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TECHNICAL
NOTE

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THE **BOEING** COMPANY

COMMERCIAL AIRPLANE DIVISION

RENTON, WASHINGTON

DOCUMENT NO. 16-25520TN

TITLE: STEADY STATE HEAT TRANSFER ANALYSIS

OF 727 "B" HYDRAULIC SYSTEM

MODEL General

ISSUE NO. 7 TO: _____ (DATE) _____

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HYDRAULIC SYSTEM
THERMAL
COMPUTER PROGRAM
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TABLE OF CONTENTS

	<u>Page</u>
I. ABSTRACT	3
II. SUMMARY	4
III. INTRODUCTION	5
IV. ANALYSIS	7
V. VERIFICATION OF ANALYSIS	17
VI. PROGRAM DESCRIPTION AND USE	19
VII. GUIDE FOR PROGRAMMING OTHER SYSTEMS	22
VIII. REFERENCES	23
APPENDIX	24
LIST OF NOMENCLATURE	60
CALCULATIONS OF PUMP COEFFICIENT	61
LIST OF ACTIVE PAGES	62
REVISIONS	63

AD 1546 D

REV SYM

BOEING NO. D6-25520FN
PAGE 2



6-7000

I. ABSTRACT

~~This technical note~~ ^{THE DOCUMENT} contains the procedure for and an example of a hydraulic system heat transfer analysis. Linear equations are used to describe the heat balance in the hydraulic components, and the system of equations are solved on a digital computer. The application of this procedure is currently limited to the prediction of steady state temperatures in systems with constant mass flows.

The hydraulic circuit selected for illustration is the 727 "B" Hydraulic System. Actual test data and results obtained in the analysis are compared. ()

It is proposed that the analytical techniques and programming procedures be used in all future hydraulic system heat transfer studies because of the reduced computer time involved and the accuracy of the solution.

AD 1546 D

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BOEING | NO. D6-25520TN
PAGE 3

6-7000

II. SUMMARY

A digital computer program for heat-transfer analysis of the 727 hydraulic systems has been developed. Though not general in its present form, its algorithm can be applied to the analysis of any hydraulic system.

This program has been successfully applied, and the results obtained compare very satisfactorily with the data obtained from ground tests.

This technique has been developed specifically for the steady-state analysis of hydraulic systems. A description of the analytical approach leading to this program is contained in section IV.

A copy of the actual input and output data for the 727 "B" system is included for reference.

A general line equation for the transient case has been established. Similar transient analysis is needed for the other components of the aircraft hydraulic system. The development of a digital computer program for a transient study of heat transfer in hydraulic systems should be pursued.

AD 1546 D

REV SYM

BOEING

NO. D6-25520TN

PAGE 4

6-7000 

III. INTRODUCTION

There have been several attempts within the Boeing Company to develop computer programs that would simulate hydraulic system temperature data obtained from flight tests. Relevant to these efforts is the "Thermal Analyzer (Beta II) Program Procedures for Heat Transfer Analysis of Aircraft Hydraulic Systems" (Reference 1).

Beta II was originally developed for analyzing structures not involving fluid flow, and the program uses a finite difference approach for problem solution. The heat transfer equations applied to hydraulic systems are, however, basically linear, leading to a set of linear algebraic equations for steady state analysis. The latter can be solved very effectively by standard matrix methods. The application of BETA II to hydraulic systems have produced unsatisfactory results. Not only does it take several computer runs to determine the proper control parameters necessary for convergence of the solution towards steady state temperatures, but each computer run also takes several minutes of CDC 6600 time. To overcome these problems, a new approach utilizing linear algebraic equations has been undertaken.

The new technique described herein has been used to predict steady state temperatures. Linear equations based on energy balance approach for each control volume examined were developed. These equations have been applied satisfactorily, through the use of digital computer, to simulate test data recorded during ground tests of the 727 "B" hydraulic system.

The digital computer program has been included in this report. However,

AD 1346 D

this program is not a general program, and it has been specifically developed for the 727 "B" hydraulic system. But it can be used as a model for preparing computer programs for similar hydraulic systems. In addition, it is possible to extend its basic concept to develop a general program that can be applied to any hydraulic system.

The need to understand heat distribution in hydraulic systems has led to this contribution. The analysis and program described in this paper should be of benefit to the engineer engaged in thermal design in aircraft hydraulics.

AD 1546 D

REV SYM

BOEING

NO. D6-25520TN

PAGE 6



6-7000

IV. ANALYSIS

A satisfactory analysis of the heat transfer problem requires that each of the components in the system be simulated. The analysis that follows is based on the principle of heat balance within each of the control volumes (system components) in the hydraulic diagram.

1. (a) Line Model

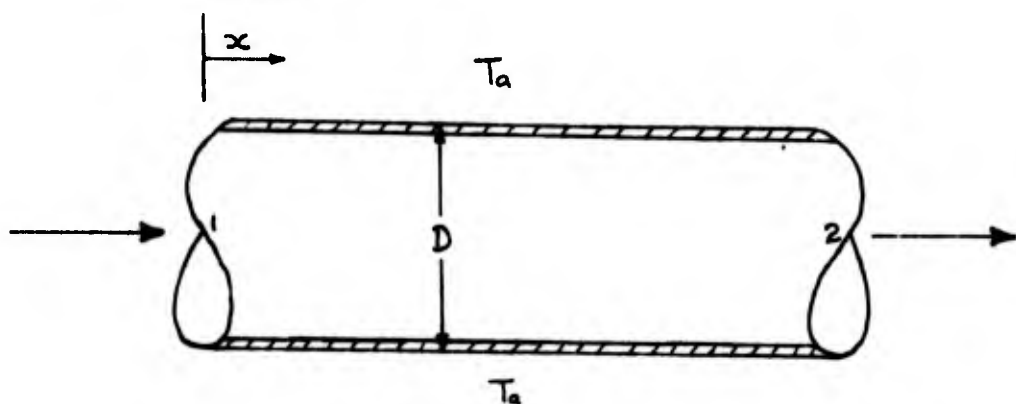


Figure 1.

Net heat input from node 1 to node 2 as the fluid moves in the direction of flow is given as

$$\dot{m}C_p T - \dot{m}C_p \left(T + \frac{\partial T}{\partial x} \Delta x \right) \quad (1)$$

Heat exchange between the inside of the tube and the ambient is expressed as

$$-K(2\pi r)\Delta x (T - T_a) \quad (2)$$

where

- \dot{m} = flow rate
- T = temperature
- Δx = displacement
- K = heat transfer coefficient
- C_p = specific heat
- r = radius of tube

AD 1546 D

The rate of change of heat energy in the control volume is given as

$$C_p \rho A \frac{\partial T}{\partial t} \Delta x \quad (3)$$

Following the basis of heat balance in each control volume,

$$\therefore (1) + (2) = (3)$$

Equating (1) and (2) to (3) and rearranging terms leads to

$$\frac{\partial \bar{T}}{\partial t} = -a \frac{\partial \bar{T}}{\partial x} - b \bar{T} \quad (4)$$

where

$$\begin{aligned} \bar{T} &= T - T_a \\ a &= \dot{m}/\rho A \\ b &= K\pi D/\rho C_p A \end{aligned}$$

(1) Steady State Solution

For a steady-state solution, $\frac{\partial \bar{T}}{\partial t} = 0$ and equation (4) becomes

$$\frac{\partial T}{\partial x} + \beta T = \beta T_a \quad (5)$$

where $\beta = b/a = \frac{K\pi D}{C_p \dot{m}}$

Equation (5) is a first order linear differential equation whose complete solution is

$$T_2 = T_1 e^{-Ax} + T_a(1 - e^{-Ax}) \quad (6)$$

where the indices refer to Fig. 1.

(c) Transient Solution (not used herein)

The general equation of continuity is given by equation (4) as

$$\frac{\partial T}{\partial t} = - \frac{\dot{m}}{\rho A} \frac{\partial T}{\partial x} - \frac{k(2\pi r)}{C_p \rho A} (T - T_a) \quad (7)$$

where $\frac{\dot{m}}{\rho A} = v = \frac{dx}{dt}$

and $\frac{k(2\pi r)}{C_p \rho A} = Q$

Substituting for v and Q in (7) leads to

$$\frac{\partial T}{\partial t} + \frac{\partial T}{\partial x} \frac{dx}{dt} + Q(T - T_a) = 0 \quad (8)$$

But $T = T(x, t)$

$$\frac{dT}{dt} = \frac{\partial T}{\partial t} + \frac{\partial T}{\partial x} \frac{dx}{dt} \quad (9)$$

Applying (9) to (8) leads to

$$\frac{dT}{dt} + Q(T - T_a) = 0$$

$$\text{or } \frac{dT}{dt} + QT = QT_a \quad (10)$$

Equation (10) is a first order linear equation whose solution is

$$T = (T_o - T_a)e^{-\frac{Qz}{V}} + T_a \quad (11)$$

where

- m = mass flow rate LBM/min
- C_p = specific heat BTU/LBM $^{\circ}$ F
- r = radius of tube ft
- Δz = length of tube ft
- A = tube area ft^2
- T_o = Downstream node temperature (steady state) $^{\circ}$ F
- T_i = Upstream node temperature (steady state) $^{\circ}$ F
- T_o = Node temperature at time, $t = 0$ (transient) $^{\circ}$ F
- T = Node temperature at any time, t (transient) $^{\circ}$ F
- T_a = Ambient Temperature $^{\circ}$ F

2. Pump Cavity Model

The two pumps and the hydraulic reservoir of the 727 "B" Hydraulic System are located very near each other, and the components are thereby regarded as being located in the same cavity in this analysis.

AD 1546 D

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PAGE 10

6-7000

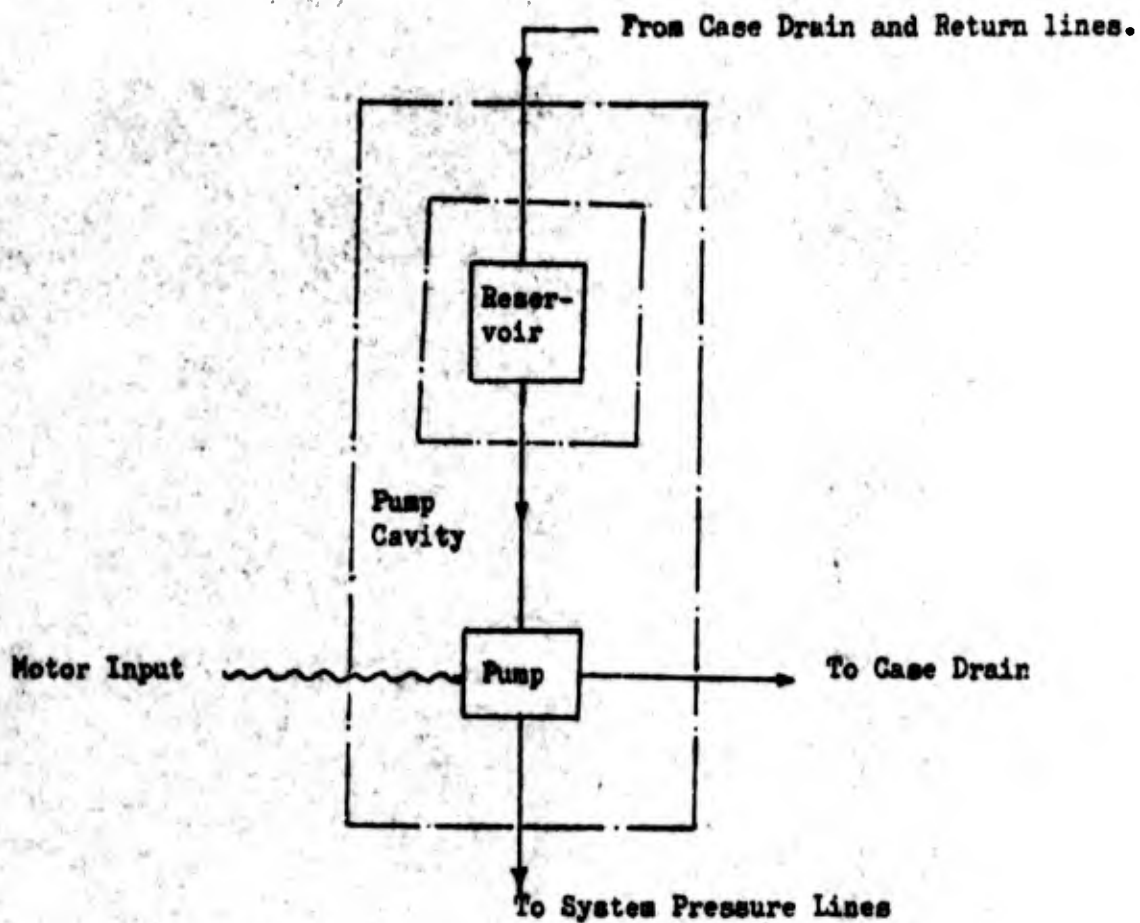


Figure 2.

- Let Q_m = Heat Input due to the electrical motor
 T_m = Temp of fluid entering pump cavity
 T_{cd} = Temp of fluid entering case drain line
 T_{ps} = Temp of fluid entering pressure line
 T_{cav} = Temp of pump cavity
 T_a = Ambient temperature outside cavity
 Q_p = Potential energy due to differential pressure
 M = Mass flow rate

AD 1548 D

REV SYM

DEING NO. D6-25530TH
 PAGE 11

6-7000

The heat balance equation for the pump cavity can be expressed as

$$Q_n + T_{in} C_p M_{in} = T_{out} C_p M_{out} + K_{cav} (T_{cav} - T_a) + Q_p \quad (12)$$

where C_p = specific heat, K_{cav} = Coefficient of heat transfer of cavity.

3. Reservoir Model

Let T_{inr} = Temp. of fluid entering the reservoir
 T_{outr} = Temp. of fluid leaving the reservoir
 T_r = Temp. of fluid in the reservoir
 T_{cav} = Temp of cavity of pump and reservoir
 K_r = Coefficient of heat transfer for reservoir

The heat balance equation for the reservoir model can be expressed as

$$T_{outr} C_p M_{outr} = T_{inr} C_p M_{inr} + K_r (T_r - T_{cav}) \quad (13)$$

4. Valve Model

Let DLP = Differential pressure across the valve - psi
 m = Flow rate in gpm
 C = Conversion factor (0.002475)

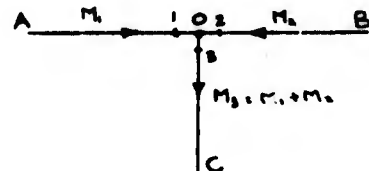
The amount of heat generated by and transferred to the fluid by the valves is

$$Q_{valves} = (DLP) m C \quad \text{BTU/min} \quad (14)$$

AD 1548 D

5. Branches

The junction temperature at point 3 for the converging flows from AO and BO is represented as



$$T_3 = \frac{M_1 T_1 + M_2 T_2}{M_1 + M_2} \quad (15)$$

where M_i = flow rate in tube i

T_i = Temperature ($^{\circ}$ F) at point i

6. Set of Equations Applied to the 727 "B" Hydraulic Model

The solution of this problem requires that each component in the hydraulic system be simulated. The latter is achieved by a linear equation for each component.

Equations (6), (12), (13), (14), and (15) are the ones that have been applied to the 727 "B" hydraulic system.

In the set of equations presented below, the subscript refers to the component number in Figure 3. All other variables are explained in the Nomenclature. Note that the representative equation states, in words, that the temperature at a specified node is a function of the upstream temperature, the ambient temperature and the geometric characteristics of the component, the flow rate, and the thermal characteristic of the fluid flowing through the component. (Refer to Table I).

