Cryogenic Boiling Manufacturing Plan

Cryogenic Boiling Team 1 (aka Charlie)

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I. Introduction

Cryogenic Boiling Team 1, aka Charlie, aims to understand heat transfer and cooling properties of liquid nitrogen by measuring the temperature gradients on several individual spheres with different sensor locations and orientations. For long term space travel to be possible, storage and transfer of cryogenic propellants like hydrogen and oxygen are crucial for mission success. The propellants are very prone to boiling off and this inevitably leads to significant loss. To help prevent this, a more thorough understanding of boiling, cool down, and heat transfer characteristics are essential. The objective is to improve the accuracy of heat transfer measurements for spheres in liquid nitrogen by addressing the inconsistency caused by the nitrogen vapor envelope surrounding the sphere. This will be achieved by measuring temperature within the same plane of the sphere's surface and comparing the results across different planes, which is anticipated to help to reduce uncertainty in the boiling data of the sphere in liquid nitrogen by determining the orientation least effected by changes in the violent boiling. Another way of improving the precision of the measurements is to measure varying temperature gradients throughout the sphere. The method that will be used to measure heat transfer from the change in temperature is by using the heat transfer equation I, which measures heat transfer using thermal conductivity and temperature gradients ($\frac{dT}{dr}$). Ultimately the objective of this experiment will be to provide improved uncertainty in the analysis of sphere quenching for use in cryogenic storage and transfer systems for long-term space missions by obtaining quantitative data on heat transfer during submersion in liquid nitrogen. The units of q will be measured in watts or joules per second, while the area will be measured in square meters.

$$q = -k\frac{dT}{dr} \tag{1}$$

In preparation for this experiment, we were given a published report by NASA[1] This report effectively compiled studies from the past 70 years. The data from these studies shows large fluctuations, giving rise to high levels of uncertainty. Methodology is also not always clear from study to study, nor is it consistent, so comparing results is difficult. In this experiment, team Charlie hopes to use average results from this paper as guidelines to verify our test procedure is working. The data from this report covered several geometries, sizes, and materials for quenching materials in liquid nitrogen. Our focus will be on the quenching of aluminum spheres in particular.

II. Technical Description

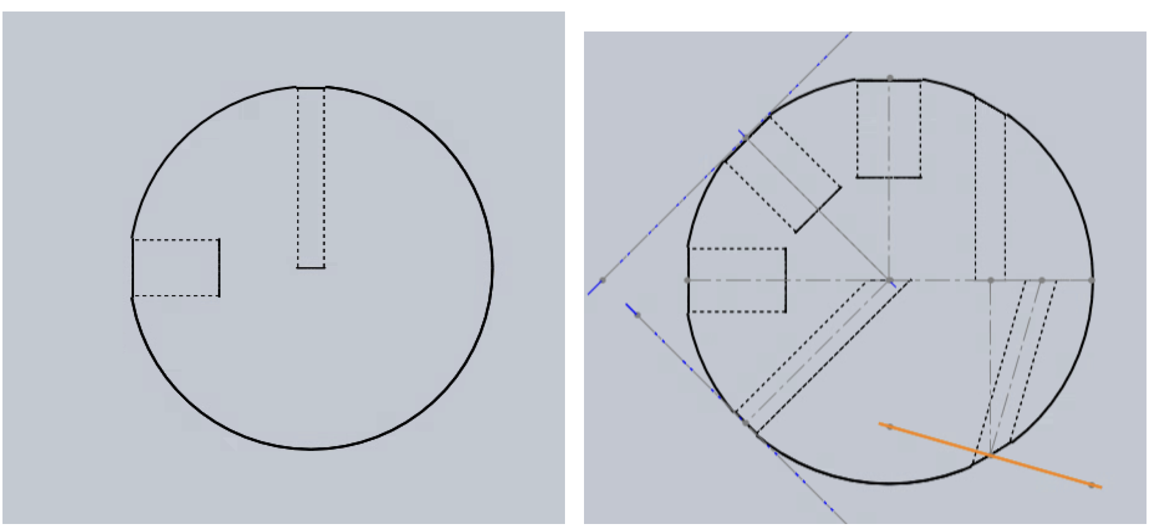
A. Overview

In this experiment, two 25 mm diameter aluminum spheres will be tested in liquid nitrogen. These two spheres will be manufactured by the team in the AA Machine Shop, and the liquid nitrogen and dewar pot are provided by the UW Chemistry Research Stockroom or the Aerospace Thermal Lab for the experiment itself.

