

**AIR FORCE FLIGHT DYNAMICS LABORATORY
DIRECTOR OF LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE OHIO**



**ACQUISITION AND REDUCTION OF THIN-SKIN HEATING
DATA FROM THE AFFDL HIGH TEMPERATURE FACILITY**

Robert G. Christophel

and

William A. Rockwell

November 1973

**High Speed Aero Performance Branch
Flight Mechanics Division
Air Force Flight Dynamics Laboratory**

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**Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio 45433**

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AFFDL-TM-74-14-FXG

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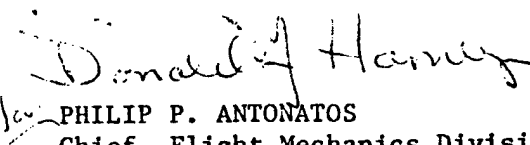
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Wright-Patterson Air Force Base, Ohio 45433

FOREWORD

This report presents the results of a study concerning the acquisition and reduction of thin-skin heating data from the Air Force Flight Dynamics Laboratory's High Temperature Facility. The work was done in-house under Project 1366 "Aeroperformance and Aeroheating Technology", Task 136603 "Aerodynamic Heating to Military Vehicles" and was conducted from June to October 1973.

This technical memorandum has been reviewed and approved.


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ABSTRACT

This report presents a method to acquire and reduce thin-skin heat transfer data from the AFFDL High Temperature Facility. The calculation method used in this work is based on the equation

$$h = \frac{[\rho C_p b]_M}{t_H - t_L} \left\{ \text{Ln} \left[\frac{T_O - T_{WH}}{T_O - T_{WL}} \right] \right\}$$

which is obtained from standard thin skin heating equations. The calculations are done on the CDC 160A computer and approximately .1 minutes per thermocouple are required for the reduction of the heating data. The entire data reduction process - including data handling, reduction of miscellaneous tunnel data, and heat transfer calculations-is accomplished in 10 - 15 minutes.

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List of Symbols

| | |
|----|-------------------------------------------------------|
| b | Thin-skin thickness; ft |
| Cp | Thin-skin specific heat; BTU/lbm °R |
| h | Heat transfer coefficient; BTU/ft ² sec °R |
| q | Heat flux; BTU/ft ² sec |
| T | Temperature; °R |
| t | Time; sec |
| ρ | Thin-skin density - lbm/ft ³ |

Subscripts

| | |
|---|----------------------------------|
| c | Calculated by curve fit equation |
| H | High Temperature Condition |
| i | Initial Condition |
| L | Low Temperature Condition |
| M | Of the model |
| q | Measured by quartz thermometer |
| w | Of the wall or thin-skin |
| o | Stagnation condition |

Section I - Introduction

The Air Force Flight Dynamics Laboratory's High Temperature Facility (HTF) is a Mach 10 blowdown wind tunnel used by laboratory personnel to conduct research for the design and development of high speed missiles and aircraft. During an interference heating test conducted recently in this tunnel, it was found that the procedures previously used for the reduction of thin-skin thermocouple data were not compatible with the data taken in the interference heating test. Thus, it was necessary to develop a new procedure for the acquisition and reduction of thin-skin heat transfer data for this facility. The purpose of this report is to document the procedure and to provide recommendations for its future use. The procedure is completely general and may be applied to any thin-skin heat transfer data which are not influenced by thermal conduction.

Section II - Facility

A detailed discussion of the entire HTF and its associated systems, as shown in figure 1, is given in reference 1.

Data Acquisition System

The HTF thermocouple data acquisition system is shown schematically in Figure 2. In this system, the thermocouples are connected to a Thermo Electric 48 channel reference junction with a 150°F reference temperature. The output from each reference junction used is amplified by one of the three brands of DC amplifiers listed in Table I and then routed to a 160 channel Control Data Corporation 8032C Analog/Digital converter. The 160 channels of this converter are scanned continuously with a time period between scans of the same channel of 0.0175 seconds. Each scan of data, containing the digital information from all 160 channels, is then stored on magnetic tape in chronological order.

It is currently facility practice to record a set of tunnel data both before and after each run for use as reference data. The reference data are separated from the test data by end of file marks on the data tape. If the test data is taken intermittently during a run, the intermittent groups of data are also separated by end of file marks. The complete data for a particular run, including the test data, are separated from the previous and subsequent runs by double end of file marks on the data tape.

Computer Facilities

There are two computer facilities available for use in the reduction of the thermocouple data. The first of these is a CDC 160A. The primary disadvantage of this computer is its relatively small memory of 8000 octal

storage spaces. However, by utilizing the two CDC 603 tape units which are part of this facility and the calculation methods discussed in later sections, it is possible to completely reduce the data from a thin-skin heat transfer run in less than 15 minutes.

The other computer facility available is the CDC 6600 located in building 676 on WPAFB. This facility has ample storage and computational space but it is the primary computer facility for scientific and engineering use on WPAFB. It is estimated that the minimum turn around time to reduce the data from one thin-skin heat transfer run would be two hours and, in most cases, the reduced data would not be available until the following day.

Section III - Test Program

The data used as test cases in the development of the thin-skin heat transfer data reduction method were produced during a Shock Wave-Boundary Layer Interference Heating test program using the geometry shown in Figure 3. Interference data are exceptionally well suited for this application because of the wide range of heating rates produced in the interaction region. The heat transfer portion of the interference test program consisted of 50 runs of which the three runs listed in Table II were selected for use in this work.

Model Description

The models used in this test consisted of a shock wave generator and a receiver plate. The shock wave generator is a stainless steel sharp flat plate 9 inches wide, 12 inches long, and 0.5 inches thick. The generator angle of attack may be varied in nominal one degree increments from -2° to $+10^{\circ}$. It has no instrumentation. The receiver plate is a stainless steel sharp flat plate 18 inches long, 12 inches wide, and 2 inches thick with interchangeable pressure and thin-skin thermocouple inserts. These inserts are 10.6 inches long and 2.25 inches wide. The heat transfer insert is 0.030 inches thick and has 38 chromel-alumel thermocouples located as shown in Figure 4.

Model Calibration

The receiver plate thermocouples were calibrated over a temperature range of 566.5°R to 663.4°R in approximately 20°R increments by soaking the receiver plate in a Delta Design MK6300H Temperature Chamber until the temperature in

the chamber and the voltage output of the thermocouples were stable. The chamber temperature was measured by a Hewlett Packard 2801A quartz thermometer and recorded manually as a simultaneous magnetic tape record of the thermocouple output was made through the data acquisition system. A first order least squares curve fit relating thermocouple voltage to temperature was then obtained for each thermocouple. Approximately 20-25 hours of tunnel occupancy time was required to complete the calibration.

This calibration process resulted in an individual calibration equation for each thermocouple. The coefficients for these equations are listed in table III along with an indication of the accuracy of the curve fits. The index used here is obtained from the expression,

$$\left[\frac{1}{N} \sum_{i=1}^N \frac{T_{c_i} - T_{q_i}}{T_{c_i}} \right]$$

where N is the number of calibration points used. This index is the average absolute difference, in percent, between the temperatures measured by the quartz thermometer and the temperatures calculated by the individual calibration equation for each thermocouple. The largest average difference is .211% indicating that the calibration curve fits are quite accurate.

Usual practice in the HTF is to use a standard facility curve fit in lieu of a formal calibration procedure for thin-skin heat transfer models. These curve fits were obtained by tunnel personnel from standard thermocouple temperature/voltage tables. The coefficients of the standard facility curve fit provided for this test program are also given in Table III.

Plots showing the temperature and heat transfer coefficients obtained for a particular test run using the calibrated curve fits as compared to the values obtained using the standard facility curve fit are shown in Figures 5 and 6, respectively. The difference in the values calculated by the different curve fits is not significant in most cases. However, the data for thermocouples 7, 20, and 25 appears much more consistent and reasonable when calculated by the individually calibrated equations. The data from these thermocouples must be used judiciously because the calibration coefficients (Table III) deviate considerably from the other coefficients.

Section IV - Data Acquisition and Reduction

The objective in the reduction of thin-skin heat transfer data is to calculate a heating rate and/or a convective heat transfer coefficient from a set of temperature-time data for each thermocouple in the model. In this section, the selection of the technique used to acquire the necessary set of temperature-time data and the methods used to calculate the desired heating rate and convective heat transfer coefficient are discussed. A listing of the computer program is given in Appendix A.

Data Acquisition

The technique for acquiring a valid set of temperature-time data evolved in the following manner. Initially intermittent short bursts (12-15 scans) of data were recorded once per second over a time period of approximately 5 seconds with the first burst of data starting at the time the model reached the centerline of the test section. The set of temperature-time data produced by this procedure was unacceptable because no definitive temperature change was realized in the low heating regions in the time period (.2-.3 sec) of the data burst.

In order to acquire heating rates in the low heating regions it was decided to record data continuously for a period of approximately 5 seconds starting at the time the model reached the centerline of the test section. The set of temperature-time data produced by this method was completely acceptable in every case. It should be noted that the time period of 5 seconds over which data was recorded was more than adequate in all instances and, in most cases, could have been shortened to two seconds or less with no loss in

The output from selected thermocouples was recorded on a Sanborn strip chart as shown in Figure 7 for the purpose of real time monitoring of the thermocouple response during a test run. The position of the model and the time period during which data is recorded is also indicated on the strip chart.

