MSAS – Assignment #2: Modeling

Student Name, 123456

Exercise 1

The rocket engine in Figure 1 is fired in laboratory conditions. With reference to Figure 1, the nozzle is made up of an inner lining (k_1), an inner layer having specific heat c_2 and high conductivity k_2, an insulating layer having specific heat c_4 and low conductivity k_4, and an outer coating (k_5). The interface between the conductor and the insulator layers has thermal conductivity k_3.

1.1) Part 1: Parameters definition

Select the materials of which the nozzle is made of*, and therefore determine the values of k_i ($i = 1, \ldots, 5$), c_2, and c_4. Assign also the values of ℓ_i (i=1,...,5), L, and A in Figure 1.

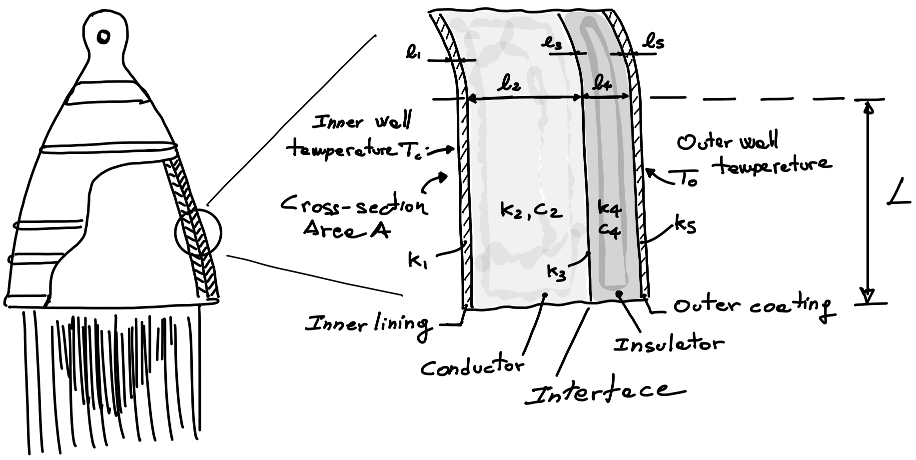

Figure 1: Real thermal system.

1.2) Part 2: Causal modeling

Derive a physical model and the associated mathematical model using one node per each of the five layers and considering that only the conductor and insulator layers have thermal capacitance. The inner wall temperature, T_i, as well as the outer wall temperature, T_o, are assigned. Using the mathematical model, carry out a dynamic simulation in MATLAB to show the temperature profiles across the different sections. At initial time, $T_i(t_0) = T_o(t) = 20$ C°. When the rocket is fired, $T_i(t) = 1000$ C°, $t \in [t_1, t_f]$, following a ramp profile in $[t_0, t_1]$. Integrate the system using $t_1 = 1$ s and $t_f = 60$ s.

1.3) Part 3: Acausal modeling

a) Reproduce in Simscape the physical model derived in Part 2. Run the simulation from $t_0 = 0$ s to $t_f = 60$ s and show the temperature profiles across the different sections. Compare the results with the ones obtained in point 1.2). b) Which solver would you choose? Justify

*The interface layer is not made of a physically existing material, though it produces a thermal resistance. For this layer, the value of the thermal resistance R_3 can be direcly assumed, so avoiding to choose k_3 and ℓ_3.

the selection based on the knowledge acquired from the first part of the course. c) Repeat the simulation in Simscape implementing two nodes for the conductor and insulator layers and show the temperature profiles across the different sections.

(15 points)

Write your answer here

- Develop one Matlab script for Exercise 1; name the file `lastname123456_Assign2.m`. If needed, organize the script in sections and use local functions.
- Develop one Simulink model for Exercise 1; name the file `lastname123456_Assign2.slx`.
- Develop two Dymola models for Exercise 2; name the files `lastname123456_Assign2_Part_1.mo` and `lastname123456_Assign2_Part_2.mo`.
- Create a single .zip file containing the report in PDF, the MATLAB file, the Simulink model, and the two Dymola models. The name shall be `lastname123456_Assign2.zip`.
- Red text indicates where answers are needed; be sure there is no red stuff in your report.
- In your answers, be concise: to the point.
- **Deadline for the submission: Dec 18 2023, 23:59.**
- **Load the compressed file to the Homework folder on Webeep.**

Exercise 2

The real system of an electric propeller engine is depicted in Figure 2. It is composed by a DC permanent magnet motor which drives a propeller shaft. Between the motor and propeller shaft there is a single stage gear box to regulate the angular speed ratio. Moreover, to avoid overheating of the gear unit, the system is augmented by a cooling system where a fluid exchanges heat with the gear box itself. In Figure 3 a functional breakdown structure of the system is shown.