The first sphere that will be tested has two holes drilled into it, one for a thermocouple and the other for a mounting screw. This sphere is depicted in Figure 1a. The first hole is drilled from the top of the sphere with a 5/64 inch drill bit, and all drilling measurements will have a ±0.005 inch uncertainty. There is also a mounting screw drilled into the side of Sphere 1, enabling us to mount the sphere in a specific direction during the experiment. The mounting screw is drilled in with 0.159 inch diameter and a 1/4 inch depth. Once the drilling is complete and the mounting screw is screwed in, a Type T thermocouple will be inserted into the 5/64 inch diameter hole at the top of the sphere. This thermocouple tip has a diameter of 1/16 inch, which should fit easily into the hole even with small uncertainties. The thermocouple will be adhered with PTFE Tape and has a 3 inch probe with a lead wire to be attached to a sensor control box outside the liquid nitrogen.

The second sphere that will be tested will have three holes for thermocouples and 3 holes for mounting screws (all thermocouples and mounting spheres have the same dimensions). See Figures 1b and 2. The first thermocouple drill will be at a 45 degree angle (±2 degree uncertainty for all angles) from the bottom left of the sphere to the center of the sphere. The depth will be 12.5 mm (0.49 inches). The second thermocouple drill will be from the top right of the sphere, 1/4 inch to the right of the center of the sphere. The last thermocouple drill will be at the same vertical placement, but from the bottom of the sphere going at a 16.1 degree angle towards the right edge of the sphere. The diameter of these holes remains at 5/64 inch and the depth varies due to angles, see the figure for specific depth values. For this sphere, there will be three mounting screws, one in the initial placement from sphere 1, one at a 45 degree angle between the top and left sides of the sphere, and one at the very top. The depth remains at 1/4 inch and the diameter of the screws is still 0.159 inch. After drilling, the thermocouples will be attached the same way and hooked up to a sensor control box.

B. Detailed Drawings



(a) Sphere 1 **(b) Sphere 2**

Fig. 1 Diagram of (a) Sphere 1 (b) and Sphere 2 seen from a front view.

