Failure Modes and Effects Analysis

RETF ALTITUDE TEST STAND B

May 8, 1985

I. SCOPE

The purpose of this report is to identify the principal hazards resulting from operating the RETF B Stand Altitude Exhaust System while testing rocket engines using hydrogen and oxygen gaseous propellants.

II. GENERAL SYSTEM DESCRIPTION

The B Stand altitude exhaust rocket engine test will make use of several new systems and minor modifications to several other systems at the RETF. These systems are:

1. Altitude exhaust system
2. Motive fluid nitrogen system
3. Water spray cooling system
4. Diffuser cooling water system
5. Mechanical vacuum pump system
6. Gaseous hydrogen system
7. Gaseous oxygen system

1. ALTITUDE EXHAUST SYSTEM CF100881, 43086M245103

The rocket engine is fired in an evacuated test chamber. The rocket exhaust is collected by a second throat exhaust diffuser and passes into the spray cooler. In the spray cooler, water is sprayed into the exhaust stream to cool it and condense a large portion of the rocket exhaust. Theremaining exhaust passes out of the spray cooler and into two parallel trains of ejectors which produce the altitude condition. These ejectors are driven by gaseous nitrogen motive fluid. At the exit of the ejectors the mixed rocket exhaust (H_2O & GH_2) and nitrogen is exhausted to atmosphere through two stacks.

2. MOTIVE FLUID NITROGEN SYSTEM CF100881, 43086M245103

The motive fluid gaseous nitrogen is stored in two separate bottle storage farms at the RETF. 370000 SCF are stored in the 6000 psi bottle farm which is an existing, operational bottle farm. A new three inch XXS stainless steel pipe connects this farm to the ejector platform. At the ejectors, the pressure is reduced to 500 psi with two regulators N4486 and N4463. These are then connected through annin shutoff valves and flow switches to three of the four ejectors. In the ejector the nitrogen mixes with the rocket exhaust and is eventually dumped to atmosphere. A second, new bottle farm located atop the water detention tank stores 330000 SCF of additional nitrogen at 4000 psi. This farm is connected to the ejector platform with a 3 inch SCH160 stainless pipe. Regulator N4473 is used to reduce the pressure to 500 psi. The flow passes through a flow switch and a shutoff valve before entering the fourth ejector.

3. WATER SPRAY COOLING SYSTEM CF 100881, 43086M245103

Cooling water from the RETF 500000 Gallon water reservoir is routed through a new 18 inch water line to the spray cooler. There the flow splits to five spray banks inside the cooler. Shutoff valves on three of these allow differing amounts of water cooling. The spray banks consist of pipe manifolds with many brass spray nozzles, located such that an even spray covers the whole cross section of the cooler. The cooling water collects in the bottom of the spray cooler before draining through an 18 inch drain line to the detention tank. A control valve in this drain is used to maintain 18 inches of water in the bottom of the cooler.

4. DIFFUSER COOLING WATER SYSTEM CF100881, 43086M245103

A separate six inch water line takes reservoir water and routes it to a pump which will pump 1800 gpm at 75 psid. This flow passes through a shutoff valve and then to the diffuser cooling jacket. Upon exiting the diffuser, the water passes through a flow switch and a back pressure regulator before being routed to the detention tank.

5. MECHANICAL VACUUM PUMP SYSTEM 43086M245103

A 350 CFM Stokes mechanical vacuum pump located under the test cell is connected to the test chamber through a 6 inch vacuum line. Shutoff valves at the pump and at the test chamber isolate the pump, with an atmospheric vent valve in-between. This system is used to pump down the altitude system prior to each run and is valved off and the pump shut down during actual rocket firing.

6. GASEOUS HYDROGEN SYSTEM 43086M245104

Gaseous hydrogen propellant for rocket combustion comes from one of two possible sources. The primary source will be NASA tube trailers that are located in the upper south forty next to Building 305. This trailer station is connected to the RETF with a $1^1/2$ inch stainless pipe line. A solenoid at the trailer station allows remote operation of the trailer pneumatic shutoff valves. The line is routed across the pipe bridge and onto the roof of the fuel pit before entering the test cell. A shutoff valve at this location isolates the RETF from the hydrogen source and is tied into the prop-stop abort. A regulator (located next to the shutoff valve) reduces the pressure to 1800 psi. Downstream of the regulator, a swing elbow allows selection of the second possible source for hydrogen, mainly, the existing 4000 psi bottle farm and pipeline. This system has its own regulator, shutoffs, and controls and is an existing approved, operational system. Downstream from the swing elbow, the flow (from either source) passes through a venturi flowmeter and through the fire valve and into the rocket injector.

7. GASEOUS OXYGEN SYSTEM 43086M245100

Gaseous oxygen propellant comes from a NASA tube trailer located in the upper south forty. This trailer has been operational for previous B Stand testing. The pipeline connecting it to RETF has been enlarged to $1^1/2$ inch. This line is routed down the hill and through the pipe trench underneath the lower road. The pipe then enters the ox pit where the main shutoff valve is located. The line then enters the test cell where a regulator reduces the pressure to 1800 psi before the flow passes through a venturi and then to the fire valve. From the fire valve, the gas enters the rocket injector.

ELECTRICAL SYSTEMS

This portion of the hazard analysis is concerned exclusively with the sequential control logic for the fluid systems. The logic is directed by a Modicon 384 Programmable Controller (P.C.) by way of a user-constructed program.

The principal hazard associated with any programmable controller's sequential logic is the inadvertent or unauthorized alteration of the program. To control this hazard, the P.C. manufacturer furnishes a key-operated MEMORY PROTECT switch which, when in the ON position, prevents any attempt to alter the program. Also, a data entry system has been devised and programmed such that the set point of certain timers and counters can be changed by entering new data into the proper holding register from a digital thumbwheel switch bank on an operator's panel. This supplants the need to change these set points from the programming unit, thereby avoiding the possibility of an inadvertent alteration of the program.

The risk of an unintentional alteration of a set point is reduced because the DATA ENTRY pushbutton is a guarded-type pushbutton.

Another hazard experienced with programmable controller applications is the spurious energization of an output in the absence of any command, especially while the control station is unattended. To control this hazard, all source power to all output modules is turned off during idle periods.

The program, for this application, employs a somewhat unique four zone control scheme. As the name implies, the logic is divided into four distinct but interrelated zones; identified as PRERUN (Zone 1), RUN (Zone 2), NORMAL SHUTDOWN (Zone 3), and ABORT (Zone 4). In addition, the logic includes an emergency stop provision identified as PROP STOP (propellant stop), and a first-out annunciator network.

The duration of each of the four zones is goverened by its zone timer. Also, within each zone, any P.C. output is capable of being energized and de-energized during various time bands, as directed by the program. In order to accomplish this type of control, the P.C. program has 200 timers, each of which can be independently set via the data entry system previously described. In addition, in Zone 2, the NAVEC timer operates to control certain portions of the test sequence.

Prior to the start of the automatic sequencing, the P.C. outputs are programmed to respond to several operator's commands (pushbutton actuations). And, where the program so dictates, certain process variables are monitored as permissive conditions to these responses. This action is to prepare or set up the equipment for the actual test run. These outputs must also be de-energized at the end of the day's testing.

Zone 1 is begun when the RUN pushbutton is actuated. If all goes well the program will automatically proceed through Zone 1 and Zone 2 while monitoring various process variables. Should something go awry, the program will either alert the operator or will alert the operator and immediately proceed to Zone 4, depending upon the fault which has occurred.

A preset up-counter allows Zone 2 to be repeated several times. Upon completion of the last Zone 2 cycle, the program automatically proceeds to Zone 3 (NORMAL SHUTDOWN) where the systems are shut down in an orderly manner.

The program will only enter Zone 4 (ABORT) if the ABORT pushbutton is actuated or if a serious fault is detected during operation in one of the other zones. Zone 4 is also an orderly shutdown but is more rapid than Zone 3 and does not necessarily follow the same sequence.

The PROP STOP is an instantaneous function, initiated by pushbutton or other inputs, which immediately closes all fuel valves and opens all vent valves. PROP STOP does not rely on the Modicon and is totally hard wired.

During the check-out phase and during trouble shooting procedures it is a common practice to use the DISABLE ON/OFF FEATURE IN THE PROGRAMMER TO "freeze" one or more elements (inputs, outputs and/or coils) in the on or the off state. Once disabled, these elements are no longer under control, each element must be individually ENABLED. A hazard could arise if an element is not enabled when the systems are returned to normal operation. To control this hazard, the startup check list will include instructions to search the P.C. program for disabled elements. This search procedure is outlined in the manufacturer's user's manual.

FMEA, RETF Altitude Test Stand B

Hazard	Effects	Criticality	Control
Asphyxiation of personnel entering test capsule	Death or injury to personnel	4	Capsule purged with air, then rolled back. Personnel will not enter capsule thru manway.
Propellant explosion in exhaust system	Damage exhaust system components	2	Procedural detection of propellant leaks, interlocks on capsule pressure prevent ignition at unsafe pressure levels.
Engine fires with ejector isolation valves closed.	Damage exhaust system components	2	Interlocks prevent engine start sequence unless valves are open, or pressure in capsule is low enough.
Water floods spray cooler and capsule through level control failure	Damage capsule, engine.	2	Level switch detects high level condition, aborts run.
Diffuser coolant water failure	Damage diffuser, engine.	2	Flow switches and pres. transducer detect condition and abort run.
Spray cooler water supply failure.	Damage spray cooler, engine.	2	Flow switch detects condition, aborts run.
Ejector motive fluid regulator fails open.	Burst ejector motive fluid piping.	2	Properly sized rupture discs and relief valves.

Hazard	Effects	Criticality	Control
Diffuser aerodynamic design faulty.	Damage engine.	1	Capsule pressure tied to auto abort system, and will detect condition and abort run.
Ejector motive fluid system failure or ejector design faulty	Damage engine.	1	Motive fluid flow switch and capsule pressure detect condition and abort run.

Hazard	Effects	Criticality	Control
Failure of Nav-Tec sequence timer.	Facility aborts not sampled, damage to engine, exhaust system components.	2	Technicians monitor timer operation during run and abort run if timer inoperative.
Failure of Calex voltage comparator (auto abort) circuits.	Facility aborts inoperative, damage to engine or exhaust system components.	2	Voltage comparator operation is fail-safe. Failure causes alarm and abort of the run.
Failure of annunciator.	Inability to signal alarm condition.	1	Annunciators tested each run day.
Programmable Controller:			
a. CPU failure.	Inability to control valves, etc.	1	All outputs turned off. Propellant valves close and vent valves open.
b. Remote I/O modem failure.	Inability to energize circuits, valves, etc.	1	System will automatically shut itself down on I/O failure.
c. I/O module failure in nonconducting condition.	Inability to energize circuits, valves, etc.	1	Auto abort system detects unsage conditions and aborts run.
d. I/O module failure in conducting condition.	Inability to de-energize circuits, valves, etc.	2	Prop stop system closes all shutoff valves and stops all propellant flow and is independent of Modicon.
e. CRT/Programmer failure.	Improper or incorrect program elements entered into CPU, damage to engine, facility.	2	Printout of program is always checked vs. the source documents.

Hazard	Effects	Criticality	Control
f. Altitude sequence failure.	Damage engine, exhaust system components.	2	Sequence failure will terminate test cycle and shutdown the test.

<u>Failure Modes</u> are categorized according to criticality, that is, the seriousness of effects that could be generated. These failure mode categories are:

<u>Category 1</u> Failure that results in temporary or permanent malfunction or loss of function with no potential for injury to personnel. Proper function can be restored in a short time using normal repair or maintenance procedures.

<u>Category 2</u> Failure with no potential for injury to personnel. The distinction between Category 2 and Category 1 failure modes lies in the increased time, difficulty or cost of effort required to restore function in the case of Category 2.

<u>Category 3</u> Failure that results in potential for causing injury to personnel.

<u>Category 4</u> Failure that results in potential for causing death or multiple injuries to personnel.

