SNPO-C

Records

WANL-TME-1057
REVISION 1

August 6, 1965

Westinghouse Astronuclear Laboratory

PRELIMINARY EVALUATION OF PRESSURE DROP AND TEMPERATURE RISE
IN EST PUMP SUCTION LINE

MASTER

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Westinghouse Electric Corporation

Astronuclear Laboratory

Box 10864, Pittsburgh, Pa. 15236

TSD-N-370

AUG 12 1965

Mr. J. L. Dooling
NERVA Subcontract Manager
Rocket Engine Operations - Nuclear
Department 7140
Aerojet-General Corporation
Post Office Box 1947
Sacramento, California

Attention: Mr. W. E. Durkee

Subject: Transmittal of WANL-TME-1057, REVISION 1, "Preliminary Evaluation
of Pressure Drop and Temperature Rise in EST Pump Suction Line"

Gentlemen:

Transmitted herewith are ten (10) copies of the subject report. This revision covers predicted performance of the NRX/EST pump suction line as it is now installed. Your attention is called, in particular, to Paragraph 2C, which discusses the significance of FE-4 venturi throat pressure vs. NPSH at the test car interface.

Respectfully,

Original signed by

H F Faught PM
H. F. Faught
Program Manager
NERVA Nuclear Subsystem

Enclosures (10)

cc: ✓ R. W. Schroeder, SNPO-C, w/enclosures (3)
SNPO-C/WANL Resident Office, w/o enclosures
AGC/WANL Resident Office, w/o enclosures
K. Kasschau, Special Assistant to the NERVA Project Manager, at
AGC/Sacto, w/o enclosure
A. Schaff, Jr., REON/Sacto, w/enclosure

INFORMATION CATEGORY

UNCLASSIFIED

WANL-TME-1057
REVISION 1

August 6, 1965

N. G. Farquhar
Authorized Classifier

8/10/65
Date

PRELIMINARY EVALUATION OF PRESSURE DROP AND TEMPERATURE RISE
IN EST PUMP SUCTION LINE

PREPARED BY:

N. G. Farquhar
N. G. Farquhar
Test Systems Design

MASTER

APPROVED BY:

D. J. McDonald
D. J. McDonald, Supervisor
Test Systems Design

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Westinghouse Electric Corporation
Astronuclear Laboratory
Pittsburgh, Pennsylvania 15236

DISTRIBUTION

SW

PRELIMINARY EVALUATION OF PRESSURE DROP AND TEMPERATURE RISE
IN EST PUMP SUCTION LINE

INTRODUCTION

The Test Cell "A" propellant piping installation is now being modified to provide a piping system which will be suitable for NRX/EST tests. Details of the new system are covered in TME-1092, "Propellant Feed System Design Package No. 1," dated January 28, 1965. As a part of the new system there will be a new pump suction line to supply liquid hydrogen from the dewars to the NRX/EST test car interface. A schematic view of the layout and the main components in the pump suction line is shown in Sketch No. TME 1057-1.

This technical memo provides predicted operating characteristics of the pump suction line. It has been prepared to assist in the planning of facility checkout tests which will establish the actual operating characteristics. The revision is necessary to reflect design changes and to provide additional predicted performance data.

SUMMARY AND CONCLUSIONS

I. TEMPERATURE (See Curve No. TME 1057-1)

- A. Liquid hydrogen flowing from the dewars to the test car interface will be heated by heat leaking through pipe insulation, instrumentation leads, etc., and by fluid friction. The resultant increase in

fluid temperature is shown as a function of flowrate in Curve No. TME 1057-1. At flowrates above 3 lb/sec, the temperature rise between the dewars and the test car interface will be less than 1°R. Therefore, if the usual temperature of 38°R is maintained in the dewars, the liquid temperature at the test car interface will be less than 39°R for all flows above 3 lb/sec. The prediction of temperatures for flowrates below 3 lb/sec becomes increasingly unsatisfactory as the flowrate decreases, because in this region small changes in estimated heat leak make large changes in fluid temperature.

- B. By reference to Curve No. TME 1057-1, it is seen that at low flowrates the temperature rise will be controlled by heat leak through the insulation. At high flowrates the controlling factor will be heat generated by fluid friction. The combination of these factors will result in a minimum temperature rise of 0.15°R at approximately 30 lb/sec flowrate.

II. PRESSURE (See Curve Nos. TME 1057-2 and 3)

- A. The performance of the system can perhaps be best understood by considering a typical pressure profile as shown on Curve No. TME 1057-2. The profile selected is for a flowrate of 76.5 lb/sec. Starting with a maximum allowable system pressure of 77 psig, there is a gradual drop in static pressure between the dewars and venturi inlet FE-4. In the convergent section of the venturi, an isentropic

expansion lowers the static pressure to 46 psig at the venturi throat. In the divergent section of the venturi most of the drop in the convergent section is recovered. Based on experimental data this recovery has been estimated at 85%. A conservative estimate of 10 psi is shown for filter F-56. At the test car interface a delivery pressure of 54 psig is predicted.