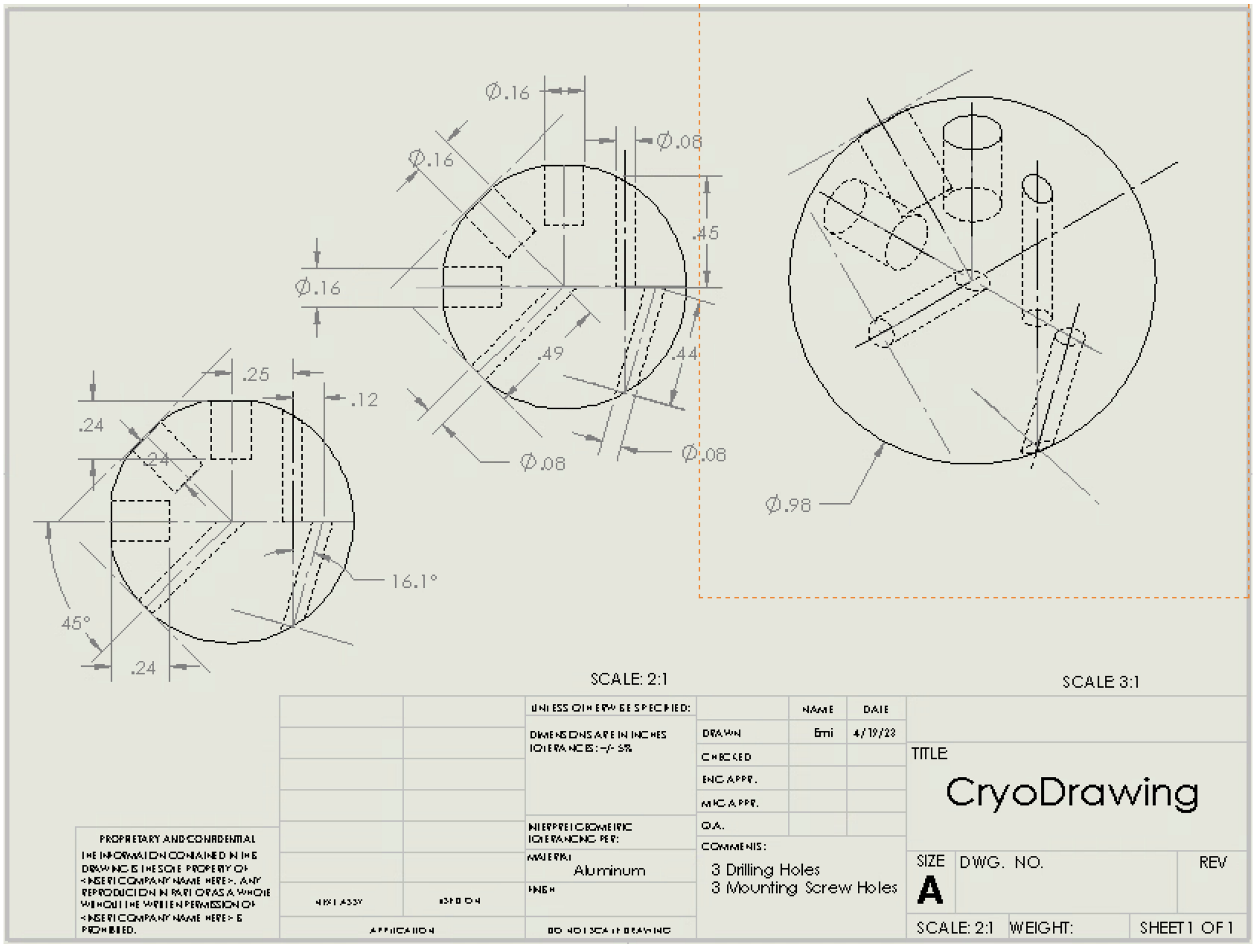


Fig. 2 Diagram of Sphere 2 with 3 drilled holes to 1/2 from the edge, 1/4 diameter from the edge, and 1/8 diameter from the edge. The mounting screw areas are also drilled.

III. Bill of Materials

A. Purchased

The information for each purchased item is organized as follows:

- Manufacturer Part Number
- Supplier
- Supplier Stock Number
- Quantity
- Cost
- Stock Status / Delivery Time

1) Type T Thermocouple Immersion Probes with insulated lead wires, grounded (0.062 in. diameter, 3 in. length)
    - Mfr #TTSS-116G-3
    - Omega Engineering, Inc.
    - Item #TTSS-116G-3
    - Two (2) thermocouples
    - $80.76
    - 0 in stock / 4 week lead time
2) Liquid Nitrogen
    - N/A
    - UW Chemistry Research Stockroom (Bagley 36)
    - Item #7557
    - Twenty (20) liters
    - $30-40
    - In stock / Self pick-up
3) Aluminum Spheres (25mm diameter)
    - Mfr #42014 (762047800981)
    - Thomas Scientific
    - Item #1201B83
    - Six (6) spheres
    - $35.46
    - In stock / 10 day lead time
4) Poly-temp (PTFE) Thread Sealing Tape (1/2 in x 43 ft)
    - Mfr #26135
    - Grainger, Inc
    - Item #3AB55
    - One (1) roll
    - $1.06
    - In stock / 4 day lead time
5) Zinc-Plated Steel Routing Eyebolt (10-24 thread size, 2-5/16" thread length)
    - N/A
    - McMaster-Carr
    - Item #9490T1
    - One (1) pack of twenty (20) eyebolts

