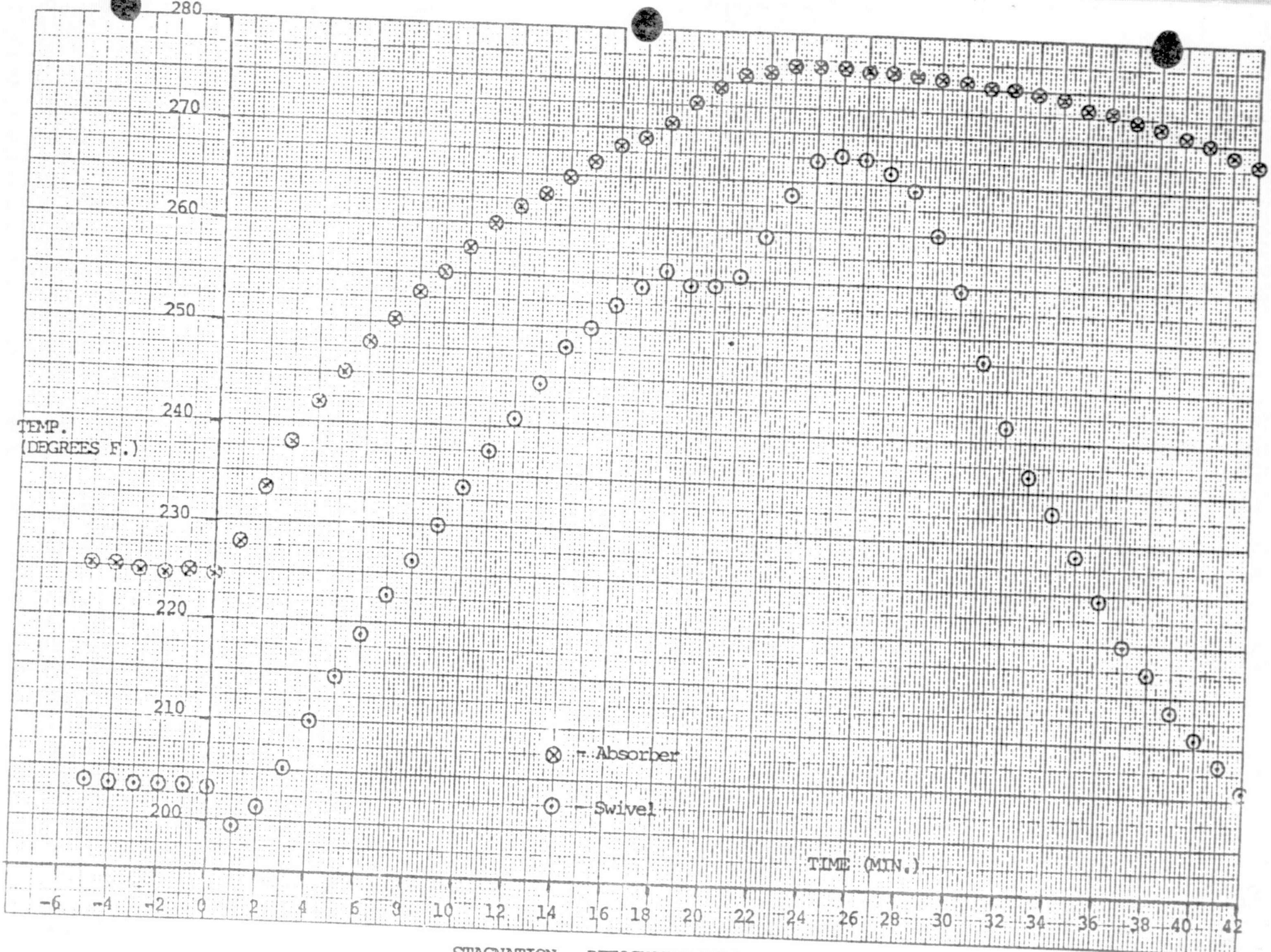
The outlet water temperature was monitored and found to be virtually the same as the swivel data. This was not surprising and served as a check on the swivel thermocouple.

As soon as the water was stagnated and tracking stopped the receiver temperature began to rise. The plot of the receiver temperature is a reasonably smooth curve. This indicates that the effective heat transfer coefficient from the tube to ambient did not change significantly during the test. In other words, the small variance in wind speed throughout had little effect on the heat transfer of the receiver.

When the water flow was cut off the swivel temperature dropped then began to rise. This was probably due to a time lag for the natural convection of the water inside the tube to establish itself. Also, there appears to be good conduction from the upper swivel to the manifold and return line which would explain the rapid cool down at the beginning and end of the test. The reason for the inflection point at about 20 minutes in the swivel plot is not immediately obvious. There was no sudden drop in insolation or a large increase in wind speed to account for this. One possible explanation is a "shift" in the natural convection of the water may have occurred. The inflection point is not due to a phase change. If it were, there would have been another such point on the cool down side of the plot. This test should give a good approximation of the critical temperatures. These approximate temperatures (276.8°F for the receiver and 267.7°F for the swivel from this test) are well within the operating range of the materials.

TEST DATA

Time (Minutes)	Absorber T (°F)	Swivel T (°F)	Ambient T (°F)	Wind Velocity (mph)	Direct Insolation (BTU/hr-ft2)
-5	225.4	203.6	85.6	4.4	263
-4	225.2	203.3	85.4	3.7	262
-3	224.9	203.2	86.2	7.9	263
-2	224.4	203.4	83.7	3.9	263
-1	224.9	203.3	84.8	2.4	263
0	224.5	202.9	83.9	8.4	262
1	227.9	199.4	84.8	7.4	262
2	233.6	201.3	85.1	9.2	262
3	238.2	205.2	85.7	5.3	262
4	242.1	210.0	84.6	5.3	261
5	244.9	214.6	84.8	4.2	262
6	247.7	218.8	86.5	4.2	263
7	250.4	222.8	86.5	4.4	262
8	252.8	226.4	85.8	1.7	262
9	255.1	230.1	87.9	2.3	263
10	257.6	233.8	87.8	2.1	263
11	259.9	237.6	86.9	6.4	263
12	261.6	240.8	86.1	4.2	262
13	263.0	244.4	85.8	4.7	262
14	264.8	248.0	86.1	3.7	261
15	266.5	249.7	87.8	2.0	262
16	268.2	252.2	87.6	3.5	262
17	269.2	254.2	88.2	1.4	260
18	270.7	255.8	88.3	6.7	260
19	272.8	255.4	88.8	1.5	259
20	274.6	254.6	88.5	2.5	260
21	275.7	255.5	86.6	5.4	259
22	276.1	259.6	87.3	4.2	259
23	276.8	263.8	87.1	3.4	259
24	276.8	267.2	87.8	1.2	260
25	276.8	267.7	87.6	.5	260
26	276.6	267.4	87.5	3.1	260
27	276.5	266.1	88.3	3.1	260
28	276.2	264.4	86.8	2.3	259
29	275.9	260.1	87.5	2.3	259
30	275.6	254.7	87.7	4.4	260
31	275.3	247.8	88.6	2.4	260
32	275.2	241.3	88.1	2.4	260
33	274.8	236.6	88.7	1.1	260
34	274.2	233.0	88.8	11.6	257
35	273.2	228.7	87.0	5.7	258
36	272.8	224.4	88.1	4.1	258
37	272.1	220.0	87.7	2.0	259
38	271.7	217.2	89.6	3.0	260
39	270.6	213.6	90.0	2.8	260
40	270.0	210.9	89.4	7.1	259
41	269.2	208.2	88.7	2.9	258
42	268.3	205.6	86.9	3.8	259



STAGNATION - DEFOCUSING TEMP. vs. TIME

STAGNATION - DEFOCUSING TEST
May 9, 1978

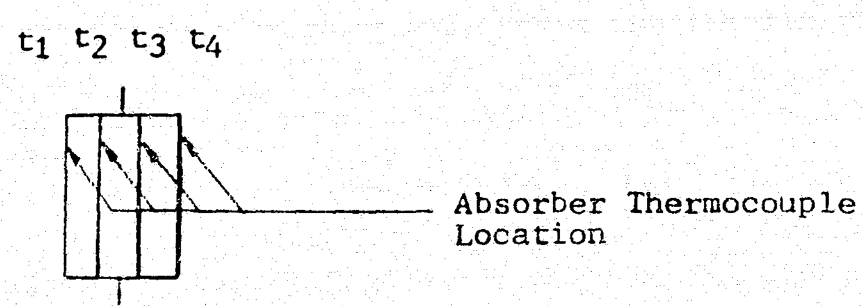
INTRODUCTION

The purpose of this test is to determine the maximum absorber and swivel temperatures during a stagnation-defocusing period corresponding to a power failure. The absorber temperature must not rise above 550° F or the black chrome coating may be permanently damaged. The inlet or outlet temperature must not rise above 350° F or the swivel O-ring may be damaged.

