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ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		NAA-SR- TDR NO 11350	APPROVALS <i>A Nickols</i>
TECHNICAL DATA RECORD		PAGE 1 OF 37	<i>W F Brown</i>
AUTHOR Elizabeth L. Bramblett <i>Elizabeth L Bramblett</i>	DEPT & GROUP NO. 795 50	DATE May, 1965	
		GO NO 7636	
TITLE BOMPUP - SNAP 2 Thermoelectric Boiling Mercury Pump Model		S/A NO 2711	TWR
		SECURITY CLASSIFICATION	
PROGRAM	SUBACCOUNT TITLE	(CHECK ONE BOX ONLY) UNCL. ☒ AEC ☐ DOD CONF. ☐ SECRET ☐	(CHECK ONE BOX ONLY) RESTRICTED DATA ☐ DEFENSE INFO. ☐
DISTRIBUTION W. F. Brown * 795-50 Cano 2 E. Bramblett*(2) 795-50 Cano 5 H. M. Dieckamp* 720-10 Cano 2 H. H. Hanlin* 722-22 SS 036 J. M. Hochman* 722-22 SS 036 R. D. Keen* 722-22 SS 036 A. N. Nickols* 795-50 Cano 5 E. Ash Cano-2 E. Baumeister C-2 R. Castle Cano-2 G. Duncan SS-36 D. Ellis Cano-2 J. Hagel Cano-2 J. Howard Cano-2 H. Juell SS-37 R. Lancet Cano-2 J. McDonald Cano-2 D. Miller Cano-2 F. Poucher SS-37 W. Spalding SS-37 W. Velie Cano-2 F. Wimberly Cano-2 R. Wallerstedt Cano-2		STATEMENT OF PROBLEM To simulate a SNAP 2 thermoelectric, boiling mercury pump so as to compute certain pressure and temperature properties of the group.	
		ABSTRACT BOMPUP, by iteration between pressure and temperature, computes the pressure and temperature changes across the pump, the diffuser pressure drop, hydraulic losses pressure drop, and pump developed pressure.	

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I INTRODUCTION

BOMPUP, a code to simulate a boiling mercury pump, is on file at Department 792 as deck number 4W019. The code was written for J. M. Hochman, Department 722-22 by Elizabeth Lee Bramblett, Department 795-50, Atomics International.

II PURPOSE

While many of the properties of the SNAP 2 boiling mercury thermoelectric pump are known, some are not. The BOMPUP model views the pump as a series of adjoining sections. By computing the qualities of each section, the pump qualities can be determined. In particular, for each pump section the pressure, temperature, heat transfer coefficient, pump section length, chromel and constantan temperature changes, pressure drop across the diffuser, hydraulic losses pressure drop, and pump developed pressure are calculated and output. A more detailed technical discussion can be found in J. M. Hochman's report, "The Boiling Mercury Thermoelectric Pump," NAA-SR-TDR-11227.

III RESTRICTIONS

BOMPUP is written in FORTRAN IV for use with NAASYS on the IBM 7094. Necessary library subroutines are SQRT (square root), ALOG (natural logarithm), FORED (floating point data input), and EXP (exponential).

IV PROGRAM USE

A. Input Data

Each item of input data is associated with a numerical address and is input according to the following card format:

Column 1	Blank except for the last card of data, then a 1.
Column 2 - 6	Address of first item of data on the card.

A maximum of five pieces of data in format 5E12.8. Data is stored in the specified address and consecutively higher locations. A blank results in no change in storage.

For the first case a minimum of six data cards must be included. After that, only the data which is to be changed must be input. A given address retains data until it is altered by another input. Thus many cases may be run, back to back, with a minimum of data cards.

ADDRESSABLE DATA

Numeric Location	Report Symbol*	Description
1	a	Channel width, IN
2	b	Channel height, IN
3	D _{Hg}	Diameter of mercury tubes, IN
4	t	Mercury tube wall thickness, IN
5	PITCH	Mercury tube pitch, IN
6	D _{CØIL}	Mercury coil diameter, IN
7	W _{NAK}	NAK flow rate, LB/HR
8	W _{Hg}	Mercury flow rate, LB/HR
9	t _{CØ}	Thermoelectric element thickness (constantan), IN
10	t _{CH}	Thermoelectric element thickness (chromel), IN
11	t	NAK wall channel thickness, IN
12	t _{CU}	Thickness of copper, IN
13	T _{NAK,0}	Inlet NAK temperature, °F

*See Appendix III for associated program symbols.

