FOREWORD

This report was prepared by Arthur D. Little, Inc., Cambridge, Massachusetts under Air Force Contract No. AF 33(657)-8695, under Task No. 308404 of Project No. 3084, "Propulsion Fluid and Heat Transfer Sub-systems". The work was administered under the direction of the Ram-Jet Division, Air Force Aero-Propulsion Laboratory, Aeronautical Systems Division, Mr. D. H. Mudd was project engineer for the Ram-Jet Division.

The work covered in this report began in April 1962, and was concluded in June 1963. Mr. R. B. Hinckley was the program director at Arthur D. Little, Inc., responsible for this activity.

The chief areas of interest of the other authors were: J. C. Burke, report preparation, data correlation and "hand calculation" solutions; F. E. Ruccia, design, construction and operation of the experimental facility; R. P. Berthiaume, design and fabrication of the test heat exchanger; R. C. Reid, analyses of deposition mechanisms and frost properties; E. M. Drake, mass transfer analysis; I. W. Dingwell, variable heat transfer computer program; and M. E. Weber, constant heat transfer computer program.

In addition to the authors mentioned on the title page, several other individuals performed significant contributions to this program. Acknowledgement should be made to James Franklin, Raymond McMillen and David Coombs for their efforts in construction and operation of the test facility; to Walter Liebfried and John Burke for the construction and instrumentation of the test heat exchangers; to Henry Survilas and Charles Hansen for the photographic aspects of the test program; and to Robert Gallagher for his assistance in programming the variable heat transfer computer solutions.

This report is the final report and it concludes the work on Contract No. AF 33(657)-8695.

ABSTRACT

As part of an analytical and experimental study of water and carbon dioxide freeze-out in heat exchangers, a test program was conducted covering a wide range of air stream pressures, temperatures, mass flow and concentration conditions. The test program consisted of 42 tests, grouped by objective, into five test series. This volume presents the detail test data obtained in the test program. The test data includes mass flow rates, heat balances, contaminant concentrations at the heat exchanger inlet and outlet, notes on the deposit appearance, and tabulations of heat exchanger pressures and temperatures as functions of time and position for each test. In addition, brief summaries of the data obtained in each test series are included. The overall objectives of this test work and the analyses of the results are presented in Volume II to the basic report.

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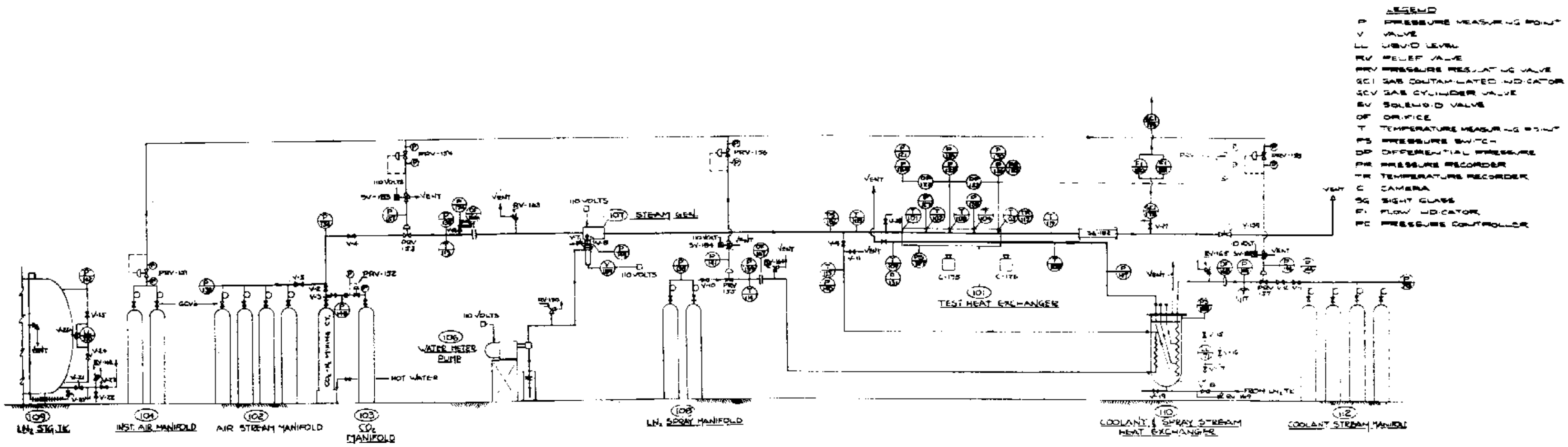


FIGURE 1 FLOW SHEET - FREEZE-OUT TEST FACILITY

ASD-TDR-63-508, Volume III

Manuscript released by author on July 1, 1963
for publication as an ASD Technical Documentary Report.

FLOW TEST SERIES DATA

ASD-TDR-63-508, Volume III

TABLE OF CONTENTS

Summary Memorandum-Flow Test Series

The reduced data includes the following information for each test:

1. Summary Sheet

The test summary sheet includes the nominal test parameters, the primary variable investigated, a time sequence of important events during the test, a brief summary of the photographic information, and general test notes.

2. Flow Data

The flow data sheets include the air and coolant flows calculated from both orifice pressures and high pressure bottle blow down. Spray flow data is also presented for the LN_2 spray tests F-13 and F-14.

3. Temperature Data

The air and coolant temperature data sheets include air and coolant temperatures tabulated as a function of time. Temperature differential tabulations have also been prepared in which the individual Δ T's in the heat exchanger air stream as well as the overall air and coolant Δ T's have been listed as a function of time.

4. Air Pressure Data

Heat exchanger air pressure and air pressure drops have been tabulated as a function of time on the heat exchanger air pressure data sheets.

5. Contaminant Data

Water and carbon dioxide concentration, as measured by sample probes in the inlet and exit of the test heat exchanger, have been tabulated as a function of time. Inlet contaminant concentrations, as calculated from the measured rates of contaminant addition, are included on the data sheets. In addition, these sheets contain comparisons between the measured air stream concentration and the saturation concentrations based on the air temperature.

6. Energy Balances

Energy balances for all of the flow series tests have been completed. In these energy balances, the air and coolant heat flows have been computed from the measured mass flow rates and the inlet and outlet temperatures and pressures. The coolant heat flows are subject to some error since the coolant inlet and outlet measurement points are located some distance from the test heat transfer section inlet and outlet. For this reason the energy balances were prepared for two conditions:

1. The coolant heat flows were based on actual (uncorrected) coolant inlet and outlet temperatures.

2. The coolant heat flows were based on coolant inlet and outlet temperatures corrected for the estimated heat leaks between the measurement points and the heat transfer section.

Some observations which are apparent from the test data are as follows:

1 Flow Rates

The agreement between the flow rates computed from the orifice pressures and from the bottle blow down is generally good. The air flow data agrees very well with the bottle blow down data; the agreement is generally within 5% and no constant bias exists between the orifice results and the bottle blow down results. For the coolant flow, the agreement between orifice and bottle blow down results is not quite as satisfactory. The orifice coolant flow is generally less than the coolant flow computed from bottle blow down. The discrepancies between these two methods of calulation is most apparent at low flow rates. It is our belief that this discrepancy is primarily caused by leakage between the bottle minifold and the flow orifice. We have observed some leakage in this piping but were not able to define it quantitatively before the facility was dismantled for liquid hydrogen tests. We will continue to monitor both orifice flow and bottle blow down flow in our subsequent testing and hope to be able to resolve this apparent discrepancy.

On the basis of the good agreement on the air circuit, we feel that the orifice measurements are most indicative of the true flow rates. The orifice flows will be assumed to be the correct flow rates in this test series.

2. Energy Balances

The energy balances show reasonably good agreement between the calculsted air side heat flow and coolant side heat flow. For most of the tests, the coolant heat flow based on incorrected coolant temperatures is of the order of 10 to 20% higher than the air side heat transfer. The increased heat transfer on the coolant side is believed to be primarily due to heat transfer to the coolant piping between the temperature measurement points and the ends of the transfer section test heat exchanger. The agreement is better when the coolant heat flow is based on corrected temperatures.

3. Contaminant Data

The carbon dioxide contaminant data appears to be very consistent. The Carbon dioxide concentration measured at the inlet to the test heat exchanger agrees very well with the carbon dioxide concentration computed from the mixing bottle data. The carbon dioxide concentration measured at the exit of the heat exchanger is very close to the saturation quantity based on the exit air temperature.

The water contaminant data does not present as clear a picture. The water content measured at the inlet to the test heat exchanger is generally of the order of 20 to 30 % less than the water concentration computed from the water injection pump flow and the air flow and, in some instances, considerably lower. This situation is evidentaly due to incomplete vaporization at the point of water injection and/or water meter calibration errors. This discrepancy was most marked in the early tests in which steam was ejected into the inlet air. An improvement was realized by injecting the water into a coiled section of the inlet air line. However, some discrepancies in inlet water content still exist. We have found virtually no correlation between the measured exit water concentration and the saturation concentration corresponding to the exit air temperature. We believe that the primary reason is that the saturation water content is well below readable concentrations on the water meter. The conclusions above are tentative at this time since we are still evaluating the water content data.

4. Air Pressure Drop Data

The air pressure drop data appears at this point to be quite reasonable. Generally the locations of high pressure drop correspond with the locations of maximum frost concentration. For the tests run to date, the pressure drop due to carbon dioxide deposition is generally much less than that due to water deposition. In some cases, the carbon dioxide pressure drop affect is almost within the range of instrumentation accuracy. It may be desirable in the verification test series to run an extended length test of say one hour or so to get good data on the pressure rise due to carbon dioxide.

5. Air Temperature Data

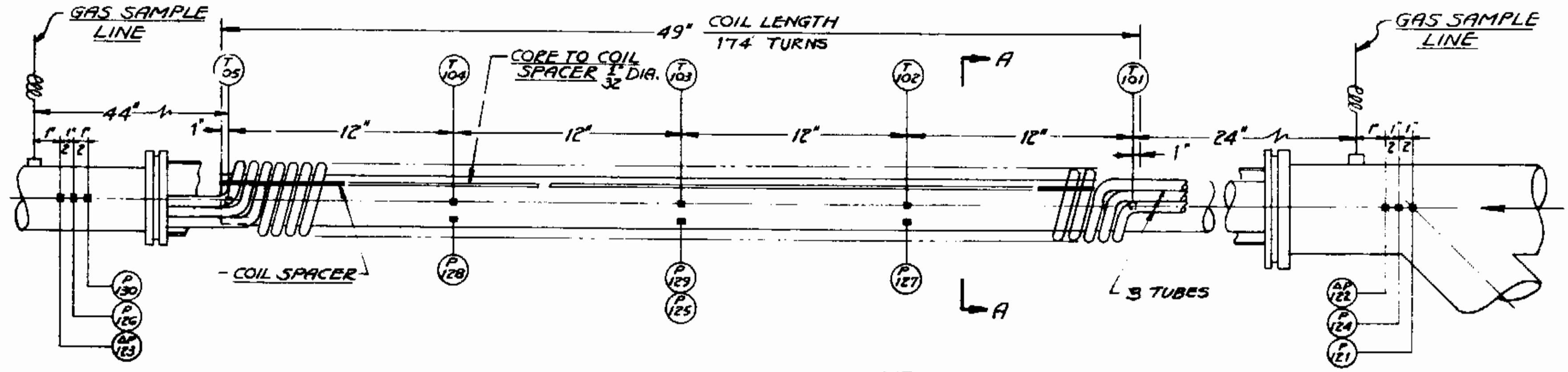
The air temperature data appears to be quite good. The energy balances have shown that, on an overall sense, the air temperature drops are reasonable. The individual temperature differentials measured axially along the test heat exchanger appear to be reasonably consistent. It is interesting to note that after the cooldown of the test heat exchanger is complete the overall change in air temperature appears to be only slightly affected by contaminant deposition. However, there appears to be some noticeable differences in heat transfer in the individual axial sections.

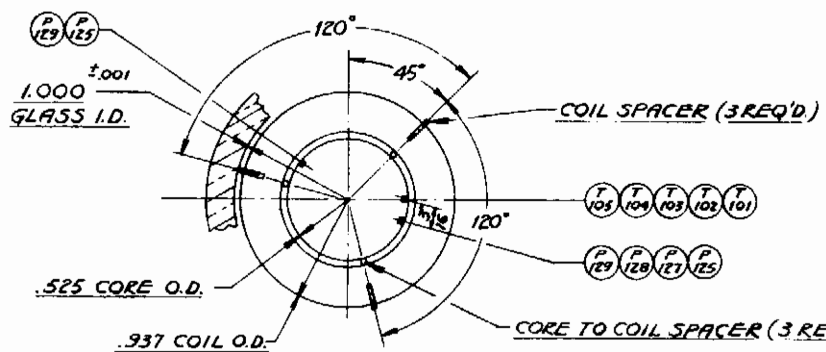
FLOW TEST SERIES 1 PARAMETER SUMMARY

Attachment No. 1 to Progress Report for August 1962
Pursuant to Contract No. AF 33(657)-8695

	Air Stream				Coolant			Spray	
Test No.	Ga lb/sec ft^2	Pa psia	% H_2O	% CO_2	Press (psig)	Inlet Temp. (° F)	$\frac{(Wc_p)_c}{(Wc_p)_a}$	$\frac{(Wc_p)_s}{(Wc_p)_a}$	Variable Investigated
F-1	10	30	.005	0	70	-200	1.0	0	low pressure
F-2	30	90	.006	0	180	-156	1.0	0	H_2O content
F-3	30	90	.026	0	180	-156	1.0	0	H_2O content
F-4	30	90	.045	0	180	-156	1.0	0	H_2O content
F-5	30	90	.052	0	180	-156	1.0	0	H_2O content
F-7	30	90	.001	.05	700	-290	1.0	0	gas-wall Δ T
F-8	30	90	.016	.05	600	-290	1.0	0	gas-wall Δ T
F-9	30	90	.020	.05	700	-290	.5	0	gas-wall Δ T
F-12	30	90	.018	.05	600	-310	2.0	0	gas-wall Δ T
F-10	50	90	.018	.05	600	-290	1.0	0	flow velocity
F-11	15	90	.030	.05	700	-280	1.0	0	flow velocity
F-13	30	90	.012	.05	600	-290	1.0	.5	LN_2 spray
F-14	30	90	.012	.05	600	-290	1.0	.3	LN_2 spray
F-17	100	300	.017	.05	650	-310	1.0	0	High pressure

NOTES:
1. Configuration No. 1 used in all tests.
2. Nitrogen used for air, coolant and spray streams in all tests.
3. Test period 7/18/62 - 8/31/62.
4. All values shown are nominal based on preliminary survey of test data.





SECT. A-A

HEAT EXCHANGER DATA:

TUBE SIZE: 3/16" O.D. × .030 WALL, ANNEALED COPPER ,

TOTAL AIR SIDE SURFACE AREA: 1.76 $FT.^2$

AIR TO COOLANT SURFACE AREA RATIO: 1.472

AIR SIDE FLOW AREA: .150 $IN.^2$
.00104 $FT.^2$

COOLANT SIDE FLOW AREA: .0379 $IN.^2$
.000263 $FT.^2$

AIR TO COOLANT - FLOW AREA RATIO: 3.96

δ - HALF CLEARANCE: .031 IN.

NOTES:

1. PRESSURE GAGE P-129 AND TRANSDUCER P-125 ARE CONNECTED TO A COMMON SENSE LINE. THIS SENSE LINE IS FOR REASONS OF RELIABILIT FED BY DOUBLE PNEUMATIC LEADS FROM THE TEST CORE.
2. 94% OF TUBE SPACES ARE BETWEEN .055" AND .070"

TEST HEAT TRANSFER SECTION DETAILS - 1-INCH SPIRAL CONFIGURATION

BY J.C. Buoie DATE 9/6/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 9 OF

APPROVED DATE | SKETCH NO.

CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-1 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	30	10	1.0	0	.005	0	N_2 70 PSIG −205°F	36	7/18/62

VARIABLE INVESTIGATED: LOW PRESSURE

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS } DATA TEST
9	ESTABLISH STABLE COOLANT TEMPERATURE
15	STABLE H.E. AIR TEMP
32	INLET AIR PRESSURE FALLING
33	INJECT WATER @ ABOUT 1cc/MIN AS STEAM } FOR VISUAL OBSERVATION – NO REAL DATA
36	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

B&W MOVIE (RATHER POOR LIGHTING)

TRAVERSE @ 25-27 MIN SHOWS LIGHT FROST STARTING @ 20 INCHES

GENERAL NOTES:

1. IN DATA TEST, WATER CONTENT WAS "NATURAL" BOTTLE CONTENT, NO WATER INJECTED

TEST F-2 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	1.0	0	.006	0	N_2 180 PSIA −156°F	41½	7/24/62

VARIABLE INVESTIGATED: WATER CONTENT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
2	START REDUCING COOLANT TEMP
10	COOLANT INLET TEMP STABILIZED
12	STABLE H.E. AIR TEMP
41½	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

B&W MOVIE (BETTER THAN F-1 BUT BOTTOM LIGHTING STILL POOR) TRAVERSES @ 20, 30, 35 MIN
@ 35 MIN FROST STARTS @ ABOUT 11", FAIRLY HEAVY @ 20 IN, TAPERING OFF @ 30 IN

GENERAL NOTES:

1. WATER CONTENT WAS NATURAL BOTTLE CONTENT, NO WATER INJECTED

BY J.C. Burke DATE 9/6/62 — ARTHUR D. LITTLE, INC. — CAMBRIDGE, MASS. — SHEET NO. 11 OF ______
APPROVED ______ DATE ______ — SKETCH NO. ______
CLIENT ASD / EXPERI ______ — CASE NO. 64607

TEST F-3 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	1.0	0	.026	0	N_2 180 PSIA −156°F	48½	7/25/62

VARIABLE INVESTIGATED: WATER CONTENT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
1½	START TO COOL COOLANT
11	COOLANT INLET TEMP STABILIZED
12	INSERT WATER
13	STABLE H.E. AIR TEMP
20	INLET HUMIDITY METER STARTS TO RESPOND
48½	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

B&W MOVIE (IMPROVED BOTTOM LIGHTING)
TRAVERSES @ 20, 30, 45 MIN
@ 20 MIN FROST STARTS @ ABOUT 13 IN.
HEAVY 20-24, THINNING 30-34, VERY LIGHT @ 40 IN
@ 30 MIN FROST STARTS @ 5.5 IN

GENERAL NOTES:

BY J.C. Burke DATE 9/6/62 **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. SHEET NO. 12 OF ______

APPROVED ______ DATE ______ SKETCH NO. ______

CLIENT ASD/EXPERI CASE NO. 64607

TEST F-4 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	1.0	0	.045	0	N_2 180 PSIG −156°F	39 1/2	7/27/62

VARIABLE INVESTIGATED: WATER CONTENT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
2 1/4	START COOLING COOLANT
11	COOLANT TEMP STABILIZED
13	STABLE H.E. AIR TEMP, TURN ON WATER
20	INLET HUMIDITY METER STARTS TO RESPOND
39 1/2	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

COLOR MOVIE TRAVERSES @ 15, 27, 36, 90 MIN

@ 36 MIN FROST STARTS @ 2", HEAVY @ 10"

THINNING 24 - 30, VERY LIGHT BELOW 30"

GENERAL NOTES:

BY J C Burns DATE 9/6/62 | APPROVED ______ DATE ______ | CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 13 OF ______ | SKETCH NO. ______ | CASE NO. 64607

TEST F-5 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	1.0	0	.052	0	N_2 -180 -156°F	38½	8/3/62

VARIABLE INVESTIGATED: WATER CONTENT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
1¼–3¼	SHUT DOWN } TROUBLE WITH
3½–11	SHUT DOWN } DIFF. PRESS. SWITCH
13	START COOLING COOLANT
17	START H_2O INJECTION
18	STABLE COOLANT INLET TEMP
20	STABLE H.E. AIR TEMP
38½	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

COLOR MOVIE TRAVERSES @ 20, 25, 35 MIN
@ 35 MIN FROST STARTS @ 6", VERY
HEAVY (NEAR PLUGGING) 12–16, THINNING 20–30,
LIGHT BELOW 30
SIGHT GLASS FOGGING BELOW 35 W

GENERAL NOTES:

BY J. C. Burke DATE 9/6/62
APPROVED ______ DATE ______
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 14 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST F-7 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	.5	0	.0008	.05	N_2 700 PSIG -280°F	46	7/31/62

VARIABLE INVESTIGATED: WALL - GAS ΔT ("NORMAL" ΔT)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
3	START TO COOL COOLANT
10	STABLE COOLANT TEMP
20	STABLE H.E. AIR TEMP
46	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

COLOR MOVIE TRAVERSES @ 15, 20, 24, 38 MIN
@ 24 MIN — FROST START 16", FAIRLY THICK
20-33 CO_2 FROST STARTS 40"

SIGHT GLASS HEAVILY FOGGED BELOW 35"

GENERAL NOTES:

1. WATER CONTENT WAS "NATURAL" BOTTLE CONTENT — NO WATER INJECTED

BY J.C.Burke DATE 9/10/62 ARTHUR D. LITTLE, INC. SHEET NO. 15 OF

APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.

CLIENT ASD / EXPERI CASE NO. 64607

TEST F-8 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	.5	0	.016	.05	N_2 600 PSIG -290 °F	48½	8/1/62

VARIABLE INVESTIGATED: WALL - GAS ΔT ("NORMAL" ΔT)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
3	START TO COOL COOLANT
10	STABLE COOLANT INLET TEMP
10	INJECT WATER
12	STABLE H.E. AIR TEMP
48½	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

COLOR MOVIE - TRAVERSES @ 10, 15, 20, 25, 30 MIN @ 30 MIN. FROST STARTS @ 11½", HEAVY 15-25 THINNING 25-30"

SIGHT GLASS HEAVILY FOGGED BELOW 35"

OVERALL STILL PHOTOS DURING TEST

GENERAL NOTES:

BY JCBurr DATE 9/18/62 ARTHUR D. LITTLE, INC. SHEET NO. 16 OF

APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.

CLIENT ASD/EXPERI CASE NO. 64607

TEST F-9 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_B	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	.25	0	.02	.05	N_2 700 PSIG -290°F	45	8/14/62

VARIABLE INVESTIGATED: GAS-WALL ΔT (HIGH COLD END ΔT)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
3	START TO COOL COOLANT
11	STABLE COOLANT INLET TEMP
15	WATER ON
17	STABLE H.C. AIR TEMP
45	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

COLOR MOVIE TRAVERSES @ 18, 21, 26, 30, 35, 46 MIN
@ 40 MIN FROST STARTS @ 35'

OVERALL STILL PHOTOS DURING TEST

GENERAL NOTES:

BY: J.C. Buble DATE 9/18/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 17 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT: ASD / EXPERI | CASE NO. 64607

TEST F-10 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	50	.5	0	.018	.05	N_2 600 PSIG −290°F	23 3/4	8/15/62

VARIABLE INVESTIGATED: FLOW VELOCITY (HIGH FLOW)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, AIR AND COOLANT STREAMS
1/2	START TO COOL COOLANT
6	WATER ON
7 1/2	STABLE COOLANT INLET TEMP
11	STABLE H.E. AIR TEMP
23 3/4	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

COLOR MOVIE TRAVERSES @ 9, 13, 16, 21 MIN
@ 21 MIN FROST STARTS 13", NEAR 15-30,
LIGHT 35-42 CO_2 FROST STARTS 42"

OVERALL & CLOSE-UP STILLS

GENERAL NOTES:

BY J. Burke DATE 9/18/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 18 OF ______

APPROVED ______ DATE ______ | SKETCH NO. ______

CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-11 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	15	.5	0	.03	.05	N_2 700 PSIG -280 °F	45½	8/17/62

VARIABLE INVESTIGATED: FLOW VELOCITY (LOW FLOW)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS AND STREAMS
2	START TO COOL COOLANT
5½	STABLE COOLANT INLET TEMP
-1	START WATER
18	STABLE H.E. AIR TEMP.
45½	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

COLOR MOVIE TRAVERSES @ 20, 31, 36, 42

@ 31 MIN FROST STARTS @ 1.5', HEAVY 4-14

THINNING 15-28 CO_2 FROST ? 30-48

OVERALL & CLOSE-UP STILL PHOTOS

GENERAL NOTES:

1. WATER ADDED BEFORE H.E. TEMP STABILIZED. FROST DISTRIBUTION NON-TYPICAL DUE TO H_2O FROST FORMATION AT COLD END DURING H.E. COOLDOWN

TEST F-12 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	1.0	0	.018	.05	N_2 600 PSIG −310°F	52	8/21/62

VARIABLE INVESTIGATED: GAS-WALL ΔT (HIGH WARM END ΔT)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS AND STREAMS
2½	START TO COOL COOLANT
14½	STABLE COOLANT INLET TEMP
16	WATER ON
18½	STABLE H.E. AIR TEMP
52	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

COLOR MOVIE – TRAVERSES AT 16, 20, 25, 34 MIN.
@ 25 MIN HEAVY FROST STARTS @ 0", FLAKING @ 4",
BLOWN POWDER 5"-10", FAIRLY CLEAN 12-15"
CO_2 FROST STARTS 15", HEAVY 15-32, THINNING 32-44
LIGHT 44-48
OVERALL AND CLOSEUP STILLS

GENERAL NOTES:

VISIBLE EVIDENCE OF SOLID PARTICLE FORMATION DUE TO FLAKING AND/OR NUCLEATION – GOOD MOVIE SHOTS OF FLAKING DEPOSIT

BY A C Burke DATE 9/20/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 20 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-13 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	.5	.4	.012	.05	N_2 600 PSIG -290°F	53¼	8/24/62

VARIABLE INVESTIGATED: LN2 SPRAY
(HIGH SPRAY FLOW)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, STREAMS AND RECORDERS
4¼	START COOLING SPRAY (VENTED) AND COOLANT STREAMS
15	STABLE COOLANT & H.E. AIR TEMP (VENTED SPRAY)
16	INJECT SPRAY INTO INLET AIR
19½	WATER ON
23	H.E. AIR TEMP REACH NEW STABLE LEVEL
53¼	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

COLOR MOVIE — TRAVERSES @ 17, 21, 24, 29, 37, MIN
@ 29 MIN HEAVY FROST 1"—5", "DRIFTED POWDER"
5"—40" CO_2 FROST 42—48
OVERALL & CLOSE-UP STILLS — AT END OF TEST
CONSIDERABLE DRIFTED POWDER PRESENT THRU-OUT
HEAT EXCHANGER

GENERAL NOTES:

MIGRATION OF WATER FROST EVIDENT IN
MOVIES

TEST F-14 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_B	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	30	.5	a) .125 b) .250	.012	.05	N_2 600 PSIG −290°F	57	8/29/62

VARIABLE INVESTIGATED: LN_2 SPRAY (LOW SPRAY FLOW)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, STREAMS, AND RECORDERS
6	START COOLING COOLANT AND (VENTED) SPRAY
13½	STABLE COOLANT TEMP. – INJECT SPRAY INTO AIR STREAM
23½	STABLE H.E. AIR TEMP (INLET TEMP TOO HIGH)
28¾	TRY REDUCING AIR FLOW
31¼–32½	SHUT DOWN TO CHANGE TO LARGER SPRAY ORIFICE
40	NEW STABLE H.E. AIR TEMP – ADD WATER
50	CHANGE INST. AIR
57	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

COLOR MOVIE TRAVERSES @ 44, 50, 59 MIN
OVERALL & CLOSEUP STILLS

RESULTS INDICATE COMBINATION OF MASS DIFFUSION AND DRIFTING "SNOW". HEAVY PILE UP OF "SNOW" AT H.E. INLET

GENERAL NOTES:

SPRAY FLOW INCREASED @ 32½ MIN TO REDUCE MIXED INLET AIR TEMP

BY J.C. Burke DATE 9/20/62
APPROVED ______ DATE ______
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 22 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST F-17 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	300	100	.5	0	.017	.05	N_2 650 PSIG −310°F	27¼	8/3/62

VARIABLE INVESTIGATED: HIGH PRESSURE

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS AND STREAMS
3/4	START COOLING COOLANT
12	STABLE COOLANT INLET TEMP
15	STABLE H.E. AIR TEMP
15¾	WATER ON
27¼	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS

COLOR MOVIES TRAVERSES @ 23, 27, 37 MIN
@ 27 MIN FROST STARTS 13.5", ALMOST PLUGGED
@ 22" LIGHT 39"–43", CO_2 FROST 43"–48

OVERALL & CLOSE-UP STILLS

GENERAL NOTES

BY: D.M. Kinas DATE: 8/25/62 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 23 OF ______

APPROVED ______ DATE ______ — SKETCH NO. ______

CLIENT: ASD / ELPERI — CASE NO. 64607

Test F-1 Air and Coolant Flow

A. Orifice Data

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1 / 1000$
$W_* = f$ (A orifice)
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

See ADL calculations "Orifice Flow Calculations" D.C. Burke 8/20/62 for details

	Stream	θ (min)	P_1 (psia)	P_2 (psia)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_t	F_{PR}	W_* (lb/sec)	W_o lb/sec	$\bar{W}_o$ lb/sec
$T_1 = T$-113	Air, Orifice No. 3, Nom Dia: .035	10	575	30	.0522	No Data	70	1.00	1.003	.01815	.1045	.01045
		20	✓	31	.0539		✓	✓	✓	✓	✓	
		30	✓	✓	✓		✓	✓	✓	✓	✓	
$T_1 = T$-117	Coolant, Orifice No. 2, Nom Dia: .031	10	815	85	.1043	T_1 is 70°F (assumed)	70	1.00	1.001	.01434	.0117	.0115
		20	✓	✓	✓		✓	✓	✓	✓	.0117	
		30	705	✓	.1205		✓	✓	1.000	✓	.0101	

B. Bottle Data

$V_B = 1.75N + .1$ (ft³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \frac{ft^3}{°F\ in^2}$

Air	Coolant
$V_B = 17.6$ ft³	$V_B = 17.6$ ft³
@ θ = 10 min, P_{B1} = 2100 psia	@ θ = 10 min, P_{B1} = 1290 psia
@ θ = 30 min, P_{B2} = 1925 psia	@ θ = 30 min, P_{B2} = 1110 psia
$\bar{T}_B$ = 70 °F 530	$\bar{T}_B$ = 70 °F 530
Z_1 = 1.022 ; Z_2 = 1.015	Z_1 = .999 ; Z_2 = .997
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 151 psi	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 177 psi
ΔM_B = 13.1 lb, Δθ = 1200 sec	ΔM_B = 15.35 lb, Δθ = 1200 sec
$\bar{W}_B$ = .0109 lb/sec	$\bar{W}_B$ = .0128 lb/sec

Flow	Orifice	Bottles	$\bar{W}_o/\bar{W}_B$	Best Estimate
Air	.01045	.0109	.96	.0105
Coolant	.0115	.0128	.90	.0115

BY M KATS DATE 8/25/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 24 OF ____

APPROVED ____ DATE ____ | SKETCH NO. ____

CLIENT ASD/ELPERI | CASE NO. 64607

TEST F-2 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" S.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	585	90	.1539	6.09	60	1.010	.996	.0521	.0307	
	ORIFICE NO. 6	20	✓	✓	✓	6.07	59	✓	✓	✓	✓	.0307
		30	✓	✓	✓	6.08	60	✓	✓	✓	✓	
	NOM DIA: .0595	40	✓	✓	✓	6.12	62	1.008	✓	✓	.0306	
T_1 = T-117	COOLANT	10	785	201	.256	5.91	52	1.018	.98	.0399	.0312	
	ORIFICE NO. 5	20	787	195	.248	5.92	56	1.013	.982	✓	.0312	.0312
		30	785	✓	.2495	5.86	50	1.02	.981	✓	.0314	
	NOM DIA: .052	40	786	✓	.249	5.93	53	1.016	✓	✓	.0312	

B. BOTTLE DATA

$V_B = 1.75N + .1 \; (FT^3)$

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \; \frac{FT^3}{°F \, IN^2}$

AIR	COOLANT
$V_B = 35.1 \; FT^3$	$V_B = 35.1 \; FT^3$
@ θ = 10 MIN, P_{B1} = 1370 PSIA	@ θ = 10 MIN, P_{B1} = 2170 PSIA
@ θ = 35 MIN, P_{B2} = 1080 PSIA	@ θ = 35 MIN, P_{B2} = 1835 PSIA
$\bar{T}_B$ = 70 °F 530 °R	$\bar{T}_B$ = 70 °F 530 °R
Z_1 = .1010 ; Z_2 = .0995	Z_1 = .1024 ; Z_2 = .0997
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 270 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 275 PSI
ΔM_B = 46.6 LB, Δθ = 1500 SEC	ΔM_B = 47.6 LB, Δθ = 1500 SEC
$\bar{W}_B$ = .0311 LB/SEC	$\bar{W}_B$ = .0316 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0307	.0311	0.99	.0307
COOLANT	.0313	.0316	0.99	.0313

BY M. KATES DATE 8/25/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 25 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD/EXPERI | CASE NO. 64607

TEST F-3 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	585	90	.154	6.28	69	1.00	.996	.0521	.0304	
	ORIFICE NO. 6	20	✓	✓	✓	6.28	69	✓	✓	✓	✓	.0304
		30	✓	✓	✓	6.30	70	✓	✓	✓	✓	
	NOM DIA: .0595	40	587	✓	.153	6.38	74	.995	✓	✓	.0304	
T_1 = T-117	COOLANT	10	785	200 (≈147)	.255	6.20	66	1.004	.980	.0399	.0308	
	ORIFICE NO. 5	20	775	194	.2505	6.19	65	✓	.982	✓	.0305	.0308
		30	785	195	.2485	6.20	66	✓	✓	✓	.0310	
	NOM DIA: .052	40	✓	✓	✓	6.28	69	1.00	✓	✓	.0308	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT^3)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
$V_B = 35.1\ FT^3$	$V_B = 35.1\ FT^3$
@ θ = 10 MIN, P_{B1} = 1125 PSIA	@ θ = 10 MIN, P_{B1} = 1665 PSIA
@ θ = 40 MIN, P_{B2} = 810 PSIA	@ θ = 40 MIN P_{B2} = 1330 PSIA
$\bar{T}_B$ = 78 °F = 538°R	$\bar{T}_B$ = 78 °F = 538°R
Z_1 = 1.001 ; Z_2 = 1.00	Z_1 = 1.012 ; Z_2 = 1.004
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 312 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 320 PSI
ΔM_B = 53 LB, Δθ = 1800 SEC	ΔM_B = 64.5 LB, Δθ = 1800 SEC
$\bar{W}_B$ = .0295 LB/SEC	$\bar{W}_B$ = .0303 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0304	.0295	1.03	.0304
COOLANT	.0308	.0303	1.015	.0308

TEST F-4 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" S.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR ORIFICE NO. 6 NOM DIA: .0595	10	582	90	.1545	6.18	64	1.005	.998	.0521	.0304	
		20	✓	✓	✓	6.20	66	1.002	✓	✓	✓	.0304
		30	✓	✓	✓	6.15	63	1.006	✓	✓	✓	
T_1 = T-117	COOLANT ORIFICE NO. 5 NOM DIA: .052	10	785	205	.261	5.89	52	1.018	.980	.0399	.0312	
		20	787	195	.2475	5.90	52	✓	.982	✓	.0314	.0314
		30	790	✓	.2470	5.85	50	1.020	✓	✓	.0316	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT³	$V_B = 35.1$ FT³
@θ = 10 MIN, P_{B1} = 1115 PSIA	@θ = 10 MIN, P_{B1} = 2235 PSIA
@θ = 30 MIN, P_{B2} = 915 PSIA	@θ = 30 MIN P_{B2} = 1985 PSIA
$\bar{T}_B$ = 70 °F 530	$\bar{T}_B$ = 70 °F 530
Z_1 = .997 ; Z_2 = .998	Z_1 = .1028 ; Z_2 = .1018
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 200 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 220 PSI
ΔM_B = 34.6 LB, Δθ = 1200 SEC	ΔM_B = 38.1 LB, Δθ = 1200 SEC
$\bar{W}_B$ = .0285 LB/SEC	$\bar{W}_B$ = .0317 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0304	.0285	1.068	.0304
COOLANT	.0314	.0317	.977	.0314

TEST F-5 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	20	585	90	.1537	6.03	58	1.010	.997	.0581	.0307	
	ORIFICE No. 6	25	✓	✓	✓	6.02	57	1.011	✓	✓	✓	.0307
		30	✓	✓	✓	6.01	56	1.012	✓	✓	✓	
	NOM DIA: 0.0595	35	586	89	.1515	6.02	57	1.011	.998	✓	.0308	
T_1 = T-117	COOLANT	20	785	195	.2385	6.49	78	0.991	.984	.0399	.0306	
	ORIFICE No. 5	25	✓	✓	✓	6.51	79	0.990	✓	✓	✓	
		30	✓	✓	✓	6.50	✓	✓	✓	✓	✓	.0306
	NOM DIA: 0.052	35	790	✓	.2370	6.52	80	0.989	.985	✓	.0307	

B. BOTTLE DATA

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \ \frac{FT^3}{°F \ IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT³	$V_B = 35.1$ FT³
@ θ = 20 MIN, $P_{B1} = 2370$ PSIA	@ θ = 20 MIN, $P_{B1} = 1515$ PSIA
@ θ = 35 MIN, $P_{B2} = 2175$ PSIA	@ θ = 35 MIN $P_{B2} = 1340$ PSIA
$\bar{T}_B = 86$ °F 546	$\bar{T}_B = 86$ °F 546
$Z_1 = 1.040$; $Z_2 = 1.031$	$Z_1 = 1.010$; $Z_2 = 1.006$
$P_{B1}/Z_1 - P_{B2}/Z_2 = 170$ PSI	$P_{B1}/Z_1 - P_{B2}/Z_2 = 165$ PSI
$\Delta M_B = 28.6$ LB, $\Delta\theta = 900$ SEC	$\Delta M_B = 27.7$ LB, $\Delta\theta = 900$ SEC
$\bar{W}_B = .0318$ LB/SEC	$\bar{W}_B = .0308$ LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0307	.0318	.966	.0307
COOLANT	.0306	.0308	.995	.0306

TEST F-7 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1 / 1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MIN)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	585	90	.1539	6.00	56	1.012	.996	.0521	.0308	
	ORIFICE NO. 6	20	✓	✓	✓	5.92	51	1.019	✓	✓	.0310	.0308
		30	583	✓	✓	5.99	56	1.012	✓	✓	.0307	
	NOM DIA: .0595"	40	585	✓	✓	6.04	58	1.011	✓	✓	.0308	
T_1 = T-117	COOLANT	10	815	720	.8840	6.10	61	1.009	.485	.0399	.0158	
	ORIFICE NO. 5	20	✓	✓	✓	6.07	60	1.010	✓	✓	✓	
		30	✓	690	.8460	6.07	✓	✓	.556	✓	.0182	.0164
	NOM DIA: .052"	40	✓	720	.8840	6.09	✓	✓	.485	✓	.0158	

B. BOTTLE DATA

$V_B = 1.75N + .1 \quad (FT^3)$

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \ \frac{FT^3}{°F \ IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT³	$V_B = 35.1$ FT³
@ θ = 10 MIN, P_{B1} = 1875 PSIA	@ θ = 10 MIN, P_{B1} = 1815 PSIA
@ θ = 40 MIN, P_{B2} = 1540 PSIA	@ θ = 40 MIN, P_{B2} = 1630 PSIA
$\bar{T}_B$ = 74 °F 534	$\bar{T}_B$ = 74 °F 534
$Z_1 = 1.016$; $Z_2 = 1.008$	$Z_1 = 1.015$; $Z_2 = 1.010$
$P_{B1}/Z_1 - P_{B2}/Z_2 = 315$ PSI	$P_{B1}/Z_1 - P_{B2}/Z_2 = 175$ PSI
ΔM_B = 54.1 LB, Δθ = 1800 SEC	ΔM_B = 30.1 LB, Δθ = 1800 SEC
$\bar{W}_B$ = .0300 LB/SEC	$\bar{W}_B$ = .0167 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0308	.0300	1.02	.0308
COOLANT	.0164	.0167	.984	.0164

TEST F-8 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	585	90	.1538	6.25	68	1.001	.997	.0521	.0304	
	ORIFICE NO. 6	20	✓	✓	✓	6.28	69	1.00	✓	✓	✓	.0304
		30	✓	✓	✓	6.30	70	✓	✓	✓	✓	
	NOM DIA: .0595"	40	✓	91	.1555	6.32	71	.999	✓	✓	✓	
T_1 = T-117	COOLANT	10	865	635	.734	6.11	62	1.01	.709	.0238	.0147	
	ORIFICE NO. 4	20	✓	620	.717	6.10	61	1.01	.727	✓	.0151	.0151
		30	✓	✓	✓	6.11	62	1.01	✓	✓	✓	
	NOM DIA: .040"	40	✓	✓	✓	6.12	✓	✓	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1 \ (FT^3)$

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $\qquad R = .383 \ \frac{FT^3}{°F \ IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT³	$V_B = 35.1$ FT³
@ θ = 10 MIN, P_{B1} = 1480 PSIA	@ θ = 10 MIN, P_{B1} = 2320 PSIA
@ θ = 40 MIN, P_{B2} = 1120 PSIA	@ θ = 40 MIN, P_{B2} = 2100 PSIA
T_B = 78 °F 538 °R	T_B = 78 °F 538 °R
Z_1 = 1.006 ; Z_2 = 1.0005	Z_1 = 1.0345 ; Z_2 = 1.0255
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 350 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 190 PSI
ΔM_B = 59.7 LB, Δθ = 1800 SEC	ΔM_B = 32.4 LB, Δθ = 1800 SEC
$\bar{W}_B$ = .0331 LB/SEC	$\bar{W}_B$ = .0180 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0304	.0331	.925	.0304
COOLANT	.0151	.0180	.840	.0151

BY J.L. Wall DATE 8/27/62 ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 32 OF ______
APPROVED ______ DATE ______ SKETCH NO. ______
CLIENT ASD / ELPERI CASE NO. 64607

TEST F-9 AIR AND COOLANT FLOW

A. ORIFICE DATA

$$\omega_o = \omega_* F_P F_{PR} F_T$$

$F_P = P_1/1000$
$\omega_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	ω_* (LB/SEC)	ω_o LB/SEC	$\bar{\omega}_o$ LB/SEC
T_1 = T-113	AIR	10	585	90	.1539	6.19	65	1.004	.997	.0521	.0305	
	ORIFICE NO. 6	20	583	✓	.1545	6.23	67	1.002	.996	✓	.0304	.0304
		30	✓	✓	✓	6.30	70	1.000	✓	✓	.0303	
	NOM DIA: .0595"	45	584	110	.1885	6.28	69	✓	.991	✓	.0302	
T_1 = T-117	COOLANT	10	910	725	.797	6.25	68	1.001	.680	.01434	.00824	
	ORIFICE NO. 2	20	✓	705	.784	6.29	70	1.000	.648	✓	.00844	.00839
		30	✓	715	.787	6.33	71	.999	.646	✓	✓	
	NOM DIA: .031"	45	913	✓	.783	✓	✓	✓	.647	✓	.00845	

B. BOTTLE DATA

V_B = 1.75N + .1 (FT³)

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right] \qquad R = .383 \ \frac{FT^3}{°F\ IN^2}$$

AIR	COOLANT
V_B = 35.1 FT³	V_B = 35.1 FT³
@ θ = 10 MIN, P_{B1} = 1720 PSIA	@ θ = 10 MIN, P_{B1} = 1780 PSIA
@ θ = 45 MIN, P_{B2} = 1350 PSIA	@ θ = 38 MIN P_{B2} = 1660 PSIA
T_B = 74 °F 534 °R	T_B = 74 °F 534 °R
Z_1 = 1.010 ; Z_2 = 1.0015	Z_1 = 1.012 ; Z_2 = 1.009
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 355 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 109 PSI
ΔM_B = 61.1 LB, Δθ = 2100 SEC	ΔM_B = 20.6 LB, Δθ = 2100 SEC
$\bar{\omega}_B$ = .0291 LB/SEC	$\bar{\omega}_B$ = .00985 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{\omega}_o/\bar{\omega}_B$	BEST ESTIMATE
AIR	.0304	.0291	1.045	.0304
COOLANT	.00839	.00985	.851	.00839

TEST F-10 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" D.C. BURKE 8/20/62 FOR DETAILS

STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113 — AIR, ORIFICE NO. 7, NOM DIA: .076"	5	587	90	.1531	6.45	76	.993	.998	.0855	.0497	.0498
	10	593	✓	.1517	6.49	78	.990	✓	✓	.0501	
	15	590	91	.1541	6.51	79	✓	✓	✓	.0498	
	20	✓	110	.1865	6.56	82	.988	.992	✓	.0494	
T_1 = T-117 — COOLANT, ORIFICE NO. 5, NOM DIA: .052"	5	915	545	.595	6.45	76	.993	.837	.0399	.0304	[illegible]
	10	✓	620	.678	6.52	80	.990	.768	✓	.0278	
	15	✓	635	.695	6.55	81	.989	.750	✓	.0271	
	20	✓	✓	✓	6.57	82	.988	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1 \ (FT^3)$

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \ \frac{FT^3}{°F \ IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT3	$V_B = 35.1$ FT^3
@θ = 5 MIN, P_{B1} = 1280 PSIA	@θ = 5 MIN, P_{B1} = 1605 PSIA
@θ = 20 MIN, P_{B2} = 990 PSIA	@θ = 20 MIN P_{B2} = 1435 PSIA
$\bar{T}_B$ = 77 °F 537 °R	$\bar{T}_B$ = 77 °F 537 °R
Z_1 = 1.002 ; Z_2 = .999	Z_1 = 1.009 ; Z_2 = 1.005
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 284 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 163 PSI
ΔM_B = 48.4 LB, Δθ = 900 SEC	ΔM_B = 27.9 LB, Δθ = 900 SEC
$\bar{W}_B$ = .0538 LB/SEC	$\bar{W}_B$ = .0309 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0498	.0538	.927	.0498
COOLANT	.0281	.0309	.911	.0281

BY M. Kates DATE 9/1/62 APPROVED ______ DATE ______ CLIENT ASD/ELPERI

TEST F-11 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	300	90	.300	6.29	70	1.000	.970	.0521	.01515	
	ORIFICE NO. 6	20½	✓	✓	✓	6.32	71	.999	✓	✓	✓	.01515
		30	✓	✓	✓	6.31	70	1.000	✓	✓	✓	
	NOM DIA: .0595"	40½	✓	✓	✓	6.33	72	.998	✓	✓	✓	
T_1 = T-117	COOLANT	10	915	725	.793	6.29	70	1.000	.637	.01434	.00837	
	ORIFICE NO. 2	20½	✓	✓	✓	6.33	72	.998	✓	✓	.00835	.00835
		30	✓	✓	✓	6.35	72	✓	✓	✓	✓	
	NOM DIA: .031"	40½	✓	✓	✓	6.36	72	✓	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1 \; (FT^3)$

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \; \frac{FT^3}{°F \; IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT³	$V_B = 17.6$ FT³
@ θ = 10 MIN, P_{B1} = 760 PSIA	@ θ = 10 MIN, P_{B1} = 1350 PSIA
@ θ = 40½ MIN, P_{B2} = 600 PSIA	@ θ = 40½ MIN P_{B2} = 1120 PSIA
T_B = 80 °F 540 °R	T_B = 80 °F [illegible] °R
Z_1 = 1.000 ; Z_2 = 1.000	Z_1 = 1.0045 ; Z_2 = 1.0015
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 160 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 227 PSI
ΔM_B = 27.2 LB, Δθ = 1830 SEC	ΔM_B = 19.3 LB, Δθ = 1830 SEC
$\bar{W}_B$ = .01485 LB/SEC	$\bar{W}_B$ = .01053 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.01515	.01485	1.02	.0152
COOLANT	.00835	.01053	.783	.00835

Test F-12 Air and Coolant Flow

A. Orifice Data

$$\omega_0 = \omega_* F_p F_{PR} F_T$$

$F_p = P_1/1000$; $\omega_* = f(\text{orifice})$; $F_{PR} = f(P_2/P_1)$; $F_T = f(T_1)$ — See ADL calculations "Orifice Flow Calculations" J.C. Burke 8/29/62 for details

	Stream	θ (min)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	ω_* (lb/sec)	ω_0 lb/sec	$\overline{\omega_0}$ lb/sec
T_1 = T-113	Air Orifice No. 7 Nom. Dia .0760"	10	363	90	.2481	5.94	54	1.014	.982	.0855	.0301	
		25	360	✓	.2501	6.00	56	1.012	✓	✓	.0306	.0305
		36	✓	✓	✓	6.02	57	✓	✓	✓	✓	
		50	363	✓	.2481	6.10	61	1.009	✓	✓	.0307	
T_1 = T-117	Coolant Orifice No. 6 Nom Diam. .0595"	10	815	635	.781	6.25	68	1.000	.650	.0521	.0276	
		25	818	620	.759	6.36	72	.998	.680	✓	.0289	.0282
		36	815	625	.767	6.44	76	.992	.666	✓	.0281	
		50	818	✓	.765	6.57	82	.989	✓	✓	✓	

B. Bottle Data

$$\Delta M_B = \frac{V_B}{R\,T_B}\left[\frac{P_{B_1}}{Z_1} - \frac{P_{B_2}}{Z_2}\right]$$

$V_B = 1.75N + .1$ (Ft³)

$R = .383 \ \frac{Ft^3}{°F\ in^2}$

Air	Coolant
$V_B = 35.1$ Ft³	$V_B = 17.6$ Ft³
@ θ = 10 min P_{B_1} = 2075 psia	@ θ = 10 min P_{B_1} = 1880 psia
@ θ = 50 min P_{B_2} = 1615 psia	@ θ = 50 min P_{B_2} = 1040 psia
$\overline{T_B}$ = 76 °F 536 °R	$\overline{T_B}$ = 76 °F 536 °R
Z_1 = 1.022 ; Z_2 = 1.008	Z_1 = 1.015 ; Z_2 = .998
$P_{B_1}/Z_1 - P_{B_2}/Z_2$ = 425 psi	$P_{B_1}/Z_1 - P_{B_2}/Z_2$ = 809 psi
ΔM_B = 72.6 LB, $\Delta\theta$ = 2400 sec	ΔM_B = 69.4 LB, $\Delta\theta$ = 2400 sec
$\overline{\omega_B}$ = .0303 LB/sec	$\overline{\omega_B}$ = .0289 LB/sec

Flow	Orifice	Bottles	$\overline{\omega_0}/\overline{\omega_B}$	Best Estimate
Air	.0305	.0303	1.006	.0305
Coolant	.0282	.0289	.976	.0282

BY M Kates DATE 9/1/62 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 34 OF ______
APPROVED ______ DATE ______ — SKETCH NO. ______
CLIENT ASD/Experi — CASE NO. 64697

Test F-13 Air and Coolant Flow

A. Orifice Data

$\omega_o = \omega_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$\omega_* = f(A\ \text{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

See ADL calculations "Orifice Flow Calculations" J.C. Burke 8/20/62 For Details

	Stream	θ (min)	P_1 (psia)	P_2 (psia)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	ω_* (lb/sec)	ω_o lb/sec	$\bar{\omega}_o$ lb/sec
$T_1 = T\text{-}113$	Air	10	587	90	.1532	6.23	67	1.001	.998	.0521	.0306	
	Orifice	25	✓	✓	✓	6.28	69	1.000	✓	✓	✓	.0305
	No. 6 Nom. Diam	38	✓	✓	✓	6.32	71	.999	✓	✓	.0304	
	.0595	52	✓	95	.1628	6.34	72	.998	.995	✓	✓	
$T_1 = T\text{-}117$	Coolant	10	865	635	.734	6.09	60	1.010	.707	.0238	.0147	
	Orifice	25	✓	620	.717	6.19	65	1.005	.725	✓	.0150	
	No. 4	38	✓	✓	✓	6.21	66	1.003	✓	✓	✓	.0146
	Nom. Diam. .040	52	✓	665	.769	6.25	68	1.000	.666	✓	.0137	

B. Bottle Data

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B_1}}{Z_1} - \frac{P_{B_2}}{Z_2}\right]$$

$V_B = 1.75N + .1$ (Ft³)

$R = .383 \frac{Ft^3}{°F\ in^2}$

Air	Coolant
$V_B = 35.1$ Ft³	$V_B = 17.6$ Ft³
@ θ = 10 min $P_{B_1} = 1300$ psia	@ θ = 10 min $P_{B_1} = 2210$ psia
@ θ = 52 min $P_{B_2} = 845$ psia	@ θ = 48 min $P_{B_2} = 1690$ psia
$\bar{T}_B = 73$ °F 533 °R	$\bar{T}_B = 73$ °F 533 °R
$Z_1 = .999$; $Z_2 = .995$	$Z_1 = 1.027$; $Z_2 = 1.009$
$P_{B_1}/Z_1 - P_{B_2}/Z_2 = 456$ psi	$P_{B_1}/Z_1 - P_{B_2}/Z_2 = 480$ psi
$\Delta M_B = 78.4$ LB, $\Delta\theta = 2520$ sec	$\Delta M_B = 41.4$ LB, $\Delta\theta = 2520$ sec
$\bar{\omega}_B = .0311$ LB/sec	$\bar{\omega}_B = .01645$ LB/sec

Flow	Orifice	Bottles	$\bar{\omega}_o/\bar{\omega}_B$	Best Estimate
Air	.0305	.0311	.982	.0305
Coolant	.0146	.01645	.889	[illegible]

TEST F-13 [redacted] SPRAY FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_f	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-114	[redacted]	20	915	615	.674	5.95	54	1.014	.77	.01434	.0102	
	ORIFICE NO. 2	30	✓	✓	✓	5.97	55	✓	✓	✓	.0102	.0102
	NOM DIA: .031	42	✓	635	.694	6.00	56	✓	.75	✓	.010	
T_1 = T-117	COOLANT ORIFICE NO. NOM DIA:											

B. BOTTLE DATA

$V_B = 1.75N +$ [redacted]

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \frac{FT^3}{°F\ IN^2}$

[redacted] SPRAY	COOLANT
$V_B = 7.0\ FT^3$	$V_B = \quad FT^3$
@ θ = 20 MIN, P_{B1} = 1830 PSIA	@ θ = MIN, P_{B1} = PSIA
@ θ = 42 MIN, P_{B2} = 1335 PSIA	@ θ = MIN, P_{B2} = PSIA
$\bar{T}_B$ = 72 °F = 532°R	$\bar{T}_B$ = °F
Z_1 = 1.017 ; Z_2 = 1.004	Z_1 = ; Z_2 =
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 470 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = PSI
ΔM_B = 16.1 LB, Δθ = 1320 SEC	ΔM_B = LB, Δθ = SEC
$\bar{W}_B$ = .0122 LB/SEC	$\bar{W}_B$ = LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
SPRAY [redacted]	.0102	.0122	.84	.0102
COOLANT				

BY M. Kates DATE 9/14/62 | APPROVED ______ DATE ______ | CLIENT ASD / ELPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 36 OF ______ | SKETCH NO. ______ | CASE NO. 64607

TEST F-14 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1 / 1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

STREAM		θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	11	585	89	.1521	5.64	40	1.030	.998	.0521	.0313	
	ORIFICE NO. 6	27	✓	90	.1539	5.69	42	1.028	✓	✓	.0312	.0312
	NOM DIA:	44	✓	✓	✓	5.72	44	1.026	✓	✓	✓	
	.0595"	56	✓	108	.1221	5.78	46	1.022	1.000	✓	.0312	
T_1 = T-117	COOLANT	11	865	605	.700	5.81	48	1.021	.748	.0238	.0154	
	ORIFICE	27	✓	645	.746	✓	✓	✓	.695	✓	.0143	.0162
	NO. 4	44	✓	630	.728	5.85	50	1.000	.718	✓	.0206	
	NOM DIA: .040"	56	✓	625	.723	5.90	52	1.018	.720	✓	.0151	

B. BOTTLE DATA

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \ \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 35.1 FT³	V_B = 17.6 FT³
@ θ = 11 MIN, P_{B1} = 2030 PSIA	@ θ = 11 MIN, P_{B1} = 2090 PSIA
@ θ = 56 MIN, P_{B2} = 1550 PSIA	@ θ = 56 MIN P_{B2} = 1560 PSIA
$\bar{T}_B$ = 74 °F 534 °R	$\bar{T}_B$ = 74 °F 534 °R
Z_1 = 1.020 ; Z_2 = 1.006	Z_1 = 1.022 ; Z_2 = 1.006
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 450 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 495 PSI
ΔM_B = 77.3 LB, $\Delta\theta$ = 2700 SEC	ΔM_B = 42.7 LB, $\Delta\theta$ = 2700 SEC
$\bar{W}_B$ = .0285 LB/SEC	$\bar{W}_B$ = .0158 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0312	.0285	1.095	.0312
COOLANT	.0162	.0158	1.025	.0162

BY M. Kates DATE 9/15/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 37 OF ____
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD/EXPERI | CASE NO. 64607

TEST F-14 [redacted] SPRAY FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-114	[redacted] ORIFICE NO. 1 NOM DIA: .020	11	915	665	.735	6.1	61	1.01	.71	.0057	.00374	.00374
		22	915	665	.735	6.0	56	1.012	.71	✓	.00374	
T_1 = T-114	SPRAY ORIFICE NO. 2 NOM DIA: .031	44	795	615	.775	5.9	52	1.02	.66	.01434	.00766	.00766
		50	795	615	.775	5.9	✓	✓	.66	✓	✓	
		56	795	635	.775	5.9	✓	✓	.66	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \frac{FT^3}{°F\ IN^2}$

[redacted] SPRAY (11–22 MIN)	[redacted] SPRAY (44–56 MIN)
V_B = 7.0 FT³	V_B = 7.0 FT³
@ θ = 11 MIN, P_{B1} = 2185 PSIA	@ θ = 44 MIN, P_{B1} = 1680 PSIA
@ θ = 22 MIN, P_{B2} = 2010 PSIA	@ θ = 56 MIN, P_{B2} = 1475 PSIA
$\bar{T}_B$ = 74 °F 534°R	$\bar{T}_B$ = 74 °F 534°R
Z_1 = 1.024 ; Z_2 = 1.019	Z_1 = 1.009 ; Z_2 = 1.004
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 100 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 200 PSI
ΔM_B = 3.42 LB, Δθ = 660 SEC	ΔM_B = 6.84 LB, Δθ = 720 SEC
$\bar{W}_B$ = .00517 LB/SEC	$\bar{W}_B$ = .00950 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
SPRAY (11–22)	.00374	.00517	.724	.0038
SPRAY (44–56)	.00766	.00950	.806	.0077

TEST F-17 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" S.C. BURKE 8/20/62 FOR DETAILS

	Stream	θ (min)	P_1 (psia)	P_2 (psia)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_t	F_{PR}	W_* (lb/sec)	W_o lb/sec	$\bar{W}_o$ lb/sec
T_1 = T-113	AIR	.10	750	300	.4000	6.06	59	1.010	.942	.1485	.1062	
	ORIFICE NO. 9	17	✓	✓	✓	6.12	62	1.008	✓	✓	.1057	.1059
		20	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	NOM DIA: .0995"	26 1/4	753	290	.3855	6.19	65	1.004	.946	✓	.1061	
T_1 = T-117	COOLANT	10	850	650	.765	6.21	66	1.003	.670	.0855	.0489	
	ORIFICE NO. 7	17	✓	660	.777	6.24	67	1.002	.655	✓	.0477	.0492
		20	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	NOM DIA: .0760"	26 1/4	853	615	.721	6.21	66	1.003	.721	✓	.0527	

B. BOTTLE DATA

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 35.1 FT³	V_B = 35.1 FT³
@ θ = 10 MIN, P_{B1} = 1865 PSIA	@ θ = 10 MIN, P_{B1} = 2240 PSIA
@ θ = 26 1/4 MIN, P_{B2} = 1220 PSIA	@ θ = 25 MIN P_{B2} = 1920 PSIA
$\bar{T}_B$ = 71 °F 531	$\bar{T}_B$ = 71 °F 531
Z_1 = 1.015 ; Z_2 = 1.000	Z_1 = 1.028 ; Z_2 = 1.016
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 614 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 285 PSI
ΔM_B = 106.0 LB, Δθ = 975 SEC	ΔM_B = 49.2 LB, Δθ = 900 SEC
$\bar{W}_B$ = .1085 LB/SEC	$\bar{W}_B$ = .0547 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.1059	.1085	.975	.1059
COOLANT	.0492	.0547	.899	.0492

BY M. Katcs DATE 10/5/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 39 OF
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD/Expert | CASE NO. 64607

Test Heat Exchanger Energy Balance

			Uncorrected Coolant Temperature		Corrected Coolant Temperature	
Test No.	Time (min)	q_a (Btu/HR)	q_c (Btu/HR)	q_c/q_a	q_c (Btu/HR)	q_c/q_a
F-1	30	1,820	2,740	1.51	1,360	.747
F-2	30	4,850	5,720	1.18	4,840	1.00
F-3	30	4,920	5,860	1.19	5,101	1.04
F-4	30	4,600	5,550	1.20	4,840	1.051
F-5	33	4,960	6,200	1.25	5,220	1.051
F-7	30	8,200	9,340	1.14	8,300	1.011
F-8	30	9,050	9,060	1.00	8,040	.889
F-9	30	4,340	4,710	1.09	3,520	.810
F-12	32	10,100	12,650	1.25	10,450	1.035
F-10	15	14,300	17,100	1.20	15,810	1.105
F-11	30	4,650	4,630	1.00	3,760	.809
F-13	30	6,160	6,470	1.05	5,810	.944
F-14	44	6,750	8,240	1.22	7,240	1.072
F-17	25	30,000	31,000	1.03	28,700	.957

BY J C Burke DATE 9/25/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 40 OF
APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.
CLIENT ASD / EXPERI CASE NO. 64607

HEAT EXCHANGER ENERGY BALANCE DATA

q_a – AIR-SIDE HEAT TRANSFER

TEST NO	θ (MIN)	ω (LB/SEC)	T_1 T-101 (°F)	P_1 P-121 (PSIA)	h_1 (BTU/LB)	T_2 T-105 (°F)	P_2 P-130 (PSIA)	h_2 (BTU/LB)	Δh h_1-h_2 (BTU/LB)	q_a (BTU/SEC)	q_a (BTU/HR)
F-1	30	.0105	66	27.3	129	-132	21.2	80	49	.515	1854
F-2	30	.0307	60	88	127	-117	72.5	83	44	1.35	4860
F-3	30	.0304	70	88	129	-113	61.6	84	45	1.37	4932
F-4	30	.0304	57	88	126	-118	56	84	42	1.28	4608
F-5	33	.0307	74	88	130	-113	54	85	45	1.38	4968
F-7	30	.0308	48	88	124	-236	76.5	50	74	2.28	8200
F-8	30	.0304	101	88	137	-232	65.3	54	83	2.52	9050
F-9	30	.0304	84	88	133	-82	47.7	93	40	1.21	4340
F-12	32	.0305	87	88	134	-270	69.3	42	92	2.80	10,100
F-10	15	.0498	103	89	139	-216	18.1	59	80	3.98	14,300
F-11	30	.0152	87	88	134	-244	68	49	85	1.29	4650
F-13	30	.0407*	-64	88	96	-232	72	54	42	1.71	6,160
F-14	44	.0390*	-44	88	101	-236	68.2	53	48	1.87	6,750
F-17	25	.1059	[illegible]	288.5	137	-184	117.5	65	72	8.31	30,000

*ω = ω_AIR + ω_SPRAY

BY J C Burke DATE 9/25/62 **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. SHEET NO. 41 OF

APPROVED DATE SKETCH NO.

CLIENT ASD / EXPERI CASE NO. 64607

HEAT EXCHANGER ENERGY BALANCE DATA

q_c – COOLANT-SIDE HEAT TRANSFER
(BASED ON UNCORRECTED COOLANT TEMPERATURES)

TEST NO	θ (MIN)	ω (LB/SEC)	T_1 T-108 (°F)	P_1 P-147 (PSIA)	h_1 (BTU/LB)	T_2 T-109 (°F)	P_2 P-131 (PSIA)	h_2 (BTU/LB)	Δh h_2-h_1 (BTU/LB)	q_c (BTU/SEC)	q_c (BTU/HR)
F-1	30	.0115	-208	70	60	50	15	126	66	.76	2740
F-2	30	.0313	-154	180	71	36	35	122	51	1.59	5720
F-3	30	.0308	-152	180	71	44	35	124	53	1.63	5860
F-4	30	.0314	-156	180	71	29	35	120	49	1.54	5550
F-5	33	.0306	-166	180	68	44	35	124	56	1.72	6200
F-7	30	.0164	-290	690	-40	42	685	118	158	2.59	9340
F-8	30	.0151	-289	620	-39.5	74	605	127	167	2.52	9060
F-9	30	.00839	-270	715	-30	70	705	126	156	1.31	4710
F-12	32	.0282	-309	615	-48	-110	605	77	125	3.52	12,650
F-10	15	.0281	-289	635	-40	81	620	129	169	4.75	17,100
F-11	30	.00835	-280	725	-35	42	720	119	154	1.285	4,630
F-13	30	.0146	-299	620	-44	-67	615	79	123	1.795	6470
F-14	44	.0162	-290	630	-40	-22	620	101	141	2.285	8240
F-17	20	.0492	-306	615	-45	82	560	130	175	8.60	31,000

Corrected Coolant Temperatures

Test	Time	Coolant Outlet T-109 (°F)	Coolant Outlet Corrected (°F)	Coolant Inlet T-108 (°F)	Coolant Inlet Corrected (°F)
F-1	30	50	47	-208	-167
F-2	30	36	32	-154	-133
F-3	30	44	40	-156	-133
F-4	30	29	25	-156	-137
F-5	33	44	37	-166	-145
F-7	30	42	39	-290	-257
F-8	30	74	69	-289	-258
F-9	30	70	65	-270	-224
F-12	32	-110	-150	-309	-288
F-10	15	81	79	-289	-265
F-11	30	42	25	-280	-243
F-13	30	-67	-68	-299	-255
F-14	44	-22	-27	-290	-258
F-17	25	82	80	-306	-275

Note: Coolant temperature correction based on estimated heat leak between coolant measurement point and start of test heat transfer section.

HEAT EXCHANGER ENERGY BALANCE DATA

q_c ~ Coolant-SIDE HEAT TRANSFER

(Based on Corrected coolant Temperatures)

TEST NO	θ (MIN)	w (LB/SEC)	T_1 T-108 corrected (°F)	P_1 P-147 (PSIA)	h_1 (BTU/LB)	T_2 T-109 corrected (°F)	P_2 P-131 (PSIA)	h_2 (BTU/LB)	Δh h_2-h_1 (BTU/LB)	q_c (BTU/SEC)	q_c (BTU/HR)
F-1	30	.0115	-167	70	71.1	46.8	15	104	32.9	.378	1360
F-2	30	.0313	-133	180	77.0	32.4	35	120	43	1.345	4840
F-3	30	.0308	-133	180	76.9	40.1	35	123	46.1	1.42	5101
F-4	30	.0314	-137	180	76.2	24.5	35	119	42.8	1.345	4840
F-5	33	.0306	-145	180	74.6	37.4	35	122	47.4	1.45	5220
F-7	30	.0164	-257	690	-23.4	39.2	685	117	140.4	2.305	8300
F-8	30	.0151	-258	620	-23.9	68.9	605	124	147.9	2.23	8040
F-9	30	.00839	-224	715	7.4	65.4	705	124	116.6	.979	3520
F-12	32	.0282	-288	615	-38.8	-149.8	605	65	103.8	2.905	10,450
F-10	15	.0281	-265	635	-27.3	79.1	620	129	156.3	4.39	15,810
F-11	30	.00835	-243	725	-13.2	84.6	780	112	125.2	1.045	3760
F-13	30	.0146	-255	620	-21.7	-67.7	615	89	110.7	1.615	5810
F-14	44	.0162	-258	630	-23.9	-27.1	620	100	123.9	2.01	7240
F-17	25	.0492	-275	615	-32.3	80.4	560	130	162.3	7.98	28,700

BY M. Kates DATE 9/15/62 | **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. | SHEET NO. 44 OF ____

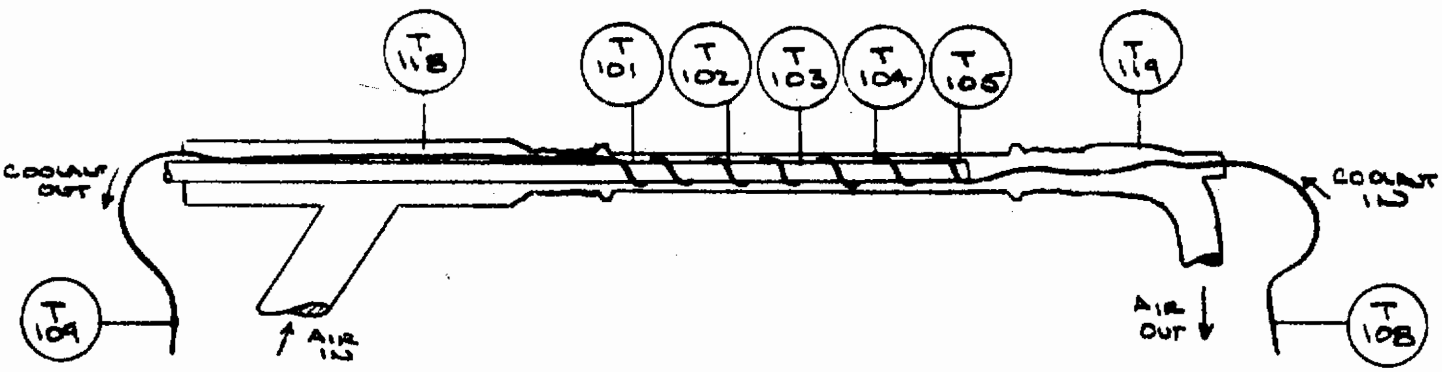
APPROVED ____ DATE ____ | SKETCH NO. ____

CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-1

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.40	74	6.4	74	6.27	68	6.4	74	6.4	74	6.40	74			6.4	74	6.4	74
3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			6.3	70	✓	✓
5	6.41	75	6.35	72	✓	✓	6.31	70	6.19	65	6.43	76			4.55	-12	6.37	74
8	6.45	76	6.18	65	5.9	52	6.05	22	4.29	-26	6.42	75			1.81	-168	6.37	73
10	6.41	75	5.90	52	5.4	29	4.60	-10	3.55	-64	6.41	✓			1.54	-188	6.30	70
12	✓	✓	5.65	40	4.99	9	4.01	-36	3.10	-88	✓	✓			1.42	-146	6.25	68
15	6.39	74	5.31	24	4.65	-12	3.65	-58	2.72	-112	✓	✓			1.35	-200	6.11	62
18	6.35	72	5.10	14	4.20	-30	3.34	-76	2.56	-101	6.39	74			1.30	-204	6.00	56
20	6.31	70	5.00	10	4.10	-35	3.21	-83	2.49	-125	6.35	72			1.29	-206	5.97	55
25	6.24	67	4.81	0	3.90	-46	3.05	-92	2.35	-134	6.31	70			1.25	-208	[illegible]	[illegible]
30	6.20	66	4.84	2	✓	✓	✓	✓	2.37	-132	6.30	✓		28 (2)	✓	✓	5.85	✓
35	✓	✓	5.47	32	4.32	-24	3.35	-75	2.52	-124	6.31	✓			1.12	-218	[illegible]	[illegible]



NOTES:

(1) T-119 T/C Not Reading

(2) ESTIMATE BASED ON TEMP RISE ($T_{119}-T_{105}$) IN TESTS F-1 & F-2

BY M. Kates DATE 9/4/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 45 OF

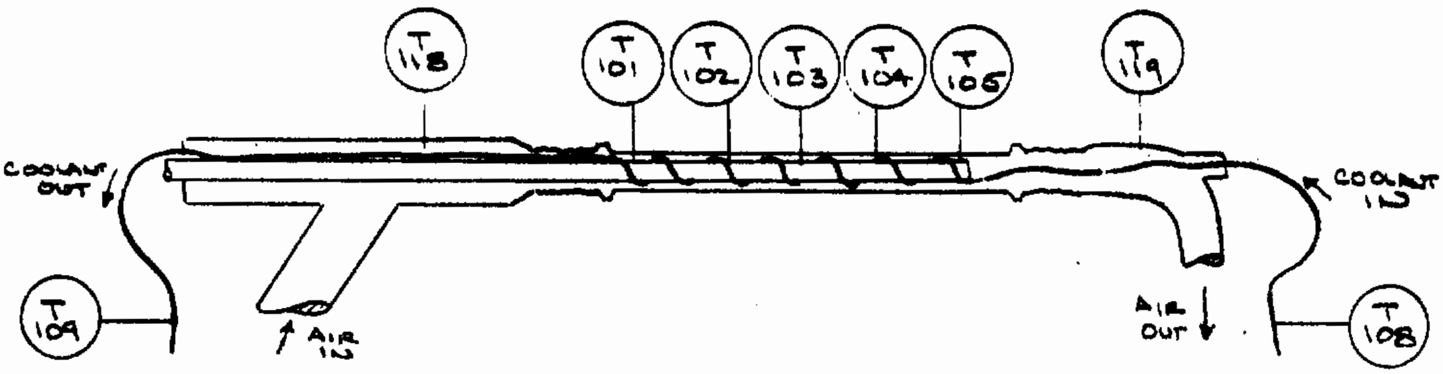
APPROVED ____ DATE ____ CAMBRIDGE, MASS. SKETCH NO. ____

CLIENT ASD / EXPERI CASE NO. 64607

TEST F-2

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.60	83	6.60	83	6.60	83	6.60	83	6.60	83	6.60	83	6.60	83	6.60	83	6.60	83
5	6.55	81	6.55	81	6.55	81	6.55	81	6.55	81	6.55	81	6.55	81	6.55	81	6.55	81
6	✓	✓	✓	✓	✓	✓	6.39	✓	6.28	✓	✓	✓	✓	✓	5.11	15	✓	✓
7	6.47	78	6.31	70	6.17	64	5.85	50	5.25	22	6.49	78	6.05	58	3.31	-78	6.40	74
8	6.42	75	6.06	59	5.63	40	5.15	17	4.25	-28	✓	✓	5.45	31	2.71	-112	6.30	70
9	6.39	74	5.80	47	5.24	21	4.55	-12	3.74	-54	6.45	76	5.00	10	2.30	-136	6.15	63
10	6.35	72	5.56	36	4.86	3	4.09	-36	3.33	-76	6.41	75	4.74	-1	2.06	-152	6.05	58
12	6.30	70	5.25	22	4.36	-22	3.55	-64	2.82	-105	6.38	74	4.21	-30	1.97	-158	5.84	48
15	6.21	66	5.01	10	4.06	-37	3.25	-80	2.62	-114	6.32	71	3.89	-46	✓	✓	5.67	41
20	6.14	63	4.95	8	4.00	-40	3.20	-84	2.66	-118	6.35	72	3.67	-58	✓	✓	5.59	38
26	6.10	61	4.91	6	3.99	-41	✓	✓	2.61	-118	6.21	66	3.55	-64	2.05	-152	5.55	36
30	6.08	60	4.89	4	3.96	-42	✓	✓	2.62	-117	6.20	66	3.57	-66	2.02	-154	5.55	36
35	6.07	✓	4.77	-2	3.95	-44	3.10	-89	2.58	-120	6.19	65	3.48	-68	1.99	-156	5.47	32
40	✓	✓	4.73	-4	✓	✓	3.12	-88	2.61	-118	✓	✓	3.45	-70	2.04	-153	✓	✓



NOTES:

BY M. Kates DATE 9/15/63 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 46 OF

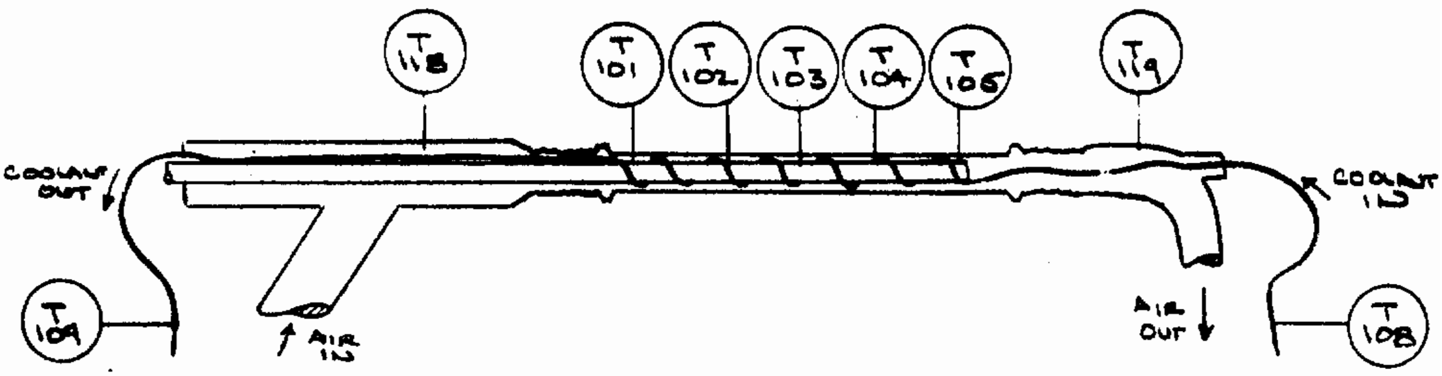
APPROVED DATE | SKETCH NO.

CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-3

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR IN		AIR OUT		COOLANT IN		COOLANT OUT	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
1 1/2	6.70	88	6.65	86	6.65	86	6.65	86	6.65	86	6.79	92	6.75	90	6.65	86	6.65	86
3	6.75	90	6.65	86	6.65	86	6.65	86	6.65	86	6.73	88	6.75	90	6.65	86	6.65	86
6	6.61	84	6.43	76	6.17	64	5.90	52	5.14	16	6.67	86	6.06	59	3.44	-70	6.52	80
10	6.51	79	5.69	42	5.00	10	4.23	-28	3.50	-67	6.59	83	4.61	-10	2.43	-128	6.11	62
12	6.48	78	5.42	30	4.59	-10	3.74	-54	3.05	-92	6.54	80	4.34	-23	2.10	-150	6.00	56
15	6.41	73	5.25	22	4.31	-24	3.42	-68	2.85	-104	6.50	79	4.02	-40	2.10	-150	5.87	50
20	6.33	71	5.14	16	4.17	-32	3.34	-76	2.70	-112	6.46	77	3.79	-52	1.98	-158	5.79	47
25	6.31	70	5.09	14	4.15	-32	3.30	-78	2.65	-116	6.43	76	3.65	-58	1.98	-158	5.75	45
30	6.31	70	5.09	14	4.17	-32	3.34	-76	2.69	-113	6.41	75	3.59	-62	1.99	[illegible]	5.70	44
35	6.30	70	5.08	14	4.17	-32	3.31	-78	2.69	-113	6.40	74	3.55	-64	2.01	-156	5.71	43
40	6.31	70	5.05	12	4.13	-34	3.30	-78	2.69	-113	6.41	75	3.51	-66	2.01	[illegible]	[illegible]	[illegible]
45	6.31	70	5.05	12	4.09	-36	3.31	-78	2.71	-112	6.41	75	3.51	-66	2.04	[illegible]	5.69	[illegible]
47	6.31	70	5.05	12	4.09	-36	3.31	-78	2.71	-112	6.41	75	3.51	-66	2.01	-156	5.69	42
48 1/2	6.31	70	5.03	11	4.07	-36	3.29	-78	2.70	-112	6.41	75	3.51	-66	2.00	-156	5.70	42

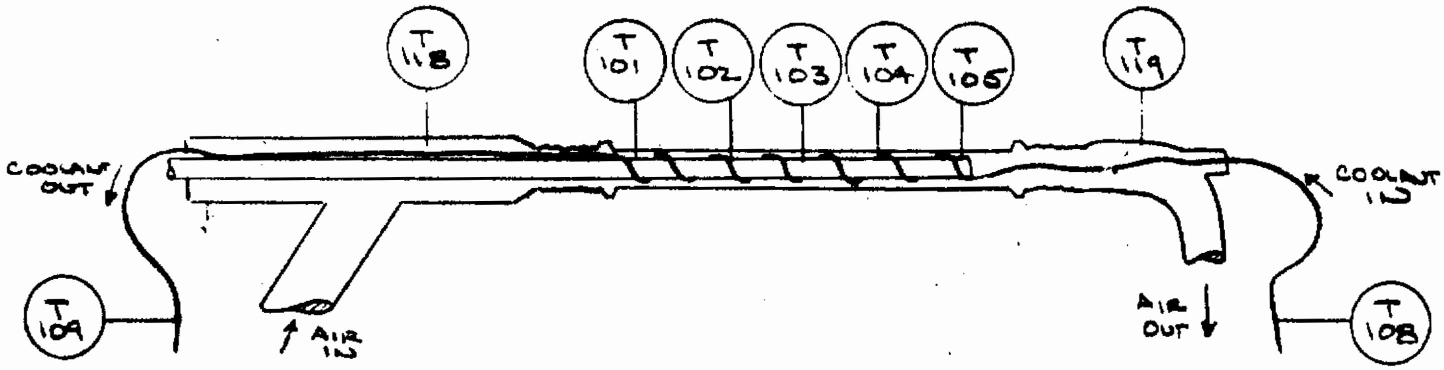


NOTES:

TEST F-4

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
5	6.37	73	6.31	70	6.31	70	6.27	68	6.27	68	6.40	74	6.35	72	6.15	63	6.20	70
7	6.34	72	6.20	66	6.20	66	5.89	52	5.60	38	6.38	✓	6.15	63	4.49	-16	6.23	67
9	6.28	69	5.79	47	5.39	28	4.69	-6	3.99	-41	6.32	71	5.15	17	2.50	-124	6.07	60
11	6.22	66	5.32	25	4.60	-10	3.90	-46	3.19	-84	6.29	70	4.51	-14	2.18	-144	5.80	47
15	6.14	63	4.99	9	4.08	-36	3.30	-78	2.70	-112	6.23	67	3.90	-46	1.95	-160	5.55	36
20	6.09	60	4.81	0	3.85	-43	3.13	-88	2.59	-119	6.18	64	3.62	-60	1.97	-158	5.45	31
25	6.06	57	4.86	3	3.97	-44	3.16	-86	2.60	-118	6.14	63	3.52	-66	1.98	✓	5.40	29
30	6.02	57	4.84	2	3.95	-43	3.20	-84	2.61	✓	6.18	62	3.48	-68	2.00	-156	5.41	✓
35	✓	✓	✓	✓	3.99	-41	✓	✓	2.62	✓	6.10	61	3.45	-70	✓	✓	5.40	✓
39	6.00	56	4.77	-2	3.97	-44	✓	✓	2.67	-114	6.03	58	3.57	-63	2.03	-154	✓	✓



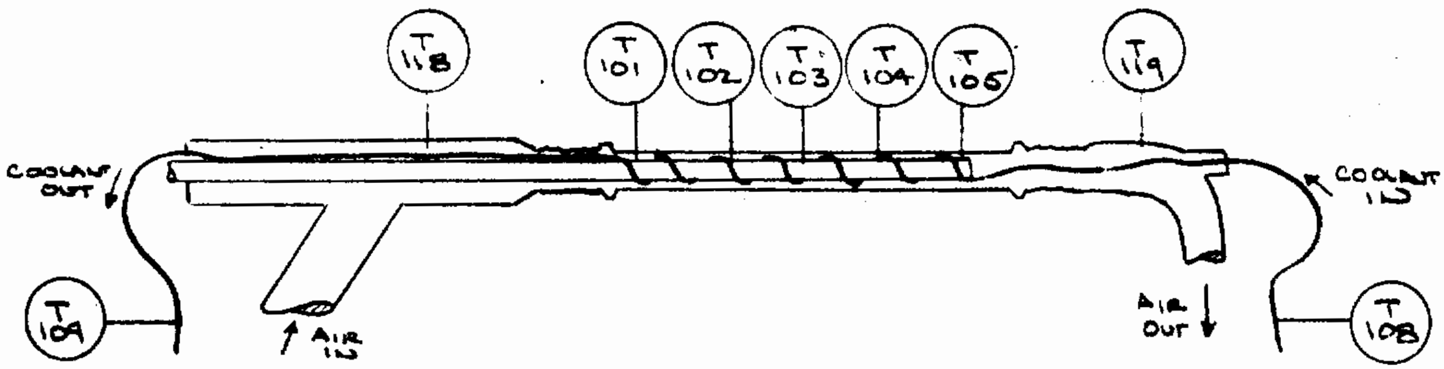
NOTES:

BY M Kates DATE 9/6/62	ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS.	SHEET NO. 48 OF
APPROVED DATE		SKETCH NO.
CLIENT ASD / EXPERI		CASE NO. 64607

TEST F-5

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
15	6.62	84	6.50	79	6.49	78	6.43	76	6.40	74	6.64	85	6.50	79	6.10	61	6.50	79
17	6.61	✓	6.31	70	6.09	60	5.65	40	4.97	8	6.62	84	5.77	46	2.75	-110	6.44	76
19	6.57	83	5.77	46	5.11	15	4.25	-28	3.37	-74	6.60	83	4.74	-3	1.97	-158	6.20	66
21	6.54	80	5.46	32	4.60	-10	3.73	-54	2.96	-97	6.56	82	4.28	-26	1.95	-160	6.00	56
25	6.50	79	5.24	21	4.42	-19	3.54	-64	2.82	-106	6.52	80	3.88	-46	1.92	-162	5.84	49
29	6.44	76	5.18	18	4.31	-24	3.45	-70	2.74	-110	6.50	79	3.69	-56	1.87	-164	5.78	46
33	6.40	74	5.13	16	4.22	-29	3.36	-74	2.69	-113	6.48	78	3.57	-63	1.84	-166	5.73	44
35	6.40	74	5.11	15	4.20	-30	3.39	-73	2.75	-110	6.48	78	3.57	-63	1.97	-158	5.71	43
38 1/2	6.39	74	5.09	14	4.15	-32	3.35	-75	2.70	-112	6.41	75	3.60	-62	1.87	-164	5.71	43



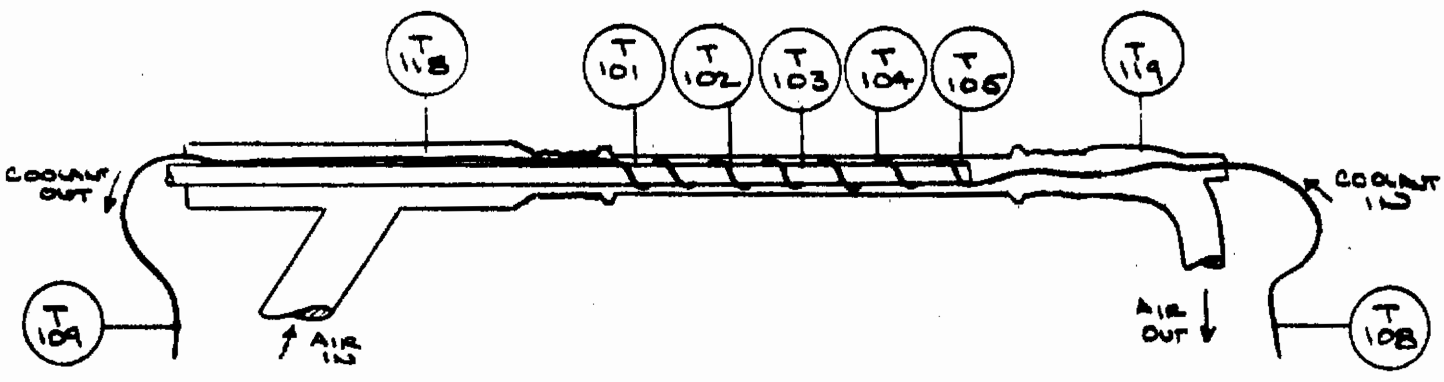
NOTES:
Prior to 15 min all pts are 6.40 mv (74°F) → 6.50 mv (79°F) approximately but not distinguishable individually

BY M Kates DATE 9/8/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 49 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-7

AIR AND COOLANT TEMPERATURE DATA

	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR				COOLANT			
											IN		OUT		IN		OUT	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
TIME (MIN)	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.45	76	6.45	76	6.45	76	6.45	76	6.45	76	6.57	82	6.69	87	6.69	72	6.50	76
3	6.32	71	6.27	68	6.12	62	5.77	46	4.90	5	6.39	74	5.46	32	2.58	-120	6.33	71
6	6.18	64	6.17	64	6.08	60	5.53	35	4.12	-34	6.26	68	4.67	-6	1.18	-214	6.23	67
9	6.13	62	6.13	62	6.11	62	5.76	46	4.32	-24	6.19	65	4.53	-14	0.72	-250	6.19	65
12	6.02	59	5.84	49	5.09	14	3.19	-84	1.54	-188	6.13	62	3.25	-80	0.29	-290	6.11	62
15	5.99	56	5.42	30	4.04	-38	1.94	-158	1.09	-220	6.08	60	2.74	-110	✓	✓	5.99	56
20	5.85	50	5.01	10	3.15	-86	1.55	-186	0.95	-232	6.01	57	2.35	-134	✓	✓	5.85	50
25	5.85	50	4.83	2	2.81	-106	1.41	-196	0.90	-236	5.99	56	2.16	-146	✓	✓	5.74	44
30	5.81	48	4.75	-2	2.75	-110	1.38	-198	✓	✓	5.95	54	2.06	-152	0.28	✓	5.69	42
35	5.76	46	4.64	-8	2.58	-120	1.33	-202	0.89	-236	5.91	52	2.01	-156	✓	✓	5.63	40
40	5.75	45	4.51	-14	2.45	-128	1.29	-206	0.87	-238	5.89	52	1.97	-158	✓	✓	5.59	38
46	5.71	43	4.46	-17	2.34	-134	1.27	-206	0.85	-240	5.89	52	1.92	-161	✓	✓	5.54	37

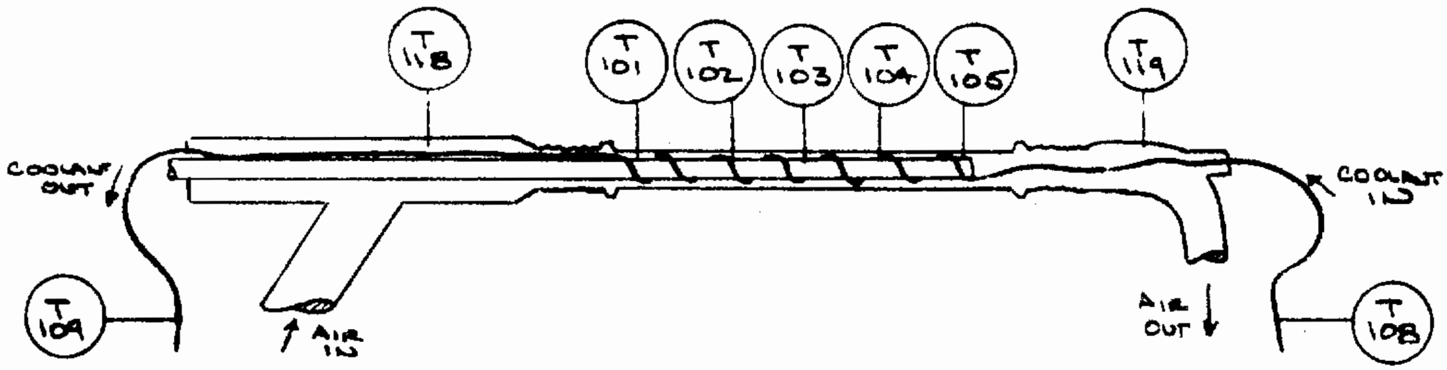


NOTES:

TEST F-8

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.65	86	6.65	86	6.65	86	6.65	86	6.65	86	6.75	90	6.80	92	4.82	1	6.50	79
3	✓	✓	✓	✓	✓	✓	✓	✓	6.29	70	6.70	88	6.38	74	2.15	-146	6.57	82
6	6.47	78	6.34	72	6.34	72	6.28	69	6.27	68	6.39	74	5.85	50	0.90	-236	6.69	87
9	6.96	99	6.69	87	6.00	56	4.11	-34	2.00	-156	6.95	98	4.11	-34	0.33	-286	6.79	92
12	7.01	101	6.38	74	5.09	17	2.58	-120	1.29	-206	6.99	100	3.24	-82	0.30	-289	6.79	✓
15	✓	✓	6.02	57	4.18	-31	1.90	-162	1.09	-220	7.01	✓	2.79	-107	0.35	-284	6.69	87
20	7.04	102	5.60	38	3.61	-61	1.65	-180	1.00	-228	7.02	102	2.41	-130	0.32	-287	6.55	81
24	✓	✓	5.38	28	3.33	-77	1.56	-186	✓	✓	7.03	✓	2.29	-138	0.32	-281	6.47	78
30	7.01	101	6.28	23	3.02	-94	1.45	-194	0.95	-232	✓	✓	2.15	-146	0.30	-289	6.39	74
33	7.04	102	5.05	12	2.86	-103	1.42	-196	0.94	✓	✓	✓	2.18	-144	0.32	-287	6.36	72
35	✓	✓	✓	✓	✓	✓	1.41	✓	✓	✓	✓	✓	2.10	-150	✓	✓	6.35	✓
40	✓	✓	✓	✓	2.85	-104	1.40	-198	✓	✓	✓	✓	2.05	-156	✓	✓	✓	✓
42	✓	✓	5.00	10	2.73	-110	1.38	✓	0.92	-234	✓	✓	✓	✓	✓	✓	6.32	71
45	✓	✓	✓	✓	✓	✓	1.35	-200	✓	✓	✓	✓	✓	✓	0.31	-288	✓	✓
48	7.02	102	4.83	2	2.49	-125	1.29	-206	0.88	-237	✓	✓	✓	✓	✓	✓	6.09	70



NOTES:

BY M. Kates DATE 9/6/62 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 51 OF ______

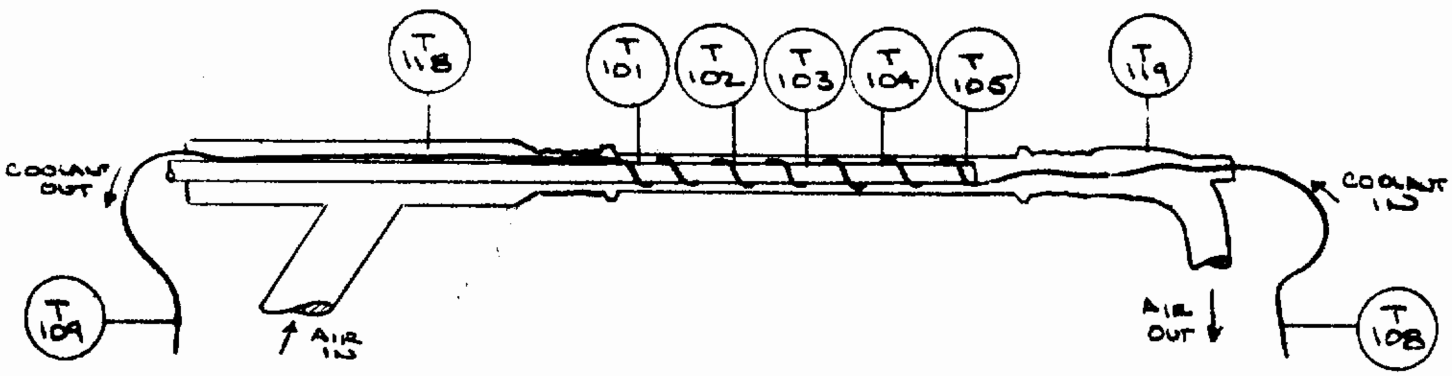
APPROVED ______ DATE ______ — SKETCH NO. ______

CLIENT ASD / EXPERI — CASE NO. 64607

TEST F-9

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR IN		AIR OUT		COOLANT IN		COOLANT OUT	
	T-101 (4,12)		T-102 (3,11)		T-103 (1,9)		T-104 (5,13)		T-105 (2,10)		T-118 (8)		T-119 (16)		T-108 (6,14)		T-109 (7,15)	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.25	68	6.25	68	6.25	68	6.25	68	6.25	68	6.51	79	6.79	91	4.28	-26	6.25	68
2	6.35	72	6.35	72	6.30	72	6.35	72	5.84	49	6.35	72	6.35	72	2.27	-139	6.35	72
4	6.25	68	6.23	67	6.21	66	6.19	65	5.67	41	6.25	68	5.90	52	2.35	-134	6.13	62
6	6.20	66	6.20	66	6.20	✓	✓	✓	5.20	19	6.27	✓	5.60	38	1.08	-222	6.07	60
8	6.19	65	✓	✓	✓	✓	6.09	60	5.13	16	6.20	66	5.14	16	0.50	-244	6.00	56
10	✓	✓	✓	✓	✓	✓	6.15	63	5.67	41	✓	✓	5.20	19	0.70	-252	✓	✓
16	6.15	63	6.11	62	6.04	58	5.61	38	3.50	-67	6.15	63	4.10	-35	0.23	-296	5.95	54
20	6.09	60	6.10	61	5.90	52	5.00	10	2.85	-104	6.13	62	3.67	-56	0.21	-298	5.92	53
25	6.21	66	6.25	68	6.05	58	5.01	✓	2.94	-98	6.37	73	3.52	-66	0.35	-284	6.00	56
28	6.41	75	6.41	75	6.15	63	5.13	16	3.05	-92	6.55	81	3.55	-64	0.40	-279	6.15	63
30	6.62	84	6.59	83	6.39	74	5.33	26	3.22	-82	6.65	86	3.60	-62	0.50	-270	6.30	76
36	✓	✓	6.51	79	6.35	72	5.49	33	3.45	-70	6.55	81	3.65	-58	0.49	-271	✓	✓
39	6.50	79	6.42	75	6.25	68	5.22	20	2.99	-96	6.49	78	3.53	-64	0.27	-292	6.23	67
43	6.39	74	6.31	70	6.19	65	5.11	15	2.85	-104	6.39	74	3.46	-70	0.29	-290	6.14	63
45	6.27	68	5.99	56	5.20	19	4.12	-34	2.50	-124	6.28	69	3.42	-71	0.30	-289	6.05	58



NOTES:

BY M. Kates DATE 9/8/62

APPROVED ________ DATE ________

CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 52 OF ____

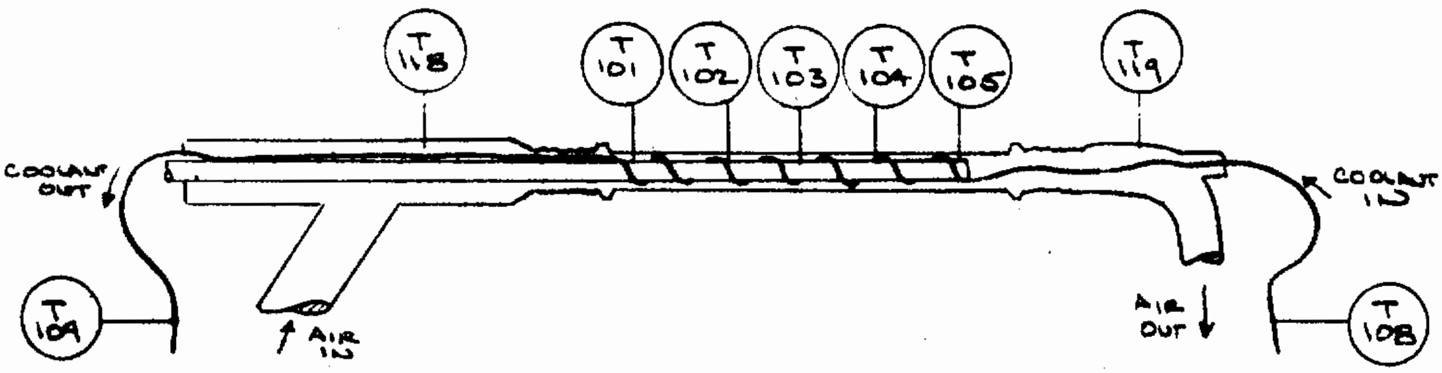
SKETCH NO. ________

CASE NO. 64607

TEST F-10

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
0	6.50	79	6.41	75	6.41	75	6.41	75	6.41	75	6.69	87	6.90	96	5.29	24	6.45	76
3	6.65	86	6.56	82	6.59	83	5.43	30	3.87	-47	6.72	88	5.11	15	1.21	-212	6.57	82
6	6.85	94	6.75	90	6.42	75	5.45	31	3.10	-89	6.90	96	4.06	-37	0.72	-250	6.73	89
9	6.99	100	6.29	70	4.84	2	2.20	-143	1.32	-203	6.99	100	3.00	-94	0.31	-284	6.71	88
12	7.03	102	5.94	54	4.10	-33	2.18	-144	1.18	-214	7.03	102	2.60	-118	✓	✓	6.59	83
15	7.04	✓	5.88	51	4.03	-38	2.10	-150	1.15	-216	✓	✓	2.39	-132	0.30	-289	6.55	81
20	7.08	104	5.73	44	3.75	-54	1.99	-156	1.09	-220	7.05	103	2.18	-144	✓	✓	6.50	79
23 3/4	✓	✓	5.63	40	3.56	-64	1.88	-164	1.05	-224	7.00	100	2.07	-152	0.29	-290	6.48	78



NOTES:

BY M. Kates DATE 9/8/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 53 OF

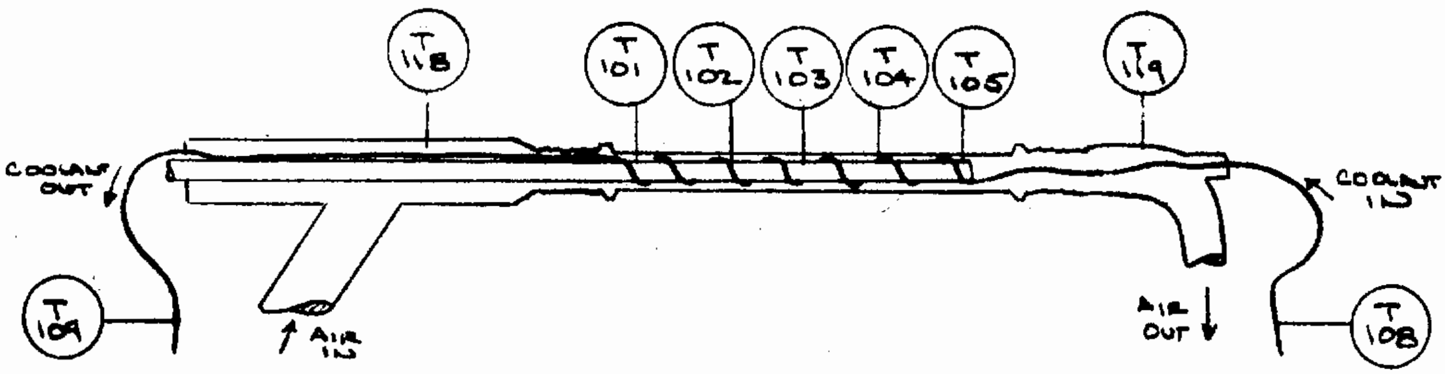
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______

CLIENT ASD / EXPERI CASE NO. 64607

TEST F-11

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
1	6.45	76	6.45	76	6.45	76	6.45	76	6.40	76	6.40	76	6.80	92	5.02	10	6.40	76
2	6.49	78	6.42	75	✓	✓	6.42	75	6.39	74	6.50	79	6.68	87	2.85	-104	✓	✓
3	✓	✓	6.49	78	✓	✓	6.31	70	5.89	52	✓	✓	6.45	76	1.46	-192	✓	✓
4	✓	✓	✓	✓	6.38	74	6.02	57	4.84	4	6.57	83	6.00	56	1.11	-218	6.46	77
5	✓	✓	6.45	76	✓	✓	5.89	52	4.31	-24	✓	✓	5.80	47	0.74	-249	6.41	75
8	6.60	83	6.20	66	5.36	27	3.49	-62	1.68	-178	6.60	83	4.61	-10	0.42	-276	6.49	78
10	✓	✓	5.81	48	4.31	-24	2.26	-140	1.21	-212	6.64	85	4.09	-36	0.41	-278	6.41	75
12	6.65	86	5.37	28	3.61	-61	1.69	-176	1.07	-222	6.70	88	3.72	-55	0.40	-278	6.38	74
15	6.69	87	4.79	0	2.75	-110	1.36	-200	0.95	-232	6.72	✓	3.42	-72	✓	-278	6.21	66
20 1/2	6.70	88	3.91	-45	1.82	-168	1.11	-218	0.85	-240	6.71	✓	3.06	-92	0.39	-280	5.90	52
25	6.69	87	3.64	-60	1.65	-180	1.08	-221	0.82	-242	✓	✓	2.88	-102	✓	✓	5.75	45
30	✓	✓	3.49	-68	1.57	-185	1.04	-224	0.80	-244	6.72	✓	2.78	-108	✓	✓	5.70	42
36	✓	✓	3.29	-78	1.49	-190	1.01	-226	0.79	✓	6.71	✓	2.69	-113	✓	✓	5.65	40
40 1/2	6.65	86	3.07	-90	1.40	-198	0.99	-228	0.75	-248	6.72	✓	2.68	-114	0.35	-284	5.07	38
44	✓	✓	2.83	-104	1.31	-204	0.91	-234	0.71	-252	6.70	✓	2.75	-110	✓	✓	5.54	35
45	✓	✓	2.80	-106	1.30	✓	✓	✓	0.70	✓	6.71	✓	2.77	-108	✓	✓	✓	✓



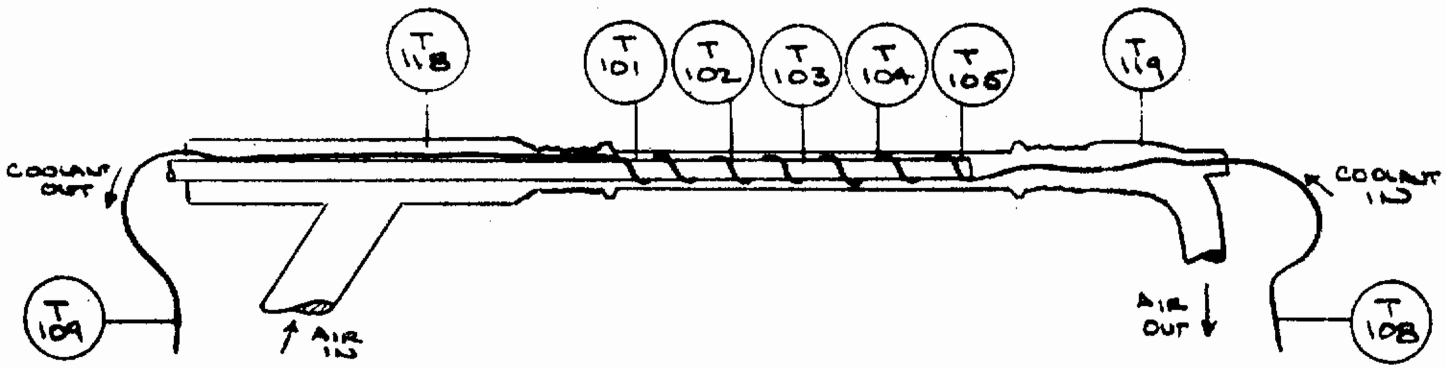
NOTES:

BY M. Kates DATE 9/13/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 54 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-12

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures T-101 (4,12) mV	T-101 °F	T-102 (3,11) mV	T-102 °F	T-103 (1,9) mV	T-103 °F	T-104 (5,13) mV	T-104 °F	T-105 (2,10) mV	T-105 °F	Air In T-118 (8) mV	T-118 °F	Air Out T-119 (16) mV	T-119 °F	Coolant In T-108 (6,14) mV	T-108 °F	Coolant Out T-109 (7,15) mV	T-109 °F
1	6.49	78	6.32	71	6.29	70	6.21	66	6.01	57	6.56	82	6.67	82	5.17	18	6.35	72
2	6.50	79	6.25	68	6.00	56	5.62	39	4.94	7	6.60	83	6.26	68	3.00	-94	6.41	75
4	6.61	84	6.15	63	5.60	38	5.02	10	4.47	-16	6.71	88	5.70	42	3.89	-46	6.40	74
6	6.75	90	6.17	64	5.51	34	4.84	2	3.95	-48	6.80	92	5.25	22	1.76	-172	6.50	79
8	6.83	93	5.75	45	4.69	-6	3.31	-78	2.18	-144	6.85	94	4.25	-28	1.12	-218	6.32	71
12	6.92	97	5.24	21	3.47	-68	1.90	-162	1.22	-210	6.91	97	3.28	-79	0.91	-234	6.15	63
16	6.71	✓	3.11	-88	1.45	-194	0.89	-236	0.59	-262	✓	✓	2.58	-120	0.17	-302	5.30	24
20	6.77	91	2.01	-156	1.02	-226	0.69	-253	0.49	-271	6.93	98	2.12	-148	0.13	-306	2.92	-96
24	6.71	88	2.20	-143	1.16	-216	0.75	-248	0.50	-270	6.85	94	1.93	-160	0.11	-308	2.87	-102
28	6.70	✓	✓	✓	✓	✓	0.76	-246	✓	✓	6.82	93	1.60	-170	✓	✓	2.79	-107
32	6.69	87	2.15	-146	✓	✓	0.79	-244	✓	✓	✓	✓	1.77	-172	0.10	-309	2.74	-110
36	6.70	88	2.17	-144	✓	✓	0.81	-243	✓	✓	✓	✓	1.72	-174	✓	✓	2.81	-106
40	6.69	87	2.08	-150	1.10	-220	0.79	-244	0.49	-271	✓	✓	1.70	-176	✓	✓	2.65	-116
45	6.67	86	1.95	-160	1.05	-224	0.72	-250	0.42	-277	✓	✓	1.69	-176	✓	✓	2.53	-122
50	6.65	✓	1.85	-166	1.01	-226	0.69	-253	0.40	-279	✓	✓	✓	✓	✓	✓	2.40	-130
52	6.63	84	1.84	✓	1.00	-227	✓	✓	✓	✓	6.80	92	✓	✓	✓	✓	2.36	-133



NOTES:

T-101 Not operating reliably

BY M. Kates DATE 9/13/62 — ARTHUR D. LITTLE, INC. — CAMBRIDGE, MASS. — SHEET NO. 55 OF

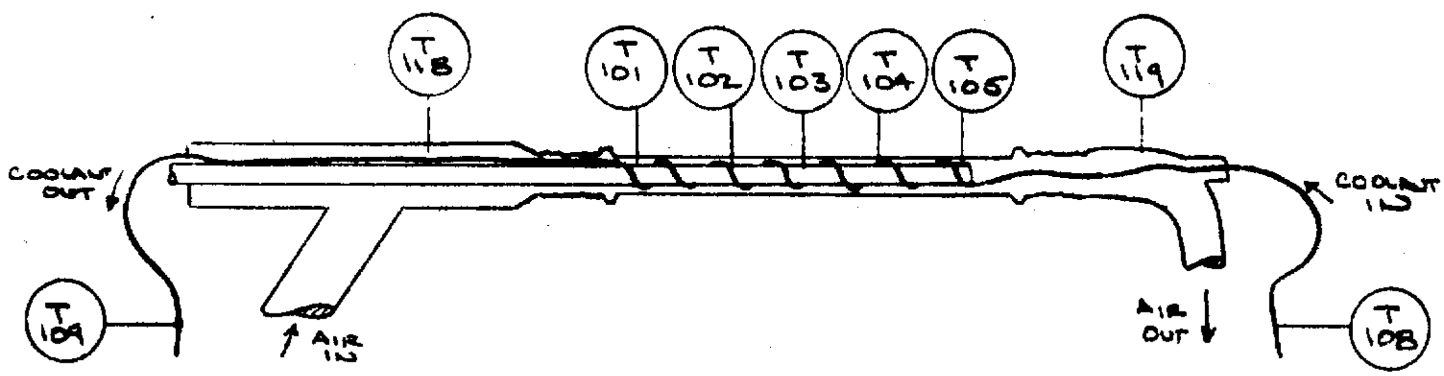
APPROVED DATE — SKETCH NO.

CLIENT ASD / EXPERI — CASE NO. 64607

TEST F-13

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
2 1/2	6.53	80	6.51	79	6.46	77	6.15	63	5.37	28	6.61	84	6.19	65	2.66	-114	6.51	79
4	6.50	79	6.55	81	6.37	73	5.89	52	4.90	5	6.70	88	5.83	48	2.59	-119	6.60	83
6	6.75	90	6.66	86	6.41	75	6.00	56	4.99	9	6.80	92	5.61	38	2.71	-112	6.69	87
8	6.87	95	6.75	90	6.48	78	5.79	47	4.10	-35	6.89	96	4.92	6	1.09	-220	6.79	92
10	6.95	98	✓	✓	6.31	70	5.05	12	2.81	-106	6.93	98	4.19	-30	1.00	-228	6.82	93
13	7.03	102	6.95	98	6.74	91	5.89	52	3.84	-48	7.00	100	4.20	✓	0.37	-282	6.89	96
15	7.07	104	✓	✓	6.61	84	5.44	30	2.70	-112	7.01	101	3.75	-54	0.29	-290	6.91	97
18	5.08	14	5.09	14	5.28	23	4.25	-28	2.32	-136	4.91	6	3.40	-70	0.21	-298	5.52	34
20	4.25	-28	4.29	-26	4.01	-40	2.83	-104	1.46	-192	4.30	-25	2.88	-102	0.19	-300	4.62	-9
25	3.62	-60	3.52	-66	3.00	-94	2.75	-110	1.06	-222	3.82	-50	2.30	-136	0.21	-298	3.91	-45
30	3.45	-70	3.10	-89	2.29	-138	1.45	-194	0.95	-232	3.61	-61	2.08	-150	0.20	-299	3.50	-67
38	3.55	-64	3.02	-94	2.11	-148	1.44	✓	0.99	-228	3.69	-56	2.05	-152	✓	✓	3.40	-72
42	3.45	-70	2.83	-104	1.94	-160	1.31	-204	0.91	-234	3.65	-58	1.99	-156	✓	✓	3.10	-89
45	✓	✓	2.81	-106	1.91	-162	✓	✓	✓	✓	✓	✓	1.98	-158	✓	✓	3.02	-94
48	3.29	-78	2.71	-112	1.81	-168	1.29	-206	0.90	-236	3.49	-68	1.99	-156	✓	✓	2.89	-102
52	3.50	-67	2.86	-103	2.00	-156	1.57	-187	1.00	-228	3.64	-60	2.00	✓	✓	✓	2.98	-96



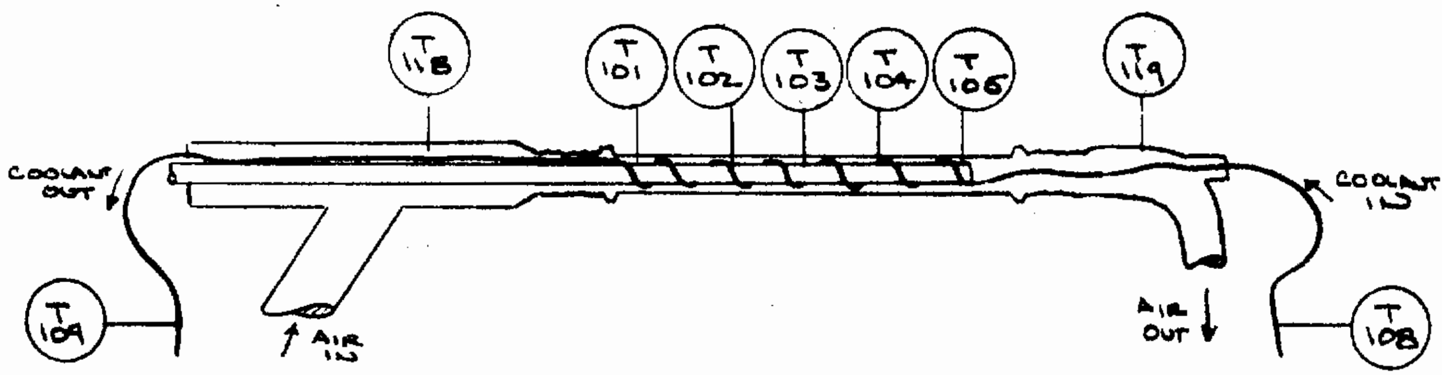
NOTES:

BY M. Kates DATE 9/13/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 56 OF
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 64607

Test F-14

Air and Coolant Temperature Data

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
1/2	6.51	79	6.51	79	6.56	82	6.51	79	6.51	79	6.51	79	6.75	90	3.91	-45	6.49	78
2 1/2	6.54	80	6.50	✓	6.29	70	5.86	50	4.62	-9	6.62	84	5.95	54	1.64	-180	6.57	79
4 1/2	6.65	86	6.55	81	6.28	69	5.56	36	4.28	-26	6.75	90	5.38	28	2.00	-156	6.61	84
6	6.75	90	6.62	84	6.37	73	5.61	38	4.41	-20	6.81	92	5.70	42	2.31	-136	6.69	87
8	6.85	94	6.79	92	6.61	84	6.01	57	4.08	-36	6.87	95	4.93	6	1.01	-226	6.76	90
11	6.95	98	6.80	✓	6.39	74	5.19	19	2.65	-116	6.91	97	4.01	-40	0.79	-244	6.82	93
16	6.79	92	6.71	88	6.85	94	6.01	57	3.90	-46	6.21	66	4.00	✓	0.38	-281	6.91	97
19	5.75	45	5.75	45	5.87	50	5.09	14	2.88	-102	5.87	50	3.64	-60	0.34	-285	5.98	56
22	5.59	38	5.48	32	4.80	0	2.89	-102	1.26	-208	5.79	47	2.97	-96	0.28	-291	5.70	45
27	5.39	28	5.31	24	4.61	-10	2.82	-106	1.31	-204	5.64	40	2.50	-124	0.29	-290	5.60	38
33	5.61	38	5.51	34	3.61	-61	2.15	-146	1.10	-220	6.31	70	2.56	-120	0.30	-289	5.78	46
38	4.39	-20	4.48	-16	4.06	-37	2.59	-119	1.29	-206	4.62	-9	2.11	-148	0.29	-290	4.80	47
44	3.92	-44	3.80	-50	2.71	-112	1.42	-196	0.89	-236	4.33	-24	2.00	-156	✓	✓	4.35	-22
50	4.10	-35	4.08	-36	3.29	-78	1.81	-168	1.10	-220	4.45	-18	2.01	✓	✓	✓	4.44	-18
54	4.05	-38	3.60	-62	2.33	-134	1.31	-204	0.81	-243	4.41	-20	1.98	-158	0.28	-291	4.24	-28
56	✓	✓	3.52	-66	2.25	-140	1.29	-206	0.84	-240	4.42	-19	1.93	-160	✓	✓	4.18	-31



NOTES:

BY M Kates DATE 9/14/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 52 OF ______

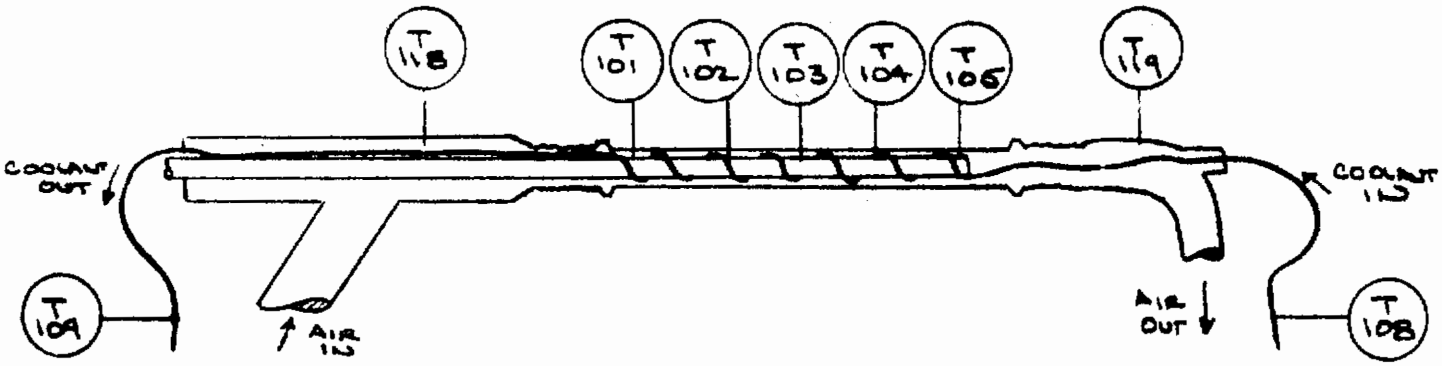
APPROVED ______ DATE ______ | SKETCH NO. ______

CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-17

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	4,12		3,11		1,9		5,13		2,10		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
1	6.59	83	6.48	78	6.09	60	6.05	12	3.96	-42	6.79	92	5.72	44	1.21	-212	6.50	79
2	6.71	88	6.67	86	6.39	74	5.71	43	4.51	-14	6.85	94	4.85	8	1.69	-176	6.71	88
5	6.99	100	6.79	92	6.72	88	6.12	62	4.65	-8	6.99	100	4.73	-4	1.34	-202	6.90	96
7	7.00	✓	6.89	96	6.57	82	5.79	77	4.00	-40	7.00	✓	4.21	-30	1.12	-218	6.92	97
10	7.01	101	6.91	97	6.60	83	5.85	50	3.56	-64	7.01	101	3.65	-58	0.88	-237	6.95	98
13	7.02	102	6.86	94	6.41	75	4.91	6	2.61	-118	7.02	102	2.85	-104	0.15	-304	6.91	97
17	✓	✓	6.63	84	5.71	43	3.35	-54	1.91	-162	✓	✓	2.17	-144	✓	✓	6.81	92
20	✓	✓	6.45	76	5.29	24	3.60	-62	1.87	-164	✓	✓	2.01	-156	0.12	-307	6.71	88
23	7.01	101	6.26	68	4.94	7	3.30	-78	1.71	-176	7.01	101	1.91	-162	0.11	-308	6.61	84
25	✓	✓	6.12	62	4.70	-5	3.03	-93	1.59	-184	✓	✓	1.85	-166	0.13	-306	6.58	82
26¼	7.00	100	6.02	57	4.57	-12	2.77	-108	1.45	-194	✓	✓	1.82	-168	0.11	-308	6.51	79
27¼	✓	✓	5.92	53	3.96	-42	2.51	-124	1.20	-212	6.79	92	1.91	-162	0.07	-312	6.45	76



NOTES:

BY [illegible] DATE 9/18/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 58 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD/EXPERI | CASE NO. 64607

TEST F-1

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
0	0	6	−6	0	0	0
3	0	6	−6	0	0	4
5	2	4	−2	5	10	86
8	11	12	36	48	102	241
10	23	23	39	54	139	258
12	30	21	45	53	164	214
15	50	36	46	54	186	262
18	58	42	46	45	193	260
20	60	45	48	[illegible]	195	261
25	61	46	46	42	201	258
30	64	44	46	40	198	258
35	34	2[illegible]	31	49	19[illegible]	274

TEST F-2

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1	AIR ΔT_2	AIR ΔT_3	AIR ΔT_4	AIR OVERALL ΔT	COOLANT OVERALL ΔT
	$T_{101} - T_{102}$	$T_{102} - T_{103}$	$T_{103} - T_{104}$	$T_{104} - T_{105}$	$T_{101} - T_{105}$	$T_{109} - T_{108}$
0	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	66
7	8	6	14	28	56	152
8	16	19	23	45	103	182
9	25	26	33	42	128	199
10	36	33	39	40	148	210
12	48	44	42	41	175	206
15	56	47	42	38	184	199
20	55	48	44	34	181	196
25	55	47	43	34	179	188
30	56	46	42	33	177	190
35	62	46	41	31	180	188
40	64	44	40	30	178	185

BY M. [illegible] DATE 9/19/62 ARTHUR D. LITTLE, INC. SHEET NO. 60 OF
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO.
CLIENT ASD/EXPERI CASE NO. 64607

TEST F3

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT1 T-101 − T102	ΔT2 T102 − T103	ΔT3 T103 − T104	ΔT4 T104 − T105	OVERALL ΔT T101 − T105	OVERALL ΔT T109 − T108
1½	2	0	0	0	2	0
3	4	0	0	0	4	0
6	8	12	12	36	68	150
10	37	32	38	39	146	190
12	48	40	44	38	170	206
15	51	48	44	36	179	200
20	55	48	44	36	183	205
25	56	46	46	35	186	203
30	56	46	44	35	183	[illegible]
35	56	46	46	35	183	[illegible]
40	58	46	44	35	182	198
45	58	48	42	34	182	196
47	58	48	42	34	182	197
48½	59	47	42	34	182	198

BY ______ DATE 9/19/6_

APPROVED ______ DATE ______

CLIENT ASD/EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 61 OF ______

SKETCH NO. ______

CASE NO. 64607

TEST F-2

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
5	3	0	2	0	5	7
7	6	0	14	14	34	[illegible]
9	22	19	34	35	110	18[illegible]
11	41	35	36	38	150	191
15	54	45	42	34	175	19[illegible]
20	60	43	45	31	179	[illegible]
25	56	47	42	32	17[illegible]	18[illegible]
30	55	45	41	34	175	185
35	55	43	43	34	175	185
39	58	42	40	30	170	[illegible]

BY *[illegible]* DATE *9/19/62* **ARTHUR D. LITTLE, INC.** SHEET NO. *62* OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT *ASD/EXPERI* CASE NO. *64607*

TEST F-5

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{101}-T_{105}$	$T_{109}-T_{108}$
15	5	1	2	2	10	18
17	14	10	20	32	[illegible]	186
19	[illegible]	31	43	46	155	222
21	48	[illegible]	44	43	177	216
25	58	40	45	42	185	211
29	58	42	46	46	186	210
33	58	[illegible]	45	[illegible]	185	210
35	59	45	40	37	184	[illegible]
38½	60	46	43	37	186	[illegible]

TEST F-7

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT₁ T-101 − T102	AIR ΔT₂ T102 − T103	AIR ΔT₃ T103 − T104	AIR ΔT₄ T104 − T105	AIR OVERALL ΔT T101 − T105	COOLANT OVERALL ΔT T109 − T108
0	0	0	0	0	0	34
3	3	6	16	41	66	191
6	0	4	25	69	98	281
9	0	0	16	70	[illegible]	315
12	10	25	98	104	[illegible]	[illegible]
15	26	68	120	62	[illegible]	346
20	40	96	100	46	282	340
25	48	108	90	40	286	334
30	50	112	88	38	284	332
35	54	112	82	34	282	330
40	59	114	78	32	283	328
46	60	117	72	34	283	[illegible]

BY [illegible] DATE 9/19/62 ARTHUR D. LITTLE, INC. SHEET NO. 64 OF
APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.
CLIENT ASD/EXPERI CASE NO. 64607

TEST F8

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1 T-101 − T102	ΔT_2 T102 − T103	ΔT_3 T103 − T104	ΔT_4 T104 − T105	OVERALL ΔT T101 − T105	COOLANT OVERALL ΔT T109 − T108
0	0	0	0	0	0	78
3	0	0	0	16	16	228
6	6	0	3	1	10	323
9	12	31	90	122	255	378
12	37	60	134	86	307	381
15	44	88	131	58	321	371
20	64	99	119	48	330	368
24	74	105	109	42	330	359
30	78	117	100	38	333	363
33	90	115	93	36	334	359
35	90	115	93	36	334	359
40	90	116	94	34	334	359
42	92	120	88	36	336	358
45	92	120	90	34	336	359
48	100	127	81	31	339	358

BY M. Shaw DATE 9/19/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 65 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD/EXPERI | CASE NO. 64607

TEST F-9

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
0	0	0	0	0	0	94
2	0	0	0	23	23	211
4	1	1	1	24	27	196
6	0	0	1	46	47	282
8	−1	0	6	44	49	300
10	−1	0	3	22	24	308
16	1	4	20	105	130	350
20	−1	9	42	114	164	351
25	−2	10	48	108	164	340
28	0	12	47	108	147	342
30	1	9	48	108	166	340
36	5	7	39	103	154	341
39	4	7	48	116	125	359
43	4	5	50	119	178	353
45	12	37	53	90	192	347

TEST F-10

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101} - T_{102}$	$T_{102} - T_{103}$	$T_{103} - T_{104}$	$T_{104} - T_{105}$	$T_{101} - T_{105}$	$T_{109} - T_{108}$
0	4	0	0	0	4	52
3	4	-1	53	77	133	294
6	4	15	44	120	183	339
9	30	68	145	60	303	376
12	48	87	111	70	316	371
15	51	89	112	66	318	370
20	60	98	104	64	324	368
23 3/4	64	104	100	60	328	368

BY M. Thayer DATE 9/19/62 | Contrails | SHEET NO. 62 OF

APPROVED........DATE........ | SKETCH NO.

CLIENT ASD/EXPERI | CASE NO. 64607

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

TEST F-11

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1 T-101 − T102	AIR ΔT_2 T102 − T103	AIR ΔT_3 T103 − T104	AIR ΔT_4 T104 − T105	AIR OVERALL ΔT T101 − T105	COOLANT OVERALL ΔT T109 − T108
1	0	0	0	0	0	66
2	3	−1	1	1	4	180
3	0	2	6	18	26	268
4	0	4	17	53	74	295
5	2	2	22	76	102	294
8	17	39	95	110	261	354
10	35	72	116	70	[illegible]	[illegible]
12	58	89	115	46	308	352
15	87	110	90	32	319	344
20½	133	123	50	22	328	332
25	147	120	41	21	329	325
30	155	117	39	20	331	322
36	165	112	36	18	331	320
40½	176	108	30	20	334	322
44	190	100	30	18	338	319
45	192	98	30	18	338	319

BY M. Haynes DATE 9/19/62.

APPROVED .... DATE ....

CLIENT ASD/EKPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 68 OF ....

SKETCH NO. ....

CASE NO. 64607

TEST F-12

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101} - T_{102}$	$T_{102} - T_{103}$	$T_{103} - T_{104}$	$T_{104} - T_{105}$	$T_{101} - T_{105}$	$T_{109} - T_{108}$
1	7	1	4	9	21	64
2	11	12	17	32	72	169
4	19	35	28	26	100	128
6	34	30	32	50	138	251
8	48	51	72	66	237	289
12	76	89	94	48	307	297
16	185	106	42	26	359	326
20	245	70	[illegible]	18	362	402
24	231	73	32	22	358	206
28	231	73	30	24	358	201
32	233	70	28	26	357	199
36	232	72	27	27	358	203
40	237	70	24	27	358	193
45	246	64	26	27	363	187
50	252	60	27	26	365	179
52	250	61	26	26	363	176

BY M. Thayer DATE 9/19/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 69 OF

APPROVED ____ DATE ____ | SKETCH NO. ____

CLIENT ASD/EXPERI | CASE NO. 64607

TEST F-13

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
2½	1	2	14	35	[illegible]	193
4	-2	8	21	47	74	204
6	4	11	19	47	81	199
8	5	12	31	82	130	312
10	8	20	58	118	204	321
13	4	7	39	100	150	378
15	6	14	54	142	216	[illegible]
18	0	-9	51	108	150	332
20	-2	14	60	88	160	291
25	6	28	16	112	162	253
30	19	49	56	38	162	232
38	30	54	46	34	160	[illegible]
42	34	56	44	30	160	210
45	36	56	42	30	164	200
48	34	56	38	30	158	197
50	36	53	31	41	161	203

TEST F-14

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT₁ $T_{101}-T_{102}$	AIR ΔT₂ $T_{102}-T_{103}$	AIR ΔT₃ $T_{103}-T_{104}$	AIR ΔT₄ $T_{104}-T_{105}$	AIR OVERALL ΔT $T_{101}-T_{105}$	COOLANT OVERALL ΔT $T_{109}-T_{108}$
1/2	0	-3	3	0	0	123
2 1/2	1	9	20	59	89	260
4 1/2	5	12	33	62	112	[illegible]
6	6	11	35	[illegible]	110	[illegible]
8	2	8	33	93	130	316
11	6	18	66	135	214	[illegible]
16	2	-6	[illegible]	103	138	[illegible]
19	0	-5	36	116	145	341
[illegible]	6	32	102	106	246	336
[illegible]	4	34	116	98	232	328
32	4	95	85	72	258	325
[illegible]	-4	21	82	87	186	[illegible]
40	6	62	92	40	192	268
50	1	42	90	[illegible]	185	[illegible]
[illegible]	24	72	70	39	205	265
56	28	74	66	34	202	[illegible]

BY M. Thayer DATE 9/19/62 | APPROVED ________ DATE ________ | CLIENT ASD/EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 71 OF ______ | SKETCH NO. ______ | CASE NO. 64607

TEST F-17

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR: ΔT_1	AIR: ΔT_2	AIR: ΔT_3	AIR: ΔT_4	AIR: OVERALL ΔT	COOLANT: OVERALL ΔT
	$T_{101}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{101}-T_{105}$	$T_{109}-T_{108}$
1	5	18	48	52	125	391
2	2	12	31	57	102	264
5	8	2	26	40	108	298
7	4	14	35	8[illegible]	140	[illegible]
10	4	14	33	114	165	355
13	8	19	68	124	230	401
17	18	41	92	108	264	396
20	26	52	86	102	266	395
23	32	61	85	98	277	[illegible]
25	39	64	88	91	285	388
26¼	43	69	96	86	294	385
30¼	40	95	82	88	312	388

BY [illegible] DATE 9/4/62 ARTHUR D. LITTLE, INC. SHEET NO. 72 OF ____

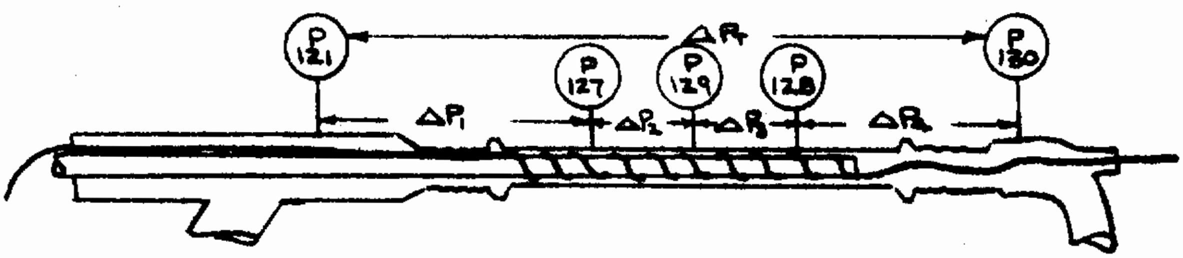
APPROVED [illegible] DATE 9/24/62 CAMBRIDGE, MASS. SKETCH NO. ____

CLIENT [illegible] CASE NO. 64607

TEST E-1

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
0	11.3	9	4.9	–	–	2.3	4.1	4.9	0	11.3
5	11.3	9	4.9			2.3	4.1	4.9	0	11.3
10	11.3	8	3.9	–		3.3	4.1	3.9	0	11.3
15	12.3	11	8.9	6.6	6.2	1.3	2.1	2.3	.4	6.1
20	12.3	11	8.9	6.6	6.2	1.3	2.1	2.3	.4	6.1
25	12.3	11	8.9	6.6	6.2	1.3	2.1	2.3	.4	6.1
30	12.3	11	8.9	6.6	6.2	1.3	2.1	2.3	.4	6.1
35	11.3	9	7.9		3.2	2.3	1.1			8.1



NOTES:

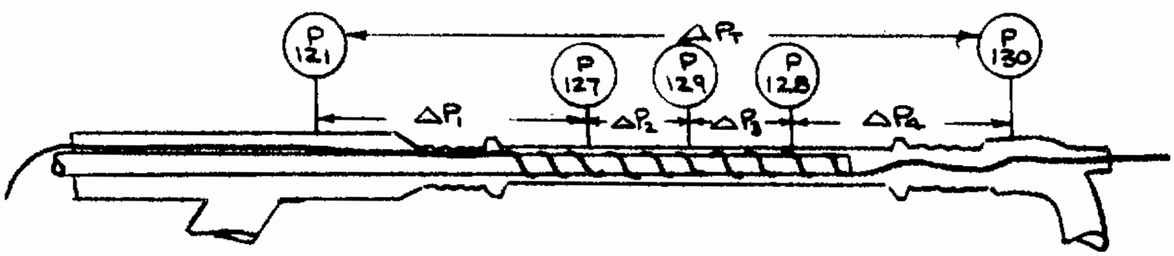
1. ~~PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA [illegible]~~

BY R. Durrah DATE 9/11/62 — **ARTHUR D. LITTLE, INC.** — SHEET NO. 73 OF ____
APPROVED CB DATE 9/24/62 — CAMBRIDGE, MASS. — SKETCH NO. ____
CLIENT ASD / ENPERL — CASE NO. 64607

Test F-2

Heat Exchanger Air Pressures

Time (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
0										
5	73	69	65	62.5	58.5	4	4	2.5	4	14.5
10	73	69	65	62.5	60.5	4	4	2.5	2	12.5
15	73	69	67	65.5	62.5	4	2	1.5	3	10.5
20	73	69	67	64.5	61.5	4	2	2.5	3	11.5
26	73	68	64	60.5	58.5	5	4	3.5	2	14.5
30	73	69	65	62.5	59.5	4	4	2.5	3	13.5
35	73	68	64	62.5	58.5	5	4	1.5	4	14.5
40	73	69	65	63.5	60.5	4	4	1.5	3	[illegible]



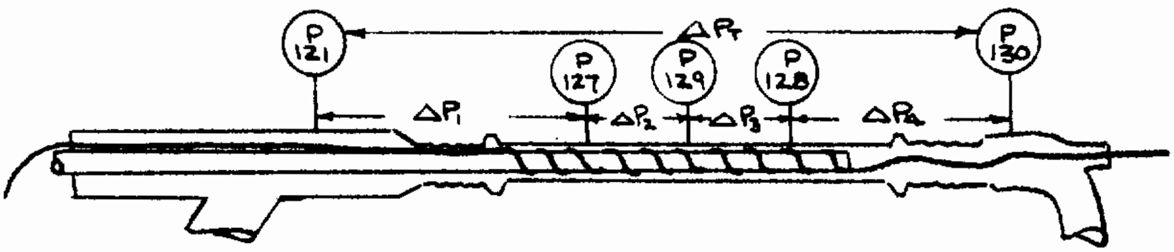
NOTES:

1. Pressure gage data corrected per calibration data ~~of FG Baldwin's memo of 9/6/62~~

TEST F-3

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
0										
1:30	73	69	66	62.5	57.5	4	3	3.5	5	15.5
6	73	69	66	62.5	57.5	4	3	3.5	5	15.5
10	73	69	68	62.5	60.5	4	1	5.5	2	12.5
15	73	69	67	64.8	62.5	4	2	2.5	2	10.5
20	73	69	66	62.5	60.5	4	3	3.5	2	12.5
25	73	69	66	61.5	58.5	4	3	4.5	3	14.5
30	73	66	58.9	53.4	49.2	7	7.1	5.5	4.2	23.8
35	73	64	52.7	[illegible]	45	9	11.3	4.4	3.3	28
40	73	59	42.4	35.3	31.7	14	16.6	7.1	3.6	41.3
45	73	54	26.5	18.4	11.4	19	27.5	6.1	7	61.6
47	74	53	23.6	12.7	4.4	21	29.4	10.9	8.3	69.6
48.5	76									



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY R. DURRAH DATE 9/11/62
APPROVED JEB DATE 9/29/62
CLIENT ASD / EXPERI

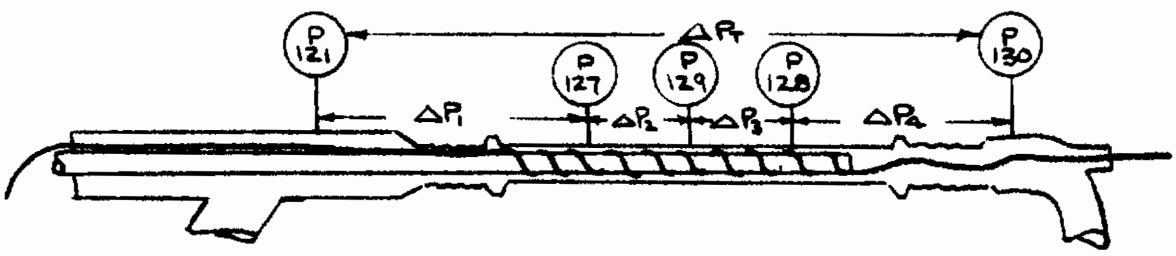
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 75 OF
SKETCH NO.
CASE NO. 6A607

TEST F-4

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1:15	73	68	64	63.5	61.5	5	4	.5	2	11.5
5:15	73	69	65	63.5	60.5	4	4	1.5	3	12.5
10	73	69	67	63.5	61.5	4	2	3.5	2	11.5
15	73	69	67	63.5	61.5	4	2	3.5	2	11.5
20	73	69	65	63.5	61.5	4	4	1.5	2	11.5
25	73	64	58.9	54.5	51.5	9	5.1	4.4	3	21.5
30	73	58	48.8	43.5	41	15	9.2	5.3	2.5	32
35	73	51	36.7	29.5	26.7	22	14.3	7.2	2.8	46.3
38	73	43	20.3	13.5	2.3	30	22.7	6.8	11.2	70.7



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY R. Dunn DATE 9/14/62 | **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. | SHEET NO. 76 OF ____

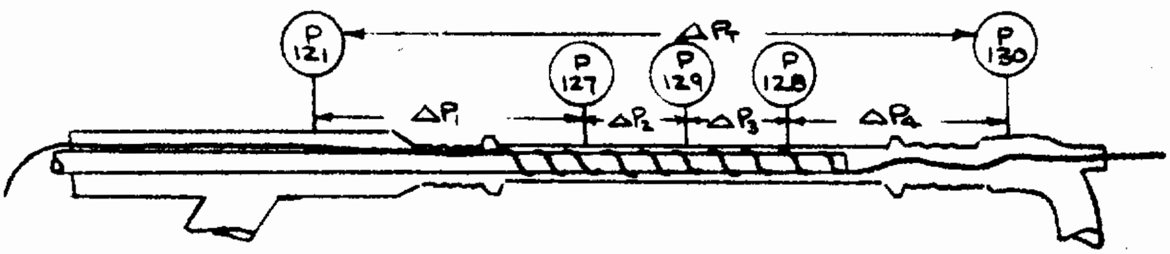
APPROVED JCB DATE 9/24/62 | SKETCH NO. ____

CLIENT ASD / EXPERI | CASE NO. 64607

TEST F-5

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP₁ (PSI)	ΔP₂ (PSI)	ΔP₃ (PSI)	ΔP₄ (PSI)	ΔP_T (PSI)
[illegible]	73	69	67	64.5	61.5	4	2	2.5	3	11.5
-	73	69	65	63.5	59.5	4	4	1.5	4	13.5
	73	[illegible]	65	63.0	59.5	4	4	1.5	4	13.5
	73	[illegible]	64	59.5	56.5	4	[illegible]	4.5	3	[illegible]
30	73	[illegible]	49.8	44.5	38.9	8	15.2	5.3	5.6	34.1
31	71	[illegible]3	28.5	18.6	10.2	8	34.5	9.9	8.4	[illegible]
33	72	59	28.5	17.6	10.2	13	30.5	10.9	7.4	[illegible]
31:30	77.5				.9					78.6



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

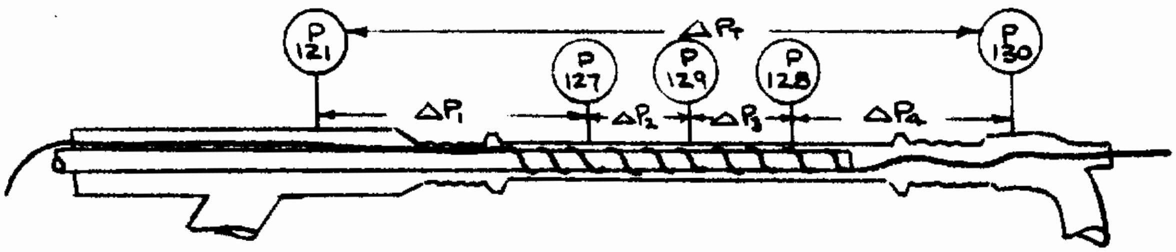
BY K. Kuenah DATE 9/11/62
APPROVED CB DATE 9/24/62
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

TEST F-7

HEAT EXCHANGER AIR PRESSURES

	X/L=0	X/L=1/4	X/L=1/2	X/L=3/4	X/L=1.0					
TIME (MIN)	P-121 (PSIG)	P-127 (PSIG)	P-129 (PSIG)	P-128 (PSIG)	P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
11:45	73	71	68	64.5	61.5	2	3	3.5	3	11.5
5	73	69	65	62.5	58.5	4	4	2.5	4	14.5
10	73	69	67	64.5	62.5	4	2	2.5	2	10.5
15	73	69	66	62.5	61.5	4	3	3.5	1	11.5
20	73	69	66	64.5	62.5	4	3	1.5	2	10.5
25	73	69	66	64.5	62.5	4	3	1.5	2	10.5
30	73	69	66	64.5	61.5	4	3	1.5	3	11.5
35	73	69	66	64.5	60.5	4	3	1.5	4	12.5
40	73	69	66	64.5	60.5	4	3	1.5	4	12.5
45	73	69	66	64.5	59.5	4	3	1.5	5	13.5



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION
~~DATA OF [illegible]~~

BY L. Duggah DATE 9/17/62 | APPROVED CB DATE 9/24/62 | CLIENT ASD / EXPERI

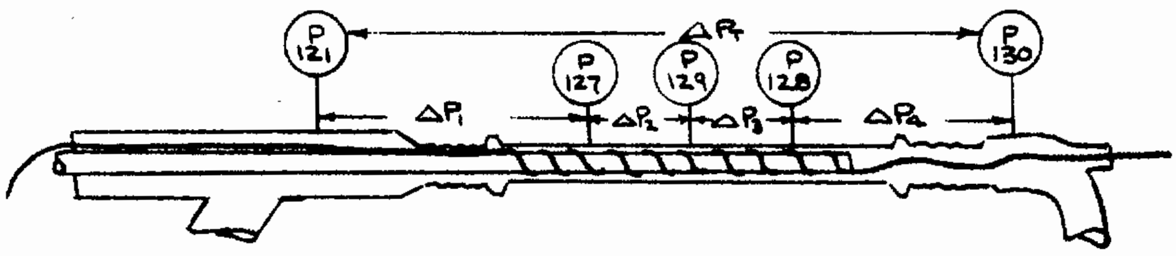
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 78 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST F-8

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1:30	73	69	65	63.3	60.4	4	4	1.7	2.9	12.6
5	73	69	65	62.3	59.4	4	4	2.7	2.9	13.6
10	73	69	65	65.3	62.5	4	4	-.3	2.8	13.5
15	73	69	66	64.3	63.5	4	3	1.7	.8	9.5
20	73	69	64	62.3	59.4	4	5	1.7	2.9	13.6
25	73	69	64	62.3	59.4	4	5	1.7	2.9	13.6
30	73	69	56.7	54.4	50.3	4	13.3	2.3	4.1	22.7
35	73	69	48.7	47.4	42	4	20.3	1.3	5.4	31
40	74	69	42.6	39.4	31.6	5	26.4	3.2	7.8	42.1
45	73	69	32.5	28.6	16.1	4	36.5	3.9	12.2	56.6
48	74	69	23	20.6	0	5	46.0	2.4	20.6	74



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~OF [illegible]~~

BY K. Purra DATE 9/17/62 APPROVED JCB DATE 9/24/62 CLIENT ASD / ENPERI

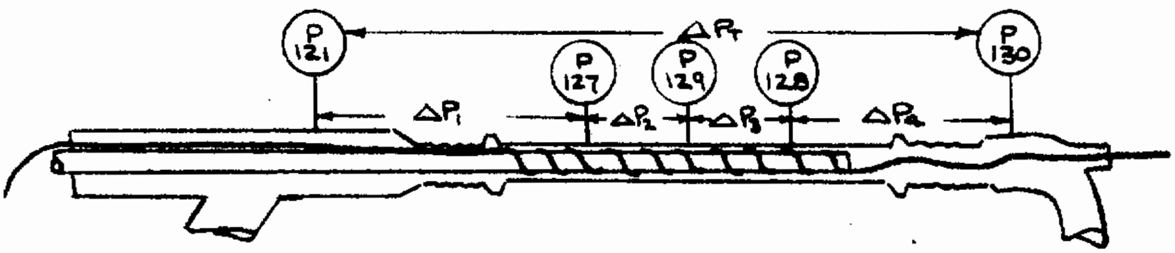
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 79 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST F-9

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP1 (PSI)	ΔP2 (PSI)	ΔP3 (PSI)	ΔP4 (PSI)	ΔPT (PSI)
1:30	73	68	64	59.5	54.3	5	4	4.5	5.2	18.7
5	73	68	64	61.5	57.5	5	4	2.5	4	15.5
10	73	69	64	61.5	58.5	4	5	2.5	3	14.5
15	72	68	64	61.5	57.5	4	4	2.5	4	14.5
20	73	69	65	62.5	57.5	4	4	2.5	5	15.5
25	73	69	65	62.5	47.2	4	4	2.5	5.3	25.8
28	75	70	64	62.5	43	5	3	4.5	19.5	32
30	73	69	64	59.5	32.7	4	5	4.5	26.8	40.3
36	73	69	65	61.5	23.5	4	4	3.5	38	49.5
39	73	69	64	61.5	8.9	4	5	2.5	52.6	64.1
41:30	76	71	69	64.5	.9	5	2	4.5	63.6	75.1
[illegible]	83.5	79	77	44.3	.9	4.5	2	2.5	73.4	82.6
45	94									



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY J. DURRAN DATE 9/14/62 APPROVED LCB DATE 9/24/62 CLIENT ASD / ENPERA

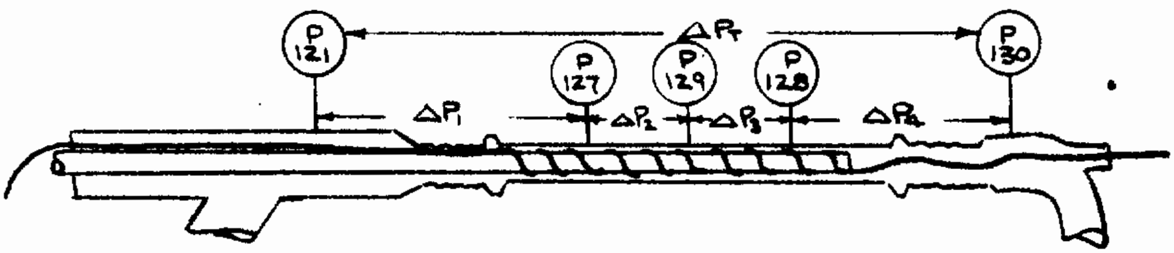
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 80 OF ____
SKETCH NO. ____
CASE NO. 64607

TEST F-10

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1:30	73	63	51.8	41.5	27.7	10	11.2	10.3	13.8	46.3
5:00	73	63	52.8	42.5	30.2	10	10.2	10.3	12.3	42.8
10:00	73	63	52.8	41.5	34.7	10	10.2	11.3	6.8	38.3
15:00	74	64	41.7	23.6	3.1	10	22.3	18.1	20.5	70.9
17:00	80.4	70	41.7	22.6	7.2	10.4	28.3	19.1	15.4	73.2
19:00	88.6	79	41.7	23.6	7.2	9.6	37.3	18.1	16.4	81.4
20:00	93.7	85	41.7	23.6	7.2	8.7	43.3	18.1	16.4	86.5
23:00	106	104	41.7	24.5	7.2	2	62.3	17.2	17.3	98.8



NOTES:

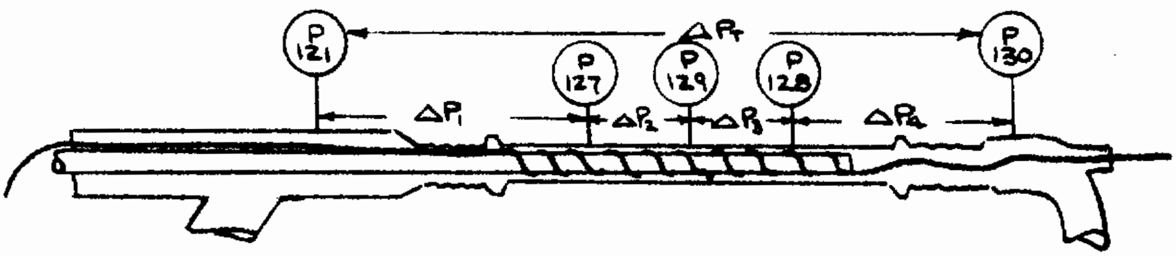
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA OF [illegible]

BY R. DURRAH DATE ________ ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 81 OF ______
APPROVED ________ DATE ________ SKETCH NO. ________
CLIENT ASD / EXPERI CASE NO. 64607

TEST F-11

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP1 (PSI)	ΔP2 (PSI)	ΔP3 (PSI)	ΔP4 (PSI)	ΔPT (PSI)
2:00	73	72	71	69.5	70.5	1	1	1.5	-1	2.5
5:00	71	69	69	67.4	65.4	2	0	1.6	2	5.6
10:00	73	72	72	69.5	69.5	1	0	2.5	0	3.5
15:00	73	72	67	66.4	66.4	1	5	.6	0	6.6
20:30	73	64	67	66.4	66.4	4	2	.6	0	6.6
25	71	63	59.9	54.3	54.3	8	3.1	5.6	-3	3.7
30	73	58	55.4	54.3	53.2	15	2.6	1.1	1.1	19.8
36	73	41	39.2	36.5	36.4	32	1.8	2.7	.1	36.6
40:30	73	19	16.1	13.6	9.2	54	2.9	2.5	4.4	63.8
44	80.4	13	9	14.6		67.4	4	-5.6	14.6	80.4
45:30	85.5									



NOTES:

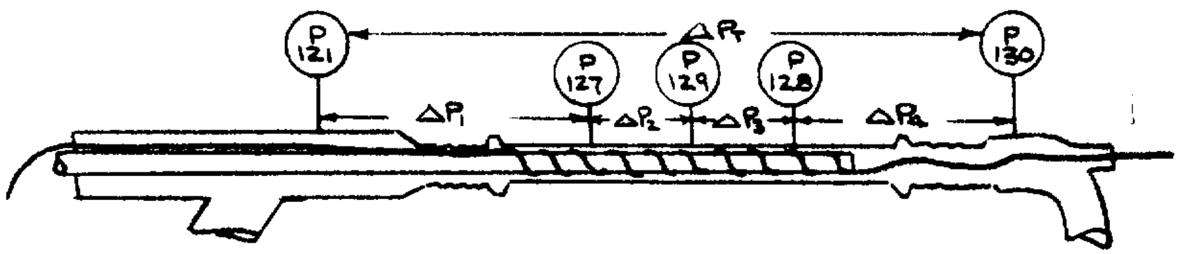
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~
2. P-128 @ 44 MIN IS EVIDENTLY INCORRECT

BY Darral DATE 8/14/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 82 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / [illegible] | CASE NO. 64607

TEST F-12

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1:30	73	69	66	63.3	60.3	4	3	5.7	3	
6:00	73	69	65	62.3	58.3	4	4	2.7	4	14.7
10:00	73	69	65	62.3	61.3	4	4	2.7	1	11.7
15:00	73	69	65	65.4	63.4	4	4	-.4	2	9.6
20:00	73	69	66	64.4	62.4	4	3	2.6	2	11.6
23:00	74	69	66	64.4	62.4	5	3	2.6	2	12.6
31:00	73	64	60.9	57.4	54.3	9	3.1	3.5	3.1	18.7
36:00	73	59	55.9	51.4	48.2	14	3.1	4.5	3.2	24.8
40:00	73	55	51.8	46.5	44	18	3.2	5.3	2.5	29
45:00	72	43	38.7	29.5	26.5	29	4.3	9.2	3	45.5
50:00	73	29	22.3	9.6	0	44	6.7	12.7	9.6	73
52.	78.1					78.4				



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA [illegible]

BY D. Akrap DATE 8/18/62 | APPROVED ______ DATE ______ | CLIENT ASD / EXPERI

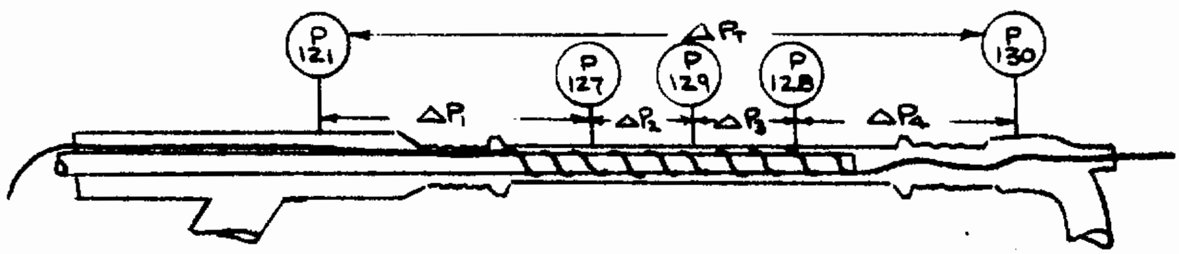
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 83 OF ______ | SKETCH NO. ______ | CASE NO. 64607

TEST F-13.

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2:30	73	69	66	63.3	58.3	4	3	2.7	5	14.7
6:30	73	69	65	62.3	58.3	4	4	2.7	4	14.7
10:00	73	69	64	62.3	57.3	4	5	1.7	5	15.7
15:00	73	69	64	61.3	59.3	4	5	2.7	2	13.7
20:00	73	67	61.9	57.4	54.3	6	5.1	4.5	3.1	18.7
25:00	73	59	52.8	47.5	44	14	6.2	5.3	3.5	29
30:00	73	57	51.8	47.5	42	16	5.2	4.3	5.5	31
38:00	73	51	44.7	41.5	29.7	22	6.3	3.2	11.8	43.3
42:00	73	49	42.7	38.5	29.7	24	6.3	4.2	8.8	43.3
45:00	73	48	41.7	36.5	19.4	25	6.3	5.2	17.[illegible]	53.6
48:00	71	42	34.6	29.5	6.2	29	7.4	5.1	23.3	64.8
52:00	78.4	48	38.7	32.6	6.2	30.4	9.3	6.1	26.4	72.2



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY Durrah DATE 8/12/62 | APPROVED ______ DATE ______ | CLIENT ASD / [illegible]

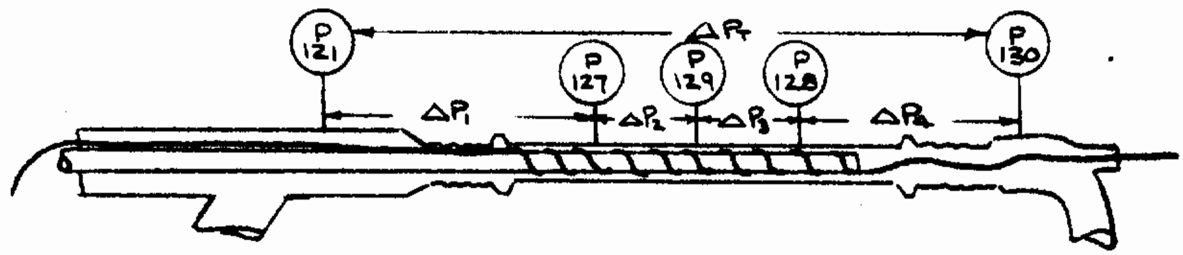
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 84 OF ______ | SKETCH NO. ______ | CASE NO. 64607

Test F-14

Heat Exchanger Air Pressures

Time (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
4:30	73	69	65	63.3	56.3	4	4	1.7	7	16.7
11:00	72	67	64	59.3	54.3	5	3	4.7	5	18.7
16:00	73	65	63	57.4	50.6	5	5	5.6	6.8	22.4
22:00	70	64	58.9	54.4	50.6	6	5.1	4.5	3.8	19.4
27:00	73	69	64	59.3	57.3	4	5	4.7	2	15.7
38:00	73	67	61.9	56.4	50.6	6	5.1	5.5	5.8	22.4
44:00	73	66	61.9	59.3	53.2	7	4.1	2.6	6.1	19.8
50:00	73	44	38.6	33.5	19.4	29	5.4	5.1	14.1	53.6
54:00	79.4	34	27.5	23.6	6.2	45.4	6.5	3.9	17.4	73.2
56:00	91.7	34	28.5	22.6	6.2	57.7	5.5	5.9	16.4	75.5



NOTES:

1. Pressure gage data corrected per calibration data [illegible]

BY DARRAH DATE 5-19-62
APPROVED ______ DATE ______
CLIENT ASD / ENPOSA

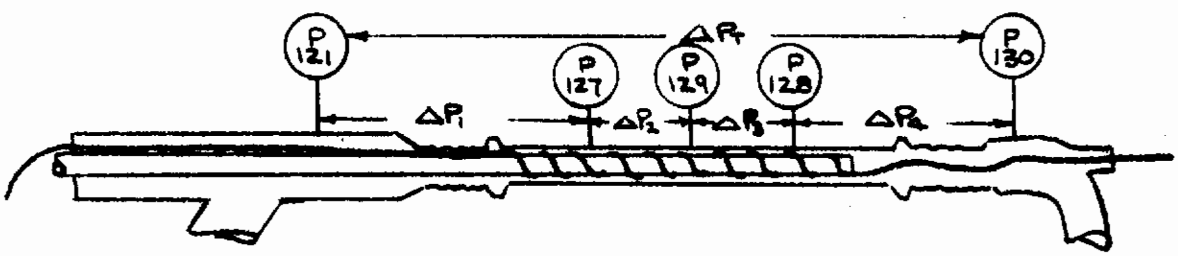
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 85 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST F-14.

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2:00	283.5	272	262.7	248.3	236.7	11.5	9.3	14.4	11.6	46.8
5:00	283.5	272	262.7	249.3	238.7	11.5	9.3	13.4	10.6	44.8
10:00	283.5	272	262.7	248.3	234.7	11.5	9.3	14.4	13.6	48.8
17:00	283.5	272	265.7	252.3	237.7	11.5	6.3	13.4	14.6	45.8
20:00	283.5	272	260.8	236.4	209.6	11.5	11.2	24.4	26.8	73.9
23:00	283.5	273	236.5	168.3	152.5	10.5	36.5	68.2	15.8	131
25:00	273.5	274	204.8	124	102.5	-.5	69.2	80.8	21.5	171
26.15	273.5	272	179.4	84.2	52.1	1.5	92.6	95.2	32.1	221.4



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY ________ DATE ________
APPROVED ________ DATE ________
CLIENT ________

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 86 OF ____
SKETCH NO. ________
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST F1
DATE 7-18-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: Conc. ① ppm-vol.	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT.	REMARKS
													No data on recorder.
5	75	26.0	160	.0042									[illegible] 1930 psig
10.	75	26.0	100	.0026									1750
15	74	2[illegible].0	90	.0024									1500
20	70	27.0	80	.0021									1220
25	67	27.0	80	.0021									1000
30							-132	20.9	60	.0012			
31							-130	19.9	50	.0010			
32							-129	18.9	40	.0008			Start [illegible]
35							-124	17.9					[illegible] - water condensing
36.5													Shutdown

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	w_A lbs/hr	① CALCULATED ppm-(wt)	INLET CONC. PPM (VOL) ②
No data.							

Note: p_w = partial press. H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([redacted] w_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST F-2
DATE 7-24-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-vol.	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC.① ppm-vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
													Bottle water only - No water addition.
15	66	87.7	80	.0070									Avg = Table 0-15 min
23							-118	74.7	20-25	.00015	4×10^{-6}		
40	60	87.7	87	.0076									Steady
41.5													Shutdown

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ① ppm-(wt)	ppm (vol) ②
No data							

Note: p_w = partial press. H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([redacted] W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST F-3
DATE 7-25-62

TIME MIN.	RECORDER & VISUAL OBSERVATIONS — IN: T °F	P psia	CONC.① ppm-VOL	p_w psia	p_{sat} psia	% of SAT.	OUT: T °F	P psia	CONC.① ppm-VOL.	p_w psia	p_{sat} psia	% of SAT	REMARKS
0 - 20 MIN	71	87.5	130	.012									Water from bottle only
12 MIN													Steam On.
25	70	87.5	370	.038									
30	70	87.5	410	.040									
40							-113	47.3	10	.0005	7×10^{-6}		
45	70	87.5	550	.048									
48.5	70	90.7	630	.055									Shutdown.

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ② ppm-(wt)	② ppm (vol)
Calibration after Test gave rate ~				30.6	119	550	860

Note: p_w = partial press. H_2O
p_{SAT} = VAPOR " "

① Average - Approx. Steady State Value
② ppm (wt) = RATE (cc/hr) × (1/454) × 10⁶/([redacted] W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST F-4
DATE 7-27-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
0-17	62	87.7	60	5.2×10^{-3}									steady - water only from bottle.
13													Turn on Steam.
20	60	87.7	400	3.5×10^{-2}									NOT Steady
23	60	87.7	460	$4.0 \times$ "									" "
25	59	87.7	500	$4.4 \times$ "									almost "
35							-11.8	41.4	50	2×10^{-3}			nearly stable from t = 32-37
39	56	87.7	780	6.8×10^{-3}									Cond (?) Shutdown

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/sec	CALCULATED INLET CONC. ① ppm - (wt)	CALCULATED INLET CONC. ppm (vol) ②
13		60.0					
44	31	18.0	42.0	82.0	.0312	1000	[illegible]

Note: p_w = partial press. H_2O
p_{SAT} = vapor " "

① Average - Approx. Steady State Value
② $ppm (wt) = Rate (cc/hr) \times (1/454) \times 10^6 / (3600\, W_A) = ppm (vol) \times 18/29$

BY __________ DATE ______ | **ARTHUR D. LITTLE, INC.** | SHEET NO. 90 OF ______
APPROVED ______ DATE ______ | CAMBRIDGE, MASS. | SKETCH NO. ______
CLIENT ______________________ | | CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST F5
DATE 8-3-62

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-vol	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC.① ppm-vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
17	84	87.7	200	1.7×10^{-2}									water from bottles. steam [illegible]
25	79	87.7	740	$6.5\times$"									
30	76	87.7	820	$7.2\times$"									
35							-110	24.6	160	3.9×10^{-3}			Still [illegible] slowly
38	74	87.7	760	$6.6\times$"									
38.5													Shut down.

(Recorder & Visual Observations)

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ① ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
17 → 38.5	21.5		18.3	51	112	1000	1600

Note: p_w = partial press. H_2O
p_{SAT} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([redacted] W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST F-7
DATE 7-31-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-VOL	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC① ppm-VOL.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
9	62	87.7	33	2.8×10^{-3}									No water added - bottle water only. Steady?
15							-220	76.2	20	1.5×10^{-3}			} dropping slowly
20							-232	77.2	9	0.7×10^{-3}			
28	0	87.7	17	1.5×10^{-3}									Steady
35							-234	75.2	5	0.4×10^{-3}			"
40	-14	87.7	12	1.1×10^{-3}									"
45							-239	74.2	6	$.05\times10^{-3}$			"
46													Shut down.

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ① ppm-(WT)	ppm (VOL) ②
No data taken.							

Note: p_w = partial press H_2O
p_{SAT} = VAPOR " "

① Average - Approx. Steady State Value
② ppm (WT) = RATE (cc/hr) × (1/454) × 10^6 / ([redacted] W_A) = ppm (VOL) × 18/29

WATER CONTAMINANT TEST RESULTS

TEST F-8
DATE 8-7-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psig	IN: CONC① ppm-vol	IN: p_N psia	IN: p_{SAT} psia	IN: % SAT	OUT: T °F	OUT: P psig	OUT: CONC① ppm-vol	OUT: p_W psia	OUT: p_{SAT} psia	OUT: % SAT	OUT: Probe up-down	REMARKS
10														WATER ON
20	102	87.5	262	2.3×10^{-2}										
23							-185	74.1	95	7.0×10^{-3}				
25							-228	74.1	85	6.2×"				
26							-229	74.1	72	5.3×"				
27							-230	74.1	65	4.8×"				
32	102	87.5	253	2.2×10^{3}										
35							-232	59.4	65	3.8×"				
36							"	56.4	48	2.7×10^{-3}				
38							"	50.4	40	2.0×10^{-3}				
40							"	45.3	32	1.4×10^{-3}				
45	102	87.5	235	2.1×10^{3}										
48.5							-237	~14.7	30	4.4×10^{-4}				
48.5														WATER OFF

DATA FROM BURETTE MEASUREMENTS

TIME MIN	TIME INTERVAL MIN	BURETTE CC	DIFFERENCE CC	RATE CC/HR	CALCULATED INLET CONC. PPM (WT) ②	CALCULATED INLET CONC. PPM VOL ②	W_A lbs/hr.
10							112
	20	14.7	3.5	10.5			
30					205	320	112
	18.5	19.2	3.2	10.4			
48.5							112

① AV. APPROX. STEADY STATE VALUES

② $ppm\ (wt) = RATE\ (cc/hr) \times \frac{1}{454} \times \frac{10^6}{W_A \times 3600} = ppm\ (vol) \times \frac{18}{28}$

NOTE: p_w = partial pressure H_2O
p_{SAT} = vapor " "

BY ________ DATE ________
APPROVED ________ DATE ________
CLIENT ________

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 93 OF ________
SKETCH NO. ________
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST F-9
DATE 8-14-62

Recorder & Visual Observations

Time min.	IN: T °F	IN: P psia	IN: Conc ① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	Remarks
15	65	86.7	12	1.0×10^{-4}									Water on
25	66	86.7	336	2.9×10^{-3}									Steady
35	[illegible]						-72	39.7	60	2.4×10^{-3}	2.4×10^{-4}		Reading dropping slowly but is dependent of direction of probe [illegible]
45													Shutdown

Data From Burette Measurements

Time min.	Time Interval min.	Burette cc	Difference cc	Rate cc/hr	w_A lbs/hr	Calculated ② ppm-(wt)	Inlet Conc. ppm (vol) ②
26	20.7	16.0	5.9	17.2	112	340	550
46.7		21.9					

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([illegible] w_A) = ppm (vol) × 18/29

BY________ DATE________
APPROVED________ DATE________
CLIENT________

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 97 OF ____
SKETCH NO. ____
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST F-10
DATE 8-15-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-Vol	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
6	94	87.7	30	2.6×10^{-3}									Water on
15	102	98.7	280	2.5×10^{-2}									Steady
23							-224	25.3	36	9.1×10^{-4}			dropping slowly
23.75													Shut down

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ① ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
11.25	4.75	13.93	2.67	34	186	405	650
16		16.6					

Note: p_w = partial press H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② $ppm\,(wt) = Rate\,(cc/hr) \times (1/454) \times 10^6 / ($[redacted] $W_A) = ppm\,(vol) \times 18/29$

— Water Contaminant Test Results —

Test F-11
Date 8-17-62

Recorder & Visual Observations

Time min.	IN: T °F	IN: P psia	IN: Conc.① ppm-vol	IN: p_w psia	IN: p_{sat} psia	IN: % of Sat.	OUT: T °F	OUT: P psia	OUT: Conc.① ppm-vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of Sat	Remarks
14 min.	86	87.7	740	6.5×10^{-2}									Water started at t = -1 min, constant from t = 0
22							-240	77.5	24	1.8×10^{-3}			constant
33							-244	59.5	24	1.4×10^{-3}			"
37	87	87.7	500	4.4×10^{-2}									
45.5													Shutdown

Data From Burette Measurements

Time min.	Time Interval min.	Burette cc	Difference cc	Rate cc/hr	W_A lbs/hr	Calculated ② ppm-(wt)	Inlet Conc. ppm (vol) ②
From 11 min to 45 min, the various readings averaged				8.4	56	330	530

Note: p_w = partial press. H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6/(WA) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST F-12
DATE 8-21-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-VOL	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC① ppm-VOL.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
16	97	87.7	6	5.2×10^{-4}									Water on at 16 MIN.
20							-271	77.1	~0	0			
26	88	87.7	260	2.3×10^{-2}									
39							-271	60	~18	6×10^{-4}			at 33:40 frost was blowing but direction of down-stream probe had no effect. DD
45	86	86.7	291	2.5×10^{-2}									
51													Shut down

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	② CALCULATED ppm-(WT)	INLET CONC. ppm (VOL) ②
Water flow measured very close to over all the test				13.2	112	260	420

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6/([redacted] W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST F-13
DATE 8-24-62

TIME MIN.	RECORDER & VISUAL OBSERVATIONS — IN: T °F	P psia	Conc.① ppm-Vol	p_w psia	p_{SAT} psia	% of SAT.	OUT: T °F	P psia	Conc① ppm-Vol.	p_w psia	p_{SAT} psia	% of SAT	REMARKS
19	0	87.7	~0	~0									water on at 19.5
23	-46	87.7	~0	~0									
38	-64	87.7	200	1.7×10^{-2}									held const from t=27
45							-234	34.1	18	6.2×10^{-4}			
52	-67	93.1	180	1.7×10^{-2}									
53.25													Shut down

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ② ppm-(wt)	ppm (vol) ②
29.75		11.2					
37.1	7.35	12.9	1.7	13.8	112	270	430
43.1	6.0	14.3	1.4				

Note: p_w = partial press H_2O
p_{SAT} = VAPOR " "

① Average - Approx Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6/([redacted] W_A) = ppm (vol) × 18/29

BY________ DATE________
APPROVED________ DATE________
CLIENT________

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 98 OF________
SKETCH NO.________
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST F-14
DATE 8-29-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN	IN: T °F	IN: P psia	IN: CONC. ① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
12	98	87.7	60	5.2×10^{-4}									
22	38	│	30	2.6 × "									
38	-70	│	18	1.6 × "									
40		│											Start water
50	-35	│	180	1.6×10^{-2}									
56	-38	│	205	1.8×10^{-2}									
57													Shut down

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ① ppm-(wt)	② ppm (vol)
21.75		9.4					
29.75	8.0	11.2	1.8	13.3	112	~ 275	445
37.12	7.37	12.9	1.7	14.5			
43.08	5.96	14.3	1.4	13.9			

Note: p_w = partial press. H_2O
p_{SAT} = vapor " "

① Average - Approx Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([redacted] W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST F17
DATE 8-31-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-vol	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC① ppm-vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
15.5	102		30										Start water at 15.5
25	101	300	325	0.1									
27.25													Shutdown

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ② ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
15.75	5.25	0.5					
21	3	4.9	4.4	50.3	374		
24	3.25	7.35	2.45	49.0		295	470
27.25		10.1	2.75	50.8			

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([redacted] W_A) = ppm (vol) × 18/29

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F-7
DATE 7-31-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	CONC ① ppm-VOL	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	CONC ① ppm-VOL	p_{CO_2} psia	p_{SAT} psia	% of SAT	
9	62	87.7	300	2.6×10^{-2}									
20							-232	77.2	30	2.3×10^{-3}	2.3×10^{-3}		
28	0	87.7	305	2.7×10^{-2}									
35							-236	75.2	15	1.1×10^{-3}	1.6×10^{-3}		Very Steady
40	-14	87.7	320	2.8×10^{-2}									
45							-239	74.2	10	0.8×10^{-3}	1.1×10^{-3}		
46													Shutdown

No. of Bottles in Manifold 20
Pressure in Manifold 2400 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

Pressure after Mixing = 2280 psia
$ppm\ CO_2\ (vol) = \frac{14.7}{2280} \times 21 = 310$
$ppm\ CO_2\ (wt) = ppm(vol) \times \frac{44}{28}$
$= 490$

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Average - Approx Steady State Value

BY ______ DATE ______
APPROVED ______ DATE ______
CLIENT ______

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 101 OF ______
SKETCH NO. ______
CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F-8
DATE 8-7-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
10	100	87.5	390	3.4×10^{-2}									
20	102	87.5	390	"									
25							-228	74.1	45	3.3×10^{-3}	3×10^{-3}		
32	101	87.5	380	"									
40							-232	45.3	35	1.6×10^{-3}	2.5×10^{-3}		
45	102	87.5	390	"									
48.5													Shutdown

No. of Bottles in Manifold 20
Pressure in Manifold 2200 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

Pressure after Mixing = 2090 psia
Ppm CO_2 (vol) = $\frac{14.7}{21} \times 2090 = 336$
ppm CO_2 (wt) = ppm(vol) $\cdot \frac{44}{28}$
= 530.

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

BY ________ DATE ________
APPROVED ________ DATE ________
CLIENT ________

SHEET NO. 102 OF ________
SKETCH NO. ________
CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F-9
DATE 8-14-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
15	65	86.7	300	2.6×10^{-3}									
25	66	86.7	300	"									
35							-72	39.7	300	1.3×10^{-2}	72		dropping slowly
40							-98	24.6	270	6.6×10^{-3}	24		steady
45													shut down

No. of Bottles in Manifold 20
Pressure in Manifold 2275 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

Pressure after Mixing = 2180 psia
ppm CO_2 (vol) = 14.7 / 2180 × 21 = 320
ppm CO_2 (wt) = ppm (vol) × 44/28
= 503

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

BY ________ DATE ________
APPROVED ________ DATE ________
CLIENT ________

SHEET NO. 103 OF ________
SKETCH NO. ________
CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F-10
DATE 8-15-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-VOL	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-VOL	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
6	94	87.7	330	2.9×10^{-2}									
15	102	88.7	330	"									
23							-224	253	120	3.0×10^{-3}	5×10^{-3}		Dripping slowly
23.75													Shut down

No. of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia
} as F-9

Pressure after Mixing: ____ psia

ppm CO_2 (vol) = ____ × ____ / ____ = 320

ppm CO_2 (wt) = ppm(vol) × $\frac{44}{28}$

= 503

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Average - Approx Steady State Value

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F 11
DATE 8-17-62

TIME MIN.	RECORDER & VISUAL OBSERVATIONS — IN: T °F	IN: P psia	IN: Conc ① ppm-Vol	IN: p_{CO_2} psia	IN: p_{sat} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-Vol	OUT: p_{CO_2} psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
14	86	87.7	320	2.8×10^{-2}									constant.
22							-240	77.5	12	9.3×10^{-4}	1×10^{-3}		
33							-244	59.5	8	4.8×10^{-4}	5×10^{-4}		
37	87	87.7	320	2.8×10^{-2}									
45.5													Shutdown

No. of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia
} see F-9

Pressure after Mixing: psia

ppm CO_2 (vol) = ___ × ___ / ___ = 320

ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$

= 503

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{sat} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F-12
DATE 8-21-62

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-VOL	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-VOL	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
16	97	87.7	380	2.6×10^{-2}									
20							-271	77.1	13	1.0×10^{-3}	2×10^{-5}		
26	88	87.7	300	"									
39							-271	60	~0	~0			
45	86	86.7	295	"									
51													Shutdown.

