Team Honeywell

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Temperature Analysis Revisit

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1 Introduction

The oil chip detector (OCD) housing, hereinafter referred to as housing, project came about as Honeywell began building a new, turboprop engine and elected to allow students from Northern Arizona University to design the housing to suit rigorous engine requirements. Team Honeywell's direct contact is Chris Temme, hereinafter referred to as Honeywell, a control system engineer at Honeywell. The OCD sensor is used to protect the OCD sensor from harmful shock and thermal damage, as well as slow the flow of oil within the housing to allow the sensor to pick up any metal chips that are within the oil. The chips within the oil will inform the mechanics when the bearings within the engine need to be replaced. Honeywell has produced many engines in the past but has normally subcontracted engine components to other suppliers. The new engine consists of scaled parts from other engines, and some parts are directly lifted from previous designs, this includes the OCD. In order to accommodate these same parts from the bigger engine with smaller oil lines and a smaller capacity, the housing for the detector would have to be redesigned to decrease the flow velocity and pressures across the detector to acceptable nominal values. Other requirements include fire, structural, and environmental resistance. This report is intended to focus on the temperature analysis of the housing, including the fire test.

The results from last semesters analysis were all within the requirements set for by Honeywell. The main reason this analysis is being revisited is because the geometry of the housing has changed greatly since last semester and it warrants conducting the analysis again to ensure the new housing still operates within the engineering requirements set by Honeywell. The temperature analysis conducted will be the same tests as were conducted on the old housing as those tests were enough for Honeywell last semester.

The temperature analysis will focus on the temperature requirements for the housing set by Honeywell. This includes: -65 °F to 260 °F for operating temperatures, 310 °F for 2 minutes to simulate a non-operational period after engine shutdown, and a fire test requiring normal operation at 2000 °F for five minutes. These tests will be carried out by Honeywell on-site in the spring. For this report the use of SOLIDWORKS will be used to conduct temperature analysis on the housing. A model of the housing used for this analysis can be seen in figure 1.