9-12-85

SPRAY COOLER DRAIN LINE ANALYSIS

PROBLEM: AT 7200 GPM THE SPRAY COOLER WATER LEVEL IS TOO HIGH RESULTING IN WATER FILLING THE TEST CAPSULE

APPROACH: ANALYZE DESIGN OF DRAIN LINE TO DETERMINE CAUSE

SUMMARY OF FINDINGS

1. AT 10000 GPM DESIGN CONDITION THE SPRAY COOLER WILL OVERFLOW IF THE DETENTION TANK IS MORE THAN 10' FILLED

2. IF DETENTION TANK IS FILLED + OVERFLOWING THE SPRAY COOLER WILL OVERFLOW IF THE FLOW IS GREATER THAN 5600 GPM

3. ANALYSIS PREDICTS LOWER WATER LEVELS THAN ACTUAL WATER FLOW TEST

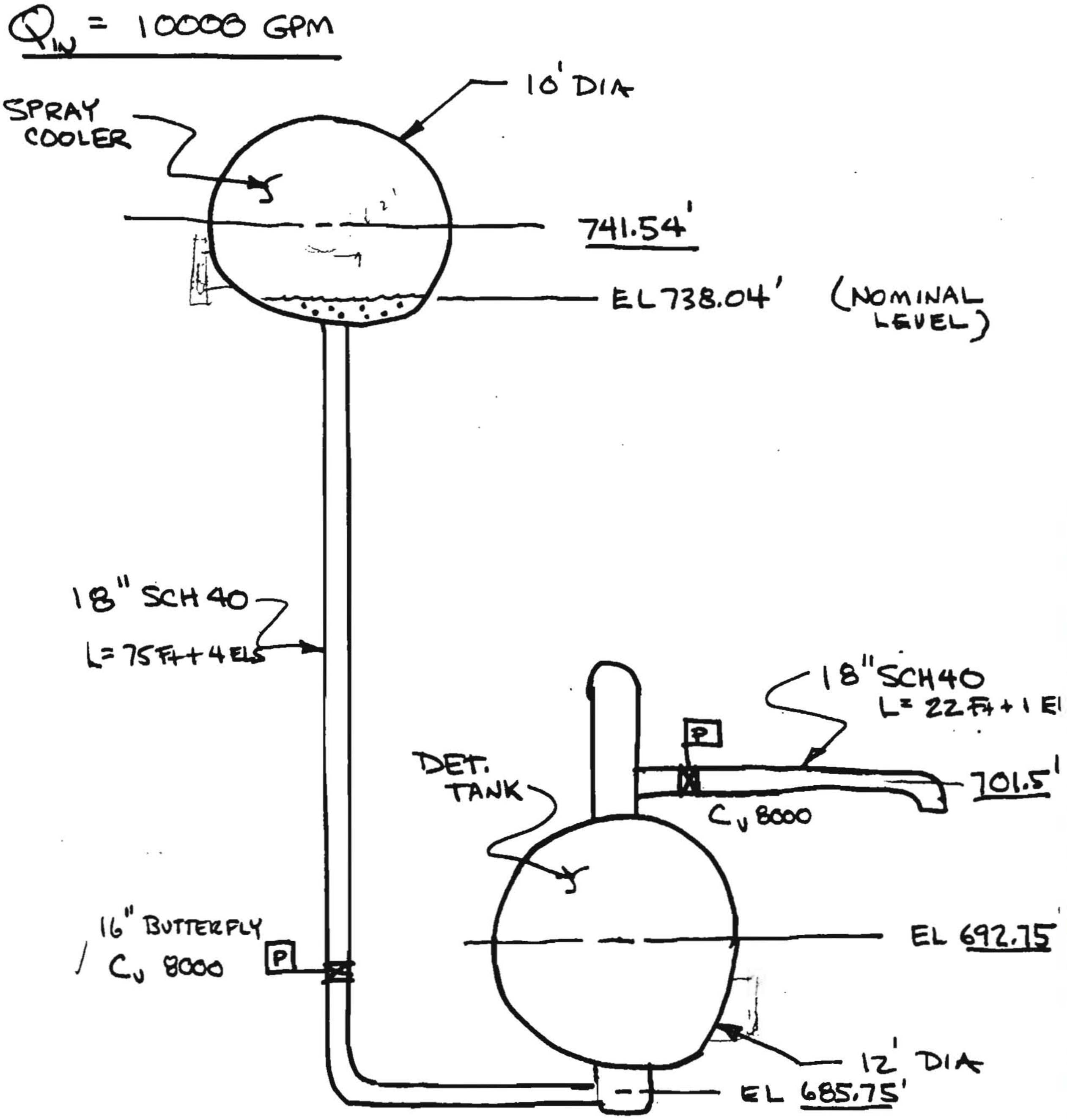
4. ANALYSIS SHOWS ADDITION OF 1 MORE 18 INCH DRAIN LINE + OVERFLOW WILL JUST SOLVE THE PROBLEM FOR 10000 GPM NOMINAL FLOW

RECOMMENDATION

- ADD ADDITIONAL DRAIN LINE, 24 INCH IF INCLUDING VALVES

-OR-

- ADD ADDITIONAL 18 IN LINE, ELIMINATE VALVES



SIMPLIFIED DIAGRAM

SPRAY COOLER DRAIN SYSTEM

CALCULATE FRICTIONAL PIPE LOSS FOR SPRAY COOLER DRAIN LINE

DRAIN LINE

LENGTH = 75' + 4 ELS

EQUIVALENT L = 75 + 72 = 147'

$$Re = 50.6 \frac{Q\rho}{d\mu} = 50.6 \frac{10000\,(62.4)}{18\,(.85)}$$

$$Re = 2 \times 10^6 \Rightarrow f = .0127$$

$$K = K_{ENT} + f\frac{L}{D} + K_{EXIT}$$

$$K = .50 + .0127\left(\frac{147}{1.5}\right) + 1.0 \qquad \frac{4}{\pi}$$

$$K = 2.745 \qquad \rho \frac{V^2}{2g}K \qquad \dot{m} = \rho A V = \rho \pi \frac{d^2}{4} V \qquad V = \dot{m}\frac{4}{\pi}\frac{1}{\rho d^2}$$

$$\Delta P = 3.63 \frac{\dot{m}^2 K}{d^4 \rho} \qquad \dot{m} = 10000 \frac{GAL}{MIN} \times 8.34 \frac{lb}{GAL} \times \frac{1}{60} \qquad \dot{m} = 1390\ lb/SEC$$

$$\Delta P = 3.63 \frac{(1390\ lb/SEC)^2 (2.745)}{(16.876)^4 (62.4)} \qquad \frac{4 \times 12^4}{\pi \times 144 \times 64.4}$$

$$\Delta P = 3.80\ PSI \qquad 1.056$$

$$\Delta h = 3.80 \times \frac{144}{62.4} = 8.78\ Ft \qquad 8.04$$

2.43

OVERFLOW LINE

LENGTH = 22' + 1 EL

EQUIVALENT L = 22' + 18' = 40'

$$K = K_{ENT} + f\left(\frac{L}{D}\right) + K_{EXIT} =$$

$$= .50 + .0127\left(\frac{40}{1.5}\right) + 1.0$$

$K_{TOT} = 1.839$

$$\Delta P = 3.63 \frac{\dot{m}^2 K}{d^4 \rho}$$

$$= 3.63 \frac{(1390)^2 (1.839)}{(16.876)^4 \, 62.4}$$

$\Delta P = 2.55$ PSI .7

$\Delta h = 5.88$ ft. 1.63

VALVES 16" BUTTERFLY, $C_v = 8000$

$$\Delta P = \frac{.0160 \, \rho \, Q^2}{C_v^2}$$

$\Delta P = \left(\frac{Q}{C_v}\right)^2 \frac{\rho}{62.4} = \left(\frac{Q}{C_v}\right)^2$ for water

$$\Delta P = \frac{.0160 (62.4)(10000)^2}{8000^2}$$

$C_v =$ 21,500 for 24"

$\Delta P_v = 1.56$ PSI

$\Delta P_{24''} = .216 = .5$ ft

$\Delta h_v = 3.60$ Ft

TOTAL FRICTIONAL + VALVE LOSSES
WITH FLOW OUT OVERFLOW

$$\Delta h_{TOT} = \Delta h_{LINE\,1} + \Delta h_{VALVE\,1} + \Delta h_{LINE\,2} + \Delta h_{VALVE\,2}$$

$$\Delta h_{TOT} = 8.78\ Ft + 3.60\ Ft + 5.88\ Ft + 3.60\ Ft$$

$\Delta h_{TOT} = 21.86\ Ft$	TOTAL FRICTIONAL + VALVE LOSSES

for 24" $\Delta h_{TOT} = 2.43 + .5 + 1.63 + .5 = 5.06\ ft$

HEAD LOSS AVAILABLE FOR PIPE FLOW

$$z_1 + \frac{144 P_1}{\rho} + \frac{V_1^2}{2g} = z_2 + \frac{144 P_2}{\rho_2} + \frac{V_2^2}{2g} + h_L$$

$$V_1 = V_2 \quad \therefore$$

$$z_1 + \frac{144 P_1}{\rho_1} = z_2 + \frac{144 P_2}{\rho_2} + h_L$$

$$h_L = z_1 - z_2 + \frac{144}{\rho}\left(P_1 - P_2\right)$$

$z_1 = 738.04'$

$z_2 = 701.5'$ WORST CASE

$P_1 = 1.5$ PSIA

$P_2 = 14.3$ PSIA

$$h_L = 738.04 - 701.5 + \frac{144}{62.4}\left(1.5 - 14.3\right)$$

$$h_L = 36.54 - 29.54$$

$h_L = 7.00$ Ft — AVAILABLE FOR FRICTIONAL PIPE LOSS <u>WORST CASE DETENTION TANK FULL</u>

$h_L = 2.62$ F — ASSUMING PERFECT VACUUM, DET TANK FULL

CHECK CALCULATION METHOD VS MEASURED FLOW DATA

$Q = 7200$ GPM

SPRAY COOLER LEVEL = 27"

DETENTION TANK LEVEL = 8 Ft

$$\Delta h = \left(\frac{7200}{10000}\right)^2 \times (8.78 + 3.60)$$

$$\Delta h = 6.42 \text{ Ft}$$

SPRAY COOLER WATER LEVEL ELEVATION

$$z_1 = 741.54' - 5' + \frac{27}{24}' = 737.67'$$

DETENTION TANK WATER LEVEL ELEVATION

$$z_2 = 692.75' - 6' + 8' = 694.75'$$

$$\Delta z = 42.915$$

CHECK AVAILABLE HEAD LOSS:

$$h_L = z_1 - z_2 + \frac{144}{\rho}(P_1 - P_2)$$

$$h_L = 42.915 - \frac{144}{62.4}(1.0 - 14.3) =$$

$$h_L = 12.25 \text{ Ft}$$

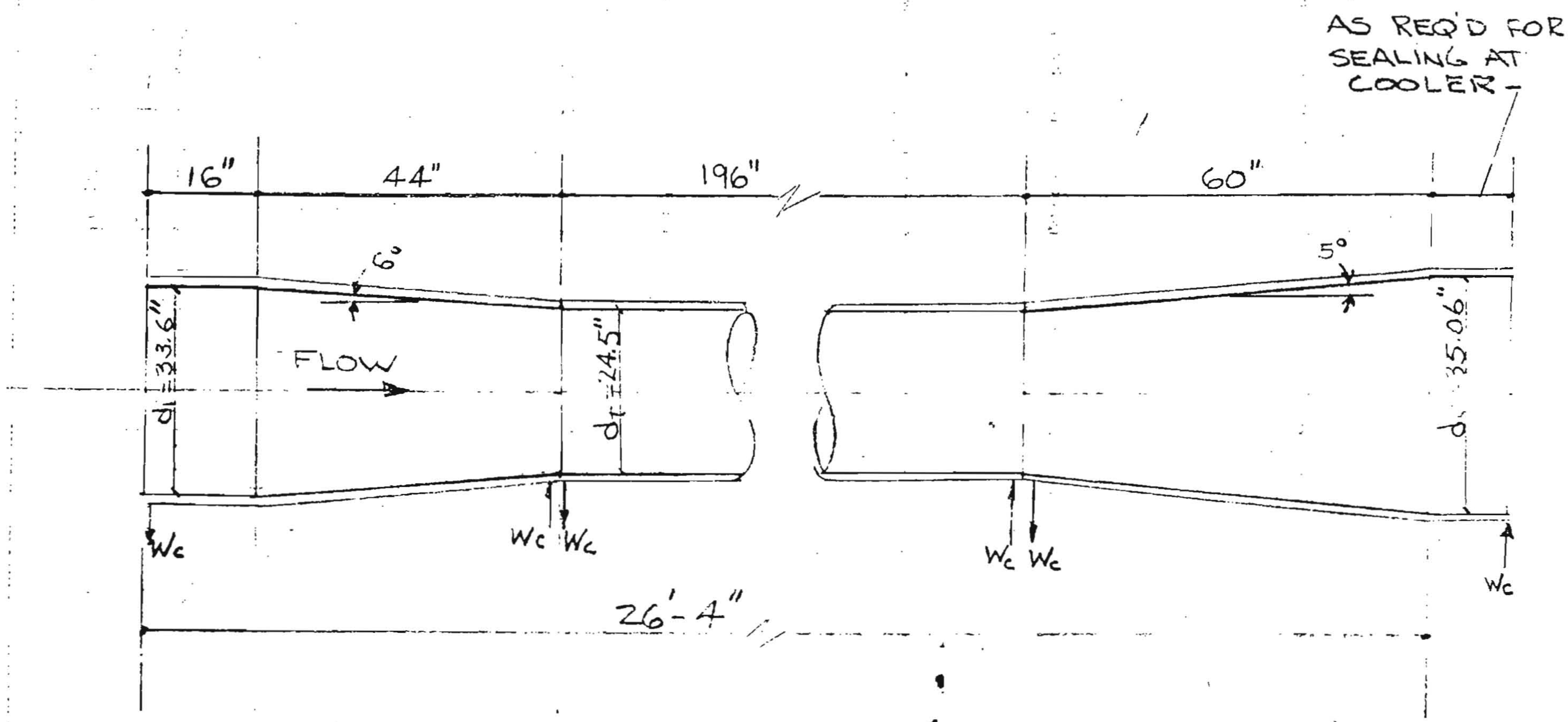
FOR 5400 GPM

h_L = 3.61 Ft OR 2.8 Ft LESS THAN THAT FOR 7200 GPM

DATA :

FOR 5400 GPM THE SPRAY COOLER LEVEL WAS 16 INCHES OR ONLY 11 INCHES LESS THAN FOR 7200 GPM ??