Data Reduction Method

The computer program used to perform the calculations for the data reduction is based on equation (4) below. This relationship is obtained by combining the equation defining the convective heat transfer coefficient,

$$\dot{q} = h (T_o - T_w) \quad (1)$$

with the energy balance equation for an element of a thin-skin model in which there is no heat conduction or radiation,

$$\dot{q} = (\rho C_p b)_M \frac{dT_w}{dt} \quad (2)$$

which results in

$$h (T_o - T_w) = (\rho C_p b)_M \frac{dT_w}{dt} \quad (3)$$

Since the model properties are essentially constant over the temperature range experienced during a single run, equation (3) can be integrated over the time increment t_L to t_H to produce the expression

$$h = \frac{(\rho C_p b)_M}{t_H - t_L} \left\{ \text{Ln} \left[\frac{T_o - T_{wL}}{T_o - T_{wH}} \right] \right\} \quad (4)$$

This equation was used to calculate the convective heat transfer coefficient and then the heating rate was determined from equation (1).

The heat transfer coefficients for each run were calculated several times using a different value of the quantity $(t_H - t_L)$ each time the calculations were performed. The results of the calculations using values of 1, 2, and 3 seconds for $(t_H - t_L)$ are presented in figure 8. This figure indicates that there is no significant difference in the results of calculations based on different time intervals.

In performing the calculations for a particular value of $(t_H - t_L)$ the wall temperatures T_{W_H} and T_{W_L} were taken as the average over a short time period symmetric about the times t_H and t_L , respectively. The specific heat of the model was then obtained by substituting the average of T_{W_H} and T_{W_L} into a third order curve fit. The density and skin thickness of the model were assumed to be independent of temperature and, since measurements from reference 2 indicate that the skin thickness is the same at all thermocouple locations, constant values were used for these quantities.

The validity of the assumptions that there is no thermal conduction in the model and that radiation is negligible can be ascertained by rewriting equation (3) in the form

$$\frac{h}{(\rho C_p b)_M} = \frac{1}{T_0 - T_w} \frac{dT_w}{dt} \quad (5)$$

which is equivalent to

$$\frac{h}{(\rho C_p b)_M} = \frac{d}{dt} \left\{ \text{Ln} \left[\frac{T_0 - T_{w_i}}{T_0 - T_w} \right] \right\} \quad (6)$$

Since the left side of equation (6) is a constant when no conduction or radiation is present, the function

$$\text{Ln} \left[\frac{T_0 - T_{w_i}}{T_0 - T_w} \right]$$

must be linear with time. This function was calculated and plotted for all thermocouples and was found to be linear in all cases except a small region near the 12 inch location where a portion of the model had been modified with sealing material (RTV). The non-linearity of the function in this region indicates that the data are influenced by conduction or radiation.

Examples of the linear data plots are shown in Figures 9, 10, and 11. Figure 12 is an example of the non-linear data plots. The excessive data scatter in the first .3 seconds of Figure 9 is a characteristic of this and three other channels. This scatter does not appear to affect the general trend of the data and, in most cases, the scatter diminished to an acceptable level by .5 seconds. The effects of this scatter was eliminated by setting $t_L = .5$ seconds in all calculations involving equation (4). Note that this excessive scatter does not appear in the other figures.

There is, however, an anomalous sinusoidal noise signal apparent in all the figures. This noise signal has a constant frequency and appears on all channels. The amplitude is constant on any particular channel but varies from channel to channel. The period of the noise is 12 to 13 data scans or about .21 seconds. For this reason, the averaged wall temperatures, T_{w_H} and T_{w_L} , were based on 12 scans of data. In a few cases these temperatures were also calculated using 24 data scans but no significant change was noted.

Both the sinusoidal noise signal and the excessive data scatter problem are currently being investigated by tunnel personnel. As yet, however, the cause of either problem has not been determined.

Other Calculation Methods Considered

Two other calculation procedures were considered for use in this work before it was decided to use the method based on equation (4). The first of these involves obtaining a linear curve fit of the quantity

$$\text{Ln} \left[\frac{T_0 - T_{w_i}}{T_0 - T_w} \right]$$

as a function of time and then substituting the slope of the curve fit into equation (6). Some data were reduced in this manner and generally produced heat transfer coefficients about 2% higher than those produced by evaluating equation (4). This technique is impractical to use on the CDC 160A because of the space and excessive time - about four minutes per thermocouple-required to produce the curve fits.

The other procedure which was considered is based on the assumption that, due to the large stagnation to wall temperature ratio characteristically obtained in the HTF, the heating rate is constant, and thus the temperature time relationship is linear, for the first few seconds after the model is injected into the flow. This allows equation (2) to be written in the finite difference form,

$$\dot{q} = (\rho C_p b)_M \left[\frac{T_{w_H} - T_{w_L}}{t_H - t_L} \right] \quad (7)$$

into which information can be substituted directly from the set of temperature time data. A few calculations were performed using this method and the results agree extremely well, within 1%, with the results obtained from equation (4).

Section V - Summary

The methods recommended for the acquisition and reduction of heat transfer data from the HTF can be summarized as follows:

1. Thermocouple data is recorded continuously on magnetic tape for about 3.5 seconds from the time the model reaches the centerline of the tunnel. Auxiliary data, if desired, can be recorded on strip charts or visicorder.

2. Calculate and plot the function

$$\text{Ln} \left[\frac{T_0 - T_{W_i}}{T_0 - T_W} \right]$$

versus time to check for conduction effects in the model and extraneous noise in the recording system. It is not necessary to prepare these plots for each run. The most critical cases are those with the highest heating rates.

3. Calculate the heat transfer coefficient from the equation

$$h = \left[\frac{(\rho C_p b)_M}{t_H - t_L} \right] \left\{ \text{Ln} \left[\frac{T_0 - T_{W_i}}{T_0 - T_{W_H}} \right] \right\} \quad (4)$$

using appropriate model properties. The time increment, $t_H - t_L$, used in these calculations must be long enough to allow for a definitive temperature change in the low heating regions and yet short enough so that conduction does not affect the data in the high heating regions. The temperature function versus time plots can be useful in determining the appropriate $t_H - t_L$. Also,

it is presently necessary to calculate T_{W_H} and T_{W_L} as the average temperature over a specific number of data scans in order to eliminate the anomalous sinusoidal noise mentioned in the previous section. The correct number of scans used for this averaging is also determined from the temperature function versus time plots.

4. Calculate the heating rate from

$$\dot{q} = h(T_0 - T_w) \quad (1)$$

The decision to perform a model calibration, such as the procedure described in Section III, must be determined on an individual basis. If the condition of the model is questionable or if the model has been modified, it is recommended that the model be fully calibrated. In other cases it is recommended that a check calibration at two or three reference temperatures be performed. This check can be completed in a few hours and assures the reliability of the thermocouple data.

References

1. Smith, R.R. and Funderburg, J.A. "Calibration of the Pebble Bed Heated Facility", Air Force Flight Dynamics Laboratory TM-73-40-FXG April 1973
2. Burke, G.L. unpublished notes.

Appendix A

This program was designed to meet the requirements of a specific test program and it is not meant to be a universal heat transfer program for the HTF. Its purpose in this report is to serve only as an example of a calculation procedure based on equation (4) given in Section IV.

Symbols

| | |
|--------------------|--------------------------------------------------------------------------------------------------------|
| A1 | Speed of sound in free stream- ft/sec |
| AG | Generator angle of attack |
| ALPHA | Read from magnetic tape as sting angle. printed as generator angle of attack |
| BT | Thin-skin thickness - ft |
| CPS | Thin-skin specific heat - BTU/LBM °R |
| CWTO(I) CWT1(I) | Coefficients in specific heat curve fit |
| DAYNUM | Run of day number |
| DELT | Time interval ($t_H - t_L$) - sec |
| DLH | $\ln \left[\frac{(T_o - T_w)}{(T_o - T_{w_i})} \right]$ |
| DLL | $\ln \left[\frac{(T_o - T_w)}{(T_o - T_{w_L})} \right]^H$ |
| DTWDT | Temperature time slope - °R/sec |
| FAVG | Number of scans used in averaging |
| H | Convective heat transfer coefficient - BTU/ft ² sec °R |
| HREF | Convective heat transfer coefficient based on Eckerts reference method - BTU/ft ² sec °R |
| HHREF | H/HREF |
| ICH | Channel number |
| IDATE | Day of month that the run was made |
| IRUN | Annual run number |

| | |
|----------------|-----------------------------------------------------------------|
| JDATA | Raw data from magnetic tape |
| NAVG | Number of scans used in averaging |
| NAVG1 | Number of scans between data used for TWI and data used for TWL |
| NAVG2 | Number of scans between data used for TWH and data used for TWH |
| NCH | Channel number |
| NDAY | Run of day number |
| NSCN | Scan counter |
| NT | Number of thermocouples in model |
| PO | Stagnation pressure - psia |
| PT2 | Probe pressure (not used) |
| PINF | Free stream pressure - MM Hg |
| Q | Heating rate - BTU/ft ² sec |
| QFP | Heating rate for undisturbed case - BTU/ft ² sec |
| QINF | Free stream dynamic pressure (not used) |
| QQFP | Q/QFP |
| RCB | RHOS*CPS*BT |
| RDATA(I) | JDATA(I)/1023.5 - Volts |
| RE | Free stream Reynolds number - per ft |
| RESTAR | Reynolds number based on Eckerts reference temperature |
| RHO1 | Free stream density - lbm/ft ³ |
| RHOS | Thin-skin density - lbm/ft ³ |
| T ₀ | Stagnation Temperature - °R |
| TINF | Free Stream Temperature - °R |
| TSTAR | Eckert reference temperature - °R |

