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LIQUID ROCKET PLANT

OPERATIONAL AND TECHNICAL DISCUSSION

OF

NOZZLE TUBE PROGRAM

Report No. 8209-64-5

17 February 1964

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OPERATIONAL AND TECHNICAL DISCUSSION
OF
NOZZLE TUBE PROGRAM

Job 18111 (U) or Job 18110 (C-RD)

Report No. 8209-64-5

17 February 1964

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APPENDIX B - INPUT SHEETS

1.0 PURPOSE

The purpose of this report is to explain the operation and provide a technical discussion of the nozzle tube heat transfer and pressure drop program.

2.0 PROGRAM PURPOSE AND CAPABILITIES

This program was designed to analyze heat transfer and pressure drops in the NERVA nozzle tubes for a steady state point. As all geometric configurations are input values, the program may be used for other configurations including skirt coolant tubes.

The program will check for throat choking and raise the inlet pressure to pass the input flow rate. If the nozzle is not choked, input pressure will remain the same.

The program also has an option to calculate a discontinuous pressure drop after the throat. This is used in case there is choking both in the nozzle tubes and in another point downstream in the system.

The program results may be obtained as unclassified (Job No. 18111) or Confidential Restricted Data (Job No. 18110).

3.0 TECHNICAL DISCUSSION

3.1 Glossary of Terms

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
A_c	Cold Flow Area	in ²
C_c	Cold side wetted perimeter	in
C_H	Hot side wetted perimeter	in
C_p	Specific Heat	BTU/lb °R

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
D_H	Hot side diameter	in
f	Friction factor (cold side)	
g_c	Gravitational constant	ft/sec ²
h_c	Cold side heat transfer coefficient	BTU/in ² sec°R
h_h	Hot side heat transfer coefficient	BTU/in ² sec°R
K	Thermal conductivity metal	BTU-in/in ² °R sec
K_I	Manifold pressure drop constant	
L_i	Factor in heat transfer coefficient equations	$K_{gas} \left(\frac{4}{\pi \mu} \right)^{.8} N_{PR}^{.4}$
L	Length from cold side entrance	in
N	Number of distance increments	
P	Pressure (absolute)	lbs/in ²
q	Rate of heat transfer	BTU/sec
R	Recovery factor	
t	Temperature	°R
V	Velocity	ft/sec
W	Mass flow rate	lbs/sec
X	Wall thickness	in
ΔZ	Distance increment	in
δ	Factor in hot side heat transfer equation	
	$\delta = 2 \frac{T_{static}}{T_{stagnation}}$	
$@$	Density	lbs/ft ³

3.2 Equations

1. Initial Exit Temperature Guess

$$T_{HN} = .98 R_N T_6 \dots\dots\dots 1$$

Obtain R_N from table of recovery factor vs distance (input) T_6 is input.

2. Inlet Pressure

$$P_{in} = P_3 - K_I \frac{w^2}{\rho_3}$$

P_3 and K_I are input. K_I factor was obtained combining empirical entrance, turning, velocity change, and exit loss factors.

3. Guess Q_i 2

4. Obtain D_{HN} and R_N from table of distance vs diameter and R_N .

$$5. \quad T_{HN+1} = R_{N+1} \frac{T_{HN}}{R_N} + \frac{Q_i}{w_H C_{PHN}}$$

Find C_{pHN} from T_{HN} , P_{HN} table.

$$6. \quad T_{Hi} = \frac{T_{HN+1} + T_{HN}}{2}$$

$$7. \quad T_{CN+1} = T_{CN} + \frac{Q_i}{w_C C_{PCN}}$$

$$8. \quad T_{Ci} = \frac{T_{CN} + T_{CN+1}}{2}$$

$$9. \quad P_{CN+1} = P_{CN} - f_c \frac{C_{CN} \Delta Z W_c^2 144}{e_{CN} A^3 2g}$$

Obtain A_c , C_c from distance table

e_{CN} from P_{CN} and $T_{c_{avg}}$.

At throat and other input prints add input distance to ΔZ .

9a. At throat check for choke.

$$P'_0 = \frac{\sqrt{T_0 W}}{.14 A_c}$$

$P'_0 \leq P_0$ (Equation 9) proceed to Equation 10

$P'_0 \geq P_0$ (Equation 9

(1) Print out choke message.

