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ZERO-G REPORT

"LH_2 BOILING THRESHOLD"

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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 surface, but a 6°R ΔT was required for a plate finished to 1.25 micro inch RMS.

Author

TABLE OF CONTENTS

1.0 INTRODUCTION:

During the coast or orbital phase of a typical Centaur flight, the liquid hydrogen fuel will be in a zero gravity field. Under such conditions 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 required to initiate nucleate boiling of LH_2 near atmospheric pressure and under one-g was previously 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 influence 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 TEST PROCEDURE:

3.1 Normal Test Run:

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 stabilised 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 Method of Obtaining Readings:

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 BTU/Hr) was dissipated through the disc to the LH_2. The result was a 7×10^{-5} 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 repeated.

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° temperature 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 formation 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 required 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 Summary of Results:

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.

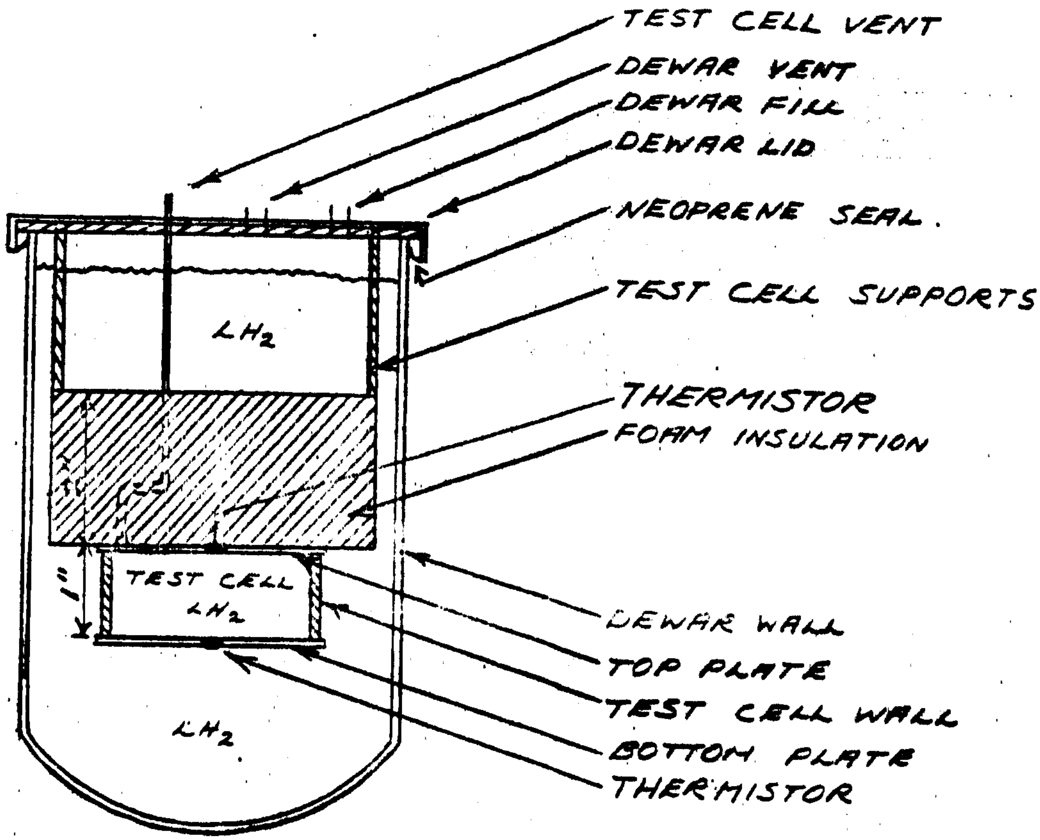
6.0 CONCLUSION:

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 nucleation points --- the welds alone supply an almost infinite number. While it is possible to obtain several degrees of super heat with especially prepared 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.

