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TECHNICAL MEMORANDUM

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TITLE: EVALUATION OF HRL CONDENSING TEMPERATURE CONTROLS

ABSTRACT

A decision was made to develop a condensing temperature control so that it will be available in the event that such a control is found to be necessary at a later date. This report covers the results of an investigation which was conducted to evaluate three HRL loop controls including a condenser bypass control, a radiator bypass control, and a pump bypass control. The results of this analysis indicate that the condenser bypass system has a higher sensitivity to control flow. Also, a qualitative analysis indicates that the condenser bypass control has a slightly better dynamic response.

Therefore, it is recommended that the condenser bypass control be considered for further development.

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NOTE: This document is considered preliminary and is subject to revision as analysis progresses and additional data are acquired. The general reader may encounter internal reference not available to him.

EVALUATION OF HRL CONDENSING TEMPERATURE CONTROLS

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FIGURES

I. INTRODUCTION

Investigations have been conducted to determine the effects of system tolerances and component degradations on net output power and on condensing temperature. The results of these investigations have been reported in TM 340:64-1-226. The conclusions of these investigations have been that on the basis of the estimated tolerances and component degradations a system which is comprised of components having -1 design flow rates can provide the required net power output and a satisfactory NPSH at the mercury pump without the use of any additional controls. However, since there is insufficient data to substantiate the component performance estimates which have been made in these previous studies, it has been decided that a control shall be developed so that it will be available if required. Further, it has been decided that the system shall be designed to operate without the control until it is required.

This report covers a study which was made to evaluate several HRL loop temperature controls and to determine their effectiveness in controlling the mercury condensing temperature under adverse conditions resulting from system tolerances and degradations.

II. SUMMARY AND CONCLUSIONS

Three HRL controls were evaluated. These include a condenser bypass control, a radiator bypass control and a pump bypass control. The condenser bypass control was found to provide the highest sensitivity (produce a greater change in condensing temperature for a given change in control flow). A qualitative analysis was also made to evaluate the dynamic response of these controls. The results of this analysis indicates that the condenser bypass control has a slight advantage with respect to fast response due to system perturbations causing changes in condensing temperature.

The characteristics of the condenser bypass have been evaluated for conditions in which the most adverse accumulation of tolerances and degradations yield a high condensing temperature and a low condensing temperature. The results indicate that the maximum excursion of condensing temperatures can be reduced from 87°F with no controls to approximately 50°F with a condenser bypass control. The minimum mercury pump NPSH can be increased from .925 ft without controls to approximately 2 ft. The limiting control valve gain needs to be evaluated and specified on the basis of the control dynamic stability.

III. DISCUSSION

A. SENSITIVITY OF HRL LOOP FLOW CONTROLS

Assuming that a condensing temperature control will be used to minimize the excursion of condensing temperature due to system tolerances and component degradations, investigations were conducted to determine the most effective method for controlling the condensing temperature. A condenser mercury inventory control was investigated and the results of this investigation are reported in TM 340:64-1-228. The controls investigated in this study are those in which the flow through various parts of the HRL loop is modulated by means of a control valve. The three systems were analyzed to determine their sensitivity to control flow; these included 1) a condenser bypass control, 2) a radiator bypass control and 3) a pump or system bypass control. The analysis of these controls is presented in Appendix A.

1. Condenser Bypass Control

The condensing temperature control is depicted in Figure 1. Control of the condensing temperature is achieved indirectly by the condenser bypass control valve which senses the NaK temperature leaving the condenser. The valve modulates the condenser bypass flow, which in turn controls the flow through the condenser. This causes a change in the temperature drop across the condenser and causes a corresponding change in the NaK outlet temperature and in the mercury condensing temperature. The net pressure drop across the pump varies slightly when the control valve is modulated. This causes only a slight change in the flow through the radiator. An analysis was made to evaluate the flow and temperature characteristics of the HRL loop as a function of control flow.

The conditions for evaluating this control, and the other two controls as well, were assumed to be as follows:

a. Operating under sun conditions at the beginning of 10,000 hours

b. The mercury interface was at the nominal position and the temperature difference between the incoming mercury and the outgoing NaK was 15°F

The flow characteristics for the condenser bypass control are depicted in Figure 2. It should be noted that the condenser flow varies significantly as a function of the control flow whereas the flow through the radiator and pump varies only slightly. For a given heat rejection rate the radiator discharge temperature varies only slightly with changes in control flow, approximately 2.4°F/lb/sec.

The condenser NaK outlet temperature and condensing temperature variation as a function of control flow are depicted in Figure 3. The average change of temperature with respect to control flow for the HRL loop with this bypass control is approximately 15.1 °F/lb/sec.

2. Radiator Bypass Control

A similar analysis was made on a radiator bypass control which is depicted in Figure 4. As in the condenser bypass control the valve modulates the control flow which in turn causes changes in the condenser and radiator flows. The flow characteristics as a function of control flow are depicted in Figure 5. It should be noted that both the condenser flow and the radiator flow vary significantly with changes in control flow. To increase the condenser NaK outlet temperature the control flow is increased. This causes a decrease in radiator flow which increases the temperature drop across the radiator and causes a lower radiator outlet temperature. The net effect is an increase in condenser inlet and outlet temperatures.

The temperature characteristics of the radiator bypass control are depicted in Figure 6. The average sensitivity for the controlled HRL loop is approximately 4.8 °F/lb/sec.

3. Pump Bypass Control

A pump bypass control, depicted in Figure 7, was investigated using a similar analysis. The HRL loop flow and temperature characteristics as a function of control flow are depicted in Figures 8 and 9. The HRL loop gain with respect to control flow is approximately 2.4°F/lb/sec.

B. COMPARISON OF THE HRL FLOW CONTROLS

1. Sensitivity

The results of these analyses indicate that the condenser bypass control has the highest sensitivity of the three bypass controls investigated. Therefore, a higher change in NaK outlet temperature is obtained for a given change in control flow. The higher sensitivity permits a smaller excursion of the condensing temperature with accumulations of component tolerances and degradations.

2. Dynamic Response

The relatively fast perturbations which affect the condensing temperature are as follows:

vehicle load changes with related speed changes
sun-shade perturbations
mercury inventory shifts

The dynamic response of all three control systems is approximately the same for the first two perturbations listed above since they involve the radiator and its long time constant. The condenser bypass control provides a better response to the last perturbation listed above because under this situation the response of this control system is somewhat independent of the radiator response. The other two controls will have a significant feed back effect from the radiator following a mercury inventory shift. Therefore, the condenser bypass control provides a slight advantage when considering dynamic response to system perturbations.

The condenser bypass control offers more advantages than the other two controls, hence it is the preferred method for controlling the condensing temperature if such a control is found to be necessary.

C. THE EFFECT OF BYPASS FLOW ON CONDENSER NaK OUTLET TEMPERATURE

Additional analyses were made to evaluate the effect of bypass flow under conditions associated with the most unfavorable accumulation of tolerances and degradations tending to cause either a high condensing temperature or a low condensing temperature. The tolerance and degradation effects have been described in TM 340:64-1-226.

1. Nominal Operating Conditions

The nominal operating parameters for the HRL control loop at the beginning of 10,000 hr. have been tentatively selected as follows:

Control flow = 0
Condensing temperature = 680°F
Condenser NaK outlet temperature = 665°F
NaK flow = 41,600 lb/hr
Mercury flow = 11,200 lb/hr
Operating in the sun

The flow and temperature characteristics for the HRL controlled loop have been evaluated at the nominal "in sun" operating conditions. The characteristics are shown in Figures 10 and 11.

2. Maximum Condensing Temperature Conditions

The maximum condensing temperature occurs at the beginning of the mission with the most unfavorable accumulation of tolerances which are as follows:

Emissivity	.825
Heat Rejection	426 kw
HRL flow	3% Low
Turbine Speed	1% High
Mercury Flow	1% High
Operating in the sun	

The HRL flow and temperature characteristics as a function of control flow are also depicted in Figures 10 and 11. It should be noted that the condenser NaK outlet temperature increases as the control flow is increased and that this characteristic curve is very nearly parallel to the curve at nominal rated conditions. At zero control flow the condensing temperature is approximately 704°F. This corresponds to the uncontrolled system at the beginning of 10,000 with -1 component characteristics. The net power output under this condition has been calculated to be 42.6 kw which provides a surplus of 7.6 kw hence, condensing temperature control is not really required for this situation.

A high condensing temperature can also occur at the end of 10,000 hours with the most adverse accumulation of tolerances and degradations. The temperature under these conditions is not quite as high as indicated in the preceding discussion. The TAA power output is a minimum under these conditions; however, there is still a 1 kw surplus margin.

3. Minimum Condensing Temperature Conditions

The minimum temperature conditions occur near the end of the 10,000 hour mission with the most unfavorable accumulation of parameter tolerances and component degradations which are indicated in the following:

Emissivity	.85
Heat Rejection	381 kw
HRL flow	2% Low
Hg flow	8.5% Low
Turbine Speed	1% Low
Operating in the shade	
Cond. Temp - NaK outlet	Δ T 5°F

The flow and temperature characteristics at these conditions are depicted in Figures 10 and 11.

