DIVISION OF ENGINEERING RESEARCH

LSU/MTF

REPORT

RESEARCH FACILITIES FOR THE MEASUREMENT OF THE
MA-3 ATLAS VERNIER ENGINE PLUME PROPERTIES

LOUISIANA
STATE
UNIVERSITY

COMPONENTS SERVICE FACILITIES

COMBUSTION LABORATORY

MISSISSIPPI TEST FACILITIES

Report on the

Research Facilities for the Measurement of the MA-3 Atlas Vernier Engine Plume Properties

by

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ACKNOWLEDGEMENTS

The senior author wishes to acknowledge the assistance of Mr. Jim Coward, Mr. Boyce Mix and Dr. Dave Johnson of NASA/MTF, the support personnel of G.E. and Mr. John Witherspoon of NAR for making the establishment of this Combustion Laboratory a reality.

SUMMARY

Building 8110 of the Compnents Service Facilities at NASA's Mississippi Test Facilities houses a most complete array of hardware making it a complete and modern combustion laboratory.

The facilities include engine, probe, control panels, gas analysis and a data acquisition system; all of them already installed and in ready condition to perform tests. These facilities have already been used; the MA-3 Atlas Vernier Engine used for these experiments has been fired five times and in the last three experiments all hardware available was used. All systems performed flawlessly with the exception of the probe. Negotiations are taking place in order to obtain a sturdier probe.

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INTRODUCTION

Due to the great interest in space travel in the last decade, the state of the arts in rocketry is today so advanced that we are able to send to and bring back men from the moon. Even though most of the field in rocketry has been thoroughly researched, certain areas lag behind to an extent where little is known about them. One of these little understood areas is the physical phenomena involved in the combustion of rocket propellants. An understanding of these physical phenomena is needed in order to make proper design calculations.

The purpose of the Combustion Laboratory is the study of the physical phenomena involved in the combustion of rocket propellants. All the necessary equipment is already installed in Building 8110 at the Mississippi Test Facilities, Bay St. Louis, Miss. The objective of this report is to familiarize the reader with these facilities and with the state-of-the-art in plume measurements.

FACILITIES

Building 8110, or the Components Service Facilities Complex, houses a very complete array of hardware which makes the study of the physical properties of the MA 3 Vernier Engine plume an almost easy task. The facilities are ready for usage. Five tests have already been performed (See Table 1).

Engine

The engine available for studies is the MA 3 Atlas Vernier Engine. This engine is manufactured by North American Rockwell, Rocketdyne Division.

TABLE I

MA-3 Vernier Engine Tests

Test Number	Date	Use of Probe	Comments
3090-10		NO	Test stand checkout.
3090-11	10/21/69	NO	Test stand checkout.
3093-12	12/2/69	YES	Vibration caused the valve controlling flow of probe coolant to shut off. Test had to be aborted.
3093-13	3/2/70	YES	Leaks developed on the probe, presumably late on the test. Early data looked reasonable and is used on sample calculation. A gas sample could not be taken as the filters on the sample bottles were crushed and blocked the flow.
3093-14	5/18/70	YES	Leaks developed on the probe. It is suspected that the orifice valve did not open during the test rendering the data unuseable. However, good gas samples were obtained results are shown in Table III.

The engine to be used in this study has been mounted and all connections necessary have been made (See Figures 1 and 2). The fuel used was JP-5 with liquid oxygen as oxidizer. Geometrical details of the engine are shown in Figures 3a and 3b which is taken from reference 1.

The mounted engine is located in cell 309 of Building 8110 (See page 10). The engine is operated from the control panel shown in Figure 4.

Building

The Combustion Laboratory is located in Building 8110 which is part of the Components Service Facilities Comples. Building 8110 (See Figure 5) has two main rooms inside and five outside test cells. The small inside room, adjacent to cells 309 and 310 houses the rocket engine control panel. There is a small observation window between cell 309 and this room. The large inside room contains a part of the data acquisition system.

Cell 308 contains a 200 gallon, 2000 psia rated liquid oxygen tank and a high pressure water tank. The high pressure water tank is used in the cooling system of the enthalpy probe. Cell 309 has the mounted MA-3 Atlas Vernier engine and the transversing mechanism with the probe. Cell 310 contains a 200 gallon 2000 psia rated fuel tank. Hydrogen tanks are located outside of the building. See Fig. 6.

Data Acquistion System

A most complete data acquisition system is available to record data from the experiments performed on the MA-3 Atlas Vernier Engine.

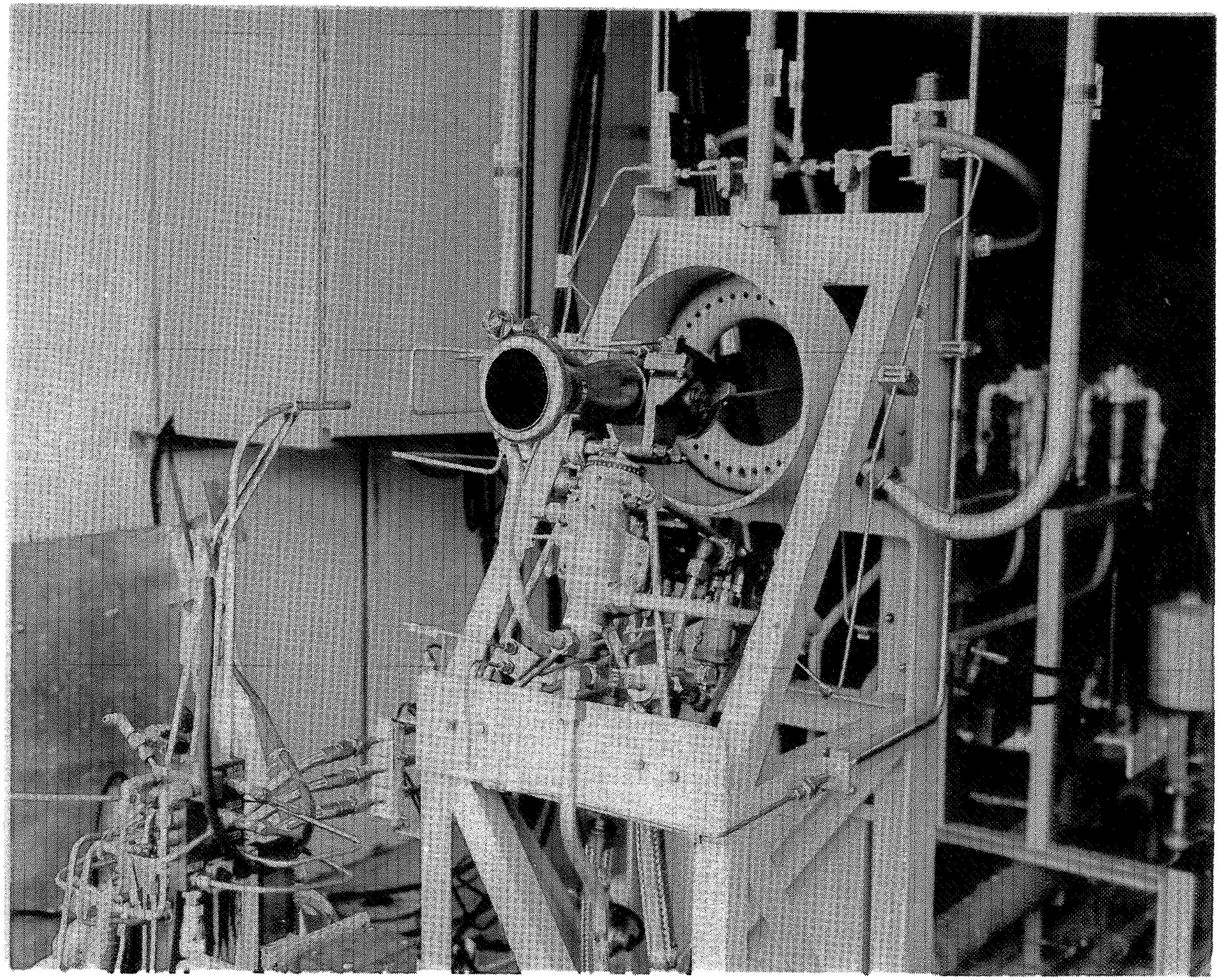


Figure 1. Mounted MA-3 Atlas Vernier Engine and Enthalpy Probe

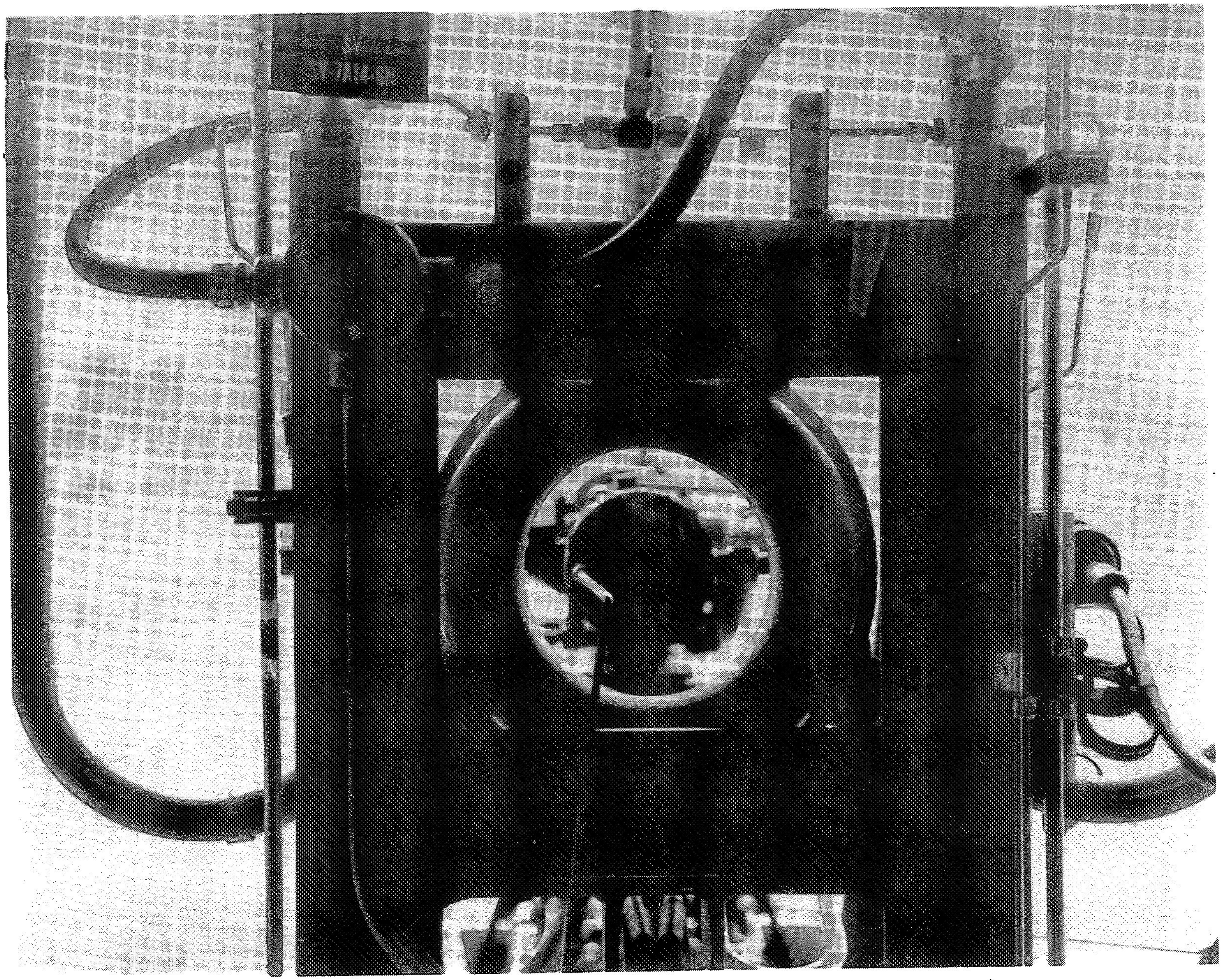


Figure 2. Back View of Vernier Engine

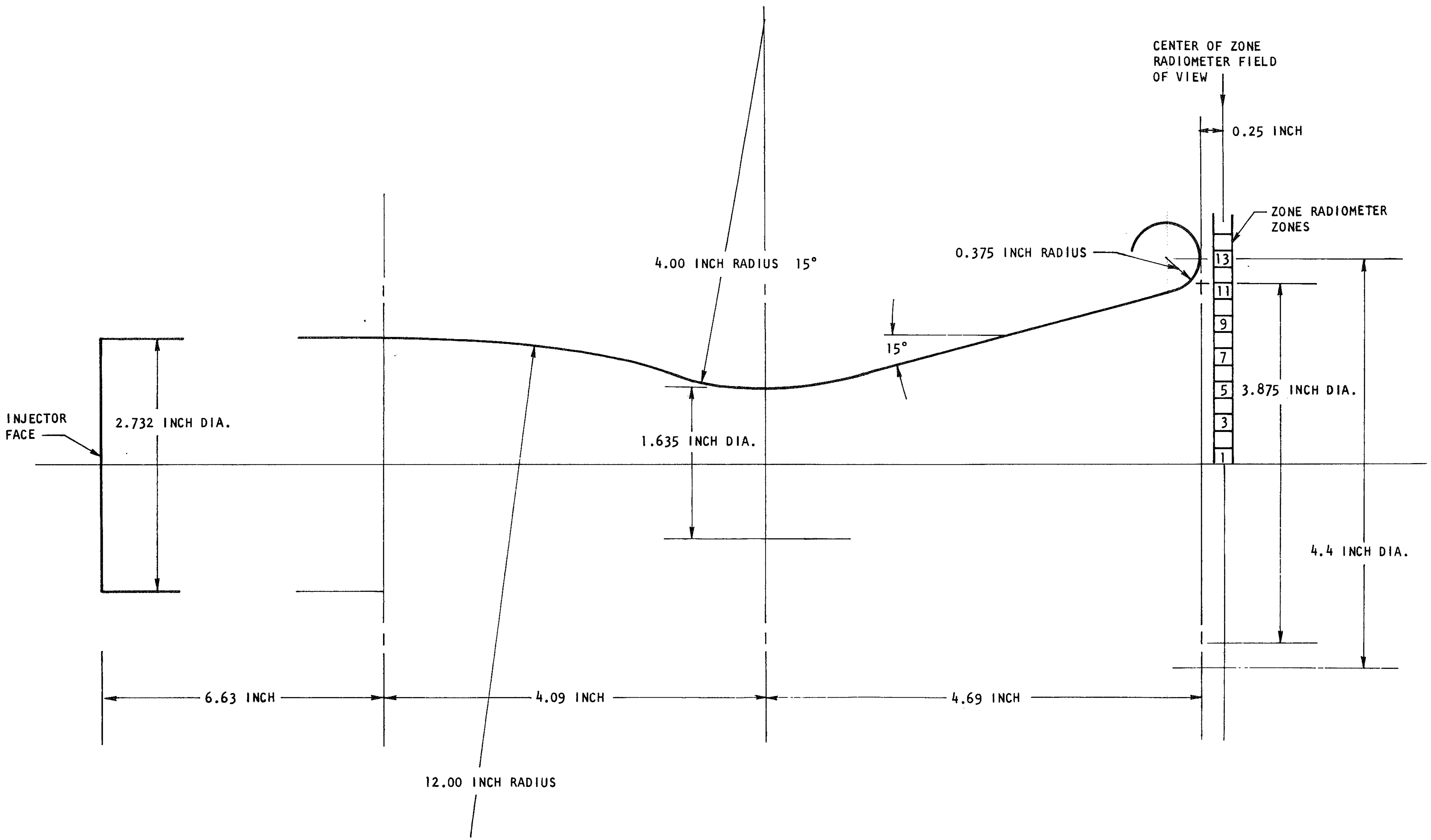


Figure 3a. Dimensions of Atlas Vernier Engine

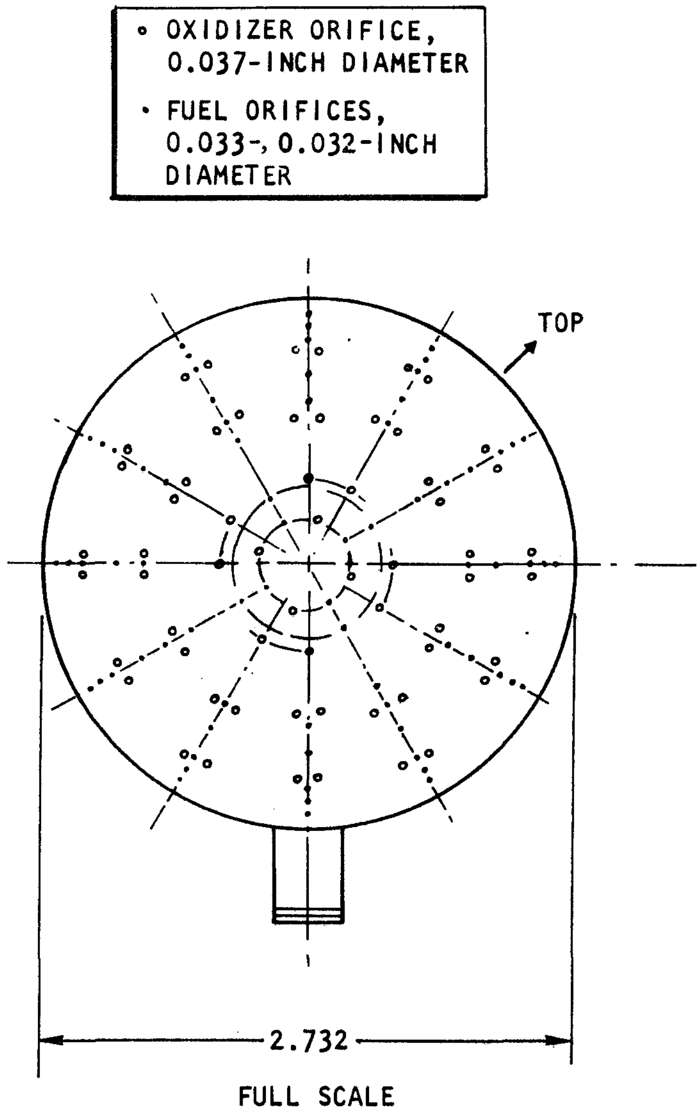


Figure 3b. Injector Schematic

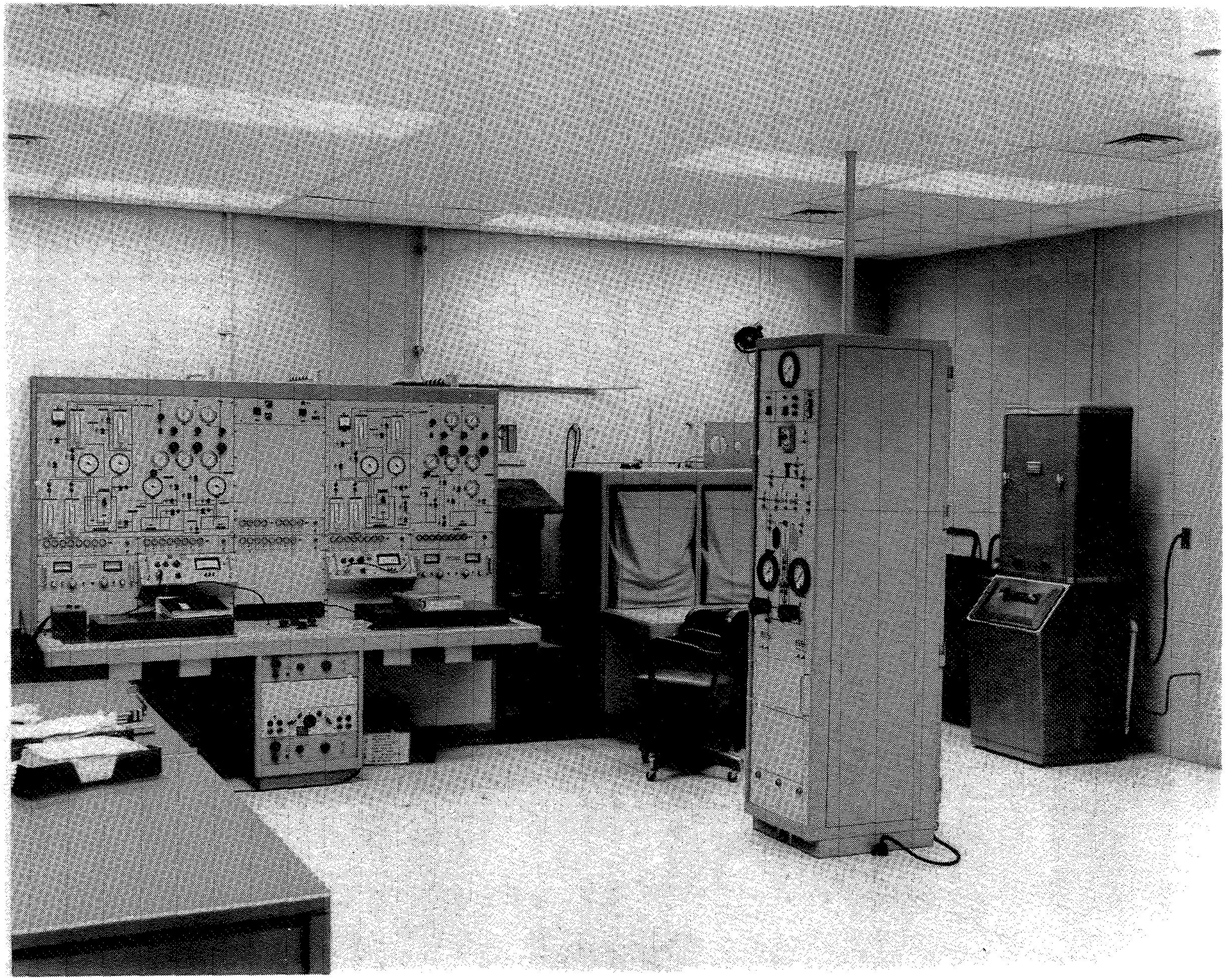


Figure 4. Engine Control Panel

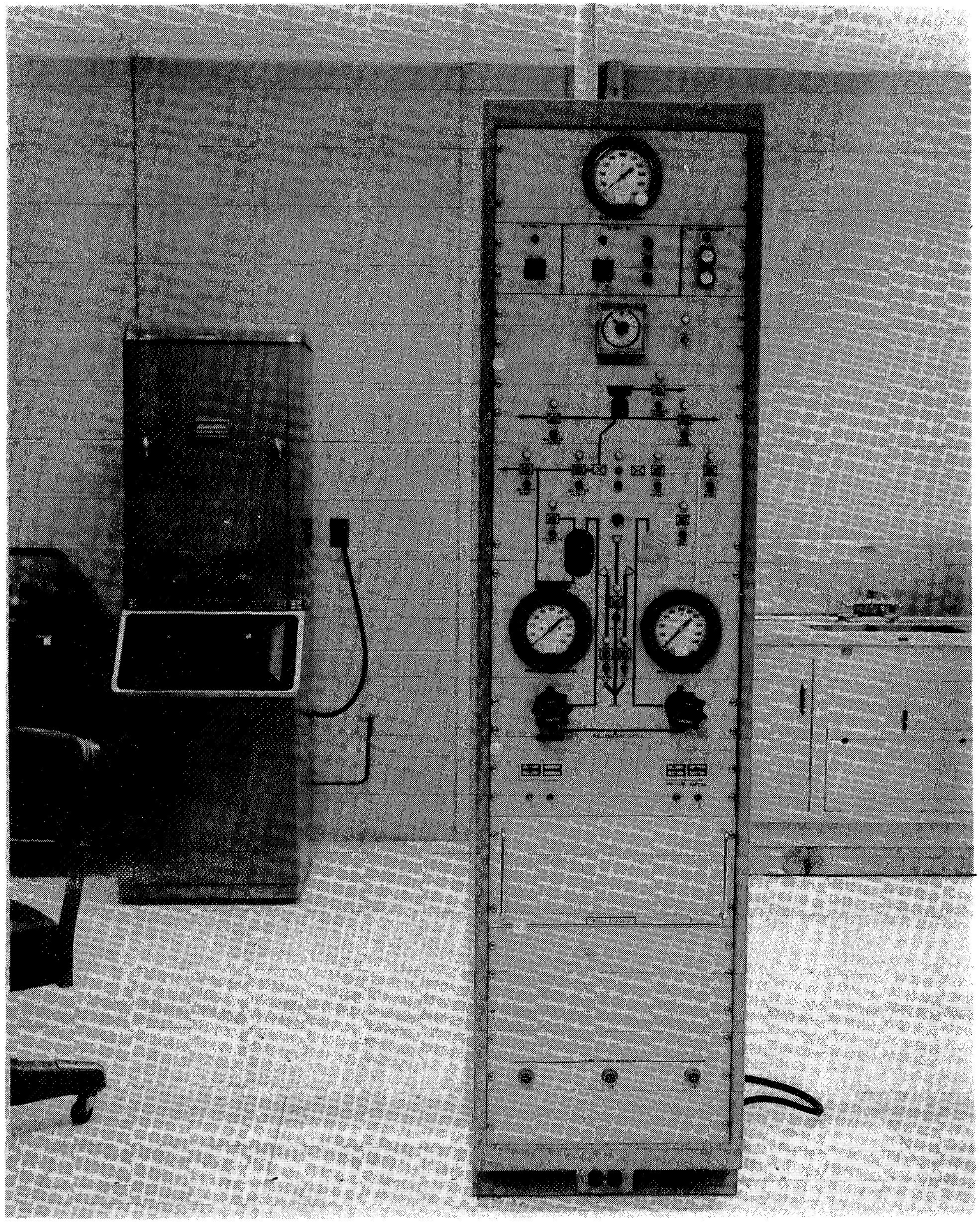
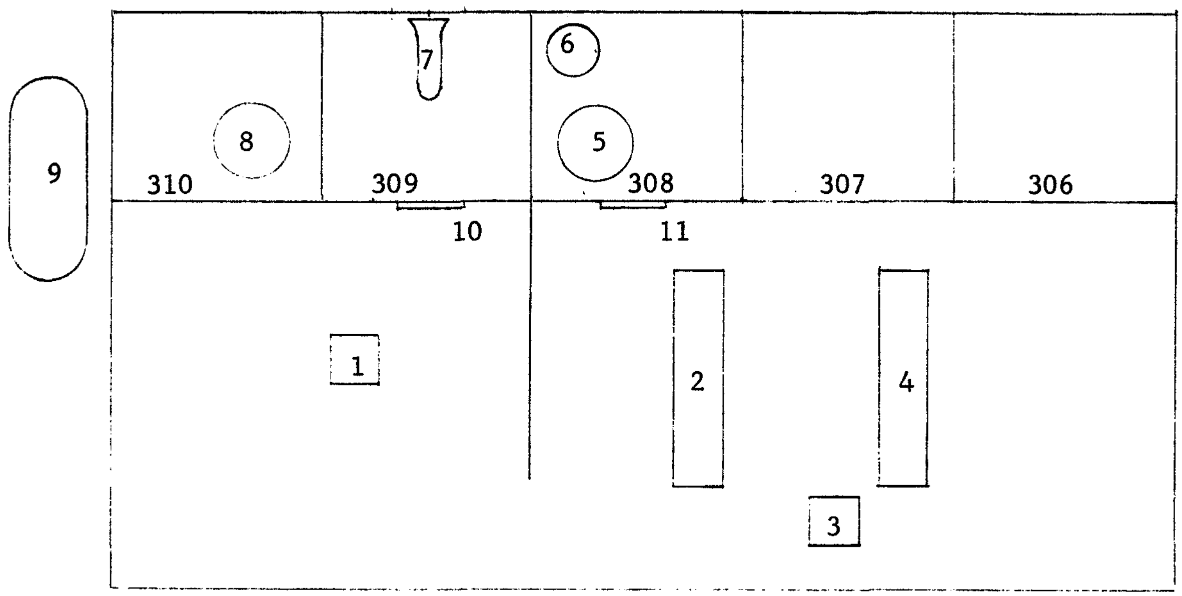


