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ZERO-G REPORT

"LH$_2$ BOILING THRESHOLD"

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REVISIONS

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"LH_2 BOILING THRESHOLD"

S U M M A R Y

11242

A test was conducted to determine the minimum
temperature difference (between a heated wall and
LH_2 at its boiling point) required to initiate
boiling (i.e., the formation of bubbles) in zero-g.
A cell of LH_2 in normal gravity was heated from
the top to eliminate convection currents and thus
to simulate zero-g conditions. Boiling started
at less than 0.2°R ΔT on a relatively rough sur-
face, but a 6°R ΔT was required for a plate
finished to 1.25 micro inch RMS.

Butler

TABLE OF CONTENTS

1.0   <u>INTRODUCTION</u>:

During the coast or orbital phase of a
typical Centaur flight, the liquid hydrogen fuel
will be in a zero gravity field. Under such con-
ditions the liquid would wet the walls of an
unheated tank, leaving the ullage space in the
center. The heat absorbed by the tank walls is
a function of the wall temperature, but can that
temperature be above the temperature of the LH_2?
This question is answered in this report.

The threshold temperature and heat flux re-
quired to initiate nucleate boiling of LH_2 near
atmospheric pressure and under one-g was pre-
viously measured using a thin lead film deposited
on a standard laboratory glass slide (cf. Ref: A).
The film was immersed in a horizontal position
(lead on top) and heated by passing a current
through the film. This procedure produced boiling
with associated convection currents. Under these
conditions the temperature difference (from heat
source to liquid) required to produce nucleate
boiling was 2.3 to 3.5 R°.

A separate test was required to determine
the minimum temperature difference that would
initiate nucleate boiling under essentially
steady state conditions and zero-g. The test,
called the "LH_2 Boiling Threshold", was run during
the winter of 1961 - 62. This report contains a
description of that test and discusses the results.

When a liquid in one-g is heated from the
bottom of the container, convection currents are
produced by the cooler (and denser) upper portion
of the liquid displacing the hotter (and less
dense) liquid nearer the bottom due to the in-
fluence of gravity. Obviously, no such free
convection pumping will occur in zero-g. In
this test, therefore, the liquid was heated
from the top, hence the lighter portion of the
liquid was already on the top and no convection
currents were produced. Consequently, the test
simulated a zero-g condition.

2.0   TEST EQUIPMENT:

The test equipment (See Figure 1) consisted of an isolated cell of LH_2 arranged so that the top plate of the cell could be heated and the formation of bubbles observed. The cell was immersed in a 25 liter glass dewar of LH_2. Three different top plates were used in the test. All were made of copper with heater wires installed inside. The wires were spaced to supply a uniform heat flux per unit area to the surface of the plate. Figure No. 2 shows the geometry of these plates.

Plate No. 1 was a disc surrounded by a guard ring and was assembled with epoxy between the two pieces.

Plate No. 2 was a single disc with a modified edge geometry to improve the drainage of bubbles from the initial LH_2 cell filling.

Plate No. 3 was Plate No. 2 with a polished coin-silver disc (1½ inches in diameter and 3/32 inches thick) soldered to the bottom.

The bottom of the test cell was a flat copper plate, and the cylindrical wall, made from Plexiglas, allowed visual observation into the cell. The complete cell contained a cylinder of LH_2 that was isolated from the convection currents in the dewar.

The test cell was filled through two small holes in the Plexiglas located near the bottom plate and vented through a tube through the top plate and a pressure control valve to the atmosphere. The filling holes also insured that the pressure in the test cell was the same as the pressure in the rest of the dewar. The dewar ullage pressure was controlled by throttling the vent. (The Neoprene seal between the dewar top and side limited the maximum pressure to about 25 inches of water.)

For all plates, temperatures were monitored with two thermistors (Keystone Carbon Co., Type L0904), one in the top plate and one in the bottom plate. Figure No. 3 shows a schematic of the test instrumentation.

3.0   <u>TEST PROCEDURE</u>:

3.1   <u>Normal Test Run</u>:

       After purging the test assembly, the dewar was filled with LH_2 and topped off five minutes later. In about 15 minutes there were no bubbles in the test cell and the thermistor resistance had stabilized at the initial temperature. The resistance was then recorded and a heater current set. Due to the lag in the temperature monitoring system, about two minutes was required to determine an equilibrium resistance value. This equilibrium value, translated into temperature, is the temperature recorded.

