MTF236 Assignment 2

Underhood Thermal Management

Group 8

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March 19, 2021

Contents

1 Question 1

Calculate the temperature of the coolant at each point in the LT circuit and the heat transferred across the LT radiator if the temperature of the coolant entering the pump is 25°C

The LT circuit consists of the pump, battery, electric motor, DC DC Converter and the radiator. The inlet temperature of the coolant entering the pump is given as 298.15 K. Since it is assumed to be an adiabatic process, the output temperature of the coolant is also 298K which is considered as the inlet temperature of coolant at the battery. The cumulative cell heat rate can be given as,

$$\texttt{Q\_b} = \texttt{cell\_heat\_rate} \cdot n \tag{1}$$

The outlet temperature at the battery can be found by the equation,

$$\texttt{outlet\_temp2} = \frac{\texttt{Q\_b}}{\texttt{m\_dot} \cdot \texttt{cp\_coolant}} + \texttt{inlet\_temp2} \tag{2}$$

With the above value as the input temperature at the Electric motor, the outlet temperature is given by the equation,

$$\texttt{outlet\_temp3} = \frac{\texttt{Q\_b}}{\texttt{m\_dot} \cdot \texttt{cp\_coolant}} + \texttt{inlet\_temp3} \tag{3}$$

Similarly, the output temperature of the DC-DC Converter can be found by the equation,

$$\texttt{outlet\_temp4} = \frac{\texttt{Q\_b}}{\texttt{m\_dot} \cdot \texttt{cp\_coolant}} + \texttt{inlet\_temp4} \tag{4}$$

The values are recorded in the table below.

Component	**Inlet temperature**	**Outlet temperature**
Pump	298.15	298.15
Battery	298.15	298.167
Electric Motor	298.167	302.023
DC-DC Generator	302.023	305.0

The total heat transferred across the radiator is -14440 W which is found by the equation,

$$\texttt{Q\_lt\_rad= m\_dot*cp\_coolant*(inlet\_temp1-outlet\_temp4)} \tag{5}$$

2 Question 2

Calculate the pressure drop across each component in the LT circuit. Include frictional pressure drop using the Darcy-Weisbach equation.

The pressure drop across the pump can be found by interpolating the values of the coolant pump characteristics data at 4000 rpm linearly for the value of Q_flow of 34.8 L/min. The pressure drop across the electric motor is given by the equation,

$$dP_{EM} = 0.02 \cdot Q_{flow}^2 - 0.18 \cdot Q_{flow} \tag{6}$$

Similarly the pressure drop equations for the battery and DC-DC Converter can be given by the equations,

$$dP_{DC-DC} = 0.001 \cdot Q_{flow}^3 - 0.0035 \cdot Q_{flow}^2 + 0.016 \cdot Q_{flow} \tag{7}$$

$$dP_{Bat} = 0.00375 \cdot Q_{flow}^{2.5} - 0.2797 \cdot Q_{flow} \tag{8}$$

The frictional pressure drop can be found by Darcy- Weisbach equation. The value is 3.48 Pa.

$$dP_{friction} = \frac{f \cdot p \cdot v^2 \cdot L}{2 \cdot D} \tag{9}$$

The total pressure drop in the LT radiator can be found by subtracting all the pressure drop values with the pump's pressure drop value.

$$dP_{rad} = dP_{pump} - (dP_{EM} + dP_{DC-DC} + dP_{Bat} + dP_{friction}) \tag{10}$$

All the above values of pressure drop are represented in the form of a bar graph.