PRELIMINARY DIFFUSER CONFIGURATION



WATER COOLED DIFFUSER

COOL DIFFUSER THREE SECTIONS

SKETCH B
EPM 8/12/82

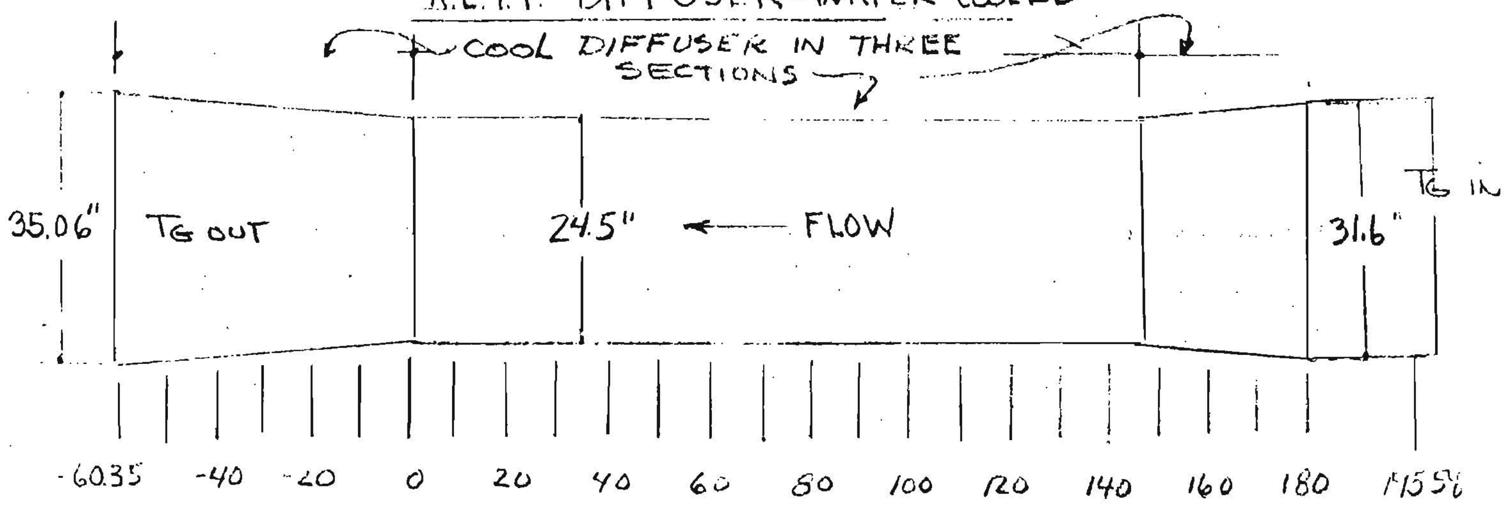
DATE ____ SUBJECT HEAT TRANSFER STUDY SHEET NO. ____
JOB NO. ____

X IN.	Q BTU/SEC IN²	TGW °R	TCW °R	TC °R
-60.35	0.534	866	692	530
-40	0.640	920	709	536
-20	0.772	986	726	543
0	0.864	1025	731	550
21	0.612	891	691	556
42	0.443	803	662	561
63	0.324	742	641	564
84	0.245	701	626	566
105	0.192	674	615	568
126	0.155	655	608	569
147	0.127	641	603	571
158	0.103	630	599	571
169	0.086	622	596	572
180.78	0.071	615	594	572
196.58	0.071	616	594	573

TG IN = 6300 °R
TG OUT = 5700 °R
TGW - GAS SIDE WALL TEMP
TCW - COOLANT SIDE WALL TEMP
TC - COOLANT TEMP
Q - HEAT FLUX (LOCAL)
X - LOCATION OF Q

MAT. 1010 STL
WALL TK. 0.25" IN
1/2" DEEP WATER PASSAGE
44 PSI MIN. WATER PRESS REQ'D

R.E.T.F. DIFFUSER - WATER COOLED



SKETCH C
EFM 8/17/82

FMEA - S 40, REFT 1960

Mode	Mechanism	Cause	Effect	Crit	Detection	Action To Reduce Failure Occurrence	Action To Reduce Failure Effect
High/Low Chamber Pressure	1. Too much or too little propellant 2. Failure to light 3. Engine Burnout	1. Faulty Controller 2. Incorrect Timing	1. Burst Chamber 2. Accumulate Propellants	1	Pressure Transducer	1. Auto Abort System 2. Cold Flow Systems 3. Prerun Setup & Checkout	Remote Test Cell Location - Exclusion Area
High/Low LOX Flow	1. Engine failure 2. Instrumentation failure	1. Engine burnout 2. Incorrect Instrument setup 3. Faulty Instrumentation	1. Cause cell damage 2. Improper Engine Operation	1	2nd Flowmeter	1. Auto Abort System 2. Cold Flow Systems 3. Prerun Setup & Checkout	Abort Test Run and Remote Test Cell Location - Exclusion Area
Low Water Coolant Flow	1. Pump Fails 2. Supply Valve closes	1. Motor failure 2. Valve System failure	Burnout Engine	1	Orifice and Press. Trans.	1. Auto Abort System 2. Cold Flow Systems 3. Prerun Setup & Checkout	Remote Test Cell Location - Exclusion Area and Abort Test Run
High/Low LH_2 Coolant Flow	1. Faulty Controller 2. Instrumentation failure 3. Engine Failure	1. Electronic Failure 2. Incorrect Setup 3. Material Failure	1. Burnout Engine 2. Burst Engine 3. Bad data	1	Venturi and Press. Trans.	1. Auto Abort System 2. Cold Flow Systems 3. Prerun Setup & Checkout	Remote Test Cell Location - Exclusion Area and Abort Test Run
High/Low Coolant Back Pressure	1. Faulty Controller 2. Instrumentation Failure	1. Electronic Failure 2. Engine too hot	1. Burnout Engine 2. Burst Engine	1	Pressure Transducer	1. Auto Abort System 2. Prerun Setup & Checkout	Remote Test Cell Location - Exclusion Area and Abort Test Run
High/Low GH_2 Fuel Flow	1. Instrumentation Failure 2. Controller Problem	1. Hydraulic Failure 2. Electronic Failure 3. Material Failure	1. Engine Operation Off Condition 2. Engine Failure	1	Orifice and Press. Trans.	1. Auto Abort System 2. Prerun Setup & Checkout	Remote Test Cell Location - Exclusion Area and Abort Test Run
Electric Igniter Failure	1. No spark 2. No Propellants 3. Incorrect Pressures	1. Electrical Component failure 2. Valves Fail Closed 3. Incorrect Setup Procedures	1. No Engine Ignition 2. Propellant Accumulation	1	Pressure Transducer	1. Auto Abort System and Prerun Setup & Checkout 2. Manual Torch Check	Remote Test Cell Location - Exclusion Area and Abort Test Run
High/Low Hydrocarbon Flow	1. Instrumentation failure 2. Controller Problem 3. Engine Failure	1. Electronic Failure 2. Material Failure	1. Engine Operation Off Condition 2. Engine Failure	1	Turbine flowmeter	1. Auto Abort System 2. Cold Flow Systems 3. Prerun Setup & Checkout	Remote Test Cell Location - Exclusion Area and Abort Test Run
H_2 Burnoff Torch Flame out	1. Goes out 2. Fails to light	Ignitor Failure	Hydrogen Accumulation and delayed ignition	1	Purple peeper	1. Auto Abort System and Prerun Setup & Checkout 2. Manual Ignition Check	Remote Test Cell Location - Exclusion Area and Abort Test Run
Engine Fire-test Cell Fire-explosion	1. Material Failure 2. Propellant Accumulation	1. Propellant Line 2. Valve Open incorrectly	1. Burn up Test Cell Components 2. Blow walls off cell	2	TV & Visual Observation	1. Early Detection of Leak/spill 2. Auto Abort System 3. Concrete Blast Walls	1. Personnel in Protected Areas 2. Blow Off Cell Walls 3. Fire Fighting Systems 4. Exclusion Lockout Areas 5. Manual Abort & Prop. Stop
Hydraulic Fire Valve Failures	1. Valve Fails Open 2. Valve Fails to operate	1. Controller Probs. 2. Power Failure 3. Blast Damage	1. Loss of Propellants 2. Test Cell Fire or Blast	1 or 2	1. Indirect Measurement by Flow Systems Above. 2. Data System Readout 3. Prerun Setup & Checkout	1. Battery Clamp Switched on Valves except for operation 2. Auto Abort System 3. Moogs Mech. Bias Closed	1. Remote Test Cell Location - Exclusion Area and Abort Test Run and Fail Safe Design 2. Prop. Stop System
LH_2 or LOX Tank Press. Reg. Runaway	1. Pressurization Controller Prob. 2. Incorrect setting	1. Electronic Problem 2. Hydraulic System Failure 3. Human Error	1. Possible System over Pressure 2. Incorrect Propellant flow	1 or 2	1. Automatic Relief Systems 2. Indirect Measurements by Flow Systems Above 3. Visual Gages	1. Good Design Practices 2. Check Sheet Operation.	1. System Pressure Relief Valves 2. Prop. Stop System

Mode	Mechanism	Cause	Effect	Crit	Detection	Action To Reduce Failure Occurrence	Action To Reduce Failure Effect
H_2 Vent Stack Fire	Fire Triangle Completed	1. Too High Vent Rate 2. Stack Contamination 3. Improper Stack Grounding	1. Destroy Vent Stack 2. Frighten Personnel	1 or 2	Visual and TV	1. Control Vent Rate 2. Stack Ground Check 3. Mission Check Valves 4. Corona Discharge Design	1. Overdesign Stack 2. Extra High Stack
High Pressure Venting Thru Low Press Vent Valves	1. Incorrect Procedure 2. Valve Failure	1. Human Error 2. Low Pressure Valve Failed Open	1. Stack Fire 2. Bend Vent Stack 3. Worry Neighbors	2	Visual, Sound	1. Check Sheet Operation 2. Dual Permissive, Electro-Pneumatic System	Remote Test Cell Location - Exclusion Area and Abort Test Run
Bottle Farms Over Pressure	1. Incorrect Procedure 2. Relief System Failure	1. Human Error 2. Mechanical Malfunction	1. Vent GH_2 2. Blow Burst Discs	2 or 3	Automatic Relief	1. Good Design Practices 2. Prerun Setup & Checkout	Multiple Relief Systems Fail Safe Design
LH_2 Trailer Overpressure	1. Valve Failure 2. Human Error	Back Pressure from Facility System	1. Vent GH_2 2. Blow Burst Discs	2 or 3	Prerun Setup & Checkout Automatic Relief System	1. Good Design Practices 2. Prerun Setup & Checkout	Remote Test Cell Location - Exclusion Area Multiple Relief Systems
Fire Around LH_2 Tanks	Fuel Burning Under Tank	Fuel Line Leak	Damage Tank	3	Visual and TV	1. Good Design Practices 2. Automatic Relief System	1. Remote Test Cell Location - Exclusion Area and Abort Test Run 2. CO_2 and Water Spray
H_2 Leaks Into Enclosed Areas	Open System in Unvented Area	Fuel Line Leak	Blast Hazard	2	1. Hydrogen Sniffer Systems	1. Prop Stop System 2. Carefull Design	Remote Test Cell Location - Exclusion Area
Loss of GN_2 Valva Energy Source	1. Valve Fails to Operate or Fails in Wrong Position	Depletion of GN_2 Source	1. Terminate Operations 2. Trap Propellants	1	GN_2 Bottle Pressure Readout	1. Design, Valves Spring to Close 2. Automatic GN_2 Pumping System	Fail Safe Design
LOX System Burnout	1. Pipe Leaks 2. Oxidation Reaction Started	1. System Contaminated 2. Water Hammer 3. Cross Mixing of Propellants 4. Cryogenic System Trap	1. Damage Adjacent Equipment	2		1. Passivate System with GF_2 2. Clean Components for LOX Service 3. Good Design Practices	1. Remote Test Cell Location - Exclusion Area 2. Prop Stop System
Hydrocarbon Fuel Spill	1. Joint Leaks 2. Valve Open at Wrong Time	1. System Overpressure 2. Human Error	1. Environmental Pollution	1	Visual Inspection	Good Design Practices	1. Build Dike Around Possible Spill Areas 2. Use Oil Separator
Persons Enter Locked out Area	1. Lock outs Ignored 2. Lock outs not seen	1. Person Determined To Enter Area 2. Instructions not Understood	Person Hurt from Normal Firing or System Failure	3 or 4	1. Guard Report 2. Block House Observer 3. Closed Circuit TV	1. Public Relations 2. Learn From Past Mistakes 3. Enforcement of Rules	1. Abort Test Operations 2. Warn Person Via PA System 3. Siren on During Test Firing
Scrubber Explosion	Propellant Accumulation and ignition source	1. Abort System Failure 2. Human Error	Big Bang	2	Hydrogen Sniffer System	1. Air and Oxygen Addition with Torches Lit to Burn Fuel Before it can Accumulate 2. Prop Stop System	1. Scrubber Over Design 2. Remote Test Cell Location - Exclusion Area and Abort Test Run
Too High Vent Stack Flow Rate	Pressure Too High for Vent System being used	1. Poor Design 2. Human Error	1. Possible Stack Failure 2. Stack Fire on H_2 System	1	Visual	Good Design Practices	Remote Test Cell Location – Exclusion Area
Electric Power Loss (Partial or Total)	ROB Power Loss RETF Power Loss	1. CEI Outage 2. Local Breaker Opens	Valves Inoperable	1	Lights Out	Good Design Practices	1. Remote Test Cell Location - Exclusion Area and Relief Systems 2. Fail Safe Design
Dual Instrument Failure	Series or Parallel Instruments lost	1. Common Instrument Power Source 2. Incorrect setup	1. Engine Operating outside Open Envelope 2. Unnecessary Abort	1	Prerun Setup and Checkout	Cold Flow Systems	Indirect Measurement by Flow Systems Above
Installation Errors	Mechanical, Electrical Instrumentation Systems Assembled Incorrectly	1. Poor Design 2. Human Error	1. System Abort 2. System Malfunction	1	1. System End to End Check 2. Document Accurately	1. Clear Instructions, drawings to Installers 2. Maintain Good Lines of Communication with Field Personnel	Cold Flow Systems and Prerun Setup and Checkout

