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COOLANT PRESSURE DROP AND ENTHALPY RISE EQUATIONS

FOR THE PHOEBUS-2 NOZZLE

APRIL 1967

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FOR THE PHOEBUS-2 NOZZLE

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I. INTRODUCTION

Closed-form equations for the coolant pressure drop and coolant enthalpy rise through the Phoebus-2 nozzle were desired by the Los Alamos Scientific Laboratory for incorporation into an analytical model of the Phoebus-2 system. These equations have been derived over the range of conditions anticipated for start-up, shut-down, full power and intermediate hold points. The two distinct regimes considered were full nozzle flow with supercritical coolant and separated nozzle flow with supercritical coolant. The ranges of conditions considered were:

Chamber Temperature	1000 to 5000°R
Chamber Pressure	100 to 800 psia
Flow Rate through Chamber	59.3 to 369 lbm/sec
Coolant Inlet Pressure	200 to 1600 psia
Coolant Inlet Enthalpy	+4 to -94.9 Btu/lb

II. SUMMARY

Closed form equations have been derived to describe the coolant pressure drop and enthalpy rise in the Phoebus-2 nozzle. The following equations are recommended:

$$\text{Separated Flow } \Delta P = e^{-4.434 T_c^{-0.119352} W_g^{1.7738} P_{in}^{0.198195} P_{out}^{-0.83392}}$$

$$\text{Full Flow } \Delta P = e^{-3.21237 T_c^{0.420277} W_g^{1.77756} P_{in}^{0.383691} P_{out}^{-1.00745}}$$

$$\text{Separated Flow } \Delta H = e^{-6.70512 T_c^{1.61981} W_g^{-0.323526} P_{in}^{0.156687} (H_{in} + 100)^{-0.0592244}}$$

$$\text{Full Flow } \Delta H = e^{-5.34266 T_c^{1.52306} W_g^{-0.369167} P_{in}^{0.0561104} (H_{in} + 100)^{0.0199182}}$$

These equations apply when the ratio of coolant to gas flow equals 245/285. For a variable W_c/W_g ratio from 0.25 to 0.95 the following equations are recommended:

$$\text{Separated Flow } \Delta P = e^{-4.434 T_c^{-0.119352} W_g^{1.7738} P_{in}^{0.198195} P_{out}^{-0.83392}} \\ (W_c/0.86 W_g)^{1.7738}$$

$$\text{Full Flow } \Delta P = e^{-3.21237 T_c^{-0.420227} W_g^{1.77756} P_{in}^{0.383691} P_{out}^{-1.00745}} \\ (W_c/0.86 W_g)^{1.77756}$$

$$\text{Separated Flow } \Delta H = e^{-6.70512 T_c^{1.61981} W_g^{-0.323526} P_{in}^{0.156687}} \\ (H_{in} + 100)^{-0.0592244} (0.86 W_g/W_c)^{0.885}$$

$$\text{Full Flow } \Delta H = e^{-5.34266 T_c^{1.52306} W_g^{-0.369167} P_{in}^{0.0561104}} \\ (H_{in} + 100)^{0.0199182} (0.86 W_g/W_c)^{0.885}$$

III. PROCEDURE

The basic model used to generate the analytical data points for the map was the Aerojet nozzle Computer Program 8047. This program models a regeneratively cooled nozzle and the basic model has been used at Aerojet since the inception of Titan (Reference 1). Supplementary programs which provide input to 8047 are Program 166 and Program 8070. Program 166 models an isentropic expansion process and generates chemical composition and free stream pressures and temperatures in the nozzle chamber. Program 8070 generates factors to account for the film cooling effect of core peripheral flow and is based on the model of Hatch and Papell (Reference 2).

A. HEAT TRANSFER CORRELATIONS AND FACTORS

The gas-side heat transfer coefficient was calculated from a slightly modified form of the simplified Bartz equation with a variable C_g .

$$C_g = h_g \left(\frac{d}{k_f} \right) / \left[\left(\frac{W_g}{A} \frac{d}{\mu_f} \right)^{0.8} Pr_f^{0.4} \left(\frac{\rho_f}{\rho_b} \right)^{0.8} \right]$$

The C_g was derived from the Bartz (Reference 3) boundary layer analysis. The C_g was modified in the cylindrical and convergent sections of the nozzle to account for gas impingement as indicated by scale model data (Reference 4). The C_g 's are shown in Table I. The coolant-side heat transfer coefficient for supercritical coolant was described by the modified Hess and Kunz (Reference 5) equation:

$$h_c = 0.0208 C_1 (k_f/d) \left(\frac{\rho_f V_b d}{\mu_f} \right)^{0.8} Pr_f^{0.4} (1 + 0.01457 v_w/v_b)$$

where C_1 was taken as 0.85 outside the throat region and assumed the value 1.0 in the throat region. The coolant-side correlation is discussed in detail in Reference (6). The effective heated area of the nozzle was taken as 0.8 of the total wetted area in the nozzle chamber. The Nikuradse (Reference 7) smooth tube friction factor was multiplied by the empirical correction factor 1.65. Thermal radiation from the core face was accounted for by a variable factor, FeFv, in the equation:

$$h_r = \sigma FeFv \frac{(\epsilon T_o^4 - T_{wg}^4)}{(\epsilon T_o - T_{wg})}$$

The FeFv's are shown in Table I. The effect of gamma heating on the coolant was ignored. Coolant properties used were those of Reference (8). Gas-side properties were calculated with subroutine Program 287A. The above correlations and factors have yielded good agreement with

experimental pressure drop, enthalpy rise, and wall temperature on the NERVA technology nozzle (Reference 4).

B. INPUT

The Phoebus-2 nozzle geometry is shown in Table I. These values are nominal design dimensions.

The flow separation criteria is nozzle exit pressure = 0.3 ambient pressure, which has yielded good agreement with NRX-A3 results (Reference 9). The separation criteria is illustrated in Figure 1.

Coolant inlet temperature as a function of inlet pressure was based on Phoebus-2 normal startup and normal shutdown conditions as supplied by Los Alamos (Reference 10). Inlet temperature is plotted in Figure 2.

The film coolant flow rate injected at the core support was taken as 0.01754 of the gas flow rate through the chamber. The enthalpy of the film coolant at the injection point was taken as 0.1427 (chamber enthalpy) + 0.8573 (nozzle coolant outlet enthalpy). These relationships were provided by Los Alamos per Reference (11). They were used in all cases with the exception of seventeen points shown in Table VIII which were calculated to study the effect of variation in film coolant flow rate and injection temperature.

Coolant flow rate was specified to be 245/285 of the gas flow rate through the chamber as in the nominal case.

Gas flow rates were calculated from:

$$W_g = \frac{P_c A_t g_c}{C^*}$$

where Phoebus-2 $A_t = 224.636 \text{ in.}^2$

Characteristic exhaust velocities, C^* 's, were obtained from Aerojet Computer Program 166. The C^* 's are plotted in Figures 3 through 6. It is seen that C^* becomes a significant function of chamber pressure at chamber temperatures of 4000°R and above. Furthermore the data at 4000°R and above do not form smooth curves. For this reason smooth curves were drawn through the region of the data as shown.

A total of 263 points were calculated by the above ground rules. Input parameters thus determined are listed in the first ten columns of Table 2. Some of the initially specified chamber pressures were found to be too low in that they would result in subcritical coolant flow in the nozzle tubes. Per Los Alamos direction (Reference 12) these cases were adjusted into the supercritical region by increasing the chamber pressures, holding the P_{in}/P_c ratios as specified.

C. DERIVATION OF EQUATIONS

Of the 263 cases calculated for the map the following 25 were deleted from the regression analysis: 20, 21, 25, 39, 40, 56, 76, 241, 242, 244, 245, 201, 208, 209, 214, 217, 225, 226, 230, 233, 234, 235, 237, 239 and 240. These cases were excluded either because the gas flow rate exceeded 280 lb/sec, which was finally determined to be outside the range of interest, or because the random error (discussed in the Appendix) was felt to be too great. The pressure drops and enthalpy rises of the remaining 238 cases were then input to the Aerojet Multiple Regression and Correlation Analysis Program AS222U. This program does a complete regression analysis for up to 30 variables and 500 observations. It generates closed-form, least-squares curve fits and also generates a table of residuals which lists observed and predicted values and their differences.

IV. RESULTS

The output data for the 263 state points are listed in Columns 11 through 16 of Table II. The pressure drop and enthalpy rise apply from the nozzle torus to the nozzle discharge plenum. The following equations were derived as curve fits to these data:

A. SEPARATED FLOW PRESSURE DROP EQUATIONS

$$\begin{aligned}
 1. \quad \Delta P &= e^{-4.13981 T_c - 0.112247 W_g + 1.70105 P_{in} + 0.197612 \rho_{out} - 0.810442} \\
 2. \quad \Delta P &= e^{-5.05408 T_c + 0.078126 W_g + 1.82271 \rho_{out} - 0.760144} \\
 3. \quad \Delta P &= e^{-13.2453 T_c + 1.75403 W_g + 1.59721 P_{in} - 0.67281} \\
 4. \quad \Delta P &= e^{-4.65394 W_g + 1.65401 P_{in} + 0.181101 \left(\frac{P_{in}}{P_c}\right) - 0.0807905 - 0.755151 \rho_{out}} \\
 5. \quad \Delta P &= e^{-4.7247 W_g + 1.72508 P_{in} + 0.127142 \rho_{out} - 0.770522} \\
 6. \quad \Delta P &= e^{-4.59818 W_g + 1.8568 \rho_{out} - 0.798861} \\
 7. \quad \Delta P &= e^{45.9155 T_c - 7.5072 W_g - 12.4601 P_{in} + 14.2964 - 14.3464 \left(\frac{P_{in}}{P_c}\right) - 0.639776 \rho_{out}}
 \end{aligned}$$

B. COMBINED REGIMES, SEPARATED AND FULL FLOW, PRESSURE DROP EQUATIONS

$$\begin{aligned}
 8. \quad \Delta P &= e^{25.5828 T_c - 4.4291 W_g + 6.40409 P_{in} + 8.35485 - 8.24036 \left(\frac{P_{in}}{P_c}\right) - 0.785938 \rho_{out}}
 \end{aligned}$$

9. $\Delta P = e^{-4.434 T_c^{-0.119352} W_g^{1.7738} P_{in}^{0.198195} \rho_{out}^{-0.83392}}$
10. $\Delta P = e^{-5.69352 T_c^{0.124461} W_g^{1.88052} \rho_{out}^{-0.751567}}$
11. $\Delta P = e^{-13.9877 T_c^{1.77086} W_g^{1.81148} P_{in}^{-0.738999}}$
12. $\Delta P = e^{-5.03702 W_g^{1.77624} P_{in}^{0.140468} \left(\frac{P_{in}}{P_c}\right)^{-0.0159694} \rho_{out}^{-0.783733}}$
13. $\Delta P = e^{-5.05193 W_g^{1.79089} P_{in}^{0.129471} \rho_{out}^{-0.787102}}$
14. $\Delta P = e^{-5.04566 W_g^{1.95172} \rho_{out}^{-0.816862}}$

C. FULL FLOW PRESSURE DROP EQUATIONS

15. $\Delta P = e^{11.0817 T_c^{-2.46553} W_g^{-2.00986} P_{in}^{4.16365} \left(\frac{P_{in}}{P_c}\right)^{-3.81511} \rho_{out}^{-0.986421}}$
16. $\Delta P = e^{-3.21237 T_c^{-0.420277} W_g^{1.77756} P_{in}^{0.383691} \rho_{out}^{-1.00745}}$
17. $\Delta P = e^{-6.13314 T_c^{0.159544} W_g^{1.90866} \rho_{out}^{-0.745915}}$
18. $\Delta P = e^{-5.91452 T_c^{1.66879} W_g^{2.00634} P_{in}^{-0.821912}}$
19. $\Delta P = e^{-5.91452 W_g^{2.34425} P_{in}^{-0.237071} \left(\frac{P_{in}}{P_c}\right)^{0.553028} \rho_{out}^{-0.953569}}$

$$20. \quad \Delta P = e^{-5.35091 W_g^{1.83749} P_{in}^{0.136433} P_{out}^{-0.814193}}$$

$$21. \quad \Delta P = e^{-5.26568 W_g^{1.99268} P_{out}^{-0.830487}}$$

$$22. \quad \Delta P = -0.15285 T_c - 3.49665 W_g + 1.01299 P_{in} + 0.0000262825 T_c^2 + 0.0113516 W_g^2 + 0.00060267 P_{in}^2 + 0.0000000527724 T_c^2 W_g + 0.000931069 T_c W_g - 0.00032338 T_c P_{in} - 0.00483888 W_g P_{in} + 0.0000000960572 T_c W_g P_{in} + 269.448$$