(2) Raise P_3 and repeat Equation 1 thru 9 iterating to close

P'_0 Equation 9a $\leq P_0$ Equation 9.

$$10. \quad h_{ci} = \frac{11^{.8 W_c .8 L_{ci}} \left(\frac{T_{ci}}{T_{cwi}} \right)^{.34} .0217 C_{cN}^{.2}}{4 A_{cN}}$$

Thompson's "B" Equation

Find L_{ci} from P, T table, guess T_{cwi} 3

$$11. \quad T_{cwi} = T_{ci} + \frac{Q_i}{h_{ci} C_{HN} \Delta Z}$$

Find C_H vs distance table. Check vs T_{CWN} Equation 10. Iterate to close

3

$$12. \quad h_{hi} = \frac{.021 W_H^{.8} L_{Hi}}{D_{HN}^{1.8}} \left(\frac{\rho^{T_{Hi}}}{T_{Hi} + T_{HWi}} \right)^{.8}$$

Find L_{Hi} (table), ρ (table) Guess T_{HWN} 4

Bartz Equation Modified:

a. Viscosity ratio ignored, assume $\left(\frac{\mu_c}{\mu_l}\right)^{0.2} \approx 1$

b. Coefficient changed to .021 to more closely agree with test data.

$$c. \quad L_{Hi} = K \left(\frac{4}{\pi \mu} \right)^{.8} N_{PR}^{.4}$$

$$d. \quad \rho = \frac{2 T_{static}}{T_{stagnation}}$$

$$13. \quad T_{HWi} = T_{Hi} - \frac{Q_i}{h_{hi} C_H \Delta Z}$$

Check against T_{HWN} Equation 12. Iterate to close (4)

$$14. \quad T_M = \frac{T_{HWi} + T_{CW_i}}{2}$$

$$15. \quad K_M = (1.385 + .001017 T_M)^{10-4}$$

Obtained from NERVA Materials Data Book and curve fitted.

$$16. \quad Q_i = \frac{(T_{Hi} - T_{Ci}) C_{HN} \Delta Z}{\frac{X}{K_M} + \frac{1}{h_{hi}} + \frac{1}{h_{ci}}}$$

Check against Q_i guess iterate to close (2)

17. Take next segment return to Equation 4

* 18. Test computed T_6 ($T_{H_{final}}$) against error = .01 ($T_{6_i} - T_3$)

Iterate close (1)

18a. Use only if expansion wave is input.

At end of last node check $P_{cold} = P_4$ (input)

$$(1) \quad P_{Cold(Eq. 9)} = P_4(input)$$

$$(2) \quad P_{Cold(Eq. 9)} > P_4(input)$$

Lower P_3 until $R_{cold} = P_4$ or P'_o at throat (Eq. 9a) =

P_o (Eq. 9) If $P_{cold} > P_4$ and P'_o throat (eq. 9) =

P_o Eq. 9

Subtract a discontinuous pressure drop at the end of the node containing the throat. Iterate until $P_{cold} = P_4$.

(3) $P_{cold} < P_4$ input. Raise P_3 and repeat program iterating to close $P_{cold} = P_4$.

* NOTE:: Initial guess (Equation 1) is usually close enough so that this iteration is rarely needed.

3.3 Logic Flow Chart

4.0 PROGRAM OPERATING INSTRUCTIONS

4.1 Input Location and Loading

<u>Location</u>	<u>Description</u>	<u>Units</u>	<u>Comments</u>
L0	Cold Gas Inlet Pressure	psia	
L1	Cold Gas Inlet Temperature	°R	
L2	Cold Side Flow Rate	lbs/sec	
L3	Hot Gas Pressure	psia	
L4	Stagnation Temperature Hot Gas Inlet	°R	
L5	Friction Factor		f as used in Form $\Delta P = \frac{4f L}{D} \frac{\rho v^2}{2}$
L6	Tube Wall Thickness	inches	
L7	Number of Nodes		
L8	Initial Q	BTU/sec	Guess for first node heat transfer.
L9	Hot Side Flow Rate	lb/sec	
L10	Manifold Drop Constant		K as used in $\Delta P = \frac{K W^2}{e}$
L11	Total Tube Length	inches	
L12	Throat	inches	Distance from cold inlet.
L13	Throat Bend	inches	Equivalent length of throat bend.
L14	Number of pairs of Bend Drops		Use only when Tables 30 thru 69 is used.
L15	Outlet Cold Gas Pressure	psia	Use only when expansion wave option is used