Numeric Location	Report Symbol	Description
14	P_O	First guess at pressure, PSI
15	N_F	Total number of pump sections, ≤ 20
16	N_T	Number of pump sections to give 100% quality
17	N_{HgT}	Number of mercury coolant tubes
18 - 20		Unused
21	ARC	Area ratio constant
22	PLIM	Pressure convergence test value
23	B	Flux density, LINES/SQ. IN.
24	S_1	Seebeck coefficient of chromel, $V\phi LT/^{\circ}F$
25	S_2	Seebeck coefficient of constantan, $V\phi LT/^{\circ}F$
26	Q_6	Experimental MHD loss coefficient
27	D_{EXT}	Connecting tube diameter, IN
28	K_L	Entrance-exit loss coefficient
29	L_{BUS}	Bus length, IN
30	t_C	Bus thickness, IN

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APPENDIX I
Code Equations

A. PRINCE - Principal Program

The outlet pressure of a pump can be measured, but it is also desirable to know the inlet pressure and hence the pressure changes across the pump. Given an initial guess, P_0 , for the inlet pressure, the temperature and pump properties are calculated. Then the inlet pressure is computed based on these pump properties. An iteration is established between temperature and pressure until the difference between two consecutive pressure calculations is less than PLIM (an input value).

Assume initially that

$$PSAV = P_0$$

$$P_i = P_0, \quad i = 1, 2, \dots, N_F$$

where PSAV = the last computed value of pressure, to be used to test convergence.

P_0 = Initial guess for inlet pressure

P_i = Pressure of i-th section of the pump

N_F = Number of pump sections

For each section i of the pump, $i = 1, 2, \dots, N_F$, compute the pump properties defined by equations 1 - 19.

1. Mercury temperature, °F

$$T_i = 445.0490 + 70.55305(\ln P_{i-1}) + 7.113852(\ln P_{i-1})^2$$

2. Mercury properties

a. Liquid thermal conductivity, BTU/HR-°F-FT

$$k_{L,i} = 5.4 + .0047 T_i$$

b. Vapor thermal conductivity, BTU/HR-°F-FT

$$k_{v,i} = 3.8890909 \times 10^{-4} + 7.8690908 \times 10^{-6}(T_i)$$

c. Liquid density, LB/FT³

$$\rho_{L,i} = 851. - .083 T_i$$

d. Vapor density, LB/FT³

$$\rho_{v,i} = -1.8029786 + 1.0740586 \times 10^{-2}(T_i) \\ - 2.1742902 \times 10^{-5}(T_i)^2 + 1.5306810 \times 10^{-8}(T_i)^3$$

e. Latent heat of vaporization, BTU/LB

$$\lambda_i = 128.8 - \frac{128.8}{28641.}(T_i)$$

f. Liquid specific heat, BTU/LB-°F

$$C_{p,L,i} = .0313 + .160 \times 10^{-5}(T_i)$$

g. Vapor specific heat, BTU/LB-°F

$$C_{p,v,i} = 2.4756279 \times 10^{-2} + 1.0483414 \times 10^{-7}(T_i) \\ - 5.2140042 \times 10^{-10}(T_i)^2 + 8.2558775 \times 10^{-13}(T_i)^3$$

h. Liquid viscosity, LB/FT²-SEC

$$\mu_{L,i} = .00075 - .278 \times 10^{-6}(T_i)$$

i. Vapor viscosity, LB/FT²-SEC

$$\mu_{v,i} = 3.4361595 \times 10^{-6} + 5.6718831 \times 10^{-8}(T_i)$$

3. NAK Properties

Assume $T_{NAK,0} = T_{EMIN}$, an input value

a. Specific heat, BTU/LB-°F

$$C_{P_{NAK}} = .2075 + .208 \times 10^{-5} (T_{NAK,i-1})$$

where

$T_{NAK,j}$ = NAK temperature in j-th section

b. Temperature, °F

$$T_{NAK,i} = T_{NAK,i-1} - \frac{i(\lambda_i)(W_{Hg})}{N_T(W_{NAK})(C_{P_{NAK,i}})}$$

where

W_{Hg} = Mercury flow rate, LB/HR

W_{NAK} = NAK flow rate, LB/HR

N_T = Number of pump sections to produce 100% outlet quality. (e.g. If each section has 20% quality, then $N_T = 5$.)