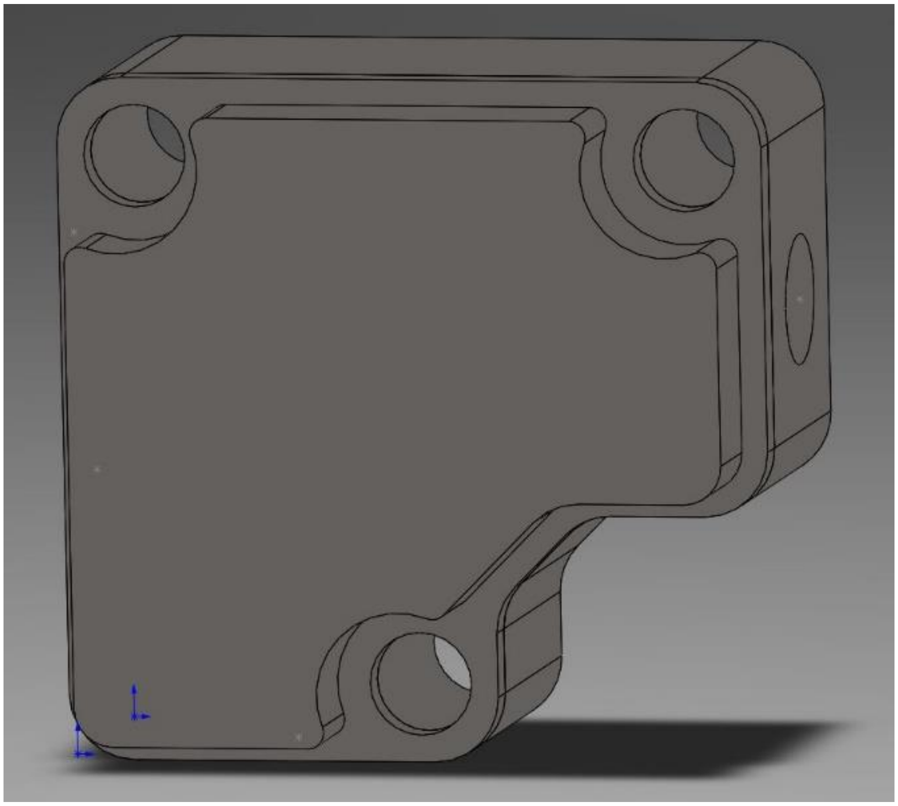

Figure 1. Isometric View of Prototype Housing

The material selected for this prototype is 304 Stainless Steel. This material was selected because of its properties to withstand corrosion, oxidation, and its high melting temperature. The melting range of 304 Stainless Steel is 2550 °F to 2650 °F [1]. This information lead Team Honeywell to select this as the material used for the housing as it can withstand the fire test without the loss of structural integrity.

2 Temperature Simulations

Beginning the temperature analysis, the first aspect examined is the cool down period of the engine, where the temperature is at 310 °F and looking at this with SOLIDWORKS to find the final temperature of the housing after the two-minute cool down period. This is verified by Newton's Law of Cooling, equation (1) below, where: t is time taken for the cooling, T(t) is the temperature of the given object at time t, T_s is the surrounding temperature, T_0 is the initial temperature of the object, and k is the decay constant [2].

$$\boldsymbol{T(t) = T_s + (T_0 - T_s)e^{-kt}} \quad \textbf{(1)}$$

SOLIDWORKS accomplishes this thermal analysis using Finite Element Analysis. This is done by breaking the structure down into a mesh grid and then analyzing every element and how it effects the elements around it. Completing a full (FEA) on the prototype by hand or manually with MATLAB is out of the scope for this report. But using SOLIDWORKS' built in thermal simulation the following analysis is completed by selecting the correct materials and boundary conditions.

2.1 Cool Down Simulation

The result from SOLIDWORKS after the two-minute cool down shows a max temperature of 84.227 °F and a minimum temperature of 81.016 °F. The highest heat concentrations are around the corners of the housing while the lid is cooling off faster than the rest of the housing. The results of the cooldown simulation can be seen in figure 2, the initial temperature is set at 310 °F. The housing loses heat due to convection at a rate of 9.8 $\frac{BTU}{hr*ft*°F}$ [1].