D. SEPARATED FLOW ENTHALPY RISE EQUATIONS

$$23. \quad \Delta H = e^{-6.70512 T_c^{1.61981} W_g^{-0.323526} P_{in}^{0.156687} (H_{in} + 100)^{-0.0592244}}$$

$$24. \quad \Delta H = 0.370352 T_c - 10.0581 W_g - 2.93175 P_{in} + 3.01279 (H_{in} + 100) - 68.4295 \ln T_c + 1119.17 \ln W_g + 464.635 \ln P_{in} - 47.2132 \ln (H_{in} + 100) - 0.00458962 T_c W_g + 0.000246727 T_c P_{in} + 0.000512421 T_c (H_{in} + 100) + 0.00688072 W_g P_{in} + 0.00107658 W_g (H_{in} + 100) + 0.0000155001 T_c W_g^2 - 5696.21$$

$$25. \quad \Delta H = 0.154076 T_c + 19.2531 W_g + 2.74493 P_{in} - 18.0283 (H_{in} + 100) + 0.00000571739 T_c^2 - 0.0557478 W_g^2 - 0.00304265 P_{in}^2 - 0.157013 (H_{in} + 100)^2 + 137.635 \ln T_c - 725.336 \ln W_g - 559.937 \ln P_{in}$$

25. (Cont)

$$\begin{aligned}
 & - 12.5039 \ln (H_{in} + 100) - 0.00194677 T_c W_g \\
 & + 0.0000859201 T_c P_{in} + 0.00398684 T_c (H_{in} + 100) \\
 & + 0.00568836 W_g P_{in} + 0.126049 W_g (H_{in} + 100) \\
 & + 3522.66
 \end{aligned}$$

E. FULL FLOW ENTHALPY RISE EQUATIONS

$$\begin{aligned}
 26. \quad \Delta H = & e^{-5.34266 T_c^{1.52306} W_g^{-0.369167} P_{in}^{0.0561104}} \\
 & (H_{in} + 100)^{0.0199182}
 \end{aligned}$$

$$\begin{aligned}
 27. \quad \Delta H = & 0.06779 T_c + 4.11699 W_g - 0.592896 P_{in} + \\
 & 0.0913086 (H_{in} + 100) + 0.0000117827 T_c^2 \\
 & - 0.00471935 W_g^2 - 0.0002051 P_{in}^2 - 0.0399189 \\
 & (H_{in} + 100)^2 + 47.7412 \ln T_c - 423.998 \ln W_g \\
 & + 346.477 \ln P_{in} - 137.969 \ln (H_{in} + 100) \\
 & - 0.000321832 T_c W_g - 0.0000293851 T_c P_{in} \\
 & + 0.000827968 T_c (H_{in} + 100) - 0.000158191 \\
 & W_g P_{in} + 0.0157032 W_g (H_{in} + 100) - 203.47
 \end{aligned}$$

V. DISCUSSION AND CONCLUSIONS

Of the above equations, 1, 2, 3, 5, 6, 10, 11, 13, 14 and 18 were found to be poor fits. Each of these equations has from thirteen to eighty-two residuals which exceed ten percent (See Table III). Equation 7 is unusable as the large exponents overload both an IBM 7094 and 360 computer. Equations 4, 7, 8, 12, 15 and 19 were not tested for residuals, in view of the P_{in}/P_c term, although the

multiple correlation coefficients* in general appear promising. Table IV lists the multiple correlation coefficients and number of residuals exceeding 10% for the equations which appear promising. Although Equation 9 exhibits 33 residuals exceeding 10% it appears to be the best fit obtained for the separated flow data. Equation 16 is the best full flow equation which was tested for residuals. Equations 23 and 26 are good fits to the enthalpy data and are in a more usable form than Equations 24, 25 and 27.

VI. RECOMMENDATIONS

The map data is plotted in Figures 7 through 14. Superimposed on the data are lines representing the recommended equations: Equation 9 for separated flow ΔP , equation 16 for full flow ΔP , Equation 23 for separated flow ΔH , and Equation 26 for full flow ΔH . Residuals for these four equations are listed in Table II. The recommended equations were tested for interpolatability at randomly chosen points and found to be interpolatable. Results are shown in Tables V and VI.

*The multiple correlation coefficient is defined as the square root of the coefficient of determination. The coefficient of determination is the proportion of the total variation (from the average value) in the dependent variable that has been recognized by the equation. Thus the nearer the multiple correlation coefficient is to unity, the better the equation fits the data.

APPENDIX A

CASES TO STUDY VARIATION IN H_{in} AND W_c/W_g

In addition to the 263 cases computed for the map equations, the Los Alamos Scientific Laboratory specified (Reference 13) 16 cases in which inlet enthalpy deviated from the assumed values and 109 cases in which the W_c/W_g ratio deviated from the assumed value of 245/285. Input and output data for these cases are listed in Table VII.

Based on an analysis of these additional cases, J. C. Hedstrom (Reference 14) recommends use of the following equations to recognize a variable W_c/W_g over the range of the data.

$$\text{Separated Flow } \Delta P = e^{-4.434 T_c^{-0.119352} W_g^{1.7738} P_{in}^{0.193195} \rho_{out}^{-0.83392} (W_c/0.86 W_g)^{1.7738}}$$

$$\text{Full Flow } \Delta P = e^{-3.21237 T_c^{-0.420227} W_g^{1.77756} P_{in}^{0.383691} \rho_{out}^{-1.00745} (W_c/0.86 W_g)^{1.77756}}$$

$$\text{Separated Flow } \Delta H = e^{-6.70512 T_c^{1.61981} W_g^{-0.323526} P_{in}^{0.156687} (H_{in} + 100)^{-0.0592244} (0.86 W_g/W_c)^{0.885}}$$

$$\text{Full Flow } \Delta H = e^{-5.34266 T_c^{1.52306} W_g^{-0.369167} P_{in}^{0.0561104} (H_{in} + 100)^{0.0199182} (0.86 W_g/W_c)^{0.885}}$$

APPENDIX B

CASES TO STUDY VARIATION IN FILM COOLANT FLOW RATE AND INJECTION TEMPERATURE

In addition to the 263 cases computed for the map equations, the Los Alamos Scientific Laboratory specified (Reference 13) 17 cases in which the core peripheral flow (nozzle film coolant) entered the nozzle at other than the assumed conditions of flow rate and inlet temperature. Input and output data for these cases are listed in Table VIII.

APPENDIX C

DISCUSSION OF RANDOM ERROR IN PROGRAM 8047 OUTPUT

It is seen in Figures 7 through 14 that the analytical data, particularly pressure drops, do not form smooth lines. The deviations from smooth lines were termed random errors and an effort was made to eliminate them. Potential causes of the random error which were investigated were as follows:

1. The cases exhibiting the random error were checked for mistakes and found to be calculationally correct.

2. The increasing of the number of calculational nodes in Program 8047 from the standard 34 to several hundred was suspected. This was sometimes necessary to obtain convergence. There was found to be no correlation between the random error and the number of nodes.

3. The T_{in} vs P_{in} input was suspected as not being sufficiently smooth. It does not seem, however, that the irregularities seen in Figure 2 can account for the random error.

4. It was thought that the effect might be legitimate and due to the coolant bulk temperature being in the transposed critical region at locations of large pressure gradient. Detailed examination showed this not to be the case.

5. The convergence limits in Program 8047 were checked and found to be $\pm 1.0^\circ R$, $\pm 1.0^\circ R$, $\pm 0.1^\circ R$ and ± 1.0 psia on gas-side wall temperature, coolant-side wall temperature, coolant bulk temperature and coolant static pressure respectively. The limits on bulk temperature and static pressure were varied and found to have a negligible effect on overall ΔP and ΔH .

6. The input to Program 8047 from Program 166 was suspected, but the 166 output did not appear sufficiently irregular to cause the random error.

7. The input data to Program 8047 from the film cooling Program 8070 were suspected, but were determined not to be the cause.

8. A pressure drop map which had been constructed for technology nozzle S/N-24 was examined and found to exhibit the random error. Points on this map had been calculated for a constant coolant inlet temperature, a constant ratio of chamber pressure to coolant inlet pressure and a constant ratio of coolant flow to gas flow. Film cooling had not been considered. This suggested that the random error was inherent in the 8047 calculational procedure.

9. The double, linear interpolation scheme applied to the coolant property tables in Program 8047 was suspected and the S/N-24 map was recalculated on Program 6019 which was identical to Program 8047 with the exception that a non-linear interpolation scheme was used on a different set of hydrogen properties. However the 6019 calculations also exhibited the random error.

Further investigation of the random error problem was not pursued at this time because it would have involved extensive analysis of the Program 8047 logic and this was felt to be unjustified since the maximum magnitude of the error was only about 5%.

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NOMENCLATURE

A	cross sectional flow area of nozzle chamber
A_t	nozzle throat area
C_g	coefficient in simplified Bartz equation
C_ℓ	coefficient in Hess and Kunz equation
C^*	characteristic exhaust velocity
d	diameter
e	base of natural logarithms
FeFv	product of emissivity and view factors
g_c	32.174 ft-lbm/lb _f -sec ²
h_c	coolant-side heat transfer coefficient
h_g	gas-side heat transfer coefficient
H_{in}	coolant enthalpy in nozzle inlet torus
h_r	radiation heat transfer coefficient
ΔH	coolant enthalpy rise from nozzle torus to discharge plenum
k_f	thermal conductivity at film temperature
P_c	nozzle chamber pressure
P_{in}	coolant static pressure in nozzle inlet torus
Pr_f	Prandtl number at film temperature
ΔP	coolant pressure drop from nozzle inlet torus to discharge plenum
Re_f	Reynolds number at film temperature
T_c	nozzle chamber temperature
T_o	stagnation temperature
T_{wg}	temperature on gas side of coolant tube crown
W_c	coolant flow rate through nozzle tubes
W_{film}	flow rate of core peripheral flow
W_g	gas flow rate through nozzle chamber
β	ratio of recovery temperature corrected for film cooling to stagnation temperature
μ_f	viscosity at film temperature

ρ_b	density at bulk temperature
ρ_f	density at film temperature
ρ_{out}	outlet density of nozzle coolant at exit end of coolant tube
σ	Stefan-Boltzmann constant
ν_b	kinematic viscosity at bulk temperature
ν_w	kinematic viscosity at wall temperature

Figure 1

NU. 340-10 1/2 DIETZGEN GRAPH PAPER
10 X 10 PER HALF INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