c. Thermal conductivity, BTU/HR-°F-FT

$$k_{NAK,i} = 16.45 - .00133(T_{NAK,i})$$

d. Density, LB/FT³

$$\rho_{NAK,i} = 54.1 - .0084 (T_{NAK,i})$$

e. Viscosity, LB/FT-SEC

$$\mu_{NAK,i} = .000183 - .672 \times 10^{-7} (T_{NAK,i})$$

4. Average temperatures, °F

a. $TT1_i = T_{NAK,i} - T_i$

b. $TT2_i = T_{NAK,i-1} - T_{i-1}$

c. $T_{AVG,i} = (T_{NAK,i} + T_i) / 2.$

d. $T^2_{AVG,i} = (TT1_i + TT2_i) / 2.$

when $\frac{TT1_i}{TT2_i} < 2.$

$$T^2_{AVG,i} = \frac{TT1_i - TT2_i}{\ln \left(\frac{TT1_i}{TT2_i} \right)}$$

when $\frac{TT1_i}{TT2_i} \geq 2.$

5. Pump Materials Properties

a. Thermal conductivity of channel wall, BTU/HR-°F-FT

$$k_{w,i} = 9.05 - 4.62 \times 10^{-3} (T_{NAK,i})$$

b. Thermal conductivity of constantan, BTU/HR-°F-FT

$$k_{cp,i} = 13.547150 + 4.9361661 \times 10^{-3} (T_{AVG,i})$$

c. Thermal conductivity of chromel, BTU/HR-°F-FT

$$k_{ch,i} = 9.7890667 + 5.9666665 \times 10^{-3} (T_{AVG,i})$$

d. Thermal conductivity of mercury tubes, BTU/HR-°F-FT

$$k_{w,i} = 4.9 - .00629(T_i)$$

e. Thermal conductivity of copper, BUT/HR-°F-FT

$$k_{cu,i} = 226. - .021(T_{NAK,i})$$

6. Area ratio - heat transfer area of NAK channel wall divided by heat transfer area of mercury tubes

$$ARR = \frac{4b(ARC)}{\pi(D_{Hg})(N_{HgT}) \sqrt{\left[\frac{\pi(D_{COIL})^2}{PITCH} \right]^2 + 1.}}$$

where

b = NAK channel height, IN

ARC = Area ratio constant

D_{Hg} = Diameter of mercury tubes, IN

N_{HgT} = Number of mercury coolant tubes in parallel

D_{COIL} = Mercury coil diameter, IN

PITCH = Mercury tube pitch, IN

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7. NAK Reynold's Number

$$NRe_{NAK,i} = \frac{2.(\lambda_i)(W_{Hg})}{300.(a+b)(\mu_{NAK,i})}$$

where a = NAK channel width, IN

8. NAK heat transfer coefficient, BTU/HR-°F-FT²

$$h_{NAK,i} = \frac{436.(12)(a+b)(k_{NAK,i})}{2ab}$$

when $NRe_{NAK,i} < 2300$.

$$h_{NAK,i} = \frac{.625(12)(a+b)(k_{NAK,i})}{2ab} \left[\frac{3600.(C_{pNAK,i})(\mu_{NAK,i})(NRe_{NAK,i})}{k_{NAK,i}} \right]$$

when $NRe_{NAK,i} \geq 2300$.

9. Overall heat transfer coefficient on constantan side, BTU/HR-°F-IN²

$$R_{i,i} = \left[\frac{144.}{h_{NAK,i}} + \frac{144(ARR)}{h_{Hg,i}} + \frac{12.(t_{c\phi})}{k_{c\phi,i}} + \frac{12.(t_w)}{k_{w,i}} + \frac{12.(t_{cu})}{k_{cu,i}} + \frac{12.(t_w)(ARR)}{k_{w',i}} \right]^{-1}$$

where

- $h_{Hg,i}$ = Mercury heat transfer coefficient computed in subroutine HETRA, BTU/HR-°F-FT²
 t_{cp} = Constantan thermoelectric element thickness, IN
 t_w = Thickness of NAK channel wall, IN
 t_{cu} = Thickness of copper, IN
 t_w = Thickness of mercury tubewalls, IN

10. Overall heat transfer coefficient on chromel side, BTU/HR-°F-IN²

$$R_{2,i} = \left[\frac{144.}{k_{NAK,i}} + \frac{144.(ARR)}{h_{Hg,i}} + \frac{12.(t_{CH})}{k_{CH,i}} + \frac{12.(t_w)}{k_{w,i}} + \frac{12.(t_{cu})}{k_{cu,i}} + \frac{12.(t_w)(ARR)}{k_{w',i}} \right]^{-1}$$

where

- t_{CH} = Chromel thermoelectric element thickness, IN

11. Overall heat transfer coefficient, BTU/HR-°F-IN²

$$R_{TOTAL} = R_{1,i} + R_{2,i}$$

12. Length of i-th section, IN

$$L_i = \frac{W_{Hg}(\lambda_i)}{N_T(b)(R_{TOTAL})(T_{2,AVG,i})}$$

13. Mercury vapor Reynold's number

$$Rev_i = \frac{1}{300} \frac{(N_F + \frac{1}{2} - i)}{N_T} \frac{(4 \times W_{Hg})}{\pi (\mu_{L,i}) (D_{Hg}) (N_{HgT})}$$

14. Liquid mercury Reynold's number

$$Rel_i = \frac{1}{300} \left[\frac{N_T + i - (N_F + \frac{1}{2})}{N_T} \right] \left[\frac{4 (W_{Hg})}{\pi (\mu_{L,i}) (D_{Hg}) (N_{HgT})} \right]$$