| | |
|----------|----------------------------------------------------------------------------------------------|
| TWA(I) | $(T_{WL}(I) + T_{WH}(I))/2$. - °R |
| TWI(I) | Average temperature at t_i - °R |
| TWH(I) | Average temperature at t_H - °R |
| TWL(I) | Average temperature at t_L - °R |
| VINF | Free stream velocity - ft/sec |
| XDATA | Impact pressure in test section - MM Hg |
| XDIST(I) | Location of thermocouples - in |
| XMINF | Free stream Mach number |
| XMU | Viscosity (not used) |
| XMUI | Viscosity based on Sutherland low temperature equation - lb sec/ft ² |
| XMUS | Viscosity based on Sutherland high temperature equation - lb sec/ft ² |
| XZM | Distance, along receiver surface, from receiver leading edge to generator trailing edge - in |
| ZM | Height of generator trailing edge above receiver plate - in |

H16 LAMINAR-TRANSITIONAL INTERFERENCE HEATING TEST
 HEAT TRANSFER REDUCTION PROGRAM

7 001 73

THIS PROGRAM IS CURRENTLY CONFIGURED FOR NOMINAL TIME INTERVALS
 OF MULTIPLES OF ONE SECOND. THE ACTUAL TIME INTERVALS ARE

MULTIPLES OF .0975 SECONDS,

DIMENSION JDATA(91), PDATA(37), INT(37), TNA(37), TUL(37), TMH(37),

*XOIST(37), DTMO(37), CFW1(37)

I=153E(4)

1001 FCRMAT (15,5E3,2,15)

1003 FCRMAT (214,515,7)

1004 FCRMAT (5E15,5)

1010 FCRMAT (1H1,48H1F LAMINAR/TRANSITION INTERFERENCE HEATING TEST/

*1X,13,1X,8HMAY 1973, 5X,10HRJN OF DAY, I3,10X,

*13H1ME INTERVAL, F7.4, 2X, 7HSECONDS//)

1011 FCRMAT (1X,3HRUN, 3X, 5HSCANS, 3X, 4HMACH, 5X, 2HPO, 5X, 2HTC, 5X,

*5HALPHA, 5X, 2HZM, 5X, 3HX ZM/23X, 4HPS1A, 3X, 5HDEG R, 4X, 3HDEG, 6X, 2H1N,

*6X, 2H1N/ I4, I5, F9, 2, F8, 1, F8, J, F7.2, 2F8.2/)

1012 FCRMAT (1X, 5HT-INF, 5X, 5HP-INF, 5X, 5HV-INF, 5X, 7HRH0-INF, 5X, 6HMU-INF,

*5X, 5HRE/FT/1X, 5HDEG R, 6X, 4HMMHG, 5X, 5HFT/SEC, 2X, 11HL3-SEC2/FT4/

*F6.1, 2X, F9.3, 4X, F6.0, 3X, E10.4, 2X, E9.3, 2X, E9.3//)

1013 FCRMAT (2X, 2HTC, 2X, 2HCH, 4X, 1HX, 5X, 5HQDOTW, 5X, 6HQDOTFP, 6X, 4HQQFP,

*5X, 2HTW, 5X, 5HDTWDT, 7X, 1HH, 9X, 4HREF, 10X, 5HHREF/11X, 2HIN, 6X, 4HBTU/

* , 6X, 4HBTU/,

*15X, 5HDEG R, 3X, 5HJEG R, 4X, 8HBTU/FT2-, 4X, 8HBTU/FT2-/16X, 7HFT2-SEC,

*3X, 7HFT2-SEC, 22X, 4H/SEC, 5X, 9HSEC-DEG R, 5X, 9HSEC-DEG R)

1014 FCRMAT (1H, I3, I3, F7.2, 2E11.4, F9.4, F8.1, E10.3, 3E11.4)

1015 FCRMAT (3I5)

1016 FCRMAT (I5, F5, 2, 5E11.5)

1017 FCRMAT (I5, 2E15, 8)

```

1018 FORMAT (1H ,2I5,3F10.1,F10.4)
1019 FORMAT (1H ,2X,1-I,4X,3NCH,7X,3HTWI,7X,3HTWL,7X,3HTWH)
1 PAUSE 1
2 READ DATE OF RUN
3 READ 1001, IDATE
4 READ MODEL DATA AND NUMBER OF SCANS USED IN OBTAINING TWL AND TWH
5 READ 1001,NT,BT,2HDS,ZM,XZM,AG,NAVG
6 DO 2 I=1,NT
7 READ 1017,NCH,CTWJ(I),CTW1(I)
8 CONTINUE
9 READ 1004,(XDIST(I),I=1,NT)
10 READ RUN NUMBER AND TUNNEL DATA. THIS INFORMATION IS CURRENTLY
11 OBTAINED FROM STANDARD FACILITY PROGRAM NUMBER TWO.
12 READ 1003,IRUN
13 READ 1004,P0,T0,ALPHA,PT2,XMINF
14 READ 1004,RE,PINF,IINF,OINF,RH01
15 READ 1004,XMU,A1
16 VINF=XMINF*A1
17 ALPHA=A3
18 FAVS=NAVG
19 READ BY FIRST SET OF REFERENCE ZEROS
20 READ TAPE 2,JDATA
21 IF(XEOF(X))4,3,4
22 CONTINUE
23 ZERO TWI AND TWL
24 DO 5 I=1,NT
25 TWI(I)=0.
26 TWL(I)=0.
27 CONTINUE
28 READ AND SUM FIRST NAVG SCANS FOR EACH THERMOCOUPLE. ALSO CHECK TO
29 INSURE THAT THE PROGRAM IS WORKING WITH THE DESIRED DATA.

```

```

00 8 NSCN=1, NAVG
   READ TAPE 2, JDATA
   IF (XEOF(X)) 22, 6, 22
6  X DATA=JDATA(5)
   XDATA=XDATA/1023.5
   IF (XDATA-.07) 22, 22, 7
7  CONTINUE
   DAYNJM=JDATA(6)/1023.5
   GAYNJM=JAYNUM*100.+0.2
   DAY=DAYNUM
00 9 I=1, NT
   NCH=75-I
   RDATA(I)=JDATA(NCH)
   RDATA(I)=RDATA(I)/1023.5
   TWI(I)=TWI(I)+CTWO(I)+CTW1(I)*RDATA(I)
8  CONTINUE
   CALCULATE TWI AS THE AVERAGE OF THE FIRST NAVG SCANS
00 9 I=1, NT
   TWI(I)=TWI(I)/FAVG
9  CONTINUE
   READ BY THE NEXT NAVG1 SCANS
   NAVG1=28-NAVG-(NAVG/2)
00 11 I=1, NAVG1
   READ TAPE 2, JDATA
   IF (XEOF(X)) 22, 10, 22
10 CONTINUE
   READ AND SUM THE NEXT NAVG SCANS FOR TWL
00 12 NSCN=1, NAVG
   READ TAPE 2, JDATA
   IF (XEOF(X)) 22, 11, 22

```

```

11 CONTINUE
DO 12 I=1,NT
  NSCH=76-I
  RDATA(I)=JDATA(NSCH)
  RDATA(I)=RDATA(I)/1023.5
  TWL(I)=TWL(I)+CTW0(I)+CTW1(I)*RDATA(I)
12 CONTINUE
C   CALCULATE TWL AS AVERAGE OF NAVG SCANS
DO 13 I=1,NT
  TWL(I)=TWL(I)/FAVG
13 CONTINUE
DELT=0.0
14 PAUSE 14
C   INCREMENT DELT AND ZERO TWH AND TWA
DELT=DELT+0.0075
DC 15 I=1,NT
  TWH(I)=0.
  TWA(I)=0.
15 CONTINUE
C   READ BY THE NEXT NAVG2 SCANS
  NAVG2=57-NAVG
DO 15 I=1,NAVG2
  READ TAPE 2,JDATA
  IF (XEOF(X))22,15,22
16 CONTINUE
C   READ AND SUM THE NEXT NAVG SCANS FOR TWH
DO 13 NSCN=1,NAVG
  READ TAPE 2,JDATA
  IF (XEOF(X))22,17,22
17 CONTINUE
DC 13 I=1,NT

```

```

NCH=76-I
RDATA(I)=JDATA(NCH)
RDATA(I)=RDATA(I)/1023.5
TWH(I)=TWH(I)+CTWO(I)+CTW1(I)*RDATA(I)
18 CONTINUE
C CALCULATE TWH AS THE AVERAGE OF NAV3 SCANS
DO 19 I=1,NT
TWH(I)=TWH(I)/FAV3
TWA(I)=TWH(I)*.5+TWL(I)*.5
C CALCULATE TWA AS THE AVERAGE OF THL AND TWH
19 CONTINUE
C PRINT HEADING , TUNNEL DATA, AND RUN INFORMATION
PRINT 1010,IDATE,NDAY,DELTA
PRINT 1011,IRUN,NAVG ,XMINF,P0,T0,ALPHA,ZM,XZM
PRINT 1012,TINF,PINF,VINF,RHO1,XMU,RE
PRINT 1019
C PRINT OJT TEMPERATURE DATA
DO 20 I=1,NT
NCH=76-I
PRINT 1018,I,NCH,TWI(I),TWL(I),TWH(I)
20 CONTINUE
PRINT 1010,IDATE,NDAY,DELTA
PRINT 1011,IRUN,NAVG ,XMINF,P0,T0,ALPHA,ZM,XZM
PRINT 1012,TINF,PINF,VINF,RHO1,XMU,RE
PRINT HEADING , TUNNEL DATA, AND RUN INFORMATION
PRINT 1013
C CALCULATE HEAT TRANSFER COEFFICIENT, HEATING RATE, AND THEORETICAL
C HEAT TRANSFER COEFFICIENT. THEN READ IN THE EXPERIMENTAL
C UNDISTURBED HEATING RATE.