PROCEDURE

A 4-lens concentrating collector panel was allowed to come to steady state operating conditions: collector tracking and water flowing into the collector at approximately 1.7 gpm with an inlet temperature above 200° F. After approximately 15 minutes of operating time, the water flow and tracking were simultaneously turned off. Absorber, inlet and outlet temperatures, direct insolation, wind velocity, and ambient temperature were recorded in one-minute intervals beginning five minutes before the point of fluid and tracking cut-off and extending to 45 minutes afterwards.

Positions of the absorber thermocouples are shown in the following diagram:



Bottom View

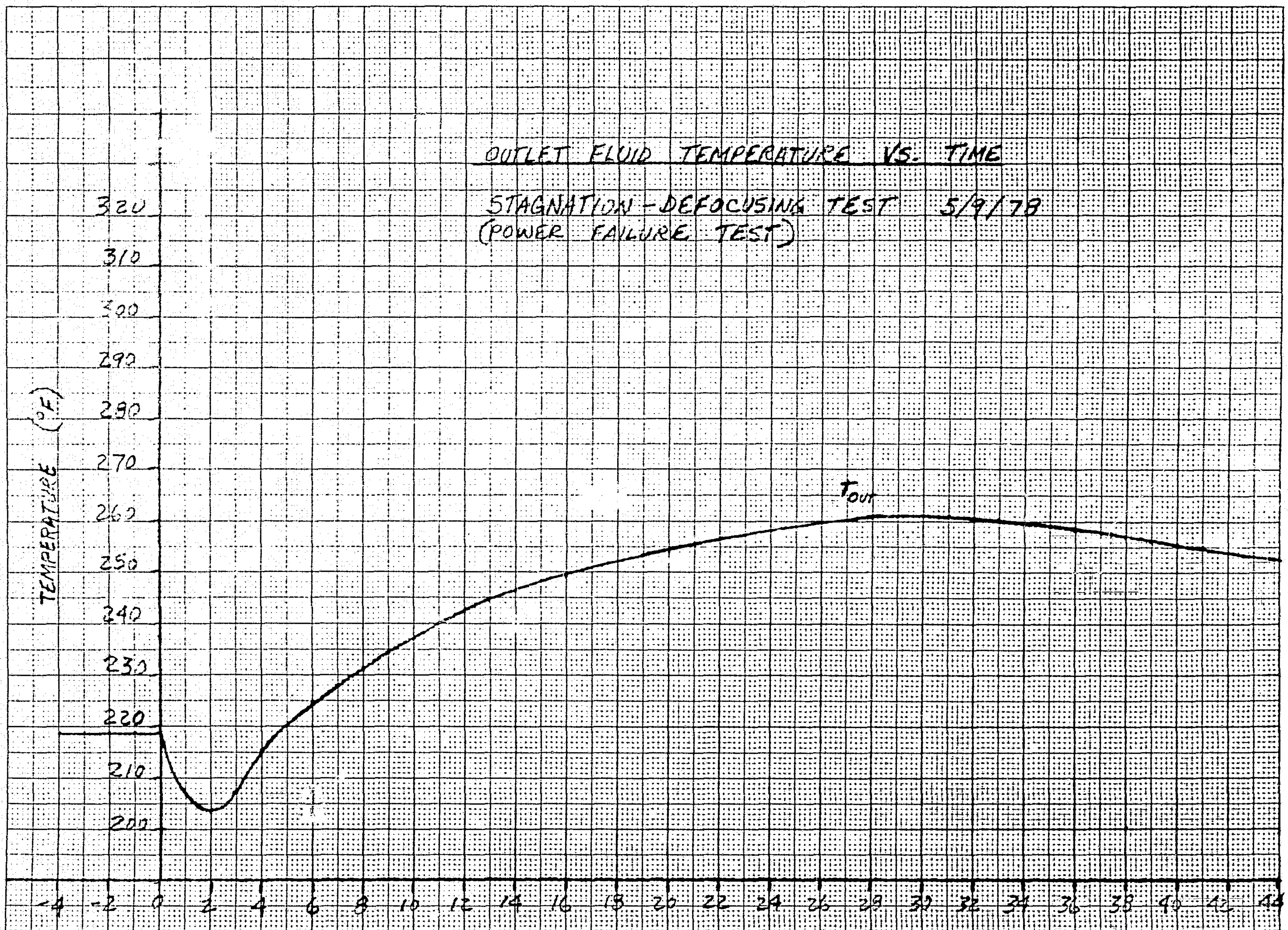
EQUIPMENT

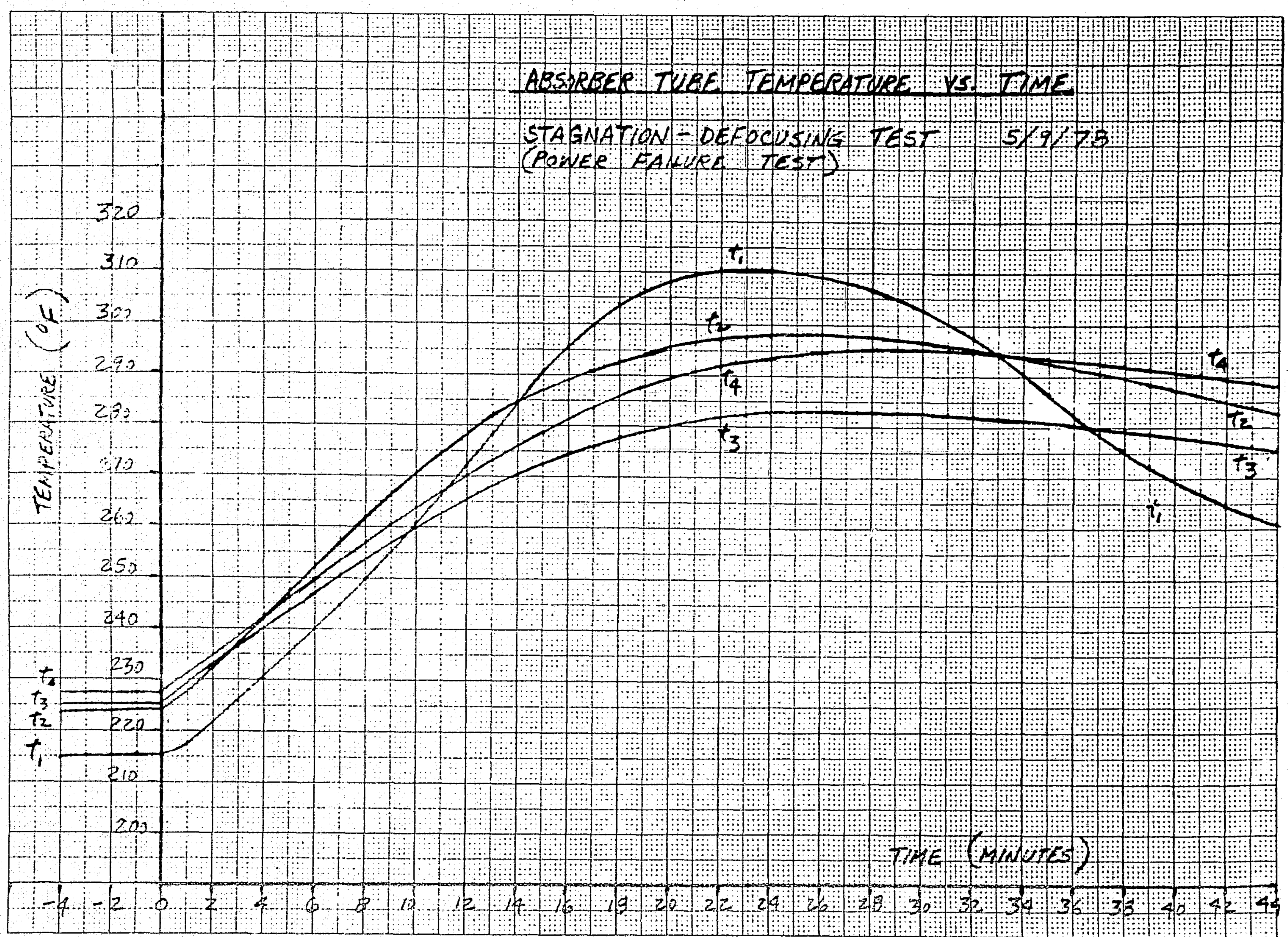
See the "Thermal Performance (Efficiency) " Verification "