PHOEBUS-2 NOZZLE FLOW SEPARATION CRITERIA

COOLANT INLET TEMPERATURE VS INLET PRESSURE FOR PHOEBUS-2 NOZZLE

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 12

Figure 14

TABLE I

PHOEBUS-2 NOZZLE GEOMETRY, C_g 's AND FeFv's

Station No.	Axial Distance inches	Diameter inches	U-Tube Flow Area in ²	C_g	FeFv
1	83.9240	44.7449	.237	.0324	0
2	81.0207	42.9141	.222	.0326	0
3	78.1174	41.0833	.207	.0328	0
4	75.2140	39.2524	.193	.0332	0
5	72.3107	37.4216	.179	.0336	0
6	69.4073	35.5907	.166	.0340	0
7	66.5040	33.7599	.153	.0344	0
8	63.6006	31.9290	.141	.0344	0
9	60.6973	30.0982	.129	.0344	0
10	57.7939	28.2673	.117	.0340	0
11	54.8906	26.4365	.106	.0336	0
12	51.9872	24.6056	.096	.0323	0
13	49.0839	22.7748	.085	.0304	0
14	46.1805	20.9440	.075	.0280	0
15	43.2772	19.1131	.066	.0236	0
16	40.3738	17.2823	.057	.0178	0
17	39.1710	16.9120	.056	.0180	0
18	37.1004	17.4572	.058	.0278	.1007
19	35.1710	19.0556	.063	.0290	.2020
20	33.5141	21.5983	.073	.0292	.2965
21	31.3887	25.8492	.089	.0272	.3476
22	29.2633	30.1000	.105	.0276	.3708
23	27.1378	34.3509	.120	.0282	.3931
24	25.0124	38.6018	.135	.0287	.4118
25	22.8870	42.8527	.149	.0316	.4297
26	20.7615	47.1035	.163	.0346	.4440
27	18.6361	51.3544	.177	.0382	.4533
28	16.5106	55.6053	.190	.0420	.4559
29	14.5641	58.2066	.196	.0454	.4390
30	12.2680	59.1200	.168	.0484	.3631
31	8.8125	59.1200	.168	.0564	.3213
32	5.3570	59.1200	.168	.0636	.3613
33	1.9015	59.1200	.168	.0750	.4050
34	0.0000	59.1200	.168	.0804	.4524

TABLE II

Page 1 of 8

STATE POINTS FOR PHOEBUS-2 NOZZLE OPERATING MAP

Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in, film} °R	H _{in} Btu/lb	T _{wg} , °F Aft End	T _{wg} , °F Real Throat	T _{wg} , °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	P _{out} lbm/ft ³	Eqn ΔP	ΔP Resid. % Diff	Eqn ΔH	ΔH Resid. % Diff
1	100	1000	2.0	200	41.0	99.79	85.78	1.75	175	-94.9	-116	103	-330	32.3	43.5	1.44	38.6	19.4	41.6	-4.3
2	100/150	1500	1.6	240	41.6	121.85	104.75	2.14	249	-91.6	34	344	-254	39.2	85.3	2.83	30.9	-21.1	75.2	-11.9
3	100/140	1500	1.8	252	41.8	113.73	97.77	1.99	249	-90.8	27	339	-257	34.7	83.1	2.77	28.1	-19.0	77.0	-7.3
4	100/140	1500	2.0	280	42.2	113.73	97.77	1.99	250	-89.1	10	332	-260	34.7	74.8	2.80	28.5	-18.0	77.5	3.7
5	100/125	1500	2.2	275	42.1	101.54	87.29	1.78	250	-89.5	12	327	-260	28.2	75.9	2.75	23.5	-16.5	80.4	5.9
6	100/180	2000	1.6	288	42.3	126.13	108.13	2.21	323	-88.5	179	545	-208	49.0	120.3	1.98	44.3	-9.5	119.6	-0.5
7	100/160	2000	1.8	288	42.3	112.12	96.38	1.97	322	-88.5	178	536	-214	40.0	123.0	1.88	37.6	-6.1	124.3	1.1
8	100/145	2000	2.0	290	42.4	101.61	87.35	1.78	322	-88.3	192	527	-217	33.6	126.2	1.84	32.2	-4.3	128.3	1.7
9	100/150	2000	2.2	255	42.5	91.10	78.31	1.60	322	-87.0	178	520	-220	27.8	134.0	1.76	27.4	-1.3	131.8	-1.6
10	100/150	2500	2.0	300	42.5	93.64	80.50	1.64	403	-85.0	337	607	-178	38.7	181.0	1.06	43.2	11.7	187.4	3.5
11	100/185	3000	1.6	296	42.4	104.98	90.25	1.84	498	-86.0	504	839	-138	68.1	241.0	0.65	77.7	14.0	243.1	0.9
12	100/165	3000	1.8	297	42.4	93.63	80.49	1.64	500	-86.0	503	824	-136	55.6	249.0	0.645	63.8	14.8	252.4	1.4
13	100/150	3000	2.0	300	42.5	85.12	73.17	1.49	505	-85.0	500	811	-138	46.6	253.0	0.647	53.9	15.6	259.6	2.6
14	100/135	3000	2.2	297	42.4	76.60	65.85	1.34	509	-87.0	501	796	-139	33.8	263.0	0.632	45.5	17.2	270.5	2.8
15	100/140	3500	2.0	280	42.2	73.23	62.95	1.28	510	-87.0	670	896	-84	55.1	347.0	0.392	60.7	10.1	349.1	0.6
16	100/190	4000	1.6	304	42.6	92.40	79.43	1.62	713	-85.0	824	1062	-15	108.1	392.0	0.311	111.2	2.9	403.7	3.0
17	100/170	4000	1.8	306	42.7	82.65	71.05	1.45	715	-85.0	822	1032	-17	88.9	412.0	0.312	91.1	2.5	419.0	1.7
18	100/150	4000	2.0	300	42.5	72.91	62.60	1.28	716	-85.0	823	997	-19	72.4	431.0	0.306	73.9	2.0	435.0	0.9
19	100/140	4000	2.2	308	42.7	68.00	58.46	1.19	717	-85.0	819	984	-20	61.4	443.0	0.318	63.5	3.5	446.7	0.8
20	100/190	4500	1.6	304	42.6	86.31	74.20	1.51	830	-85.0	988	1151	49	139.5	483.0	0.207	136.5	-2.2	499.5	3.4
21	100/170	4500	1.8	306	42.7	77.18	66.35	1.35	840	-85.0	987	1112	56	111.1	519.0	0.228	103.4	-6.9	518.4	-0.1
22	100/150	4500	2.0	300	42.5	68.06	58.51	1.19	845	-85.0	989	1081	55	89.6	545.0	0.227	82.7	-7.7	538.3	-1.2
23	100/140	4500	2.2	308	42.7	63.50	54.59	1.11	845	-85.0	985	1072	54	75.7	562.0	0.237	70.9	-6.3	552.8	-1.6
24	100/190	5000	1.6	304	42.6	80.69	69.37	1.42	972	-85.0	1172	1248	131	238.8	558.0	0.104	212.3	-11.1	605.5	8.5
25	100/170	5000	1.8	306	42.7	72.12	62.00	1.26	982	-85.0	1173	1233	139	143.8	639.0	0.154	125.6	-12.7	628.5	-1.6
26	100/155	5000	2.0	310	42.8	65.70	56.48	1.15	990	-84.0	1172	1229	138	111.6	657.0	0.181	93.3	-16.4	646.6	-3.1
27	100/140	5000	2.2	308	42.7	59.29	50.97	1.04	1000	-84.0	1175	1216	137	91.5	697.0	0.184	76.6	-16.3	667.8	-4.2
28	150	1500	2.0	300	42.5	121.85	104.75	2.14	250	-87.8	-5	331	-262	39.2	74.0	2.83	32.3	-17.6	76.1	2.9
29	150/160	2000	1.6	256	41.8	112.12	96.38	1.97	322	-90.0	199	538	-211	39.7	129.2	1.94	35.8	-9.9	123.0	-4.8
30	150	2000	1.8	270	42.1	105.11	90.36	1.84	322	-89.6	189	532	-213	35.9	128.5	1.84	33.7	-6.2	126.4	-1.6

*The dual P_c values indicate Hedstrom's original P_c value/adjusted P_c to change the case from sub-critical coolant to super-critical coolant. The higher P_c will be used.

Table II
Page 2 of 8

Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in} , Film °R	H _{in} Btu/lb	T _{wg} , °F Aft End	T _{wg} , °F Real Throat	T _{wg} , °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	ρ _{out} lbm/ft ³	Eqn ΔP	ΔP Resid. % Diff	Eqn ΔH	ΔH Resid. % Diff
31	150	2000	2.0	300	42.5	105.11	90.36	1.84	323	-87.8	168	529	-217	33.3	123.5	1.90	33.5	-5.1	127.3	3.1
32	150	2000	2.2	330	43.3	105.11	90.36	1.84	323	-85.1	152	520	-218	33.5	114.8	2.17	30.5	-8.8	127.7	11.2
33	150/160	2500	1.6	256	41.8	99.89	85.87	1.75	408	-88.0	364	694	-176	46.5	190.5	0.921	52.8	13.6	121.4	-4.8
34	150	2500	1.8	270	42.1	93.64	80.50	1.64	408	-87.0	356	686	-179	41.4	187.0	0.917	47.8	15.3	125.9	-0.6
35	150	2500	2.2	330	43.3	93.64	80.50	1.64	410	-82.0	322	687	-177	34.9	177.0	1.24	38.6	10.7	128.1	6.3
36	150/170	3500	1.6	270	42.1	88.92	76.44	1.56	605	-87.0	676	917	-80	76.8	325.0	0.389	85.6	11.4	326.0	0.3
37	150/160	3500	1.8	288	42.2	83.69	71.94	1.47	608	-87.0	668	923	-82	67.7	332.0	0.411	74.3	9.8	355.8	1.1
38	150	3500	2.2	330	43.3	78.46	67.45	1.38	609	-82.0	648	912	-83	50.5	335.0	0.500	57.8	14.5	321.0	4.8
39	150/190	4500	1.6	304	42.6	86.31	74.20	1.51	828	-85.0	988	1151	49	139.5	483.0	0.196	142.8	2.4	499.5	7.4
40	150/165	4500	1.8	297	42.4	74.90	64.39	1.31	831	-87.0	992	1104	56	107.9	525.0	0.221	100.0	-7.3	525.5	-0.1
41	150	4500	2.2	330	43.3	68.06	58.51	1.19	833	-82.0	977	1089	55	80.6	554.0	0.256	76.2	-5.4	540.5	-2.4
42	200	2000	1.6	320	43.0	140.15	120.48	2.46	326	-86.0	159	548	-208	58.9	115.0	2.05	53.0	-9.9	116.2	1.0
43	200	2000	1.8	360	44.0	140.15	120.48	2.46	326	-82.5	136	537	-211	56.6	107.3	2.27	49.9	-11.9	116.8	8.9
44	200	2000	2.2	440	45.4	140.15	120.48	2.46	328	-73.0	91	515	-226	58.2	121.0	2.13	54.7	-6.0	117.5	-2.9
45	200	2500	2.0	400	45.0	124.86	107.34	2.19	411	-75.0	281	697	-179	60.0	171.0	1.34	62.7	-4.5	173.3	1.3
46	200	3000	1.6	320	43.0	113.49	97.56	1.99	497	-83.0	494	852	-138	74.8	234.0	0.712	83.9	12.2	237.2	1.4
47	200	3000	1.8	360	44.0	113.49	97.56	1.99	498	-79.0	473	852	-138	66.2	235.0	0.854	73.8	11.5	238.6	1.5
48	200	3000	2.2	440	45.4	113.49	97.56	1.99	501	-73.0	434	832	-143	63.0	241.0	0.966	69.3	9.7	242.6	0.7
49	200	3500	1.6	320	43.0	104.61	89.93	1.83	601	-83.0	656	968	-81	93.7	310.0	0.461	102.5	9.4	312.6	0.8
50	200	3500	1.8	360	44.0	104.61	89.93	1.83	602	-80.0	636	961	-81	80.8	309.0	0.560	89.2	10.4	315.4	2.1
51	200	3500	2.0	400	45.0	104.61	89.93	1.83	603	-76.0	613	948	-83	79.3	312.0	0.615	84.2	6.2	317.2	1.7
52	200	3500	2.2	440	45.4	104.61	89.93	1.83	603	-73.0	601	947	-85	72.1	318.0	0.672	79.7	10.6	319.7	0.5
53	200	4000	1.6	320	43.0	97.28	83.63	1.71	711	-83.0	820	1075	-14	115.1	385.0	0.327	118.1	2.6	397.3	3.2
54	200	4000	1.8	360	44.0	97.28	83.63	1.71	712	-80.0	802	1040	-15	102.6	402.0	0.375	107.8	5.1	400.8	-0.3
55	200	4000	2.2	440	45.4	97.28	83.63	1.71	712	-73.0	770	1056	-17	87.1	406.0	0.488	90.1	3.4	406.3	0.1
56	200/220	4500	1.6	352	43.8	100.00	85.96	1.75	826	-80.0	972	1170	49	173.2	479.0	0.239	161.8	-6.6	479.1	0.02
57	200	4500	1.8	360	44.0	90.88	78.12	1.59	828	-80.0	967	1147	47	136.0	507.0	0.260	127.9	-6.0	495.0	-2.2
58	200	4500	2.2	440	45.4	90.88	78.12	1.59	829	-73.0	940	1180	46	102.1	507.0	0.374	98.3	-3.8	502.7	-0.8
59	200/210	5000	1.6	336	43.4	89.27	76.74	1.57	966	-82.0	1162	1280	135	243.0	562.0	0.121	228.4	-6.0	588.9	4.8
60	200	5000	1.8	360	44.0	84.98	73.05	1.49	972	-80.0	1152	1289	133	165.9	619.0	0.195	142.5	-14.1	601.1	-2.9
61	200	5000	2.2	440	45.4	84.98	73.05	1.49	975	-73.0	1129	1325	131	117.3	622.0	0.299	103.8	-11.5	609.4	-2.0
62	250	2000	2.0	500	46.0	175.19	150.60	3.07	332	-70.0	77	524	-227	87.2	115.0	2.23	80.2	-8.0	110.8	-3.6
63	250	2500	1.6	400	45.0	156.07	134.17	2.74	412	-75.0	284	726	-172	88.6	167.0	1.41	89.2	0.7	161.2	-3.5