```

```

DO 21 I=1,NT
CPS=.12325067-.220544171E-04*TWA(I)+.352494567E-07*TWA(I)**2-
* .872973221E-11*TWA(I)**3
RCB=3T*CPS*RHOS
DLL=.06*((TO-TWI(I))/(TO-TWL(I)))
DLH=.06*((TO-TWI(I))/(TO-TWH(I)))
H=RC3*(DLH-DLL)/DELT
Q=H*(TO-TWA(I))
TSTAR=.5*TWA(I)+.187*TO+.031*TINF
XMUS=2.27E-08*(TSTAR**.5)/(1+198.6/TSTAR)
XMUI=8.05E-10*TINF
RESTAR=TINF/TSTAR*XMUI/XMUS*REXDIST(I)/12.
HREF=(.332*6006.*1.24*12.)/XDIST(I)*XMUS*(RESTAR**.5)*.001285
HREF=H/HREF
READ 1004,QFP
QQFP=Q/QFP
ICH=75-I
DTWDT=(TWH(I)-TWL(I))/DELT
PRINT 1014,I,ICH,XDIST(I),Q,QFP ,QQFP,TWA(I),DTWDT,H,HREF,HHREF
21 CONTINUE
GO TO 14
ENDING EOF HAS BEEN ENCOUNTERED. SET UP FOR NEXT RUN.
22 READ TAPE 2,JDATA
IF(XEOF(X))23,22,23
23 READ TAPE 2,JDATA
IF(XEOF(X))1,24,1
IF PAUSE 24, SOMETHING IS WRONG WITH DATA TAPE
24 PAUSE 24
GO TO 1
END

```

Table I Amplifiers

| Brand | Model | Number Available |
|---------|-------|------------------|
| Neff | 119 | 24 |
| Preston | 611B | 24 |
| Video | 8300S | 24 |

Table II Test Conditions

| Run | Stagnation Pressure | Stagnation Temperature | Free Stream Reynolds Number | Generator Angle | Receiver Angle |
|-----|--------------------------|------------------------|-----------------------------|-----------------|----------------|
| 187 | 602.4 lb/in ² | 2304 °R | .518x10 ⁶ /ft | 6.3° | -6.0° |
| 198 | 603.9 " | 2091 " | .618x10 ⁶ " | None | -0.1° |
| 202 | 603.8 " | 2179 " | .572x10 ⁶ " | 5.3° | -0.1° |

Table III - Calibration Coefficients

| T/C Number | CDC Channel | X Position (ins) | Oven Calibration | | | Standard Coefficients | |
|------------|-------------|------------------|------------------|----------------|-------|-----------------------|----------------|
| | | | A ₁ | A ₂ | Index | A ₁ | A ₂ |
| 1 | 75 | 7.00 | 609.00 | 99.06 | .049 | 149.64 | 83.57 |
| 2 | 74 | 7.25 | 605.79 | 93.17 | .043 | | |
| 3 | 73 | 7.75 | 604.12 | 87.15 | .034 | | |
| 4 | 72 | 8.00 | 609.09 | 89.74 | .058 | | |
| 5 | 71 | 8.25 | 608.17 | 96.83 | .034 | | |
| 6 | 70 | 8.50 | 609.28 | 87.76 | .062 | | |
| 7 | 69 | 8.75 | 605.66 | 542.86 | .026 | | |
| 8 | 68 | 9.00 | 608.71 | 87.77 | .031 | | |
| 9 | 67 | 9.25 | 608.32 | 86.91 | .083 | | |
| 10 | 66 | 9.50 | 608.75 | 87.55 | .016 | | |
| 11 | 65 | 9.75 | 608.77 | 88.12 | .015 | | |
| 12 | 64 | 10.00 | 610.49 | 88.71 | .112 | | |
| 13 | 63 | 10.25 | 611.59 | 92.89 | .106 | | |
| 14 | 62 | 10.50 | 610.89 | 87.73 | .017 | | |
| 15 | 61 | 10.75 | 611.06 | 87.55 | .020 | | |
| 16 | 60 | 11.00 | 610.27 | 87.25 | .014 | | |
| 17 | 59 | 11.25 | 610.28 | 87.25 | .016 | | |
| 18 | 58 | 11.50 | 609.81 | 87.24 | .011 | | |
| 19 | 57 | 11.75 | 610.17 | 87.29 | .011 | | |
| 20 | 56 | 11.90 | 608.77 | 147.47 | .211 | | |
| 21 | 55 | 12.00 | 610.43 | 87.11 | .011 | | |
| 22 | 54 | 12.25 | 609.65 | 87.24 | .005 | | |
| 23 | 53 | 12.50 | 610.25 | 86.90 | .011 | | |
| 24 | 52 | 12.75 | 610.01 | 86.79 | .016 | | |
| 25 | 51 | 13.00 | 447.18 | -83.66 | .076 | | |
| 26 | 50 | 13.25 | 609.82 | 86.90 | .009 | | |
| 27 | 49 | 13.50 | 609.85 | 87.02 | .014 | | |
| 28 | 48 | 13.75 | 609.39 | 86.89 | .012 | | |
| 29 | 47 | 14.00 | 601.34 | 86.38 | .012 | | |
| 30 | 46 | 14.25 | 609.92 | 87.10 | .012 | | |
| 31 | 45 | 14.50 | 610.32 | 86.79 | .012 | | |
| 32 | 44 | 14.75 | 609.89 | 86.73 | .009 | | |
| 33 | 43 | 15.00 | 610.40 | 86.84 | .012 | | |
| 34 | 42 | 15.50 | 610.22 | 86.70 | .009 | | |
| 35 | 41 | 16.00 | 609.56 | 86.57 | .016 | | |
| 36 | 40 | 16.50 | 609.82 | 86.46 | .011 | | |
| 37 | 39 | 17.00 | 609.71 | 86.24 | .031 | | |

Oven Calibration: $T_w = A_1 + A_2 * (\text{Voltage}) \quad ^\circ\text{R}$

Standard Coeff: $T_w = A_1 + A_2 * (\text{Voltage}) + 459.69 \quad ^\circ\text{R}$

- ① QUICK CLOSING ISOLATION VALVE
- ② PRE-REGULATOR VALVE
- ③ HIGH PRESSURE AIR LINE
- ④ MASS FLOW CONTROL VALVE
- ⑤ BURNER CONTROL PANEL
- ⑥ BURNER EXHAUST SYSTEM
- ⑦ PEBBLE BED HEATER
- ⑧ 250 GPM. WATER PUMP
- ⑨ 50 GPM. WATER PUMP
- ⑩ HIGH PRESSURE WATER PUMP
- ⑪ HOT VALVE
- ⑫ AIR/WATER HEAT EXCHANGER
- ⑬ 1700 GPM WATER PUMP
- ⑭ WATER/WATER HEAT EXCHANGER

- ⑮ VACUUM ISOLATION VALVE
- ⑯ DATA MONITORING SYSTEMS
- ⑰ DATA CONDITIONING CONSOLE
- ⑱ MODEL PRESSURE MEASURING SYSTEM
- ⑲ INSTRUMENTATION CONSOLE
- ⑳ DIFFUSER PRESSURE MEASUREMENT CONTROLS
- ㉑ FACILITY CONTROL CONSOLE

