# Preliminary Housing Thermal Modeling

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## 1 Purpose

In the new model of the Reefscan Deep, many of the electronic components are being consolidated into a single housing to simplify the cable management and reduce the number of hull penetrations required. While the batteries will remain in a separate pressure housing, there is still a thermal concern that the heat generated by multiple electronic devices will raise the temperature within the electronics housing to above the operating threshold for one or more components resulting in reduced performance and/or damage. Using a basic first-principles thermal model, we can approximate the heat flow and understand the important factors to consider within the design.

## 2 Housing Design

The housing is still being designed but will be in the shape of a cylinder, with a hemispherical camera dome on one end, and an end cap with hull penetrators on the other end. The hemispherical dome will be 4" in diameter, consisting of optical glass, with an approximate thickness of 5mm. The tube and endcap will be approximately 250mm long, with an inside diameter of 78mm, and will be manufactured out of either Delrin or Aluminium. The dimensions are sketched in Figure 1. The housing will host primarily a Jetson Orin Nano, Allied Vision 1800 camera, a Seeed J603 board, and a 1 TB 2242 SSD consuming 23.9W of power during operation. The camera, board, and SSD have upper operating limits of $65°C$.


Figure 1: Sketch of Basic Housing Design

## 3 First-principles Model

### 3.1 Principles

This model will focus on finding steady state solutions to the first law of thermodynamics stating that the rate of work done on the system will equal rate of heat transfer out of the system. The result is the total energy (and thus temperature) of the system remains constant in time.

$$0 = \frac{dE}{dt} = \dot{Q} - \dot{W}$$

The work being done on the system is the electrical power provided from the external battery which is converted to heat by the electronics. The heat transfer from the system is due to the interactions with the ambient environment. These interactions are governed by conduction (1) and convection (2).

$$\dot{Q}_{cond} = KA\frac{\Delta T}{L} \tag{1}$$

$$\dot{Q}_{conv} = hA\Delta T \tag{2}$$

where K is the thermal conductivity, h is the convective coefficient, A is the area of the interface, and $\Delta T$ is the difference in temperature from one side of the material or interface to the other.

## 3.2 Assumptions

For the purpose of this model, many assumptions will be made:

- 100% of input energy to electronics components becomes heat
- The air inside the housing is a uniform temperature throughout at all times
- The seawater around the housing is an infinite heat sink at 30°C
- Delrin ($K = 0.37\frac{W}{m \cdot K}$) behaves as a perfect insulator
- Natural convection governs heat transfer between the interior air and the boundaries materials, and again between the boundary materials and the sea water
- Either the endcap or the tube itself will be made of aluminium and the other delrin

## 3.3 Model

The system will be modeled as a closed system consisting of air contained within a perfectly insulating chamber with two interfaces, one with optical glass and one with aluminium. Those materials, of given thicknesses and areas, will then have an interface with the sea. The resulting block diagram is in Figure 2.

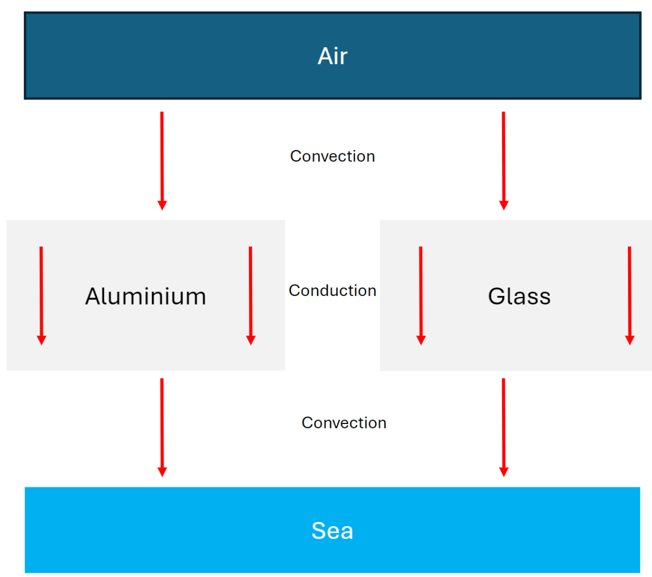


Figure 2: Thermal Model of Housing

### 3.4 Values

From the design specifications the following values will be used initially:

- $\dot{W}_{elec} = 23.9W$
- $A_{glass} = 0.0162m^2$
- $A_{tube} = 0.122m^2$
- $A_{cap} = 0.0078m^2$
- $T_{sea} = 30°C$
- $K_{alum} = 235\frac{W}{m \cdot K}$
- $K_{glass} = 1.38\frac{W}{m \cdot K}$
- $h_{water} = 75\frac{W}{m^s \cdot K}$
- $h_{air} = 20\frac{W}{m^2 \cdot K}$
- $L_{glass} = 0.005m$
- $L_{alum} = 0.008m$

The geometric constraints are derived from the design specifications, thermal conductivity from online tables, and convective coefficients from moderate values from the ranges given in Mills, A.F., *Heat and Mass Transfer*, Richard D Irwin, Inc., 1995, p.22.

### 3.5 Mathematical Representation

The model can be represented using equivalent thermal resistance of two parallel resistors between the air inside the housing and the sea outside, one for aluminium and one for glass. Each of these parallel resistors consists of three in series, convection between the air and the material, conduction through the material, and convection between the material and the sea. The resulting model is

$$\dot{Q}_{elec} = \dot{W}_{totalEq} = R_{tot}\Delta T \tag{3}$$

where

$$R_{tot} = R_{alum} + R_{glass}$$

$$\Delta T = (T_{air} - T_{sea})$$

$$\frac{A_{alum}}{R_{alum}} = \frac{1}{h_{water}} + \frac{L_{alum}}{K_{alum}} + \frac{1}{h_{air}} \tag{4}$$

$$\frac{A_{glass}}{R_{glass}} = \frac{1}{h_{water}} + \frac{L_{glass}}{K_{glass}} + \frac{1}{h_{air}} \tag{5}$$

# 4 Results and Discussion

The steady state air temperature within the housing was calculated for configurations of an aluminium tube with Delrin cap and a Delrin tube and aluminium cap.

With the aluminium end cap, $T_{air}$ **= 95.47 °C**. With an aluminium tube, $T_{air}$ **= 41.03 °C**. On initial inspection, thermal considerations are necessary since the internal temperature can reach above the operating threshold of 65 °C. It is clear that the significantly larger surface area of the tube greatly improves the heat transfer compared to the relatively small end cap. Furthermore, in practice, the hull penetrators will further reduce the surface area of aluminium, raising the internal temperature. As the aluminium tube already reduces the internal temperature to below the threshold, **it is recommended to use aluminium for the tube material and not the end cap**.

Expanding beyond the initial question, if a Delrin tube is required for some reason, or additional cooling is required beyond a simple aluminium tube, the convective heat transfer can be improved by changing the characteristics of the flow. This could include adding fins for more surface area or introducing forced convection with fans or pumps. Given that the housing will be in motion from the forward motion of the towed platform, a pseudo forced convection may take place, increasing $h_{water}$. However, even with a 100-fold increase in $h_{water}$, near the upper limit of forced fluid convection, the aluminum end cap temperature only decreases to $T_{air} = 82.32°C$, still above the operating threshold. Given the series nature of the conduction and convection, the total $\dot{Q}$ is limited by the air-material convection and increases to $h_{water}$ will have limited effects. As such, an increase in $h_{air}$ is necessary. An increase of $h_{air}$ to $52\frac{W}{m^2 \cdot K}$, on the lower end of forced air convection, decreases $T_{air}$ to 64.79 °C, below the threshold.

# 5 Conclusion

From the first-principles model, using aluminium as the tube material and not just the end cap should keep the temperature within operating bounds, however if additional efforts are required or a Delrin tube is necessary, efforts should focus on the air-aluminium interface to keep the housing temperature acceptable.

# 6 Future Work

As this study was a first-principles model, there are many elements that should be more thoroughly considered in further exploration. The primary items of note are:

- The assumption that all of the air within the housing is constant temperature is an oversimplification and the specific location of the heat sources within the housing compared to each other and the interfaces should be considered
- Delrin can be added into the basic model as another parallel thermal resistor with minimal additional effort to increase accuracy
- Experimentally collected data can better estimate the heat generated by the electronic components and provide baselines on the temperature of built-in component thermometers compared to ambient temperature
- Modeling or experimentation can provide more accurate numbers for the natural convective coefficient between the specific materials and geometries
- If the device is only going to be used for short periods of time, steady state may not be reached. The temperature as a function of time can be solved for by solving the differential format of the first law to determine a safe operating duration