AD 1546 D

REV SYM

BOEING

NO. D6-25520TH

PAGE 13



6-7000

Table I

LINEAR EQUATIONS DERIVED FOR AND APPLIED TO THE 727 "B" HYDRAULIC SYSTEM

$T_1 = a_1 T_{80} + b_1 T_{81} \dots$ Reservoir	$T_{26} = E_{22} T_{25} + E_{25} T_{28}$
$T_2 = u_2 T_1 + \alpha_2 T_{81} \dots$ Pump #1 In	$T_{27} = u_{27} T_{26} + \lambda_{27}$
$T_3 = u_3 T_1 + \alpha_3 T_{81} \dots$ Pump #2 In	$T_{28} = u_{28} T_{18} + \lambda_{28}$
$T_4 = T_3 + \Delta T_{CD1} \dots$ Case Drain In	$T_{29} = T_{28} + \Delta T_{VAL} \dots$ Rudder
$T_5 = T_3 + \Delta T_{CD2} \dots$ Case Drain In	$T_{30} = u_{30} T_{29} + \lambda_{30}$
$T_6 = u_6 T_4 + \alpha_6 T_{81}$	$T_{31} = E_{27} T_{27} + E_{28} T_{30}$
$T_7 = u_7 T_6 + \alpha_7 T_{81}$	$T_{32} = u_{32} T_{31} + \lambda_{32}$
$T_8 = E_6 T_6 + E_7 T_7$	$T_{33} = u_{33} T_{31} + \lambda_{33}$
$T_9 = u_9 T_8 + \lambda_9 \dots$ Mt. Exchg. In	$T_{34} = u_{34} T_{33} + \lambda_{34}$
$T_{10} = u_{10} T_9 + \lambda_{10} \dots$ Mt. Exchg. Out	$T_{35} = u_{35} T_{34} + \lambda_{35}$
$T_{11} = u_{11} T_{10} + \lambda_{11}$	$T_{36} = T_{35} + \Delta T_{VAL} \dots$ R. H. Spoiler
$T_{12} = T_2 + \Delta T_{VAL1} \dots$ Pump 1 Out	$T_{37} = u_{37} T_{36} + \lambda_{37}$
$T_{13} = u_{13} T_{12} + \alpha_{13} T_{81}$	$T_{38} = E_{32} T_{32} + E_{37} T_{37}$
$T_{14} = T_3 + \Delta T_{VAL2} \dots$ Pump 2 Out	$T_{39} = u_{39} T_{38} + \lambda_{39}$
$T_{15} = u_{15} T_{14} + \alpha_{15} T_{81}$	$T_{40} = u_{40} T_{38} + \lambda_{40}$
$T_{16} = E_{13} T_{13} + E_{15} T_{15}$	$T_{41} = T_{40} + \Delta T_{VAL} \dots$ Aileron
$T_{17} = u_{17} T_{16} + \lambda_{17}$	$T_{42} = u_{42} T_{41} + \lambda_{42}$
$T_{18} = u_{18} T_{17} + \lambda_{18}$	$T_{43} = E_{39} T_{39} + E_{42} T_{42}$
$T_{19} = u_{19} T_{18} + \lambda_{19}$	$T_{44} = u_{44} T_{43} + \lambda_{44}$
$T_{20} = u_{20} T_{19} + \lambda_{20}$	$T_{45} = u_{45} T_{44} + \lambda_{45}$
$T_{21} = T_{20} + \Delta T_{VAL} \dots$ L. H. Elevator	$T_{46} = T_{45} + \Delta T_{VAL} \dots$ L. H. Spoiler
$T_{22} = u_{22} T_{21} + \lambda_{22}$	$T_{47} = u_{47} T_{46} + \lambda_{47}$
$T_{23} = u_{23} T_{19} + \lambda_{23}$	$T_{48} = E_{44} T_{44} + E_{47} T_{47}$
$T_{24} = T_{23} + \Delta T_{VAL} \dots$ R. H. Elevator	$T_{49} = u_{49} T_{48} + \lambda_{49}$
$T_{25} = u_{25} T_{24} + \lambda_{25}$	$T_{50} = E_{47} T_{47} + E_{49} T_{49}$
$T_{81} = \frac{1}{K_{81}} \left\{ Q_{motor(1+2)} + C_p (T_{80} \dot{m}_{80} - T_8 \dot{m}_8 - T_{16} \dot{m}_{16}) + T_{80} K_{81} - Q_{loss} \right\}$ Pump Cavity	

AD 1546 D

7. Solution to the Linear Equations for Steady State Flow

Equations (6), (12), (13) and (14) contain all the parameters necessary to analyze the hydraulic system. Each component of the system is represented by a linear equation, and there are as many equations as there are unknown temperatures. (See the preceding section IV-6). These equations are then arranged in a matrix form.

$$\begin{bmatrix} A_{11} & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & A_{nn} \end{bmatrix} \begin{bmatrix} T_1 \\ \dots \\ \dots \\ \dots \\ \dots \\ T_n \end{bmatrix} = \begin{bmatrix} B_1 \\ \dots \\ \dots \\ \dots \\ \dots \\ B_n \end{bmatrix}$$

Where $T_1 \dots \dots \dots T_n$ are the unknown temperatures, and A and B are functions of the components characteristics. This system of equations is solved by a standard matrix inversion technique (Boeing sub-routine "GLESOS", Ref. 2)

The solution to the set of linear equations is the temperature at each node.

AD 1546 D



V. VERIFICATION OF ANALYSIS

The digital computer program developed on the basis of the analytical work described in Section IV was applied to the 72, "B" Hydraulic System. Shown below is a comparative result of temperature values from Test (References 1 and 2) and Analysis. The nodes mentioned in this table correspond to those in Figure 3.

72, "B" Hydraulic System Heat Transfer Analysis

1. Comparison of Temp. Values from Test & Analysis

		Ambient Temp. = 58 F			Ambient Temp. = 79 F		
		Pump #1 Delivery = 2.22 gpm			Pump #1 Delivery = 2.4 gpm		
		Pump #2 Delivery = 0.15 gpm			Pump #2 Delivery = 0.00 gpm		
Node	Description	Test			Test		
		Result	(1)*	(2)*	Result	(1)*	(2)*
1	Reservoir	151	130	152			
2	Pump #1 Inlet	151	130	152	164	146	167
3	Pump #2 Inlet	151	130	152	164	146	167
4	Case Drain #1	177	157	179	190	175	195
9	Heat Exchg. Inlet	172	156	177			
10	Heat Exchg. Outlet	154	136	155			
12	Pump #1 Delivery	166	144	166			
14	Pump #2 Delivery	166	144	166	180	160	182
51	Pump Cavity	141	92	133			

(1)* Values obtained using the coefficients shown in Coordination Sheet No. 6-8525-69-75, in Appendix D.

(2)* Values obtained using 88% of the line coefficients and 0.277 as the Pump Cavity coefficient. See the calculations shown on page 61. The value of 0.277 (instead of 2.32 shown in coordination sheet No. 6-8525-69-75) is being used because the latter was found to be erroneous.

AD 1546 D

2. The Heat Transfer Coefficients Used in the Verification

The effective overall heat transfer coefficients used were derived from the following equations based on steady state condition.

$$Q = UA\Delta T_{oa} \quad (16)$$

$$Q = MC_p\Delta T_o \quad (17)$$

where Q = Heat flow rate

U = Overall heat transfer coefficient

A = Effective area of the component being analyzed

ΔT_{oa} = Difference between bulk oil temperature and overall ambient temperature.

M = Mass flow rate

C_p = Specific heat of oil

ΔT_o = Difference between the oil temperature in and out of the component being analyzed.

Equating (16) to (17) for steady-state condition leads to

$$U = (MC_p\Delta T_o)/A\Delta T_{oa} \quad (18)$$

Equations (16) and (18) and test data were used in developing heat transfer coefficients for the pump cavity and the hydraulic lines, respectively. Appendix D.

However, the application of the derived heat transfer coefficients resulted in very low temperatures, as shown in column (1) of the comparison table. Correction factors were thus applied, using 0.85 of the line coefficients and 0.25 of the pump cavity coefficient to obtain the results shown in column (2).

AD 1546 D

VI. PROGRAM DESCRIPTION AND USE

1. Introduction

The digital program described below has been successfully applied, under various flows and different ambient temperatures to the '727' "B" hydraulic system. The results obtained compare very satisfactorily with the data obtained from ground tests. The application of this program is currently limited to the prediction of steady state temperatures in systems with constant mass flows. The predicted node temperature is dependent on the upstream and the ambient temperatures, and it is also function of the characteristics of the component whose temperature is being determined.

2. Program Description

The program (listed in Appendix A) comprises of tables, function statements, directions for flow computation and solution of the linear equations by a standard matrix inversion technique (Boeing sub-routine, "GLEBOS", Ref. 2). The line data cards (which carry the line nodes, diameters, lengths, and heat transfer coefficients) are arranged immediately after the 'end of record' card which is superseded by the "END" card.

The user may wish to try different flow rates through the load devices. Consequently, four tables for each pump have been introduced in the program. These are tables of pump delivery, of energy input into the pump, of the case drain flow, and of the fraction of energy input that goes into the case drain and into the pressure line respectively. These tables have been introduced into the program using the subroutine.

TELUI (Ref. 3)

3. Input



To use this program, the user should specify seven variables for any run as shown above. The downward arrow head locates the position of the decimal point. The variables are defined as follows:

<u>VARIABLE</u>	<u>DESCRIPTION</u>	<u>DIMENSION</u>
PCT	Fraction of total delivery supplied by Pump #1.	None
TAMB	Outside Ambient Temperature	°F
TAMBHE	Heat Exchanger Fuel Temperature	°F
ELEV	Elevator Leakage	gpm
RUDDR	Rudder leakage	gpm
SPOL	Spoiler leakage	gpm
AILRON	Aileron leakage	gpm

There is no limit to the number of input data cards that can be supplied.

4. Output

The output of this program will provide steady-state temperature values at each node of the system being simulated.

AD 1946 D

5. Core Space and Time Estimate

For the 727 "B" Hydraulic System, the core space used was 45,000 and the computer processing time for each set of input data was four seconds.

AD 1546 D

REV SYM

BOEING

NO. D6-25520TN

PAGE 21

6-7000 

VII. GUIDE FOR PROGRAMMING OTHER SYSTEMS

1. Draw a complete schematic of the hydraulic system, showing the locations of the pumps, load devices, heat exchangers, tubings, etc. (See Figure 3).
2. Assign numbers to the line junctions and to all the entrances and exits of each hydraulic component (See Figure 3). Note that each line is designated by its downstream node number, hence the number at a junction is that of the delivery line.
3. Determine the flow rates through the load devices (i.e. aileron, rudder, elevator and spoiler).
4. Express the flow rates in other lines as functions of those through the load devices. e.g. $XM(22) = ELEV \cdot W$
5. Determine the pressure drop across the load devices. Determine the ambient temperatures.
6. Determine the tube lengths and diameters.
7. Determine the heat transfer coefficients of each element in the hydraulic diagram.
8. Model the tubes, pumps and reservoirs as shown in Section IV.
9. Derive the applicable linear equations (See IV, Paragraph 6).
10. Prepare program as shown in "Program Listing."

The heat transfer coefficients used in this analysis are those derived from ground test data on the 727 "B" hydraulic system. It is expected that these coefficients should be valid for all the existing subsonic Boeing commercial aircraft. Any major departure from these established values would result only from, (a) aircraft size and (b) aircraft configuration.

AD 1566 D

REV SYM

BOEING

NO. D6-255201N

PAGE 22



6-7000

VIII. REFERENCES

1. Thermal Analyzer (Beta II) Program Procedures for Heat Transfer Analysis of Aircraft Hydraulic Systems. Document No. D6-58389.
2. Handbook of Mathematical Routines. Vol. 6a, Linear Algebra. D6-29720-6a.
3. Handbook of Mathematical Routines. Vol. 5, Interpolation, Approximation, Quadrature, Numerical Differentiation. D6-29720-5.

AD 1546 D

REV SYM

BOEING | NO. D6-25520TN
PAGE 23



8-7000

		<u>Page</u>
APPENDIX A	Program Listing, Input and Output	25
APPENDIX B	Coordination Sheet 6-8525-68-41	34
APPENDIX C	Coordination Sheet 6-8525-69-15	45
APPENDIX D	Coordination Sheet 6-8525-69-75	55

AD 1546 D

REV SYM

BOEING | NO. D6-25520TN
PAGE 24



APPENDIX A
PROGRAM LISTING
Heat Transfer Analysis of 727 "B" Hydraulic System

A27B.T74.CM95000.
ACCT 850901 A27B6840/AB10DUN,A.A. /59 /655-4036/6-8505 /
RUN(S.....1)
SETCORE.
LGO.

```

PROGRAM A27B (INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT)
C PROGRAM CALCULATES STEADY STATE TEMPERATURES IN 727 B HYDRAULIC SYSTEM
  DIMENSION DELV(7), POWR(7), PCTCD(7), PCTSY(7), QCD(7)
  DIMENSION A(51,51),B(51),D(51),XL(51),XK(51),XM(51),IPR(51)
  EXTERNAL VIPDA
C ALL FORMAT STATEMENTS USED IN THIS PROGRAM
  2 FORMAT(1H1,*            PCT            TAMB            TAMBHE            EL
     1EV            RUDR            SPOL            AILRON    */**)
  6 FORMAT (7E10.5)
  7 FORMAT(7E15.5)
 10 FORMAT (110,3E10.5)
 11 FORMAT(1H1,*            QCS1            QCS2            PCTCD1            PCT
     1CD2            PCTSY1            PCTSY2            QMT1            QMT2*//)
 12 FORMAT(8E15.5)
 20 FORMAT (110,4E15.5)
 65 FORMAT(* SINGULAR MATRIX*)
 70 FORMAT(1H0,110,F20,10)
100 FORMAT(1H1,*    LINE NO    DIA.IN FEET    LENGTH IN FT COEF.OF HT.TR
     1F    FLOW-LB/MIN*//)
400 FORMAT(1H1,*            STEADY-STATE SOLUTION*//    NODE    TEMP DEG
     1 F*//)
C CONSTANTS USED IN THE HEAT TRANSFER ANALYSIS
C NL,(N,NR),DLP,CP, ARE NUMBER OF LINES, OF NODES, DIFF. PRESS., SPEC. HEAT
  DATA PI/3.14927/,DLP/2950./,CP/0.4/,NL/31/,N/51/,NR/51/
C TAMB,TAMBHE STAND FOR AMBIENT TEMPS IN THE WING - BODY AND HEAT EXCHANGER
C XKCAV=PUMP CAVITY COEFF. & QMT=MOTOR HEAT IMPUT
C PCTCD=PERCENT OF IMPUT ENERGY GOING INTO CASE DRAIN
C PCTSY=PERCENT OF IMPUT ENERGY GOING INTO PRESSURE LINE
C U1=RESERVOIR HT.COEFF. AR1=RESERVOIR AREA.
  DATA U1/0.664/,AR1/3.28/,XKCAV/.277/,W/8.45/
C THE FOLLOWING ARE TABLES OF PUMP DELIVERY (DELV) IN LBS/MIN., ENERGY IMPUT
C INTO THE PUMP (POWR), THE CASE DRAIN FLOW (QCD), AND THE FRACTION OF THE
C ENERGY IMPUT THAT GOES INTO THE CASE DRAIN (PCTCD), AND INTO THE PRESSURE LINE
C (PCTSY)
  DATA (DELV(I),I=1,7)/0.,4.225,8.45,12.675,16.90,21.125,25.35/    DEL TBLE
  DATA (POWR(I),I=1,7)/267.,287.,309.,331.,356.,385.,415./    POW TBLE
  DATA (QCD(I),I=1,7)/17.75,16.80,16.35,15.80,15.07,14.20,13.35/    CSD FLOW
  DATA (PCTCD(I),I=1,7)/0.750,0.655,0.606,0.540,0.455,0.395,0.340/
  DATA (PCTSY(I),I=1,7)/0.000,0.088,0.130,0.189,0.267,0.320,0.368/
C FUNCTION STATEMENTS USED IN COMPUTING THE MATRIX ARRAY
  ANST(I)=EXP(-PI*D(I)*0.88*XK(I))*XL(I)/XM(I)/CP)
  GNCT(J,K)=XM(J)/(XM(J)+XM(K))
  TA(J)=-TAMB*(1.-ANST(J))
  DLPT=-0.00293*DLP/CP
C PROGRAM READS ALL THE CHARACTERISTICS OF EACH LINE
C EACH LINE IS DESIGNATED BY ITS DOWNSTREAM NODE NUMBER
C D,XL,XK,XM ARE DIA.,LENGTH,COEFF OF HEAT TRANSFER AND FLOW RATE RESPECTIVELY
DO 5 I=1,NL

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AD 1546 D

APPENDIX A
PROGRAM LISTING (Continued)