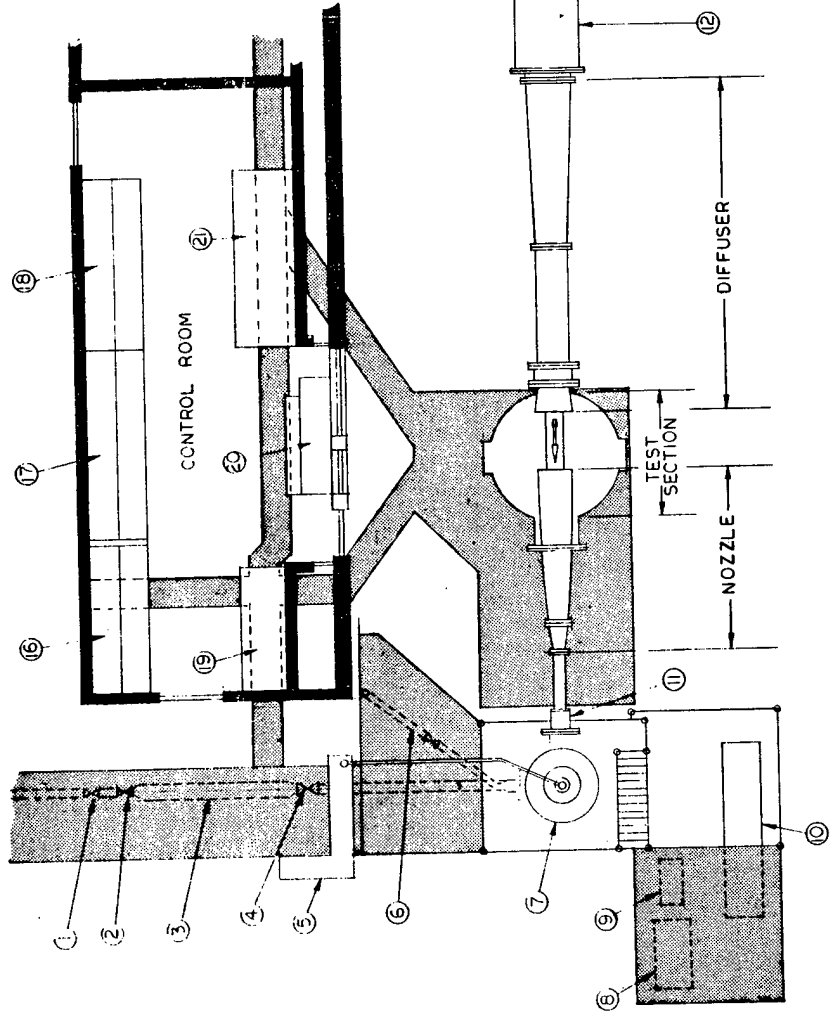


FIGURE 1. GENERAL ARRANGEMENT OF HIGH TEMPERATURE FACILITY

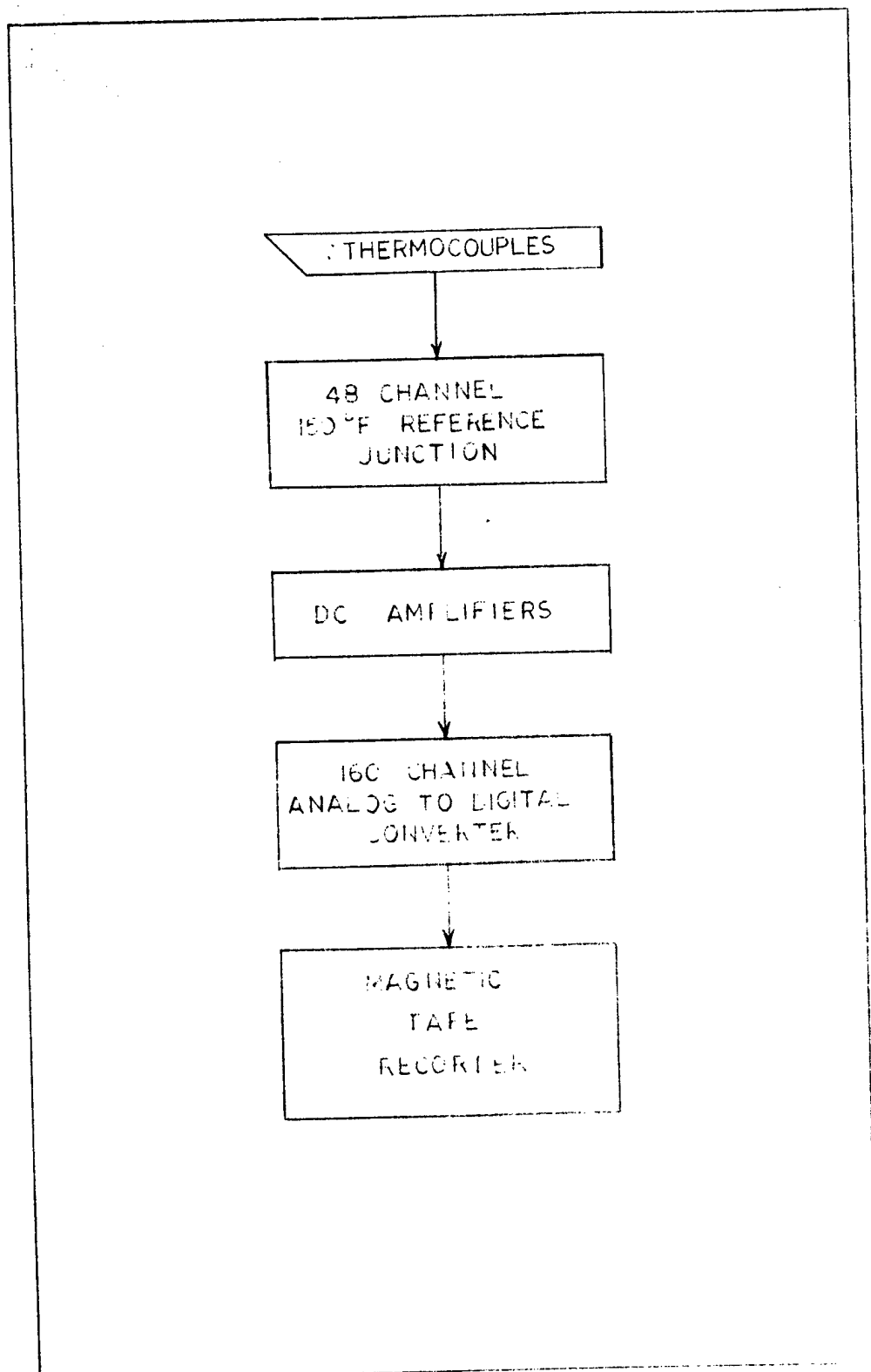


Figure 2. Data Schematic

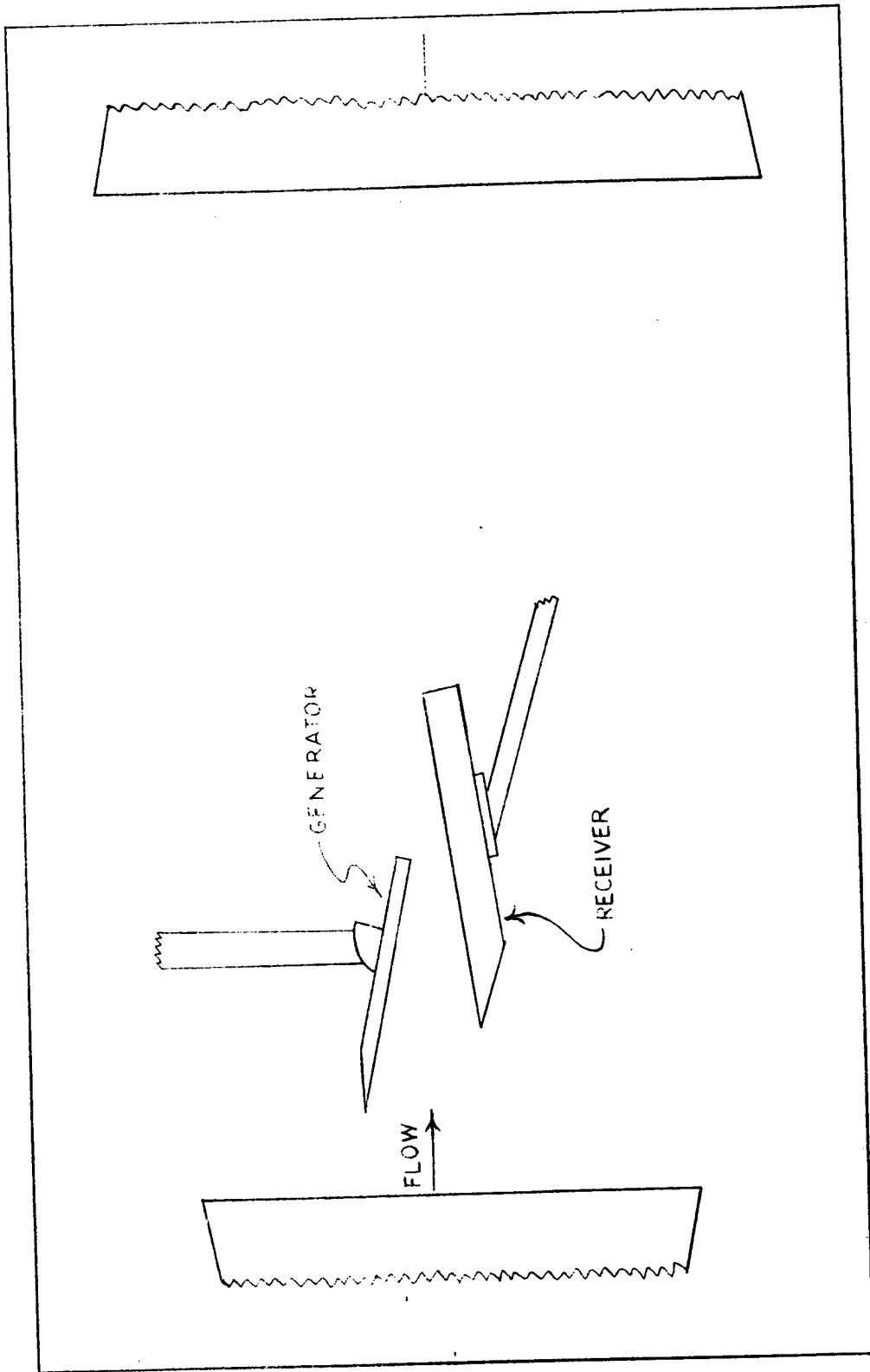


Figure 3. Test Geometry