       There was usually time to get several temperature steps before the LH_2 had boiled off enough to expose the insulation on top of the test cell. At this point, the heaters were shut off, the thermistor stabilized and the zero readings checked. Then the ullage pressure was raised to 20 inches of water and calibration readings were taken as soon as the thermistors stabilized. The last step was usually repeated for 10 and 0 inches of water pressure. This procedure provided a daily thermistor calibration over the range of test temperatures.

3.2   <u>Method of Obtaining Readings</u>:

       With top plates No.'s 1 and 2, there was a lower heat rate below which bubbles could not be produced. Increasing the heat rate slightly produced bubbles, but the heat rate had to be increased still further to produce a measurable temperature indication. This value (about 0.2 R°) was used as a maximum or limit.

4.0 ACCURACY:

The thermistors were calibrated at the conclusion of each run as described in Section 3.1. Since pressures were measured on a water manometer (one inch of water equals 0.036 psi which is approximately 0.012R°), negligible error was introduced in the calibrating procedure.

The resistance of the thermistors (100K to 500K ohms), was reproducible to within ± 0.1% on the resistance bridge. Because of the daily thermistor calibration, reproducibility of measurements determined the accuracy of the temperature values. The maximum drift of a thermistor during any one run was 0.3% of its resistance value, corresponding to approximately 0.03R°.

The run with Plate No. 3 involved a further consideration of the temperature drop across the silver disc. An upper-limit calculation was performed assuming that all the power used in that run (48 PTU/Hr) was dissipated through the disc to the LH_2. The result was a 7×10^{-3} R° temperature drop across the disc. Consequently the temperature indicated by the thermistor in the copper plate was considered as the temperature of the silver disc and any slight error so introduced was neglected.

The Plate No. 3 thermistor was calibrated after the test over the temperature range involved in the run. From this calibration and previous experience with this type of thermistor, the accuracy of the stated temperature differential is estimated to be ± 1 R°.

5.0   RESULTS AND DISCUSSIONS:

5.1   Plate No. 1 Results:

      The finish of top Plate No. 1 was a 16 to 32 RMS microinch finish lightly polished with a clean cloth. When examined under a microscope there were occasional pits of around 0.010 inch in diameter and possibly half as deep. In the epoxy between the two pieces, there were a few slightly larger pin holes.

      As this plate was heated, the bubbling always began in the largest pin hole in the epoxy. The next few nucleation points to appear were also in the epoxy. Only after 5 or 6 nucleation points were active in the epoxy did one appear on the copper.

      Three runs were made in LH_2 with this plate and the results were the same. The temperature differential was less than 0.2R°, the minimum measurable quantity.

5.2   Plate No. 2 Results:

      The finish of Plate No. 2 was the same as No. 1. Note that the plate was made out of one piece and had no epoxy. The results were the same ---- less than 0.2R°.

5.3   Plate No. 3 Results:

      This plate had the coin silver disc. The disc was hand polished with jewelers rouge to a 1.25 RMS microinch finish. Prior to the test the finish was examined under a microscope and no pits were visible. A post test examination showed several pits of about 10 mils diameter. Very probably, the original hand polishing had filled all pits with a mixture of polish and silver power. The subsequent thermal cycle from room temperature to 40°R and back to room temperature was sufficient to loosen up the powder-polish mixture so that it fell out. Presumably, the pits appeared after the test was completed.

(Continued)

5.0   RESULTS AND DISCUSSIONS: (Cont)

5.3   Plate No. 3 Results: (Cont)

The temperature of the plate was increased in
approximately 0.4R° steps. Bubbles began on the
copper at the usual small temperature differential
and by the time the plate temperature reached a 6R°
temperature differential, the top of the copper was
one big bubble. At this time a single nucleation
point appeared on the silver disc, followed several
seconds later by another. The heat was shut off,
the plate cooled and this one temperature point re-
peated.