Mode	Mechanism	Cause	Effect	Crit	Detection	Action To Reduce Failure Occurrence	Action To Reduce Failure Effect
General Operational Mistakes	1. Operate Valves during Engine Inspection 2. Operate Wrong Valve 3. Open Wrong Vent 4. Set Wrong Pressure on System 5. Incorrect System Setup	1. Human Error 2. Poor Design	1. System Abort 2. System Fire 3. Destroy Test Item	1 to 3	Cold Flow Systems, Prerun Setup & Checkout	1. Keep Morale and Job Interest High 2. Trained Operators 3. Up to Date Checksheet to be used. 4. Team Effort 5. Keep Communications Systems in good Condition - PA, Phone, Radio, Written, Verbal	1. Dual System Valves Shut 2. Fail Safe Design
Incorrect Firing Sequence	1. Incorrect Procedure 2. Timer Failure	1. Human Error 2. Electronic Part Failure	1. System Abort 2. Destroy Test Item	2	Cold Flow Systems Prerun Setup and Checkout	Auto Abort System	Remote Test Cell Location - Exclusion Area and Abort Test Run
Cryogenic Trapping	Series Valves Both Shut on Cryo. line	Power Failure or Mistake	Burst Line	2	Visual	Relief Valves or Burst Discs on These Lines	Remote Test Cell Location - Exclusion Area and Good Design
Fire at Bottle Farm	Static Discharge Ignition After Burst Disc Failure	Over Pressure or Burst Disc Fatigue	Start Secondary Fires	2 or 3	Visual	Safety Relief Valves Installed with Lower Set Pressures Than Burst Discs	Relief Device Orifices Sized to Minimum Allowable per CGA Code to Minimize Size of Fire
Fire at Roadable Dewar	LH_2 Leak on Transfer Line	Joint or Hose Failure	Endanger Dewar and Personnel	2 or 3	Visual and H_2 Sniffer	Prerun Setup & Checkout and Check Sheet Operation plus Remote Control of Transfer Valves	1. Shut off H_2 Flow 2. CO_2 + Water System 3. Prerun Setup & Checkout and Remote Test Cell Location - Exclusion Area
Catastrophe at Bottle Farm	Bottle Failure	Over Pressure or Fatigue	Destroy Bottle and People	4	Periodic Testing of Bottles and Relief Systems	1. Tripple Safety Relief Systems at RETF 2. Check Sheet Operation for Charging 3. Good Design Practices	Remote Test Cell Location - Exclusion Area

Rev. 3-28-80
WAT

CRITICALITY RATING

1. Category 1. Negligible. Failure of an element, subsystem, or system that results in temporary or no loss of function with no potential for injury to personnel. Function can be restored in a short time using normal repair or maintenance procedures.

2. Category 2. Minor. Failure of an element, subsystem, or system that results in loss of function with no potential for injury to personnel. Characteristically, the distinction between Category 2 and Category 1 failures lies in the time required to restore function. Category 2 failures will result in a significant interruption to operations, generally in excess of 48 hours.

3. Category 3. Critical. Failure of an element, subsystem, or system that results in loss of function with potential for injury to personnel or severe damage to major facilities.

4. Category 4. Catastrophic. Failure of an element, subsystem, or system that results in loss of functions with potential for causing death or serious injuries to personnel.

Space Administration

Lewis Research Center
Cleveland, Ohio
44135

Reply to Attn of: 6152

June 2, 1980

TO: 4150/Chairman, Area 5 Safety Committee

FROM: 6152/Wayne A. Thomas

SUBJECT: Abort Parameters for Rocket Engine Testing at RETF

The following abort parameter list is submitted as part of the operational safety permit request for the RETF.

	System	Parameter	Limit
1.	Rocket	Chamber Pressure (Pc)	Hi/Lo
2.	Rocket	LOX Flow Rate (Turbine FM)	Hi/Lo
3.	Rocket	Chamber water coolant flow (venturi ΔP)	Lo
4.	Burnoff	LH_2 coolant flow rate (venturi ΔP)	Hi/Lo
5.	Burnoff	Coolant back pressure (pressure)	Hi/Lo
6.	Rocket	GH_2 Fuel flow (orifice ΔP)	Hi/Lo
7.	Rocket	Electric igniter on (101P)	Hi/Lo
8.	Rocket	Coolant inlet temp. (CCIT)	Hi
9.	Rocket	Hydrocarbon fuel flow (venturi ΔP)	Hi/Lo
10.	Rocket	Nozzle water flow rate (orifice ΔP)	Lo
11.	Burnoff	Purple peeper (flame out)	Off

If any one of these automatic abort parameters exceeds the set boundary limits, the entire system (rocket and coolant burnoff) is automatically shut down.

Wayne A. Thomas

cc:
6150/PPO File
6152/W. A. Thomas

Addendum to Safety Permit

S-40, RETF
RUN CONFIGURATIONS

Config. No.	Propellants	Chamber Pressure (psia)	FUEL Vessel	FUEL Working Pressure (psia)	FUEL PRESSURANT Vessel	FUEL PRESSURANT Working Pressure (psia)	OXIDANT Vessel	OXIDANT Working Pressure (psia)	OXIDANT PRESSURANT Vessel	OXIDANT PRESSURANT Working Pressure (psia)	COOLANT Vessel	COOLANT Working Pressure (psia)	COOLANT PRESSURANT Vessel	COOLANT PRESSURANT Working Pressure (psia)
1.	RP-1/LOX	600	(I)** 55 ft^3	1440	(F) GN2	3000	(H) 53 ft^3	5000	(E) GHe	4000	---			
2.	Heavy Hydroc./ LOX	600	(J) 78 ft^3	4670	(F) GN2	3000	(H) 53 ft^3	5000	(E) GHe	4000	---			
3.	RP-1/LOX- LOX Cooling	600	(I) 55 ft^3	1440	(F) GN2	3000	(H) 53 ft^3	5000	(E) GHe	4000	(H) 53 ft^3	5000	(E) GHe	4000
4.	RP-1/LOX- LOX Cooling	2000	(J) 78 ft^3	4670	(F)GN2	4000	(H) 53 ft^3	5000	(N)GHe	6000	(H) 53 ft^3	5000	(N)GHe	6000
5.	H2/LOX- LH2 Cooling	600	(A) GH2 bottles	4000	—		(H) 53 ft^3	5000	(E) GHe	4000	(C) 175 ft^3	1440	(A) GH2	4000
6.	H2/LOX- LH2 Cooling	2000	(A) GH2 bottles	4000	—		(H) 53 ft^3	5000	(E) GHe	4000	(D) 133 ft^3	5000	(A) GH2	4000
7.	H2/LOX- LOX Cooling	600	(A) GH2 bottles	4000	---		(H) 53 ft^3	5000	(E) GHe	4000	(H) 53 ft^3	5000	(E) GHe	4000
8.	H2/LOX- LOX Cooling	2000	(A) GH2 bottles	4000	---		(H) 53 ft^3	5000	(E) GHe	4000	(H) 53 ft^3	5000	(E) GHe	4000
9.	Water Flow Inj., Chambers	1440	---		---		----		----	---	(K) 175 ft^3	1440	(F) GN2	3000
10.	H2/LOX- Water Cooling	2000	(A) GH2 bottles	4000	---		(H) 53 ft^3	5000	(E) GHe	4000	(L) 78 ft^3	4670	(E) GHe	4000
11.	Pumped Water Cooled Chambers	600					(H) 53 ft^3	5000	(E) GHe	4000	PUMP, 650 gpm, 450 psi, 250 HP PUMP, 1400 gpm, 450 psi, 450 HP			
12.	H2/LOX LH2 Cooling	600 "B" Std	(A)GH2 Bottles	4000	--		(G)55 ft^3	1440	(E)GH2	4000	(C)175 ft^3	1440	(A)GH2	4000
	H2/GOX LH2 Cooling	600 "B" Std	(A) GH2 Bottles	4000	--		(M) NASA 2200 (Tuber)		---		(C) 175 ft^3	1440	(A) GH2	4000

NOTE: 1. **Letter refers to item number on RETF Pressure Vessel List

2. Fuel and Oxidant Injector feed lines purged with GHe from gas bottles (E).

5-28-80
WAT

RETF PRESSURE VESSEL LIST

REF. LETTER	SERVICE	NUMBER OF VESSELS	WORKING PRESSURE (PSIG)	CAPACITY	WATER VOLUME	VESSEL DRWG #	PRIMARY RETF SYST. DRWG #	REMARKS
A	GH_2	6	4000	389,388 SCF	1431 ft^3	CF622676 & 7	CF620915, CF 623224	
B	GH_2	3	6000	---	9000 ft^3	CF622417	CR622663	Plan Operation, Summer '81
C	LH_2	1	1500	---	175 ft^3	CE79784	CF621961, CF 623224	
D	LH_2	1	5000	---	133 ft^3	E-12079P-27	CF1-1232	
E	GHe	4	4000	159,292, SCF	586 ft^3	CF622675	CF620915	
F	GN_2	2	2935	199,659 SCF	1000 ft^3	CF622577	CF622689	
G	LOX	1	1500	---	55 ft^3	CE101632	CD 623223	
H	LOX	1	5000	---	53 ft^3	E-12079P-1	CF101233	
I	HYDROCARBON	2	1500	411 gal/ea	55 ft^3	CR-101635	CF622505	RP-1
J	HYDROCARBON	1	6000	587 gal	78.5 ft^3	CF622578	CD622504	RP-1
K	WATER	1	1500	1309 gal	175 ft^3	(NAS3-7055)	CD621877	
L	WATER	1	6000	587 gal	78.5 ft^3	CD622578	CD622262	
M	GOX	1	2200	50,000 SCF		(NASA tuber)	CD621916	
N	GHe	1	6000	---	300 ft^3	CF622417	CF101525, CR622663	

3-28-80
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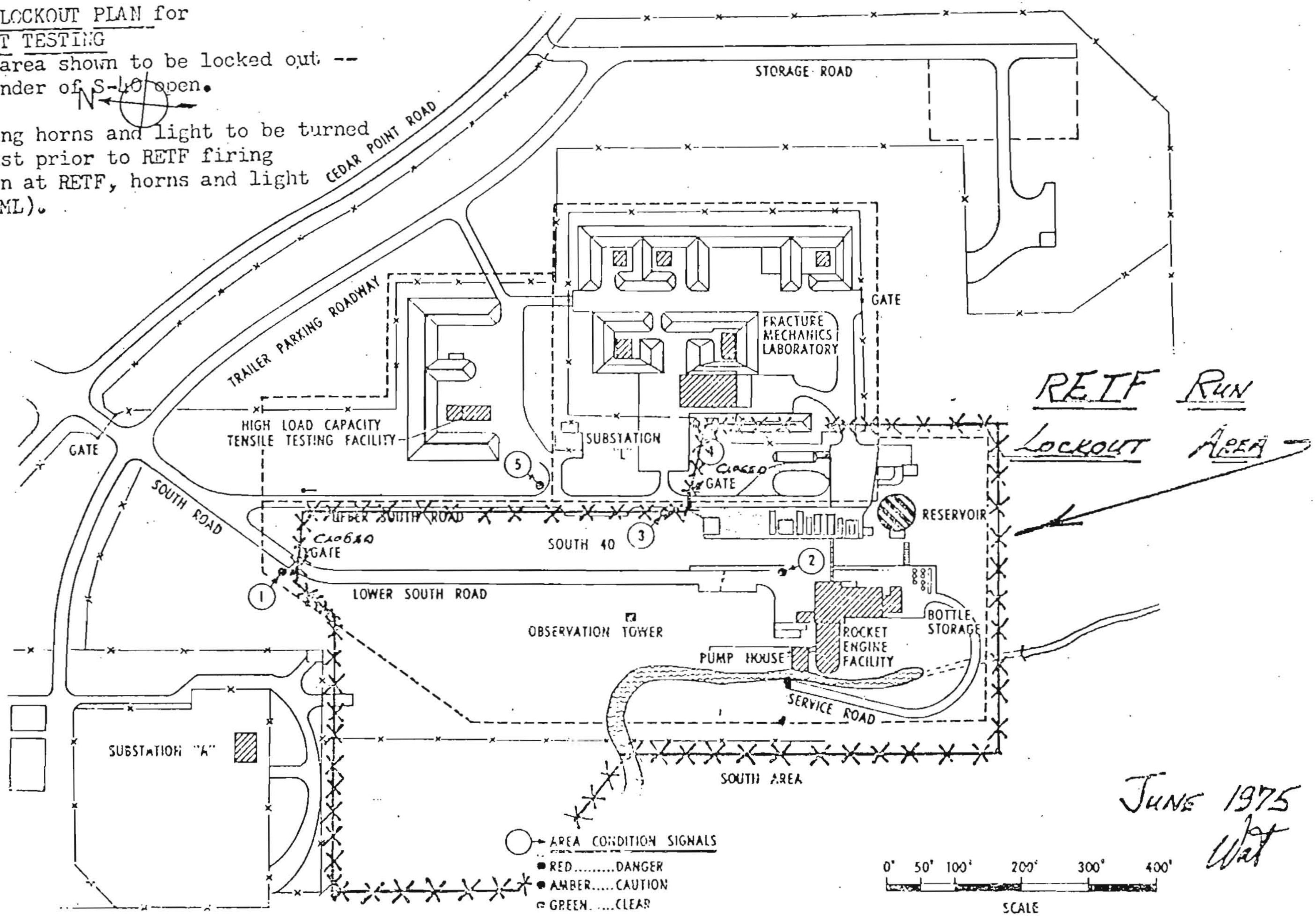
LEWIS RESEARCH CENTER
SOUTH 40 AREA SAFETY PRECAUTIONS