Table II
Page 3 of 8

Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in, Film} °R	H _{in} Btu/lb	T _{wg} , °F Aft End	T _{wg} , °F Real Throat	T _{wg} , °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	ρ _{out} lbm/ft ³	Eqn ΔP	ΔP Resid. % Diff	Eqn ΔH	ΔH Resid. % Diff
64	250	2500	1.8	450	45.5	156.07	134.17	2.74	414	-73	263	715	-177	87.9	165.0	1.47	88.2	0.4	163.4	-0.9
65	250	2500	2.0	500	46.0	156.07	134.17	2.74	414	-70	236	709	-181	84.3	168.0	1.58	84.8	0.6	165.1	-1.7
66	250	2500	2.2	550	47.0	156.07	134.17	2.74	416	-66	214	701	-185	82.0	168.0	1.68	82.1	0.2	166.4	-1.0
67	250	3000	1.6	400	45.0	141.86	121.95	2.49	496	-75	453	877	-130	99.1	223.0	0.917	105.5	6.5	223.4	0.2
68	250	3000	1.8	450	45.5	141.86	121.95	2.49	497	-73	433	867	-133	95.4	226.0	0.999	100.6	5.4	226.5	0.2
69	250	3000	2.2	550	47.0	141.86	121.95	2.49	500	-66	386	867	-138	84.0	227.0	1.20	89.8	6.9	230.6	1.6
70	250	3500	1.6	400	45.0	130.77	112.42	2.29	600	-76	616	1000	-74	115.8	291.0	0.630	122.6	5.9	295.1	1.4
71	250	3500	1.8	450	45.5	130.77	112.42	2.29	600	-73	599	989	-77	111.0	295.0	0.689	116.5	5.0	298.5	1.2
72	250	3500	2.2	550	47.0	130.77	112.42	2.29	601	-67	556	1006	-80	91.9	298.0	0.872	99.6	4.4	304.4	2.1
73	250	4500	1.6	400	45.0	113.74	97.78	1.99	825	-75	950	1207	51	195.9	466.0	0.269	189.0	-3.5	462.7	-0.7
74	250	4500	1.8	450	45.5	113.74	97.78	1.99	825	-73	940	1230	50	158.3	474.0	0.362	151.0	-4.6	469.2	-1.0
75	250	4500	2.2	550	47.0	113.74	97.78	1.99	826	-66	906	1269	48	118.8	467.0	0.508	118.4	-0.3	477.6	2.3
76	250	5000	1.6	400	45.0	106.46	91.52	1.87	961	-75	1134	1344	135	231.1	540.0	0.151	268.5	4.5	560.7	3.8
77	250	5000	1.8	450	45.5	106.46	91.52	1.87	951	-73	1126	1372	134	188.1	579.0	0.271	168.8	-10.2	568.5	-1.8
78	250	5000	2.2	550	47.0	106.46	91.52	1.87	962	-66	1096	1411	131	134.2	571.0	0.410	124.4	-7.3	578.7	1.4
79	300	2500	1.6	480	45.8	187.29	161.00	3.29	406	-73	251	738	-173	118.8	159.0	1.570	111.6	-6.0	156.7	-1.5
80	300	2500	1.8	540	46.8	187.29	161.00	3.29	409	-67	221	729	-179	116.0	160.0	1.680	109.1	-6.0	158.3	-1.0
81	300	2500	2.2	660	48.6	187.29	161.00	3.29	410	-59	166	709	-187	109.5	159.0	1.880	105.2	-3.9	160.8	1.2
82	300	3000	1.6	480	45.8	170.23	146.34	2.99	494	-72	424	896	-128	127.4	213.0	1.030	126.0	-1.1	214.4	0.7
83	300	3000	1.8	540	46.8	170.23	146.34	2.99	496	-67	395	894	-172	119.5	210.0	1.230	116.7	-2.3	216.5	3.1
84	300	3000	2.2	660	48.6	170.23	146.34	2.99	497	-59	344	886	-139	108.3	214.0	1.430	108.3	0.01	220.0	2.8
85	300	3500	1.6	480	45.8	156.92	134.90	2.75	589	-72	592	1032	-75	148.0	277.0	0.742	150.5	1.7	279.4	0.9
86	300	3500	1.8	540	46.8	156.92	134.90	2.75	590	-67	565	1042	-77	130.6	274.0	0.882	132.3	1.3	282.2	3.0
87	300	3500	2.2	660	48.6	156.92	134.90	2.75	591	-59	517	1044	-83	115.2	279.0	1.060	118.8	3.1	286.6	2.7
88	300	4000	1.6	480	45.8	146.00	125.51	2.56	702	-72	761	1160	-17	176.6	354.0	0.517	180.2	2.0	351.7	-0.7
89	300	4000	1.8	540	46.8	146.00	125.51	2.56	703	-67	737	1175	-18	149.0	353.0	0.640	152.0	2.0	355.1	0.6
90	300	4000	2.0	600	48.0	146.00	125.51	2.56	708	-62	708	1180	-20	135.5	357.0	0.718	141.0	4.1	358.3	0.4
91	300	4000	2.2	660	48.6	146.00	125.51	2.56	709	-59	692	1189	-22	125.2	357.0	0.805	130.3	4.1	360.7	1.0
92	300	4500	1.6	480	45.8	136.61	117.44	2.40	821	-72	935	1286	53	216.8	442.0	0.354	217.0	0.1	431.2	-2.4
93	300	4500	1.8	540	46.8	136.61	117.44	2.40	821	-67	914	1309	51	172.3	437.0	0.481	171.4	-0.5	435.5	-0.3
94	300	4500	2.0	600	48.0	136.61	117.44	2.40	822	-65	888	1323	50	154.8	446.0	0.554	154.8	0.01	438.3	-1.7
95	300	4500	2.2	660	48.6	136.61	117.44	2.40	823	-59	874	1335	49	138.9	439.0	0.638	139.3	0.3	442.3	0.8
96	300	5000	1.6	480	45.8	127.99	110.03	2.24	950	-71	1120	1423	127	270.2	533.0	0.248	272.1	0.7	519.0	-2.6
97	300	5000	1.8	540	46.8	127.99	110.03	2.24	950	-67	1101	1452	125	201.3	535.0	0.367	191.8	-4.7	523.7	-2.1

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Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in} Film °R	H _{in} Btu/lb	T _{wg} , °F Aft End	T _{wg} , °F Real Throat	T _{wg} , °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	ρ _{out} lbm/ft ³	Eqn ΔP	ΔP Resid. % Diff	Eqn ΔH	ΔH Resid. % Diff
98	300	5000	2.2	660	48.6	127.99	110.03	2.24	952	-59	1006	1487	123	153.7	536.0	0.519	146.1	-4.9	532.0	-0.8
99	350	2500	2.0	700	49.0	218.50	187.83	3.83	412	-57	152	728	-160	144.3	156.0	1.940	137.1	-5.0	152.6	-2.2
100	350	3000	1.6	560	47.2	198.60	170.73	3.48	496	-65	383	924	-127	158.3	203.0	1.240	154.4	-2.5	203.2	1.1
101	350	3000	1.8	630	48.3	198.60	170.73	3.48	496	-61	356	920	-132	147.5	204.0	1.390	144.0	-2.4	207.0	1.5
102	350	3000	2.0	700	49.0	198.60	170.73	3.48	497	-57	331	915	-136	142.1	207.0	1.490	139.8	-1.6	208.6	0.8
103	350	3000	2.2	770	49.7	198.60	170.73	3.48	497	-53	300	910	-140	137.9	206.0	1.570	137.6	-0.2	210.1	2.0
104	350	3500	1.6	560	47.2	183.07	157.38	3.21	588	-66	559	1078	-77	172.4	264.0	0.897	173.5	0.6	267.3	1.2
105	350	3500	1.8	630	48.3	183.07	157.38	3.21	590	-60	529	1080	-80	157.8	267.0	1.010	161.1	2.1	270.0	1.1
106	350	3500	2.0	700	49.0	183.07	157.38	3.21	590	-57	506	1082	-84	147.4	267.0	1.120	151.1	2.5	272.0	1.8
107	350	3500	2.2	770	49.7	183.07	157.38	3.21	591	-53	477	1083	-87	141.7	268.0	1.210	145.0	2.3	273.9	2.2
108	350	4000	1.6	560	47.2	170.42	146.50	2.99	699	-66	732	1218	-16	197.3	334.0	0.642	202.3	2.5	336.3	0.7
109	350	4000	1.8	630	48.3	170.42	146.50	2.99	700	-61	705	1225	-18	175.8	340.0	0.747	181.7	3.4	337.5	-0.2
110	350	4000	2.2	770	49.7	170.42	146.50	2.99	701	-53	658	1242	-23	150.5	340.0	0.946	154.7	2.8	344.6	1.4
111	350	4500	1.6	560	47.2	159.48	137.10	2.80	810	-65	910	1354	54	232.4	413.0	0.464	237.3	2.1	412.6	-0.1
112	350	4500	1.8	630	48.3	159.48	137.10	2.80	812	-60	886	1372	52	200.1	417.0	0.573	200.8	0.3	416.5	-0.1
113	350	4500	2.0	700	49.0	159.48	137.10	2.80	813	-57	868	1385	51	173.7	416.0	0.681	175.7	1.1	419.5	0.9
114	350	4500	2.2	770	49.7	159.48	137.10	2.80	814	-53	844	1394	50	161.3	418.0	0.761	162.9	1.0	422.5	1.1
115	350	5000	1.6	560	47.2	149.53	128.54	2.62	942	-65	1098	1497	130	286.5	503.0	0.336	280.3	-2.2	496.1	-1.4
116	350	5000	1.8	630	48.3	149.53	128.54	2.62	943	-61	1076	1521	129	229.6	509.0	0.449	219.0	-4.6	500.5	-1.7
117	350	5000	2.2	770	49.7	149.53	128.54	2.62	944	-53	1042	1554	126	176.4	511.0	0.625	167.5	-3.9	508.0	-0.6
118	400	3000	1.6	640	48.4	226.97	195.11	3.98	495	-59	355	948	-129	192.4	202.0	1.350	199.2	-1.7	197.4	-2.3
119	400	3000	1.8	720	49.2	226.97	195.11	3.98	496	-56	325	943	-134	181.7	201.0	1.490	179.2	-1.4	199.0	-1.0
120	400	3000	2.2	880	51.2	226.97	195.11	3.98	498	-46	257	924	-141	172.6	206.0	1.670	172.5	-0.1	202.1	-1.9
121	400	3500	1.6	640	48.4	209.23	179.86	3.67	587	-59	529	1113	-74	205.4	257.0	0.989	209.9	2.2	257.3	0.1
122	400	3500	1.8	720	49.2	209.23	179.86	3.67	588	-56	501	1115	-78	189.6	259.0	1.130	192.0	1.3	259.4	0.1
123	400	3500	2.2	880	51.2	209.23	179.86	3.67	591	-45	437	1106	-85	173.4	262.0	1.320	177.3	2.3	263.5	0.6
124	400	4000	1.6	640	48.4	194.80	167.46	3.42	690	-60	706	1261	-18	231.0	323.0	0.730	237.3	2.7	323.6	0.2
125	400	4000	1.8	720	49.2	194.80	167.46	3.42	692	-56	681	1273	-20	203.9	324.0	0.871	207.8	1.9	326.3	0.7
126	400	4000	2.2	880	51.2	194.80	167.46	3.42	695	-46	620	1274	-25	181.2	331.0	1.050	185.9	2.6	331.4	0.1
127	400	4500	1.6	640	48.4	182.33	156.74	3.20	805	-60	887	1409	55	262.2	398.0	0.553	265.6	1.3	396.7	-0.3
128	400	4500	1.8	720	49.2	182.33	156.74	3.20	806	-55	863	1429	53	222.9	397.0	0.684	224.3	0.6	400.3	0.8
129	400	4500	2.0	880	51.2	182.33	156.74	3.20	810	-52	835	1437	52	202.2	402.0	0.784	203.6	0.7	405.4	0.8
130	400	4500	2.2	880	51.2	182.33	156.74	3.20	810	-46	810	1437	50	192.7	406.0	0.854	193.7	0.5	406.3	0.1
131	400	5000	1.6	640	48.4	171.05	147.04	3.00	936	-60	1076	1560	133	313.5	481.0	0.405	310.4	-1.0	476.9	-0.9
132	400	5000	1.8	720	49.2	171.05	147.04	3.00	937	-55	1058	1588	131	248.2	483.0	0.548	239.5	-3.5	481.2	-0.4