15. Parameter for two-phase pressure drop for

a. viscous-viscous flow

$$ARG1_i = \left[\frac{P_{v,i} (\mu_{L,i}) (N_T + i - (N_F + \frac{1}{2}))}{P_{L,i} (\mu_{v,i}) (N_F + \frac{1}{2} - i)} \right]^{1/2}$$

when $Rev_i < 2000$.

b. viscous-turbulent flow

$$ARG1_i = \left[\frac{16 (P_{v,i}) (\mu_{L,i}) (N_T + i - (N_F + \frac{1}{2}))}{.046 (P_{L,i}) (\mu_{v,i}) (N_F - i + \frac{1}{2})} \right]^{1/2} \left[\frac{1}{Rev_i} \right]^{.4}$$

when $Rev_i \geq 2000$ and $Rel_i < 2000$.

c. turbulent-turbulent flow

$$ARG1_i = \left(\frac{P_{v,i}}{P_{L,i}} \right)^{1/2} \left(\frac{\mu_{L,i}}{\mu_{v,i}} \right)^{.1} \left[\frac{N_T + i - (N_F + \frac{1}{2})}{N_F + \frac{1}{2} - i} \right]^{.9}$$

when $Rev_i \geq 2000$ and $Rel_i \geq 2000$.

16. Lockhart-Martinelli type factor for two-phase pressure drop

$$\Phi_g^2 = \text{a function of } ARG1_i, Re_{L,i}, Re_{v,i} \text{ determined by the curve fitting code SADI}$$

17. Friction factor for

- a. laminar vapor flow

$$F_{T,i} = \frac{64}{Re_{v,i}} \quad \text{if } Re_{v,i} < 2000.$$

- b. turbulent flow

$$F_{T,i} = \frac{775}{(Re_{v,i})^{.85}} \quad \text{if } Re_{v,i} \geq 2000.$$

18. Total pump length, IN

$$L_{TOT,i} = \sum_{j=1}^i L_j$$

19. Temperature drop across the pump, °F

- a. constantan portion

$$\Delta T_{cf,i} = \frac{12. (TT1_i) (R_{1,i})}{k_{cf,i}}$$

- b. chromel portion

$$\Delta T_{ch,i} = \frac{12. (TT1_i) (R_{2,i})}{k_{ch,i}}$$

Having computed equations 1-19 for all sections, proceed to compute the pressure drop across the pump.

20. Pressure drop per unit length, PSI/IN

$$\left(\frac{\Delta P}{L}\right)_i = \frac{1}{300^2} \left\{ \frac{\Phi_{gi}^2 (F_{T,i}) (N_F + \frac{1}{2} - i) (4) (W_{Hg})}{N_T (D_{Hg}) (N_{HgT}) (\pi (D_{Hg})^2 (64.4) (\rho_{v,i}))} \right. \\ \left. + \frac{2. (N_F - i)}{32.2} \left[\left(\frac{(\pi (D_{C\phi IL}))^2}{PITCH} \right)^2 + 1 \right] \left(\rho_{v,i} (L_{TOT,i}) \right)^{-1} \right\} (FACT)$$

$$FACT = \left[\frac{4. (W_{Hg}) (N_F)}{\pi (D_{Hg})^2 (N_{HgT}) (N_T)} \right]^2$$

for $i = 1, 2, \dots, N_F$

21. Pressure in each section, PSI

$$P_i = P_o + \sqrt{\left(\frac{(\pi (D_{C\phi IL}))^2}{PITCH} \right)^2 + 1} \left[\sum_{j=1}^i \left(\frac{\Delta P}{L} \right)_j (L_{TOT,j}) \right]$$

for $i = 1, 2, \dots, N_F$

22. Pressure convergence test

$$\text{If } \left| \frac{P_{N_F} - P_{SAV}}{P_{SAV}} \right| > PLIM \quad \text{set } P_{SAV} = P_{N_F}$$

and return to equation 1 to proceed with another iteration.

$$\text{When } \left| \frac{P_{N_F} - P_{SAV}}{P_{SAV}} \right| \leq PLIM$$

proceed to equation 23 to compute other pump properties. For all pump sections, i.e., $i = 1, 2, \dots, N_F$, compute equations 23 - 42.