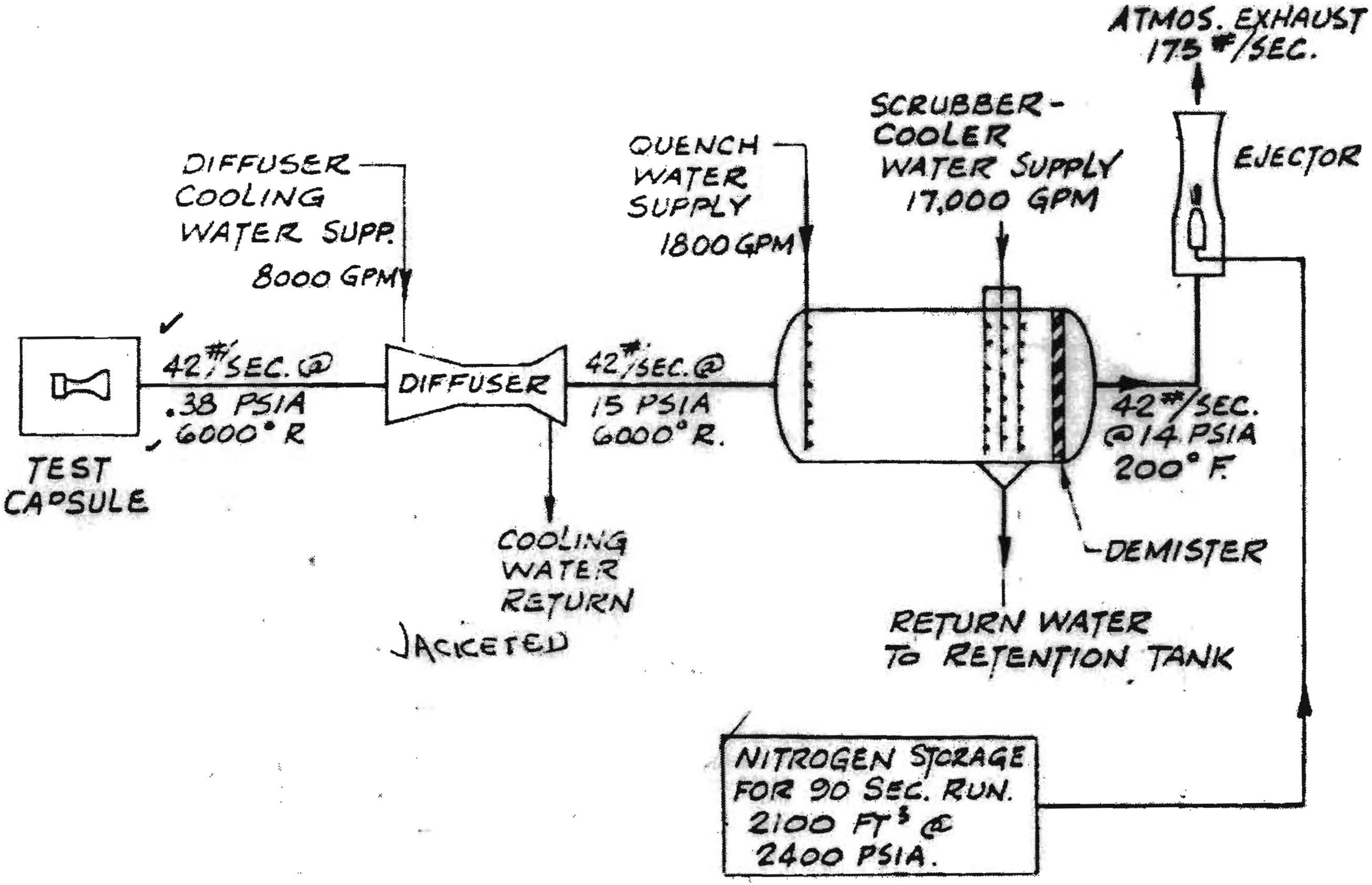
RETF LOCKOUT PLAN for
ROCKET TESTING

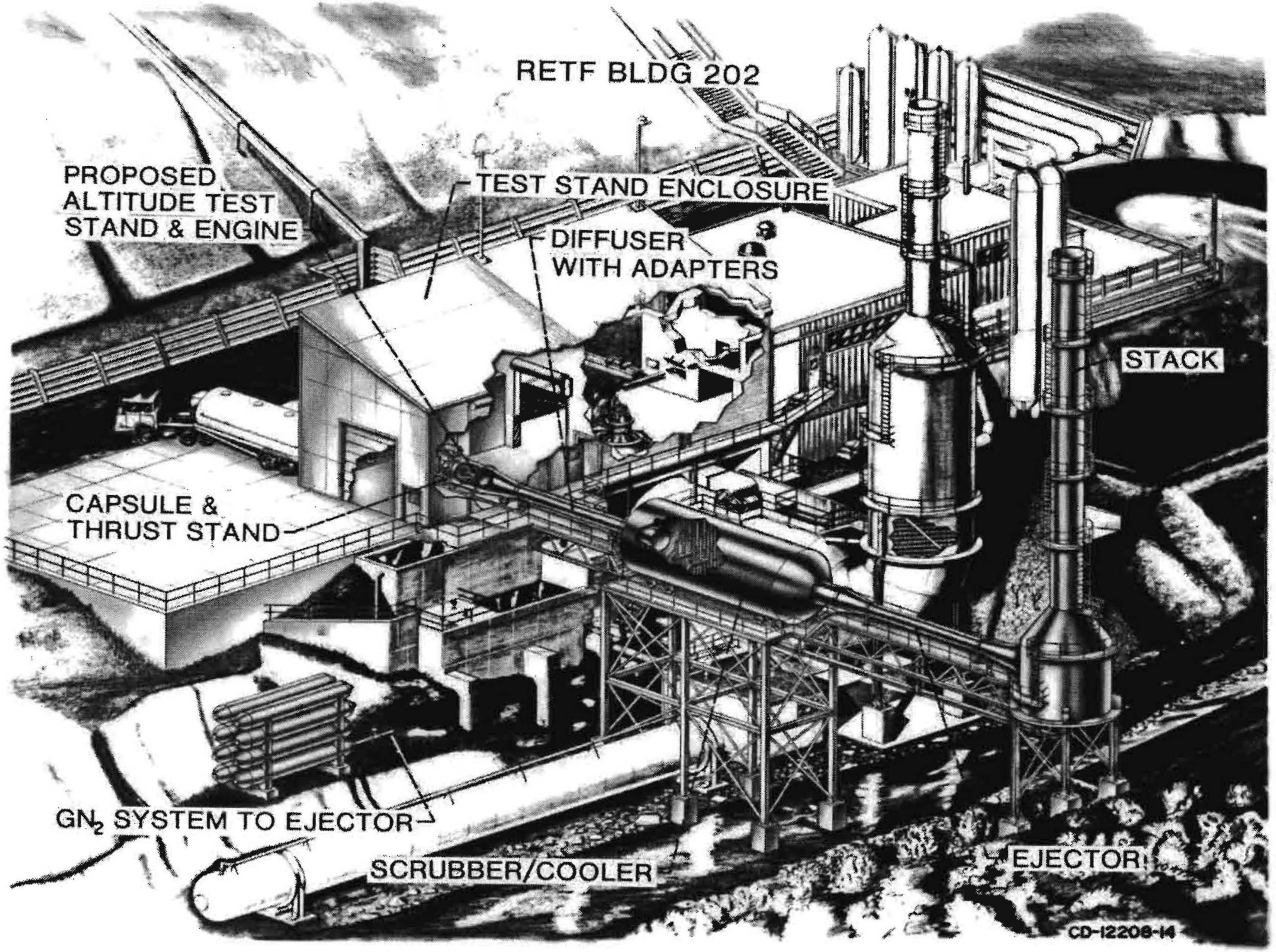
1. Only area shown to be locked out -- remainder of S-40 open.

2. Warning horns and light to be turned on just prior to RETF firing (siren at RETF, horns and light at FML).

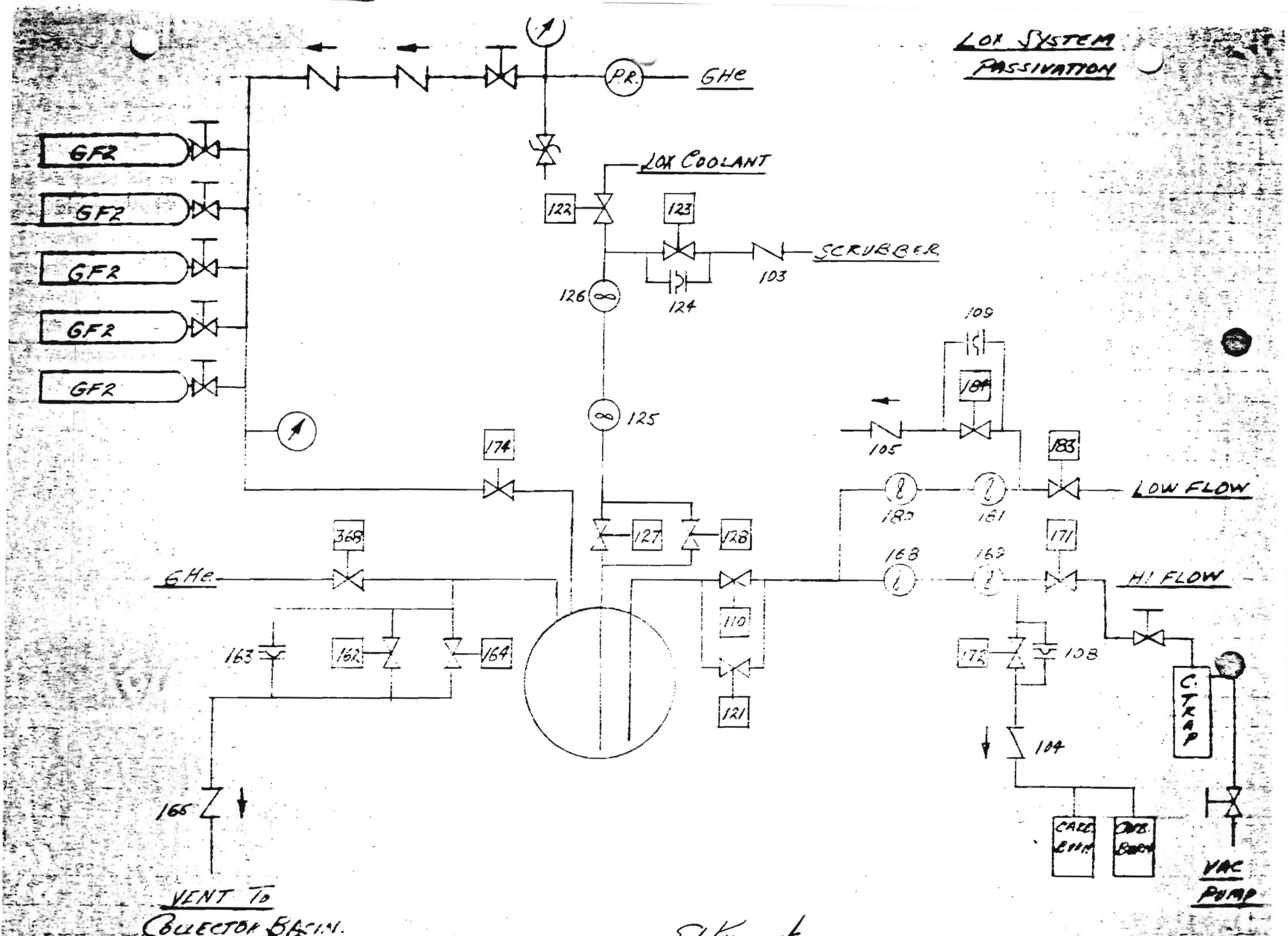


SCHEMATIC
RETF ALTITUDE CAPABILITY




RETF BLDG 202
PROPOSED ALTITUDE TEST STAND & ENGINE
TEST STAND ENCLOSURE
DIFFUSER WITH ADAPTERS
STACK
CAPSULE & THRUST STAND
GN_2 SYSTEM TO EJECTOR
SCRUBBER/COOLER
EJECTOR
CD-12208-14

LOX SYSTEM PASSIVATION



March 1978

FORM 10.2

KINEMA INC.

