To: Dr. Sarah Oman
From: John Selee
Date: 11/27/2019
Re: Individual Analysis

Introduction

A housing is needed to direct the flow of engine oil and metallic fragments past a sensor. The assembly is part of a monitoring system for engine component wear of a turboprop driven aircraft. The system allows maintenance personnel to monitor engine wear conditions and schedule appropriate service intervals. The component dimensions are constrained by the design envelope stated in the Honeywell procurement specification (PSC) [1]. The design envelope is constrained to a 3x3x2 in volume of space. Sharp bend and expansion features are chosen to direct and decrease fluid velocity across the sensor. Several materials for the housing were selected for consideration. The materials include titanium and various stainless steel (SST) alloys. The housing is expected to withstand several loads. The housing is expected to perform as a leak-free conduit and pressure vessel. Furthermore, the housing shall be subject to forces due to aeronautical maneuvers and engine vibration. The current design variant was chosen for its relatively simple geometry. Given the above design elements and head loss, we expect that flow will decrease and be directed perpendicularly across the sensor.

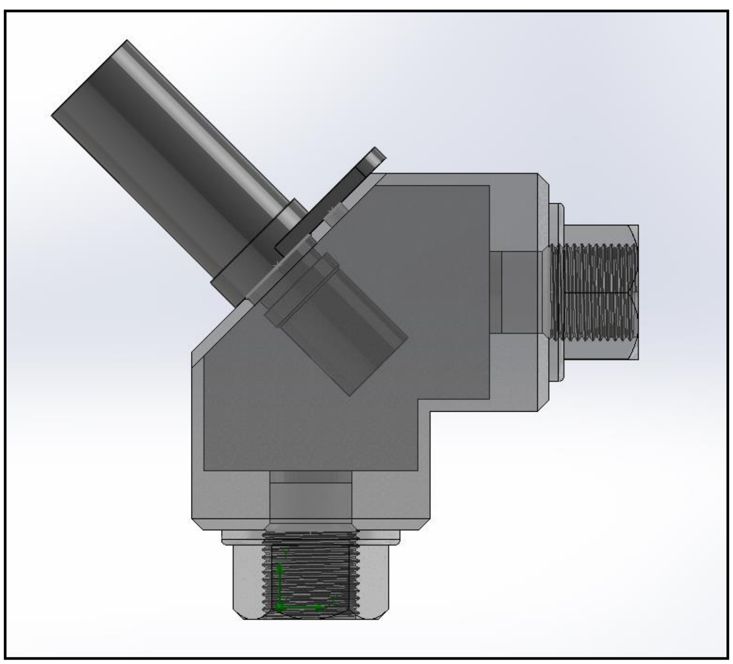

Figure 1: Team Honeywell’s oil chip detector housing design.

Assuming steady, incompressible flow we expect total head loss to account for lost mechanical energy. Energy balance is represented by the modified Bernoulli equation (1).

$$\left(\frac{p_1}{\rho g} + z_1 + \frac{V_1^2}{2g}\right) = \left(\frac{p_2}{\rho g} + z_2 + \frac{V_2^2}{2g}\right) + h_L \tag{1}$$

P: Pressure
Rho: Fluid density
Z: Elevation
V: Velocity
g: Earth gravitational constant
h: Head loss

Continuity for a steady, incompressible flow is given by equation 2 where *A* represents cross-sectional area.

$$A_1 V_1 = A_2 V_2 = Q \tag{2}$$

The calculation for the head loss and resulting velocity drop assume a value for the loss coefficient, K [4]. The given *K* value corresponds to a threaded long radius 90 degree elbow. Minor head loss, *h* is given by solving equation 3 where *V* is the inlet velocity.

$$h_i = K_i \frac{V^2}{2g} \tag{3}$$

The resulting minor head loss represents the pressure difference seen below in equation 4. Using the density of the working fluid and head loss, the resulting velocity can be calculated.

$$V = \sqrt{\frac{2(p_0 - p)}{\rho}} \tag{4}$$

The second velocity measurement reflects what is expected across the sensor surface.

Method

Guiding assumptions for the modeling process help to define conditions of the analysis. This fluid flow analysis assumes that the fluid compressibility and heat transfer are negligible. Additionally, the modeling assumes steady, viscous flow with steady temperature conditions. The fluid and flow characteristics were derived from the Honeywell PSC and the datasheet of an approved engine oil [1,2]. Initial flow conditions were generated from values in the PSC. The fluid velocity at the inlet is expected to range from 1-4fps. The static pressure in the housing is expected to range from 5-15PSIG. A loss coefficient value of 0.7 was assigned. Given the supply velocity and loss coefficient, the minor head loss is calculated using equation 3. The expected velocity drop across the sensor is calculated from the minor head loss using equation 4. The calculations and SOLIDWORKS analysis assume maximum fluid velocity and pressure values.

