Preliminary Housing Thermal Modeling

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1 Overview

The first principles model was re-constructed to remove the assumption of Delrin as a perfect insulator and to include more geometric accuracy. The result shows that while Delrin is significantly more insulating than glass or aluminium, there is still a significant amount of heat transfer through a Delrin housing. Coefficients were recalculated to match the experimental data from the photo logs and then extrapolated to the Reefscan Deep design.

2 Revised First-principles Model

2.1 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).

$$\dot{Q}_{cond} = KA\frac{\Delta T}{L} = \frac{2\pi KL}{\log\left(R_o/R_i\right)}\Delta T \tag{1}$$

$$\dot{Q}_{conv} = hA\Delta T = h2\pi RL\Delta T \tag{2}$$

where K is the thermal conductivity, h is the convective coefficient, A is the area of the interface, and ΔT is the difference in temperature from one side of the material or interface to the other. For cylindrical geometries, R_o is the outer radius, R_i is the inner radius and L is the length of the cylinder.

2.2 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
- Natural convection governs heat transfer between the interior air and the boundaries materials, and again between the boundary materials and the sea water

2.3 Model

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

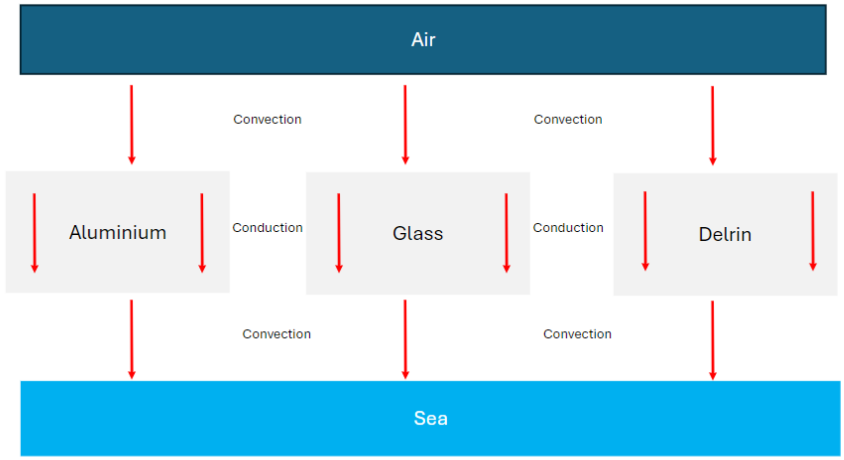

Figure 1: Thermal Model of Housing

2.4 Values

From the design specifications the following values will be used. These values were largely derrived from the CAD model of the Reefscan Transom camera housing.

$\dot{W}_{elec}$	$4.5W$	h_{water}	$50\frac{W}{m^s \cdot K}$	R_o	$0.045m$
A_{glass}	$0.0114m^2$	h_{air}	$10\frac{W}{m^2 \cdot K}$	R_i	$0.035m$
$A_{cap-outer}$	$0.005404m^2$	L_{glass}	$0.004m$	L_{tube}	$0.164m$
$A_{cap-inner}$	$0.003185m^2$	L_{alum}	$0.015m$	T_{sea}	$30°C$
K_{glass}	$1.38\frac{W}{m \cdot K}$	K_{alum}	$235\frac{W}{m \cdot K}$	K_{Delrin}	$0.37\frac{W}{m \cdot K}$

2.5 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

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

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

$$\frac{1}{R_{alum}} = \frac{1}{A_{cap_o} h_{water}} + \frac{L_{alum}}{\frac{A_{cap_o} + A_{cap_i}}{2} K_{alum}} + \frac{1}{A_{cap_i} h_{air}} \tag{4}$$

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

$$\frac{1}{R_{Delrin}} = \frac{1}{h_{air} 2\pi R_i L_{tube}} + \frac{\log(R_o/R_i)}{2\pi K_{Delrin} L_{tube}} + \frac{1}{h_{water} 2\pi R_o L_{tube}} \tag{6}$$

3 Results and Discussion

The resulting T_{air} is 41.83 °C. This is not consistent with the historical data. In order to achieve consistency, the H_{air} value need to be lowered to $3.5\frac{W}{m^2 \cdot K}$ to reflect a $T_{air} = 58.36°C$. This value would represent the very lower bound of a natural air convection. The small size and lack of air circulation within the housing would support the hypothesis of poor convection coefficient but still leads to some concern over accuracy since the value is very low.

4 Extrapolation to Reefscan DEEP

Using the same method considering all three interfaces with relevant geometry and the new convection coefficient but adjusting for the dimension of the Reefscan Deep housing, the comparison between a Delrin aluminium housing can be rerun. With no additional modifications, the T_{air} for a Delrin housing and aluminium endcap is 131.80 °C. The T_{air} for an aluminium body and Delrin endcap is 126.06 °C.

Evaluating just the heat transfer through the cylindrical section, the difference between the Delrin tube and aluminium tube is only 1.5 W. There is a non-zero difference in temperature between the inside of the Delrin housing and the exterior, around 8 °C compared to 0.2 °C for aluminium.

In order to maintain an internal temperature below 65 °C, h_{air} needs to be increased. For a delrin body and aluminium endcap, h_{air} needs to increase to $14\frac{W}{m^2 \cdot K}$ to achieve 64.12 °C. For an aluminium body and Delrin endcap h_{air} needs to increase to $11\frac{W}{m^2 \cdot K}$ to achieve 64.48 °C.

5 Conclusion

From the revised first-principles model, it was determined that the effectiveness of the convection within the housing is far worse than previous estimated. When applied to the Reefscan Deep, overheating appears inevitable if there are not thermal controls engineered into the design. The primary need is for additional methods to draw heat away from the internal components and move it into the housing.