P. O. Box 176 • Elizabeth, PA 15037 WESTERN UNION
Phone (412) 384-3610 • Telex No. 709981 EASYLINK NO. 62254930

TRIP REPORT

TO: Feldman Mechanical Contractors Co.
2195 Drydock Avenue
Cleveland, Ohio 44113

DATE: 4/30/85
5/5,6,7/85
6/9,10,11/85

Attention: Jim Cater

PLANT LOCATION: Same as above.

KINEMA ORDER NO.:84WW002
KINEMA S/N:843141
843151
847401

CUSTOMER'S PO NO.: 41397

START-UP SERVICE
FELDMAN-NASA CLEVELAND
6/10,11/85

PART ONE - TESTING

This report covers testing completed on 6/11/85 of the ejector system S/N 843141 installed at NASA's Lewis Research Center in Cleveland, Ohio. The test procedure and collected data will be discussed along with various aspects of the results with regard to performance and motive flow conditions. The events herein may not be in chronological order.

I arrived at the installation at 8:00 a.m., 6/10/85 and proceeded to set up Kinema's test equipment per the approved test procedure. Instrument ports in the 16N14 system (train 2) were fitted with vacuum valves and fittings to connect to the mercury manometers. The manometers were located on the lower level of the platform at the liquid level gauge area. Clear tygon tubing connected the ejectors and manometers. A stainless "surge pot" was installed in each line to prevent possible mercury contamination in the event of a system upset. Kinema's sound level meter was placed at this point to facilitate a sound scan during the testing. The air loading orifices listed in the test procedure were assembled with the load header, this header having been bolted up earlier by Feldman's crew. An emergency shut off switch and voice communications were set up by NASA personnel at the position on the lower level of the ejector platform.

After the equipment was in place we held a meeting in the control room to finalize the timing and signals to be used during the test. It was decided at this time that no one would be permitted on the upper level of the tower during the test and that only myself and one of Feldman's crew would be on the platform at any time the ejectors were on. A set of hand signals were set up in the event of voice communication failure. At the conclusion of this meeting we returned to the site to begin the tests.

The system was pressurized in accordance with NASA's control room procedure and started up following Kinema's recommendations, i.e., second stage on to a pressure of 5 PSIA and then start first stage. I immediately found that I could not hear anything in my headset. When I felt that the system was stable with both first and second stages in, I proceeded with the test using hand signals and talking into the headset. The test run was completed with all test points documented successfully. All of the data recorded in both tests will be found in the enclosures attached to this report.

After experiencing some difficulties with the valving on the 24N20 (train 1) system, we decided to continue the testing the next morning. I left my instruments in place to expedite start up.

When the valve had been repaired we initiated the second test along the lines described above. This set of data was successfully recorded and we met again in the control room to discuss the findings and decide on the need, if any, for further testing.

Based on the results and in my opinion I felt that both trains of ejectors were operating a bit better than design and from Kinema's standpoint no further testing was needed. After reviewing the data with Feldman and NASA personnel, it was decided that this was in fact the case and I proceeded to remove my equipment from the platform.

When I had retrieved my instruments I returned to the control room and left copies of the pertinent "rough" data collected during the tests. This information has been changed into a more formal format for this report. Copies of the "rough" data will not be included. As all the required testing was completed I left the installation at 2:00 p.m. on 6/11/85.

PART TWO - PERFORMANCE

The main object of these tests was to determine if the ejectors would operate as designed or if some adjustment, or "tune up" work, would be needed.

In running the ejectors and analyzing the data, we found that at the design performance points the actual pressures achieved by the systems were a bit better than expected. The results are plotted against the expected curves submitted with the proposal and can be found in the enclosures. With the exception of the final points taken on train 1, with the motive pressure reduced drastically to 343 PSIG, both systems ran stably and handled the varied load ranges smoothly. This indicates that changes in loading during operation will not be accompanied by wildly fluctuating suction pressures or instability.

Again returning to the plotted curves, we see a more obvious variance from design at the lower load points. The fact that the offset of the curve is to the "good" side suggests two things. These ejectors, being air operated for all intents, work better at the lower load ranges than other "air operated" ejector systems we have designed. The usual dramatic falling off of the capacity at the reduced load levels is not present here. The second point to be made regards the design of the systems themselves. The advantage in capacity found here is due in part to some conservative design by Kinema.

Again, the design points are found to be a few percent to the better, but this brings up another factor. If it is found in the future that the actual operating gas loads are below the expected values, then a possible refit with the idea of saving motive gas could be considered. To explore this point, it would be necessary to conduct further testing on the ejectors while in actual operation and analyzing that data with respect to the information collected and described in this report.

Based on my experience on Kinema's test floor and in the field, I can state that both ejector systems performed better than expected with regard to suction pressure and stability. The operational problems sometimes found with air operated ejectors are not present here.

I also feel that if the proper "bleed back" system were installed, a particular pressure could be maintained by the ejectors and this pressure would be repeatable to a fine degree.

PART THREE - MOTIVE CONSUMPTION

The total amount of motive gas used during a run was another point that demanded an actual test to determine. Several theories and estimates were put forward and can now be compared to the flow rates found during the tests described above.

At each load point during the test the motive gas temperature and pressure was recorded. This would allow us to construct a performance profile based on changing motive gas conditions. We expected to maintain a pressure around 500 PSIG and we knew that we had no control over the motive temperature. It was established that the lowest temperature experienced was -41°F. There was no effect on the ejector performance during the test that could be attributed to the changing mass flow due to gas temperature. The only time that gas pressure affected the performance was when this pressure dropped to 343 PSIG and was coupled with a low ejector load. Under these conditions instability can be expected in any ejector.

The obvious effect on the system of the conditions listed above was the increased motive gas consumption. The average increase in usage on train 2 was 9% for the first section and 15% for the second section of the second stage tests. The first stage used 7% over design on the average. This total amounts to about 17533 lb/hr excessive gas usage for the duration of the test. This is due to the temperature change and the overpressurization found during this test.

Contrast this to the consumption of the first stage, train 1 which amounted to a saving of some 3%. Note also that the average gas pressure on the train 1 test was 483 PSIG or about 3.4% below design.

This leads me to believe that the excessive gas usage can be alleviated by lowering the motive pressure to a point of 5 to 8% below design. The lower gas pressure does not appear to have much effect on performance until it drops well below the 10% range. This point can be developed to a finer degree by further testing.

PART FOUR - MOTIVE CALCULATIONS

In this section I will review the calculations used to determine gas flow based on temperature and pressure.

The formula used is: $$W = \frac{At \times Cu \times V2s}{v2s}$$

The following explanation applies.

W = motive flow in lb/sec

Cu = nozzle coefficient = 1

V2s = square root of [2 x gc x Cp x (To - T2s) x 778]

$v2s = \frac{R \times T2S}{Pt \times 144}$

Cp = from temperature chart

$T2s = To \times \left(\frac{Pt}{Po}\right) \exp \left(\frac{K-1}{K}\right)$

$Pt = Po \text{ (absolute)} \times \frac{Pt}{Po}$

K = From temperature chart

$\frac{Pt}{Po}$ = critical pressure ratio from chart

$\frac{lb}{hr} = W \times 3600$

At = nozzle area in square feet

gc = 32.17 constant

To = Absolute gas temperature degree R

$R = \frac{1545}{\text{molecular weight}}$

Po = gas pressure (absolute)

778 = constant

The charts necessary for determining certain values for this equation will be found in the enclosures. These are sectional copies of graphs that were submitted earlier. I have adjusted the scales to more closely match the actual conditions found during the tests.

PART FIVE - CONCLUSION

In the form of a wrap up, I would start by saying that from Kinema's standpoint, the test was a complete success. The information gathered allowed us to prove the design of our ejector systems and the theories we had concerning motive flow. The ejectors run a bit better than design and the change in motive gas flow does not seriously affect the performance until extremes are reached.

The methods discussed for calculating gas flow are fairly straightforward and repeatable. The secondary method based on percentages allows relatively quick checks of the flow in lieu of the final form of the gas flow equation.

I want at this time to thank all the people from Feldman and NASA who assisted in the tests and without whose help they could have not been completed successfully. If any questions arise from either the test or the report do not hesitate to call.

PART SIX - ENCLOSURES

The enclosures mentioned in the report are to be found in this section. They consist of:

Enclosure No. 1 - Test data and calculated motive flows

Enclosure No. 2 - Performance curves

Enclosure No. 3 - Motive flow calculations and graphs needed

Enclosure No. 4 - Motive flow temperature and pressure adjustment curves

Enclosure No. 1 lists the data recorded during the ejector tests including the suction pressures, load points in DAE, motive pressures, motive temperatures and the results of the sound level scan. It also lists the calculated motive flows based on the actual motive gas conditions during the test.

Enclosure No. 2 transfers the suction pressure readings and DAE values to performance curves. The base curves are the expected performance curves submitted to NASA. The curves plotted over the base are the actual performance values recorded during the tests. Noting that a couple of points do not exactly follow the actual curve, I would explain this with the fact that due to the rather short duration allowed for testing based on motive gas consumption, complete leveling out of the suction presure was not effected. The general parallelism of the curves tells me that the ejectors are operating very well.

Enclosure No. 3 contains motive flow calculation information. It consists of the needed graphs, calculations based on design information and examples.

Enclosure No. 4 is the information to be used to calculate motive flows based on temperature and pressure - vs - percentage of flow. I developed these curves from the information gathered during the tests. They are a quick method of determining mass flow based on the observed conditions.

Charles Braum/daw

Charles Braum

50198

copies as follows:

✓Orig. - Feldman Mechanical Contractors Co.
Mr. Jim Cater

Acct. Payable - this copy attached to Mr. Cater's copy

cc/Dave Hall, W. M. Wilson Co., Inc.

cc/Scott Meyer - NASA

cc/Joe Morgan - NASA

cc/Dave Herb - NASA

cc/Extra Copy - NASA

NASA's address as follows:

NASA Lewis Research Center
21000 Brook Park Rd.
Cleveland, Ohio 44135

Mailing Station 500-218

ENCLOSURE NO. 1

NASA LEWIS RESEARCH CENTER

6/10, 6/11/85

EJECTOR TEST DATA

16 N 14 SYSTEM TEST 1

LOAD POINTS			SUCTION P.	SUCTION P.	MOTIVE P.		MOTIVE T.		MOTIVE FLOW	
	lb/hr	lb/sec	S1 mm HgA	S2 mm HgA	1 psig	2	1 deg.F.	2	1 lb/hr	2
1.	0	0	4.66	99.56	516	517	+47	+25	8490	71226
2.	925	.256	8.66	106.17	523	524	+29	+13	8789	73331
3.	2180	.605	8.66	115.82	523	524	+14	+ 7	8978	73896
4.	2520	.700	12.66	118.87	524	525	+ 7	- 7	9133	75479
5.	2705	.751	16.66	118.87	523	524	- 3	-17	9263	76281
6.	4360	1.211	48.66	161.54	521	522	-15	-29	9351	77487
7.	4360	1.211		76.66		526		-33		78340
8.	2705	.751		50.66		522		-36		78198
9.	2520	.700		50.66		520		-38		78216
10.	2180	.605		48.66		520		-40		78559
11.	925	.256		32.66		521		-41		78721
12.	0	0		8.66		522		-41		78868

SOUND SCAN RESULTS Both stages with 4360 lb/hr DAE.

db level	overall	63	125	250	500	1K	2K	4K	8K
reading	+140	98	104	110	113	114	111	105	100