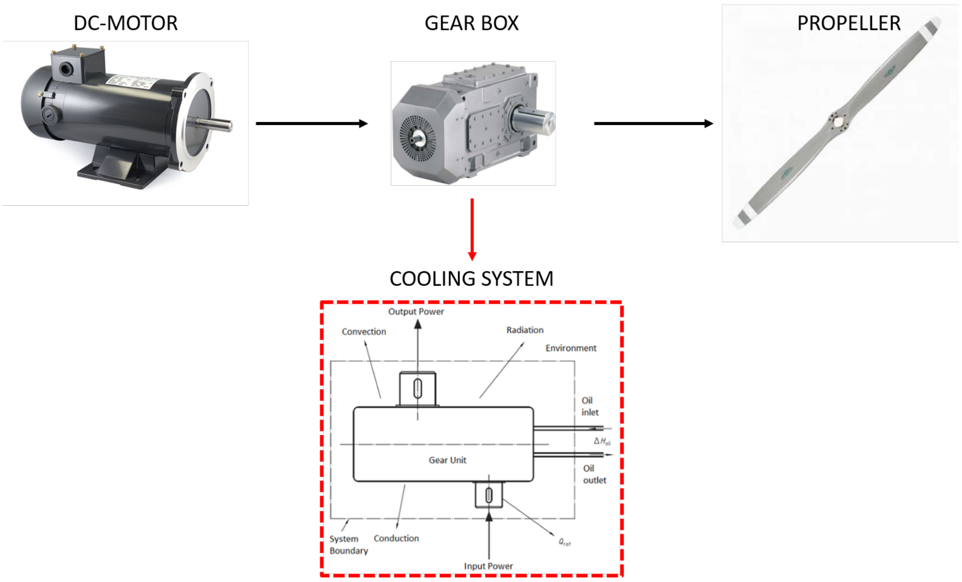

Figure 2: Real system.

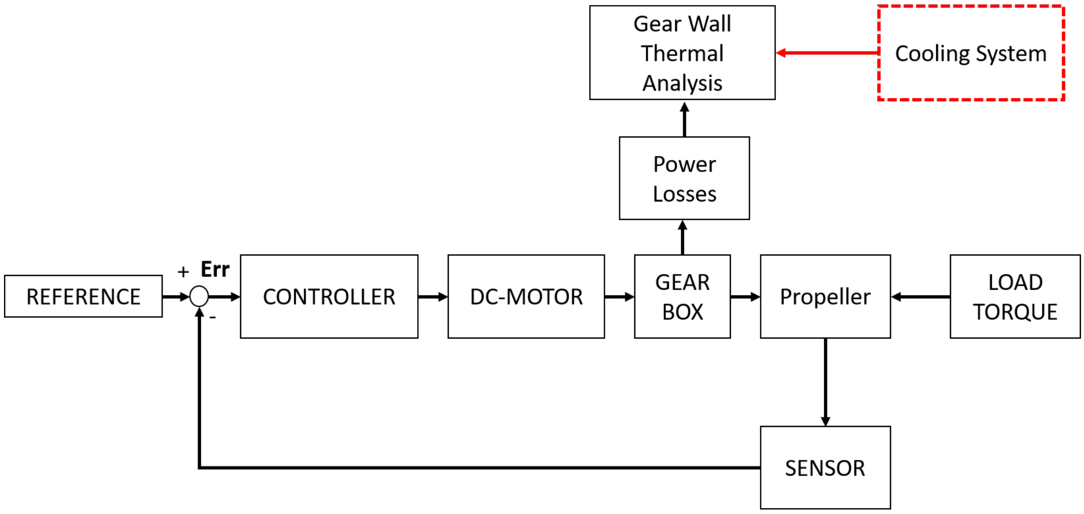

Figure 3: Functional block scheme of the system.