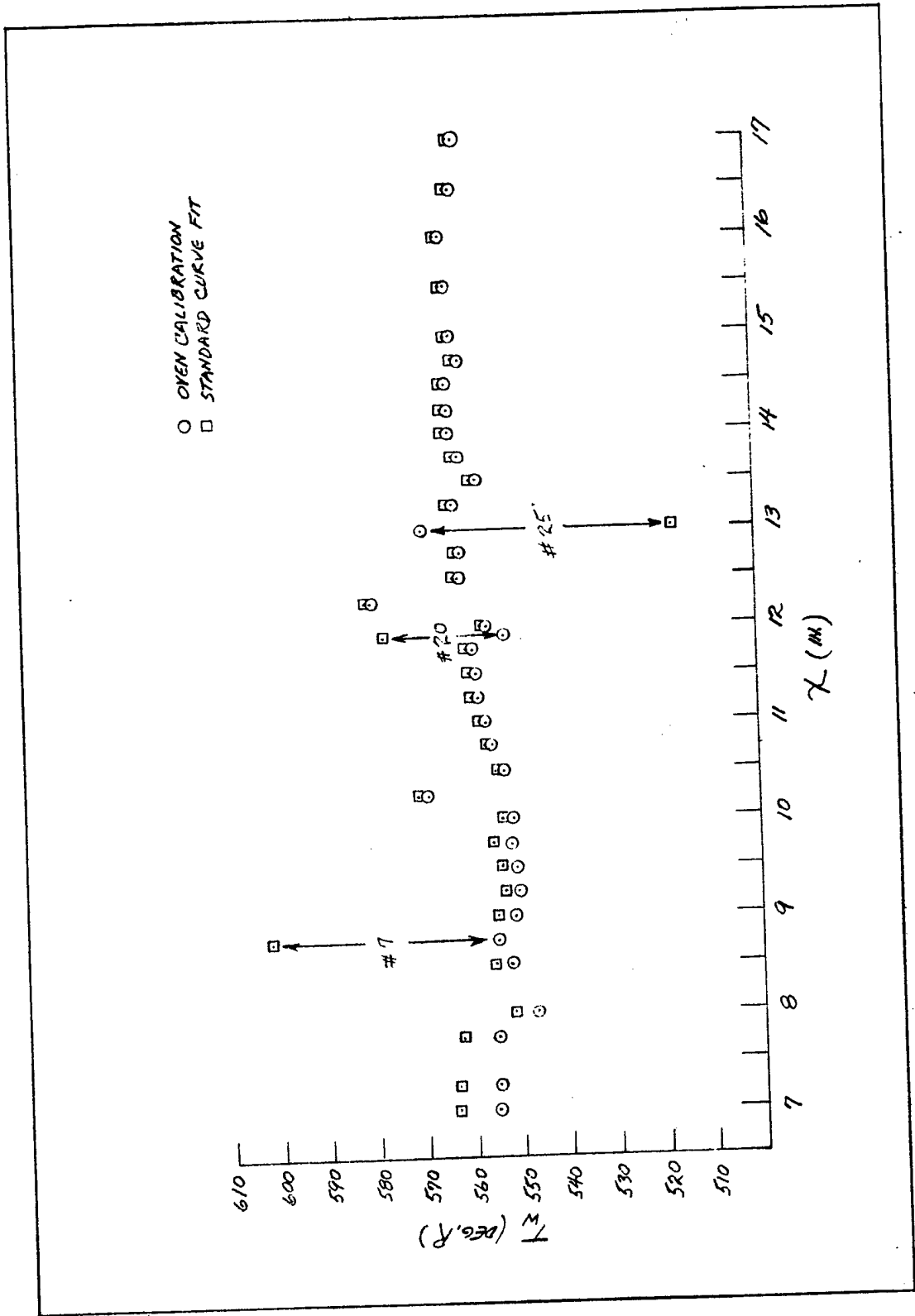


Figure 5. Calibration Comparison - Temperatures

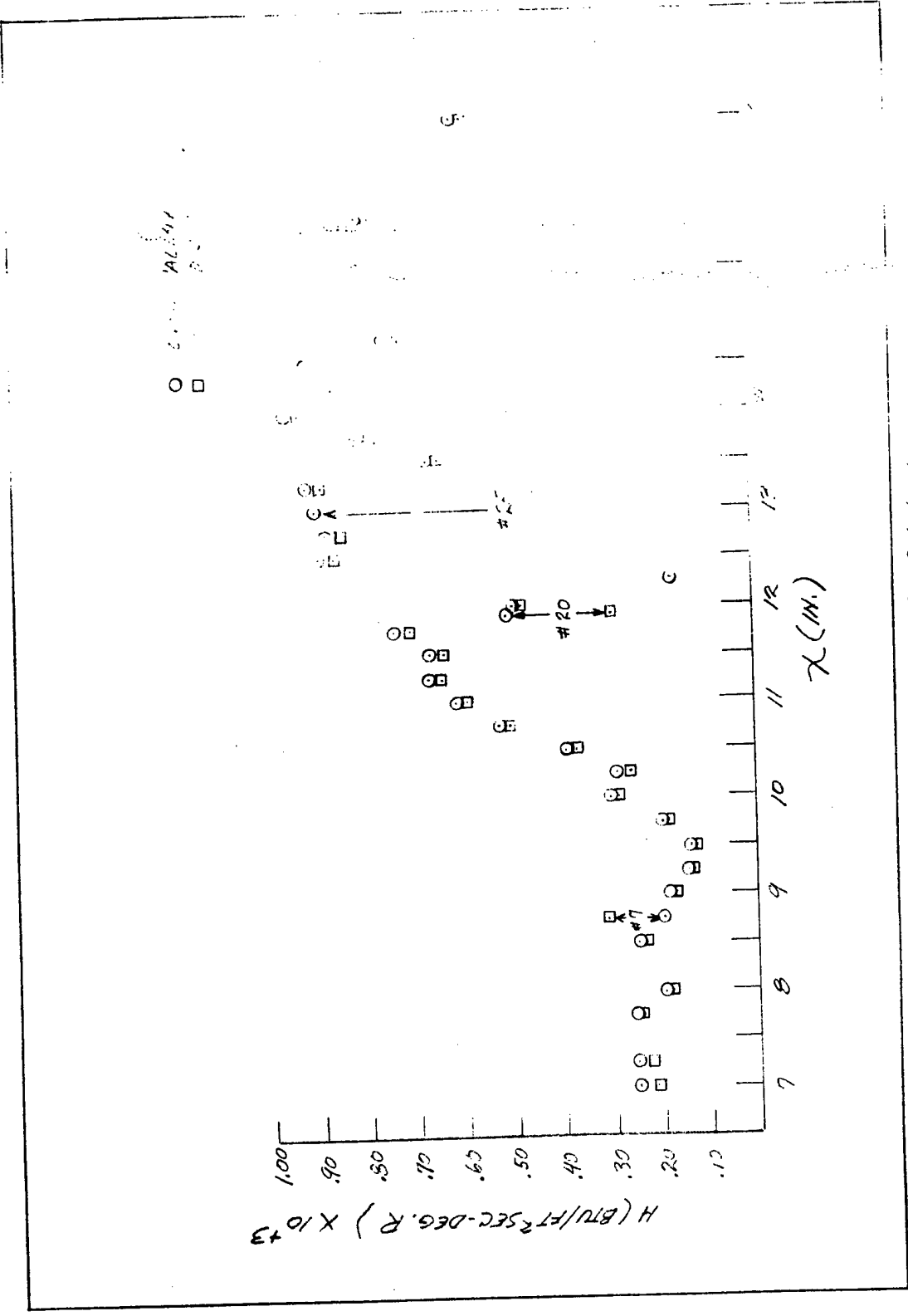


Figure 6. Calibration Comparison - Heat Transfer Coefficients

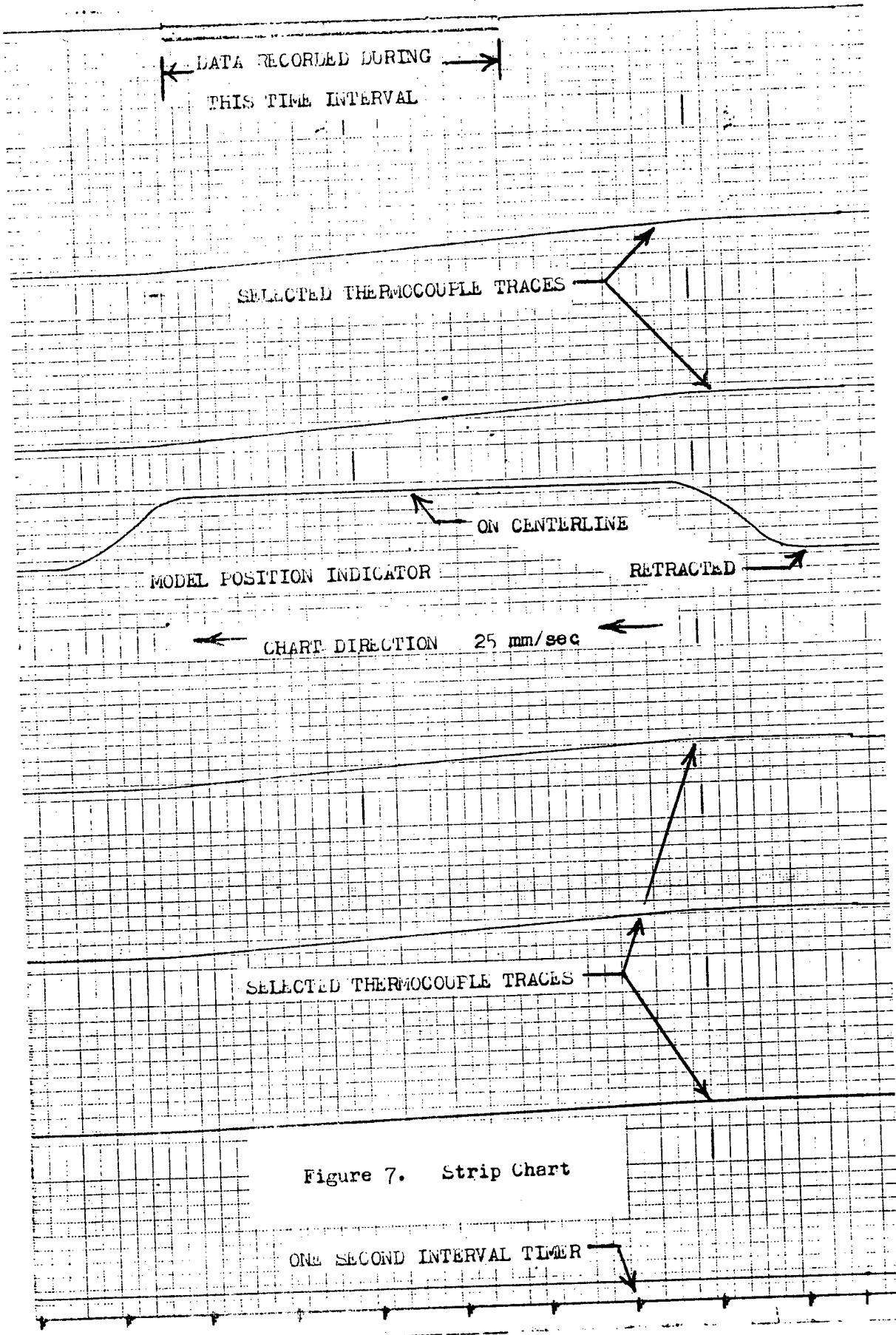