Paragraph 1.3.1, test for a description of the equipment. The "Stagnation Test" took place within about two weeks after the "Thermal Performance (Efficiency)" test so the equipment was not recalibrated.

The highest absorber temperature reached was less than 320 $^{\circ}$F while the highest swivel temperature (outlet swivel) reached less than 270°F. These are well below the recommended high limits of 550°F for the absorbers and 350°F for the swivels. Furthermore, this test caused absolutely no damage to the collector system. Therefore, there is no danger of the system overheating (<u>when installed properly</u>) due to a power failure.

Included with this report are plots of the absorber and outlet fluid temperatures as a function of time. All test data is documented. Note that the average direct insolation was greater than 280 BTU/Hr-Ft^2 and the average wind velocity was lower than 10 mph, which means that conditions were excellent for this test.


OUTLET FLUID TEMPERATURE VS. TIME
STAGNATION - DEFOCUSING TEST 5/9/78
(POWER FAILURE TEST)
TEMPERATURE (°F)
320
310
300
290
280
270
260
250
240
230
220
210
200
T_{OUT}
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44


ABSORBER TUBE TEMPERATURE VS. TIME
STAGNATION - DEFOCUSING TEST 5/9/75
(POWER FAILURE TEST)
TEMPERATURE (°F)
TIME (MINUTES)
320
310
300
290
280
270
260
250
240
230
220
210
200
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
t_1
t_2
t_3
t_4

TITLE: NASA CONCENTRATOR - 4-UNIT STAGNATION

DATE: 9 MAY 78

PERSONNEL: C. JACOBS / D. SEITER

WIND SPEED: 1.9 MPH - 7.3 MPH

TEST No.: N 0004

WIND DIRECTION:

COLLECTOR APERTURE: 43.0 ft²

CONDITIONS: CLEAR, CALM

t (absorber tube temp - °F)

$$EFF = \frac{m \cdot C_p (T_{out} - T_{in})}{A_c \cdot I''} \; ; \; \frac{\Delta T'}{I''} = \frac{(T_{in} - T_a)}{I''}$$

TIME	T_a	T_{in}	T_{out}	t_1	FLOW	I_{DN}	t_2	m	I''	ΔT	t_3	EFF	ΔT'/I'	t_4	V_{wind} MPH
1108	79.5	211.8	218.6	214.6	1.75	283.3	223.5		316.6		225.3			227.4	3.8
1109	80.1	211.9	218.7	215.2	1.75	284.1	223.9		317.1		225.2			227.2	4.7
1110	79.0	211.9	218.8	215.2	1.75	284.5	224.0		316.5		225.2			227.2	1.9
1111	77.8	212.1	218.8	215.4	1.75	283.8	224.3		316.3		225.2			227.3	4.1
1112	78.3	212.2	219.0	215.6	0	283.0	224.3		316.4		225.2			227.5	4.5
1113	78.9	206.6	207.1	217.4	↓	282.9	227.4		315.7		228.4			230.5	4.1
1114	79.2	201.2	203.2	221.3		282.8	232.4		315.9		232.6			235.0	3.7
1115	79.9	202.6	207.4	225.8		283.8	237.6		317.2		236.2			239.0	3.2
1116	81.1	197.9	215.4	230.3		284.5	242.2		317.1		240.1			242.4	3.3
1117	79.9	194.8	223.1	235.1		285.6	247.8		317.7		243.8			246.7	4.0
1118	79.0	193.0	224.8	240.0		284.1	252.6		317.6		247.1			250.1	3.1
1119	79.6	192.1	228.1	244.9		283.1	257.5		317.0		250.5			253.8	3.7
1120	79.6	190.9	231.3	250.0		283.2	262.1		317.1		253.7			257.2	3.5
1121	79.9	190.0	234.4	255.3		283.9	266.5		317.8		256.9			260.6	8.8
1122	79.7	188.7	237.0	260.9		282.7	270.6		317.5		259.8			263.8	5.9
1123	79.8	186.5	240.2	266.5		284.2	274.6		317.7		262.8			267.1	4.1
1124	80.9	184.8	242.7	272.0		284.6	278.2		317.8		265.5			270.2	5.1
1125	81.3	183.5	244.6	278.1		283.9	281.5		318.1		268.1			273.1	3.1
1126	81.5	182.2	247.1	284.6		283.7	284.5		317.8		270.6			276.1	4.2
1127	80.7	180.9	248.2	290.5		284.2	287.1		318.3		272.7			278.9	7.1
1128	80.6	179.2	248.7	295.3		282.7	289.1		315.7		274.6			281.4	7.3
1129	79.8	177.3	249.7	299.8		284.5	290.9		318.2		276.3			283.6	6.4
1130	79.4	175.8	251.1	303.8		286.6	[illegible]		318.9		277.9			285.0	3.6
1131	79.1	174.2	252.2	306.6		283.9	294.2		318.1		279.1			287.7	4.5
1132	79.8	172.9	253.1	[illegible]		[illegible]	295.4		318.3		[illegible]			287.2	4.6
1133	80.9	[illegible]	[illegible]	[illegible]		286.2	[illegible]		318.9		[illegible]			[illegible]	4.3
1134	79.7	170.1	[illegible]	310.7		283.9	[illegible]		318.5		281.5			291.8	[illegible]
1135	81.0	169.3	[illegible]	310.2		283.5	297.4		317.2		282.2			292.9	[illegible]
1136	80.1	167.3	258.4	[illegible]		283.5	297.9		317.0		282.5			293.7	4.3
1137	80.9	167.6	259.3	309.9		284.3	298.1		317.8		282.9			294.2	4.1
1138	81.5	166.8	260.1	309.0		285.7	298.2		318.0		283.0			295.0	[illegible]

TITLE: NASA CONCENTRATOR 4 UNIT – STAGNATION

PERSONNEL: G. JACOBS / D. SEITER

TEST No.: N0004

COLLECTOR APERTURE: 43.0 ft²

DATE: 9 MAY 78

WIND SPEED:

WIND DIRECTION:

CONDITIONS: CLEAR

$$EFF = \frac{m \cdot Cp(T_{out} - T_{in})}{A_c \cdot I'^{*}} \; ; \; \frac{\Delta T'}{I'^{*}} = \frac{(T_{in} - T_a)}{I'^{*}}$$