<u>Location</u>	<u>Description</u>	<u>Units</u>	<u>Comments</u>
L30 thru L69	Bend Location and Equivalent Length	inches inches	Location of bend (or plenum) in inches from cold inlet vs equiva- lent length of bend or other drop.
L70 thru L119	Distance and Cold Flow Area	inches inches ²	Distance from cold inlet and cold flow area.
L120 thru L169	Distance and Cold Flow Wetted Perimeter	inches + inches	Distance from cold inlet vs cold flow wetted perimeter (C_c).
L170 thru L209	Distance and Hot Side Diameter	inches inches	Distance from cold inlet vs nozzle inside diameter.
L210 thru L249	Distance and Recovery Factor	inches $^{\circ}R/^{\circ}R$	Distance from cold inlet vs hot side temp. recovery factor (R) $R = \frac{T_r}{T_o}$
L250 thru L299	Distance and Circum- ference Hot Side	inches inches	Distance from cold inlet vs circumference C_H (see Fig. 1 Glossary Section 3.1).
L300	Distance and ϕ	inches	Distance from cold inlet vs ϕ $\phi = \frac{2 T_{static}}{T_{stagnation}}$ See Eq. 12 for deriv- ation.

4.2 T Card

All locations except column 3 and 4 may contain anything or be blank. For instructions on columns 3 and 4 see below:

4.2.1 Column 3 - Blank if only final result print out is wanted. Punch "1" if P_{cold} , T_{cold} , $T_{\text{cold wall}}$, $T_{\text{hot wall}}$, Q_1 are printed out for each node.

4.2.2 Column 4 - Blank if expansion wave option is not used. (L15 must also be blank in this case).
Punch "1" if expansion wave option is used.
L15 must contain a value in this case.

4.3 Standard Input Deck

Locations L0-L10 are not standard and must be input whenever program is used.

Locations L-11 - L14 and tables L30-L380 contain values for NRX nozzle tubes Drawing No. 284800. This current deck is Confidential. These values may be overridden by input. If no values are input at these locations, program values will be used.

L-15 is only used if expansion wave option is used.
(See T Card Section).

4.4 Stacking Cases

Cases may be stacked by following the following steps:

1. Insert card containing values to be changed after previous T-Card.
2. Insert T card. Card must be made out in accordance with Section 4.2.

4.5 Program Number and Security Classification

If the results are to be UNCLASSIFIED fill out "Program No. 18111" on computing sciences change card.

If the results are to be CLASSIFIED (Confidential Restricted Data), fill out "Program No. 18110" on computing sciences control card.

4.6 Program Options

4.6.1 Print Out Option

- a. Only final results are printed out.
(Appendix A, Fig. 1 for example) Column 3 of T card, must be blank.
- b. Results of each node are printed out.
(Appendix A, Fig. 2 for example) Column 3 of T card must contain "1".

4.6.2 Expansion Wave Option

If this option is used, an expansion wave will be calculated in the nozzle to match a fixed output pressure.

- a. L-15 must contain a value.
- b. Column 4 of T card must contain "1".

If this option is not used nozzle tube output pressure will be that calculated by program.

- a. L-15 must be blank.
- b. Column 4 of T card must be blank.

APPENDIX A, Figure 1

Sample Output Final Result Printout

FINAL RESULTS OF NOZZLE TUBE PROGRAM

P3	T3	WR	P6	T6	WN	F FACT	X	DELTA	K IN	QT	P4	T4
900.000	40.000	72.0000	550.000	4100.0	70.0000	.0055	.001	8.08	.025	26622	760.830	136.786

NOTE: All values are fictitious to keep report unclassified.