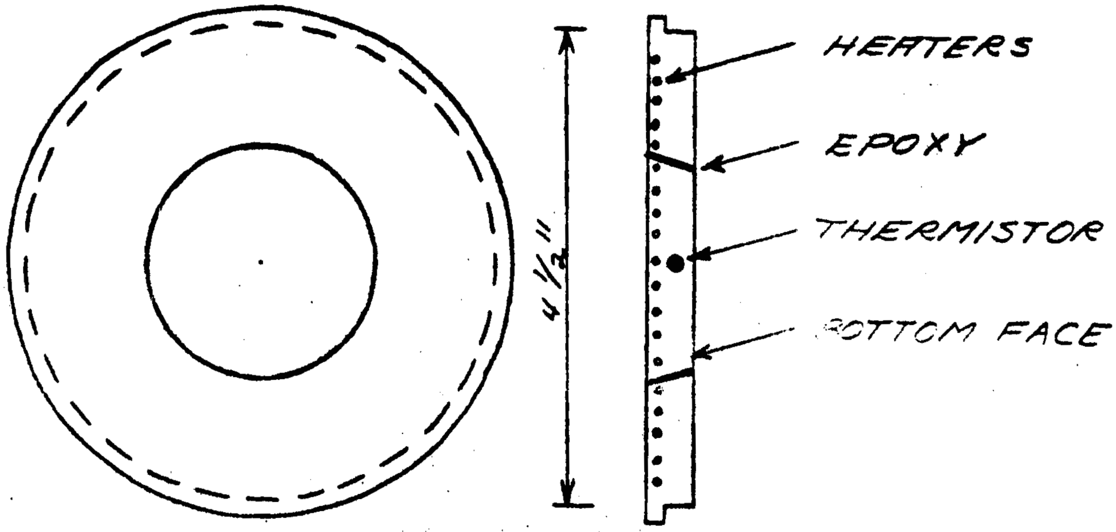


A RADIATION GUARD OF ALUMINUM SURROUNDED THE DEWAR. THE GUARD HAD SEVERAL VIEWING HOLES.