23. NAK resistivity, $\emptyset$ HM-IN

$$\rho_n = .55 \times 10^{-5} + .225 \times 10^{-7} (T_{NAK,i})$$

24. NAK tube resistivity, $\emptyset$ HM-IN

$$\rho_w = .2884 \times 10^{-4} + .146 \times 10^{-7} (T_{NAK,i})$$

25. Constantan resistivity, $\emptyset$ HM-IN

$$\rho_2 = 18.75 \times 10^{-6} + 4.5 \times 10^{-10} (T_{AVG,i})$$

26. Chromel resistivity, $\emptyset$ HM-IN

$$\rho_1 = .25 \times 10^{-4} + .6 \times 10^{-7} (T_{AVG,i})$$

27. Bus resistivity, $\emptyset$ HM-IN

$$\rho_c = .599 \times 10^{-7} + .244 \times 10^{-8} (T_i)$$

28. Area ratio (cross sectional area of pump throat/cross sectional area of the connecting pipe)

$$\frac{A_1}{A_2} = \frac{4ab}{\pi(D_{EXT})^2}$$

where

D_{EXT} = Connecting tube diameter, IN

29. Volumetric NAK flow rate, IN³/SEC

$$q = \frac{1728. (W_{NAK,i})}{3600. (\rho_{NAK,i})}$$

30. Pressure drop across diffuser, PSI

$$\Delta P_{DIFF,i} = K_L \left(1 - \frac{A_1}{A_2}\right)^2 \left[\frac{(\rho_{NAK,i} V_{NAK,i})^2}{144 (64.4)} \right]$$

where

K_L = Entrance-exit loss coefficient

$$V_{NAK,i} = \frac{1}{12} \left(\frac{q}{ab} \right)$$

31. Equivalent diameter, IN

$$D_{NAK,i} = \frac{2ab}{(a+b)}$$

32. Friction factor for NAK

$$F_i = \frac{16}{Re_{NAK,i}} \quad \text{if } Re_{NAK,i} < 2000.$$

$$F_i = .046 (Re_{NAK,i})^{-.2} \left[1 + \frac{.43}{e^{\left(\frac{.435 L_{T\Phi T,i}}{12 D_{NAK,i}} \right)}} \right] \quad \text{if } Re_{NAK,i} \geq 2000.$$

33. Hydraulic losses (frictional) pressure drop, PSI

$$P_{Hyd,i} = \frac{4 (F_i) (L_i)}{144 (D_{NAK,i})} \frac{(\rho_{NAK,i} V_{NAK,i})}{(64.4)}$$

34. Chromel resistance, Ω HM

$$R_i = \frac{\rho_i (t_{CH})}{b (L_i)}$$

35. Constantan resistance, $\emptyset$ HM

$$R_2 = \frac{\rho_2 (t_{co})}{b(L_i)}$$

36. Channel wall (normal to current) resistance, $\emptyset$ HM

$$R_{w'} = \frac{2(t_w)(\rho_w)}{b(L_i)}$$

37. Bus resistance, $\emptyset$ HM

$$R_b = \frac{\rho_c (L_{BUS})}{2(t_c)(L_i)}$$

where

L_{BUS} = Bus length, IN

t_c = Bus thickness, IN

38. Combined resistance of channel wall in parallel with NAK and end leakage, $\emptyset$ HM

$$R_{||} = \frac{\left[\frac{a(\rho_w)(\rho_n)(N_F)}{.8(t_w)(L_i)(b)} \right]}{\left[\frac{\rho_n(N_F)}{.4b} + \frac{a(\rho_w)}{b(L_i)} \right]}$$

39. NAK resistance, $\emptyset$ HM

$$R_n = \frac{a(\rho_n)}{b(L_i)}$$

40. Total resistance, Ω HM

$$R_{SUM} = R_1 + R_2 + R_w + R_b + \frac{R_{11} R_n}{R_{11} + R_n}$$

41. Magneto-hydrodynamic pressure drop, PSI

$$P_{Mhd,i} = \frac{8.83 \times 10^{-16} (Q_6)(B^2)(q)}{b(L_i)}$$

where

Q_6 = Experimental MHD loss coefficient

B = Flux density, LINES/SQ. IN.

42. Pump developed pressure per section, PSI

$$P_{Dev,i} = 8.83 \times 10^{-8} \left(\frac{B}{b}\right) (DEV2) - P_{Mhd,i} - P_{Hyd,i} - \Delta P_{DIFF,i}$$

$$DEV2 = \left[\frac{S_1 (\Delta T_{CH,i}) - S_2 (\Delta T_{C\phi,i}) - \frac{R_{11} (10^{-8})(Bq)}{(R_{11} + R_n) b}}{R_{SUM}} \right] \left(\frac{R_{11}}{R_{11} + R_{SUM}} \right) - \frac{(10^{-8})(Bq)}{b(R_{11} + R_n)}$$

where

S_1 = Seebeck coefficient of chromel, VOLTS/ $^{\circ}$ F

S_2 = Seebeck coefficient of constantan, VOLTS/ $^{\circ}$ F

43. Total pump developed pressure, PSI

$$P_{T\phi T} = \sum_{j=1}^{N_F} P_{Dev,j}$$

B. Subroutine HETRA

Every time i is incremented in the equations in PRINCE, a heat transfer coefficient is required. With all subscripts and values intact, the equations in HETRA are computed. When convergence to a coefficient has occurred, the coefficient becomes available for completion of the computations in PRINCE. If the coefficient diverges, an error procedure selects the coefficient from the first iteration.

The flow chart for HETRA indicates the tests to select the mode of boiling activity for the determination of the heat transfer coefficient.