(Recorder & Visual Observations)

No. of Bottles in Manifold ~~23~~ 20
Pressure in Manifold 2340 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

Pressure after Mixing: 2215 psia
ppm CO_2 (vol) = 14.7 / 2215 × 21 = 315
ppm CO_2 (wt) = ppm(vol) × 44/28
= 495

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F13
DATE 8-24-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-Vol	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
15	104	87.7	340	3.0×10^{-2}									Spray limited to inlet shut vent.
23	-46	87.7	240	2.1×10^{-2}									
38	-64	87.7	240	"									
45							-234	34.1	30	1.0×10^{-3}	1.8×10^{-3}		
52	-67	93.1	240	2.2×10^{-2}									
53.25													shut down

No. of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia
} see F-12

Pressure after Mixing: ____ psia
ppm CO_2 (vol) = ____ × ____ / ____ = 315
ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$
= 495

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Average - Approx Steady State Value

BY______ DATE______

APPROVED______ DATE______

CLIENT______

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 107 OF ______

SKETCH NO. ______

CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F-14
DATE 8-29-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: Conc ① ppm-vol	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-vol	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
12	98	87.7	290	2.5×10^{-2}									Turned spray on 13.5.
16	92		255	2.2 " "									
22	38		250	2.2 " "									
38	-20		225	2.0 " "									
50	-35		240	2.1 " "									
56	-38		240	"									
57													Shutdown

No. of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia
} as F-13

Pressure after Mixing: psia

ppm CO_2 (vol) = ____ × ____ / ____ = 315

ppm CO_2 (wt) = ppm(vol) × $\frac{44}{28}$

= 495

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Average - Approx Steady State Value

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST F17
DATE 8-31-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
15.5	102		300										
25	101		300										
27.75													Shut down

No. of Bottles in Manifold 20
Pressure in Manifold 2425 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

Pressure after Mixing: 2325 psia
ppm CO_2 (vol) = $\frac{14.7}{2325} \times \frac{21}{1}$ ... = 300
ppm CO_2 (wt) = ppm (vol) $\cdot \frac{44}{28}$
= 475

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

CONFIGURATION TEST SERIES REDUCED DATA

ASD-TDR-63-508, Volume III

TABLE OF CONTENTS

REDUCED DATA FOR FREEZE-OUT CONFIGURATION TEST SERIES

The reduction of the test data for the six tests performed in the configuration test series is completed. Four tests were performed with the 2-inch baffled tube configuration and two tests were performed with the 2-inch spiral tube configuration This information is presented in the following pages of this report. The format follows the pattern established in the Flow and Test Series and consists of the following information for each test.

1. Summary Sheet

The test summary sheets include the nominal test parameters, primary variables investigated and a time sequence of the important events occurring during the test progress.

2. Flow Data

The flow data sheets contain the calculations establishing the air coolant and spray stream flow rates both from the orifice and high pressure manifold data. Generally, the orifice rate is smaller than bottle rate. However, the maximum scatter is plus 3 percent and minus 8 percent for the fourteen stream determinations in the series.

For each test the required stream rates were accurately set up and maintained during the critical portion of the test. Spray stream to air stream flow ratios based upon energy balance in the inlet air confirm the ratios determined from calculated absolute rates. However, coolant to air stream flow ratios similarly determined by an energy balance are out of agreement by as much as 28 percent. This is due in part to the difficulty in estimating the heat leaks to the coolant stream at the inlet and exit of the test heat exchanger.

3. Temperature Data

The air and coolant temperature data sheets include the air and coolant temperatures for each test as a function of time. Temperature differential tabulations have also been prepared in which the individual Δ T's in the heat exchanger air stream as well as the overall coolant Δ T's have been listed versus time.

With the exception of the T-101 indicated temperature in test C-1, the air temperatures in the heat exchanger are reasonably consistent. The coolant temperatures at the inlet and exit to the heat exchanger have been difficult to determine because of the large amount of tube surface between temperature measuring points and the heat exchanger. We have insulated these surfaces as best as we could in tests C-2 through C-6 to render the heat losses negligible.

During the critical time in the test (from water on to wide open vent valve) there appears generally to be a loss in heat transfer as indicated by a reduction in each stream ΔT with time. In tests C-1 and C-2 where there is an increase in the air stream ΔT there is no corresponding increase in the coolant stream temperature. It is to be noted, however, that the entrant and exit coolant line connections contain significant surface area that may tend to mask these small effects.

4. Air Pressure Data

The air stream absolute and differential pressures determined at the quarter points along the heat exchanger have been tabulated versus time for each test. Consistent with previously reported data the location for the high pressure drop corresponds with the regions of maximum water frost formation. The pressure drop in the region of the carbon dioxide frost formation is significantly less than that due to the water formation although the weight percent of CO_2 content of the stream is approximately twice that of the water.

5. Contaminant Data

Carbon dioxide and water concentrations measured at the inlet and exit of test heat exchanger with gas analysers have been tabulated versus time for each test.

Our ability to accurately establish water inlet concentrations has greatly improved in this test series over the Flow and Hydrogen Test Series. The CO_2 infrared analyser is now used as a standard for establishing inlet stream concentrations. Consistent with our previously reported data, the CO_2 in the exit air stream checks usually within a factor of 2 compared with the saturation concentration. Typically the analyser determined concentration of water in the air exit stream is many magnitudes greater than that predicted from the stream temperature. We believe that the water absorption-desorption phenomena taking place in the gas sampling system significantly increases the system response time making it difficult to reach concentrations below 50 ppm.

During the balanced flow runs represented by C-1 and C-5, the water frost formed in the heat exchanger was characteristic of that resulting from mass diffusion. In tests C-2 where nucleation was induced in the air stream up stream of the heat exchanger by liquid nitrogen injection, a frost powder was formed that packed and plugged the first passes of the heat exchanger causing plug-up in 2-1/4 minutes. Low supersaturation were used in C-2. This contrasted significantly with test C-4 where supersaturation ratios an order of magnitude larger resulted in operation of the heat exchanger for approximately 15 minutes. In the latter case we evidently succeeded in obtaining homogeneous nucleation in the air stream that resulted in small particles that are finally entrained only after many heat exchanger passes. Air stream nucleation was also obtained in the unbalanced heat exchanger test (ie, high gas-wall Δ T test) C-6 where both the diffusion and nucleation mechanism were important with regard to water freeze-out.

Test C-3 also an unbalanced flow test resulting in a high coolant-air Δ T at the warm end. However, since the coolant heat transfer coefficients were less than the air-side coefficients (due to the relatively large coolant flow areas in the baffled heat exchanger configuration) the air-wall ΔT was actually quite small. Therefore the performance of C-3 was not markedly different than that of C-1.

The freeze-out of carbon dioxide was characteristic of that produced by mass diffusion mechanism in all tests. In tests C-2 and C-4 where liquid nitrogen injection was used and in tests C-3 and C-6 where high temperature gradients were achieved in the air stream with unbalanced coolant flow, no effects on the CO_2 frost were noted except that as we approached heat exchanger plug-up, the measured CO_2 concentration at the outlet became erratic and generally increased.

6. Energy Balances

Energy balances for the configuration series are completed and presented herein. Corrections have been applied to the coolant stream at the inlet and outlet lines between the heat exchanger and the temperature measuring points (T-108 and T-109) where reasonable estimates could be made. In tests C-2 through C-6 the majority of these lines were insulated and heat leak is negligible. However, in tests C-1, 3, 4, and 6, the computed coolant heat flow rate in the heat exchanger is from 14 to 28 percent greater than the computed heat flow rate from the air stream. This may be due to condensation of the air stream on small areas of the exposed coolant line in the low velocity region of the heat exchanger where the coolant lines are connected and an expansion joint provided.

CONFIGURATION TEST SERIES

TEST PARAMETER SUMMARY

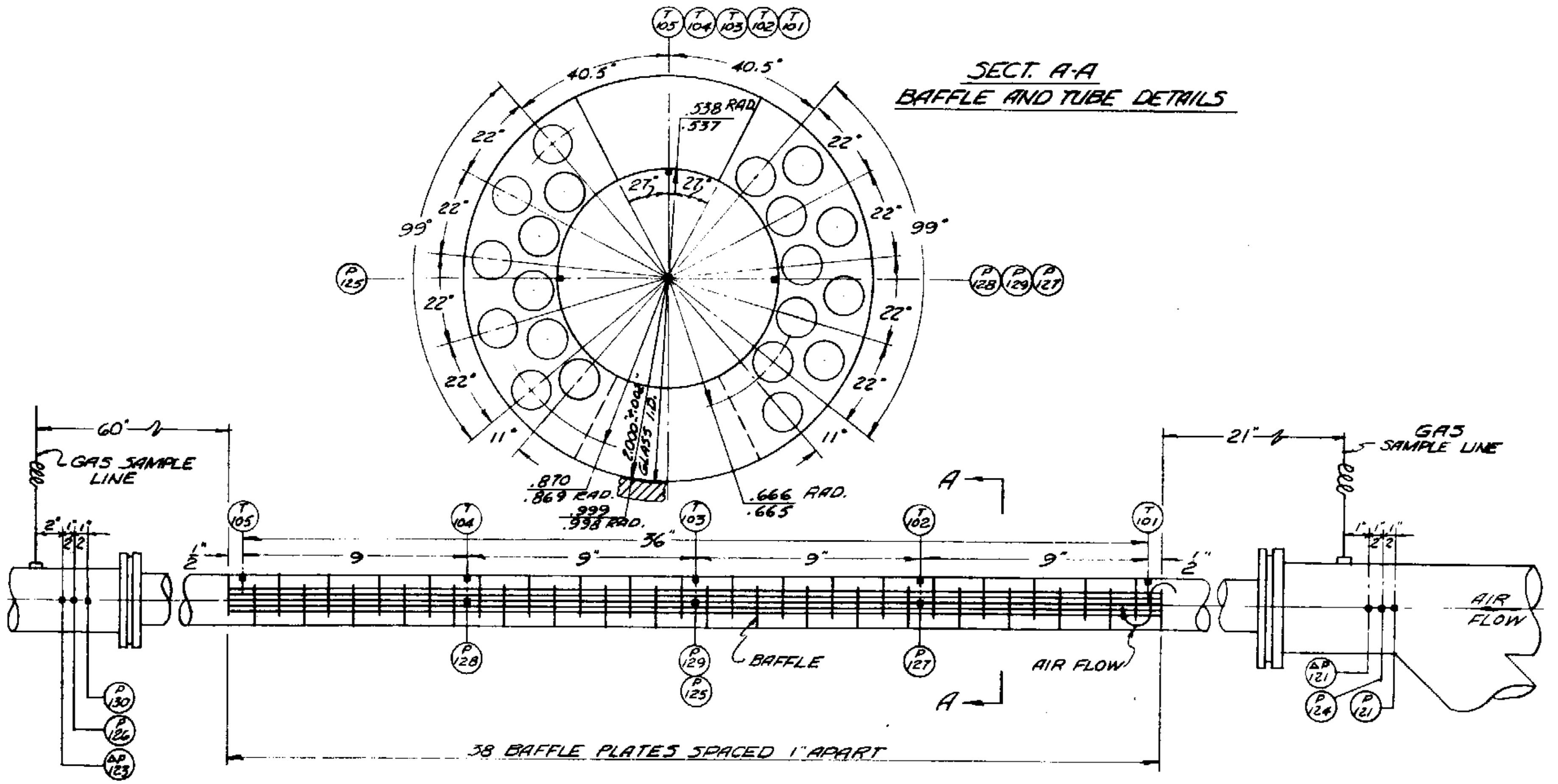
Test			Air				Coolant	Spray	
No.	Date	Configuration	Ga (lb/secFt^2)	Pa (PSIA)	$\%H_2O$	$\%CO_2$	$\frac{(Wc_p)_c}{(Wc_p)_a}$	$\frac{(Wc_p)_s}{(Wc_p)_a}$	Variable Investigated
C-1	9/12/62	4	30	90	.025	.05	1.0	none	Basic staggered tube effect - low ΔT no spray
C-2	10/26/62	4	30	90	.025	.05	1.0	.5	LN_2 spray low Supersaturation
C-3	10/29/62	4	30	90	.025	.05	2.0	none	High air-coolant ΔT (3)
C-4	11/1/62	4	27	90	.025	.05	1.0	.7	LN_2 spray high supersaturation
C-5	11/7/62	2	30	90	.025	.05	1.0	none	Basic configuration tube size effect low ΔT no spray
C-6	11/9/62	2	30	90	.025	.05	20	none	High gas-wall ΔT

NOTES:

1. Nitrogen used for air coolant and spray streams. For coolant and spray streams nitrogen inlet pressure and temperature were approximately 600 psig and - 300°F.

2. All values shown are nominal based on preliminary survey of test data.

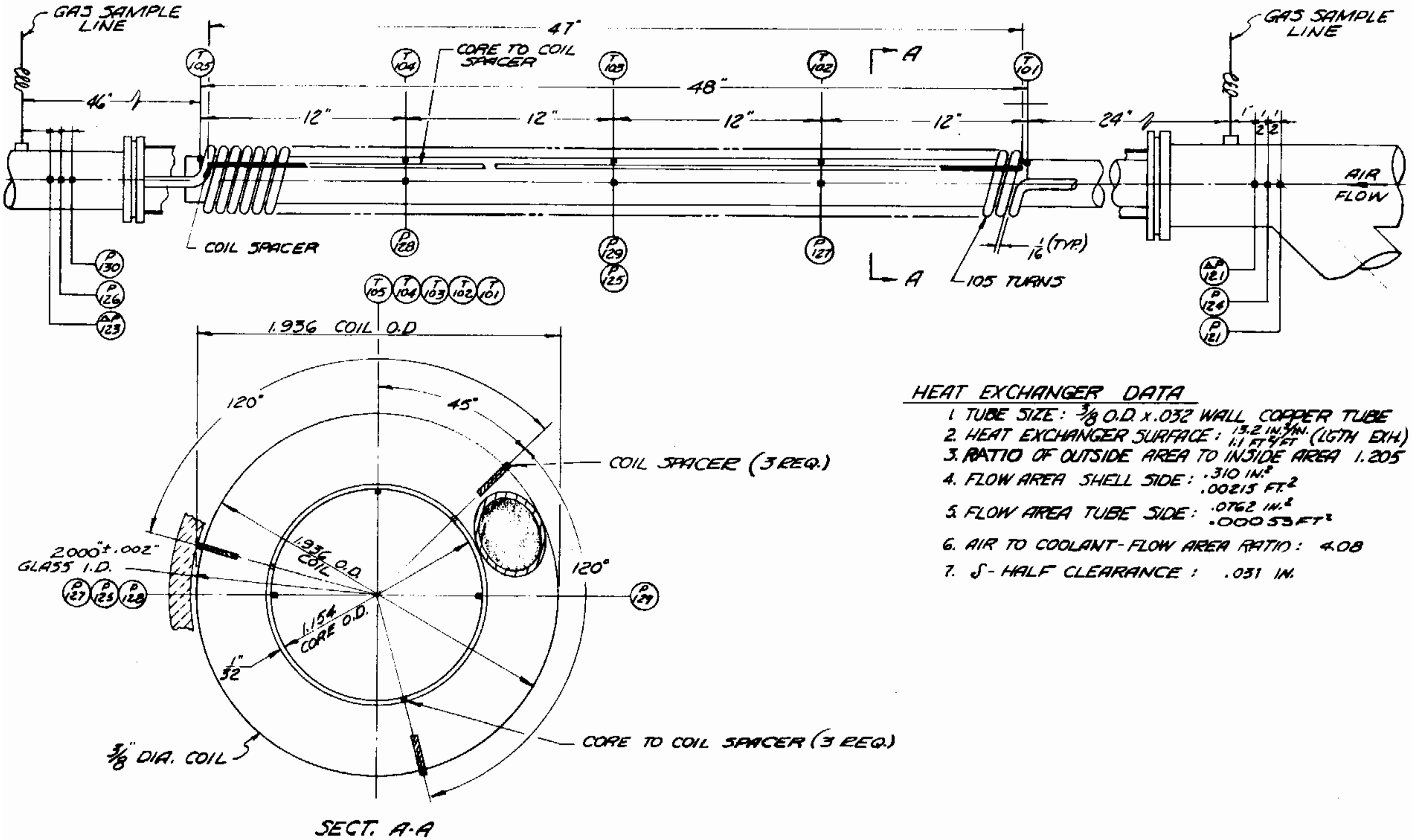
3. Intended as high gas-wall ΔT test. See discussion.



HEAT EXCHANGER DATA

1. TUBE SIZE: 3/16 O.D. X .032 WALL, HARD DRAWN COPPER.
2. TOTAL AIR SIDE SURFACE AREA: 3.0 FT^2
3. RATIO AIR TO COOLANT SURFACE AREA: 1.535
4. AIR SIDE FLOW AREA: .278 $IN.^2$ / .00193 $FT.^2$
5. COOLANT SIDE FLOW: .234 IN^2 / .001625 $FT.^2$
6. AIR TO COOLANT-FLOW AREA RATIO: 1.19
7. δ-HALF CLEARANCE: .035 IN.

TEST HEAT TRANSFER SECTION DETAILS - 2 - INCH BAFFLE CONFIGURATION



TEST HEAT TRANSFER SECTION DETAILS - 2-INCH SPIRAL CONFIGURATION

Test Heat Exchanger Heat Rate Balance

Test No	q_c (Btu/Hr) Calc	Correction	Corrected	q_a Btu/hr	q_c/q_a
C-1	16800	3145	13655	12,010	1.14
C-2	14330	640	13690	12,900	1.06
C-3	20850	850	20,000	15,670	1.28
C-4	11150	750	10400	8,250	1.26
C-5	19490	365	19125	18640	1.03
C-6	24850	900	23,950	20,600	1.16

Heat Exchanger Energy Balance Data

q_a ~ Air-Side Heat Transfer

Test No	θ (MIN)	ω (LB/SEC)	T_1 T-101 (°F)	P_1 P-121 (PSIA)	h_1 (BTU/LB)	T_2 T-105 (°F)	P_2 P-130 (PSIA)	h_2 (BTU/LB)	Δh h_1-h_2 (BTU/LB)	q_a (BTU/SEC)	q_a (BTU/HR)
C-1	40	.0575	79	88	131	-162	39.6	73	58	3.335	12,010
C-2	33½	.0744	-27	90	105	-220	71.5	57	48	3.57	12,900
C-3	41	.0588	36	90	121	-258	48	47	74	4.350	15,670
C-4	35	.0717	-94	90	89	-221	44.8	57	32	2.29	8,250
C-5	27½	.0616	116	90	142	-220	58.5	58	84	5.170	18,640
C-6	25	.0609	96	90	136	-277	56.5	42	94	5.730	20,600

BY M. Kates DATE 12/4/62 ARTHUR D. LITTLE, INC. SHEET NO. 119 OF
APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.
CLIENT ASD/EXPERI CASE NO. 64607

HEAT EXCHANGER ENERGY BALANCE DATA

q_c ~ Coolant-SIDE HEAT TRANSFER

TEST NO	θ (MIN)	ω (LB/SEC)	T_1 T-108 (°F)	P_1 P-147 (PSIA)	h_1 (BTU/LB)	T_2 T-109 (°F)	P_2 P-131 (PSIA)	h_2 (BTU/LB)	Δh h_2-h_1 (BTU/LB)	q_c (BTU/SEC)	q_c (BTU/HR)
C-1	40	.0288	-294	615	-42	48	615	120	162	4.66	16,800
C-2	33½	.0299	-304	625	-46	-72	615	87	133	3.980	14,330
C-3	41	.0562	-311	620	-50	-180	615	53	103	5.79	20,850
C-4	35	.0258	-308	607	-48	-128	605	72	120	3.10	11,150
C-5	27½	.0302	-296	645	-43	105	625	136	179	5.41	19,470
C-6	25	.0622	-315	645	-51	-162	625	60	111	6.90	24,850

BY FER DATE

APPROVED DATE

CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 120 OF

SKETCH NO.

CASE NO. 64607

TEST C-1 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	ω_c/ω_a	ω_s/ω_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
4	90	30	.5	—	.026	.046	SUPER CRITICAL GN_2	5 1/2	9-12-62

VARIABLE INVESTIGATED: LOW ΔT ON STAGGERED TUBE BAFFLED HEAT EXCHANGER

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AND STREAM FLOWS.
1¼	STREAM PRESSURES SET.
18	STABLE TEST HEAT EXCHANGER GRADIENTS.
22	WATER STREAM ON -
40	$\Delta P/\Delta P_o \sim 2$ (?)
46	VENT WIDE OPEN $\Delta P/\Delta P_o = 2.67$
51 1/2	SHUTDOWN

PHOTOGRAPHIC OBSERVATIONS

STILLS - WATER FROST - 14½ - 29½ - IN REGION.
CO_2 FROST - FORMED MAINLY ON COOLANT TUBES AT INLET TO HEAT EXCHANGER.

GENERAL NOTES:

1. COOLANT INLET LINES NOT INSULATED.
2. 2" HEAT EXCHANGER GLASS FAILED AFTER TEST FROM TEMP STRESSES.
3. NO MOTION PICTURES - CAMERA MECHANISM JAMMED.

BY FER DATE ________ ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 121 OF ______
APPROVED ______ DATE ______ SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 64607

TEST C-2 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
4	90	30	.5	.23	.025	.050	SUPERCRITICAL GN_2	37	10-26-62

VARIABLE INVESTIGATED: LN_2 SPRAY
LOW SUPERSATURATION RATIO.

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS AND STREAM FLOW.
19	START SPRAY STREAM FLOW
22	START AIR AND SPRAY STREAM MIXING
29	STABLE TEST HEAT EXCHANGER TEMP GRADIENTS.
31	WATER STREAM ON
33	WATER CONC ON AIR INLET STREAM STARTS TO INCREASE
33½	$\Delta P/\Delta P_o$ = 2 (?)
35	WATER CONC ON AIR INLET STREAM @ 97% OF MAX
35¼	VENT VALVE WIDE OPEN, $\Delta P/\Delta P_o$ = 3
37	SHUTDOWN

(2¼ MIN — from 33 to 35¼)

PHOTOGRAPHIC OBSERVATIONS

STILLS: H_2O FROST POWDER PACKED INTO REGION 1-3-IN OF HX
CO_2 FROST - (MASS DIFFUSION TYPE) 32-37 IN REGION

GENERAL NOTES:

1. VACUUM INSULATED SINGLE COOLANT INLET LINE AND FOAM INSULATED HEADER TUBES.

BY PER DATE ARTHUR D. LITTLE, INC. SHEET NO. 122 OF
APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.
CLIENT ASD / EXPERI CASE NO. 64607

TEST C-3 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
4	90	30	1.0	—	.025	.05	SUPER-CRITICAL GN_2	56½	10-29-62

VARIABLE INVESTIGATED: HIGH ΔT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS AND GAS STREAMS.
19	STABLE TEST HEAT EXCHANGER TEMP GRADIENT.
20	WATER STREAM ON.
22	H_2O CONC. IN AIR INLET STARTS TO INCREASE. (ANALYSER INFO)
24½	✓ ✓ ✓ ✓ ✓ @ 95% OF MAX. ✓
40	$\Delta P/\Delta P_0 = 2.0$ (?)
≈ 47	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0 \approx 3.5$
56½	SHUTDOWN

(Margin: 2 ↑ between 22 and 24½; $\sqrt{2}$ ↓ from 24½ to 47)

PHOTOGRAPHIC OBSERVATIONS

OBSERVATIONS: – AT t = 36½ NOTICED FLAKING FROST DEPOSIT AT 6"
STILL PHOTOS: H_2O – DIFFUSION TYPE FROST – 0-6" REGION
✓ PARTICLE NUCLEATION – 6-12" ✓
CO_2 – DIFFUSION TYPE FROST – 19-37" ✓

GENERAL NOTES:

1. LARGE LEAK DISCOVERED AT T-109 FITTING AT t = 34 MIN. THIS HAS NO ADVERSE EFFECT ON TEST.
2. COOLANT INLET LINES INSULATED AS FOR C-2

BY FER DATE ______ ARTHUR D. LITTLE, INC. SHEET NO. 123 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 64607

TEST C-4 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
4	90	27	.50		.025	.050	SUPER CRITICAL GN_2	45 3/4	11-1-62

VARIABLE INVESTIGATED: LN_2 SPRAY
HIGH SUPERSATURATION RATIO.

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR, AND COOLANT STREAMS.
8 1/2	PRELIMINARY TEMP GRADIENTS ESTAB IN HEAT EX
10 1/2	SPRAY STREAM MIXING WITH AIR STREAM.
29	STABLE TEST HEAT EXCHANGER GRADIENTS.
30	WATER STREAM ON
45 3/4	SHUTDOWN

(margin: ~2 MIN)

PHOTOGRAPHIC OBSERVATIONS

OBSERVATIONS: HEAVY PLUGGING W/ FROST POWDER 1-3" REGION
✓ CHALK LIKE DEPOSIT ALL THRU HX
✓ FROST BAND ON 2" GLASS (INSIDE) 26 1/2" TO 29 1/2"
PHOTO STILLS: SAME AS ABOVE
CO_2 FROST - DIFFUSION TYPE - 21 - 37" REGION

GENERAL NOTES:

1. COOLANT INLET LINES INSULATED AS IN TEST C-2
2. PR-132 OPERATION ERRATIC - NOT USED DURING TEST.

TEST C-5 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
2	90	30	.49	—	.025	.048	SUPER-CRITICAL GN_2	39½	11-7-62

VARIABLE INVESTIGATED: TUBE SIZE
LOW ΔT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START RECORDERS, CLOCK, AIR AND COOLANT STREAMS.
10	START TEST HX TEMP GRADIENT
11	WATER STREAM ON
11½	H_2O CONC IN AIR INLET STREAM STARTS TO INCREASE
13½	H_2O " " " " " AT 95% OF MAX.
21½	$\Delta P/\Delta P_0$ = 2.0
37½	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0$ = 7.8
39½	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

STILLS: H_2O FROST (DIFFUSION TYPE) 18 - 35" REGION
FLAKING 27 - 35" REGION
CO_2 FROST (DIFFUSION TYPE) 38 - 47" "

GENERAL NOTES:

1. COOLANT INLET LINE VACUUM INSULATED.
2. INITIAL TEST ABORTED AFTER 28 MIN BECAUSE OF OF LOSS OF COOLANT LN_2 FLOW

BY FER DATE
APPROVED DATE
CLIENT ASD /EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO 125 OF
SKETCH NO.
CASE NO. 64607

TEST C-6 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
2	90	30	1.0	—	.025	.05	SUPER-CRITICAL GN_2	39	11-9-62

VARIABLE INVESTIGATED: TUBE SIZE
HIGH ΔT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAMS.
8	STABLE TEST HX TEMP. GRADIENTS
9	WATER STREAM ON
10¾	H_2O CONC. AIR STREAM STARTS TO INCREASE.
12¾	✓ ✓ ✓ ✓ ✓ AT 95% OF MAX
15	$\Delta P/\Delta P_0$ = 2.0
33½	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0$ = 13.4
39	SHUTDOWN.

2 MIN (margin note beside 10¾–12¾)

PHOTOGRAPHIC OBSERVATIONS

STILL PHOTOS H_2O – DIFFUSION FROST 0 – 3½" REGION
✓ PATCH & POSSIBLE FLAKING 3½ – 6" ✓
✓ NUCLEATION - COATING INSIDE GLASS 6" – 12" ✓
CO_2 – DIFFUSION FROST 13 – 45 ✓
✓ PATCH & POSSIBLE FLAKING 45 – 47 ✓
INCREASES THROUGHOUT RUN TO 32 – 47 ✓

GENERAL NOTES

1. COOLANT INLET LINE VACUUM INSULATED –

TEST C-1 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_O = W_* F_P F_{PR} F_T$

$F_P = P_1 / 1000$
$W_* = f$ (A orifice)
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_O LB/SEC	$\bar{W}_O$ LB/SEC
T_1 = T-113	AIR	10	665	90	.135	5.92	53	1.015	1.0	.0855	.0576	
	ORIFICE NO. 7	28	665	90	✓	6.0	56	1.012	✓	✓	.0575	.0575
	NOM DIA: .076	49	665	90	✓	6.13	62	1.008	✓	✓	.0574	
T_1 = T-117	COOLANT	10	925	625	.675	6.2	66	1.002	.77	.0399	.0284	
	ORIFICE NO. 5	28	925	615	.665	6.15	63	1.007	.78	✓	.0290	.0288
	NOM DIA: .052	49	925	615	.665	6.22	66	1.002	.78	✓	.0288	

B. BOTTLE DATA

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 36.8 FT³	V_B = 35.1 FT³
@ θ = 10 MIN, P_{B1} = 2045 PSIA	@ θ = 10 MIN, P_{B1} = 1800 PSIA
@ θ = 46 MIN, P_{B2} = 1305 PSIA	@ θ = 46 MIN P_{B2} = 1400 PSIA
$\bar{T}_B$ = 76 °F = 536 °R	$\bar{T}_B$ = 76 °F 536 °R
Z_1 = 1.024 ; Z_2 = 1.004	Z_1 = 1.015 ; Z_2 = 1.006
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 700 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 385 PSI
ΔM_B = 125 LB, Δθ = 2160 SEC	ΔM_B = 65.5 LB, Δθ = 2160 SEC
$\bar{W}_B$ = .0578 LB/SEC	$\bar{W}_B$ = .0304 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_O/\bar{W}_B$	BEST ESTIMATE
AIR	.0575	.0578	.992	.0575
COOLANT	.0288	.0304	.945	.0288

BY M. Kates DATE 11/8/62 ARTHUR D. LITTLE, INC. SHEET NO. 127 OF
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD/ELPERL CASE NO. 64607

TEST C-2 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{FLUID})$
$W_* = f(A_{\text{ORIFICE}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	11	665	75	.1125	5.09	14	1.057	1.000	.0850	.0621	
	ORIFICE NO. 7	18	✓	✓	✓	5.11	15	1.056	✓	✓	✓	.0620
		32½	✓	✓	✓	5.21	20	1.051	✓	✓	.0619	
	NOM DIA: .076"	35	✓	92	.138	5.23	✓	✓	.999	✓	✓	
T_1 = T-117	COOLANT	11	925	675	.730	5.26	22	1.05	.713	.0399	.0276	
	ORIFICE NO. 5	18	✓	625	.676	5.23	20	1.051	.770	✓	.0296	
		32½	✓	✓	✓	5.26	22	1.050	✓	✓	✓	.0299
	NOM DIA: .052"	35	✓	615	.665	✓	✓	✓	.780	✓	.0302	

B. BOTTLE DATA

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \frac{\text{FT}^3}{\text{°F IN}^2}$

AIR	COOLANT
V_B = 36.8 FT³	V_B = 35.1 FT³
@ θ = 11 MIN, P_{B1} = 1875 PSIA	@ θ = 11 MIN, P_{B1} = 2005 PSIA
@ θ = 35 MIN, P_{B2} = 1405 PSIA	@ θ = 35 MIN P_{B2} = 1750 PSIA
$\bar{T}_B$ = 36 °F 496 °R	$\bar{T}_B$ = 36° °F 496 °R
Z_1 = 1.014 ; Z_2 = 1.002	Z_1 = 1.018 ; Z_2 = 1.011
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 447 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 241 PSI
ΔM_B = 86.6 LB ; Δθ = 1440 SEC	ΔM_B = 44.5 LB , Δθ = 1440 SEC
$\bar{W}_B$ = .0574 LB/SEC	$\bar{W}_B$ = .0309 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0620	.0602	1.033	.0620
COOLANT	.0299	.0309	.968	.0299

TEST C-2 [redacted] Spray Flow FLOW

A. ORIFICE DATA

$W_O = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{LIQUID})$
$W_* = f(A_{\text{ORIFICE}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" S.C. BURKE 8/20/62 FOR DETAILS

STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113: Spray, ORIFICE NO. 4, NOM. DIA: .040	32½	855	700	.819	5.92	53	1.016	.600	.0238	.0123	.0124
	35	857	✓	.816	✓	✓	✓	.603	✓	.0125	
T_1 = T-117: COOLANT, ORIFICE NO., NOM DIA:											

B. BOTTLE DATA

$V_B = 1.75N$ (FT³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

Spray	COOLANT
V_B = 7.0 FT³	V_B = FT³
@θ = 11 MIN, P_{B1} = 2250 PSIA	@θ = MIN, P_{B1} = PSIA
@θ = 35 MIN, P_{B2} = 1675 PSIA	@θ = MIN, P_{B2} = PSIA
$\bar{T}_B$ = 74 °F 534°R	$\bar{T}_B$ = °F
Z_1 = 1.028 ; Z_2 = 1.008	Z_1 = ; Z_2 =
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 527 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = PSI
ΔM_B = 18.05 LB ; Δθ = 1440 SEC	ΔM_B = LB, Δθ = SEC
$\bar{W}_B$ = .01251 LB/SEC	$\bar{W}_B$ = LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_O/\bar{W}_B$	BEST ESTIMATE
Spray [redacted]	.0124	.01251	.992	.0124
COOLANT				

BY M. Kutes DATE 11/19/62 ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 629 OF

APPROVED ___ DATE ___ SKETCH NO. ___

CLIENT ASD / EXPERI CASE NO. 64607

TEST C-3 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_0 = W_* F_P F_{PR} F_T$

$F_P = P_1 / 1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" S.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_0 LB/SEC	$\bar{W}_0$ LB/SEC
T_1 = T-113	AIR	10	520	90	.173	5.35	26	1.045	.994	.1098	.0593	
	ORIFICE NO. 8	26	✓	✓	✓	5.44	30	1.040	✓	✓	.0590	.0588
	NOM DIA:	41	✓	✓	✓	5.52	34	1.036	✓	✓	.0587	
	.086"	55	✓	111	.2135	5.62	39	1.030	.989	✓	.0581	
T_1 = T-117	COOLANT	10	870	620	.713	5.41	29	1.041	.732	.855	.0567	
	ORIFICE NO. 7	26	✓	✓	✓	5.50	34	1.036	✓	✓	.0565	.0562
	NOM DIA:	41	✓	✓	✓	5.59	38	1.031	✓	✓	.0563	
	.076"	55	✓	625	.719	5.68	42	1.027	.725	✓	.0554	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 36.8 FT³	V_B = 35.1 FT³
@ θ = 10 MIN, P_{B1} = 1570 PSIA	@ θ = 10 MIN, P_{B1} = 1885 PSIA
@ θ = 55 MIN, P_{B2} = 735 PSIA	@ θ = 55 MIN, P_{B2} = 1005 PSIA
$\bar{T}_B$ = 41° °F 501 °R	$\bar{T}_B$ = 41 °F 501 °R
Z_1 = .991 ; Z_2 = .984	Z_1 = 1.000 ; Z_2 = .994
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 839 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 875 PSI
ΔM_B = 160 LB, Δθ = 2700 SEC	ΔM_B = 160 LB, Δθ = 2700 SEC
$\bar{W}_B$ = .0594 LB/SEC	$\bar{W}_B$ = .0593 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_0/\bar{W}_B$	BEST ESTIMATE
AIR	.0588	.0594	.990	.0588
COOLANT	.0562	.0593	.950	.0562

TEST C-4 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_0 = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$; $F_K = f(\text{FLUID})$; $W_* = f(\text{ORIFICE})$; $F_{PR} = f(P_2/P_1)$; $F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BUEKE 8/20/62 FOR DETAILS.

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_0 LB/SEC	$\bar{W}_0$ LB/SEC
T_1 = T-113	AIR	8½	600	90	.150	5.40	29	1.041	.998	.855	.0533	
	ORIFICE NO. 7	22	✓	✓	✓	5.45	31	1.039	✓	✓	.0531	.0531
		29	✓	✓	✓	5.49	33	1.037	✓	✓	.0530	
	NOM DIA: .076"	44½	✓	✓	✓	5.55	36	1.033	✓	✓	.0529	
T_1 = T-117	COOLANT	8½	870	630	.724	6.12	62	1.007	.720	.0399	.0252	
	ORIFICE NO. 5	22	✓	625	.718	5.55	36	1.033	.728	✓	.0261	.0258
		29	✓	618	.711	✓	✓	✓	.731	✓	.0262	
	NOM DIA: .052"	44½	✓	630	.724	✓	✓	✓	.720	✓	.0258	

B. BOTTLE DATA

$V_B = 1.75N + .1 \ (FT^3)$

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \ \frac{FT^3}{°R \ IN^2}$

AIR	COOLANT
V_B = 36.8 FT³	V_B = 30.1 FT³
@ θ = 8½ MIN, P_{B1} = 2065 PSIA	@ θ = 8½ MIN, P_{B1} = 2185 PSIA
@ θ = 44½ MIN, P_{B2} = 1415 PSIA	@ θ = 38½ MIN P_{B2} = 1880 PSIA
$\bar{T}_B$ = 41 °F or 508 °R	$\bar{T}_B$ = 48 °F or 508 °R
Z_1 = 1.014 ; Z_2 = .994	Z_1 = 1.018 ; Z_2 = 1.006
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 610 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 255 PSI
ΔM_B = 115.3 LB ; Δθ = 2160 SEC	ΔM_B = 4.61 LB , Δθ = 1800 SEC
$\bar{W}_B$ = .0509 LB/SEC	$\bar{W}_B$ = .0256 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_0/\bar{W}_B$	BEST ESTIMATE
AIR	.0531	.0534	.994	.0531
COOLANT	.0258	.0256	1.010	.0258

TEST C-4 ~~[illegible]~~ Spray Flow FLOW

A. ORIFICE DATA

$W_O = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$; $F_K = f$(fluid); $W_* = f(A_{orifice})$; $F_{PR} = f(P_2/P_1)$; $F_T = f(T_1)$ } SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" D.C. BURKE 8/20/62 FOR DETAILS

STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_O LB/SEC	$\bar{W}_O$ LB/SEC
~~T_1 = T-113; Spray ~~AIR~~; ORIFICE NO. 4; NOM DIA: .040"~~	~~1~~	~~1065~~	~~615~~	~~.576~~	~~6.40~~	~~74~~	~~.995~~	~~.980~~	~~.0238~~	~~.0225~~	
	~~21~~	~~✓~~								~~✓~~	
T_1 = T-117; Spray ~~COOLANT~~; ORIFICE NO. 4; NOM DIA: .040"	35	965	615	.636	6.10	61	1.009	.803	.0238	.0186	.0186
	35½	✓	✓	✓	6.10	✓	✓	✓	✓	✓	
	42	✓	✓	✓	6.12	62	1.007	✓	✓	✓	
	44½	✓	✓	✓	6.13	✓	✓	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N$ (FT³)

$\Delta m_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

~~AIR~~ Spray (8½ – 29)	~~COOLANT~~ Spray (35 – 44½)
~~V_B = 7 FT³~~	V_B = FT³
~~@ θ = 8½ MIN, P_{B1} = 2425 PSIA~~	@ θ = 35 MIN, P_{B1} = 1270 PSIA
~~@ θ = 29 MIN, P_{B2} = 1530 PSIA~~	@ θ = 44½ MIN P_{B2} = 945 PSIA
~~$\bar{T}_B$ = 74 °F 534°R~~	$\bar{T}_B$ = 74 °F 534°R
~~Z_1 = 1.037 ; Z_2 = 1.005~~	Z_1 = .998 ; Z_2 = .997
~~$P_{B1}/Z_1 - P_{B2}/Z_2$ = 820 PSI~~	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 333 PSI
~~Δm_B = 28.0 LB; Δθ = 1230 SEC~~	Δm_B = 11.4 LB, Δθ = 570 SEC
~~$\bar{W}_B$ = .0228 LB/SEC~~	$\bar{W}_B$ = .0200 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_O/\bar{W}_B$	BEST ESTIMATE
~~Spray AIR~~				
Spray ~~COOLANT~~	.0186	.0200	.93	.0186

BY M. Kates DATE 11/19/62 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 132 OF ______
APPROVED ______ DATE ______ — SKETCH NO. ______
CLIENT ASD / EXPERI — CASE NO. 64607

Test C-5 Air and Coolant Flow

Aborted

A. Orifice Data

$W_0 = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

See ADL calculations "Orifice Flow Calculations" J.C. Burke 8/20/62 for details

	Stream	θ (min)	P_1 (psia)	P_2 (psia)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_t	F_{PR}	W_* (lb/sec)	W_0 lb/sec	$\bar{W}_0$ lb/sec
T_1 = T-113	Air	10	705	90	.1277	5.57	37	1.082	1.000	.0855	.0622	
	Orifice No. 7	15	✓	✓	✓	✓	✓	✓	✓	✓	✓	.0622
		20	✓	✓	✓	5.60	38	1.081	✓	✓	✓	
	Nom Dia: .076"	25	✓	✓	✓	5.61	✓	✓	✓	✓	✓	
T_1 = T-117	Coolant	10	950	645	.680	5.71	43	1.026	.767	.0399	.0285	
	Orifice No. 5	15	✓	640	.675	5.70	42	1.027	.770	✓	.0290	.0289
		20	✓	645	.680	5.69	✓	✓	.767	✓	✓	
	Nom Dia: .052"	25	✓	✓	✓	5.68	✓	✓	✓	✓	✓	

B. Bottle Data

$V_B = 1.75N + .1 \ (FT^3)$

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \ \frac{FT^3}{°F \ IN^2}$

Air	Coolant
V_B = 35.1 FT3	V_B = 35.1 FT3
@ θ = 10 min, P_{B1} = 2115 PSIA	@ θ = 10 min, P_{B1} = 2190 PSIA
@ θ = 25 min, P_{B2} = 1725 PSIA	@ θ = 25 min, P_{B2} = 2005 PSIA
$\bar{T}_B$ = 52 °F or 512 °R (outside; inside = 72 °F)	$\bar{T}_B$ = 52 °F or 512 °R (outside; inside = 72 °F)
Z_1 = 1.014 ; Z_2 = 1.002	Z_1 = 1.018 ; Z_2 = 1.012
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 365 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 165 PSI
ΔM_B = 65.4 LB, Δθ = 900 SEC	ΔM_B = 29.5 LB, Δθ = 900 SEC
$\bar{W}_B$ = .0726 LB/SEC	$\bar{W}_B$ = .0329 LB/SEC

Flow	Orifice	Bottles	$\bar{W}_0/\bar{W}_B$	Best Estimate
Air	.0622	.0726	.856	.0622
Coolant	.0289	.0329	.878	.0289

BY M. Kates DATE 11/19/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 133 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / ELPERI | CASE NO. 64607

Test C-5 Air and Coolant Flow

A. Orifice Data

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1 / 1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

See ADL calculations "Orifice Flow Calculations" J.C. Burke 8/20/62 for details.

	Stream	θ (min)	P_1 (psia)	P_2 (psia)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_f	F_{PR}	W_* (lb/sec)	W_o lb/sec	$\bar{W}_o$ lb/sec
T_1 = T-113	Air, Orifice No. 7, Nom. Dia: .076"	10	705	90	.1275	5.69	42	1.027	1.000	.0855	.0617	
		20	✓	✓	✓	5.75	45	1.024	✓	✓	✓	
		30	✓	✓	✓	5.80	47	1.022	✓	✓	.0615	.0616
		38½	✓	95	.1348	5.85	50	1.020	✓	✓	✓	
T_1 = T-117	Coolant, Orifice No. 5, Nom. Dia: .052"	10	950	640	.674	5.68	42	1.027	.771	.0399	.0300	
		20	✓	635	.669	5.71	43	✓	.777	✓	.0303	.0302
		30	✓	640	.674	5.70	42	✓	.771	✓	.0300	
		38½	✓	635	.669	✓	✓	✓	.777	✓	.0303	

B. Bottle Data

$V_B = 1.75N + .1 \; (ft^3)$

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $\qquad R = .383 \frac{ft^3}{°F \, in^2}$

Air	Coolant
V_B = 36.8 ft³	V_B = 35.1 ft³
@ θ = 10 min, P_{B1} = 1395 psia	@ θ = 10 min, P_{B1} = 1870 psia
@ θ = 34 min, P_{B2} = 910 psia	@ θ = 38½ min, P_{B2} = 1560 psia
$\bar{T}_B$ = 47 °F or 507 °R	$\bar{T}_B$ = 47 °F or 507 °R
Z_1 = .992 ; Z_2 = .989	Z_1 = 1.003 ; Z_2 = .996
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 485 psi	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 295 psi
ΔM_B = 92.0 lb, Δθ = 1440 sec	ΔM_B = 53.4 lb, Δθ = 1710 sec
$\bar{W}_B$ = . lb/sec	$\bar{W}_B$ = .0312 lb/sec

Flow	Orifice	Bottles	$\bar{W}_o/\bar{W}_B$	Best Estimate
Air	.0616	.0640	.965	.0616
Coolant	.0302	.0312	.968	.0302

TEST C-6 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	550	90	.1635	5.85	50	1.020	.995	.1098	.0613	
	ORIFICE NO. 8	20	✓	✓	✓	5.91	52	1.017	✓	✓	.0610	.0609
		30	✓	✓	✓	5.99	56	1.013	✓	✓	.0607	
	NOM DIA: .086"	38	✓	107.5	.1955	6.00	✓	✓	.990	✓	.0605	
T_1 = T-117	COOLANT	10	940	640	.682	5.79	47	1.022	.764	.0855	.0626	
	ORIFICE NO. 7	20	✓	645	.686	5.84	49	1.020	.760	✓	.0623	.0622
		30	✓	✓	✓	5.88	51	1.018	✓	✓	.0620	
	NOM DIA: .076"	38	✓	✓	✓	5.89	52	1.017	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \; \frac{FT^3}{°F \; IN^2}$

AIR	COOLANT
V_B = 36.8 FT³	V_B = 35.1 FT³
@ θ = 15 MIN, P_{B1} = 1275 PSIA	@ θ = 15 MIN, P_{B1} = 1995 PSIA
@ θ = 30½ MIN, P_{B2} = 915 PSIA	@ θ = 30½ MIN, P_{B2} = 1575 PSIA
$\bar{T}_B$ = 58° OF 518°R	$\bar{T}_B$ = 58° OF 518°R
Z_1 = .994 ; Z_2 = .992	Z_1 = 1.012 ; Z_2 = 1.001
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 363 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 402 PSI
ΔM_B = 67.5 LB, $\Delta\theta$ = 1050 SEC	ΔM_B = 71.2 LB, $\Delta\theta$ = 1050 SEC
$\bar{W}_B$ = .0642 LB/SEC	$\bar{W}_B$ = .0676 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0609	.0642	.948	.0609
COOLANT	.0622	.0676	.920	.0622

BY M. Kates DATE 9/15/62 **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. SHEET NO. 135 OF ____

APPROVED ____ DATE ____ SKETCH NO. ____

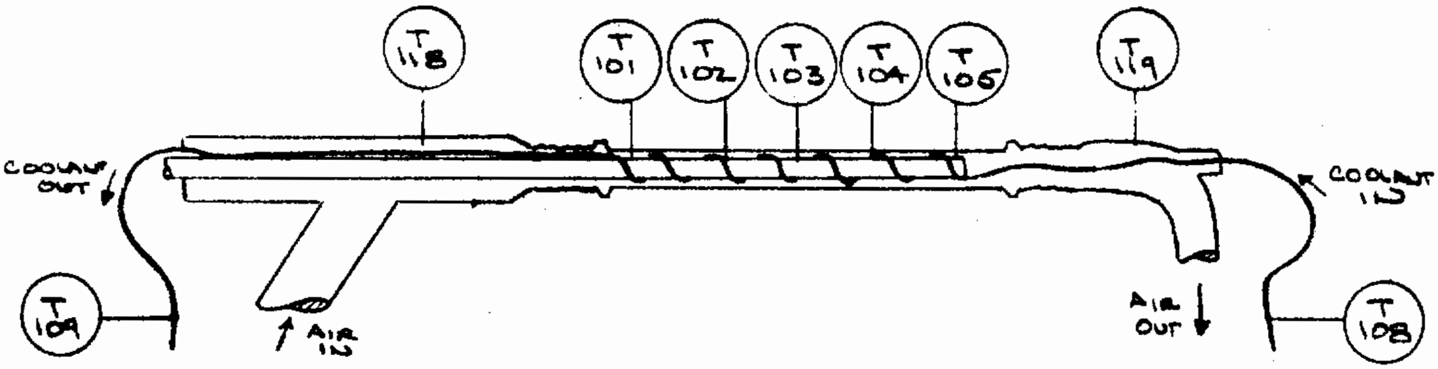
CLIENT ASD / EXPERI CASE NO. 64607

TEST C-1

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR				COOLANT			
											IN		OUT		IN		OUT	
	T-101 1,9		T-102 2,10		T-103 3,11		T-104 4,12		T-105 5,13		T-118 8		T-119 16		T-108 6,14		T-109 7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
1 1/2	6.65	86	6.61	84	6.51	79	6.39	74	6.19	65	6.69	87	6.48	78	1.72	-174	6.51	79
3	6.75	90	6.71	88	6.29	70	5.87	50	5.30	24	6.75	90	5.55	36	2.21	-142	✓	✓
5	6.81	92	6.79	92	6.20	66	5.69	42	4.95	8	6.81	92	4.88	4	1.15	-216	6.55	81
7	6.85	94	6.80	✓	5.96	54	5.19	19	4.30	-25	6.89	96	4.21	-30	1.05	-224	✓	✓
10	6.90	96	6.89	96	6.25	68	5.41	29	4.15	-32	6.91	97	3.67	-58	0.49	-271	6.51	79
13	6.87	95	6.85	94	5.85	50	4.72	-4	3.09	-36	6.95	98	3.02	-94	0.25	-294	6.46	77
16	6.65	86	6.57	83	5.19	19	3.77	-52	2.27	-138	6.92	97	2.59	-119	✓	✓	6.20	66
21	6.59	83	6.55	81	4.99	9	3.50	-67	2.02	-154	6.95	98	2.29	-138	✓	✓	5.95	54
2[illegible]	6.51	79	6.49	78	4.97	8	3.49	-68	2.06	-152	6.92	97	2.19	-144	✓	✓	5.90	52
34	6.54	80	✓	✓	4.85	2	3.35	-75	1.99	-156	6.91	98	2.15	-146	✓	✓	5.85	50
40	6.51	79	✓	✓	✓	✓	3.30	-78	1.92	-162	✓	✓	✓	✓	✓	✓	5.82	48
43	6.49	78	6.45	76	4.79	0	3.25	-80	1.90	✓	6.95	98	2.11	-148	✓	✓	5.81	✓
46	6.51	79	✓	✓	✓	✓	3.21	-83	1.85	-166	✓	✓	✓	✓	✓	✓	✓	✓
49	6.49	78	6.41	75	4.75	-2	3.19	-84	✓	✓	✓	✓	2.09	-150	✓	✓	5.80	47
51 1/2	6.51	79	6.50	79	4.71	-4	3.15	-86	1.80	-170	6.97	99	✓	✓	✓	✓	✓	✓

H_2O DATA (21 to 46 min)

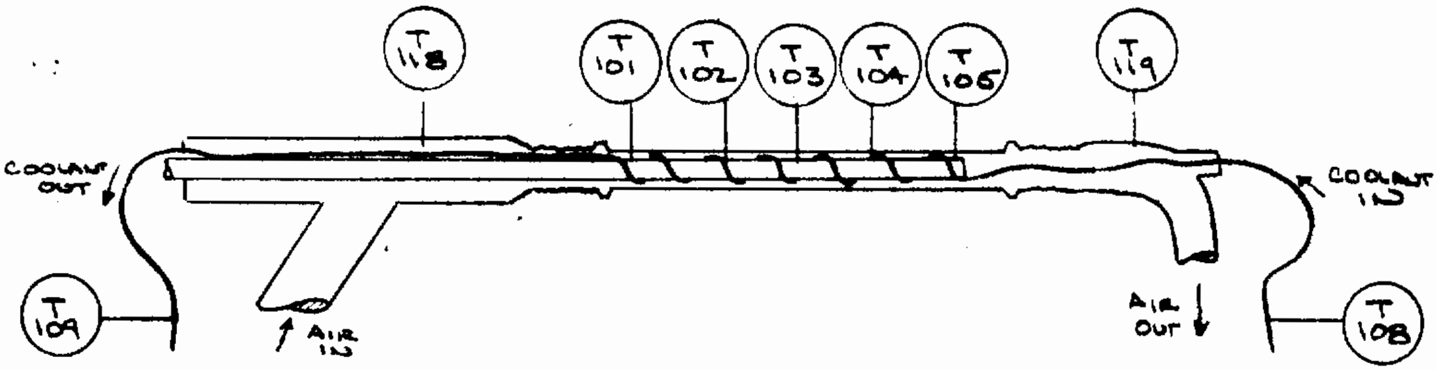


NOTES:

TEST C-2

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	1, 9		2, 10		3, 11		4, 12		5, 13		8		16		6, 14		7, 15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.38	74	6.33	71	6.23	67	6.02	57	5.64	40	6.60	83	6.60	83	3.08	-90	6.41	75
2	6.42	75	6.11	62	5.71	43	5.09	14	4.41	-20	6.55	81	5.49	33	1.75	-172	6.31	70
4	6.48	78	6.17	65	5.78	46	5.13	16	4.43	-18	✓	✓	5.07	13	1.71	-176	6.15	64
6	6.45	76	5.99	56	5.40	29	4.49	-16	3.44	-70	✓	✓	4.43	-18	1.05	-224	6.11	62
8	6.41	75	5.85	50	5.19	19	4.18	-31	3.05	-92	6.52	80	3.89	-46	1.01	-226	6.01	57
11	✓	✓	6.01	57	5.42	30	4.41	-20	2.89	-102	6.53	✓	3.51	-66	0.39	-280	5.90	52
14	6.40	74	5.59	38	4.69	-6	3.24	-82	1.97	-158	✓	✓	2.90	-100	0.18	-301	5.79	47
16	6.32	71	5.30	24	4.19	-30	2.65	-118	1.58	-184	✓	✓	2.51	-124	✓	✓	5.41	29
18	6.24	67	5.21	20	4.09	-36	2.57	-124	1.50	-190	✓	✓	2.35	-134	✓	✓	5.19	19
22	✓	✓	5.19	19	4.05	-38	2.50	✓	1.47	-192	6.25	68	2.15	-146	✓	✓	5.01	10
26½	4.24	-28	3.65	-58	2.91	-100	1.92	-162	1.28	-206	5.81	66	2.00	-156	0.17	-302	3.89	-46
32½	4.26	-27	3.50	-67	2.63	-116	1.68	-178	1.10	-220	4.91	6	1.77	-172	0.15	-304	3.41	-72
35	4.20	-30	3.51	-66	2.71	-112	1.76	-172	1.14	-216	4.87	4	1.84	-166	✓	✓	3.36	-74
37	4.15	-32	3.46	-69	2.65	-116	1.75	✓	1.11	-218	4.85	2	1.84	✓	✓	✓	3.29	-78



NOTES:

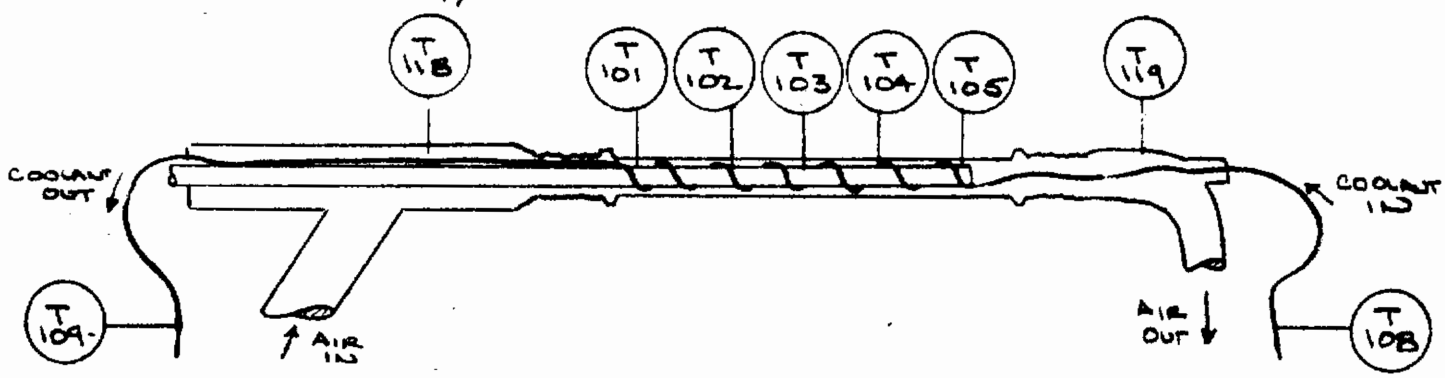
1. TR-112 RECORDER PRINT KEY PER TEST C-1 CHART

BY M. Kates DATE 11/21/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 137 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 64607

TEST C-3

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	1,9		2,10		3,11		4,12		5,13		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
1½	6.41	75	5.51	34	4.88	4	4.09	-36	3.52	-66	6.58	82	5.22	20	1.95	-160	5.87	50
5	6.47	78	5.11	15	4.05	-38	2.94	-98	2.17	-144	6.71	88	3.49	-68	1.04	-224	5.22	20
10	6.37	73	4.77	-2	3.56	-64	2.43	-128	1.71	-176	6.79	92	2.69	-56	✓	✓	4.50	-15
15	6.13	62	3.54	-64	2.00	-156	1.21	-212	0.85	-240	6.78	91	2.06	-152	0.09	-310	3.57	-58
21	5.62	39	2.39	-132	1.39	-198	0.85	-240	0.57	-264	6.69	87	1.61	-182	✓	✓	1.93	-160
26	5.61	38	2.83	-104	1.59	-184	0.98	-229	0.63	-258	6.65	86	1.56	-186	✓	✓	1.81	-168
30	✓	✓	2.88	-102	1.61	-182	0.99	-228	0.65	-256	6.61	85	1.53	-188	✓	✓	1.73	-174
33	5.59	✓	2.89	✓	✓	✓	✓	✓	✓	✓	✓	✓	1.51	-190	0.08	-311	1.65	-180
35	✓	✓	2.91	-100	1.64	-180	1.00	✓	✓	✓	✓	✓	✓	✓	✓	✓	1.68	-178
38	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1.50	✓	✓	✓	1.69	-176
41	5.55	36	✓	✓	✓	✓	0.99	✓	0.63	-258	✓	✓	✓	✓	✓	✓	1.63	-180
43	5.50	34	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1.50	-190
45	5.45	31	2.95	-98	✓	✓	✓	✓	0.59	-262	✓	✓	✓	✓	✓	✓	✓	✓
48	5.39	28	2.97	-96	✓	✓	✓	✓	✓	✓	✓	✓	1.51	✓	✓	✓	1.51	✓
52	5.29	24	3.12	-88	1.75	-172	1.01	-226	0.62	-259	6.63	84	1.60	-182	✓	✓	1.59	-184
55	5.18	18	3.19	-84	1.79	-170	1.03	-225	0.65	-256	✓	✓	1.51	-190	0.09	-310	1.52	-188



NOTES:

1. TRHZ RECORDER PRINT KEY PER TEST C-4 CHART

BY Mc Kates DATE 11/21/62 | APPROVED ______ DATE ______ | CLIENT ASD / EXPER'L

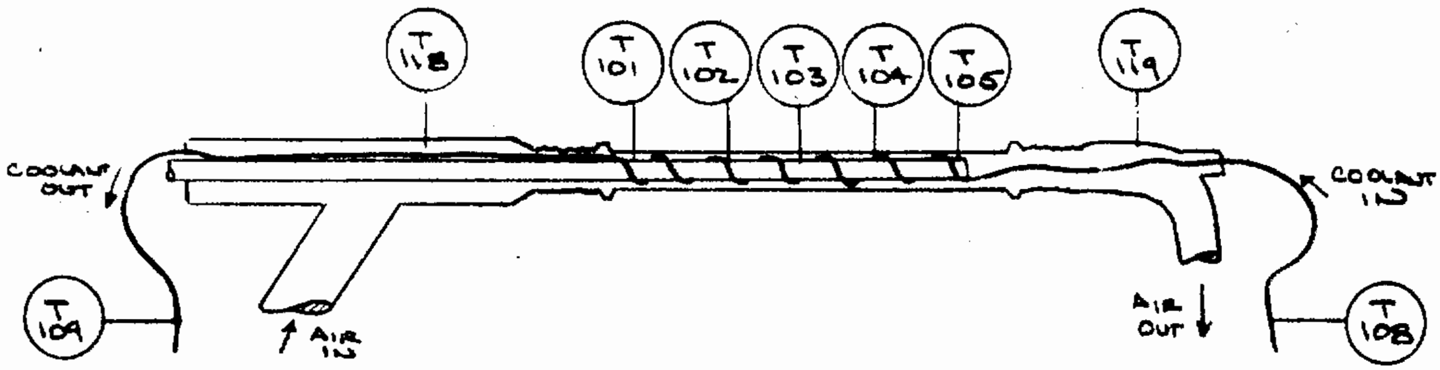
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 138 OF ______ | SKETCH NO. ______ | CASE NO. 64607

TEST C-4

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	1,9		2,10		3,11		4,12		5,13		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.11	62	5.99	56	5.69	42	5.29	24	4.71	-4	6.48	78	6.85	98	2.54	-122	6.82	93
1½	6.39	74	5.95	54	5.40	29	4.59	-10	3.51	-66	6.49	✓	5.10	14	0.59	-262	6.27	68
5	6.67	86	5.72	44	4.67	-6	3.10	-89	1.66	-178	6.62	84	3.16	-86	0.15	-304	5.74	44
8½	6.85	94	5.95	54	4.92	6	3.38	-74	1.79	-170	6.78	91	2.74	-110	0.12	-307	5.85	50
11	6.18	64	5.81	48	5.08	14	3.81	-50	2.25	-140	6.09	60	2.56	-120	0.11	-308	5.79	47
14	4.19	-30	3.41	-72	2.99	-96	2.17	-144	1.41	-196	5.00	10	2.25	-140	✓	✓	4.46	-17
15	4.57	-10	3.40	✓	3.00	-94	2.11	-148	1.38	-198	4.35	-22	2.16	-146	✓	✓	4.15	-32
16	4.45	-18	3.38	-74	2.89	-102	2.09	-150	1.35	-200	4.23	-28	2.09	-150	✓	✓	3.99	-41
22	3.50	-67	2.85	-104	2.39	-132	1.69	-176	1.13	-218	4.11	-34	1.83	-168	✓	✓	3.04	-82
25	3.20	-84	2.75	-110	2.22	-142	1.55	-186	1.08	-221	4.09	-36	1.73	-174	✓	✓	2.94	-98
29	3.00	-94	2.63	-116	2.11	-148	1.50	-190	1.05	-224	4.00	-40	1.69	-176	✓	✓	2.71	-112
35	3.01	✓	2.71	-112	2.20	-143	1.53	-188	1.08	-221	3.99	-41	1.73	-174	✓	✓	2.43	-128
38½	3.12	-88	2.75	-110	2.21	-142	1.55	-186	1.05	-224	4.01	-40	1.75	-172	✓	✓	2.33	-134
42	2.99	-96	2.71	-112	✓	✓	1.60	-182	1.11	-218	3.91	-45	1.80	-169	✓	✓	2.30	-136
44½	3.03	-93	2.79	-107	2.30	-136	1.63	-180	1.15	-216	3.94	-44	1.82	-168	✓	✓	2.24	-104



NOTES:

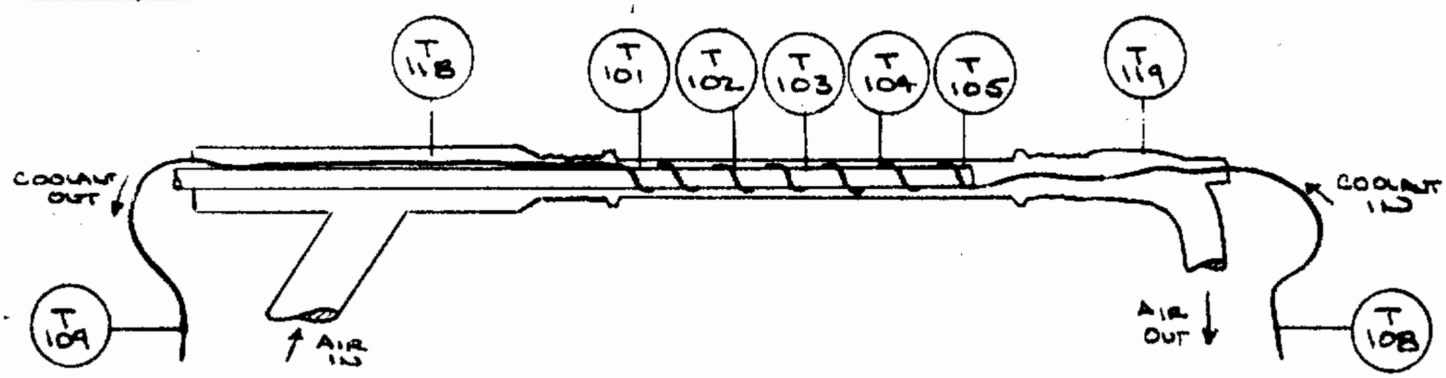
1. TR-112 RECORDER PRINT KEY PER TEST C-4 CHART

BY M. Kates DATE 11/26/62 | **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. | SHEET NO. 139 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / EXPERI | CASE NO. 64607

Test C-5 Aborted

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	5,13 [illegible]		4,12 [illegible]		3,11		2,10 [illegible]		1,9 [illegible]		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.45	76	6.45	76	6.45	76	6.45	76	6.45	76	6.45	76	6.57	82	6.45	76	6.45	76
1½	6.53	80	6.53	80	6.49	78	6.45	✓	6.26	68	6.66	86	6.20	66	1.14	-224	6.55	81
3	6.79	92	6.71	88	6.49	✓	5.28	23	2.29	-138	6.85	94	3.96	-42	0.37	-282	6.75	90
5	6.99	100	6.87	95	6.31	70	3.82	-50	1.36	-200	7.02	102	3.11	-88	0.31	-288	6.91	97
7½	7.17	108	6.95	98	6.04	58	2.99	-96	1.11	-218	7.18	108	2.43	-128	0.29	-290	7.02	102
10	7.23	110	6.98	100	5.90	52	2.70	-112	1.08	-221	7.24	111	2.22	-142	0.30	-289	7.09	104
15	7.30	114	6.93	98	5.41	29	2.79	-107	1.19	-212	7.29	117	2.16	-146	0.35	-284	7.11	105
20	7.31	✓	6.55	81	4.79	0	3.10	-89	1.64	-180	7.29	113	2.47	-126	1.12	-218	7.00	100
25	7.31	✓	7.21	110	6.82	93	5.40	29	2.40	-106	7.30	114	3.30	-78	0.91	-234	7.19	109
27	7.32	✓	7.25	111	7.00	100	5.32	25	2.57	-120	✓	✓	3.26	-80	0.50	-270	7.21	110



NOTES:

1. TR-112 RECORDER PRINT KEY PER TEST C-4 CHART

BY M. Kates DATE 11/26/62 ARTHUR D. LITTLE, INC. SHEET NO. 140 OF

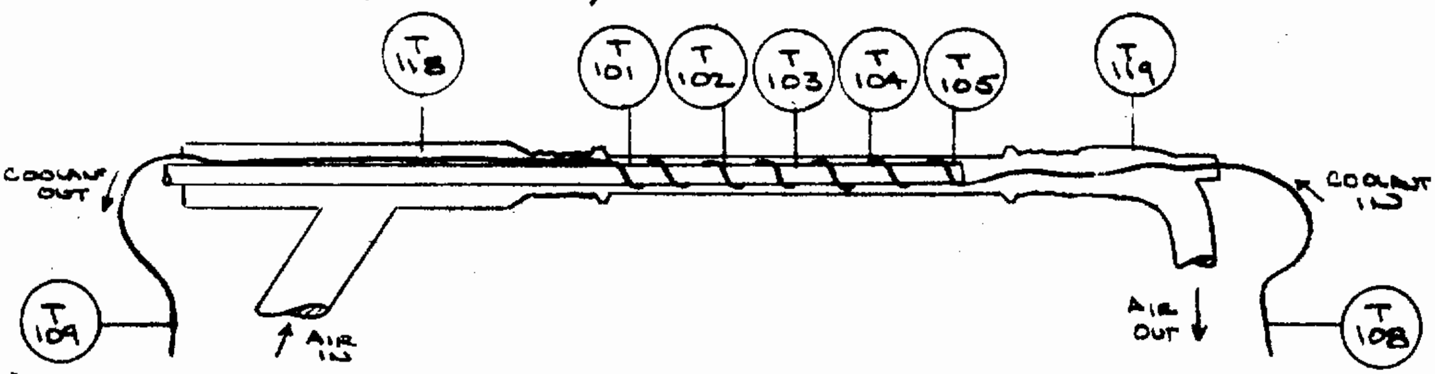
APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.

CLIENT ASD / EXPERI CASE NO. 64607

TEST C-5

AIR AND COOLANT TEMPERATURE DATA

TIME (MIN)	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR IN		AIR OUT		COOLANT IN		COOLANT OUT	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	1,9		2,10		3,11		4,12		5,13		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.83	93	6.87	92	6.76	90	6.72	88	6.61	84	6.81	92	6.32	71	1.75	-172	6.54	80
1½	7.11	105	7.09	104	6.84	94	5.32	25	2.36	-133	7.19	109	4.58	-11	0.32	-287	7.01	101
3	7.23	110	7.14	106	6.65	86	4.12	-34	1.47	-192	7.26	112	3.34	-76	0.29	-290	7.13	106
5	7.30	114	7.19	109	6.51	79	3.59	-62	1.30	-204	7.30	114	2.71	-112	0.28	-291	7.19	109
7½	7.35	116	7.19	✓	6.47	78	3.21	-83	1.22	-210	7.36	116	2.33	-134	0.26	-293	7.21	110
10	7.33	115	7.17	108	6.29	70	3.06	-92	1.20	-212	7.31	114	2.19	-144	✓	✓	✓	✓
15	7.35	116	6.99	100	5.20	19	2.80	-106	✓	✓	7.32	✓	2.11	-148	✓	✓	7.18	108
20	✓	✓	6.80	92	4.80	0	2.60	-118	1.13	-218	7.31	✓	2.01	-156	0.25	-294	7.11	105
23	✓	✓	6.77	90	4.66	-7	2.50	-124	1.09	-220	✓	✓	1.98	-158	0.23	-296	7.10	✓
25	✓	✓	6.78	91	4.70	-5	✓	✓	✓	✓	✓	✓	1.93	-160	✓	✓	✓	✓
27½	✓	✓	6.76	90	4.69	-6	2.44	-128	✓	✓	✓	✓	1.90	-162	✓	✓	✓	✓
30	7.32	114	6.75	✓	✓	✓	2.39	-132	1.05	-224	✓	✓	1.87	-164	✓	✓	✓	✓
32	7.34	115	✓	✓	4.65	-8	2.29	-138	1.01	-226	✓	✓	✓	✓	✓	✓	✓	✓
34	7.33	✓	6.73	89	4.59	-10	2.17	-144	0.99	-228	✓	✓	✓	✓	0.25	-294	7.09	104
38½	7.34	✓	6.72	88	4.57	-12	2.00	-156	0.95	-232	✓	✓	✓	✓	✓	✓	✓	✓
39½	7.32	114	6.74	89	4.68	-6	2.19	-144	1.00	-228	✓	✓	2.00	-156	0.30	-289	7.00	100



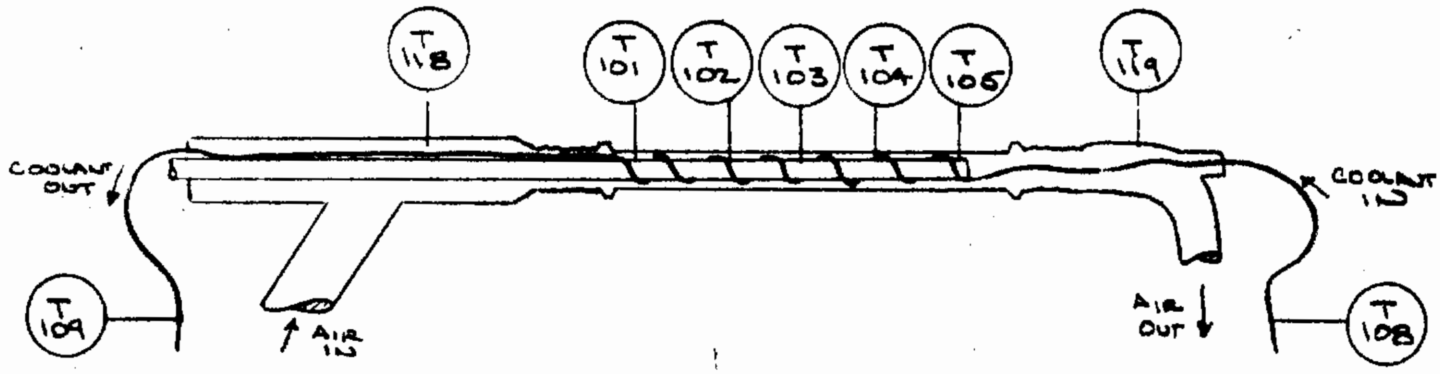
NOTES:

1. TR-82 RECORDER PRINT KEY PER TEST C-4 CHART

TEST C-6

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures: T-101 (1,9) mV	T-101 °F	T-102 (2,10) mV	T-102 °F	T-103 (3,11) mV	T-103 °F	T-104 (4,12) mV	T-104 °F	T-105 (5,13) mV	T-105 °F	Air In: T-118 (8) mV	T-118 °F	Air Out: T-119 (16) mV	T-119 °F	Coolant In: T-108 (6,14) mV	T-108 °F	Coolant Out: T-109 (7,15) mV	T-109 °F
0	6.50	79	6.50	79	6.50	79	6.50	79	6.50	79	6.50	79	6.50	79	6.19	65	6.50	79
1½	6.61	84	6.61	84	6.50	✓	5.46	32	3.41	-72	6.75	90	4.31	-24	0.51	-269	6.61	84
3	6.82	93	3.18	-84	1.62	-192	0.89	-236	0.51	-269	6.98	100	3.07	-90	0.09	-310	4.80	-30
5	6.90	96	1.88	-164	0.89	-236	0.51	-269	0.28	-291	7.09	104	2.05	-152	0.05	-315	2.40	-130
8	6.96	99	1.76	-172	0.85	-240	✓	✓	✓	✓	7.19	109	1.51	-190	✓	✓	2.23	-142
10	✓	✓	1.81	-168	0.90	-236	0.54	-266	✓	✓	7.21	110	1.31	-204	✓	✓	2.36	-136
12½	6.92	97	2.61	-118	1.21	-212	0.79	-244	✓	✓	✓	✓	1.21	-212	✓	✓	2.03	-154
15	✓	✓	2.60	✓	1.25	-208	0.84	-240	✓	✓	✓	✓	1.19	✓	✓	✓	1.98	-158
20	✓	✓	2.63	-116	1.23	-210	0.86	-238	0.38	-281	7.23	✓	1.25	-208	✓	✓	1.99	-156
22	✓	✓	2.50	-124	1.20	-212	✓	✓	0.40	-279	✓	✓	1.29	-206	✓	✓	✓	✓
25	6.89	96	2.41	-130	1.15	-216	0.83	-240	0.42	-277	✓	✓	✓	✓	✓	✓	1.91	-162
27½	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	7.21	✓	1.32	-203	✓	✓	1.87	-164
30	6.83	93	2.27	-138	1.11	-218	0.79	-244	0.39	-280	✓	✓	✓	✓	✓	✓	1.80	-170
32½	6.80	92	2.25	-140	✓	✓	✓	✓	0.35	-284	7.19	109	✓	✓	✓	✓	1.79	✓
36	6.74	89	2.21	-142	1.10	-220	0.70	-252	0.31	-288	✓	✓	1.35	-200	✓	✓	1.63	-180
38	6.63	84	2.10	-150	0.99	-228	0.61	-260	0.29	-290	7.15	107	1.31	-204	✓	✓	1.34	-202



NOTES:

1. TR-112 RECORDER PRINT KEY PER TEST C-4 CHART

BY W. Mayer DATE 9/19/6– ARTHUR D. LITTLE, INC. SHEET NO. 142 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD/EXPERI CASE NO. 64607

TEST C-1

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101} - T_{102}$	$T_{102} - T_{103}$	$T_{103} - T_{104}$	$T_{104} - T_{105}$	$T_{101} - T_{105}$	$T_{109} - T_{108}$
1 1/2	2	5	5	9	21	253
3	2	18	20	26	76	221
5	0	26	24	34	84	297
7	2	38	35	44	119	305
10	0	28	41	61	128	350
13	1	44	54	32	131	371
16	3	64	71	86	224	360
21	2	72	76	87	237	348
28	1	70	76	84	231	346
34	2	76	77	81	236	344
40	1	76	80	84	241	342
43	2	76	80	82	240	342
46	3	76	85	83	245	342
49	3	77	82	82	244	341
51 1/2	0	83	82	84	249	341

BY M. Kates DATE 11/26/62 APPROVED .... DATE .... CLIENT ASD/EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 143 OF .... SKETCH NO. .... CASE NO. 64607

TEST C-2

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T109	T109 − T108
0	3	4	10	17	34	165
2	13	19	29	34	95	242
4	✓	19	30	34	96	240
6	20	27	45	54	146	286
8	25	31	50	61	167	283
11	18	27	✓	82	177	332
14	36	44	76	76	232	348
16	47	54	88	66	255	330
18	✓	56	✓	66	157	320
22	48	57	86	68	159	311
26½	30	42	62	44	178	256
32½	40	49	62	42	193	232
35	36	46	60	44	186	230
37	37	47	56	46	186	226

BY M. Kates DATE 11/26/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 144 OF
APPROVED ______ DATE ______ | SKETCH NO.
CLIENT ASD/EXPERI | CASE NO. 64607

TEST C-3

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT₁ T101 − T102	AIR ΔT₂ T102 − T103	AIR ΔT₃ T103 − T104	AIR ΔT₄ T104 − T105	AIR OVERALL ΔT T101 − T105	COOLANT OVERALL ΔT T109 − T108
1½	41	30	40	30	141	210
5	63	53	60	46	222	244
10	75	62	64	48	249	209
15	126	92	56	28	302	252
21	171	66	42	24	303	150
26	142	80	45	29	296	142
30	140	✓	46	28	294	136
33	✓	✓	✓	✓	✓	131
35	138	✓	48	✓	✓	133
38	✓	✓	✓	✓	✓	135
41	136	✓	✓	30	✓	131
43	134	✓	✓	✓	292	120
45	129	82	✓	34	293	✓
48	124	84	✓	✓	290	✓
52	112	✓	54	33	283	127
55	102	86	55	31	274	123

BY M. Kates DATE 11/26/62 ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 145 OF ____

APPROVED ____ DATE ____ SKETCH NO. ____

CLIENT ASD/EXPERI CASE NO. 64607

TEST C-4

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	COOLANT OVERALL ΔT
	$T_{101}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{101}-T_{109}$	$T_{109}-T_{108}$
0	6	14	18	28	66	215
1½	20	25	39	56	140	330
5	42	50	83	89	264	348
8½	40	48	80	96	264	357
11	16	34	64	90	204	355
14	42	24	48	52	166	291
15	62	22	54	50	188	276
16	66	28	48	50	182	267
22	37	28	42	42	151	226
25	26	32	44	35	137	210
29	22	32	42	34	130	196
35	18	31	45	33	127	180
38½	22	32	44	38	136	174
42	16	30	40	36	122	172
44½	14	29	44	36	123	204

TEST C-5 Aborted

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT₁					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{101}-T_{105}$	$T_{109}-T_{108}$
0	0	0	0	0	0	0
1½	0	2	2	8	12	205
3	4	10	55	161	230	372
5	5	25	120	150	300	385
7½	10	40	154	122	326	392
10	10	48	164	109	331	393
15	16	69	136	105	326	389
20	25	81	89	91	294	318
25	4	17	64	135	220	343
27	3	11	75	145	234	380

BY M. Kates DATE 11/26/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 142 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD/EXPERI | CASE NO. 64607

TEST C-5

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1 T101 − T102	AIR ΔT_2 T102 − T103	AIR ΔT_3 T103 − T104	AIR ΔT_4 T104 − T105	AIR OVERALL ΔT T101 − T105	COOLANT OVERALL ΔT T109 − T108
0	1	2	2	4	9	252
1½	1	10	69	158	238	388
3	4	20	120	226	302	396
5	5	30	141	142	318	400
7½	7	31	161	127	326	403
10	7	38	162	120	327	✓
15	6	81	125	106	328	401
20	24	92	118	100	334	399
23	26	97	117	76	336	401
25	25	96	119	✓	✓	✓
27½	26	✓	122	92	✓	✓
30	24	✓	126	92	338	✓
32	25	98	130	88	341	✓
34	26	99	134	84	343	398
38½	27	100	144	76	347	✓
39½	25	95	138	84	342	389

BY M. Kates DATE 11/26/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 148 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD/EXPERI | CASE NO. 64607

TEST C-6

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

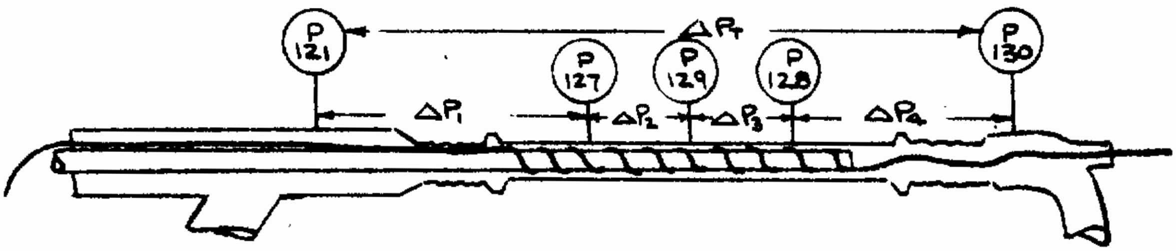
TIME (MIN)	AIR ΔT_1 T-101 − T102	AIR ΔT_2 T102 − T103	AIR ΔT_3 T103 − T104	AIR ΔT_4 T104 − T105	AIR OVERALL ΔT T101 − T105	COOLANT OVERALL ΔT T109 − T108
0	0	0	0	0	0	14
1 1/2	0	5	47	104	156	353
3	177	98	54	33	362	280
5	260	72	33	22	387	185
8	271	68	29	✓	390	173
10	267	68	30	25	✓	179
12 1/2	215	94	32	47	388	161
15	✓	90	32	51	✓	157
20	213	94	28	43	378	157
22	221	88	26	41	376	✓
25	226	86	24	37	373	153
27 1/2	✓	✓	✓	✓	✓	151
30	231	80	26	36	373	145
32 1/2	232	78	✓	40	376	✓
36	231	78	32	36	377	135
38	234	78	32	30	374	113

BY Dukpik DATE 8/24/62 | **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. | SHEET NO. 149 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD / EXPERI | CASE NO. 64607

TEST C-1

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1:30	73	66	60.4	54.4	48.1	7	5.6	6	6.3	24.9
5:00	73	66	60.4	54.4	48.1	7	5.6	6	6.3	24.9
10:00	73	66	60.4	54.4	49.1	7	5.6	6	6.3	24.9
15:00	73	66	62	56.4	53.2	7	4	5.6	3.2	19.8
20:00	73	66	62	57.4	54.2	7	4	4.6	3.2	18.8
28:00	73	66	60.4	50.4	47.1	7	5.6	10	3.3	25.9
34:00	73	64	58.4	44.4	39.4	6	8.6	14	5	33.6
40:00	73	67	54.3	31.5	24.6	6	12.7	22.8	6.9	48.4
43:00	73	67	53.3	25.5	18.4	6	13.7	27.8	7.1	54.6
46:00	75.3	69	51.3	17.6	9.2	6.3	17.7	33.7	8.4	66.1
49.00	78.4	74	53.3	17.6	9.2	4.4	20.7	35.7	8.4	69.2



NOTES:

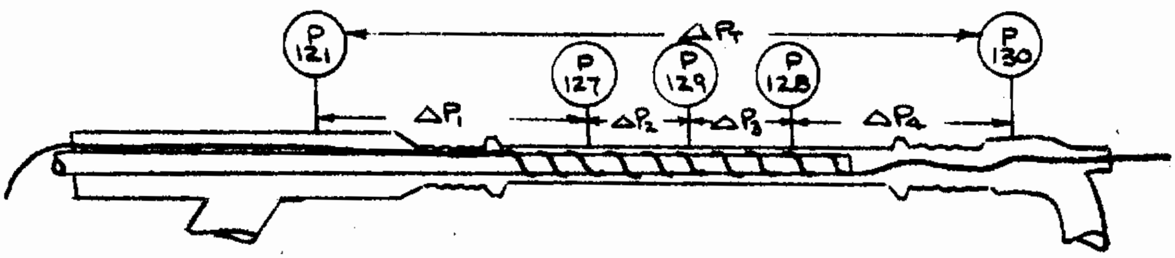
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~OF 8/9/62 [illegible]~~

BY: O. Kates DATE 11/21/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 150 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT: ASD / [illegible] | CASE NO. 6A607

TEST C-2

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2	75	68.5	63.5	58.5	53.5	6.5	5	5	5	21.5
6	✓	68	63	58	53	7	5	5	5	22
11	75.5	68.5	63.5	59	54.5	7	5	4.5	4.5	21
14	75	✓	✓	60	56	6.5	✓	3.5	4	19
16	✓	✓	64	61	57.5	✓	4.5	3	3.5	17.5
18	✓	69	64.5	✓	58	6	4.5	3.5	3	17
26 1/2	✓	68	64	58.5	54	7	4	5.5	4.5	21
32 1/2	✓	68.5	✓	61	56.5	6.5	4.5	3	4.5	18.5
35	77	40	31	24.5	13	37	9	5.5	11.5	64



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA [redacted]

BY M. Kates DATE 11/21/62 APPROVED ______ DATE ______ CLIENT ASD / EXPERI

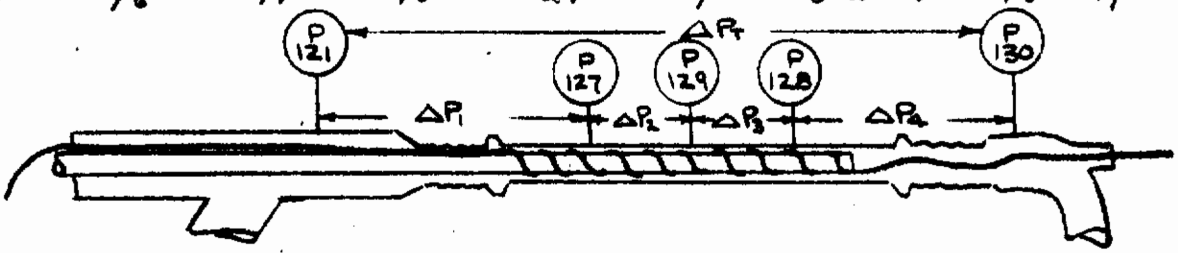
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 151 OF ______
SKETCH NO. ______
CASE NO. 6A607

TEST C-3

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1 1/2	75	69	64.5	60	56	6	4.5	4.5	4	19
5	✓	68.5	✓	61	57	6.5	4	3.5	✓	18
10	✓	69	65	62	59	6	✓	3	3	16
15	✓	70	67	65	62	5	3	2	✓	13
21	✓	71	68.5	66	62.5	4	2.5	2.5	3.5	12.5
26	76	57.5	65	61.5	57	18.5	-7.5	3.5	4.5	19
30	75	64	61.5	57	52.5	11	2.5	4.5	✓	22.5
33	✓	62.5	59.5	55	49.5	12.5	3	✓	5.5	25.5
35	✓	60	57	52	46.5	15	✓	5	✓	28.5
38	✓	56.5	53.5	47	41	18.5	✓	6.5	6	34
41	✓	51.5	48	41	33	23.5	3.5	7	8	42
43	✓	47.5	43.5	35	26	27.5	4	8.5	9	49
45	✓	42.5	38.5	28	17	32.5	✓	10.5	11	58
48	77				8					71
50	82	40	36	22	8	42	4	14	14	80
52	86	42	38	23	7.5	44	✓	15	15.5	78.5
55	96	44	40	24	7	52	✓	16	17	89



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION
~~DATA [illegible]~~

BY M. Kates DATE ________ ARTHUR D. LITTLE, INC. SHEET NO. 152 OF ________

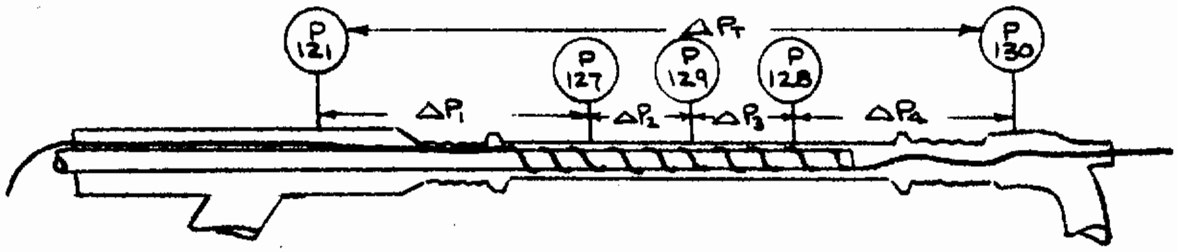
APPROVED ________ DATE ________ CAMBRIDGE, MASS. SKETCH NO. ________

CLIENT ASD / EXPERI CASE NO. 64607

TEST C-4

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1 1/2	75	71	67	64	60	4	4	3	4	15
5	✓	70	66.5	62	58.5	5	4.5	4.5	3.5	16.5
8 1/2	✓	69.5	66	61.5	57	5.5	3.5	✓	4.5	18
14	79	72				7				
15	75	69	61	55	49	6	8	6	6	26
16	✓	67	✓	54	48	8	6	7	✓	27
22	✓	66	60	✓	47	9	✓	6	7	28
25	✓	✓	58.5	✓	48	✓	7.5	4.5	6	27
29	✓	64.5	56.5	50.3	43	10.5	8	6.2	7.3	32
35	✓	57.9	49.2	39.5	29.8	17.1	8.7	9.7	9.7	45.2
38 1/2	✓	58	44.3	43.2	22	17	13.7	1.1	21.2	53
42	76.5	54	44.5	37.5	35.5	22.5	9.5	7	2	41
44 1/2	✓	52.5	42.5	35.5	23	24	10	✓	12.5	53.5



NOTES:

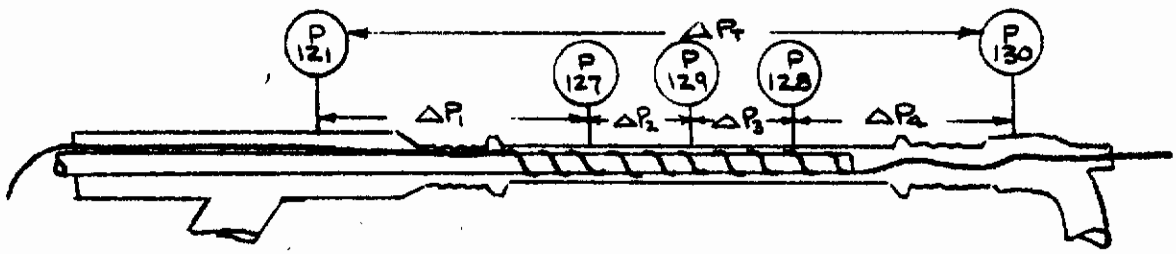
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA [illegible]

BY M. Kates DATE 11/21/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 153 OF
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / ENPERI | CASE NO. 64607

Test C-5 Aborted

Heat Exchanger Air Pressures

Time (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1½	75	72	70.5	68	67	3	1.5	2.5	1	8
5	✓	✓	69.5	✓	66	✓	2.5	1.5	2	9
10	✓	✓	✓	✓	67	✓	✓	✓	1	8
15	✓	✓	70	67	66	✓	2	3	✓	9
20	✓	✓	69	63.5	61.5	✓	3	5.5	2	13.5
25	✓	71.5	✓	66	59	3.5	2.5	3	7	16



NOTES:

1. ~~PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA~~

BY M. Kates DATE 11/21/62 | APPROVED ______ DATE ______ | CLIENT ASD / [illegible]

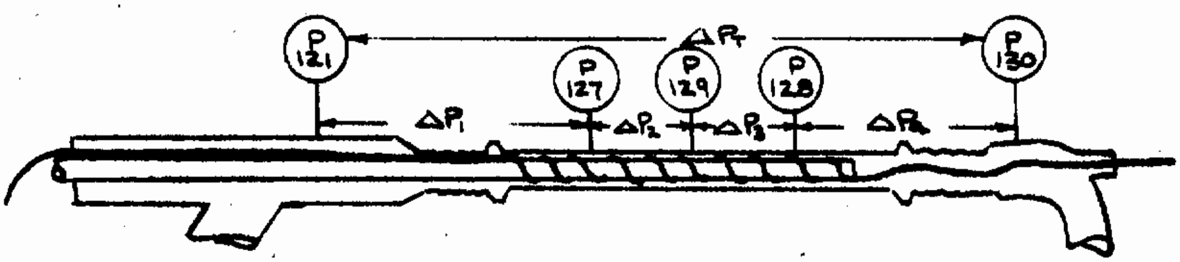
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 154 OF ______ | SKETCH NO. ______ | CASE NO. 64607

TEST C-5

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1½	75	72	70	68	67	3	2	2	1	8
5	✓	✓	69	✓	66.5	✓	3	1	1.5	8.5
10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
15	✓	✓	✓	66.5	65	✓	✓	2.5	✓	10
20	✓	✓	68.5	62	59.5	✓	3.5	6.5	2.5	15.5
23	✓	✓	67	58	55	✓	5	9	3	20
25	✓	72.5	66.5	55	51	2.5	6	11.5	4	24
27½	✓	72	64	48	43.5	3	8	16	4.5	31.5
30	✓	✓	61.5	41	36	✓	10.5	20.5	5	39
32	✓	✓	58.5	33	26	✓	13.5	25.5	7	49
34	✓	✓	55	26	17	✓	17	4.9	9	58
38.5	80	78	52.5	22	9.5	2	25.5	30.5	12.5	65.5



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION ~~DATA [illegible]~~
"

BY M. Kates DATE

APPROVED DATE

CLIENT ASD / ENPERL [illegible]

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 155 OF

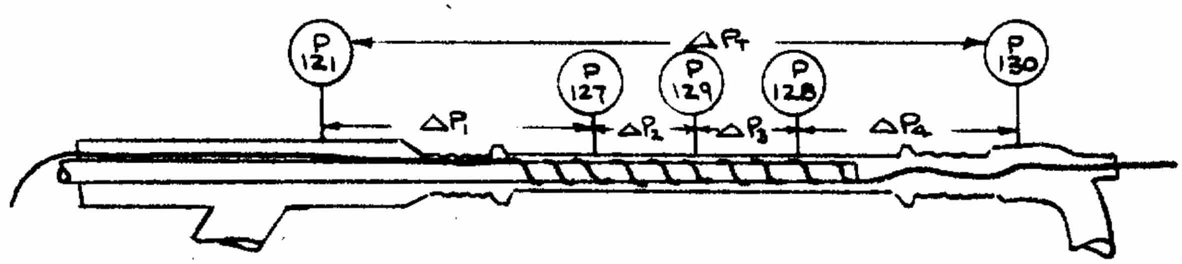
SKETCH NO.