    - $8.71
    - In stock / 1 day lead time
6) Chicago-Latrobe Jobber #25 Drill Bit (1 7/8 in. flute length, 3 in. overall)
    - Mfr #46695
    - Grainger, Inc
    - Item #1G965
    - Two (2) drill bits
    - $9.62
    - In stock / 4 day lead time
7) Chicago-Latrobe Jobber 5/64" Drill Bit (1 in. flute length, 2 in. overall)
    - Mfr #44005
    - Grainger, Inc
    - Item #1F491
    - Four (4) drill bits
    - $7.72
    - In stock / 4 day lead time
8) Cleveland Straight Flute Tap: #10-24 Thread (1/2 in. thread length, 2 3/8 in. overall)
    - Mfr #C54326
    - Grainger, Inc
    - Item #435M19
    - One (1) tap
    - $9.13
    - In stock / 6 day lead time

B. Manufactured

The information for each manufactured item is organized as follows:

- Manufacturing Method (Options if available)
- Manufacturing Facility
- Expected Time
- Quantity
- Cost

1) Sphere 1 (5/64 in. diameter hole to center and a threaded mounting indentation)
    - Mill or watch drill press
    - A&A Charlie Bossart Machine Shop
    - 2 hours
    - 1 sphere of the above design
    - N/A (no additional cost than materials/tools)
2) Sphere 2 (three 5/64 in. diameter holes to center, half radius, and surface plus three threaded mounting indentations)
    - Mill or watch drill press
    - A&A Charlie Bossart Machine Shop
    - 6 hours

    - 1 sphere of the above design
    - N/A (no additional cost than materials/tools)
3) (Optional/Contingency) Sphere 2 without the half-radius hole (two 5/64 in. diameter holes to center and surface plus three threaded mounting indentations)
    - Mill or watch drill press
    - A&A Charlie Bossart Machine Shop
    - 5 hours
    - 1 sphere of the above design
    - N/A (no additional cost than materials/tools)

C. Borrowed

The information for each borrowed item is organized as follows:

- Owner
- Where to find it
- Quantity
- Lend status

1) Type T Thermocouple Immersion Probes with insulated lead wires, grounded (0.062 in. diameter, 3 in. length)
    - Professor Jim Hermanson (Andrew Jacob, graduate student)
    - Aerospace Thermal Lab, AERB 223
    - Two (2) thermocouples
    - Confirmed and available for the remainder of the quarter with supervision
2) Cryogenic Dewar (13.75 in. outer diameter, 8 in. inner diameter, 17.75 in. external height, 15 in. internal height)
    - Professor Jim Hermanson (Andrew Jacob, graduate student)
    - Aerospace Thermal Lab, AERB 223
    - One (1) dewar
    - Confirmed and available for the remainder of the quarter with supervision
3) Aliant Mill - 48CV and/or Bridgeport Mill - Series I
    - A&A Charlie Bossart Machine Shop
    - A&A Charlie Bossart Machine Shop
    - Two (2) manual mills
    - Available on reservation/submission of request form
4) Watch Drill Press
    - A&A Charlie Bossart Machine Shop
    - A&A Charlie Bossart Machine Shop
    - One (1) drill press
    - Available for in lab use

IV. Assembly Plans

Sphere 1:

1) Each sphere must be mounted in a vice in order to hold it stationary to enable drilling of precise holes. Holes will be drilled using a watchmakers drill press in order to drill quality, small sized holes. A watchmakers drill press operates at speeds above 6000RPM. At these speeds frequent lubrication of drill bits is necessary to avoid damaging the drill bits and the spheres.
2) Orientation of the sphere will be defined by the hole for the mounting, so this will be the first hole drilled. Using a #25 drill bit, a 0.1495" ±0.005" diameter hole with an angularity of 0° ±2° will be created. The depth of the hole will be 0.250" ±0.005". Hole depth can be verified using the depth gauge on digital calipers. Angularity can be measured using the digital calipers depth gauge and a carpenter's square on the surface of the sphere. The square should sit flush against the calipers with the depth gauge extended to the bottom of the hole.
3) The second hole in Sphere 1 is where the thermocouple will be installed to measure the temperature at the center of the sphere. Orientation of this hole is less important since it is the only other hole on this sphere, assuming the thermocouple measurement still reads at the center of the sphere, but the new hole should be a minimum of 45° and a maximum of 90° relative to the mounting hole. The hole will be drilled with a diameter of 0.0781"±0.005". The hole will be drilled perpendicular to the surface of the sphere, with an angular tolerance of 0° ±2° relative to the horizontal. The depth of the hole will be 0.492"±0.005". Hole specifications are to be checked using a similar procedure to the mounting hole.
4) Upon completion of drilling the holes, the mounting hole must be threaded using a #10 bottoming tap with a thread pitch of 24, in a proper tap socket attached to a 1/4" ratchet. Care must be taken to back the tap out approximately 1/4 turn for every full turn it cuts in order to avoid damaging the threads. The threads are cut by turning the tap clockwise, and the tap is backed out by turning it counter clockwise. After threading is complete the hole will be cleaned first by emptying large metal shavings into a proper recepticle, then cleaning out the smaller shavings using shop hand soap and warm water. The 2 $\frac{5}{16}$" zinc plated eyebolt can then be installed into the threaded hole. Finger tightening the eyebolt until it bottoms out in the hole will be sufficient as this eyebolt is not expected to carry any load.

Sphere 2:

1) The sizes and tolerances of Sphere 2 are the same as those of Sphere 1 respectively for the mounting and sensor holes and measurements.
2) The first hole drilled will be the top mounting hole at a diameter of 0.1495"±0.005", an angularity of 0°, and a depth of 0.250". All other holes will be drilled relative to that hole.
3) An additional two mounting holes will be created with the same sizes. The first additional mounting hole will be drilled at an angle of 45° ±2°, which is 0.386" along the surface, relative to the initial mounting hole. The second additional mounting hole will be drilled at 90° ±2°, which corresponds to 0.773" along the surface, relative to the initial mounting hole. All three holes must be drilled in the same plane.
4) Three holes are to be drilled for the thermocouple measurements. These holes must also be drilled on the same plane. The plane of the thermocouple holes must be perpendicular to the plane of the mounting holes.
5) The first hole must be drilled a minimum of 45°, and a maximum of 90° relative to the initial mounting hole. This hole, as with all other thermocouple holes, must be drilled to 0.0781"±0.005" diameter. This hole will be drilled perpendicular to the surface with an angularity of 0° and a depth of 0.432" ±0.005".
6) The second hole is to be drilled at a distance of 0.246" along the surface from the center of the initial mounting hole. This hole is to be drilled vertically into the sphere to a depth of 0.425" ±0.005", so as to keep the

thermocouple measurement locations in a single line through the radius of the sphere.

7) The final thermocouple hole will be drilled at a distance of 1.30" along the surface from the initial mounting hole, in the same plane as the other two thermocouple holes. This hole must be drilled at a 16° degree angle with a tolerance of ±2° relative to the vertical. This angular measurement must be done using a protractor. The hole will be drilled to a depth of 0.44"±0.005".
8) Hole specifications will be checked in the manner described for Sphere 1.
9) Threads will be made in the three mounting holes and the eyebolts will be installed using the procedure described for Sphere 1.