1. Vapor quality

$$XXN = \frac{N_F + \frac{1}{2} - i}{N_T}$$

2. Factors for equations

$$\beta = .43$$

$$C = 2.3$$

$$\text{when } 0. \leq XXN \leq .4$$

$$\beta = 1.$$

$$C = 3.$$

$$\text{when } .4 < XXN < 1.$$

3. Mercury flow rate/area, LB/HR-FT²

$$G = \frac{4 \cdot (W_{Hg})}{\pi (D_{Hg})^2 (N_{HgT})}$$

4. Total resistance to heat transfer (except for mercury heat transfer), ØHM

$$K = \frac{144}{h_{NAK,i}} + \frac{6 \cdot t_{cH}}{k_{cH,i}} + \frac{6 \cdot t_{c\phi}}{k_{c\phi,i}} + \frac{12 \cdot t_w}{k_{w,i}} + \frac{12 \cdot t_{c_v}}{k_{c_v,i}} + \frac{12 \cdot t_{w'}}{k_{w'}}$$

5. Critical temperature change, °F

a.

$$\Delta T_{CRIT,1} = \frac{(7488.)^{\frac{1}{2}}}{12.} \frac{C^2}{N_{\mu_g}} \frac{D_{Hg}}{\tan \alpha} \left(\frac{g}{D_{Hg}} \right)^{\frac{3}{2}} \left(\frac{\lambda_i \mu_{v,i}}{\mu_{v,i} k_{v,i}} \right) \left(\frac{k_{v,i}}{k_{L,i}} \right)^3 \left(\frac{\rho_{L,i}}{\rho_{v,i}} \right)^{\frac{1}{2}} (XXN)(1.-XXN)^{\frac{1}{2}}$$

b.

$$\Delta T_{CRIT,2} = \frac{(936.)^{\frac{3}{4}}}{12.(6.)^{\frac{1}{4}}} \frac{C^3 D_{Hg}}{\tan \alpha} \left(\frac{g}{D_{Hg}} \right)^{\frac{3}{2}} \left(\frac{\lambda_i \mu_{v,i}}{\mu_{v,i} k_{v,i}} \right) \left(\frac{k_{v,i}}{k_{L,i}} \right)^3 \left(\frac{\rho_{L,i}}{\rho_{v,i}} \right)^{\frac{1}{2}} (XXN)(1.-XXN)^{\frac{1}{2}}$$

where

$$N_{\mu_g} = .8$$

$$g = .04$$

$$\tan \alpha = .867$$

6. Heat transfer coefficient for contact boiling, BTU/HR-°F-FT²

a.

$$h_{Hg,i} = h_{CONTACT} = \frac{12.}{32.} N_{\mu_g}^2 \left(\frac{k_{v,i}}{D_{Hg}} \right) \left(\frac{D_{Hg}}{g} \right)^2 \left(\frac{k_{L,i}}{k_{v,i}} \right)^2 \left(\frac{\rho_{v,i}}{\rho_{L,i}} \right) \frac{(1.-XXN)^{\frac{1}{3}}}{XXN}$$

b.

$$DEL F = \frac{144. (ARR)(TTI_i)}{144. (ARR) + K(h_{CONTACT})}$$

where K = Total resistance to heat transfer except for mercury heat transfer.

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7. Heat transfer coefficient for intermittent boiling, BTU/HR-°F-FT²

a.

$$\gamma_1 = 2(K)(144)(ARR)$$

b.

$$\gamma_2 = \frac{[144.(ARR)(TTI_i)]^2}{\gamma_3}$$

c.

$$\gamma_3 = \frac{234.(C^4)}{12.} \left(\frac{k_{v,i}}{D_{Hg}} \right) \left(\frac{8}{D_{Hg}} \right) \left(\frac{k_{v,i}}{k_{l,i}} \right)^4 \left[\frac{(tan \alpha)(D_{Hg})(G)(\lambda_i)(\mu_{v,i})}{\mu_{v,i}(k_{v,i})} \right]^2 (XXN)(1.-XXN)^{4/3}$$

d.

$$VAL1 = \frac{-(\gamma_1 - \gamma_2) + \sqrt{(\gamma_1 - \gamma_2)^2 - \gamma_1^2}}{2K^2} = \frac{(\gamma_2 - \gamma_1) + \sqrt{\gamma_2^2 - 2\gamma_1\gamma_2}}{2K^2}$$

e.