5.4   Thermal Aspects of the System:

5.4.1   The test cell consisted of a small cylinder
surrounded on the bottom and sides by boiling LH_2
and on the top by 2 inches of foam insulation.
The LH_2 outside was in a state of agitation with
convection currents along the walls and the outer
1/8 inch of the top plate. Heat supplied to the
top plate (17 BTU/Hr being a typical value) has 3
possible paths to the LH_2. One was a heat loss
upward through the foam. The magnitude of this
loss can be calculated by assuming a 0.2R° tem-
perature difference from the top plate to the top
of the foam. The value obtained is 4.8×10^{-4}
BTU/Hr. The heat used for bubble formation in the
cell can be estimated by observing the number and
approximate size of the bubbles produced when slowly
boiling. The result from a typical situation was
17×10^{-3} BTU/Hr. Heat conducted from the top plate
through the LH_2 can be calculated directly and is
15×10^{-3} BTU/Hr. The heat that flows from the edge
of the top plate directly to the LH_2 outside or from
the plate through the Plexiglas ring to the LH_2
cannot be calculated with any reasonable accuracy
because of the variable convection currents outside
the cell and insufficient available data on heat
transfer coefficients.

(Continued)

5.0   RESULTS AND DISCUSSIONS: (Cont)

5.4.1 (Cont)

However, it is the difference between those losses
discussed above and the total power input. Using
this result, 99.8% of the heat supplied to the top
plate goes directly to the LH_2 outside the cell.
From the above considerations, one can make the
following statements:

1)   No heat transfer coefficients can be
     obtained from these data for general
     calculations.

2)   There is no close correlation between
     the heat input to the plate and the
     plate temperature.

5.5   Effect of Sunlight:

The runs were normally made with the light
shield around the dewar. On one occasion while
adjusting equipment with the light shield removed,
bubbles were observed forming on the top plate.
No heat was being supplied to the plate. The
sunlight was passing through the dewar walls, the
LH_2, the Plexiglas ring and being reflected from
the bottom plate to the top plate. Bubbles were
being formed on the top plate evidently due to
the sunlight. These bubbles were approximately
1 mm in diameter and being formed at the rate of
one bubble per 2 or 3 seconds. The bubble forma-
tion stopped about 2 minutes after the dewar was
shaded.

5.0   RESULTS AND DISCUSSIONS: (Cont)

5.6   Result with LN$_2$:

       LN$_2$ was used to perform the preliminary checkout
of the equipment. The temperature differential re-
quired to initiate bubbles in the LN$_2$ using the top
Plate No. 1 was less than 1 R°. This same run was
repeated and this time no bubbles occurred for 18
minutes after the heat had been turned on. At this
time, a gentle tap on the dewar top was sufficient
to produce immediate bubbling from a single nucleation
point. No attempt was made to refine this measurement.
The value is stated as 1°R, because there was no
accurate calibration of this thermistor in the LN$_2$
region. The true value could easily be a factor of
5 or 10 less than this.

5.7   Time Dependency of Nucleate Boiling:

       In Reference A, Zero-G Report: LH$_2$ Nucleate
Boiling, we said that we would discuss the "time-
dependency" of nucleate boiling in this report.
There was some evidence from the aircraft tests
that the threshold of nucleate boiling was time
dependent. The tests herein reported investigated
the case of minimum temperature difference. Following
the application of a power sufficient to cause boiling
there was a delay of between 10 and 60 seconds (usually
about 30) before the formation of the first bubble.
The time delay based on the heat capacity of the plate
and the layer of LH$_2$ next to the plate is under ½
second. It appears therefore that there is a real
time delay associated with the formation of bubbles
in liquid hydrogen.

5.0   RESULTS AND DISCUSSIONS: (Cont)

5.8   <u>Summary of Results:</u>

Top Plate	Calib. Method	ΔT (°R)	Liquid
1	Rough Calib.	< 1	LN_2
1	Rough Calib.	$<$*1	"
1	Dewar Pressure	< 0.2	LH_2
1	" "	< 0.2	"
1	" "	< 0.2	"
2	" "	< 0.2	"
2	" "	< 0.2	"
2	" "	< 0.2	"
3	Cryostat (Post Test)	6 ± 1	"