- B. Inasmuch as the venturi throat pressure is a low point in the profile, it is equally important with the interface pressure. For this reason Curve No. TME 1057-3 has been prepared to show the variation of these pressures with liquid hydrogen flowrate. Required dewar pressures can be predicted from this curve.
- C. The significance of the dip in static pressure at the throat of the venturi can be seen by the following analysis. Curve No. TME 1057-3 shows that at high flowrates the predicted venturi throat pressure is almost 10 psi lower than the test car interface pressure. The actual dip in pressure could easily be 10 psi or more since predicted pressure losses between the venturi throat and the interface are believed to be conservatively high. In this case, a specification of 10 psi minimum NPSH at the interface would not prevent vapor formation in the venturi. If this should occur, there would be an unstable pressure profile in the system, reduced flowrate, and the probability that vapor bubbles would reach the pump inlet. For these reasons it is recommended that the NPSH requirement should be

established at a value sufficiently high to insure a minimum subcooling (perhaps 10 psi) at the venturi throat. The example shown on Curve TME 1057-3 predicts that an NPSH of 19 psi at the interface will insure 10 psi subcooling at the venturi throat when flowing 80 lb/sec of liquid hydrogen.

SCHEMATIC OF TEST CELL "A"
LIQUID PROPELLANT SYSTEM
FOR NRX/EST

SKETCH No. TME 1057-1

NG.F 8/3/65

N G F 8-3-65

CURVE NO TME 1057-1

TYPICAL PRESSURE PROFILE NRX/EST PUMP SUCTION LINE

76.5 LB/SEC FLOW

PRESSURE - PSIG.

001 06 09 07 09 05 04 03 02 01 0

DEWAR
A

JBV-1

JBV-3

IN THROAT OUT
FE-4

F-56

TEST CAR
INTERFACE

SYSTEM LOCATION

NOT TO SCALE

SOLID LINE - PRESSURE AT FE-4 VENTURI THROAT
DASH " - " " " TEST CAR INTERFACE

NOTES:

1-THIS FAMILY OF CURVES SHOWS HOW THE TWO ABOVE STATIC PRESSURES WILL VARY WITH FLOW WHEN DEWAR PRESSURE IS 30, 40, 50, 60, 70, & 77 PSIG WHEN FLOW IS ZERO ALL POINTS IN THE SYSTEM ARE AT DEWAR PRESSURE.

2- AT 80 LB./SEC. FLOWRATE, A MIN. DEWAR PRESSURE OF 45 PSIG WILL BE REQ'D TO MAINTAIN A MIN. NPSH OF 10 PSI. HOWEVER, 54 PSIG WILL BE REQ'D TO MAINTAIN 10°R SUBCOOLING AT THE VENTURI THROAT.

3.- INTERMEDIATE POINTS ARE LOCATED BY MOVING ENTIRE CURVES UP OR DOWN. ALL POINTS ON A CURVE SHOULD BE MOVED THE SAME DISTANCE

19 PSI NPSH

-10 PSI NET POS. SUCT. HD

PRESSURE OF SAT. LIQ.
AT 39° R.

WESTINGHOUSE ELECTRIC CORPORATION

TEMPERATURE RISE DUE TO HEAT LEAK

THE SIGNIFICANCE OF CALCULATIONS OF TEMPERATURE RISE DUE TO HEAT LEAK DEPENDS ALMOST ENTIRELY ON THE ESTIMATE OF PROBABLE OPERATING HEAT LEAKS. THE FOLLOWING FIGURES ALLOW FOR POSSIBLE POOR VACUUM IN JACKETED PIPE, AND ARE BELIEVED TO BE CONSERVATIVELY HIGH.

VAC. JACK. PIPE, 150 FT. $\times$ 80 Btu/ft./hr = 12,000 Btu/hr.
 FOAM INSUL. " , 20 FT. $\times$ 150 " " " = 3,000 " "
 MISC. VALVES, FITTINGS, etc. 10,000 " "
 ESTIMATED TOTAL 25,000 " "

$$\Delta T = \frac{25,000 \text{ Btu/hr}}{\text{FLOW (lb./sec.)} \times \text{Sp. Ht. (Btu/lb.}^\circ\text{R)} \times 3600 (\text{sec/hr})}$$

Sp. Ht. = APPROX. 2.4 Btu/lb. $^\circ$ R.

$$\Delta T = \frac{2.9}{\text{FLOW (lb./sec.)}}$$

FLOW	ΔT
1	2.9
10	.29
20	.15
etc.	