The reading when the rupture disk failed was +157

NASA LEWIS RESEARCH CENTER

6/10, 6/11/85

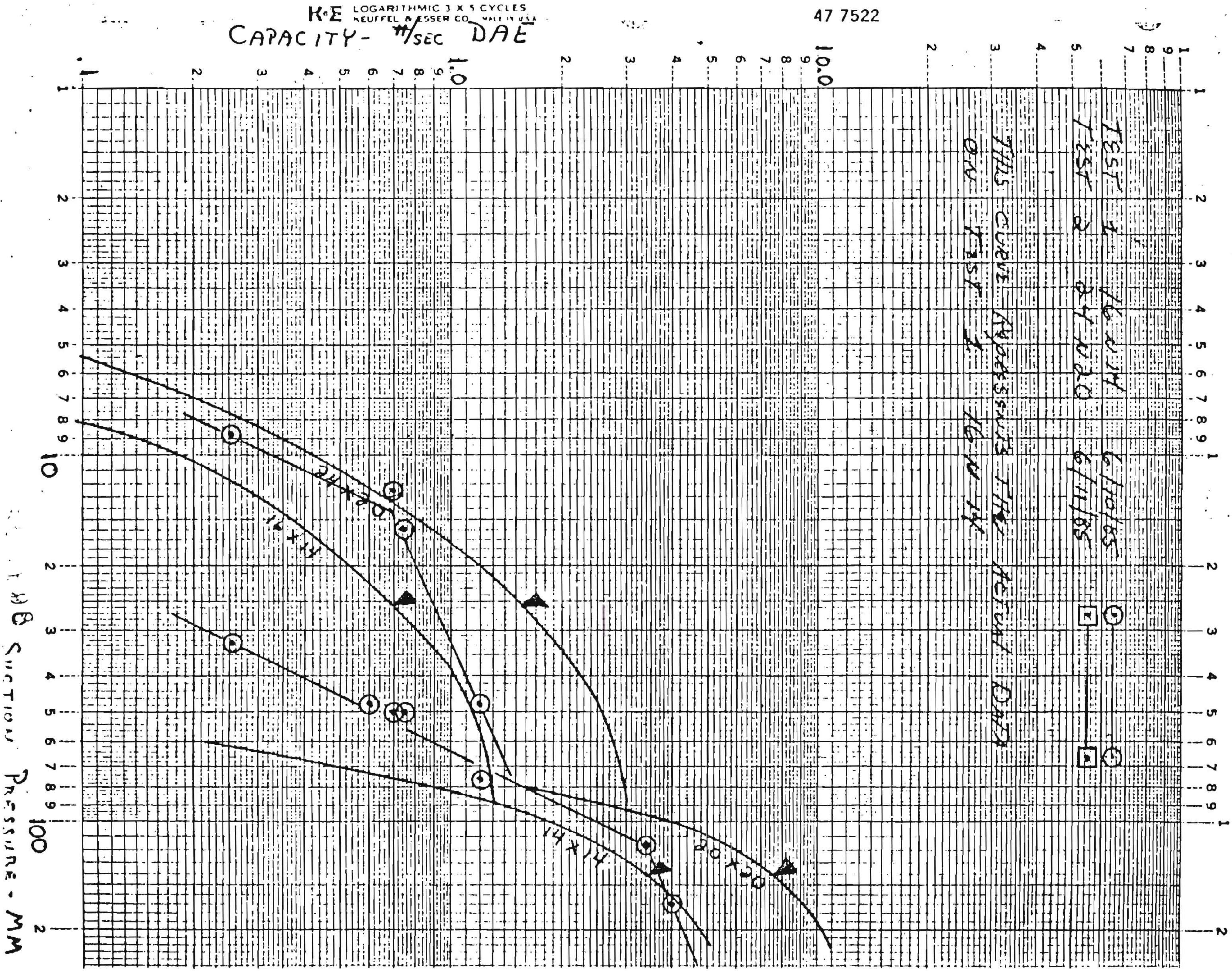
EJECTOR TEST DATA

24 N 20 SYSTEM TEST 2

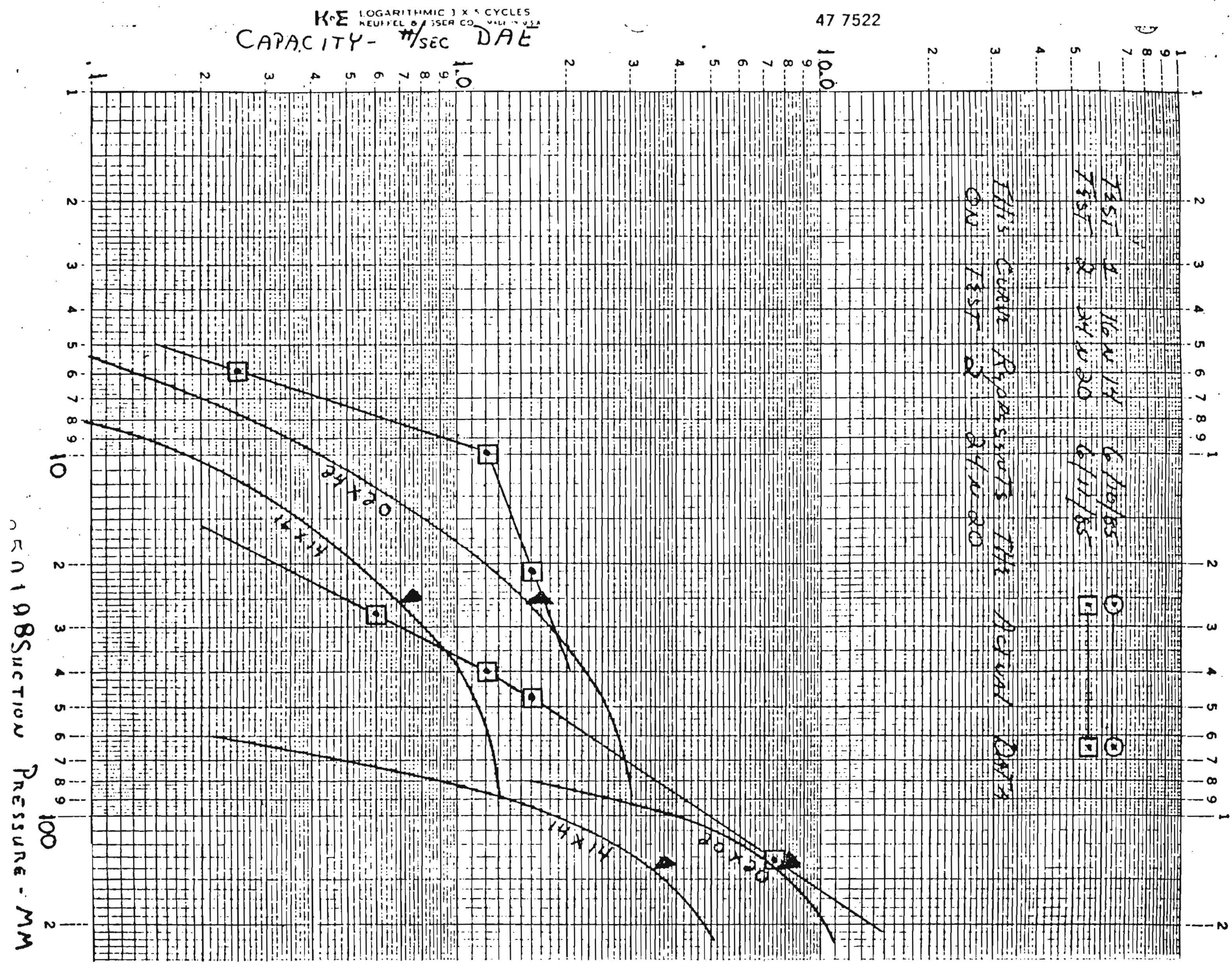
	LOAD POINTS lb/hr	lb/sec	SUCTION P. S1 mm HgA	SUCTION P. S2 mm HgA	MOTIVE P. 1 psig	MOTIVE P. 2 psig	MOTIVE T. 1 deg.F.2	MOTIVE FLOW 1 lb/hr 2
1.	0	0	3.87	103.88	487	490	+42	18008
2.	925	.256	5.87	108.96	483	479	+35	18014
3.	2180	.605	5.87	114.04	482	471	+31	18068
4.	4360	1.211	9.87	120.65	482	464	+28	18136
5.	5810	1.613	21.87	133.35	482	449	+27	18156
6.	5810	1.163		47.75		381		
7.	4360	1.211		39.62		371		
8.	2180	.605		27.68		343		
9.	925	.256		unstable				
10.	0	0		unstable				

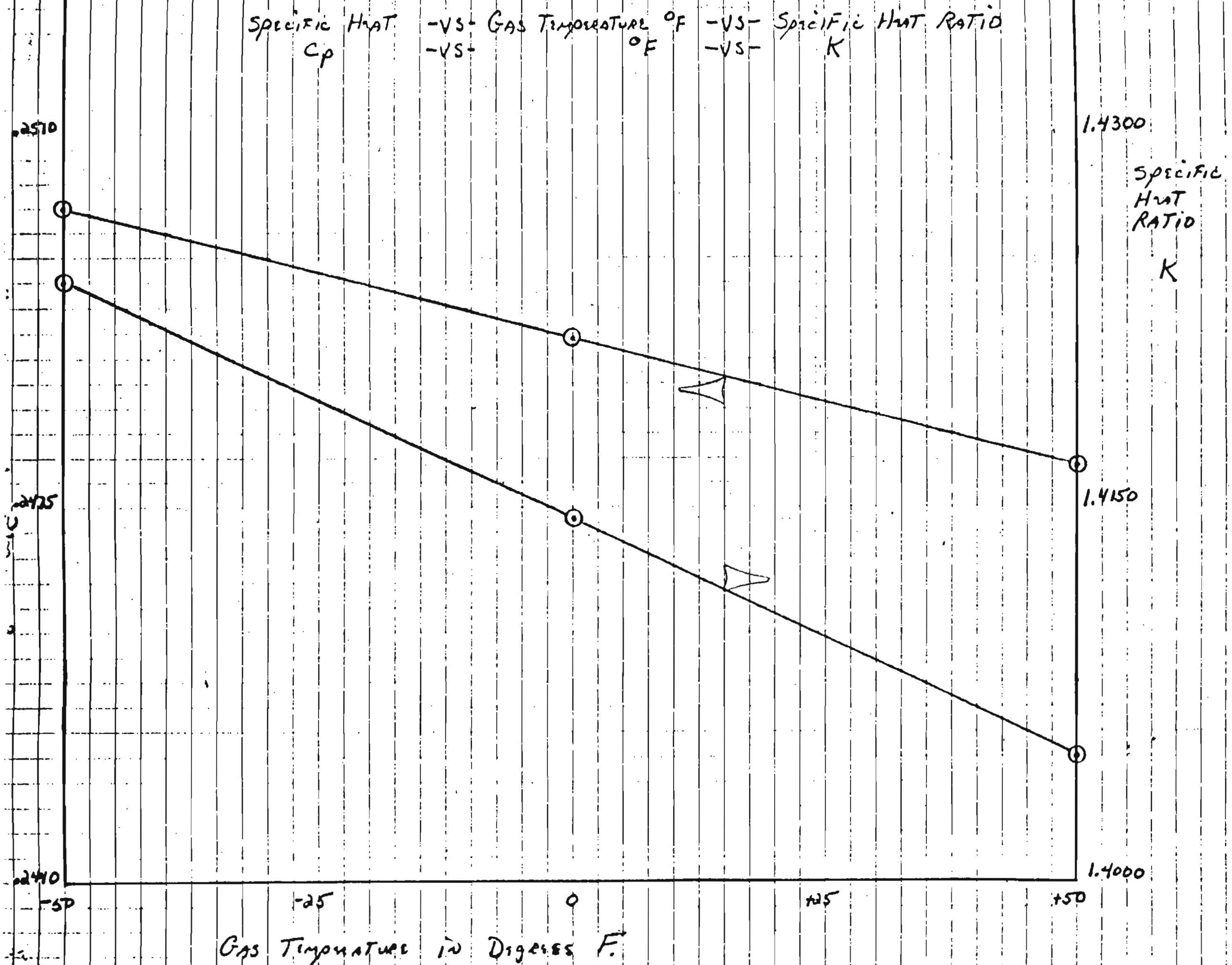
SOUND SCAN RESULTS Both stages with 5810 lb/hr DAE.

db level	overall	63	125	250	500	1K	2K	4K	8K
reading	+140	100	103	112	116	116	117	120+	120+

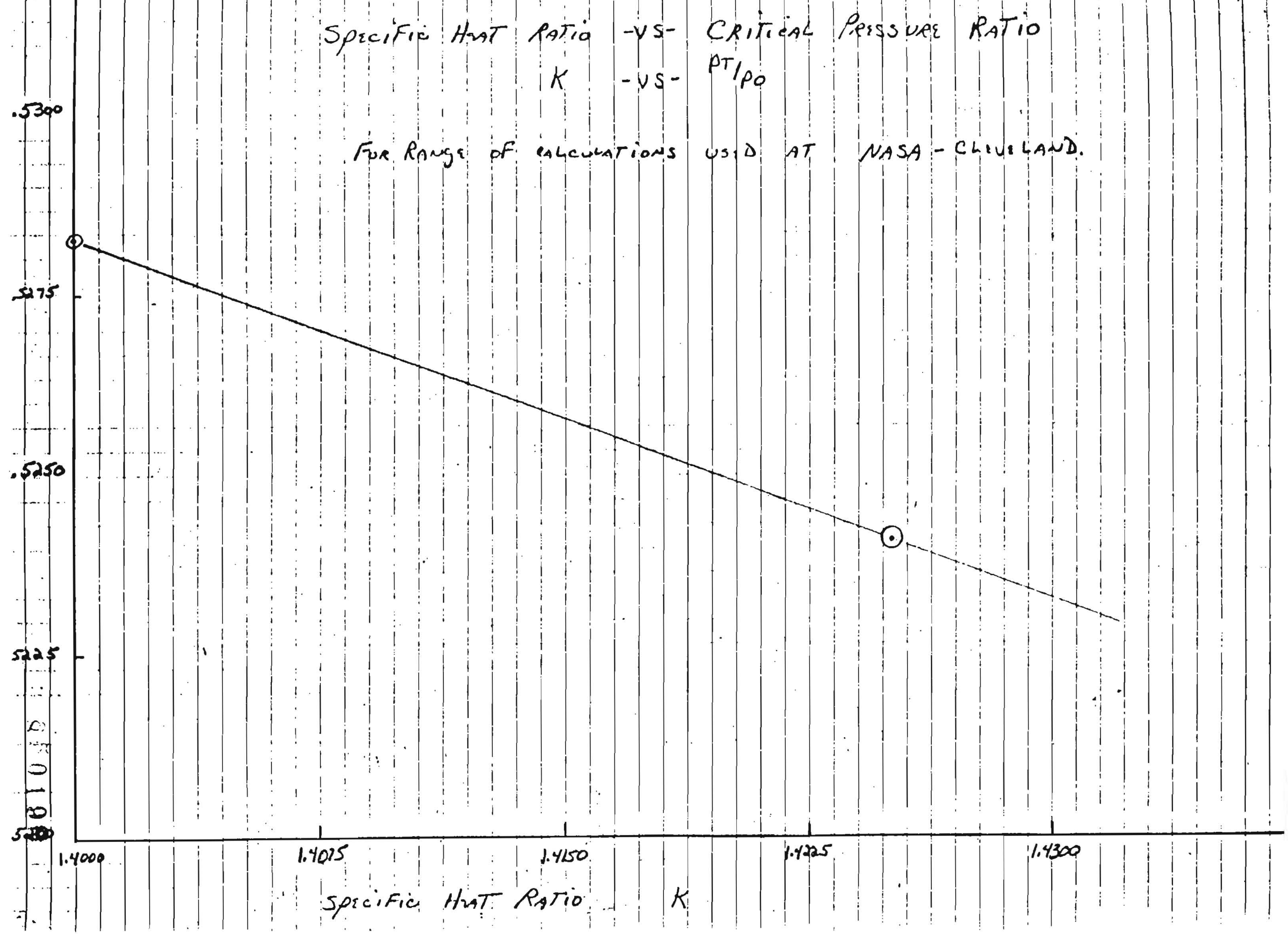


K+E LOGARITHMIC 3 X 5 CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 7522
CAPACITY - #/SEC DAE
1.0
10.0
TEST 1 16 W 14 6/10/85
TEST 2 24 W 20 6/11/85
THIS CURVE REPRESENTS THE ACTUAL DATA ON TEST 1 16 W 14
20 x 20
14 x 14
10
100
SUCTION PRESSURE - MM