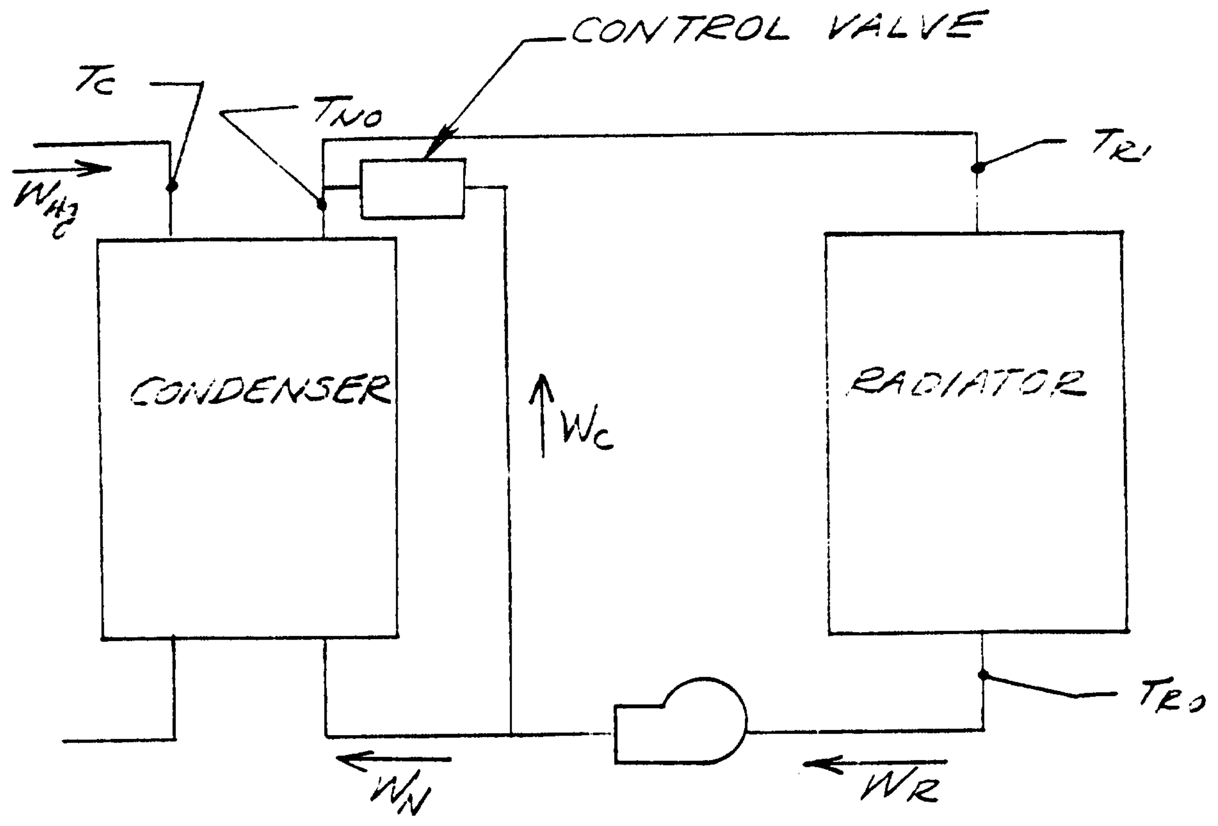
As indicated in the two previous cases, the condensing temperature can be increased by increasing the bypass control flow.

D. APPLICATION OF CONDENSER BYPASS CONTROL VALVE

The application of the control valve utilizes the characteristics of the HRL loop with respect to condenser bypass flowrate. The valve which is a thermostatic type valve and senses condenser NaK outlet temperature will provide a flow which is nearly proportional to the temperature of condenser NaK outlet.

The valve temperature characteristics will provide for reduction in flow as the temperature increases. The valve set point (no control flow) and control gain are determined by the maximum allowable condensing temperature for which sufficient vehicle output power is produced and by the minimum NPSH to be provided at the mercury pump. As indicated in a preceding discussion, at this time it appears that no bypass flow is required at maximum condensing temperature conditions, hence, the set point for which the control valve would permit no flow can be 680°F. The intersection of valve characteristic curve and the HRL control loop characteristic curves constitute the operating point under any other given conditions. The intersection of these curves can be adjusted by adjusting the set point and gain of the control valve. For example, if a valve gain of -.2 #/sec/°F is utilized, the condensing temperature will be approximately 658°F instead of 623°F with no control at the end of 10,000 hours with the worse accumulation of tolerances and component degradations. The NPSH with this control valve gain is approximately 2.15 ft of mercury as compared to .925 ft without control. If the absolute value of the control gain is increased the minimum condensing temperature and NPSH can be increased. The extent to which this gain can be increased is limited by mechanical considerations of the valve and by the dynamic stability of HRL loop and valve. The mechanical considerations do not, at this time, seem to present any serious limitation. The dynamic stability limitation on control valve gain will be evaluated in the near future.

The temperature characteristic curves of the condenser as shown on Figure 11 can be shifted up or down, if so desired, by changing the radiator size. The curves can also be shifted, although less effectively, by adjusting the nominal third loop flowrate.



CONDENSER BYPASS CONTROL

FIG. 1

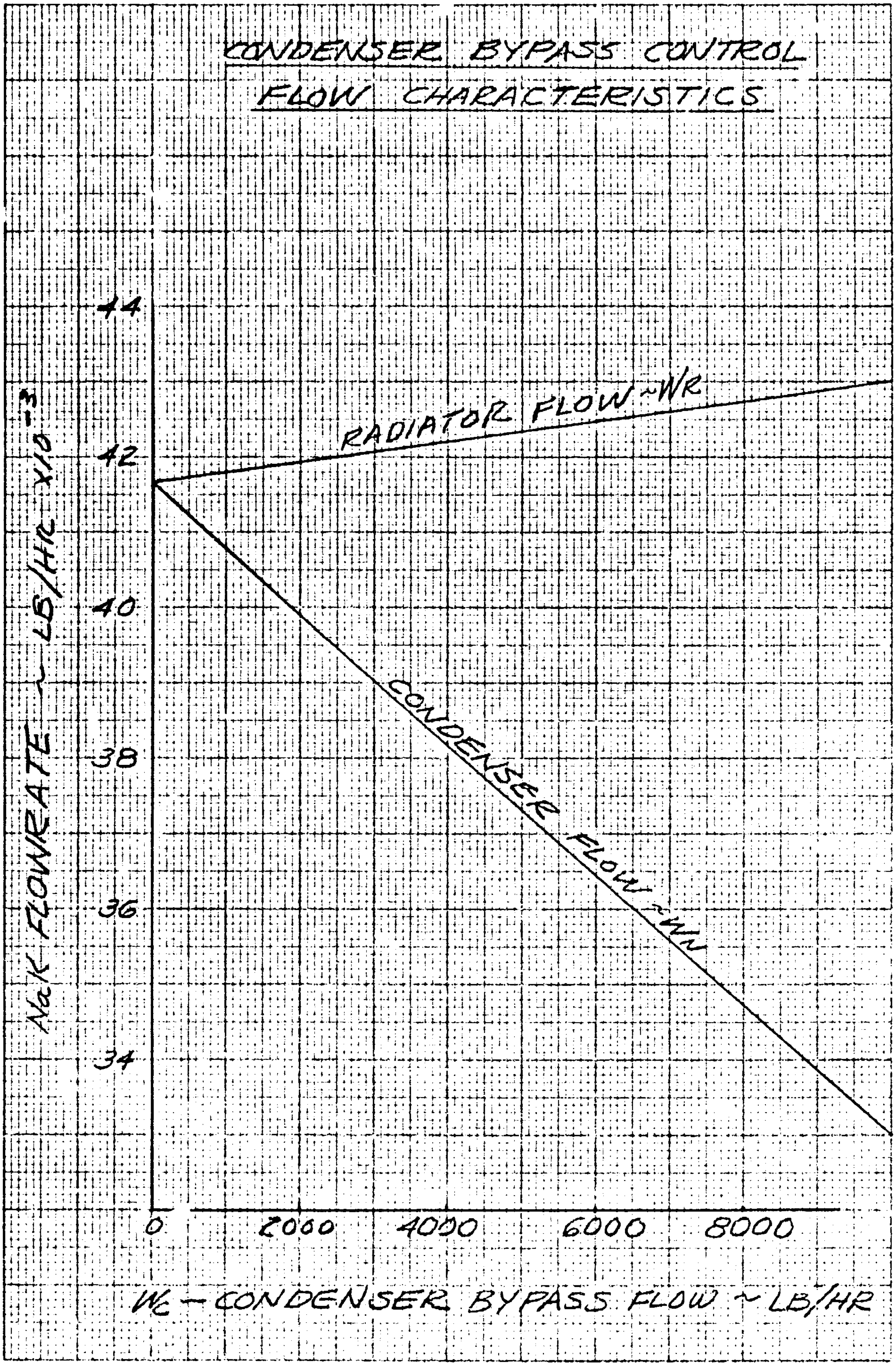

CONDENSER BYPASS CONTROL
FLOW CHARACTERISTICS
NaK FLOWRATE ~ LB/HR x10^-3
44
42
40
38
36
34
RADIATOR FLOW ~ WR
CONDENSER FLOW ~ WN
0
2000
4000
6000
8000
Wc — CONDENSER BYPASS FLOW ~ LB/HR