$$VAL2 = \frac{(\gamma_2 - \gamma_1) - \sqrt{\gamma_2^2 - 2\gamma_1\gamma_2}}{2K^2}$$

f. $h_{Hg,i} = h_{INTER}$ = maximum positive value of VAL1, VAL2

8. Heat transfer coefficient for film boiling, BTU/HR-°F-FT²

$$h_{Hg,i} = h_{FILM} = \frac{(12.6)^{1/3}}{4.} \beta^{4/3} \left(\frac{k_{v,i}}{D_{Hg}} \right) \left(\frac{D_{Hg}}{8} \right) \left[\frac{D_{Hg}(G)(tan \alpha)(\lambda_i)(\mu_{v,i})}{\mu_{v,i}(k_{v,i})(DEL T2)} \right]^{2/3} \left(\frac{\rho_{v,i}}{\rho_{l,i}} \right)^{2/3} \frac{(1.-XXN)^{2/3}}{XXN^{1/3}}$$

where

$$DEL T2 = \frac{144.(ARR)(TTI_i)}{144.(ARR) + K(h_{FILM})}$$

APPENDIX II

PRINCE Flow Chart

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HETRA Flow Chart

APPENDIX III

Symbols Dictionary*

Report Symbol

Program Symbol

 T_i
 $T(I)$
 P_i
 $P(I)$
 $k_{L, i}$
 KL
 $k_{V, i}$
 KV
 $\rho_{L, i}$
 $RH\emptyset L$
 $\rho_{V, i}$
 $RH\emptyset V$
 λ_i
 LAM
 $C_{P_L, i}$
 CPL
 $C_{P_V, i}$
 CPV
 $\mu_{L, i}$
 MUL
 $\mu_{V, i}$
 MUV
 $T_{NAK, i}$
 $TNAK(I)$
 $C_{P_{NAK}, i}$
 $CPNAK$
 W_{Hg}
 WHG
 N_T
 XNT
 W_{NAK}
 $WNAK$
 $k_{NAK, i}$
 $KNAK$
 $\rho_{NAK, i}$
 $RH\emptyset NAK = RH\emptyset N(I)$
 $\mu_{NAK, i}$
 $MUNAK$
 $TT1_i$
 $TT1$
 $TT2_i$
 $TT2$
 $T_{AVG, i}$
 $TAVG$

*In order of appearance in equations.

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Report SymbolProgram Symbol $T^2_{AVG, i}$

TAVG2

 $k_{W, i}$

KW

 $k_{C\emptyset, i}$ KC $\emptyset$ $k_{CH, i}$

KCH

 k_w, i

KT

 $k_{CU, i}$

KCU

ARR_i

ARR

b

CHAH

ARC

ARC

 D_{Hg}

HGD

 N_{HgT}

XNHGT

 $D_{C\emptyset IL}$

HGCD

PITCH

HGP

NRe_{NAK}

RENAK

a

CHAW

 $h_{NAK, i}$

HNAK

 R_l, i RC $\emptyset$ $h_{Hg, i}$

HG(I)

 $t_{C\emptyset}$ TC $\emptyset$ t_w

TW

 t_{CU}

TCU

 t_w

HGT

 t_{CH}

TCH

 R_2, i

RCH

 $R_{T\emptyset TAL}$ RT $\emptyset$ T L_i

LG(I)

Rev_i

REV

Report SymbolProgram Symbol

Rel_i	REL
$ARG1_i$	ARG1
ϕ^2_{gi}	ARG3
$F_{T, i}$	FT
$L_{T\phi T, i}$	LGT ϕ T(I)
$\Delta T_{C\phi, i}$	DTC ϕ
$\Delta T_{CH, i}$	DTCH
ρ_n	RHNAK
ρ_w	RHTB
ρ_2	RHC ϕ
ρ_1	RHCH
ρ_c	RHBUS
$\frac{A1}{A2}$	ARAT
D_{EXT}	DEXT
q	QQ
$\Delta P_{DIFF, i}$	PDIF(I)
$D_{NAK, i}$	DNAK
$P_{Hyd, i}$	PHYD
r_1	R1
r_2	R2
r_w	RWP
r_b	RB
L_{BUS}	BUSLG
t_c	THBUS
r_{11}	R11

Report SymbolProgram Symbol

r_n	RN
r_{SUM}	RSUM
$P_{Mhd, i}$	PMHD(I)
Q_6	Q6
B	FLUX
$P_{Dev, i}$	PDEV(I)
S_1	SCH
S_2	SCØ
$P_{TØT}$	PDTØT
XXN	XXN
β	BETA
C	CC
G	G
K	RESH
$\Delta T_{CRIT, 1}$	DT1
$\Delta T_{CRIT, 2}$	DT2
$N_{\mu 8}$	NU8
δ	DELTA
$\tan \alpha$	TANT
$h_{Hg, i}$	HG(I)
$h_{CØNTACT}$	HG(I)
h_{INT}	HG(I)
h_{FILM}	HG(I)