Figure 4. Engine Control Panel



Building 8110

(1) Rocket Control Panel

(2) Strip Chart Recorder Panel

(3) Timing System & Event Recorder

(4) Signal Conditioning Group and Patching Panel

(5) Liquid Oxygen Tank

(6) High Pressure Water Reservoir

(7) MA-3 Atlas Vernier Engine

(8) JP-5 Fuel Tank

(9) Liquid Hydrogen Tank

(10-11) Observation Windows

(306-310) Test Cells

Figure 5. Building 8110 - Layout

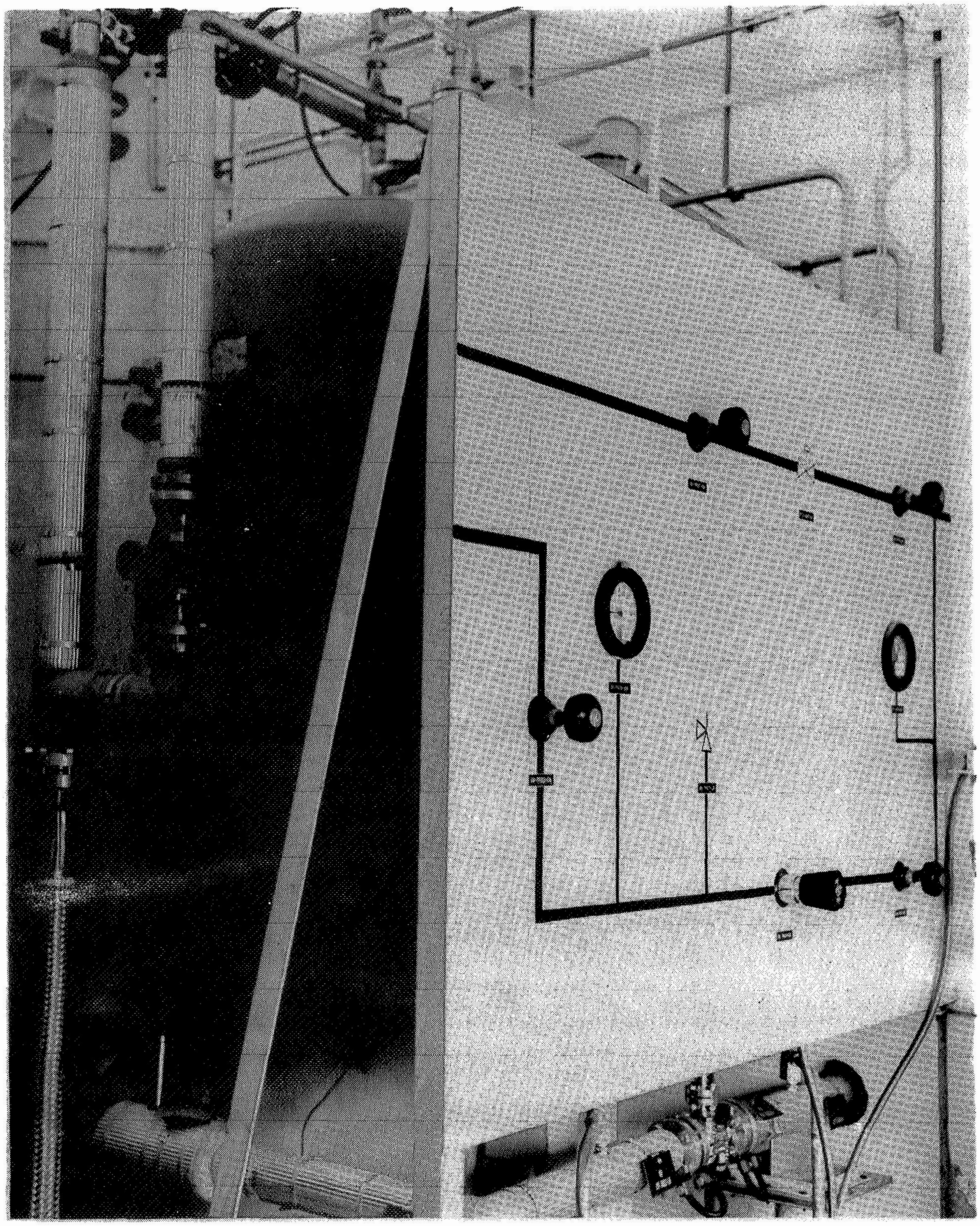


Figure 6. Liquid Oxygen Propellant Tank

Part of this system is located in Building 8110. The components in Building 8110 are:

(1) Signal Conditioning Group (Figure 7)

(2) Instrumentation Patch System (Figure 7)

(3) Strip Chart Recorder Group (Figure 8)

(4) Event Recorder (Figure 9)

(5) Timing System (Figure 9)

(6) Oscillograph Recorder Group (Figure 8)

The rest of the data acquistion system is located in the main building of the Components Service Facilities Complex, Room 118. This equipment completes the acquistion data systems and also serves as a back up system to insure all data available are recorded and easily retrieved. The components in Room 118 are:

(1) Analog Recorder (Figure 10)

(2) Oscillograph Recorder Groups I & II (Figure 11)

(3) Analog/Digital Recorder System (Figure 12 and 13)

(4) Ship Chart Recorder Groups I & II (Figure 14)

(5) Event Recorder (Figure 15)

(6) Signal Conditioning Group (Figure 16)

(7) Instrumentation Patch System (Figure 16)

(8) Multipoint Recorder (Figure 17).Not used but available for this program.

Table II lists the parameters which are recorded, the parameter range, and in what recorder they are being registered (by code number).

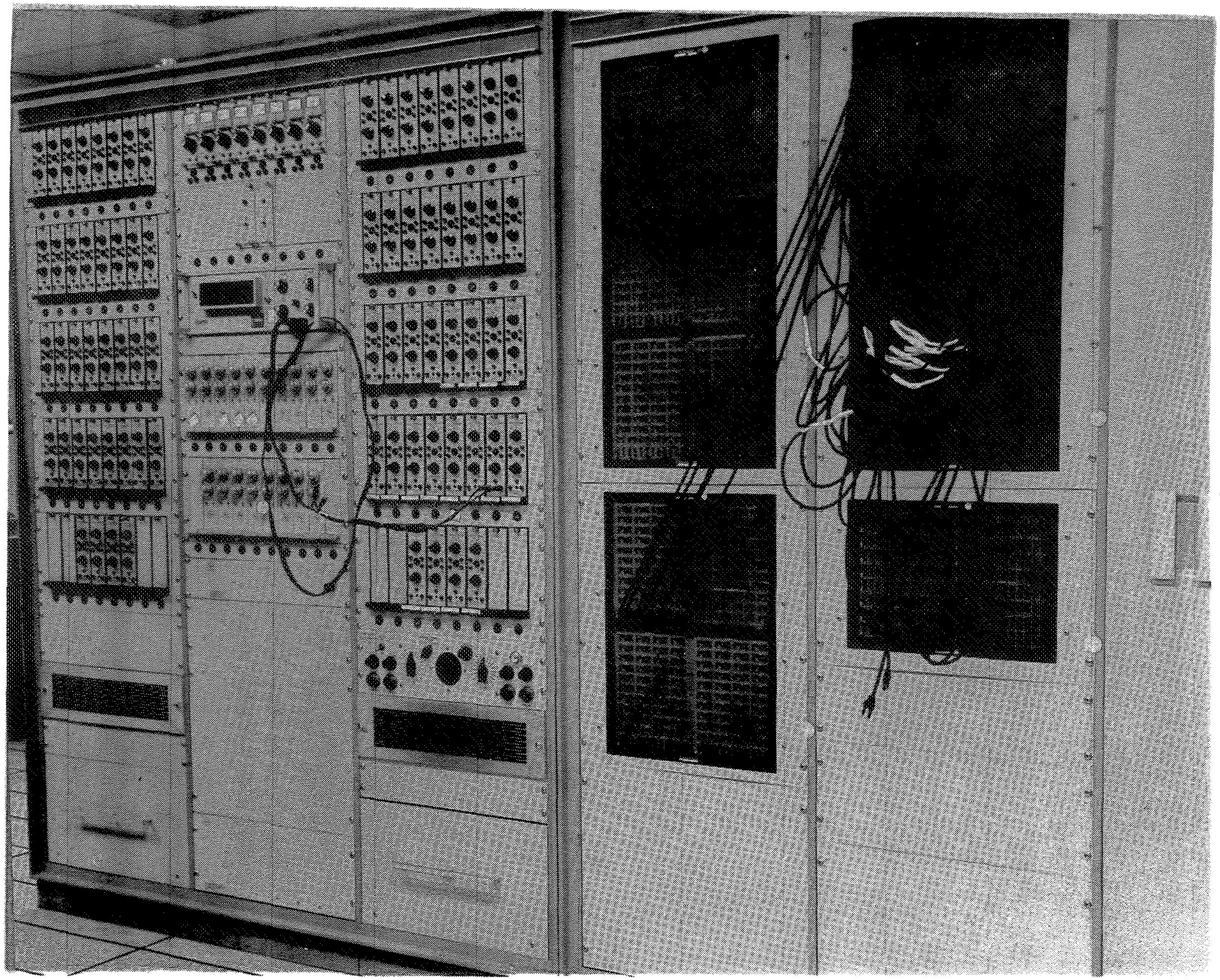


Figure 7. Signal Conditioning Group and Instrumentation Patch System (Bldg. 8110)

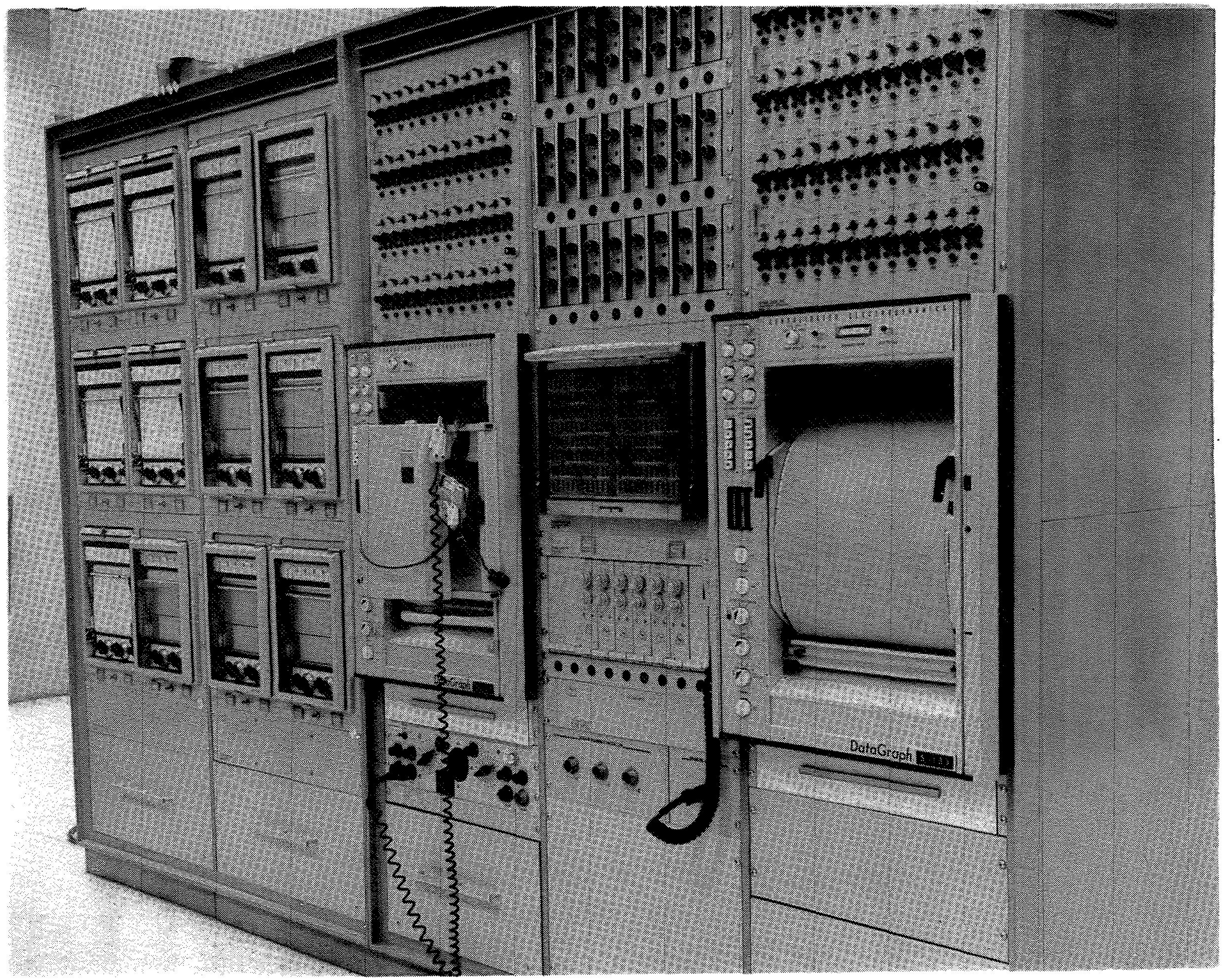


Figure 8. Strip Chart Recorder Group and Oscillograph Recorder Group (Bldg. 8110)

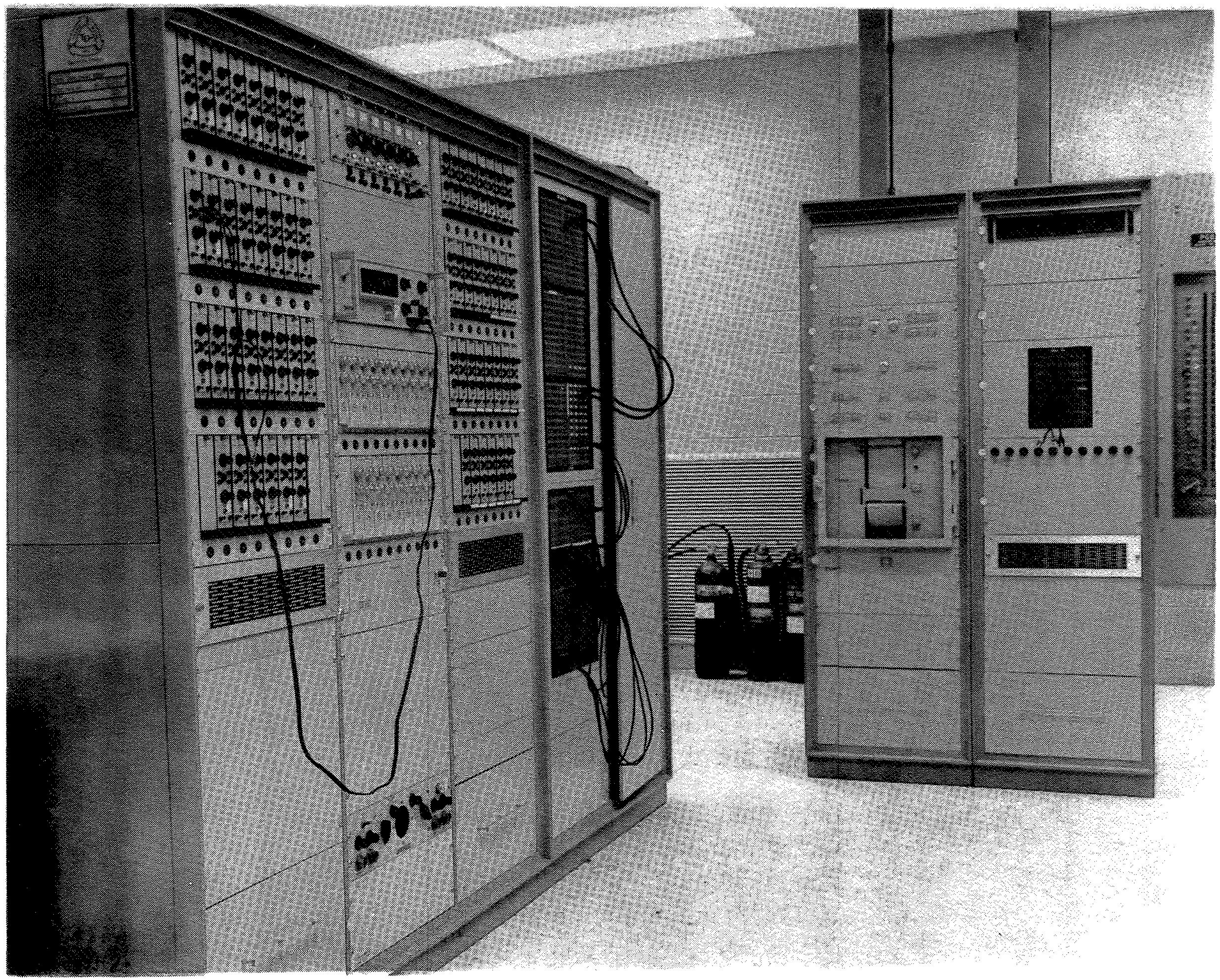


Figure 9. Signal Cond. Group, Instrumentation Patch System, Event Recorder and Timing System (Bldg. 8110)

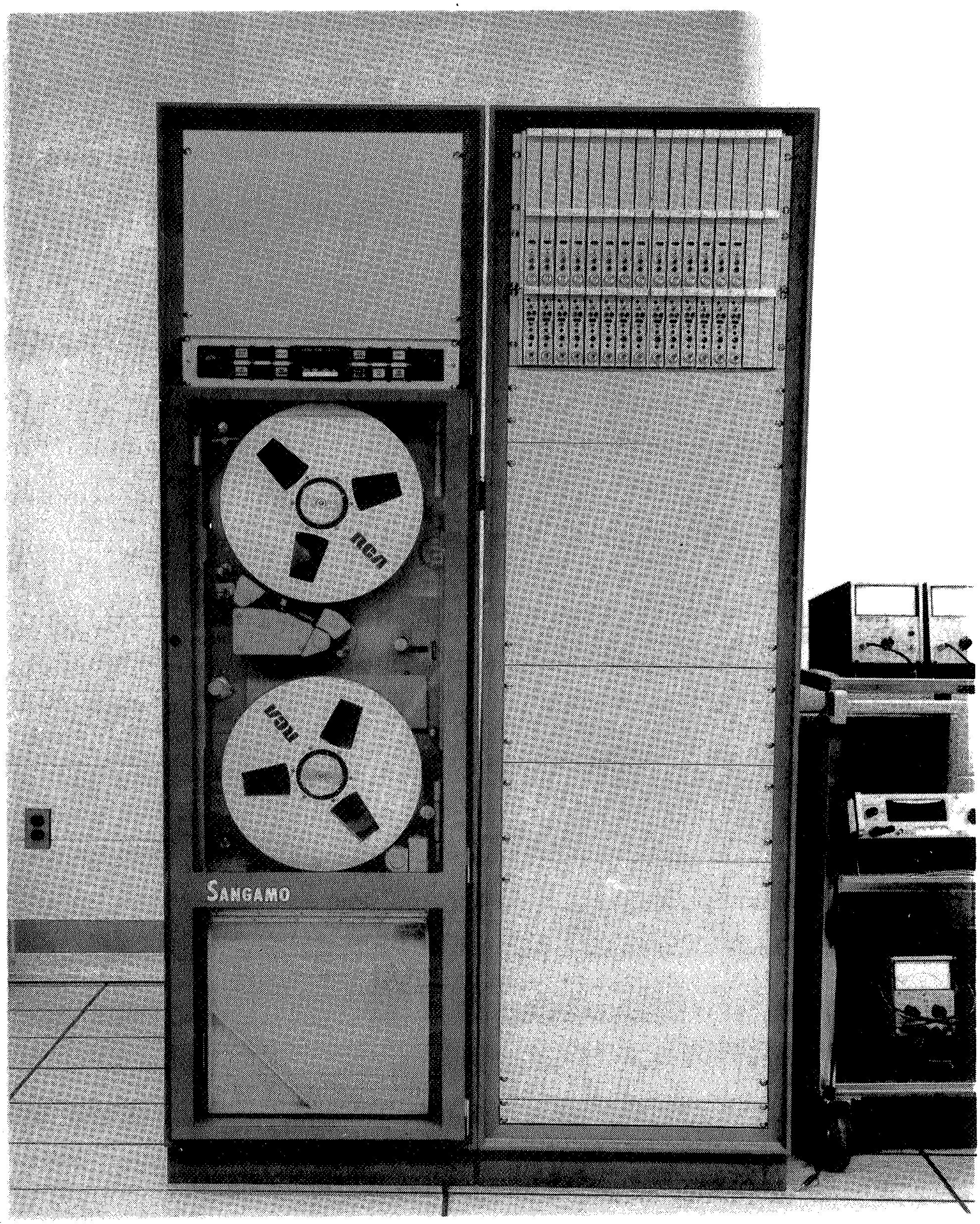


Figure 10. Analog Recorder, Backup System (Rm. 118, Bldg. 8100)

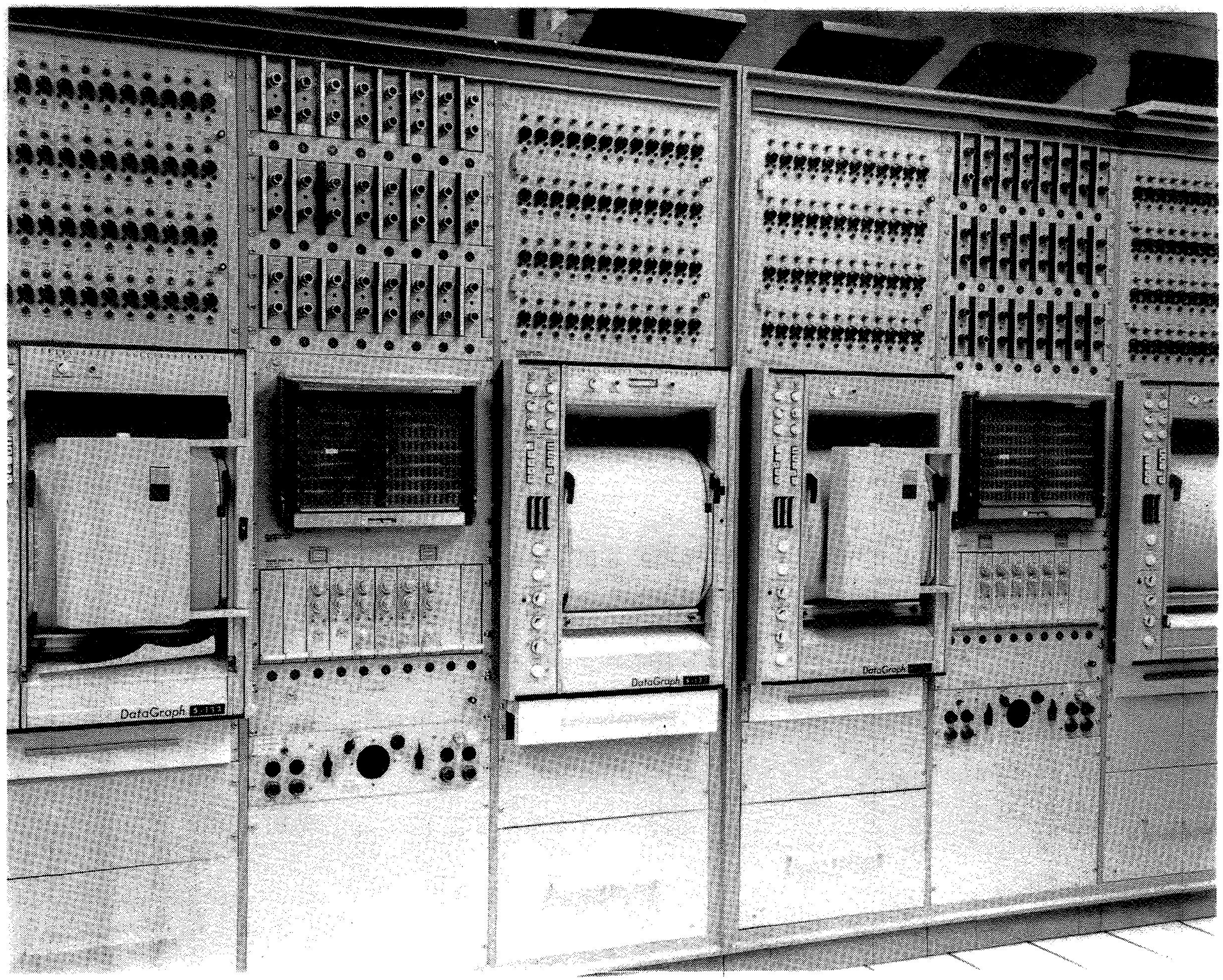


Figure 11. Oscillograph Recorder Groups I and II (Rm. 118, Bldg. 8100)

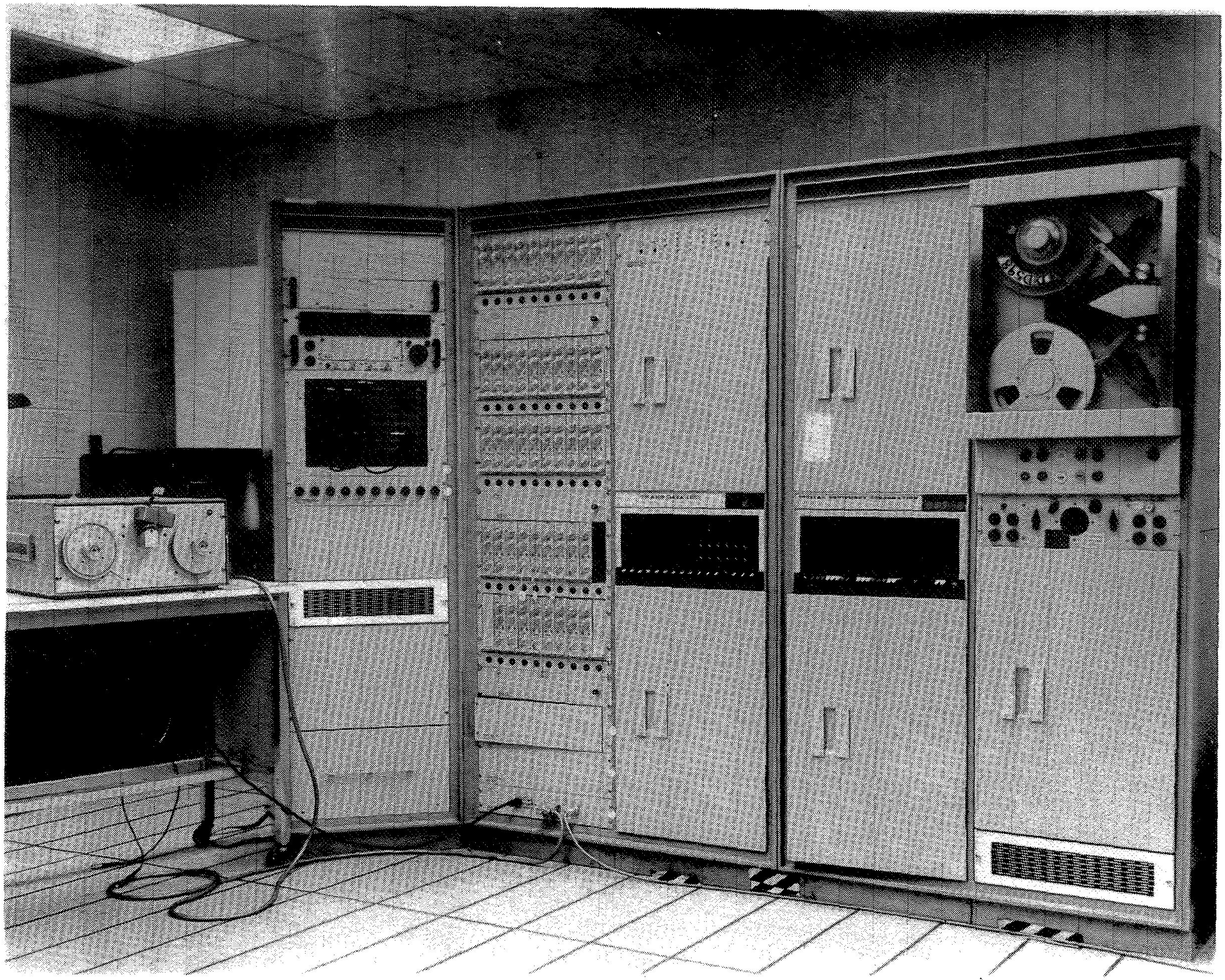


Figure 12. Analog Digital Recorder System (Rm. 118, Bldg. 8100)