TIME	T_a	T_{in}	T_{out}	t_1	FLOW	I	t_2	m	I'*	ΔT	t_3	EFF	ΔT'/I'	t_4	WIND V (MPh)
1139	80.7	166.2	260.4	308.0	0	285.8	298.0		319.1		282.9			295.3	6.7
1140	80.0	165.4	260.7	306.6	↓	284.9	297.7		318.7		282.9			295.3	5.7
1141	80.8	164.3	261.2	304.8		286.7	297.3		318.4		282.9			295.7	3.8
1142	79.7	163.0	261.3	303.4		285.5	296.8		318.4		282.6			295.6	4.6
1143	80.3	162.0	261.3	300.9		286.2	296.2		319.4		282.4			295.3	4.9
1144	80.4	160.8	260.8	298.3		285.2	295.3		318.7		282.0			294.8	2.9
1145	81.7	160.0	260.5	294.3		289.7	294.6		318.0		281.6			295.0	4.7
1146	81.8	158.9	259.8	290.7		285.2	293.8		317.8		281.2			294.1	4.9
1147	80.9	158.0	259.1	286.5		284.6	292.3		317.9		280.9			293.8	2.9
1148	80.9	157.1	258.9	281.8		283.0	291.6		316.2		280.4			293.2	3.0
1149	81.1	156.2	257.6	278.9		284.0	290.7		316.5		279.8			292.7	3.9
1150	80.5	155.3	256.9	275.6		284.4	289.6		317.7		279.3			292.3	4.3
1151	81.1	154.4	256.1	272.6		284.9	288.3		317.4		278.6			291.6	3.4
1152	82.1	153.5	255.5	270.3		283.8	287.2		316.8		278.[illegible]			290.8	3.3
1153	81.3	152.5	255.0	267.9		284.2	286.4		317.2		277.5			290.3	2.5
1154	82.3	151.5	254.5	265.2		284.4	285.2		317.8		276.9			289.7	3.8
1155	82.7	150.8	253.9	262.9		283.5	284.1		316.7		276.3			[illegible]	3.9
1156	83.1	152.1	253.0	260.6		285.7	282.7		317.6		275.6			288.2	3.0
1157	82.4	149.4	252.1	258.8		283.5	281.4		316.6		274.8			287.4	6.2
1158	82.2	148.8	251.1	256.9		283.2	279.7		316.5		274.3			286.6	4.0

4.2.2 AUTOMATIC PRESSURE RELIEF VALVES

The automatic pressure relief valve is located on the bottom manifold of the system. The automatic relief valve is specified to open at 125 psi, which is 25% greater than the working pressure of 100 psi. Located on the top of the manifold system is an air relief vent rated at 150 psi. These relief valves have provided more than adequate safety measures when used on similar Northrup concentrating collectors. See ver. par. 2.3.1 for pressure test results on the relief valves.

4.3.1 Applicable Fire Standards

There are no combustible materials adjacent to high temperature components. There are no combustible fluids used in this system. Control box is vented and experience has proved that maximum temperatures reached inside the box could be 160^{0}F at which temperature the wiring is approved by N.E.C. and lubricant flashpoint or working temperature is not reached. There are no other fire hazards.

4.5.2. IDENTIFICATION AND LOCATION OF CONTROLS

The only controls internal to this system are limit switches for the tracking system which are identified in the Installation, Operation and Maintenance Manual. The power supply is external and is required to be identified per N.E.C. as described in the above manual.

4.6.1. CONTAMINATION BY MATERIALS

The fluid handling system, which is included in this contract, is composed of components which are all accepted and recognized materials and which are compatible with potable water. The hard copper tubing, pipe fitting, pressure relief valve, and automatic air vents are componets which are commonly used in domestic hot water systems without affecting the taste, odor or physical quality and appearance of the water. The swivel fitting is not commonly used in potable water systems but the materials used in its construction are commonly used. The swivel fitting is constructed of brass, ethylene propylene rubber and silicone rubber and these materials are commonly used in potable water systems without effecting the quality or appearance of the water.

4.6.4 GROWTH OF FUNGI

The growth of fungi, which generally applies to air handling systems does not appropriatly apply to this system. All of the components used in the fluid handling system meet or exceed national plumbing code standards so that they will be as safe from growth of fungi as any potable plumbing system. The extremely high absorber temperatures will inhibit the growth of fungi, mold or mildew inside the collector housing.

4.7.1 PROTECTION FROM HEATED COMPONENTS

Though the design intent of this system was not to locate such a system in an area normally subjected to public traffic, sufficient safety measures have been taken to protect the public from the collector absorber surface and fluid loop both of which may be maintained at temperatures in excess of 140°F. This protection was added for functional reasons rather than a safety measure. Insulation was wrapped around the fluid system including the absorbers to prevent excessive heat losses. The fluid manifold loop is well insulated and contained within a manifold structure which is actually part of the collector structure. The absorbers are equally well insulated. They are enclosed in a metal casing, and covered with the lens which also serves as an outer glazing. Provided the ambient temperature does not exceed 100°F no part of the collector system exterior will be maintained at temperatures in excess of 140°F.

This design is similar to the Northrup concentrating collector systems presently in use. There has never been any evidence indicating there was inadaquate protection from heated components in any of these installations.

5.1.1 SOLAR DEGRADATION

The current Northrup production concentrating collector which utilizes an acrylic lens and sensor lensing has no history of decreasing efficiency performance which would be attributed to yellowing of embrittlement of the lens. Neither have any problems in the current tracking sensor been attributed to the degradation of the housing by solar radiation.

5.1.3 AIRBORNE POLLUTANTS

System materials which are exposed to airborne pollutants are the same materials of construction used in the single absorber concentrator.

Following is a list of single absorber concentrator installations and the dates of initial exposure.

Name	Location	Exposure Date
New Mexico State University	Las Cruces, New Mexico	1-75
Trinity University	San Antonio, Texas	4-76
Radian Corporation	Austin, Texas	6-76
Institute of Gas Technology	Dallas, Texas	9-76
American Motor Inns	St. Thomas, Virgin Islands	1-77
Sundance, Inc.	Sundance, Utah	9-77
Brefeld Plumbing	Trenton, Illinois	6-76
College House Apartments	Austin, Texas	6-77
A.C.E.S.	Incline Village, Nevada	8-77

Since initial exposure, airborne pollutants have not significantly impaired the performance of the components of any of these systems. Therefore, airborne pollutants are not expected to adversely affect the present system.

5.1.4 DIRT RETENTION ON COVER PLATE SURFACE

The lens of this concentrator design is analogous with the cover plate of a conventional flat plate collector. The absorber is contained within casing and sealed with an outer glazing of acrylic which acts also to concentrate the transmitted light by refraction. The outer glazing in this particular design has an eight inch radius of curvature which should facilitate the natural cleaning of the collector plate by rainfall. Since the collectors are mounted aligned with the polar axis, the lens surface has a slope equal to the latitude angle. This longitudinal design slope, the radius of curvature, and the daily rotation of the collector will minimize dirt retention on the cover plate. Water spots and any fine particles which do tend to cling to the surface will have no greater effect on the lens performance than they would have on any other conventional flat plate cover. Simple hosing of the lens is sufficient to clean dirt from the acrylic surface.

5.1.5 ABRASIVE WEAR

Acrylic is a relatively soft material as compared to glass, however, the use of glass lens is quite impractical under these conditions. Abrasive wear might be expected to present a possible problem in areas subject to wind driven sands. However, outdoor aging studies by Sandia Laboratories* indicate that transmission loss due to abrasive wear over a 17 year exposure period amounted to only ten per cent. Of this ten per cent loss, three per cent was attributed to a chemical change in the material, a slight yellowing, while the other seven per cent was attributed to pitting by sand particles. Only a ten per cent loss over seventeen years due to surface erosion in such wind driven sand area as Albuquerque, New Mexico indicates an ability to resist surface wear which would significantly impair the collector from functioning at its design capacity.

*L.G.Rainhart and W.P.Schimmel, Jr., "Effects of Outdoor Aging on Acrylic Sheet", Solar Energy, 17, 259-264 (1975).