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE _____ of _____ JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 1		Address of data
13 .8		a
25 .8		b
37 3.35 -01		D _{Hg}
49 2. -02	73 80	t _w
61 2.5		PITCH
1 6		
13 3.06		D _{CØIL}
25 5.1 +03		W _{NAK}
37 1.344 +02		W _{Hg}
49 1.	73 80	t _{CØ}
61 1.		t _{CH}
1 11		
13 2. -02		t _w
25 3 +00		t _{CU}
37 1200.		T _{NAK, 0}
49 6.	73 80	P _o
61 5.		N _F
1 16		
13 5.		N _T
25 2.		N _{HgT}
37		
49	73 80	
61		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE _____ of _____ JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	21		
13	1.		ARC
25	1. -02		PLIM
37	1.45 +04		B
49	1.86 -05	73 80	S ₁
61	-2.94 -05		S ₂
1	26		
13	27 +00		Q ₆
25	1.		D _{EXT}
37	.5		K _L
49	3.44	73 80	L _{BUS}
61	.25		t _C
1			
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			

APPENDIX IV

Printed Output

The input data is identified by its description. The calculated data is defined as follows:

I = J = Pump section number
P(I) = Pressure, PSI
T(I) = Mercury temperature, °F
TNAK(I) = NAK temperature, °F
HG(I) = Heat transfer coefficient
LG(I) = Section length, IN
DTCØ(I) = Temperature change in constantan
portion of pump, °F
DTCH(I) = Temperature change in chromel
portion of pump, °F
LGTØT = Total pump length, IN

Region of activity indicates the region of
boiling (contact, intermittent or film).

PDIF(J) = Pressure drop across the diffuser, PSI
PHYD(J) = Hydraulic losses pressure drop, PSI
PDEV(J) = Developed pressure, PSI
PDTØT = Total developed pressure, PSI

**** SIMULATED BOILING MERCURY PUMP ****

*** INPUT VALUES ***

CHANNEL WIDTH, IN	8.0000E-01	CHANNEL HEIGHT, IN	8.0000E-01
DIAMETER OF MERCURY TUBES, IN	3.3500E-01	NUMBER MERCURY COOLANT TUBES	2.0000E 00
HG TUBE WALL THICKNESS, IN	2.0000E-02	HG TUBE PITCH, IN	2.5000E 00
HG COIL DIAMETER, IN	3.0600E 00	THICKNESS OF COPPER, IN	3.0000E-01
HG FLOW RATE, LB/HR	1.3440E 02	NAK FLOW RATE, LB/HR	5.1000E 03
NAK WALL CHANNEL THICKNESS, IN	2.0000E-02	INLET NAK TEMPERATURE, DEG F	1.2000E 03
T/E ELEMENT THICKNESS-CONST., IN	1.0000E 00	T/E ELEMENT THICKNESS-CHROMEL, IN	1.0000E 00
TOTAL NUMBER OF PUMP SECTIONS	5.0000E 00	NO SECTIONS FOR 100 PERCENT QUAL.	5.0000E 00
OUTLET PRESSURE, PSI	6.0000E 00	AREA RATIO CONSTANT	1.0000E 00
TEST FOR PRESSURE CONVERGENCE	10.0000E-03		
FLUX DENSITY, LINES/SQ IN	1.4500E 04	CONNECTING TUBE DIAMETER, IN	1.0000E 00
SEEBECK COEFF. OF CHROMEL	1.8600E-05	SEEBECK COEFF. OF CONSTANTAN	-2.9400E-05
EXPERIMENTAL MHD LOSS COEFF.	2.7000E-01	ENTRANCE-EXIT LOSS COEFF.	5.0000E-01
BUS LENGTH, IN	3.4400E 00	BUS THICKNESS, IN	2.5000E-01

I	P(I)	T(I)	TNAK(I)	HG(I)	LG(I)	DTC0(I)	DTCH(I)
1	4.0246E 01	8.0287E 02	1.1969E 03	3.0075E 00	7.5490E 01	1.5919E 01	1.8635E 01
2	4.5463E 01	8.1798E 02	1.1937E 03	1.2699E 01	2.5454E 01	4.9376E 01	5.6674E 01
3	4.7740E 01	8.2410E 02	1.1906E 03	2.3400E 01	1.7475E 01	7.7997E 01	8.8284E 01
4	5.0095E 01	8.3016E 02	1.1874E 03	1.0747E 01	3.3780E 01	4.0212E 01	4.6268E 01
5	5.0122E 01	8.3023E 02	1.1843E 03	2.0268E 01	2.0500E 01	6.6945E 01	7.6043E 01
				LGT0T=	1.7270E 02		

I REGION OF
ACTIVITY

1 FILM
2 FILM
3 FILM
4 FILM
5 FILM

I	PDIF(J)	PHYD(J)	PDEV(J)
1	4.2624E-03	3.7858E-01	-7.6583E 00
2	4.2598E-03	1.2642E-01	-2.1804E 00
3	4.2573E-03	8.6562E-02	-1.2854E 00
4	4.2547E-03	1.6704E-01	-3.0111E 00
5	4.2522E-03	1.0132E-01	-1.5991E 00
		PDT0T=	-1.5734E 01