FIG. 2

CONDENSER BYPASS CONTROL
TEMPERATURE CHARACTERISTICS

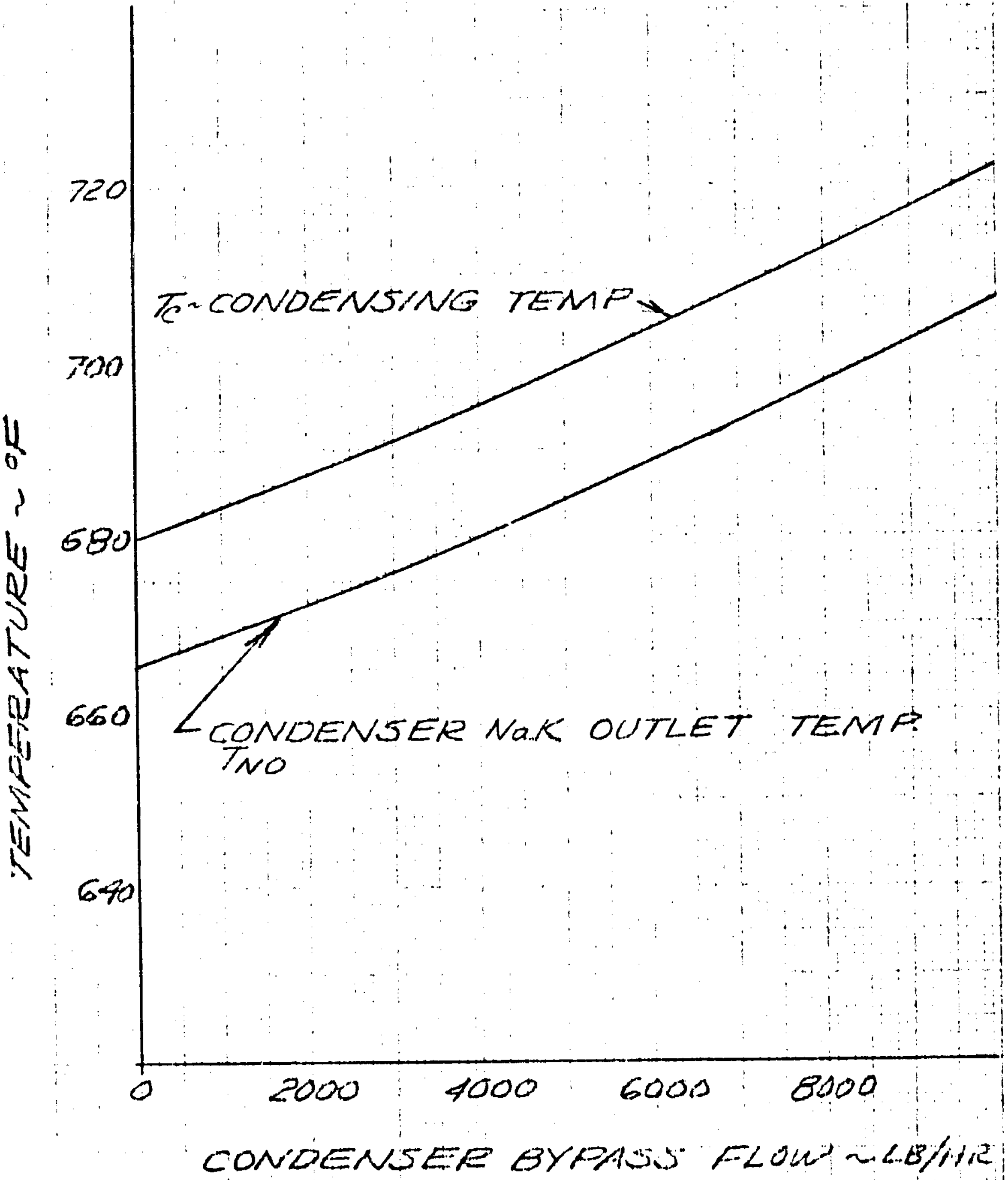
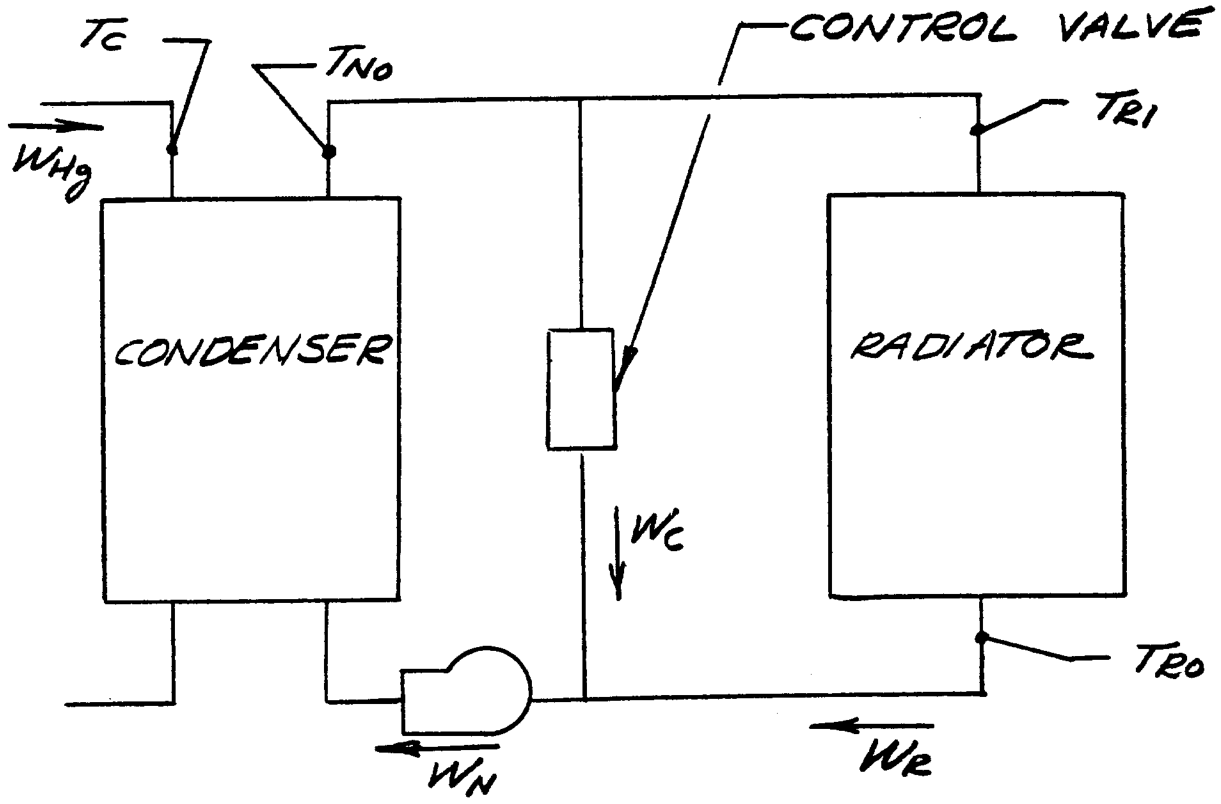


FIG. 3



RADIATOR BYPASS CONTROL

FIG. 4

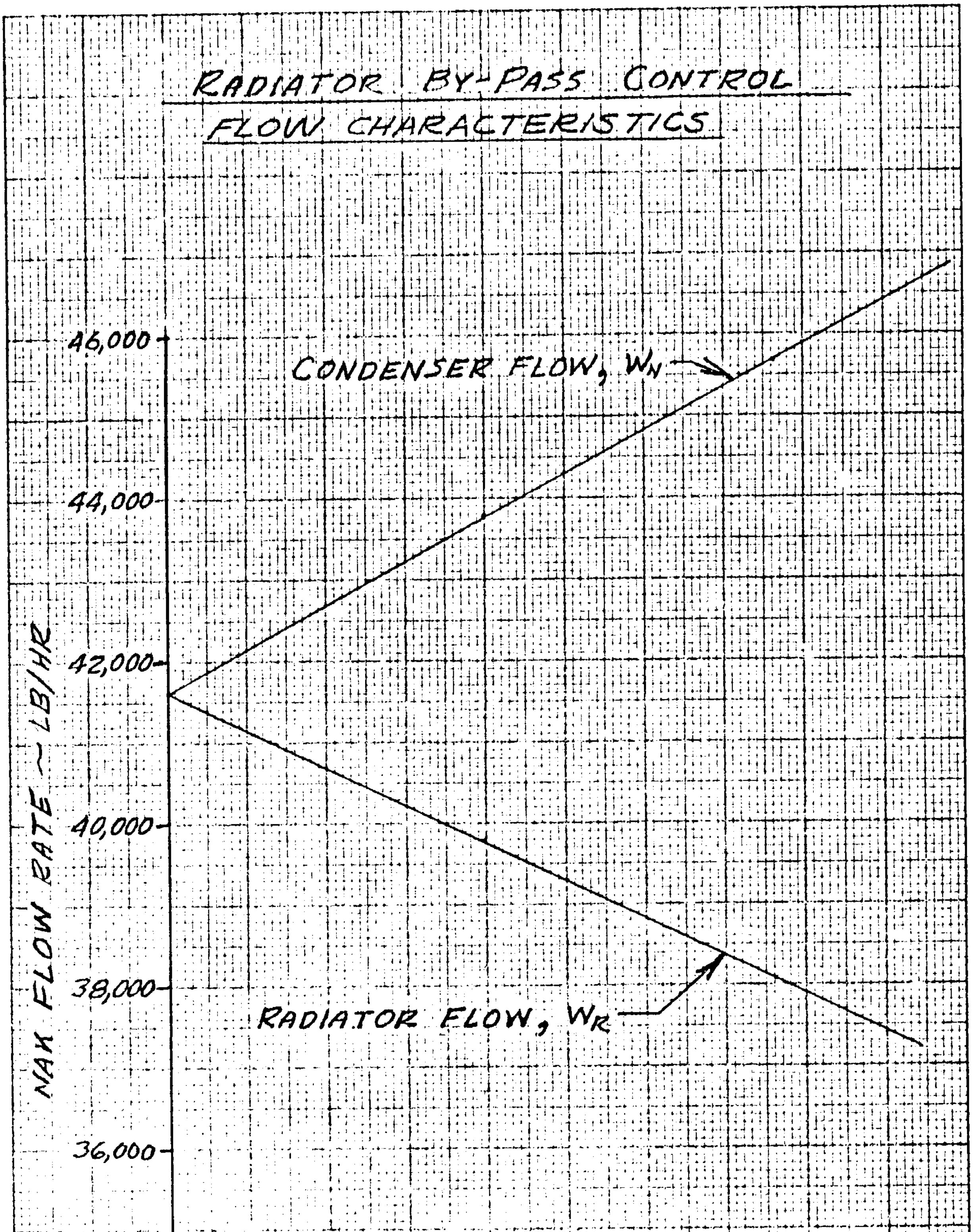
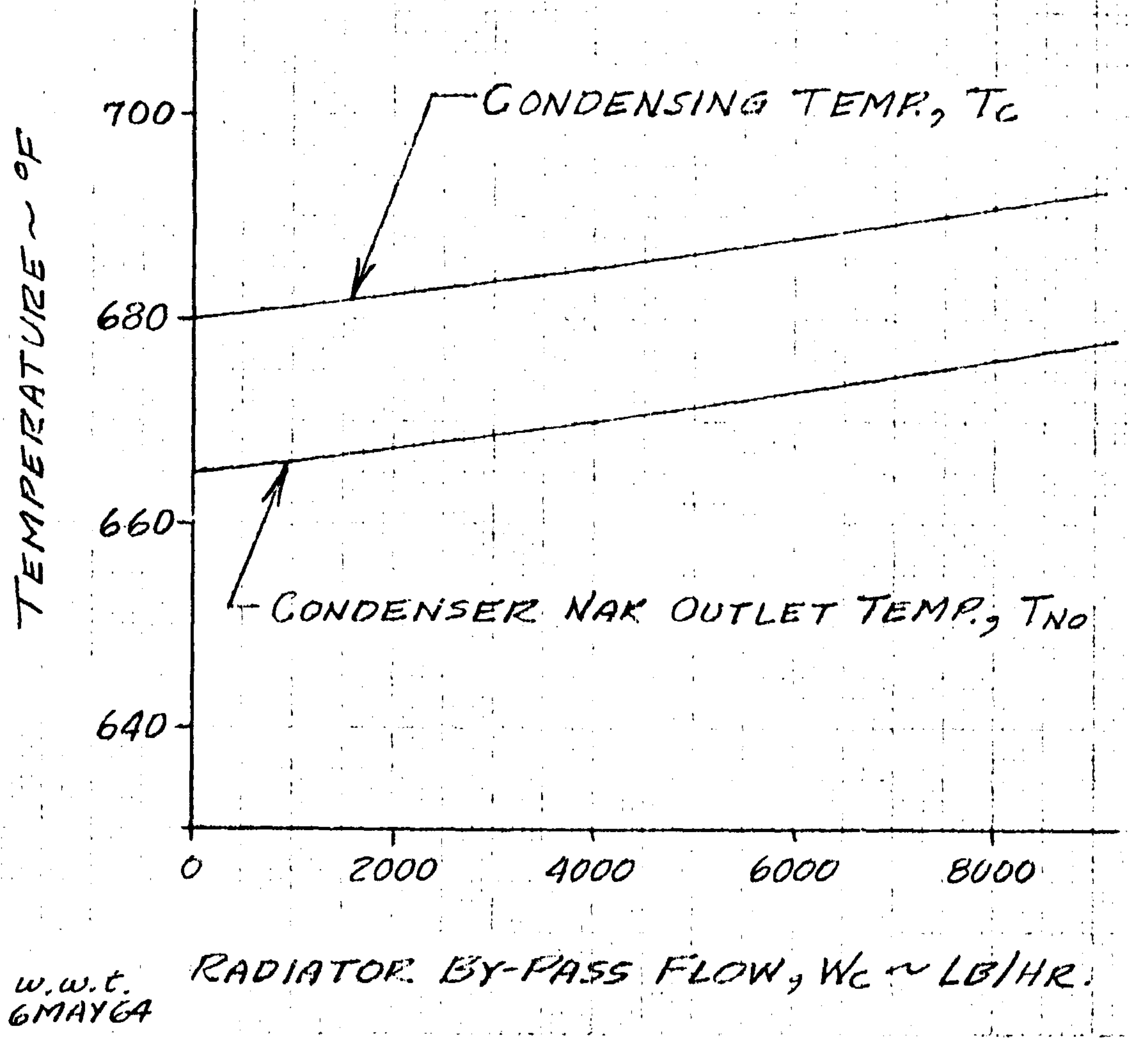