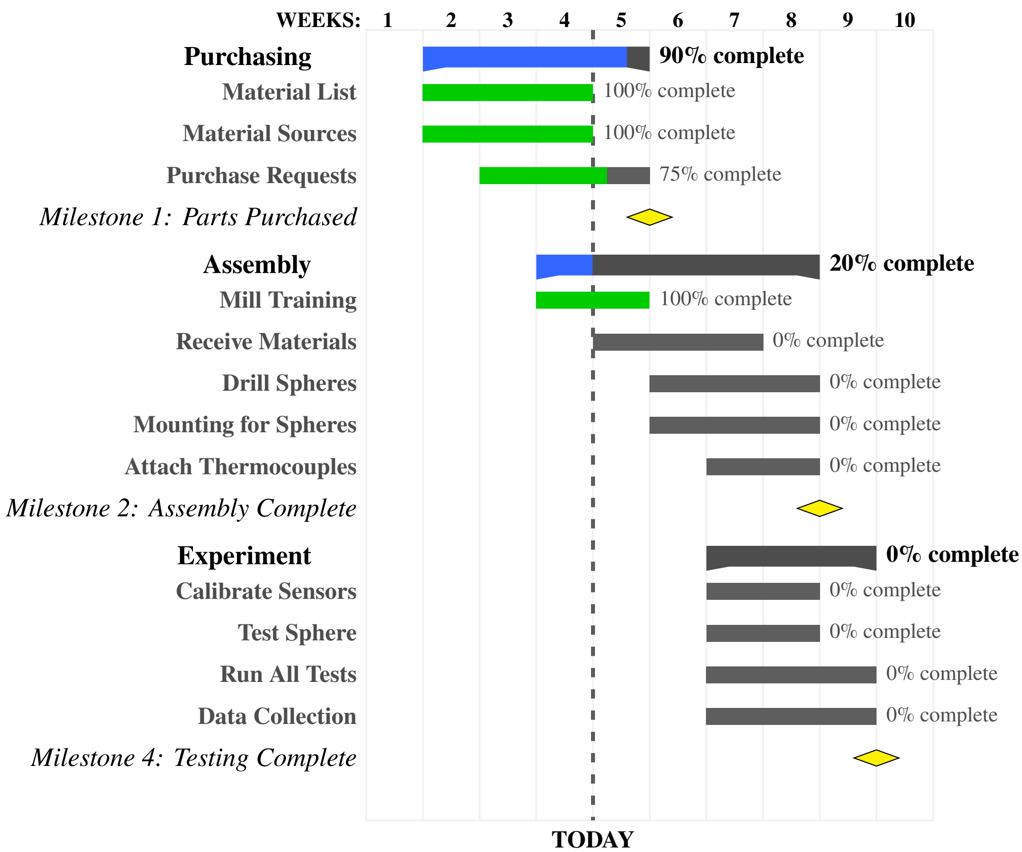
Assembling of thermocouples into spheres:

1) Upon completion of manufacturing, the thermocouples will need to be calibrated. This can be done using known temperature values. The boiling point of liquid nitrogen is 77K, so that will be our lower data point. The freezing point of water is 273K, so that can be our upper value. If a third data point is needed or desired, the boiling point of water at 373K can be used.
2) After calibration the thermocouples will be inserted into the 5/64" holes in the spheres. A single layer of PTFE tape will be wrapped around the thermocouple probe lead at the appropriate depth of the hole that the thermocouple is going into. The thermocouple probe will then be inserted into the hole using a gentle twisting motion, taking care to not disturb the sealing tape. The fit should be snug; this can be verified by gently pulling on the thermocouple, which should not move.

V. Check-out Procedure

1) Before carrying out the experiment, the sealing of the thermocouples into the spheres must be verified. This can be done by immersing the probe of the thermocouple by itself into the liquid nitrogen and observing the change in temperature reading. The probes can then be sealed into the sphere and the sphere immersed in the liquid nitrogen. The temperature change of the sealed thermocouple should be significantly slower than that of the unsealed thermocouple and also match the time calulated previously for the cooling time of an aluminum sphere during quenching in liquid nitrogen. During this step the data transmission to LabVIEW can also be verified. The known boiling temperature of liquid nitrogen is 77K, so the LabVIEW reading should indicate that temperature after the sphere has reached the same temperature throughout.
2) The process of verifying thermocouple sealing must be ongoing. The temperature change of each probe must be continuously monitored for any drastic changes to the rate of temperature change, which could indicate a failure of sealing.
3) After each sphere has been immersed in liquid nitrogen, then brought back to room temperature, the areas around each hole should be inspected for cracking due to stress concentration at the holes from thermal shock.

VI. Schedule



References

[1] Moore, R. C., and Hermanson, J. C., "Evaluating the Comlete Pool Boiling Curve for LIquid Nitrogen," 2019-2021.