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Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in} Film °R	H _{in} Btu/lb	T _{wg} , °F Aft End	T _{wg} , °F Real Throat	T _{wg} , °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	ρ _{out} lbm/ft ³	Eqn ΔP	ΔP Resid. % Diff	ρ _{in} ΔH	ΔH Resid. % Diff
133	400	5000	2.2	880	51.2	171.05	147.04	3.00	933	-46	1009	1606	123	203.2	493.0	0.707	200.1	-3.0	488.4	-0.9
134	450	3000	2.0	900	51.5	255.35	219.51	4.48	497	-44	253	946	-139	215.4	197.0	1.680	213.2	-1.0	193.9	-0.2
135	450	3500	1.6	720	49.2	235.38	202.34	4.13	505	-57	506	1144	-74	241.0	249.0	1.110	241.0	0	248.2	-0.3
136	450	3500	1.8	812	50.1	235.38	202.34	4.13	509	-51	466	1143	-78	222.6	252.0	1.250	223.7	0.5	250.5	-0.6
137	450	3500	2.0	900	51.5	235.38	202.34	4.13	510	-44	433	1134	-82	216.8	254.0	1.330	218.8	0.9	252.7	-0.5
138	450	3500	2.2	990	52.8	235.38	202.34	4.13	511	-38	394	1126	-85	203.0	255.0	1.470	205.2	1.1	254.5	-0.2
139	450	4000	1.6	720	49.2	219.18	188.42	3.84	687	-56	685	1306	-15	262.1	313.0	0.837	266.8	1.8	312.4	-0.2
140	450	4000	1.8	812	50.1	219.18	188.42	3.84	688	-52	649	1314	-18	234.7	314.0	0.987	236.4	0.7	315.1	0.3
141	450	4000	2.2	990	52.8	219.18	188.42	3.84	692	-38	579	1308	-23	207.1	318.0	1.200	209.7	1.2	320.3	0.7
142	450	4500	1.6	720	49.2	205.18	176.38	3.60	802	-56	869	1463	56	289.7	383.0	0.640	295.9	2.1	383.1	0.02
143	450	4500	1.8	810	50.1	205.18	176.38	3.60	803	-50	836	1474	54	248.5	384.0	0.783	252.6	1.7	386.6	0.70
144	450	4500	2.0	900	51.5	205.18	176.38	3.60	805	-44	806	1474	52	239.5	381.0	0.859	239.6	0.04	389.8	2.3
145	450	4500	2.2	990	52.8	205.18	176.38	3.60	805	-39	771	1480	50	213.9	391.0	0.991	215.2	0.6	392.5	0.4
146	450	5000	1.6	720	49.2	192.59	165.56	3.38	931	-56	1063	1623	134	332.6	461.0	0.491	330.3	-0.7	460.4	-0.1
147	450	5000	1.8	810	50.1	192.59	165.56	3.38	935	-51	1034	1641	132	276.6	466.0	0.626	270.6	-2.2	454.4	-0.3
148	450	5000	2.2	990	52.8	192.59	165.56	3.38	936	-38	974	1653	128	225.3	471.0	0.827	220.7	-2.0	471.9	0.2
149	500	3500	1.6	800	50.0	261.53	224.82	4.59	588	-52	474	1170	-72	276.9	242.0	1.210	277.4	0.2	240.7	-0.5
150	500	3500	1.8	900	51.5	261.53	224.82	4.59	590	-45	436	1162	458	267.1	245.0	1.320	265.9	-0.4	242.9	-0.8
151	500	3500	2.2	1100	55.0	261.53	224.82	4.59	592	-29	397	1141	-83	242.6	246.0	1.550	244.3	0.7	246.9	0.4
152	500	4000	1.6	800	50.0	243.56	209.38	4.27	685	-52	656	1342	-14	295.1	301.0	0.932	300.6	1.9	302.8	0.6
153	500	4000	1.8	900	51.5	243.56	209.38	4.27	688	-44	621	1340	-18	278.9	305.0	1.040	281.7	1.0	305.8	0.3
154	500	4000	2.2	1100	55.0	243.56	209.38	4.27	692	-28	548	1332	-23	243.5	308.0	1.280	246.8	1.3	310.8	0.9
155	500	4500	1.6	800	50.0	227.89	195.91	4.00	802	-52	843	1509	58	322.8	369.0	0.727	326.5	1.2	371.3	0.6
156	500	4500	1.8	900	51.5	227.89	195.91	4.00	803	-44	810	1511	55	296.8	376.0	0.839	295.7	-0.4	374.9	-0.3
157	500	4500	2.0	1000	53.0	227.89	195.91	4.00	804	-37	770	1516	53	263.6	377.0	0.971	265.7	0.8	378.0	0.3
158	500	4500	2.2	1100	55.0	227.89	195.91	4.00	805	-29	739	1515	51	248.3	377.0	1.070	250.0	0.7	381.0	1.1
159	500	5000	1.6	800	50.0	214.15	184.09	3.76	927	-52	1040	1675	134	362.9	445.0	0.564	361.2	-0.5	446.1	0.2
160	500	5000	1.8	900	51.5	214.15	184.09	3.76	928	-44	1010	1682	132	320.3	454.0	0.686	310.2	-3.1	450.4	-0.8
161	500	5000	2.2	1100	55.0	214.15	184.09	3.76	933	-30	943	1696	128	258.1	455.0	0.908	252.6	-2.1	457.6	0.6
162	550	3500	2.0	1100	55.0	287.69	247.31	5.05	590	-29	366	1168	-80	291.4	239.0	1.540	291.3	-0.04	238.4	-0.3
163	550	4000	1.6	880	51.2	267.95	230.34	4.70	683	-46	632	1341	-12	338.8	294.0	1.000	344.2	1.6	294.6	0.2
164	550	4000	1.8	990	52.8	267.95	230.34	4.70	686	-38	587	1337	-16	318.3	298.0	1.120	321.3	0.9	297.4	-0.2
165	550	4000	2.2	1210	57.5	267.95	230.34	4.70	692	-20	513	1320	-21	280.5	303.0	1.370	283.2	1.0	302.3	-0.2

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Case No	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in} Film °R	H _{in} Btu/lb	T _{wg} °F Aft End	T _{wg} °F Real Throat	T _{wg} °F Fwd End	Coolant ΔP psi	Coolant ΔH Btu/lb	P _{out} lbm/ft ³	Eqn ΔP	Resid. % Diff	Eqn ΔH	Resid. % Diff
166	550	4500	1.6	880	51.2	250.91	215.69	4.40	801	-46	821	1543	58	365.1	356.0	0.794	367.7	0.7	361.1	1.4
167	550	4500	1.8	990	52.8	250.91	215.69	4.40	803	-38	779	1546	54	333.2	363.0	0.918	332.4	-0.2	364.5	0.4
168	550	4500	2.0	1100	55.0	250.91	215.69	4.40	804	-30	744	1548	52	300.3	363.0	1.070	296.6	-1.2	367.6	1.3
169	550	4500	2.2	1210	57.5	250.91	215.69	4.40	805	-20	704	1542	51	281.8	368.0	1.170	281.2	-0.2	370.5	0.7
170	550	5000	1.6	880	51.2	235.71	202.63	4.13	928	-46	1019	1720	127	403.6	432.0	0.622	402.6	-0.3	433.9	0.4
171	550	5000	1.8	990	52.8	235.71	202.63	4.13	929	-38	980	1727	125	353.9	438.0	0.753	347.4	-1.8	438.0	0
172	550	5000	2.2	1210	57.5	235.71	202.63	4.13	934	-20	907	1751	121	290.7	445.0	0.988	285.4	-1.8	445.2	0.04
173	600	4000	1.6	960	52.4	292.33	251.30	5.13	687	-40	604	1397	-12	392.3	289.0	1.050	395.5	0.8	287.3	-0.6
174	600	4000	1.8	1080	54.6	292.33	251.30	5.13	690	-30	561	1391	-16	356.3	290.0	1.210	352.7	0.7	290.1	0.02
175	600	4000	2.2	1320	57.6	292.33	251.30	5.13	692	-15	488	1378	-20	317.6	297.0	1.460	320.6	1.0	294.5	-0.8
176	600	4500	1.6	960	52.4	273.78	235.35	4.80	800	-40	795	1577	58	414.1	346.0	0.858	410.6	-0.8	352.1	1.8
177	600	4500	1.8	1080	54.6	273.78	235.35	4.80	801	-32	754	1580	54	365.2	350.0	1.010	364.5	-0.2	355.4	1.5
178	600	4500	2.0	1200	57.5	273.78	235.35	4.80	804	-20	710	1575	52	342.6	352.0	1.130	338.9	-1.1	358.6	1.9
179	600	4500	2.2	1320	57.6	273.78	235.35	4.80	805	-15	682	1578	50	317.9	355.0	1.260	315.0	-0.9	361.0	1.7
180	600	5000	1.6	960	52.4	257.28	221.17	4.51	924	-41	994	1757	120	452.7	420.0	0.670	451.3	-0.3	422.9	0.7
181	600	5000	1.8	1080	54.6	257.28	221.17	4.51	926	-32	954	1764	118	386.2	426.0	0.828	381.4	-1.2	426.9	0.2
182	600	5000	2.2	1320	57.6	257.28	221.17	4.51	929	-16	888	1771	114	324.2	434.0	1.070	318.2	-1.9	433.6	-0.1
183	625	4500	2.0	1250	57.5	285.21	245.18	5.00	804	-17	702	1591	53	359.4	351.0	1.170	357.5	-0.5	354.3	0.9
184	390	3300	2.0	780	49.8	210.00	180.50	5.94	525	-53	404	1041	-103	169.3	237.0	1.360	169.5	0.1	238.2	0.5
185	650	4500	1.6	1040	53.8	296.66	255.02	5.20	802	-34	770	1606	59	472.3	337.0	0.895	468.0	-0.9	344.0	2.1
186	650	4500	1.8	1170	56.7	296.66	255.02	5.20	804	-25	726	1606	56	411.3	342.0	1.090	401.5	-2.4	347.2	1.5
187	650	4500	2.0	1300	57.5	296.66	255.02	5.20	805	-15	692	1607	54	372.3	342.0	1.230	370.1	-0.6	350.1	2.4
188	650	4500	2.2	1430	58.6	296.66	255.02	5.20	805	-10	646	1602	51	364.4	351.0	1.310	360.3	-1.1	352.4	0.4
189	650	5000	1.6	1040	53.8	278.84	239.70	4.89	922	-34	971	1792	152	505.4	411.0	0.719	500.0	-1.1	413.3	0.6
190	650	5000	1.8	1170	56.8	278.84	239.70	4.89	926	-23	927	1798	149	429.3	415.0	0.896	419.1	-2.4	417.3	0.6
191	650	5000	2.2	1430	58.6	278.84	239.70	4.89	928	-10	854	1805	144	368.6	427.0	1.120	361.5	-1.9	423.3	-0.9
192	390	3300	1.6	624	48.2	210.00	180.50	6.39	520	-61	464	1043	-95	192.6	233.0	1.100	192.7	0.03	234.3	0.6
193	390	3300	1.8	702	49.0	210.00	180.50	6.39	523	-57	437	1043	-100	178.8	235.0	1.240	178.7	-0.1	236.3	0.6
194	390	3300	2.2	858	50.3	210.00	180.50	6.39	530	-48	372	1032	-107	164.9	241.0	1.430	167.1	1.3	239.9	-0.4
195	625	4500	1.6	1000	53.0	285.21	245.18	5.60	800	-38	780	1593	58	448.8	347.0	0.864	444.8	0	347.9	0.3
196	625	4500	1.8	1125	55.6	285.21	245.18	5.60	803	-28	741	1594	55	388.6	351.0	1.040	386.1	-0.6	351.2	0.1
197	625	4500	2.2	1375	57.9	285.21	245.18	5.60	805	-13	666	1592	51	341.8	357.0	1.280	338.0	-1.1	356.6	-0.1
198	700	5000	1.6	1120	55.6	300.39	258.23	5.27	921	-27	950	1824	183	564.1	402.0	0.751	562.0	-0.4	404.6	0.6
199	700	5000	1.8	1260	57.5	300.39	258.23	5.27	924	-17	910	1832	179	471.6	404.0	0.955	461.6	-2.1	408.3	1.1
200	700	5000	2.2	1540	60.8	300.39	258.23	5.27	929	-01	812	1830	174	418.3	421.0	1.160	409.8	-2.0	414.4	-1.6