The model assumes operating temperatures of 212F (100C). The model further assumes that fluid density of 59.4lb/ft^3 (951 kg/m^3) undergoes minimal change at operating temperatures. The fluid viscosity is modeled at 3.03E-3 Pa-s. The thermal properties of the fluid were assumed for a generic engine oil. A specific heat capacity of 2220J/kgK and thermal conductivity of 0.145W/mK were used in the SOLIDWORKS modeling [3].

SOLIDWORKS Flow Simulation was utilized for fluid flow analysis. The Flow Simulation assumes user-defined values for fluid properties. The current CAD model was adapted with addition of a sensor probe. Lids were constructed to block all openings and create and enclosed control volume. Boundary conditions of flow velocity and static pressure were applied to the model and the simulation was loaded.

Results & Discussion

From the calculations, a head loss of approximately 2.09in is expected. The head loss results in a fluid velocity of 3.35fps across the sensor. The velocity drop of ~16% is considered to be a conservative estimate. The *K* value of 0.7 represents a threaded long radius elbow and does not account for expansion effects. Additional calculation values may be referenced in the appendix.

The calculations and modeling give us insight into the design space. The housing directs fluid flow across the sensor at values between 1-4fps. The current design does not cause dramatic increase in pressure.

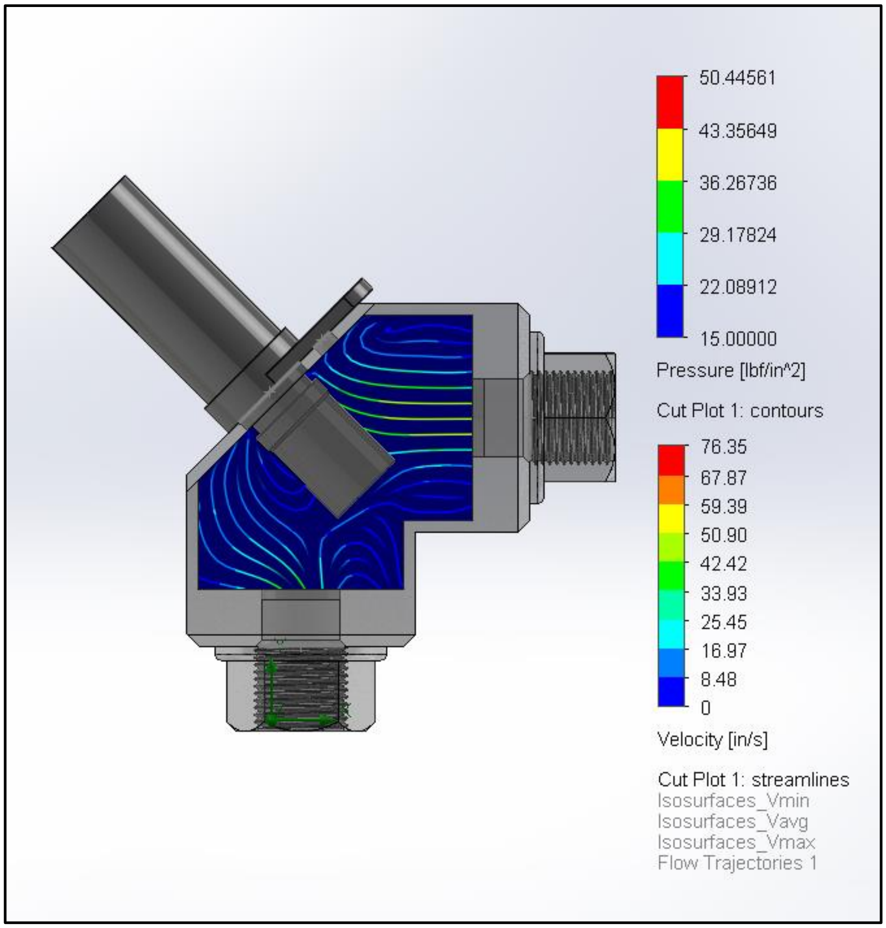

Figure 2: Pressure contour map with velocity streamlines.

The CAD and CFD modeling allow for faster calculation and better resolution of pressure and velocity gradients in the housing. A table of results is available in the appendix. Analysis of the fluid through Flow Simulation allows us to view regions of a specified flow velocity. Below are regions where the fluid velocity is expected to fall within our target range.