5.1.6 FLUTTERING BY WIND

The only components in this design that would be subject to wind fluttering to an extent that might be functionally damaging is the lens. However, as can be seen in the design drawings the lens is held securely to the casing along each side of the lens. Even without this secure fastening the .090" minimum lens thickness is more than adequate in providing support for the 12" span. Since fluttering of the lens will not occur even at moderately high wind speeds, no damage is expected as the result of this influence. Similar concentrating collectors, including structural components, have shown no indication of degradation either functionally or cosmetically which would be attributed to wind fluttering.

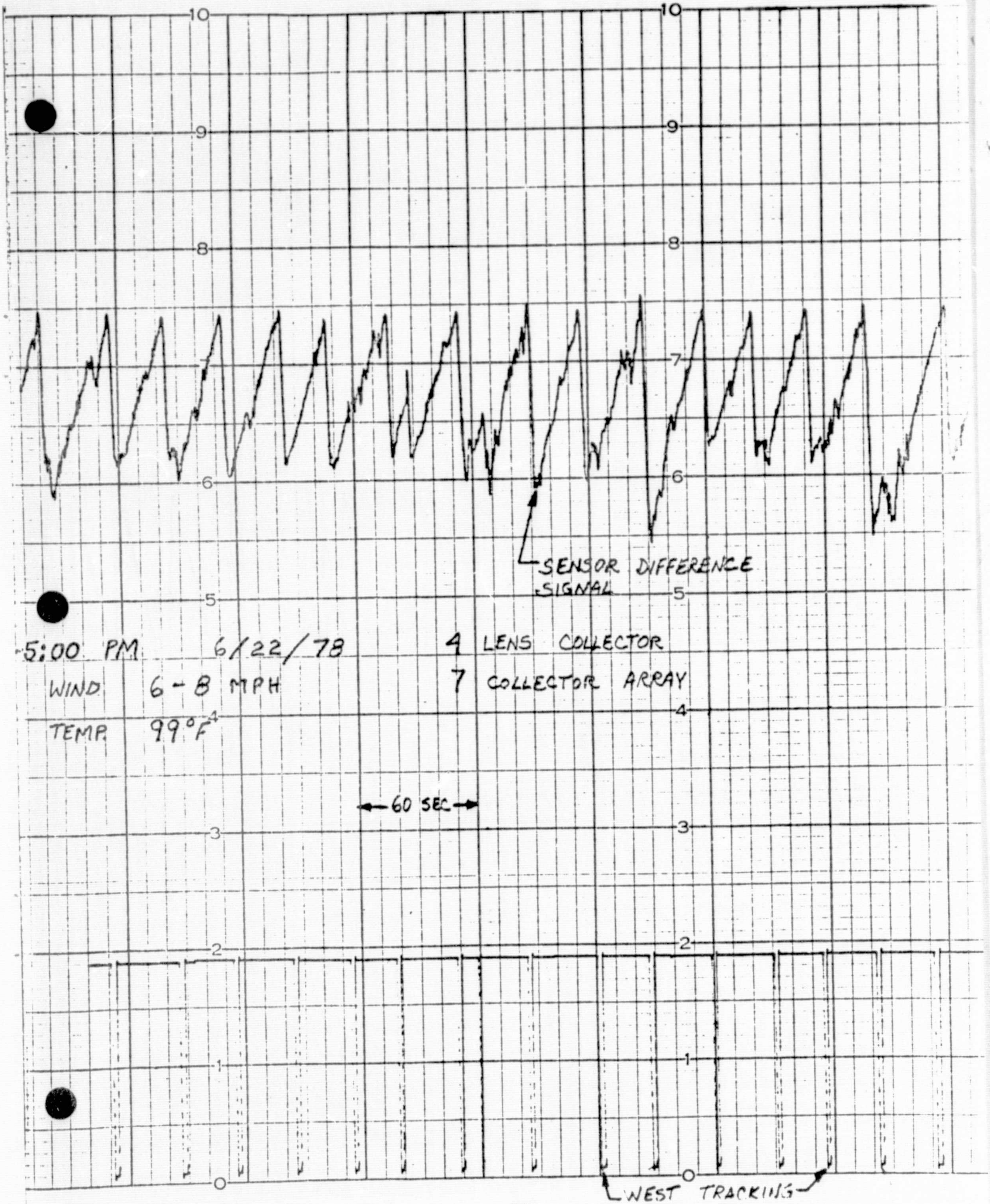
5.1.6 FLUTTERING TEST

Procedure

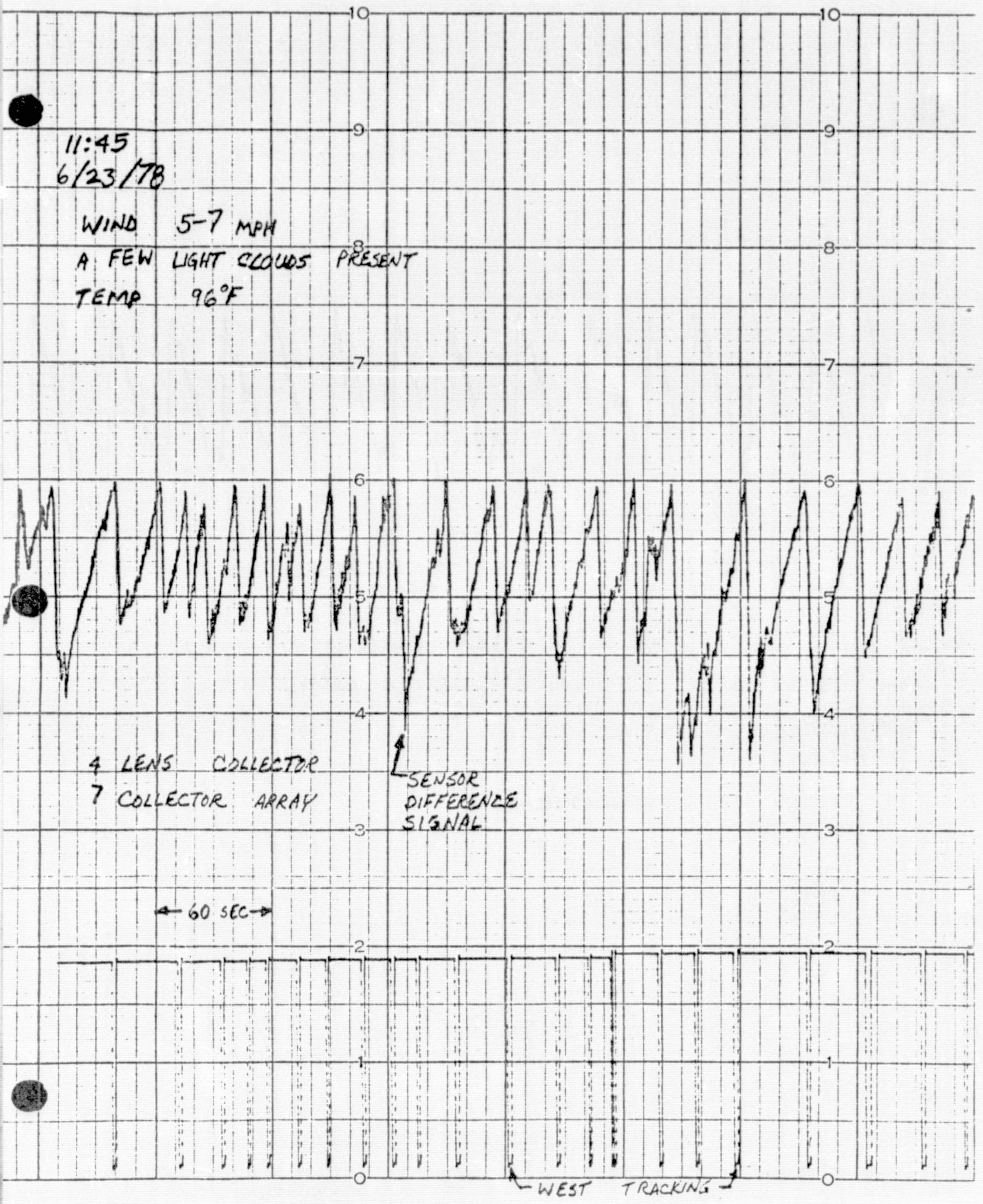
Wind flutter for the entire collector array was checked by inspection during eight days of tracking (6/22/78 through 6/29/78). Wind and temperature data were taken by our instrumentation. The voltage across the solar sensor was recorded by a strip-chart recorder. In addition, impulses from the electronic control board that indicate tracking direction were recorded.