(a) Pressure drop (pa)

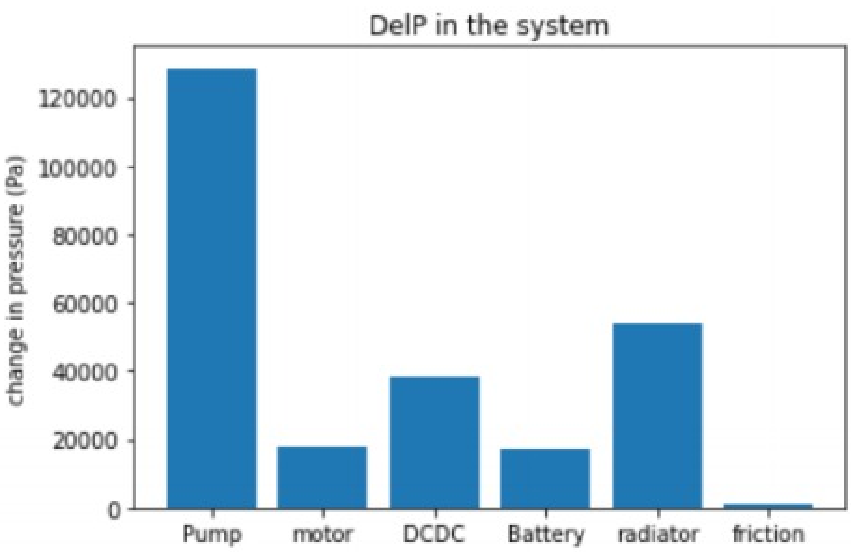


Figure 1: The absolute values of the pressure change over each component in the LT circuit.

3 Question 3

Write a function named 'air circuit' that solves for the state variables, pressure, temperature and density, at each step in the air circuit, with mass flow rate and heat transferred across the radiators as inputs.

A function named air circuit is defined with mass flow rate of air and heat transferred across the HT Radiator. There are 6 zones in the air circuit as follows.

- before grille
- after grille
- after LT Radiator
- after Condenser
- after HT Radiator
- after fan

The temperature and static pressure before the air enters the grille is provided as 287.15K and 83400 Pa respectively. The dynamic pressure can be found by using the formula,

$$\texttt{dyn\_p\_g} = \frac{1}{2} \cdot \rho \cdot V^2 \tag{11}$$

The total pressure is,

$$\texttt{Stagnation pressure} \quad \texttt{P\_0} = \texttt{s\_p\_g} + \texttt{dyn\_p\_g} \tag{12}$$

The temperature will be the same before and after the grille. It is also provided that there is a loss in static pressure which accounts to 35 percent of dynamic pressure. Hence the equation will look like,

$$\texttt{P\_1} = (\texttt{s\_p\_g} - (0.35 \cdot \texttt{dyn\_p\_g})) + \texttt{dyn\_p\_g} \tag{13}$$

The pressure drop when the air passes through the LT and HT Radiators and the condenser can be given by the formula,

$$dP_{HX} = k_0 \cdot \frac{m_{dot}^2}{\rho} + k_1 \cdot \frac{m_{dot}}{\rho} + k_2 \tag{14}$$

In the above equation, the values of k_0, k_1 and k_2 changes for each of the radiators and the condenser. The pressure temperature and density after passing through each of the components can be found by the formulae,

$$P_x = P_{x-1} - dP_{HX} \tag{15}$$

$$T_{out} = \frac{\texttt{Q\_lt\_rad}}{(\texttt{m\_air} * \texttt{cp\_air})} + T_{in} \tag{16}$$

$$\rho_x = \frac{P_x}{(R_{air} * T_x)} \tag{17}$$

The pressure recovery by the fan can be found by finding the volumetric flow rate and interpolating to its corresponding pressure rise value at zone 4. The volumetric flow rate is found using the formula,

$$volFlowRate = \frac{\texttt{m\_air}}{\rho} \tag{18}$$

The final pressure P_5 can be found by adding the interpolated value of pressure rise to the pressure at zone 4.