CASE NO. 64607

TEST C-6

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1 1/2	75	72	70	69	68	3	2	✓	1	7
5	✓	73	72	71.5	70.5	2	1	0.5	✓	4.5
8	75.5	73.5	72.5	✓	71	✓	1	1	0.5	4.5
10	75	73	71.5	70.5	70	✓	1.5	✓	✓	5
15	✓	69	67	66.5	65	6	2	1.5	✓	10
20	✓	61	57.5	55.5	54.5	14	3.5	2	1	20.5
22	✓	57	54	52	50.5	18	3	✓	1.5	24.5
25	✓	49.5	45.5	43	41.5	25.5	4	2.5	1.5	33.5
27 1/2	✓	42.5	38	35	33	33	4.5	3	2	42
31	✓	33	28	24	22	42	5	4	✓	53
32 1/2	✓	27.5	21	16.5	14.5	47.5	6.5	4.5	✓	60.5
36	87	22	15	10	8	65	7	5	✓	79
38	92.5	20	13	2.5	7	72.5	✓	10.5	-4.5	85.5



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA OF [illegible]

— WATER CONTAMINANT TEST RESULTS —

TEST C-1
DATE 9-12-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ● ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
37½	78	90	84	.036	.47	8							
38	✓	✓	90	.081	✓	17							
39	✓	✓	325	.29	✓	62							
40	✓	✓	371	.334	✓	71			No outlet concentration				
46	✓	92	390	.360	✓	76.5			measured during test				
49	✓	95	382	.363	✓	77							

$\frac{390}{406} = .96$

DATA FROM BURETTE MEASUREMENTS

TIME MIN	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/sec	CALCULATED ① ppm-(wt)	INLET CONC. ppm (vol) ②
22		9.6					
26	4.0	11.3	1.7	25.5			
33.66	11.66	14.35	4.75	24.4	.0575	261	406
43.75	21.75	18.5	8.90	24.5			
50.66	28.66	21.3	11.70	24.5			

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / (3600 W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST C-2
DATE 10-26-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-VOL	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-VOL.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
$32\frac{1}{2}$	-28	90	5.85		3.7×10^{-3}								
33	✓	✓	10.4		✓								
34	-30	✓	200.		3.5×10^{-3}								
35	✓	✓	250.		✓								
36	-31	96	258		✓								
37	✓	108	259		✓								WATER CONC. STILL RISING @ 37 MIN.

$\frac{259}{299} = .87$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/sec	CALCULATED INLET CONC. ② ppm-(wt)	ppm (vol) ②
31		9.5					
37	6	11.9	2.4	24	.0764	192	299

$W_a = .0620$
$W_s = .0144$
$.0764$

Note: p_w = partial press H_2O
P_{SAT} = VAPOR " "

① Average - Approx. Steady State Value
② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6 / (3600 W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST C-3
DATE 10-29-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ● ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
22	38	90	10	9×10^{-4}	.11								
23	✓	✓	265	.024	✓	22							
24	✓	✓	314	.028	✓	25							
26	✓	✓	335	.03	✓	27							
28	✓	✓	336	.03	✓	27							
35							-257	61.2	16	9.8×10^{-4}	$<10^{-12}$		
40							✓	49.7	11	5.4×10^{-4}	$<10^{-12}$		
45							-261	31.7	10	3.2×10^{-4}	$<10^{-12}$		
52	24	101	345	.031	.066	47							
56½	15	108	350	.032	.039	82							

(Ave) $\frac{340}{365} = .93$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE CC/hr	W_A lbs/sec	CALCULATED ② ppm-(wt)	INLET CONC. ppm (vol) ②
20		23.1					
27	7	25.8	2.7	23.2		235	365
29½	9½	26.7	3.6	22.7			
38¾	18¾	30.2	7.1	22.7			
~~48¾~~	~~28¾~~	~~32.9~~	~~10.8~~	~~22.6~~	.0588		
56	36	36.9	13.8	23.0			

{ USE THIS AVERAGE

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx Steady State Value

② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6 / (3600 W_A) = ppm (vol) × 18/29

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

BY ______ DATE ______
APPROVED ______ DATE ______
CLIENT ASD / EXPER.

SHEET NO. 159 OF ______
SKETCH NO. ______
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST C-4
DATE 11-1-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
30							-228	57.7	47				
35							-221	44.5	25		3×10^{-12}		
38½							✓	36.7	17		✓		
42							-219		14		4×10^{-12}		

DATA FROM BURETTE MEASUREMENTS

TIME MIN	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	w_s + w_A lbs/sec	② CALCULATED ppm-(wt)	INLET CONC. ppm (vol) ②
30		12.5					
32	2	13.25	.75	22.5	.0717	200	310
40¼	10¼	16.4	3.9	22.3			
46½	16½	18.9	6.4	23.3			

w_s = .0186
w_a = .0531

Note: p_w = partial press H_2O
P_{SAT} = vapor " "

① Average - Approx Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10⁶/(3600 w_A) = ppm (vol) × 18/29

BY________DATE________ ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 160 OF______
APPROVED________DATE________ SKETCH NO.________
CLIENT ASD / EXPER CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST C-5
DATE 11-7-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-Vol.	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC.① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
1½	108	89.7	24	.0022	1.2								
5	114	✓	15	.0013	1.43								
10	✓	✓	14	.0013	✓								
15	115	✓	368	.033	1.47								
20	✓	✓	374 *	(16 min) .035	✓		-216	59½	275	1.6×10^{-3}	APPROX 5×10^{-12}	APPROX 10^{10}	
23							-219	55	17.2	9.5×10^{-4}	✓	✓	
25							✓	51	13.8	7×10^{-4}	✓	✓	
27½							✓	43½	12.4	5.4×10^{-4}	✓	✓	
30							-223	36	12.4	4.5×10^{-4}	✓	✓	
32			AND RISING				-226	26	15.0	2.9×10^{-4}	✓	✓	374
34	114	89.7	350	.031	1.43								391
38½	✓	94.7	391 *	.037	1.43								765/2 = 383 AVG = .97 ; 386

* STEADY STATE VALUE.

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ② ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
11	—	19.5	—				
16	5	21.65	2.15	25.8			
28:20	17.33	26.9	7.90	25.4			
35:30	24.50	30.1	10.60	25.9			
41	30.00	32	12.50	25.0	222	249	386

Note: p_w = partial press. H_2O
P_{SAT} = VAPOR " "

① Average - Approx. Steady State Value
② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6 / ([illegible] W_A) = ppm (vol) × 18/29

BY ______ DATE ______ APPROVED ______ DATE ______ CLIENT ASD / EXPER

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 161 OF ______ SKETCH NO. ______ CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST C-6
DATE 11-9-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ① ppm-VOL	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-VOL.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
10	97	90	10	.0009	.87								
20	96	✓	374	.034	.84	4							
23							-279	56.2	103	5.8×10^{-3}	$<10^{-12}$		
25							-275	42.7	64	3×10^{-3}	✓		
27½							✓	36.7	47	1.7×10^{-3}	✓		
29							✓	35.7	40	1.4×10^{-3}	✓		
32½	92	90	374	.034	.74	4.6							
36	90	102	395	.04	.70	5.7							
38	83	107	402	.043	.56	7.7							
													$\frac{374}{400} = .94$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE cc	DIFFERENCE cc	RATE cc/hr	W_A lbs/hr	CALCULATED ② ppm-(WT)	INLET CONC. ② ppm (VOL)
9		12.0					
11	2	12.9	.9	27			
19½	10½	16.5	4.5	25.7			
31	22	21.4	9.4	25.6	219	257	400
39½	30½	25.0	13.0	25.6			

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx Steady State Value

② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([redacted] W_A) = ppm (vol) × 18/29

BY ________ DATE ________ ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 162 OF ____

APPROVED ________ DATE ________ SKETCH NO. ________

CLIENT ASD/EXPERI CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST C-1
DATE 9-12-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-Vol	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
5	92	90	293										
15	86	✓	297										
25	81	✓	293										
29	79	✓	287										
34							-158	57.7	170	.0098	1.0		
37							-160	47.1	175	.0084	1.0		
40	78	✓	293										
46	✓	92	297										
49	✓	95	293										

No of Bottles in Manifold ____
Pressure in Manifold ____ psia
No of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure After Mixing: psia
ppm CO_2 (vol) = ____ × ____/____ =
ppm CO_2 (wt) = ppm(vol) × $\frac{44}{28}$
=

① Average - Approx Steady State Value

Note p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST C-2
DATE 10-26-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
2	75	90	312										
6	76	✓	305										
11	75	✓	308										
16	70	✓	300										
22	67	✓	297										
② 23	-12	✓	237										
② 30	-29	✓	247										
② 35	-31		247										

No of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure after Mixing: psia
ppm CO_2 (vol) = ____ × ____ / ____ =
ppm CO_2 (wt) = ppm (vol) × 44/28
=

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Average - Approx Steady State Value
② Spray Stream Added To Air Stream

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST C-3
DATE 10-29-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
5	76	90	338										
15	61	✓	327										
25	38	✓	332										
35							-257	61.2	3	1.8×10^{-4}	7.5×10^{-5}	240	at t=43 to t=47 CO_2 outlet conc. very erratic
43							-259	40.7	3	1.2×10^{-4}	6.0×10^{-3}	200	
48	28	92	337										
56½	15	108	337										

No of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure After Mixing: ____ psia
ppm CO_2 (vol) = ____ × ____ / ____ =
ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$
=

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Having approx. Steady State Value

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST C-4
DATE 11-1-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
5	86	90	285										
10	94	✓	287										
22	-67	✓	177										
25	-85	✓	172										
30							-228	57.7	65	3.75×10^{-3}	3.4×10^{-3}	110	
35							-221	44.5	95	4.2×10^{-3}	8.2×10^{-3}	51	Readings erratic in this region
$38\frac{1}{2}$							✓	36.7	110	4.0×10^{-3}	✓	50	
42									117				
$44\frac{1}{2}$	-92	92	116										

No of Bottles in Manifold ____
Pressure in Manifold ____ psia
No of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure after Mixing: ____ psia
ppm CO_2 (vol) = ____ × ____ / ____ =
ppm CO_2 (wt) = ppm (vol) × 44/28
=

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Heavy - Heavy Steady State Value

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST C-5
DATE 10-7-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	CONC ① ppm-VOL	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	CONC ① ppm-VOL	p_{CO_2} psia	p_{SAT} psia	% of SAT	
1½	108	89.7	312										
5	114	✓	306										
10	✓	✓	300										
11	115	✓	306										
20							-216	59½	72	4.3×10^{-3}	1.2×10^{-3}	36	
23							-219	55	67	3.7×10^{-3}	8.5×10^{-3}	44	
25							✓	51	70	3.5×10^{-3}	✓	41	
27½							✓	43½	72	3.1×10^{-3}	✓	37	
30							-223	36	76	2.7×10^{-3}	5.7×10^{-3}	47	
32							-226	26	85	2.2×10^{-3}	4.5×10^{-3}	49	
34	114	89.7	312										
38½	✓	94.7	310										

No. of Bottles in Manifold 21
Pressure in Manifold 2300 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

$$\frac{14.7}{21} \times \frac{1}{2300} \times \frac{10^6}{10^6} = 304 \text{ ppm (Vol)}$$

① Average - Approx Steady State Value

Pressure after Mixing: 2300 psia

ppm CO_2 (vol) = ____ × ___1___ = 304

ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$

$$= 304 \times \frac{44}{28} = 478$$

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST C-6
DATE 11-9-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
10	97	90	357										
20	96	✓	357										
23							-279	42	7	3.9×10^{-4}	2.5×10^{-6}		
25							-275	42.7	11	5.2×10^{-4}	5.5×10^{-6}		
27½							✓	36.7	20	7.3×10^{-5}	✓		ERRATIC CONC. AT OUTLET.
29							✓	35.7	32	1.1×10^{-4}	✓		
32½	92	90	360										
36	90	102	360										
38	83	107	362										

No. of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure after Mixing: ____ psia
ppm CO_2 (vol) = ____ x ____ / ____ =
ppm CO_2 (wt) = ppm (vol) x $\frac{44}{28}$
=

① Average – Average Steady-state Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

HYDROGEN TEST SERIES REDUCED DATA

ASD-TDR-63-508, Volume III

TABLE OF CONTENTS

SUMMARY OF RESULTS

This reduced data includes the following information for each test.

1. Summary Sheet

The test summary sheets include the nominal test parameters, the variables investigated, the time sequence of the important events during the progress of the test and notes from photographic data.

2. Flow Data

The flow data sheets included the air and coolant flows that were calculated from both the orifice pressures and the manifold cylinder pressures.

The air stream flow rates computed from orifice and manifold pressures agree in all cases within 15 percent for both helium and nitrogen for the 6 tests performed in this test series. No bias exists between the air stream flow values that are computed both from the manifold and pressure data. These results are consistent with our experience in the flow test series although the accuracy is less. With regard to the coolant flow measurements our experience in the hydrogen test series is contrary to our flow test series experience, i.e.: the coolant flow computed from orifice data is considerably greater than that computed from manifold pressures. This discrepancy can be attributed to air ice and water ice formed in the liquid hydrogen cooling coil in the period between tests. We believe that this ice restricted the flow and thereby caused the measuring orifice to become unchoked. While no pressure measurements were made downstream of the measuring stream orifices, other process information, such as venting through pressure relief valve (PRU-165) during the test, has led us to this conclusion. Prior to placing the system in operation we thoroughly check both the air and coolant manifold lines for leaks and would expect negligible errors to be introduced from this source in the flow rate calculations. Therefore, for the coolant, we have taken the bottle pressure data as the "best estimate" flow value.

3. Temperature Data

The air and coolant temperature data sheets include air and coolant temperatures tabulated as a function of time. Temperature differential tabulations have also been prepared in which the individual Δ T's in the heat exchanger air stream as well as the overall and coolant Δ T's have been listed as a function of time.

The air stream temperatures were generally quite good in the cases where both hydrogen and helium were both used. When nitrogen was used for the air stream, condensation occurred in the cold end of the heat exchanger. The measured temperature at the cold end agreed usually within 5° of the saturated temperature from the heat exchanger pressure.

In test H-2 where helium was used as the air stream, the cold end "air" temperatures has a probable accuracy of about (+) or (-) 10° because of the low sensitivity of the copper-constant an thermocouple at temperatures below liquid nitrogen temperatures.

The coolant inlet temperatures were measured using hydrogen vapor bulb thermometer and a gold cobalt and copper-constant an thermometers. The results among these three measurements were not consistent when measuring the helium stream at the inlet to the heat exchanger after it had been cooled to liquid hydrogen temperatures. Subsequent calibration of the hydrogen vapor bulb with liquid hydrogen indicated good reliability of this measurement and it was, therefore, used in the heat balance calculations.

4. Air Pressure Data

Heat exchanger air pressure and air pressure drops have been tabulated vs time on the heat exchanger where pressure data change. This data appears quite reasonable. As evidenced by the data presented in the flow test series and data obtained for this series, the locations of high pressure drop correspond with the regions of maximum frost concentrations. The pressure drop due to carbon dioxide deposition again is generally much less than that due to water deposition. The total heat exchanger pressure drop for tests H-1 and H-2 is quite low because of our use of helium in the air stream.

5. Contamination Data

Carbon dioxide and water concentrations measured at the inlet and exit of the test heat exchanger with the CO_2 and H_2O analysers respectively have been tabulated as a function of time.

As established in the flow test series measured carbon dioxide inlet concentrations are consistent with the mixes prepared in the air stream manifold when nitrogen is used. In tests H-1 and H-2 which utilized helium, the stream concentration measurements appear erratic and the mixture preparation considerably less than the .05% we were trying to achieve. We have not determined the cause of these errors. Concentrations measured at the outlet were in general higher than those determined from the saturated air stream conditions. This is due mainly to the limitations of the CO_2 analyser for measurements below 5 ppm.

The measured air stream inlet water concentrations were lower than those established by the air stream flow and water metering pump as was the case with the flow test series. The water analyser flow meter was calibrated and found to be in error by about 15% at the principle sampling rate. This correction improved the correspondence between the measured and mixed values, but still did not bring them into complete agreement. In subsequent tests, we have re-oriented the water-air stream mixer to substantially increase the area of the surface used for water vaporization. We tentatively conclude at this time that good correspondence between the prepared and measured stream concentrations can now be obtained. Thus the concentrations measured with the water analyser and appropriately corrected for sample flow are taken to represent the correct air stream inlet and outlet concentrations. Again, as for the CO_2 measurements the outlet water concentration is considerably higher than is determined from saturated air stream conditions. This we feel can be attributed to the limited response capabilities of the water analyser at water concentrations below 10 ppm.

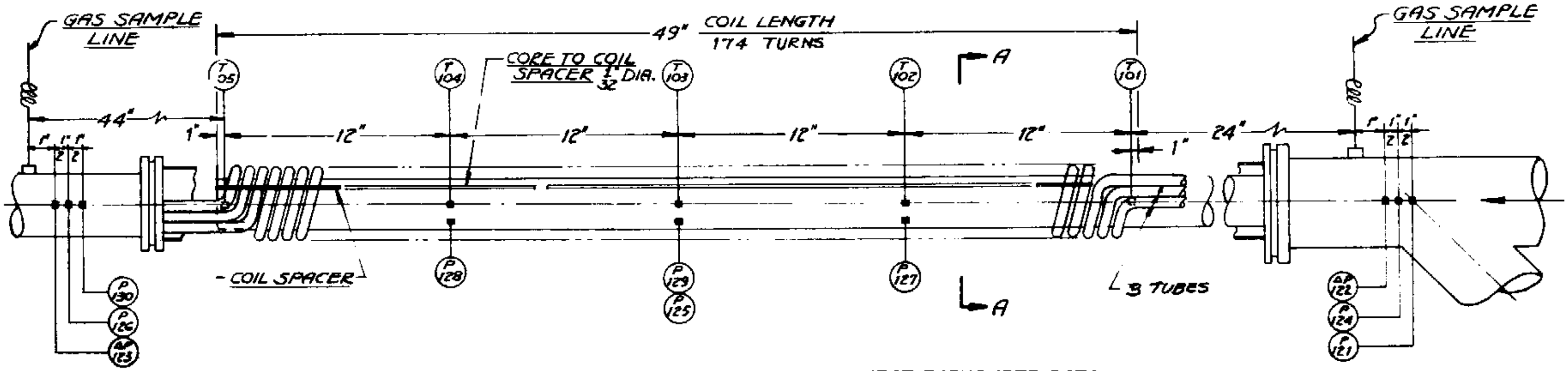
6. Energy Balances

Energy balances for all of the hydrogen series tests have been completed. In these energy balances the coolant heat flow was computed from the measured flow rates and the inlet and outlet pressures. For this test series no correction was made for temperature rise between the measuring points and the inlet and outlet of the test heat exchanger. This simplification was justified since the inlet coolant line was vacuum insulated, and since experience on the flow test series has shown that the coolant outlet temperature rise is generally quite small. For tests H-1 and H-2, in which helium was used as the "air" stream the "air" heat flow was computed from the measured flow rate and from the inlet and outlet pressures and temperature. For tests H-3A through H-6 the "air" stream was nitrogen. For these tests the exit "air" stream was partially condensed and it was not possible to define the exit enthalpy from the measured temperature and pressure at the heat exchanger exit. To cope with this problem, we used two procedures: (1) we assumed that exit nitrogen was vapor, saturated at the exit pressure. Energy balances prepared on this basis indicated that the computed air heat flow was generally much less than the coolant heat flow. This result was not unexpected since the exit nitrogen stream, in fact, was partially liquefied. (2) We computed the exit quality for tests H-3A through H-6 assuming closure of the energy balances. The results of the calculations indicated that for test H-4 through H-6, the exit nitrogen quality was of the order of 50%. For H-3A the exit quality was approximately 100% indicating that very little condensation had occurred.

LIQUID HYDROGEN TEST SERIES
TEST PARAMETER SUMMARY

Test		Air Stream					Coolant Stream			
No.	Date	Fluid	Ga lb/sec ft^2	Pa (psia)	% H_2O	% CO_2	Inlet Press (psig)	Inlet Temp (° F)	$\frac{(Wc_p)_c}{(Wc_p)_a}$	Variable Investigated
H-1	10/2/62	He	30 (1)	90	min	.05	300	-300	1.0	System check run CO_2 freeze-out @-300°F
H-2	10/5/62	He	30 (1)	90	min	.05	300	-400	1.0	CO_2 freeze-out @ -400°F
H-3A	10/6/62	N_2	30	90	min	.05	300	-400	1.0	CO_2 freeze-out at high ΔT
H-4	10/6/62	N_2	13	90	min	.05	300	-400	2.3	CO_2 freeze-out and air condensation (reduced air flow)
H-5	10/9/62	N_2	30	90	min	.05	300	-400	1.75	CO_2 freeze-out and air condensation
H-6	10/9/62	N_2	30	90	.025	.05	300	-400	1.75	CO_2 freeze-out and air condensation with water

NOTES:
1. Equivalent volumetric helium flow.
2. Configuration No. 1 used in all tests.
3. Helium coolant used in all tests.
4. For complete condensation $(Wc_p)_c/(Wc_p)_a \simeq 1.75$.
5. All values shown are nominal based on preliminary survey of data.



HEAT EXCHANGER DATA:

TUBE SIZE: 3/16" O.D. × .030 WALL, ANNEALED COPPER,

TOTAL AIR SIDE SURFACE AREA: 1.76 $FT.^2$

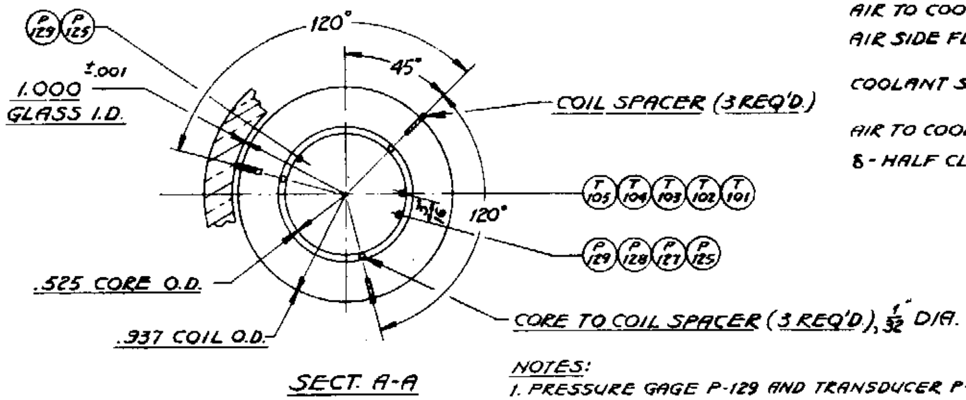
AIR TO COOLANT SURFACE AREA RATIO: 1.472

AIR SIDE FLOW AREA: .150 $IN.^2$
.00104 $FT.^2$

COOLANT SIDE FLOW AREA: .0379 $IN.^2$
.000263 $FT.^2$

AIR TO COOLANT - FLOW AREA RATIO: 3.96

δ - HALF CLEARANCE: .031 IN.



NOTES:
1. PRESSURE GAGE P-129 AND TRANSDUCER P-125 ARE CONNECTED TO A COMMON SENSE LINE. THIS SENSE LINE IS FOR REASONS OF RELIABILIT FED BY DOUBLE PNEUMATIC LEADS FROM THE TEST CORE.
2. 94% OF TUBE SPACES ARE BETWEEN .055" AND .070"

TEST HEAT TRANSFER SECTION DETAILS - 1-INCH SPIRAL CONFIGURATION

BY F.E. Ruccia DATE 11-5-62 ARTHUR D. LITTLE, INC. SHEET NO. 175 OF ______

APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______

CLIENT ASD / EXPERI CASE NO. 64607

TEST H-1 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1 1" SPIRAL TUBE	90	30	1.0	—	.001	.95	LN_2	53	10-2-62

VARIABLE INVESTIGATED: SYSTEM CHECK-OUT @ LN_2 TEMP

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR & COOLANT
5	STABLE COOLANT INLET TEMP A
10	QUASI STABLE AIR TEMP
53	SHUTDOWN.

PHOTOGRAPHIC OBSERVATIONS:

NO STILL PHOTOS

FROM MOVIE TRAVERSE @ 50-53 MIN:

WATER FROST 15-22

NO FROST 22-41

CO_2 FROST 41-48

GENERAL NOTES:

TEST H-1 WAS RUN PRINCIPALLY FOR CHECK OUT OF THE TEST EQUIPMENT. LIQUID NITROGEN WAS USED TO COOL COOLANT STREAM.

BY F. Clevenger DATE 11-6-62

APPROVED ______ DATE ______

CLIENT ASD / ELPER

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 176 OF ______

SKETCH NO. ______

CASE NO. 64007

TEST H-2 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1 1" SPIRAL TUBE	90	30	1.0	—	.0007	.05	LH_2	43	10-5-62

VARIABLE INVESTIGATED: CO_2 FREEZE-OUT @ -400°F

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
-0	LH_2 IN COOLANT HEAT EXCHANGER.
0	START CLOCKS, AIR AND COOLANT STREAMS
1	STREAM RATES SET
7	STABLE COOLANT INLET TEMP
10	STABLE TEST HEAT EXCHANGER TEMP DISTRIBUTION
43	SHUTDOWN

PHOTOGRAPHIC OBSERVATIONS

OVERALL STILLS @ 8, 18, 23, 28, 34, 39, 43, 47, 52

CLOSE-UP STILLS 44 - 47.5 MIN

MOVIE TRAVERSES @ 15, 30, 40, 50

@ 34 MIN LT. H_2O FROST 5-15 CO_2 21-25 HEAVY

ALSO FROST 45-49 (PRESUMABLY CO_2 DEPOSITION DURING COOLDOWN)

GENERAL NOTES:

TEST H-3A SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1 1" SPIRAL TUBE	90	30	1.0	—	~.0007	.05	LH_2	25	10-5-62

VARIABLE INVESTIGATED: CO_2 FREEZE-OUT @ HIGH ΔT

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
−0	LH_2 IN COOLANT HEAT EXCHANGER
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAMS.
3	STABLE
10	QUASI STABLE TEST HEAT EXCHANGER TEMP DISTRIBUTN
① 25	END OF TEST 3A

PHOTOGRAPHIC OBSERVATIONS:

OVERALL STILLS @ 15 & 25 MIN

CLOSE-UP STILLS 10-13 MIN

MOVIES OF COLD END (45"-49") @ 2, 7, 10, 16, 21 MIN

@ 25 MIN CO_2 FROST 45"-49"!

GENERAL NOTES:

① AFTER 25 MINUTES OF RUN TIME AIR STREAM FLOW RATE WAS REDUCED TO ACHIEVE NEW HEAT EXCHANGER TEMP DISTRIBUTIONS.

② CONDENSATION OF AIR STREAM AT COOLANT INLET END RESULTED IN UNSATISFACTORY TEMP DISTRIBUTION IN AIR STREAM.

BY JC Burke DATE 10/8/62 ARTHUR D. LITTLE, INC. SHEET NO. 178 OF

APPROVED ____ DATE ____ CAMBRIDGE, MASS. SKETCH NO. ____

CLIENT ASD / ELPERI CASE NO. 64607

TEST H-4 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_2 (PSIA)	G_2 (LB/SEC FT²)	W_c/W_a	W_3/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1	90	13	.46	—	—	.05	HELIUM 300 PSIG −400°F	47½	10/6/62

VARIABLE INVESTIGATED: CO_2 FREEZE-OUT & AIR CONDENSATION

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, CHARTS, AND STREAMS
8	STABLE H.E. AIR TEMP
47½	COMPLETE QUANTITATIVE DATA ON CONTAMINANT FREEZEOUT. REDUCE AIR FLOW TO OBTAIN ADDITIONAL DATA ON EFFECT OF AIR COOLANT FLOW RATIO ON AIR AND COOLANT TEMP PROFILES
71	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

OVERALL STILLS @ 3¾, 10, 12, 18, 21, 32, 52

NO CLOSE-UP STILLS

MOVIE TRAVERSE @ 10 & 25 MIN

@ 32 MIN CO_2 FROST 31"-45" CONDENSING LIQ. 45"-48"

GENERAL NOTES:

BY Peluccio DATE 11-6-62
APPROVED .... DATE ....
CLIENT ASD / ELPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 179 OF ....
SKETCH NO. ....
CASE NO. 64607

TEST H-5 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_2 (PSIA)	G_2 (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1 1" SPIRAL TUBE	90	30	1.0	—	.0004 To .001	.05	LH_2	53	10-9-62

VARIABLE INVESTIGATED: CO_2 FREEZE-OUT AND AIR CONDENSATION

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
-0	LH_2 IN COOLANT HEAT EXCHANGER
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAMS
1	STREAM RATES SET.
1½	STABLE COOLANT INLET TEMP
10	STABLE AIR STREAM TEMPS.
① 22	COOLANT COIL PLUGGED - FROST DIST SHIFTED.
53	SHUTDOWN.

PHOTOGRAPHIC OBSERVATIONS:

OVERALL STILLS* @ 4, 10, 16, 20, 23, 31, 35, 43, 48, 52, 55, 58
CLOSEUP STILLS OF WARM END @ 18 MIN
MOVIE TRAVERSES @ 11 & 25 MIN
@ 18-20 MIN H_2O FROST 0-7", CO_2 FROST 17"-37".

* POOR EXPOSURES - FROST FORMATION NOT CLEAR

GENERAL NOTES:

① COOLANT HEAT EXCHANGER IN LIQUID HYDROGEN BATH BECAME PLUGGED AT APPROX 22 MIN OF RUN TIME CAUSING COOLANT STREAM FLOW TO DECREASE SIGNIFICANTLY.

BY H Chuan DATE 11-6-62 APPROVED ____ DATE ____ CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 180 OF ____ SKETCH NO. ____ CASE NO. 64007

TEST H-6 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
#1 1" SPIRAL TUBE	90	30	1.0	—	.025	.05	LH_2	35¼	10-9-62

VARIABLE INVESTIGATED: H_2O & CO_2 FREEZE-OUT WITH AIR CONDENSATION

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
-0	LH_2 IN COOLANT HEAT EXCHANGER.
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAMS
1	AIR AND COOLANT STREAM RATES SET
1¼	STABLE COOLANT INLET TEMP.
5	QUASI STABLE AIR TEMP DISTRIBUTION
6½	WATER & AIR STREAM MIXING INITIATED
25	TEST HEAT EXCHANGER PLUGGING RATE SHARP INCREASE
35¼	SHUTDOWN.

PHOTOGRAPHIC OBSERVATIONS:

OVERALL STILLS @ 2, 7, 13, 26, 32, 37, 41

CLOSE-UP STILLS @ 10-12, 18-20, 38-40

MOVIE TRAVERSES @ 13, 27, 37

@ 26-27 MIN H_2O FROST: 1-7 HEAVY 7-15 LIGHT

CO_2 FROST: 17-36 HEAVY 36-43 LIGHT

LN_2 CONDENSATION: 43-49

GENERAL NOTES:

TEST H-1 AIR AND COOLANT FLOW

A. ORIFICE DATA

$$\omega_o = \omega_* F_P F_{PR} F_T F_K$$

$F_P = P_1/1000$
$F_K = f$ (fluid)
$\omega_* = f$ (A orifice)
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} SEE A.D.L. CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS Rev 9/28/62

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	ω_* (LB/SEC)	ω_o LB/SEC	$\bar{\omega}_o$ LB/SEC
T_1 = T-113	~~AIR~~ Helium Air	10	475	90	.1895	6.39	74	.995	.994	.0238	.00446	
	ORIFICE NO. 4	20	✓	✓	✓	6.36	72	.998	✓	✓	✓	.00446
		40	✓	✓	✓	6.39	74	.995	✓	✓	✓	
	NOM DIA: .04"	50	✓	✓	✓	6.35	72	.998	✓	✓	✓	
T_1 = T-117	Helium COOLANT	10	675	315	.467	6.39	74	.995	.915	.01815	.00446	
	ORIFICE	20	✓	320	.474	6.32	71	.999	.910	✓	.00445	
	NO. 3	40	✓	325	.481	6.35	72	.998	.908	✓	✓	.00445
	NOM DIA: .035"	50	✓	✓	✓	6.31	70	1.000	✓	✓	✓	

B. BOTTLE DATA

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$$

$V_B = ~~1.70~~\ 1.63\ N + .1$ (FT³)

$R = ~~385~~\ 2.68$ $\frac{FT^3}{°F\ IN^2}$

AIR Helium	COOLANT Helium
V_B = 30.7 FT³	V_B = 30.7 FT³
@ θ = 10 MIN, P_{B1} = 1750 PSIA	@ θ = 10 MIN, P_{B1} = 1890 PSIA
@ θ = 50 MIN, P_{B2} = 1235 PSIA	@ θ = 50 MIN P_{B2} = 1360 PSIA
$\bar{T}_B$ = 67 °F 527 °R	$\bar{T}_B$ = 67 °F 527 °R
Z_1 = 1.063; Z_2 = 1.04	Z_1 = 1.068; Z_2 = 1.048
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 460 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 470 PSI
ΔM_B = 10.0 LB, Δθ = 2400 SEC	ΔM_B = 10.2 LB, Δθ = 2400 SEC
$\bar{\omega}_B$ = .00416 LB/SEC	$\bar{\omega}_B$ = .00425 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{\omega}_o/\bar{\omega}_B$	BEST ESTIMATE
AIR	.00446	.00416	1.070	.00446
COOLANT	.00445	.00425	1.045	.00425

TEST H-2 AIR AND COOLANT FLOW

A. ORIFICE DATA

$$\omega_o = \omega_* F_P F_{PR} F_T F_K$$

$F_P = P_1/1000$
$F_K = f(Fluid)$
$\omega_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	ω_* (LB/SEC)	ω_o LB/SEC	$\bar{\omega}_o$ LB/SEC
T_1 = T-113	~~AIR~~ Helium	10½	475	90	.1895	6.26	68	1.000	.994	.0238	.00450	
	ORIFICE NO. 4	21	✓	✓	✓	6.21	66	1.001	✓	✓	.00451	.00451
		30	✓	✓	✓	6.20	✓	✓	✓	✓	.00451	
	NOM. DIA: .04″	40	✓	✓	✓	6.19	65	1.004	✓	✓	.00452	
T_1 = T-117	Helium COOLANT	10½	675	310	.467	6.26	68	1.000	.915	.01815	.00449	
	ORIFICE NO. 3	21	✓	✓	✓	6.19	65	1.004	✓	✓	.00451	.00451
		30	✓	✓	✓	6.12	62	1.008	✓	✓	.00452	
	NOM. DIA: .035″	40	✓	✓	✓	6.09	60	1.010	✓	✓	.00453	

B. BOTTLE DATA

V_B = ~~1.70N~~ 1.53N + .1 (FT³)

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$$

R = ~~.383~~ 2.68 $\frac{FT^3}{°F\ IN^2}$

AIR Helium	COOLANT Helium
V_B = 30.7 FT³	V_B = 15.4 FT³
@ θ = 10½ MIN, P_{B1} = 1465 PSIA	@ θ = 10½ MIN, P_{B1} = 1685 PSIA
@ θ = 40 MIN, P_{B2} = 1080 PSIA	@ θ = 40 MIN P_{B2} = 815 PSIA
$\bar{T}_B$ = 68° °F 528 °R	$\bar{T}_B$ = 68° °F 528 °R
Z_1 = 1.051 ; Z_2 = 1.038	Z_1 = 1.058 ; Z_2 = 1.028
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 350 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 800 PSI
ΔM_B = 7.61 LB, $\Delta\theta$ = 1770 SEC	ΔM_B = 8.7 LB, $\Delta\theta$ = 1770 SEC
$\bar{\omega}_B$ = .00430 LB/SEC	$\bar{\omega}_B$ = .00492 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{\omega}_o/\bar{\omega}_B$	BEST ESTIMATE
AIR	.00451	.00430	1.050	.00451
COOLANT	.00451	.00492	.917	.00492

BY M. Kates DATE 10/24/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 183 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / ELPERI | CASE NO. 64607

Test H-3A Air and Coolant Flow

A. Orifice Data

$$\omega_o = \omega_* F_P F_{PR} F_T F_K$$

$F_P = P_1/1000$
$F_K = f(F(\omega/d))$
$\omega_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} See ADL calculations "Orifice Flow Calculations" J.C. Burke 8/20/62 for details Rev 9/30/62

	Stream	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_t	F_{PR}	ω_* (LB/SEC)	ω_o LB/SEC	$\bar{\omega}_o$ LB/SEC
T_1 = T-113	Nitrogen Air	10½	585	90	.1537	5.48	32	.1037	.996	.0521	.0305	
	Orifice No. 6	15	✓	✓	✓	5.49	33	.1036	✓	✓	✓	.0305
		20	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Nom Dia: .0595"	24	✓	✓	✓	6.51	34	.1035	✓	✓	✓	
T_1 = T-117	Helium Coolant	10½	485	315	.650	6.31	70	1.000	.793	.0399	.00613	
	Orifice No. 5	15	✓	✓	✓	6.30	✓	✓	✓	✓	✓	.00613
		20	✓	✓	✓	6.28	69	✓	✓	✓	✓	
	Nom Dia: .052"	24	✓	✓	✓	6.26	68	✓	✓	✓	✓	

B. Bottle Data

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$$

$V_B = N_2\ 1.75N + .1$ (FT³) (He 1.53)

$R = N_2\ .383$ (He 2.68) $\frac{FT^3}{°F\ IN^2}$

Air Nitrogen	Coolant Helium
$V_B = 35.1$ FT³	$V_B = 15.4$ FT³
@ θ = 10½ MIN, P_{B1} = 2030 PSIA	@ θ = 10½ MIN, P_{B1} = 1870 PSIA
@ θ = 24 MIN, P_{B2} = 1880 PSIA	@ θ = 24 MIN P_{B2} = 1550 PSIA
$\bar{T}_B$ = 66 °F 526	$\bar{T}_B$ = 66 °F 526
Z_1 = 1.015 ; Z_2 = 1.01	Z_1 = 1.065 ; Z_2 = 1.055
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 154 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 335 PSI
ΔM_B = 26.8 LB, Δθ = 810 SEC	ΔM_B = 3.66 LB, Δθ = 810 SEC
$\bar{\omega}_B$ = .0331 LB/SEC	$\bar{\omega}_B$ = .00451 LB/SEC

Flow	Orifice	Bottles	$\bar{\omega}_o/\bar{\omega}_B$	Best Estimate
Air	.0305	.0331	.921	.0305
Coolant	.00613	.00451	1.359	.00451

BY M. Kates DATE 10/20/62 APPROVED ______ DATE ______ CLIENT ASD / ELPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 184 OF ______ SKETCH NO. ______ CASE NO. 64607

TEST H-4 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_0 = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{fluid})$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_0 LB/SEC	$\bar{W}_0$ LB/SEC
T_1 = T-113	Nitrogen AIR	10	265	90	.339	5.45	31	1.040	.26	.0521	.0138	
	ORIFICE NO. 6	30½	✓	✓	✓	✓	✓	✓	✓	✓	✓	.0125
		35½	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	NOM DIA: .0595	45½	175	✓	.514	5.50	34	1.035	.89	✓	.0084	
T_1 = T-117	Helium COOLANT	10	485	325	.671	6.16	64	1.005	.773	.0399	.00601	
	ORIFICE NO. 5	30½	✓	✓	✓	6.11	62	1.007	✓	✓	.00604	.00604
		35½	✓	✓	✓	6.10	61	1.009	✓	✓	✓	
	NOM DIA: .052	45½	✓	✓	✓	6.09	60	1.010	✓	✓	✓	

B. BOTTLE DATA

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B =$ (He 1.53; N_2 1.75) $N + .1$ (FT^3)

$R =$ (He 2.64; N_2 .383) $\frac{FT^3}{°F\ IN^2}$

AIR Nitrogen	COOLANT Helium
$V_B = 35.1$ FT³	$V_B = 30.7$ FT³
@ θ = 10 MIN, P_{B1} = 1670 PSIA	@ θ = 10 MIN, P_{B1} = 1100 PSIA
@ θ = 45½ MIN, P_{B2} = 1495 PSIA	@ θ = 45½ MIN, P_{B2} = 745 PSIA
$\bar{T}_B$ = 66 °F 526 °R	$\bar{T}_B$ = 66 °F 526 °R
Z_1 = 1.005 ; Z_2 = 1.000	Z_1 = 1.040 ; Z_2 = 1.018
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 165 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 327 PSI
ΔM_B = 28.7 LB ; Δθ = 2130 SEC	ΔM_B = 7.13 LB , Δθ = 2130 SEC
$\bar{W}_B$ = .0133 LB/SEC	$\bar{W}_B$ = .00330 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_0/\bar{W}_B$	BEST ESTIMATE
AIR	.0125	.0133	.940	.0125
COOLANT	.00604	.0033	1.830	.0033

BY M. Kates DATE 10/29/62 | **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. | SHEET NO. 185 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD/EXPERI | CASE NO. 64607

TEST H-5 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_O = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f$ (FLUID)
$W_* = f$ (A ORIFICE)
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" D.C. PUEKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_O LB/SEC	$\bar{W}_O$ LB/SEC
T_1 = T-113	Nitrogen AIR	10	585	90	.154	.515	17	1.054	.996	.0521	.0321	
	ORIFICE NO. 6	15	✓	✓	✓	.515	✓	✓	✓	✓	.0321	.0320
		20	✓	✓	✓	.526	22	1.050	✓	✓	.0319	
	NOM DIA: .059											
T_1 = T-117	Helium COOLANT	10	765	315	.413	6.01	57	1.011	.937	.0399	.0116	
	ORIFICE NO. 5	15	✓	✓	✓	5.99	56	1.013	✓	✓	.01161	
		20	✓	✓	✓	5.95	54	1.015	✓	✓	.01165	.0116
	NOM DIA: .052											

B. BOTTLE DATA

V_B = (N_2) 1.75 N + .1 (He 1.53) (FT^3)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

R = (N_2) .383 (He 2.68) $\frac{FT^3}{°F\ IN^2}$

AIR Nitrogen	COOLANT Helium
V_B = 35.1 FT^3	V_B = 30.7 FT^3
@ θ = 10 MIN, P_{B1} = 2115 PSIA	@ θ = 10 MIN, P_{B1} = 1960 PSIA
@ θ = 20 MIN, P_{B2} = 1995 PSIA	@ θ = 20 MIN P_{B2} = 1680 PSIA
$\bar{T}_B$ = 59 °F 519°	$\bar{T}_B$ = 59 °F 519°
Z_1 = 1.015 ; Z_2 = 1.013	Z_1 = 1.071 ; Z_2 = 1.06
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 110 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 241 PSI
ΔM_B = 19.45 LB ; $\Delta\theta$ = 600 SEC	ΔM_B = 5.33 LB , $\Delta\theta$ = 600 SEC
$\bar{W}_B$ = .0324 LB/SEC	$\bar{W}_B$ = .00886 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_O/\bar{W}_B$	BEST ESTIMATE
AIR	.0320	.0324	.987	.0320
COOLANT	.0116	.00886	1.320	.00886

Test H-6 Air and Coolant Flow

A. Orifice Data

$W_O = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{fluid})$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} See ADL calculations "Orifice Flow Calculations" J.C. Burke 8/20/62 for details

	Stream	θ (min)	P_1 (psia)	P_2 (psia)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (lb/sec)	W_O lb/sec	$\bar{W}_O$ lb/sec
T_1 = T-113	Nitrogen Air	10 1/2	585	90	.154	5.51	34	1.035	.996	.0521	.0314	
	Orifice No. 6	18	✓	✓	✓	5.53	35	✓	✓	✓	✓	
		25	✓	✓	✓	5.55	36	1.033	✓	✓	✓	.0314
	Nom. Dia. .0595"	32	✓	✓	✓	5.58	37	✓	✓	✓	✓	
T_1 = T-117	Helium Coolant	10 1/2	765	315	.413	5.85	54	1.015	.937	.0399	.0116	
	Orifice No. 5	18	✓	✓	✓	5.90	52	1.017	✓	✓	✓	.01165
		25	✓	✓	✓	5.85	50	1.020	✓	✓	.0117	
	Nom. Dia. .052"	32	✓	✓	✓	5.80	49	✓	✓	✓	✓	

B. Bottle Data

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B = 1.75N + .1$ (ft³) (He 1.53, N_2 1.75)

$R = 4.383 \frac{ft^3}{°F\ in^2}$ (He 2.68)

Air Nitrogen	Coolant Helium
V_B = 35.1 ft³	V_B = 30.7 ft³
@ θ = 10 1/2 min, P_{B1} = 1230 psia	@ θ = 10 1/2 min, P_{B1} = 1440 psia
@ θ = 32 min, P_{B2} = 1005 psia	@ θ = 32 min, P_{B2} = 825 psia
$\bar{T}_B$ = 56 °F or 516 °R	$\bar{T}_B$ = 56 °F or 516 °R
Z_1 = .9915 ; Z_2 = .9895	Z_1 = 1.053 ; Z_2 = 1.031
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 220 psi	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 605 psi
ΔM_B = 39.1 lb ; Δθ = 1290 sec	ΔM_B = 13.5 lb, Δθ = 1290 sec
$\bar{W}_B$ = .0303 lb/sec	$\bar{W}_B$ = .01045 lb/sec

Flow	Orifice	Bottles	$\bar{W}_O/\bar{W}_B$	Best Estimate
Air	.0314	.0303	1.035	.0303
Coolant	.01165	.01045	1.115	.01045

Test Heat Exchanger Energy Balance
(based on uncorrected coolant temperatures)

Test	q_a Btu/Hr	q_c Btu/Hr	q_c/q_a
H-1	6690	8290	1.258
H-2	8760	9380	1.070
H-3A	1010*	9460	.937
H-4	4230*	6080	1.439
H-6	9250*	13,550	1.465
H-5	9910*	12,590	1.270

* ASSUMING EXIT AIR IS VAPOR SATURATED AT EXIT PRESSURE (SEE FOLLOWING PAGE)

CALCULATION OF EXIT QUALITY FOR TESTS H-3A, H-4, H-5, H-6

ASSUME ENERGY BALANCE CLOSURE AND CALCULATE RESULTING AIR EXIT QUALITY

$$\Delta h_a = \Delta h_e \frac{w_e}{w_a} \quad ; \quad h_{2a} = h_{1a} - \Delta h_a$$

X = VAPOR FRACTION IN EXIT AIR

$$h_{2a} = x h_{sv} + (1-x) h_{sL}$$

$$x (h_{sv} - h_{sL}) = h_{2a} - h_{sL}$$

$$X = \frac{h_{2a} - h_{sL}}{h_{sv} - h_{sL}}$$

	H-3A	H-4	H-6	H-5
Δh_e	581	512	360	394
w_e/w_a	.148	.264	.332	.277
Δh_a	86	135	120	109
h_{1a}	127	129	120	121
h_{2a}	41	-6	0	12
h_{sv}	35	35	34	35
h_{sL}	-42	-38	-44	-39
X	1.08	.44	.565	.69
1-X	0	.66	.435	.31

HEAT EXCHANGER ENERGY BALANCE DATA

q_a ~ Air -SIDE HEAT TRANSFER

	TEST NO	θ (MIN)	ω (LB/SEC)	T_1 T-101 (°F)	P_1 P-121 (PSIA)	h_1 (BTU/LB)	T_2 T-105 (°F)	P_2 P-130 (PSIA)	h_2 (BTU/LB)	Δh h_1-h_2 (BTU/LB)	q (BTU/SEC)	q (BTU/HR)
He	H-1	30	.00446	80	88	680	-246	86.5	270	410	1.83	6590
He	H-2	30	.00451	70	88	662	-362	77.5	122	540	2.439	8760
N_2	H-3A	20	.0305	60	88	127	-295	73.5	35*	92	2.81	1010
N_2	H-4	30½	.0125	68	88	129	-291	86.5	35*	94	1.75	4230
N_2	H-6	30	.0314	32	88	120	-291	51	38*	82	2.57	9250
N_2	H-5	20	.0320	34	89	121	-300	78.5	35*	86	2.75	9910

* ASSUME EXIT AIR IS VAPOR SATURATED @ P-120

Heat Exchanger Energy Balance Data

q_c ~ Coolant-side Heat Transfer
(based on uncorrected Coolant Temperatures)

Test No	θ (MIN)	ω (LB/SEC)	T_1 T-108 (°F)	P_1 P-147 (PSIA)	h_1 (BTU/LB)	T_2 T-109 (°F)	P_2 P-131 (PSIA)	h_2 (BTU/LB)	Δh h_2-h_1 (BTU/LB)	q (BTU/SEC)	q (BTU/HR)
H-1	30	.00425	-308	315	105	56	325	647	542	2.305	8290
H-2	30	.00492	-408	315	66	15	315	596	530	2.610	9380
H-3A	20	.00451	-408	315	66	56	315	647	581	2.625	9460
H-4	30½	.0033	-408	315	66	0	325	578	512	1.690	6080
H-6	30	.01045	-408	315	66	-120	315	426	360	3.770	13,550
H-5	80	.00886	-408	315	66	-92	316	460	394	3.499	12,590

BY M. Kates DATE 10/26/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 191 OF

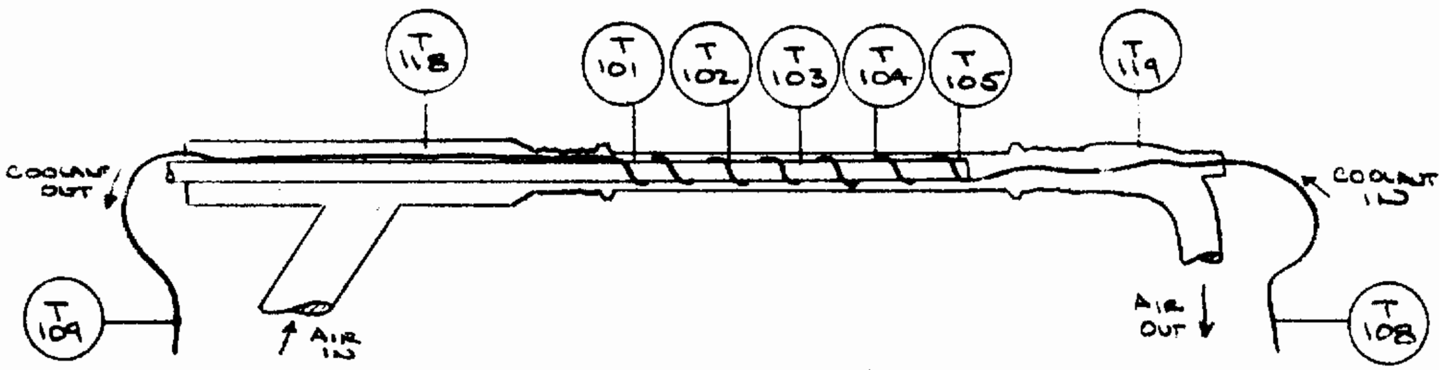
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______

CLIENT ASD / EXPERI CASE NO. 64607

TEST H-1

AIR (HE) AND COOLANT (HC) TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	1,9		2,10		3,11		4,12		5,13		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.2	66	6.2	66	6.15	63	6.21	66	5.90	52	6.44	76	6.60	81		-308	6.23	67
2	6.36	72	6.00	56	5.27	22	3.60	-62	1.50	-190	6.55	81	3.95	-43		-308	6.36	72
5	6.61	84	5.00	10	3.59	-62	2.05	-152	0.84	-240	6.75	90	2.95	-98		-308	6.22	66
7	6.73	89	4.47	-16	2.91	-96	1.67	-178	0.71	-252	6.79	92	2.59	-119		-308	6.05	58
10	6.65	86	4.20	-30	2.71	-112	1.49	-190	0.67	-256	6.72	88	2.17	-144		-308	5.97	55
12	6.61	84	4.10	-35	2.62	-118	1.42	-196	0.65	✓	6.71	✓	2.01	-156		-308	5.90	52
15	6.56	82	4.02	-40	2.58	-120	1.40	-198	✓	✓	6.69	87	1.90	-162		-308	5.89	✓
20	6.51	79	4.01	✓	2.56	✓	1.39	✓	✓	✓	6.67	86	1.71	-176		-308	5.83	48
25	✓	✓	4.16	-32	2.72	-112	1.49	-190	0.71	-252	6.65	✓	1.65	-180		-308	6.00	52
28	✓	✓	4.69	-6	3.15	-86	1.73	-174	0.81	-243	✓	✓	1.77	-172		-308	6.11	62
30	6.52	80	4.36	-22	2.94	-98	1.61	-182	0.78	-246	6.68	87	1.71	-176		-308	5.99	56
35	6.58	82	4.51	-14	3.10	-89	1.71	-176	0.82	-242	6.69	✓	1.69	✓		-308	6.08	[illegible]
40	6.57	✓	4.55	-12	3.14	-87	1.73	-174	✓	✓	✓	✓	1.61	-182		-308	✓	✓
45	✓	✓	4.57	✓	3.17	-83	1.75	-172	✓	✓	✓	✓	1.59	-184		-308	6.09	✓
50	6.58	✓	4.51	-14	3.11	-88	1.71	-176	0.81	-243	✓	✓	✓	✓			✓	✓



NOTES:

(1) T-108 ESTIMATED ON BASIS OF 12°F RISE BETWEEN COOLANT TANK AND INST. POINT (TYPICAL OF VAPOR BULB RESULTS IN TESTS H-2 – H-6)

(2) 25-28 MIN – INSTR. BOTTLE CHANGE

BY M. Kates DATE 10/27/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 192 OF ______

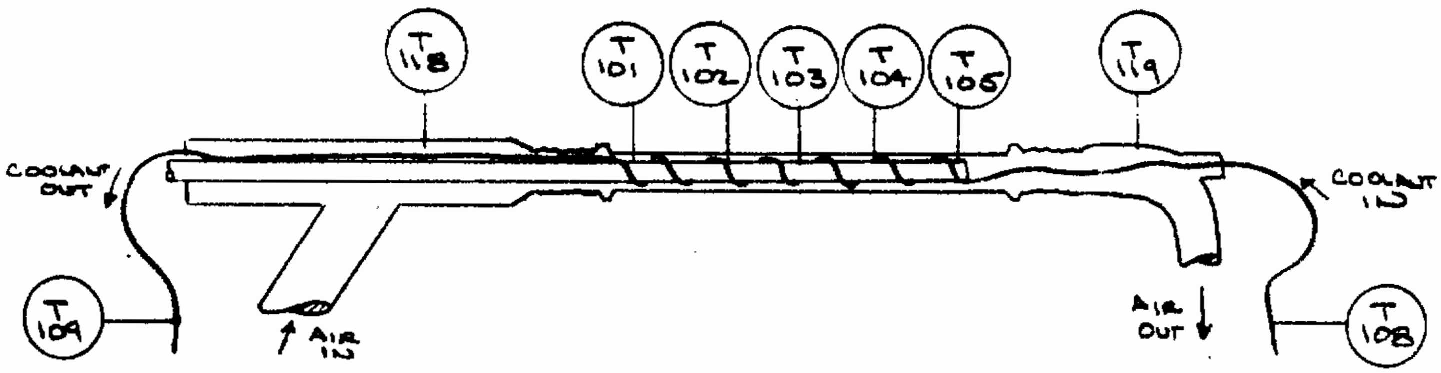
APPROVED ______ DATE ______ | SKETCH NO. ______

CLIENT ASD / EXPERI | CASE NO. 64607

TEST H-2

AIR (He) AND COOLANT (He) TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101 1,9		T-102 2,10		T-103 3,11		T-104 4,12		T-105 5,13		T-118 8		T-119 TR-112		T-108 6,14		T-109 16	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
0	5.49	33	1.36	-200	0.72	-250	0.35	-294		-324	6.15	63	6.57	82		-408	4.21	-30
2½	5.95	54	3.80	-50	2.19	-144	0.85	-240		-301	6.51	79	3.28	-74		-408	5.45	31
5½	6.42	75	3.41	-72	1.61	-182	0.61	-269		-325	6.71	88	2.15	-146		-408	5.50	34
7	6.51	79	2.87	-102	1.11	-218	0.15	-304		-356	6.72	✓	1.89	-164		-408	5.41	29
9½	6.49	78	2.69	-113	1.01	-226	0.10	-309		-360	✓	✓	1.68	-178		-408	5.23	20
16½	6.40	74	2.65	-116	1.02	✓	✓	✓		✓	6.65	86	1.35	-200		-408	5.20	19
21	6.35	72	2.71	-112	1.07	-222	✓	✓	.39	-362	✓	✓	1.19	-212		-408	✓	✓
26½	6.32	71	2.69	-113	1.03	-224	0.09	-310	✓	✓	6.60	83	1.06	-222		-408	5.13	16
30	6.31	70	✓	✓	✓	✓	0.06	-314	✓	✓	✓	✓	0.99	-228		-408	5.11	15
36	✓	✓	2.89	-102	1.19	-212	0.15	-304	0.36	-366	✓	✓	0.89	-236		-408	5.21	20
40	6.29	✓	2.80	-106	1.08	-222	0.10	-309	0.39	-362	✓	✓	0.61	-260		-408	5.12	16
42	6.30	✓	2.69	-113	1.00	-228	0.05	-315	✓	✓	6.58	82	0.57	-264		-408	5.04	14



NOTES:

(1) T-105 0-16½ min T/C off scale. Temp. Extrapolated. 21-42 min Polarity reversed. mV reading are for below -320°F.

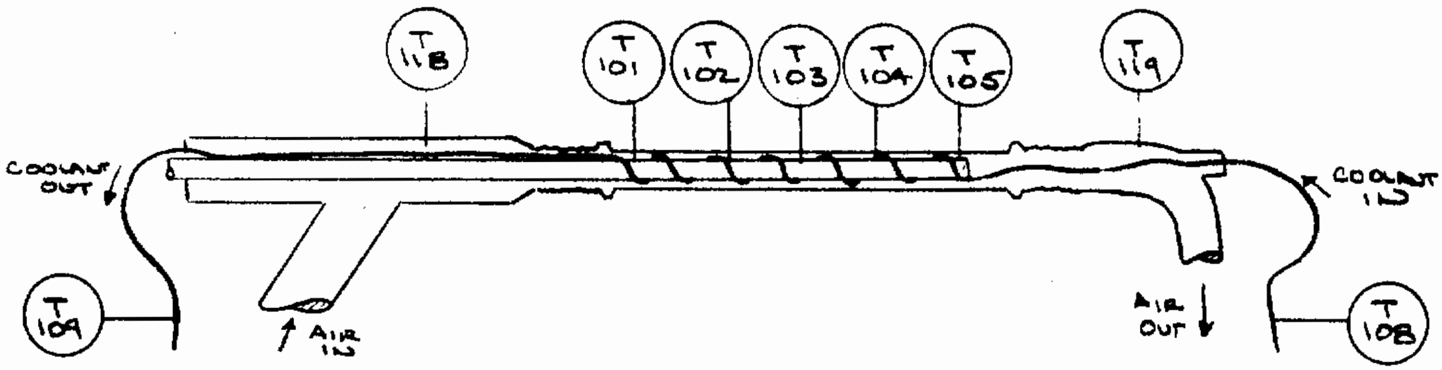
(2) T-108 Estimated from read vapor bulb data.

BY M. Kates DATE 10/27/62 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 193 OF ______
APPROVED ______ DATE ______ — SKETCH NO. ______
CLIENT ASD / EXPERI — CASE NO. 64607

TEST H-3A

AIR (N₂) AND COOLANT (He) TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures: T-101 (1,9) mV	T-101 °F	T-102 (2,10) mV	T-102 °F	T-103 (3,11) mV	T-103 °F	T-104 (4,12) mV	T-104 °F	T-105 (5,13) mV	T-105 °F	Air In: T-118 (8) mV	T-118 °F	Air Out: T-119 (TR-118) (5,11,12) mV	T-119 °F	Coolant In: T-108 (6,17) mV	T-108 °F	Coolant Out: T-109 (16) mV	T-109 °F
0	6.29	70	6.29	70	6.25	68	6.21	66		-296	6.25	68	6.23	67		-408	6.29	70
1½	6.35	72	6.40	74	6.31	70	6.18	64		-296	6.50	79	5.30	24		-408	6.41	75
3½	6.55	81	6.32	71	5.69	87	4.21	-30		-295	6.51	✓	3.72	-55		-408	6.49	78
6½	✓	✓	6.12	62	5.44	30	3.92	-44		-295	6.39	74	3.00	-94		-408	6.31	70
10½	6.38	74	5.99	56	5.30	24	3.77	-52		-295	6.25	68	2.60	-118		-408	6.20	66
15	6.19	65	5.81	48	5.12	16	3.69	-62		-295	6.15	63	2.37	-132		-408	6.09	60
17½	6.13	62	5.79	47	5.09	14	3.55	-64		-295	6.14	✓	2.27	-138		-408	6.02	57
20	6.09	60	5.73	44	5.07	13	3.50	-67		-295	6.09	60	2.19	-144		-408	6.00	56
24	6.05	58	5.71	43	5.00	10	3.42	-72		-295	6.05	58	2.10	-150		-408	5.99	✓



NOTES:

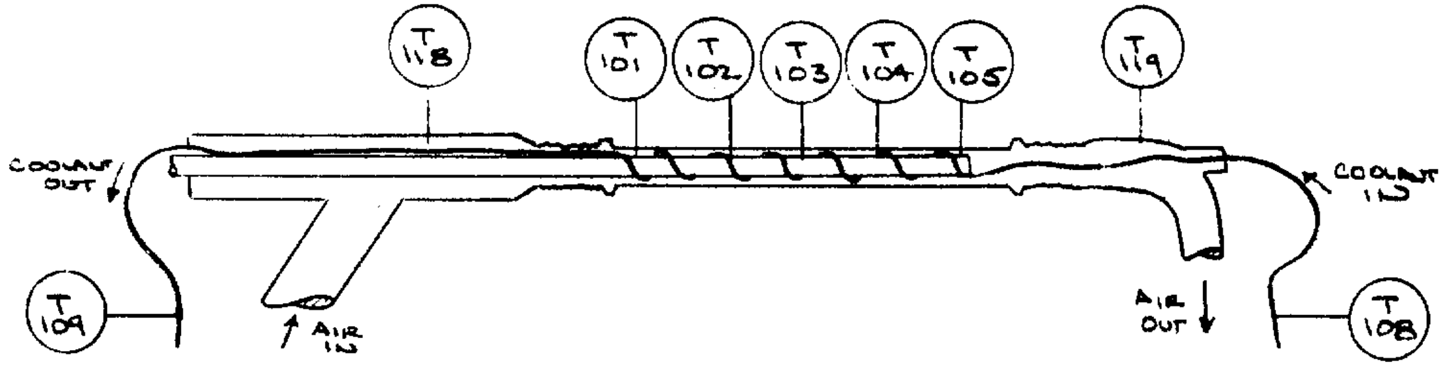
1. TR-112 RECORDER PRINT KEY PER TEST C-1 CHART (EXCEPT AS NOTED)
2. T-119 RECORDED ON TR-118 RECORDER
3. T-105 off scale Temp. from Kellogg Chart at Saturation
4. T-108 ESTIMATED FROM HEAD VAPOR BULB DATA

BY M. Kates DATE 10/27/62 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 194 OF ____
APPROVED ____ DATE ____ — SKETCH NO. ____
CLIENT ASD / EXPERI — CASE NO. 64607

TEST H-4

AIR (N2) AND COOLANT (He) TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119 (TR-118)		T-108		T-109	
	1,9		2,10		3,11		4,12		5,13		8		6, 11,16					
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.42	75	6.12	62	5.62	39	4.49	-16		-292	6.28	69	5.91	52		-408	5.50	34
1½	6.51	79	5.70	42	4.71	-4	3.30	-78		-291	6.40	74	5.18	18		-408	6.35	72
3	6.50	✓	4.88	4	4.00	-40	1.91	-162		-291	6.49	78	4.65	-8		-408	5.90	52
5	6.51	✓	4.06	-37	2.70	-112	1.35	-200		-291	✓	✓	4.42	-19		-408	5.65	40
7	✓	✓	3.60	-62	2.20	-143	1.09	-220		-291	6.50	79	4.27	-26		-408	5.32	25
10	6.49	78	3.33	-76	1.95	-160	0.95	-232		-291	6.44	76	3.99	-41		-408	5.19	19
12	6.45	76	3.30	-78	1.92	-162	0.99	-228		-291	✓	✓	3.75	-54		-408	5.15	17
15	6.32	71	3.29	✓	1.91	✓	1.00	✓		-291	6.41	75	3.50	-67		-408	5.01	10
20	6.35	72	3.25	-80	1.89	-164	0.99	✓		-291	6.35	72	3.20	-84		-408	5.05	12
25	6.17	64	3.17	-85	1.85	-166	✓	✓		-292	6.31	70	3.03	-93		-408	4.91	6
30½	6.25	68	3.10	-89	1.89	-164	0.98	-229		-291	✓	✓	2.90	-100		-408	4.81	0
35½	6.21	66	3.12	-88	✓	✓	✓	✓		-291	6.32	71	2.81	-106		-408	✓	✓
41½	6.15	63	3.02	-94	1.73	-174	0.91	-234		-291	6.25	68	2.74	-110		-408	4.61	-10
45½	6.08	60	✓	✓	✓	✓	✓	✓		-291	6.29	70	2.71	-112		-408	4.78	-1



NOTES:

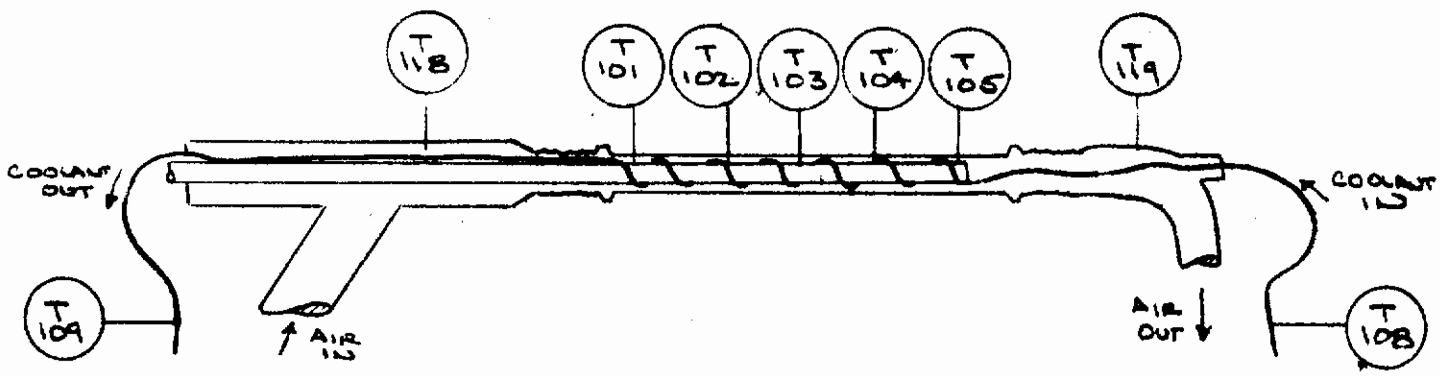
1. TR-112 RECORDER PRINT KEY PER TEST C-1 CHART (EXCEPT AS NOTED)
2. T-119 ON RECORDER TR-118
3. T-108 ESTIMATED FROM MEAN VAPOR BULB DATA

4. T-105 off scale Temp. from Kellogg Chart at Saturation

TEST H-5

AIR (N_2) AND COOLANT (He) TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119 TR-118		T-108		T-109	
	1,9		2,10		3,11		4,12		5,13		8		[illegible] 11,16		[illegible]		[illegible]	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.07	60	5.93	53	5.90	52	5.81	48	5.02	10	6.18	62	6.16	64		-408	6.12	62
1½	6.11	62	5.85	50	5.13	16	3.80	-50	2.01	-156	6.20	66	4.22	-29		-408	✓	✓
3	6.09	60	2.61	-118	1.27	-206	0.71	-252	0.19	-300	6.15	63	3.72	-44		-408	3.67	-58
5	6.11	62	2.41	-130	1.11	-218	0.62	-259	✓	✓	6.18	64	3.64	-60		-408	3.47	-68
7	✓	✓	2.42	✓	1.13	✓	0.65	-256	0.21	-298	6.20	66	3.40	-72		-408	3.39	-73
10	6.10	61	2.31	-136	1.09	-220	0.69	-253	0.23	-296	6.10	61	3.13	-88		-408	3.29	-78
12	5.64	40	2.21	-142	✓	✓	0.62	-259	0.15	-304	6.05	58	2.95	-98		-408	3.21	-83
15	5.66	41	2.19	-144	1.05	-224	0.66	-256	0.19	-300	6.09	60	2.83	-104		-408	3.12	-88
17	5.64	40	2.15	-146	1.10	-220	0.69	-253	✓	✓	6.11	62	2.77	-108		-408	3.09	-90
20	5.50	34	2.12	-148	1.07	-222	0.61	-260	✓	✓	6.09	60	2.65	-116		-408	3.05	-92



NOTES:

1. TR-112 RECORDER PRINT KEY PER TEST C-1 CHART (EXCEPT AS NOTED)
2. T-119 ON RECORDER TR-118
3. T-108 ESTIMATED FROM MEAN VAPOR BULB DATA

BY M. Kates DATE 9/27/62 | ARTHUR D. LITTLE, INC. | SHEET NO. 196 OF ____

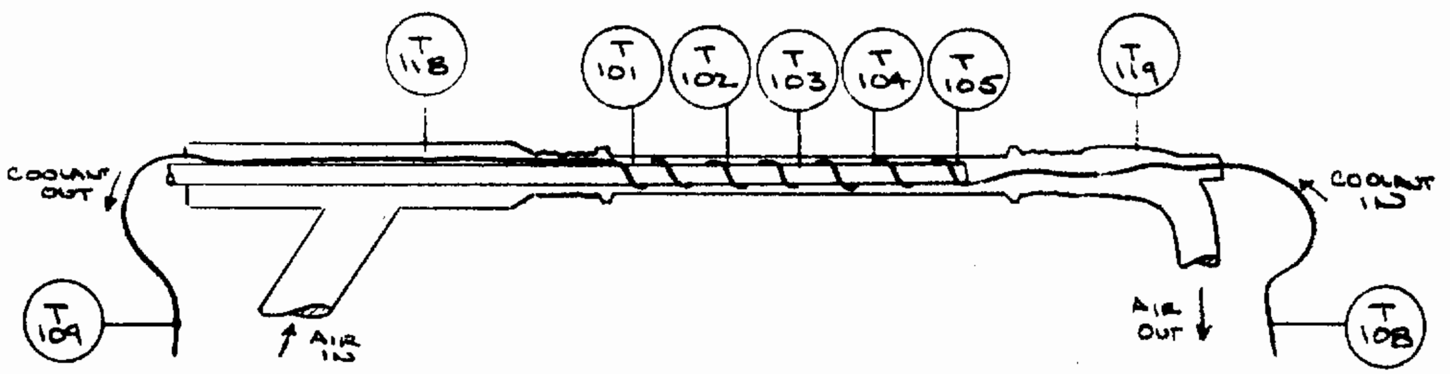
APPROVED ____ DATE ____ | CAMBRIDGE, MASS. | SKETCH NO. ____

CLIENT ASD / EXPERI | CASE NO. 64607

TEST H-6

AIR (N2) AND COOLANT (He) TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119 TR-112		T-108		T-109	
	1,9		2,10		3,11		4,12		5,13		8		[illegible]		[illegible]		[illegible]	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.05	58	5.63	40	6.02	57	4.09	-36	2.71	-176	6.16	64	6.09	60		-408	6.06	59
1½	5.89	52	3.15	-86	1.91	-162	0.99	-228	0.32	-287	6.23	67	4.06	-37		-408	4.10	-35
3	5.90	✓	2.41	-130	1.11	-218	0.60	-261	0.29	-290	6.30	70	3.98	-41		-408	3.27	-74
5	✓	✓	2.20	-143	1.06	-222	✓	✓	0.31	-288	6.22	66	4.01	-40		-408	3.15	-86
7	5.80	47	2.13	-148	1.02	-226	✓	✓	0.32	-287	5.95	54	3.81	-50		-408	3.01	-94
10½	5.63	40	2.31	-136	1.11	-218	0.69	-253	0.39	-280	6.10	61	3.49	-68		-408	2.81	-106
15	5.50	34	2.60	-118	1.23	-210	0.71	✓	0.34	-285	6.09	60	3.18	-84		-408	2.71	-112
18	5.49	33	✓	✓	✓	✓	0.75	-248	0.35	-284	6.10	61	3.02	-94		-408	2.67	-114
20	5.47	32	2.65	-116	1.28	-206	0.73	-250	✓	✓	5.90	52	2.93	-98		-408	✓	✓
22	✓	✓	2.61	-118	1.22	-210	0.75	-248	0.31	-288	5.81	48	2.86	-103		-408	2.62	-118
25	5.46	✓	2.59	-119	1.23	✓	0.73	-250	0.33	-286	6.09	60	2.70	-112		-408	2.60	✓
30	5.48	✓	2.49	-125	1.10	-220	0.63	-258	0.28	-291	5.88	51	2.33	-134		-408	2.58	-120
32	✓	✓	2.40	-130	1.09	✓	0.57	-264	0.22	-297	6.05	58	2.11	-148		-408	2.52	-124
34	5.49	33	2.33	-134	0.99	-228	0.50	-270	0.20	-299	6.19	65	1.98	-160		-408	2.46	-126



NOTES:

1. TR-112 RECORDER PRINT KEY PER TEST C-4 CHART (EXCEPT AS NOTED)
2. T-119 ON RECORDER TR-118
3. T-108 ESTIMATED FROM HELIUM VAPOR BULB DATA

BY M. Kates DATE 10/27/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 192 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD/EXPERI | CASE NO. 64607

TEST H-1

AIR (He) AND COOLANT (He) AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
0	0	3	−3	14	14	375
2	16	34	84	128	262	380
5	74	72	90	88	324	374
7	105	80	82	74	341	366
10	116	82	78	66	342	363
12	119	83	78	60	340	360
15	122	80	78	58	338	360
20	110	80	78	58	335	356
25	111	80	78	62	331	360
28	85	80	88	69	322	370
30	102	76	84	64	326	364
36	96	75	85	66	324	368
40	94	75	87	68	324	368
45	94	71	89	70	324	368
50	96	74	88	67	325	368

BY M. Kates DATE 10/27/62 APPROVED ______ DATE ______

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 198 OF ______
SKETCH NO. ______
CASE NO. 64607

CLIENT ASD/EXPERI.

TEST H-2

AIR (He) AND COOLANT (He) AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101} - T_{102}$	$T_{102} - T_{103}$	$T_{103} - T_{104}$	$T_{104} - T_{105}$	$T_{101} - T_{105}$	$T_{109} - T_{108}$
0	233	50	44	30	357	378
2 1/2	104	94	96	61	355	439
5 1/2	147	110	87	56	400	442
7	181	116	86	52	435	437
9 1/2	191	113	83	51	438	428
16 1/2	190	110	83	51	434	427
21	184	110	87	53	434	427
26 1/2	184	111	86	52	433	424
30	183	111	90	48	432	423
36	172	110	92	62	436	428
40	176	116	87	53	432	424
42	183	115	87	47	432	422

BY M. Katz DATE 10/27/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 199 OF

APPROVED .... DATE .... | SKETCH NO. ....

CLIENT ASD/EXPERI | CASE NO. 64607

TEST H-3A

AIR (N_2) AND COOLANT (He) AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1	AIR ΔT_2	AIR ΔT_3	AIR ΔT_4	AIR OVERALL ΔT	COOLANT OVERALL ΔT
	$T_{101} - T_{102}$	$T_{102} - T_{103}$	$T_{103} - T_{104}$	$T_{104} - T_{105}$	$T_{101} - T_{105}$	$T_{109} - T_{108}$
0	0	2	2	362	366	478
1½	-2	4	6	360	368	483
3½	10	-16	117	265	376	486
6½	19	32	74	251	376	478
10½	18	32	76	243	369	474
15	17	32	78	233	360	468
17½	15	33	78	231	357	465
20	16	31	80	228	355	464
24	15	33	82	223	353	464

BY M. Kates DATE 10/27/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 200 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD/EXPERI | CASE NO. 64607

TEST H-4

AIR (N2) AND COOLANT (He) AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT1	ΔT2	ΔT3	ΔT4	OVERALL ΔT	OVERALL ΔT
	T101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
0	13	23	55	276	367	442
1 1/2	37	46	74	213	370	480
3	75	44	112	129	370	460
5	116	75	88	91	370	448
7	141	81	77	71	370	433
10	154	84	72	59	369	417
12	154	84	66	63	367	425
15	149	84	66	63	362	418
20	152	84	64	63	363	420
25	149	81	62	64	356	414
30 1/2	157	75	65	62	359	408
35 1/2	154	76	65	62	357	408
41 1/2	157	80	60	57	354	398
45 1/2	154	80	60	57	351	407

BY M. Kates DATE 10/07/62 ARTHUR D. LITTLE, INC. SHEET NO. 201 OF

APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______

CLIENT ASD/EXPERI CASE NO. 64607

TEST H-5

AIR (N_2) AND COOLANT (He) AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT1	ΔT2	ΔT3	ΔT4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
0	7	1	4	38	50	470
1½	12	34	66	106	218	470
3	178	88	46	48	360	350
5	192	88	41	41	362	340
7	192	88	36	42	360	335
10	197	84	33	43	357	330
12	182	78	39	45	344	325
15	185	70	32	44	341	320
17	186	74	33	47	340	318
20	182	74	38	40	334	316

BY M. Kates DATE 10/27/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 202 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD/EXPERI | CASE NO. 64607

TEST H-6

AIR (N_2) AND COOLANT (He) AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{101}-T_{105}$	$T_{109}-T_{108}$
0	18	-17	93	140	234	467
1½	138	76	66	59	339	373
3	182	88	43	29	342	334
5	195	79	39	27	340	322
7	195	78	35	26	334	314
10½	176	82	35	27	320	302
15	152	92	43	32	319	296
18	151	92	38	36	317	294
20	148	90	46	34	316	294
22	150	92	38	40	320	290
25	151	91	40	46	318	290
30	157	95	38	33	323	288
32	168	80	48	33	329	284
34	167	94	42	29	332	282

BY M. Kates DATE 10/26/62
APPROVED ______ DATE ______
CLIENT ASD / ENPERA

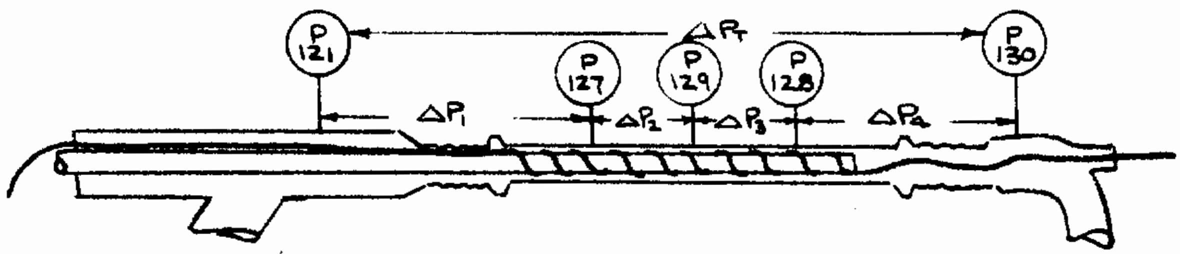
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO 203 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST H-1

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2	73	72	69	69.5	67.5	1	3	-1/2	2	5 1/2
5	71	69	✓	68.5	66.5	2	0	1/2	✓	4 1/2
10	73	72	71	71.5	70.5	1	1	-1/2	1	2 1/2
15	✓	✓	72	✓	✓	✓	0	1/2	✓	✓
20	✓	✓	✓	72.5	71.5	✓	✓	-1/2	✓	1 1/2
28	✓	71	71	70.5	68.5	2	✓	1/2	2	5 1/2
30	✓	72	72	72.5	71.5	1	✓	-1/2	1	1 1/2
36	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
40	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
45	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
50	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓



NOTES:

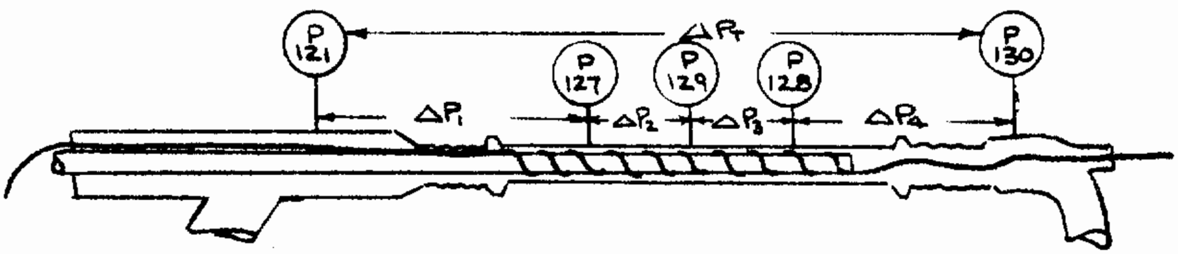
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA

BY M. Kates DATE 10/26/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 204 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD / [illegible] | CASE NO. 6A607

TEST H-2

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2 1/2	73	73	69	69.5	68.5	0	4	-1/2	1	4.5
5 1/2	✓	72	71	71.5	70.5	1	1	-1/2	1	2.5
9 1/2	✓	70	70	70.5	✓	3	0	-1/2	0	✓
16 1/2	74.5	72	72	71.5	72.5	2 1/2	0	1/2	-1	2
21	73	71	71	70.5	70.5	2	0	1/2	0	2.5
26 1/2	74.5	72	72	✓	✓	2 1/2	0	1 1/2	0	4
30	73	✓	69	64.5	62.5	1	3	4.5	2	8.5
36	✓	71	65	53.5	53.5	2	6	11.5	0	19.5
40	72	✓	48.5	23.5	24.5	1	22.5	45	-1	47.5
42	83.5	77	41.5	0	0	6 1/2	35.5	41.5	0	83.5



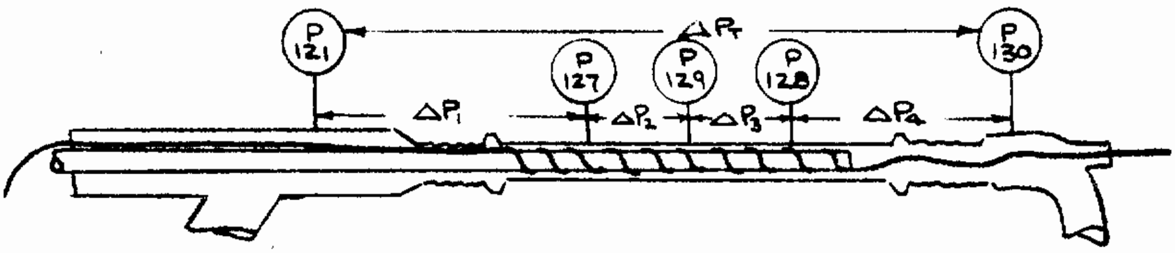
NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~OF [illegible]~~

TEST H-3A

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L = 0 P-121 (PSIG)	x/L = 1/4 P-127 (PSIG)	x/L = 1/2 P-129 (PSIG)	x/L = 3/4 P-128 (PSIG)	x/L = 1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1½	72	68	64	59.5	57.0	4	4	4.5	2	14.5
3½	73	✓	✓	✓	✓	5	✓	✓	✓	15.5
6½	✓	✓	✓	61.0	58.5	✓	✓	2.5	3	14.5
10½	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
15	✓	✓	65	✓	✓	✓	3	3.5	✓	✓
17½	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
24	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION
~~DATA OF [illegible]~~

BY M. Kates DATE 10/26/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 206 OF

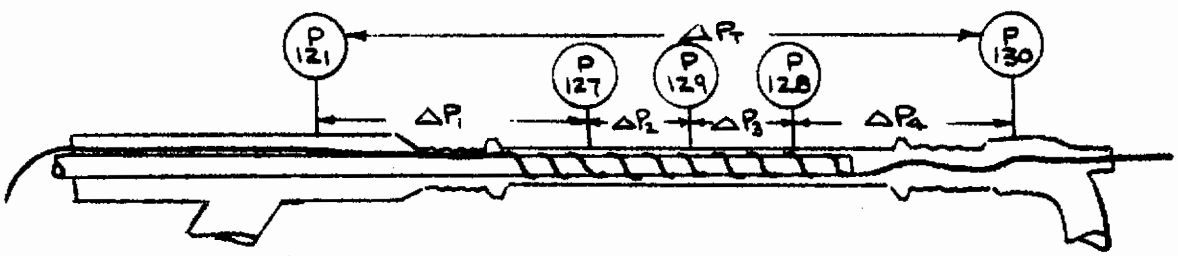
APPROVED ______ DATE ______ | SKETCH NO. ______

CLIENT ASD / [illegible] | CASE NO. 64607

TEST H-4

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1½	73	72	71	69.5	70.5	1	1	1½	-1	2½
5	✓	✓	72	70.5	71.5	✓	0	✓	✓	1½
10	✓	✓	71	✓	✓	✓	1	½	✓	✓
15	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
25	✓	✓	✓	69.5	70.5	✓	✓	1½	✓	2½
30½	✓	✓	✓	70.5	71.5	✓	✓	½	✓	1½
35½	✓	✓	✓	✓	70.5	✓	✓	✓	0	2½
41½	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
45½	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
52	✓	73	✓	73.5	72.5	0	2	-2½	1	½
60	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
65½	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
70	72	72	72	72.5	71.5	✓	0	-½	✓	✓



NOTES:

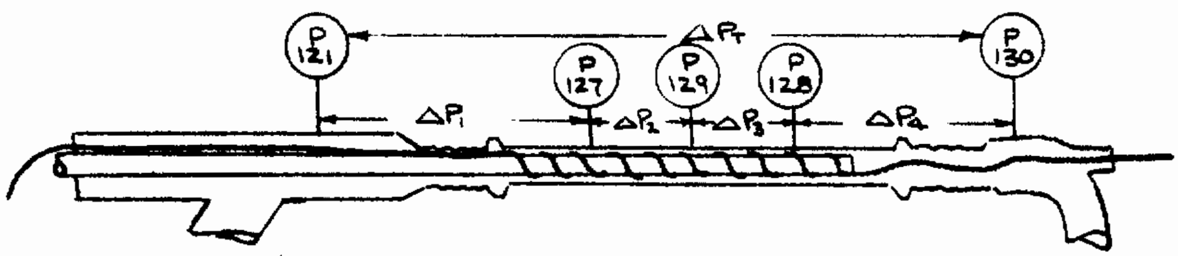
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA

BY M. Kates DATE 10/26/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 202 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 64607

TEST H-5

HEAT EXCHANGER AIR PRESSURES

Time (MIN)	x/L = 0 P-121 (PSIG)	x/L = 1/4 P-127 (PSIG)	x/L = 1/2 P-129 (PSIG)	x/L = 3/4 P-128 (PSIG)	x/L = 1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1½	73	69	67	67.5	66.5	4	2	-½	1	6½
5	✓	✓	68	64.5	64.5	✓	1	3½	0	8½
10	✓	✓	✓	65.5	65.5	✓	✓	2½	✓	7½
15	71	✓	66	63.5	61.5	2	3	✓	2	9½
20	74	70	67	64.5	63.5	4	✓	✓	1	10½
26½	73	69	64	60.5	52	✓	5	3½	8½	21
30½	✓	✓	✓	59.5	50	✓	✓	4½	1½	23
36	✓	✓	✓	56.5	52	✓	✓	7½	4½	21
40½	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
49	✓	✓	65	53.5	49	✓	4	9½	6½	24
52	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓



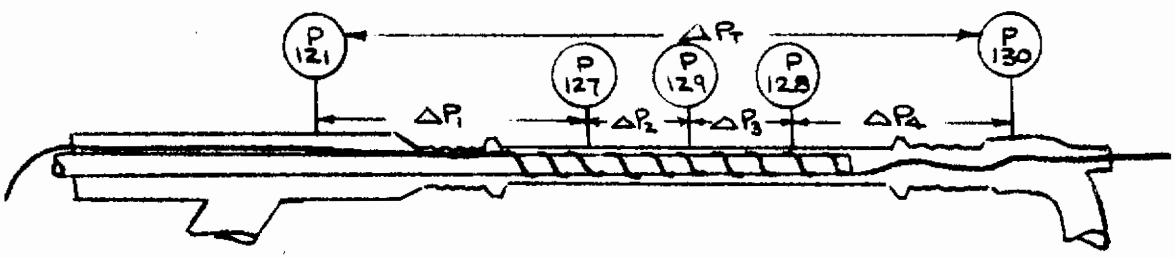
NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

TEST H-6

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1 1/2	73	69	69	67.5	65.5	4	0	1 1/2	2	7 1/2
5	✓	70	✓	68.5	67.5	3	1	1/2	1	5 1/2
10 1/2	✓	69	✓	65.5	65.5	4	0	3 1/2	0	7 1/2
15	✓	67	65	62.5	62.5	6	2	2 1/2	0	8 1/2
18	✓	66	63	59.5	58.5	7	3	3 1/2	1	14 1/2
20	✓	64	61	56.5	56	9	3	4 1/2	1/2	17
22	✓	62	59	55.5	55	11	3	3 1/2	1/2	18
25	✓	59	56	51.5	50	14	3	4 1/2	1 1/2	23
30	✓	46	43.5	36.5	36	27	2 1/2	7	1/2	37
32	✓	40	34.5	27.5	26.5	33	5 1/2	7	1	46 1/2
34	✓	29	22.5	14.5	11	44	6 1/2	8	3 1/2	62



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION ~~DATA [illegible]~~

BY.......... DATE..........
APPROVED.......... DATE..........
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 209 OF ....
SKETCH NO. ....
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST H-1
DATE 10/2/62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ①③ ppm-Vol.	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC. ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
2	72	89.7	67	6×10^{-3}	.389	1.55	-183	84.7			2.4×10^{-9}		
5	84	87.7	31	2.1×10^{-3}	.577		-244	73.7			$<10^{-12}$		
10	86	89.7	$18\frac{1}{2}$	1.6×10^{-3}	.615		-254	87.7			✓		
15	82	✓	15	1.3×10^{-3}	.541		-258	✓			✓		
20	79	✓					-258	88.7	$7\frac{1}{4}$	6.4×10^{-4}	✓		Loss of Inst Air Supply Caused Transient +26 to +28 min.
28	✓	✓					-238	85.7	$4\frac{1}{4}$	3.8×10^{-4}	✓		
30	80	✓					-248	88.7	$4\frac{1}{4}$	3.8×10^{-4}	✓		
36	82	✓	16	1.4×10^{-3}	.541		-242	✓			✓		
40	✓	✓	16	1.4×10^{-3}	.541		-242	✓			✓		
45	✓	✓					-292	✓	$5\frac{1}{2}$	4.6×10^{-4}	✓		
50	✓	✓					-244	✓	$3\frac{1}{2}$	3.1×10^{-4}	✓		

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	WA lbs/hr	CALCULATED INLET CONC. ② PPM-(WT)	PPM (VOL) ②
	NOT APPLICABLE — ONLY WATER CONTAMINANT WAS THAT PRESENT IN MANIFOLD CYLINDER GAS.						