Results

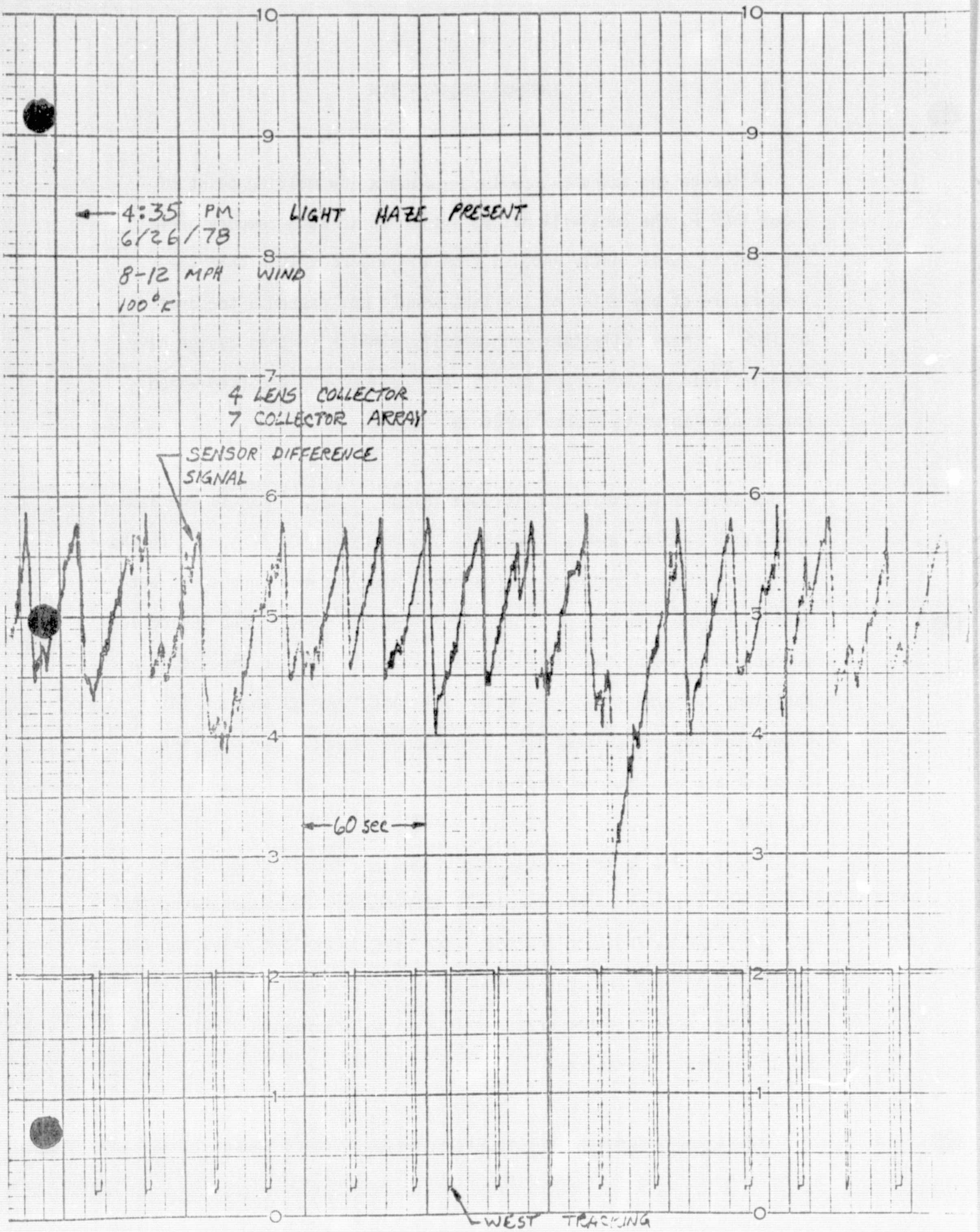
As evidenced by the strip-chart recordings, the wind did not interfere with tracking. That is, the time space between west tracking update periods remained reasonably constant throughout each test and there was never any evidence that wind had caused the collectors to track east. The strip chart recordings immediately follow.



10
9
8
7
6
5
4
3
2
1
0
SENSOR DIFFERENCE SIGNAL
5:00 PM 6/22/78
WIND 6 - 8 MPH
TEMP. 99°F
4 LENS COLLECTOR
7 COLLECTOR ARRAY
60 SEC
WEST TRACKING



11:45
6/23/78
WIND 5-7 MPH
A FEW LIGHT CLOUDS PRESENT
TEMP 96°F
4 LENS COLLECTOR
7 COLLECTOR ARRAY
SENSOR DIFFERENCE SIGNAL
60 SEC
WEST TRACKING
10
9
8
7
6
5
4
3
2
1
0


4:35 PM
6/26/78
LIGHT HAZE PRESENT
8-12 MPH WIND
100°F
4 LENS COLLECTOR
7 COLLECTOR ARRAY
SENSOR DIFFERENCE SIGNAL
60 sec
WEST TRACKING
10
9
8
7
6
5
4
3
2
1
0

5.2.1 THERMAL DEGRADATION

Lens

Although the extruded acrylic lens has a low melting point of about 180° F, the lens will not be subjected to such temperatures. The lens is sufficiently removed from the absorber tube that the temperature at any point on the lens should not exceed a temperature of 150° F. Many collectors mechanically similar to this design have been in field use for years and not one failure has occurred which can be attributed to thermal degradation.

Casing

A semi-rigid insulation is used in the design. This is the same insulation used in previous Northrup Concentrating Collectors. In these collectors thermal performance has never been impared because of out-gassing of the insulation. Condensate does not form on the inside lens surface which means that light transmission will not be impeded. In addition, the semi-rigid insulation will not lose its shape. This eliminates any chance that the insulation will fall down over the absorber and obstruct incident sunlight.

Manifold

The fluid loop manifold system is constructed of hard copper tubing and will not be detrimentally affected by the temperatures that are generated by these collectors. The pressure relief valve and the automatic air vent are constructed of materials capable of withstanding normal design service temperatures as well as the design pressure at these service temperatures.

Absorber

The absorber will be constructed of type M, hard copper tubing and

5.2.1 (Continued)

has a maximum rated temperature in excess of 600°F. The selective coating of bright nickel and black chrome has a maximum temperature of about 650°F before the selective properties of the coating are permanently affected. Stagnation temperatures should never exceed 400°F and therefore should not affect the performance of the selective coating.

The swivel joints which are used to connect the absorbers and manifold are also subject to extreme fluid temperatures. These swivel joints are designed to withstand temperatures of 300°F at pressures greater than 125 psi. The swivels have been tested in actual operating conditions. No leaks were detectable under these conditions. See ver. par. 5.2.5 for the test results.

Tracking System

The components of the tracking system are exposed only to the ambient temperatures and are not subjected to the extreme temperatures of the collector. Therefore, the components of the tracking system have been selected based on the consideration that they will be exposed to extreme outdoor temperature conditions.

5.2.2 DETERIORATION OF HEAT TRANSFER FLUIDS

For warm to mild climates where freezing occurs only several days of the year or not at all, the recommended heat transfer fluid is water. Freeze protection will be accomplished by forced circulation during extreme cold periods. The all copper absorber and manifolding meet domestic water codes. As a result the manifold absorber fluid loop is analogous to a conventional hot water system. Therefore, precipitation and scaling should not occur to any greater extent than it does in conventional domestic water systems.

In colder climates ethylene glycol, pure or in solution with water, recommended for use with the system. This fluid is recommended for use with all the materials it comes in contact with, as outlined in Section 5.3.1. The design operating pressure of 100 psi will allow service temperatures in excess of 300°F before boiling occurs with either water or ethylene glycol as the fluid.