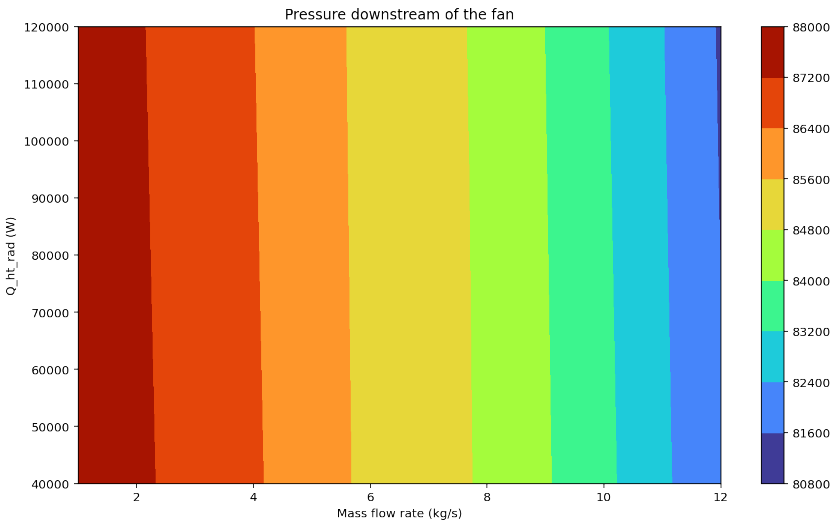
$$\texttt{P\_5} = \texttt{P\_4} + dP_{fan} \tag{19}$$

4 Question 4

Design of Experiment (DOE) analysis: Vary the heat transferred across the 'HT RAD' from 40kW-120kW and mass flow rate of air at the inlet from 1kg/s to 12kg/s. Use the function 'air circuit' to compute the state variables in the circuit for all the scenarios. Create contour plots for pressure, temperature and density downstream of the fan.

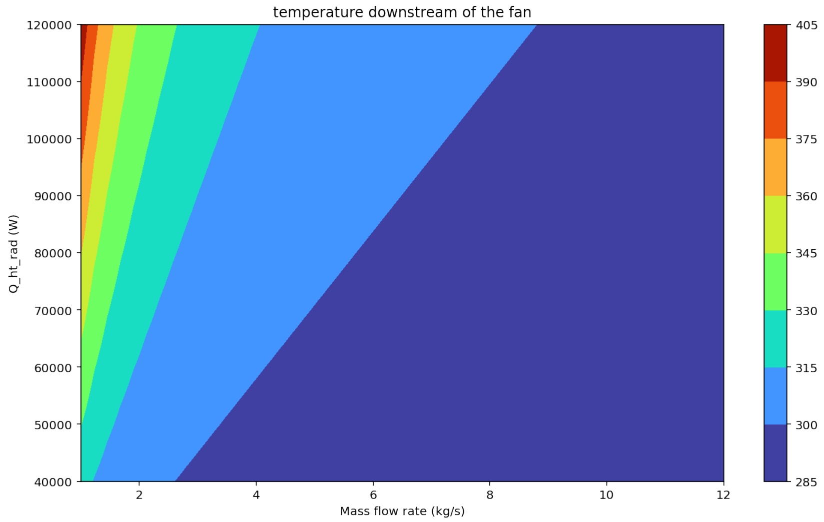
The mass flow rate and the heat transferred across the HT Radiator are varied as given. For every value of heat transferred across the HT Radiator, the mass flow rate is varied. Then by calling the air circuit function, the output values are stored in a dataset and the contour plots are plotted.