RADIATOR BY-PASS CONTROL
FLOW CHARACTERISTICS
46,000
44,000
42,000
40,000
38,000
36,000
NAK FLOW RATE ~ LB/HR
CONDENSER FLOW, W_N
RADIATOR FLOW, W_R
0
2000
4000
6000
8000
RADIATOR BY-PASS FLOW, W_C ~ LB/HR
w.w.t.
6MAY64

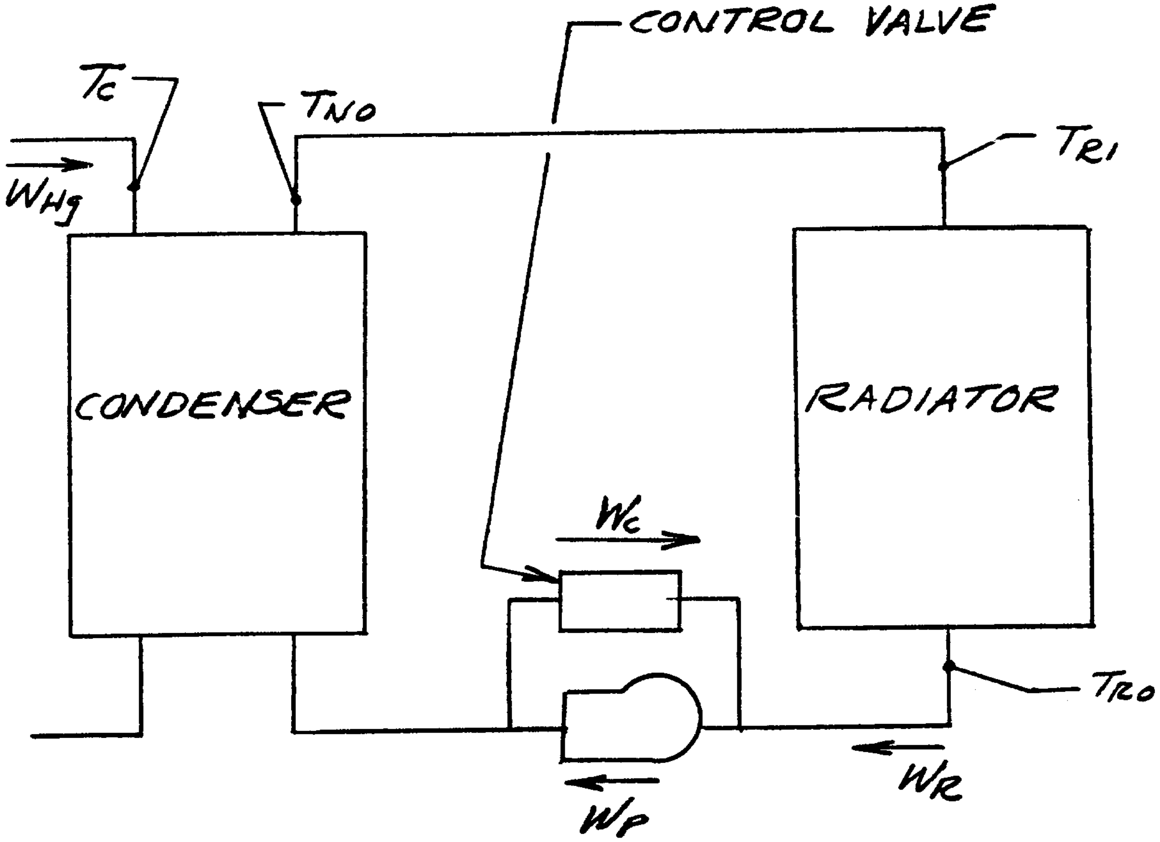
FIG. 5

RADIATOR BY-PASS CONTROL
TEMPERATURE CHARACTERISTICS



w.w.t.
6MAY64

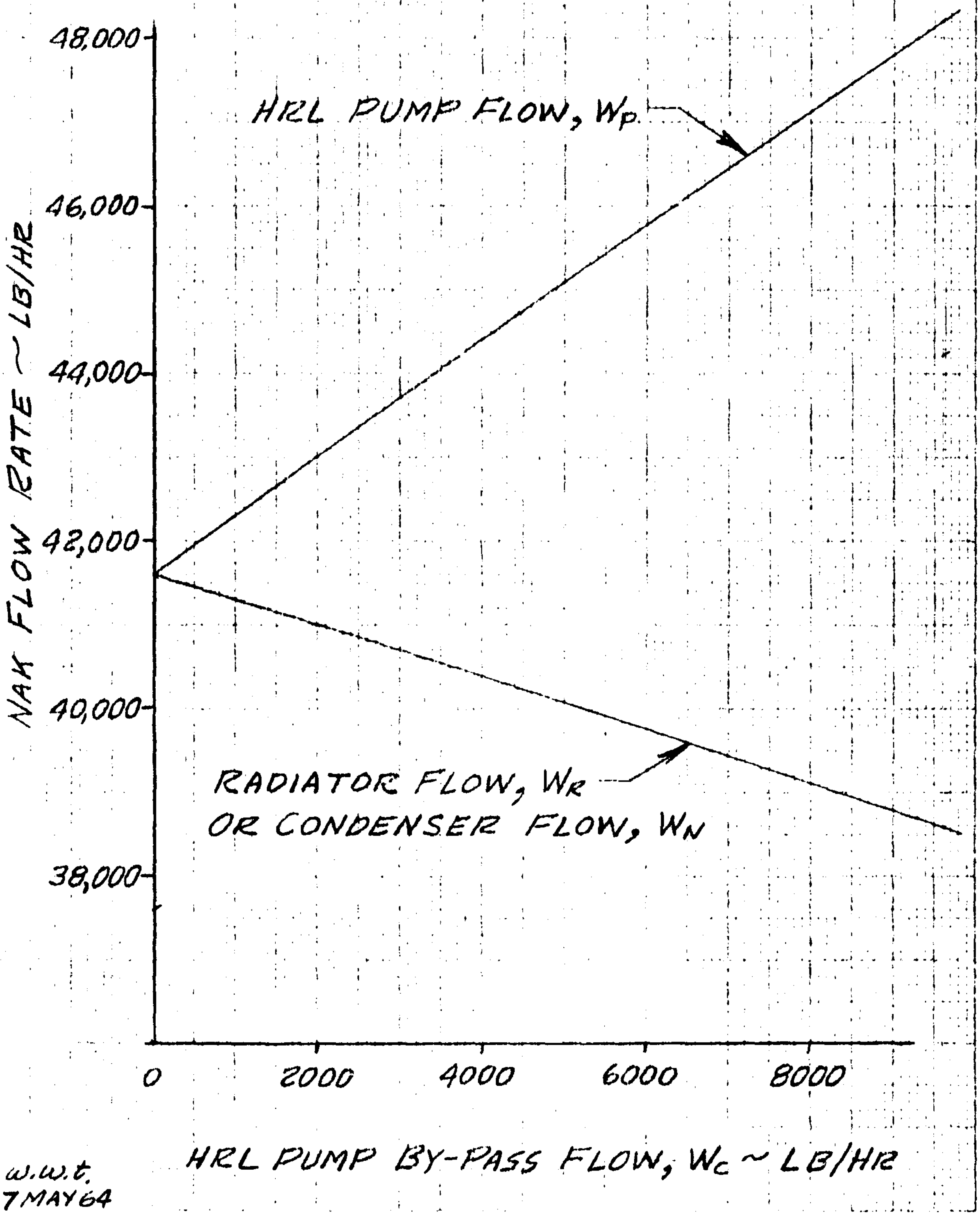
FIG. 6



PUMP BYPASS CONTROL

FIG 7

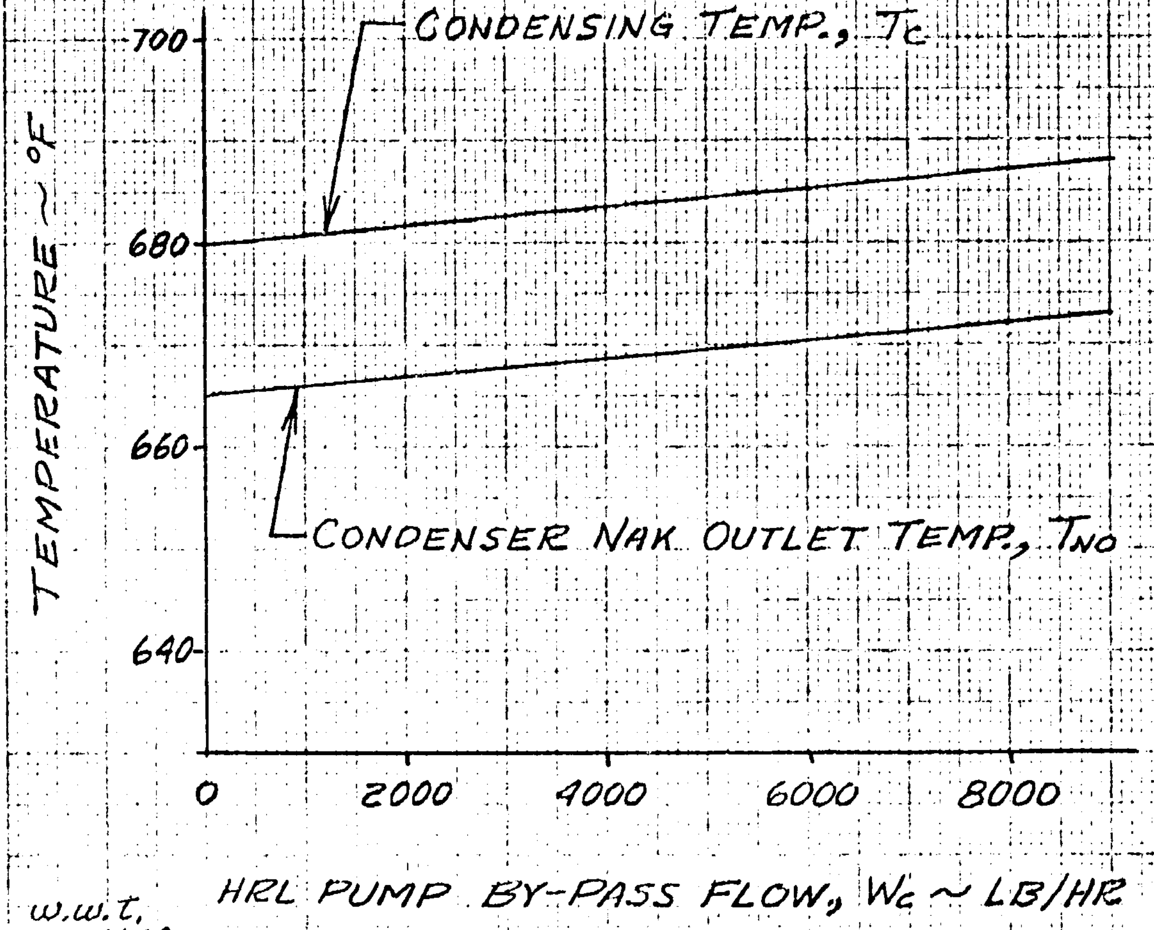
PUMP BY-PASS CONTROL
FLOW CHARACTERISTICS