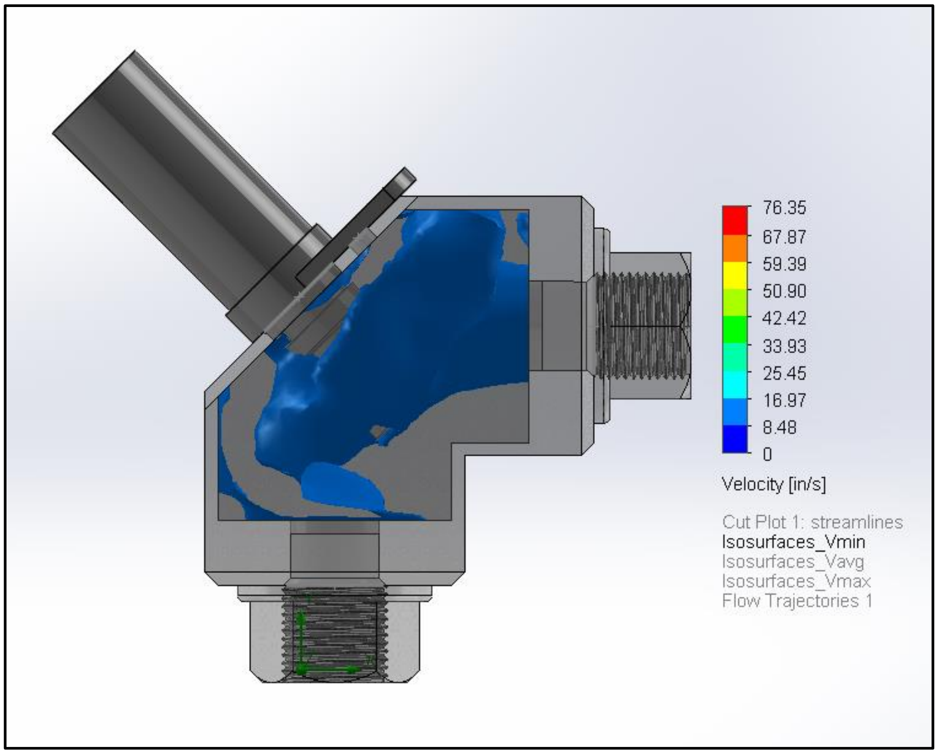

Figure 3: Regions where the flow velocity is at 1fps, the minimum desired value.

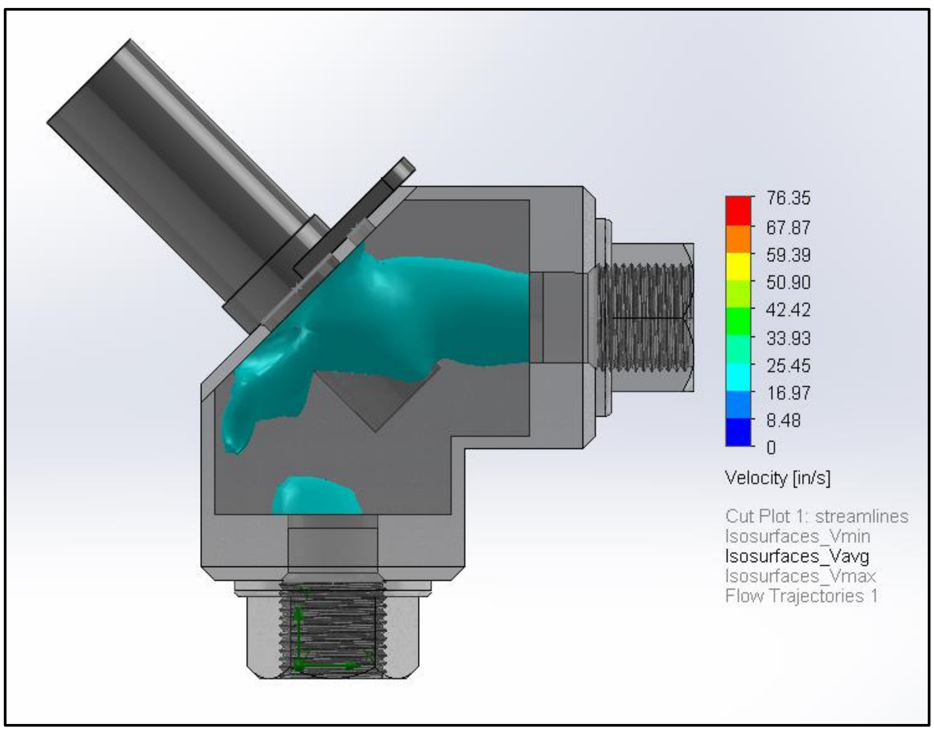

Figure 4: Regions where the flow velocity is at 2fps, the average desired value.