```

5 READ(5,10) J,D(J),XL(J),XK(J)
1 CONTINUE
  READ(5,6) PCT,TAMB, TAMBHE, ELEV, RUDR, SPOL, AILRON
  IF(EOF,5)80,3
3 WRITE(6,2)
  WRITE(6,7) PCT, TAMB, TAMBHE, ELEV, RUDR, SPOL, AILRON
  QSYT1=PCT*(ELEV+RUDR+SPOL+AILRON)*W
  QSYT2=(1.-PCT)*(ELEV+RUDR+SPOL+AILRON)*W
  XM(13)=QSYT1 $ XM(15)=QSYT2
  QCD1=TBLU1(XM(13),DELV,QCD,2,7)
  QCD2=TBLU1(XM(15),DELV,QCD,2,7)
  XM(6)=QCD1 $ XM(7)=QCD2 $ XM(9)=XM(6)+XM(7)
  XM(2)=XM(6)+XM(13) $ XM(3)=XM(7)+XM(15)
  XM(10)=XM(9) $ XM(11)=XM(10)
  XM(27)=ELEV*W $ XM(20)=0.5*XM(27) $ XM(22)=XM(20) $ XM(23)=XM(20)
  XM(25)=XM(20) $ XM(19)=XM(27)
  XM(30)=RUDR*W $ XM(28)=XM(30) $ XM(18)=XM(27)+XM(30) $ XM(32)=XM(18)
  XM(34)=SPOL*W $ XM(35)=0.5*XM(34) $ XM(37)=XM(35) $ XM(45)=XM(35)
  XM(47)=XM(35) $ XM(39)=XM(32)+XM(37)
  XM(42)=AILRON*W $ XM(40)=XM(42) $ XM(33)=XM(34)+XM(40)
  XM(44)=XM(39)+XM(42) $ XM(49)=XM(44)+XM(47) $ XM(17)=XM(49)
  XM(16)=XM(13)+XM(15)
  XM(50)=XM(11)+XM(49) $ XM(8)=XM(7)+XM(6)
  PCTCD1=TBLU1(XM(13),DELV,PCTCD,1,7)
  PCTCD2=TBLU1(XM(15),DELV,PCTCD,1,7)
  PCTSY1=TBLU1(XM(13),DELV,PCTSY,1,7)
  PCTSY2=TBLU1(XM(15),DELV,PCTSY,1,7)
  QMT1=TBLU1(XM(13),DELV,POWR,2,7)
  QMT2=TBLU1(XM(15),DELV,POWR,2,7)
  WRITE(6,11)
  PRINT 12,QCD1,QCD2,PCTCD1,PCTCD2,PCTSY1,PCTSY2,QMT1,QMT2
C PRINT INPUT CHARACTERISTICS FOR EACH LINE
  WRITE (6,100)
  DO 8 J=1,N
  WRITE (6,20) J,D(J),XL(J),XK(J),XM(J)
  8 CONTINUE
C COMPUTE, ARRANGE AND PRINT 51x51 MATRIX AND THE 51 VECTORS
  DO 25 I=1,N
  DO 25 J=1,N
25 A(I,J)=0.
  DO 30 I=1,NR
30 B(I)=0.
  DO 35 I=1,N
35 A(I,1)=-1.
  A(1,50)=CP*XM(50)/(U1*AR1+CP*XM(50))
  A(1,51)=U1*AR1/(U1*AR1+CP*XM(50))
  A(2,1)=ANST(2) $ A(2,51)=1.-A(2,1)
  A(3,1)=ANST(3) $ A(3,51)=1.-A(3,1)
  A(4,2)=1. $ B(4)=-PCTCD1*QMT1/CP/XM(6)
  A(5,3)=1. $ B(5)=-PCTCD2*QMT2/CP/XM(7)
  A(6,4)=ANST(6) $ A(6,51)=1.-A(6,4)
  A(7,5)=ANST(7) $ A(7,51)=1.-A(7,5)
  A(8,6)=GNCT(6,7) $ A(8,7)=GNCT(7,6)
  A(9,8)=ANST(9) $ B(9)=TA(9)

```

PRESLINE

CDR FLOW

HT.EXCHG

ELEV.LKG

ELEV.LKG

SPOL.LKG

SPOL.LKG

AILR.LKG

RTRN.PRE

RESERVOR

RESERVOR

PMP 1 IN

PMP 2 IN

CSDR =1

CSDR =2

LINE 6

LINE 7

JNCT 6-7

LINE 9

AD 1546 D



APPENDIX A
PROGRAM LISTING (continued)

<pre> A(10,9)=ANST(10) \$ B(10)=-TAMBHE*(1.-ANST(10)) A(11,10)=ANST(11) \$ B(11)=TA(11) IF(XM(13))13,13,14 13 A(12,2)=1. A(13,12)=1. GO TO 18 14 A(12,2)=1. \$ B(12)=-PCTSY1*QMT1/CP/XM(13) A(13,12)=ANST(13) \$ A(13,51)=1.-ANST(13) 18 IF(XM(15))15,15,16 15 A(14,3)=1. A(15,14)=1. GO TO 17 16 A(14,3)=1. \$ B(14)=-PCTSY2*QMT2/CP/XM(15) A(15,14)=ANST(15) \$ A(15,51)=1.-ANST(15) 17 A(16,13)=GNCT(13,15) \$ A(16,15)=GNCT(15,13) A(17,16)=ANST(17) \$ B(17)=TA(17) A(18,17)=ANST(18) \$ B(18)=TA(18) A(19,18)=ANST(19) \$ B(19)=TA(19) A(20,19)=ANST(20) \$ B(20)=TA(20) A(21,20)=1. \$ B(21)=DLPT A(22,21)=ANST(22) \$ B(22)=TA(22) A(23,19)=ANST(23) \$ B(23)=TA(23) A(24,23)=1. \$ B(24)=DLPT A(25,24)=ANST(25) \$ B(25)=TA(25) A(26,22)=GNCT(22,25) \$ A(26,25)=GNCT(25,22) A(27,26)=ANST(27) \$ B(27)=TA(27) A(28,18)=ANST(28) \$ B(28)=TA(28) A(29,28)=1. \$ B(29)=DLPT A(30,29)=ANST(30) \$ B(30)=TA(30) A(31,27)=GNCT(27,30) \$ A(31,30)=GNCT(30,27) A(32,31)=ANST(32) \$ B(32)=TA(32) A(33,17)=ANST(33) \$ B(33)=TA(33) A(34,33)=ANST(34) \$ B(34)=TA(34) A(35,34)=ANST(35) \$ B(35)=TA(35) A(36,35)=1. \$ B(36)=DLPT A(37,36)=ANST(37) \$ B(37)=TA(37) A(38,32)=GNCT(32,37) \$ A(38,37)=GNCT(37,32) A(39,38)=ANST(39) \$ B(39)=TA(39) A(40,33)=ANST(40) \$ B(40)=TA(40) A(41,40)=1. \$ B(41)=DLPT A(42,41)=ANST(42) \$ B(42)=TA(42) A(43,39)=GNCT(39,42) \$ A(43,42)=GNCT(42,39) A(44,43)=ANST(44) \$ B(44)=TA(44) A(45,34)=ANST(45) \$ B(45)=TA(45) A(46,45)=1. \$ B(46)=DLPT A(47,46)=ANST(47) \$ B(47)=TA(47) A(48,44)=GNCT(44,47) \$ A(48,47)=GNCT(47,44) A(49,48)=ANST(49) \$ B(49)=TA(49) A(50,11)=GNCT(11,49) \$ A(50,49)=GNCT(49,11) A(51,8)=-CP*XM(8)/XKCAV \$ A(51,16)=-CP*XM(16)/XKCAV A(51,50)=CP*XM(50)/XKCAV B(51)=-QMT1+QMT2+TAMB*XKCAV-(0.02475*DLP*2.670)/XKCAV </pre>	<pre> HEAT EXG LINE 11 SYS-OUT1 LINE 13 LINE 15 JNC13-15 LINE 17 LINE 18 LINE 19 LINE 20 LH ELEV. LINE 22 LINE 23 RH ELEV. LINE 25 JNC22-25 LINE 27 LINE 28 RUDDER LINE 30 JNC27-30 LINE 32 LINE 33 LINE 34 LINE 35 RH SPOLR LINE 37 JNC32-37 LINE 39 LINE 40 AILERON LINE 42 JNC39-42 LINE 44 LINE 45 LH SPOLR LINE 47 JNC44-47 LINE 49 JNC11-49 PMP CAVT PMP CAVT PMP CAVT </pre>
<p>C SOLVE THE 51 LINEAR EQUATIONS USING THE SUB-PROGRAM CALLED GLESOS CALL GLESOS (A,NR,N,IPR,B,D1)</p>	

AD 1545 D

APPENDIX A
PROGRAM LISTING (continued)