Figure 7. Strip Chart

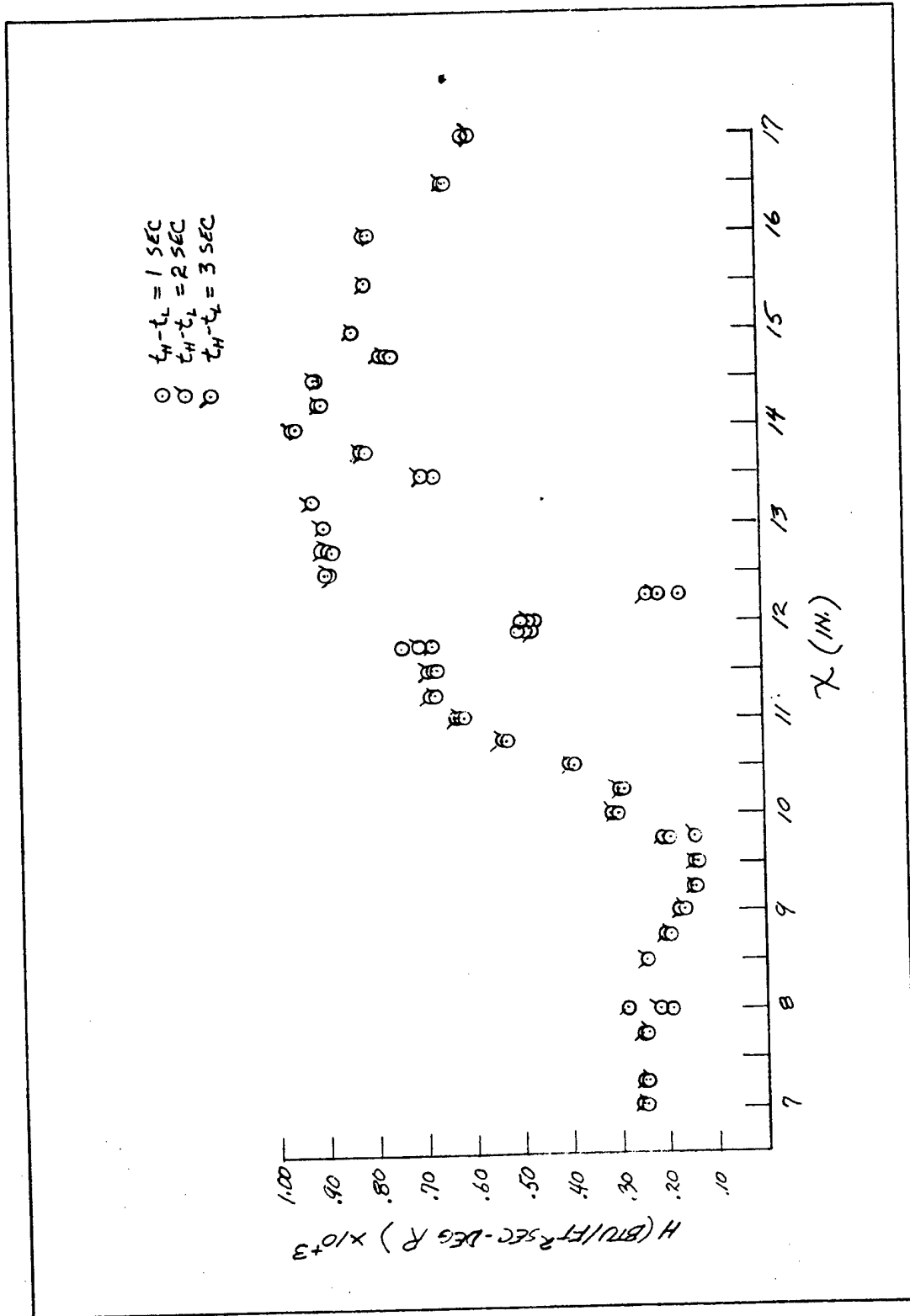


Figure 8. Heat Transfer Coefficients

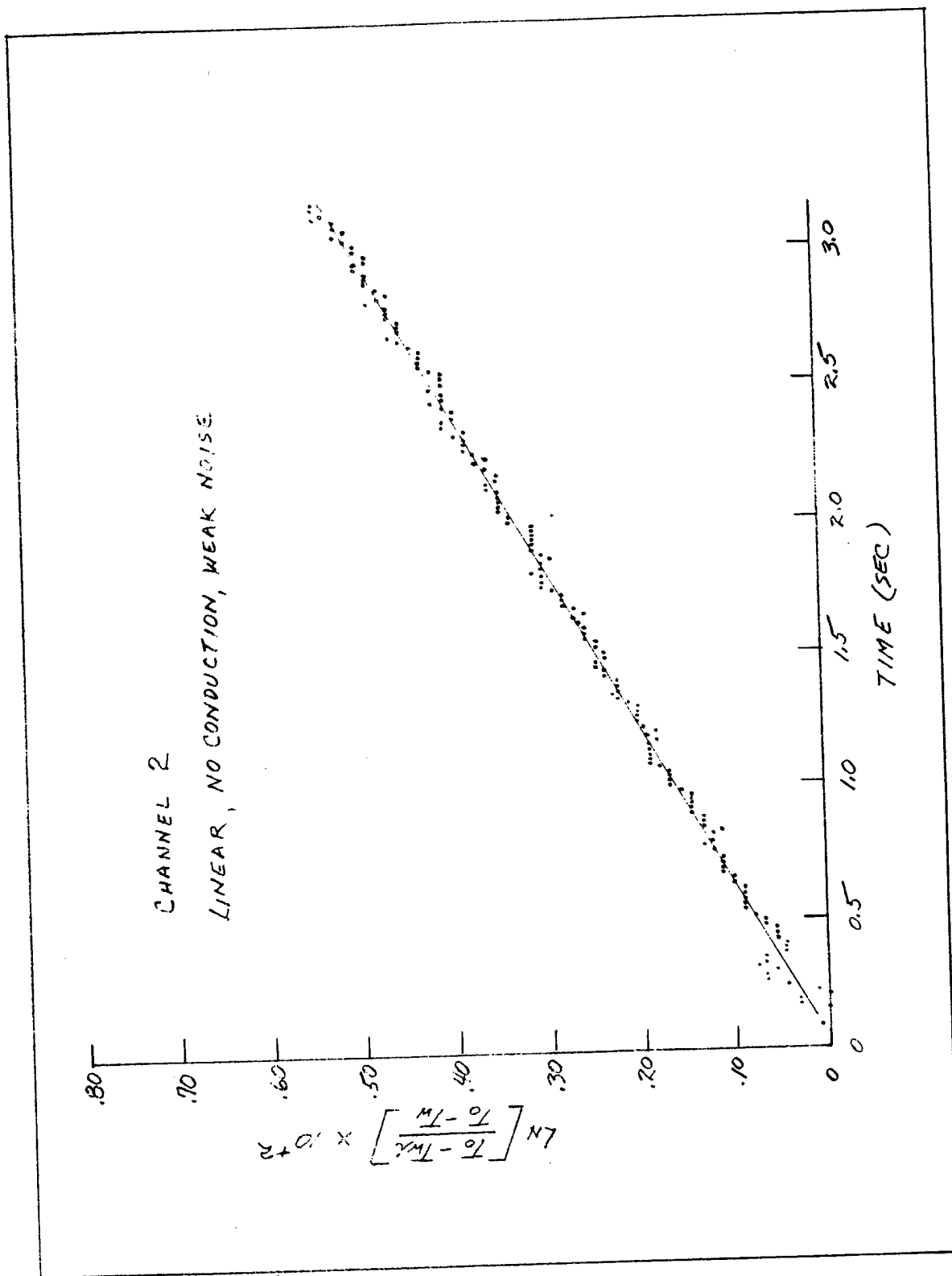


Figure 9. Temperature Function - Run 202 Channel 2