w.w.t.
7 MAY 64

FIG. 8

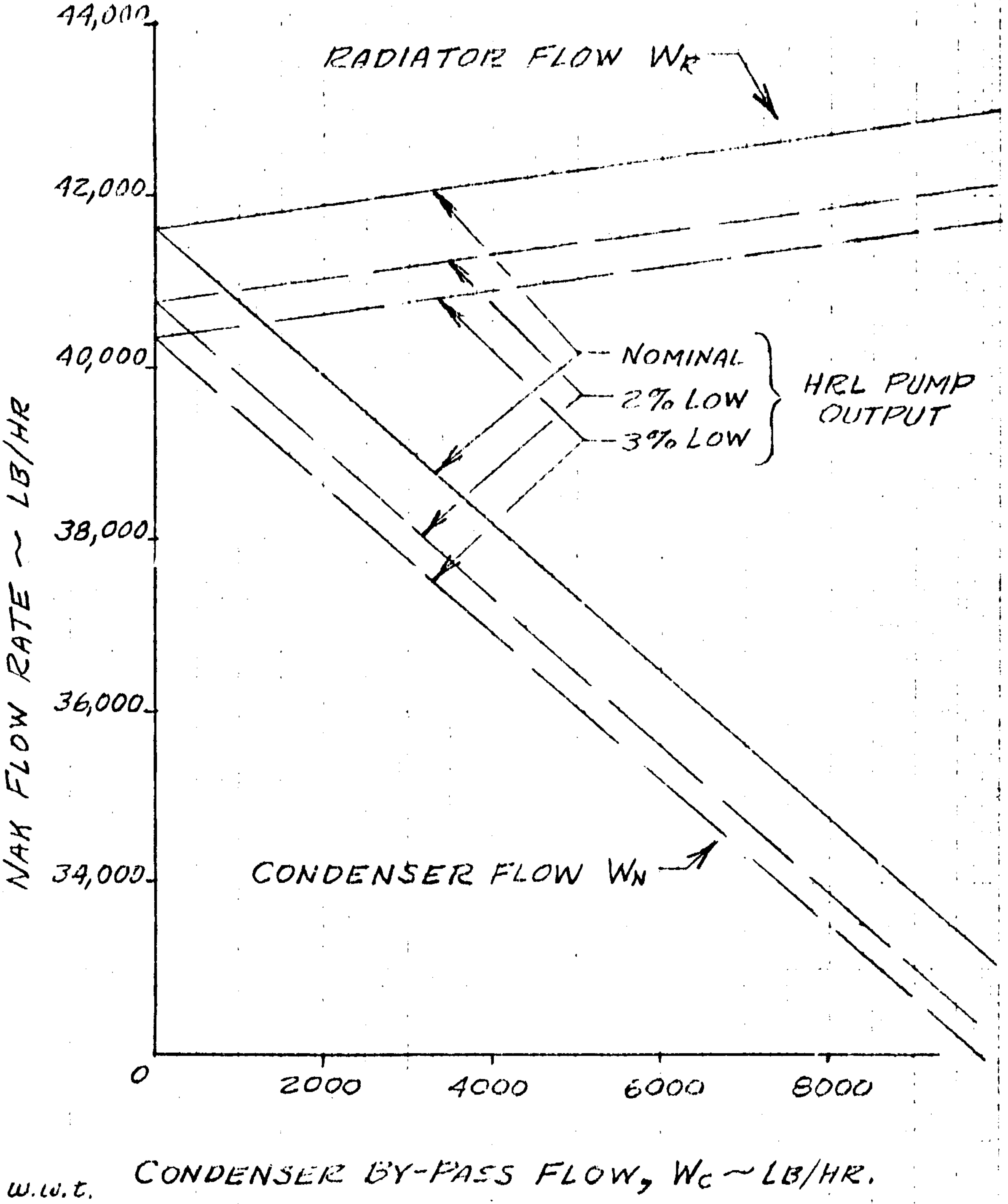
PUMP BY-PASS CONTROL
TEMPERATURE CHARACTERISTICS



w.w.t.
7MAY64

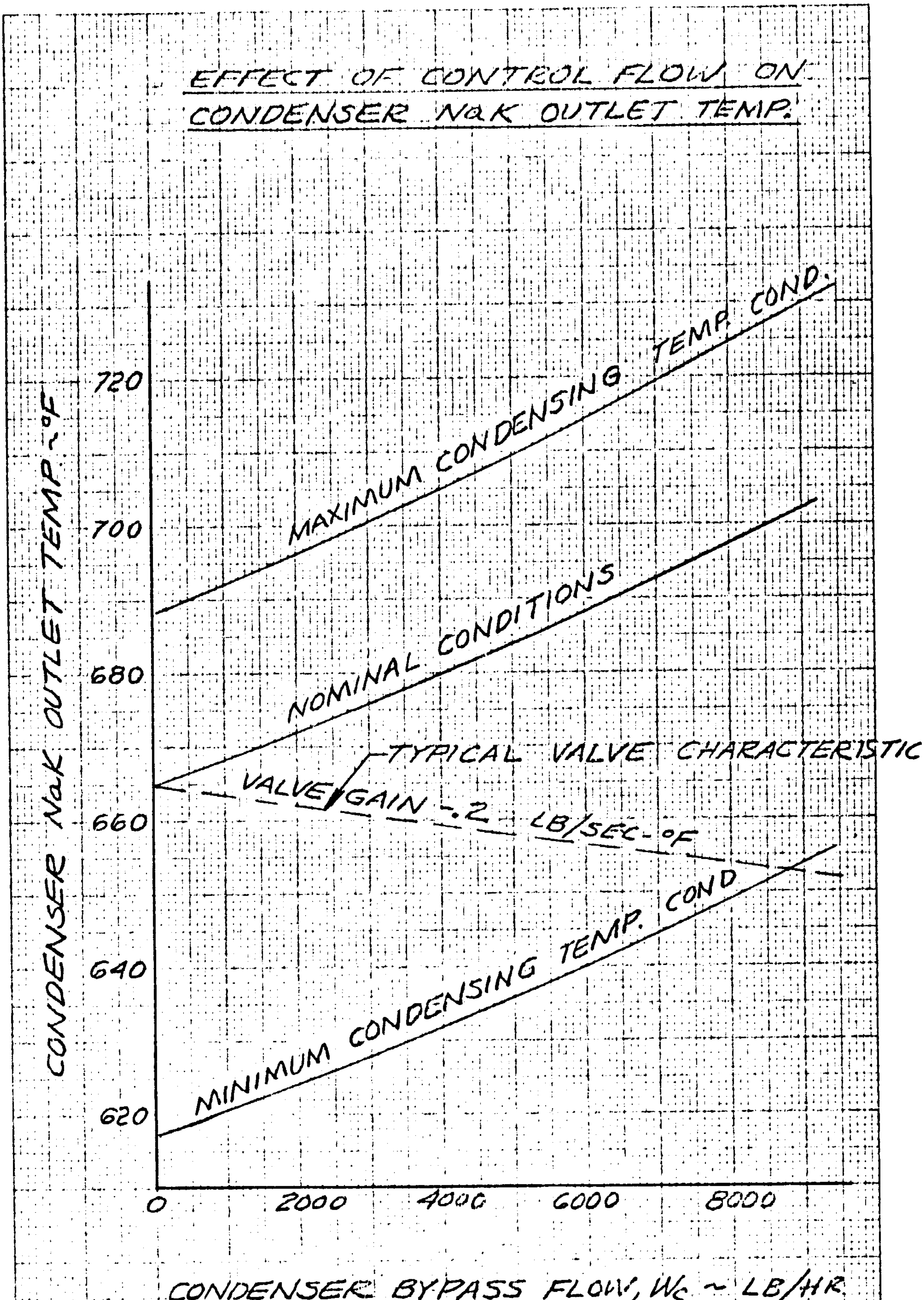
FIG 9

HRL CONDENSER BYPASS FLOW CHARACTERISTICS



w.w.t.
5-MAY64

FIG. 10



EFFECT OF CONTROL FLOW ON CONDENSER NaK OUTLET TEMP.

FIG. 11

01-071-002

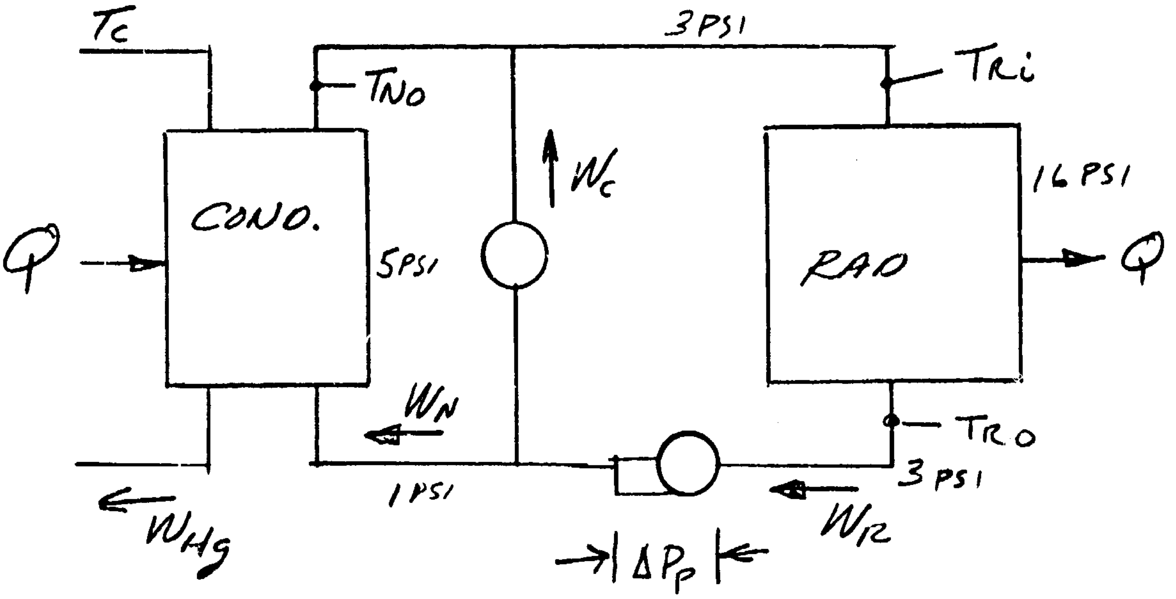
QUADRILLE WORK SHEET

AEROJET GENERAL **AEROJET-GENERAL CORPORATION**
AZUSA, CALIFORNIA

PAGE ____ OF ____ PAGES
DATE 5/5/64
SUBJECT APPENDIX A BY E7P & W.WT. WORK ORDER ____

HRL CONDENSING TEMPERATURE CONTROLS

I CONDENSER BYPASS CONTROL



NOMINAL CONDITIONS AT START OF MISSION

$W_{Hg} = 11,200$ LB/HR $Q = 411$ KW

$W_C = 0$, $W_N = 41,600$ LB/HR, $W_R = 41,600$ LB/HR

$T_{NC} = 665\,°F$ $T_C = 680\,°F$

$\Delta P_p = 28$ PSIA

NOMINAL PRESSURE DROPS IN VARIOUS PARTS OF THE HRL LOOP ARE INDICATED IN THE FIGURE ABOVE