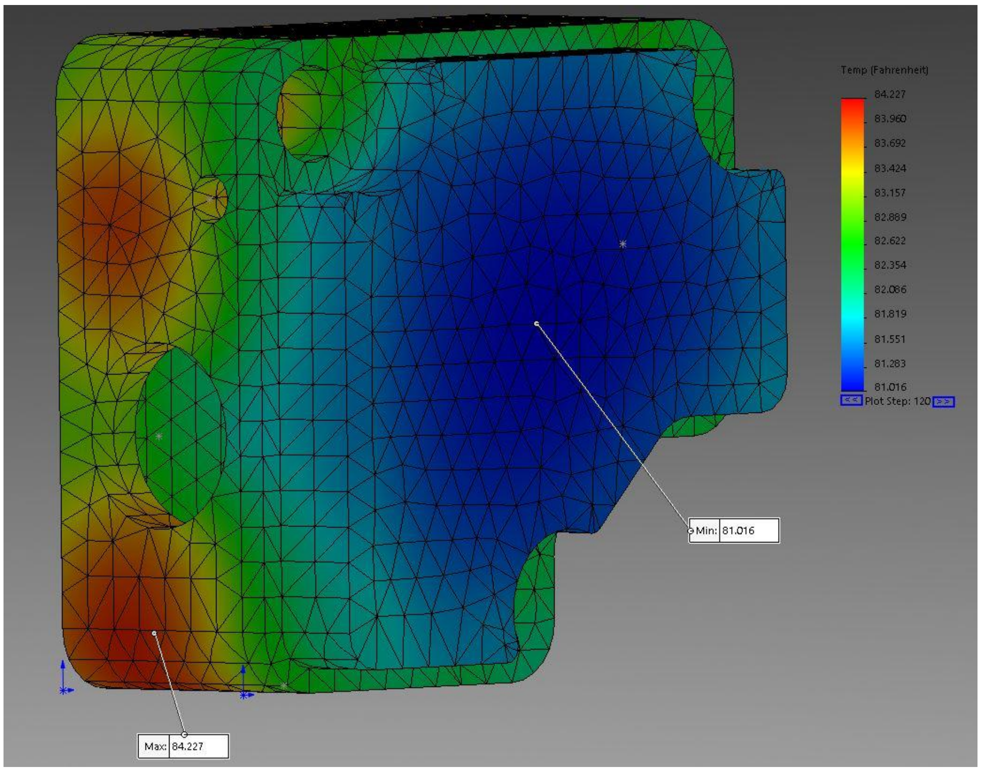

Figure 2. Housing after 2 minute cool-down (initial temperature 310 °F)

These results are well within the normal operation temperate and should not pose any issues for the housing or gaskets used in the design. The gasket chosen by Team Honeywell can withstand temperatures up to 1000 °F. The lid of the housing dissipates heat the fastest and this will be even faster as that is the side of the housing facing away from the engine. This is great for the housing overall as the system can be cooled even faster when exposed to outside air flow.

2.2 Fire Test Simulation

The fire test as stated in the Honeywell PSC is as follows: The housing shall be capable of withstanding a fire resistance test consisting of exposure to a 2000 °F flame for 5 minutes [3]. The fire test is typically conducted while the housing is in operation, this means that oil would be flowing through the housing and as such the temperature would be reduced as the fluid moves through the housing. The following simulations are run on the housing using SOLIDWORKS without any oil flowing through the housing. Fouriers Law shows that heat transfer can be quantified in terms of appropriate rate equations. These equations can be used to compute the amount of energy being transferred per unit time. Fouriers Law deals with conduction and is described in equation (2) [4].

$$q_x'' = -k\frac{dT}{dx} \quad (2)$$

Where, $q_x^"$ is heat flux (W/m^2), which is the heat transfer rate in the x-direction per unit area perpendicular to the direction of transfer. $\frac{dT}{dx}$ is the temperature gradient. The thermal conductivity is k (W/m·K) [4]. This is how well a material will conduct heat. In a steady-state situation the temperature distribution is linear and decreases from the initial temperature to the final temperature. For the fire test the housing is not at steady-state as the torch is supplying 2000 °F at one point for five-minutes. This causes the need to take into consideration generation, this is handled by SOLIDWORKS using (FEA). The fire test is typically conducted by positioning a torch close to the surface of the housing and keeping the flame in that position for the entire five minutes. The area selected to position the torch is the weakest point of the design, this will be determined through more analysis from Team Honeywell. For this simulation the point selected is the angle on the front side of the housing. Figure 3 shows the initial temperature at 70 °F with the position of the torch being simulated as a 2000 °F temperature on the curved front edge of the housing. The 304 Stainless Steel can withstand the 2000 °F temperature for five minutes without losing structural integrity [1]. There are some risks with prolonged exposure to temperatures of this magnitude as 304 Stainless Steel may be more subjective to oxidation and corrosion if regularly operated at temperatures as high as the fire test [1]. But as the normal operation temperature for the housing is -65 °F to 260 °F this should not be an issue. If an engine fire did occur parts would have to be inspected and cleared for further operation, at such a time the housing would be retested.