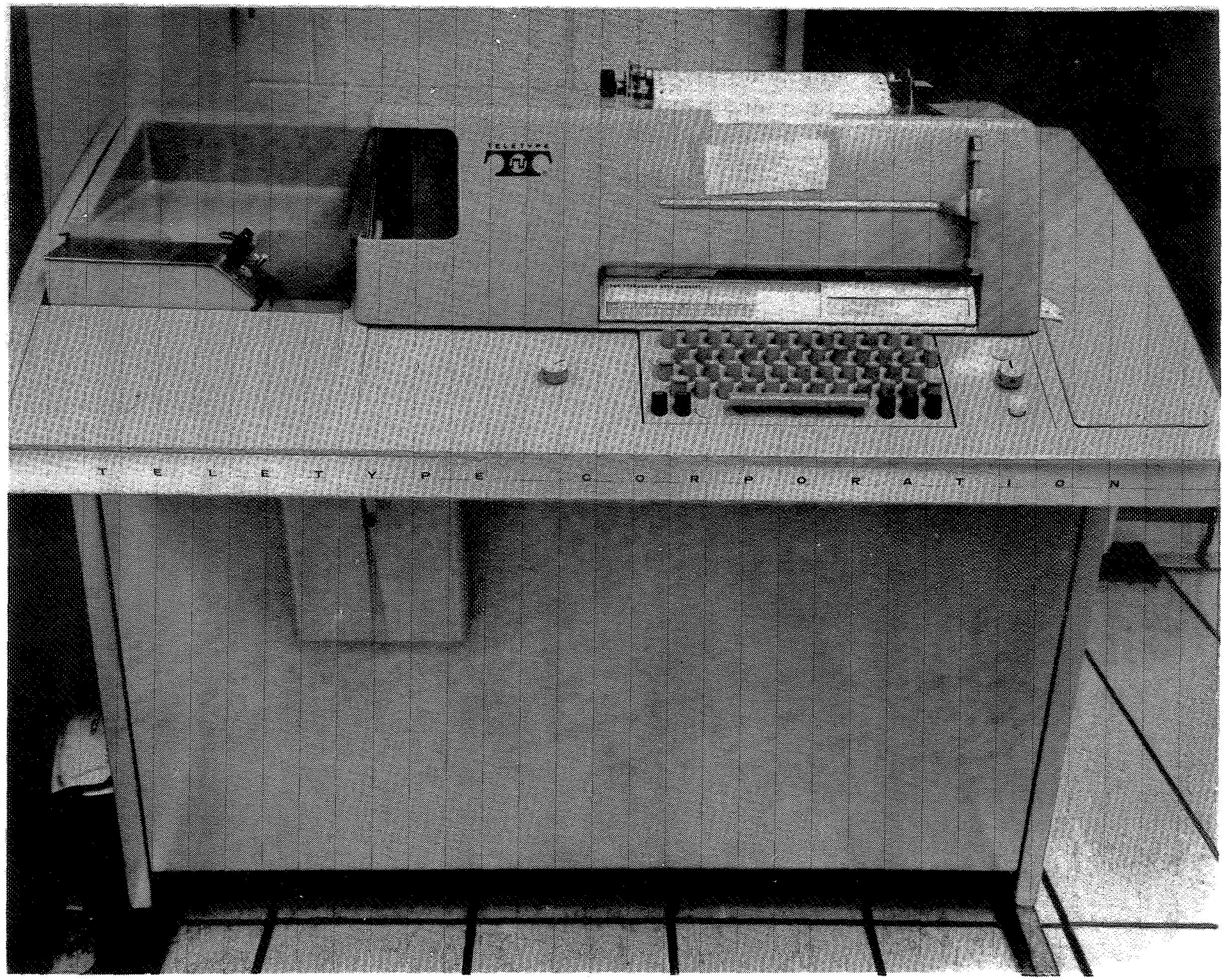


Figure 13. Teletype Unit of A/D Recorder System (Rm. 118, Bldg. 8100)

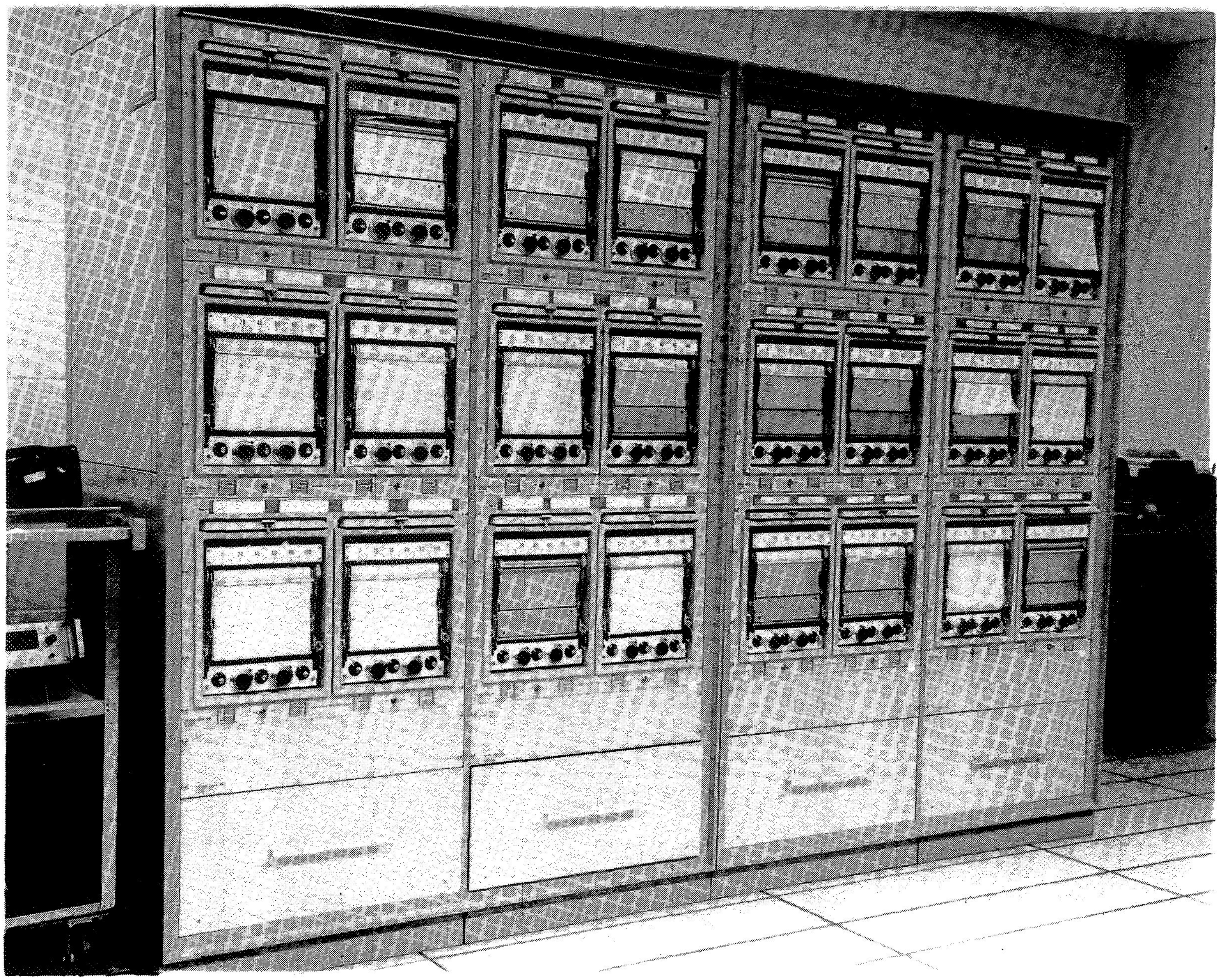


Figure 14. Strip Chart Recorders Groups I and II (Rm. 118, Bldg. 8100)

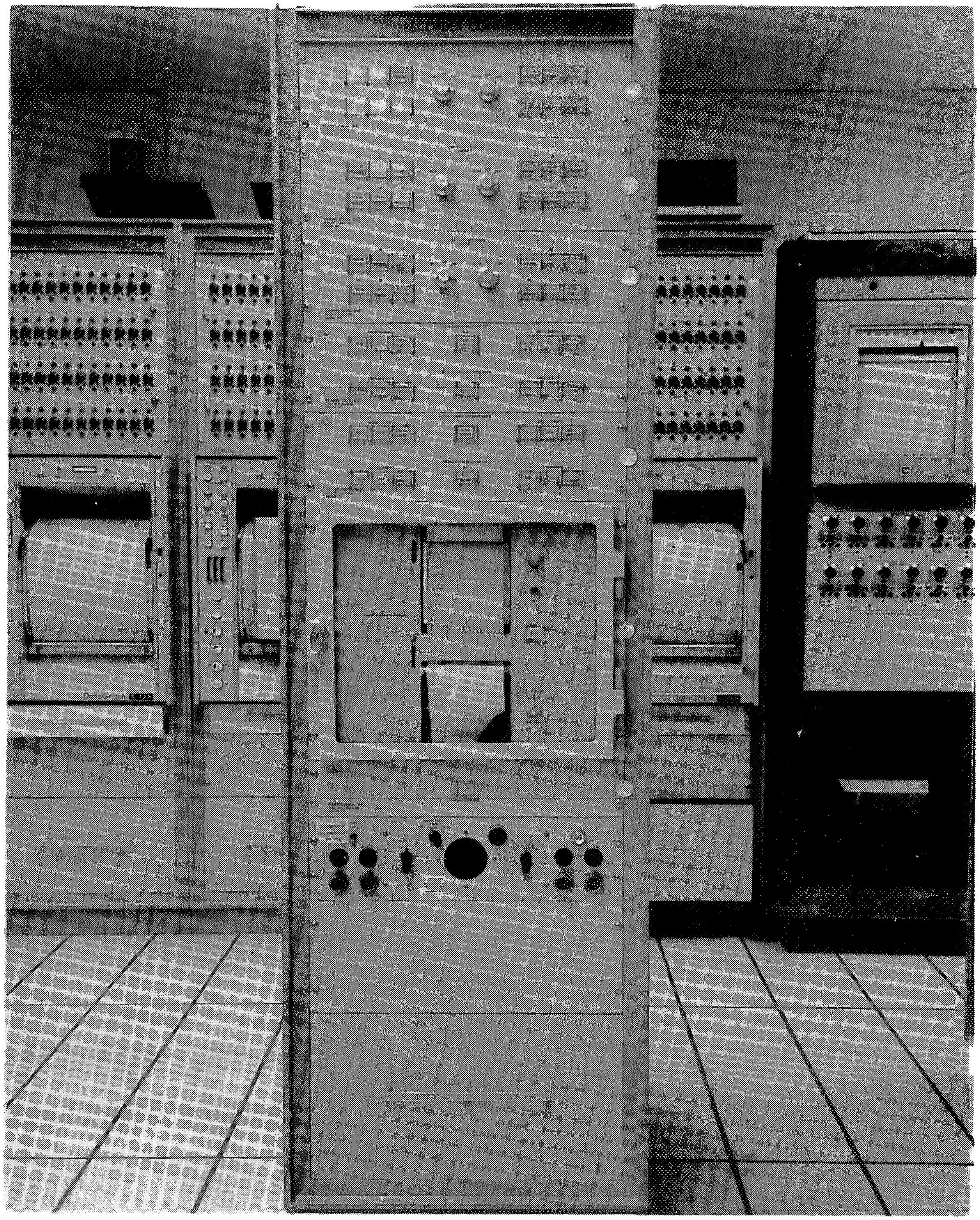


Figure 15. Event Recorder (Rm. 118, Bldg. 8100)

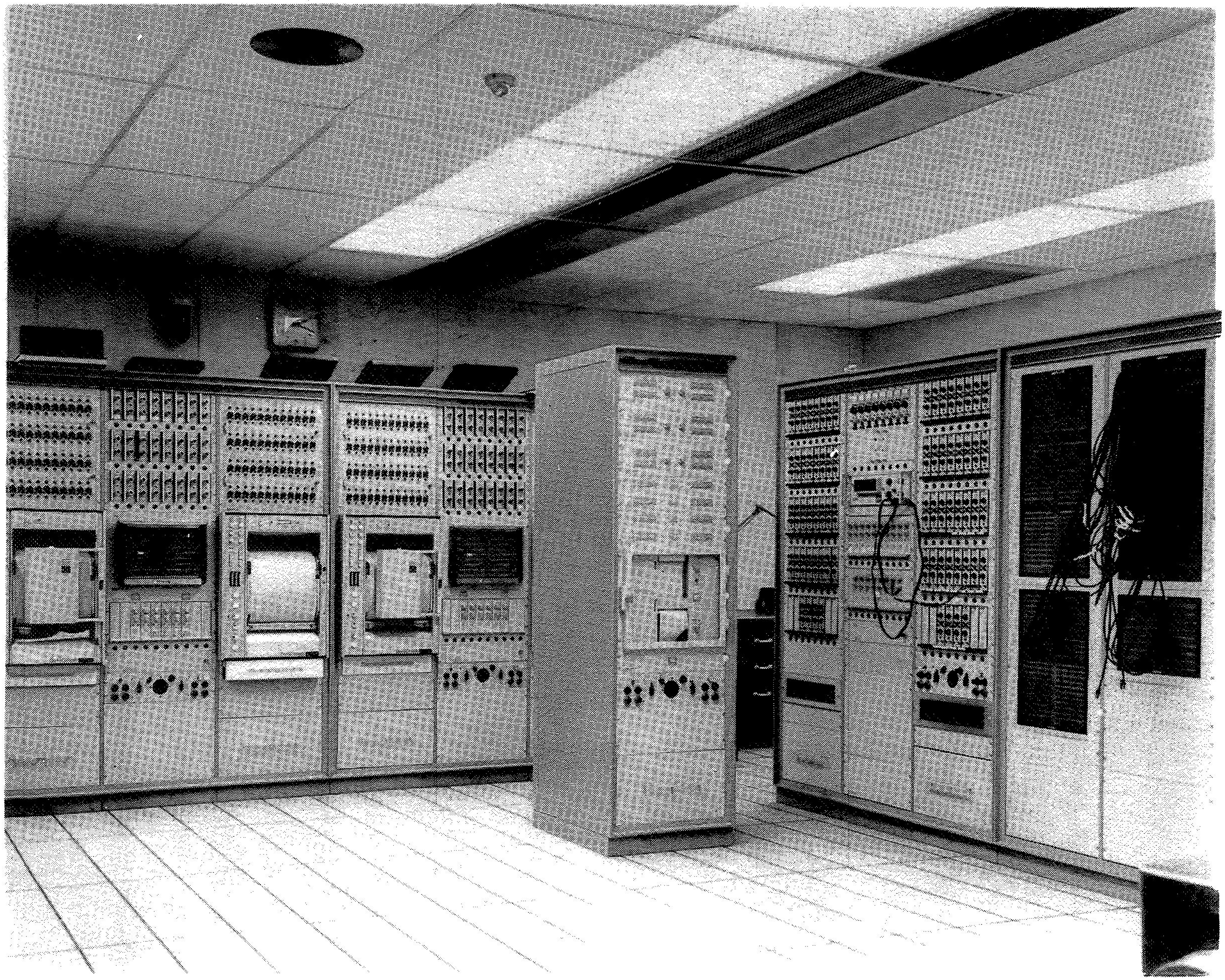


Figure 16. Layout of Instrument Room 118 Including Signal Conditioning Group and Patch System (Bldg. 8100)

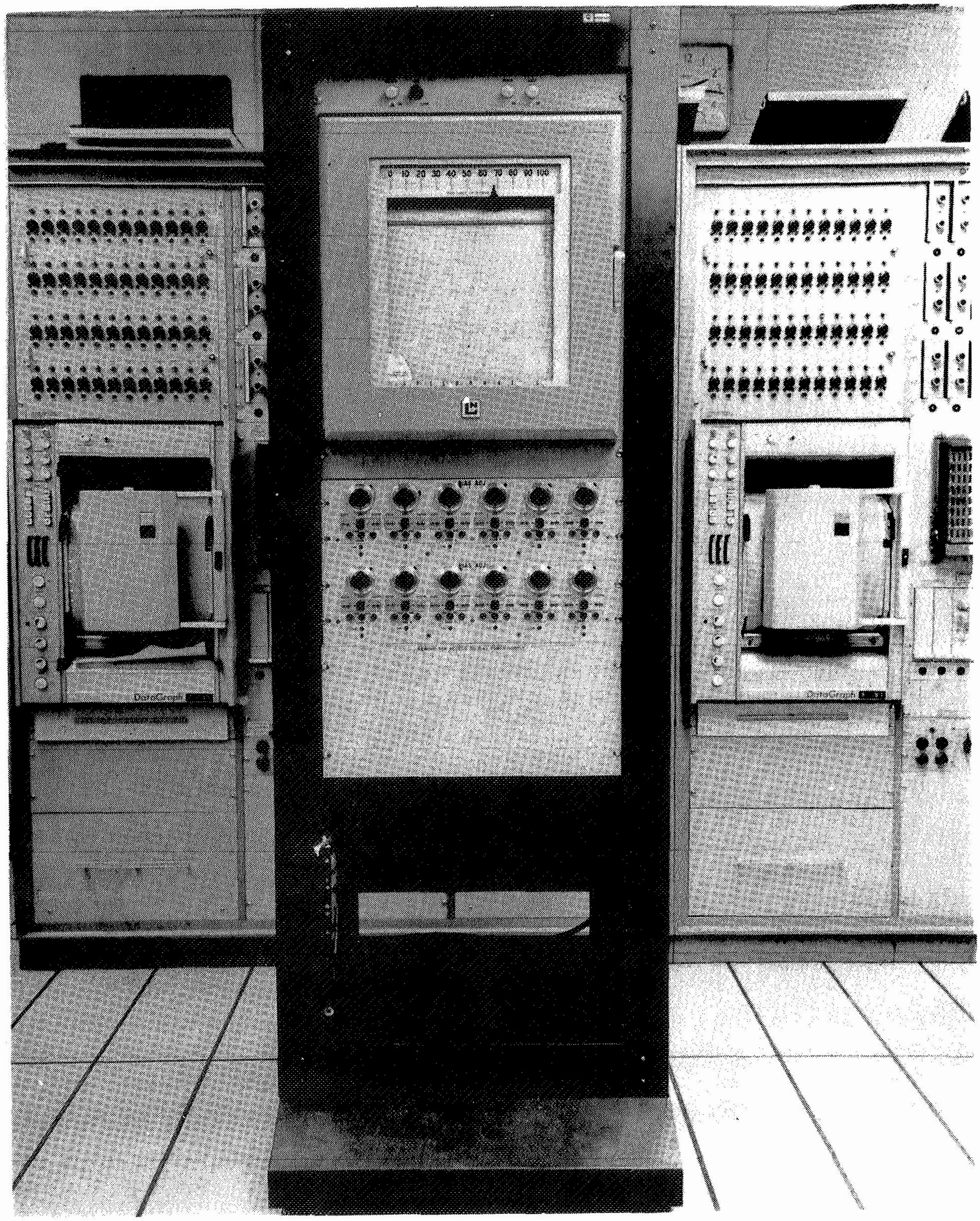


Figure 17. 12-Point, Multipoint Recorder

TABLE II

Variables Measured - Instrumentation Code List

Code	Variable	Range of Measuring Instrument
LC1	Temperature, LOX Inlet	(-300°F) - (-250°F)
LC3	Temperature, Fuel Flow Meter	0 - 100°F
LC100	Temperature, Probe H_2O O.J. Inlet	0 - 100°F
LC101	Temperature, Probe H_2O I.J. Inlet	0 - 100°F
LC102	Temperature, Probe H_2O O.J. Outlet	0 - 500°F
LC103	Temperature, Probe H_2O I.J. Outlet	0 - 500°F
LC104	Temperature, Probe gas sample	0 - 500°F
LD1	Pressure, LOX tank	0 - 1000 psig
LD2	Pressure, LOX inlet	0 - 1000 psig
LD3	Pressure, Fuel tank	0 - 1000 psig
LD4	Pressure, Fuel inlet	0 - 1000 psig
LD5	Pressure, LOX Dome	0 - 1000 psig
LD6	Pressure, Engine Chamber 1	0 - 500 psig
LD7	Pressure, Engine Chamber 2	0 - 500 psig
LD8	Pressure, Fuel trunnion	0 - 1000 psig
LD9	Pressure, Water tank	0 - 1000 psig
LD100	Pressure, Probe, Static	0 - 20 psia
LD101	Pressure, Probe, Stagnation	0 - 500 psig
LD102	Pressure, I. J. Outlet	0 - 250 psig
LD103	Pressure, Gas sample	0 - 500 psig
LD104	Pressure, Probe inlet	0 - 1000 psig
LD105	Pressure, O.J. Outlet	0 - 250 psig
LD106	Pressure, Strut Outlet	0 - 250 psig
LF1	Flowrate, LOX	0 - 30 GPM

TABLE II (Cont'd)

Code	Variable	Range of Measuring Instrument
LF2	Flowrate, Fuel	0 - 30 GPM
LF100	Flowrate, H_2O I.J.	0 - 1 GPM
LF101	Flowrate, H_2O O.J.	0 - 1.5 GPM
LF102	Flowrate, H_2O Strut	0 - 5 GPM
LG100	Position, Probe, Horizontal	0 - 12 in.
LG101	Position, Probe, Vertical	0 - 12 in.
LK1	Ignition Command	28 - 0 VDC
LK3-1	LOX Tank Vent	OFF - ON
LK3-2	LOX Tank Vent	OFF - ON
LK4-1	LOX Bleed	OFF - ON
LK4-2	LOX Bleed	OFF - ON
LK5-1	LOX Supply	OFF - ON
LK5-2	LOX Supply	OFF - ON
LK6-1	Fuel Tank Vent	OFF - ON
LK6-2	Fuel Tank Vent	OFF - ON
LK7-1	Fuel Bleed	OFF - ON
LK7-2	Fuel Bleed	OFF - ON
LK8-1	Fuel Supply	OFF - ON
Lk8-2	Fuel Supply	OFF - ON
Lk9	Deluge Valve	OFF - ON
LK10	Engine Fuel Purge Valve	OFF - ON
LK11	Engine LOX Purge Valve	OFF - ON
LK13	Fuel Cell Deluge open	OFF - ON
LK14	LOX Cell Deluge open	OFF - ON
LK15	Probe water open	OFF - ON
LK16	Orifice Sample open	OFF - ON

TABLE II (Cont'd)

Code	Variable	Range of Measuring Instrument
LK17	Sample Supply open	OFF - ON
LK18	Sample Bottle #2 open	OFF - ON
LK19	Sample Bottle #3 open	OFF - ON

Probe

There are two main techniques used to study the physical phenomena involved in the plume of a rocket engine, these are radiation measurements and probe measurements. In the former, radiation from the plume is compared with radiation from a known calibrated source or a calculated model. The instruments are not exposed to the severe environment, but only average values across the plume are obtained. Using probe techniques, direct measurement inside the plume eliminates temperature averaging. However, the probe must be capable of withstanding the severe environment of the plume. Both of these techniques have been used. Studies using radiation techniques are described in reference 1; studies using probe techniques, in references 2 - 9.

Radiation measurements can be analyzed by assuming axial symmetry of the plume, and local properties of temperature and composition, thusly are deduced. This is called zone radiometry. However, the probe remains the only means of directly measuring a local property.

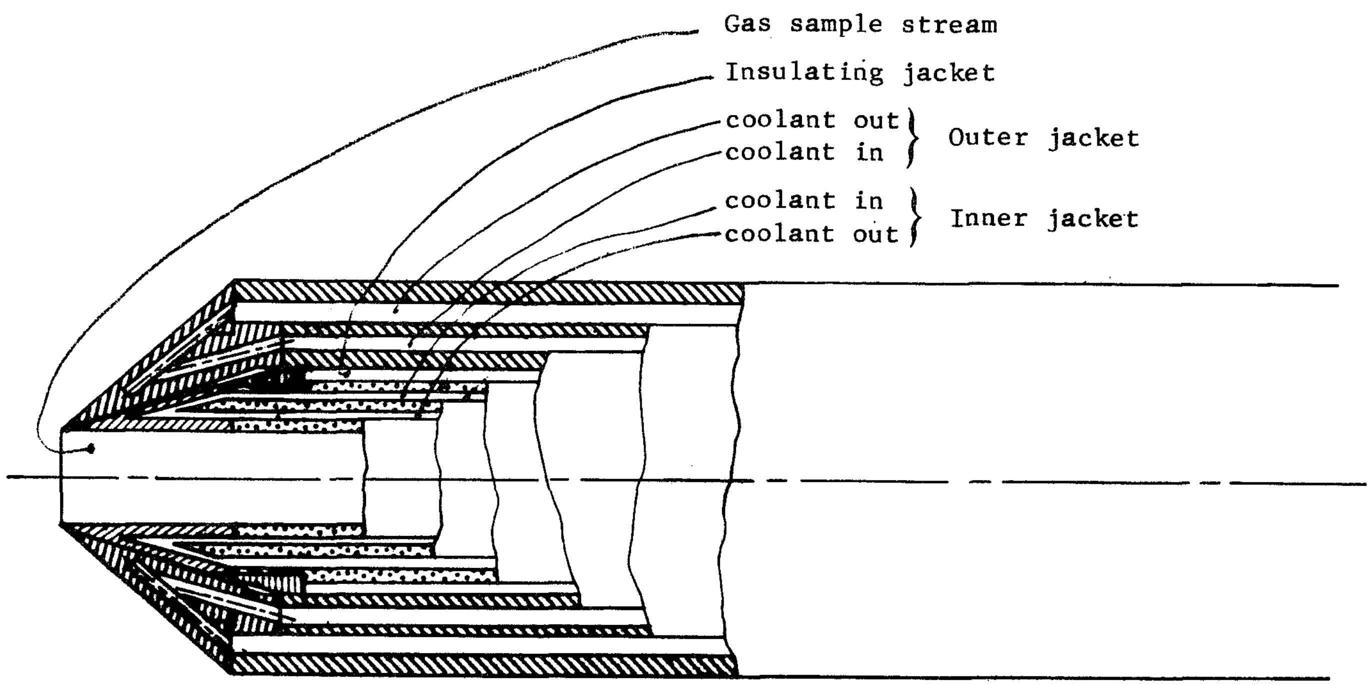
Unfortunately, probes which may be used to determine static and total pressure, temperature, and composition, even though they are commercially available, have not yet proven to be dependable enough to provide consistent data. Therefore, discussion not only of the probe used but probes in general will be presented.

The probe used in this program is an enthalpy probe. The probe system consists of an external assembly, an internal calorimetric assembly and a strut each of which is provided with a separate cooling system. The primary function of the external assembly which completely surrounds, and is insulated from the inner calorimetric probe is to protect the inner assembly from the severe external environment. Instruments are installed in all tubes which allow for measuring flows and temperatures.