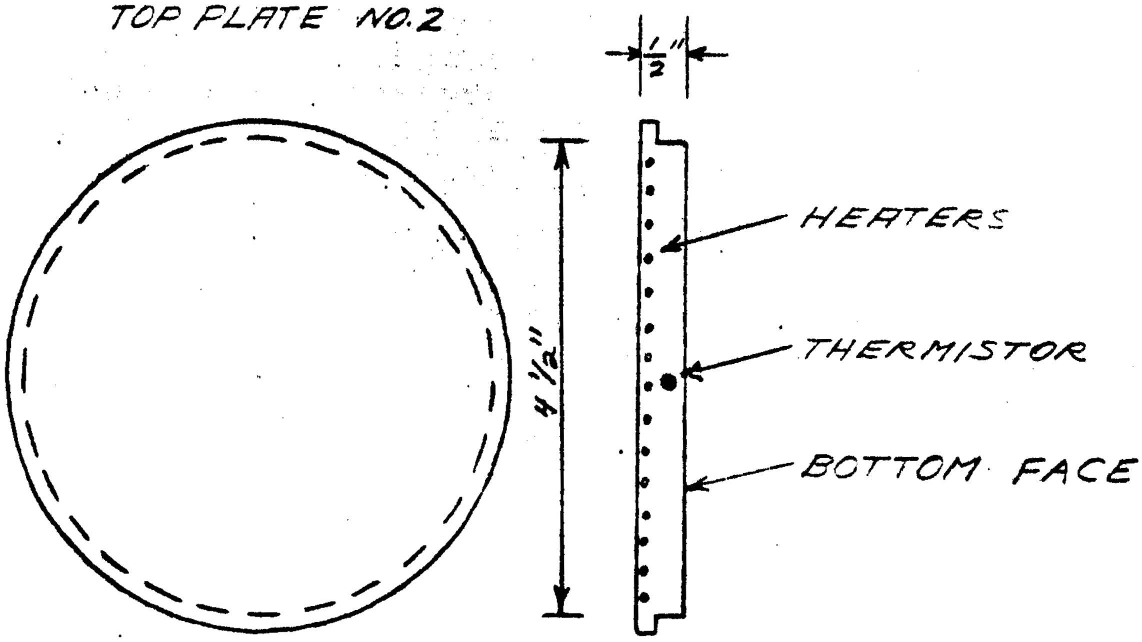
CROSS SECTION OF TEST EQUIPMENT

FIGURE 1

TOP PLATE NO. 1



TOP PLATE NO. 2

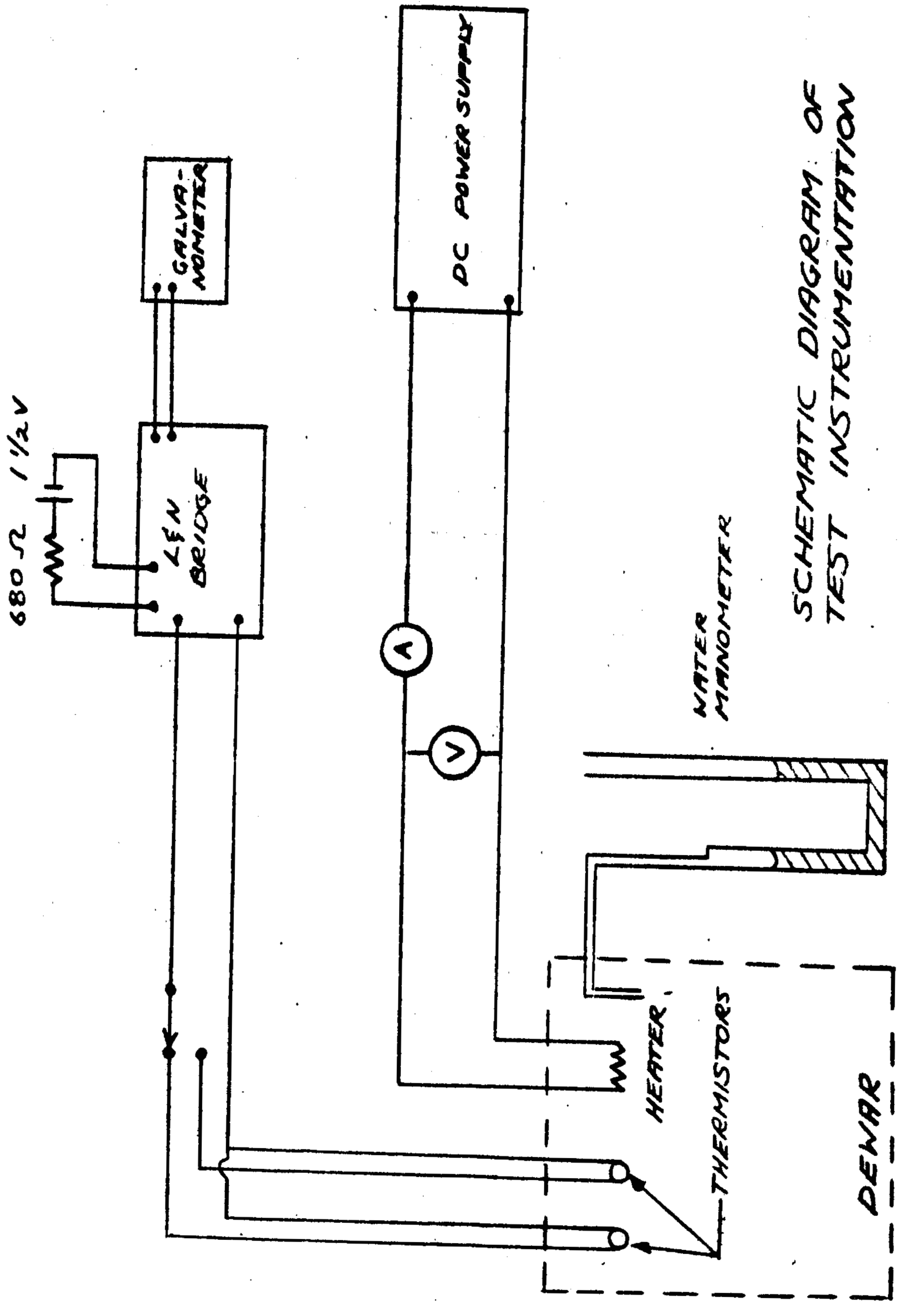


TOP PLATE NO. 3

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