Note: p_w = partial press. H_2O
p_{SAT} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([illegible] Wa) = ppm (vol) × 18/29
③ Cell Flow Meter Correction - 100 cc/min Indicated = 81 cc/min Actual

BY.................DATE.........

APPROVED.........DATE.........

CLIENT ASD / EXPER.

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 210 OF ....

SKETCH NO. ....

CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST H-2
DATE 10/5/62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC① ppm-vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
2½	54	89.7	19	1.8×10^{-3}	.21	.08%	-370④	85.7			$<10^{-12}$		
5½	75	✓	13	1.2×10^{-3}	.43		✓	89.7			✓		
9½	78	✓	11	1.0×10^{-3}	.47		✓	✓			✓		
16½	74	90.7	10½	$.9\times10^{-3}$	.42		✓	✓			✓		
21	72	89.7	10½	✓	.39		✓	✓			✓		
26½	71	90.7			.38		✓	✓	7½	$.7\times10^{-3}$	✓		
30	70	89.7			.36		✓	79.7	5½	$.4\times10^{-3}$	✓		
36	✓	✓			✓		✓	70.7	4½	$.3\times10^{-3}$	✓		
40	✓	88.7	7½	$.7\times10^{-3}$	✓		✓	42.7			✓		
42	✓	99.7	8½	$.8\times10^{-3}$	✓		✓	14.7			✓		

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	WA lbs/hr	CALCULATED INLET CONC. ② ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
	NOT APPLICABLE - ONLY WATER CONTAMINANT WAS THAT PRESENT IN MANIFOLD CYLINDER GAS.						

④ ESTIMATED AT -370 FROM NBS STD Cu-Con THERMOCOUPLE CALIB

① Average - Approx. Steady State Value

② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6 / ([illegible] WA) = ppm (vol) × 18/28

③ CELL FLOW METER CORRECTION - 100 CC/MIN INDICATED = 81 CC/MIN He ACTUAL

Note: p_w = partial press. H_2O
P_{SAT} = VAPOR " "

— Water Contaminant Test Results —

Test H-3A
Date 10/6/62

Recorder & Visual Observations

Time min.	IN T °F	IN P psia	IN Conc.① ppm-Vol.	IN p_w psia	IN p_{sat} psia	IN % of Sat.	OUT T④ °F	OUT P psia	OUT Conc.① ppm-Vol.	OUT p_w psia	OUT p_{sat} psia	OUT % of Sat	Remarks
1½	72	86.7	12	1.05×10^{-3}	.39								
3½	81	87.7	12	✓	.52								
6½	✓	✓	10	$.88\times10^{-3}$	✓								
10½	74	✓	9	$.79\times10^{-3}$	.42								
15	65	✓					-290	75.7	16	1.2×10^{-3}	$< 10^{-12}$		
17½	62	✓					✓	✓	10	$.8\times10^{-3}$	✓		
20	60	✓					✓	✓	8	$.6\times10^{-3}$	✓		
24	58	✓					✓	✓	5	$.4\times10^{-3}$	✓		

Data from Burette Measurements

Time min.	Time Interval min.	Burette cc	Difference cc	Rate cc/hr	W_A lbs/hr	Calculated Inlet Conc. ② ppm-(wt)	Calculated Inlet Conc. ppm (vol) ②
	Not Applicable - Only Water Contaminant Was That Present In Manifold Cylinder Gas.						

④ Measured Temp Not Available. Temp Estimated at Sat LN_2 Conditions.

Note: p_w = partial press. H_2O
P_{SAT} = vapor " "

① Average - Approx Steady State Value

② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6/(W_A) = ppm (vol) × 18/29

③ Cell Flow Meter Correction - 100 cc/min = 87 cc/min GN_2 Flow.

.290

— WATER CONTAMINANT TEST RESULTS —

TEST H-4
DATE 10/6/62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ① ppm-VOL.	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T ④ °F	OUT: P psia	OUT: CONC. ① ppm-VOL.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
1½	79	89.7	8.6	$.77 \times 10^{-3}$									
5	✓	✓	11	$.98 \times 10^{-3}$									
10	78	✓	8.6	$.77 \times 10^{-3}$									
15	71	✓					-286	88.7	6	$.5 \times 10^{-3}$	$< 10^{-12}$		
20	72	✓					✓	✓	3½	$.3 \times 10^{-3}$			
25	64	✓					✓	87.7	2	$.18 \times 10^{-3}$	✓		
30½	68	✓					✓	88.7	1½	$.13 \times 10^{-3}$	✓		
35½	66	✓					✓	87.7	1	$.09 \times 10^{-3}$	✓		
41½	63	✓					✓	✓	1	✓	✓		
45½	60	✓					✓	✓	1	✓	✓		

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ② ppm-(wt)	CALCULATED INLET CONC. PPM (VOL) ②

Note: p_w = partial press. H_2O
p_{SAT} = vapor " "

④ Measured and GN_2 Saturation temperature agree
① Average - Approx. Steady State Value
② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6 / ([illegible] W_A) = ppm (vol) × 18/29
③ Cell Flow Meter Correction - 100 cc/min = 87 cc/min GN_2 Flow

— WATER CONTAMINANT TEST RESULTS —

TEST A-5
DATE 10/9/62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: Conc.① ppm-Vol.	IN: p_w psia	IN: p_{sat} psia	IN: % of Sat.	OUT: T °F	OUT: P psia	OUT: Conc.① ppm-Vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of Sat	REMARKS
1½	62	89.7	–		.275		-284	83.7	—	—	$<10^{-12}$		
5	✓	✓	65	6.8×10^{-3}	✓		-299	81.7	—	—	✓		
10	61	✓	32	2.9 ✓	.266		✓	82.7	—	—	✓		
15	41	✓	22	2 ✓	.127		✓	78.7	—	—	✓		
20	34	90.7	16	1.4 ✓	.096		-301	70.7	—	—	✓		

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	WA lbs/hr	CALCULATED INLET CONC. ① ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
	NOT APPLICABLE. ONLY WATER CONTAMINANT WAS THAT PRESENT IN MANIFOLD CYLINDER GAS.						

Note: p_w = partial press. H_2O
P_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6/(3 WA) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST H-6
DATE 10/9/62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ① ppm-Vol.	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC. ① ppm-Vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
1 1/2	52	89.7	14	1.25×10^{-3}	.19								
5	✓	✓	12	1.08 ✓	.19								
10 1/2	40	✓	90	8×10^{-3}	.12								
15	34	✓	306	27 ✓	.10								
18	33	✓	345	31 ✓	.09								
20	32	✓					-286	73.7	150	11×10^{-3}	$< 10^{-12}$		
22	✓	✓					✓	72.7	35	2.5 ✓	✓		
25	✓	✓					✓	67.7	9	.6 ✓	✓		
30	✓	✓					-291	53.7	10	.54 ✓	✓		
32	✓	✓					-298	44.7	9	.4 ✓	✓		
34	33	✓	—										

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN. FROM 6 1/2	BURETTE CC	DIFFERENCE CC FROM 15.2	RATE cc/hr	WA lbs/hr	CALCULATED INLET CONC. ① ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
6 1/2	—	15.2	—				
9	2 1/2	15.8	.6	14.4			
19	12 1/2	18.05	2.85	13.7			
33 3/4	27 1/4	21.3	6.1	13.5	.0298		

Note: p_w = partial press. H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([illegible] WA) = ppm (vol) × 18/29

BY.................DATE.......... ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 015 OF ....

APPROVED..........DATE.......... SKETCH NO. ....

CLIENT ASD/CVPRL CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST H-1
DATE 10-2-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-VOL	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-VOL	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
2	72	[illegible]	72	6.3×10^{-3}			-183	89.7					
5	84	87.7	80	7.0×10^{-3}			-244	73.7					
10	86	89.7	85	7.5×10^{-3}			-256	87.7					
15	82	✓					-258	✓	35	3.1×10^{-3}	6.6×10^{-5}		
20	79	✓					✓	88.7	27	2.4×10^{-3}	✓		
25	✓	✓					-238	85.7	—				
30	80	✓					-248	88.7	32	2.8×10^{-3}	4×10^{-4}		
36	82	✓	82	1.4×10^{-3}			-242	✓					
40	✓	✓	82	1.4×10^{-3}			✓	✓					
45	✓	–					✓	✓	37	3.8×10^{-3}	5.5×10^{-2}		
50	✓	✓					-244	✓	37	3.6×10^{-3}	5.5×10^{-2}		

No. of Bottles in Manifold 20
Pressure in Manifold 1890 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

$$\frac{14.7}{21} \times \frac{1}{1890} \times \frac{10^6}{10^6} = 370 \text{ ppm (vol)}$$

① Average - Approx Steady State Value

Pressure after Mixing: 1890 psia

ppm CO_2 (vol) = ———— = 370

ppm CO_2 (wt) = ppm (vol) $\times \frac{44}{28}$

= 580

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST H-2
DATE 10-5-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
2½	54	89.7	185	16.6×10^{-3}			-370	84.7			$<10^{-10}$		
5½	75	✓	210				✓	87.7			✓		
9½	78	✓	212				✓	✓			✓		
16½	74	90.7	220				✓	✓			✓		
21	72	89.7	230				✓	✓			✓		
26½	71	90.7					✓	✓	< 5		✓		
30	70	89.7					✓	79.7	< 5		✓		
36	✓	✓					✓	70.7	5	$.35\times10^{-3}$	✓		
40	✓	88.7	285				✓	42.7			✓		
42	✓	99.7	305				✓	19.7			✓		

No. of Bottles in Manifold 20
Pressure in Manifold ~2000 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

$$\frac{14.7}{21} \times \frac{1}{2000} \times \frac{10^6}{10^6} = 350 \text{ ppm (vol)}$$

① Average - Approx Steady State Value

Pressure after Mixing = ~2000 psia
ppm CO_2 (vol) = [illegible] = 350
ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$
= 550

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST H-3A
DATE 10-6-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-VOL	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T ② °F	OUT: P psia	OUT: CONC ① ppm-VOL	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
1½	72	86.7	270	.0234									
3½	71	87.7	298	.0261									
6½	✓	✓	295	.0259									
10½	74	✓	295	.0259									
14	65	✓					-290	75.7	120	91000×10^{-7}	3×10^{-7}		Concentration reading erratic - Range ppm ~ 100 to 130
17½	62	✓					✓	✓	108	82000×10^{-7}	✓		
20	60	✓					✓	✓	112	88000×10^{-7}	✓		
24	58	✓					✓	✓	112	✓	✓		

No. of Bottles in Manifold 20
Pressure in Manifold ___ psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

$$\frac{14.7}{21} \times \frac{1}{2145} \times \frac{10^6}{10^6} = 326 \text{ ppm (vol)}$$

Pressure after Mixing: ___ psia

ppm CO_2 (vol) = ___ = 326

ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$

= 572

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " "

① Average - Approx Steady State Value
② Measured Temp Not Available - Temp Est at Sat CO_2 Conditions.

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST H-4
DATE 10-6-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P PSIA	CONC ① ppm-VOL	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	CONC ① ppm-VOL	p_{CO_2} psia	p_{SAT} psia	% of SAT	
1½	79	89.7	390	30.5×10^{-3}									
5	✓	✓	322	29 ✓									
10	78	✓	315	28.3 ✓									
15							-286	88.7	< 5	$< 4400 \times 10^{-7}$	8×10^{-7}		
20							✓	✓	✓	✓	✓		
25							✓	87.7	✓	✓	✓		
30½							✓	88.7	✓	✓	✓		
35½							✓	87.7	✓	✓	✓		
41½							✓	✓	✓	✓	✓		
45½							✓	✓	✓	✓	✓		

No. of Bottles in Manifold 20
Pressure in Manifold 1715 psia
No. of CO_2 Bottles ___
Pressure of CO_2 Bottles ___ psia

Pressure after Mixing: ___ psia
ppm CO_2 (VOL) = ___ × ___ / ___ =
ppm CO_2 (WT) = ppm (VOL) × $\frac{44}{28}$
=

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST H-5
DATE 10-9-62

RECORDER & VISUAL OBSERVATIONS -

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
1½	62	89.7	—	—			-284	83.7	—	—	9×10^{-7}		
5	✓	✓	262	.0235			-299	81.7	—	—	8.7×10^{-8}		
10	61	✓	282	.0252			✓	82.7	—	—	✓		
15	41	✓	282	✓			✓	78.7	—	—	✓		
20	34	90.7	282	.0256			-301	70.7	—	—	✓		

No. of Bottles in Manifold 20
Pressure in Manifold 2225 psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

$$\frac{14.7}{21} \times \frac{1}{2225} \times \frac{10^6}{10^6} = 314$$

① Average - Approx Steady State Value

~~Pressure after Mixing - psia~~

$$\text{ppm } CO_2 \text{ (vol)} = \frac{\quad}{\quad} = 314$$

$$\text{ppm } CO_2 \text{ (wt)} = \text{ppm (vol)} \times \frac{44}{28}$$

$$= 495 \text{ ppm (vol)}$$

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST H-6
DATE 10-9-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: Conc ① ppm-Vol	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-Vol	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
1½	52	89.7	355	31.8×10^{-3}									
5	✓	✓	325	29.1 ✓									
10½	40	✓	325	29.1 ✓									
15	34	✓	322	28.8 ✓									
18	33	✓	317	28.4 ✓									
20	32	✓					-286	73.7	5	$.37\times10^{-3}$	8×10^{-7}		
22	✓	✓					✓	72.7	<5	< ✓	✓		
25	✓	✓					✓	67.7	✓	✓	✓		
30	✓	✓					-291	53.7	✓	✓	3×10^{-7}		
32	✓	✓					-298	44.7	✓	✓	3.5×10^{-8}		
34	33	✓	317										

No. of Bottles in Manifold 20
Pressure in Manifold ___ psia
No. of CO_2 Bottles 1
Pressure of CO_2 Bottles 14.7 psia

$$\frac{14.7}{21} \times \frac{1}{2100} \times \frac{10^6}{10^6} = 332 \text{ ppm (vol)}$$

① Average - Approx Steady State Value

~~Pressure after Mixing: ___ psia~~

ppm CO_2 (vol) = ___ × ___ / ___ = 332

ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$

= 522

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

VERIFICATION TEST SERIES REDUCED DATA

ASD-TDR-63-508, Volume III

TABLE OF CONTENTS

Verification Data

REDUCED DATA FOR VERIFICATION SERIES TESTS

Nine tests were performed with the 1-inch configuration in this test series. Generally, the purpose of this series has been to extend the range covered by previous experiments and to substantiate earlier data by repeating tests. In two tests of this series our efforts were concentrated specifically on obtaining property data for water and carbon dioxide frost formations. A summary of the parameters for each test is presented on pages 1 and 2. More specific objectives for each test performed are given subsequently in this report.

The data reduction for this test series is completed and the tabulated information is presented in the body of the report. The presentation follows the format established in the earlier data reports. The brief comments of the data contents follow.

1. Summary Sheets

The test summary sheets include information on the nominal test parameters, primary variables investigated and the time sequence of the important events during the progress of the test. Observations on the frost formation made during the test progress and from motion picture and still photos are also included.

2. Flow Data

The flow data sheets contain the calculations establishing the air, coolant and spray stream flow rates both from the orifice and high pressure manifold data.

Generally, the calculated orifice flow rate is smaller than the rate given by the manifold data. The ratio $\bar{w}_o/\bar{w}_b$ (average orifice flow to average bottle flow) scatters between .86 and 1.01 for the air stream and from .76 to .96 for the coolant stream. If the ratio is plotted versus the change in manifold cylinder pressure from beginning to end of the test, a correlation is apparent that shows good agreement (.95 - 1.01) for pressure changes of 800 psi and poor agreement (.76 - .98) at the 100 psi level. As the manifold gauges have an accuracy within 1/2 percent (15 psi for a 3000 psi manifold gauge), a fair portion of the disagreement can be accounted for.

The negative bias is more difficult to account for. The orifice pressure gauges P-135, 139 and 145 were check calibrated on 19 October 1962, and a maximum bias of 5 psi existed in each gauge. Further, all gauges were tapped before taking every reading to overcome the drag normally associated with the gauge mechanism and thus insure correct readings.

We consider also errors in the manifold pressure gauges. Calibration errors have large effect on measured mass expelled from the bottle only if the gauge error changes markedly with pressure. Check calibrations of the manifold gauges have not shown this tendency to exist.

We have adapted the procedure of utilizing the flow information calculated from the orifice data. The energy balance and other checks performed on this basis show good agreement and, therefore confirm this procedure.

3. Temperature Data

The air and coolant temperature data sheets include the air and coolant temperature as a function of time. Temperature differential tabulation have also been prepared in which the individual Δ T's in the heat exchanger air stream as well as the overall coolant Δ T's have been listed versus time.

Plots of the temperature versus heat exchanger length profiles appear reasonable except for V-9 where there appears initially to be a rise in air stream temperature in the first quarter of the heat exchanger.

A significant improvement was made in establishing the coolant inlet temperature as compared to the flow test series. The coolant inlet line was vacuum insulated from the location of the temperature sensor, T-108, to the inlet of the heat exchanger. Thus no corrections need be applied to measure temperature at T-108 to obtain the coolant inlet temperature. The two exceptions are test V-1 and V-2 which were performed in September prior to the modification. In tests V-1 and V-2, the rise in coolant inlet temperature downstream of T-108 must be calculated from heat transfer relationships.

4. Air Pressure Data

The air stream absolute and differential pressure determined at the quarter points along the heat exchanger have been tabulated versus time for each test.

Prior to 24 October, these pressures have been measured with 0-400 psig gauges. These gauges have an accuracy of 1/2 percent and seriously mask the differences in pressure along the heat exchanger under clean conditions. Thus, these gauges were replaced with 0-100 psig gauges having 1/2 percent accuracy and were used on tests C-2 through C-6 and V-3 through V-9.

As can be deduced from the data, the maximum pressure drop occurs in the region of the heat exchanger where the greatest thickness of frost deposit are located. At the concentrations of contaminant that we normally used the water frost created a greater pressure drop than the carbon dioxide frost except in test V-7 which contained a small concentration of water and, and, therefore, the significant pressure loss occurred across the carbon dioxide frost.

5. Contaminant Data

Carbon dioxide and water concentrations measured in the air stream at the inlet and exit of the test heat exchanger with gas analysers have been tabulated separately for each test versus time. We have come to consider these measurements very reliable except for the outlet water measurements at low concentrations.

In this series of tests as well as the configuration series, the inlet water cencentrations measurement obtained with the gas analyser show excellent agreement (within 10 percent) with the water input measurement made with a burrette. This was brought about through the repositioning of the water-gas mixer in the air stream which allowed better distribution of the water over the heated surface and, therefore, greater evaporation rates. Thus the inlet water concentration now rises to 63 percent of maximum in 30 to 45 seconds and the humidity concentrations are within 10 percent of the computed values based on water input, an improvement in both cases over previous results.

The exit water concentration measurements have not correlated well with our tests and, therefore, test V-5 was performed to determine the possible reasons for nonconformance. The results are discussed under the test V-5 test objective.

No water concentration data is reported for test V-6 and V-7 as these tests were primarily carbon dioxide contaminant runs.

Carbon dioxide contaminant is introduced into the air stream by filling one of the manifold cylinders with one atmosphere of carbon dioxide gas and approximately 160 atmospheres of nitrogen gas. This method has given excellent results in all of our tests for obtaining the requisite .05 percent (wt) air stream concentration.

Carbon dioxide concentration measurements at the air stream inlet and outlet have been made with a Beckmann infrared analyser. Previous comparision between prepared stream data and the analyser data are excellent. Carbon dioxide analyser data are presented for tests V-1, 7, 8 and 9 only. In tests V-2 and V-5, no carbon dioxide was used; tests V-3 and V-4 were high water concentration tests of short duration and the carbon dioxide contaminant play a secondary role; test V-6 was aborted because of equipment failure and no useful data was obtained.

6. Heat Rate Balance

Heat Rates have been computed from the air stream and to the coolant stream within the heat exchanger based upon the boundary conditions of each stream. While the air stream temperatures are measured directly the coolant stream measured temperatures must be corrected for heat losses occurring between the heat exchanger and measuring points. The agreement between the two heat rates is generally good having an average deviation for the entire series of 8 percent.

7. Individual Test Objectives

Test V-1

Test V-1 was performed with the purpose of providing additional information at an air stream pressure of 30 psia. This duplicates test F-1 except that the inlet water cencentration was increased and carbon dioxide contaminant was added to the air stream. Because of the low water concentration in the air stream, 30 minutes of test F-1 operation were not sufficient to provide a significant amount of data. Thus, test V-1 is an attempt to provide additional data at the low stream pressure level for comparison with test V-4, the F-8 to F-12 group and F-17, as well as test F-1.

Test V-1 was 74 minutes in duration and was terminated at plug-up of the heat exchanger. All systems operated satisfactory and the test objectives were met.

Tests V-2, V-3 and V-4

In the flow test series, we studied the effect of air stream water concentration on heat exchanger performance in tests F-2 through F-5. With this group of tests we explored a range of water concentration from .006 to .052 percent. In the first tests of our experimental program, the maximum concentration was limited by the performance of the water-air mixers which formed a part of our air stream preparation system. This system was subsequently improved and we, therefore, performed three tests in the verification series, i.e., V-2, V-3 and V-4; that were used to extend the range in successive steps of .1, .33, and1.0 percent (wt).

The results of these tests were very satisfactory. All systems in each test performed at their designated operating conditions. In V-2, with an inlet water concentration of .1 percent (wt) the saturation temperature was 43^{o}F. The tubes frosted in the region of the heat exchanger from 8 to 27 inches. The tubes upstream of the frosted section for a distance of about 2 inches also appeared wetted and may have been coated with clear ice. The water frost formed in the cold section of the heat exchanger was similar in appearance to diffusion type frost deposits observed in previous tests. In this test, water droplets approximately .01 inch in diameter were observed on the inner glass surface moving in the direction of the air stream towards the frosted section of the heat exchanger. They appeared not to modify the deposition of frost except that there was some clear ice noticeable near the longitudinal baffle in the region from 9-11 inches.

In tests V-3 and V-4, water concentrations of .33 and 1.0 percent respectively were obtained with a single value of water pumping rate by decreasing the mass flow velocity from 30 lbs/secft^2 in V-3 to 10 lbs/sec ft^2 in V-4. In both tests the heat exchanger plugged in about 3 minutes. Plugging was probably due to the formation of clear ice in the flow passages as well as the usual frost formation on the tubes. In V-3 frost formed in the region from approximately 13 to 24 inches and water ice was superimposed on; this is the region from 13 to 16 inches. In V-4 the frost formed in the 19-30 inch region and the ice in the 21-1/2 to 23-1/2 inch region. In both tests we observed water droplets on the glass up-stream of the frost starting point being formed in great profusion and carried along with the air stream. Also for both tests, the location and icing point agree very closely with point at which the air stream temperature is 32^{o} F.

Test V-5

In previous tests, comparision of the information on the exit air stream water concentration obtained both from the gas analyser and exit stream temperature indicated large percentage differences between the measurements. Based on the assumption that the air exit stream was saturated at the prevailing temperature, the calculated water concentration was generally many magnitudes smaller than the simultaneous concentrations indicated by the analyser. Our experience with the analyser also indicated that at concentrations in the range of 30 ppm (vol) and below the response time of the instrument was comparable to the test length. We felt, therefore, that if the poor correlation between the two measurements were due to long analyser response, a better correlation would be obtained if the exit air concentration were made higher by operating with an exit temperature in the range of -50 to -30^{o}F. which corresponds approximately to an H_2O concentration of 10 to 40 ppm (vol.). Thus, this was one of the objectives of test V-5.

A second objective of V-5 was to obtain information during the progress of the test on the volume occupied by the frost so that through use of the inlet and outlet water concentration data we could obtain estimates of the frost density. A quick succession of close up photos of the entire heat exchanger were taken at three times during the tests from which frost thickness and volume were computed.

All the objectives of test V-5 were achieved. Good agreement was obtained between the two methods of determining water concentration in the exit air. Thus in the analysis of the data, concentrations obtained through use of exit temperature are valid. The final density at the end of test was estimated to be 19.4 lbs/ft^3.

Test V-6 and Test V-7

In the flow series and other tests we observed that the effect of the carbon dioxide on the pressure drop performance of the heat exchanger was considerably less than the effect of the water contaminant although the carbon dioxide concentration in the stream was usually greater than the water concentration. It was the purpose of the test V-6, therefore, to run the heat exchanger to plug-up with carbon dioxide being the only contaminant in the air stream and thus obtain information on the pressure and heat transfer effects of the carbon dioxide as well as information on the frost density.

During the progress of V-6, a cold leak developed at a packing gland located at the air inlet side of the heat exchanger. The leak caused the mass flow through the heat exchanger to vary which shifted the temperature gradients and resulted in a continuous redistribution of the frost deposits. Thus, the test was aborted. While the reduced data is presented as a matter of record we do not consider it useful data.

After removing all system leaks we performed the successful test V-7 with the same parameters used in test V-6. No water was purposely added to the air stream. However, the high pressure cylinder nitrogen used for the air stream contained small amounts of water that became trapped in the heat exchanger. This did not prevent the successful attainment of all test objectives.

Test V-8

The test parameters and conditions of F-11 were repeated in test V-8. In F-11, there was considerable spreading of the frost in the heat exchanger because the water contaminant flow was initiated before the temperature gradients in the heat exchanger had stabilized. The "clean" heat exchanger pressure drop was thus abnormally high and gave anomolus results when the frosted-to-clean pressure drop ratio was calculated at subsequent intervals during the test. Further, the flow rates computed for test F-11 from the orifice and bottle data were in poor agreement. Thus, it was decided that test V-11 should be repeated.

Test V-8 was successfully run and its objectives were met. The "clean" experimental heat exchanger pressure drop was in excellent agreement with calculated pressure drop. As in F-11, we again experienced poor agreement between the stream flows calculated both from the orifice and bottle data. We believe, however, that because of the small quantity of gas consumed from the bottles during the test that the accuracy is compromised. Thus, we have used the orifice computed flows in our analysis which give good agreement such as obtained from the heat rate balance.

Test V-9

The purpose of test V-9 was to determine if frost particles nucleated in the air stream would pass through the heat exchanger or be entrapped on the coils. Nucleation from a supersaturated humid gas stream was achieved with liquid nitrogen spray at a rate equal to about 45 percent of the air flow rate. This reduced the air stream temperature at the inlet of the heat exchanger to approximately - 90°F.

The water flow was initiated at 22 minutes of test time after air, coolant and spray streams were established and stable heat exchanger gradients were achieved. Plug-up of the heat exchanger occurred at 65 minutes. Water concentration at the exit could not be measured after 60 minutes at the exit with the humidity analyser because of the low stream pressure. The analyser gave water concentration value in the order of 10 ppm (vol) with the gas sampling pilot tube pointing up stream so as to capture solid particles present in the gas sample stream.

Overall the close-up photos of the heat exchanger indicate that the particles were trapped on the tubes and glass shell of the heat exchanger . Initially the trapped frost was observed only in the upstream half of the heat exchanger. As plug-up was approached the frost powder loading increased throughout the heat exchanger. At near plug-up the downstream loading point had extended to the coolant inlet end of the heat exchanger.

The change in heat exchanger loading can be seen from the pressure drop data presented on page 54. In general, it may be concluded that in this case the downstream tubes of the heat exchanger act as impingement type separators to the frost ladden stream until the heat exchanger becomes significantly loaded.

VERIFICATION TEST SERIES

TEST PARAMETER SUMMARY

Contract No. AF 33(657)-8695

Test			Air				Coolant	Spray	
No.	Date	Configuration	Ga $\frac{Lbs}{ft^2\text{-sec}}$	Pa psia	% H_2O	% CO_2	$\frac{(Wc_p)_c}{(Wc_p)_a}$	$\frac{(Wc_p)_s}{(Wc_p)_a}$	Variable Investigated
V-1	9-18-62	1	10	30	.025	.05	1.0	--	Low pressure rerun of test F-1 with CO_2 added
V-2	9-19-62	1	30	90	.1	none	1.0	--	Water content similar to F-2 to F-5 series
V-3	11-17-62	1	30	90	.32	.05	1.0	--	High water content
V-4	11-17-62	1	10	30	1.0	.05	1.0	--	High water content
V-5	11-29-62	1	30	90	.027	none	1.0	--	Water concentration in outlet air stream
V-6(3)	12-4-62	1	30	90	Neg.	.05	1.0	--	CO_2 Frost Properties CO_2 Heat Transfer Effects

~~Page 1~~

Attachment No. 1 to Progress Report for December 1962 pursuant to Contract No. AF 33(657)-8695

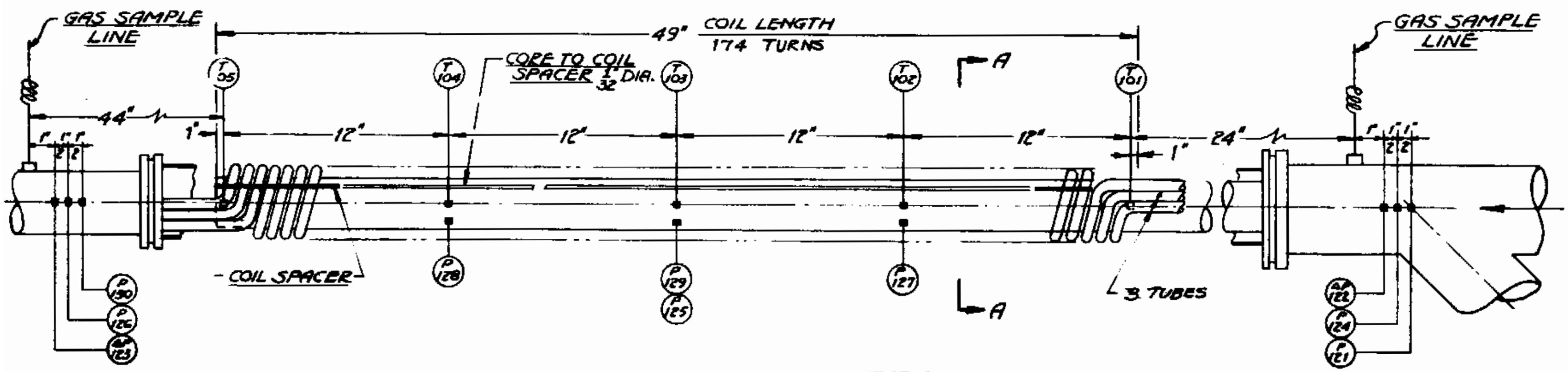
Test			Air				Coolant	Spray	
No.	Date	Configuration	Ga $\frac{lbs}{ft^2\text{-sec}}$	Pa psia	% H_2O	% CO_2	$\frac{(Wc_p)_c}{(Wc_p)_a}$	$\frac{(Wc_p)_s}{(Wc_p)_a}$	Variable
V-7	12-10-62	1	30	90	Neg.	.044	1.0	--	CO_2 Frost Properties CO_2 Heat Transfer Effects
V-8	12-12-62	1	15	90	.025	.047	1.0	--	Low Air Flow Velocity Rerun of F-11
V-9	12-14-62	1	24	90	.029 (4)	.046 (4)	1.0	.9	High LN_2 Spray Rate

NOTES:

1. Nitrogen was used for both the air and coolant streams.
2. Inlet temperature and pressure of coolant stream was approximately -300°F and 600 psig respectively.
3. Test V-6 aborted due to cold-leak at inlet end of the test heat exchanger.
4. Air stream concentration prior to liquid nitrogen injection point based on Burette data for water and analyser data for CO_2.
5. All values shown are nominal based on preliminary survey of test data.

~~Page 2 of~~

Attachment No. 1 to Progress Report for
December 1962 pursuant to Contract No. AF 33(657)-8695



HEAT EXCHANGER DATA:

TUBE SIZE: 3/16" O.D. × .030 WALL, ANNEALED COPPER,

TOTAL AIR SIDE SURFACE AREA: 1.76 FT.²

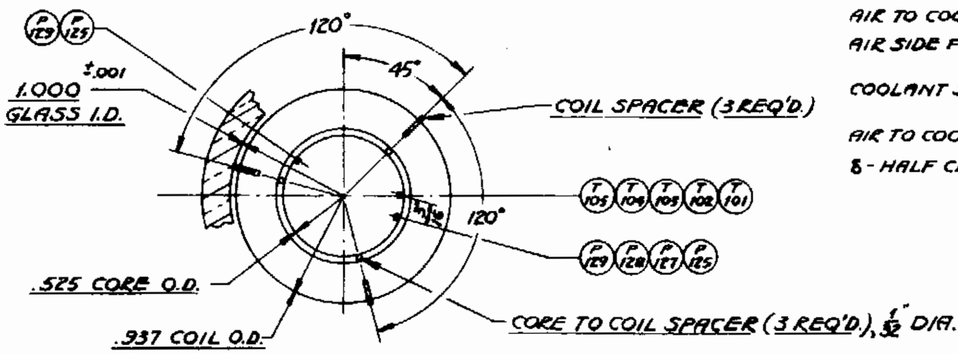
AIR TO COOLANT SURFACE AREA RATIO: 1.472

AIR SIDE FLOW AREA: .150 IN.² .00104 FT.²

COOLANT SIDE FLOW AREA: .0379 IN.² .000263 FT.²

AIR TO COOLANT - FLOW AREA RATIO: 3.96

δ - HALF CLEARANCE: .031 IN.



SECT. A-A

NOTES:
1. PRESSURE GAGE P-129 AND TRANSDUCER P-125 ARE CONNECTED TO A COMMON SENSE LINE. THIS SENSE LINE IS FOR REASONS OF RELIABILIT FED BY DOUBLE PNEUMATIC LEADS FROM THE TEST CORE.
2. 94% OF TUBE SPACES ARE BETWEEN .055" AND .070"

TEST HEAT TRANSFER SECTION DETAILS - 1-INCH SPIRAL CONFIGURATION

BY M. Kates DATE 11/27/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 233 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD/Experi | CASE NO. 64607

Test Heat Exchanger Energy Balance

Test	q_a Btu/Hr	q_c Btu/Hr	q_c/q_a
V-1	2940	2985	1.015
V-2	5800	6410	1.105
V-3	6170	6700	1.085
V-4	3135	3140	1.001
V-5	4370	4720	1.078
V-6	Aborted Test.		
V-7	9890	9490	.960
V-8	5180	4560	.881
V-9	4250	5060	1.192

BY M. Kates DATE 11/28/62
APPROVED ______ DATE ______
CLIENT ASD/EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 234 OF ______
SKETCH NO. ______
CASE NO. 64607

Heat Exchanger Energy Balance Data

q_a ~ Air-side heat transfer

Test No	Θ (MIN)	ω (LB/SEC)	T_1 T-101 (°F)	P_1 P-121 (PSIA)	h_1 (BTU/LB)	T_2 T-105 (°F)	P_2 P-130 (PSIA)	h_2 (BTU/LB)	Δh $h_1 - h_2$ (BTU/LB)	q_a (BTU/SEC)	q_a (BTU/HR)
V-1	45	.01072	56	31.5	132	-232	24.2	56	76	.816	2,940
V-2	20	.0310	98	88	136	-116	43.6	84	52	1.610	5,800
V-3	18	.0317	104	90	138	-114	72	84	54	1.715	6,170
V-4	18½	.01087	94	30	136	-235	21	56	80	.871	3,135
V-5	70	.0304	110	90	139	-55	56	99	40	1.215	4,370
V-6	ABORTED TEST										
V-7	40	.0323	113	90	140	-232	69.5	55	85	2.745	9,890
V-8	50	.0160	102	90	137	-255	77	47	90	1.438	5,180
V-9	35	.0251	-90	90	90	-220	62.5	43	47	1.181	4,250

HEAT EXCHANGER ENERGY BALANCE DATA

q_c ~ Coolant-SIDE HEAT TRANSFER

TEST NO	θ (MIN)	ω (LB/SEC)	T_1 T-108 (°F)	P_1 P-147 (PSIA)	h_1 (BTU/LB)	T_2 T-109 (°F)	P_2 P-131 (PSIA)	h_2 (BTU/LB)	Δh h_2-h_1 (BTU/LB)	q_c (BTU/SEC)	q_c (BTU/HR)
V-1	45	.00525	-269	615	-30	77	615	128	158	.830	2985
V-2	20	.0312	-160	220	70	58	25	127	57	1.78	6410
V-3	18	.0315	-156	230	70	66	35	129	59	1.86	6700
V-4	18 1/2	.00527	-279	595	-35	84	585	130	165	.871	3140
V-5	70	.0312	-82	240	90	78	40	132	42	1.310	4720
V-6	ABORTED TEST										
V-7	40	.0154	-290	620	-39	90	615	132	171	2.630	9490
V-8	50	.00767	-290	615	-39	70	610	126	165	1.265	4560
V-9	35	.01203	-278	625	-33	-86	620	84	117	1.409	5060

TEST V-1 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	30	10	.5	—	.025	.05	SUPER-CRITICAL GN_2	78	9-18-62

VARIABLE INVESTIGATED: LOW PRESSURE
RERUN OF F-1
CO_2 ADDED.

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR & COOLANT STREAMS
22	STABLE TEST HX TEMP GRADIENT.
23	WATER ON.
28¾	WATER CONC IN INLET AIR STREAM BEGINS TO RISE.
30½	" " " " " " @ 95% OF MAX.
47	$\Delta P/\Delta P_0 \approx 2.0$
60	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0 \approx 4.4$
78	SHUTDOWN.

(28¾ to 47: 18¼ MIN)

$x/L = 1.0$ $x/L = ¾$ $x/L = ½$ $x/L = ¼$ $x/L = 0$

DISTRIBUTION HX → CO_2 48" – 41"; H_2O 28" – 17"; 0

PHOTOGRAPHIC OBSERVATIONS

STILLS – H_2O FROST DIFFUSION TYPE 17–24"
PATCHY 24–28
CO_2 " DIFFUSION " 41–48"

GENERAL NOTES:

TEST V-2 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_2 (PSIA)	G_2 (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	1.0	—	.1	NONE	LOW PRESS GN_2	26½	11-19-26

VARIABLE INVESTIGATED: WATER CONCENTRATION

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAM.
11	STABLE TEMP GRADIENTS IN TEST HX.
12	WATER STREAM ON, ΔP_0 = 11 PSI.
13	WATER CONC IN AIR STREAM BEGINS TO RISE.
15¼	" " " " " @ 95% OF MAX CONC
15¾	$\Delta P/\Delta P_0$ = 2.0
22½	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0$ = 6.35
26½	SHUTDOWN

PHOTOGRAPHIC OBSERVATIONS:

STILLS: 1) WATER FROST THROUGHOUT TEST IN REGION 8" TO 27"

2) TUBES IN 5 - 8" REGION APPEAR WETTED.

GENERAL NOTES:

BY............DATE......
APPROVED........DATE......
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 238 OF ....
SKETCH NO. ....
CASE NO. 64607

TEST V-3 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_2 (PSIA)	G_2 (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	1.0	—	.32	.05	LOW PRESS GN_2	22 3/4	11-17-62

VARIABLE INVESTIGATED: High Water Concentration.

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAMS
17	STABLE TEMP GRADIENTS IN TEST HX
18	WATER ON - $\Delta P_0 = 12$ psi -
18 3/4	H_2O CONC. IN AIR INLET STREAM BEGINS TO INCREASE. ALSO ΔP ACROSS TEST HX BEGINS TO INCREASE.
20 1/2	$\Delta P / \Delta P_0 = 2.0$
21 3/4	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0 = 6.0$
22 3/4	SHUTDOWN.

(3 MIN bracket spanning 18 3/4 to 21 3/4)

PHOTOGRAPHIC OBSERVATIONS:

STILLS: WATER FROST IN 12" - 20" REGION. WATER ICE FORMED IN 13"-17" REGION; HEAVIEST IN 13-16" REGION. UP STREAM TUBES APPEAR WETTED.

GENERAL NOTES:

1. WATER CONCENTRATION IN AIR STREAM INLET WAS RISING THROUGHOUT THE 3 MINUTE TEST PERIOD. AT 21 3/4 MIN THE CONC. INDICATED BY THE ANALYZER WAS 3950 ppm (VOL). THE COMPUTED WATER AND AIR STREAM FLOWS INDICATE A MAX POTENTIAL CONC. OF 4970 ppm (VOL).

BY ________ DATE ________ **ARTHUR D. LITTLE, INC.** SHEET NO. 239 OF ______
APPROVED ________ DATE ________ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 64607

TEST V-4 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	30	10	.475	—	.955	.05	SUPER-CRITICAL GN_2	21	11-17-62

VARIABLE INVESTIGATED: High Water Concentration

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAM
16	STABLE TEMP ACHIEVED IN HEAT EXCHANGER
17	WATER STREAM ON - , ΔP_o = 6.5 PSIA
17¼	WATER CONC IN AIR INLET STREAM BEGINS TO INCREASE
17½	GAS SAMPLE LINE SHUT - H_2O ANALYSER READS OFF SCALE
19¼	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_o$ = 2.1
21	SHUTDOWN -

2½

PHOTOGRAPHIC OBSERVATIONS:

WATER FROST IN REGION 19" to 30". WATER ICE VISIBLE ON INSIDE OF INNER GLASS AND TUBE BAFFLE IN REGION 20 TO 23½ INCHES. HEAVIEST ICE FORMATION IN 21½ TO 23 INCH REGION.

GENERAL NOTES:

BY.................DATE..........
APPROVED..........DATE..........
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 240 OF..........
SKETCH NO..........
CASE NO. 64607

TEST V-5 SUMMARY SHEET

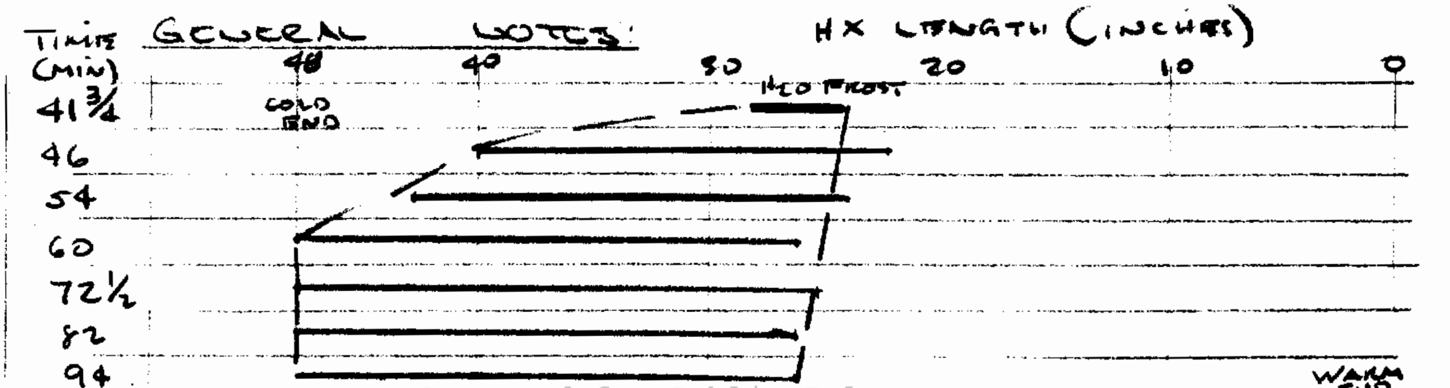
NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	1.025	—	.027	NONE	LOW PRESS GN_2	94	11-29-62

VARIABLE INVESTIGATED:

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAMS.
37	TEMP GRADIENTS QUASI STABILIZED.
38	WATER STREAM ON.
42½	WATER CONC 95% OF MAX VALUE @ INLET AIR.
62	$\Delta P/\Delta P_0$ = 2.0
94	SHUTDOWN - $\Delta P/\Delta P_0$ = 4.5
38-94	OUTLET AIR TEMP FLUCTUATES - DUE TO POOR
	CONTROL ON COOLANT STREAM TEMP.
	OUTLET AIR -20 F MAX, -54 MIN

PHOTOGRAPHIC OBSERVATIONS

GENERAL NOTES:



BY __________ DATE __________ ARTHUR D. LITTLE, INC. SHEET NO. 241 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / ELPERI CASE NO. 64607

TEST V-6 SUMMARY SHEET

ABORTED TEST

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_3/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	.51	—	NEG-	.05	SUPERCRITICAL GN_2	90	12-4-62

VARIABLE INVESTIGATED: 1) CO_2 PROPERTIES
2) FROST EFFECT ON HX PERFORM

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0.	START CLOCKS, RECORDERS, AIR AND COOLANT STREAM
35	ΔP ACROSS HX DECREASES.
60	TEMP GRADIENT IN HX STABILIZES
87	DISCOVERED LARGE LEAK IN AIR INLET STREAM.
90	SHUTDOWN —

PHOTOGRAPHIC OBSERVATIONS:

GENERAL NOTES:

1. 60 MIN REQ'D FOR TEST HX TEMP TO STABILIZE
2. AT 35 MIN HX ΔP DECREASES.
3. LEAK DISCOVERED AT ≈ 87 MIN

TEST ABORTED —

BY .... DATE .... | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 242 OF ....

APPROVED .... DATE .... | SKETCH NO. ....

CLIENT ASD / EXPERI | CASE NO. 64607

TEST V-7 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	.48	—	Neg.	.047	SUPER CRITICAL GN_2	71¾	12-10-62

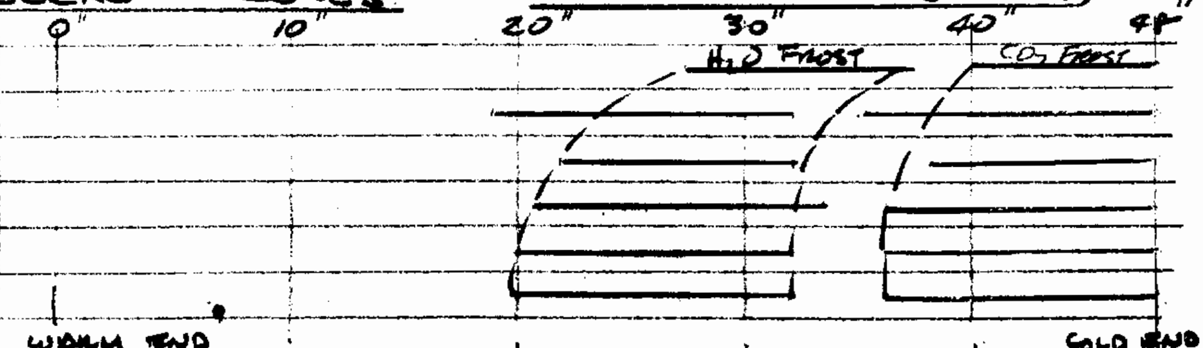
VARIABLE INVESTIGATED: 1) CO_2 PROPERTIES
2) FROST EFFECT ON HX PERFORMANCE

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS & AIR AND GN₂ STREAMS.
15	STABLE TEMP GRADIENT TEST HX
50	$\Delta P/\Delta P_0$ = 2.0
68	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0$ = 5.3
71¾	SHUTDOWN —

PHOTOGRAPHIC OBSERVATIONS

GENERAL NOTES: TEST HX LENGTH (INCHES)

TIME (MIN)	SOURCE
7½	TEST NOTES
21	✓
30½	✓
41½	✓
60	STILL PHOTOS
67	✓



BY.......... DATE..........	ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS.	SHEET NO. 243 OF .....
APPROVED.......... DATE..........		SKETCH NO. ....
CLIENT ASD / EXPERI		CASE NO. 64607

TEST V-8 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	15	.5	—	.025	.05	SUPER-CRITICAL GN₂	73½	12-12-62

VARIABLE INVESTIGATED: LOW FLOW VELOCITY RERUN OF F-11

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START RECORDERS, CLOCKS, AND AIR AND COOLANT.
22	STABLE TEST HX TEMP GRADIENT
23	WATER STREAM ON -
26	H_2O CONC. IN AIR STREAM INLET STARTS TO INCREASE
28	✓ ✓ ✓ ✓ ✓ ✓ @ 95% OF MAX
40	$\Delta P/\Delta P_0 = 2.0$
72	AIR STREAM VENT VALVE WIDE OPEN, $\Delta P/\Delta P_0 = 21.5$
73½	SHUTDOWN

PHOTOGRAPHIC OBSERVATIONS

GENERAL NOTES

OBSERVATIONS -

TIME 35½ H_2O - Start 9", heavy 11"-18", THINNING 19"-26", SPARKLING APPEARANCE 29-42"
✓ ✓ CO_2 ✓ 24" ✓ 24-48, DULL ✓ 42-48
✓ 46½ H_2O Start 8½ ✓ 10-20 Thinning 20-25
✓ ✓ CO_2 ✓ 24" ✓ 30-48 SPARKLING - 24-41, DULL 41-48

TEST V-9 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	24	.5	.6	.025	.05	SUPER-CRITICAL GN_2	66 1/4	12-14-62

VARIABLE INVESTIGATED: High LN_2 Spray

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START CLOCKS, RECORDERS, AIR AND COOLANT STREAMS
4	START LN_2 SPRAY.
21	STABLE TEMP GRADIENTS IN THE HX.
22	START WATER STREAM.
35	$\Delta P/\Delta P_0$ = 2.0
51	1st SERIES OF CLOSE-UP PHOTOS -
65	$\Delta P/\Delta P_0$ = 4.5
66 1/4	SHUTDOWN
67	CLOSE-UP PHOTOS -

13 MIN

8L
92
60

PHOTOGRAPHIC OBSERVATIONS:

GENERAL NOTES:
t = 45 · FROST POWDER HEAVY, 0-6; VERY HEAVY, 6-16, THINNING, 16-37
FROST MIGRATING DOWN STREAM.

TEST V-1 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1 / 1000$
$W_* = f$ (A orifice)
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	575	35	.0609	5.75	45	1.024	1.00	.01815	.01071	
	ORIFICE NO. 3	30	✓	✓	✓	5.70	42	1.027	✓	✓	.01075	.01072
		50	✓	✓	✓	5.79	47	1.021	✓	✓	.01070	
	NOM DIA: .035"	70	✓	45	.0783	5.81	48	1.020	✓	✓	✓	
T_1 = T-117	COOLANT	10	1065	615	.5774	5.92	53	1.017	.850	.00570	.00525	
	ORIFICE NO. 1	30	✓	✓	✓	5.88	51	1.019	✓	✓	✓	
		50	✓	✓	✓	5.95	54	1.015	✓	✓	✓	.00525
	NOM DIA: .0200"	70	✓	✓	✓	✓	✓	✓	✓	✓	✓	

B. BOTTLE DATA

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 36.9 FT³	V_B = 35.1 FT³
@ θ = 10 MIN, P_{B1} = 2240 PSIA	@ θ = 10 MIN, P_{B1} = 2350 PSIA
@ θ = 70 MIN, P_{B2} = 2005 PSIA	@ θ = 70 MIN P_{B2} = 2200 PSIA
$\bar{T}_B$ = 72.5 °F 532.5 °R	$\bar{T}_B$ = 72.5 °F 532.5 °R
Z_1 = 1.028 ; Z_2 = 1.018	Z_1 = 1.033 ; Z_2 = 1.026
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 215 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 120 PSI
ΔM_B = 39.0 LB, Δθ = 3600 SEC	ΔM_B = 20.7 LB, Δθ = 3600 SEC
$\bar{W}_B$ = LB/SEC	$\bar{W}_B$ = .00575 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.01072	.01083	.99	.01072
COOLANT	.00525	.00575	.914	.00525

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TEST V-2 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{ORIFICE})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	Θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	585	90	.1539	5.85	50	1.020	.996	.0521	.0310	
	ORIFICE NO. 6	15	✓	✓	✓	5.86	✓	✓	✓	✓	✓	
		20	✓	✓	✓	5.81	48	✓	✓	✓	✓	.0310
	NOM DIA: .0595"	25	✓	103	.1760	✓	✓	✓	.993	✓	.0309	
T_1 = T-117	COOLANT	10	785	225	.287	5.85	50	1.020	.973	.0399	.0311	
	ORIFICE NO. 5	15	✓	✓	✓	✓	✓	✓	✓	✓	✓	.0312
		20	✓	220	.281	5.80	47	1.021	.975	✓	.0312	
	NOM DIA: .052"	25	✓	✓	✓	✓	✓	✓	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1 \ (FT^3)$

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $\quad R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT3	$V_B = 35.1$ FT3
@ Θ = 10 MIN, P_{B1} = 1660 PSIA	@ Θ = 10 MIN, P_{B1} = 2000 PSIA
@ Θ = 25 MIN, P_{B2} = 1485 PSIA	@ Θ = 25 MIN P_{B2} = 1795 PSIA
$\bar{T}_B$ = 70 °F 530°R	$\bar{T}_B$ = 70 °F 530°R
Z_1 = 1.008 ; Z_2 = 1.004	Z_1 = 1.014 ; Z_2 = 1.012
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 170 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 190 PSI
ΔM_B = 29.3 LB, ΔΘ = 900 SEC	ΔM_B = 32.9 LB, ΔΘ = 900 SEC
$\bar{W}_B$ = .0325 LB/SEC	$\bar{W}_B$ = .0365 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0310 ✓	.0325	.955	.0310
COOLANT	.0312	.0365	.855	.0312

BY M. Kates DATE 11/28/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 247 OF ____
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TEST V-3 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR ORIFICE NO. 6 NOM. DIA: .0595"	10	585	90	.1531	5.42	30	1.040	.997	.0521	.0316	
		15	✓	✓	✓	5.39	28	1.043	✓	✓	.0317	.0317
		20	✓	✓	✓	✓	✓	✓	✓	✓	✓	
T_1 = T-117	COOLANT ORIFICE NO. 5 NOM DIA: .052"	10	785	245	.312	5.49	33	1.038	.968	.0399	.0314	
		15	✓	230	.293	5.46	32	1.037	.973	✓	.0316	.0315
		20	✓	✓	✓	✓	✓	✓	✓	✓	.0316	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 36.9 FT³	V_B = 35.1 FT³
@ θ = 10 MIN, P_{B1} = 2090 PSIA	@ θ = 10 MIN, P_{B1} = 2165 PSIA
@ θ = 20 MIN, P_{B2} = 1975 PSIA	@ θ = 20 MIN P_{B2} = 2040 PSIA
$\bar{T}_B$ = 51 °F 511 °R	$\bar{T}_B$ = 51 °F 511 °R
Z_1 = 1.014 ; Z_2 = 1.010	Z_1 = 1.017 ; Z_2 = 1.012
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 105 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 115 PSI
ΔM_B = 19.3 LB, Δθ = 600 SEC	ΔM_B = 20.6 LB, Δθ = 600 SEC
$\bar{W}_B$ = .0323 LB/SEC	$\bar{W}_B$ = .0343 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0317	.0323	.98	.0317
COOLANT	.0315	.0343	.92	.0315

TEST V-4 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T$

$F_P = P_1/1000$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	10	575	30	.0523	5.45	31	1.040	1.001	.01815	.01087	
	ORIFICE NO. 3	15	✓	✓	✓	5.43	30	✓	✓	✓	✓	.01087
	NOM DIA: .035"	20	✓	43	.0747	5.41	29	✓	1.00	✓	✓	
T_1 = T-117	COOLANT	10	1065	595	.557	5.80	47	1.020	.865	.00570	.00526	
	ORIFICE NO. 1	15	✓	✓	✓	5.70	45	1.025	✓	✓	.00529	.00527
	NOM DIA: .0200"	20	✓	600	.563	5.72	44	✓	.860	✓	.00525	

B. BOTTLE DATA

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 36.9 FT³	V_B = 35.1 FT³
@ θ = 10 MIN, P_{B1} = 1875 PSIA	@ θ = 10 MIN, P_{B1} = 1980 PSIA
@ θ = 20 MIN, P_{B2} = 1835 PSIA	@ θ = 20 MIN P_{B2} = 1950 PSIA
$\bar{T}_B$ = 47° °F 507 °R	$\bar{T}_B$ = 47° °F 507 °R
Z_1 = 1.002 ; Z_2 = 1.001	Z_1 = 1.006 ; Z_2 = 1.005
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 40 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 30 PSI
ΔM_B = 7.6 LB, $\Delta\theta$ = 600 SEC	ΔM_B = 5.43 LB, $\Delta\theta$ = 600 SEC
$\bar{W}_B$ = .01265 LB/SEC	$\bar{W}_B$ = .00904 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.01087	.01265	.86	.01087
COOLANT	.00527	.00904	.58	.00527

BY M. Kates DATE 12/13/62 ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 249 OF ___

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TEST V-5 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{fluid})$
$W_* = f(A_{\text{orifice}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR ORIFICE NO. 6 NOM. DIA: .0595"	10	585	90	.1539	5.61	38	1.031	.997	.0521	.0304	
		30	✓	✓	✓	5.60	✓	✓	✓	✓	✓	
		60	✓	✓	✓	5.64	40	1.030	✓	✓	.0303	.0304
		90	✓	✓	✓	✓	✓	✓	✓	✓	✓	
T_1 = T-117	COOLANT ORIFICE NO. 5 NOM. DIA: .052"	10	785	245	.312	5.69	42	1.028	.968	.0399	.0312	
		30	✓	240	.301	5.68	✓	✓	.970	✓	✓	
		60	✓	✓	✓	5.69	✓	✓	✓	✓	✓	.0312
		90	✓	✓	✓	5.65	40	1.030	✓	✓	.0313	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
$V_B = 35.1$ FT³	$V_B = 35.1$ FT³
@ θ = 10 MIN, P_{B1} = 1735 PSIA	@ θ = 10 MIN, P_{B1} = 1955 PSIA
@ θ = 90 MIN, P_{B2} = 855 PSIA	@ θ = 90 MIN P_{B2} = 1050 PSIA
$\bar{T}_B$ = 58 °F 518 °R	$\bar{T}_B$ = 58 °F 518 °R
Z_1 = 1.003 ; Z_2 = .992	Z_1 = 1.010 ; Z_2 = .992
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 867 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 887 PSI
ΔM_B = 153.5 LB, Δθ = 4800 SEC	ΔM_B = 157.0 LB, Δθ = 4800 SEC
$\bar{W}_B$ = .0320 LB/SEC	$\bar{W}_B$ = .0327 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0304	.0320	.950	.0304
COOLANT	.0312	.0327	.954	.0312

Test V-6 Air and Coolant Flow

Aborted Test

A. Orifice Data

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\Delta_{\text{orifice}})$
$W_* = f(\Delta_{\text{orifice}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

See ADL calculations "Orifice Flow Calculations" S.C. Burke 8/20/62 for details Rev 1/62

	Stream	θ (min)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	Air	15	585	90	1.539	5.19	19	1.052	.997	.0521	.0320	
	Orifice No. 6	35	✓	✓	✓	5.25	22	1.050	✓	✓	✓	.0318
	Nom Dia:	60	✓	✓	✓	5.31	24	1.048	✓	✓	.0318	
	.0595"	86	✓	✓	✓	5.42	30	1.040	✓	✓	.0316	
T_1 = T-117	Coolant	15	885	625	.706	5.37	28	1.042	.741	.0238	.01615	
	Orifice No. 4	35	✓	✓	✓	5.35	26	1.049	✓	✓	.01625	
	Nom Dia:	60	✓	615	.695	5.39	28	1.042	.751	✓	.01635	.01636
	.040"	86	✓	✓	✓	5.45	31	1.040	✓	✓	.01632	

B. Bottle Data

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$V_B = 1.75N + .1$ (FT³)

$R = .383 \frac{FT^3}{°F\ IN^2}$

Air	Coolant
V_B = 36.95 FT³	V_B = 35.1 FT³
@ θ = 15 min, P_{B1} = 1975 PSIA	@ θ = 15 min, P_{B1} = 2190 PSIA
@ θ = 60 min, P_{B2} = 1505 PSIA	@ θ = 65 min, P_{B2} = 1835 PSIA
$\bar{T}_B$ = 46 °F 506 °R	$\bar{T}_B$ = 46 °F 506 °R
Z_1 = 1.005 ; Z_2 = .992	Z_1 = 1.013 ; Z_2 = 1.000
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 446 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 325 PSI
ΔM_B = 85.0 LB, Δθ = 2700 SEC	ΔM_B = 58.9 LB, Δθ = 3000 SEC
$\bar{W}_B$ = .0315 LB/SEC	$\bar{W}_B$ = .0196 LB/SEC

Flow	Orifice	Bottles	$\bar{W}_o/\bar{W}_B$	Best Estimate
Air	.0318	.0315	1.009	.0318
Coolant	.01636	.01961	.834	.0164

TEST V-7 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{FLUID})$
$W_* = f(A_{\text{ORIFICE}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_f	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR	5	585	.75	.128	5.15	17					
	ORIFICE NO. 6	45	✓	✓	✓	5.02	11	1.06	~1.0	.0521	.0323	.0323
	NOM DIA: .0595"	71	✓	✓	✓	5.11	15					
T_1 = T-117	COOLANT	5	850	605	.712	5.55	36					
	ORIFICE NO. 4	45	✓	✓	✓	5.28	23	1.042	.73	.0238	.0154	.0154
	NOM DIA: .040"	71	✓	✓	✓	5.20	19					

B. BOTTLE DATA

$V_B = 1.75N + .1 \; (FT^3)$

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $\quad R = .383 \frac{FT^3}{°F \; IN^2}$

AIR (21 CYLINDERS)	COOLANT (20 CYLINDERS)
V_B = 36.9 FT³	V_B = 35.1 FT³
@ θ = 5 MIN, P_{B1} = 2130 PSIA	@ θ = 5 MIN, P_{B1} = 1870 PSIA
@ θ = 71 MIN, P_{B2} = 1425 PSIA	@ θ = 71 MIN P_{B2} = 1480 PSIA
$\bar{T}_B$ = 32 °F	$\bar{T}_B$ = 32 °F
Z_1 = 1.011 ; Z_2 = .991	Z_1 = 1.001 ; Z_2 = .991
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 660 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 375 PSI
ΔM_B = 129 LB, Δθ = 3960 SEC	ΔM_B = 69.8 LB, Δθ = 3960 SEC
$\bar{W}_B$ = .0326 LB/SEC	$\bar{W}_B$ = LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0323	.0326	.991	.0323
COOLANT	.0154	.0176	.875	.0164

BY M. Kates DATE 12/13/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 252 OF

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TEST V-8 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{FLUID})$
$W_* = f(A_{\text{ORIFICE}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

} SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
AIR (T_1 = T-113)	10	300	90	.300	5.19	19	1.053	.970	.0521	.0152	
ORIFICE No. 6	30	✓	✓	✓	4.98	9	1.064	✓	✓	.0162	.0160
	50	✓	✓	✓	4.94	7	✓	✓	✓	✓	
NOM DIA: .0595"	70	✓	✓	✓	✓	✓	✓	✓	✓	✓	
COOLANT (T_1 = T-117)	10	790	615	.779	5.68	42	1.028	.652	.01434	.00759	
ORIFICE No. 2	30	✓	✓	✓	6.41	29	1.041	✓	✓	.00770	.00767
	50	✓	✓	✓	5.39	28	1.043	✓	✓	✓	
NOM DIA: .031"	70	✓	✓	✓	✓	✓	✓	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1 \ (\text{FT}^3)$

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$$

$R = .383 \ \frac{\text{FT}^3}{\text{°F IN}^2}$

AIR	COOLANT
V_B = 36.98 FT3	V_B = 35.1 FT^3
@ θ = 10 MIN, P_{B1} = 2040 PSIA	@ θ = 15 MIN, P_{B1} = 1750 PSIA
@ θ = 70 MIN, P_{B2} = 1700 PSIA	@ θ = 65 MIN P_{B2} = 1565 PSIA
T_B = 30 °F 490°R	T_B = 30 °F 490°R
Z_1 = 1.000 ; Z_2 = .989	Z_1 = .987 ; Z_2 = .986
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 320 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 164? PSI
ΔM_B = 63 LB, $\Delta\theta$ = 3600 SEC	ΔM_B = 30.7 LB, $\Delta\theta$ = 3000 SEC
$\bar{W}_B$ = .0175 LB/SEC	$\bar{W}_B$ = .01022 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0160	.0175	.914	.0160
COOLANT	.00767	.01022	.750	.00767

BY M. Kates DATE 12/10/62 | ARTHUR D. LITTLE, I[illegible] | SHEET NO. 253 OF
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TEST V-9 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\ldots)$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS Rev. [illegible]

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\overline{W_o}$ LB/SEC
T_1 = T-113	AIR	25	455	90	.1975	4.89	4	1.068	.991	.0521	.0251	
	ORIFICE NO. 6	35	✓	✓	✓	4.91	6	1.067	✓	✓	✓	.0251
		45	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	NOM DIA: .0595"	60	✓	✓	✓	4.96	8	1.064	✓	✓	.0250	
T_1 = T-117	COOLANT	25	875	615	.703	5.35	26	1.045	.743	.01815	.01232	
	ORIFICE NO. 3	35	✓	625	.714	5.33	✓	✓	.730	✓	.01212	.01203
		45	✓	635	.726	✓	✓	✓	.715	✓	.01187	
	NOM DIA: .035"	60	✓	✓	✓	5.40	29	1.041	✓	✓	.01182	

B. BOTTLE DATA

$V_B = 1.75N + .1 \ (FT^3)$

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right] \qquad R = .383 \ \frac{FT^3}{°F \ IN^2}$$

AIR	COOLANT
$V_B = 36.98$ FT3	$V_B = 17.6$ FT3
@ θ = 25 MIN, P_{B1} = 1455 PSIA	@ θ = 25 MIN, P_{B1} = 1280 PSIA
@ θ = 60 MIN, P_{B2} = 1185 PSIA	@ θ = 60 MIN P_{B2} = 1000 PSIA
$\overline{T_B}$ = 15 °F 475 °R	$\overline{T_B}$ = 15 °F 475 °R
Z_1 = .9755 ; Z_2 = .974	Z_1 = .974 ; Z_2 = .975
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 274 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 290 PSI
ΔM_B = 55.7 LB, $\Delta\theta$ = 2100 SEC	ΔM_B = 28.1 LB, $\Delta\theta$ = 2100 SEC
$\overline{W_B}$ = .0265 LB/SEC	$\overline{W_B}$ = .01335 LB/SEC

FLOW	ORIFICE	BOTTLES	$\overline{W_o}/\overline{W_B}$	BEST ESTIMATE
AIR	.0251	.0265	.949	.0251
COOLANT	.01203	.01335	[illegible]	[illegible]

BY M. Kates DATE 12/19/62 — **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. — SHEET NO. 254 OF

APPROVED ______ DATE ______ — SKETCH NO. ______

CLIENT ASD/EXPERI — CASE NO. 64607

TEST V-9 ~~AIR AND COOLANT~~ Spray FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{fluid})$
$W_* = f(A_{\text{orifice}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" D.C. BURKE 8/20/62 FOR DETAILS REV. 1/…

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_t	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	~~AIR~~ Spray ORIFICE No. 4 NOM DIA: .040"	25	850	715	.842	5.85	50	1.019	.565	.0238	.01164	.01143
		35	✓	✓	✓	5.87	✓	✓	✓	✓	✓	
		45	✓	725	.853	5.89	52	1.017	.547	✓	.01123	
		60	✓	✓	✓	5.97	55	1.014	✓	✓	.01122	
T_1 = T-117	COOLANT ORIFICE NO. NOM DIA:											

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$

$R = .383 \frac{FT^3}{°F\ IN^2}$

~~AIR~~ Spray	COOLANT
V_B = 7.1 FT³	V_B = FT³
@ θ = 30 MIN, P_{B1} = 1625 PSIA	@ θ = MIN, P_{B1} = PSIA
@ θ = 60 MIN, P_{B2} = 1005 PSIA	@ θ = MIN P_{B2} = PSIA
$\bar{T}_B$ = 73 °F 533 °R	$\bar{T}_B$ = °F
Z_1 = 1.008 ; Z_2 = .997	Z_1 = ; Z_2 =
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 608 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = PSI
ΔM_B = 21.2 LB, Δθ = 1800 SEC	ΔM_B = LB, Δθ = SEC
$\bar{W}_B$ = .01179 LB/SEC	$\bar{W}_B$ = LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
Spray ~~AIR~~	.01143	.01179	.971	.0114

BY M. Katz DATE 9/20/60 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 255 OF ______

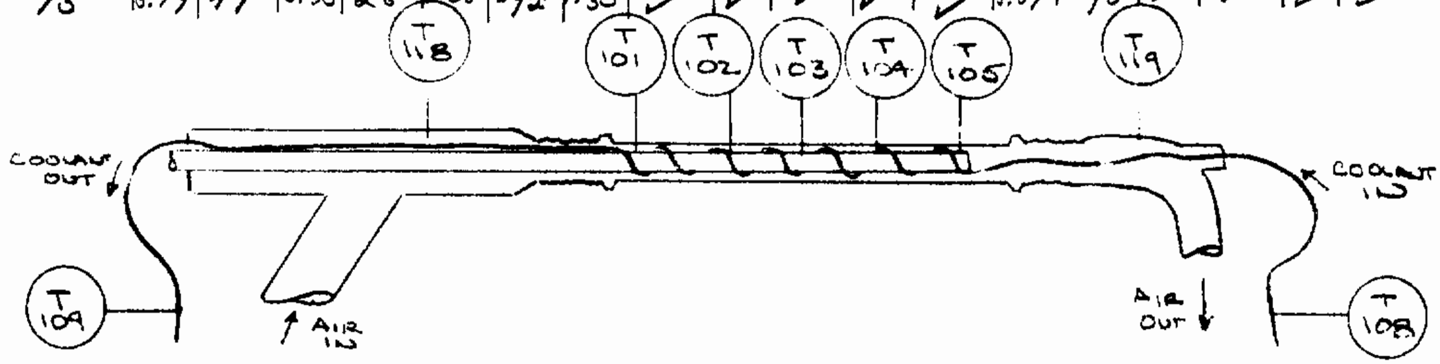
APPROVED ______ DATE ______ — SKETCH NO. ______

CLIENT ASD / EXPERI — CASE NO. 64607

TEST V-1

AIR AND COOLANT TEMPERATURE DATA

	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR				COOLANT			
											IN		OUT		IN		OUT	
TIME (MIN)	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	5,13		4,12		3,11		2,10		1,9		8		16		[illegible]		[illegible]	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.41	75	6.42	75	6.42	75	6.42	75	6.42	75	6.52	80	6.70	88	6.03	58	6.40	74
2.5	6.39	74	6.41	✓	6.41	✓	6.27	68	5.75	45	6.49	78	6.47	78	1.51	-190	6.41	75
6	6.41	75	6.45	76	6.40	74	6.21	66	5.11	15	6.51	79	5.89	52	1.02	-226	6.49	74
10	6.45	76	✓	✓	6.01	57	4.30	-25	1.75	-172	6.56	82	4.85	2	0.55	-265	6.49	78
15½	6.35	72	6.25	68	5.19	19	2.69	-113	1.19	-212	6.64	83	4.00	-40	✓	✓	6.51	79
21	6.38	74	6.01	57	4.50	-15	1.91	-162	1.05	-224	6.68	87	3.62	-60	✓	✓	6.50	✓
25	6.21	66	5.90	52	4.12	-37	1.65	-180	1.00	-228	6.65	86	3.45	-70	✓	✓	✓	✓
30	6.09	60	5.74	44	3.83	-49	1.51	-190	0.95	-232	✓	✓	3.35	-75	✓	✓	6.49	78
36	6.05	58	5.61	38	3.69	-56	✓	✓	✓	✓	6.69	87	3.27	-80	0.51	-269	✓	✓
40	6.00	56	5.62	39	3.71	✓	1.55	-186	✓	✓	6.70	88	3.21	-83	0.50	-270	6.46	77
45	5.99	✓	5.69	42	3.62	-60	1.52	-188	✓	✓	6.71	✓	3.19	-84	0.51	-269	✓	✓
50	✓	✓	5.55	36	3.55	-64	1.49	-190	✓	✓	6.72	✓	3.15	-86	✓	✓	6.45	76
55	5.90	52	5.49	33	3.39	-73	1.45	-194	✓	✓	✓	✓	✓	✓	0.50	[illegible]	✓	✓
60	5.87	50	5.41	29	3.22	-82	1.39	-198	0.91	-234	✓	✓	✓	✓	✓	✓	6.42	[illegible]
65	5.85	✓	5.40	✓	3.18	-84	✓	✓	✓	✓	✓	✓	3.13	-88	✓	✓	6.41	✓
70	5.77	46	✓	✓	3.13	-88	1.37	-200	✓	✓	✓	✓	3.11	✓	✓	✓	✓	✓
75	5.79	47	5.35	26	3.05	-92	1.35	✓	✓	✓	✓	✓	3.09	-90	✓	✓	✓	✓



NOTES:

BY M. Kates DATE 9/20/62

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

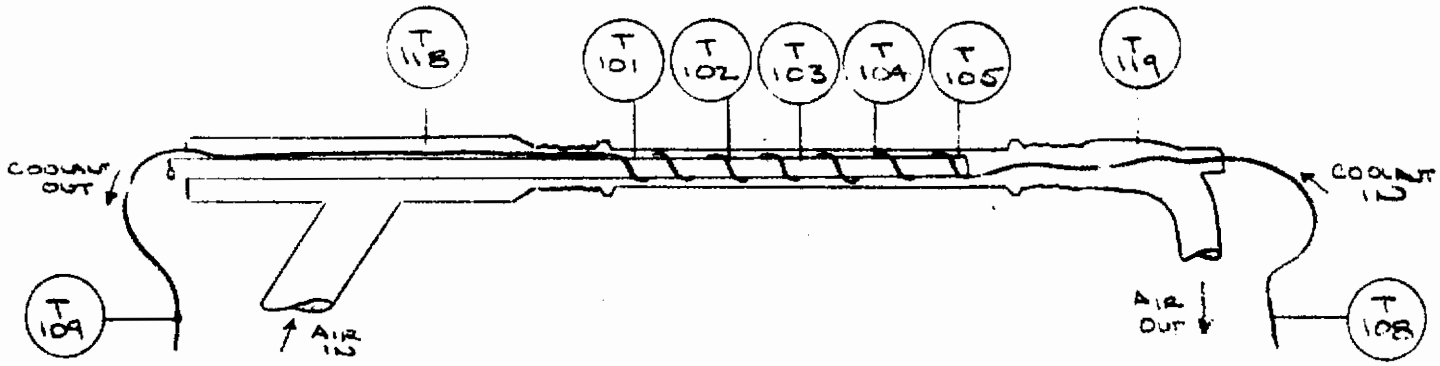
SHEET NO. 256 OF
SKETCH NO.
CASE NO. 64607

APPROVED DATE
CLIENT ASD / EXPERI

TEST V-2

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	[redacted] 1,9		[redacted] 2,10		[redacted] 3,11		4,12 [redacted]		5,13 [redacted]		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.31	70	6.31	70	6.31	70	6.31	70	6.35	72	6.30	70	6.65	86	6.35	72	6.35	72
1	6.45	76	6.35	72	✓	✓	✓	✓	6.29	70	6.50	79	6.49	78	6.25	68	✓	✓
4	6.55	81	6.49	78	6.35	72	6.25	68	6.12	62	6.68	87	6.39	74	5.71	43	6.00	56
6	6.69	87	6.31	70	5.79	47	5.11	15	4.49	-16	6.75	90	5.79	47	2.89	-102	6.50	77
8	6.80	92	5.90	52	5.09	14	4.21	-30	3.40	-72	6.80	92	5.00	10	2.49	-125	6.29	70
10	6.87	95	5.65	40	4.70	-5	3.81	-50	3.05	-92	6.85	94	4.55	-12	2.25	-140	6.15	63
12½	6.92	97	5.51	34	4.45	-18	3.51	-66	2.77	-108	6.90	96	4.15	-32	2.09	-150	6.09	60
15	6.96	99	5.50	✓	4.50	-15	3.50	-65	2.70	-112	6.91	97	3.95	-43	1.99	-156	✓	✓
17½	6.99	100	5.49	33	✓	✓	3.49	✓	2.69	-113	6.90	96	3.79	-52	✓	✓	6.05	58
20	6.95	98	5.45	31	4.45	-18	✓	✓	2.65	-116	6.91	97	3.69	-56	1.95	-160	✓	✓
23	6.99	100	5.41	29	4.35	-22	3.40	-72	2.61	-118	✓	✓	3.60	-62	1.90	-162	6.01	57
25	✓	✓	5.35	26	4.25	-28	3.32	-76	2.55	-122	6.93	98	3.55	-64	1.89	-164	6.00	56
26½	✓	✓	✓	✓	4.21	-30	3.31	-78	✓	✓	✓	✓	3.50	-67	1.85	-166	✓	✓



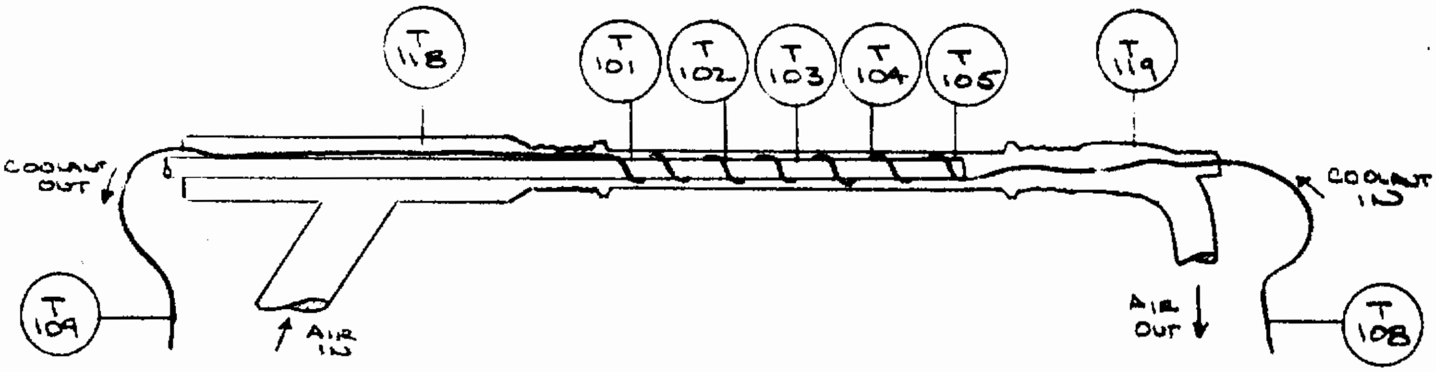
NOTES:

BY M. Kates DATE 11/28/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 257 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD / EXPERI | CASE NO. 64607

TEST V-3

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	5,13		4,12		3,11		2,10		1,9		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.45	76	6.45	76	6.45	76	6.45	76	6.45	76	6.45	76	6.61	84	6.45	76	6.45	76
1½	6.51	79	✓	✓	6.39	74	6.35	72	6.35	72	6.64	85	6.50	79	6.37	74	✓	✓
3	6.60	83	6.50	79	6.40	✓	✓	✓	6.32	71	6.71	88	6.46	77	6.29	70	6.51	79
5	6.75	90	6.59	83	6.41	75	6.29	70	6.21	66	6.85	94	6.38	74	6.07	60	6.62	84
7½	6.70	96	6.60	✓	6.34	72	6.06	59	5.78	46	6.93	98	6.21	66	4.65	-8	6.69	87
10	7.00	100	6.05	58	5.31	24	4.49	-16	3.69	-56	7.00	100	5.10	14	2.15	-146	6.48	78
15	7.07	104	5.55	36	4.45	-18	3.50	-67	2.75	-110	7.04	102	4.00	-40	2.05	-152	6.17	64
20	✓	✓	5.57	38	4.55	-12	3.43	-70	2.65	-116	✓	✓	3.61	-61	1.99	-156	6.21	66
22	✓	✓	5.55	36	4.50	-15	3.49	-68	2.70	-112	7.02	✓	3.58	-62	2.01	✓	6.23	67



NOTES:

~~[illegible]~~

BY M. Kates DATE 11/28/62 — **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. — SHEET NO. 258 OF

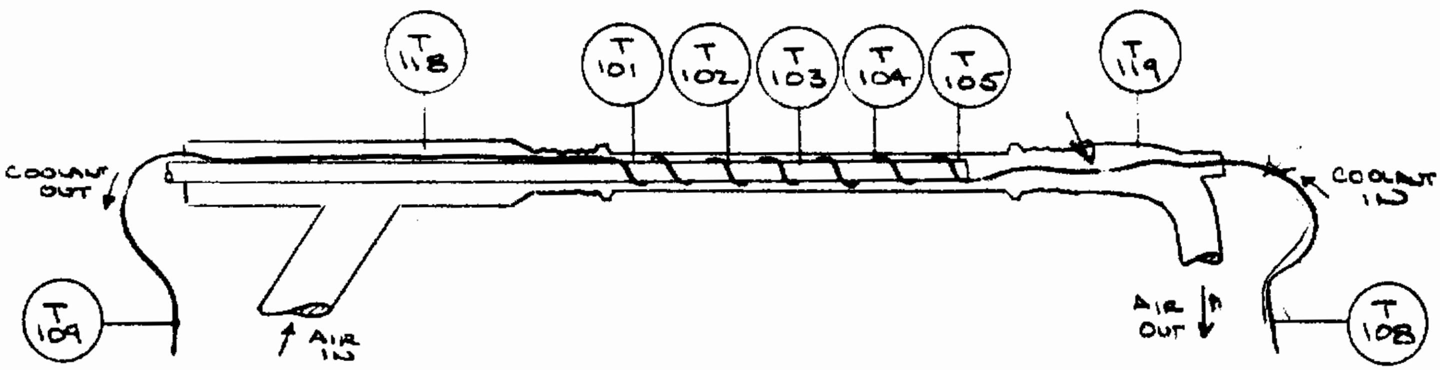
APPROVED ____ DATE ____ — SKETCH NO. ____

CLIENT ASD / EXPERI — CASE NO. 64607

TEST V-4

AIR AND COOLANT TEMPERATURE DATA

	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101 (5,13)		T-102 (4,12)		T-103 (3,11)		T-104 (2,10)		T-105 (1,9)		T-118 (8)		T-119 (16)		T-108 (6,14)		T-109 (7,15)	
Time (Min)	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
0	6.72	88	6.71	88	6.67	86	6.59	83	6.50	79	6.74	89	5.90	52	2.01	-156	6.40	74
2	6.76	90	6.72	✓	6.69	87	6.63	84	6.57	82	✓	✓	6.00	56	[illegible]	-122	6.48	78
5	6.79	92	6.70	✓	6.59	83	5.77	47	3.05	-92	6.76	90	5.37	22	0.79	-244	6.64	85
7½	6.80	✓	6.60	83	6.09	60	4.18	-31	1.61	-182	6.78	91	4.49	-16	0.49	-271	6.67	87
10	✓	✓	6.48	78	5.55	36	3.10	-89	1.19	-212	6.79	92	[illegible]	-43	0.45	-274	✓	✓
12½	6.82	93	6.31	70	5.08	14	2.36	-133	1.05	-224	✓	✓	3.67	-58	0.41	-278	6.65	86
15	✓	✓	6.18	64	4.69	-6	1.90	-162	0.95	-232	✓	✓	3.48	-68	0.40	-277	✓	✓
18	6.85	94	6.25	68	4.81	0	1.79	-170	0.90	-236	6.80	✓	3.35	-75	✓	✓	6.61	[illegible]
20	✓	✓	6.37	74	✓	✓	1.95	-160	0.93	-233	✓	✓	3.29	-78	✓	✓	✓	✓



NOTES:

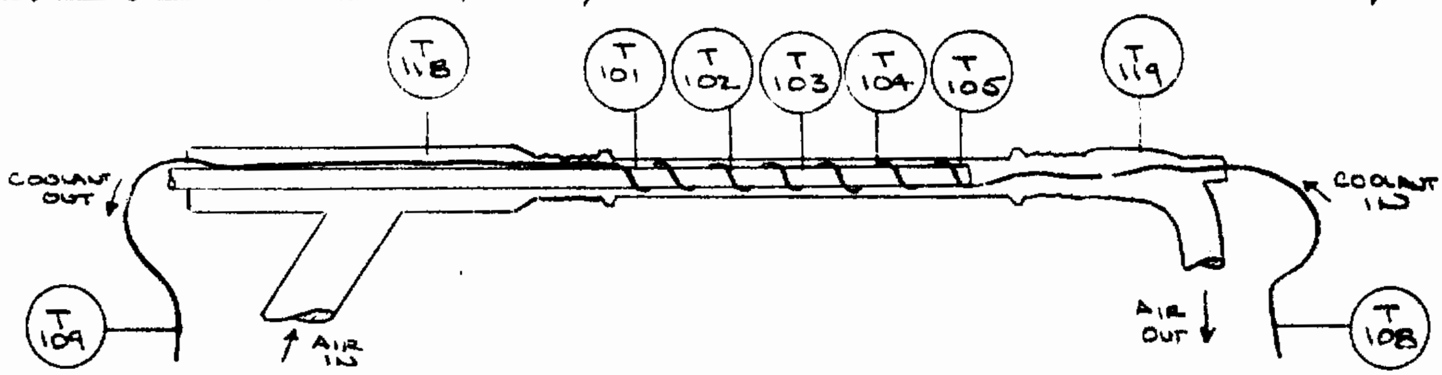
1. ~~[illegible]~~

BY M. Katos	DATE 12/13/62	ARTHUR D. LITTLE, INC.	SHEET NO. 259 OF
APPROVED	DATE	CAMBRIDGE, MASS.	SKETCH NO.
CLIENT ASD / EXPERI			CASE NO. 64607