PAGE_____ OF_____ PAGES

DATE_____

SUBJECT_____ BY_____ WORK ORDER_____

A. EXTRAPOLATE HRL PUMP CURVE TO NEW DESIGN POINT:

$\Delta P = 28$ PSI
$W = 41,600$ #/HR.
$\rho = 50.8$ #/FT^3
$t = 500$ °F.

$$P_D = \frac{50.8}{144} H_D = .3528\ H_D$$

$$W_D = \frac{60 \times 50.8}{144} Q_D = 407.5\ Q_D$$

$$H_D = \beta^2 H_0 \qquad \beta = \frac{Q}{Q_0} = \frac{102}{117.7} = .8666 \quad (.751)$$

$$Q_D = \beta Q_0 \qquad \beta^2 = \frac{79.4}{105.6} = .7519$$

$$\therefore P_D = .2653\ H_0$$

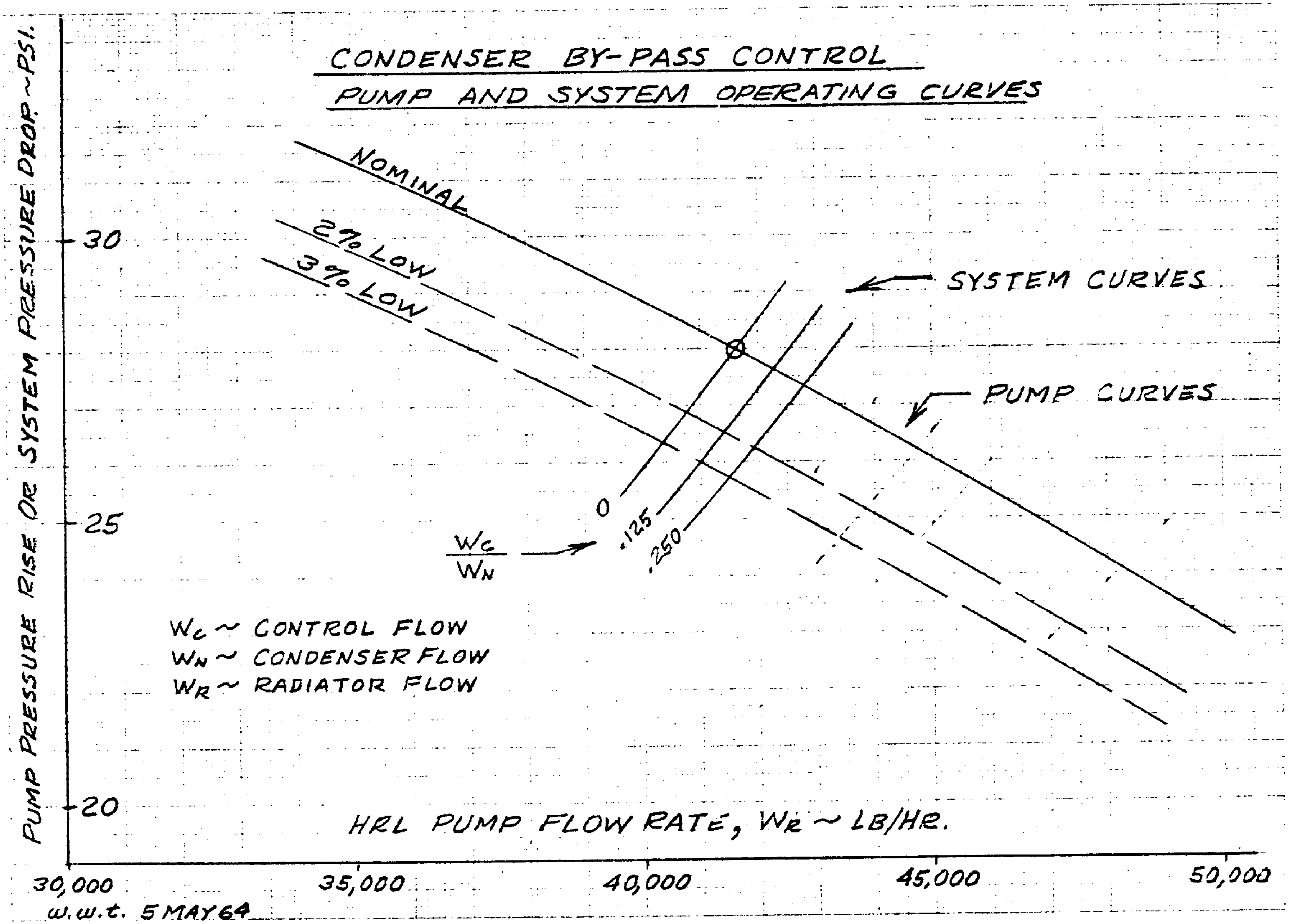
$$W_D = 353.1\ Q_0$$

AFTER 10,000 HRS
$W'_D = .95\ W_D$
$P'_D = .9025\ P_D$

Q_0 GPM	H_0 FT	W_D #/HR	P_D PSI	W'_D	P'_D
0	143	0	37.94		
25	142.5	8828	37.81		
50	138.8	17655	36.82		
75	130.3	26483	34.57	25159	31.20
100	117.5	35351	31.17	33583	28.13
125	100.4	44138	26.64	41931	24.04
140	88.0	49434	23.35	46962	21.07
87.5	124.4	30896	33.00	29351	29.79
112.5	109.5	39723	29.05	37738	26.22