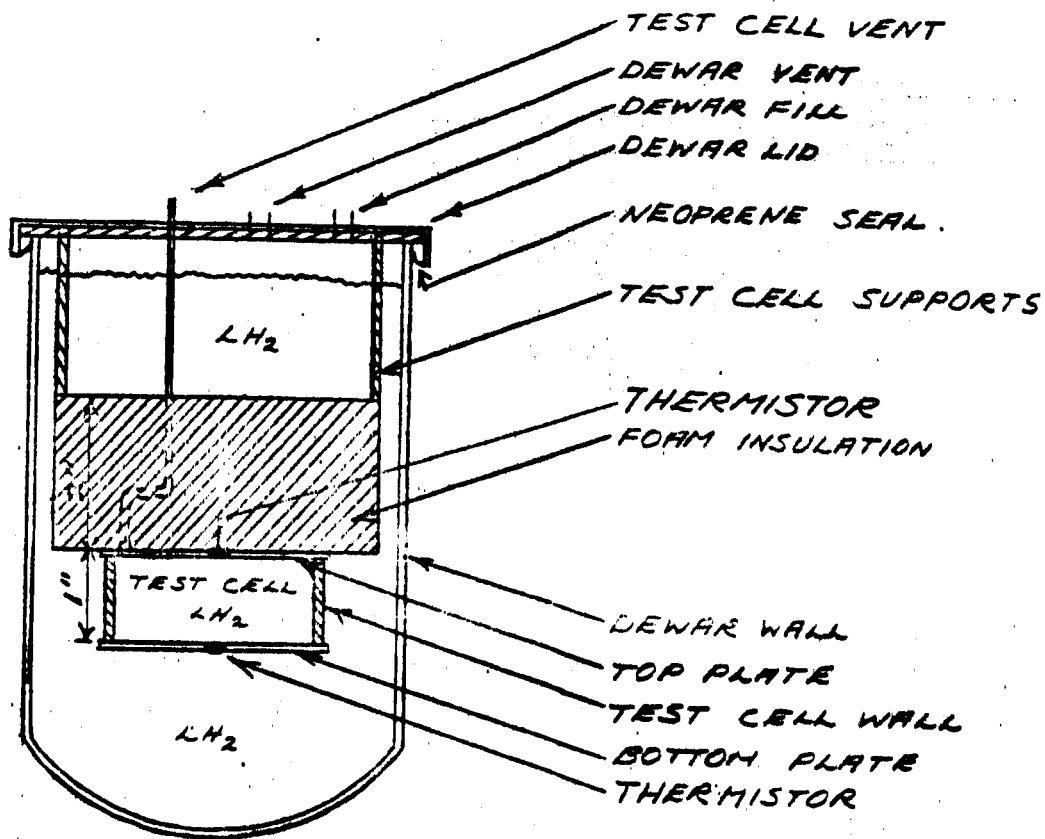(*)   Required a gentle tap to initiate boiling.

6.0   CONCLUSION:

In our tests even polished copper plates had
visible pits which acted as nucleation points to
initiate boiling in LH_2 at a very low super heat.
The Centaur tank walls will be covered with nuclea-
tion points --- the welds alone supply an almost
infinite number. While it is possible to obtain
several degrees of super heat with especially pre-
pared materials, the temperature of the Centaur
tank walls will not be appreciably above the LH_2
boiling point.

R E F E R E N C E S

A) O'Hanlon, T. W.; Zero-G Report: LH$_2$
Nucleate Boiling; Test Laboratories
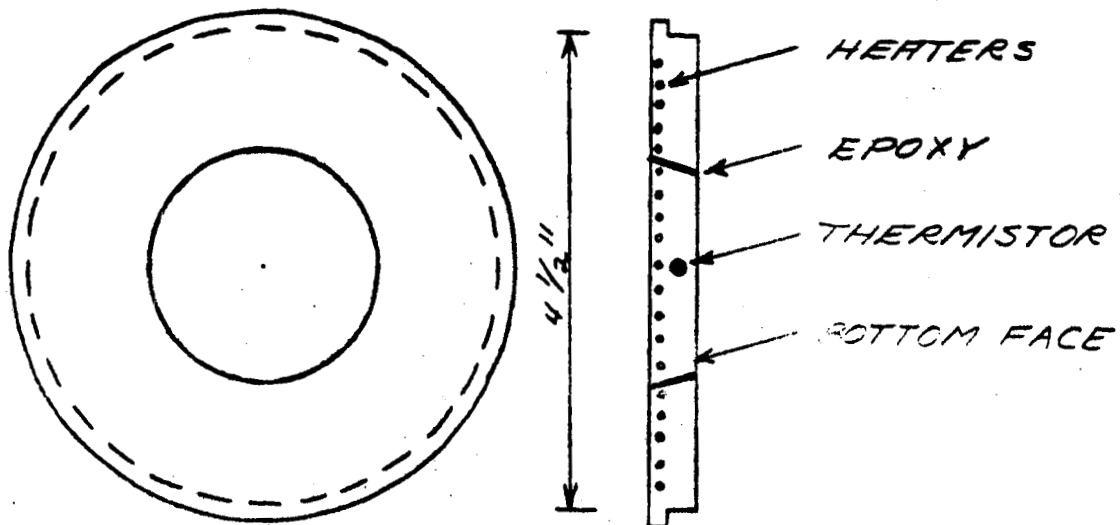Report 55D 859-1; January 1962.