APPENDIX A, Table 2

Output (All Node Printout)

PC	TC	TCW	THW	Q	DELTA
871.245	46.875	428.431	439.044	1055.345	8.080
869.025	54.762	508.970	526.699	1437.417	8.080
864.449	63.972	659.236	689.712	1991.623	8.080
849.025	73.414	924.413	978.198	2544.395	7.210
844.575	75.297	1168.139	1260.759	624.047	.870
803.006	95.208	678.596	751.068	6781.232	8.080
789.444	110.367	585.400	622.782	4937.130	8.080
771.786	124.218	454.107	476.152	3964.109	8.080
760.830	136.786	430.755	449.232	3287.095	8.080

FINAL RESULTS OF NOZZLE TUBE PROGRAM

P3	T3	WR	P6	T6	WN	F FACT	X	DELTA	K IN	QT	P4	T4
900.000	40.000	72.0000	550.000	4100.0	70.0000	.0055	.001	8.08	.025	26622	760.830	136.786

NOTE: All values are fictitious to keep report unclassified.

Sample Output (All Node Printout)

	TC	TCW	THW	Q	DELTA
5	46.875	428.431	439.044	1055.345	8.080
5	54.762	508.970	526.699	1437.417	8.080
9	63.972	659.236	689.712	1991.623	8.080
5	73.414	924.413	978.198	2544.395	7.210
5	75.297	1168.139	1260.759	624.047	.870
6	95.208	678.596	751.068	6781.232	8.080
4	110.367	585.400	622.782	4937.130	8.080
6	124.218	454.107	476.152	3964.109	8.080
0	136.786	430.755	449.232	3287.095	8.080

FINAL RESULTS OF NOZZLE TUBE PROGRAM

	T3	WR	P6	T6	WN	F FACT	X	DELTA	K IN	QT	P4	T4
0	40.000	72.0000	550.000	4100.0	70.0000	.0055	.001	8.08	.025	26622	760.830	136.786

All values are fictitious to keep report unclassified.

CUSTOMER INSTRUCTIONS		KEYPUNCH INSTRUCTIONS		CUSTOMER		DATE
<p>1. ENTER DATA LEGIBLY WITHIN SPACES PROVIDED</p> <p>2. DISTINGUISH BETWEEN 1 vs l, 8 vs 0, 2 vs 2, ll vs V, 5 vs S</p> <p>3. INCLUDE ALL DECIMAL POINTS IN HAND POSTED NUMBERS.</p> <p>4. T CARD IS THE LAST CARD FOR EACH TEST CASE.</p>		☒ PUNCH 1 CARD PER HAND POSTED LINE ITEM		JOB NO. 1811		PROGRAMMER
		☐ PUNCH ALL * LINES WHETHER POSTED OR NOT. IF NECESSARY PROVIDE BLANK CARDS				
		☐ PUNCH ALL * LINES THAT ARE HAND POSTED		TITLE NOZZLE TUBE HEAT TRANSFER PCM.		
		PAS INCLUDING SPACES				
		ALL SPACES MAY BE IGNORED				
ALL SPACES MAY BE IGNORED EXCEPT ON T CARD		☐ DO NOT PUNCH PRE-PRINTED SIGNS SHOWN AFTER LAST HANDWRITTEN VALUE ENTRY		FORM APPROVED (KEY PUNCH)		DATE
ALL SPACES MAY BE IGNORED EXCEPT (Specify cols.)		☒ KP L FIELD ONLY IF HAND POSTED				
ALL SIGNS ON KEY PUNCH LINES MUST BE PUNCHED		☒ T CARD MUST ALWAYS BE KP				
<div><div>1234567891011121314151617181920212223242526272829303132333435363738394041424344454647484950515253545556575859606162636465666768697071727374757677787980</div><div><div>DISTANCE</div><div>DIAMETER (HOT SIDE)</div><div>L 1 1 0 + 0 + 3 0 + 3 0 + 1 0 + 6 0 + 4 0 + 7 2 + 4 0</div></div><div><div>DISTANCE</div><div>RECOVERY FACTOR</div><div>L 1 1 0 + 0 + . 9 + 2 0 + . 9 8 + 6 0 + 7 1 + 1</div></div><div><div>DISTANCE</div><div>CIRCUMFERENCE HOT FLOW AREA</div><div>L 2 5 0 + 0 + 4 0 + 3 0 + 1 5 . 2 + 4 0 + 1 1 . 7 + 6 0 + 4 8 + 1 1 + 4 8</div></div><div><div>DISTANCE</div><div>SIGMA</div><div>L 3 0 0 + 0 + . 5 3 1 + 1 0 + . 9 5 + 2 0 + 1 . 3 + 3 0 + 1 . 6 6 + 6 0 + 2 . 0 + 7 2 + 1 . 0</div></div></div>						