The enthalpy probe is a simple calorimetric device which allows one to measure the enthalpy of a gas sample drawn through a tube located on the axis of the instrument. The gas was withdrawn at a mass flux unequal to the stream mass flux, i.e. no attempt was made to "swallow the shock". As the sample travels down the tube energy is transferred to the tube walls and in turn to the cooling water flowing on the outer surface of the tube wall (see Figure 18). At the end of this tube an orifice is located. When the flow is choked, pressure measurements can be used to obtain the mass flow rate of the gas. From a simple energy balance, the enthalpy of the gas stream can be calculated using the mass flow rate and temperature differential of the cooling water of the inner probe (See SAMPLE CALCULATION, page 39). References 10-12 discuss the theory and performance of enthalpy probes.

All the necessary connections and instrumentation for the probe operation are installed in cell 309. A transversing mechanism was designed and built. This mechanism serves to move the probe to any desired position in the plume of the MA-3 Atlas Vernier Engine. (See Figure 19 and 20).

The original enthalpy probe used in this program was a High-Sensitivity Stagnation Calorimetric Probe, Model G-13-3K, manufactured by Grayrad Corporation, 12 Station Drive, Princeton, New Jersey. The thermal stresses produced on this probe by the plume of the MA-3 Atlas Vernier engine proved to be excessive. This probe was used twice and



SPLIT — FLOW ENTHALPY PROBE

PROBE TIP ASSEMBLY

Figure 18. Cross-Sectional View of the Enthalpy Probe Tip

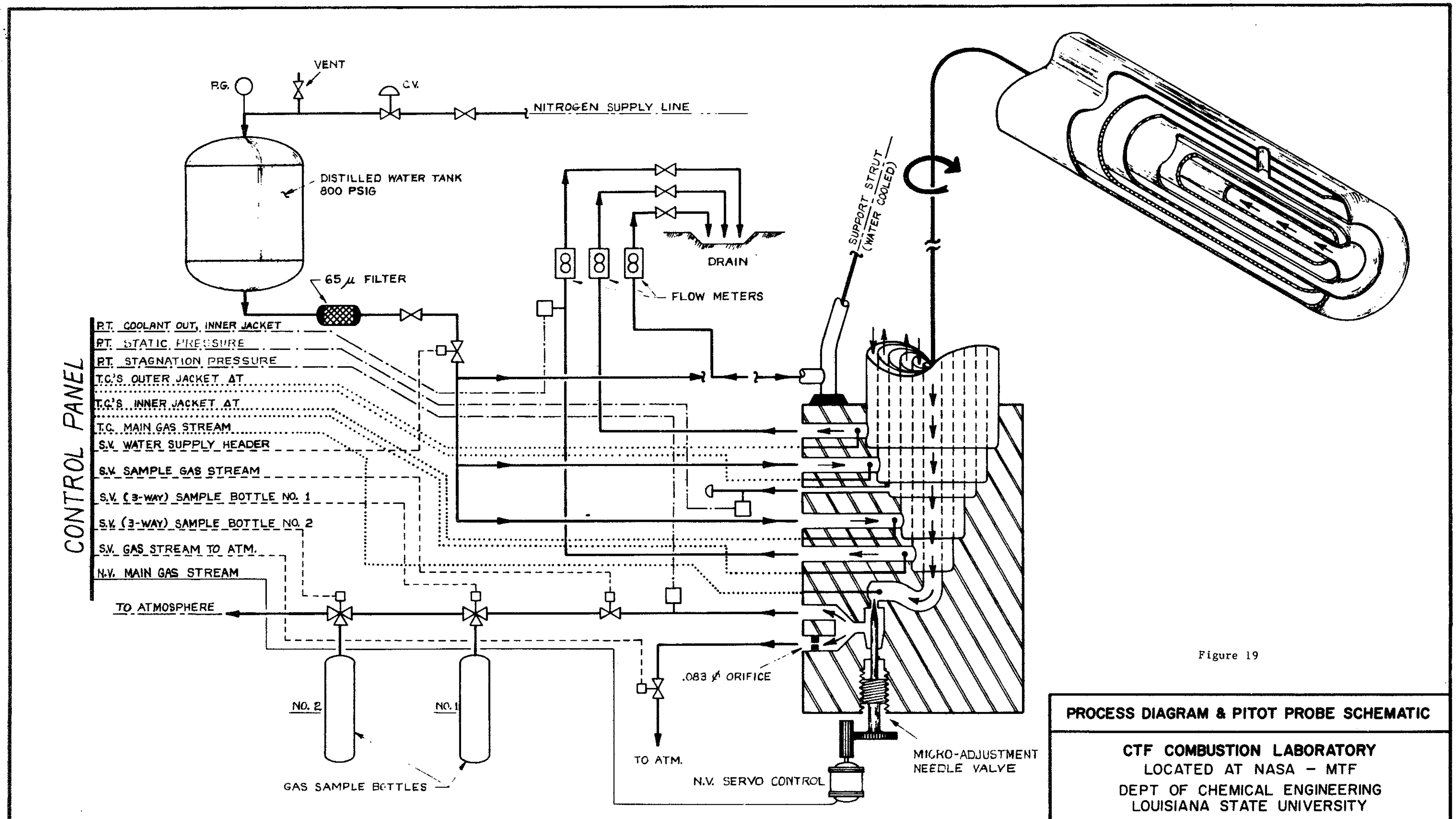


Figure 19

PROCESS DIAGRAM & PITOT PROBE SCHEMATIC

CTF COMBUSTION LABORATORY
LOCATED AT NASA – MTF
DEPT OF CHEMICAL ENGINEERING
LOUISIANA STATE UNIVERSITY

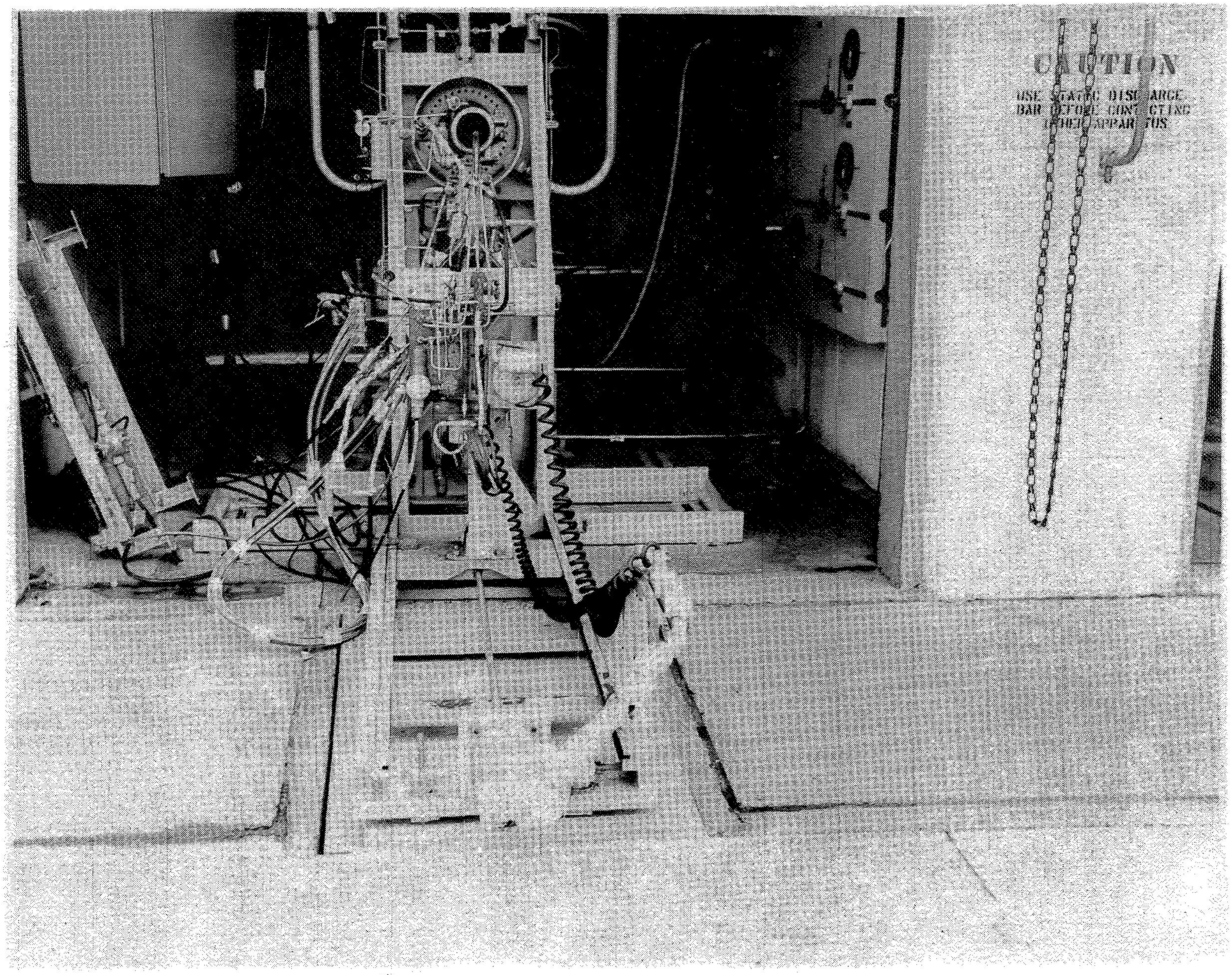


Figure 20. Transversing Mechanism and Probe in Front of MA-3 Vernier Engine

repaired between runs. In each occasion the probe developed cracks, and subsequently leaks which render the data unreliable as it was impossible to make an energy balance around the probe.

With the basic idea of the Grayrad probe, a sturdier probe, more amenable to the conditions encountered in the plume of the Vernier Engine, should be used. Negotiations are in progress in order to obtain such a probe.

Since the Grayrad probe was purchased, Avco Corporation has accomplished a detailed design program for the Manned Spacecraft Center. This is reported in reference 13. This probe has the tip design features shown in Figure 18. It also has the very desirable bend features shown in Figure 21,i.e. it does not depend on concentric tubes remaining concentric during a bending operation.

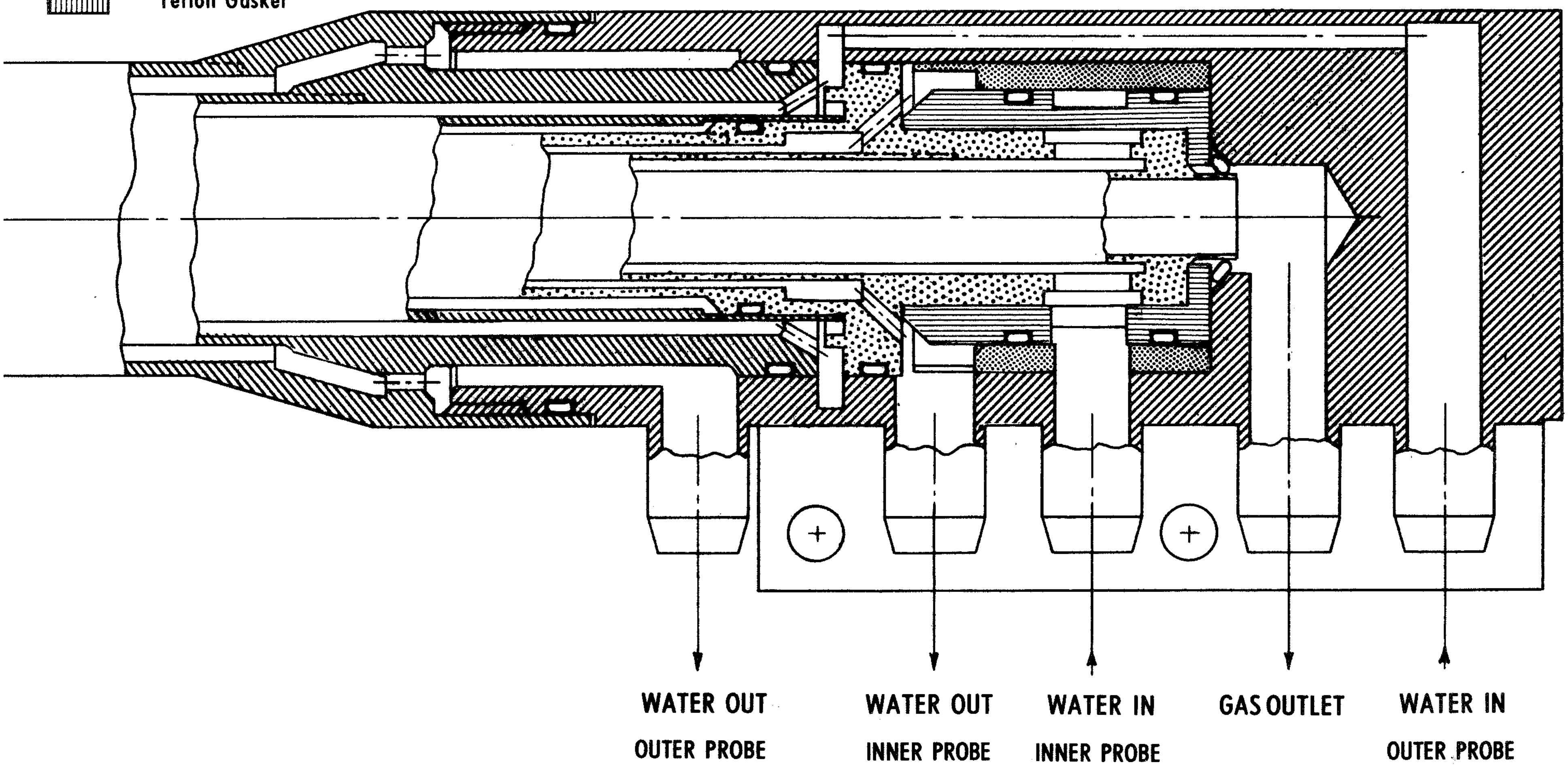
Upon contacting Avco (ref. 14), they recommended a probe design which they supplied to Aerotherm Corp. for use in large arc jet test. Upon contacting Aerotherm (ref. 15), we learned that the probe assembly survived an environment which is similar to a Venier plume but the base of the probe assembly was inadequately protected.

In summary, successful probe operation at enthalpy levels experienced in the Vernier plume have not yet been accomplished, but they appear to be possible with a modest effort.

Figure 21

"SPLIT — FLOW ENTHALPY PROBE"

PROBE BEND ASSEMBLY



Gas Sampling and Analysis

Gas samples are collected in bottles at various probe locations. These samples are analyzed to determine (1) the local O/F ratio and (2) the amount of ambient air which has mixed with the exhaust plume at a particular location.

To accomplish this determination, the gas phase portion of the sample was analyzed by gas chromotography, the liquid phase was assumed to be water and could be picked up by a dry gas then analyzed for water content, and the solid phase was assumed to be soot and was collected on millipore filter disc, which was weighed for the soot.

On test 13 the filters were broken and subsequently plugged the sample line so that a gas sample was not obtained. They were omitted from test 14. At best, this measurement has severe limitations because an undeterminable amount of soot will deposit on the walls of the sample tubes, but it can be made.

Duplicate gas samples were obtained on test 14 at one probe position. The results of the gas chromotography analyses are given in Table III. Water was not determined, although the testing procedure and equipment are available. 30 psia of gas in the small Hoke bottles was collected; this is adequate for analyses.

Liquid phase analysis was not made on test 14, although this is a routine analysis for water in RP-1. Since the probe was known to have leaked in test 14, the absence of these data are not a severe loss.

In summary, the sample analyses necessary to determine O/F and local mixing can be performed and the sample collection system is adequate, if millipore filters are handled with suitable care.

TABLE III

Gas Phase Sample Compositions (in mol percent)

	Sample #1 Hoke Bottle #1271	Sample #2 Hoke Bottle #849
H_2	7.70	7.80
CH_4	0.02	0.02
CO	10.20	10.30
O_2	3.10	3.20
N_2	1.30	1.50
CO_2	77.00	76.00

SAMPLE DATA OUTPUT

The data display from test event number 11 is included as the next few pages to give an indication of the capability of the Data Acquisition System. On all tests that the probe was used, the output of the instruments listed in Table II was collected in the output format given in this data sample. These data are available from the authors of this report and from the Mississippi Test Facility.

Event sequence data on solenoid valve positions are available but are not displayed in this data sample, but are given in Table IV, following the data sample.

The data are shown to be preliminary because at the time of their printing the instrument engineers at MTF had not had an opportunity to review the data. This comment no longer applies to the data.

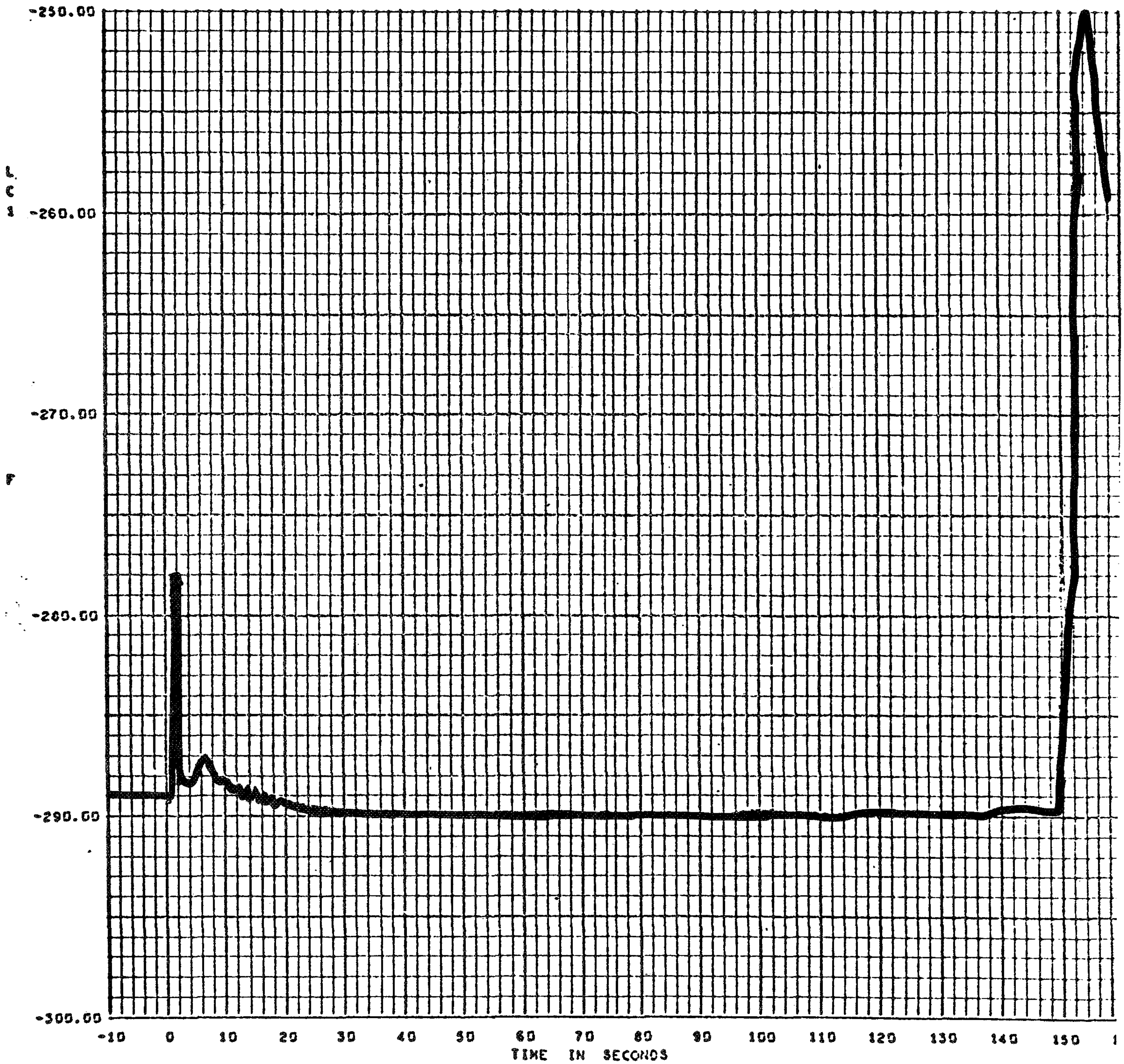
To run the tests for which these data were obtained, the procedures listed in the Appendicies were used. These procedures assure maximum range safety.

VERNIE
GROUND MEASUREMENTS
BECKMAN SYSTEM
A/D SYSTEM NO. 1
COMBUSTOR TEST
TEST NO. 309011
DATE 10/21/69
START 12 05 38
STOP 12 08 27

PRELIMINARY
------------->

VEH. ID VERNIE A/O 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/4

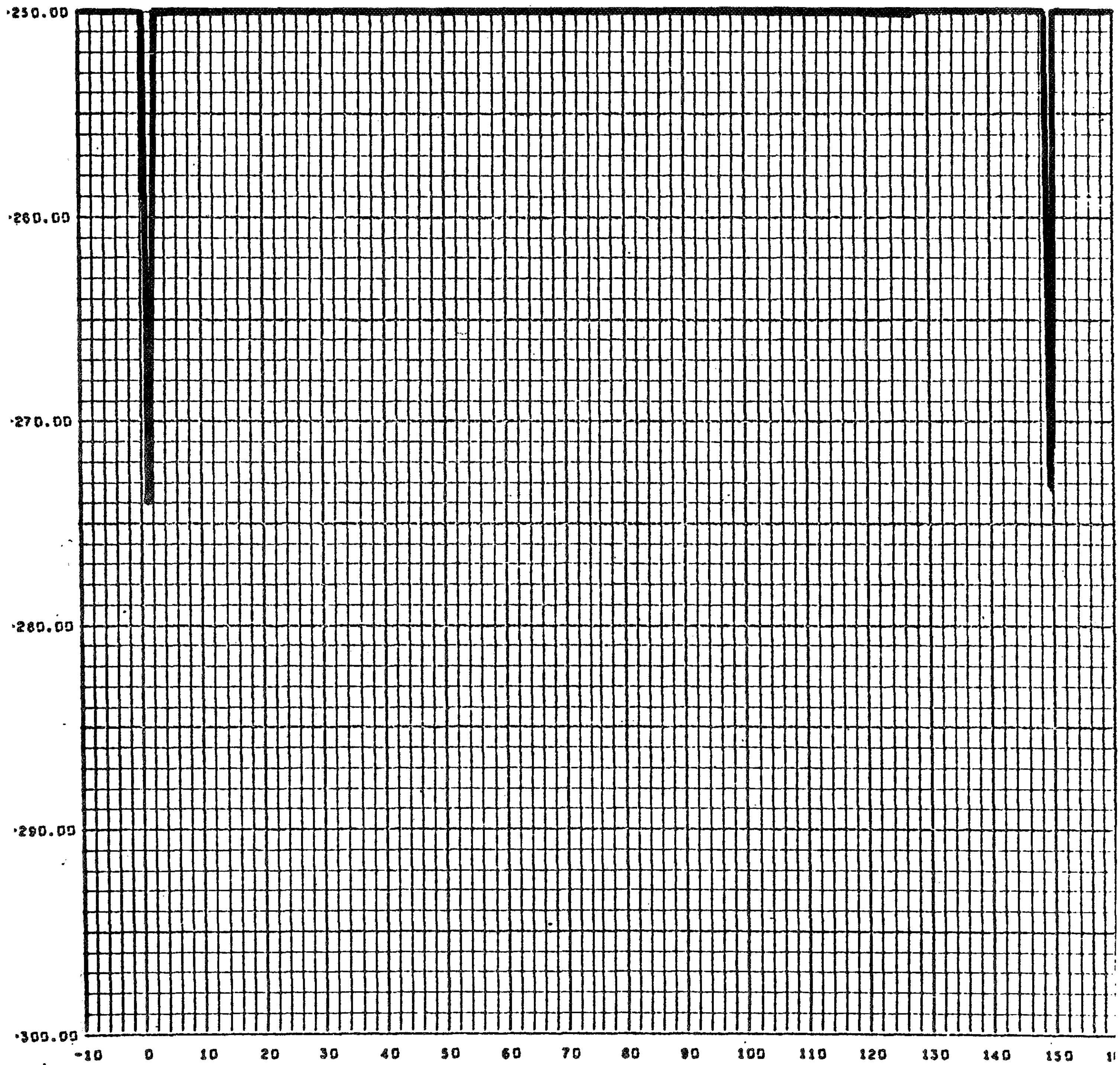
MEAS. TITLE - TEMP,LOX INLET 1FC



TIME SLICE IN HH/MM/SS/HHH= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =015

. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48

MEAS. TITLE = TEMP,L/X - FLOWMETER 1FC



TIME IN SECONDS

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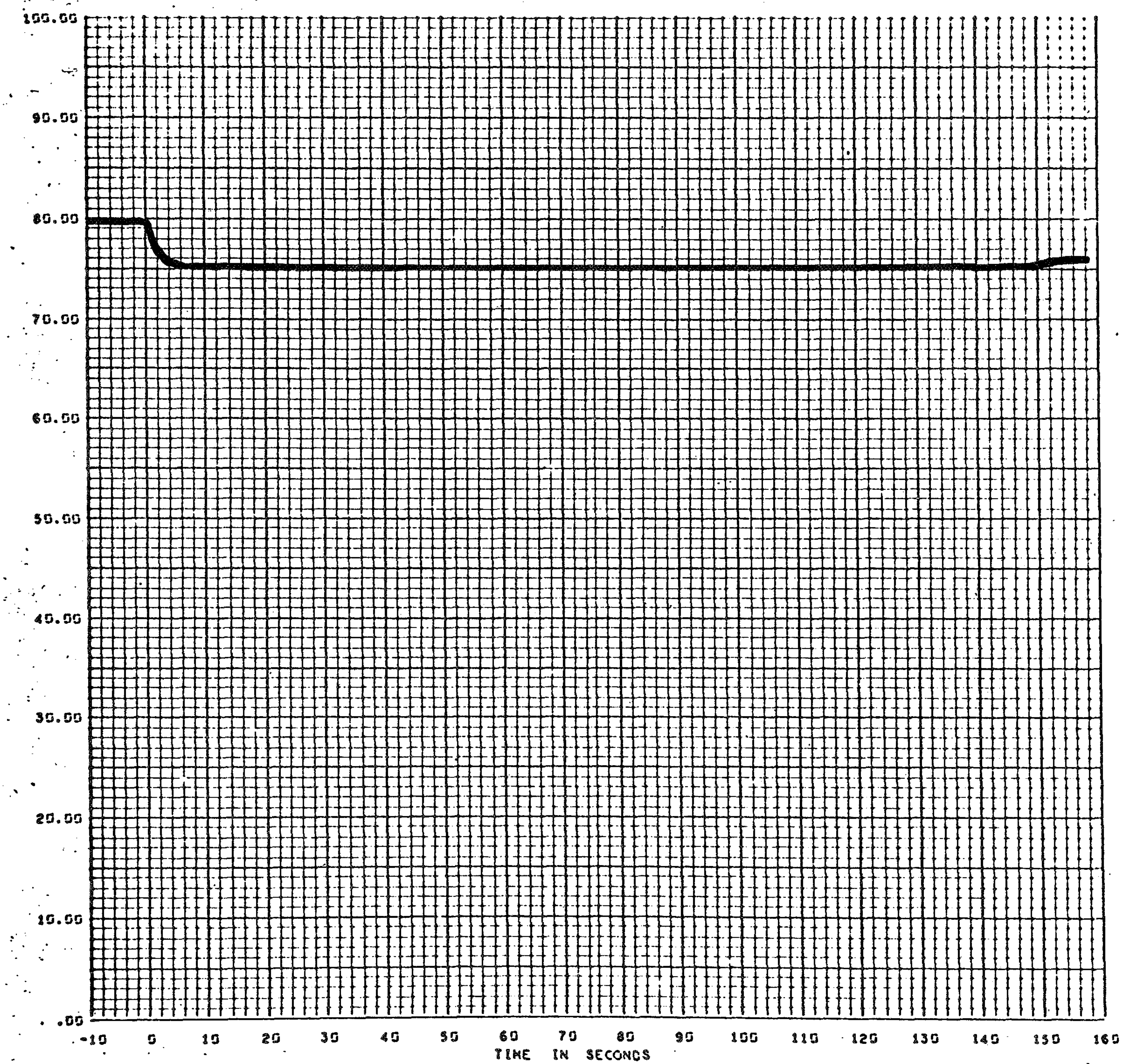
VEH. ID VERNIE A/C 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48/0