5.2.3 THERMAL CYCLING STRESSES

Lens

The acrylic lens is the major component of this collector system design which is most susceptible to thermal cycling. Long term exposure tests have indicated that there is little physical damage which would be associated with thermal cycling provided proper allowances have been made in the design for stresses due to the lens thermal expansion and contraction. The expansion and contraction of the lens results in a difference of 0.047" per foot between ambient temperatures of 20 to 120^{O}F. The follwing table illustrates the thermal expansion and contraction of the acrylic

(MILS PER FOOT)*

% RH	10	20	30	40	50	60	70	80	90
% Moisture	.18	.32	.46	.61	.76	.90	1.05	1.20	1.35
Temp., °F									
20	−33	−31	−29	−26	−22	−18	−13	−8	−2
30	−29	−27	−25	−22	−18	−14	−9	−4	+2
40	−25	−23	−21	−18	−14	−10	−5	0	+6
50	−21	−19	−17	−14	−10	−6	−1	+4	+10
60	−16	−14	−12	−9	−5	−1	+4	+9	+15
70	−11	−9	−7	−4	0	+4	+9	+14	+20
80	−6	−4	−2	+1	+5	+9	+14	+19	+25
90	−1	+1	+3	+6	+10	+14	+19	+24	+30
100	+4	+6	+8	+11	+15	+19	+24	+29	+35
110	+9	+11	+13	+16	+20	+24	+29	+34	+40
120	+14	+16	+18	+21	+25	+29	+34	+39	+45

*1 MIL = 0.001 inches

In order to accomodate this size cycling the casing and lens are designed so as to provide a sliding attachment for the lens. Screws at the top of the casing provide a fixed point for the lens. The bottom end of the lens is not fastened to the casing but is allowed to move in order to accomodate the dimensional changes of

5.2.3. (Continued)

the lens which might be as great as one inch depending on temperature, and humidity conditions. Therefore, the slide design allows free movement of the lens due to thermal expansion and alleviates the thermal stress in the lens.

Absorber

Thermal stress in the absorber assembly should not be a problem due to allowances of adequate space for expansion (see 2.2.5).

The lens and absorber design are similar to the ones incorporated in the many Northrup concentrators now in the field. In these collectors, stress due to thermal cycling has not resulted in physical damage.

5.2.4 LEAKAGE

See verification paragraph 2.3.1.

5.2.5. DETERIORATION OF GASKETS AND SEALANTS

There is only one gasket or sealant which is in contact with the heat transfer fluid in the design. The o-ring seal of the GRA-TEC swivel is exposed to the transfer fluid. Ethylene propylene rubber, EPR, would be recommended for systems using water as the heat transfer fluid. Although the recommended temperature range for EPR is 65° to 300°F, this material is recommended for water or steam lines up to 400°F. The material is also quite good at resisting drying and embrittlement. An accelerated swivel life test indicates that the EPR o-ring seal can endure 20 years of the rotations it will be subjected to in actual field installations. The test write-up immediately follows.

ACCELERATED SWIVEL & FLEXIBLE JOINT LIFE TEST

PROCEDURE

The proposed swivel-flexible hose joint will be mounted on a test fixture that will simulate actual field operation. The hose end will be connected to a stationary tube while the swivel end will be connected to a tube that will rotate 180° in one direction, then will rotate back 180° to the original position. This complete cycle will take place every 69 seconds as opposed to an actual collector-swivel arrangement which would undergo a cycle once a day. During the accelerated test, approximately a 50% ethylene glycol-water solution will flow through the swivel. The fluid temperature will be varied so that its temperature will be about 160° F for a portion of each day and about 260° F for the remaining part of each day. It is hoped that the swivel-flexible hose joint will survive six (6) days of testing without leaking which corresponds to more than twenty (20) years of cycles in a real collector situation. There is ample reason to believe that this swivel will pass the test since a similar design has easily met this requirement.

RESULTS

The accelerated swivel-flexible joint life test was performed according to the above procedure. The test was started May 15, 1978, and allowed to run at 80 psig for a duration of six days.

The test was repeated at 100 psig beginning May 23, 1978, and run for a duration of six days. Once each day in both tests the pressure was reduced to zero psig to ensure that there would be no leaks at low pressure. For the second test the fluid temperature was maintained at approximately 200° F throughout.

In either test there was no leaking of the swivel joint. The flexible hose and the O-ring showed no signs of deterioration.

5.2.6 TRANSMISSION LOSSES DUE TO OUTGASING

A semi-rigid insulation is used in the design. This is the same insulation used in previous Northrup concentrating collectors. In these collectors thermal performance has never been impaired because of outgassing of the insulation. Condensate does not form on the inside lens surface which means that sunlight transmission will not be impeded.

5.3.1. MATERIALS/TRANSFER FLUID COMPATIBILITY

This system is designed so as to provide domestic hot water as well as hot water for heating and cooling applications. Since potable water is recommended as the normal heat transfer fluid, all the components of the fluid line must be chemically compatible with potable water. The copper lines used in the manifold and absorbers are composed of materials identical with that used in domestic hot watter applications. Similarly the pressure relief valve and automatic air vent are components which are designed for use with potable water. The swivels are made of brass and silicone rubber are also compatible with potable water and finally the ethylene propylene rubber o-ring is recognized as a standard seal material for hot water applications. Therefore, all of the components and materials used in the fluid handling system are recognized for potable water applications.

Ethylene glycol is also recommended for use with the system. Volume 1 of the ASM Metals Handbook gives a good corrosion resistance rating to copper, brass, and bronze when used with ethylene glycol. The air vent and the swivels are made of brass and the pressure relief valve is made of bronze so these components of the system can be used with ethylene glycol. Silicone rubber and ethylene propylene rubber, materials also used in the swivels, are compatible with ethylene glycol.

5.3.2 CORROSION OF DISSIMILAR MATERIALS

There are no non-isolated dissimilar materials in contact with each other in this design which would cause corrosion. The fluid loop including the manifold, absorber tubes, pressure relief valve, air vents, swivel fittings and expansion joints are all constructed of copper or brass and present no corrosive problem due to dissimilar metal junctions. If the user intends to connect this brass and copper system to other piping materials then he must take necessary precautions to prevent corrosion at the interface. This interface connection, however, is the responsibility of the user.

The housing and structural support utilize no dissmilar metal junctions which might cause corrosion. Therefore, there are no non-isolated dissimilar metal junctions which would result in corrosion due to electro chemical reactions.

5.3.3 CORROSION BY LEACHABLE SUBSTANCES

This system does not utilize any materials which release chemical substances that can leach other materials. The manifold housing as well as the collector housing or casing is constructed of galvanized steel and will not deteriorate if the leachable substance did exist. Furthermore, no collector system in use which was manufactured by Northrup using these same materials has corroded due to leachable substances released from another component so as to impair the ability of the component to perform its intended function over its service life.

5.3.4 EFFECTS OF DECOMPOSITION PRODUCTS

The design of this system does not utilize any material which can chemically decompose and effect the operation of any other components. Possible problem areas such as the decomposition of the absorber coating and the bearing shafts will not effect the performance of other components in the collector. The bearing is completely sealed so that any rust cannot impair the functional movement of this component. The black chrome coating on the copper tube is capable of withstanding 650°F temperatures and will not release materials or products which can condense on the inside lens surface. Therefore, it appears that there are no components or items in the collector design which are extremely susceptible to chemical decomposition. So there is little chance that any chemical decomposition products will be expelled from components under in-use conditions and cause the degradation of other components.

5.4.1 WEAR AND FATIGUE

Moving parts in the system design include the automatic air eliminator, pressure relief valve and swivels in the fluid handling system, the shaft bearing for collector rotation and finally the limit switches, relays, drive screw assembly, and electric motor of the tracking system.