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Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in} Film °R	H _{in} Btu/lb	T _{wg} °F Aft End	T _{wg} °F Real Throat	T _{wg} °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	ρ _{out} lbm/ft ³	Eqn ΔP	Resid. % Diff	Eqn ΔH	Resid. % Diff.
201*	300	1000	2.0	600	48.0	299	257	5.24	180	-62	-341	50	-337	197	50	3.370				
202	300	2000	2.0	600	48.0	210	180	3.68	329	-62	1	520	-231	118	114	2.370	109.1	-8.4	109.0	-4.4
203	300	3000	2.0	600	48.0	170	146	2.98	496	-62	364	890	-133	110	214	1.330	112.1	1.9	218.5	2.1
204	300	3500	2.0	600	48.0	157	135	2.75	598	-62	534	1042	-77	120	282	0.956	127.2	6.0	284.6	0.9
205	300	5000	2.0	600	48.0	120	111	2.26	950	-62	1068	1468	130	175	544	0.438	169.5	-3.1	526.8	-3.2
206	350	4000	2.0	700	49.0	171	147	3.00	695	-57	684	1255	-17	158	345	0.848	167.5	6.0	341.7	-0.9
207	350	5000	2.0	700	49.0	148	127	2.60	950	-57	1062	1539	133	188	517	0.542	185.2	-1.5	506.3	-2.1
208*	400	1000	2.0	800	50.0	388	334	6.81	184	-52	-335	51	-337	328	48	3.330				
209*	400	2000	2.0	800	50.0	280	241	4.91	496	-52	-94	513	-154	200	115	2.530				
210	400	3000	2.0	800	50.0	227	195	3.98	496	-52	288	936	-135	174	205	1.580	175.9	1.1	200.5	-2.7
211	400	3500	2.0	800	50.0	209	180	3.67	593	-52	465	1113	-78	178	262	1.230	183.2	2.9	261.5	-0.2
212	400	4000	2.0	800	50.0	195	168	3.42	690	-52	646	1279	-19	189	328	0.963	195.9	3.7	328.7	0.2
213	400	5000	2.0	800	50.0	171	147	3.00	950	-52	1028	1596	135	218	493	0.636	214.5	-1.6	484.7	-1.7
214*	450	2000	2.0	900	51.5	317	273	5.56	413	-46	-117	518	-197	256	111	2.520				
215	450	4000	2.0	900	51.5	220	189	3.36	690	-46	574	1244	-28	213	306	1.110	220.1	3.3	317.2	3.7
216	450	5000	2.0	900	51.5	191	164	3.35	945	-46	1007	1645	135	250	482	0.700	248.0	-0.8	469.5	-2.6
217*	500	2000	2.0	1000	53.0	350	301	6.14	331	-36	-151	518	-238	309	103	2.550				
218	500	3000	2.0	1000	53.0	234	244	4.98	495	-36	212	950	-136	252	191	1.780	253.1	0.4	188.0	-1.6
219	500	3500	2.0	1000	53.0	262	225	4.60	592	-36	394	1153	-78	247	250	1.440	254.4	3.0	245.0	-2.0
220	500	4000	2.0	1000	53.0	243	209	4.26	690	-36	578	1336	-18	250	313	1.170	259.4	3.8	308.7	-1.4
221	500	5000	2.0	1000	53.0	214	184	3.75	940	-36	971	1690	135	274	459	0.900	276.3	0.9	454.4	-1.0
222	550	3000	2.0	1100	55.0	312	268	5.47	496	-28	183	962	-135	297	185	1.850	298.4	0.5	183.0	-1.1
223	550	4000	2.0	1100	55.0	268	230	4.70	690	-28	552	1362	-15	290	300	1.260	297.2	2.5	300.0	0
224	550	5000	2.0	1100	55.0	233	200	4.09	932	-28	946	1726	130	294	448	0.920	289.6	-1.5	443.8	-0.9
225*	600	2000	2.0	1200	57.5	411	302	7.38	336	-18	-170	519	-239	448	98	2.530				
226*	600	3000	2.0	1200	57.5	341	293	5.98	497	-18	148	967	-134	354	184	1.870				
227	600	3500	2.0	1200	57.5	314	270	5.51	594	-18	335	1173	-77	339	236	1.560	347.3	-2.5	232.6	-1.4
228	600	4000	2.0	1200	57.5	292	251	5.12	690	-18	518	1379	-15	336	294	1.310	344.1	2.4	292.8	-0.4
229	600	5000	2.0	1200	57.5	257	221	4.51	925	-18	912	1762	121	350	436	0.941	348.5	-0.4	431.2	-1.1
230*	650	3000	2.0	1300	57.5	369	317	6.47	500	-16	118	981	-133	399	184	1.960				
231	650	4000	2.0	1300	57.5	317	273	5.56	700	-16	497	1406	-8	371	292	1.410	381.3	2.8	285.5	-2.2
232	650	5000	2.0	1300	57.5	276	238	4.84	975	-16	897	1797	151	372	428	1.030	372.4	1.1	422.1	-1.4
233*	700	3000	2.0	1400	58.0	397	341	6.96	502	-10	83	991	-131	450	177	2.040				
234*	700	3500	2.0	1400	58.0	366	315	6.42	606	-10	279	1212	-69	424	228	1.740			222.1	-2.6
235*	700	4000	2.0	1400	58.0	341	293	5.98	710	-10	444	1361	-10	406	272	1.530				

*Excluded from regression analysis W_g > 230 lb/sec outside range of interest

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Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in} , Film °R	H _{in} Btu/lb	T _{wg} , °F Aft End	T _{wg} , °F Real Throat	T _{wg} , °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	ρ _{out} lbm/ft ³	Eqn ΔP	ΔP Resid. % Diff	Eqn Δq	ΔH Resid. % Diff.
236	700	5000	2.0	1400	58.0	300.0	258	5.26	1025	-10	877	1834	181	421	420	1.09	419.7	-0.3	411.6	-2.0
237*	750	4000	2.0	1500	60.0	366.0	315	6.42	710	-4	427	1440	5	482	279	1.49				
238*	750	5000	2.0	1500	60.0	318.0	274	5.58	1025	-4	828	1859	158	464	408	1.13	461.0	-0.7	404.9	-0.8
239*	800	3500	2.0	1600	62.0	418.0	360	7.33	605	4	207	1231	-62	562	228	1.74				
240*	800	5000	2.0	1600	62.0	343.0	295	6.02	1025	4	813	1887	135	539	408	1.15				
241	150	2500	2.0	300	42.5	94.0	80.8	1.65	403	-85	416	678	-163	34.3	172	1.15	40.6	18.5	107.1	8.8
242	150	3000	2.0	300	42.5	85.2	73.2	1.49	505	-85	580	797	-136	48.9	268	0.602	57.3	17.2	259.5	-3.2
243	150	3500	2.0	300	42.5	78.3	67.3	1.37	610	-85	738	898	-80	60.5	350	0.405	67.4	11.4	342.4	-2.2
244	150	4000	2.0	300	42.5	73.1	62.9	1.28	716	-85	888	985	-14	74.0	445	0.294	76.7	3.7	434.6	-2.3
245	150	4500	2.0	300	42.5	68.4	58.8	1.20	845	-85	1014	1071	60	90.5	557	0.221	85.3	-5.7	537.4	-3.5
246	150	5000	2.0	300	42.5	63.6	54.6	1.12	990	-85	1180	1202	143	103.3	679	0.177	89.1	-13.7	652.6	-3.9
247	200	2000	2.0	400	45.0	140.1	120.0	2.46	326	-76	107	502	-223	58.0	116	2.000	56.5	-2.5	116.6	0.5
248	200	3000	2.0	400	45.0	113.5	97.5	2.00	497	-76	421	803	-143	64.0	228	0.740	69.6	0.8	240.7	5.6
249	200	4000	2.0	400	45.0	97.3	83.6	1.71	712	-76	778	1050	-11	94.0	410	0.431	98.1	4.3	403.1	-2.2
250	200	4500	2.0	400	45.0	90.9	78.0	1.59	828	-76	943	1168	52	111.0	516	0.327	107.9	-2.8	498.7	-3.4
251	200	5000	2.0	400	45.0	85.0	73.1	1.49	975	-76	1117	1304	138	128.0	626	0.254	116.8	-8.8	604.5	-3.4
252	225	2000	2.0	450	45.5	158.0	136.0	2.77	329	-72	168	523	-224	73.7	118	2.060	69.9	-5.2	113.2	-4.1
253	225	2500	2.0	450	45.5	141.0	121.0	2.47	411	-72	348	698	-179	73.0	179	1.390	77.2	5.8	168.5	-5.8
254	225	3000	2.0	450	45.5	128.0	110.0	2.25	496	-72	517	838	-137	81.0	244	0.937	88.4	9.2	233.6	-4.2
255	225	3500	2.0	450	45.5	117.0	101.0	2.05	603	-72	678	955	-79	93.0	318	0.654	99.9	7.4	308.8	-2.9
256	225	4000	2.0	450	45.5	110.0	94.6	1.93	714	-72	837	1074	-15	110.0	406	0.477	114.7	4.2	391.0	-3.7
257	225	4500	2.0	450	45.5	103.0	88.5	1.81	826	-72	990	1197	53	128.8	500	0.366	125.5	-2.6	483.4	-3.3
258	225	5000	2.0	450	45.5	95.4	82.0	1.67	975	-72	1138	1335	137	139.9	605	0.299	128.0	-8.5	587.8	-2.8
259	250	3000	2.0	500	46.0	142.0	122.0	2.49	496	-71	382	834	-137	84.3	221	1.160	90.8	7.7	299.2	7.7
260	250	3500	2.0	500	46.0	131.0	112.0	2.30	606	-71	578	1000	-75	98.0	300	0.786	106.9	9.1	392.0	0.7
261	250	4000	2.0	500	46.0	122.0	105.0	2.14	715	-71	748	1125	-11	111.0	380	0.585	118.7	6.9	383.7	1.0
262	250	4500	2.0	500	46.0	114.0	97.5	2.00	825	-71	921	1252	54	128.0	476	0.444	130.6	2.0	474.6	-0.3
263	250	5000	2.0	500	46.0	107.0	91.5	1.88	975	-71	1101	1391	138	146.0	580	0.351	140.2	-4.0	574.6	-0.9

*Excluded from regression analysis W_g > 280 lb/sec outside range of interest.