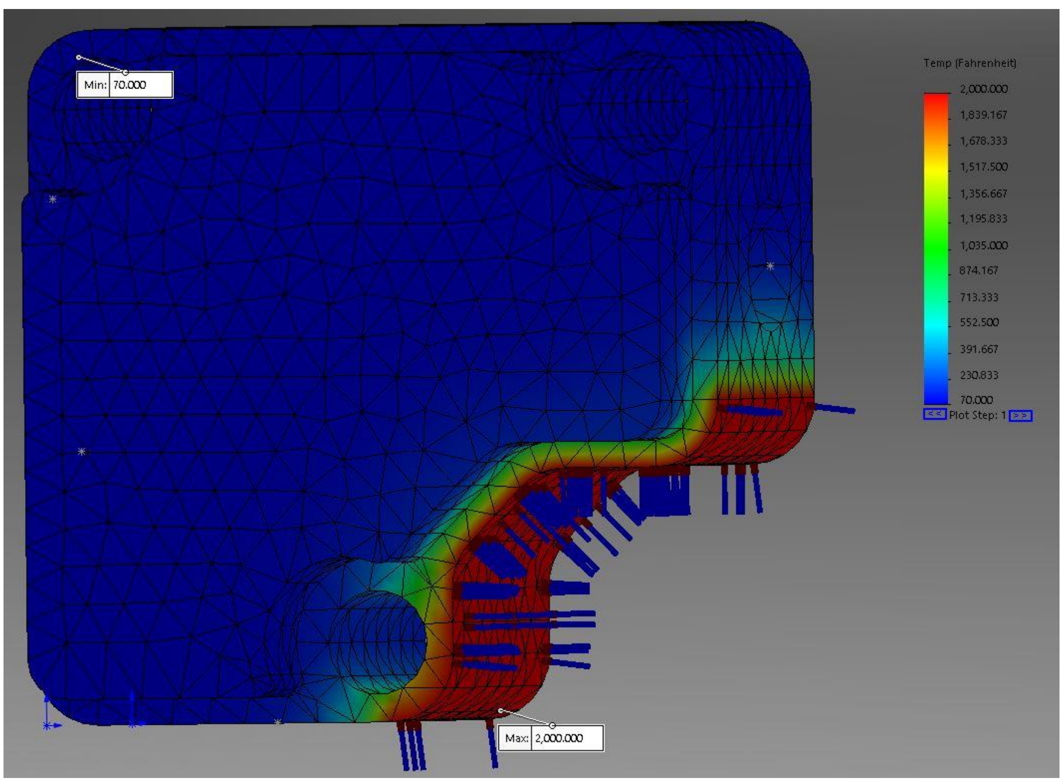

Figure 3. Fire Test Initial Point

After running the five-minute fire test simulation, the temperature distribution can be seen in figure 4. This shows a max temperature of 2000 °F and a minimum temperature of 419.152 °F. As expected, the concentration of the highest temperature starts where the flame is, and it gradually increases the housing's overall temperature. Continuing this simulation for another five minutes increases the minimum temperature to 972.553 °F , seen in figure 5 in Appendix A. The results show temperatures that 304 Stainless Steel can withstand and continue normal operation under. Stainless steel has one of the lowest thermal conductivities of metals, this causes the rate at which it transfers heat to take much longer than if the housing was made from a different metal, such as copper.