```

      IF(D1.EQ.0.) WRITE(6,65)
      C PRINT SOLUTION (STEADY STATE TEMPERATURES)
      WRITE(6,400)
      WRITE(6,70)(I,B(I),I=1,N)
      GO TO 1
      80 RETURN
      END
  
```

2	.06250	5.0	.082			
3	.06250	5.0	.082			
6	.03125	8.03	.082			
7	.03125	6.40	.082			
9	.05200	20.14	.082			
10	.05200	35.20	.567			
11	.05200	20.68	.082			
13	.04167	2.42	.082			
15	.04167	1.375	.082			
17	.04167	15.42	.0729			
18	.04167	11.12	.0657			
19	.03125	52.60	.0657			
20	.02083	7.35	.0657			
22	.03125	6.89	.0657			
23	.02083	7.24	.0657			
25	.03125	6.77	.0657			
27	.03125	51.50	.0657			
28	.03125	45.09	.0657			
30	.03125	45.40	.0657			
32	.04167	38.05	.0729			
33	.04167	2.682	.0729			
34	.04167	6.85	.0729			
35	.03125	33.33	.0729			
37	.03125	10.24	.0729			
39	.04167	6.00	.0729			
40	.02083	6.85	.0729			
42	.02083	4.65	.0729			
44	.04167	7.06	.0729			
45	.03125	33.33	.0729			
47	.03125	22.50	.0729			
49	.04167	13.00	.0340			
0.93671	58.	70.	0.70	0.70	0.87	0.1
0.000	79.	70.	0.2	1.0	1.0	0.2
0.93671	58.	70.	1.40	1.40	1.74	0.2
0.000	79.	70.	0.4	2.0	2.0	0.4

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0000
0000

AD 1546 D

REV SYM



AD 1546 D

APPENDIX A
PROGRAM INPUT

	PCT	YAMB	TAMBE	ELEV	ALCH	SPCL	ATLACH
#1	9.36710E-01	5.80000E+01	7.00000E+01	7.00000E-01	7.00000E-01	8.70000E-01	1.00000E-01
#2	0.	7.90000E+01	7.00000E+01	2.00000E-01	1.00000E+00	1.00000E+00	2.00000E-01
#3	9.36710E-01	5.80000E+01	7.00000E+01	1.40000E+00	1.40000E+00	1.74000E+00	2.00000E-01
#4	0.	7.90000E+01	7.00000E+01	4.00000E-01	2.00000E+00	2.00000E+00	4.00000E-01



APPENDIX A
PROGRAM OUTPUT
#1

Node	Temperature °F	Node	Temperature °F
1	151.7444446106	25	165.7604545206
2	151.6972504125	26	165.6881812120
3	151.6243483605	27	153.1437184527
4	178.4955430744	28	151.4986577818
5	175.8844540161	29	173.1074477818
6	178.1766744093	30	161.2016165122
7	175.5461050184	31	157.1726675029
8	178.5467046632	32	150.6814111694
9	174.7253568203	33	163.3540254444
10	155.3051499130	34	161.3080622565
11	153.6705676500	35	147.5319640320
12	165.5610917403	36	169.1407140320
13	165.8664163540	37	164.3556544729
14	165.8327525536	38	153.9239375114
15	165.0571211724	39	153.1458577150
16	165.2151560620	40	154.7411504712
17	164.0820759174	41	176.3459404712
18	162.2074771053	42	169.4425743071
19	149.8252090108	43	154.0010231202
20	147.6867304103	44	153.1325535409
21	149.2954804103	45	147.5319640320
22	165.6159039033	46	169.1407140320
23	147.7183644936	47	168.0152159847
24	165.3271148336	48	154.1920524175
		49	153.5811049464
		50	153.5130344043
		51	135.2406300270

AD 1546 D

REV SYM

NOT REPRODUCIBLE

BOEING NO. D6-25520TM

PAGE 30

6-7000

APPENDIX A
PROGRAM OUTPUT
#2

Node	Temperature °F	Node	Temperature °F
1	167.2217594389	25	150.4125566063
2	167.0711917776	26	150.7447215743
3	167.1464126676	27	175.2515224936
4	155.2754191245	28	170.6267865613
5	153.9867697877	29	152.2755745413
6	154.9277615111	30	181.9017195857
7	153.6537105760	31	174.1243536700
8	154.3567061716	32	166.5066276612
9	152.2156464805	33	175.7655882360
10	167.7230691131	34	177.1729505422
11	166.0515726915	35	166.1270955161
12	167.0711937776	36	167.7248455161
13	167.0711937776	37	167.6480725676
14	181.6064382887	38	171.8250114336
15	181.5586497136	39	171.0165469615
16	181.5486547036	40	174.1758731780
17	179.972846251	41	156.7885871780
18	177.8524590451	42	157.6277415196
19	162.6705202065	43	177.7756182855
20	177.4663091442	44	172.5461942369
21	155.0730591682	45	166.1270955161
22	150.1847467666	46	187.7288455161
23	177.5365166082	47	178.9631564671
24	159.1652466182	48	177.4513974291
		49	177.2564365436
		50	168.8394922888
		51	151.6512831891

AD 1546 D

APPENDIX A
PROGRAM OUTPUT
#3

Node	Temperature °F	Node	Temperature °F
1	204.0139194421	25	225.44490612839
2	204.0056102815	26	225.4118887758
3	204.0033076427	27	215.3592712156
4	224.9082057627	28	209.7077540179
5	232.2131069150	29	231.3145090179
6	224.6263047534	30	222.1086690855
7	232.0187614037	31	218.7339401506
8	229.1239982462	32	217.3045972306
9	225.5429641440	33	219.0348199512
10	190.4628087945	34	217.4674758140
11	187.6189097416	35	204.4567396925
12	221.1118500739	36	228.0634896925
13	221.0840003740	37	224.365371488
14	218.5186040323	38	215.9876704733
15	218.7184871921	39	215.3455467690
16	220.9089710073	40	212.3159176024
17	219.5442923106	41	233.9246674424
18	218.1601140824	42	228.9050389800
19	208.3639479588	43	216.0483905336
20	204.5429944034	44	215.3298864516
21	228.1917449036	45	204.4567396925
22	226.3567161477	46	228.0634896925
23	206.6051967895	47	220.0633837316
24	228.2174667895	48	216.1450217016
		49	215.6918172611
		50	204.1081539918
		51	202.8337954455

AD 1546 D

APPENDIX A
PROGRAM OUTPUT
#4

Node	Temperature °F	Node	Temperature °F
1	221.6767173100	26	213.7037104804
2	221.6854026407	27	187.4552792065
3	221.6811452832	28	230.5852312034
4	249.8936277524	29	252.1979512034
5	235.7157466065	30	245.7043282696
6	240.6780547087	31	235.9951517592
7	239.5385030088	32	225.5174331145
8	245.9156282035	33	237.6569263900
9	242.4351472550	34	236.3052295781
10	203.6318053873	35	226.8142481772
11	200.5612667790	36	249.4229581772
12	221.6854026407	37	245.2131911742
13	221.6854026407	38	234.4181854495
14	235.7157466065	39	233.7345660913
15	235.7772905657	40	234.7058089264
16	233.7772905657	41	255.9186489264
17	238.0951560422	42	253.3763081372
18	236.4530050964	43	235.8021271330
19	205.1851154422	44	235.0781564470
20	200.0843943647	45	226.8142481772
21	221.6571493647	46	249.4229581772
22	213.5437176497	47	241.4510882425
23	200.1631525490	48	236.8056758837
24	221.7715026490	49	235.9112311123
25	213.8637033010	50	221.5757572035
		51	222.9512570335

AP 1546 D

APPENDIX "B"
COORDINATION SHEET

TO	J. F. Kirkbride	67-26			NO. 6-8525-68-41
C.C.	A. R. Bremer	54-60	J. J. Italiane	79-25	ITEM NO.
	C. W. Clay	67-55	D. E. Lange	69-80	
	W. C. Gaffney	14-03	J. M. Lea	73-22	DATE Sept. 23, 1968
	B. C. Hainline	54-61	D. J. Melchior	54-60	
	P. R. Higgins	77-68	W. G. Nelson	54-61	MODEL 727-200
	B. A. Honsberger	73-27	G. E. Pease	14-07	
GROUP INDEX	CAD Mechanical Systems Staff - Renton Branch Hydraulic, Mechanism, and Control Systems				
SUBJECT	Preliminary Results of Hydraulic System Temperature and Flow Distribution Ground Test on N727OL (QA 001)				
REFERENCES:	(a) EWA QF 17001, 727 Hydraulic Valve Erosion Baseline for N727OL (QA 001)				
	(b) Coordination Sheet 6-8505-68-45, June 17, 1968, Heat Transfer Analysis of the 727-200 "A" Hydraulic System.				

BACKGROUND

Airline operators have been experiencing many problems with control valve erosion in their 727 airplanes over the past several months. As part of the considerable amount of effort being applied to the solution of this problem, the referenced EWA was written, in part, to measure leakage flow rates and their resulting effects upon system temperature distribution using airplane QA001 as the test vehicle. This data will be employed to check and improve the accuracy of a digital computer program which performs hydraulic system thermal analyses (Reference b). The computer program may then be used to extend this data to other operating conditions (i.e., various flow rates, ambient temperatures, system configuration changes, etc.).