TABLE III

EQUATIONS WITH EXCESSIVE RESIDUALS
OR POOR MULTIPLE CORRELATION COEFFICIENTS

<u>Equation</u>	<u>Multiple Correlation Coefficient</u>	<u>Number of Cases with Residuals Exceeding 10%</u>
<u>ΔP, Separated Flow</u>		
1	.9803	30
2	.9796	35
3	.9296	54
4	.9801	*
5	.9801	35
6	.9794	38
7	.9930	*
<u>ΔP, Combined Regimes</u>		
10	.9955	32
11	.9822	82
13	.9957	31
14	.9953	33
<u>ΔP, Full Flow</u>		
18	.9834	13

*not tested for residuals

TABLE IV

EQUATIONS WITH MINIMAL RESIDUALS
AND/OR MULTIPLE CORRELATION COEFFICIENTS APPROACHING UNITY

<u>Equation</u>	<u>Multiple Correlation Coefficient</u>	<u>Number of Cases with Residuals Exceeding 10%</u>
	<u>ΔP, Combined Regimes</u>	
8	.9976	*
**9	.9958	33
12	.9957	*
	<u>ΔP, Full Flow</u>	
15	.9991	*
**16	.9983	0
17	.9971	1
19	.9980	*
20	.9977	1
21	.9964	0
22	.9981	1
	<u>ΔH, Separated Flow</u>	
**23	.9985	2
24	.9989	2
25	.9992	2
	<u>ΔH, Full Flow</u>	
**26	.9991	0
27	.9993	1

*not tested for residuals

**recommended equation

TABLE V

 ΔP INTERPOLATION TEST OF RECOMMENDED EQUATIONS

P_c - psia	T_c - °R	Interpolated ΔP From Data Plot	Equation ΔP	Percent Difference
$\Delta P_{\text{separated flow}} = e^{-4.434} T_c^{-0.119352} W_g^{1.7738} P_{\text{in}}^{0.198195} P_{\text{out}}^{-0.83392}$				
150	3750	57.0	59.8	5.0
150	2250	34.0	35.8	5.3
175	2000	44.7	44.7	1.7
175	2500	48.0	51.1	6.4
175	3500	69.0	73.2	6.1
175	5000	118.0	109.3	-7.3
200	2750	64.0	70.0	9.3
200	3250	76.0	81.3	7.0
200	4250	118.0	116.0	-1.7
250	2750	93.0	95.9	3.1
225	3000	86.0	94.1	9.5
225	4000	133.0	121.1	-8.9
$\Delta P_{\text{full flow}} = e^{-3.21237} T_c^{-0.420277} W_g^{1.77756} P_{\text{in}}^{0.383691} P_{\text{out}}^{-1.00745}$				
325	3000	123.0	122.8	-0.2
325	4000	138.0	143.3	3.9
325	5000	165.0	167.2	1.3
400	3250	175.0	176.3	0.7
400	3750	182.0	190.9	4.9
400	4750	210.0	214.0	1.9
525	4000	298.0	299.1	0.4
525	4500	313.0	302.1	-3.5
525	5000	335.0	315.5	-5.8
600	4250	401.0	406.9	1.5
650	4750	487.0	478.4	-1.8
675	5000	535.0	535.7	0.1

TABLE VI

 ΔH INTERPOLATION TEST OF RECOMMENDED EQUATIONS

<u>P_c - psia</u>	<u>T_c - °R</u>	<u>Interpolated ΔH From Data Plot</u>	<u>Equation ΔH</u>	<u>Percent Difference</u>
$\Delta H_{\text{separated flow}} = e^{-6.70512 T_c^{1.61981} W_g^{-0.323526} P_{in}^{0.156687} (H_{in} + 100)^{-0.0592244}}$				
150	3750	382.0	391.5	2.5
150	2250	145.0	156.9	8.2
175	2000	110.0	121.9	10.8
175	2500	176.0	179.5	2.0
175	3500	329.0	327.9	-0.3
175	5000	647.0	625.0	-3.4
200	2750	203.0	204.7	0.8
200	3250	267.0	276.0	3.4
200	4250	452.0	44.23	-2.1
250	2750	195.0	191.6	-1.8
225	3000	227.0	230.3	1.5
225	4000	378.0	385.7	2.0
$\Delta H_{\text{full flow}} = e^{-5.34266 T_c^{1.52306} W_g^{-0.369167} P_{in}^{0.0561104} (H_{in} + 100)^{0.0199182}}$				
325	3000	208.0	214.8	3.3
325	4000	347.0	352.4	1.6
325	5000	523.0	519.6	-0.7
400	3250	232.0	229.9	-0.9
400	3750	290.0	294.1	1.4
400	4750	447.0	439.0	-1.8
525	4000	302.0	301.2	-0.3
525	4500	370.0	369.7	-0.1
525	5000	445.0	443.8	-0.3
600	4250	314.0	318.9	1.5
650	4750	375.0	378.2	0.8
675	5000	407.0	408.7	0.4

TABLE VII
CASES TO STUDY VARIATION IN H_{in} AND W_c/W_g

Case No.	P_c psia	T_c °R	P_{in}/P_c	P_{in} psia	T_{in} °R	W_g lb/sec	W_c lb/sec	W_{film} lb/sec	$T_{in, Film}$ °R	H_{in} 3tu/lb	$T_{wg, °F}$ Aft End	$T_{wg, °F}$ Reat Throat	$T_{wg, °F}$ Fwd End	Coolant ΔP , psi	Coolant ΔH Btu/lb	ρ_{out} lbm/ft ³
1F	150	1500	2.0	300	42.5	121.85	79.20	2.14	250	*-87.8	59	374	-258	24.4	*93.7	2.52
2F	150	1500	2.0	300	42.5	121.85	91.39	2.14	250	*-87.8	26	352	-260	31.0	*84.0	2.69
3F	150	1500	2.0	300	42.5	121.85	115.76	2.14	250	*-87.8	-27	316	-263	46.5	*67.4	2.94
4F	150	2500	2.0	300	42.5	93.64	60.87	1.64	403	-85.0	430	725	-173	28.2	235.0	0.778
5F	150	2500	2.0	300	42.5	93.64	70.23	1.64	403	-85.0	382	706	-176	32.8	205.0	0.915
6F	150	2500	2.0	300	42.5	93.64	88.96	1.64	403	*-87.8	304	673	-179	44.0	*170.8	1.17
7F	150	3500	2.0	300	42.5	78.30	50.90	1.38	609	-85.0	780	930	-61	45.4	437.0	0.330
8F	150	3500	2.0	300	42.5	78.30	58.72	1.38	609	-85.0	719	924	-73	51.5	383.0	0.376
9F	150	3500	2.0	300	42.5	78.30	74.38	1.38	609	-85.0	620	903	-89	63.7	310.0	0.474
10F	150	4500	2.0	300	42.5	68.06	44.24	1.19	845	-85.0	1133	1189	93	67.8	701.0	0.193
11F	150	4500	2.0	300	42.5	68.06	51.04	1.19	845	-85.0	1057	1124	73	78.1	619.0	0.209
12F	150	4500	2.0	300	42.5	68.06	64.66	1.19	845	-85.0	939	1073	42	96.7	494.0	0.245
13F	200	2500	2.0	400	45.0	124.86	81.16	2.19	411	-76.0	378	735	-174	42.9	222.0	1.020
14F	200	2500	2.0	400	45.0	124.86	93.64	2.19	411	-76.0	328	716	-177	51.0	197.0	1.180
15F	200	2500	2.0	400	45.0	124.86	118.62	2.19	411	-76.0	248	683	-181	68.5	157.0	1.460
16F	200	3500	2.0	400	45.0	104.61	68.00	1.83	603	-76.0	736	981	-63	60.4	405.0	0.470
17F	200	3500	2.0	400	45.0	104.61	78.46	1.83	603	-76.0	673	961	-74	69.0	354.0	0.538
18F	200	3500	2.0	400	45.0	104.61	99.38	1.83	603	-76.0	570	937	-88	87.1	284.0	0.681
19F	200	4500	2.0	400	45.0	78.0	50.70	1.59	828	-76.0	1092	1243	81	62.5	674.0	0.286
20F	200	4500	2.0	400	45.0	78.0	58.50	1.59	828	-76.0	1016	1184	62	72.9	598.0	0.310
21F	200	4500	2.0	400	45.0	78.0	74.10	1.59	828	-76.0	894	1114	32	92.7	485.0	0.361
22F	250	2500	2.0	500	46.0	156.07	101.45	2.74	414	-70.0	339	753	-174	57.7	212.0	1.260
23F	250	2500	2.0	500	46.0	156.07	117.05	2.74	414	-70.0	286	731	-178	70.0	187.0	1.420
24F	250	2500	2.0	500	46.0	156.07	148.27	2.74	414	-70.0	202	692	-183	97.2	152.0	1.720
25F	250	3500	2.0	500	46.0	131.0	85.15	2.29	600	-70.0	706	1043	-59	73.0	377.0	0.627
26F	250	3500	2.0	500	46.0	131.0	98.25	2.29	600	-70.0	640	1020	-69	84.9	332.0	0.710
27F	250	3500	2.0	500	46.0	131.0	124.45	2.29	600	-70.0	533	989	-83	110.7	270.0	0.876
28F	250	4500	2.0	500	46.0	114.0	74.10	1.99	825	-70.0	1076	1340	82	96.1	595.0	0.384
29F	250	4500	2.0	500	46.0	114.0	85.50	1.99	825	-70.0	998	1293	65	112.1	528.0	0.418
30F	250	4500	2.0	500	46.0	114.0	108.30	1.99	825	-70.0	872	1230	37	146.2	426.0	0.473
31F	300	3500	2.0	600	48.0	157.0	102.05	2.75	590	-62.0	667	1085	-62	88.2	358.0	0.772
32F	300	3500	2.0	600	48.0	157.0	117.75	2.75	590	-62.0	599	1063	-72	103.2	315.0	0.869
33F	300	3500	2.0	600	48.0	157.0	149.15	2.75	590	-62	488	1028	-85	138.0	254.0	1.050
34F	300	4500	2.0	600	48.0	136.61	88.30	2.40	822	-62.0	1043	1404	82	111.2	564.0	0.481
35F	300	4500	2.0	600	48.0	136.61	102.46	2.40	822	-62.0	963	1359	65	131.8	499.0	0.516
36F	300	4500	2.0	600	48.0	136.61	129.73	2.40	822	-62.0	833	1297	39	174.8	404.0	0.587
37F	350	2500	2.0	700	49.0	218.5	142.02	3.83	412	-57.0	261	782	-150	93.5	195.0	1.650
38F	350	2500	2.0	700	49.0	218.5	163.88	3.83	412	-57.0	206	754	-155	115.6	172.0	1.820
39F	350	2500	2.0	700	49.0	218.5	207.58	3.83	412	-57.0	112	711	-162	170.6	142.0	2.040
40F	390	3300	1.6	624	48.2	210.0	136.50	3.68	600	-61.0	591	1087	-83	131.4	300.0	0.913
41F	390	3300	1.6	624	48.2	210.0	157.30	3.68	600	-61.0	525	1067	-90	157.3	266.0	1.010
42F	390	3300	1.6	624	48.2	210.0	199.50	3.68	600	-61.0	420	1025	-98	224.7	214.0	1.160
43F	390	3300	1.8	702	49.0	210.0	136.50	3.68	600	-57.0	567	1093	-86	119.8	300.0	1.040
44F	390	3000	1.8	702	49.0	210.0	157.50	3.68	600	-57.0	500	1067	-93	145.8	265.0	1.140
45F	390	3000	1.8	702	49.0	210.0	199.50	3.68	600	-57.0	392	1025	-103	206.2	216.0	1.320
46F	390	3000	2.0	780	49.8	210.0	136.50	3.68	600	-52.0	537	1095	-88	115.5	303.0	1.110
47F	390	3000	2.0	780	49.8	210.0	157.50	3.68	600	-52.0	468	1068	-96	140.0	265.0	1.230
48F	390	3000	2.0	780	49.8	210.0	199.50	3.68	600	-52.0	357	1021	-108	195.3	217.0	1.450
49F	390	3000	2.2	858	50.9	210.0	136.50	3.68	600	-47.0	508	1088	-90	110.1	305.0	1.200
50F	390	3000	2.2	858	50.9	210.0	157.50	3.68	600	-47.0	438	1059	-99	134.9	270.0	1.310
51F	390	3000	2.2	858	50.9	210.0	199.50	3.68	600	-47.0	325	1012	-112	192.1	220.0	1.510