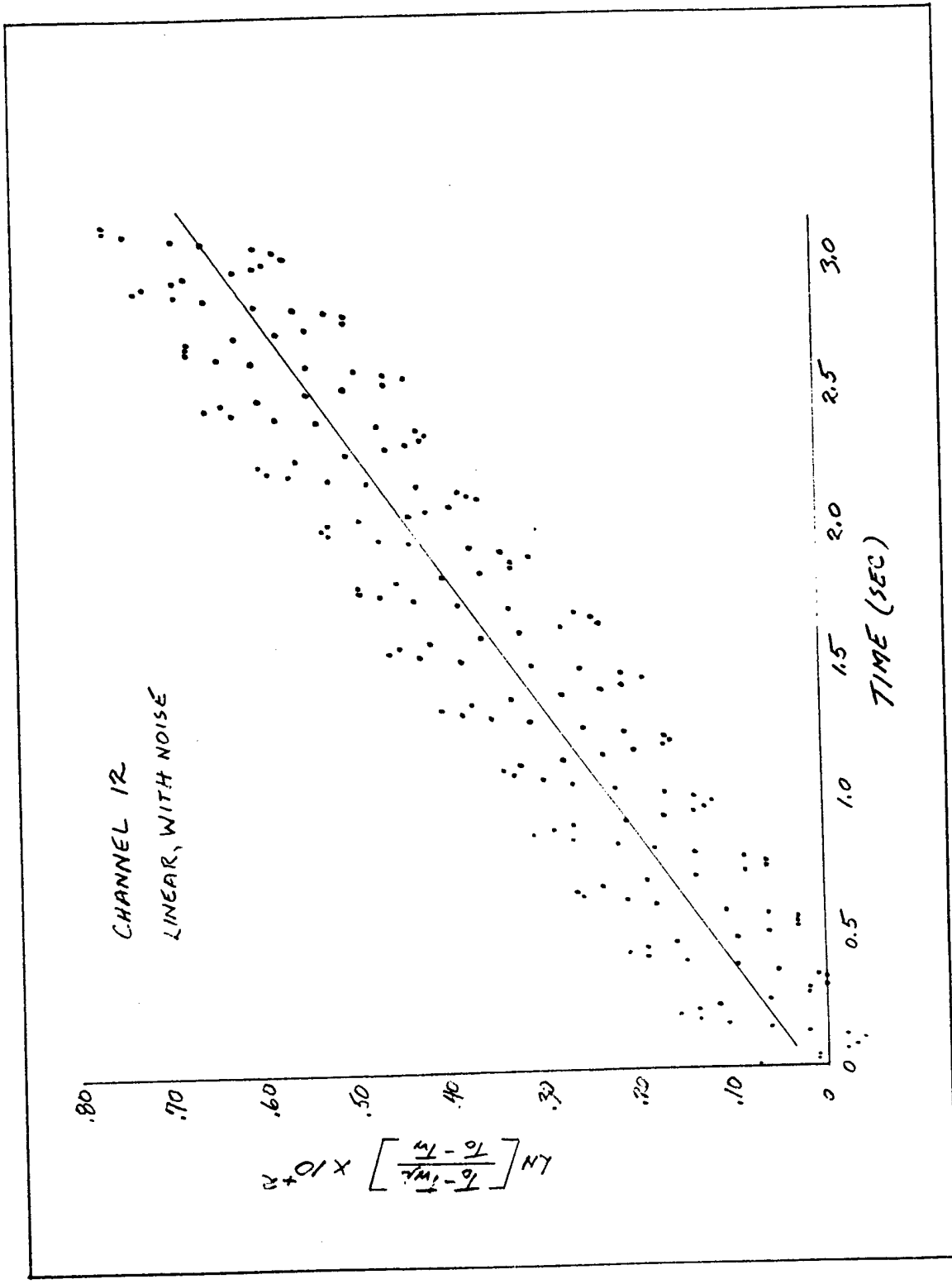


Figure 10. Temperature Function - Run 202 Channel 12

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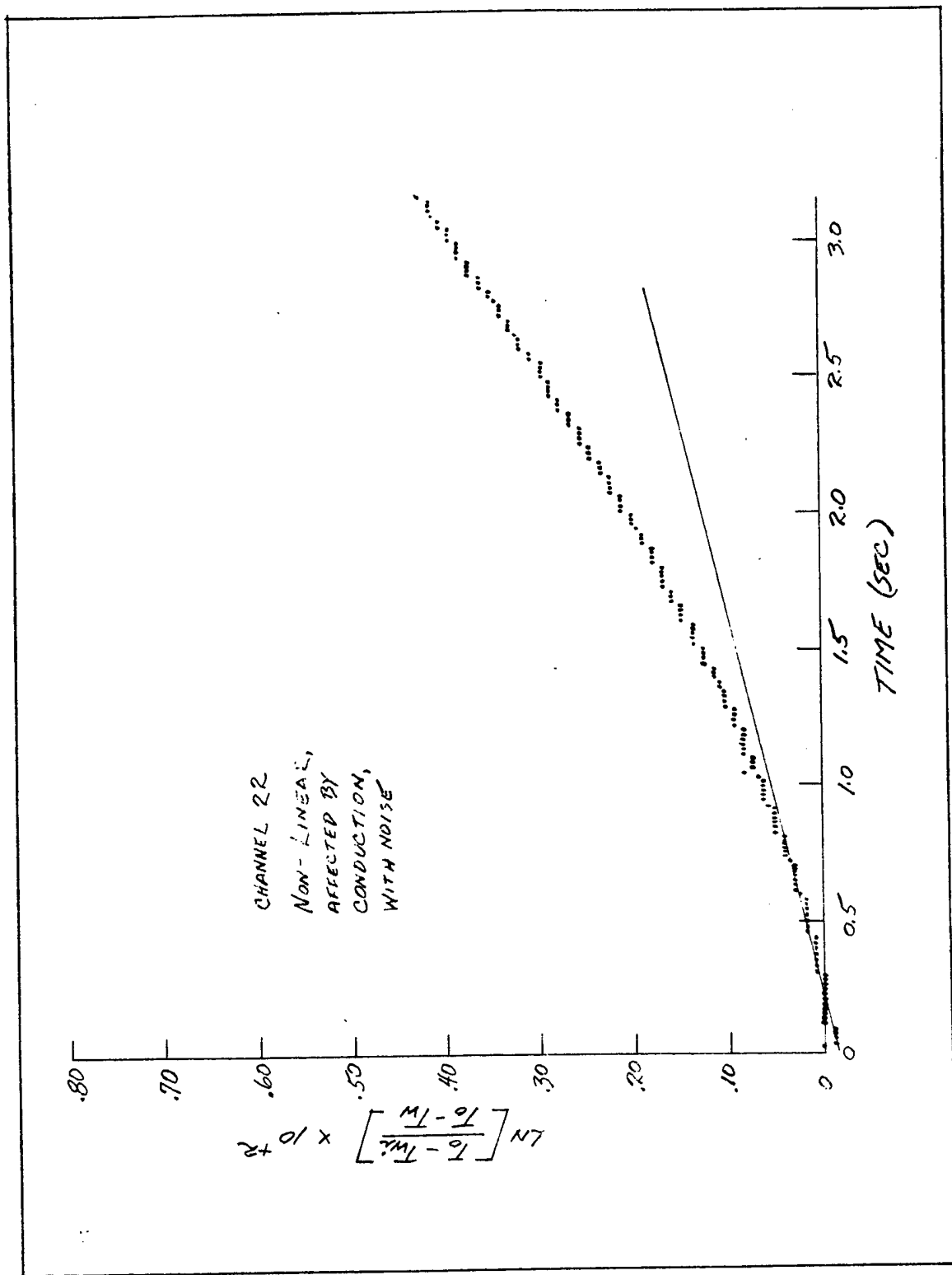


Figure 12. Temperature Function - Run 202 Channel 22