Fluid Handling System

The automatic air eliminator vent is manufactured by Maid-O Mist. The recommended vent is model number 74 and is rated at 150 psi maximum system pressure. The vent is built of non-ferrous metals, a Monel metal spring and a Neoprene valve seat. Neoprene is resistant to petroleum oils, silicone fluids and water, and has a recommended service temperature of more than 300° F. The number 74 auto-vent is a quality industry wide recognized air vent capable of long life time operation. However, being quite economical, replacement of the air vent after several years of service is quite reasonable.

Pressure Relief Valve

The pressure relief valve recommended for this system is a Watts number 3L set at 125 psi release. It has a ASME construction and is certified by the National Board of Boiler and Pressure Vessel Inspectors. The body is constructed of bronze and all other materials are isolated on the exterior of the valve seat. This valve is compatible with water and steam and has a maximum heat release capacity of about 2,500,000 BTU/HR.

5.4.1 (continued)

Collector Panel and Tracking Drive Bearings

Bearings are permanently lubricated, totally enclosed ball bearings, designed for extreme weather in unprotected applications such as farm tractors, rolling stocks, cranes, crushers, screws, etc. The lubricant is designed for a maximum 250° F constant operating temperature and 300° F maximum intermittent temperature. Under design loads and conditions, manufacturers tests are published as follows after 1,800,000 revolutions:

Loss of lubricant: 15%

Increase in friction: 0.01 inch pounds

Loosening on shaft: None

Under normal operation conditions, the collector bearings make one revolution per day or 7,300 in 20 years and tracking system bearings make 620 revolutions per day or 2,264,550 in 10 years. From the above, it is apparent that these bearings should function properly for their service lives without excessive wear or malfunctioning.

Swivel Joints

The swivel is constructed of plain brass and silicone rubber and utilizes an ethylene propylene rubber o-ring. The results of an accelerated swivel life test indicate that it can withstand the rotations involved in 20 years of actual field operations (see verification paragraph 5.2.5 for test write up).

Tracking System Relays & Limit Switches

The tracking system typically updates its position every 45 seconds. This corresponds to .35 million operations per year for the west drive relay. The relays are rated at 10 million operations, and, therefore, should have a lifetime of more than 20 years.

The limit switches will operate approximately 400 times a year. The 8,000 operations corresponding to a 20-year lifetime is well within the design limits of the switch.

Tracking Drive Screw and Nut

According to the manufacturer, the lifetime of the delrin drive nut will be as high as 10^6 inches when used in a low speed application such as in this collector system.

For purposes of lifetime calculation, it is assumed the drive screw will travel the maximum possible distance as required by the tracking components or 61.8 inches per day or 61.8 x 365 1/4 = 2.26×10^4 inches annually.

It is evident the calculated life of the drive nut is in excess of 20 years of utilization or the design life of the system.

Tracking Drive Motor

The drive motor is a permanent split capacitor gearmotor, with a permanent gearcase lube. They have shrouded cooling for continuous operation and a dual thermal and current overload sensor to further protect the motor. Life expectancy as estimated by the manufacturer is 2000 hours of running time which corresponds to 4.25 years of collector operating time. This motor is relatively inexpensive and serves 300 net sq. ft. of collectors. It is considered that replacement at a consumer cost of approximately $20.00 is in the best interest of the user rather than select a motor of twice this cost and still risk replacement. Replacement is easily facilitated without dismantling other parts of the system.

6.1.1 ACCESS FOR SYSTEM MAINTENANCE

The collector system was designed so that components would be easily accessible for inspection, service, repair, removal or replacement.

Sheet metal lids cover both manifold housings and can be easily removed after taking out the connection screws. With the lids off the manifolds can be readily inspected or repaired if necessary. Should manifold replacement be required, the sheet metal stiffeners on the housing can be easily taken off and GRA-TEC swivels quickly disconnected.

The easily disconnected swivels also will allow easy removal of collectors. The inner portion of a collector is readily accessible by removal of the lenses which merely require taking off the lens hold downs.

The electronics and drive mechanism are enclosed in a sheet metal box and are reached by unfastening a sheet metal lid. Individual components can then be inspected or replaced if needed.

6.1.2 ACCESS TO SYSTEM MONITORING

Any devices or sensors which would be required to monitor the system performance can be mounted externally to this system. Appropriate flow meters and temperature sensing devices can be mounted on the ends of the manifolds to monitor the overall performance of the collector system. No allowances have been made in the manifold system to monitor individual collectors since this would be prohibitively costly as a monitoring process. Adequate allowances have been made in the manifold support systems to accomodate instrumentation should the user decide they are appropriate. Instrumentation and application of sensing devices will be the responsibility of the user and not the responsibility of Northrup. However, special arrangements can be made to accommodate sensor mounting.

6.1.3 DRAINING AND FILLING OF LIQUIDS

The concentrator fluid loop including the manifolds and absorbers, can be drained and refilled through the bottom manifold. A single valve in the bottom manifold can serve as the drain for the entire array. Draining is accomplished by opening a drain valve in the lower manifold and opening a vent valve in the top manifold in the array. The air vent at the top of the upper manifold automatically allows air to escape and eliminate air pockets when the system is refilled. The automatic air vent is described in criterion 2.1.5. In addition to this air valve, a manual bleeder valve is provided to insure a fail-safe check for entrapped air when maintenance draining is required.

6.1.4. FLUSHING OF LIQUID SUBSYSTEM

The system should be flushed with plain tap water using the procedures outlined in the Installation, Operation, and Maintenance Manual.

6.2.1 Installation Instructions

The installation of the collector system is covered fully in the *Installation, Operation, and Maintenance Manual*.

6.2.2 Maintenance and Operation Instructions

These instructions are included in the *Installation, Operation, and Maintenance Manual*.

6.2.3 Maintenance Plan

The maintenance plan is given in the *Installation, Operation, and Maintenance Manual*.

6.2.4 Replacement Parts

Parts, components and equipment required for service, repair or replacement are available from the system manufacturer. A parts list and availability are included in the *Installation, Operation, and Maintenance Manual*.

6.3.1 MAINTENANCE OF H AND HC SYSTEMS

H and HC systems are not included as part of this collector system, but are the responsibility of the user. Therefore, this requirement is automatically satisfied.

6.3.2 MAINTENANCE OF DHW SYSTEM

A DHW System is not included as part of this collector system, but is the responsibility of the user. Therefore, this requirement is automatically satisfied.

11.2.1 CHEMICAL CORROSION

The design of this system does not utilize any material which can chemically decompose and effect the operation of any other components. Possible problem areas such as the decomposition of the absorber coating and the bearing shafts will not effect the performance of other components in the collector. The bearing is completely sealed so that any rust cannot impair the functional movement of this component. The black chrome coating on the copper tube is capable of withstanding 650°F temperatures and will not release materials or products which can condense on the inside on the inside lens surface. Therefore, it appears that there are no components or items in the collector design which are extremely susceptible to chemical decomposition. So there is little chance that any chemical decomposition products will be expelled from components under in-use conditions and cause the degradation of other components.

11.2.2 HEAT AND MOISTURE

Supports of this solar system are space 10.0' north-south and 10.0' east-west for each collector panel. These are the only points that are in contact with the mounting surface. All other components of this system are above and have free air circulation between the mounting site. The supports are well insulated from any heat producing components. Excessive conduction to the mounting points would not take place because of this insulation. Furthermore, the insulation is separated by at least 33" of metal which is exposed to ambient temperature and free air circulation.

11.3.1 MATERIAL COMPATIBILITY

There are no non-isolated dissimilar materials in contact with each other in this design which would cause corrosion. The fluid loop including the manifold, absorber tubes, pressure relief valve, air vent, swivel fittings and bleeder valves are all constructed of copper or brass and present no corrosive problem due to dissimilar metal junctions. If the user intends to connect this brass and copper system to other piping materials then he must take necessary precautions to prevent corrosion at the interface. This interface connection, however, is the responsibility of the user.

The housing and structural support utilize no dissimilar metal junctions which might cause corrosion. Therefore, there are no non-isolated dissimilar metal junctions which would result in corrosion due to electrochemical reactions.

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