The test results reported herein do not represent final data since at least one flow channel provided insufficient information, and one temperature channel gave erroneous data. It is believed, however, that the majority of results obtained is of use and therefore, the more important measurements are presented.

SUMMARY

EWA QF 17001 outlines a ground test which is conducted basically in two parts. First, with the ground interconnect closed, brake interconnect closed, and all flight controls including spoiler bypass valves turned off, the No. 1 and No. 2 "A" and "B" pumps are started and allowed to operate (engines at idle) for thirty minutes. This provides sufficient time for the hydraulic system temperatures to stabilize. Next, the flight controls are turned on consecutively with adequate time between each to allow changes of flow rate to be read. When all flight controls have been turned on the "A" and "B" system pumps are operated for an additional thirty minutes to allow temperatures to once again stabilize. The engines and pumps are then shut down and recording of data continues for an additional fifteen minutes.

During the ground test run on July 18, 1968, the OAT was 79°F. Some of the measured temperatures and flow rates are shown in Figures 1 through 4. These graphs include pump output flow rate, case drain flow rate, output flow temperature, supply flow temperature, and case drain flow temperature versus TIME for both pumps in each of the hydraulic systems. Also shown are the times at which the

APPENDIX "B"

6-8525-68-41

Page two

various events took place during the test. It will be noticed that the "A" system case drain flow rates outside the readable range (generally, the measurements corresponding to flow rates less than ten percent of flow meter scale were too noisy to read) are omitted. Conversely, some of the pump output flow rates are approximated even though their magnitudes are unreadable. This is done to illustrate the probable output flow rate suggested by the relationship between suction and outlet flow temperatures. That is, an outlet fluid temperature which is less than the inlet fluid temperature (this occurs only at the "B" system pumps) indicates there is no output flow. As soon as output flow begins, the proper relationship between the subject flow temperatures is established as may be seen in Figure 4.

Figure 1 shows the No. 1 "A" system pump flow and temperature parameters. With the flight controls turned off, the output flow is expected to be small in magnitude. The only measurable case drain flow rate was approximately 0.3 gpm which appeared to remain constant both prior to, during, and after flight controls were turned on. Before engagement of flight controls, the case drain flow temperature appeared to stabilize at approximately 164°F. The highest case drain temperature was reached at the end of test and was 180°F.

As will be seen later, the No. 2 "A" system pump output flow remained below the readable range for the duration of the ground test although it is expected that some fluid was flowing through the outlet ports. Consequently, the changes indicated by the flowmeter in the No. 1 pump pressure line during activation of the flight control systems represent the leakage flow rates in those systems. Figure 1 then shows that if there is any leakage through the "A" system portion of the aileron control unit, it is undetectable with the instrumentation used. On the other hand, the "A" system incremental flow rates resulting from activation of the remaining control systems are about 1.1 gpm (4170 cc/min), 0.9 gpm (3420 cc/min), and 0.75 gpm (2840 cc/min) for the elevators, rudder, and spoilers, respectively.

Figure 2 shows that the No. 2 "A" system pump case drain flow rate remained relatively constant at about 0.46 gpm. The output flow rate was below the readable range for the entire test. The highest case drain flow temperature measured was 175°F.

Temperatures and flows for the No. 1 "B" system pump are shown in Figure 3. A seemingly high case drain flow rate of about 2.1 gpm was measured throughout the test; it appeared there was no output flow at any time. The dip in case drain and inlet flow temperatures will be discussed later. Crossing of the inlet and outlet flow temperature lines suggests that shortly after the spoiler bypass valves were opened a small amount of fluid flowed out through the pressure line.

Figure 4 indicates that the No. 2 "B" system pump case drain flow rate was 2.0 gpm until the elevator was turned on, after which it settled out to about 1.7 gpm. The output flow rate, on the other hand, was essentially zero, except for a brief transient at the beginning of test, until flight controls were turned on. No measurable flow rate differences were noted for the ailerons and elevators. When the rudder and spoilers were turned on, however, the output flow rate increases were around 1.24 gpm (4710 cc/min) and 1.20 gpm (4550 cc/min), respectively.

APPENDIX "B"

6-8525-68-41

Page three

Once output flow was established, the proper relationship between inlet and outlet flow temperatures was established. This occurs when the ailerons were activated indicating, as is expected, that there is leakage through this unit even though it is below the range measurable with the instrumentation used.

When flow is established through the output line, the relatively cool fluid in this line mixes with the remainder of the fluid creating a small transient denoted by the dip in the temperature traces shown in Figures 3 and 4.

CONCLUSIONS

1. Based on degree for degree correction, the maximum measured and standard hot day case drain temperatures reached during extended ground idle are:

Pump	Maximum Case Drain Temperature, °F	
	Measured	Standard Hot Day
No. 1 "A" system	180	221
No. 2 "A" system	175	216
No. 1 "B" system	199	240

2. The system leakage flows corresponding to these maximum temperatures are:

	Flow Rate, gpm (cc/min)	
	"A" System	"B" System
Ailerons	Unmeasurable	Unmeasurable
Elevator	1.1 (4170)	Unmeasurable
Rudder	0.9 (3420)	1.24 (4710)
Spoilers	0.75 (2840)	1.20 (4550)

3. As soon as the ground test is redone to obtain all of the necessary flow and temperature data, correlations will be made between this data and computer results.

Prepared by

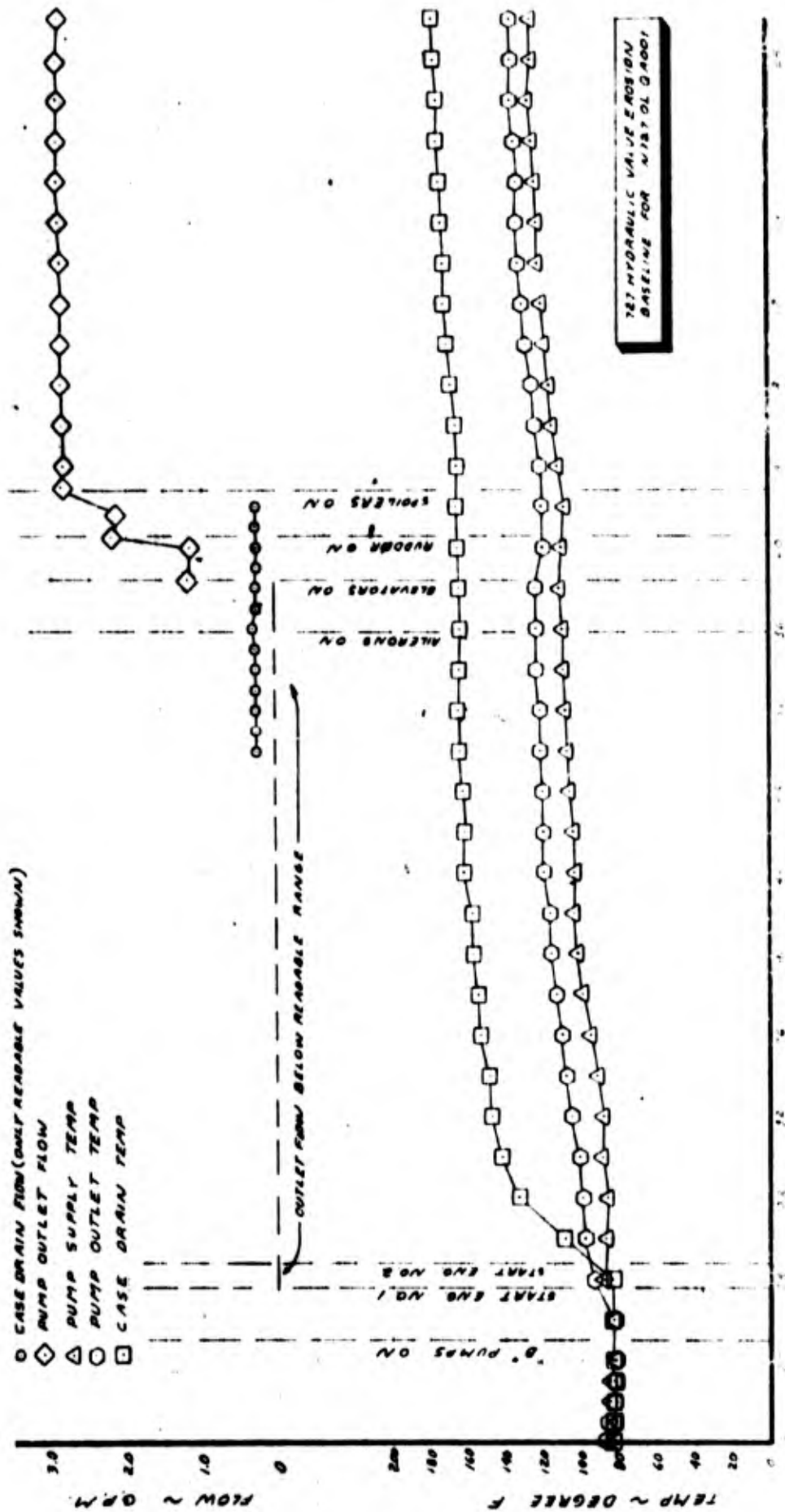
J. E. Strang
J. E. Strang
6-8525 73-22 237-7400

Approved by

D. B. Meredith
D. B. Meredith