2.1) Part 1: Propeller Electric Engine

Considering the real system in 2 **without** the cooling part, you are asked to:

1. Extract a physical model highlighting assumptions and simplifications.
2. Reproduce the model in acausal manner in Dymola.
3. According to the block scheme in 3, tune a controller (e.g., a PID controller) such that the motor input voltage remains less than 200 V and the error signal **Err** is less than 0.1 rad/s after 10 s.
4. Study the Gear box temperature and heat flux for a simulation time of $\mathbf{t_f} = 120$ s (considering only conduction as heat transfer).
5. Discuss the simulation results and the integration scheme used

For the simulation part, you shall consider: the DC motor data listed in Table 1; the gear box data listed in Table 2, with loss parameters in Table 3; a propeller made of **aluminium** with nominal angular speed $\hat{\omega}$ and a nominal quadratic speed load torque $\hat{T}_{load}$ acting on it (Table 4). The reference angular speed signal to be tracked by the propeller is given in Figure 4.

Table 1: DC motor data

Parameter	Value	Unit
Coil Resistance	0.1	Ω
Inductance	0.01	H
Motor Inertia	0.001	kg m^2
Motor Constant	0.3	Nm/A

2.2) Part 2: Cooling System

After the previous gear unit thermal analysis, now consider the steady-state condition reached by the propeller engine at the end of the simulation to model and simulate a single **fixed** volume flow rate cooling system (as shown in Figure 2) for the gear unit and considering only **convection** as heat transfer. In particular, you are asked to:

Table 2: Gear Box data

Parameter	Value	Unit
Mass	3	kg
Gear ratio	2	[-]
Specific heat	1000	J/(kg K)
Thermal Conductivity	100	Wm/K

Table 3: Gear Box Loss Table

Driver angular speed [rad/s]	Mesh efficiency[-]	Bearing friction torque [Nm]
0	0.99	0
50	0.98	0.5
100	0.97	1
210	0.96	1.5

Table 4: Propeller data

Parameter	Value	Unit
Diameter	0.8	m
Thickness	0.01	m
$\hat{\omega}$	210	rad/s
$\hat{T}_{load}$	100	Nm

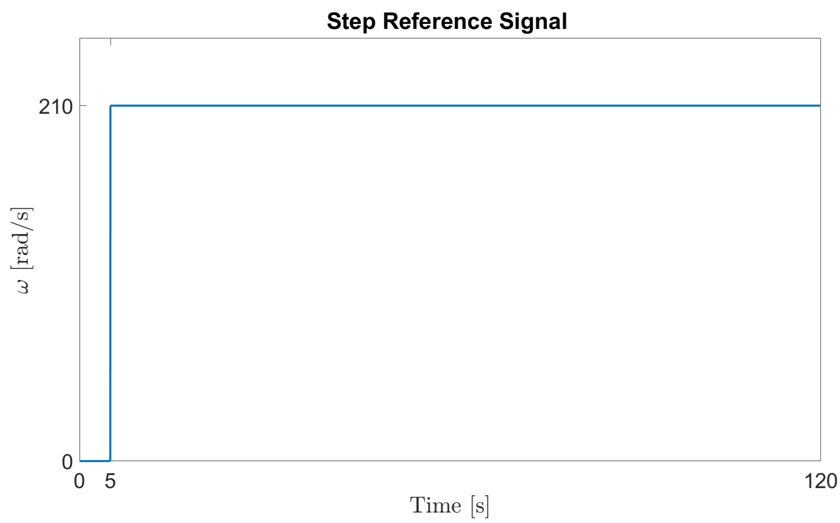

Figure 4: Angular speed reference for the propeller.

1. Derive a physical model highlighting assumptions and simplifications.
2. Reproduce the acausal model in Dymola.
3. Tune the cooling system in terms of volume flow rate, control logics, and initial fluid storage temperature such that:
   (a) the gear unit is kept between 40°C and 60°C.
   (b) the source tank does not get empty before the end simulation time
   (c) the storage tanks have a maximum height of 0.8 m and cross section area of 0.01 m^2
   (d) the system shall have a recirculating capability in order to exploit the outlet fluid for a next cooling process (when the source tank get empty)

(e) the sink heated fluid is kept between 5°C and 10°C.

(f) the power consumption of the thermal system shall be no more than 6 kW

4. Discuss the simulation results and the integration scheme used

For the simulation part consider properties of water at 10°C as cooling incompressible fluid (convective thermal conductance $\lambda_{conv} = 300$ W/K) and the cylindrical pipe line data listed in Table 5. The simulation shall last at least $\mathbf{t_{sim}} = 300$ s starting with no water along the pipe.

Table 5: Pipe line properties

Parameter	**Value**	**Unit**
Diameter	4	cm
Length	40	cm
Geodetic height	0	m
Friction losses	0	[-]

(15 points)

Write your answer here