WESTINGHOUSE ELECTRIC CORPORATION

TEMPERATURE RISE DUE TO FLUID FRICTION

HEAT EQUIVALENT TO MECHANICAL ENERGY USED TO
OVERCOME FRICTION = 1 Btu / 778 Ft. lb.

$$\Delta P \text{ IN PSI} \times \frac{144}{\text{DENSITY}} = \Delta P \text{ IN FT OF LIQ. H}_2$$

$$1 \text{ PSI} = \frac{144}{4.4} = 33 \text{ FT LIQ. H}_2$$

BASIS: 1 lb. LIQ. H₂

$$\text{Btu GENERATED} = \frac{\Delta P(\text{PSI}) \times 33}{778} = .0425 \Delta P(\text{PSI})$$

$$\Delta T = \frac{.0425 \Delta P(\text{PSI})}{\text{Sp. Ht} = 2.4 \text{ Btu/lb } ^\circ\text{R.}} = .0177 \Delta P(\text{PSI}) ^\circ\text{R.}$$

<u>FLOWRATE</u> <u>(lb/SEC.)</u>	<u>ΔP</u> <u>(PSI)</u>	<u>ΔT</u> <u>(°R)</u>
30	3.5	.062
40	6.3	.11
50	9.8	.17
etc.		

WESTINGHOUSE ELECTRIC CORPORATION

PRESSURE LOSS

A. DEWAR 'A' TO PROPELLANT HEADER (8" SCHED. 5)

ASSUME 50% OF TOTAL FLOW FROM DEWAR 'A'
BASIS: TOTAL FLOW = 76.5 lb./sec.

$$\text{VOLUME FLOWRATE} = 76.5 / 2 / 4.4 \text{ lb./ft}^3 = 8.7 \text{ ft}^3/\text{sec.}$$

$$\text{VELOCITY} = 8.7 / .3855 \text{ ft}^2 = 22.5 \text{ ft/sec.}$$

$$\text{VELOCITY HEAD} = \frac{22.5 \times 22.5}{2 \times 32.2} \times \frac{4.4}{144} = 0.24 \text{ PSI.}$$

$$\Delta P = K \times \text{VELOCITY HEAD.}$$

K = .45	STRAIGHT PIPE
.96	VALVE
<u>2.45</u>	FITTINGS
3.86	

$$\Delta P = 3.86 \times .24 = \underline{1 \text{ PSI}}$$

B. PROPELLANT HEADER TO TEST CAR INTERFACE

$$\text{VOLUME FLOWRATE} = 76.5 / 4.4 = 17.4 \text{ ft}^3/\text{sec.}$$

$$\text{VELOCITY (SCHED. 5)} = 17.4 / .3855 = 45 \text{ ft./sec.}$$

$$\text{" (SCHED. 10)} = 17.4 / .3784 = 46 \text{ " "}$$

$$\text{" (" 40)} = 17.4 / .3474 = 50 \text{ " "}$$

SINCE SEVERAL PIPE SCHEDULES HAVE BEEN INSTALLED
ASSUME VEL. = 48 ft/sec. - (WITHIN ACCURACY OF
CALCULATION)

$$\text{VELOCITY HEAD} = \frac{48 \times 48}{2 \times 32.2} \times \frac{4.4}{144} = 1.1 \text{ PSI.}$$

WESTINGHOUSE ELECTRIC CORPORATION

$$\begin{array}{rcl} K = & 2.4 & \text{STRAIGHT PIPE} \\ & 1.0 & \text{VALVE} \\ & \underline{2.85} & \text{FITTINGS} \\ & 6.25 & \end{array}$$

$$\Delta P = 6.25 \times 1.1 = 6.9 \text{ PSI}$$

$$\begin{array}{rcl} \text{ADD CONTINGENCY} & \underline{1.1} & \\ \text{USE} & \underline{8} & \text{PSI} \end{array}$$

C. FE-4 LOSS

$$\text{VELOCITY ENTERING} = 46 \text{ FT/SEC.}$$

$$\text{" IN THROAT} = 46 \times \frac{54.5}{10.4} (\text{AREA RATIO}) = 241 \text{ FT/SEC}$$

ASSUME ISENTROPIC EXPANSION

$$\begin{aligned} \Delta P &= \frac{V_{\text{THROAT}}^2 - V_{\text{ENTRANCE}}^2}{2g} \frac{\rho (\text{DENSITY})}{144} \\ &= \frac{241^2 - 46^2}{64.4} \times \frac{4.4}{144} = 26.5 \text{ PSI.} \end{aligned}$$

ASSUME 85% RECOVERY IN DIVERGENT SECTION

$$\text{LOSS} = .15 \times 26.5 = \underline{4 \text{ PSI.}}$$

D. F-56 LOSS

$$\begin{array}{l} \text{SPEC. CALLS FOR 8 PSI } \Delta P \text{ AT 75 lb/SEC - CLEAN} \\ (76.5/75)^2 \times 8 = 8.3 \text{ PSI} \end{array}$$

ASSUME SOME FOULING - USE 10 PSI.

WESTINGHOUSE ELECTRIC CORPORATION

E. TOTAL PRESSURE DROP

DEWAR "A" PIPING	-	1.0	PSI
HEADER	"	-	8.0 "
FE-4	-	4.0	"
F-56	-	<u>10.0</u>	"
TOTAL	-	23.0	"

F. BASIS FOR PRESSURE DROP CURVES

- 1) ΔP , PIPING, VARIES AS SQUARE OF FLOWRATE.
- 2) FE-4 NET LOSS ASSUMED 15% OF ΔP TO THROAT.
- 3) ΔP , F-56, VARIES AS SQUARE OF FLOWRATE.