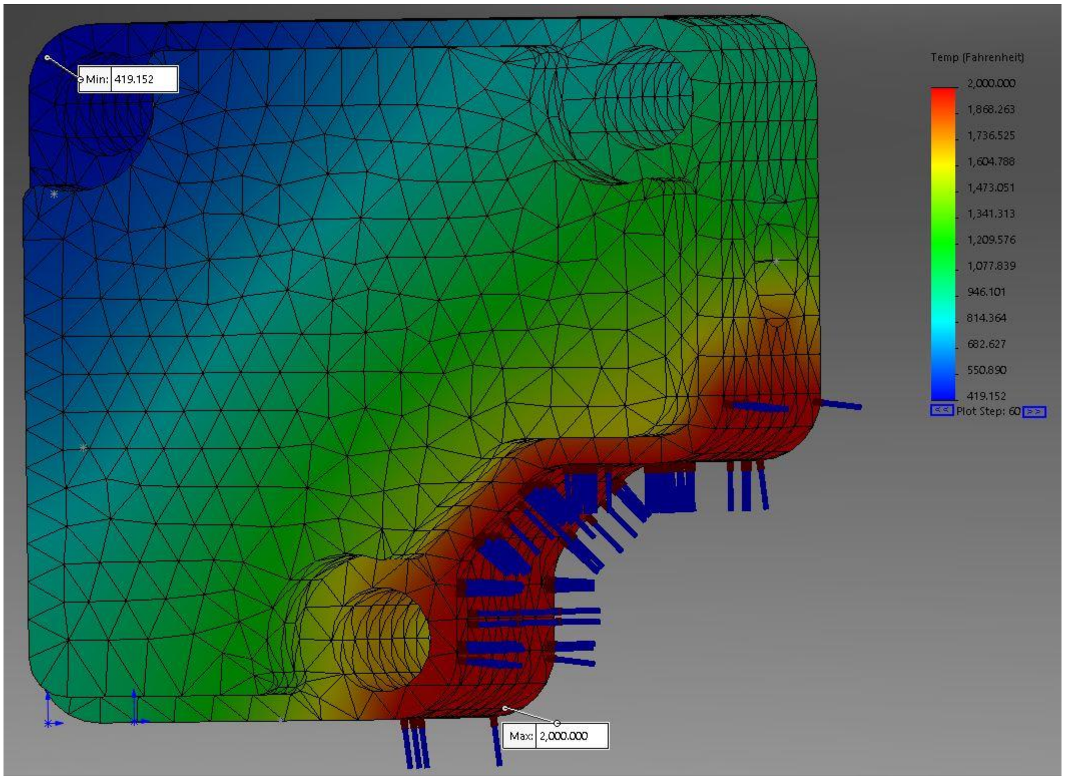

Figure 4. Temperature Distribution After Five Minutes

3 Conclusion

The results of this temperature analysis have led Team Honeywell to feel confidant in the material selection of 304 Stainless Steel. This material will meet all temperature requirements set by Honeywell. This material will also withstand corrosion and oxidation during normal operating temperatures. If normal operating temperatures are higher than 2000 °F than a different material would need to be selected, due to the weaker resistance to oxidation and corrosion of 304 Stainless Steel after prolonged exposure to temperatures close to its melting point [1]. While different materials can withstand the same temperatures as the temperatures tested in this analysis the primary reason 304 Stainless Steel is Team Honeywell's top choice is the ease of manufacturing and low cost compared to materials such as tungsten. This analysis will be used to satisfy the temperature analysis required by Honeywell on the housing.

As compared to the housing tested last semester the new housing will still perform well enough to satisfy Honeywell's requirements. The cool-down simulation showed that the lid is a great way to dissipate heat away from the housing, this was not the case with the old housing design. The new housing also has thinner walls and as such the minimum temperatures after the fire test were higher than the previous housing. This is still well within the operational temperature of 304 Stainless Steel [1]. The new housing design still satisfies all engineering requirements set forth by Honeywell and this temperature analysis proves that it can still withstand the operational temperatures as well as the fire test.

References

[1] "www.aksteel.com," 13 December 2016. [Online]. Available: www.aksteel.com. [Accessed 25 November 2019].

[2] D. Roberts, "MathBitsNotebook," 2 December 2016. [Online]. Available: https://mathbitsnotebook.com/Algebra2/Exponential/EXCooling.html. [Accessed 26 November 2019].

[3] Honeywell, "Procurement Specification for the Oil Chip Detector Housing," Honeywell, Phoenix, 2019.

[4] A. S. L. F. P. I. D. P. D. Theodore L. Bergman, Fundamentals of Heat and Mass Transfer, New York: J. Wiley, 2011.