MEAS. TITLE - TEMP,FUEL * FLOW METER 1FC



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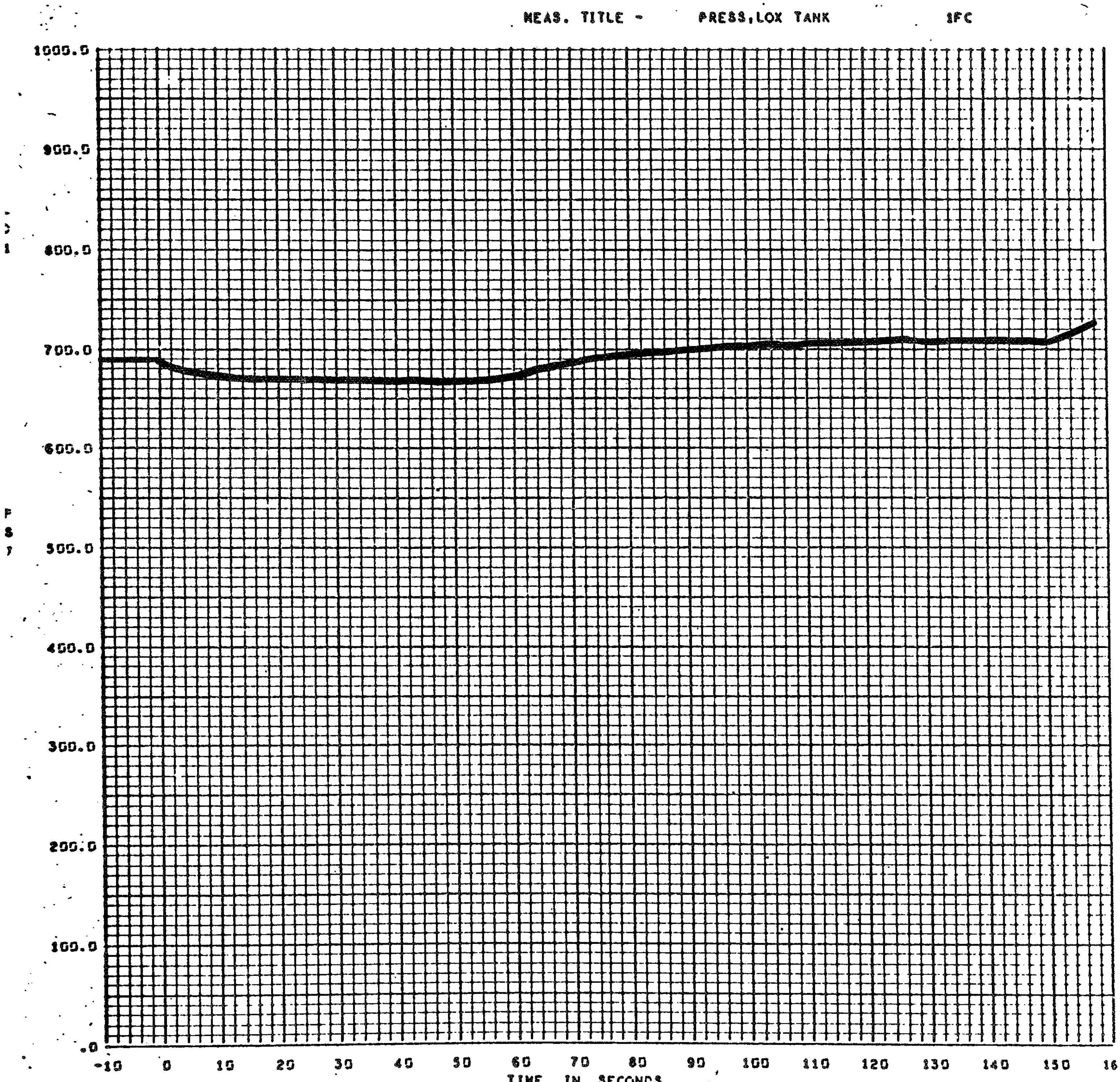
'EM , ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48/0



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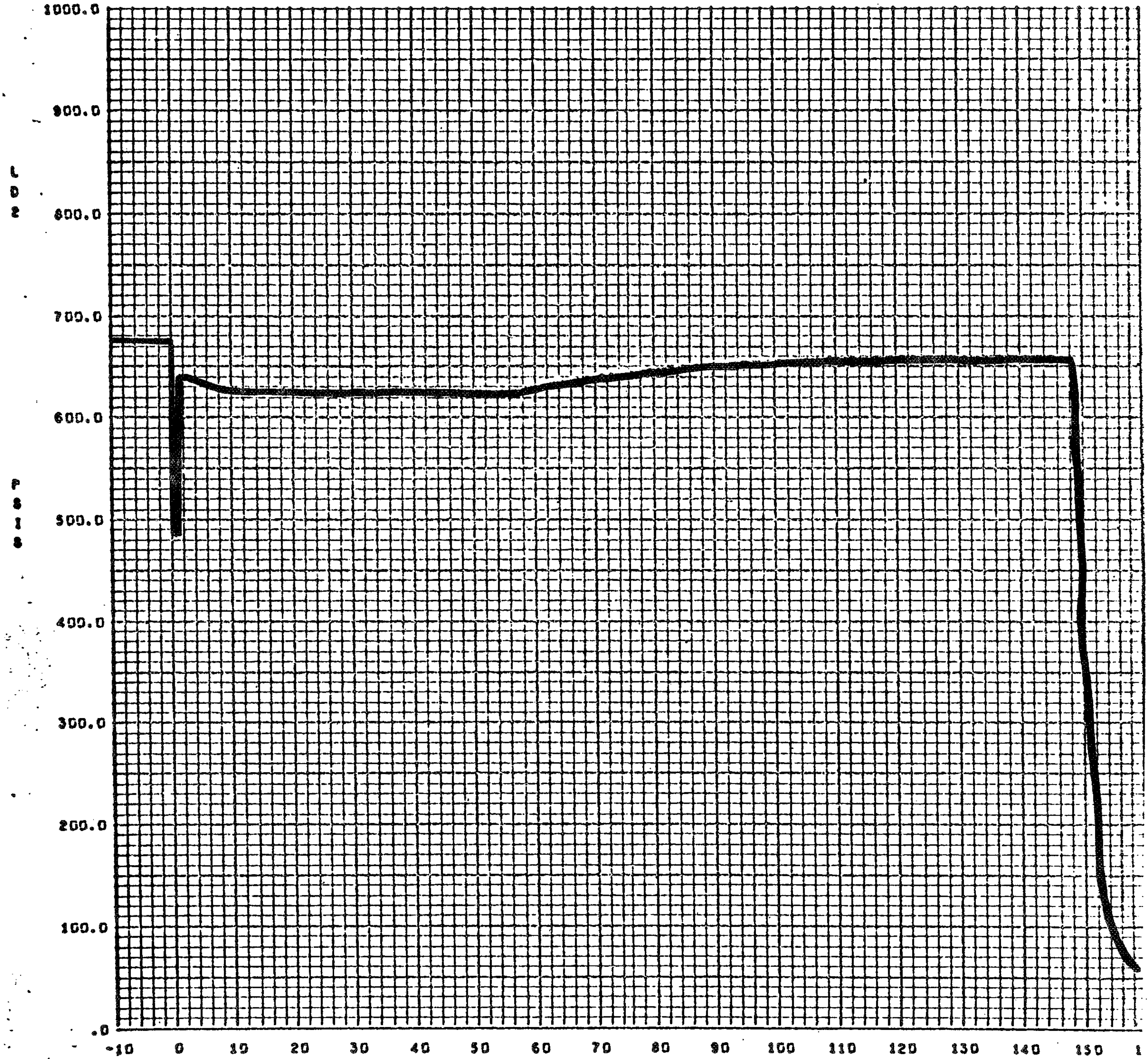
VEH. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48

MEAS. TITLE - PRESS,LOX INLET SFC

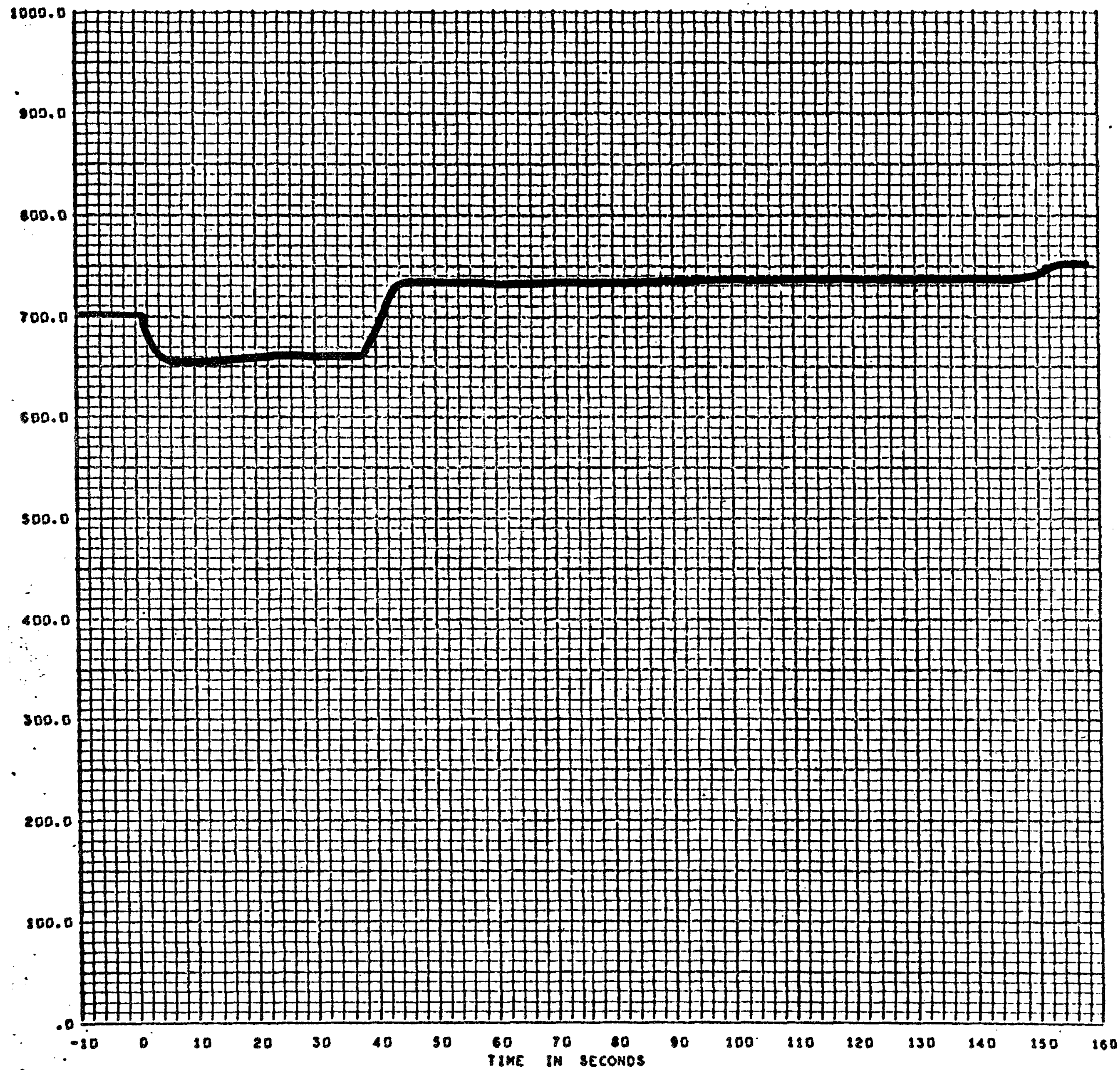


TIME IN SECONDS

TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =001

I. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48/000

MEAS. TITLE - PRESS,FUEL TANK 1FC



TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =002

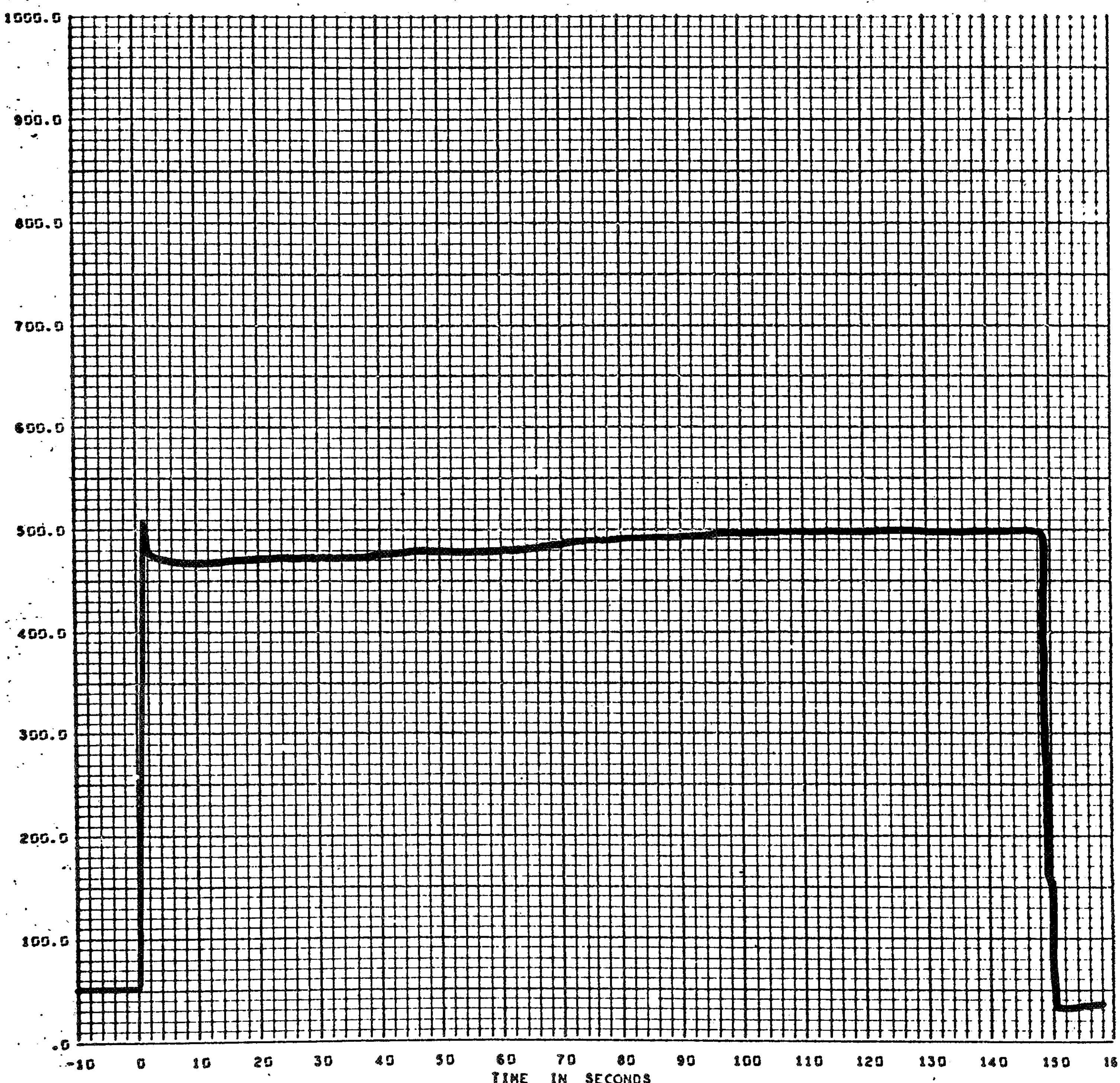
ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48/01

MEAS. TITLE - PRESS.FUEL INLET 1FC

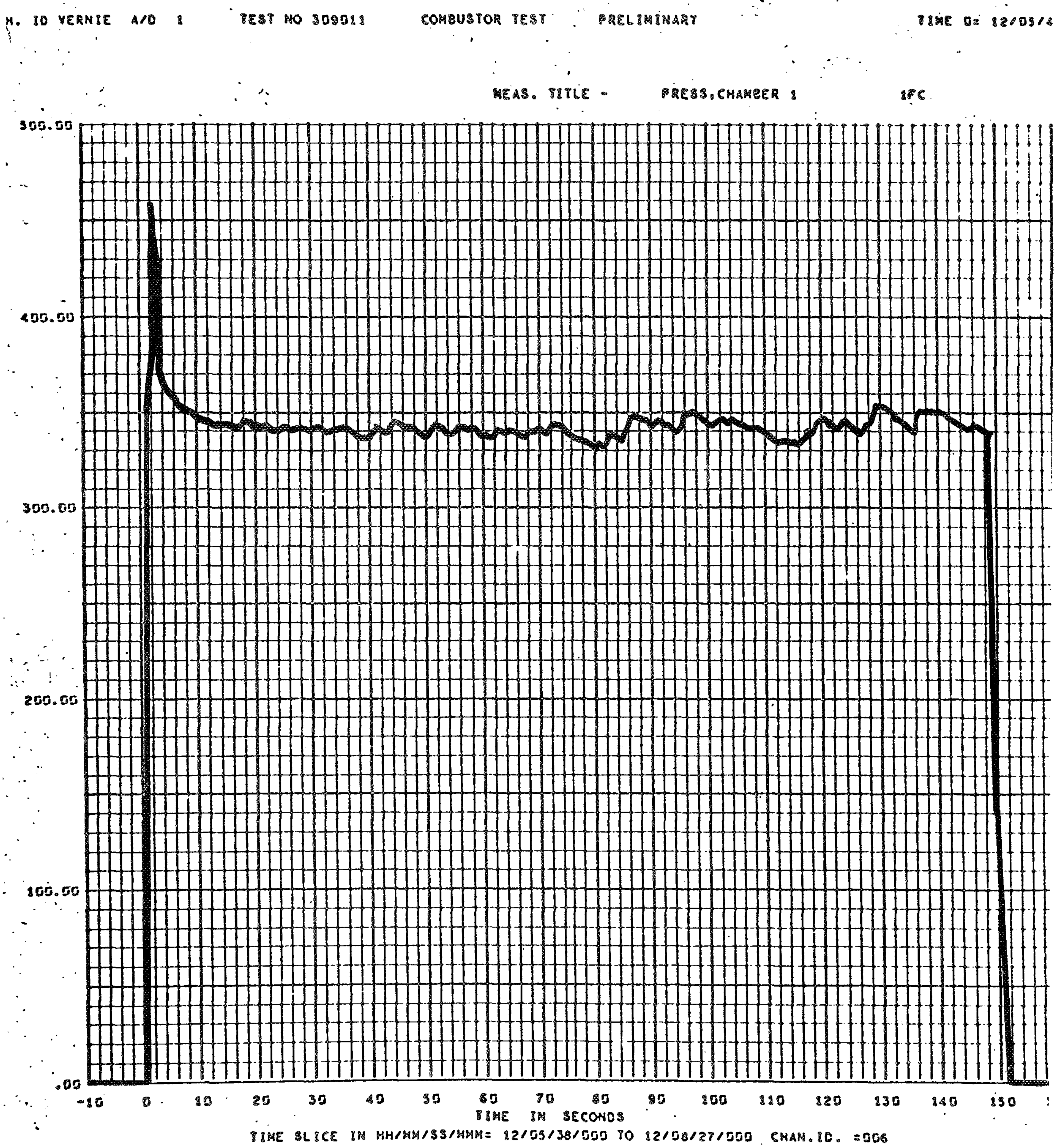
TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =003

ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48/

MEAS. TITLE - PRESS,LOX DOME 1FC



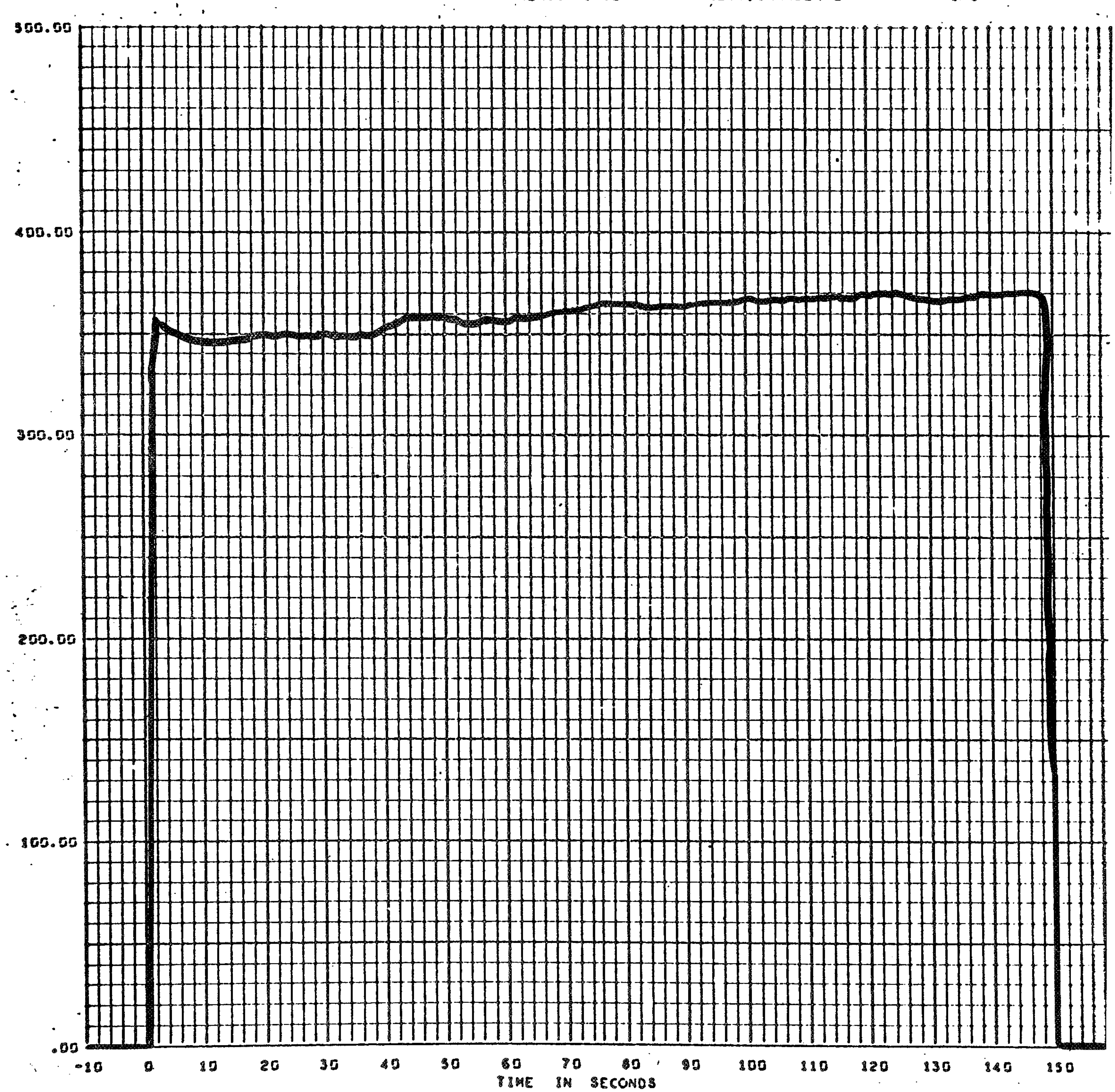
TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =007



H. ID VERNIE A/D 1
TEST NO 309011
COMBUSTOR TEST
PRELIMINARY
TIME 0= 12/05/4
MEAS. TITLE - PRESS,CHAMBER 1
1FC
500.00
400.00
300.00
200.00
100.00
.00
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
TIME IN SECONDS
TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =006

1. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/4

MEAS. TITLE - PRESS,CHAMBER 2 1FC



TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =005

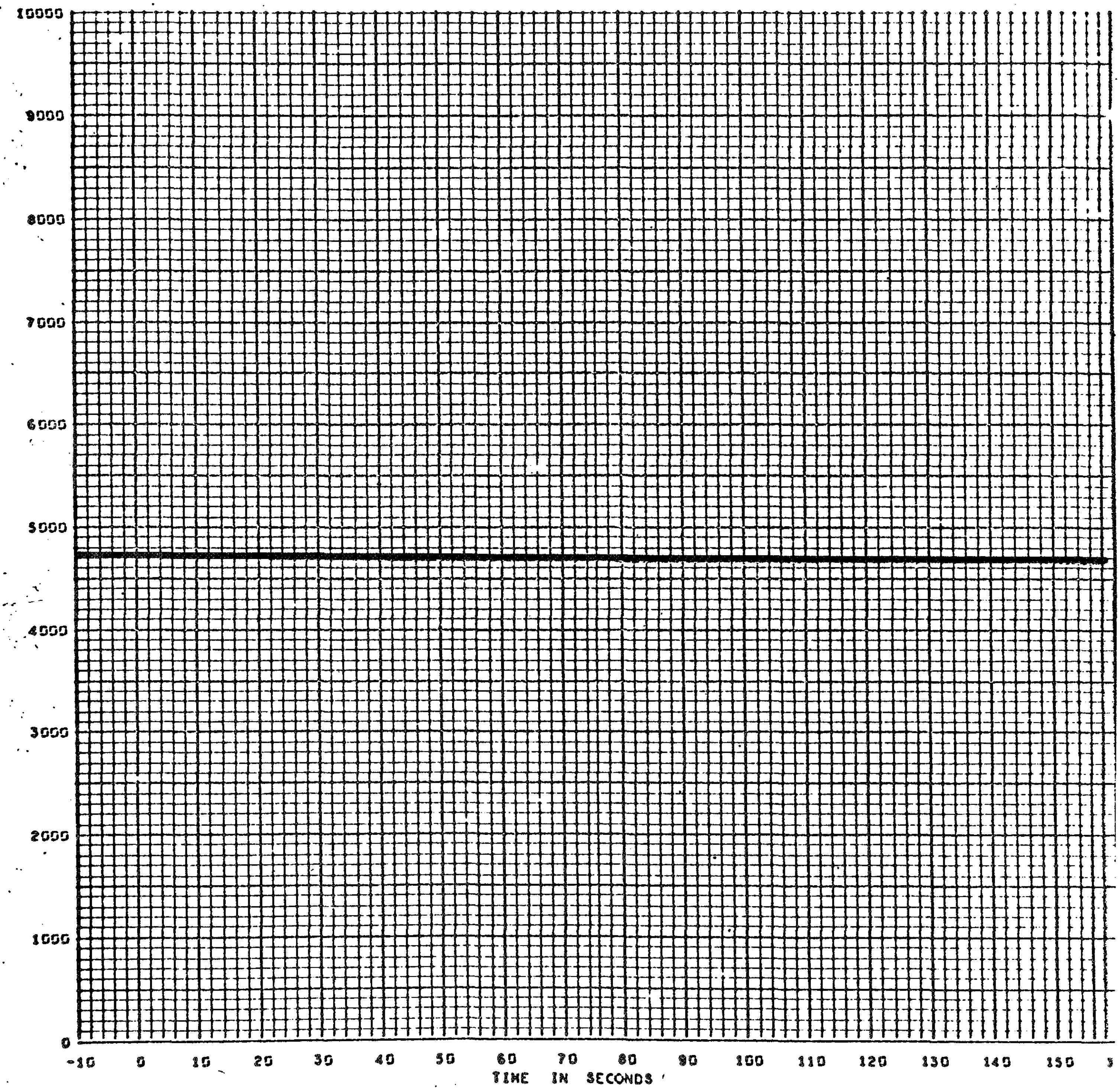
VEH. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/4