K+E LOGARITHMIC 3 X 5 CYCLES
KEUFFEL & ESSER CO. MADE IN USA
47 7522
CAPACITY - #/SEC DAE
TEST 1 16x14 6/10/85
TEST 2 24x20 6/11/85
THIS CURVE REPRESENTS THE ACTUAL DATA ON TEST 2 24x20
24x20
14x14
14x14
SUCTION PRESSURE - MM



Specific Heat -VS- Gas Temperature °F -VS- Specific Heat Ratio
Cp -VS- °F -VS- K
.2510
.2475
.2440
Cp
1.4300
1.4150
1.4000
Specific Heat Ratio
K
-50
-25
0
+25
+50
Gas Temperature in Degrees F.


SPECIFIC HEAT RATIO -VS- CRITICAL PRESSURE RATIO
K -VS- PT/PO
FOR RANGE OF CALCULATIONS USED AT NASA - CLEVELAND.
.5300
.5275
.5250
.5225
1.4000
1.4075
1.4150
1.4225
1.4300
SPECIFIC HEAT RATIO K

24 N 20

DATE 6/12/85

UNIT DESIGN 24 x 20 MOTIVE PRESSURE 500 psig MOTIVE TEMPERATURE 35 °F 1.66 °C

STEP 1 $a_T = \frac{D^2 \pi/4}{144}$ $\frac{(.7343)^2 \times .7854}{144} = 2.94^{-03} = K1$

STEP 2 $\bar{V}_{2S} = \sqrt{64.34 \times 778 \times C_p \times (T_0 - T_{2S})}$

$\bar{V}_{2S} = \sqrt{50056.52 \times (.2482) \times (495 - K3)} = 1021.38 = K2$

Cp From Temp Chart

$T_0 = {}^\circ F + 460$

STEP 3 $T_{2S} = T_0 \left(P_T/P_0\right)^{\frac{k-1}{k}}$

$T_{2S} = (495)(.5268)^{\left(\frac{.4085}{1.4085}\right)} = 411.03 = K3$

P_T/P_0 From Critical Pressure Chart

K From Temp Chart

STEP 4 $v_{2S} = \frac{R\ T_{2S}}{P_T(144)}$

$v_{2S} = \frac{(55.17)(K3)}{(271.03)(144)} = .5804 = K4$

$R = 1545/MW$

$P_T = P_0 \times P_T/P_0$

$T_{2S} = K3$

STEP 5 $w = a_T \frac{C_L \bar{V}_{2S}}{v_{2S}}$

$w = \frac{(K1)(K2)}{(K4)} = 5.174 \times 3600 = 18629$ LB/HR

850198

24 N 20 DATE 6/12/85

UNIT DESIGN 20 x 20 MOTIVE PRESSURE ____ psig MOTIVE TEMPERATURE ____ °C

STEP 1 $a_T = \frac{D^2 \pi/4}{144}$ $\frac{(2.08)^2 \times .7854}{144}$ = .0235 = K1

STEP 2 $\bar{V}_{2S} = \sqrt{64.34 \times 778 \times C_p \times (T_0 - T_{2S})}$

$\bar{V}_{2S} = \sqrt{50056.52 \times (.2432) \times (495 - K3)}$ = 1021.38 = K2

Cp From Temp CHART

T_0 = °F + 460

STEP 3 $T_{2S} = T_0 \left(P_T/P_0\right)^{\frac{K-1}{K}}$

$T_{2S} = (495)(.5268)^{\left(\frac{.4085}{1.4085}\right)}$ = 411.03 = K3

P_T/P_0 From critical Pressure CHART

K From Temp CHART

STEP 4 $v_{2S} = \frac{R \; T_{2S}}{P_T (144)}$

$v_{2S} = \frac{(55.17)(K3)}{(271.03)(144)}$ = .5804 = K4

$R = 1545/MW$

$P_T = P_0 \times P_T/P_0$

T_{2S} = K3

STEP 5 $w = \frac{a_T \; C_L \; \bar{V}_{2S}}{v_{2S}}$

$w = \frac{(K1)(K2)}{(K4)}$ = 41.52 X 3600 = 149,480 LB/HR

ENCLOSURE NO. 3

16 N 14

DATE 6/12/85

UNIT Design 16 x 14 MOTIVE PRESSURE 500 psig MOTIVE TEMPERATURE 35 °F 1.66 °C

STEP 1 $a_T = \frac{D^2 \pi/4}{144}$ $\frac{(.492)^2 \times .7854}{144} = 1.32^{-03}$ = K1

STEP 2 $\bar{V}_{2S} = \sqrt{64.34 \times 778 \times C_p \times (T_0 - T_2S)}$

$\bar{V}_{2S} = \sqrt{50056.52 \times (.2482) \times (495 - K3)} = 1021.38$ = K2

Cp From Temp Chart

$T_0 = {}^\circ F + 460$

STEP 3 $T_{2S} = T_0 \left({}^{PT}/_{P_0} \right)^{\frac{K-1}{K}}$

$T_{2S} = (495)(.5268)^{\frac{(.4085)}{1.4085}} = 411.03$ = K3

PT/P_0 From critical Pressure Chart

K From Temp Chart

STEP 4 $v_{2S} = \frac{R \; T_2S}{P_T (144)}$

$v_{2S} = \frac{(55.17)(K3)}{(271.30)(144)} = .5804$ = K4

$R = 1545/MW$

$P_T = P_0 \times {}^{PT}/_{P_0}$

$T_2S = K3$

STEP 5 $w = \frac{a_T \; c_w \; \bar{V}_{2S}}{v_{2S}}$

$w = \frac{(K1)(K2)}{(K4)} = 2.32 \times 3600 = 8363$ LB/HR

16 N 14.

DATE 6/12/85

UNIT Design 14x14 MOTIVE PRESSURE 500 psig MOTIVE TEMPERATURE 35 °F 1.66 °C

STEP 1 $a_T = \frac{D^2 \pi/4}{144}$ $\frac{(1.404)^2 \times .7854}{144}$ = .01075 = K1

STEP 2 $\bar{V}_{2s} = \sqrt{64.34 \times 778 \times C_p \times (T_0 - T_{2s})}$

$\bar{V}_{2s} = \sqrt{50056.52 \times (.2482) \times (495 - K3)}$ = 1021.38 = K2

Cp FROM TEMP CHART

T_0 = °F + 460

STEP 3 $T_{2s} = T_0 \left(P_T/P_0\right)^{\frac{K-1}{K}}$

$T_{2s} = (495)(.5268)^{\left(\frac{.4085}{1.4085}\right)}$ = 411.03 = K3

P_T/P_0 FROM CRITICAL PRESSURE CHART

K FROM TEMP CHART

STEP 4 $v_{2s} = \frac{R\ T_{2s}}{P_T (144)}$

$v_{2s} = \frac{(55.17)(K3)}{(271.30)(144)}$ = .5804 = K4

$R = 1545/MW$

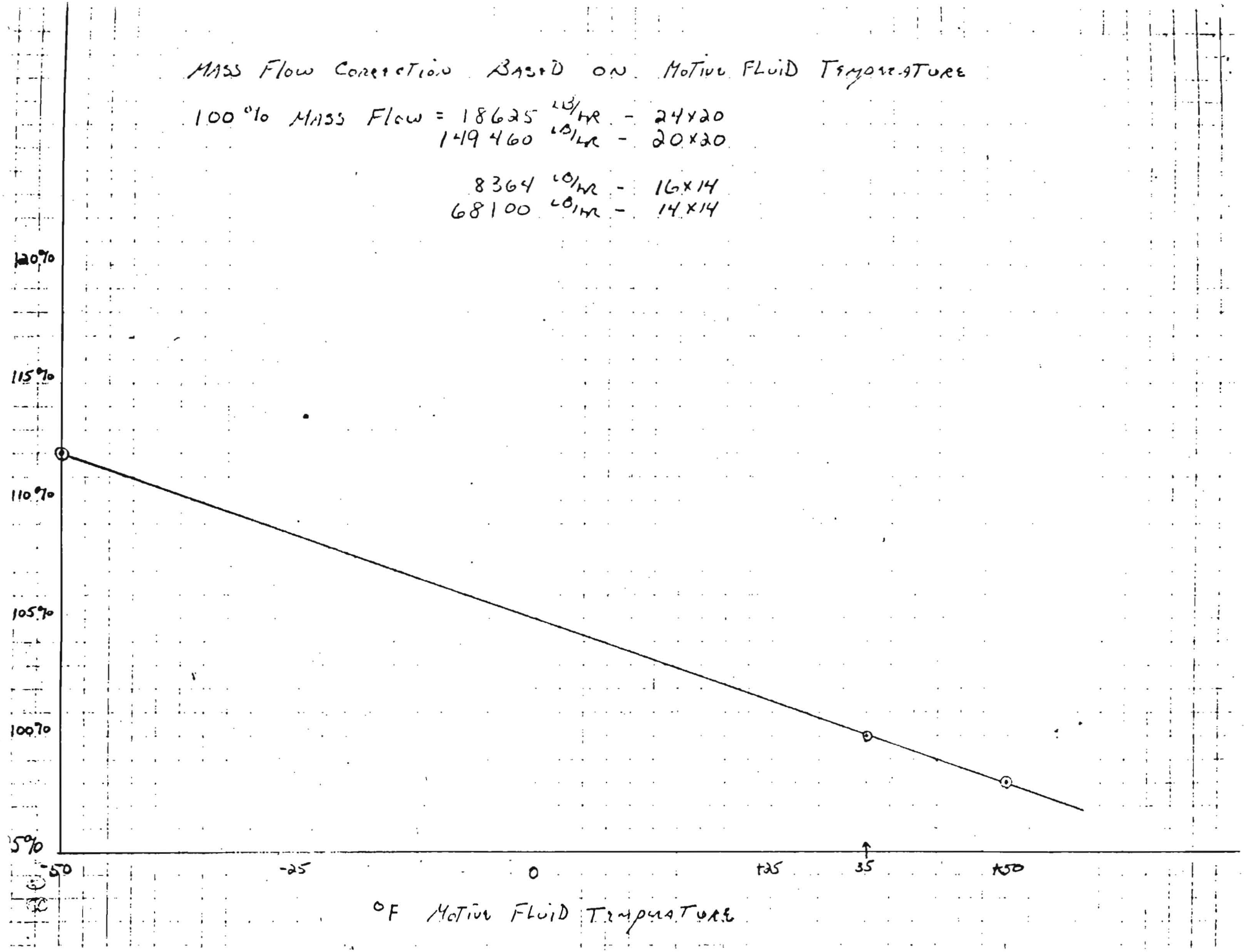
$P_T = P_0 \times P_T/P_0$

$T_2S = K3$

STEP 5 $w = \frac{a_T\ C_w\ \bar{V}_{2s}}{v_{2s}}$

$w = \frac{(K1)(K2)}{(K4)}$ = 18.91 X 3600 = 68107 LB/HR

98


MASS FLOW CORRECTION BASED ON MOTIVE FLUID TEMPERATURE
100% MASS FLOW = 18625 LB/HR - 24x20
149460 LB/HR - 20x20
8364 LB/HR - 16x14
68100 LB/HR - 14x14
120%
115%
110%
105%
100%
95%
-50
-25
0
+25
35
+50
°F MOTIVE FLUID TEMPERATURE

MASS FLOW CORRECTION BASED ON MOTIVE FLUID PRESSURE

100% MASS FLOW = 18625 LB/HR - 24×20
149460 LB/HR - 20×20

8364 LB/HR - 16×14
68100 LB/HR - 14×14