TEST V-5

AIR AND COOLANT TEMPERATURE DATA

	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR				COOLANT			
											IN		OUT		IN		OUT	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	5,13		4,12		3,11		2,10		1,9		8		16		6,14		7,15	
TIME (MIN)	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
1	6.49	78	6.41	75	6.41	75	6.41	75	6.41	75	6.59	83	6.60	83	6.41	75	6.41	75
6	6.85	94	6.05	58	5.34	26	4.59	-10	3.89	-46	6.93	98	5.21	20	3.13	-88	6.42	✓
10	7.08	104	6.10	61	5.36	27	4.77	-2	4.39	-20	7.05	103	4.97	8	4.21	-30	6.47	78
15	7.21	110	6.35	72	5.74	44	5.22	20	4.86	3	7.10	107	5.18	18	4.51	-14	6.64	85
20	7.28	112	6.25	68	5.50	34	4.80	0	4.02	-40	7.19	109	4.85	2	3.25	-80	6.63	84
25	7.29	113	6.11	62	5.30	24	4.60	-10	4.09	-36	✓	✓	4.68	-6	3.67	-58	6.61	✓
30	7.25	111	6.20	66	5.40	29	4.73	-4	4.10	-35	✓	✓	4.72	-4	3.37	-73	6.59	83
35	7.24	✓	6.04	58	5.22	20	4.56	-12	4.11	-34	7.16	108	4.52	-14	3.77	-52	6.49	78
41	✓	✓	6.00	56	5.19	19	4.27	-26	3.61	-61	7.17	✓	4.38	-21	2.83	-104	✓	✓
45	✓	✓	5.98	✓	5.10	14	4.41	-20	3.91	-45	7.15	107	4.39	-20	3.14	-86	6.45	76
50	7.22	110	6.05	58	5.21	20	4.50	-15	3.86	-48	✓	✓	4.47	-16	3.32	-76	6.50	79
55	✓	✓	6.11	62	5.32	25	4.70	-5	4.23	-28	✓	✓	4.57	-10	3.98	-42	6.51	✓
60	✓	✓	6.19	65	5.41	29	4.71	-4	4.12	-34	✓	✓	4.69	-6	3.46	-67	6.58	[illegible]
65	✓	✓	6.11	62	5.33	26	✓	✓	4.24	-28	✓	✓	4.61	-10	3.87	-47	6.51	77
70	✓	✓	6.00	56	5.11	15	4.35	-22	3.72	-55	✓	✓	4.40	-20	3.24	-82	6.48	78
75	✓	✓	6.15	63	5.39	28	4.76	-2	4.32	-24	✓	✓	4.63	-8	3.94	-44	6.51	79



NOTES:

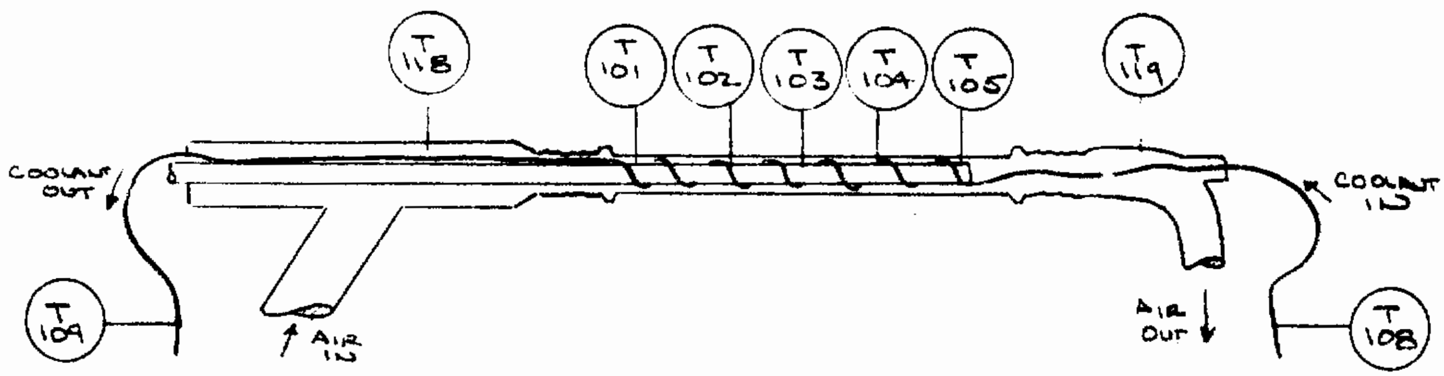
1. ~~[illegible]~~
2. T-104 and T-119 oscillate continuously between 0°F (4.80mv) and -30°F (4.2 mv)
3. T-105 oscillates continuously between -25°F (4.30mv) and -62°F (3.60mv)
4. T-108 oscillates continuously between -32°F (4.15mv) and -84°F (3.…

BY M. Kos[illegible] DATE 12/14/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 260 OF ______
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / EXPERI | CASE NO. 6A607

TEST V-5

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air				Coolant			
											In		Out		In		Out	
	T-101 (5,13)		T-102 (4,12)		T-103		T-104 (2,10)		T-105 (1,9)		T-118		T-119		T-108		T-109	
					3,11						8		16		6,14		7,15	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
80	7.22	110	6.09	60	5.23	20	4.55	-12	4.00	-40	7.15	107	4.50	-15	3.60	-62	6.50	79
85	✓	✓	6.19	65	5.41	29	4.80	0	4.27	-26	✓	✓	4.70	-5	3.79	-52	6.56	82
90	✓	✓	6.10	61	5.30	24	4.59	-10	4.10	-35	✓	✓	4.60	-10	3.73	-54	6.57	79
92	✓	✓	6.14	63	5.39	28	4.76	-2	4.33	-24	✓	✓	4.69	-6	4.10	-35	6.58	80
94	7.21	✓	6.19	65	5.42	30	4.79	0	4.30	-25	✓	✓	4.73	-4	3.79	-52	[illegible]	81



NOTES:

1. ~~[illegible]~~

BY N. Kutes DATE 12/12/62 APPROVED ______ DATE ______ CLIENT ASD / EXPERI

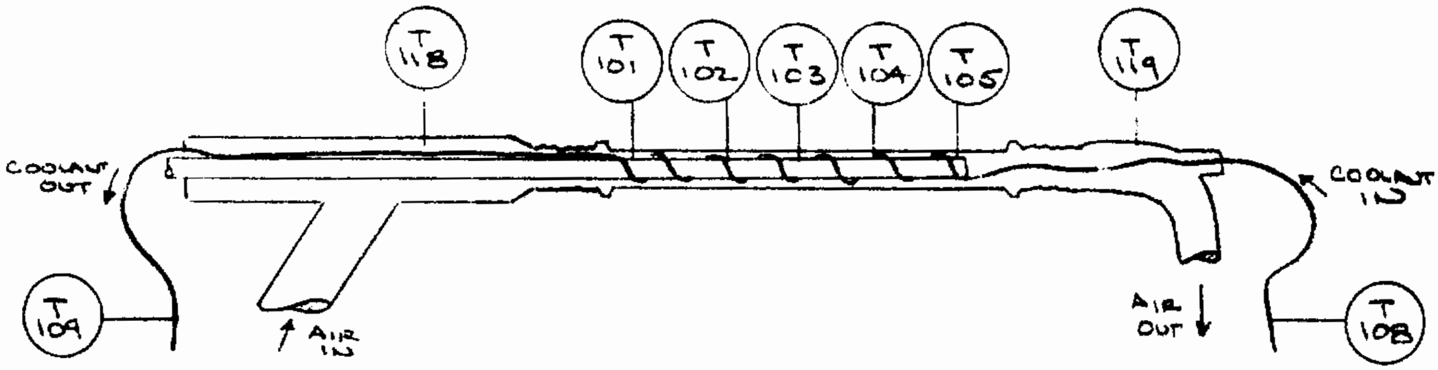
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 261 OF ______ SKETCH NO. ______ CASE NO. 64607

TEST V-6 (ABORTED TEST)

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures: T-101 (5,13)		T-102 (4,12)		T-103 (3,11)		T-104 (2,10)		T-105 (1,9)		Air In: T-118 (8)		Air Out: T-119 (16)		Coolant In: T-108 (6,14)		Coolant Out: T-109 (7,15)	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
3	6.39	74	6.31	70	6.19	65	5.55	36	3.67	-58	6.39	74	6.31	70	1.01	-226	6.31	70
5	6.30	70	5.81	48	4.52	-14	2.38	-132	1.20	-212	6.29	70	6.20	66	0.31	-288	6.14	63
10	6.03	58	4.28	-26	2.13	-148	1.09	-220	0.72	-250	6.06	59	6.09	60	0.29	-290	5.40	29
15	5.78	46	3.50	-67	1.59	-184	0.94	-232	0.65	-256	5.85	50	6.02	57	0.25	-294	4.90	5
20	5.61	38	3.21	-83	1.45	-194	0.92	-234	0.64	-258	5.75	45	5.99	56	✓	✓	4.70	-5
25	5.53	35	2.95	-98	1.35	-200	0.89	-236	0.62	-259	5.70	42	5.97	55	0.23	-296	4.55	-12
30	5.50	34	2.55	-121	1.24	-208	0.83	-241	0.59	-262	✓	✓	5.95	54	✓	✓	4.31	-24
35	5.46	32	2.07	-152	1.09	-220	0.76	-247	0.54	-266	5.65	40	5.92	53	✓	✓	3.83	-49
40	5.40	29	1.69	-176	0.99	-228	0.70	-252	0.50	-270	5.61	38	5.91	52	✓	✓	3.26	-80
45	5.33	26	1.55	-186	0.93	-233	0.67	-255	0.48	-272	5.58	37	5.93	53	✓	✓	2.91	-100
50	5.28	23	1.50	-190	0.90	-236	6.64	-258	0.46	-274	5.55	36	✓	✓	0.21	-298	2.70	-112
55	5.27	22	1.51	✓	0.91	-234	0.64	✓	0.49	-271	5.51	34	5.91	52	✓	✓	2.74	-110
60	5.25	✓	1.50	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.90	✓	✓	✓	2.60	-118
65	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2.62	✓
75	✓	✓	1.52	-188	0.93	-233	✓	✓	0.48	-272	✓	✓	5.88	51	✓	✓	2.65	-116
86	5.07	✓	1.55	-186	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2.59	-119



NOTES:

1. ~~[illegible]~~

BY M. Kates DATE 12/18/62

APPROVED ______ DATE ______

CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 262 OF ______

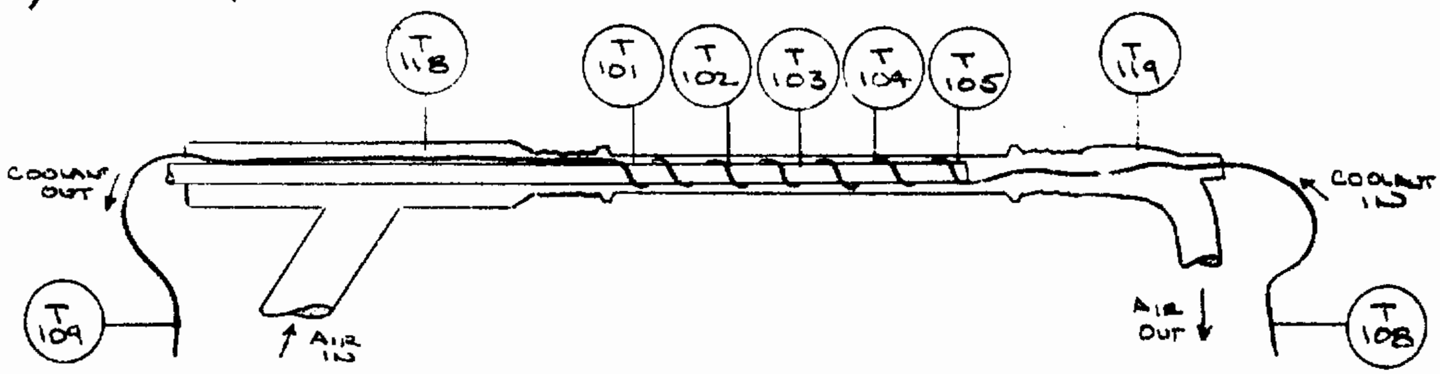
SKETCH NO. ______

CASE NO. 64607

TEST V-7

AIR AND COOLANT TEMPERATURE DATA

	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR IN		AIR OUT		COOLANT IN		COOLANT OUT	
	T-101 (5,13)		T-102 (4,12)		T-103		T-104 (2,10)		T-105 (1,9)		T-118		T-119		T-108		T-109	
	[redacted]		[redacted]		3,11		[redacted]		[redacted]		8		16		6,14		7,15	
TIME (MIN)	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
3	6.55	81	6.55	81	6.44	76	6.02	57	4.50	-15	6.65	86	6.24	67	1.25	-208	6.55	81
5	6.69	87	6.49	78	5.70	42	3.70	-56	1.60	-182	6.79	92	5.41	29	0.37	-280	6.65	86
10½	6.99	100	6.00	56	4.03	-38	1.67	-178	0.95	-232	6.99	100	5.11	15	0.31	-288	6.63	84
15	7.09	104	5.82	48	3.59	-62	1.49	-190	0.89	-236	7.01	101	5.15	17	0.30	-289	6.60	83
20	7.11	105	5.80	47	3.51	-66	1.45	-194	0.90	✓	7.05	103	5.17	18	0.29	-290	✓	✓
25	7.16	108	6.19	65	4.20	-30	1.87	-164	1.07	-222	7.10	105	✓	✓	✓	✓	6.79	92
30	7.23	110	6.02	57	3.73	-54	1.65	-180	0.99	-228	7.15	107	5.19	19	✓	✓	✓	✓
35	7.29	113	5.98	56	3.61	-61	1.55	-186	0.95	-232	7.20	109	5.15	17	✓	✓	6.75	90
40	✓	✓	5.99	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
45	✓	✓	5.93	53	3.58	-62	✓	✓	0.93	-233	✓	✓	5.12	16	0.28	-291	✓	✓
50	✓	✓	5.97	55	3.60	-60	1.57	-185	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
55	✓	✓	5.90	52	3.49	-68	1.55	-186	0.91	-234	✓	✓	✓	✓	0.25	-294	✓	✓
60	✓	✓	5.86	50	3.41	-72	1.51	-190	0.90	-236	✓	✓	5.10	14	✓	✓	6.71	88
65	7.25	111	5.70	45	3.23	-82	1.45	-194	0.85	-240	7.15	107	5.09	✓	✓	✓	6.75	90
68	7.21	110	5.79	47	3.25	-80	1.50	-190	✓	✓	7.13	106	4.93	6	✓	✓	✓	✓
71	7.20	109	5.75	45	3.30	-78	✓	✓	✓	✓	7.11	105	5.06	12	✓	✓	6.72	88



NOTES:

1. [illegible]

BY M. Kates DATE 12/14/62 APPROVED ________ DATE ______ CLIENT ASD / EXPERI

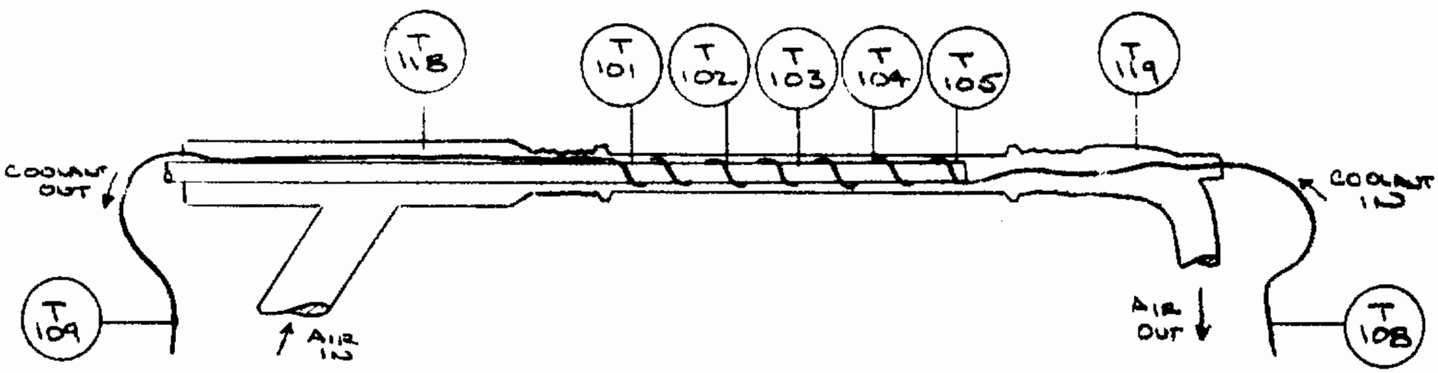
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 263 OF ______ SKETCH NO. ____________ CASE NO. 64607

TEST V-8

AIR AND COOLANT TEMPERATURE DATA

Time (Min)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101 5,13		T-102 4,12		T-103		T-104 2,10		T-105 1,9		T-118		T-119		T-108		T-109	
	~~[illegible]~~		~~[illegible]~~		3,11		~~[illegible]~~		~~[illegible]~~		8		16		6,14		7,15	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
6	6.61	84	6.58	82	6.45	76	5.84	49	3.82	-50	6.65	86	5.21	48	0.89	-236	6.60	83
10	6.71	88	6.32	71	5.16	18	2.76	-108	1.10	-220	6.79	92	4.23	-28	0.37	-282	6.69	87
[illegible]	6.89	96	5.78	46	3.67	-58	1.45	-194	0.80	-244	6.89	96	3.30	-78	0.35	-284	6.61	84
20	7.00	100	5.67	41	3.21	-81	1.21	-212	0.75	-248	6.96	99	3.02	-94	0.32	-287	6.59	83
25½	7.02	102	5.18	19	2.55	-122	1.05	-224	0.69	-253	7.02	102	2.88	-102	0.31	-288	6.50	79
30	7.04	✓	4.92	6	2.42	-130	1.03	-225	✓	✓	✓	✓	2.79	-107	✓	✓	6.42	75
35	✓	✓	4.81	0	2.37	-132	1.01	226	✓	✓	✓	✓	2.71	-112	0.30	-289	6.39	74
40	✓	✓	4.72	-4	2.25	-140	✓	✓	0.67	-255	✓	✓	2.68	-114	✓	✓	6.34	72
45	7.03	✓	✓	✓	2.22	-142	✓	✓	✓	✓	✓	✓	2.62	-118	✓	✓	6.32	71
50	✓	✓	✓	✓	2.20	-143	✓	✓	✓	✓	✓	✓	2.59	-119	0.29	-290	6.31	70
55	7.01	101	4.69	-6	2.13	-148	1.00	-228	0.65	-256	7.01	101	2.57	-120	✓	✓	✓	✓
60	✓	✓	4.70	-5	✓	✓	✓	✓	✓	✓	7.00	100	2.51	-124	✓	✓	6.30	✓
65	7.00	100	4.55	-12	2.01	-156	✓	✓	✓	✓	✓	✓	2.48	-126	✓	✓	6.29	✓
70	6.99	✓	4.39	-20	1.86	-166	0.95	-232	✓	✓	6.99	✓	2.39	-132	✓	✓	6.20	66
72½	✓	✓	4.29	-26	1.75	-172	0.90	-236	0.61	-260	6.97	97	2.33	-134	✓	✓	6.19	65



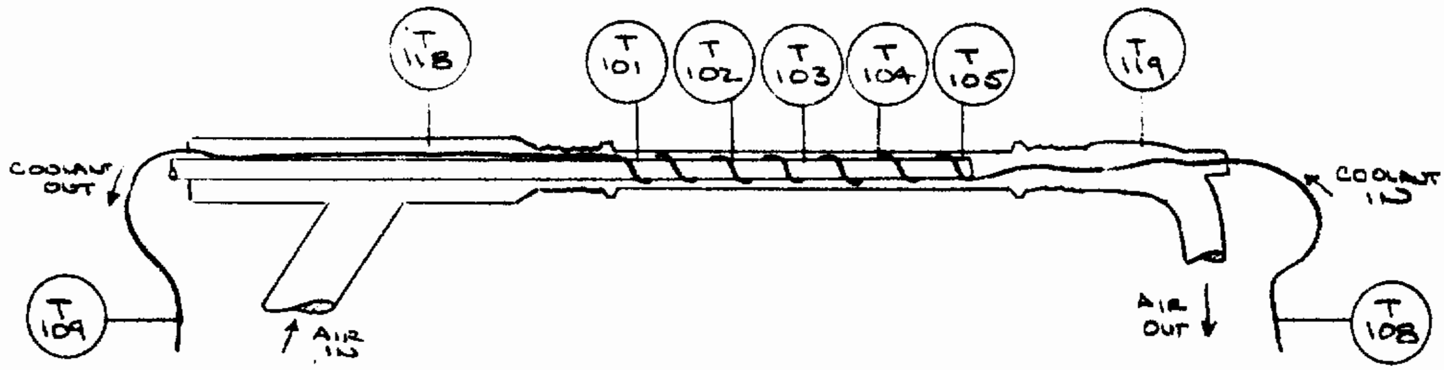
NOTES:

1. ~~[illegible]~~

TEST V-9

AIR AND COOLANT TEMPERATURE DATA

TIME (MIN)	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR IN		AIR OUT		COOLANT IN		COOLANT OUT	
	T-101 (5,13)		T-102 (4,12)		T-103 (3,11)		T-104 (2,10)		T-105 (1,9)		T-118 (8)		T-119 (16)		T-108 (6,14)		T-109 (7,15)	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
1 1/2	6.50	79	6.50	79	6.50	79	6.50	79	6.50	79	6.55	81	6.51	79	6.12	62	6.12	62
3	6.51	✓	6.51	✓	6.49	78	6.41	75	6.21	66	6.61	84	6.42	75	4.60	-10	6.18	64
7	5.21	20	5.11	15	5.59	38	5.49	33	3.65	-58	4.95	8	4.70	-5	0.86	-238	5.21	20
11	3.53	-66	3.57	-63	3.57	-63	2.86	-103	1.60	-182	3.79	-52	3.17	-85	0.52	-268	3.57	-63
15	3.01	-94	3.35	-75	3.20	-84	2.40	-130	1.35	-200	3.55	-64	2.65+	-116	0.51	-269	3.30	-78
20	✓	✓	3.30	-78	3.01	-94	2.00	-156	1.19	-212	3.50	-67	2.34	-134	0.49	-271	3.24	-82
25	3.05	-92	3.23	-82	2.89	-102	1.81	-168	1.11	-218	3.51	-66	2.18	-144	0.45	-274	3.21	-83
30	3.10	-89	3.21	-83	2.79	-107	1.77	-172	✓	✓	3.53	✓	2.13	-148	0.42	-277	3.20	-84
35	3.09	-90	3.18	-84	2.74	-110	1.71	-176	1.10	-220	3.51	✓	2.09	-150	0.41	-278	3.15	-86
40	3.07	✓	3.11	-88	2.65	-116	1.65	-180	1.08	-221	3.49	-68	2.01	-156	0.38	-281	3.09	-90
45	3.05	-92	3.08	-90	2.53	-122	1.57	-185	1.05	-224	3.50	-67	✓	✓	✓	✓	3.01	-94
50	3.01	-94	3.05	-92	2.48	-126	1.51	-190	✓	✓	3.48	-68	✓	✓	0.35	-284	3.00	✓
55	✓	✓	3.00	-94	2.41	-130	1.50	✓	✓	✓	✓	✓	2.00	✓	✓	✓	2.93	-98
60	✓	✓	✓	✓	2.36	-133	1.47	-192	1.01	-226	3.48	✓	✓	✓	✓	✓	2.90	-100
65	2.99	-96	2.91	-100	2.22	-142	1.42	-196	✓	✓	3.50	-67	1.99	✓	0.32	-287	2.80	-106



NOTES:

1. ~~[illegible]~~

BY M. Kates DATE 9/20/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 265 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD/EXPERI | CASE NO. 64607

TEST V-1

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT1	ΔT2	ΔT3	ΔT4	OVERALL ΔT	COOLANT OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
0	0	0	0	0	0	16
2 1/2	-1	0	7	23	29	165
6	-1	2	9	51	60	300
10	0	19	82	147	248	343
15 1/2	4	49	132	99	284	344
21	17	72	147	62	298	344
25	14	78	147	48	294	344
30	16	93	141	42	292	343
36	20	94	134	42	290	347
40	17	95	130	46	288	347
45	14	102	128	44	288	346
50	20	100	126	42	288	345
55	19	106	121	38	284	346
60	21	111	116	36	284	345
65	21	113	114	36	284	345
70	17	117	112	34	280	345
75	21	118	108	34	281	345

BY M. Kates DATE 9/29/62 | **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. | SHEET NO. 266 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD/EXPERI | CASE NO. 64607

TEST V-2

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT1	ΔT2	ΔT3	ΔT4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
0	0	0	0	−2	−2	0
1	4	2	0	0	6	4
4	3	6	4	6	19	13
6	17	23	32	31	103	181
8	40	38	44	42	164	195
10	55	45	45	42	187	203
12 1/2	63	52	48	42	205	210
15	65	49	50	47	211	216
17 1/2	67	48	50	48	213	214
20	67	49	47	51	214	218
23	71	51	50	46	218	219
25	74	54	48	46	222	220
26 1/2	74	56	48	44	222	222

BY M. Kates DATE 11/28/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 267 OF

APPROVED ______ DATE ______ | SKETCH NO.

CLIENT ASD/EXPERI | CASE NO. 64607

TEST V-3

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{101}-T_{105}$	$T_{109}-T_{108}$
0	0	0	0	0	0	0
1½	3	2	2	0	7	2
3	4	5	2	1	12	9
5	7	8	5	4	24	24
7½	13	11	13	13	50	95
10	42	34	40	40	156	224
15	68	54	49	43	214	216
20	66	50	58	46	220	222
22	68	51	53	44	216	223

TEST V-4

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 – T102	T102 – T103	T103 – T104	T104 – T105	T101 – T105	T109 – T108
0	0	2	3	4	9	230
2	2	1	3	2	8	200
5	4	5	36	139	184	329
7½	9	23	91	151	274	358
10	14	42	125	123	304	361
12½	23	56	147	91	317	364
15	27	70	156	70	325	365
18	26	68	170	66	330	363
20	20	74	160	73	327	363

BY M. Kates DATE 12/14/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 269 OF ....
APPROVED........DATE........ | SKETCH NO. ....
CLIENT ASD/EXPERI | CASE NO. 64607

TEST V-5

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	COOLANT OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
1	3	0	0	0	3	0
6	36	32	36	36	140	163
10	43	34	29	18	124	108
15	38	28	24	17	107	99
20	44	34	34	40	152	164
25	51	38	34	26	149	142
30	45	37	33	31	146	156
35	53	38	32	22	145	130
41	55	37	45	35	172	182
45	—	42	34	25	156	162
50	52	38	25	33	158	155
55	48	37	30	23	138	121
60	45	36	33	30	144	151
65	48	36	30	24	138	126
70	54	41	37	33	165	160
75	47	35	30	22	134	143
80	50	40	32	28	150	141
85	45	36	29	26	136	134
90	49	37	34	25	145	133
92	47	35	30	22	134	115
94	45	35	30	25	135	133

BY M. Kates DATE 12/12/62 **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. SHEET NO. 270 OF ____

APPROVED ____ DATE ____ SKETCH NO. ____

CLIENT ASD/EXPERI CASE NO. 64607

TEST V-6 (ABORT)

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
3	4	5	29	94	132	296
5	22	62	118	80	282	351
10	84	122	72	30	308	319
15	113	117	48	24	302	294
20	121	111	40	✓	296	289
25	133	102	36	23	294	284
30	155	87	33	21	296	272
35	184	68	27	19	298	247
40	205	47	24	18	299	216
45	212	46	22	17	298	196
50	213	44	✓	16	297	186
55	212	✓	24	13	293	188
60	✓	✓	✓	✓	✓	180
65	✓	45	✓	✓	✓	✓
75	210	47	25	14	294	182
86	208		✓	✓	✓	179

BY M. Kates DATE 12/13/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 271 OF
APPROVED DATE | | SKETCH NO.
CLIENT ASD/EXPERI | | CASE NO. 64607

TEST V-7

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
3	0	5	19	82	96	289
5	9	36	98	126	269	366
10½	44	94	140	54	332	372
15	56	110	128	46	340	372
20	58	113	128	42	341	373
25	43	95	134	58 ?	330 ?	382
30	53	111	126	48	338	✓
35	57	117	125	46	345	380
40	✓	✓	✓	✓	✓	✓
45	60	115	124	47	346	381
50	58	115	125	48	✓	✓
55	61	120	118	48	347	384
60	63	122	✓	46	349	382
65	66	127	112	46	351	384
62	63	127	110	50	350	✓
71	64	123	112	✓	349	382

BY M. Kates DATE 10/17/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 222 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD/EXPERI | CASE NO. 64607

TEST V-8

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{101}-T_{105}$	$T_{109}-T_{108}$
6	2	6	17	99	134	319
10	17	53	126	112	308	369
15	50	104	252	50	340	368
20	59	122	131	36	348	370
25½	83	141	102	29	355	367
30	96	136	95	28	✓	363
35	102	132	94	27	✓	✓
40	106	136	86	29	357	361
45	✓	138	84	✓	✓	360
50	✓	139	83	✓	✓	✓
55	107	142	80	28	✓	✓
60	106	143	✓	✓	✓	✓
65	112	146	72	✓	356	✓
70	120	✓	66	24	✓	356
72½	126	✓	64	24	360	355

TEST V-9

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

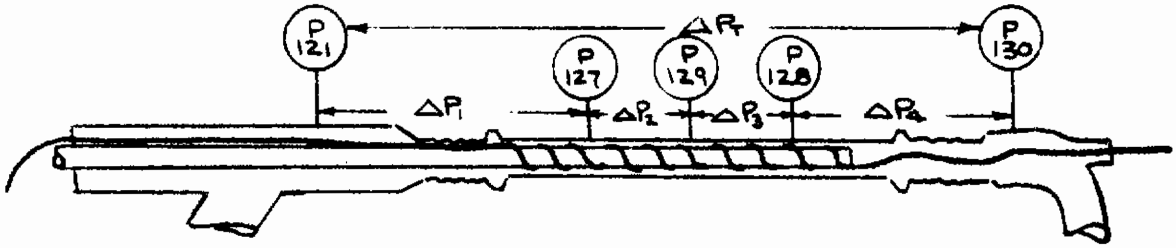
TIME (MIN)	AIR					COOLANT
	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{101} - T_{102}$	$T_{102} - T_{103}$	$T_{103} - T_{104}$	$T_{104} - T_{105}$	$T_{101} - T_{105}$	$T_{109} - T_{108}$
1½	0	0	0	0	0	0
3	✓	1	3	9	13	74
7	5	-23	5	91	78	258
11	-3	0	40	78	116	205
15	-19	9	46	70	106	191
20	-16	16	62	56	118	189
25	-10	20	66	50	126	191
30	-6	24	65	46	129	193
35	✓	26	66	44	130	192
40	-2	18	64	41	131	191
45	✓	32	63	39	132	187
50	✓	34	64	34	130	190
55	0	36	60	✓	✓	186
60	✓	39	59	✓	132	184
65	4	42	54	30	130	181

BY DARRAH DATE 8-24-[illegible] | **ARTHUR D. LITTLE, I[illegible]** CAMBRIDGE, MASS. | SHEET NO. 274 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD / EXPER[illegible] | CASE NO. 64607

TEST V-1

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2:30	16.5	14	12	12.6	9.2	2.5	2	-.6	3.4	7.3
6:00	16.5	15	13	12.6	10.2	1.5	2	.4	2.4	6.3
10:00	16.5	15	13	12.6	10.2	1.5	2	.4	2.4	6.3
15:30	15.4	13	12	12.6	9.2	2.4	1	-.6	3.4	6.2
21:00	17.5	15	14	9.6	12.3	2.5	1	4.4	-2.7	5.2
25:00	16.5	16	14	13.6	13.3	.5	2	.4	.3	3.2
30:00	16.5	16	14	14.6	13.3	.5	2	-.6	1.3	3.2
36:00	16.5	16	14	14.6	13.3	.5	2	-.6	1.3	3.2
40:00	17.5	16	13	12.6	11.3	1.5	3	.4	1.3	6.2
45:00	16.5	15	11.1	9.6	9.2	1.5	3.9	1.5	.4	7.3
50:00	16.5	15	8.1	6.7	6.2	1.5	6.9	1.4	.5	10.3
55:00	16.5	15	7.1	3.7	.9	1.5	7.9	3.4	2.8	15.6
60:00	18.5	16	2.7	0	0	2.5	13.3	2.7	0	18.5
65:00	22.6	21	0	0	0	1.6	21	0	0	22.6
70:00	26.8	26	0	0	0	.8	26	0	0	26.8
75:00	31.9	31	0	0	0	.9	31	0	0	31.9



NOTES:

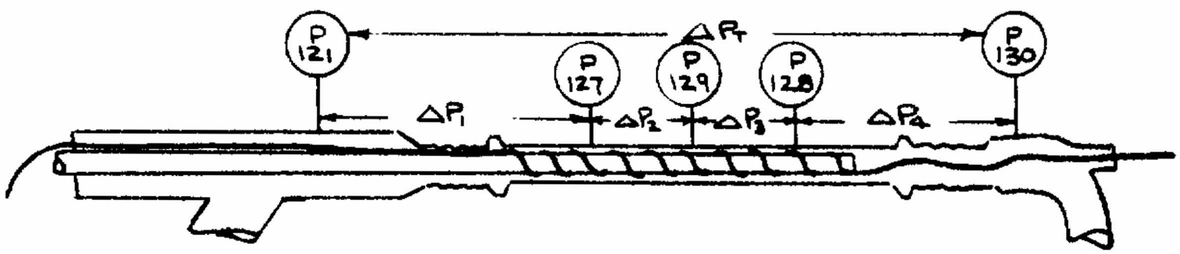
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION
~~DATA OF [illegible]~~

BY DURRAH DATE 8-24-6[illegible] | ARTHUR D. LITTLE, IN | SHEET NO. 225 OF ____
APPROVED ____ DATE ____ | CAMBRIDGE, MASS. | SKETCH NO. ____
CLIENT ASD / EXPERI | CASE NO. 64607

TEST V-2

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1:00	71	69	64	61.4	57.4	2	5	2.6	4	13.6
5:00	73	69	65	57.4	57.4	4	4	7.6	0	15.6
10:00	73	70	66	61.4	61.4	3	4	4.6	0	11.6
15:00	73	69	62	56.4	56.4	4	7	5.6	0	16.6
20:00	73	65	39.2	28.6	28.6	8	25.8	10.6	0	44.4
23:00	75.3	64	22.3	3.2	3.2	11.3	41.7	19.1	0	72.1
25:00	86.5	68	21.3	3.2	3.2	18.5	46.7	18.1	0	83.3



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION

~~DATA OF 8/1/62 P = P[illegible] + C.P. [illegible]~~

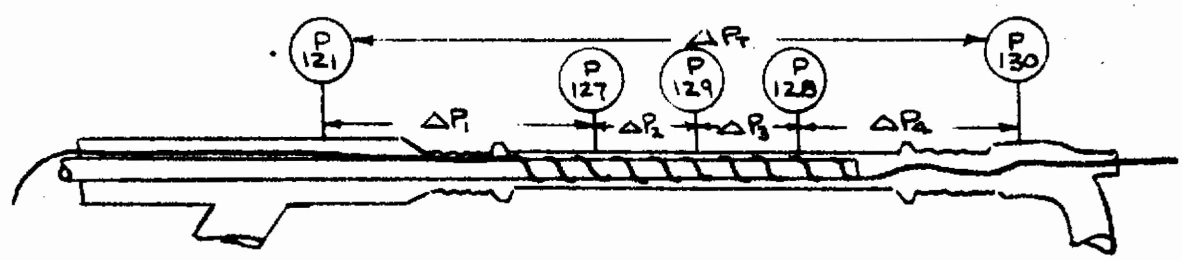
~~CP +1.0 +1.0 0 +.5 -2.5~~

BY M. Kates DATE 11/28/ | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 226 OF
APPROVED ______ DATE ______ | SKETCH NO. ______
CLIENT ASD / EXPER. | CASE NO. 64607

TEST V-3

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1½	75	71	67	63	58.5	4	4	4	4.5	16.5
5	✓	✓	✓	✓	59	✓	✓	✓	4	16
10	✓	✓	✓	64	61	✓	✓	3	3	14
15	✓	✓	68	65	62.5	✓	3	✓	2.5	12.5
20	✓	69.5	60	56	53.5	5.5	9.5	4	✓	21.5
22	84	78	21	14	5	6	57	7	9	79



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY M. Kates DATE 11/28/62 — ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. — SHEET NO. 272 OF ____

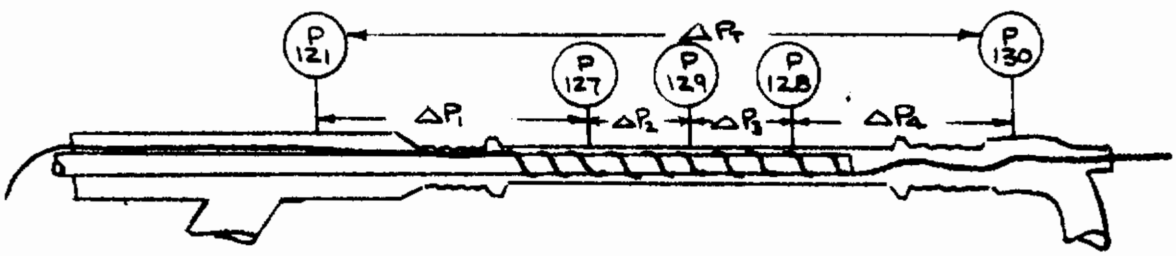
APPROVED ____ DATE ____ — SKETCH NO. ____

CLIENT ASD / ENPERL — CASE NO. 64607

TEST V-4

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2	15	12.5	10.5	9	7	2.5	2	1.5	2	8
5	✓	✓	✓	9.5	7.5	✓	✓	1	✓	7.5
10	✓	✓	✓	✓	8	✓	✓	✓	1.5	7
15	✓	12	10	✓	8.5	3	✓	0.5	1	6.5
18	✓	12.5	7.5	7.5	6	2.5	5	0	1.5	9
20	28	27	2	3	0	1	25	-1	3	28



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION ~~DATA OF 8/2/62 [illegible]~~

BY M. Kates DATE 12/13/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 228 OF ______

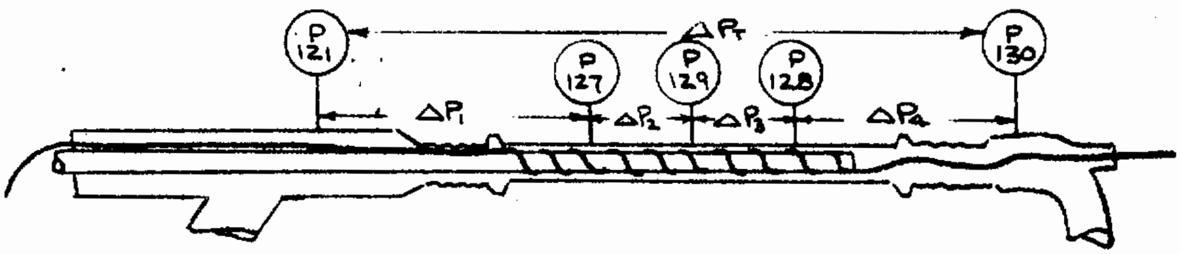
APPROVED ______ DATE ______ | SKETCH NO. ______

CLIENT ASD / EXPERI | CASE NO. 64607

TEST V-5

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1	75	69	67.5	64	60	6	1.5	3.5	4	15
6	✓	70.5	67	✓	61	4.5	3.5	3	3	14
10	✓	70	✓	✓	61.5	5	3	✓	2.5	13.5
15	✓	✓	✓	✓	60.5	✓	✓	✓	3.5	14.5
20	✓	✓	✓	✓	61	✓	✓	✓	3	14
25	✓	71	67.5	✓	61.5	4	3.5	3.5	2.5	13.5
30	✓	✓	67	✓	61	✓	4	3	3	14
35	✓	72	68	65	62	3	✓	✓	✓	13
41	✓	70.5	67	64	61.5	4.5	3.5	✓	2.5	13.5
45	75.5	71.5	68	63	60.5	4	✓	5	✓	15
50 10	75	70.5	67	60	56	4.5	✓	7	4	19
55	✓	71	67.5	58	53	4	✓	9.5	5	22
60 – 20	✓	✓	✓	57	49.5	✓	✓	10.5	7.5	25.5
65	✓	✓	✓	54	45	✓	✓	13.5	9	30
70 30	✓	✓	✓	51.5	41	✓	✓	16	10.5	34
75	✓	✓	4	47	33.5	✓	✓	20.5	13.5	41.5



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY M Kales DATE 12/13/62 ARTHUR D. LITTLE, INC. SHEET NO. 229 OF

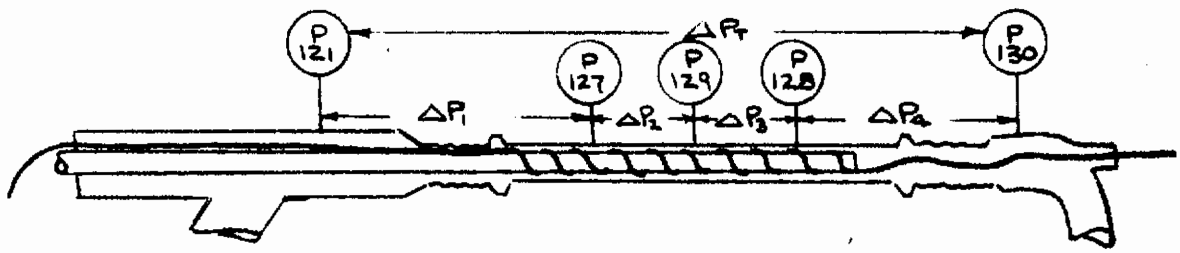
APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.

CLIENT ASD / EXPERI CASE NO. 64607

TEST V-5

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
80 40	75	71	67.5	44	28	4	3.5	23.5	16	47
85	✓	70.5	67	41.5	22	4.5	✓	25.5	19.5	53
90 50	✓	✓	67.5	38.5	14	✓	3	29	24.5	61
92	✓	✓	✓	38	12	✓	✓	29.5	26	63



NOTES:

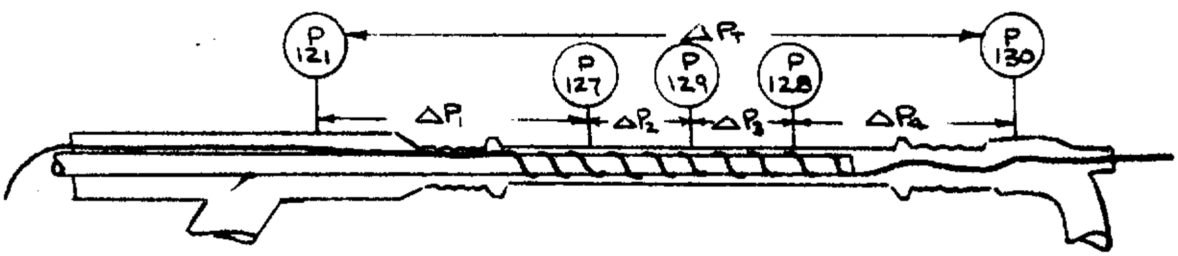
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA [illegible]

BY M. Kates DATE 12/11/62 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 280 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD / EXPERI. | CASE NO. 64607

TEST V-6

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
3	74.5	70	66	62	59	4.5	4	4	3	15.5
5	75	✓	67	64	62.5	5	3	3	1.5	12.5
10	✓	71	68.5	67	64	4	2.5	1.5	3	11
15	✓	✓	69	✓	65	✓	2	2	2	10
20	✓	71.5	✓	✓	64.5	3.5	2.5	✓	2.5	10.5
25	✓	✓	✓	66.5	63.5	✓	✓	2.5	3	11.5
30	✓	✓	69.5	✓	64	✓	2	3	2.5	11
35	✓	72	70	67	65	3	✓	✓	2	10
40	✓	73	71	68.5	67	2	✓	2.5	1.5	8
45	75.0	✓	✓	✓	67.5	2.5	✓	✓	1	✓
50	75	73.5	71.5	69	68	1.5	✓	✓	✓	7
55	✓	73	71	✓	✓	2	✓	2	✓	✓
60	✓	✓	70.5	68	67	✓	2.5	2.5	✓	8
65	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
75	✓	✓	70	✓	66.5	✓	3	2	1.5	7.5
86	✓	73.5	69	66.5	65.5	1.5	4.5	2.5	1	9.5



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA OF [illegible]

BY M. Kates DATE 12/11/62 APPROVED ______ DATE ______ CLIENT ASD / EXPERI

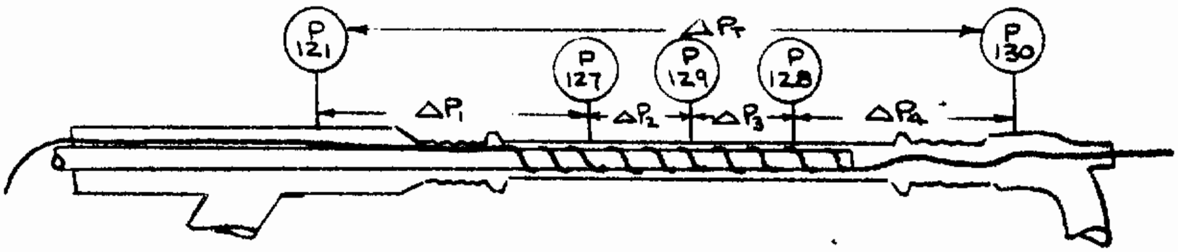
ARTHUR D. LITTLE, INC
CAMBRIDGE, MASS.

SHEET NO. 281 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST V-7

HEAT EXCHANGER AIR PRESSURES

Time (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
3	75	70.5	67	63	60	4.5	3.5	4	3	15
5	✓	✓	✓	63.5	61	✓	✓	3.5	2.5	14
10 1/2	✓	✓	✓	64	62	✓	✓	3	2	13
15 10	✓	✓	✓	✓	61.5	✓	✓	✓	2.5	13.5
20	✓	✓	66.5	63	60	✓	4	3.5	3	15
25 20	✓	✓	✓	62.5	58	✓	✓	4	4.5	17
30	✓	70	✓	✓	✓	5	3.5	✓	✓	✓
35 30	✓	✓	✓	62	56	✓	✓	4.5	6	19
40	✓	✓	✓	✓	54.5	✓	✓	✓	7.5	20.5
45 40	✓	✓	66	61.5	52	✓	4	4.5	9.5	23
50	✓	✓	✓	61	48.5	✓	✓	5	12.5	26.5
55 50	✓	✓	✓	✓	43.5	✓	✓	✓	17.5	31.5
60	✓	✓	65.5	60.5	35	✓	4.5	✓	25.5	40
65 60	✓	70.5	66	61	21	4.5	✓	✓	40	54
68	✓	71.5	66.5	61.5	4	3.5	5	✓	57.5	71
71	82	78.5	74	70	✓	✓	4.5	4	66	78



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY M. Kates DATE 12/13/'2 ARTHUR D. LITTLE, INC. SHEET NO. 282 OF

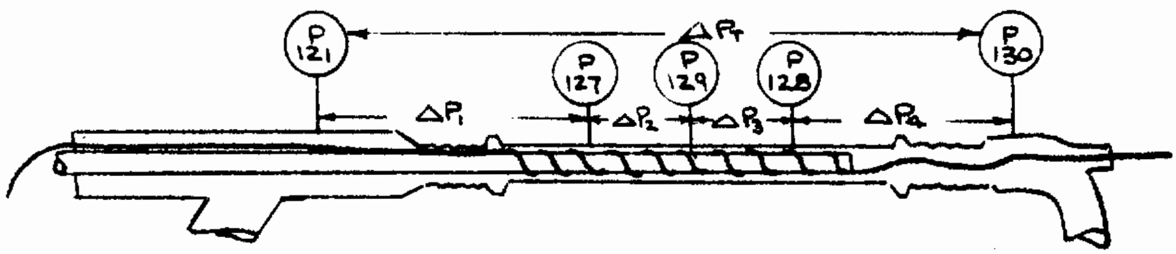
APPROVED DATE CAMBRIDGE, MASS. SKETCH NO.

CLIENT ASD / EXPERI CASE NO. 6A607

TEST V-8

HEAT EXCHANGER AIR PRESSURES

Time (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
6	75	73.5	72	71	70.5	1.5	1.5	1	0.5	4.5
10	✓	73	✓	71.5	71.5	2	1	0.5	0	3.5
15	✓	73.5	72.5	72	72	1.5	✓	✓	✓	3
20	✓	✓	72	71.5	71.5	✓	1.5	✓	✓	3.5
25 1/2	✓	73	✓	✓	✓	2	1	✓	✓	✓
30	✓	73.5	72.5	72	✓	1.5	✓	✓	0.5	✓
35	✓	73	70.5	70	69.5	2	2.5	✓	✓	5.5
40	✓	✓	69.5	68.5	68.0	✓	3.5	1	✓	7
45	✓	72.5	67	66.5	65.5	2.5	5.5	0.5	1	9.5
50	✓	71.5	63.5	63	62	3.5	8	✓	✓	13
55	✓	70	58	57.5	56.5	5	12	✓	✓	18.5
60	✓	68	49	48	46	7	19	1	2	29
65	✓	65	39	38	36	10	26	✓	✓	39
70	✓	58	23.5	21.5	18	17	34.5	2	3.5	57
72 1/2	75.5	52.5	11	8	0	23	41.5	3	8	75.5



NOTES:

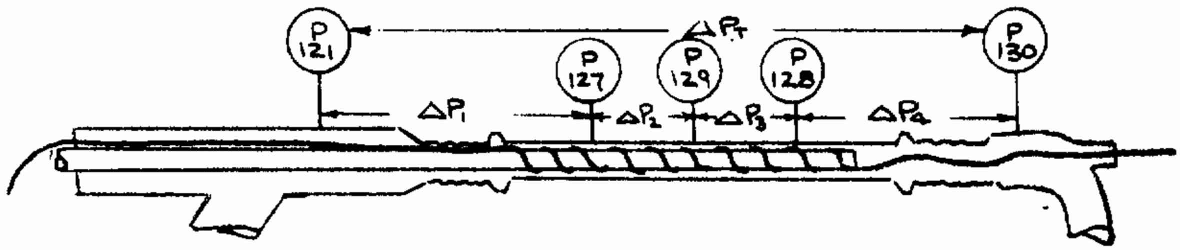
1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION ~~DATA OF 8/3/62~~

BY M. Kates DATE 12/17/62 **ARTHUR D. LITTLE, INC.** SHEET NO. 283 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 6A607

TEST V-9

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
3	75	72	70	67.5	65.5	3	2	2.5	2	9.5
7	✓	67	64	58	53	8	3	6	5	22
11	74.5	70	66	62	59	4.5	4	4	3	15.5
15	75	71	67	63.5	61	4	✓	3.5	2.5	14
20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
25	✓	70	66.5	✓	60	5	3.5	3	3.5	15
30	✓	63.5	58.5	55	51.5	11.5	5	3.5	✓	23.5
35	✓	61	55	51	47.5	14	6	4	✓	27.5
40	✓	59	53	49	45	16	✓	✓	4	30
45	74	55	47	42	37	19	8	5	5	37
50	75	52	43	38	32	23	9	✓	6	43
55	✓	52.5	42.5	37	30	22.5	10	5.5	7	45
60	✓	49	36.5	30.5	22	26	12.5	6	8.5	53
65	✓	46	32	24	12	29	14	8	12	63



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY.............. DATE..............
APPROVED.............. DATE..............
CLIENT ASD / EXPER.

Contrails

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 784 OF..........
SKETCH NO..........
CASE NO. 64607

— Water Contaminant Test Results —

Test V-1
Date 9-18-62

Recorder & Visual Observations

Time min.	IN: T °F	IN: P psia	IN: Conc ① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of Sat.	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of Sat	Remarks
28½	62	34	30	.001	.27	.004							
29	✓	✓	112	.004	✓	1.5							
30	✓	✓	435	.015	✓	5.5							
33	58	✓	590	.021	.24	8.8							
38	56	✓	620	.022	.22	10.0							
45							-231	21.7	54	1.5×10^{-7}	$<10^{-12}$		
50							-232	21.7	38	9.3×10^{-7}	$<10^{-12}$		
60	50	37	635	.024	.18	13.3							

Remarks: $\frac{625}{615} \sim 1.02$

Data from Burette Measurements

Time min.	Time Interval min.	Burette cc	Difference cc	Rate cc/hr	W_A lbs/sec	① Calculated ppm-(wt)	Inlet Conc. ppm (vol) ②
23		18.15					
34	11	19.4	1.25	6.8			
56	33	21.92	3.77	6.85	.01072	395	615
76	53	24.25	6.10	6.9			

Ave.

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / (3600 W_A) = ppm (vol) × 18/29

BY ______ DATE ______
APPROVED ______ DATE ______
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 285 OF ______
SKETCH NO. ______
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST V-2
DATE 11-17-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: Conc.① ppm-Vol	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: Conc.① ppm-Vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
13	97	90	30	.0027	.87	0.31							
14	✓	✓	1250	.112	✓	12.9							
15	99	✓	1400	.126	.92	13.7							
18	✓	✓	1500	.135	✓	14.7							
20							-114	46.7	180	8.4×10^{-3}	6×10^{-6}		
22							-116	37.2	85	3.2×10^{-3}	5.2×10^{-6}		
26½	100	✓	1425	.128	.95	13.5							

$\frac{1500}{1560} = .96$

DATA FROM BURETTE MEASUREMENTS

TIME MIN	TIME INTERVAL MIN.	BURETTE cc	DIFFERENCE cc	RATE cc/hr	W_A lbs/sec	② ppm-(wt)	CALCULATED INLET CONC. PPM (VOL) ②
12		6.5					
16	4	9.9	3.4	51	.0310	1000	1560
24	12	16.7	10.2	51			
27¾	15¾	19.95	13.45	51			

Note: p_w = partial press. H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10⁶/(3600 W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST V-3
DATE 11-17-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-VOL	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-VOL.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
18¾	104	90	50	.0045	1.07	.42							
19	✓	90	1150	.104	✓	9.7							
20	✓	90	3200	.288	✓	26.9							
21	✓	90	3650	.328	✓	30.6							
21¾	✓	90	3950	.356	✓	33.3							

No DATA AT OUTLET - DUE TO SHORT TEST DURATION.

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/sec	② CALCULATED ppm-(WT)	INLET CONC. ppm (VOL) ②
18.0		0					
21.25	3.25	9.0	9.0	164	.0317	3200	4970
23.25	5.25	14.5	14.5	166 (AVG)			

Note: p_w = partial press H_2O
p_{SAT} = VAPOR " "

① Average - Approx Steady State Value
② ppm (WT) = RATE (cc/hr) × (1/454) × 10⁶ / (3600 W_A) = ppm (VOL) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST V-4
DATE 11-17-62

Time min	IN: T °F	IN: P psia	IN: Conc ① ppm-Vol	IN: p_w psia	IN: p_{sat} psia	IN: % of Sat.	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-Vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of Sat	Remarks

(Recorder & Visual Observations)

DUE TO SHORT TEST DURATION AND HIGH CONCENTRATIONS NO WATER CONCENTRATION MEASUREMENTS COULD BE MADE AT INLET AND OUTLET OF AIR STREAM-

DATA FROM BURETTE MEASUREMENTS

Time min	Time Interval min.	Burette cc	Difference cc	Rate cc/hr	w_A lbs/sec	① Calculated ppm-(wt)	Inlet Conc. ppm (vol) ②
17.0		0					
19.62	2.62	7.4	7.4	170	.0109	9,550	14,850
21.15	4.25	12.0	12.0	170 (Ave.)			

Note: p_w = partial press H_2O
P_{sat} = vapor " "

① Average - Approx Steady State Value
② $ppm(wt) = Rate(cc/hr) \times (1/454) \times 10^6 / (3600\, w_A) = ppm(vol) \times 18/29$

BY ______ DATE ______
APPROVED ______ DATE ______
CLIENT ASD / EXPERI

ARTHUR D. LITTLE, I[illegible]
CAMBRIDGE, MASS.

SHEET NO. 288 OF ______
SKETCH NO. ______
CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST V-5
DATE 11-29-62

RECORDER & VISUAL OBSERVATIONS

Time min.	IN T °F	IN P psia	IN Conc ① ppm-Vol	IN p_w psia	IN p_{SAT} psia	IN % of SAT.	OUT T °F	OUT P psia	OUT Conc ① ppm-Vol.	OUT p_w psia	OUT p_{SAT} psia	OUT % of SAT	Remarks
35	110	91	11.5				* ↓						
45	110	90	380										
58½							-16 / 57	65	115	7.5×10^{-3}	8×10^{-3}	93	
63½							-42 / 62	63	48	3×10^{-3}	1.7×10^{-3}	177	
66							-38 / 65	59	62	3.7×10^{-3}	2×10^{-3}	184	
72							-58 / 69	53	32	1.7×10^{-3}	7.5×10^{-4}	227	
75¾							-24 / 74½	46	92	4.2×10^{-3}	5×10^{-3}	84	
80							-43 / 78½	43	49	2.1×10^{-3}	1.7×10^{-3}	124	
83							-20 / 84½	36	93	3.4×10^{-3}	6×10^{-3}	57	
90		90	391										
													$\frac{385}{417} = .925$

DATA FROM BURETTE MEASUREMENTS

Time min.	Time Interval min.	Burette cc	Difference cc	Rate cc/hr	W_A lbs/sec	② Calculated ppm-(wt)	Inlet Conc. ppm (vol) ②
38		12.4					
43	5	13.5	1.1	13.2			
62	24	17.75	5.35	13.4	.0304	268	417
81	43	22.0	9.6	13.4			

Note: p_w = partial press H_2O
P_{SAT} = vapor " "

① Average - Approx Steady State Value
② $ppm(wt) = Rate\,(cc/hr) \times (1/454) \times 10^6 / (3600\,W_A) = ppm(vol) \times 18/29$
* Time at which temp taken - Because of lag between temp max-mins and H_2O conc max-mins

— WATER CONTAMINANT TEST RESULTS —

TEST V-8
DATE 12-12-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
35	103	90	390	.035	1.038	3.4							
40							-257	82.7	22	1.8×10^{-3}	$< 10^{-12}$		
45							✓	80.2	11	9.1×10^{-4}	✓		
50							✓	76.7	8.4	6.4×10^{-4}	✓		
55							✓	71.2	7	5×10^{-4}	✓		
60							✓	60.7	6.2	3.7×10^{-4}	✓		
65							✓	50.7	5.7	2.9×10^{-4}	✓		
$72\frac{1}{2}$	100	90	390	.035	.95	3.7							

Remarks: $\frac{390}{420} = .93$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/sec	① CALCULATED ppm-(wt)	INLET CONC. PPM (VOL) ②
23		2.2					
33	10	3.4	1.2	7.2	.016	271	420
43	20	4.6	2.4	7.2			
53	30	5.75	3.55	7.1			
63	40	6.95	4.75	7.13			
72	49	8.00	5.8	7.1 Ave			

Note: p_w = partial press. H_2O
P_{SAT} = VAPOR " "

① Average - Approx Steady State Value

② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6/(3600 W_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST V-9
DATE 12-14-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
25							-218	24.7	9	2.2×10^{-4}	5.0×10^{-12}		
30							-220	66.2	6.3	4.2×10^{-4}	3.7×10^{-12}		
40	-92	90	242	2.18×10^{-2}	4.5×10^{-5}								Probe pointing upstream; Probe picking up solid H_2O
45							-224	51.7	19	9.8×10^{-4}	10^{-12}		
50							✓	46.7	9.5	4.9×10^{-4}	✓		
55							✓	44.7	6.9	3.1×10^{-4}	✓		
60							-226	36.7	6.5	2.9×10^{-4}	✓		Probe pointing upstream; Probe picking up solid H_2O
65	-98	90	241	2.17×10^{-2}	2.8×10^{-5}								

$\frac{241}{311} = .775$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	DST W_A lbs/sec	② CALCULATED INLET CONC. ppm-(wt)	ppm (vol) ②
21.5		10.1					
42.0	20.5	14.1	4.0	11.7			
64.5	43.0	18.65	8.55	11.9	.0385	200	311
69.5	46.0	19.25	9.15	11.9 Avg.			

$\omega_s = .0119$, $\omega_a = .0251$

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx Steady State Value

② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / (3600 W_A) = ppm (vol) × 18/29

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

BY ________ DATE ________
APPROVED ________ DATE ________
CLIENT ASD/CAPRI

SHEET NO. 291 OF ________
SKETCH NO. ________
CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST V-1
DATE 9-18-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-Vol	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
10	79	35	305										
20	70	✓	232										Readings erratic
30	61	✓	247										✓
38	56	✓	247										✓
45							-231	27.7	47		2.6×10^{-3}		
50							-232	24.7	52		✓		
60	50	37	247										✓

No of Bottles in Manifold ____
Pressure in Manifold ____ psia
No of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure after Mixing: ____ psia
ppm CO_2 (vol) = ____ × ____ / ____ =
ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$
=

① Average - approx steady state value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST V-7
DATE 12-10-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-VOL	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-VOL	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
3	80	90	235	2.11×10^{-2}									
5	87	✓	285	2.56×10^{-2}									
$10\frac{1}{2}$	100	✓	285	✓									
15	104	✓	283	2.54×10^{-2}									
* 20							-235	74.7	20	1.5×10^{-3}	1.7×10^{-3}	.91	[illegible]
25							-221	72.7	87	6.3×10^{-3}	8×10^{-3}	.79	[illegible]
30							-229	✓	37	2.7×10^{-3}	2.7×10^{-3}	1.00	0
40							-234	69.2	27	1.9×10^{-3}	1.6×10^{-3}	1.20	+20
45	113	90	278	2.5×10^{-2}									
50							-234	63.2	30	1.9×10^{-3}	1.6×10^{-3}	1.20	+20
55							✓	58.2	25	1.5×10^{-3}	1.6×10^{-3}	.94	-6
60							-235	49.7	25	1.2×10^{-3}	1.6×10^{-3}	.75	-21
** 65							-241	35.7	45	1.6×10^{-3}	9×10^{-4}	83	-17
71	109	90	280	2.52×10^{-2}									

No of Bottles in Manifold 21
Pressure in Manifold 2210 psia
No of CO_2 Bottles 1
Pressure of CO_2 Bottles 2175 psia

$$\frac{14.7}{21} \times \frac{1}{2210} \times \frac{10^6}{10^6} \times \frac{494R}{530R} = 295 \text{ ppm (Vol)}$$

→ Correction for outside value little trans.

~~Pressure after mixing: psia~~
ppm CO_2 (vol) = ___ × ___ / ___ = 295
ppm CO_2 (wt) = ppm (vol) × 44/28 = 465
=

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Average - approx steady state value
* Peaking transient between t = 20 and t = 25
** Readings at outlet erratic between t = 63 & t = 69½

BY________ DATE________ ARTHUR D. LITTLE, INC. SHEET NO. 293 OF ______

APPROVED______ DATE______ CAMBRIDGE, MASS. SKETCH NO.________

CLIENT ASD/CWRRI CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST V-8
DATE 12-12-62

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
6	84	90	300										
9	91	✓	303										
10		✓					-219	86.2	107	9.2×10^{-3}	8×10^{-3}		
15		✓					-244	86.7	17	1.5×10^{-3}	5×10^{-4}		
20		✓					-248	86.2	07	6.0×10^{-4}	3×10^{-4}		
25½	102	✓	300										
30	102	✓	297										
35	103	✓	292										
40		✓					-255	82.7	<5	$<4.1\times10^{-4}$	1.2×10^{-4}		
45		✓					✓	80.2	<5	<4.0 ✓	✓		
50		✓					✓	76.7	<5	<3.8 ✓	✓		
55		✓					✓	71.2	<5	<3.6 ✓	✓		
65		✓					✓	50.7	<5	<3.5 ✓	✓		
72½		✓	312										

No of Bottles in Manifold 20
Pressure in Manifold 2095 psia
No of CO_2 Bottles 1
Pressure of CO_2 Bottles 2095 psia

Pressure after Mixing: psia
ppm CO_2 (vol) = ___ × ___ / ___ =
ppm CO_2 (wt) = ppm (vol) × 44/28
=

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① Average - approx steady [illegible] value

BY________ DATE________

APPROVED________ DATE________

CLIENT ASD/CAPRI

ARTHUR D. LITTLE, INC
CAMBRIDGE, MASS.

SHEET NO. 294 OF________

SKETCH NO.________

CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST V-9
DATE 12-14-62

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN T °F	IN P psia	IN CONC ① ppm-Vol	IN p_{CO_2} psia	IN p_{SAT} psia	IN % of SAT	OUT T °F	OUT P psia	OUT CONC ① ppm-Vol	OUT p_{CO_2} psia	OUT p_{SAT} psia	OUT % of SAT	REMARKS
11	-82	89.2	192		500								
15	-93	90	199		350								
25							-218	74.7	97	7.2×10^{-3}	9×10^{-3}	80	
30							-220	66.2	103	6.4×10^{-3}	8×10^{-3}	80	
40	-92	90	205		350								
45							-224	57.7	97	5×10^{-3}	6×10^{-3}	83	
50							✓	46.7	104	4.8×10^{-3}	✓	80	
55							✓	44.7	109	4.9×10^{-3}	✓	82	
60							-226	36.7	116	4.3×10^{-3}	✓	72	
65	-88	90	200		270								

No of Bottles in Manifold ____

Pressure in Manifold ____ psia

No of CO_2 Bottles ____

Pressure of CO_2 Bottles ____ psia

Pressure after Mixing: ____ psia

ppm CO_2 (vol) = ____ / ____ =

ppm CO_2 (wt) = ppm (vol) $\cdot \frac{44}{28}$

=

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " "

REDUCED DATA FOR EXTENDED TEST SERIES

ASD-TDR-63-508, Volume III

TABLE OF CONTENTS

SUMMARY MEMORANDUM ON REDUCED DATA FOR EXTENDED TEST SERIES

I. General

Five tests were performed in this test series using the 1-inch exchanger configuration. The purpose of these tests was to investigate the effects of varying inlet conditions and constant pressure drop operation.

The presentation of the test data follows the format established in the reduced data for the previous test series. The exceptions to this format are as below:

a. By-pass Flows for Tests E-2 and E-3

In tests E-2 and E-3, by-pass flows are plotted as a function of time. In these tests, in which the pressure drop across the heat exchanger was maintained constant and the heat exchanger air flow allowed to decrease, a constant total air flow was maintained with the normal test facility air flow control system. However, as deposits accumulated in the test heat exchanger, a portion of the total air flow was by-passed around the heat exchanger and measured with a gas meter. The difference between the constant total air flow and the by-pass flow equals the heat exchanger air flow.

b. Air Temperature Profiles for Tests E-1 and E-2

Plots of air temperature vs. location for various test times are presented for tests E-1 and E-2. These plots illustrate the shifting in heat exchanger temperature profiles that occur during the course of the tests. In test E-1 the shifting was due to the progressively increasing coolant flow. In test E-2, the shifting in temperatures was due to the decreasing heat exchanger air flow.

c. Energy Balance

The energy balances were not computed for this test series both because of the difficulty of calculating energy balances in the presence of varying inlet conditions and also because results of the verification test series had indicated generally good closure of the energy balances within the accuracy of the flow measurements.

Detailed comments on instrumentation accuracy are not presented here since such comments would be in general agreement with the discussion presented in the verification test series.

II. Individual Test Objectives

Test E-1

The objective of this test was to determine the effect of spreading the deposit formation by increasing the coolant flow during the test. This test was conducted using super-critical nitrogen as the coolant. Initially, the test conditions were similar to test F-9, that is, the heat exchanger flows were unbalanced with the available enthalpy rise of the coolant being less than the available enthalpy decrease of the air stream. In the course of the test the coolant flow was increased so that at the termination of the test the flows were approximately balanced.

Test E-1 functioned satisfactorily and was shut down, at "plug-up", at 53 1/2 minutes of operation. In the course of the test the beginning of the frost formation moved from the last quarter of the heat exchanger to the heat exchanger inlet. The pressure drop tended to increase rather rapidly at the beginning of the test when the frost was concentrated at the low temperature end of the heat exchanger. However, as the coolant flow increased, spreading the deposit over a greater area, and reducing air temperature, pressure drop tended to level and even, in some time intervals actually decreased.

Tests E-2 and E-3

The objective of these tests was to compare constant pressure drop operation with constant flow operation. These tests were conducted using low-pressure nitrogen as coolant. Initial operation conditions were basically comparable to tests F-3, F-4, F-5, V-2 and V-3. The use of low-pressure coolant for these tests was chosen because of the large amount of background data available at this conditions and because the use of a constant specific heat coolant simplified analysis of the test results. Test E-2 was a low-water content test (.029% water). Test E-3 was a high-water content test (.09% water).

Both tests operated satisfactorily. Test E-2 was terminated at 71 minutes, at which time the heat exchanger air flow had dropped to about 40% of the initial air flow. Test E-3 was terminated at 56 minutes, at which time the heat exchanger air flow had dropped to about 6% of the initial air flow.

It was found that the reduction in air flow obtained in these tests correlated quite well with the pressure drop increase obtained in the constant air flow tests at similar conditions. The drop in heat transfer was much more apparent than existed in the constant air flow test. It was felt that this was due primarily to the reduction in available air side sensible heat (i.e., $q = W_a C_{pa} \Delta T_a$). However, reduction in the air side coefficient might also have some influence.

Tests E-4 and E-5

The objectives of these tests was to observe the effects of varying inlet air temperature on deposit formation. In test E-4 the air inlet air temperature was increased uniformly from 50° F to 150° F in the course of the test. In test E-5 the inlet air temperature was decreased uniformly from 160° to 30° F. These tests were conducted with super-critical nitrogen as a coolant. The initial test conditions were basically similar to those of test F-8.

Both tests operated satisfactorily. Test E-4 was terminated at plug-up after 47 minutes of operation. Test E-5 was terminated at 41 3/4 minutes, at which time the heat exchanger pressure drop had reached about 3/4 of the "plug-up" value.

Photographs of the frost formation indicated that in test E-4, increasing the inlet air temperature, had the effect of shifting the beginning of the water and carbon dioxide frost zones about 4" downstream during the course of the test. The effective length of the water frost zone did not appear to vary - i.e., the water frost zone seemed to move downstream as a unit of constant length. Presumably the same conclusion could be made for carbon dioxide, however, since this zone initially extended to the end of the heat exchanger - downstream movement of its trailing edge could not be observed.

In test E-5, decreasing the inlet air temperature had the effect of moving the beginning of the water frost zone about 18" upstream during the course of the test and the beginning of the carbon dioxide frost zone about 10" upstream in the course of the test. The downstream ends of the frost zones were not substantially affected by decreasing the inlet air temperature and, therefore, the length of the frosted zones increased with time during the test.

The pressure drop results showed that in test E-5 the pressure drop increased less rapidly than in a comparable constant inlet air temperature test, such as F-8. However, the pressure drop increase in test E-5 was somewhat higher than in test E-1, since the spreading of the frost layer, due to reducing the inlet air temperature in test E-5, was not as pronounced as that which resulted from increasing the coolant flow in test E-1. In test E-4 the increase in pressure drop seemed to be slightly, but not substantially, greater than the comparable test, such as F-8. It appeared that increasing the inlet air temperature primarily served to move the frosted layer downstream in the heat exchanger and, evidently, did not serve to concentrate frost in a small area resulting in high frost thickness and high pressure drop.

EXTENDED TEST PROGRAM - TEST PARAMETER SUMMARY

Test		Air Stream				Coolant Stream			
No.	Date	Ga lb/sec-ft^2	Pa psia	% H_2O	% CO_2	Inlet Press. psig	Inlet Temp. °F	$\frac{(Wc_p)_c}{(Wc_p)_a}$	Variable Investigated
E-1	1/24/63	30	90	.025	.055	600	-310	varies	Spreading deposit by increasing coolant flow
E-2	1/29/63	30(3)	90	.029	.051	200	-156	1.0(3)	Const. ΔP operation
E-3	1/30/63	30(3)	90	.09	.05	200	-156	1.0(3)	Const. ΔP operation
E-4	2/2/63	30	90	.025	.05	600	-315	1.0	Concentrating deposits by increasing inlet air temperature
E-5	2/2/63	30	90	.025	.05	600	-315	1.0	Spreading Deposit by decreasing inlet air temperature

NOTES:

1. Nitrogen used as air and coolant streams in all tests.
2. Configuration No. 1 used in all tests.
3. Denotes initial condition-air flow decreases during test.
4. All values shown are nominal based on preliminary survey of test data.

BY FER DATE .... ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 102 OF ....

APPROVED .... DATE .... SKETCH NO. ....

CLIENT ASD / EXPERI CASE NO. 64607

TEST E-1 SUMMARY SHEET

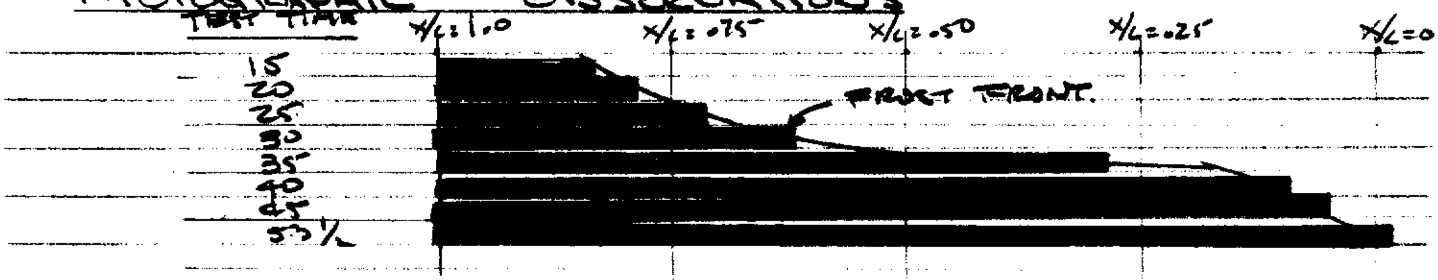
NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	VARIES	—	.025	.054	SUPER-CRITICAL GN_2	53 ½	1-24-63

VARIABLE INVESTIGATED: FROST SPREADING PHENOMENA RESULTING FROM INCREASING COOLANT FLOW.

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START RECORDERS, CLOCKS, AIR AND COOLANT STREAMS
9	STABLE TEMP GRADIENTS IN HEAT EXCHANGER
10	WATER ON.
12 ¾	WATER CONC STARTS TO INCREASE AT INLET.
13.93	WATER ✓ 63% OF MAX
14.30	✓ ✓ 95% ✓ ✓
21	INCREASE COOLANT FLOW
26	✓ ✓ ✓
31	✓ ✓ ✓
36	✓ ✓ ✓
46	✓ ✓ ✓
51	✓ ✓ ✓

53 ½ SHUTDOWN.

PHOTOGRAPHIC OBSERVATIONS



GENERAL NOTES

OVERALL PHOTOS — 15, 20, 25, 30, 35, 40, 45, 53½,

CLOSE UP STILLS — AT 40 MIN AND 52 MIN.

THICKEST FROST DEPOSITS OCCUR AT 43 IN AND 7 IN.

BY [illegible] DATE 1-24-63 APPROVED ____ DATE ____ CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 303 OF ____ SKETCH NO. ____ CASE NO. 64607

TEST B-2 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_2 (PSIA)	G_2 (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	Varies .80	Varies 1.0	—	.029	.053	LPG GN_2	71	1-27-63

(Initial Value)

VARIABLE INVESTIGATED: CONSTANT HEAT EXCHANGER ΔP (VARYING AIR FLOW)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START Recorders, Clocks, air AND Coolant Stream
16	STABLE TEMP GRADIENT -
17	WATER ON -
19½	WATER CONC. AT HEAT EXCHANGER BEGINS TO INCREASE
20¼	" " 63% OF MAX
21¼	" " 95 " "
21¼-71	MAINTAIN CONS ΔP ACROSS HEAT EXCHANGER (TS-62) = 13 psi
62	OPEN VALVES ON 10 ADDITIONAL MANIFOLD CYLINDERS
71	SHUTDOWN.

PHOTOGRAPHIC OBSERVATIONS:

OVERALL STILLS @ 26, 32, 39, 47, 60, 65, 70 MIN
CLOSE-UP STILL @ 40 & 67 MIN

GENERAL NOTES:

1. OVERALL H.E. ΔP MAINTAINED CONSTANT BY BYPASSING H.E. INLET AIR

BY J.C. BURKE DATE 2/25/63 ARTHUR D. LITTLE, INC. SHEET NO. 304 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD / EXPERI CASE NO. 64607

TEST E-3 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	$(W_c/W_a)_0 = 1.0$ W2 VARIES	—	.09	.059	N2 200 PSIG	56	1/30/63

VARIABLE INVESTIGATED: CONSTANT HEAT EXCHANGER ΔP (WORKING AIR FLOW)

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START RECORDERS, CLOCKS, AIR AND COOLANT STREAMS
15	STABLE TEMP. GRADIENTS
17	WATER ON
18	WATER METER STARTS TO RESPOND
18.4	WATER CONC 63% OF MAX
21	WATER CONC 95% OF MAX
17-56	MAINTAIN CONST 13 PSI ΔP ACROSS H.E.
56	SHUT DOWN

PHOTOGRAPHIC OBSERVATIONS:

OVERALL STILLS @ 21, 26, 32, 28, 45, 50, MINUTES
CLOSEUP STILLS @ 25, 39, 45, 50 MINUTES

GENERAL NOTES:

1. OVERALL H.E. ΔP MAINTAINED CONSTANT BY BYPASSING H.E. INLET AIR

BY J.C. Burke DATE 4/1/63 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 305 OF ____
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD / EXPERI | CASE NO. 64607

TEST E-4 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	w_c/w_a	w_s/w_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	.5	—	.028	.047	SUPER-CRITICAL N_2	47	2/2/63

VARIABLE INVESTIGATED: INCREASING INLET AIR TEMPERATURE

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START RECORDERS, CLOCKS, AIR & COOLANT STREAMS
15	STABLE TEMP GRADIENTS IN HEAT EXCHANGER
17 ½	WATER ON
17½	START PROGRAMMED INCREASE IN INLET AIR TEMP (T_{AIR} ≤ 50°F)
20½	WATER METER STARTS TO RISE
21.7	WATER METER 63% OF MAX
22.7	✓ ✓ 95% OF MAX
47	SHUT DOWN (T_{AIR} ≤ 150°F)

PHOTOGRAPHIC OBSERVATIONS:
OVERALL STILLS @ 26, 32, 38, 46, MIN
CLOSE-UP STILL @ 43 MIN.