B) O'Hanlon, T. W.; Zero-G Report: LH$_2$
Film Boiling; Test Laboratories
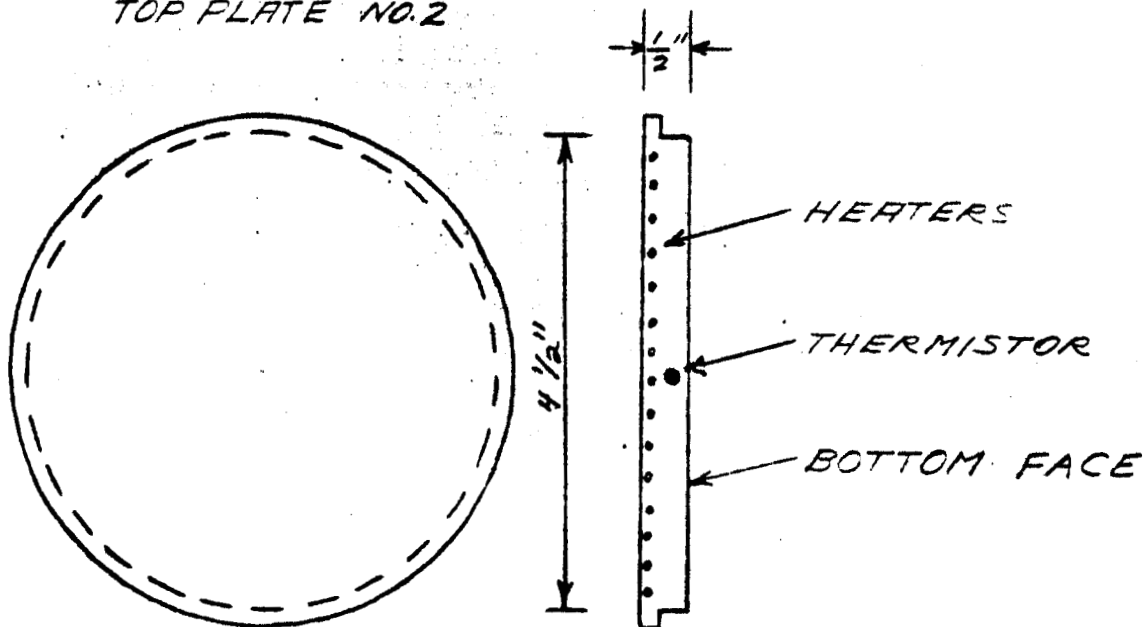Report 55D 859-2; March 1962.

TEST CELL VENT
DEWAR VENT
DEWAR FILL
DEWAR LID

NEOPRENE SEAL.

TEST CELL SUPPORTS

THERMISTOR
FOAM INSULATION

DEWAR WALL
TOP PLATE
TEST CELL WALL
BOTTOM PLATE
THERMISTOR

LH_2

TEST CELL
LH_2

LH_2

A RADIATION GUARD OF ALUMINUM SURROUNDED
THE DEWAR. THE GUARD HAD SEVERAL VIEWING
HOLES.