CONDENSER BY-PASS CONTROL

PUMP AND SYSTEM OPERATING CURVES

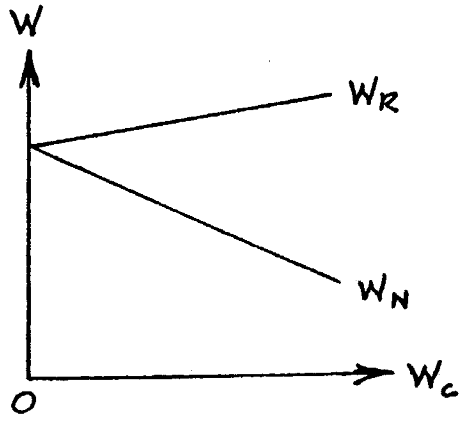


W_C ~ CONTROL FLOW
W_N ~ CONDENSER FLOW
W_R ~ RADIATOR FLOW

w.w.t. 5 MAY 64

B SYSTEM FLOW DISTRIBUTION AS A FUNCTION OF CONTROL FLOW (W_c)

PRESENT AS A CURVE AS SHOWN TO THE RIGHT →



W_R & W_N WILL BE OBTAINED FOR 3 DIFFERENT SETTINGS OF THE FLOW CONTROL VALVE:

1) CLOSED → $\frac{W_c}{W_N} = 0 = R_1$

2) APPROX. $\frac{1}{2}$ OPEN → $\frac{W_c}{W_N} = .125 = R_2$

3) APPROX. FULL OPEN → $\frac{W_c}{W_N} = .250 = R_3$

FOR EACH VALVE SETTING, PLOT A SYSTEM CURVE OF W_R VS ΔP_{SYS}

OBTAIN $\Delta P_{SYS} = k W_R^2$ AS FOLLOWS:

$$W_c = R \times W_N$$

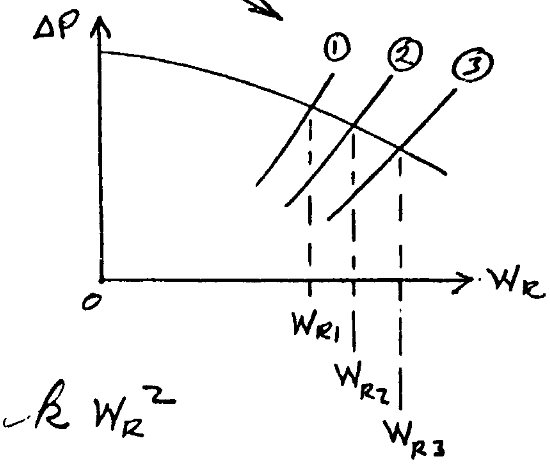
$$W'_N + W_c = W_R$$

$$W_N + R W_N = W_R$$

$$W_N = \left(\frac{1}{1+R}\right) \times W_R$$

$$\Delta P_{SYS} = a \times W_N^2 + b \times W_R^2$$

$$\Delta P_{SYS} = \frac{a}{(1+R)^2} \times W_R^2 + b \times W_R^2 = k W_R^2$$



THE INTERSECTION OF THESE SYSTEM CURVES WITH THE PUMP CURVE ESTABLISHES W_R FOR THE CORRESPONDING VALVE POSITION.

$$\left.\begin{array}{ll}\text{THEN} & W_N = \frac{W_R}{1+R} \\ \text{AND} & W_C = R \times W_N\end{array}\right\}\text{FOR EACH VALVE POSITION}$$

WITH W_C, W_N & W_R FOR FOR EACH OF 3 DIFFERENT VALVE POSITIONS, THE CURVE OF FLOW DISTRIBUTION AS A FUNCTION OF CONTROL FLOW IS MADE.

PRESSURE DROP ACROSS THE HRL PUMP

$$\Delta P_{SYS} = \Delta P_{C\&L} + \Delta P_{R\&L}$$

$$\Delta P_{SYS} = 6\left(\frac{W_N}{41,600}\right)^2 + 22\left(\frac{W_R}{41,600}\right)^2$$

$$= \left[.3468\ W_N^2 + 1.2717\ W_R^2\right] \times 10^{-8}$$

$$W_N = W_R - W_C$$

SET $\frac{W_C}{W_N} = .25$

THEN $W_N = .80\ W_R$

& $\Delta P_{SYS} = 1.4936 \times 10^{-8}\ W_R^2$

		W_R	ΔP_{SYS}	W_N	W_C
		43,000	27.62		
		42,500	26.98		
	% H-Q	41,000	25.11		
OPR. PT'S.	100	42790	27.34	34,232	855
	98	41900	26.25	33.520	838
	97	41490	25.73	33,192	829

SET $\frac{W_C}{W_N} = .125$

THEN $W_N = .88889\ W_R$

& $\Delta P_{SYS} = 1.5457 \times 10^{-8}\ W_R^2$

	43,000	28.58		
	42,000	27.27		
97	41,000	25.98	36,444	4555
98	41,400		36,800	4600
100	42,270		37,573	4697

WHEN $\frac{W_C}{W_N} = 0$

$W_N = W_R$

$\Delta P_{SYS} = 1.6185 \times 10^{-8}\ W_R^2$

	40,000	25.90		
	41,000	27.21		
100	41,600	28.00	41,600	0
98	40,750		40,750	
97	40,340		40,340	

B CONDENSER NAK OUTLET TEMP. (T_{NO}) AS A FUNCTION OF CONTROL FLOW (W_C)

1. NOMINAL CONDITIONS:

$W_N = W_R = 41{,}600$ #/HR
$W_C = 0$
$T_{NO} = 665$ °F
$T_{Ni} = 506$ °F
$Q = 411$ KW

RADIATOR CURVES ARE BASED UPON 110 TUBES. USING THESE CURVES WITH THE ABOVE TEMPS. GIVES 351 KW. NO. OF TUBES FOR THE ABOVE CONDITIONS SHOULD BE:

$$N_T = \frac{411}{351} \times 110 = 128.8 \text{ TUBES}$$

$$\% \text{ FLOW} = \frac{\text{NEW FLOW/TUBE}}{\text{CURVE FLOW/TUBE}} = \frac{41{,}600 \times 110}{\underset{4.12\ldots \times 10^{6}}{32{,}000 \times 128.8}} \times 100\% = 111\%$$

AT NOM COND'S.

$$\text{OR } W'\% = 2.669 \times 10^{-3}\, W$$

$$\text{AND } Q' = \frac{110}{128.8}\, Q = .8540\, Q$$

NOMINAL CONDITIONS WITH VARYING CONTROL FLOW

$Q = 411$ KW
$\epsilon = .85$
$Q' = 411 \times .854 = 351$ KW
H-Q CURVE NOMINAL

W_C	W_R	$W'_R\%$	W_N	T_{RO}	$\Delta T = \frac{661.7 \times 10^4}{W_N}$	T_{NO}
0	41,600	111.0	41,600	506	159.0	665
2000			39,900	506.3	165.8	672.1
4000	42,150	112.5	38,190	506.6	173.3	679.9
6000			36,460	506.9	181.5	688.4
8000	42,700	114.0	34,750	507.2	190.4	697.6

01-079-002

QUADRILLE WORK SHEET

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE______ OF______ PAGES

DATE______

SUBJECT______ BY______ WORK ORDER______

2. HIGH CONDENSING TEMPERATURE CONDITIONS

STARTING MISSION WITH H-Q CURVE 3% LOW, SUN. OPR.

$Q = 426\ KW$ $\qquad \epsilon = .825$

$Q' = 426 \times .854 = 363.8\ KW$ $\qquad \Delta N_T = -1\%$

W_C	W_R	$W_R'\%$	W_N	T_{RO}	$\Delta T = \frac{685.8 \times 10^4}{W_N}$	T_{NO}
0	40,340	107.7	40,340	518.5	170.0	688.5
2000	40,620	108.4	38,620	518.9	177.6	696.5
4000	40,900	109.2	36,920	519.3	185.8	705.1
6000	41,160	109.9	35,200	519.7	194.8	714.5
8000	41,450	110.6	33,500	520.1	204.7	724.8

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3 LOW CONDENSING TEMPERATURE CONDITIONS

AFTER 10,000 HRS. WITH H-Q CURVE 2% LOW, SHADE OPR.