	26 MIN	32 MIN	38 MIN	46 MIN
APPROX. H_2O FROST LOCATION (IN)	3-15	4-16	5½-18	7½-19
APPROX CO_2 FROST LOCATION (IN)	28-48	29-48	30-48	32-48

GENERAL NOTES:

BY J C Burke DATE 4/1/63 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 306 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD / EXPERI | CASE NO. 64607

TEST E-5 SUMMARY SHEET

NOMINAL TEST PARAMETERS									
CONFIG.	P_a (PSIA)	G_a (LB/SEC FT²)	W_c/W_a	W_s/W_a	% H_2O	% CO_2	COOLANT	TOTAL RUN TIME (MIN)	TEST DATE
1	90	30	.5	—	.028	.05	SUPER-CRITICAL GN_2	41 3/4	2/2/63

VARIABLE INVESTIGATED: DECREASING INLET AIR TEMPERATURE

TIME SEQUENCE OF IMPORTANT EVENTS	
TIME (MIN)	EVENT
0	START RECORDERS, CLOCKS, AIR & COOLANT STREAMS
13	STABLE HEAT EXCHANGER TEMP GRADIENTS (INLET AIR TEMPERATURE)
13	WATER-ON
13	START PROGRAMMED DECREASE IN INLET AIR TEMP
13 3/4	WATER METER STARTS TO RESPOND
14 1/2	✓ ✓ REACHES 63% OF MAX
16	✓ ✓ ✓ 95% OF MAX
41 3/4	SHUT DOWN (INLET AIR TEMP = 30°F)

PHOTOGRAPHIC OBSERVATIONS

OVERALL STILLS @ 18, 25, 31, 35, 40

CLOSE-UP STILLS @ 41 MINUTES

	18 MIN	25 MIN	31 MIN	35 MIN	40 MIN
APPROX. H_2O FROST LOCATION (IN)	22-31	15½-30½	11-30½	7½-30½	4-30½
APPROX. CO_2 FROST LOCATION (IN)	42½-48	40-48	37½-48	35-48	32-48

GENERAL NOTES:

TEST E-1 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f$ (FLUID)
$W_* = f$ (A ORIFICE)
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

STREAM	Θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113; AIR	.10	585	90	.1538	4.85	2	1.072	.997	.0521	.0326	
ORIFICE NO. 6	25	✓	✓	✓	4.87	4	1.080	✓	✓	.0328	.0327
	40	✓	✓	✓	4.80	0	1.074	✓	✓	.0327	
NOM. DIA: .0595"	50	✓	✓	✓	4.81	✓	✓	✓	✓	✓	
T_1 = T-117; COOLANT	10	700	615	.878	5.58	39	1.030	.502	.0238	.00864	
ORIFICE NO. 4	25	743	✓	.827	5.15	17	1.054	.590	✓	.01101	.01371
	40	897	620	.691	5.05	12	1.059	.755	✓	.01710	
NOM DIA: .040"	50	950	✓	.653	5.09	14	1.056	.791	✓	.01810	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
$V_B = 36.85$ FT3	$V_B = 12.35$ FT³ ✓
@ Θ = 10 MIN, P_{B1} = 2015 PSIA	@ Θ = 10 MIN, P_{B1} = 1985 PSIA
@ Θ = 50 MIN, P_{B2} = 1480 PSIA	@ Θ = 50 MIN P_{B2} = 1435 PSIA
$\bar{T}_B$ = 10 °F 470 °R	$\bar{T}_B$ = 10 °F 470 °R
Z_1 = 1.006 ; Z_2 = .991	Z_1 = 1.005 ; Z_2 = .991
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 510 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 535 PSI
ΔM_B = 104.5 LB, ΔΘ = 2400 SEC	ΔM_B = 35.7 LB, ΔΘ = 2400 SEC
$\bar{W}_B$ = .0435 LB/SEC	$\bar{W}_B$ = .0149 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0327	.0435	.75	.0327
COOLANT	.01371	.0149	.92	VARYING

BY J.C. BURKE DATE 2/25/63 — ARTHUR D. LITTLE, INC. — CAMBRIDGE, MASS. — SHEET NO. 308 OF ____

APPROVED ____ DATE ____ — SKETCH NO. ____

CLIENT ASD / ELPERI — CASE NO. 64607

TEST E-2 AIR* AND COOLANT FLOW

* TOTAL AIR – INCLUDES H.E. AIR & BYPASS

A. ORIFICE DATA

$W_o = W_* \, F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{fluid})$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS Rev. 1/63

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
	AIR											
T_1 = T-113 (3,9,16)	ORIFICE NO. 6	10	587	90	.158	5.2	19	1.055	1.00	.0521	.0323	.0322
		30	587	90	.153	5.2	19	✓	✓	✓	.0323	
	NOM DIA: .0595	60	585	90	.154	5.3	24	1.05	✓	✓	.032	
	COOLANT											
T_1 = T-117 (2,10,13)	ORIFICE NO. 5	10	785	230	.282	5.2	19	1.055	.975	.0399	.0322	.032
		30	785	225	.287	5.3	24	1.05	✓	✓	.032	
	NOM DIA: .052	60	785	215	.274	5.6	38	1.03	✓	✓	.0314	

B. BOTTLE DATA

$V_B = 1.75N + .1 \ (FT^3)$

$$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right] \qquad R = .383 \ \frac{FT^3}{°F \ IN^2}$$

AIR	COOLANT
$V_B = 35.1 \ FT^3$	$V_B = 17.6 \ FT^3$
@ θ = 10 MIN, P_{B1} = 1815 PSIA	@ θ = 10 MIN, P_{B1} = 1915 PSIA
@ θ = 60 MIN, P_{B2} = 1305 PSIA	@ θ = 60 MIN P_{B2} = 865 PSIA
$\bar{T}_B$ = 25 °F = 485 °R	$\bar{T}_B$ = 25 °F = 485 °R
Z_1 = 1.00 ; Z_2 = .99	Z_1 = 1.003 ; Z_2 = .987
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 495 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 1045 PSI
ΔM_B = 93.5 LB ; Δθ = 3000 SEC	ΔM_B = 98 LB , Δθ = 3000 SEC
$\bar{W}_B$ = .0312 LB/SEC	$\bar{W}_B$ = .0327 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0322	.0312	1.03	.032
COOLANT	.0320	.0327	.98	.032

F.C. Ruccia
1/29/63

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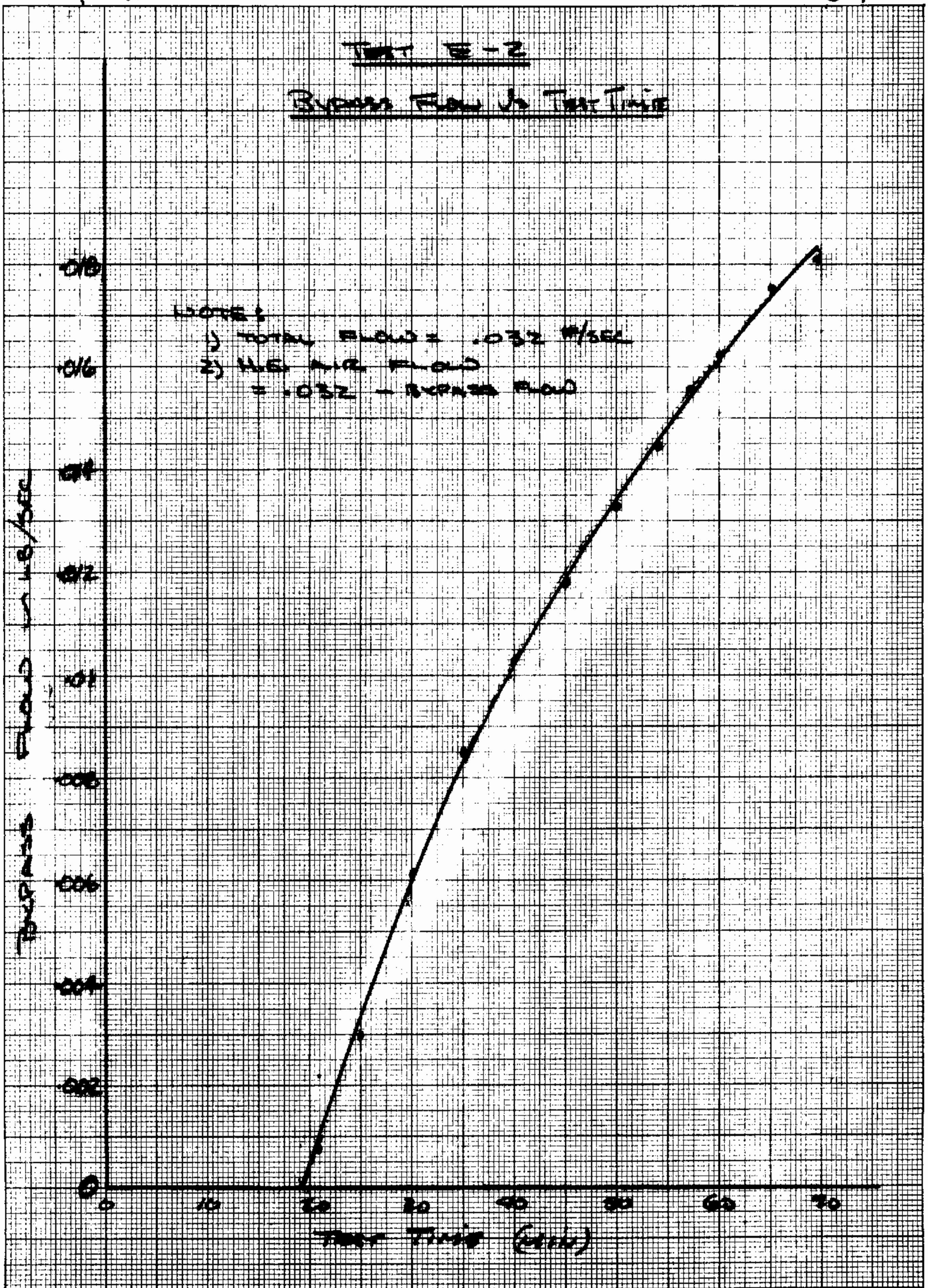
309



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BY J.C. Burke DATE 2/25/63 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 3/10 OF
APPROVED DATE | SKETCH NO.
CLIENT ASD/EXPERI | CASE NO. 64607

Test E-3 Air* and Coolant Flow

* Total air includes H.C air + bypass

A. Orifice Data

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(L/D)$
$W_* = f(A_{orifice})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

See ADL calculations "Orifice Flow Calculations" J.C. Burke 8/20/62 for details Rev. 1/4/63

	Stream	θ (min)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (lb/sec)	W_o lb/sec	$\bar{W}_o$ lb/sec
$T_1 = T\text{-}113$	Air Orifice No. 6 Nom Dia: .0395	10	585	90	.154	5.10	14	1.06	1.00	.0521	.0323	
		30	✓	✓	✓	5.15	17	1.055	✓	✓	.0322	.0322
		50	✓	✓	✓	5.3	24	1.05	✓	✓	.0320	
$T_1 = T\text{-}117$	Coolant Orifice No. 5 Nom Dia: .052	10	785	235	.300	5.15	17	1.055	.97	.0391	.0319	
		30	✓	212	.270	5.20	19	1.055	.98	✓	.0323	.0320
		50	✓	202	.255	5.40	29	1.04	.98	✓	.0319	

B. Bottle Data

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{RT_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

Air	Coolant
$V_B = 19.4$ FT³	$V_B = 17.6$ FT³
@θ = 10 min, P_{B1} = 1880 PSIA	@θ = 10 min, P_{B1} = 2000 PSIA
@θ = 50 min, P_{B2} = 1095 PSIA	@θ = 50 min, P_{B2} = 1050 PSIA
$\bar{T}_B$ = 30 °F = 490°R	$\bar{T}_B$ = 30°F = 490°R
Z_1 = 1.001 ; Z_2 = .987	Z_1 = 1.006 ; Z_2 = .987
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 765 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 923 PSI
ΔM_B = 80 LB, Δθ = 2400 sec	ΔM_B = 86.5 LB, Δθ = 2400 sec
$\bar{W}_B$ = .0333 LB/sec	$\bar{W}_B$ = LB/sec

Flow	Orifice	Bottles	$\bar{W}_o/\bar{W}_B$	Best Estimate
Air	.0322	.0333	.97	.0312 +
Coolant	.0320	.0361	.885	.032

\+ Total taken to agree with gas meter rdg

J C BURKE
2/25/63

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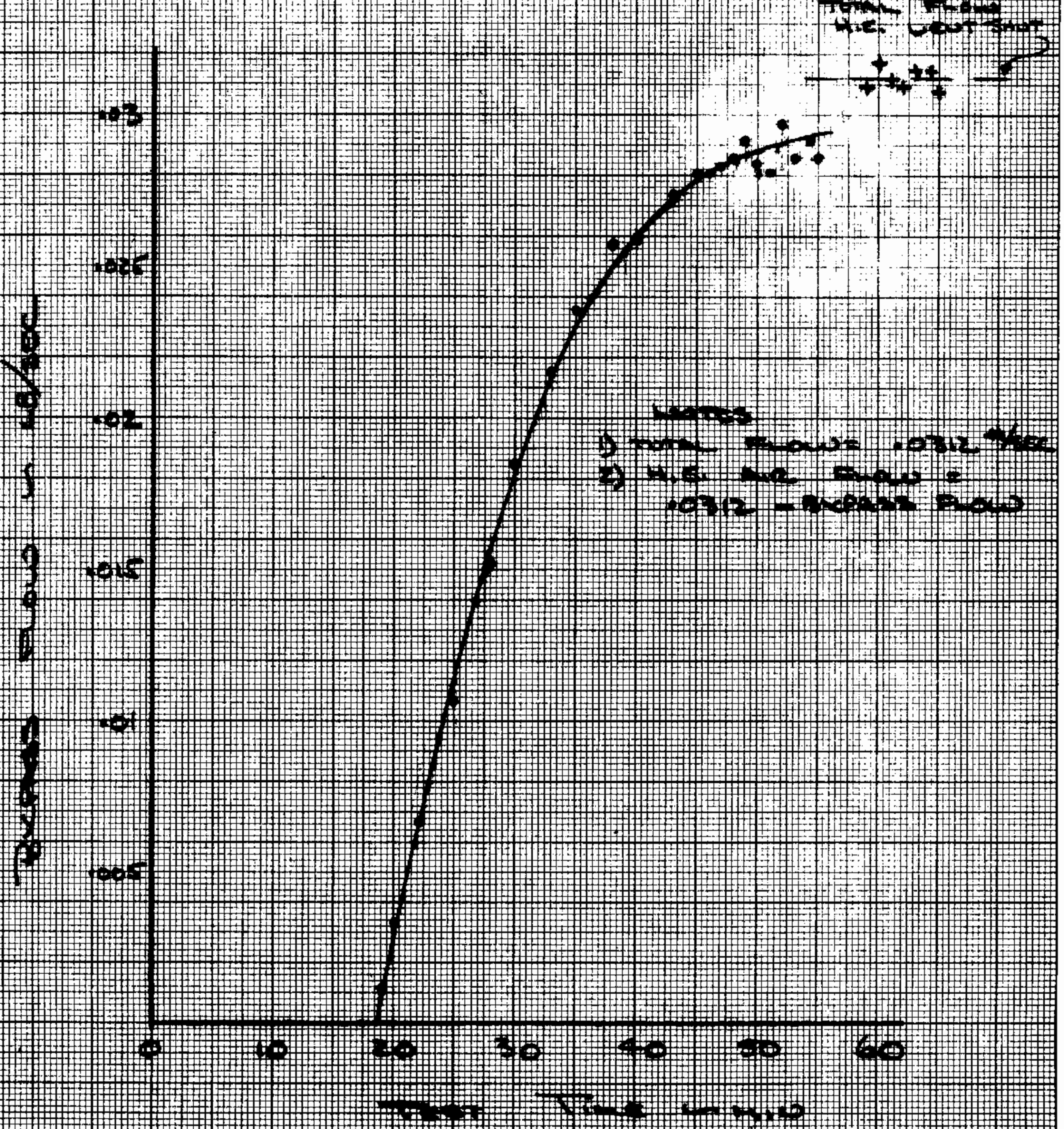
TEST E-3
BYPASS FLOW VS. TEST TIME



TEST E-4 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$, $F_K = f(\text{fluid})$, $W_* = f(A_{\text{orifice}})$, $F_{PR} = f(P_2/P_1)$, $F_T = f(T_1)$ — SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (mv)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR ORIFICE NO. 6 NOM DIA: .0595 IN	15	585	90	.154	5.14	16	1.06	.996	.0521	.0323	
		30	✓	✓	.154	5.10	14	✓	✓	✓	✓	.0322
		45	✓	97	.166	5.28	23	1.05	✓	✓	.032	
T_1 = T-117	COOLANT ORIFICE NO. 4 NOM DIA: .040 IN	15	868	615	.71	5.4	29	1.04	.736	.0238	.0158	
		30	✓	620	.714	5.38	28	1.04	.730	✓	.0157	.0157
		45	✓	620	.714	5.48	33	1.04	.730	✓	.0157	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 36.9 FT³	V_B = 17.6 FT³
@ θ = 15 MIN, P_{B1} = 2005 PSIA	@ θ = 15 MIN, P_{B1} = 2015 PSIA
@ θ = 45 MIN, P_{B2} = 1685 PSIA	@ θ = 45 MIN P_{B2} = 1625 PSIA
$\bar{T}_B$ = 34 °F = 494°R	$\bar{T}_B$ = 34 °F = 494°R
Z_1 = 1.005 ; Z_2 = .996	Z_1 = 1.005 ; Z_2 = .996
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 306 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 374 PSI
ΔM_B = 59.6 LB, Δθ = 1800 SEC	ΔM_B = 34.9 LB, Δθ = 1800 SEC
$\bar{W}_B$ = .0332 LB/SEC	$\bar{W}_B$ = .0194 LB/SEC

FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0322	.0332	.97	.0322
COOLANT	.0157	.0194	.81	.0157

TEST E-5 AIR AND COOLANT FLOW

A. ORIFICE DATA

$W_o = W_* F_P F_{PR} F_T F_K$

$F_P = P_1/1000$
$F_K = f(\text{LIQUID})$
$W_* = f(A_{\text{ORIFICE}})$
$F_{PR} = f(P_2/P_1)$
$F_T = f(T_1)$

SEE ADL CALCULATIONS "ORIFICE FLOW CALCULATIONS" J.C. BURKE 8/20/62 FOR DETAILS

	STREAM	θ (MIN)	P_1 (PSIA)	P_2 (PSIA)	P_2/P_1	T_1 (MV)	T_1 (°F)	F_T	F_{PR}	W_* (LB/SEC)	W_o LB/SEC	$\bar{W}_o$ LB/SEC
T_1 = T-113	AIR											
	ORIFICE NO. 6	10	585	90	.154	5.3	24	1.05	.996	.0521	.0319	.0318
	NOM. DIA:	25	✓	✓	✓	5.3	24	✓	✓	✓	✓	
	.0595 IN	40	✓	✓	✓	5.38	28	1.04	✓	✓	.0316	
T_1 = T-117	COOLANT											
	ORIFICE NO. 4	10	868	625	.72	5.57	37	1.03	.726	.0238	.0155	.0155
	NOM DIA:	25	✓	✓	✓	5.58	37	✓	✓	✓	✓	
	.040 IN	40	✓	✓	✓	5.59	38	✓	✓	✓	✓	

B. BOTTLE DATA

$V_B = 1.75N + .1$ (FT³)

$\Delta M_B = \frac{V_B}{R T_B}\left[\frac{P_{B1}}{Z_1} - \frac{P_{B2}}{Z_2}\right]$ $\qquad R = .383 \frac{FT^3}{°F\ IN^2}$

AIR	COOLANT
V_B = 36.9 FT³	V_B = 12.6 FT³
@θ = 10 MIN, P_{B1} = 1485 PSIA	@θ = 10 MIN, P_{B1} = 1505 PSIA
@θ = 40 MIN, P_{B2} = 1175 PSIA	@θ = 40 MIN, P_{B2} = 1155 PSIA
$\bar{T}_B$ = 34 °F = 494 °R	$\bar{T}_B$ = 34 °F = 494 °R
Z_1 = .992 ; Z_2 = .988	Z_1 = .992 ; Z_2 = .988
$P_{B1}/Z_1 - P_{B2}/Z_2$ = 307 PSI	$P_{B1}/Z_1 - P_{B2}/Z_2$ = 348 PSI
ΔM_B = 60 LB, Δθ = 1800 SEC	ΔM_B = 32.4 LB, Δθ = 1800 SEC
$\bar{W}_B$ = LB/SEC	$\bar{W}_B$ = LB/SEC

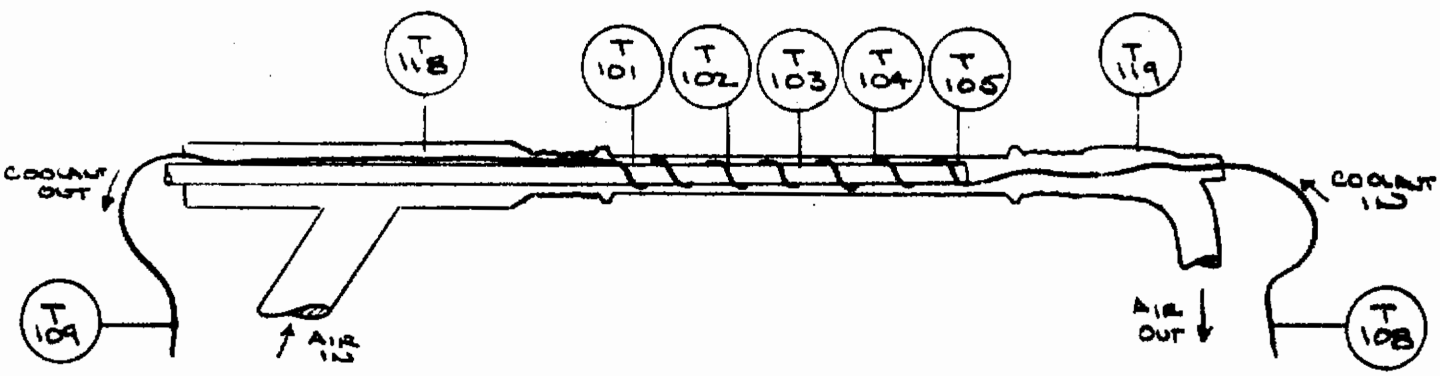
FLOW	ORIFICE	BOTTLES	$\bar{W}_o/\bar{W}_B$	BEST ESTIMATE
AIR	.0318	.0333	.955	.0318
COOLANT	.0155	.0180	.860	.0155

Test E-1

Air and Coolant Temperature Data

Note: (arrow to T-105 column)

Time (min)	Heat Exchanger Core Air Temperatures T-105 (1,9) mv	°F	T-104 (2,10) mv	°F	T-103 (3,11) mv	°F	T-102 (4,12) mv	°F	T-101 (5,13) mv	°F	Air In T-118 (8) mv	°F	Air Out T-119 (16) mv	°F	Coolant In T-108 (6,14) mv	°F	Coolant Out T-109 (7,15) mv	°F
0	6.43	76	6.43	76	6.43	76	6.43	76	6.43	76	6.43	76	6.43	76	6.43	76	6.43	76
2	6.03	58	6.43	✓	6.43	✓	6.52	80	6.52	80	6.59	83	6.12	62	1.93	-160	6.49	78
5	4.50	-15	6.38	74	6.60	83	6.61	84	6.62	84	6.61	84	5.26	22	0.35	-280	6.59	83
8	3.99	-41	6.22	66	6.59	✓	6.60	83	6.61	✓	6.62	✓	4.47	-16	0.31	-288	✓	✓
10	3.95	-43	6.22	✓	6.60	✓	6.61	84	6.64	85	6.65	86	4.29	-26	0.39	-280	6.61	84
17	3.66	-58	5.94	54	6.58	82	6.65	86	6.63	84	6.67	✓	3.91	-45	0.55	-265	6.63	✓
20	3.64	-60	5.91	52	6.59	83	6.67	✓	6.69	87	6.71	88	3.81	-50	0.45	-274	✓	✓
25	2.87	-102	5.36	27	6.43	76	6.62	84	✓	✓	6.69	87	3.35	-73	0.25	-294	✓	✓
30	1.75	-172	3.80	-50	5.80	47	6.49	78	✓	✓	✓	✓	2.29	-107	0.20	-299	6.60	83
35	0.95	-232	1.81	-168	3.83	-49	6.72	44	6.65	86	✓	✓	2.26	-140	0.17	-302	6.39	74
40	0.54	-266	0.97	-230	1.71	-176	3.81	-50	6.61	84	6.65	86	1.88	-164	0.13	-306	5.46	32
45	0.51	-269	0.95	-232	1.69	✓	3.70	-56	6.60	83	✓	✓	1.75	-172	0.12	-307	5.23	20
50	0.41	-278	0.89	-236	1.35	-200	2.90	-100	6.55	81	6.61	84	1.65	-180	0.11	-308	4.67	-6
53	0.39	-280	0.70	-252	1.21	-212	2.51	-124	6.50	79	6.59	83	1.60	-182	✓	✓	4.14	-33



NOTES:

1. [redacted]

TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-1

⊖ = Min.

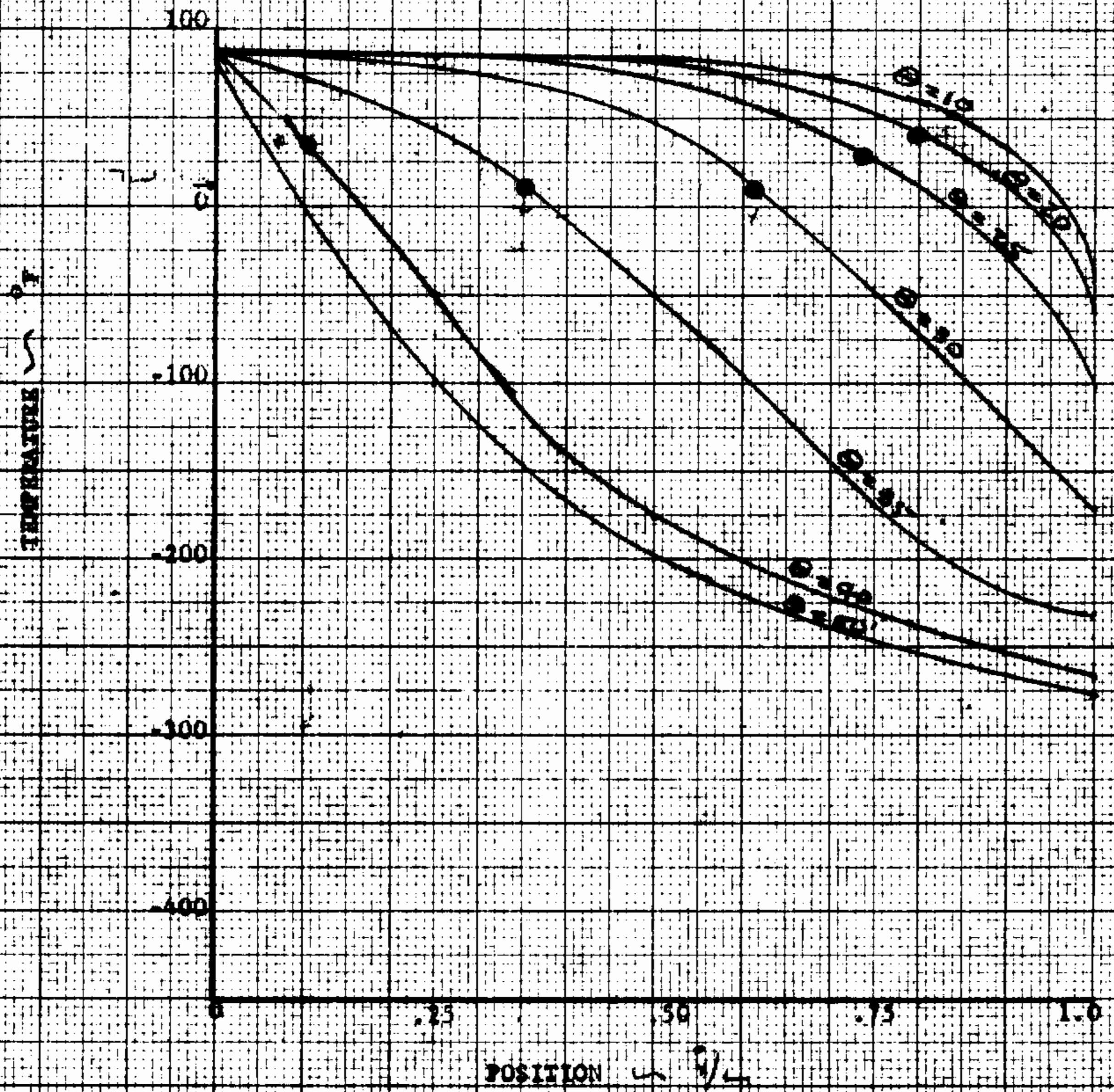
NOTES:

1. ~~Air temperature per core T/C (⊖ symbol).~~

2. ~~Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.~~

3. ~~Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.~~

2. • – DENOTES BEGINNING OF FROST



BY: Duellen DATE: 1-29-63 **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. SHEET NO. 316 OF ____

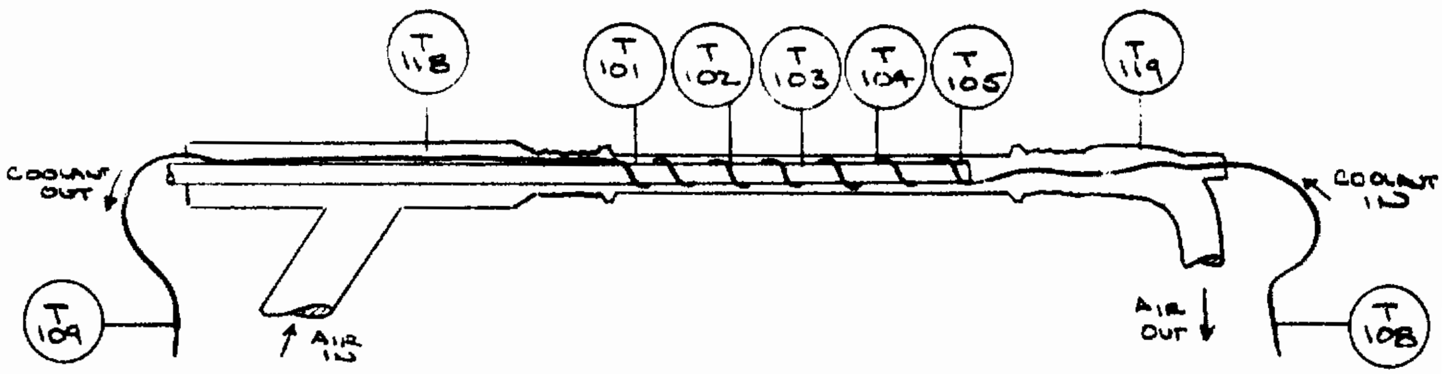
APPROVED ____ DATE ____ SKETCH NO. ____

CLIENT: ASD / EXPERI CASE NO. 64607

TEST E-2

AIR AND COOLANT TEMPERATURE DATA

TIME (MIN)	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR				COOLANT			
											IN		OUT		IN		OUT	
	T-101 (5,13)		T-102 (4,12)		T-103 (3,11)		T-104 (2,10)		T-105 (1,9)		T-118 (8)		T-119 (16)		T-108 (6,14)		T-109 (7,15)	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
5	6.85	94	6.63	71	6.90	74	6.19	65	5.95	54	7.0	100	6.25	68	6.70	88	5.30	24
10	6.10	61	5.85	50	4.9	5	4.0	-40	3.23	-82	7.10	105	4.61	-10	2.42	-129	6.38	74
15	7.17	108	5.58	37	4.45	-18	3.45	-70	2.7	-112	7.17	108	3.83	-49	2.00	-156	6.22	66
20	7.20	109	5.49	33	4.28	-26	3.25	-80	2.53	-123	7.20	109	3.5	-67	1.93	-161	6.17	64
25	7.20	✓	5.12	15	4.00	-35	3.04	-92	2.41	-130	7.20	✓	3.42	-71	1.93	✓	5.96	54
30	7.20	✓	4.73	-3	3.63	-60	2.80	-106	2.30	-136	7.18	108	3.36	-74	1.96	-159	5.68	42
36½	7.18	108	4.30	-25	3.22	-82	2.54	-122	2.20	-143	7.21	110	3.35	-75	1.95	✓	5.35	26
40	7.15	106	4.10	-35	3.02	-94	2.42	-130	2.15	-146	7.20	109	3.32	-76	1.93	-161	5.15	17
45	7.10	105	3.80	-50	2.80	-106	2.30	-136	2.10	-149	7.17	108	3.33	-76	1.92	-161	4.90	5
50	7.10	✓	3.61	-61	2.72	-112	2.35	-134	2.20	-143	7.15	107	3.40	-72	2.10	-150	4.75	-2
55	7.03	102	3.40	-72	2.56	-120	2.23	-142	2.10	-149	7.10	105	3.45	-70	2.00	-156	4.58	-11
60	7.00	100	3.17	-85	2.45	-128	2.20	-141	2.08	-151	7.12	106	3.50	-67	2.00	✓	4.38	-21
65	7.03	102	3.00	-94	2.37	-132	2.17	-145	2.08	-151	7.15	107	3.55	-64	2.00	✓	4.22	-29
70	7.00	100	2.80	-106	2.29	-137	2.12	-148	2.07	-151	7.12	106	3.62	-60	1.96	-159	4.06	-37



NOTES:

1. [illegible]

TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-2

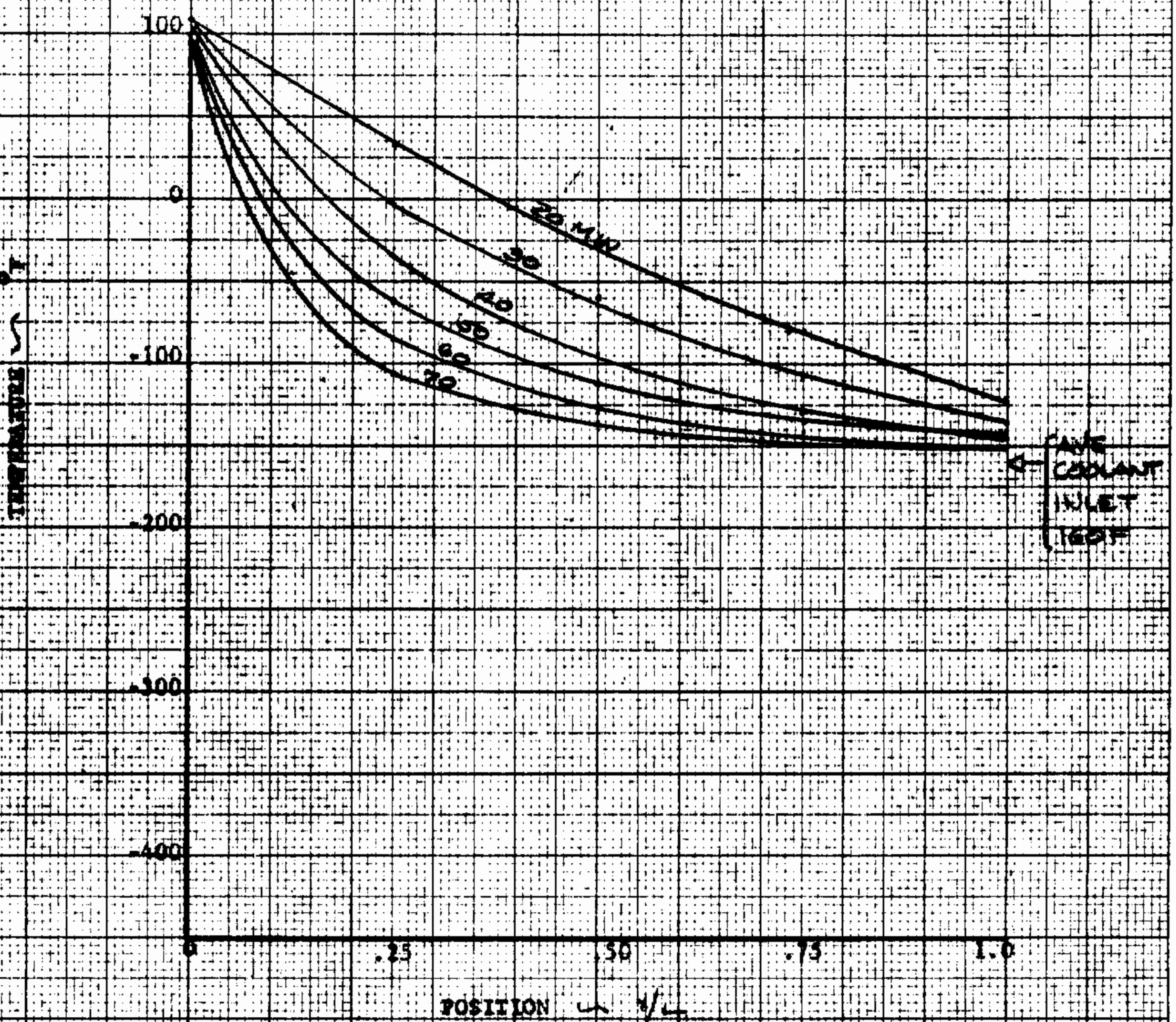
⊖ = 20-70 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).

2. ~~Coolant inlet and outlet temperatures per measured values @ T 108 and T 107 corrected for heat leak. (⊟ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.~~

3. ~~Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.~~



BY M. Kates DATE 4/11/63 **ARTHUR D. LITTLE, INC.** CAMBRIDGE, MASS. SHEET NO. 318 OF

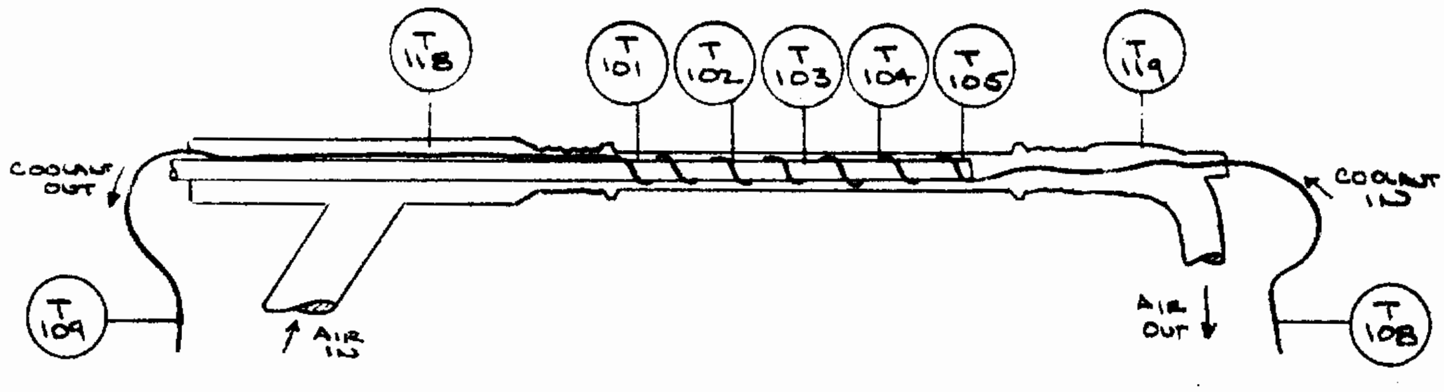
APPROVED DATE SKETCH NO.

CLIENT ASD / EXPERI CASE NO. 64607

TEST E-3

AIR AND COOLANT TEMPERATURE DATA

	HEAT EXCHANGER CORE AIR TEMPERATURES										AIR				COOLANT			
											IN		OUT		IN		OUT	
TIME (MIN)	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	5 13		4 12		3, 11		2 10		1 9		8		16		6, 14		7, 15	
	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
5	6.91	97	6.76	90	6.39	74	6.18	64	5.95	54	7.01	101	6.26	68	5.60	38	6.76	90
10	7.15	107	5.80	47	4.12	1	3.79	-116	3.02	-94	7.12	105	4.50	-15	2.22	-142	6.38	74
15	7.15	107	5.50	34	4.31	-24	3.28	-79	2.52	-124	7.15	107	3.72	-55	1.90	-162	6.15	63
20	7.15	107	5.20	19	4.11	-34	3.05	-92	2.40	-130	7.17	108	3.45	-70	1.86	-166	6.00	56
25	7.10	104	4.10	-35	3.05	-92	2.37	-132	2.06	-152	7.17	108	3.30	-78	1.86	-166	5.07	13
30	7.06	103	3.20	-84	2.42	-130	2.10	-150	2.01	-156	7.17	108	3.58	-62	1.91	-162	4.21	-30
35	7.01	101	2.45	-128	2.11	-148	2.00	-156	1.98	-158	7.15	107	3.91	-45	1.90	-162	3.41	-72
40	6.97	99	2.13	-148	2.10	-150	2.00	-156	2.00	-156	7.13	106	4.30	-25	1.93	-160	3.00	-94
45	6.95	98	2.13	-148	2.10	-150	2.05	-152	2.03	-154	7.15	107	4.60	-10	1.97	-158	2.87	-102
50	6.92	97	2.15	-146	2.09	-150	2.08	-150	2.07	-152	7.15	107	4.80	0	2.00	-156	2.79	-107
55	6.89	96	2.17	-144	2.12	-148	2.08	-150	2.09	-150	7.17	108	4.95	8	2.01	-156	2.75	-110



NOTES:

1. ~~[illegible]~~

BY J. Burke DATE 4/3/63 **ARTHUR D. LITTLE, INC.** SHEET NO. 319 OF ______

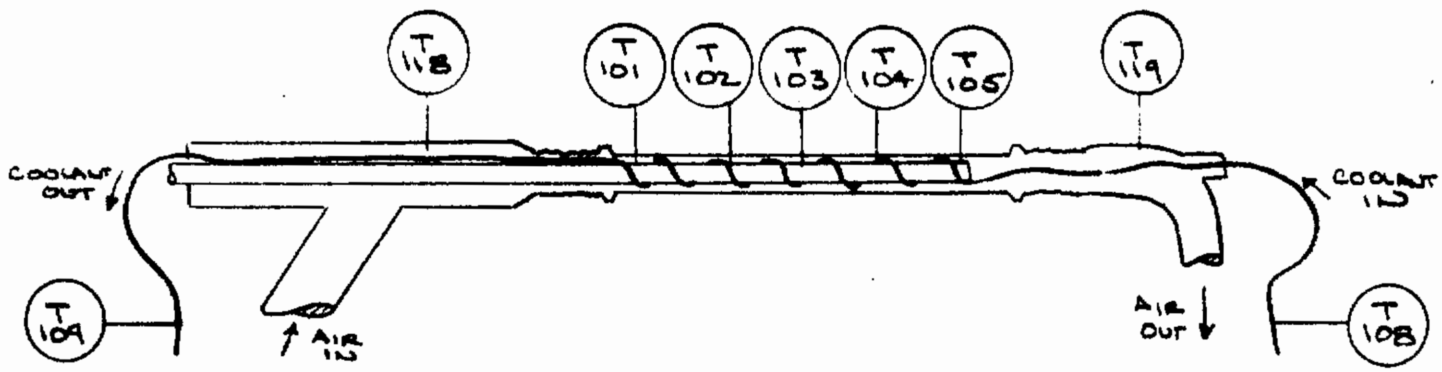
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______

CLIENT ASD / EXPERI CASE NO. 64607

TEST E-4

AIR AND COOLANT TEMPERATURE DATA

Time (MIN)	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	5,13		4,12		3,11		2,10		1,9		8		16		6,14		7,15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
2	6.5		6.5	79	6.4	74	5.9	52	4.0	-40	6.3	70	5.7	42	1.65	-180	6.5	79
5	6.35		5.7	42	4.4	-20	2.2	-143	1.1	-218	5.95	54	3.4	-72	.27	-292	6.15	63
8	6.21		4.70	-5	2.75	-110	1.30	-204	.72	-250	5.72	44	2.7	-112	.21	-298	5.68	42
10	6.15	NOTE	4.22	-29	2.15	-196	1.05	-224	.70	-252	5.5	34	2.45	-128	.21	-298	5.4	29
15	5.95		3.62	-60	1.68	-178	.90	-236	.60	-260	5.72	44	2.05	-152	.20	-299	5.1	14
20	5.85		3.85	-48	1.78	-170	.97	-230	.62	-259	5.95	54	1.9	-162	.20	-299	5.25	22
25	5.82		3.91	-45	1.81	-169	.98	-230	.62	-259	6.30	70	1.82	-168	.19	-300	5.23	20
30	5.90	SEE	4.21	-30	2.1	-148	1.1	-220	.69	-253	6.7	88	1.80	-169	.19	-300	5.50	34
35	6.10		4.50	-15	2.37	-132	1.18	-214	.75	-248	7.15	107	1.83	-168	.19	-300	5.83	48
40	6.20		4.70	-5	2.62	-118	1.23	-210	.78	-246	7.65	128	1.83	-168	.18	-301	6.20	66
45	6.60		4.92	6	2.90	-100	1.35	-200	.80	-244	8.10	147	1.90	-162	.15	-304	6.55	81



NOTES:

T-101 NOT OPERATING PROPERLY

BY J.C. Burke DATE 4/4/63

APPROVED ______ DATE ______

CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 320 OF ______

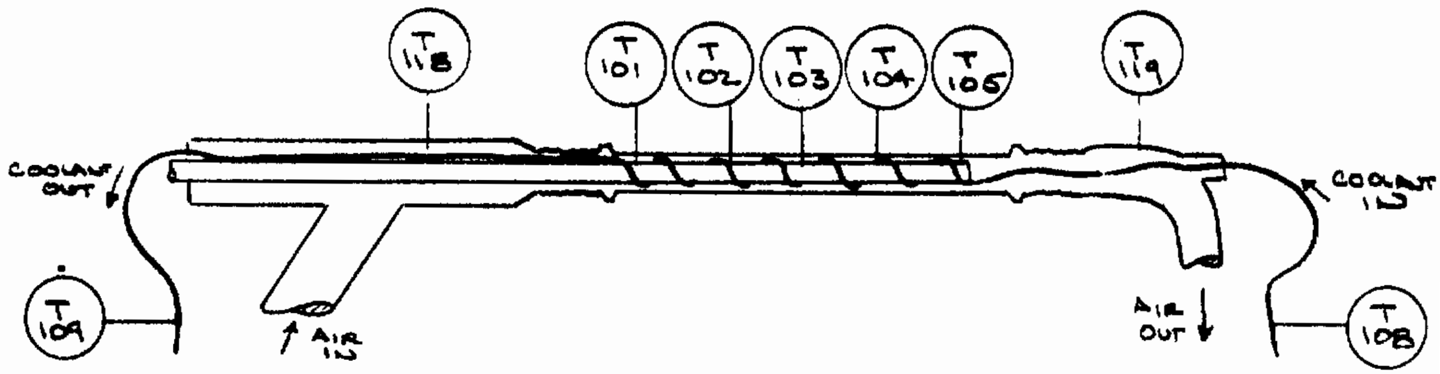
SKETCH NO. ______

CASE NO. 6A607

Test E-5

Air and Coolant Temperature Data

	Heat Exchanger Core Air Temperatures										Air In		Air Out		Coolant In		Coolant Out	
Time (Min)	T-101		T-102		T-103		T-104		T-105		T-118		T-119		T-108		T-109	
	5 13		4 12		3 11		2 10		1 9		8		16		6, 14		7, 15	
	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
2	6.95		6.5	79	6.45	76	5.5	34	3.1	-89	6.25	68	5.0	10	1.0	-228	6.55	81
5	6.75		6.22	66	4.9	5	2.6	-118	1.2	-212	7.25	111	2.58	-120	.4	-279	6.65	86
10	7.0		6.55	81	4.4	-20	1.94	-160	1.0	-228	8.35	157	2.50	-124	.3	-289	7.25	111
15	7.28		7.05	102	5.1	15	2.7	-112	1.4	-198	8.50	168	2.47	-126	.8	-244	7.70	130
20	7.35		6.68	87	4.45	-18	2.2	-143	1.1	-220	7.8	134	2.25	-140	.2	-299	7.50	122
25	7.20		5.9	52	3.55	-64	1.71	-176	.9	-235	7.22	110	2.06	-152	.18	-301	6.95	98
30	6.95		5.08	14	2.83	-104	1.4	-197	.8	-244	6.75	90	1.96	-158	.17	-302	6.42	75
35	6.62		4.4	-20	2.2	-143	1.12	-218	.7	-252	6.25	68	1.93	-160	.17	-302	5.90	52
40	6.35		3.67	-57	1.75	-172	.95	-232	.62	-259	5.65	40	1.80	-170	.17	-302	5.27	22



NOTES:

T-101 NOT OPERATING PROPERLY

TEST E-1

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT₁ T-101 − T102	ΔT₂ T102 − T103	ΔT₃ T103 − T104	ΔT₄ T104 − T105	OVERALL ΔT T101 − T105	OVERALL ΔT T109 − T108
0	0	0	0	0	0	0
2	0	4	0	18	22	238
5	0	1	9	89	99	363
8	1	0	17	107	125	371
10	1	1	17	109	128	364
17	2	4	28	112	142	349
20	1	3	29	112	147	358
25	3	8	49	129	189	378
30	9	31	97	122	259	382
35	42	93	119	164	318	376
40	134	126	54	36	350	338
45	139	120	56	37	352	327
50	181	100	36	42	359	314
53	203	88	40	28	359	341

BY Guicca DATE 1-29-63 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 322 OF
APPROVED ______ DATE ______ | SKETCH NO.
CLIENT ASD/EXPERI | CASE NO. 64607

TEST II-2

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT1	ΔT2	ΔT3	ΔT4	OVERALL ΔT	OVERALL ΔT
	T101 − T102	T102 − T103	T103 − T104	T104 − T105	T101 − T105	T109 − T108
5	15	3	9	11	40	64
10	11	45	45	42	143	3
15	71	45	52	42	220	222
20	76	59	54	43	232	225
25	94	50	57	38	239	215
30	112	57	46	20	245	201
36½	133	57	40	21	251	185
40	141	59	38	16	252	178
45	155	56	30	13	254	166
50	166	51	22	10	248	148
55	174	48	22	7	251	145
60	185	43	13	10	251	135
65	196	40	13	7	253	127
70	206	31	11	3	251	122

BY M. Kates DATE 4/11/63 APPROVED ____ DATE ____ CLIENT ASD/EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 323 OF ____
SKETCH NO. ____
CASE NO. 64607

TEST E-3

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	T-101 − T_{102}	T_{102} − T_{103}	T_{103} − T_{104}	T_{104} − T_{105}	T_{101} − T_{109}	T_{109} − T_{108}
5	7	16	10	10	43	52
10	60	46	47	50	201	216
15	73	58	55	45	231	225
20	88	53	58	38	237	212
25	139	57	40	20	256	177
30	187	46	20	6	257	132
35	229	20	18	2	259	70
40	247	2	6	0	255	66
45	246	2	2	2	252	56
50	243	4	0	2	247	47
55	240	4	2	0	246	46

BY J C Burke DATE 4/10/63 ARTHUR D. LITTLE, INC. SHEET NO. 324 OF ______
APPROVED ______ DATE ______ CAMBRIDGE, MASS. SKETCH NO. ______
CLIENT ASD/EKPERI CASE NO. 64607

TEST E-4

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

	AIR					COOLANT
TIME (MIN)	ΔT_1	ΔT_2	ΔT_3	ΔT_4	OVERALL ΔT	OVERALL ΔT
	$T_{118}-T_{102}$	$T_{102}-T_{103}$	$T_{103}-T_{104}$	$T_{104}-T_{105}$	$T_{118}-T_{105}$	$T_{109}-T_{108}$
2	-9	5	22	92	110	259
5	12	62	123	75	272	355
8	49	105	94	46	294	340
10	63	117	78	28	286	327
15	104	118	58	24	304	313
20	102	122	60	29	313	321
25	115	124	61	29	329	320
30	118	118	72	33	341	334
35	122	117	82	34	355	348
40	133	113	92	36	374	367
45	141	106	100	44	391	385

BY J Burke DATE 4/10/63 ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. SHEET NO. 325 OF
APPROVED DATE SKETCH NO.
CLIENT ASD/EXPERI CASE NO. 64607

TEST E-5

AIR AND COOLANT AXIAL TEMPERATURE DIFFERENTIALS

TIME (MIN)	AIR ΔT_1 $T_{118}-T_{102}$	AIR ΔT_2 $T_{102}-T_{103}$	AIR ΔT_3 $T_{103}-T_{104}$	AIR ΔT_4 $T_{104}-T_{105}$	AIR OVERALL ΔT $T_{118}-T_{105}$	COOLANT OVERALL ΔT $T_{109}-T_{108}$
2	-11	3	42	123	157	309
5	45	61	123	94	323	365
10	76	101	140	68	385	400
15	66	87	127	86	366	374
20	47	105	125	77	354	421
25	58	116	112	59	345	399
30	76	118	93	47	334	377
35	88	123	75	34	320	354
40	97	115	60	27	299	324

BY FER DATE .... ARTHUR D. LITTLE, INC. SHEET NO. 326 OF ....

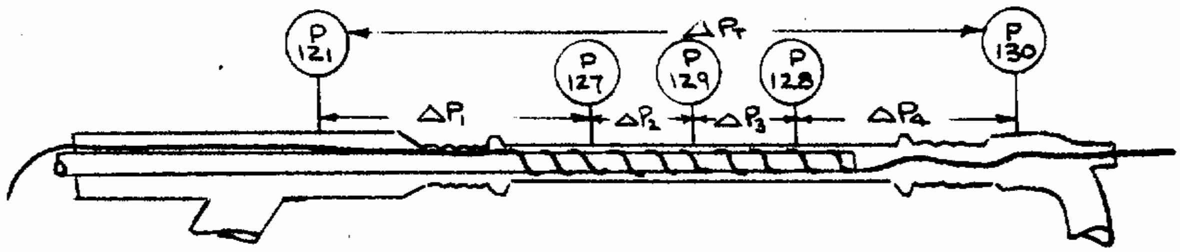
APPROVED .... DATE .... CAMBRIDGE, MASS. SKETCH NO. ....

CLIENT ASD / EXPERI CASE NO. 64607

TEST E-1

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2	75	71	67	64	60	4	4	3	4	15
8	✓	70	66	62	58	5	4	4	4	17
10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
17	✓	70.5	66.5	62.5	54	4.5	4	4	1.5	21
20	✓	70	66	62	48	5	4	4	14	27
25	✓	✓	✓	✓	35	✓	✓	✓	27	40
30	✓	✓	✓	60	32.5	✓	✓	6	27.5	42.5
35	✓	✓	65	57.5	39	✓	5	7.5	18.5	36
40	✓	67	62.5	57	33	8	4.5	5.5	24	42
45	✓	62.5	55.5	49	18	12.5	7	6.5	21	57
50	76	54	47.5	39	4	22	6.5	8.5	35	72



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA [redacted]

BY Duella DATE 1-29-63

APPROVED ______ DATE ______

CLIENT ASD / EXPERI

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 327 OF ____

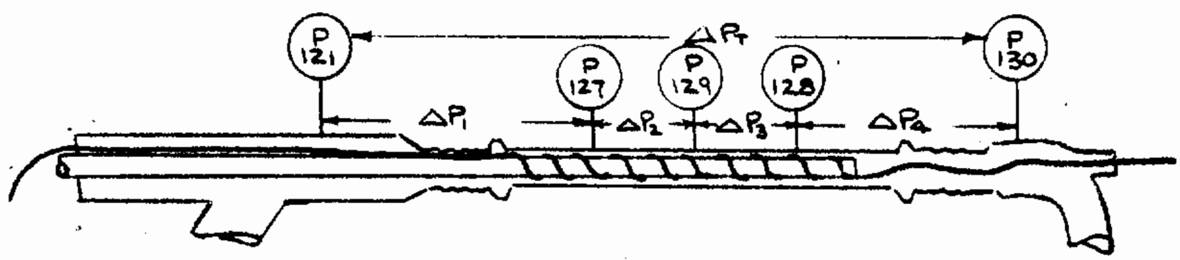
SKETCH NO. ____

CASE NO. 64607

TEST E-2

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	x/L=0 P-121 (PSIG)	x/L=1/4 P-127 (PSIG)	x/L=1/2 P-129 (PSIG)	x/L=3/4 P-128 (PSIG)	x/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1½	75	70.5	67	63	59	4.5	3.5	4	4	12
5	✓	70	66.5	62.5	58.5	5	3.5	4	4	13.5
10	✓	70.5	67	64	61	4.5	3.5	3	3	14
15	✓	70.5	67.5	64.5	62	4.5	3	3	2:5	13
20	✓	70.5	67.5	64.5	✓	4.5	3	3	2.5	✓
25	✓	71.5	67	64	✓	3.5	4.5	3	2	✓
30	✓	71.5	65.5	63.5	✓	3.5	6	2	1.5	✓
36½	✓	70.5	65	63.5	✓	4.5	5.5	1.5	1.5	✓
40	✓	69.5	64	63	✓	5.5	5.5	1	1	✓
45	✓	68.5	64 ?	63	✓	6.5	4.5	1	1	✓
50	✓	67.5	63.5	62.5	✓	7.5	4.0	1	.5	✓
55	✓	66.5	63.5	62.5	✓	8.5	3.0	1	.5	✓
60	✓	65.5	63	62.5	✓	9.5	2.5	.5	.5	✓
65	–	65	63	62.5	✓	10.0	2.0	.5	.5	✓
70	✓	64.5	62.5	62.5	✓	10.5	2.0	0	.5	✓



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA [redacted]

BY D. C. B[illegible] DATE 2/25/63 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 328 OF

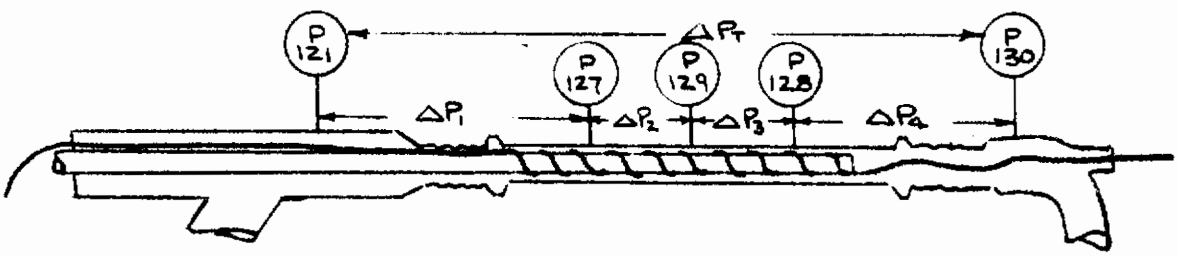
APPROVED ______ DATE ______ | SKETCH NO. ______

CLIENT ASD / EXPERI[illegible] | CASE NO. 64607

TEST E-3

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
1 1/2	75	70	66	63	59	5	4	3	4	16
5	✓	70.5	66.5	63	59	4.5	4	3.5	4	16
10	✓	70.5	67	64	61.5	4.5	3.5	3.0	2.5	13.5
13	✓	70.5	67.5	64.5	62	4.5	3.0	3.0	2.5	13
15	✓	70.5	67.5	64.5	62	4.5	3.0	3.0	2.5	✓
20	✓	70.5	65.0	63.0	61.0	4.5	5.5	2.0	2.0	14
25	✓	67.0	63.5	62.5	61.5	8.0	3.5	1.0	1.0	13.5
28	74.5	64.5	62.5	62.0	61.5	10.0	2.0	.5	.5	13
30	75	64.0	63.0	62.5	62.0	11.0	1.0	.5	.5	✓
33	✓	62.5	62.0	62.0	62.0	12.5	.5	0	0	✓
35	✓	62.0	62.0	62.0	62.0	13	0	0	0	✓
40	✓	61.5	61.5	61.5	61.5	13.5	0	0	0	13.5
45	✓	61.5	61.5	61.5	61.5	13.5	0	0	0	13.5
50	✓	62.0	62.0	62.0	62.0	13	0	0	0	13
55	✓	62.0	62.0	62.0	62.0	13	0	0	0	13



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION DATA ~~[illegible]~~

BY J. BURKE DATE 4/3/63 | APPROVED ______ DATE ______ | CLIENT ASD / EXPERI

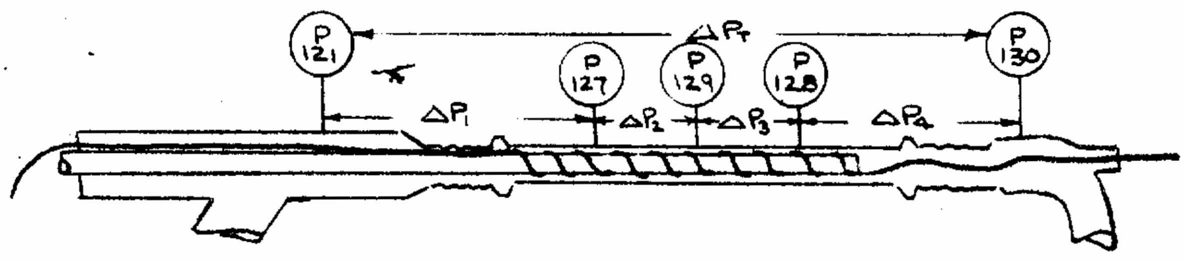
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 329 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST E-4

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP_1 (PSI)	ΔP_2 (PSI)	ΔP_3 (PSI)	ΔP_4 (PSI)	ΔP_T (PSI)
2	75	70.5	67	63.5	60.5	4.5	3.5	3.5	3.0	14.5
5	✓	✓	67.5	65	63	4.5	3.0	2.5	2.0	12.0
8	✓	✓	68.5	67	65	4.5	2.0	1.5	2.0	10.0
10	✓	71.5	69	67.5	65.5	3.5	2.5	1.5	2.0	9.5
15	✓	✓	69	67.5	65.5	3.5	2.5	1.5	2.0	9.5
20	✓	✓	69	67	64	3.5	2.5	2.0	3.0	11.0
25	✓	67	64	61.5	58	8.0	3.0	2.5	3.5	17.0
30	✓	61.5	58	54	49	13.5	3.5	4.0	5.0	26.0
35	✓	52	47	43	35	23	5.0	4.0	8.0	40.0
40	✓	43	35.5	30	16	32	7.5	5.5	14.0	59.0
45	82	44	31	26	4.5	38	13	5.0	21.5	77.5



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION

* DATA [redacted]

BY J.C. Burke DATE 4/3/63 APPROVED ______ DATE ______ CLIENT ASD / EXPERI

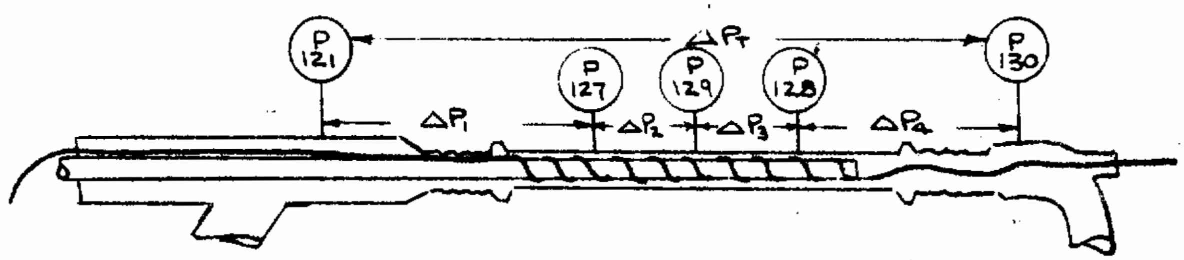
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 330 OF ______
SKETCH NO. ______
CASE NO. 64607

TEST E-5

HEAT EXCHANGER AIR PRESSURES

TIME (MIN)	X/L=0 P-121 (PSIG)	X/L=1/4 P-127 (PSIG)	X/L=1/2 P-129 (PSIG)	X/L=3/4 P-128 (PSIG)	X/L=1.0 P-130 (PSIG)	ΔP1 (PSI)	ΔP2 (PSI)	ΔP3 (PSI)	ΔP4 (PSI)	ΔPT (PSI)
2	75	71	67	63	60	4	4	4	3	15
5	✓	70.5	67.5	65	63	4.5	3	2.5	2	12
10	✓	70	67	64.5	62.5	5	3	2.5	2	12.5
15	✓	70	66	62	59	5	4	4	3	16
20	✓	70	64	56	53.5	5	6	8	2.5	21.5
25	✓	70.5	58	50	45.5	4.5	12.5	8	4.5	29.5
30	✓	70.5	50	43.5	37	4.5	20.5	6.5	6.5	38
35	✓	68.5	43	36.5	27.5	6.5	25.5	6.5	9	47.5
40	✓	62.5	37.5	31	20	12.5	25.0	6.5	11	55



NOTES:

1. PRESSURE GAGE DATA CORRECTED PER CALIBRATION
~~DATA [illegible]~~

— WATER CONTAMINANT TEST RESULTS —

TEST R-1
DATE 1-24-63

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN T °F	IN P psia	IN Conc. ① ppm-Vol	IN p_w psia	IN p_{sat} psia	IN % of Sat.	OUT T °F	OUT P psia	OUT Conc. ① ppm-Vol.	OUT p_w psia	OUT p_{sat} psia	OUT % of Sat	REMARKS
12.75	85	90	12										
13.43	✓	✓	249										
14.30	✓	✓	372										
17	84	✓	390										
20							-60	63	75				
23½	87	90	390										
27							-130	48	40				
31							-172	47	33				
38	84	90	390										
45							-269	33	17				
53	79	91	370										
													$\frac{390}{453} = .86$
													$(.86)(291) = 250$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/sec	① Calculated ppm-(wt)	Inlet Conc. ppm (vol) ②
10		20.25					
12	2	20.75	.5	15			
22	12	23.1	2.85	14.2	.0327	291	453
32	22	26.5	6.25	17.0			
37.5	27.5	26.9	6.65	14.5			
54.25	44.25	30.95	10.70	14.5			

Note: p_w = partial press H_2O
p_{sat} = vapor " "

① Average - Approx Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / (3600 W_A) = ppm (vol) × 18/29

BY: Keller DATE: 1-30-63 — ARTHUR D. LITTLE, INC., CAMBRIDGE, MASS. — SHEET NO. 332 OF ____
APPROVED ____ DATE ____ — SKETCH NO. ____
CLIENT: ASD / EXPER. — CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST E-2
DATE 1-29-63

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC.① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
19½	109	90	23										
20¼	109	✓	282 (63%)										
21¼	109	✓	426 (95%)										
25	109	✓	450										
36½							-143	77	12				
42	108	90	450										
50							-143	77	11.5				
55							-149	✓	8				
60							-151	✓	7				
65							-151	✓	6				
70	106	90	432										

Remarks: $\frac{450}{470} = .96$

$(302)(.96) = 290$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	W_A lbs/hr	CALCULATED ② ppm-(wt)	INLET CONC. ppm (vol) ②
17		23.5					
29	12	26.6	3.1	15.5	115	302	470
34	17	27.9	4.4	15.55			
41	24	29.75	6.25	15.65			
49	32	31.9	8.4	15.75			
71.5	59.5	37.95	14.45	15.9			

Note: p_w = partial press H_2O
p_{SAT} = vapor " "

① Average - Approx. Steady State Value

② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / (W_A) = ppm (vol) × 18/29

BY J C Burke DATE 2/25/63 APPROVED ______ DATE ______ CLIENT ASD / EXPER.

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO 333 OF ______ SKETCH NO. ______ CASE NO. 64607

— Water Contaminant Test Results —

Test E-3
Date 1/30/63

Recorder & Visual Observations

Time min.	IN T °F	IN P psia	IN Conc. ① ppm-Vol	IN p_w psia	IN p_{sat} psia	IN % of Sat.	OUT T °F	OUT P psia	OUT Conc. ① ppm-Vol.	OUT p_w psia	OUT p_{sat} psia	OUT % of Sat	Remarks
17			46										
18			103										
18.4			874(63)										
21			1375										
22			1400										
25									90				
30									35				
31									32				
35			1270										
37			1300										1400/1610 = 87%
40			1320										(1035)(.87) = 900

Data from Burette Measurements

Time min.	Time Interval min.	Burette cc	Difference cc	Rate cc/hr	WA lbs/hr	Calculated ① ppm-(wt)	Inlet Conc. ppm (vol) ②
17		2.25					
24½	7.5	8.80	6.55	52	112	1035	1610
31	6.5	14.45	5.65	52.1			
38	7.0	20.6	6.15	52.8			

(52.5 avg.)

Note: p_w = partial press H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = Rate (cc/hr) × (1/454) × 10^6 / ([illegible] WA) = ppm (vol) × 18/29

BY JCBurke DATE 4/15/63 | ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS. | SHEET NO. 334 OF
APPROVED ____ DATE ____ | SKETCH NO. ____
CLIENT ASD / EXPER. | CASE NO. 64607

— WATER CONTAMINANT TEST RESULTS —

TEST E4
DATE 2/2/63

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC. ① ppm-Vol	IN: p_w psia	IN: p_{sat} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-Vol.	OUT: p_w psia	OUT: p_{sat} psia	OUT: % of SAT	REMARKS
21.7			276										
22.7			414										
24			436										
30									55				
35									24				
40									21				
43			420										
45			425										
													$\frac{430}{452} = .95$
													(291)(.95) = 276

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE CC	DIFFERENCE CC	RATE cc/hr	w_A lbs/hr	CALCULATED ② ppm-(wt)	INLET CONC. ppm (vol) ②
17 1/2	—	13.0					
24	6.5	14.65	1.65	15.2	116	291	452
28 1/2	11.0	15.75	2.75	15.0			
36	18.5	17.65	4.65	15.1			
43	25.5	19.50	6.50	15.3			

Note: p_w = partial press. H_2O
p_{sat} = vapor " "

① Average - Approx. Steady State Value
② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6 / ([redacted] w_A) = ppm (vol) × 18/29

— WATER CONTAMINANT TEST RESULTS —

TEST E-5
DATE 2/2/63

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: Conc ① ppm-Vol	IN: p_w psia	IN: p_{SAT} psia	IN: % of SAT.	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-Vol.	OUT: p_w psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
14½			276										
16			415										
18			437										
25									18.4				
30									12.7				
35									11.5				
38			357										$\frac{430}{450} = .955$
39			370										
40			372										$(.955)(290) = 278$

DATA FROM BURETTE MEASUREMENTS

TIME MIN.	TIME INTERVAL MIN.	BURETTE cc	DIFFERENCE cc	RATE cc/hr	W_A lbs/hr	CALCULATED INLET CONC. ② ppm-(wt)	CALCULATED INLET CONC. ppm (vol) ②
13.0		20.8					
23½	9.5	23.4	2.6	16.4	115	290	450
33	20	25.8	5.0	15.0			
43	30	28.35	7.55	15.1			

Note: p_w = partial press. H_2O
p_{SAT} = VAPOR " "

① Average - Approx. Steady State Value
② ppm (wt) = RATE (cc/hr) × (1/454) × 10^6 / (W_A) = ppm (vol) × 18/29

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST E-1
DATE 24 JAN 63

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN T °F	IN P PSIA	IN CONC ① ppm-VOL	IN p_{CO_2} psia	IN p_{SAT} psia	IN % of SAT	OUT T °F	OUT P psia	OUT CONC ① ppm-VOL	OUT p_{CO_2} psia	OUT p_{SAT} psia	OUT % of SAT	REMARKS
10	85	90	330										
17	84	✓	343										
20			-				-60	63	327				
25							-102	50	312				
30							-172	47	252				
35	86	90	343										
40							-266	48	7				
45							-269	33	32				[illegible] INDICATION
50							-278	19	92				
													$343\left(\frac{44}{28}\right) = 540$

No of Bottles in Manifold ___
Pressure in Manifold ___ psia
No of CO_2 Bottles ___
Pressure of CO_2 Bottles ___ psia

Pressure after Mixing: ___ psia
ppm CO_2 (vol) = ___ × ___ / ___
ppm CO_2 (wt) = ppm (vol) × 44/28
=

① Average ... Steady ... Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

BY Kuma DATE 1-30-63 APPROVED ______ DATE ______

CLIENT ASD/CAPRI

SHEET NO. 337 OF ______
SKETCH NO. ______
CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST E-2
DATE 1-29-63

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	CONC ① ppm-vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
15	108	90	335										
20	109	✓	345										
30							-136	77	315				
40	109	90	322						-				
50							-143	77	327				
60							-151	✓	327				
70	106	90	335										
													$(335)\left(\frac{44}{28}\right) = 525$

No of Bottles in Manifold ______
Pressure in Manifold ______ psia
No of CO_2 Bottles ______
Pressure of CO_2 Bottles ______ psia

Pressure After Mixing: ______ psia
ppm CO_2 (vol) = ______
ppm CO_2 (wt) = ppm(vol) · 44/28
=

Note p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

① [illegible] Steady [illegible] Value

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST E-3
DATE 1/30/63

RECORDER & VISUAL OBSERVATIONS

TIME	IN						OUT						REMARKS
MIN.	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	T °F	P psia	Conc ① ppm-Vol	p_{CO_2} psia	p_{SAT} psia	% of SAT	
5			376										
10			376										
15			372										
20			376										
25									372				
30									370				
35			372										
40			376										
45									376				$(373)\left(\frac{44}{28}\right) = 585$
50									372				

No. of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure after Mixing: psia
ppm CO_2 (vol) = ____ × ____ / ____ =
ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$
=

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST E-4
DATE 2/2/63

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: Conc ① ppm-Vol	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: Conc ① ppm-Vol	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
5			275										
10			310										
15			322										
20			290										
25			310										
30									16				
35									30				
40									90	(METER BROKE)			
42			280										$300\left(\frac{44}{28}\right) = 470$
44			286										
45			286										

No of Bottles in Manifold ____
Pressure in Manifold ___ psia
No. of CO_2 Bottles ___
Pressure of CO_2 Bottles ___ psia

Pressure after Mixing: psia
ppm CO_2 (vol) = ___ × ___/___ =
ppm CO_2 (wt) = ppm (vol) × $\frac{44}{28}$
=

① Average - Approx Steady State Value

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor " " , "

BY: J.C. Burke DATE: 4/15/63 | APPROVED: DATE: | CLIENT: ASD/CAPERL

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASS.

SHEET NO. 340 OF | SKETCH NO. | CASE NO. 64607

- CARBON DIOXIDE CONTAMINANT TEST RESULTS -

TEST E-5
DATE 2/2/63

RECORDER & VISUAL OBSERVATIONS

TIME MIN.	IN: T °F	IN: P psia	IN: CONC ① ppm-vol	IN: p_{CO_2} psia	IN: p_{SAT} psia	IN: % of SAT	OUT: T °F	OUT: P psia	OUT: CONC ① ppm-vol	OUT: p_{CO_2} psia	OUT: p_{SAT} psia	OUT: % of SAT	REMARKS
10			317										
15			310										
18			310										
25									36				
30									26				
35									26				
38			310										
39			310										
40			320										$(315)\left(\frac{44}{28}\right) = 495$
41			316										

No of Bottles in Manifold ____
Pressure in Manifold ____ psia
No. of CO_2 Bottles ____
Pressure of CO_2 Bottles ____ psia

Pressure after Mixing: ____ psia
ppm CO_2 (vol) = ____
ppm CO_2 (wt) = ppm (vol) × 44/28
=

Note: p_{CO_2} = partial pressure CO_2, psia
p_{SAT} = vapor pressure, psia

① [illegible] Value

TEST HEAT EXCHANGER

AXIAL TEMPERATURE GRADIENTS

ASD-TDR-63-508, Volume III

TEST HEAT EXCHANGER

AXIAL TEMPERATURE GRADIENTS

TABLE OF CONTENTS

SUMMARY

For many of the tests, plots of air, coolant and tube wall temperature as a function of heat exchanger length were prepared at a representative time in the course of the test after steady state temperature conditions had been attained. These plots were useful in many aspects of the data anslysis, such as estimating the start and effective length of the frost zone from temperature considerations. Although this information was not completed for all tests, it is felt that the material developed is of sufficient general usefulness to be included in this report.

The air temperature data was obtained from thermocouples on the instrumentation core. The coolant inlet and outlet temperatures were determined from thermocouples T-108 and T-109 and corrected, as necessary, for heat leak between those measuring points and the actual inlet or outlet locations. Intermediate coolant temperatures were apportioned by enthalpy balances between and and coolant streams.

Tube wall temperatures were estimated from the air and coolant temperatures and the computed heat transfer coefficients on the air and coolant side. The estimation of air-side heat transfer coefficients was based on "clean conditions"--frost insulation was neglected. In computing both air and coolant coefficients, average fluid properties were used. In the case of supercritical coolant, the variation in actual heat transfer coefficient along the length of the heat exchanger was frequently significant. Based on these qualifications, the tube wall temperature must be regarded as estimates. Generally the accuracy of these estimated values is quite good when the estimated values fall close to either the air or the coolant temperature--in which case, significant errors in coefficients will tend to be damped out. However, when the estimated wall temperature falls midway between air and coolant, the error may be significant. In certain cases where uncertainties in estimating tube wall temperature were found to be especially large, this data was not presented.

Temperature plots are presented for all of the flow, configuration, and verification test series. These plots are complete with the following exceptions:

(1) Wall temperatures were not presented for tests F-14 and V-9. In these tests due to instrumentation errors, the indicated coolant temperature at the warm end tended to be slightly higher than the air temperature.

(2) Wall temperatures were not presented for test C-2 or completed for test C-1. In these tests uncertainties due to variations in coolant heat transfer coefficient were judged to be large.

For the hydrogen test series, only air and coolant temperature plots for tests H-2 and H-3A and air temperatures for test H-6 were completed.

No temperature plots for the extended test series are presented here. However, some axial temperature plots are presented in the section on the Extended Test Series Data.

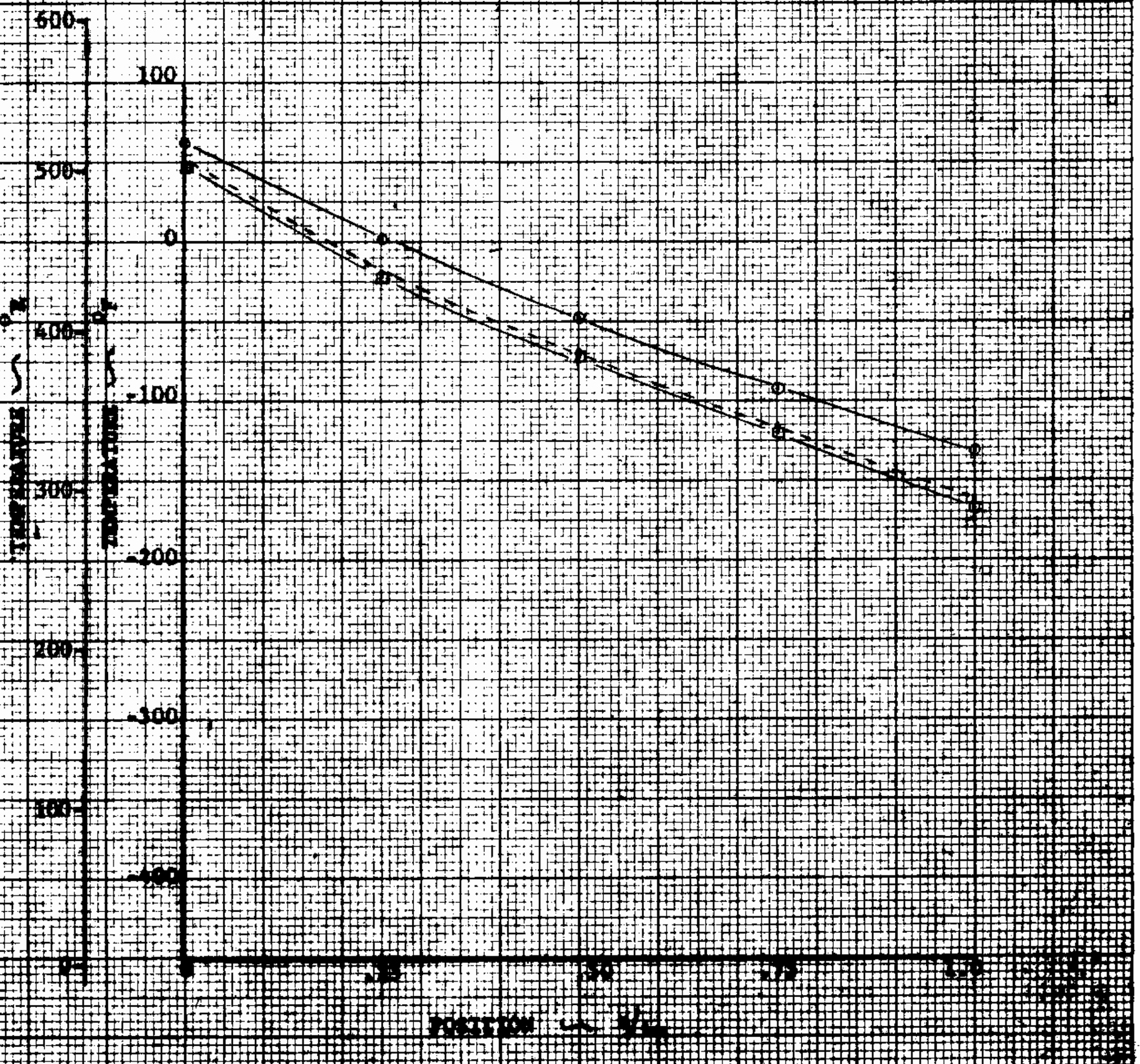
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-1

θ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



Final Revision

BY: M. Kates
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DATE: 12/4/62

64607

TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F - 2

θ = 30 Min.

NOTES:

1. ~~Air temperature per core T/C (⊖ - symbol).~~
2. Coolant inlet and outlet temperature per measured values @ ~~T-108 and T-109 corrected for heat leak. (⊟ symbol).~~ Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.

Final Revision

TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-3

θ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.

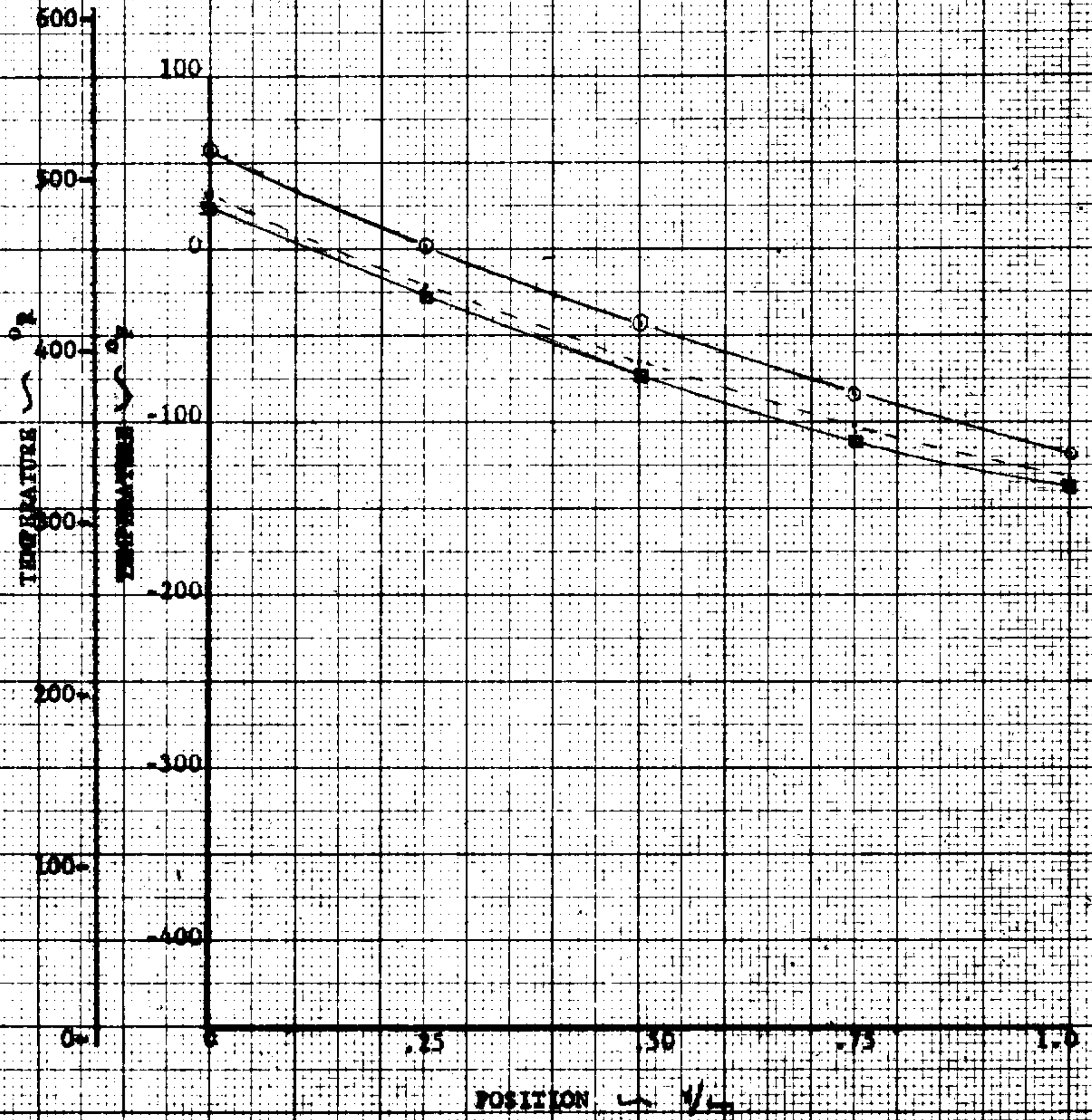
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-4

θ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



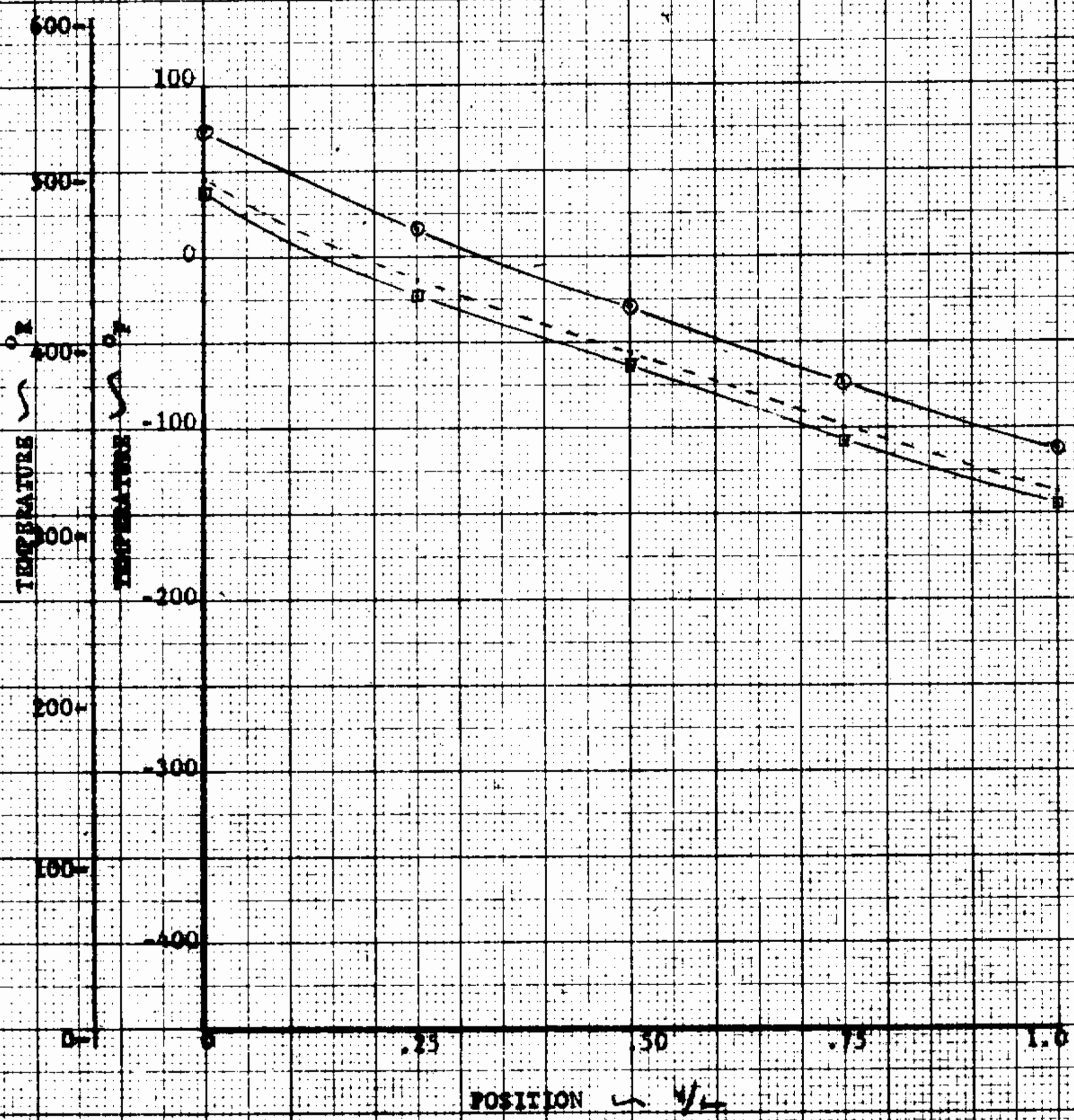
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-5

⊕ = 33 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-7

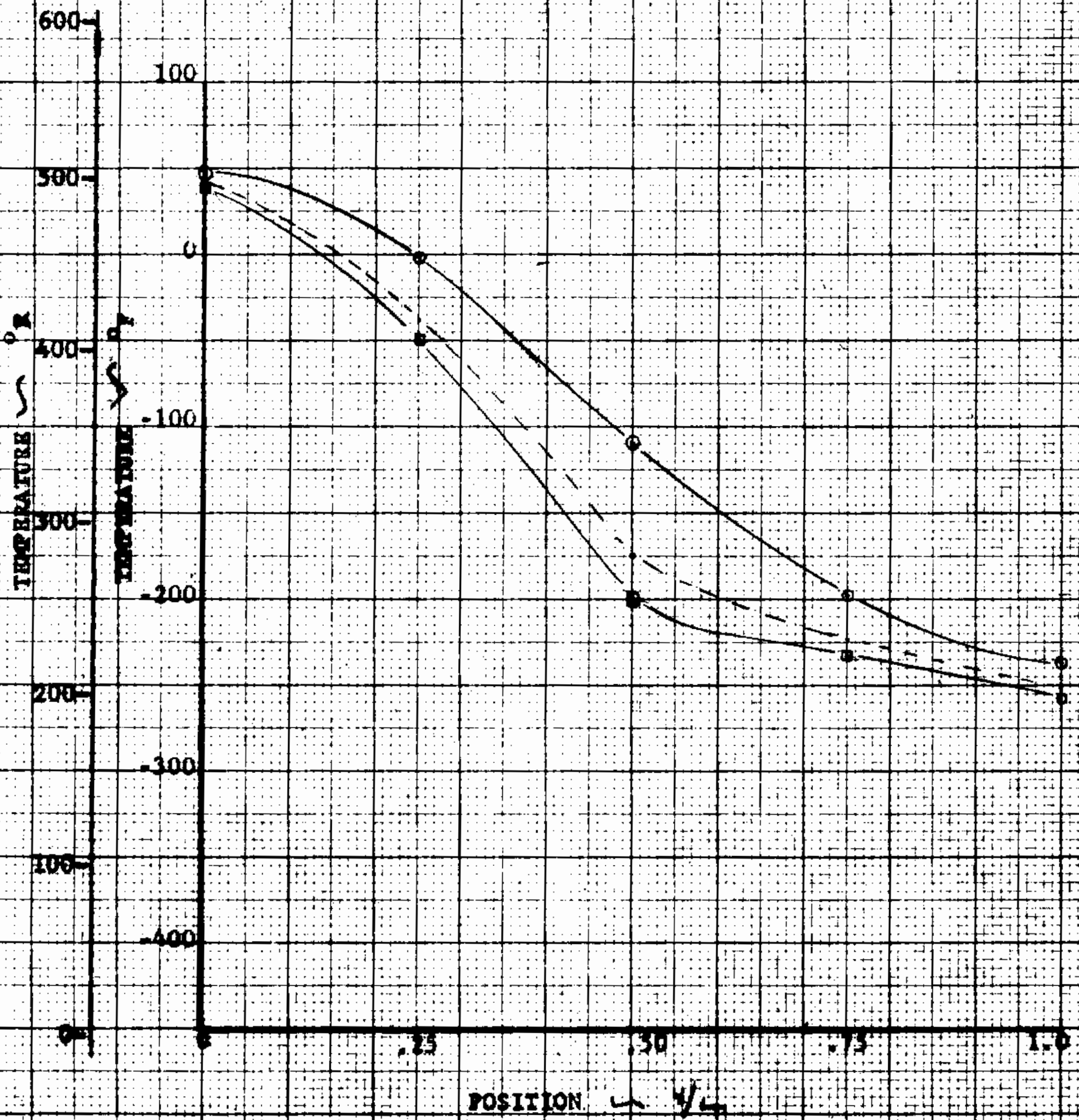
⊖ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-8

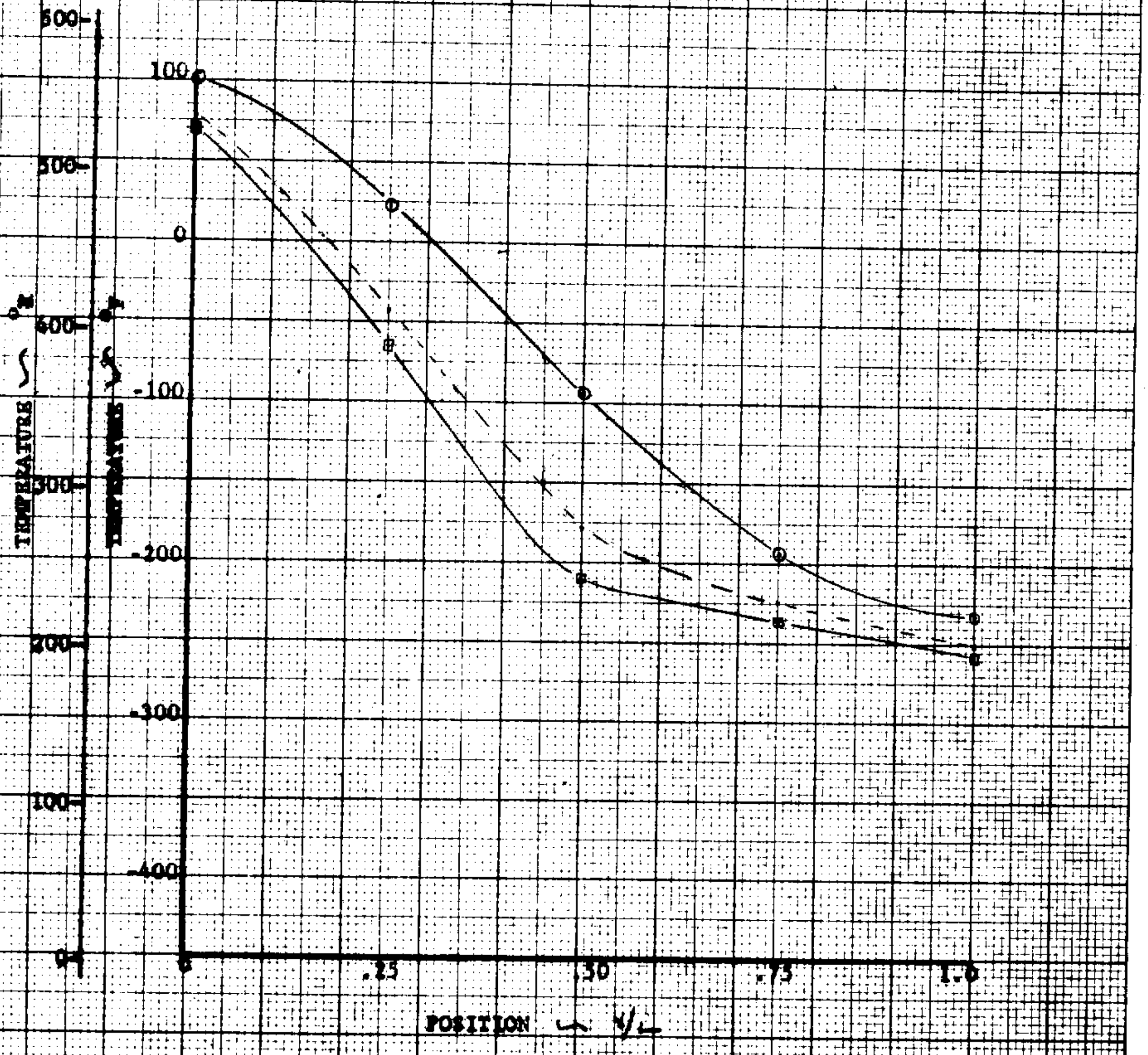
θ = 30 Min.