CROSS SECTION OF TEST EQUIPMENT
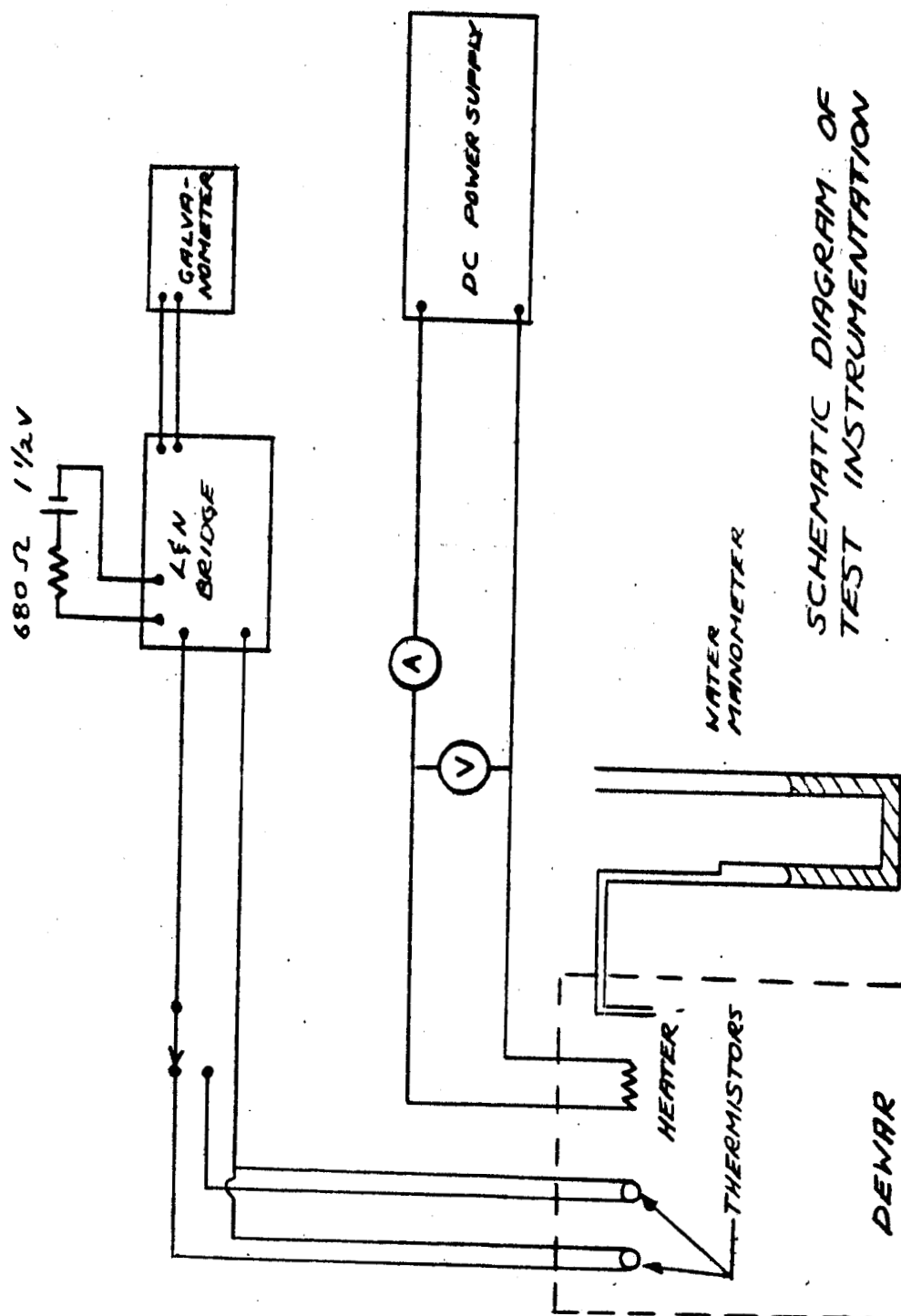
FIGURE 1

TOP PLATE NO. 1

TOP PLATE NO. 2

HEATERS

EPOXY

THERMISTOR

BOTTOM FACE

TOP PLATE NO. 3

HEATERS

THERMISTOR

BOTTOM FACE

TOP PLATE NO. 3 WAS NO. 2 WITH A COIN SILVER
DISC (1 1/2 INCHES IN DIAMETER X 3/32 INCHES THICK)
SOLDERED TO THE CENTER OF IT

TOP PLATES

FIGURE 2

SCHEMATIC DIAGRAM OF
TEST INSTRUMENTATION

FIGURE 3