Attachments (4)

APPENDIX "B"



APPENDIX "B"

- CASE DRAIN FLOW
- ◇ PUMP OUTLET FLOW
- △ PUMP SUPPLY TEMP
- PUMP OUTLET TEMP
- CASE DRAIN TEMP

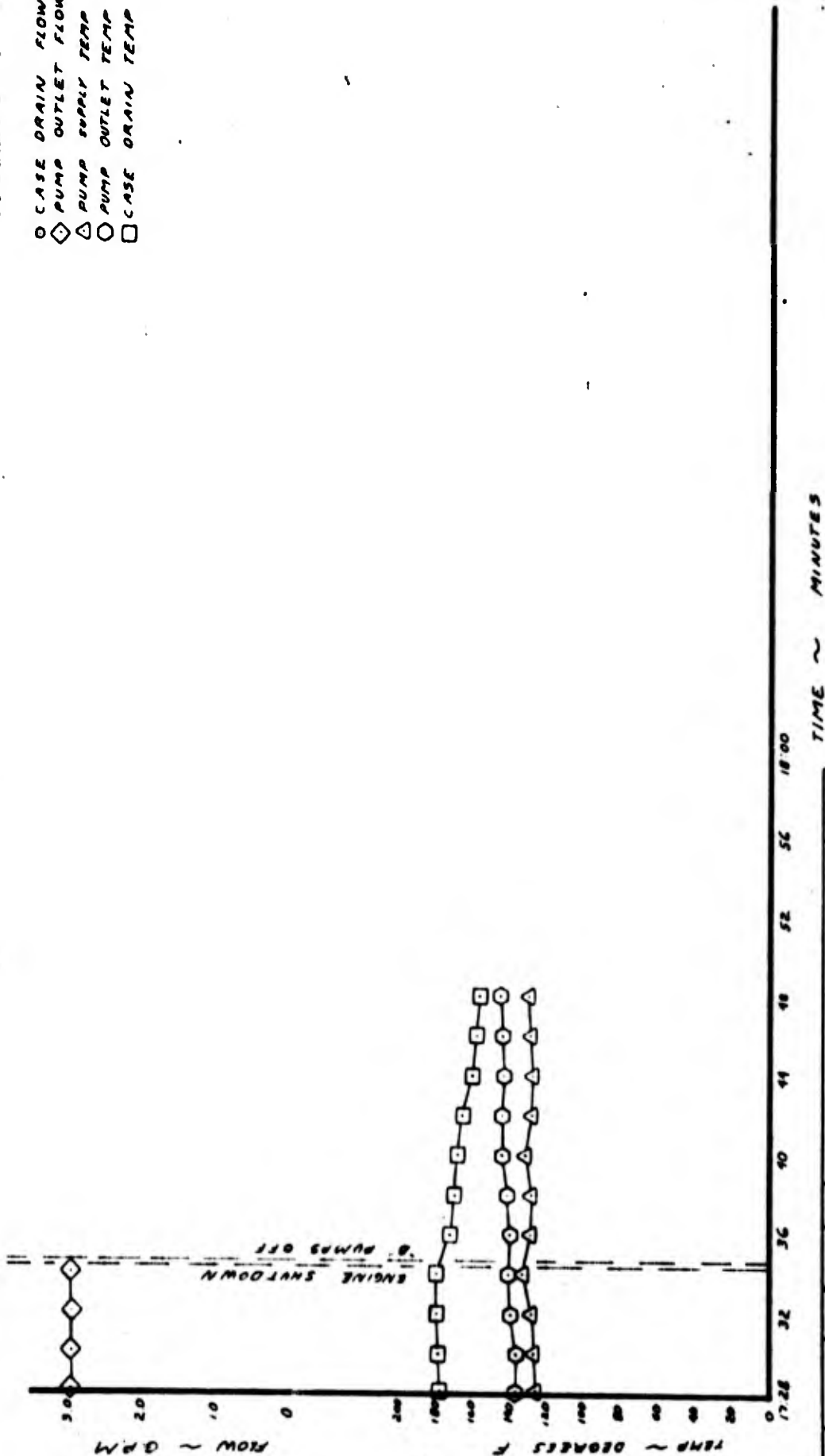
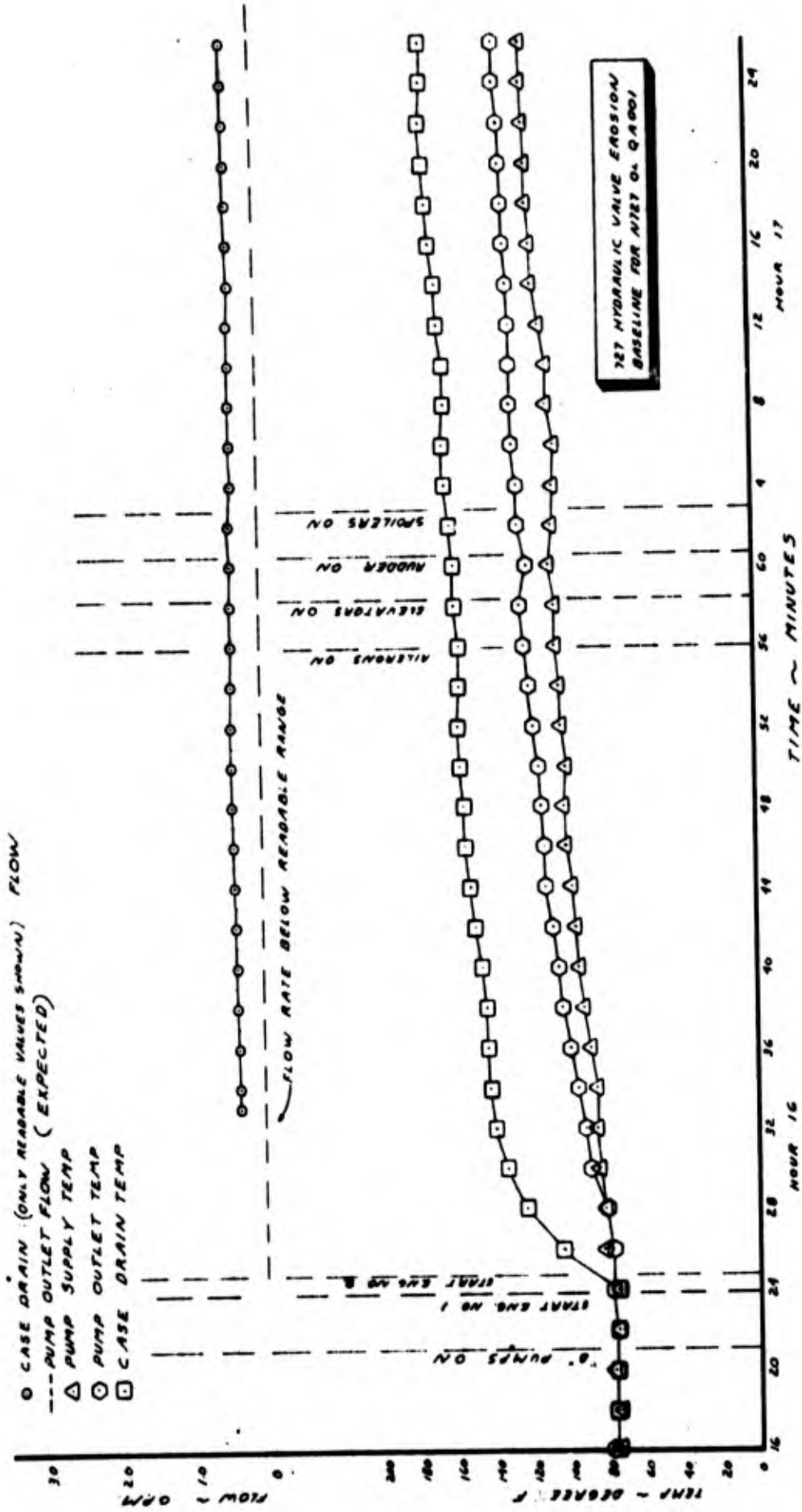


FIG. 1	DATE	REVISED	DATE	REVISED	DATE	REVISED	DATE	REVISED	DATE
(CONT'D)									
GROUND TEST RESULTS									
NO. 1 "A" SYSTEM PUMP									
THE BOEING COMPANY									
PAGE 5									

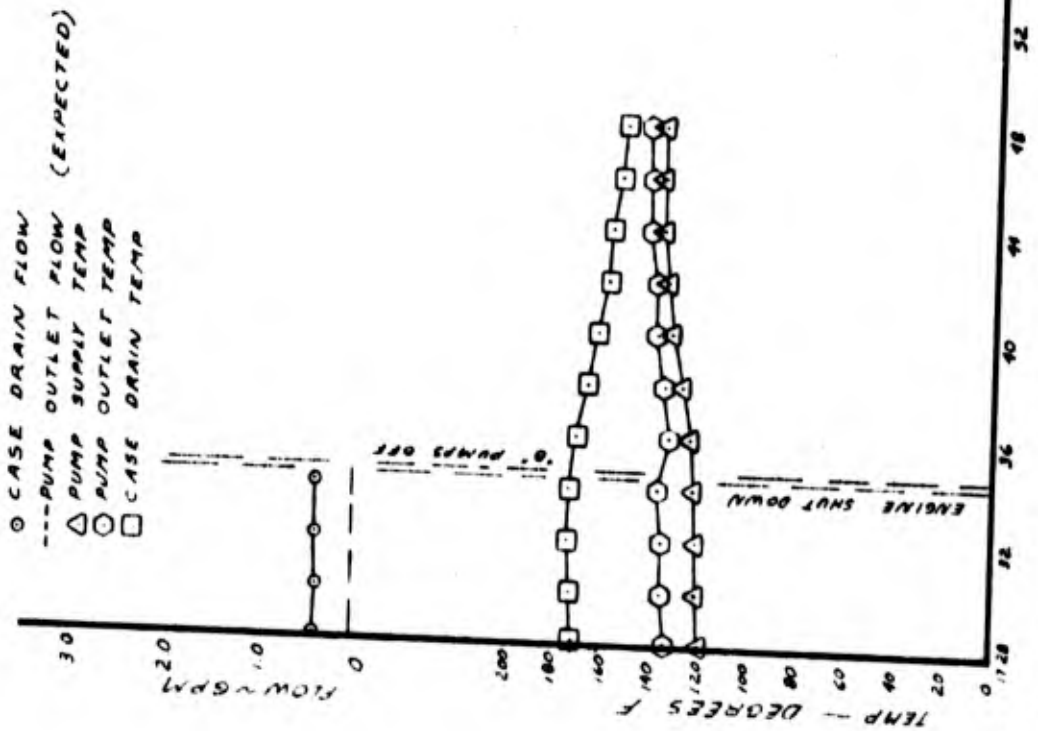
APPENDIX B



GROUND TEST RESULTS		FIG 2
DATE	REVISED	8-25-75
BY	DATE	58 41
TEST NO.	TEST DATE	PAGE 6
THE BOEING COMPANY		

16-58800-00

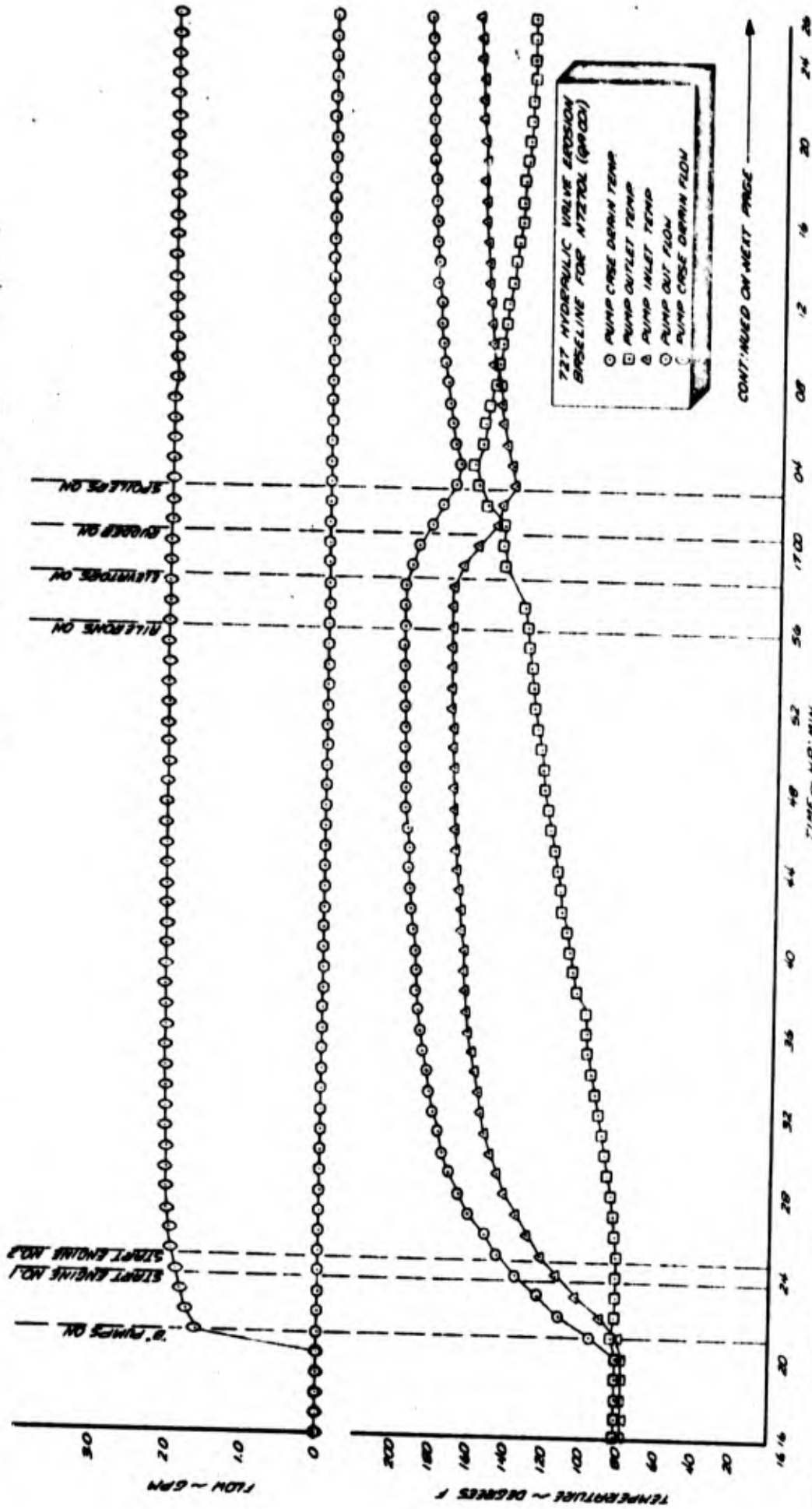
APPENDIX B



TIME - MINUTES

CALL									
ENCLER									
APPRO									
APPRO									
DATE									
GROUND TEST RESULTS		NO 2 "A" SYSTEM PUMP		THE BOEING COMPANY		PAGE 7		SEE 10-11-1953	

APPENDIX B



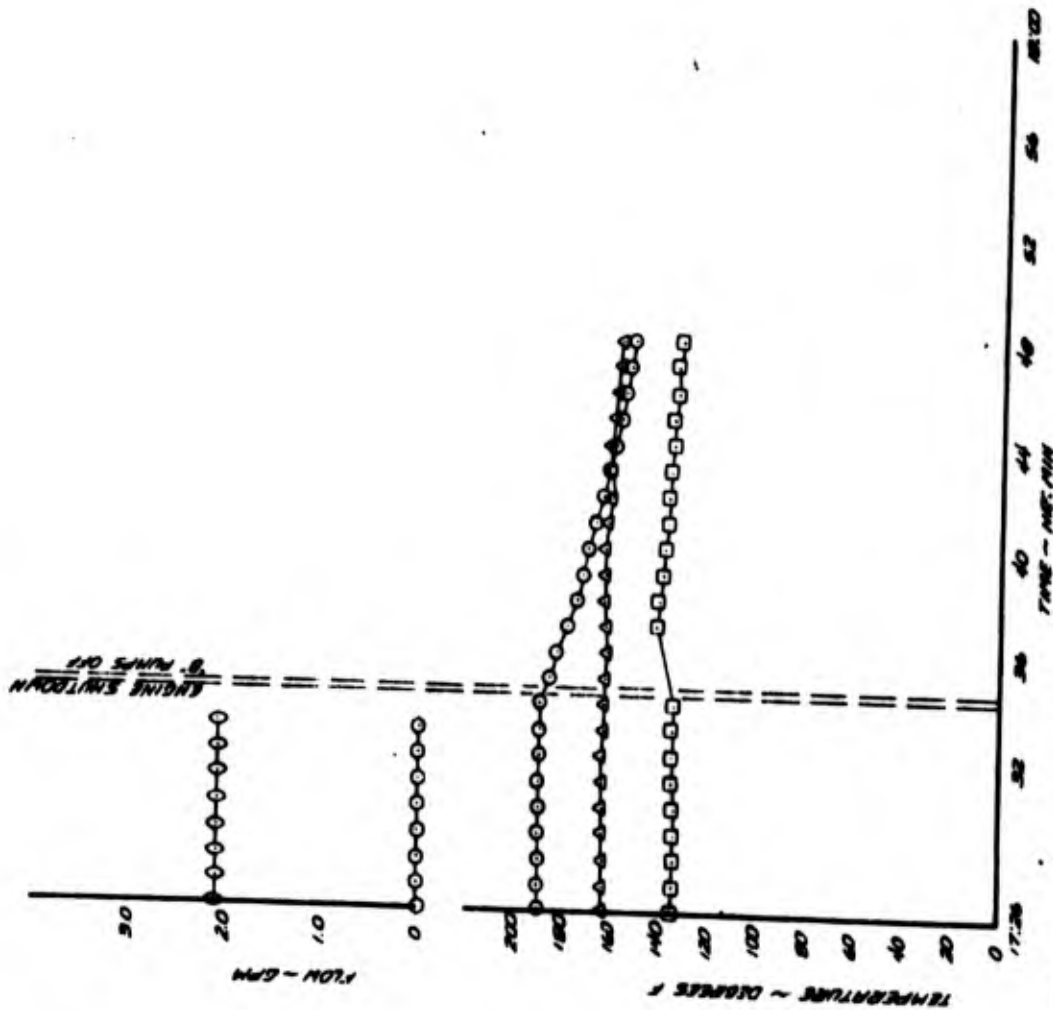
727 HYDRAULIC VALVE EROSION
BASELINE FOR NITROL (QPCD)

- PUMP CASE DRAIN TEMP
- PUMP OUTLET TEMP
- △ PUMP INLET TEMP
- ◇ PUMP CASE DRAIN FLOW

CONTINUED ON NEXT PAGE

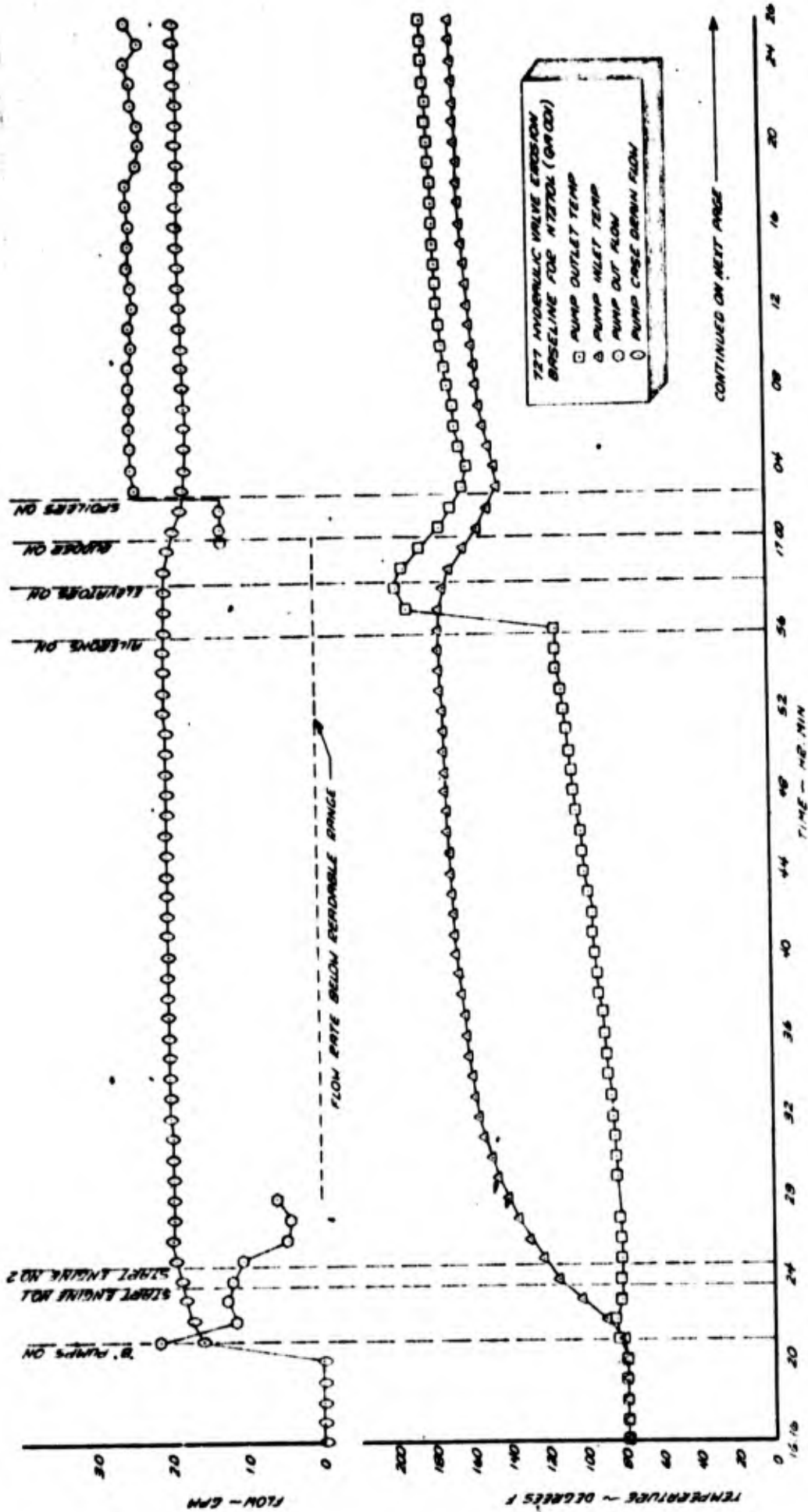
DATE	REVISED	DATE	FIG. 3
CHECK			
APPROV.			
GROUND TEST RESULTS NO. 1 "B" SYSTEM PUMPS			
THE BOON COMPANY			

APPENDIX B



DATE	REVISED	DATE	FIG 9
ENGINE			(CONT'D)
TYPE			NO. 1 "B" SYSTEM PUMP
OPER			9-5525
BY			59-41
DRY	5.2525	11.2.48	INSTR
THE BOEING COMPANY			6

APPENDIX B



DATE	REVISED	BY	TEST NO.
CHECKED			GROUND TEST RESULTS
APPROVED			NO. 2 8" SYSTEM PUMP
TESTED			THE EDGE TOOL COMPANY
TEST NO.			ATLANTA

APPENDIX C

COORDINATION SHEET

TO	J. F. Kirkbride	67-26		
C.C.	A. R. Bremer	2A-23	D. E. Lange	69-80
	W. C. Gaffney	14-03	W. G. Nelson	54-61
	B. C. Hainlice	54-61	V. L. Robinson	54-60
	P. R. Higgins	77-68		
	J. J. Italiane	79-26		

NO. 6-8525-69-15

ITEM NO.

DATE Mar. 11, 1969

MODEL 727-200

GROUP INDEX Mechanical Systems Staff - Renton Branch
Hydraulic, Mechanisms, and Control Systems

SUBJECT Final Results of Hydraulic System Temperature and Flow
Distribution Ground Test on N727OL (QA 001)

- REFERENCES:
- (a) EWA QF 17001, "727 Hydraulic Valve Erosion Baseline for N727OL (QA 001)"
 - (b) Coordination Sheet 6-8505-68-45, Dated June 17, 1968, "Heat Transfer Analysis of the 727-200 "A" Hydraulic System"
 - (c) Coordination Sheet 6-8525-68-41, September 23, 1968, "Preliminary Results of Hydraulic System Temperature and Flow Distribution Ground Test on N727OL (QA 001)"

BACKGROUND:

Reference (a) provided for a ground test and flight test to obtain hydraulic system flow rate and temperature data. This information was then to be used to check and improve the accuracy of a digital computer program (Reference (b)) which would serve to extend this data to other operating conditions. A ground test was performed in which one flow channel and one temperature channel gave erroneous results. The remainder of the data appeared to be good, however, so the more important portions of it were reported in Reference (c).

A final ground test was accomplished prior to EWA QF 17001 cancellation. The purpose of this communication is to transmit the results of that test. Unfortunately, programming problems have precluded the comparison of this data with computer obtained results. Rather than delay this report further the analytical comparison will be issued as an addendum when it is available.

DISCUSSION:

The test procedure used during this test is the same as that reported in Reference (c). Summarizing briefly, with brake and system interconnects closed and all flight controls to include spoiler bypass valve turned off, both "A" and "B" system pumps are operated (engines at idle) for thirty minutes to allow system temperatures to stabilize. The flight control systems are then turned on, one at a time, with sufficient time intervals to allow flow rates to be read. With all flight control systems on the pumps are operated for an additional thirty minutes to restabilize the temperatures.

This final ground test was performed on a dry day with an average OAT of 57 F. Flow data taken during the test is shown in Figures 1 and 2 while the majority of the temperature data is included in Figures 3 through 7. Generally, it is believed that the temperature data obtained are excellent while the flow data are as good as current instrumentation capabilities will provide. Several flow rate measurements were below the readable ranges during portions of the test.

DISCUSSION: (Cont'd)

These areas have been noted in Figures 1 and 2 and estimations of whether there was output flow from certain pumps during these times are also indicated. These deductions were made based on the relationship between pump inlet and outlet flow temperatures. An output temperature less than the input temperature indicates no output flow.

Reviewing the flow rate data shows that the Kellogg 'A' system pumps both had case drain flows of about 0.3 gpm (Figure 1). This was verified by separate test. It is expected that there was a small amount of output flow from the number one 'A' pump and none from the number two 'A' pump prior to turning on flight controls. The trailing edge flap control valve leakage undoubtedly comprised nearly all of the flow that did occur during this time. The number one 'A' pump had no measurable output flow until the elevators were energized. Flow rate increments of about 1.32 gpm, 0.88 gpm and 0.86 gpm were measured as the elevators, rudder and spoilers were turned on, respectively. The number two 'A' pump apparently began passing an unmeasurable amount of fluid through the outlet port at the time the spoiler bypass valves were opened. Total 'A' system leakage flow rate with all flight controls turned on, then, was somewhat in excess of 3.1 gpm.

The case drain flow rate of each of the Kellogg 'B' system pumps was about 2.1 gpm (Figure 2). This was non-verifiable due to system configuration. Temperature data indicates that there was no outlet flow from either pump with flight controls turned off. This could be expected, however, since, in this configuration, the only possible flow paths are through the brake metering valve or the ventral stair modular package. An unmeasurable amount of number one 'B' pump output flow was initiated when the elevators were energized and remained through the duration of the test. A small number two 'B' pump output flow was established when the ailerons were turned on, increased to 1.25 gpm with rudders on and opening spoiler bypass valve raised it to about 2.22 gpm. Therefore, with all flight controls turned on the total 'B' system leakage was somewhat in excess of 2.22 gpm.