MEAS. TITLE - PRESS,FUEL TRUNNION IFC

TIME SLICE IN HH/MM/SS/MMM= 12/55/38/000 TO 12/58/27/000 CHAN.ID. =004

EH. ID VERNIE A/C 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48

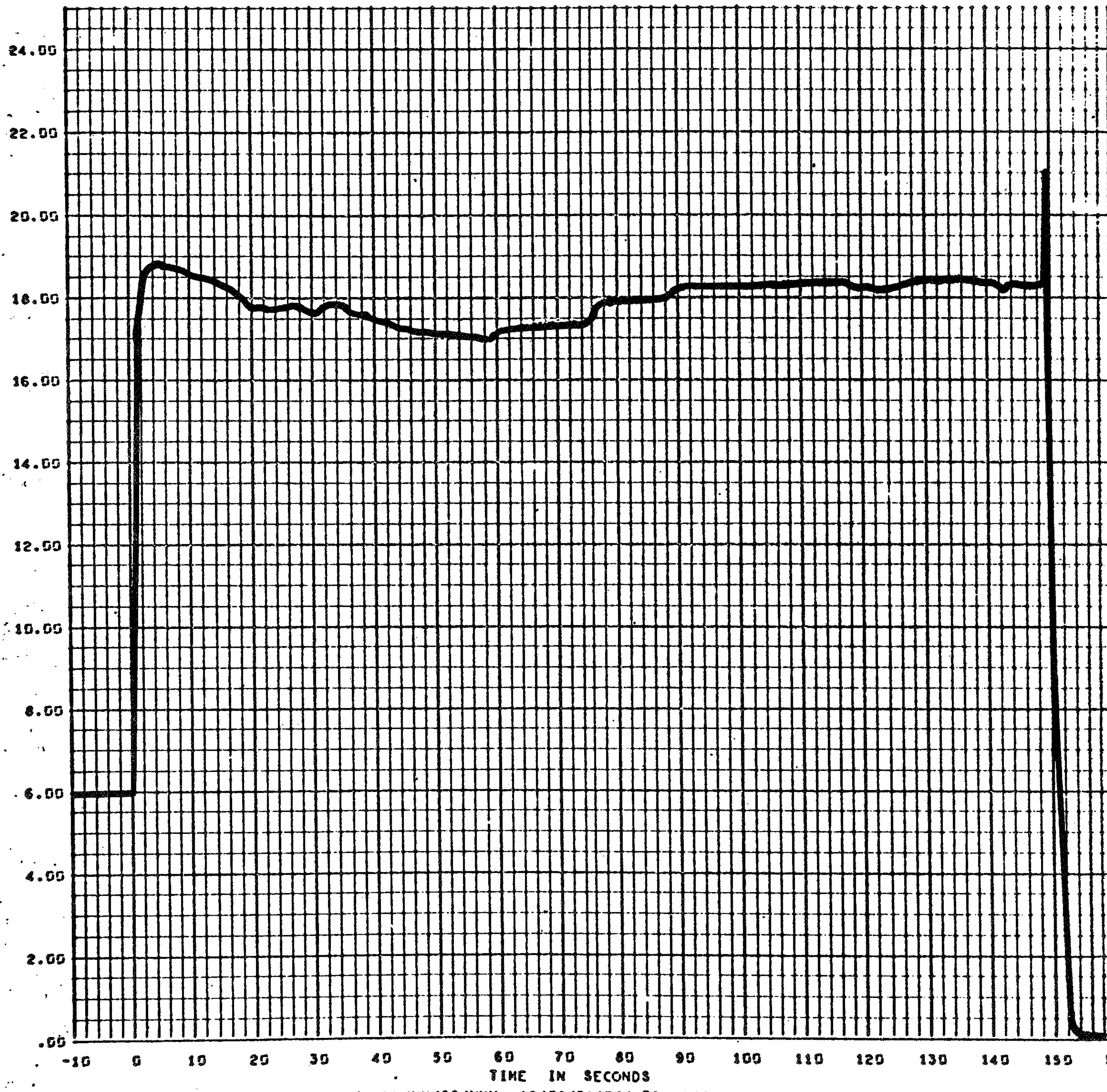
MEAS. TITLE - GN2 SUPPLY PRESSURE SFC



TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =018

I. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48

MEAS. TITLE - FLOWRATE,LOX 1FC



TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =027

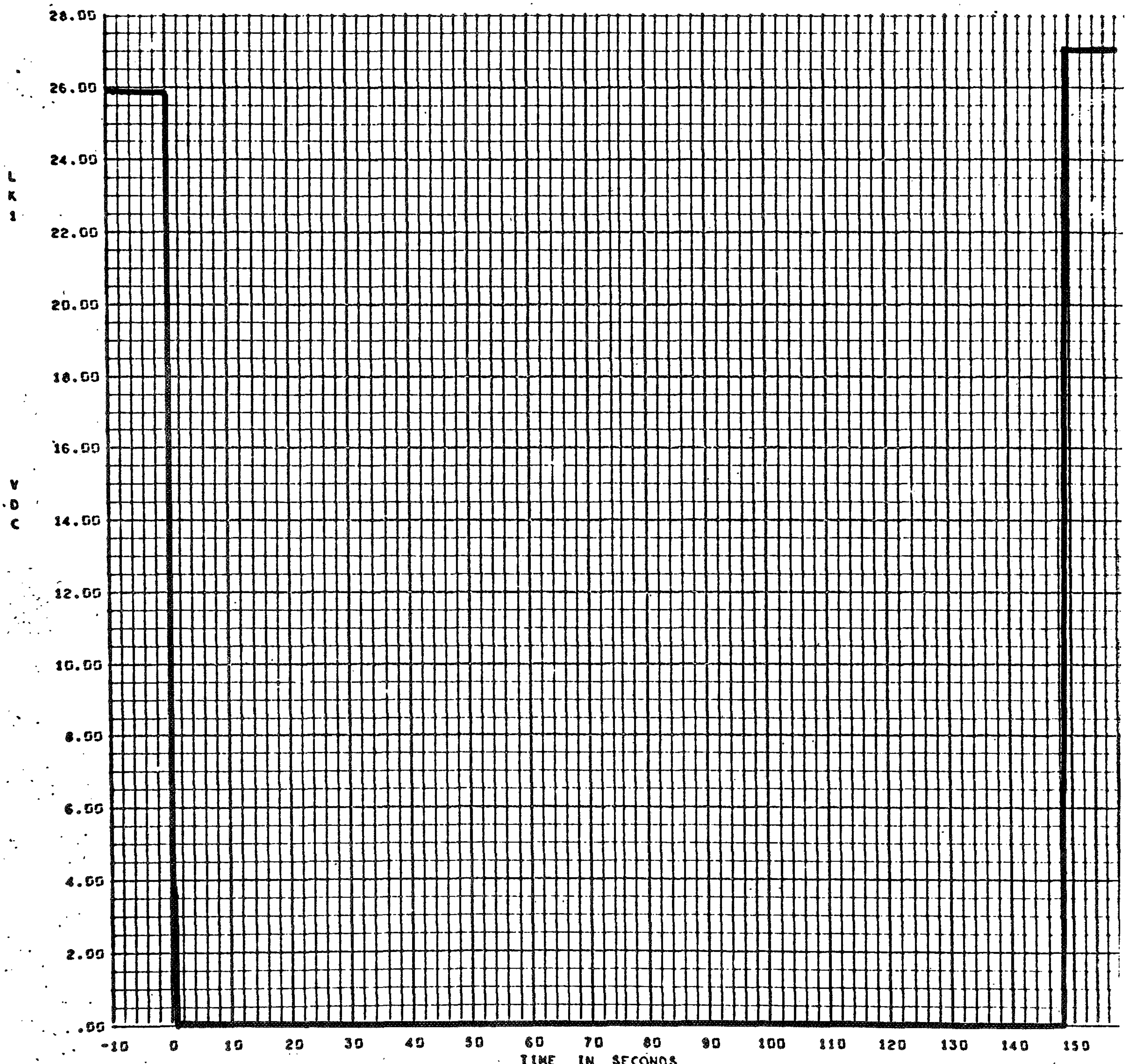
'EH. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48/

MEAS. TITLE - FLOWRATE,FUEL 1FC

TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =028

VEH. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/4

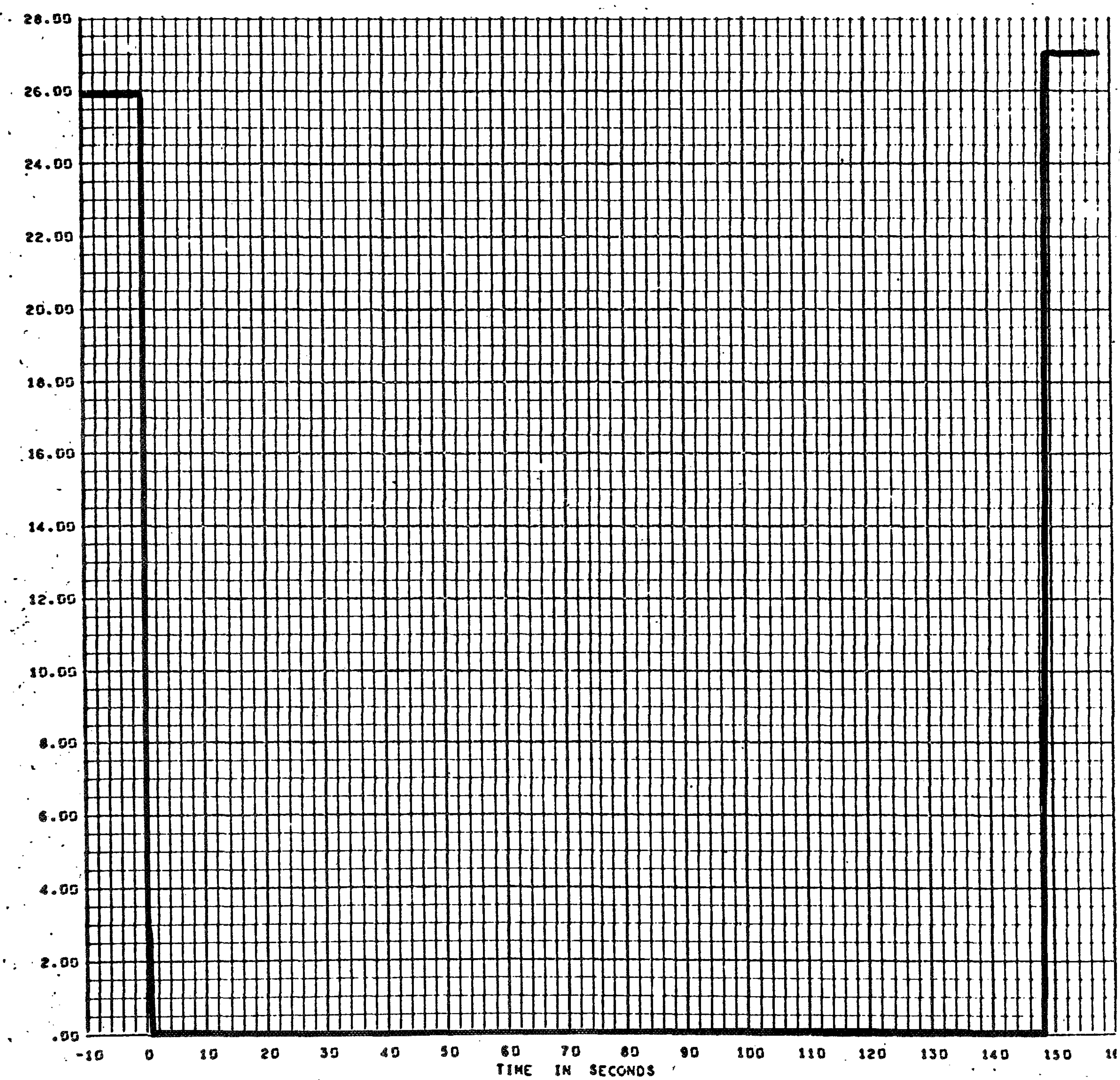
MEAS. TITLE - IGNITION COMMAND 1FC



TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =046

H. ID VERNIE A/D 1 TEST NO 309011 COMBUSTOR TEST PRELIMINARY TIME 0= 12/05/48.

MEAS. TITLE - CUTOFF COMMAND 1FC



TIME SLICE IN HH/MM/SS/MMM= 12/05/38/000 TO 12/08/27/000 CHAN.ID. =096

COMBUSTOR TEST 309-011 PRELIMINARY

-VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 48 PAGE- 1

ENG DATA 10KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

TIME	LC1	LC2	LC3	LD1	LD2	LD3	LD4	LD5	LD6	LD7	LD8	LD11
SEC	F	F	F	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS
9.993	-288.93	-231.54	79.63	690.2	676.0	702.5	703.1	53.4	-.54	-1.88	.6	4740.
8.966	-288.92	-231.54	79.59	689.8	676.0	702.6	703.2	53.1	-.29	-36.70	.7	4736.
7.939	-288.91	-231.54	79.61	689.8	675.8	702.5	703.1	52.9	-.26	-19.18	.7	4736.
6.911	-288.91	-231.54	79.59	690.0	675.8	702.5	703.2	52.7	-.31	-1.70	.6	4736.
5.884	-288.90	-231.54	79.61	689.8	675.7	702.5	703.2	52.7	-.33	-19.17	.7	4734.
4.857	-288.89	-231.54	79.60	689.7	675.6	702.5	703.2	52.6	-.24	-19.21	.6	4735.
3.829	-288.88	-231.54	79.60	689.7	675.5	702.5	703.2	52.5	-.30	-36.69	.7	4734.
2.802	-288.88	-231.54	79.61	689.5	675.3	702.5	703.1	52.5	-.25	-19.17	.7	4733.
1.775	-288.89	-231.54	79.60	689.5	675.3	702.6	703.2	52.4	-.30	-1.68	.7	4733.
0.747	-288.90	-231.54	79.60	689.5	675.1	702.6	703.2	52.4	-.34	-36.72	.7	4733.
0.265	-288.90	-231.54	79.60	689.4	675.1	702.6	703.2	52.3	-.30	-1.67	.7	4732.
1.308	-282.86	-265.39	77.71	666.8	578.3	692.7	637.1	399.1	232.76	215.28	463.7	4732.
2.335	-288.13	-254.26	76.73	684.6	641.3	679.9	657.3	476.9	414.29	355.42	565.4	4731.
3.363	-288.21	-233.92	75.74	682.8	638.0	669.5	647.5	475.5	400.57	354.96	557.8	4731.
4.390	-288.30	-231.54	75.49	681.2	636.5	662.1	640.6	474.1	365.65	352.72	552.0	4731.
5.418	-287.55	-231.54	75.41	679.7	635.0	657.6	636.1	472.9	360.81	351.03	548.5	4731.
6.445	-287.04	-231.54	75.35	678.5	633.7	655.8	634.4	471.3	357.28	349.88	547.2	4730.
7.472	-287.07	-231.54	75.31	677.4	631.4	655.4	633.8	470.8	353.98	348.50	546.9	4730.
8.500	-287.66	-231.54	75.28	676.4	630.2	655.8	634.0	469.6	352.29	348.10	546.8	4729.
9.527	-288.02	-231.54	75.24	675.6	629.5	656.4	634.6	469.9	350.34	347.72	547.1	4728.
10.555	-288.23	-231.54	75.23	675.0	628.9	657.1	635.1	470.2	348.59	347.45	547.7	4726.
11.582	-288.46	-231.54	75.21	674.5	628.3	657.8	635.8	469.4	347.27	347.21	547.0	4726.
12.609	-288.65	-231.54	75.19	674.0	627.4	658.3	636.5	469.3	345.31	346.54	547.4	4725.
13.637	-288.78	-231.54	75.17	673.5	627.1	658.9	636.8	470.3	345.20	347.34	547.8	4723.
14.664	-288.97	-231.54	75.17	673.2	627.3	659.4	637.5	470.7	344.88	347.51	548.7	4723.
15.692	-288.89	-231.54	75.15	672.9	627.4	659.8	638.0	471.3	344.33	347.74	549.4	4723.
16.719	-288.96	-231.54	75.14	672.7	626.4	660.3	638.3	470.9	343.98	348.07	549.9	4722.
17.747	-289.07	-231.54	75.13	672.6	626.8	660.7	638.7	472.2	344.70	348.94	550.0	4722.
18.774	-289.20	-231.54	75.11	672.5	627.7	661.2	639.3	473.9	346.79	350.39	552.1	4721.
19.802	-289.18	-231.54	75.12	672.5	627.3	661.4	639.6	474.6	344.44	350.70	551.4	4721.
20.829	-289.25	-231.54	75.10	672.4	626.8	661.8	639.9	473.9	344.12	349.64	551.2	4720.
21.856	-289.33	-231.54	75.11	672.3	626.7	662.0	640.1	473.3	343.59	349.48	552.0	4720.
22.883	-289.38	-231.54	75.10	672.2	626.8	662.2	640.3	474.3	342.68	350.20	552.1	4719.
23.911	-289.42	-231.54	75.10	672.2	626.7	662.3	640.4	474.2	341.03	350.31	552.6	4719.
24.938	-289.49	-231.54	75.09	672.1	626.6	662.5	640.7	474.9	342.11	350.71	551.5	4719.
25.966	-289.51	-231.54	75.09	672.1	626.8	662.8	640.9	475.9	343.35	350.89	552.5	4718.
26.993	-289.54	-231.54	75.08	672.0	626.4	662.7	640.8	475.4	342.57	350.26	551.5	4718.
28.021	-289.59	-231.54	75.07	671.9	626.5	662.8	640.8	475.0	342.96	350.39	551.9	4717.
29.048	-289.62	-231.54	75.07	671.8	626.5	662.9	641.2	474.8	342.32	350.50	551.9	4717.
30.075	-289.65	-231.54	75.06	671.9	626.3	663.0	641.0	475.7	342.01	351.04	552.0	4716.
31.103	-289.69	-231.54	75.06	671.8	626.4	663.0	641.2	475.5	343.12	350.84	551.8	4716.
32.130	-289.72	-231.54	75.06	671.7	626.2	663.1	641.1	475.5	342.30	350.70	552.7	4716.
33.158	-289.74	-231.54	75.05	671.7	626.3	663.2	641.4	475.6	340.60	350.52	552.2	4715.
34.185	-289.75	-231.54	75.06	671.6	625.8	663.2	641.3	474.9	342.18	350.03	552.3	4715.
35.213	-289.76	-231.54	75.04	671.6	626.1	663.2	641.2	475.0	342.76	350.05	552.0	4715.
36.240	-289.79	-231.54	75.04	671.4	626.1	663.3	641.3	475.6	343.23	350.69	552.7	4714.
37.267	-289.77	-231.54	75.06	671.5	626.2	663.2	641.3	475.1	340.98	350.55	552.7	4715.
38.295	-289.80	-231.54	75.04	671.3	625.9	664.4	642.2	475.5	338.68	350.79	552.7	4714.
39.322	-289.81	-231.54	75.07	671.4	626.0	676.6	653.0	476.0	338.05	352.15	561.8	4712.
40.350	-289.82	-231.54	75.10	671.1	626.2	692.7	668.1	477.8	337.55	353.99	572.0	4712.
41.377	-289.83	-231.54	75.11	670.9	626.0	707.2	682.0	477.9	343.08	355.03	581.5	4709.

COMBUSTOR TEST 309-011 PRELIMINARY

VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 48 PAGE- 2

ENG DATA 15KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

TIME SEC	LC1 F	LC2 F	LC3 F	LD1 PSIS	LD2 PSIS	LD3 PSIS	LD4 PSIS	LD5 PSIS	LD6 PSIS	LD7 PSIS	LD8 PSIS	LD11 PSIS
42.405	-289.83	-231.54	75.13	670.9	626.4	720.4	694.3	478.7	342.32	356.37	590.4	4707.
43.432	-289.83	-231.54	75.16	670.7	626.5	730.7	704.2	479.1	340.46	357.79	597.4	4706.
44.459	-289.82	-231.54	75.16	670.6	626.6	735.1	708.2	479.7	344.22	358.32	601.0	4707.
45.487	-289.82	-231.54	75.16	670.7	626.5	736.4	710.0	480.1	345.56	358.65	601.9	4706.
46.514	-289.83	-231.54	75.17	670.7	626.6	736.6	709.8	480.1	343.65	359.11	601.0	4706.
47.542	-289.84	-231.54	75.17	670.8	626.7	736.3	709.8	480.3	343.68	359.20	601.6	4705.
48.569	-289.84	-231.54	75.18	670.8	626.5	735.9	709.1	480.3	342.13	358.72	601.5	4706.
49.596	-289.84	-231.54	75.17	670.9	626.6	735.5	709.1	479.6	339.87	358.22	600.8	4706.
50.624	-289.86	-231.54	75.17	671.0	626.6	735.3	708.5	479.6	337.84	358.48	600.0	4706.
51.651	-289.85	-231.54	75.18	670.9	626.7	735.0	708.1	479.8	341.75	358.23	601.6	4705.
52.678	-289.85	-231.54	75.16	671.1	626.2	734.8	707.9	479.1	344.64	356.68	600.0	4705.
53.705	-289.84	-231.54	75.18	671.2	626.1	734.6	708.0	479.0	341.76	356.54	600.2	4705.
54.733	-289.85	-231.54	75.18	671.1	626.3	734.5	707.9	478.8	339.85	356.47	599.9	4705.
55.760	-289.85	-231.54	75.17	670.9	626.5	734.4	707.5	479.1	341.59	356.61	600.2	4705.
56.788	-289.81	-231.54	75.17	671.0	626.2	734.3	707.7	479.2	343.35	356.73	600.4	4705.
57.815	-289.81	-231.54	75.17	671.8	626.8	734.3	707.6	479.1	341.76	357.05	600.4	4705.
58.843	-289.81	-231.54	75.18	673.2	628.1	734.2	707.5	480.2	342.39	357.68	600.7	4704.
59.870	-289.82	-231.54	75.17	675.2	629.7	734.3	707.6	480.9	340.19	357.56	599.9	4703.
60.897	-289.83	-231.54	75.17	676.5	630.7	734.3	707.8	481.3	338.31	357.33	599.8	4703.
61.925	-289.83	-231.54	75.18	678.0	632.1	734.2	707.8	482.1	337.64	357.66	599.6	4703.
62.952	-289.83	-231.54	75.17	679.3	633.8	734.3	707.5	483.2	341.17	358.24	600.0	4702.
63.980	-289.82	-231.54	75.18	680.4	634.5	734.3	707.8	484.0	340.21	358.75	600.1	4702.
65.007	-289.81	-231.54	75.17	682.0	635.6	734.4	708.0	484.7	341.14	359.39	600.1	4701.
66.034	-289.79	-231.54	75.18	682.9	636.6	734.4	707.7	485.7	340.74	359.94	601.4	4700.
67.062	-289.81	-231.54	75.18	683.9	637.8	734.5	707.7	486.2	338.81	360.42	600.5	4700.
68.089	-289.82	-231.54	75.18	685.3	638.7	734.7	709.1	485.5	338.31	360.57	600.7	4698.
69.117	-289.83	-231.54	75.19	686.1	639.6	734.6	707.9	487.5	341.13	361.49	602.6	4699.
70.144	-289.87	-231.54	75.17	687.0	640.4	734.8	708.3	488.2	341.77	361.72	601.1	4698.
71.172	-289.87	-231.54	75.18	687.9	641.3	734.9	708.4	488.9	341.47	362.34	602.6	4698.
72.199	-289.86	-231.54	75.20	688.9	642.1	735.0	708.4	489.6	341.66	362.53	601.6	4697.
73.227	-289.85	-231.54	75.18	689.7	643.1	735.1	708.6	490.3	344.61	363.13	602.2	4697.
74.255	-289.84	-231.54	75.18	690.6	643.7	735.3	708.9	490.9	344.25	364.16	602.9	4697.
75.282	-289.85	-231.54	75.20	691.1	644.4	735.4	708.9	491.2	341.91	364.07	602.9	4697.
76.309	-289.86	-231.54	75.18	692.1	645.3	735.5	709.1	491.9	339.22	364.92	603.1	4697.
77.337	-289.86	-231.54	75.19	692.6	645.8	735.5	709.7	492.4	336.79	365.29	603.3	4696.
78.365	-289.88	-231.54	75.19	693.9	646.5	735.7	709.4	492.2	335.61	364.89	602.8	4697.
79.392	-289.89	-231.54	75.18	694.2	647.3	735.9	709.6	493.1	334.23	365.61	604.1	4696.
80.420	-289.91	-231.54	75.19	694.6	647.8	736.0	709.9	493.8	332.81	365.72	604.9	4695.
81.448	-289.89	-231.54	75.20	695.7	648.2	736.1	710.0	493.3	334.38	364.74	604.3	4695.
82.475	-289.88	-231.54	75.19	696.0	648.7	736.3	710.2	493.1	333.19	364.14	604.5	4694.
83.502	-289.86	-231.54	75.19	696.8	649.0	736.4	710.1	493.3	339.49	363.72	603.5	4694.
84.530	-289.86	-231.54	75.19	697.4	649.5	736.5	710.3	492.5	337.33	362.90	602.9	4694.
85.557	-289.88	-231.54	75.20	698.2	649.9	736.6	710.1	493.5	335.86	363.89	603.8	4695.
86.585	-289.89	-231.54	75.19	698.6	650.6	736.7	710.4	493.9	343.60	363.98	605.2	4693.
87.612	-289.89	-231.54	75.21	699.2	651.0	736.8	710.2	494.1	348.60	364.31	604.8	4693.
88.640	-289.90	-231.54	75.20	699.7	651.4	736.8	710.3	494.1	348.61	364.32	604.3	4693.
89.667	-289.90	-231.54	75.20	700.1	651.9	737.0	710.6	494.3	347.16	364.09	603.8	4693.
90.695	-289.91	-231.54	75.21	700.6	652.2	737.0	710.7	494.7	344.82	364.47	605.0	4693.
91.722	-289.92	-231.54	75.20	701.2	652.7	737.2	710.9	495.1	345.52	365.00	604.2	4693.
92.749	-289.94	-231.54	75.21	701.6	653.2	737.2	710.8	495.6	345.40	365.29	604.5	4692.
93.777	-289.96	-231.54	75.20	702.1	653.6	737.4	711.0	495.6	343.77	365.29	603.8	4692.