(a) Pressure contour plot

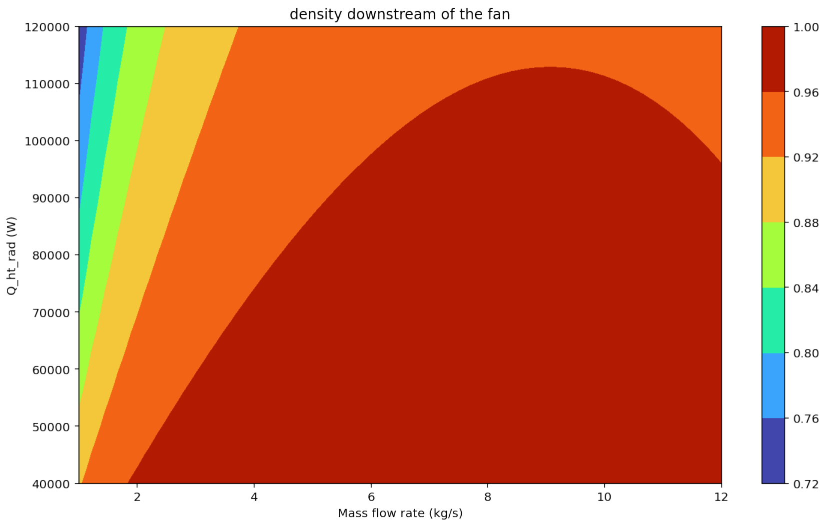


As the mass flow rate is increasing, the pressure reduces which can be clearly understood from the figure. Here, the mass flow rate through the area increases, then the velocity of the fluid increases and the pressure decreases because the area of the grill remains constant. Velocity increases with high mass flow rate through the unchanged area. Also this can be related to the poor pressure recovering capacity of the fan when the mass flow rate increases.

(a) Temperature contour plot)



(a) Density contour plot

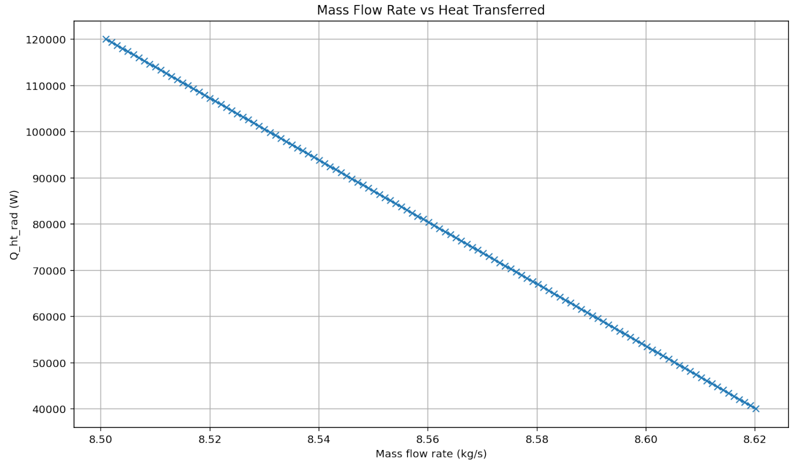


For a constant mass flow rate value (for example 2 kg/s) the temperature is found to be increasing with the amount of heat transferred. It is clearly understood that as more air passes through the circuit the temperature reduces.

In the temperature contour plot, as the temperature reduces with increasing mass flow rate and as the density reduces with increase in temperature, the density is found to increase with the mass flow rate and also the density is found to be low when the heat transfer is high as observed in the density contour plot. The above inference is reasonable because density should be lower at higher temperature. Additionally, when more mass flow rate happens through the radiator, the air gets heated up lesser than before and the density increases accordingly because of the reduced temperature.

5 Question 5

Identify the mass flow rates such that the total pressure downstream of the fan is equal to the stagnation pressure upstream of the grille at different values of heat transferred at the 'HT RAD'. Plot the heat transferred vs mass flow rates and explain the trend with supporting arguments.



The figure gives us the points at which the $P_0 \approx P_5$.

For equal inlet and outlet pressures, when the mass flow rate increases for the given small range, the amount of heat transfer reduces drastically. This line can be retrieved from the pressure downstream of the fan contour plot which depicts the pressure recovery. For increased mass flow rate values, the heat transfer required is less. The reason behind this trend to keep the same pressure at zones zero and 5 (pressure downstream of the fan and pressure entering the grille). Hence when the mass flow rate doesnt change according to this trend and stays the same, the pressure at the grille will be higher than at the outlet of the fan.

6 Question 6

Explain what happens to the heat exchanger in the RF circuit if the RF circuit acts as a heat pump.

In the RF circuit, in order to maintain the system cool, the heat is rejected in the air at the condenser and the heat is absorbed at the evaporator. But if the heat exchanger acts as a heat pump in the above circuit, the heat is absorbed at the condenser and rejected at the evaporator. Hence the system does not cool anymore.