Now, turning attention to the temperature data shown in Figures 3 through 7, some general observations can be made with regard to these results. Maximum case drain flow temperatures occur at the end of testing for the 'A' system and just prior to energizing of flight controls for the 'B' system and are 167F, 163F and 189F for the number one 'A', number two 'A', and number one 'B' pumps, respectively. It is felt that the large drop in 'B' system temperatures as flight controls are turned on, is due to purging the 'B' system pressure lines. These lines are filled with cool fluid resulting from lack of prior outlet flow. After the system overall temperature is lowered by this fluid, restabilization begins.

With flight controls on, it appears that approximately 15F of cooling is obtained in the considerable length of line between the 'A' pumps and the heat exchanger inlet, whereas the 'B' is cooled about 4F. Temperature differences through the heat exchangers are about 52F for the 'A' system and 18F for the 'B' system. This means that about 120 BTU/min and 275 BTU/min are being rejected to the fuel by the 'A' and 'B' systems, respectively.

DISCUSSION: (Cont'd)

This appears to be discrepant since the 'A' system heat exchanger has twice the surface area of the 'B' system unit. It is believed, however, that the heat transfer rates, which are a function of the internal convective heat transfer coefficients, vary appreciably for each of the heat exchangers since the Reynolds numbers are about 450 and 4,000 for the 'A' and 'B' systems, respectively. Heat transfer characteristics are considerably different for laminar and turbulent flow and are less predictable as Reynolds number is lowered.

The highest reservoir temperatures reached were 115F and 162F for the 'A' and 'B' systems, respectively.

CONCLUSIONS:

1. The leakage flow rates experienced on airplane QA 001 are:

	<u>Flow rate, gpm</u>	
	<u>'A' System</u>	<u>'B' System</u>
Ailerons	Unmeasurable	Unmeasurable
Elevators	<1.32	Unmeasurable
Rudders	0.88	<1.25
Spoilers	0.86	0.97
Maximum total	>3.06	>2.22

2. With extended ground idle, this results in the following maximum actual temperatures and standard hot day temperatures (based on degree for degree correction):

<u>Pump</u>	<u>Maximum Case Drain Temperature, F</u>	
	<u>Measured</u>	<u>Standard Hot Day</u>
No. 1 'A' system	167	230
No. 2 'A' system	163	226
No. 1 'B' system	189	252

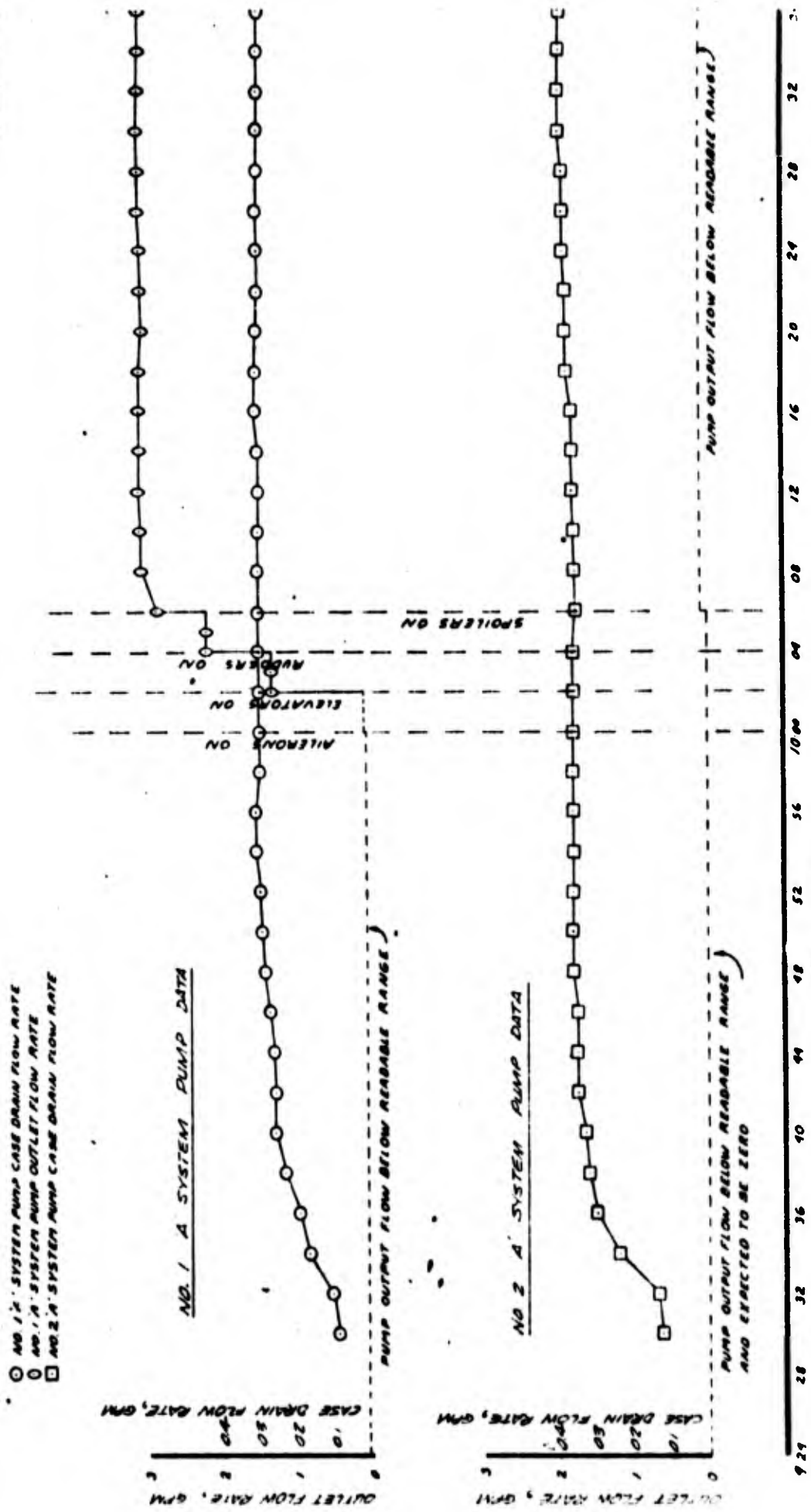
3. Other system data is as shown in Figures 3 through 7.

If there are any questions regarding the data presented herein, please contact the undersigned.

Prepared by J. E. Strang
J. E. Strang
6-8525 73-22

Approved by D. B. Meredith
D. B. Meredith

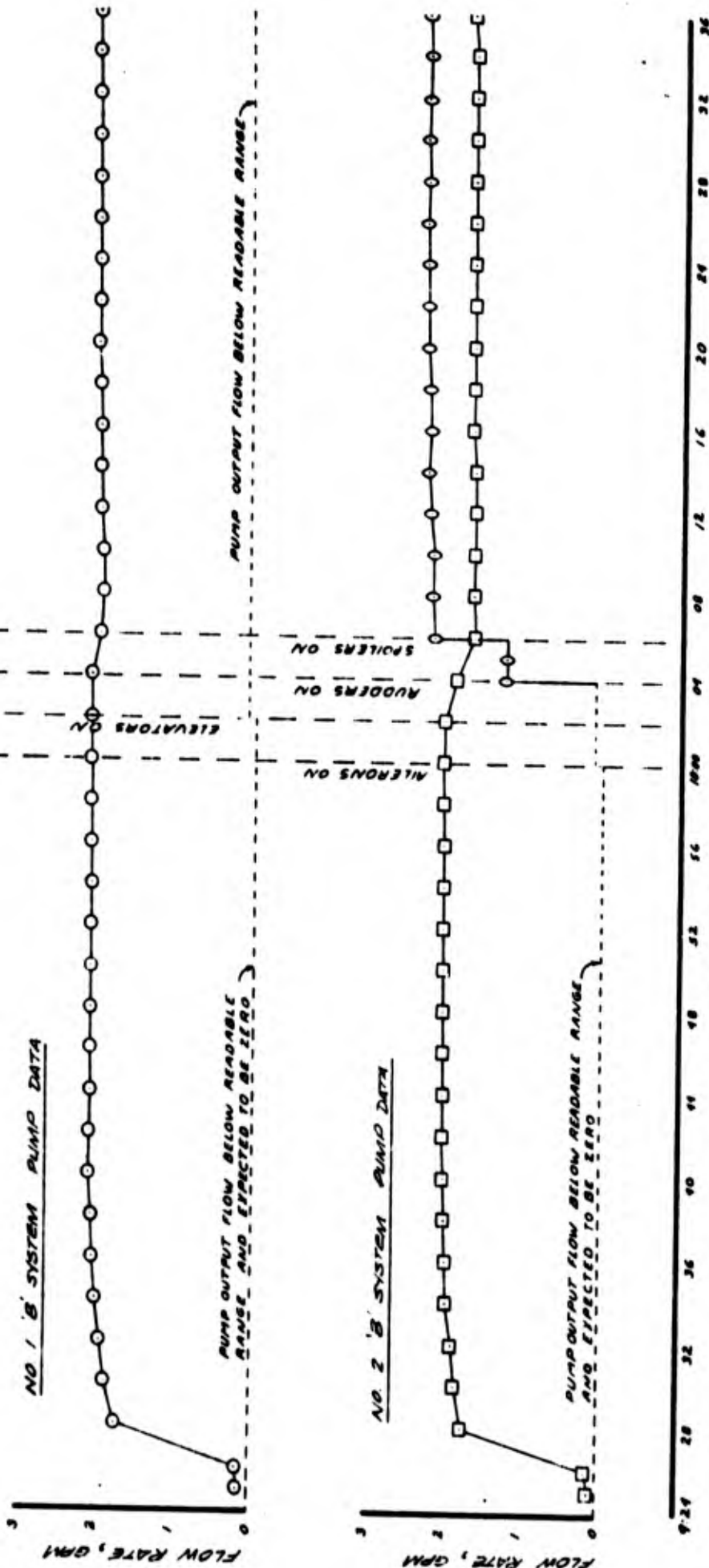
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CALL		REVISED	DATE	FIG. 1
PLATE				727-200 (2A ON) A-SYSTEM
ASD				FLOW RATE DATA - GROUND
APD				TEST
APD				6-25-55
APD				25-55
APD				4
APD				THE BOEING COMPANY

TO 1000-00
 REVISION 02
 1000-00

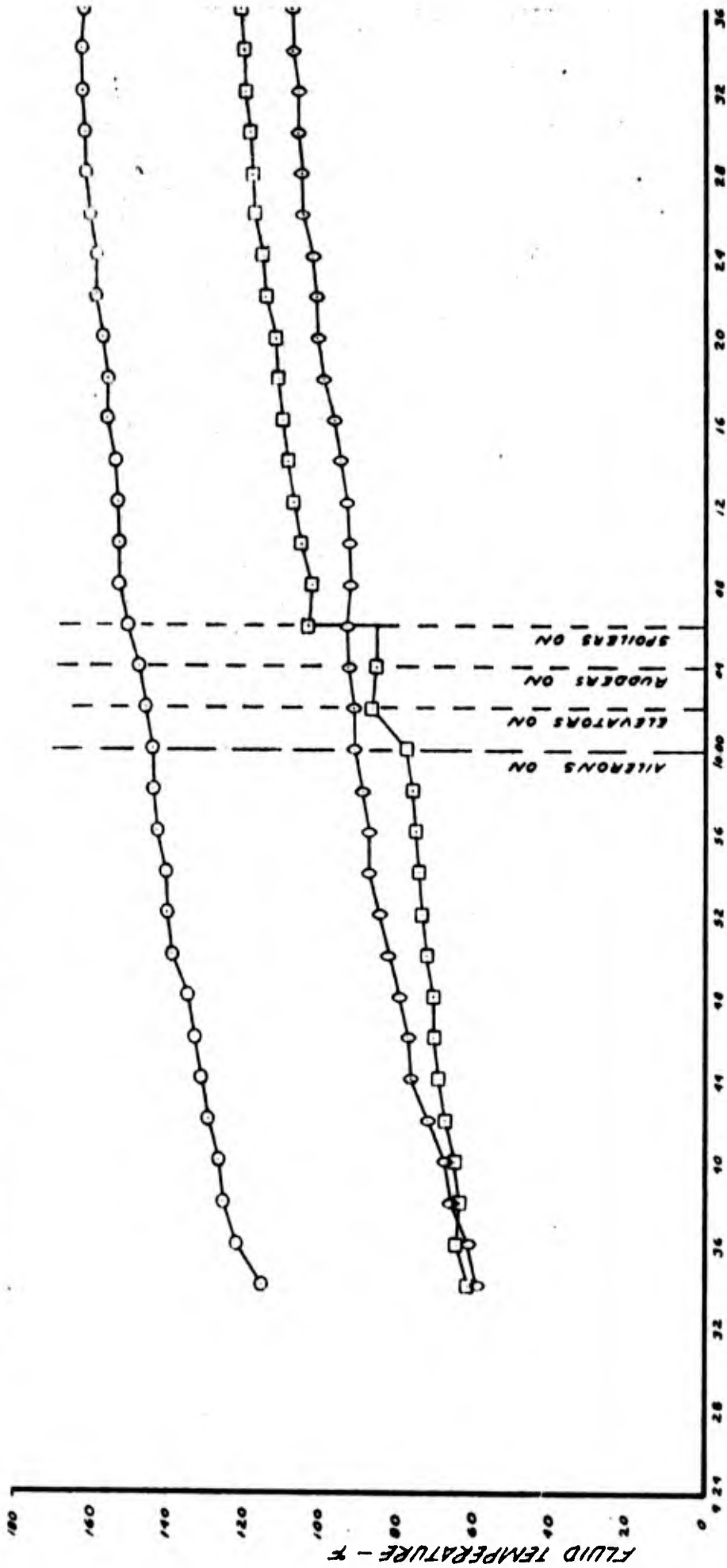
- NO. 1'S SYSTEM PUMP CASE DRAIN FLOW RATE
- NO. 2'S SYSTEM PUMP OUTLET FLOW RATE
- NO. 2'S SYSTEM PUMP CASE DRAIN FLOW RATE



DATE	REVISED	DATE	727-200 (04 00) 1'S SYSTEM	FIG 2
CHECK			FLOW RATE DATA - GROUND	5-8-5
APPD			TEST	5-8-5
APPD				
DRWN	777	5-22-57	THE BOEING COMPANY	PAGE 5

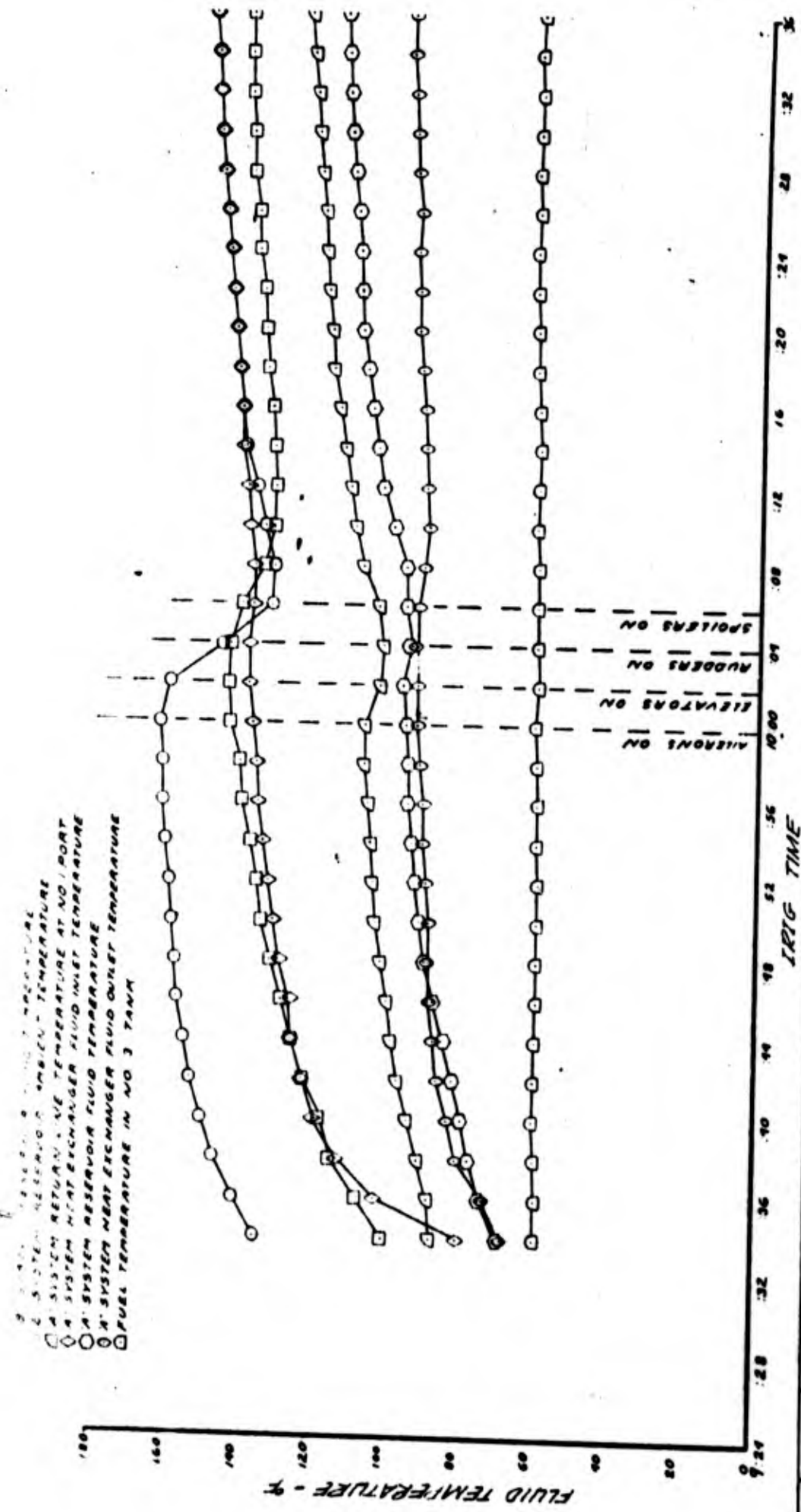
TO 10015-00
 16-55201
 64-894
 64-894

- NO 2 'A' SYSTEM PUMP CASE OR IN FLUID TEMPERATURE
- NO 2 'A' SYSTEM PUMP OUTLET FLUID TEMPERATURE
- NO 2 'A' SYSTEM PUMP INLET FLUID TEMPERATURE



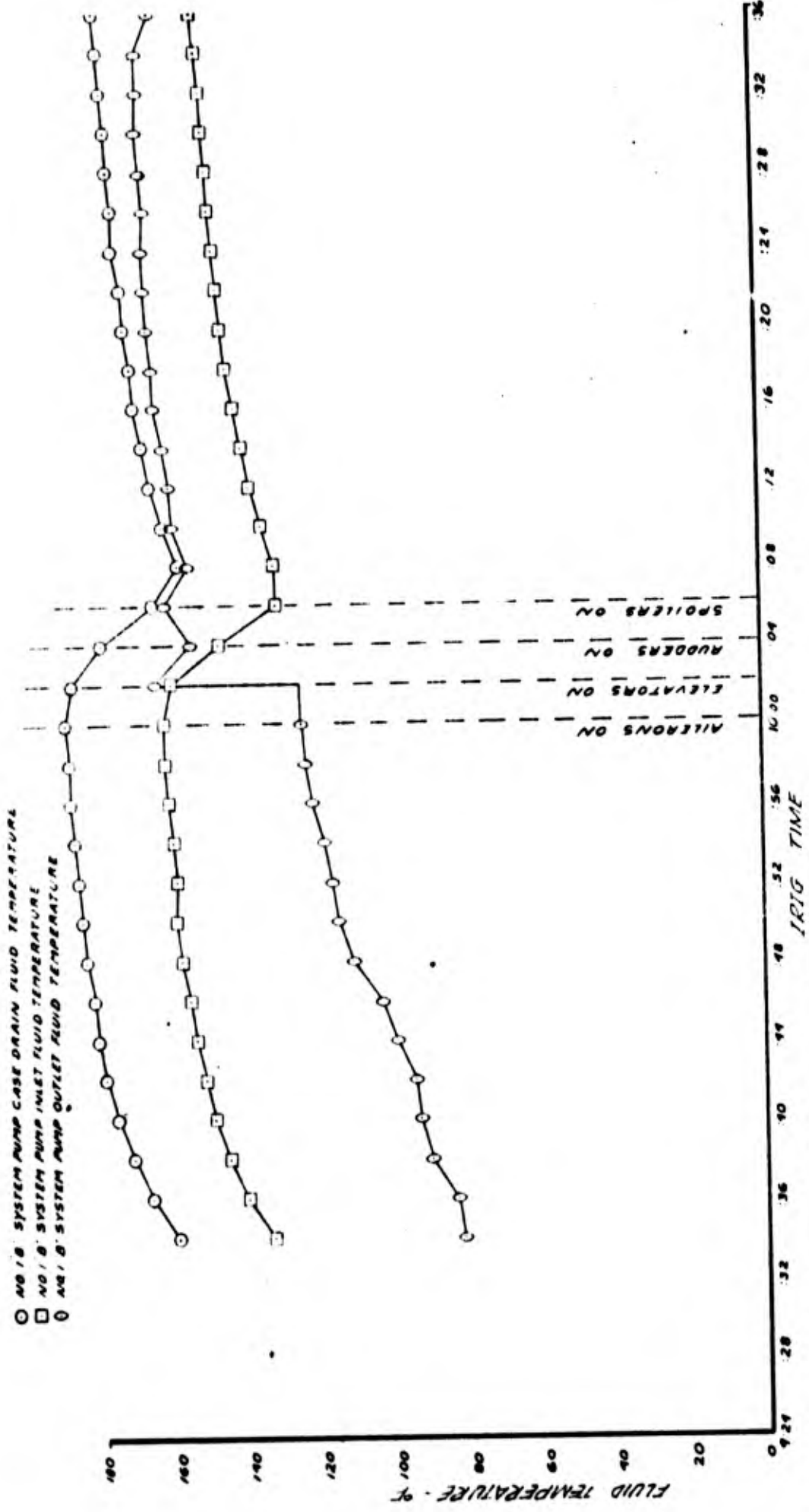
DATE	REVISED	77	8 25 51
CHECK	APPROV		
APPROV			
PAGE	THE BOEING COMPANY		PAGE 7
727-200 (24001) 'A' SYSTEM FLUID TEMPERATURE DATA - GROUND TEST			FIG. 4
			6-8522
			6-89-75

TO 8080-20
 KCE ALPHABETIC INDEX
 TRACKING PAGE

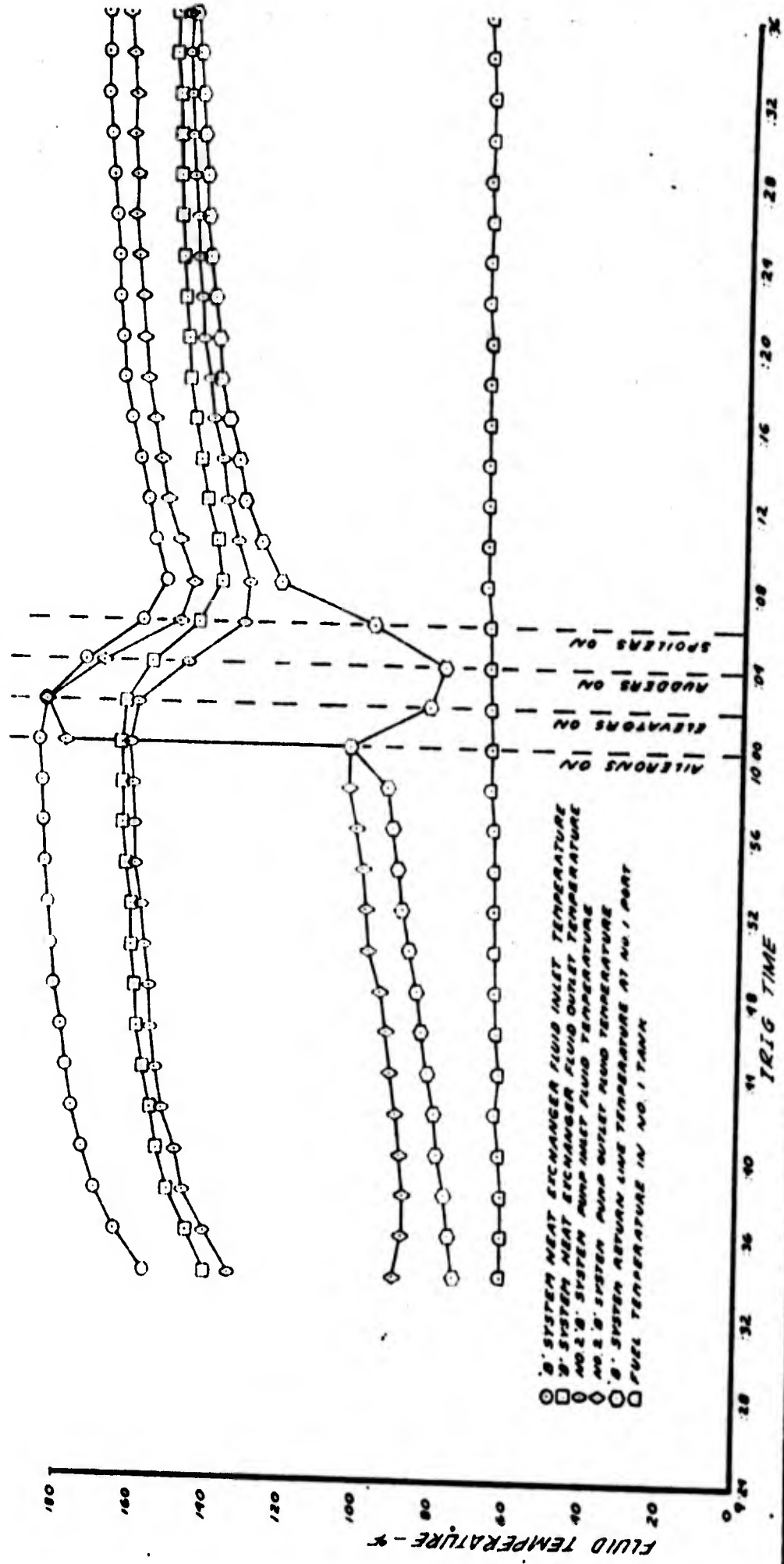


DATE	7-27-52	FIG. 5
TIME	14:00	14:00
TEST	GROUND TEST	
TESTER		
APPROVED		
THE BOEING COMPANY		

70 1000-00
REVISIONS



DATE	REVISED	DATE	FIG 6
CHECK			227-200 (3A) ON 'B' SYSTEM
APPROV			FLUID TEMPERATURE DATA
APPROV			GROUND TEST
APPROV			THE BOEING COMPANY
APPROV			PAGE 1



○ NO. 1 SYSTEM HEAT EXCHANGER FLUID INLET TEMPERATURE
 □ NO. 2 SYSTEM HEAT EXCHANGER FLUID OUTLET TEMPERATURE
 ◇ NO. 2 SYSTEM PUMP INLET FLUID TEMPERATURE
 △ NO. 2 SYSTEM PUMP OUTLET FLUID TEMPERATURE
 ○ NO. 1 SYSTEM RETURN LINE TEMPERATURE AT NO. 1 PORT
 ○ FUEL TEMPERATURE IN NO. 1 TANK

DATE	28 July 77	TIME	10
BY	FA 3517		
THE BOEING COMPANY			
727-200 (GA 001) 5 th SYSTEM FIG. 7			
FLUID TEMPERATURE DATA -			
GROUND TEST			
6-8028			
6-9-78			

COORDINATION SHEET

TO	W. G. Nelson	54-84	NO.	6-8525-69-75
CC.	B. G. Mainline	54-84	ITEM NO.	
	P. R. Higgins	77-68	DATE	Sept. 12, 1969
	E. A. Rock	73-25	MODEL	737
	W. Zielke	54-84		

GROUP INDEX CAG - 707/727 and 737 DIVISIONS - HYDRAULIC, MECHANISM, AND CONTROL SYSTEMS

SUBJECT Evaluation of Heat Transfer Coefficients

- REFERENCE:**
- (a) Coordination Sheet 6-8525-68-41, "Preliminary Results of Hydraulic Systems Temperature and Flow Distribution Ground Test on N727OL (QAC01)" Dated September 23, 1968.
 - (b) Coordination Sheet 6-8525-69-15, "Final Results of Hydraulic System Temperature and Flow Distribution Ground Test on N727OL (QAC01)" Dated March 11, 1969.

SUMMARY

The Mechanical Systems Staff research group is developing a computer program to simulate the 727 "B" hydraulic system fluid temperature distribution. The overall heat transfer coefficients for the various portions of the system as well as the heat distribution information for the pump to be used in the program are given in this coordination sheet. The parameters given were evaluated by analysis of the data presented in reference (b). A brief description of the analytical method used is also included.

BACKGROUND

A study has been undertaken to evaluate possible uses of BETA II heat transfer computer program in the thermal analysis of the 727 "B" hydraulic system. Previous attempts to use BETA II with theoretically derived heat transfer coefficients have been unsuccessful. As a result, flight test data, reported by reference (b) were analyzed to determine the actual effective overall heat transfer coefficients for the various components, tubes and regions. By programming these values rather than values derived theoretically, we hope a computer program can be developed which will simulate the temperature distribution of the 727 "B" hydraulic system in response to various flow and ambient temperature conditions.

DISCUSSION

The system was analyzed at two pump outflow rates, pump cut-out (zero outflow), and stabilized system leakage flow (no surface movement). At pump cut-out, heat transfer coefficients were derived for the "B" system heat exchanger, the "B" system reservoir, the lines from the pump to the heat exchanger, and the pump cavity. At the stabilized flow conditions, heat transfer coefficients were derived for the hydraulic lines from the "B" system pressure modules to the various actuators.