NOTES:

1. ~~Air temperature per core T/C (⊙ - symbol).~~

2. Coolant inlet and outlet temperature per ~~measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol).~~ Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



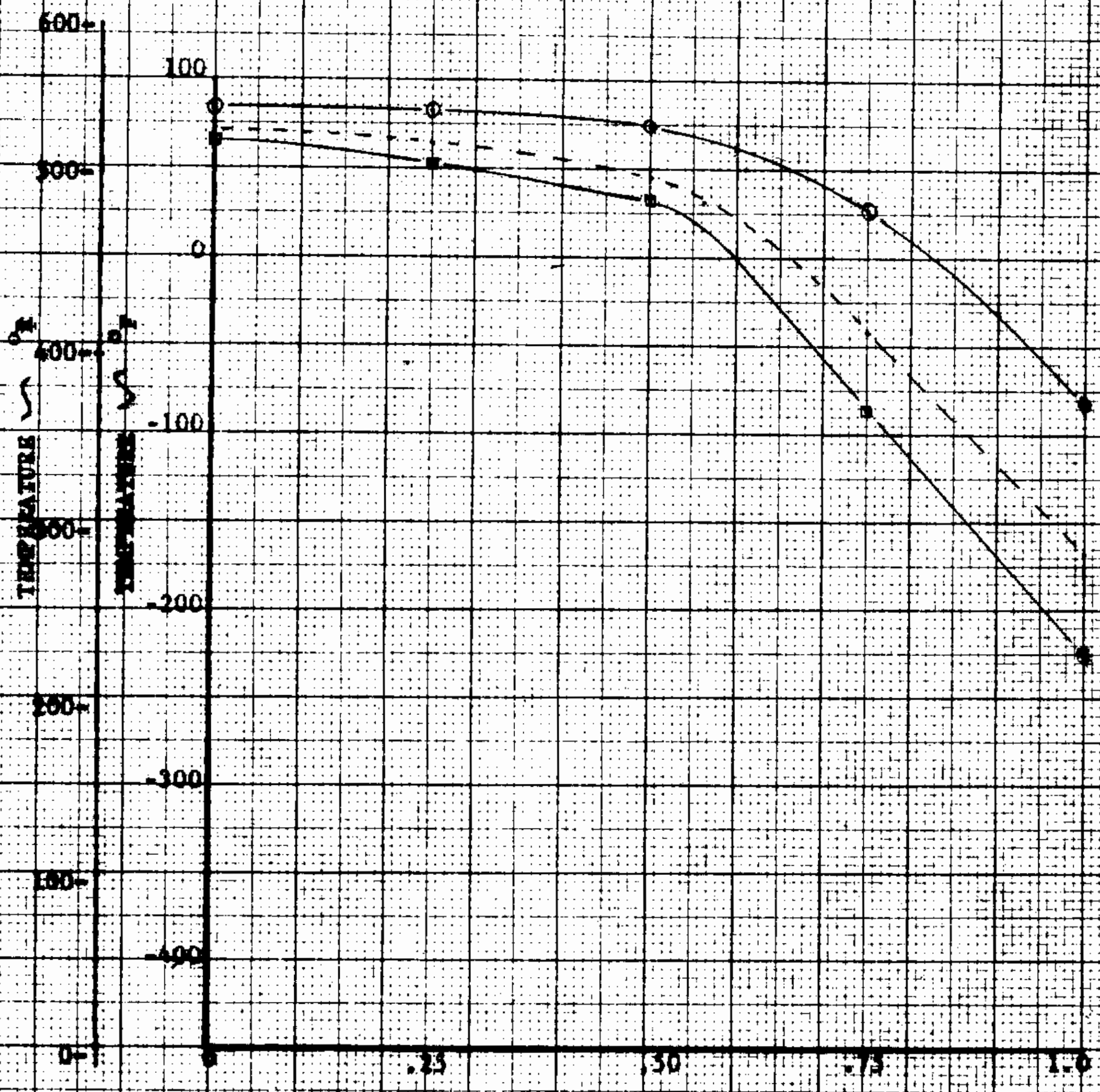
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F - 2

θ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



POSITION ~ X/L

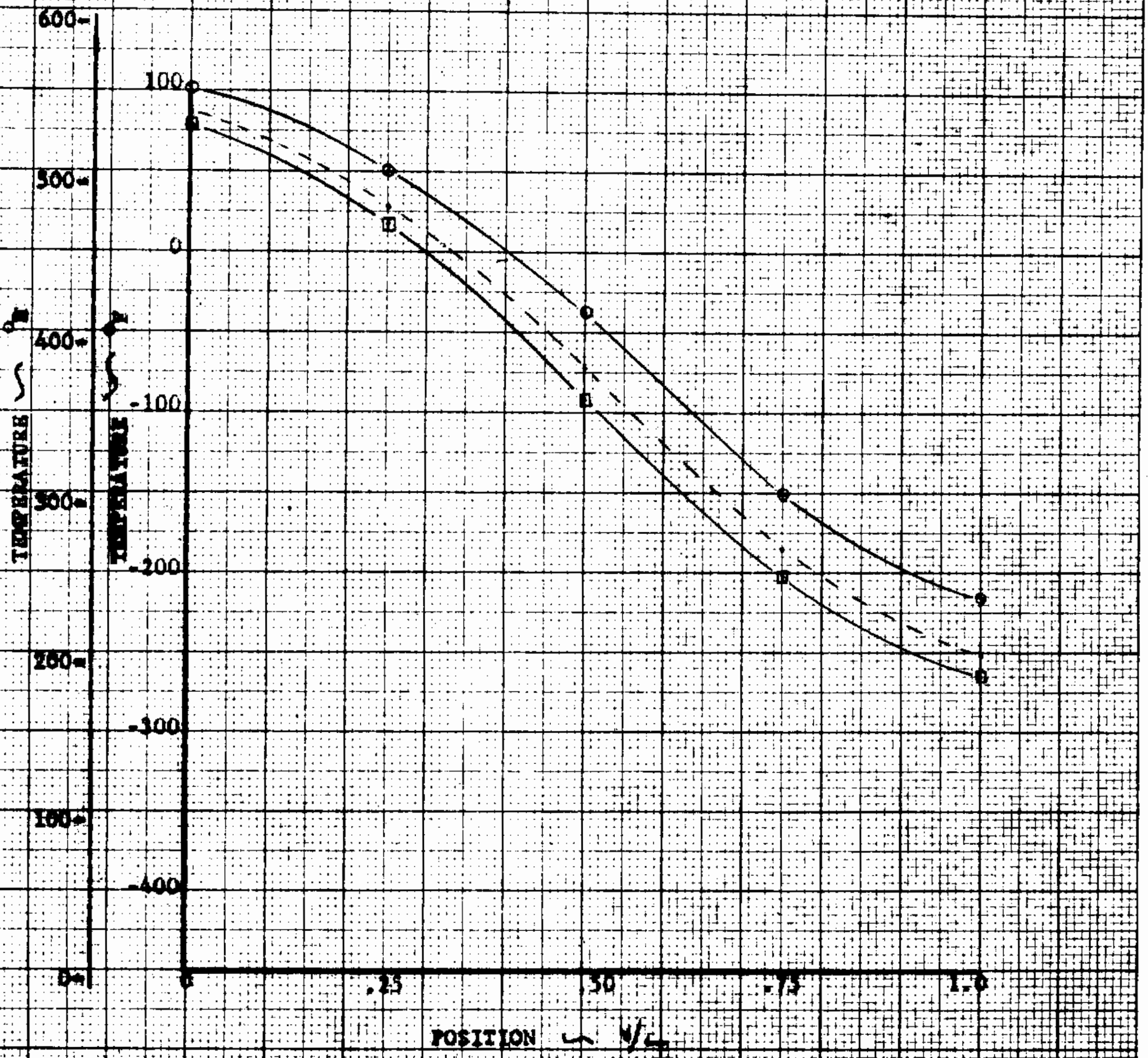
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-10

Θ = 15 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



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TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-11

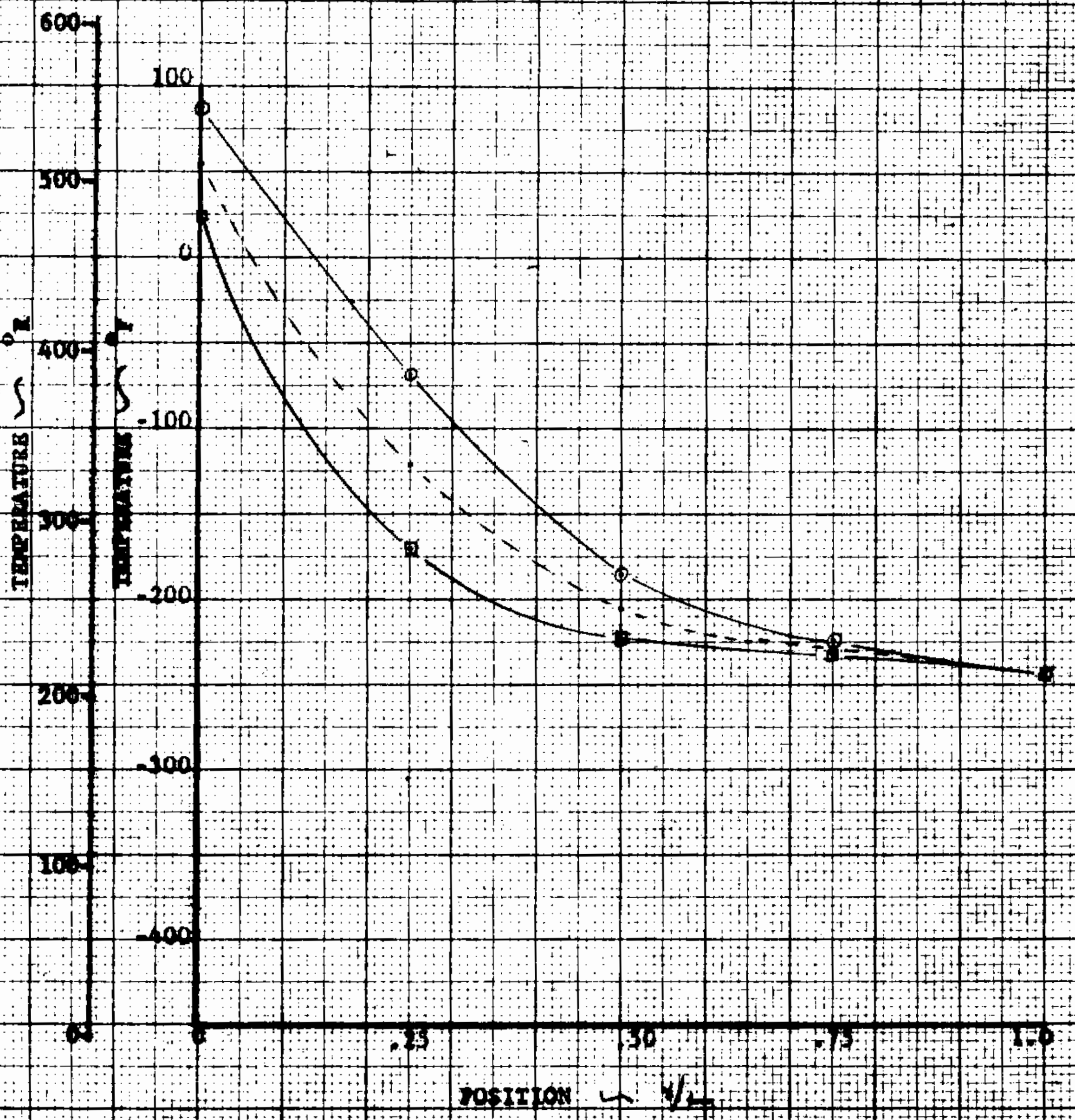
⊕ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



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TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST F-12

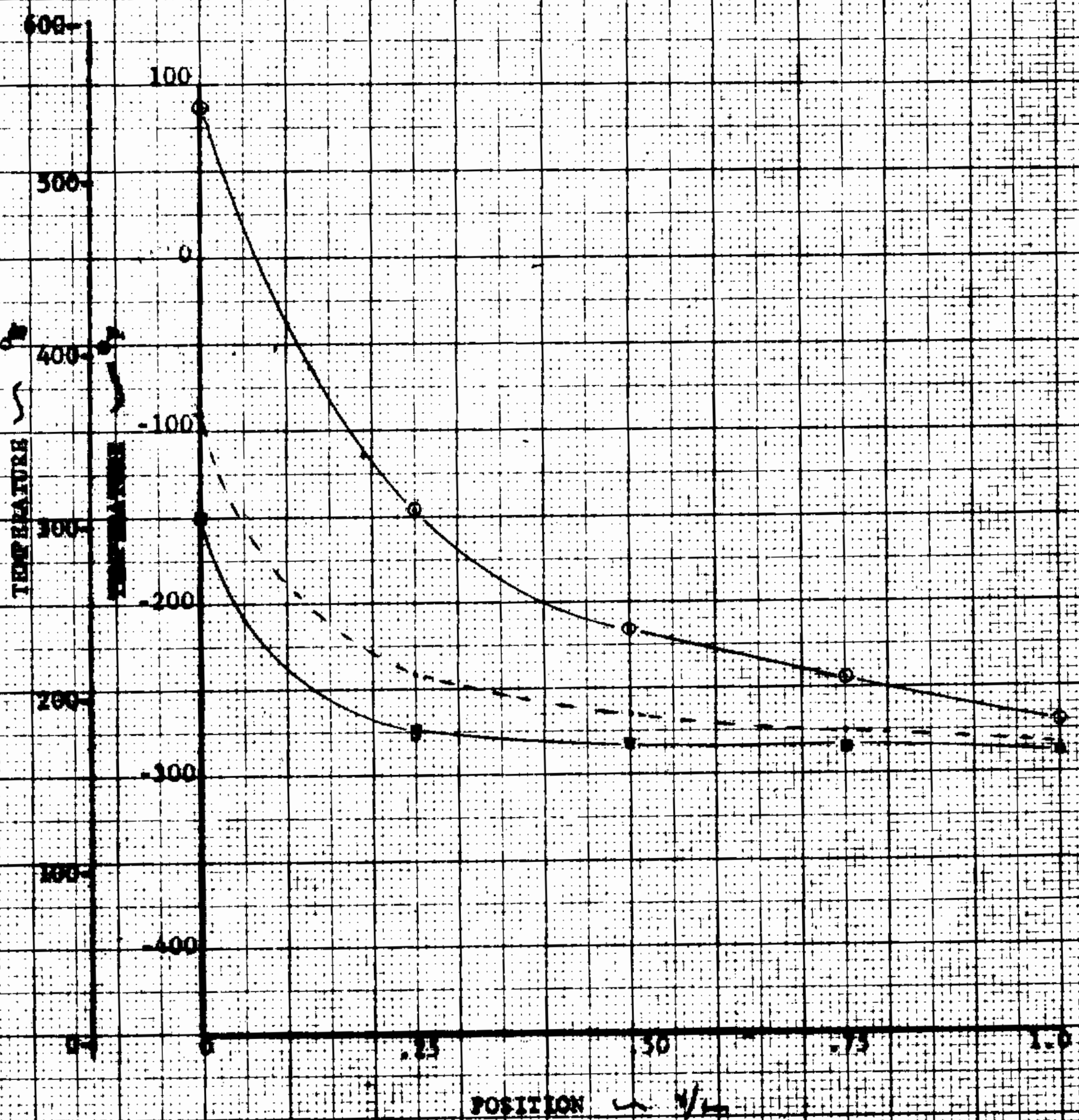
θ = 32 Min.

NOTES:

1. ~~Air temperature per core T/C (⊖ - symbol).~~

2. Coolant inlet and outlet temperature per measured values @ ~~T-108 and T-109 corrected for heat leak. (⊡ symbol).~~ Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-13

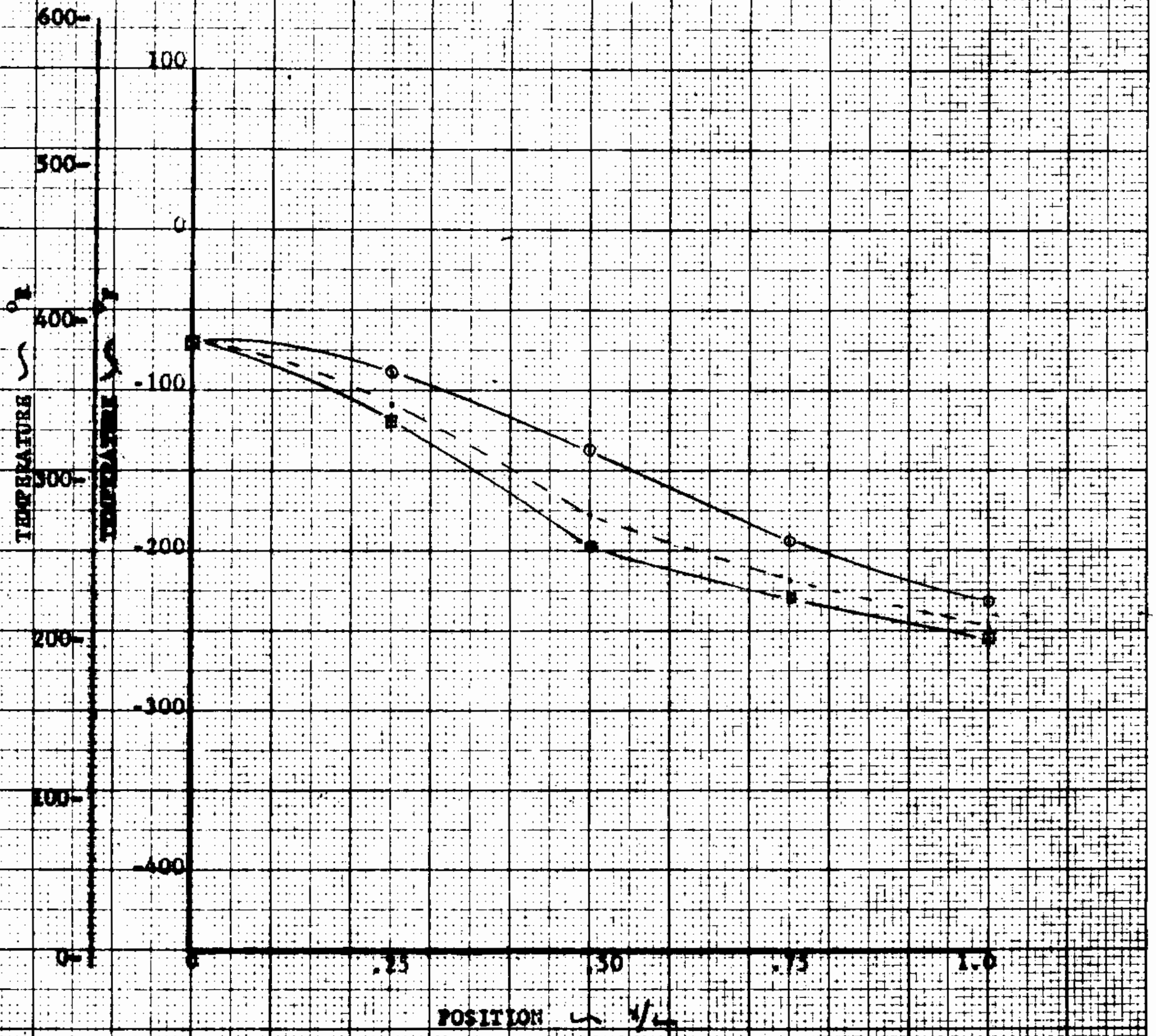
θ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-14

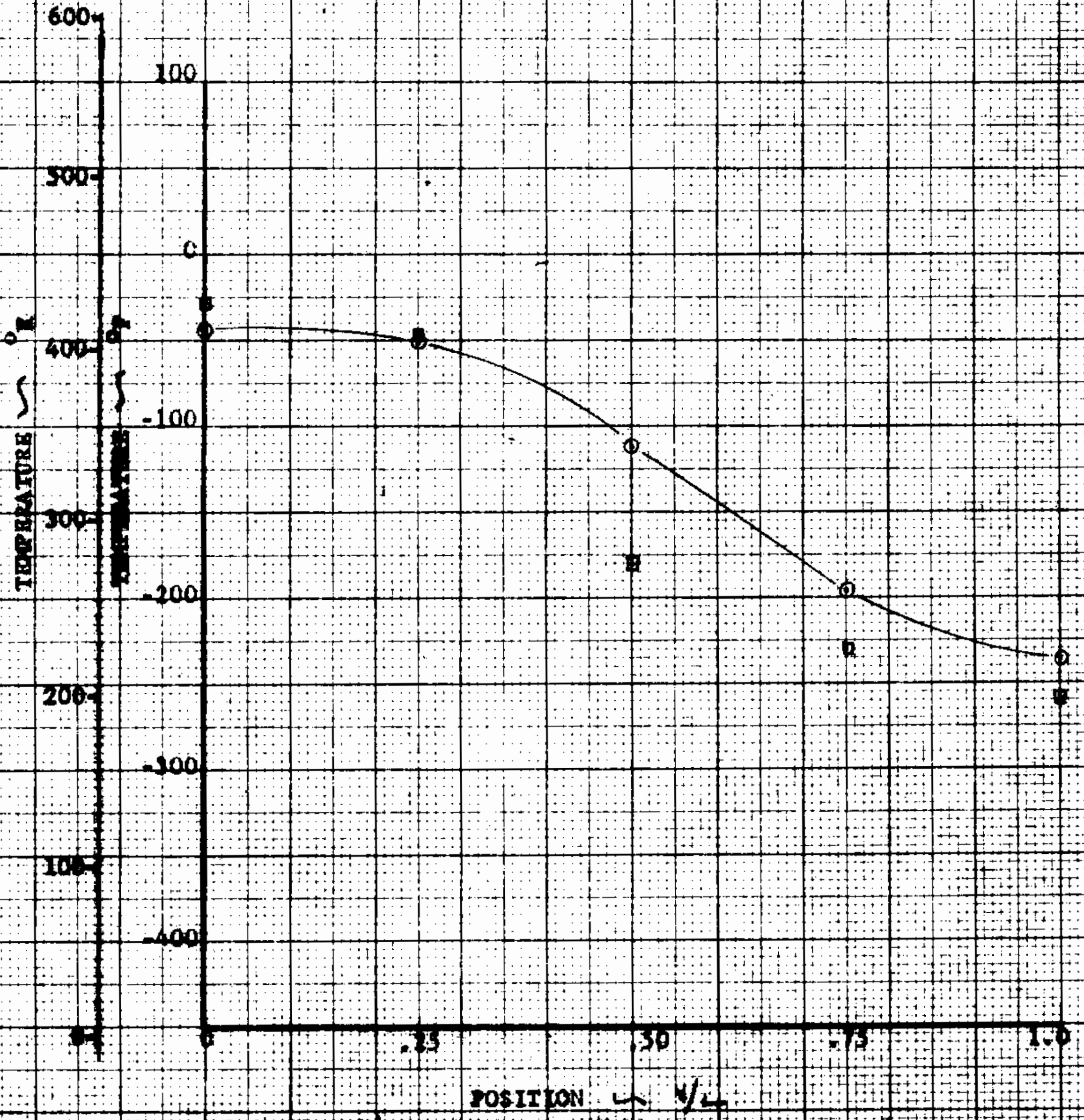
θ = 44 Min.

NOTES:

1. ~~Air temperature per core T/C (⊙ - symbol).~~

2. Coolant inlet and outlet temperature per measured values @ ~~T-108 and T-109 corrected for heat leak. (⊡ symbol).~~ Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-17

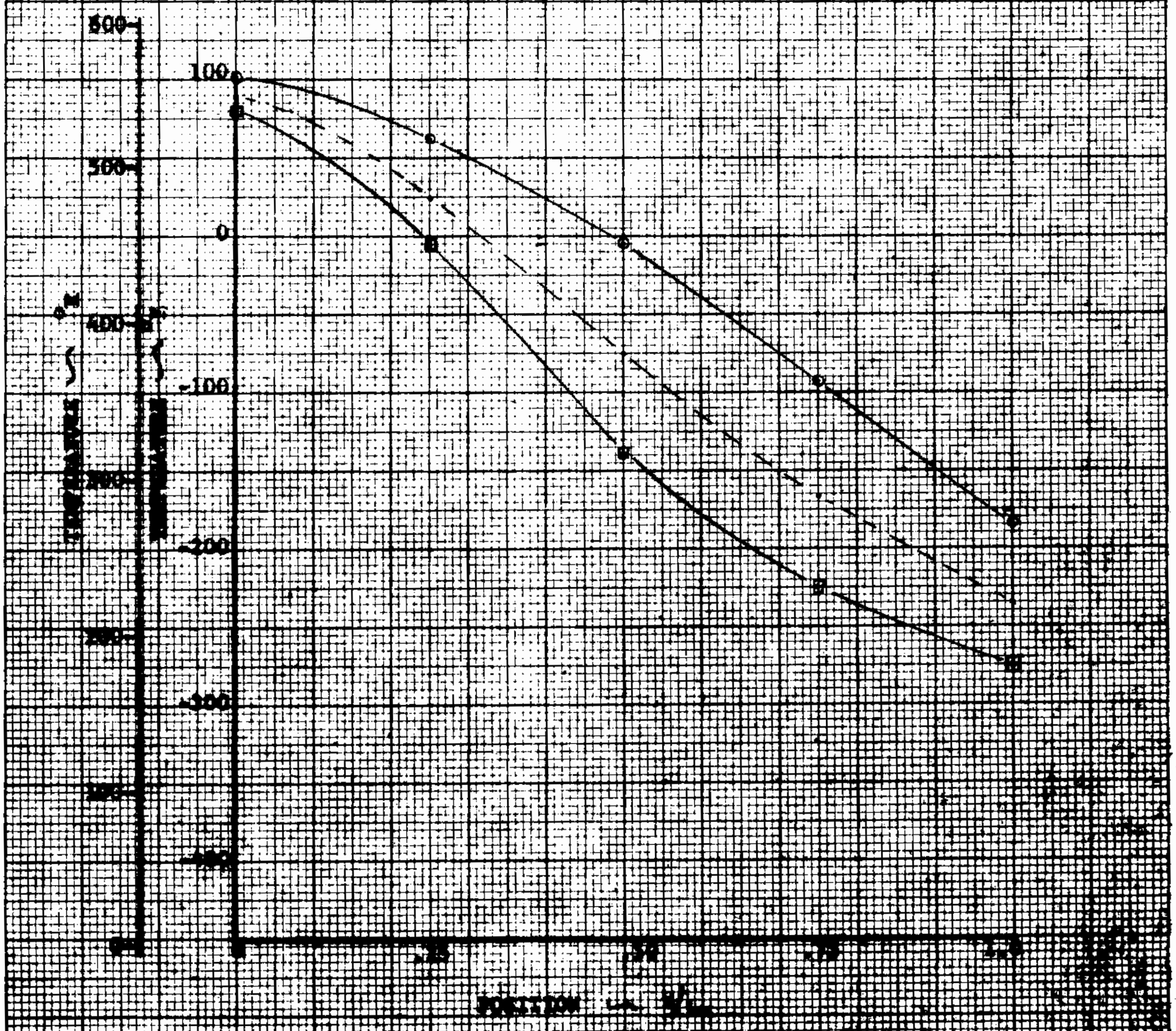
θ = 25 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



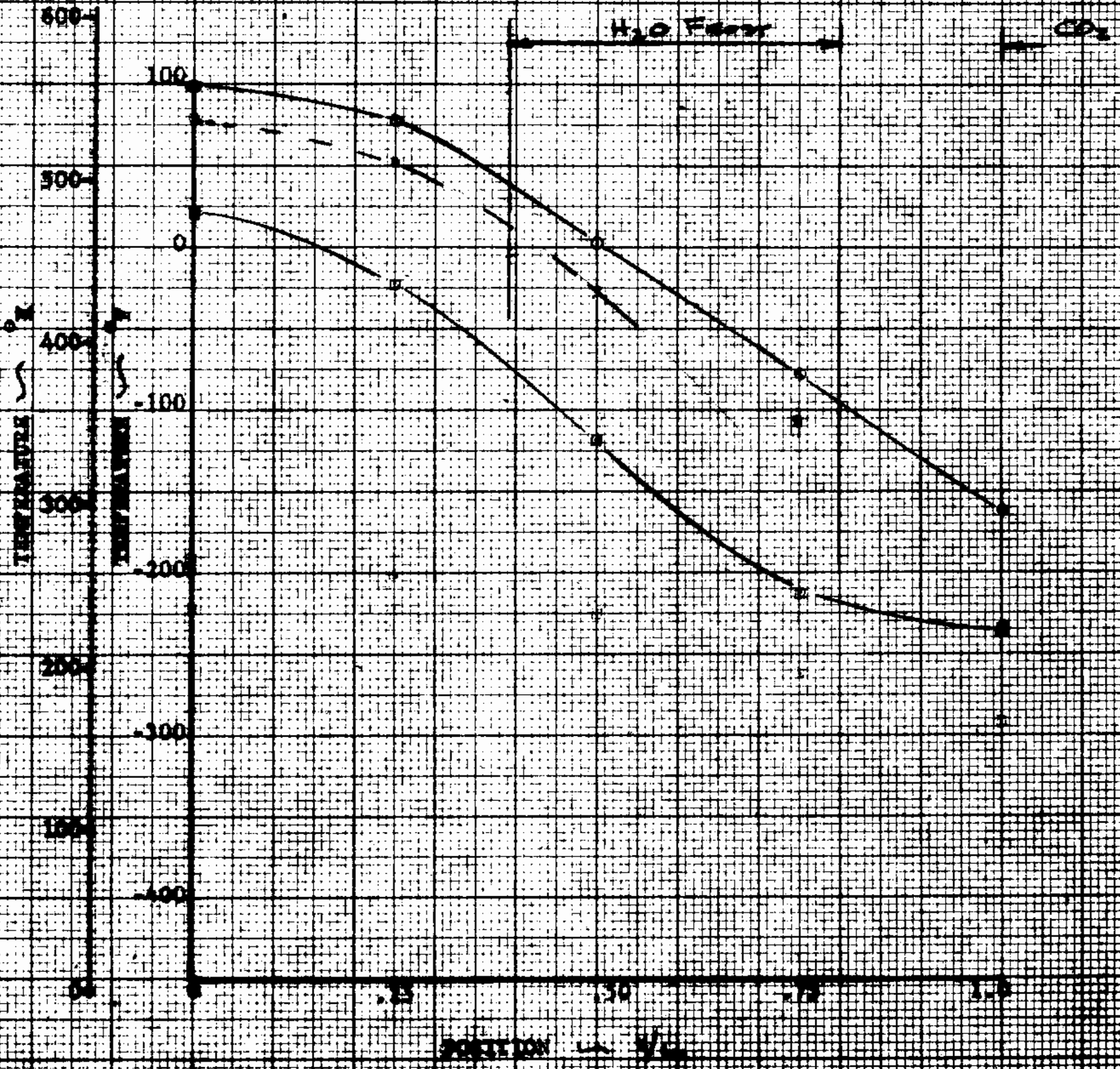
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST C-1

θ = 40 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



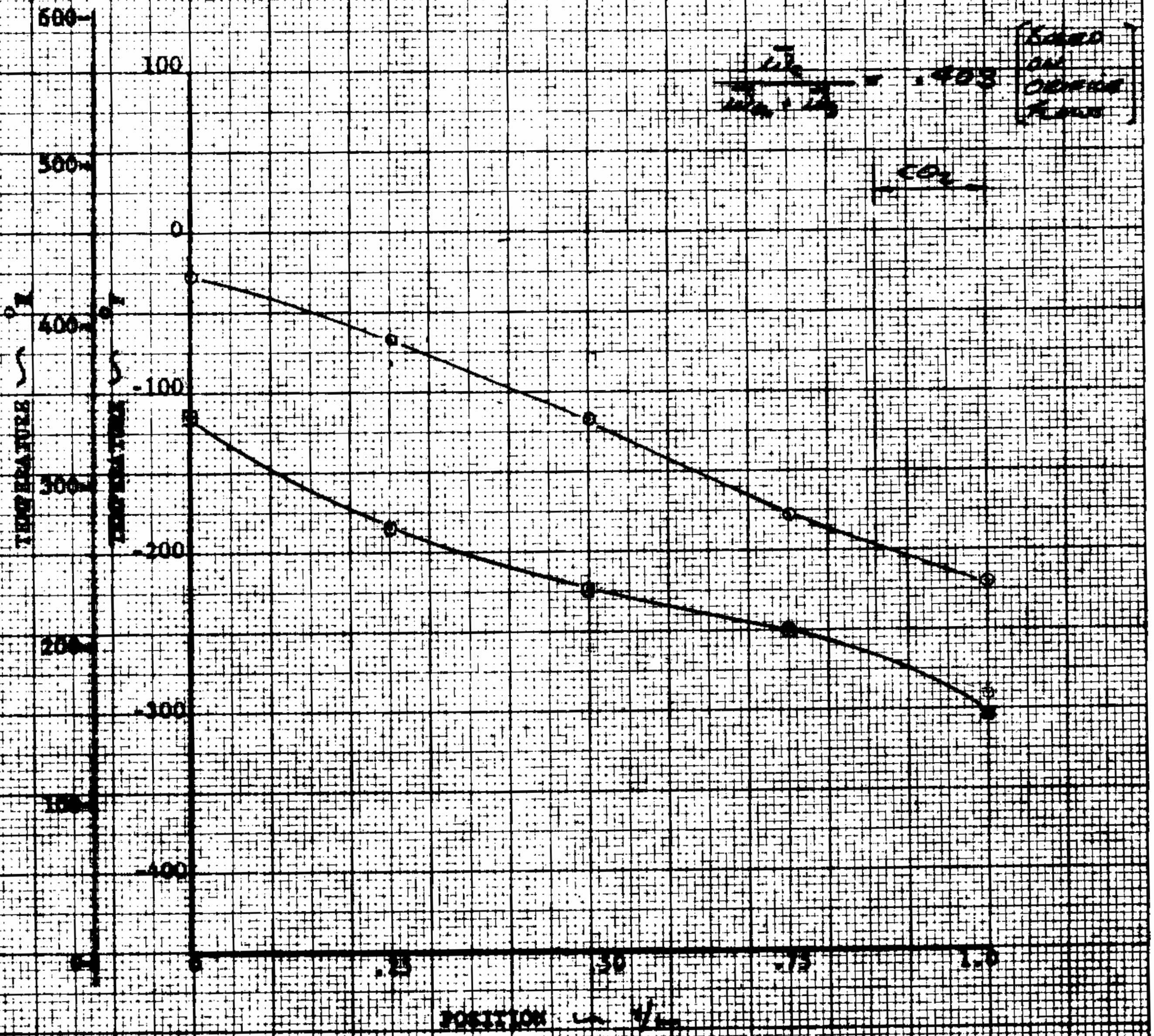
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST I-9

⊕ = 33 #/Min.

NOTES:

1. Air temperature per core T/C (⊕ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol); Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-3

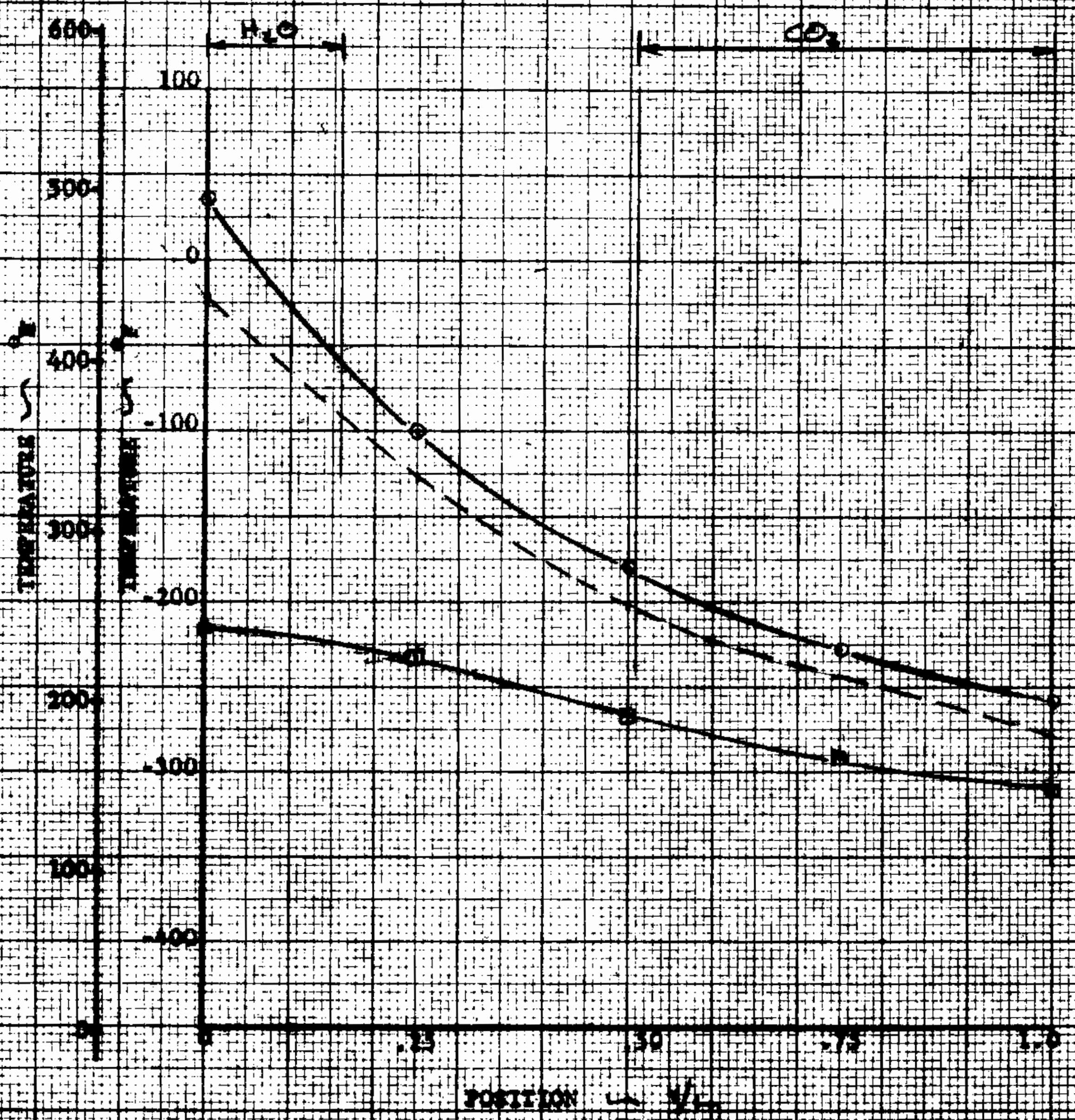
⊖ = 4/ Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).

2. Coolant inlet and outlet temperature per measured values T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST C-4

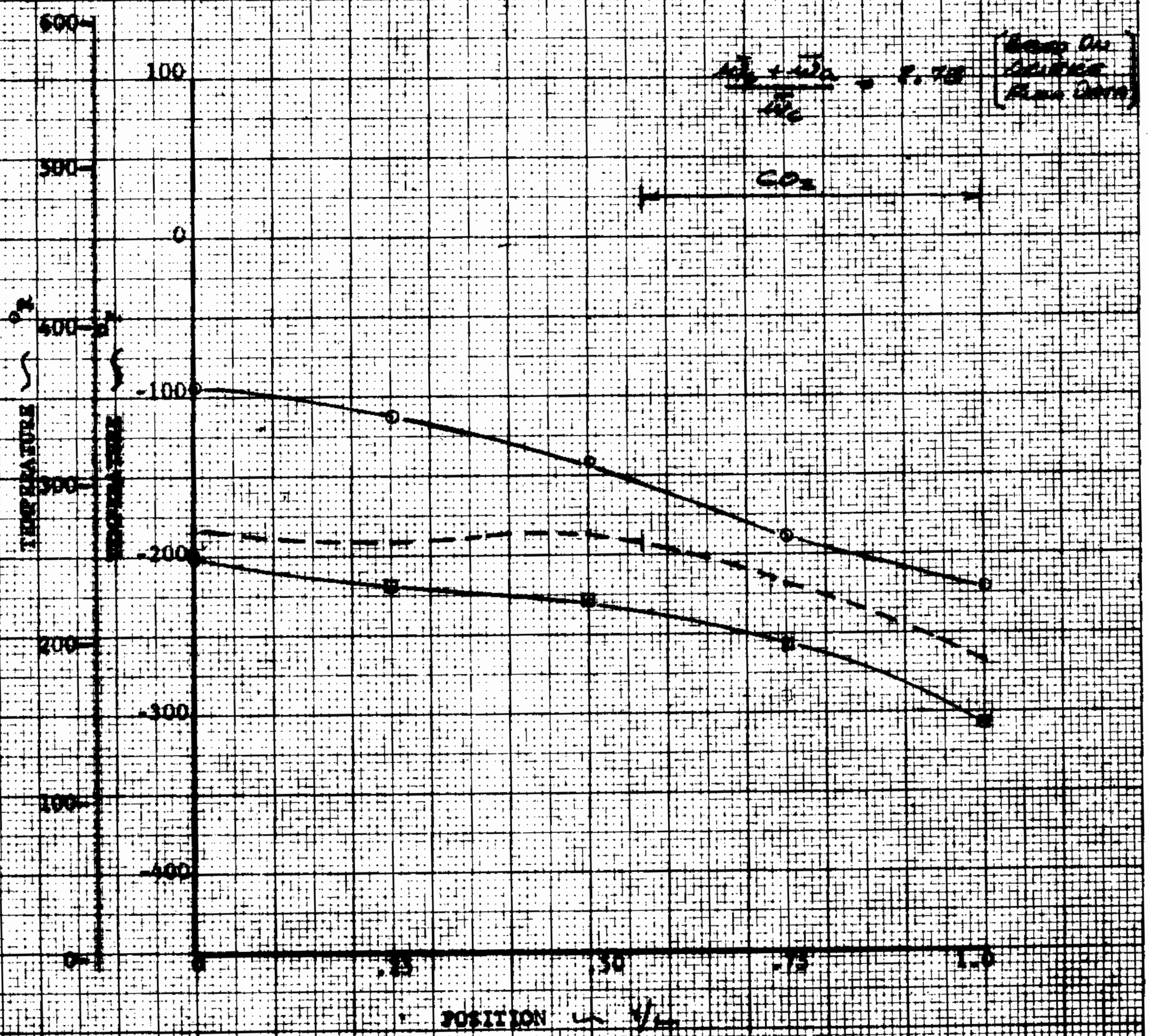
⊖ = 35 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST E-5

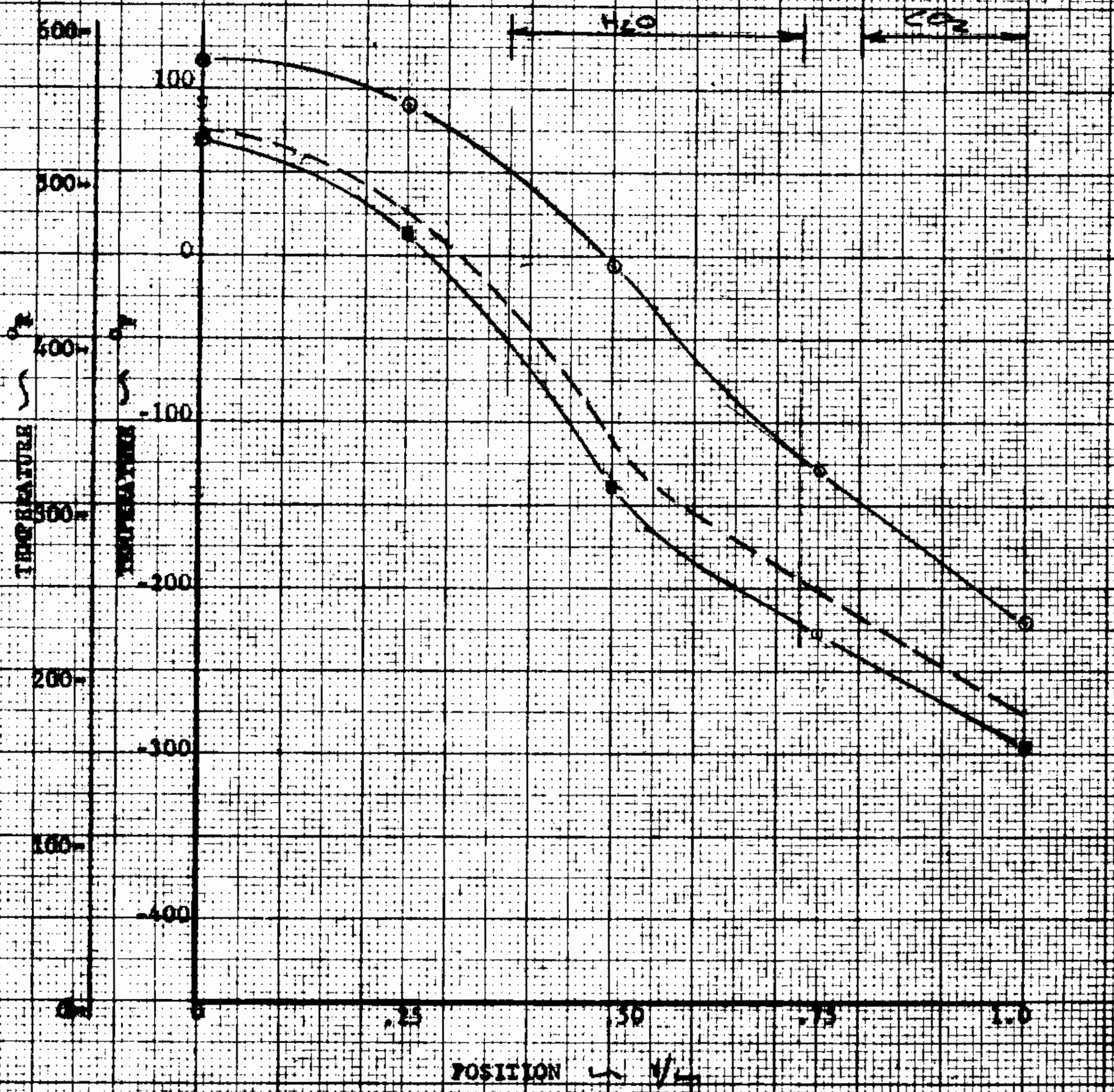
θ = 27½ Min.

NOTES:

1. Air temperature per core T/C (⊕ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



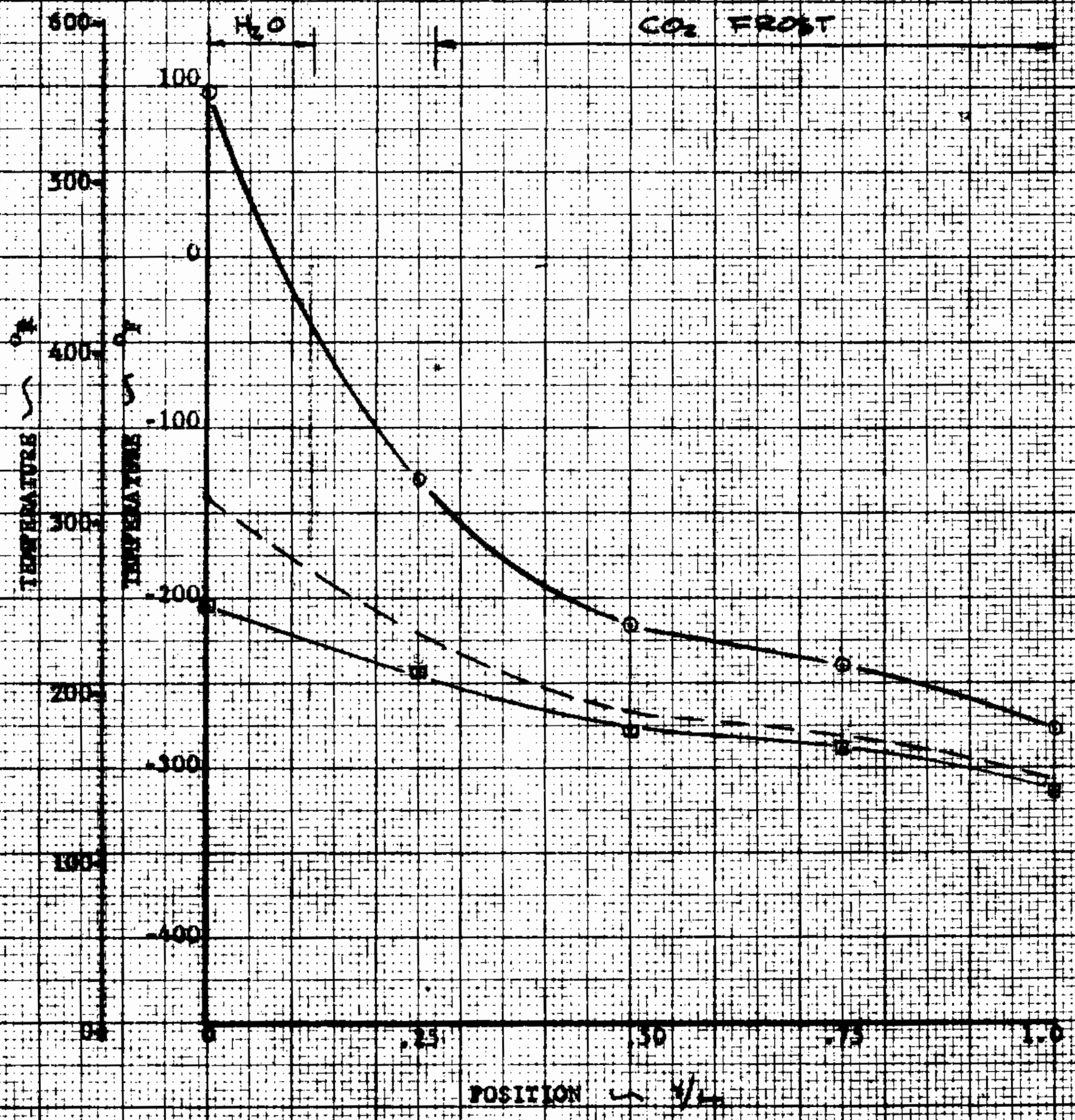
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST C-6

θ = 2.5 Min.

NOTES:

1. Air temperature per core T/C (⊙ – symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (□ – symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



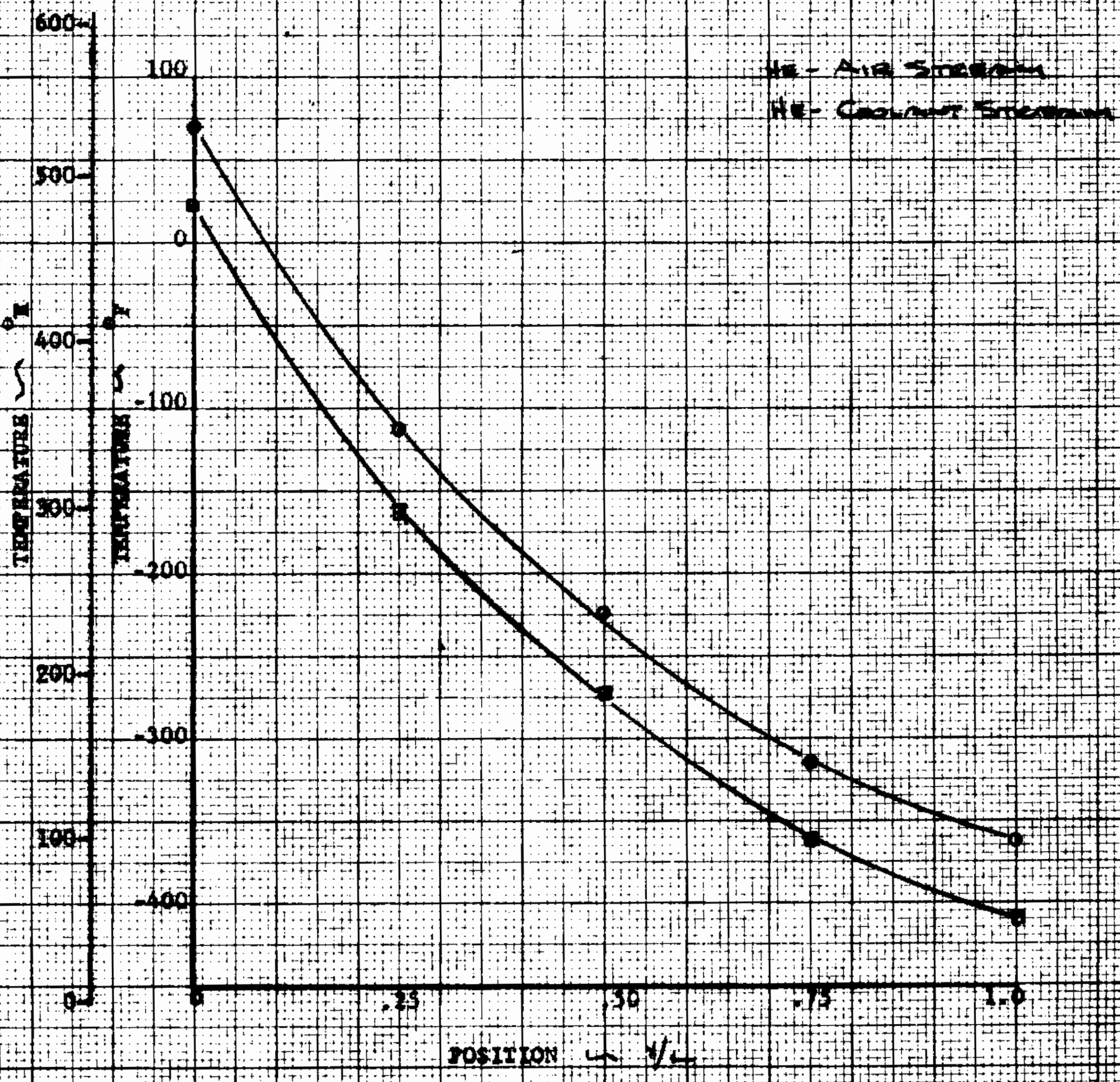
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST H-2

θ = 30 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



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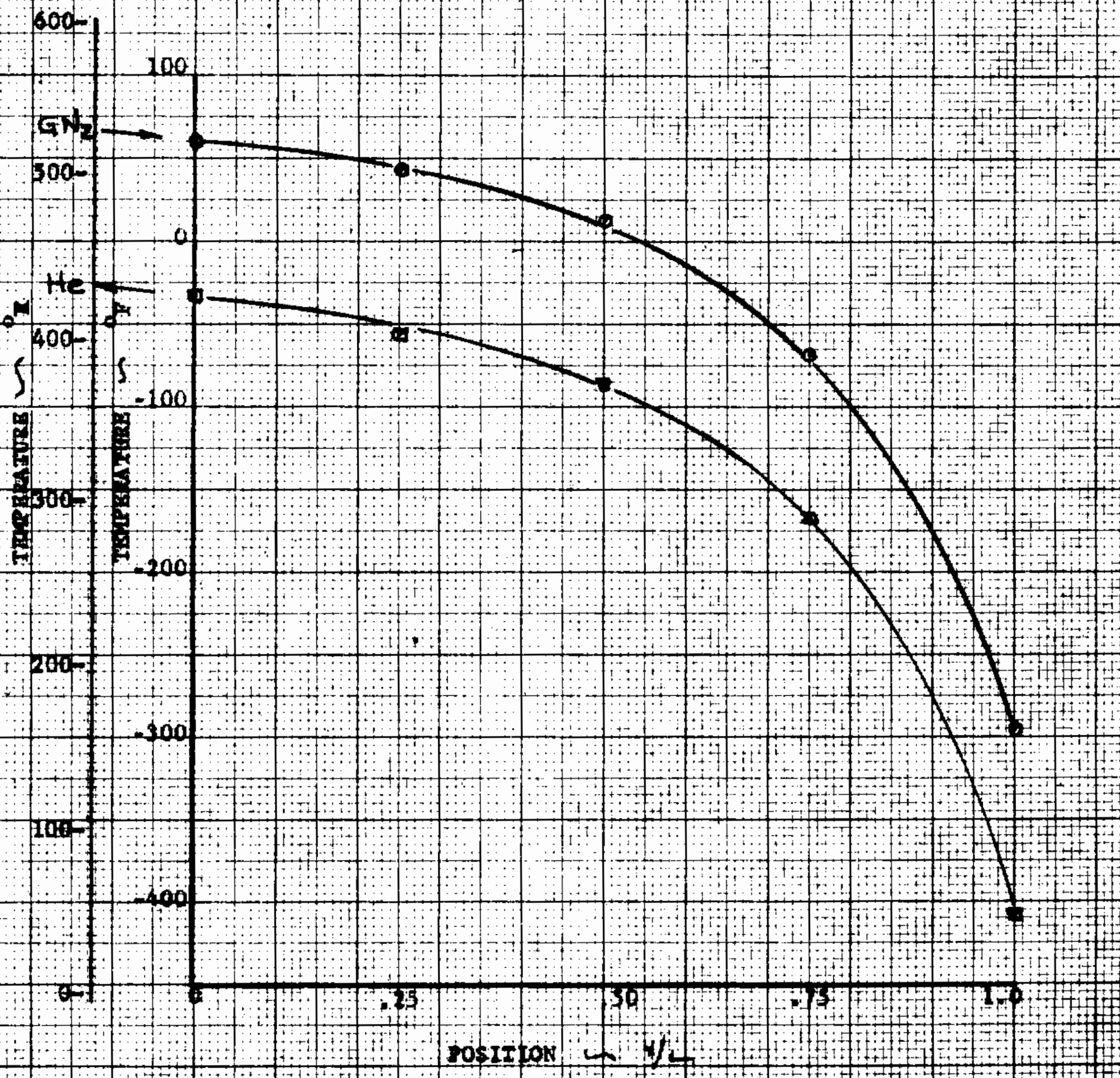
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

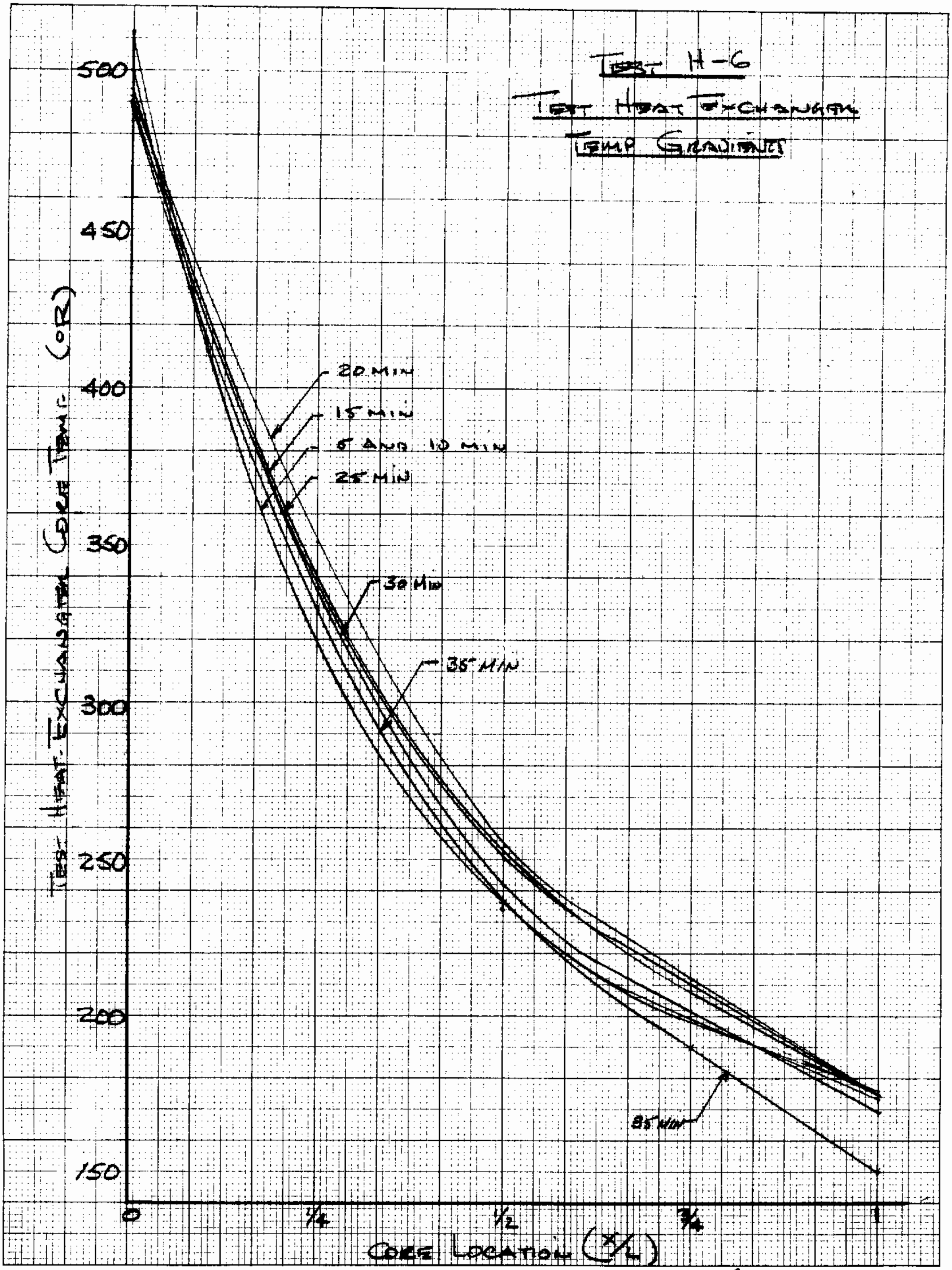
TEST H-3A

θ = 20 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.





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TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST V - 1

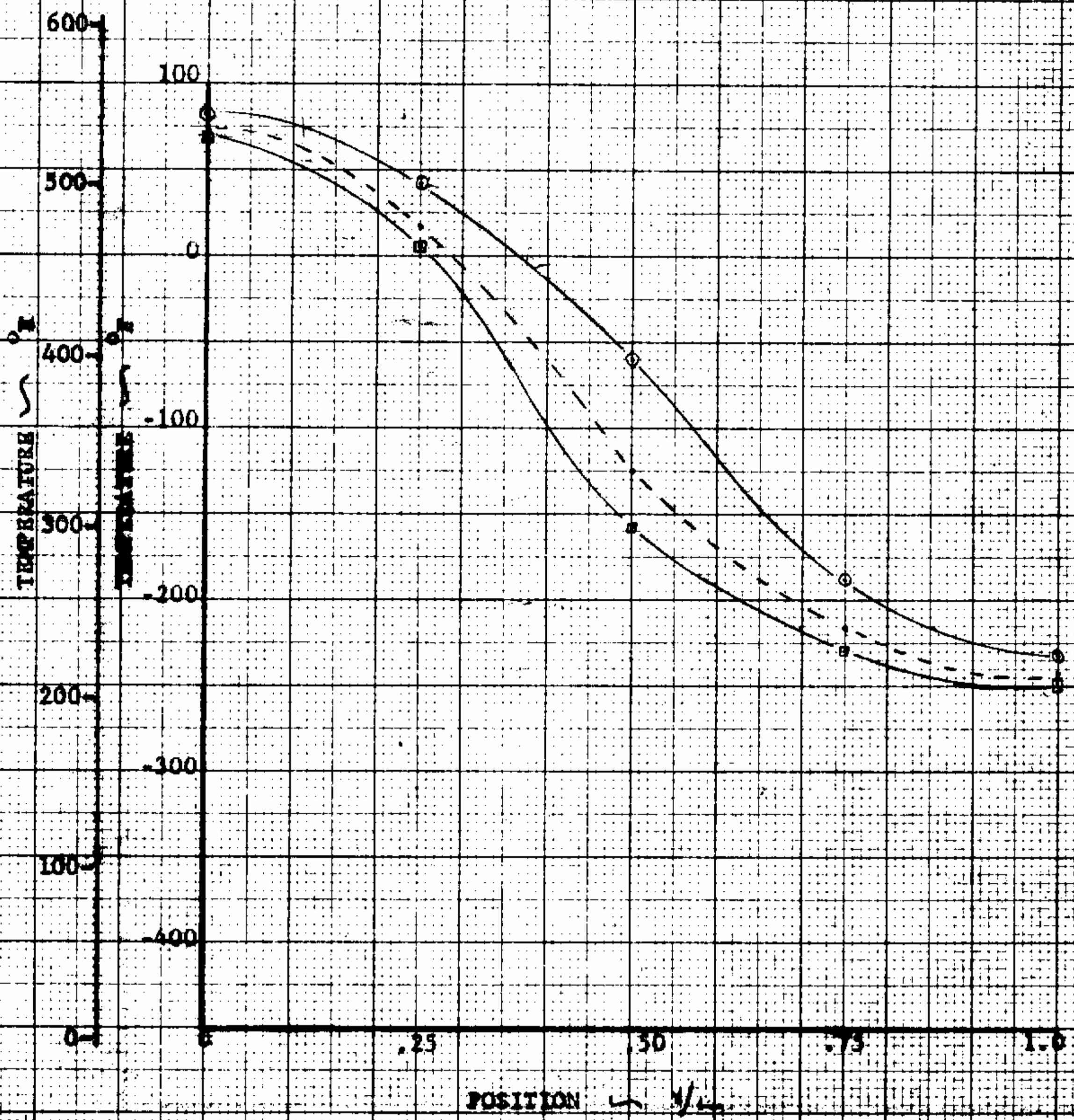
⊖ = 45 Min.

NOTES:

1. Air temperature per core T/C (⊖ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



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TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST V-2

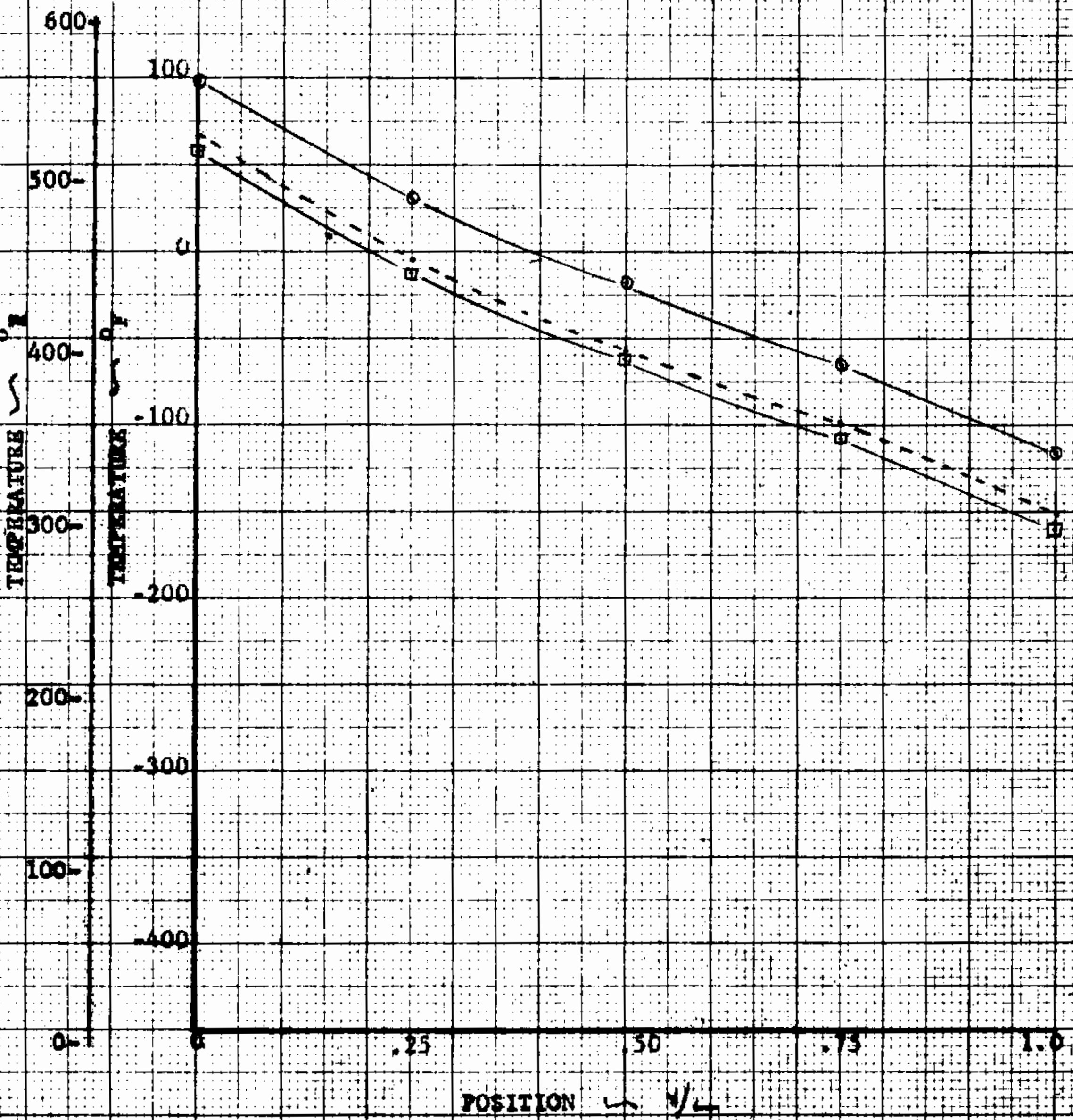
θ = 20 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



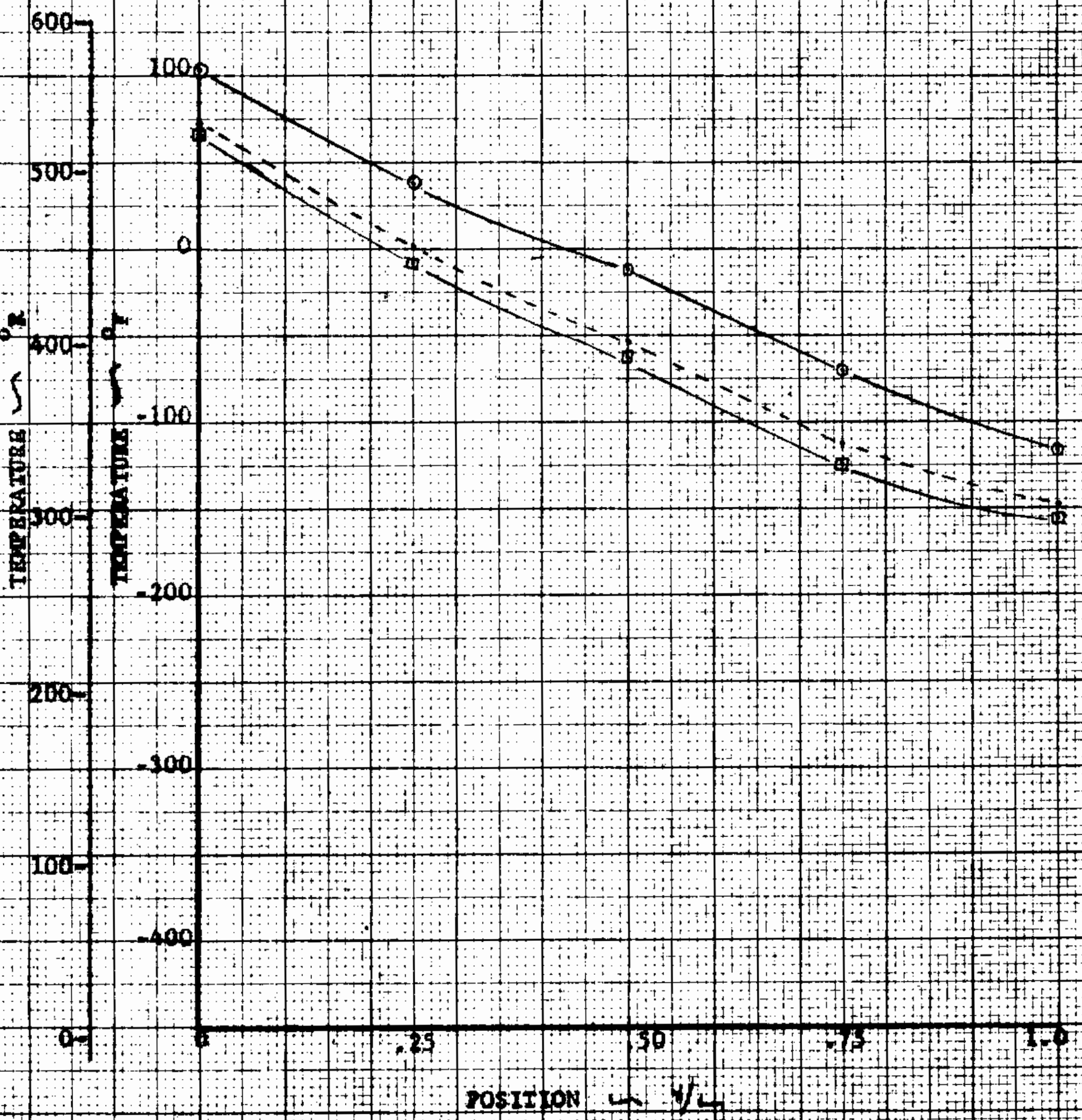
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST V-3

θ = 18 Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



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TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST V-4

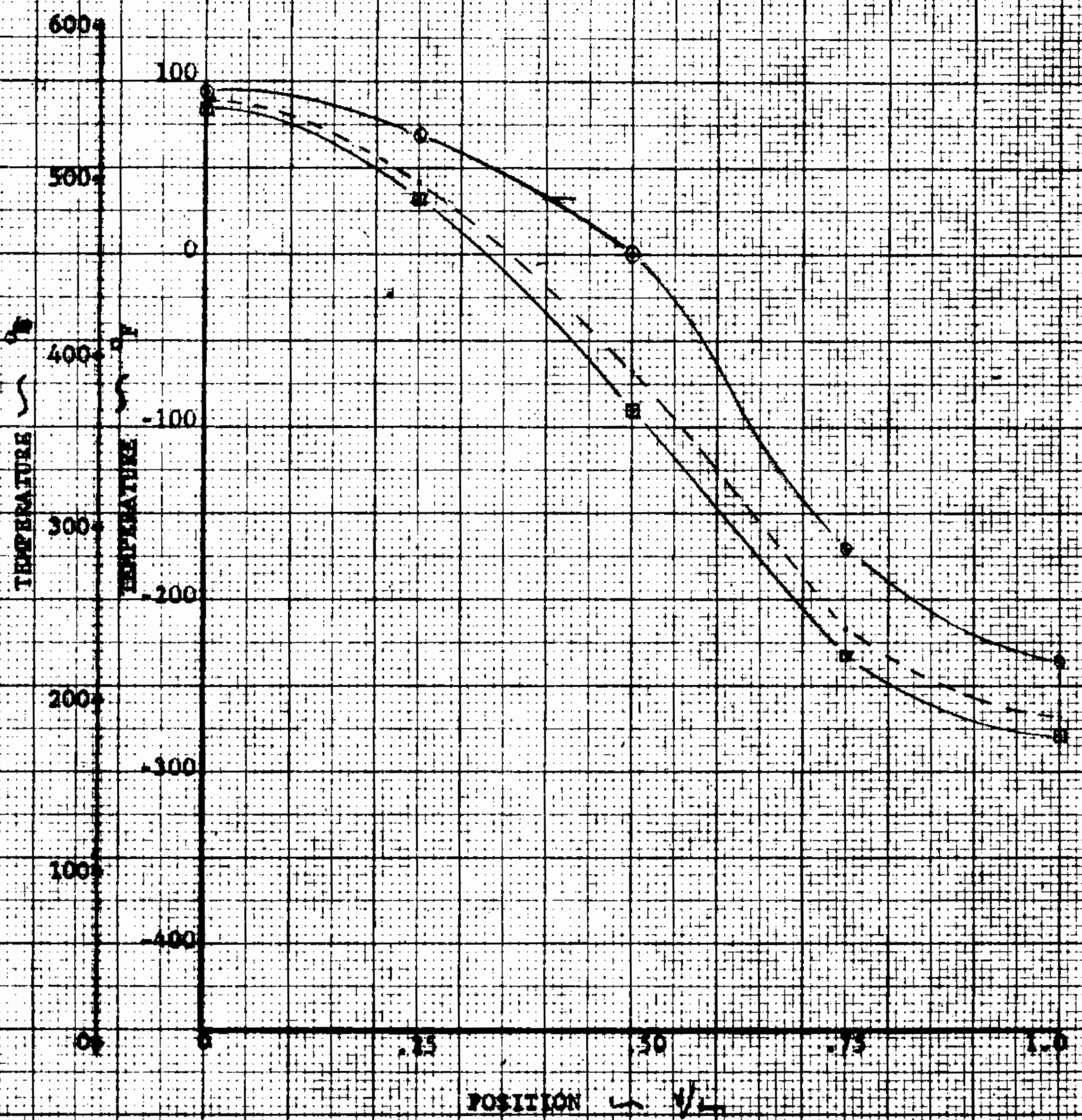
⊕ = 18½ Min.

NOTES:

1. Air temperature per core T/C (⊕ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊞ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



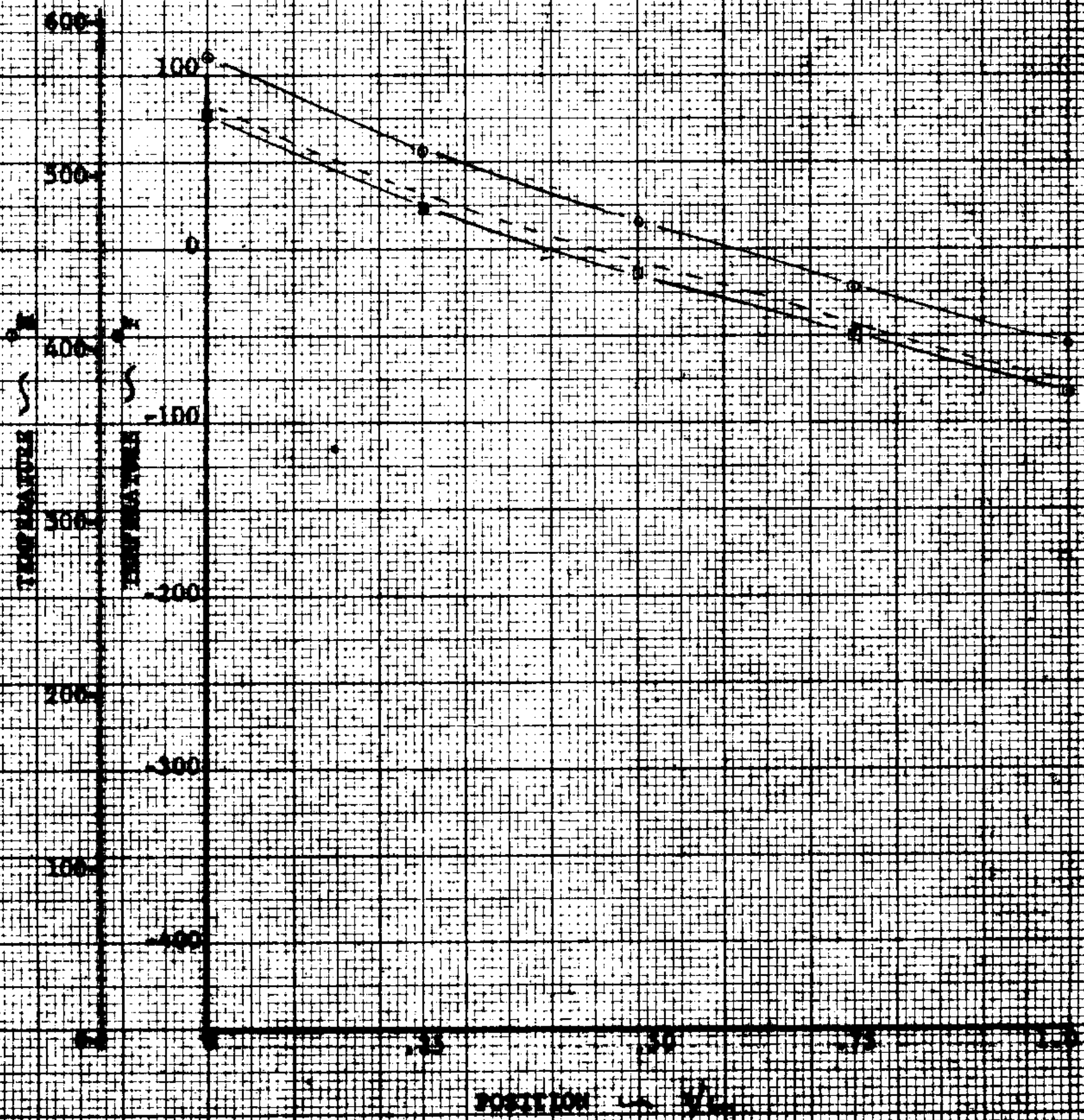
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST W-5

θ = 70 Min.

NOTES:

1. Air temperature per core T/C (⊕ - symbol).
2. Coolant inlet and outlet temperature per measured values T-108 and T-109 corrected for heat leak. (⊡ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



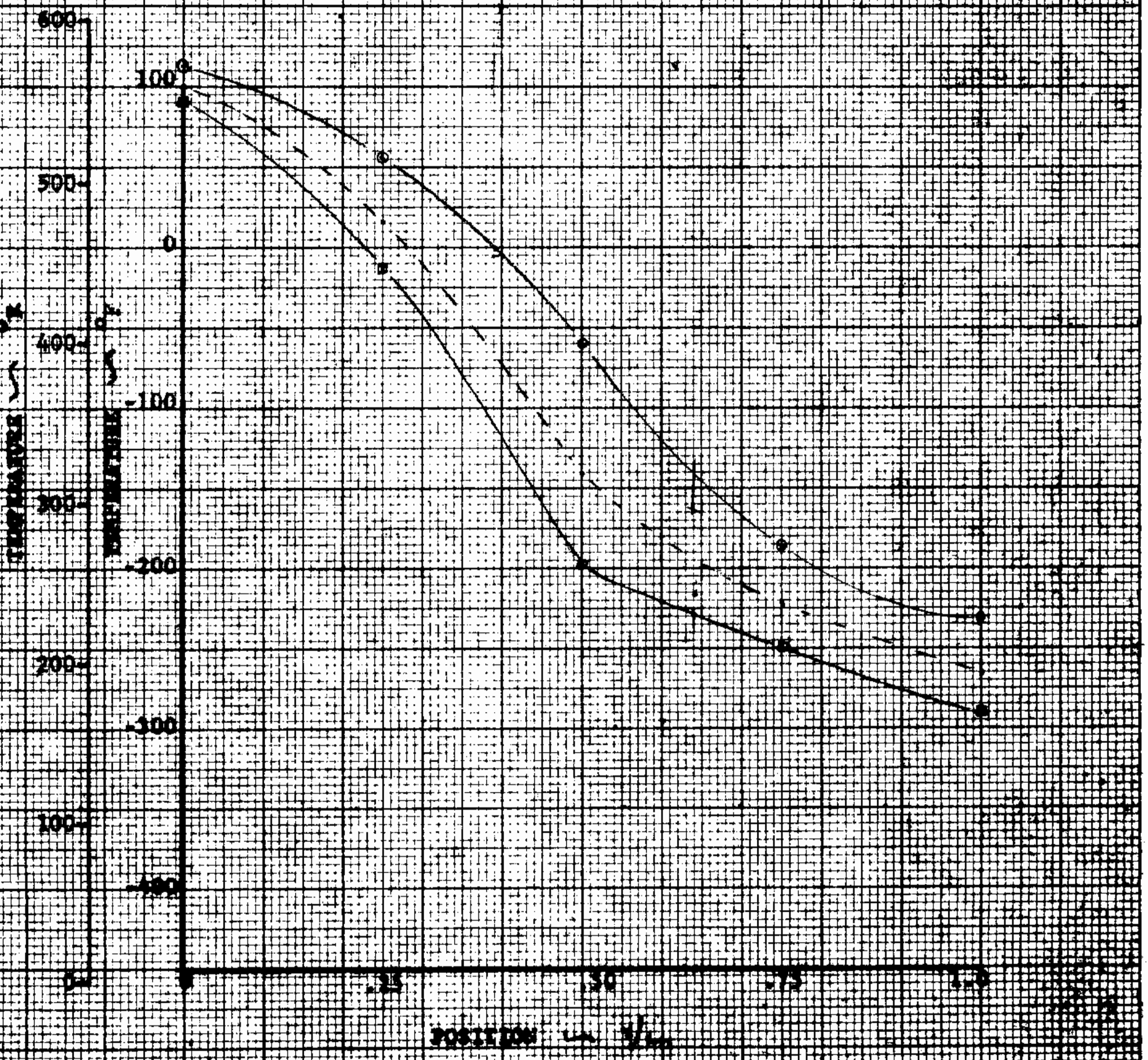
TEST HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST W-7

⊖ = Min.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).
2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.
3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



BY: *M. Katos* DATE: *12/26/62* PAGE 3[illegible] OF [illegible]

ASD/EXPERI 64607

TEST HEAT EXCHANGER
A[illegible] TEMPERATURE GRADIENTS

TEST [illegible] - [illegible]

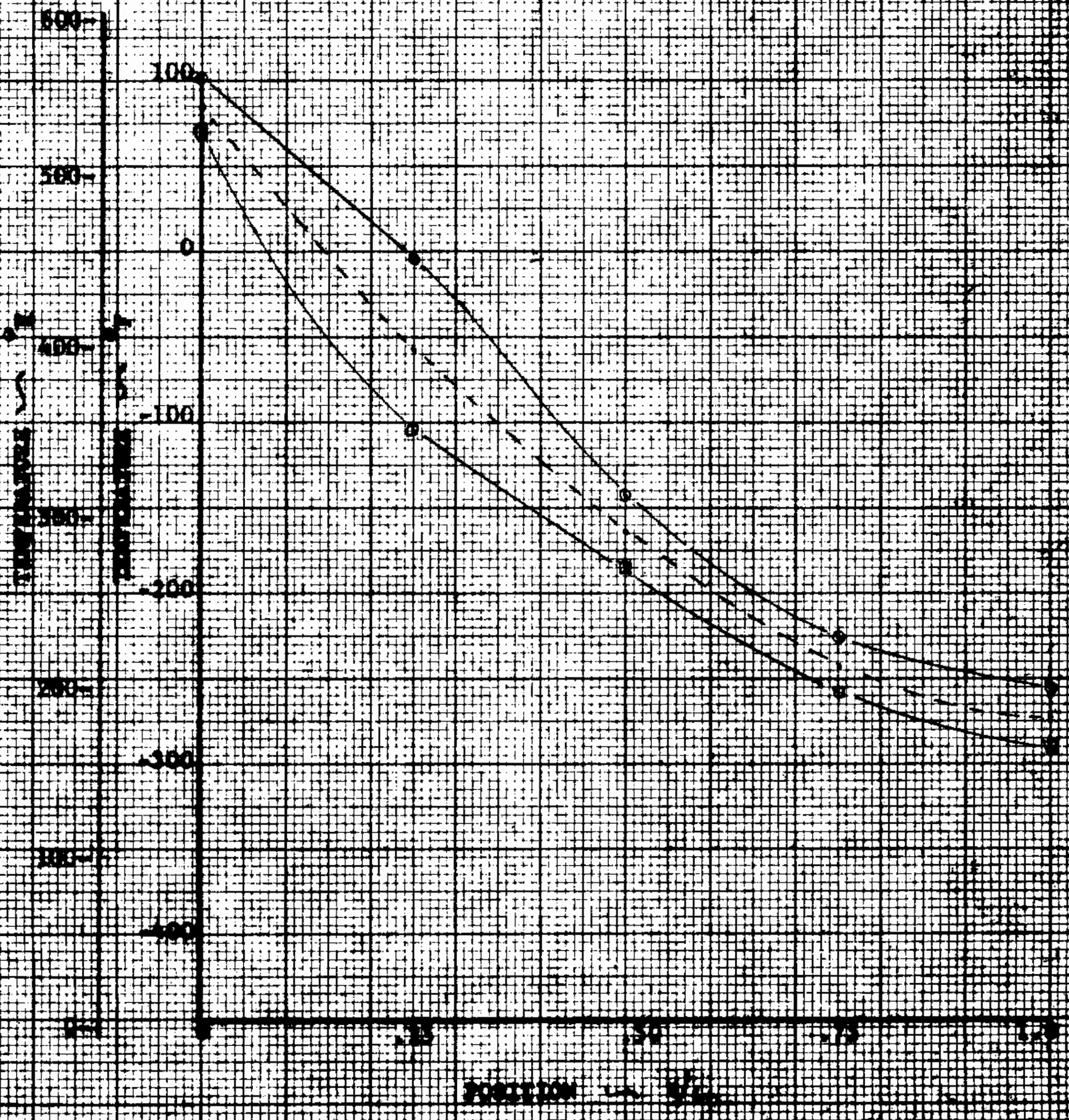
⊖ = *50* MIN.

NOTES:

1. Air temperature per [illegible] (⊙ - [illegible]).

2. Coolant inlet and outlet temperature per [illegible] values [illegible] T-108 and T-109 corrected for heat [illegible] ([illegible]). Intermediate coolant temperatures [illegible] by [illegible] balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of [illegible] transfer temperature differentials on the air and coolant [illegible].



[illegible] HEAT EXCHANGER
AXIAL TEMPERATURE GRADIENTS

TEST K-2

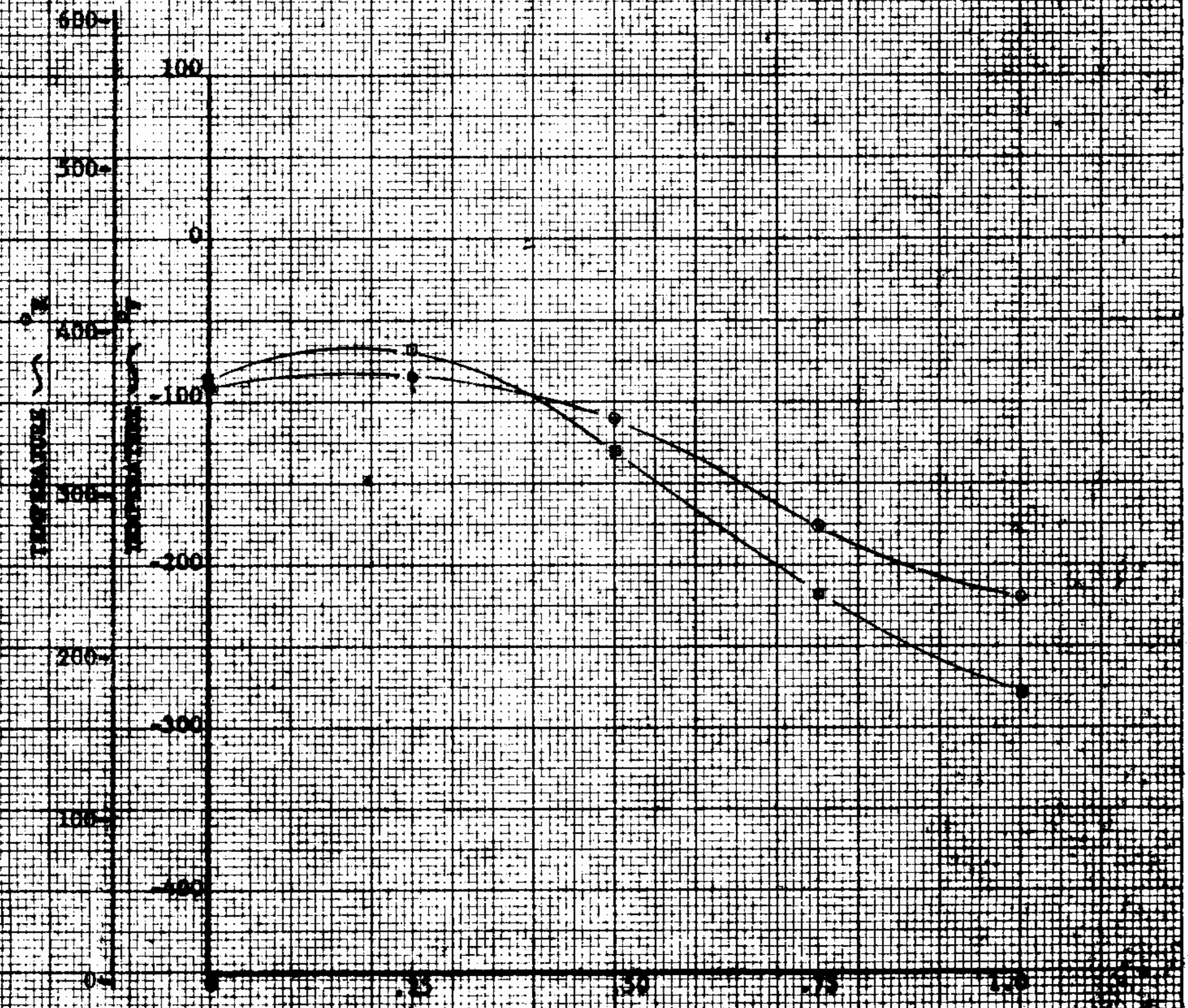
θ = 35 MIN.

NOTES:

1. Air temperature per core T/C (⊙ - symbol).

2. Coolant inlet and outlet temperature per measured values @ T-108 and T-109 corrected for heat leak. (⊡ - symbol). Intermediate coolant temperatures apportioned by enthalpy balance between air and coolant streams.

3. Wall temperature point locations by computed ratio of heat transfer temperature differentials on the air and coolant sides.



POSITION — X/L