COMBUSTOR TEST 309-011 PRELIMINARY

D.-VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 48 PAGE-

ENG DATA 10KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

TIME	LC1	LC2	LC3	LD1	LD2	LD3	LD4	LD5	LD6	LD7	LD8	LD11
SEC	F	F	F	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSI
94.804	-289.95	-231.54	75.21	702.1	654.7	737.4	711.1	496.7	341.69	365.80	604.8	4692.
95.831	-289.91	-231.54	75.22	702.9	655.3	737.5	711.4	497.0	342.39	366.02	604.3	469[illegible]
96.859	-289.83	-231.54	75.21	703.3	655.2	737.6	711.2	497.1	350.63	366.44	604.7	4691.
97.886	-289.77	-231.54	75.21	703.5	655.3	737.6	711.4	497.4	351.06	366.70	605.3	4692.
98.914	-289.72	-231.54	75.22	703.7	655.5	737.8	711.7	497.6	349.38	367.30	605.5	4692.
99.941	-289.70	-231.54	75.22	704.3	655.9	737.8	711.5	498.0	347.10	367.48	605.3	4691.
100.969	-289.70	-231.54	75.22	704.7	656.3	738.0	711.7	498.7	344.34	368.39	605.1	4691.
101.996	-289.72	-231.54	75.22	704.9	656.5	738.0	711.9	497.7	345.42	367.17	605.4	4691
103.024	-289.72	-231.54	75.22	705.2	656.8	738.1	711.9	498.3	347.31	367.20	605.2	4691
104.052	-289.74	-231.54	75.22	705.4	656.9	738.2	712.1	498.1	346.35	367.09	606.7	4690
105.079	-289.77	-231.54	75.23	705.8	657.2	738.3	711.9	498.6	346.67	367.62	605.8	4690
106.107	-289.80	-231.54	75.22	706.0	657.4	738.4	712.0	498.7	344.88	367.66	605.4	4690
107.134	-289.80	-231.54	75.23	706.0	657.4	738.4	712.0	498.7	343.58	367.77	605.4	4690
108.161	-289.81	-231.54	75.23	706.3	657.7	738.5	712.3	499.1	342.37	368.04	606.7	4690
109.189	-289.82	-231.54	75.22	706.6	657.8	738.6	712.2	498.9	342.92	367.93	606.7	4689
110.217	-289.84	-231.54	75.24	707.0	657.8	738.6	712.4	499.4	341.36	368.17	606.1	4690
111.244	-289.88	-231.54	75.22	706.9	658.0	738.7	712.2	499.2	339.08	368.14	607.6	4689
112.271	-289.91	-231.54	75.23	707.1	658.2	738.8	712.4	499.5	336.93	368.35	606.6	4689
113.299	-289.92	-231.54	75.24	707.1	658.5	738.9	712.5	500.1	334.85	368.90	607.7	4689
114.326	-289.90	-231.54	75.22	707.1	658.9	738.9	712.6	500.2	335.19	368.97	606.7	4689
115.354	-289.88	-231.54	75.24	707.5	659.3	739.0	712.7	500.6	335.21	369.39	607.9	4689
116.381	-289.83	-231.54	75.24	707.8	659.3	739.1	712.7	500.2	335.28	369.02	606.8	4688
117.409	-289.77	-231.54	75.23	707.5	659.2	739.1	712.8	500.1	335.26	368.90	607.6	4688
118.437	-289.73	-231.54	75.23	708.0	659.2	739.2	712.7	499.9	341.29	368.98	606.9	4687
119.464	-289.72	-231.54	75.24	708.0	659.1	739.2	712.8	499.7	341.83	369.03	605.8	4686
120.492	-289.70	-231.54	75.24	707.9	659.5	739.3	712.8	500.7	346.57	369.04	607.5	4686
121.519	-289.70	-231.54	75.23	708.2	659.7	739.3	713.0	500.9	346.95	370.15	607.7	4687
122.546	-289.72	-231.54	75.24	708.2	659.6	739.4	712.9	501.0	344.41	370.58	607.9	4686
123.574	-289.73	-231.54	75.24	708.4	660.1	739.5	713.0	500.9	342.47	370.60	607.6	4687
124.601	-289.73	-231.54	75.25	708.5	659.9	739.5	713.4	501.2	346.40	370.79	607.7	468
125.628	-289.74	-231.54	75.23	708.4	659.7	739.6	713.2	501.1	344.64	370.65	608.8	4687
126.656	-289.76	-231.54	75.24	708.7	659.9	739.7	713.3	500.7	342.15	369.69	608.1	4687
127.683	-289.77	-231.54	75.25	708.9	659.9	739.7	713.4	500.1	340.90	368.60	608.6	4687
128.710	-289.78	-231.54	75.25	709.0	659.8	739.7	713.4	499.9	344.26	368.54	607.8	4687
129.738	-289.78	-231.54	75.24	708.9	659.6	739.8	713.4	499.2	350.37	367.45	606.8	468
130.765	-289.79	-231.54	75.25	709.1	659.6	739.8	713.5	499.1	353.84	367.36	608.1	4687
131.793	-289.83	-231.54	75.25	708.8	659.5	739.8	713.4	499.1	353.61	367.31	607.0	4687
132.820	-289.85	-231.54	75.25	708.5	659.1	739.8	713.0	499.1	351.15	367.47	605.8	468
133.848	-289.86	-231.54	75.26	708.9	659.2	739.9	713.4	499.5	348.67	368.02	607.2	4681
134.875	-289.88	-231.54	75.25	708.8	659.1	739.9	713.4	499.7	346.00	368.14	607.0	4681
135.903	-289.89	-231.54	75.26	708.5	659.8	739.9	713.2	499.5	343.75	367.93	607.6	468
136.930	-289.88	-231.54	75.26	708.3	660.0	740.0	713.5	499.7	341.96	367.98	607.9	468
137.958	-289.82	-231.54	75.27	708.7	660.1	740.0	713.8	500.1	351.24	368.89	607.3	468
138.985	-289.72	-231.54	75.28	708.6	660.2	740.0	713.4	501.0	351.59	369.81	608.0	468
140.013	-289.66	-231.54	75.26	708.5	660.1	740.0	713.5	500.4	350.40	369.65	608.1	468
141.040	-289.61	-231.54	75.27	708.3	660.1	740.0	713.6	500.8	351.63	370.16	608.4	468
142.068	-289.60	-231.54	75.28	708.3	660.3	740.1	713.5	500.8	350.02	370.22	608.9	468
143.095	-289.56	-231.54	75.27	708.3	659.6	740.0	713.5	500.6	348.05	369.79	608.3	468
144.122	-289.55	-231.54	75.27	708.2	659.9	740.1	713.9	500.9	345.30	370.24	608.1	468
145.150	-289.53	-231.54	75.28	708.1	659.6	740.1	713.9	501.1	343.55	370.91	608.6	468
146.177	-289.57	-231.54	75.28	708.0	659.6	740.1	713.6	501.2	342.46	371.17	607.3	468

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COMBUSTOR TEST 309-011 PRELIMINARY

ID.-VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 48 PAGE-

ENG DATA 10KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

TIME	LC1	LC2	LC3	LD1	LD2	LD3	LD4	LD5	LD6	LD7	LD8	LD11
SEC	F	F	F	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS	PSIS
147.205	-289.60	-231.54	75.27	707.7	659.4	740.2	713.7	501.6	343.93	371.48	608.6	4684.
148.232	-283.64	-231.54	75.28	707.8	659.2	740.1	714.1	501.1	342.44	371.42	608.1	4685.
149.259	-289.66	-231.54	75.27	707.8	658.9	740.1	713.9	500.1	341.26	370.02	608.3	4684.
150.287	-288.60	-262.31	75.38	706.8	594.5	741.8	739.1	239.9	215.65	195.41	281.0	4684.
151.314	-275.35	-244.59	75.57	708.7	404.4	746.6	747.5	67.1	108.28	20.84	138.3	4684.
152.341	-279.79	-231.54	75.70	711.3	253.7	750.6	752.2	32.8	14.12	-2.47	88.7	4680.
153.369	-259.69	-231.54	75.79	713.8	154.4	752.5	752.7	33.6	-.86	-2.40	73.6	4682.
154.396	-251.08	-231.54	75.84	716.4	111.9	753.3	753.2	34.5	-.85	-2.39	67.9	4682.
155.423	-250.32	-231.54	75.90	719.1	100.1	753.5	753.7	35.3	-.84	-2.30	65.8	4681.
156.451	-252.76	-231.54	75.97	721.8	89.4	753.7	754.0	35.9	-.79	-2.30	64.4	4682.
157.478	-255.90	-231.54	76.01	724.3	77.9	753.8	754.3	36.6	-.80	-2.18	63.2	4681.
158.505	-258.51	-231.54	76.05	727.0	69.3	753.8	754.5	37.1	-.85	-2.14	62.4	4682.
159.059	-260.62	-231.54	76.10	728.9	62.1	754.1	754.9	37.5	-.83	-2.13	62.0	4682.

COMBUSTOR TEST 309-011 PRELIMINARY

ID.-VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 48 PAGE-

ENG DATA 10KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

TIME	LF1	LF2	LK1	LK2
SEC	GPM	GPM	VDC	VDC
-9.993	5.94	.05	25.94	25.89
-8.966	5.96	.07	25.90	25.91
-7.939	5.96	.06	25.90	25.90
-6.911	5.95	.07	25.89	25.93
-5.884	5.95	.06	25.89	25.90
-4.857	5.96	.07	25.92	25.92
-3.829	5.97	.06	25.89	25.89
-2.802	5.97	.07	25.91	25.92
-1.775	5.97	.06	25.89	25.90
-0.747	5.98	.08	25.90	25.89
0.280	5.97	.06	21.92	21.90
1.308	15.67	19.82	.00	.01
2.335	18.38	15.64	.00	.00
3.363	18.75	15.43	.01	.00
4.390	18.82	15.30	.00	.00
5.418	18.66	15.25	.00	.00
6.445	18.84	15.21	.01	.01
7.472	18.80	15.26	.00	.00
8.500	18.75	15.28	.00	.00
9.527	18.64	15.31	.00	.01
10.555	18.60	15.29	.00	.00
11.582	18.57	15.32	.01	.00
12.609	18.52	15.36	.00	.00
13.637	18.47	15.40	.00	.00
14.664	18.39	15.38	.01	.00
15.692	18.32	15.38	.00	.00
16.719	18.25	15.43	.00	.00
17.747	18.17	15.37	.01	.01
18.774	18.03	15.37	.00	.00
19.802	17.85	15.34	.00	.00
20.829	17.80	15.38	.00	.01
21.856	17.80	15.44	.00	.00
22.883	17.76	15.40	.00	.00
23.911	17.76	15.39	.00	.01
24.938	17.80	15.36	.00	.00
25.966	17.84	15.37	.00	.01
26.993	17.83	15.40	.00	.00
28.021	17.79	15.41	.00	.00
29.048	17.74	15.40	.00	.00
30.075	17.75	15.39	.00	.00
31.103	17.71	15.38	.00	.00
32.130	17.84	15.38	.01	.00
33.158	17.88	15.38	.00	.00
34.185	17.91	15.42	.00	.00
35.213	17.87	15.42	.01	.00
36.240	17.71	15.41	.00	.00
37.267	17.65	15.44	.00	.00
38.295	17.63	15.41	.00	.01
39.322	17.58	15.74	.00	.00
40.350	17.55	16.05	.00	.00
41.377	17.48	16.39	.00	.01

COMBUSTOR TEST 309-011 PRELIMINARY

).-VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 40 PAGE- 2

ENG DATA 10KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

TIME SEC	LF1 GPM	LF2 GPM	LK1 VDC	LK2 VDC
42.405	17.41	16.66	.00	.00
43.432	17.35	16.89	.00	.01
44.459	17.29	17.03	.00	.00
45.487	17.27	17.02	.00	.00
46.514	17.24	17.02	.01	.00
47.542	17.21	17.02	.00	.00
48.569	17.22	17.03	.00	.00
49.596	17.20	16.98	.00	.00
50.624	17.17	16.97	.00	.00
51.651	17.16	17.02	.01	.00
52.678	17.18	17.02	.00	.01
53.705	17.16	17.00	.00	.00
54.733	17.16	16.98	.00	.01
55.760	17.12	17.00	.00	.00
56.788	17.09	17.02	.00	.00
57.815	17.03	16.98	.00	.01
58.843	17.03	16.98	.00	.00
59.870	17.10	16.94	.00	.00
60.897	17.22	16.98	.01	.00
61.925	17.25	16.96	.00	.00
62.952	17.28	16.97	.00	.00
63.980	17.31	16.93	.01	.01
65.007	17.34	16.91	.00	.00
66.034	17.33	16.93	.00	.00
67.062	17.37	16.92	.00	.00
68.089	17.39	16.91	.00	.00
69.117	17.39	16.93	.00	.00
70.144	17.39	16.87	.00	.00
71.172	17.38	16.90	.00	.00
72.199	17.37	16.86	.00	.00
73.227	17.41	16.89	.01	.00
74.255	17.42	16.85	.00	.00
75.282	17.45	16.83	.00	.00
76.309	17.55	16.79	.00	.00
77.337	17.83	16.78	.00	.00
78.365	17.30	16.79	.00	.00
79.392	17.87	16.82	.00	.01
80.420	17.88	16.87	.00	.00
81.448	17.93	16.83	.01	.00
82.475	17.95	16.84	.00	.00
83.502	17.95	16.84	.00	.00
84.530	17.97	16.86	.00	.00
85.557	17.98	16.89	.00	.01
86.585	17.99	16.91	.00	.00
87.612	18.01	16.92	.00	.01
88.640	18.05	16.89	.00	.01
89.667	18.19	16.90	.00	.00
90.695	18.24	16.91	.00	.00
91.722	18.25	16.87	.00	.00
92.749	18.28	16.89	.00	.00
93.777	18.27	16.87	.00	.01

COMBUSTOR TEST 309-011 PRELIMINARY

D.-VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 48 PAGE- 3

ENG DATA 10KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

TIME SEC	LF1 GPM	LF2 GPM	LK1 VDC	LK2 VDC
94.804	18.29	16.87	.00	.00
95.831	18.31	16.86	.00	.00
96.859	18.30	16.89	.00	.01
97.886	18.32	16.85	.00	.00
98.914	18.31	16.80	.00	.00
99.941	18.29	16.78	.00	.00
100.969	18.30	16.82	.00	.00
101.996	18.29	16.84	.00	.00
103.024	18.31	16.84	.00	.00
104.052	18.33	16.86	.00	.00
105.079	18.32	16.84	.01	.00
106.107	18.35	16.85	.00	.00
107.134	18.35	16.84	.00	.00
108.161	18.37	16.83	.00	.00
109.189	18.38	16.85	.00	.00
110.217	18.37	16.79	.00	.00
111.244	18.38	16.87	.00	.01
112.271	18.39	16.87	.00	.00
113.299	18.37	16.86	.00	.00
114.326	18.36	16.83	.00	.01
115.354	18.35	16.80	.00	.00
116.381	18.35	16.78	.00	.00
117.409	18.36	16.82	.00	.00
118.437	18.34	16.82	.00	.00
19.464	18.28	16.81	.00	.00
120.492	18.27	16.83	.00	.00
121.519	18.26	16.80	.00	.00
122.546	18.25	16.72	.00	.00
123.574	18.24	16.72	.00	.00
124.601	18.25	16.70	.00	.00
125.628	18.24	16.73	.00	.00
126.656	18.30	16.76	.00	.00
127.683	18.34	16.76	.01	.00
128.710	18.39	16.79	.00	.00
129.738	18.38	16.78	.00	.00
130.765	18.41	16.84	.00	.00
131.793	18.44	16.81	.00	.00
132.820	18.45	16.82	.00	.01
133.848	18.43	16.78	.01	.00
134.875	18.42	16.84	.00	.00
135.903	18.43	16.87	.00	.00
136.930	18.44	16.85	.00	.00
137.958	18.42	16.77	.01	.00
138.985	18.39	16.73	.00	.00
140.013	18.39	16.74	.00	.01
141.040	18.37	16.75	.00	.00
142.068	18.36	16.76	.00	.00
143.095	18.35	16.80	.00	.00
144.122	18.32	16.76	.00	.00
145.150	18.33	16.76	.01	.00
146.177	18.35	16.74	.00	.00

COMBUSTOR TEST 309-011 PRELIMINARY

ID.-VERNIE TYP-DAF DATE-10/21/69 TABULATION OF AVERAGES TIME 0 =12 05 48 PAGE-

ENG DATA 10KC SAM RATE A/D SYSTEM NO 1 SCAN - C CALIB. STEP -N/A T-309-011

	TIME SEC	LF1 GPM	LF2 GPM	LK1 VDC	LK2 VDC
+	147.205	18.32	16.77	.00	.00
+	148.232	18.34	16.75	.00	.00
+	149.259	18.34	16.78	.00	.00
+	150.287	18.49	5.16	25.00	24.98
+	151.314	9.09	.11	27.08	27.07
+	152.341	3.74	.10	27.06	27.08
+	153.369	.62	.10	27.09	27.06
+	154.396	.20	.10	27.08	27.08
+	155.423	.15	.09	27.10	27.07
+	156.451	.14	.10	27.10	27.10
+	157.478	.13	.08	27.11	27.08
+	158.505	.13	.10	27.11	27.10
+	159.059	.12	.08	27.09	27.10

TABLE IV

Event Record

Test No.	13		14
Time of Ignition	13:43:31.7		14:32:10.6
Time in Seconds from Ignition for:			
Opening of Orifice Sample Valve	60		33
Closing of orifice sample valve		109	42
Opening of sample supply valve	66	110	44
Opening of sample bottle #2	68		110
Closing of sample bottle #2	85		122
Opening of sample bottle #3		112	129
Closing of sample bottle #3		124	141
Closing of sample supply valve	86	125	143

SAMPLE CALCULATION

Applying an energy balance about the calorimetric probe we find that:

Enthalpy of the gas at the tip of the probe	=	Enthalpy of the gas at the exit of the probe	+	Enthalpy absorbed by the cooling water of the probe

or:

$$m_g h_s = (mC_p)_g (T_g - T_r) + (mC_p)_w (T_2 - T_1)$$

$$h_s = \frac{(mC_p)_w (T_2 - T_1)}{m_g} + (C_p)_g (T_g - T_r)$$

where:

T_1 = inlet water temperature

T_2 = outlet water temperature

T_g = gas temperature at the exit of inner probe

T_r = reference temperature for enthalpy calculations

$(C_p)_g$ = heat capacity of the gas

$(C_p)_w$ = heat capacity of the water

m_g = gas mass flow rate

m_w = water mass flow rate

The best available data came from experiment 3093-13. With the probe 1.4 inches from the centerline of the plume the available data is:

Inner Jacket:

m_w = 0.233 gpm $\cong$ 0.2425 lbs/sec

T_1 = 68°F

T_2 = 84°F

Note, an approximately 5°, $(T_2 - T_1)$ difference was experience with no gas flow. The calculations are presented but same question concerning their validity remains.

Inner Probe:

T_g = 80°F   Orifice diameter = 0.083 in.

Static pressure = 13.7 psig

Stagnation Pressure = 28 psig

Liquid Oxygen:

Mass flow rate = m_{O2} = 21.3 gpm

Fuel:

Mass flow rate = m_F = 17.3 gpm
O/F = 2.165

It will be assumed that the gas composition is equal to the one obtained in experiment 3093-14. On a dry basis:

Compound	Mole % (dry basis)
H_2	7.7
CH_4	.02
CO	10.2
O_2	3.1
N_2	1.3
CO_2	77.0

Changing the composition from a dry basis to a wet basis using a simple material balance we obtain (the C/H ratio remains that of JP-5):

Compound	Mole % (wet basis)
CH_4	0.01
H_2	4.30
CO	5.70
O_2	1.73
N_2	0.72
CO_2	43.0
H_2O	44.46

From this composition we get the O/F ratio at the probe tip:

$$O/F = 3.28$$

Assuming a 3% (mole) of solid C that went unaccounted for in the gas sample and taking into account that some oxygen diffused into the plume in the same fashion as nitrogen, we can obtain a corrected gas composition, which is: (eliminating the air diffused in)

	mole %
CH_4	0.01
H_2	4.20
CO	5.56
O_2	1.54
CO_2	42.16
H_2O	43.52
C	3.00

The O/F ratio of this composition is 3.1

Had 6% mole been assumed a slightly lower, but significantly above 2.2 O/F ratio would have been obtained. Therefore, the local O/F does appear to be leaner than the mean.

From this composition we can obtain the heat capacity of the gas mixture: $C_p = 1.225 \times 10^{-3}$ BTU/lb°F.

A choked orifice is used at the end of the inner probe to calculate the mass flow rate of gas. The formula applying to this orifice is:

$$mg = AC_d \frac{P_o}{T_o} \sqrt{\frac{\gamma \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}{R/g}}$$

where:

A = area of the orifice (in^2)

C_d = nozzle discharge coefficient = 0.96

P_o = upstream stagnation pressure (psia)

T_o = upstream temperature (°R)

γ = specific heat ratio of the gas = 1.2

R = gas constant of gas (ft-lb/lb-°F) = 52.9

g = gravitational acceleration (ft/sec^2)

then:

$$m_g = (54 \times 10^{-4}) \times (.96) \frac{(42.7)}{\sqrt{540}} \sqrt{\frac{1.2 \left(\frac{2}{2.2}\right)^{2.2/2}}{52.9/32.17}}$$

$$m_g = 0.004825 \text{ lbs/sec}$$

Using the energy balance about the inner probe:

$$h_s = \frac{(0.2425 \text{ lbs/sec})(1 \text{ BTU/lb°F})(84°F-68°F)}{4.825 \times 10^{-3} \text{ lbs/sec}} + \left[(1.225 \times 10^{-3} \text{ BTU/lb°F})(80°F - 32°F)\right]$$

$$h_s \cong 804 \text{ BTU/lb}$$

By knowing that @ the tip of the probe:

$$h_s \cong 804 \quad \text{BTU/lb.}$$

and at the end of the probe

$$T = 80°F$$

and

$$h_s = \bar{\bar{C}}_p (T_2 - T_1)$$

$$\frac{h_s}{C_p} = T_2 - T_1$$

$$T_2 = \frac{h_s}{C_p} + T_1$$

$$\overline{C_p} = \text{heat capacity @ } T_{Ref} \sim 0.4 \text{ BTU/lb°F}$$

T_2 $\quad$ T_2 = temperature @ tip of probe

T_1 = temperature @ end of probe

$$T_2 = \frac{804}{0.4} + 80°F$$

$$T_2 = 2100 + 80 = 2180°F$$

This temperature lies below a 2300°F measurement made at about the same location in a vernier plume burning alcohol and LOX and above a 1800°F measurement made, again at about the same location, in a LOX- RP-1 model F-1 plume. These measurements are reported in ref.1.

The parameters found, mass flow rate and enthalpy, apply at the gas in the tip of the probe. To find these parameters for the free stream, an inverse calculation of the shock equations will have to be made using the known parameters as initial conditions.

REVIEW OF OTHER STUDIES

There are four main regions of interest in the studies of exhaust plumes. These are:

(1) Cold Flow

(2) Turbulent Jet Mixing (Mixing Region)

(3) Jet plumes

(4) High altitude plumes

Some of these areas of study present less difficulty to explore experimentally than others. Our area of study presents a most severe environment. The enthalpy probe has to be a very sturdy and well designed piece of equipment in order to be of any use given the conditions of a high stagnation pressure type regime.

In the area of Cold Flow, B. R. Delaney and W. C. Tidmore used conventional techniques to study cold exhaust plumes (6).

In the Turbulent Jet Mixng area, experimentation has been abundant, because of the physical phenomena involved i.e. after burning and free ion formation. J. A. Schetz (9) presents a unified model for this area with wide agreement of the available data. L. S. Cohen and R. U. Gulile (5) used cooled probes to study the effect of combustion on the mixing of axisymmetric, supersonic, turbulent force jets. However, the environment study of this work was not nearly as severe as the environment encountered in the plume of the MA-3 engine. These investigators recommended that further probe development and studies be accomplished.

High altitude plume studies encounter less severe conditions than plume studies at low altitudes as the plume expands considerable in the partial vacuum and thus reduces the severity of the environment. This type of experimental study presents the difficulty of experimenting in a partial vacuum atmosphere. However, some data and modeling has been done (2 and 3).

The study of physical phenomena on an axisymmetric, supersonic, high stagnation pressure exhaust plume is most difficult. Experimental work is limited by the severity of the environment. A highly sophisticated probe has to be developed to obtain satisfactory data. Some experimental work had been done in this area. D. G. Johnson et.al. (7) used calorimetric probes in their experimental work. This work was done mainly using solid fuel engines. Some data was recorded even though the high rate of erosion due to aluminum particles destroyed the probes. Rocketdyne has done some advanced work in this area using the MA-3 Atlas Vernier Engine (1). This work was done using radiometry and cold flow analysis. C. A. Bryce (4) did very interesting work in low stagnation pressure supersonic flow combining probe and radiation techniques. However, this work involved environments typical of a ramjet engine instead of a rocket engine.

RECOMMENDATIONS AND CONCLUSIONS

Building 8110 of the Components Service Facilities was originally built for cryogenic testing. Later, plans were made to use Building 8110 for a combustion laboratory. These plans were carried out and today Building 8110 is a complete and modern combustion laboratory. A facility that was to be of no use is nowadays, after a successful conversion with little expense, a most useful facility.

We recommend that a calorimetric probe be built and used for obtaining experimental data of the physical phenomena in an axisymmetric, supersonic high stagnation pressure plume exhaust. This alone would be in a major contribution to the state of the art.

APPENDIX A

TEST PROCEDURE

Vernier Engine Countdown Time Table

Event	Time From	Time To
Pre-Tanking Operations	T - 4 hours	T - 1 hour, 50 min.
LOX Loading	T - 1 hours, 50 min.	T - 21 min.
Pre-Firing Preparation	T - 21 min.	T - 11 min.
RP-1 Tank Pressurization	T - 11 min.	T - 6 min.
LOX Tank Pressurization	T - 6 min.	T - 1 min.
Engine Start Sequence	T - 1 min.	T - 0
Engine Firing	T - 0	T + 150 secs.
Propellant Systems Securing	T + 150 secs.	T + 30 min.

Complex Secure @ T + 30 minutes.

ELECTRICAL POWER SET UP

Verify/accomplish the following:

1. A.C. circuit breaker on (CB-25 Panel No PGB 120/208) ____
2. D.C. circuit breaker on (console) ____

TEST CELL 309 GN_2 SET UP

Verify/accomplish the following positions of the hand valves:

1. Cell primary GN_2 supply 4G10-2 OPEN ____
2. Cell GN_2 supply VA-7F23-GN OPEN ____
3. Verify 1000±100 psig on gage PI-7A79-GN ____

To set up motor valve supply pressure:

1. Motor valve supply dome loader DL-7A25-GN fully COUNTERCLOCKWISE ____
2. Motor valve supply hand valve VA-7F24-GN OPEN ____
3. Motor valve regulated supply hand valve VA-7F25-GN OPEN ____
4. Motor valve supply dome loader DL-7A25-GN CLOCKWISE until gage PI-7A80-GN indicates 150±15 psig ____

NOTE: The motor valve supply is ready for operation.

To set up Engine LOX and RP-1 purge supply:

1. Engine LOX purge dome loader DL-7A26-GN fully COUNTERCLOCKWISE ____
2. Engine RP-1 purge dome loader DL-7A20-GN fully COUNTERCLOCKWISE ____
3. Engine LOX and RP-1 purge supply hand valve VA-7F29-GN OPEN ____
4. Verify/accomplish engine LOX purge solenoid SV-7A05-GN CLOSED ____
5. Verify/accomplish engine RP-1 purge solenoid SV-7A09-GN CLOSED ____
6. Engine LOX purge regulated supply hand valve VA-7F30-GN OPEN ____
7. Engine RP-1 purge regulated supply hand valve VA-7F99-GN OPEN ____
8. Engine LOX purge dome loader DL-7A26-GN CLOCKWISE until gage PI-7A82-GN indicates 345±10 psig ____

9. Engine RP-1 purge dome loader DL-7A20-GN CLOCKWISE until gage PI-7A81-GN indicates 250±10 psig ____

NOTE: The engine LOX and RP-1 purge are ready for operation.

To set up engine control pressure supply:

1. Engine control pressure dome loader DL-7A34-GN fully COUNTER-CLOCKWISE ____
2. Engine control supply hand valve VA-7F28-GN OPEN ____
3. Engine control pressure dome loader DL-7A34-GN CLOCKWISE until gage PI-7B08-GN indicates 590±25 psig ____
4. Engine control regulated supply hand valve VA-7F98-GN OPEN ____

NOTE: The engine control pressure supply is ready for operation.

TEST CELL 308 GN_2 SET UP

Verify/accomplish the following positions of the hand valves:

1. Cell primary GN_2 supply 4G10-4 OPEN ____
2. Cell GN_2 supply VA-7F18-GN OPEN ____
3. Verify 1000±100 psig on gage PI-7A77-GN ____

To secure LOX line standby purge:

1. LOX line standby purge supply valve VA-7F21-GN CLOSED ____

To set up LOX tank pressurization system:

1. LOX tank pressurization dome loader DL-7A21-GN fully COUNTER-CLOCKWISE ____
2. LOX tank pressurization supply valve VA-7F19-GN OPEN ____

Verify 1000±100 psig on gage PI-7A90-GN ____

3. LOX tank pressurization valve VA-7F20-GN OPEN ____

There should be no continuous flow of GN_2.