The effective overall heat transfer coefficients were derived using the following equations.

$$Q = UA \Delta T_a$$

and

$$Q = m C_p \Delta T_o$$

APPENDIX D

6-8525-69-75
September 12, 1969
Page 2.

where

- Q is the heat flow rate
- U is the overall heat transfer coefficient
- A is the effective area of the component being analyzed
- ΔT_{oa} is the difference between bulk oil temperature and overall ambient temperature.
- \dot{m} is the mass flow rate
- C_p is the specific heat of the oil
- ΔT_o is the difference between the oil temperature in and out of the component being analyzed.

Combining the equations and solving for U , we get

$$U = \frac{\dot{m} C_p \Delta T_o}{A \Delta T_{oa}}$$

A summary of the effective overall heat transfer coefficients derived as well as the effective areas are presented as figure 1.

The remaining element to be simulated is the "B" system pump. The general heat balance expression for the pump is

$$\Sigma (\text{Heat In}) - \Sigma (\text{Work Out}) = \Sigma (\text{Heat Out})$$

The heat input consists of the electrical power input and the supply flow from the reservoir. The work output can be expressed as a function of pressure and output flow. The heat output was considered to consist of the outflow and the case drain flow. The convective heat transfer was assumed to be negligible. Figure 2 gives curves for case drain flow, electric power input, and case drain heat flow as a function of pump output flow. Using the data from figure 2, the heat balance expression for the pump can be evaluated.

Figure 3 is a "B" hydraulic system schematic diagram giving the various line lengths and sizes.

CONCLUSION

The data presented in figures 1, 2 and 3 should be used to develop a computer program for the thermal analysis of the 727 "B" hydraulic system. Temperatures produced by the resulting program should compare favorably with the temperatures given by reference (a) and reference (b). A favorable comparison is considered to be agreement within 5 to 10 degrees fahrenheit of the data.

PREPARED BY: W. R. Miller
W. R. Miller

APPROVED BY: D. B. Meredith
D. B. Meredith

WJM/lid

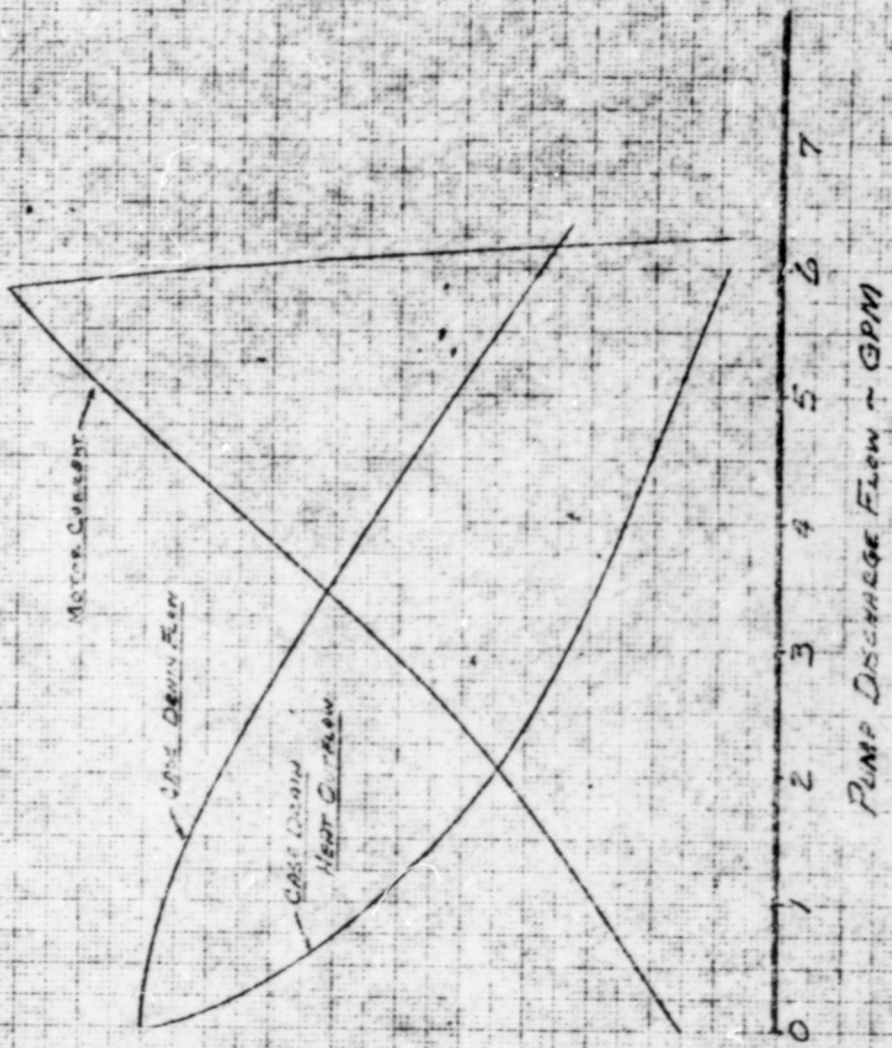
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"B" HYDRAULIC SYSTEM HEAT TRANSFER DATA

ITEM	EFFECTIVE AREA	OVERALL HEAT TRANSFER COEFFICIENT
	IN ²	$\frac{\text{BTU}}{\text{MIN FT}^2 \text{ } ^\circ\text{F}}$
1. RESERVOIR	472	0.664
2. HEAT EXCHANGER	830	0.567
3. HYDRAULIC LINES		
a. PUMP TO HEAT EXCHANGER	474	0.082
b. PRESSURE MODULE TO EMPENAGE REGION		0.066
c. PRESSURE MODULE TO SPOILERS		0.073
R. H. PRESS.	1017	
R. H. RET.	145	
L. H. PRESS.	1017	
L. H. RET.	319	
d. CENTER SECTION (WHEEL WELL)	493	0.070
4. "B" SYSTEM PUMP CAVITY		$U \cdot A = 2.32 \frac{\text{BTU}}{\text{MIN. } ^\circ\text{F}}$

ENGR.	M. MILLER	5/12/53	REVISED	DATE	"B" HYDRAULIC SYSTEM HEAT TRANSFER DATA THE BOEING COMPANY RENTON WASHINGTON	FIG 1
CHECK						6-2525-64-15
APP.						FIG 3
APP.						

NOTE: ① LINE TO MOTOR VOLTAGE = 115 VOLTS
 ② DEMAND: % = $\frac{Q_{CASE DRAIN}}{Q_{SUPPLY @ ELCC}}$



HEAT MOTOR PUMP CURRENT ~ AMPS/PHASE	CASE DRAIN HEAT OUTFLOW ~ %	CASE DRAIN FLOW ~ GPM
36	0	0
32	20	10
28	40	20
24	60	30
20	80	40
16	100	50

CHK	DATE	REVISED	DATE

"B" HYDRAULIC SYSTEM PUMP DATA

FIG. 2

6-2535-17

THE SCIENTIFIC COMPANY

PAGE 4

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LIST OF NOMENCLATURE

Definitions of symbols used in the set of equations in Section IV-5.

$$a. = C_p M_{so} / (U_a A_a + C_p M_{so})$$

$$b. = U_a A_a / (U_a A_a + C_p M_{so})$$

where

$$C_p = \text{Specific Heat of the fluid in BTU/LBM-}^\circ\text{F}$$

$$M_{so} = \text{Flow rate in lb/min through node \#50}$$

$$U_a = \text{Reservoir coefficient of heat transfer}$$

$$A_a = \text{Surface area of reservoir in ft}^2$$

$$\mu_i = e^{-\frac{\pi D_i K_i L_i}{r h_i C_p}} \quad \text{where } \pi = 3.141597$$

$$D_i = \text{Outside diameter (ft) of tube } i$$

$$K_i = \text{Heat transfer coeff. of tube } i$$

$$L_i = \text{Length of tube } i \text{ (ft)}$$

$$\epsilon_c = M_c / (M_c + M_s); \quad \epsilon_r = M_r / (M_c + M_r); \quad \epsilon_{cs} = M_c / (M_c + M_s) \text{ etc.}$$

These are junction equations. $\rightarrow \epsilon_c, \epsilon_r, \epsilon_{cs}$ etc.

$$\Delta T_{cd} = C(QMT) / C_p M_{cd} \quad \text{where } C = \text{fraction of heat input into the case drain}$$

QMT = Heat energy input into the pump by motor

M_{cd} = flow rate (lb/min) into case drain

$$\alpha_i = 1 - \mu_i$$

$$h_i = T_{amb_i}(\alpha_i) \quad \text{where } T_{amb_i} = \text{Ambient Temp. surrounding component } i$$

$$K_{cav} = \text{Heat Transfer Coefficient for the Pump Cavity}$$

$$Q_{press} = \text{Pressure Energy} = (N)(\Delta P)(\dot{M})$$

where N = coefficient = 0.02475

ΔP = Differential pressure = (2850 to 2950) psi

\dot{M} = Pump Delivery in gpm.

$$Q_{motors} = \text{Heat input into Pumps 1 \& 2 by Motors 1 \& 2}$$

$$\Delta T_{val} = (0.00293)(\Delta P) / C_p$$

where ΔP = Pressure Drop (psi) across valve

AD 1546 C

CALCULATION OF THE HEAT TRANSFER COEFFICIENT OF THE PUMP CAVITY

According to equation 12 in this document, the heat balance for the pump cavity can be represented as

$$Q_n + T_m C_p M_m = T_{co} C_p M_{co} + T_{out} C_p M_{out} + K_{cav} (T_{cav} - T_{amb}) + Q_p$$

where all the terms have been defined in the document.

$$\therefore K_{cav} = \{Q_n + T_m C_p M_m - T_{co} C_p M_{co} - T_{out} C_p M_{out} - Q_p\} / (T_{cav} - T_{amb})$$

From Test Data,

$$Q_n = 356 \text{ BTU/min} ; Q_m = 274 \text{ BTU/min} ; \therefore Q_n = 650 \text{ BTU/min}$$

$$T_m = 151^\circ \text{F}$$

$$C_p = 0.4$$

$$M_m = (6.22)(8.45) \text{ lb/min}$$

$$M_{co} = (3.85)(8.45) \text{ lb/min}$$

$$M_{out} = (2.37)(8.45) \text{ lb/min}$$

$$T_{co} = 177^\circ \text{F}$$

$$T_{out} = 166^\circ \text{F}$$

$$T_{cav} = 141^\circ \text{F}$$

$$T_{amb} = 58^\circ \text{F}$$

$$Q_p = 0.02475 \times 2950 \times 2.37 = 171 \text{ BTU/min}$$

$$\therefore K_{cav} = \{650 + (151 \times 6.22 - 177 \times 3.85 - 166 \times 2.37) 0.4 \times 8.45 - 171\} / (141 - 58)$$

$$= (650 - 627) \div 83$$

$$= 0.277 \text{ BTU/min/}^\circ \text{F}$$

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BOEING

NO. DC-25520TH

PAGE 61



LIST OF ACTIVE PAGES

SECTION	PAGE NUMBER	REV SYM	ADDED PAGES			SECTION	PAGE NUMBER	REV SYM	ADDED PAGES		
			PAGE NUMBER	REV SYM	PAGE NUMBER				PAGE NUMBER	REV SYM	PAGE NUMBER
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	3					52					
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	7					56					
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REV SYM

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PAGE 62



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REVISIONS

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REV SYM