The model will be cross referenced against experimental results generated from the physical prototype.

Figure 5: Physical prototype connected to experimental apparatus.

Results from the experimental procedure can be found by referencing Ilenn Johnson's Individual Analysis.

Several conditions have driven design features and decisions. The housing is expected to withstand several loads. The housing is expected to perform as a leak-free conduit and pressure vessel. The housing shall withstand internal operating pressures in the 5-15PSIG range. Proof and burst pressure conditions are TBD, the appropriate design and analysis will be conducted upon release of the information. The housing will also be subject to standard aeronautical maneuvers. The housing is expected to operate under flight maneuvering loads of 4*g*-6*g*. Additionally, the housing shall withstand operating shocks of 6*g* and up to 20*g* of force in the event of a crash. The structural stress-strain results may be obtained by referencing Cullen Matillano and Jered Deal's individual analyses.

Several materials for the housing were under consideration. The materials included titanium and various stainless steel (SST) alloys. The material of 304 stainless steel was chosen for its machinability, corrosion-resistance, and relative cost attributes. Factors of safety have not been considered for this fluid flow analysis. Analysis of the internal pressure at the specified fluid flow parameters does not significantly exceed the expected 15PSIG. Without consideration of stress concentration factors, internal pressure due to fluid flow is approximately 2000x less than the yield stress of 304 SST.

There is opportunity for improvement. The current design variant was chosen for its relatively simple geometry. Of all variants, the current housing design was the most feasible for manufacture. The team is consistently reiterating upon the housing design, to improve design for manufacturing and assembly (DFMA) additional variants are under consideration. Reiteration of all analyses will be conducted to test feasibility of new concept variants.

Conclusion

The current design variant adequately directs and decreases the fluid flow velocity across the sensor probe. Flow velocities across the face of the sensor occur at desirable values between 1-4fps. The current design will maintain a maximum operating pressure of ~15.3PSI. Several conditions may lead to design changes and the team is prepared to address them. First, the team will compare experimental and CFD modeling results to assess the validity of each. Next the team will coordinate to configure the model and prototypes to achieve optimal flow conditions across the sensor. Finally, the team will reassess the implemented changes and their effect on fluid flow and device manufacturability.

References

[1] Honeywell, "Procurement Specifications for the Oil Chip Detector Housing," Honeywell Aerospace, Phoenix, 2019.

[2] “Technical Datasheet Turbo Oil 2389,” *Eastman*. [Online]. Available: https://productcatalog.eastman.com/tds/ProdDatasheet.aspx?product=71097796&pn=Turbo+Oil+2389#_ga=2.167649726.1468623979.1574971820-592079339.1574971820. [Accessed: Nov-2019].

[3] “Thermal Conductivities for some common Liquids,” *Engineering ToolBox*. [Online]. Available: https://www.engineeringtoolbox.com/thermal-conductivity-liquids-d_1260.html. [Accessed: Nov-2019].

[4] P. Pritchard and J. Mitchell, *Fox and McDonald’s Introduction to Fluid Mechanics*, 9th ed., New York, Wiley, 2005

Appendix

Fluid Flow Calculation Sheet

BP Turbo Oil 2389									
Density (15C)	951.1	kg/m^3					V_fluid_min	1	fps
Viscosity (100C)	0.003034009	Pa.s					V_fluid_max	4	fps
V_fl_SI	1.2192						V_fluid_avg	2.5	fps
D_in_SI	0.01905						D_in	0.75	in
Re	7280.802508								
e	0.000015	m							
Relative Roughness	0.000787402								
Friction Factor	0.0185								
K, Loss coefficient	0.7								
head loss	0.053033336	m	2.087927	in					
head loss	494.8164555	Pa							
V_probe_SI	1.020055904	m/s							
V_sensor_Im	3.346640106	fps							
v drop	16.33399735	%							
Cp	2220	J/kgK							
Thermal Conductivity	0.145	W/mK							

SOLIDWORKS Generated Values

Parameter	Min	Max
Density (Fluid)	0.0343571 lb/in^3	0.0343571 lb/in^3
Pressure	15 lbf/in^2	15.3204 lbf/in^2
Temperature	77.3764 °F	212.002 °F
Temperature (Fluid)	77.3764 °F	212.002 °F
Velocity	0 in/s	76.3523 in/s
Velocity (X)	-48.0558 in/s	34.5619 in/s
Velocity (Y)	-73.2666 in/s	23.5953 in/s
Velocity (Z)	-37.0264 in/s	37.2222 in/s
Acoustic Power	0 lbf/(s*in^2)	6.0798e-18 lbf/(s*in^2)
Acoustic Power Level	0 dB	0 dB