Appendix A: Additional Simulations

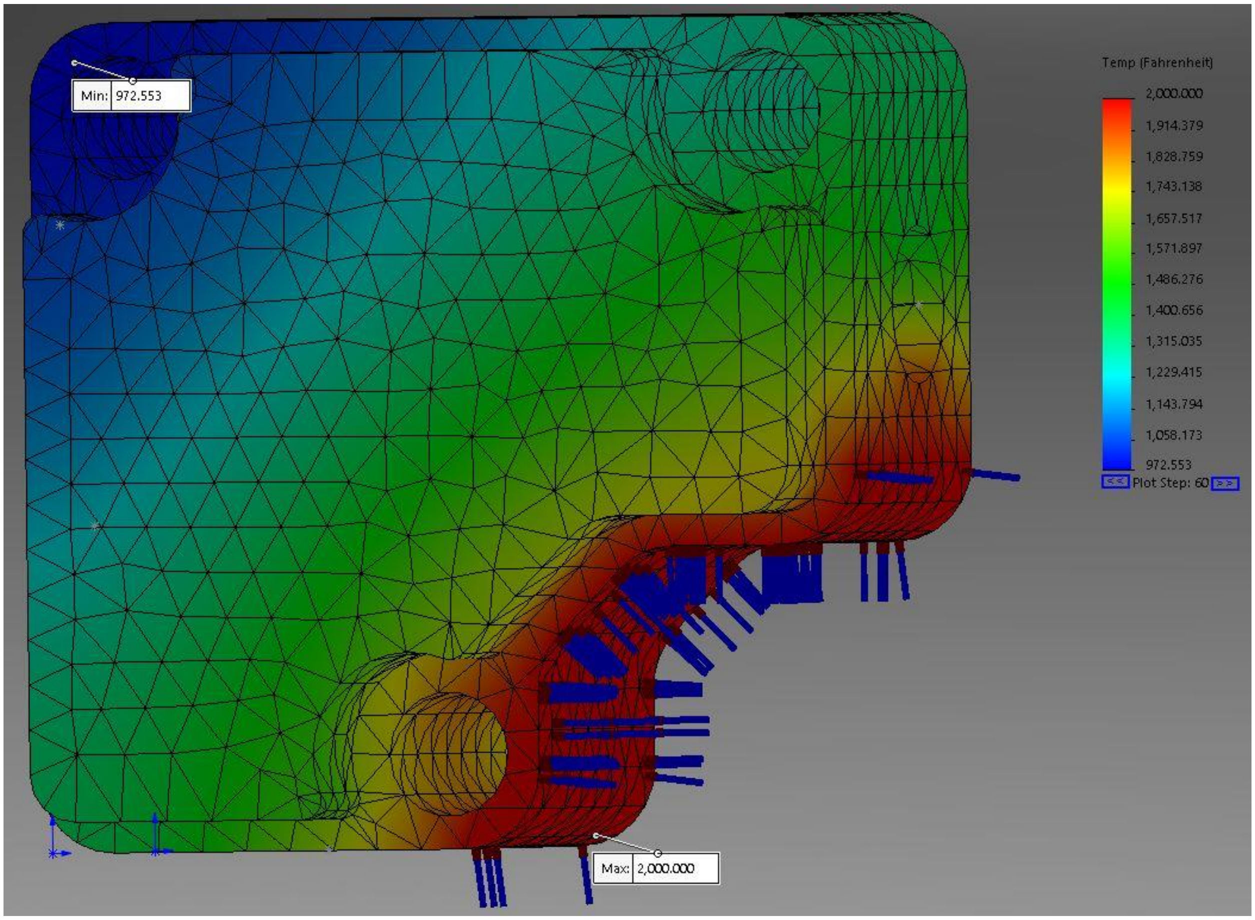

Figure 5. Ten Minute Fire Test 304 Stainless Steel