TEST CELL 310 GN_2 SET UP

Verify/accomplish the following positions of the hand valves:

1. Cell primary GN_2 supply 4G10-1 OPEN ____
2. Cell GN_2 supply VA-7F33-GN OPEN ____
3. Verify 1000±100 psig on gage PI-7A83-GN ____

To secure RP-1 line standby pressure/purge:

1. RP-1 line standby purge supply valve VA-7F36-GN CLOSED ____

To set up/checkout and leak check the RP-1 tank pressurization system:

1. RP-1 tank pressurization dome loader DL-7A23-GN fully COUNTER-CLOCKWISE ____
2. RP-1 tank pressurization supply valve VA-7F34-GN OPEN ____
3. RP-1 tank pressurization valve VA-7F35-GN OPEN ____

There should be no continuous flow of GN_2.

Set up of deluge system:

1. Verify/accomplish deluge solenoid SV-7A12-GN CLOSED ____
2. Verify/accomplish deluge solenoid SV-7A11-GN CLOSED ____
3. Verify/accomplish deluge solenoid SV-7A72-GN CLOSED ____
4. Deluge drain valve VA-7F74-PW CLOSED ____
5. Verify main water supply valve VA-7G14-PW OPEN ____
6. Deluge supply shutoff valve VA-7F31-PW OPEN ____
7. Verify 60±10 psig on PI-7A87-PW ____

Set up of instrumentation cooling water:

1. Verify probe water supply tank has been filled with distilled water ____
2. Verify that probe water coolant circuits have been primed ____
3. Verify the following valve positions:
   a. Water supply hand valve VA-7G15-PW CLOSED ____
   b. Tank bleed valve VA-7E10-GN CLOSED ____
   c. Tank pressurizing dome loader DL-7A36-GN fully COUNTERCLOCKWISE ____

d. Test valve No. 1 GN_2 supply OPEN ____

4. Tank pressure supply valve VA-7E09-GN OPEN ____

5. Dome loader DL-7A36-GN slowly CLOCKWISE until PI-7A95-GN indicates 750±50 psig ____

6. Verify probe water supply valve (console) is CLOSED ____

7. Water supply hand valve VA-7G15-PW OPEN ____

8. Verify no flow indications on water coolant flows LF 100, LF 101, and LF 102 ____

Functional checkout of engine start and cutoff system:

1. LOX line supply MV-7A18-LO OPEN ____

2. RP-1 line supply MV-7A20-RP OPEN ____

3. Remove engine nozzle protective cover ____

4. LOX purge SV-7A05-GN OPEN ____

5. Engine ON ____

6. Engine OFF ____

Verify engine propellant valve cycles ____

7. Engine ON ____

8. Set duration timer to 10 seconds ____

9. Console engine cutoff ____

Verify engine propellant valve cycles, LOX line supply MV-7A18-LO and RP-1 line supply MV-7A20-RP CLOSED and engine cutoff ON ____

10. LOX line supply MV-7A18-LO OPEN ____

11. RP-1 line supply MV-7A20-RP OPEN ____

12. Engine ON ____

13. Instrumentation cutoff, verify events in step 9 above ____

14. Repeat steps 10, 11, 12 ____

15. Test conductor cutoff, verify events in step 9 above ____

16. 120 VAC ON (console) ____

17. Auto cutoff <u>ON</u> ____

18. RP-1 line supply MV-7A20-RP <u>OPEN</u> ____

19. LOX line supply MV-7A18-LO <u>OPEN</u> ____

20. Engine <u>ON</u> ____

21. Verify engine cutoff and LOX and RP-1 line supply valves <u>CLOSED</u> ____

22. LOX purge SV-7A05-GN <u>CLOSED</u> ____

23. Auto cutoff <u>OFF</u> ____

<u>RP-1 TANKING</u>

ANNOUNCE: Attention all personnel. Propellants will be transferred in Bldg. 8110 area. During this time there will be no smoking, burning or welding except in designated areas. ____

Go to flashing amber condition and turn on tanking chimes. ____

<u>NOTE</u>: Personnel involved in RP-1 tanking operation will wear approved protective clothing. Those personnel <u>not</u> involved in RP-1 transfer shall leave the cell.

1. Connect the RP-1 fill flex hose FH-7A02-RP to the RP-1 trailer ____

2. Have RP-1 trailer crew prepare trailer for RP-1 transfer ____

3. Verify the following hand valve positions:

   a. RP-1 tank fill VA-7F40-RP <u>OPEN</u> ____

   b. RP-1 tank supply VA-7F45-RP <u>OPEN</u> ____

   c. RP-1 tank drain VA-7F39-RP <u>CLOSED</u> ____

   d. RP-1 tank Barton gage, isolation valves VA-7F27-GN and VA-7G03-GN <u>OPEN</u> ____

   e. RP-1 tank aux. vent VA-7G38-RP <u>CLOSED</u> ____

   f. RP-1 fill line low point drain VA-7G13-RP <u>CLOSED</u> ____

4. RP-1 tank vent valve MV-7A23-RP <u>OPEN</u> ____

5. RP-1 line bleed MV-7A19-RP <u>CLOSED</u> ____

6. RP-1 line suppy MV-7A20-RP <u>OPEN</u> ____

ANNOUNCE: RP-1 will be transferred. ____

7. RP-1 trailer supply valve OPEN ____
8. Fill RP-1 tank to level specified on daily test data sheet ____
9. RP-1 tank fill valve VA-7F40-RP CLOSED ____

RP-1 Supply System Set Up

1. RP-1 tank vent valve MV-7A23-RP OPEN ____
2. RP-1 tank supply VA-7F45-RP OPEN ____
3. RP-1 tank supply MV-7A20-RP OPEN ____
4. RP-1 line bleed MV-7A19-RP OPEN. Leave open for 30 seconds. ____
5. RP-1 line bleed MV-7A19-RP CLOSED ____
6. Uncap RP-1 supply line and allow to bleed until free of air then close RP-1 tank supply MV-7A20-RP ____
7. Connect RP-1 supply line to engine control valve ____
8. RP-1 tank supply valve MV-7A20-RP OPEN ____

LOX TANKING

ANNOUNCE: Attention all personnel. LOX will be transferred in Bldg. 8110 area. There will be no smoking, burning or welding except in designated areas. ____

Go to flashing amber condition and turn on tanking chimes. ____

Personnel involved in the LOX tanking operation will wear approved LOX protective clothing. Those personnel who are not assigned to the test cell will leave at this time.

1. Verify man stationed to control access to Bldg. 8110 area ____
2. Verify flashing amber condition ____
3. Flood test cell No. 308 with water hose ____
4. Connect LOX fill flex hose FH-7A01-LO to LOX trailer connection ____
5. Have LOX trailer crew pressurize tank in preparation for LOX transfer ____
6. Verify/accomplish the following hand valve positions:

a. LOX tank drain VA-7F42-LO CLOSED ____

b. LOX tank supply VA-7F44-LO OPEN ____

c. LOX tank fill VA-7F43-LO OPEN ____

d. LOX tank Barton gage isolation valves VA-7F17-LO and VA-7G04-LO OPEN ____

e. LOX tank aux vent VA-7F41-LO CLOSED ____

f. LOX fill line low point drain VA-7G12-LO CLOSED ____

7. LOX vent valve MV-7A15-LO OPEN ____

ANNOUNCE: LOX will be transferred. ____

8. LOX trailer supply valve OPEN. Begin cooldown and filling operations. ____

9. Fill LOX tank to level specified on daily test data sheet. ____

10. LOX tank fill valve VA-7F43-LO CLOSED ____

11. LOX fill line low point drain VA-7G12-LO OPEN. LOX trailer supply ____ valve CLOSED. ____

12. Have LOX trailer crew secure LOX trailer and disconnect LOX fill flex hose FH-7A01-LO from trailer. Replace protective cap in flex hose. ____

13. LOX tank Barton gage isolation valves VA-7F17-LO and VA-7G04-LO CLOSED ____

14. LOX fill line low point drain VA-7G12 CLOSED ____

15. Insure LOX trailer is clear of test cell. ____

16. Tanking chimes OFF ____

ANNOUNCE: Attention all personnel. Propellant transfer is complete. All personnel except designated test crew should proceed to a designated safe area. ____

17. Go to RED CONDITION ____

A. HYPERGOL INSTALLATION

Caution: The personnel will wear approved protective clothing and face shielding when installing or removing the hypergol.

1. Verify RP-1 purge SV-7A09-GN CLOSED ____
2. Verify LOX purge SV-7A05-GN CLOSED ____
3. Immediately prior to installing, carefully remove from packing container and inspect for leakage or damaged seals. ____
4. ANNOUNCE: The hypergol cartridge will be installed. All personnel will stand clear of test cell 309. ____
5. Remove hypergol protective closure from engine. ____

   Lubricate seals with RP-1. ____

   Carefully install cartridge. ____

   Install locking pin. ____
6. ANNOUNCE: Hypergol installation is complete. ____
7. Sample bottle hand valves OPEN ____
8. Toggle switch CLOSED ____
9. Verify probe control yellow light ON ____

Final preparations for firing:

1. Station Check:
   a. Firing console operator READY ____
   b. Instrumentation READY ____
   c. Redline observer READY ____
   d. Area coordinator READY ____
   e. Cameras READY ____
   f. Probe operator READY ____
   g. Cell No. 310 observer READY ____
   h. Cell No. 308 observer READY ____

2. ANNOUNCE: Attention all personnel. A hot firing will be conducted in Cell No. 309 in approximately five minutes. All personnel are requested to evacuate all test cells immediately and proceed to an appropriate area for firing. (X-5 minutes warning siren)

3. Go to a flashing red condition.

4. Obtain ok from safety monitor that the test cell area is cleared of personnel and the firing can proceed

5. 120 VAC ON

6. Strip Chart Recorders on SLOW

7. Pressurize RP-1 tank:

   a. RP-1 tank vent MV-7A23-RP CLOSED

   b. RP-1 tank pressurization dome loader DL-7A23-GN CLOCKWISE until tank pressure reads 790 psig

8. Pressurize LOX tank:

   a. LOX line supply MV-7A18-LO OPEN

   b. LOX line bleed MV-7A17-LO OPEN wait 10 sec. - LOX line bleed MV-7A17-LO CLOSED

   c. LOX tank vent MV-7A15-LO CLOSED

   d. LOX tank pressurization dome loader DL-7A21-GN CLOCKWISE until tank pressure reads 740 psig

9. Engine start sequence:

   a. Instrumentation ON (Strip charts, oscillographs, A/D, Analog tape)

   b. Cameras ON

   c. Probe water supply valve ON - verify water flows are ok

   d. Engine LOX purge SV-7A05-GN OPEN

   e. Verify fuel tank pressure is 790±10 psig

   f. LOX inlet temperature C-1 -285°F

g. Engine start ON

h. At X+5 seconds engine RP-1 purge SV-7A09-GN OPEN

At completion of firing duration:

i. Engine cutoff ON

Verify:

j. LOX line supply MV-7A18-LO CLOSED

k. RP-1 line supply MV-7A20-RP CLOSED

l. Probe water supply valve OFF

m. Instrumentation OFF

n. LOX line bleed MV-7A17-LO OPEN

o. LOX pressurizing dome loader DL-7A21-GN slowly COUNTERCLOCKWISE until gage indicates 100 psig

p. Cycle LOX tank vent valve MV-7A15-LO until LOX tank pressure indicates less than 150 psig

q. RP-1 line bleed MV-7A19-RP OPEN

r. RP-1 tank pressurizing dome loader DL-7A23-GN fully COUNTERCLOCKWISE

s. RP-1 tank vent MV-7A23-RP OPEN

t. Engine RP-1 purge SV-7A09-GN CLOSED

u. Cameras OFF

v. Verify that test cell Nos. 308 and 310 are clear

ANNOUNCE: Test Cell 309 is cleared for designated crew only. Other personnel are to remain in designated safe areas.

w. Go to a red condition

x. Probe water supply hand valve VA-7G14-PW CLOSED

y. Sample bottle hand valves CLOSED

B. HYPERGOL REMOVAL

1. Inspect test cell for damage during test to insure that no unusual hazards exist ____
2. Insure the engine fuel purge is off ____
3. ANNOUNCE: The spent hypergol cartridge will be removed. ____
4. Remove the locking pin and carefully remove the spent cartridge ____
5. Replace the hypergol protective closure ____
6. ANNOUNCE: Hypergol removal is complete. ____
7. Disconnect and cap RP-1 line at engine control valve inlet ____
8. Engine fuel purge SV-7A09-GN ON ____

LOX Detanking

ANNOUNCE: Attention all personnel. LOX will be transferred into dump pit, all personnel remain clear of dump pit area. ____

1. Go to amber condition, chimes ON ____
2. LOX tank drain valve VA-7F42-LO OPEN ____

At completion of detanking:

3. LOX tank pressurization dome loader DL-7A21-GN fully COUNTERCLOCKWISE ____
4. LOX tank vent MV-7A15-LO OPEN ____
5. LOX tank drain valve VA-7F42-LO CLOSED ____
6. ANNOUNCE: LOX detanking is complete. ____

Set up of LOX line standby purge/pressure:

1. LOX line standby supply valve VA-7F21-GN OPEN ____
2. Set dome loader DL-7A24-GN until PI-7A76-GN indicates 15 psig ____
3. LOX line purge valve VA-7F22-GN OPEN ____

RP-1 Detanking:

RP-1 will be held in the tank. The RP-1 supply line will be drained.

1. RP-1 tank supply VA-7F45-RP CLOSED ____
2. RP-1 tank supply valve MV-7A20 CLOSED ____
3. RP-1 line bleed MV-7A19-RP OPEN ____

ANNOUNCE: Propellant transfer is complete in Bldg. 8110 area. All areas may resume normal activities. (Green condition)

Set up RP-1 line standby pressure/purge (if required):

1. RP-1 line standby regulated purge valve VA-7F36-GN OPEN ____
2. Adjust DL-7A29-GN until PI-7A86-GN indicates 15 psig ____
3. RP-1 line purge valve VA-7F37-GN OPEN ____

Trich. Flushing of RP-1 Side of Engine:

1. Verify engine LOX purge is ON ____
2. Engine fuel purge OFF ____
3. Remove protective closure from hypergol chamber ____
4. Insert trich. flushing apparatus in thrust chamber fuel passage port and flush with trich. until all traces of fuel have been removed.

NOTE: Exercise care to assure that no Trich. is allowed to run into the upstream portion of the engine fuel supply system. ____

5. Remove flushing apparatus and replace hypergol chamber protective closure ____
6. Turn engine fuel purge ON wait 10 minutes ____
7. Turn engine fuel purge OFF ____
8. Turn engine LOX purge OFF ____
9. Install protective closure over engine nozzle exit ____

Secure probe cooling water:

1. Tank pressure supply valve VA-7E09-GN CLOSED ____
2. Tank bleed valve VA-7E10-GN OPEN ____

3. Allow tank to complete venting then CLOSE VA-7E10-GN ____
4. Pressurizing dome loader DL-7A36-GN fully COUNTERCLOCKWISE ____

GN2 System Securing:

Test Cell 309

1. Engine RP-1 purge regulated supply hand valve VA-7F99-GN CLOSED ____
2. Engine LOX purge SV-7A05-GN OPEN ____
3. Engine RP-1 purge SV-7A09-GN OPEN ____
4. Engine RP-1 purge SV-7A09-GN CLOSED ____
5. Engine LOX purge SV-7A05-GN CLOSED ____
6. Engine LOX purge regulated supply hand valve VA-7F30-GN CLOSED ____
7. Engine LOX purge SV-7A05-GN OPEN ____
8. Engine LOX purge SV-7A05-GN CLOSED ____

Engine control pressure supply:

1. Engine control regulated supply hand valve VA-7F28-GN CLOSED ____
2. Engine control valve dome loader DL-7A34-GN fully COUNTERCLOCKWISE ____
3. Wait until PI-7B08-GN indicates zero ____
4. Engine control supply hand valve VA-7F98-GN CLOSED ____

Deluge securing:

1. Deluge supply shutoff valve VA-7F31-PW CLOSED ____

APPENDIX B

PROBE OPERATION PROCEDURE

Procedure for Probe Operation

Pre-firing Conditions:

1. Valves RV-1 (LK16)* and RV-3 (LK17) are closed.
2. Valves V1, V2, V3 and needle valve are preset. Fill coolant tank and open hand valves on gas sample bottles.

Steps from Engine Operation:

1. Open RV-2 (LK15)
2. Fire Engine
3. The temperature rise of the coolant through the outer jacket must be below 150°F. Anything above this requires immediate shutdown.

Steps for Probe Operation:

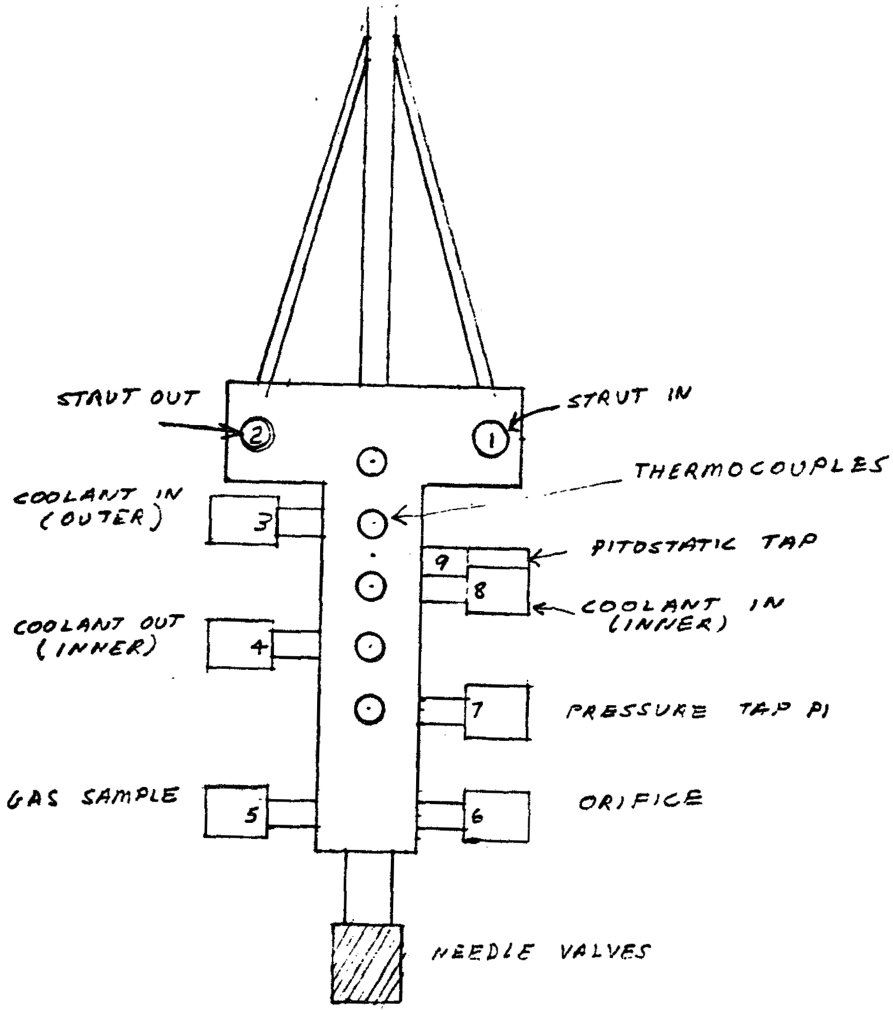
1. Move the probe to the desired position. The temperature rise of the coolant through the outer jacket must be below 150°F. Anything above this requires immediate shutdown.
2. Take the stagnation pressure, monitor that pressure P3(D101) is steady.
3. Open RV-1 and check the coolant temperature rise through the inner jacket. If above 100°F shutdown and restrict gas flow through probe by means of the needle valve. If with this new setting, the flow is no longer choked through the orifice, the needle valve will have to be controlled remotely. (Check for choked flow; determine if P4 (D 103) is greater than 40 psia. If not choked, shutdown and adjust needle valve.)
4. Close RV-1 and open RV-3. Check inner jacket temperature rise. If above 100°F shutdown and restrict gas flow through probe by means of the needle valve. If with this new setting, the flow is no longer choked through the orifice, the needle valve will have to be controlled remotely.
5. Take gas sample by opening RV-4 (LK18) for the first position or RV-5 (LK19) for the second position. When the pressure reaches 100 psia or stabilizes, close RV-3 and the valve to the bottle (RV-4 or RV-5).
6. Repeat steps 3 through 5 for another probe position.
7. Coolant flow can be shut off immediately after engine shutdown.

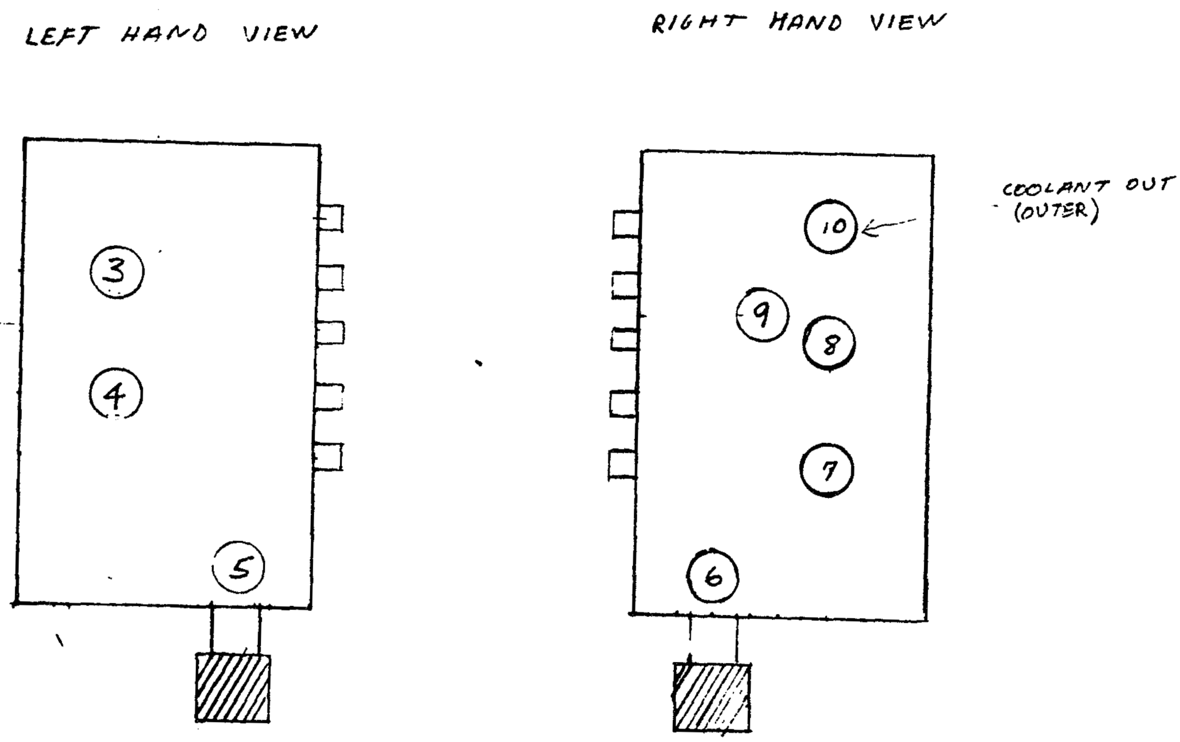
Danger Signals - Immediate Engine Shutdown

1. A water leakage may be caused by a pressure failure or a burnout.
2. If the coolant temperature change across the jackets rises with a drop in flow rate, either the probe passages are blocked or boiling has started in the probe passages. Boiling can be caused by a decrease in flow rate, coolant inlet temperature rise, a sharp increase in hot gas temperature, or scale formation due to coolant contamination.
3. Erratic changes in thermocouple output.
4. Unaccountable variations in measured impact pressure.
5. Excessive pressure drop in coolant system.

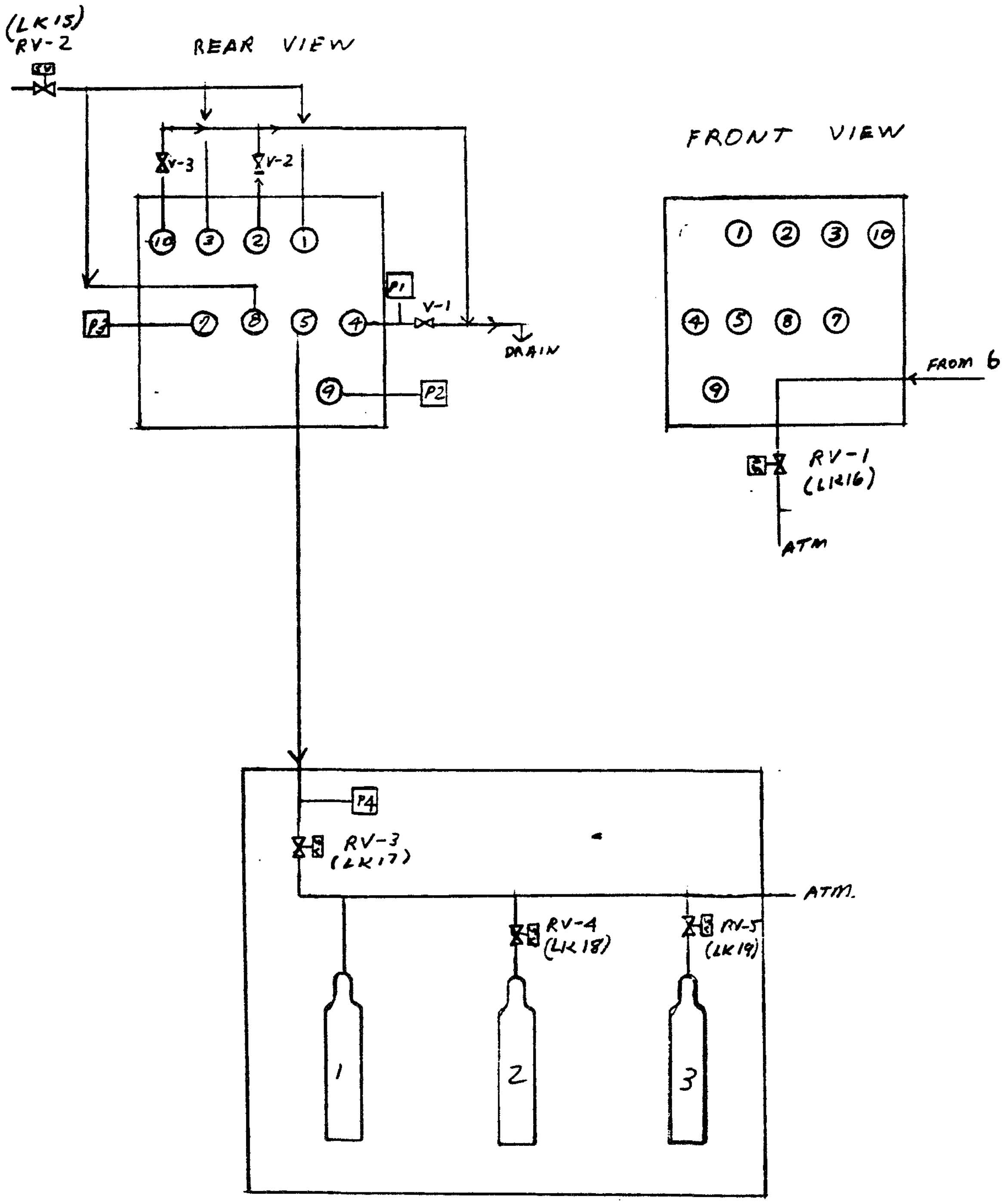
* Parenthesis indicates nomenclature from instrumentation list.

PROBE ASSEMBLY
TOP VIEW





PIPING BULKHEAD



GAS SAMPLE BOTTLE RACK

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