$Q = 381\ KW$ $\qquad \epsilon = .85$

$Q' = 381 \times .854 = 325.4\ KW$ $\qquad \Delta N_T = +1\%$

W_C	W_R	$W_R'\%$	W_N	T_{RO}	$\Delta T = \frac{613.4 \times 10^4}{W_N}$	T_{NO}
0	40750	108.8	40750	467	150.5	617.5
2000	41030	109.5	39070	467.4	157.2	624.6
4000	41310	110.3	37330	467.8	164.3	632.1
6000	41580	111.0	35600	468.2	172.3	640.5
8000	41850	111.7	33890	468.6	181.0	649.6

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QUADRILLE WORK SHEET

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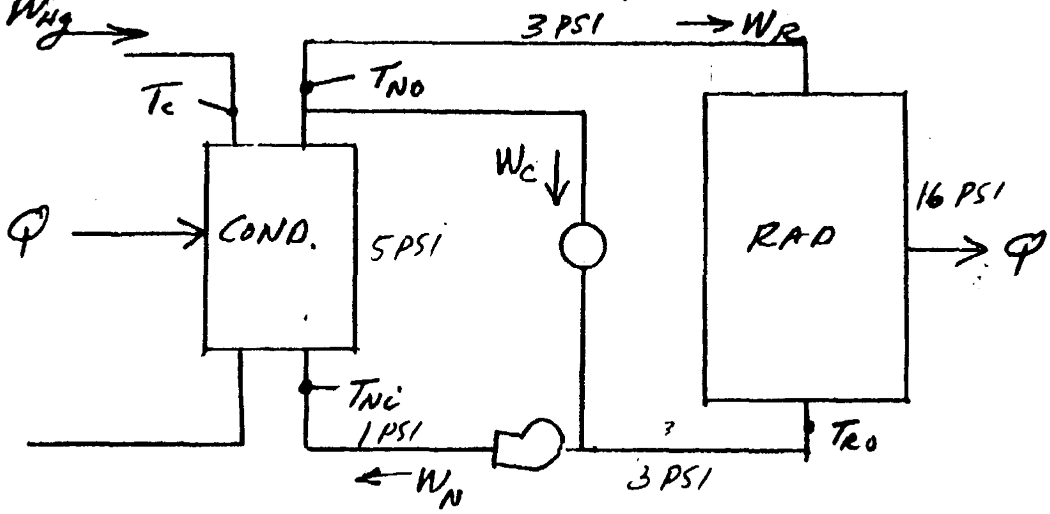
II EVALUATION OF RADIATOR BYPASS - CONDENSING TEMPERATURE (PRESS) CONTROL

ASSUME THE FOLLOWING NOMINAL CONDITIONS AT START OF MISSION



$C_p = .212$

NOMINAL - START (R GIEMER)

$W_{Hg} = 11{,}200$ #/HR

$W_N = 41{,}600$ #/HR

$W_c = 0$

$W_R = 41{,}600$ #/HR

$T_{NO} = 665$

$T_c = 680°F$

$T_{RO} = 485°F$

$\varphi = 411$ KW =

$$\Delta T_{NC} = \frac{411 \times 3413}{.212 \times 41{,}600} = 159°F$$

$T_{NI} = 506°F$

$\Delta P_{R+L} = 22$ PSI

$\Delta P_{COND+L} = 6$ PSI

$\Delta P_{PUMP} = 28$ PSI

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A SYSTEM FLOW DISTRIBUTION AS A FUNCTION OF CONTROL FLOW

$$\Delta P_{SYS} = \Delta P_{C\&L} + \Delta P_{R\&L}$$

$$\Delta P_{SYS} = 6\left(\frac{W_N}{41,600}\right)^2 + 22\left(\frac{W_R}{41,600}\right)^2$$

$$= \left[.3468\, W_N^2 + 1.2717\, W_R^2\right] \times 10^{-8}$$

$$W_R = W_N - W_C$$

SET $\frac{W_C}{W_R} = .2$

THEN $W_R = \frac{1}{1.2} W_N$

& $\Delta P_{SYS} = 1.2299 \times 10^{-8} W_N^2$

	W_N	ΔP_{SYS}	W_R	W_C
	42,000	21.69		
	45,000	24.91		
	46,000	26.02		
OPR. PT →	45,680		38,067	7613

SET $\frac{W_C}{W_R} = .1$

THEN $W_R = \frac{1}{1.1} W_N$

& $\Delta P_{SYS} = 1.3978 \times 10^{-8} W_N^2$

	W_N	ΔP	W_R	W_C
	44,000	27.06		
	43,000	25.85		
OPR. PT.	43,770		39,791	3979

B CONDENSER NAK OUTLET TEMP. TNO AS A FUNCTION OF RADIATOR BY-PASS FLOW, Wc.

THE CONSTANTS FOR USE OF THE 110 TUBE RADIATOR CURVES ARE THE SAME AS DEVELOPED FOR THE CONDENSER BY-PASS ANALYSIS, i.e:

$$W_R'\% = 2.669\times10^{-3}\,W_R$$

$$Q' = 0.854\,Q$$

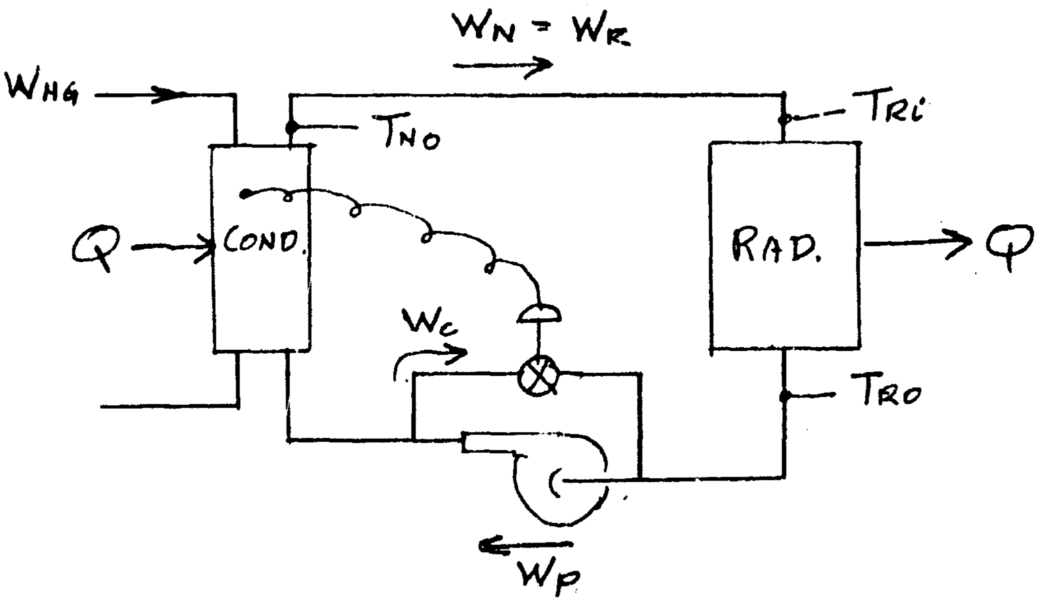
THESE CONSTANTS CONVERT THE ACTUAL VALUES TO THE PRIMED VALUES FOR USE ON THE 110 TUBE CURVES.

NOMINAL CONDITIONS WITH VARYING BY-PASS FLOW

$Q = 411$ KW $\quad \epsilon = .85$ SUN OPERATION
$Q' = 351$ KW $\quad$ H-Q CURVE NOMINAL

W_C	W_R	W_R'	$T_{Ri} = T_{NO}$
0	41,600	111.0	665
4000	39,750	106.1	670
8000	37,900	101.2	676

III. EVALUATION OF PUMP BY-PASS CONDENSING TEMP. CONTROL



NOMINAL CONDITIONS

$Q = 411 \text{ KW}$

$W_C = 0$

$W_N = W_R = W_P = 41,600 \text{ \#/HR}$

$T_{NO} = T_{Ri} = 665°F$

$T_C = T_{NO} + 15$

$$\Delta T_{NC} = \frac{411 \times 3413}{.212 \times 41,600} = 159°F$$

$\Delta P_{REL} = 22 \text{ PSI}$

$\Delta P_{C\&L} = 6$

$\Delta P_{PUMP} = 28$

01-071-002

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A. SYSTEM FLOW DISTRIBUTION AS A FUNCTION OF PUMP BY-PASS FLOW (W_C)

$$\Delta P_{SYS} = 28\left(\frac{W_R}{41600}\right)^2$$

$$= 1.6180\ W_R^2$$

$$W_R = W_P + W_C$$

SET $\frac{W_C}{W_P} = .2$

THEN $W_R = .8\ W_P$

& $\Delta P_{SYS} = 1.0355\ W_P^2$

	W_P	ΔP_{SYS}	W_R	W_C
	48,000	23.86		
	49,000	24.86		
	47,000	22.87		
OPR. PT.	48,240		38,592	9648

SET $\frac{W_C}{W_P} = .1$

THEN $W_R = .9 W_P$

& $\Delta P_{SYS} = 1.3106\ W_P^2$

	W_P	ΔP_{SYS}	W_R	W_C
	45,000	26.54		
	44,000	25.37		
	43,000	24.23		
OPR. PT.	44,730		40,257	4473

B CONDENSER NaK OUTLET TEMP. T_{NO} AS A FUNCTION OF PUMP BY-PASS FLOW, W_C

THE CONSTANTS FOR USE OF THE 110 TUBE RADIATOR CURVES ARE THE SAME AS DEVELOPED FOR THE CONDENSER BY-PASS ANALYSIS; i.e.:

$$W_R'\% = 2.669 \times 10^{-3} W_R$$

$$Q' = 0.8540 Q$$

THESE CONSTANTS CONVERT THE ACTUAL VALUES TO THE PRIMED VALUES FOR USE ON THE 110 TUBE CURVES.

NOMINAL CONDITIONS WITH VARYING BY-PASS FLOW

$Q = 411$ KW $\qquad \epsilon = .85$ SUN OPERATION

$Q' = 351$ KW $\qquad$ H-Q CURVE NOMINAL

W_C	W_R	$W_R'\%$	$T_{Ri} = T_{NO}$
0	41,600	111.0	665
4000	40,400	107.8	668.5
8000	39,120	104.4	672