*indicates farmer's tables

Table VII
Page 2 of 2

Case No.	P _c psia	T _c °R	P _{in} /P _c	P _{in} psia	T _{in} °R	W _g lb/sec	W _c lb/sec	W _{film} lb/sec	T _{in} Film °R	H _{in} Btu/lb	T _{wg} °F Aft End	T _{wg} °F Real Throat	T _{wg} °F Fwd End	Coolant ΔP, psi	Coolant ΔH Btu/lb	P _{out} lbm/ft ³
52F	400	3500	2.0	800	50.0	209.00	135.85	3.67	589	-52	605	1108	-64	122.5	334	1.020
53F	400	3500	2.0	800	50.0	209.00	156.75	3.67	589	-52	533	1141	-73	148.9	294	1.130
54F	400	3500	2.0	800	50.0	209.00	198.55	3.67	589	-52	417	1095	-87	206.3	239	1.330
55F	400	4500	2.0	800	50.0	182.33	118.51	3.20	810	-52	1000	1517	82	144.1	515	0.666
56F	400	4500	2.0	800	50.0	182.33	136.75	3.20	810	-52	915	1470	66	171.4	454	0.721
57F	400	4500	2.0	800	50.0	182.33	173.21	3.20	810	-52	777	1415	42	230.9	366	0.835
58F	450	4000	2.0	900	51.5	220.00	143.00	3.84	690	-44	773	1371	3	150.8	406	0.921
59F	450	4000	2.0	900	51.5	220.00	165.00	3.84	690	-44	692	1338	-10	186.3	358	0.988
60F	450	4000	2.0	900	51.5	220.00	209.00	3.84	690	-44	562	1289	-28	263.2	290	1.120
61F	500	3500	2.0	1000	53.0	262.00	170.30	4.59	591	-37	538	1214	-62	164.6	312	1.270
62F	500	3500	2.0	1000	53.0	262.00	196.50	4.59	591	-37	463	1183	-73	202.2	275	1.370
63F	500	3500	2.0	1000	53.0	262.00	248.90	4.59	591	-37	343	1133	-87	298.4	226	1.500
64F	500	4500	2.0	1000	53.0	227.89	148.13	4.00	804	-37	943	1594	82	177.7	478	0.859
65F	500	4500	2.0	1000	53.0	227.89	170.92	4.00	804	-37	854	1552	67	215.6	424	0.925
66F	500	4500	2.0	1000	53.0	227.89	216.50	4.00	804	-37	709	1491	43	313.5	345	0.991
67F	550	4000	2.0	1100	55.0	268.0	174.20	4.70	689	-29	712	1397	5	192.7	381	1.120
68F	550	4000	2.0	1100	55.0	268.0	201.00	4.70	689	-29	629	1363	-8	237.5	337	1.200
69F	550	4000	2.0	1100	55.0	268.0	254.60	4.70	689	-29	495	1308	-27	342.9	273	1.330
70F	600	4000	2.0	1200	57.5	292.0	189.30	5.13	691	-20	679	1449	5	217.4	377	1.200
71F	600	4000	2.0	1200	57.5	292.0	219.00	5.13	691	-20	597	1411	-13	269.7	332	1.270
72F	600	4000	2.0	1200	57.5	292.0	277.40	5.13	691	-20	464	1354	-32	400.0	267	1.370
73F	600	5000	2.0	1200	57.5	257.0	167.05	4.51	927	-20	1100	1861	148	231.3	550	0.877
74F	600	5000	2.0	1200	57.5	257.0	192.75	4.51	927	-20	1003	1811	131	285.0	487	0.916
75F	600	5000	2.0	1200	57.5	257.0	244.15	4.51	927	-20	845	1733	105	414.5	392	0.977
76F	625	4500	1.6	1000	53.0	285.0	185.25	5.00	804	-37	951	1667	84	274.2	444	0.828
77F	625	4500	1.6	1000	53.0	285.0	213.75	5.00	804	-37	863	1627	70	352.8	393	0.842
78F	625	4500	1.6	1000	53.0	285.0	270.75	5.00	804	-37	720	1569	51	523.4	314	0.859
79F	625	4500	1.8	1125	55.6	285.0	185.25	5.00	804	-27	915	1670	82	253.2	445	0.946
80F	625	4500	1.8	1125	55.6	285.0	213.75	5.00	804	-27	826	1630	68	312.9	393	1.090
81F	625	4500	1.8	1125	55.6	285.0	270.75	5.00	804	-27	680	1568	46	474.2	320	1.020
82F	625	4500	2.0	1250	57.5	285.0	185.25	5.00	804	-18	879	1672	81	236.4	451	1.050
83F	625	4500	2.0	1250	57.5	285.0	213.75	5.00	804	-18	788	1629	66	288.3	399	1.130
84F	625	4500	2.0	1250	57.5	285.0	270.75	5.00	804	-18	640	1566	43	426.4	322	1.190
85F	625	4500	2.2	1375	57.9	285.0	185.25	5.00	804	-13	849	1674	79	227.7	456	1.120
86F	625	4500	2.2	1375	57.9	285.0	213.75	5.00	804	-13	755	1629	64	279.7	404	1.200
87F	625	4500	2.2	1375	57.9	285.0	270.75	5.00	804	-13	603	1565	41	394.7	326	1.340
88H	390	3300	1.6	624	53.2	210.0	180.60	3.68	600	-45	429	1003	-97	218.7	236	0.967
89H	390	3300	1.6	624	43.2	210.0	180.60	3.68	600	-74	501	1081	-93	173.2	231	1.230
90H	390	3300	1.8	702	54.0	210.0	180.60	3.68	600	-42	405	1006	-101	198.1	239	1.110
91H	390	3300	1.8	702	44.0	210.0	180.60	3.68	600	-70	471	1078	-98	163.6	232	1.360
92H	390	3300	2.0	780	54.8	210.0	180.60	3.68	600	-37	373	1007	-105	183.7	239	1.240
93H	390	3300	2.0	780	44.8	210.0	180.60	3.68	600	-66	435	1074	-102	157.5	233	1.470
94H	390	3300	2.2	858	55.9	210.0	180.60	3.68	600	-33	344	1000	-108	179.6	246	1.310
95H	390	3300	2.2	858	45.9	210.0	180.60	3.68	600	-61	401	1063	-106	153.5	236	1.550
96H	625	4500	1.6	1000	58.0	285.0	245.10	5.00	804	-22	738	1568	58	490.0	346	0.777
97H	625	4500	1.6	1000	48.0	285.0	245.10	5.00	804	-52	826	1620	58	408.1	345	0.936
98H	625	4500	1.8	1125	60.6	285.0	245.10	5.00	804	-12	700	1570	55	426.3	352	0.945
99H	625	4500	1.8	1125	50.6	285.0	245.10	5.00	804	-42	784	1620	55	361.2	349	1.120
100H	625	4500	2.0	1250	62.5	285.0	245.10	5.00	804	-3	664	1569	53	387.0	355	1.090
101H	625	4500	2.0	1250	52.5	285.0	245.10	5.00	804	-32	741	1616	53	334.7	350	1.240
102H	625	4500	2.2	1375	62.9	285.0	245.10	5.00	804	2	632	1570	51	361.3	360	1.210
103H	625	4500	2.2	1375	52.9	285.0	245.10	5.00	804	-28	703	1615	50	323.0	356	1.340
121F	625	4500	1.6	1000	53.0	285.0	99.75	5.00	804	-37	1350	1891	148	118.7	736	0.642
122F	625	4500	1.6	1000	53.0	285.0	128.25	5.00	804	-37	1185	1792	121	165.3	604	0.720
123F	625	4500	1.6	1000	53.0	285.0	156.75	5.00	804	-37	1056	1722	100	216.8	502	0.788
124F	625	4500	1.6	1000	53.0	285.0	71.25	5.00	804	-37	1573	2047	183	75.6	956	0.517
125F	625	4500	1.6	1000	53.0	285.0	42.75	5.00	804	-37	1905	2321	236	37.8	1365	0.423

TABLE VIII

CASES TO STUDY VARIATION IN FILM COOLANT FLOW RATE AND INJECTION TEMPERATURE

Case No.	W_{film} lb/sec	T_{in} Film °R	T_{wg} , °F Aft End	T_{wg} , °F Real Throat	T_{wg} , °F Fwd End	Coolant ΔP , psi	ΔH Btu/lb	ρ_{out} lbm/ft ³
$P_c = 390$ psia, $T_c = 3300^\circ\text{R}$, $P_{\text{in}}/P_c = 2.0$, $P_{\text{in}} = 780$ psia, $T_{\text{in}} = 49.8^\circ\text{R}$, $W_g = 210$ lb/sec, $W_c = 180.5$ lb/sec, $H_{\text{in}} = -53$ Btu/lb								
104FC	2.0	300	398	1044	-234	170.8	241	1.33
105FC	2.0	600	398	1044	-83	170.9	242	1.32
106FC	2.0	900	399	1044	46	171.1	242	1.32
107FC	4.0	300	404	1042	-234	168.7	233	1.38
108FC	4.0	600	405	1041	-82	168.8	234	1.37
109FC	4.0	900	406	1040	49	169.0	235	1.37
110FC	6.0	300	407	1030	-235	165.7	223	1.44
111FC	6.0	600	408	1028	-80	166.0	225	1.43
112FC	6.0	900	408	1025	51	166.2	227	1.42
$P_c = 625$ psia, $T_c = 4500^\circ\text{R}$, $P_{\text{in}}/P_c = 2.0$, $P_{\text{in}} = 1250$ psia, $T_{\text{in}} = 57.5^\circ\text{R}$, $W_g = 285$ lb/sec, $W_c = 245$ lb/sec, $H_{\text{in}} = -17$ Btu/lb								
113FC	3.0	400	696	1595	-151	361.0	357	1.15
114FC	3.0	800	697	1595	52	361.1	358	1.15
115FC	3.0	1200	697	1595	223	361.6	360	1.15
116FC	5.0	400	702	1593	-152	358.2	348	1.18
117FC	5.0	1200	703	1591	224	358.7	350	1.17
118FC	7.0	400	705	1584	-152	354.8	341	1.21
119FC	7.0	800	705	1580	52	354.4	341	1.21
120FC	7.0	1200	706	1577	226	354.1	338	1.21

REMOVED

1937

1937