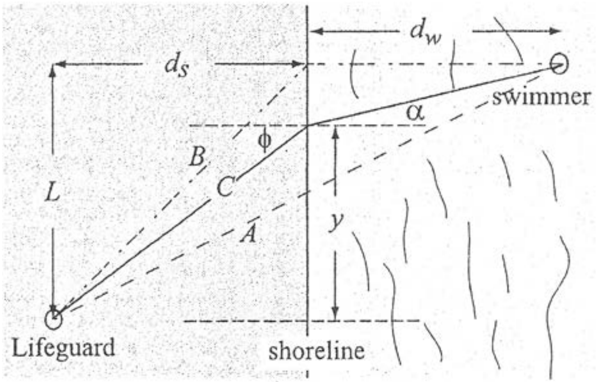
Applied Engineering Problem Solving (CHEN.3170 sec 201)

Homework Assignment #1 -- Fall 2017

Getting Started With Matlab

Problem #1: Lifeguard Duty -- Finding the Optimum Path

A student has a summer job as a lifeguard at the beach. After spotting a swimmer in trouble, the lifeguard tries to deduce the path by which he/she can reach the swimmer in the shortest time. The path of shortest distance (path A) is obviously not best since it maximizes the time spent swimming (the lifeguard can run faster in the sand than he/she can swim in the water). Similarly, path B, which minimizes the time spent swimming, is probably not the best choice, since it is the longest reasonable path. Thus, the optimal path is probably somewhere between paths A and B.



Consider an arbitrary intermediate path (such as path C in the diagram) and the following data for a particular situation:

speed in sand: $v_s = 3$ m/s   speed in water: $v_w = 1$ m/s

appropriate distances (see diagram): $L = 48$ m, $d_s = 30$ m, $d_w = 42$ m

where y is the lateral distance along the shoreline at which the lifeguard enters the water.

Now, with the above data and description of the problem, develop expressions for the total distance traveled by the lifeguard and the travel time as a function of the lateral distance y. Plot these functions on different axes on the same page using Matlab's ***subplot*** command. Do the distance vs. y and travel-time vs. y relationships make sense? What value of y gives the minimum distance traveled (i.e. path A)? What is the optimum y if the travel time is to be minimized? Clearly develop the logic for your analysis and rationalize that the resulting plots are reasonable solutions to this simple geometry problem…

Problem #2: A Simple Cooling Tank

Introduction: A vertical cylindrical vessel is to be used as a holding tank to store 1000 gal of hot water with an initial temperature T_h until it has cooled to temperature T_c, at which time the cooler water is discharged to the environment. The tank is insulated on the top and bottom, but it is exposed on its vertical sides to ambient air with temperature T_∞. An average overall heat transfer coefficient for natural convection is about U = 20 BTU/hr-ft^2-F. For simplicity, the thermal capacity of the thin metal wall can be neglected and one can also assume that the tank liquid is perfectly mixed (i.e., has a uniform temperature).

For this situation, an unsteady state energy balance gives

$$\frac{d}{dt}(mcT) = \dot{E}_{in} - \dot{E}_{out} + \dot{Q} + \dot{W} \qquad (1)$$

which, in words, states that the rate of change of energy of the liquid is equal to the energy flow rate in minus the energy flow rate out with the fluid, plus any heat transfer to the fluid and work done on the fluid. However, since the planned use of the cooling tank involves batch operation, both flow terms cancel. In addition, we will assume that the heat transfer term far exceeds the mechanical work input via the stirrer; thus the work term can also be cancelled. Finally, we also argue that the changes in water density ($m = \rho V$) and specific heat, c, over the temperature range that is expected will be small, so that average (time-independent) values can be used.

With these considerations and assumptions, eqn. (1) reduces to

$$mc\frac{d}{dt}T = \dot{Q} = -UA(T - T_\infty) \qquad (2)$$

where Newton's Law of Cooling has been used to represent the convection heat transfer to the environment. Putting this expression into final form gives the following initial value problem (IVP):

$$\frac{d}{dt}T = -\frac{UA}{mc}(T - T_\infty) \qquad \text{with} \quad T(0) = T_h \qquad (3)$$

Now, the goal here is to determine the time it takes to cool the water from its initial temperature of T_h to a final temperature T_c -- which meets regulations for discharge to the environment. Solving this simple separable ODE gives the following solution for the cooling time, t_f:

$$t_f = -\frac{mc}{UA}\ln\left(\frac{T_c - T_\infty}{T_h - T_\infty}\right) \qquad (4)$$

With eqn. (4), we can now address how the cooling time, t_f, varies with the tank diameter, D. In particular, the tank volume is given by $V = \pi D^2 H/4$ and the heat transfer surface area is $A = \pi DH$, where H is the vertical height of the tank (note that this area only includes the vertical sides). And, for constant volume, V, a change in the diameter implies a change in H, a change in the heat transfer surface area, and, via eqn. (4), a variation in the cooling time, t_f -- and the relationship for t_f vs. D is the real quantity of interest here.

Problem Statement: Based on the above development, perform the following tasks:

a. Your initial job for this problem is to **formally derive** the result given in eqn. (4). Be sure to be systematic and to show each step in the process...

b. Now, for a constant tank/liquid volume, compute and plot the cooling time vs. tank diameter over the range of diameters given by $2 \text{ ft} \le D \le 6 \text{ ft}$. Do your results make sense? Explain...

c. Based on your results, identify the best tank diameter for this application -- and be sure to justify your selection...

Data for part b:

$V = 1000$ gal
$T_h = 180$ F
$T_c = 80$ F
$T_\infty = 70$ F
$c = 1.00$ BTU/lbm-F
$\rho = 62.2$ lbm/ft^3
$U = 20$ BTU/hr-ft^2-F

Documentation

As noted in the Course Description and Requirements, developing your problem formulation, solution, and analysis skills along with proper documentation of your technical work are the main areas of focus of this course. As such, I expect a professional, well-written, informative report for each HW/Project assignment in this course. Thus, documentation for each assignment should include the following:

1. A **brief description of the data and results of your analyses for each problem** (this should be typed in Word, with proper format, grammar, spelling, etc.), a **copy of the resultant Matlab plots and any output print that may be needed,** and **a listing of the Matlab script files that generated the results presented in your report**.
2. Neatly hand-written **development of the logic, equations, or solution methodology needed for your analyses** -- as appropriate for each problem.

Please note that the material for each problem should be well organized and contained in a separate sub-section of your HW package. **Be sure to keep each problem completely separate**, since I typically grade one problem at a time for all the students. The hard copy HW package (no email submissions please!!!) should have a cover sheet that identifies the course and HW number, the names of the team members, and the date the assignment is submitted (only submit one HW package for each 2-person group). Thus, for this assignment, there should be a cover page, and two separate self-contained sections, respectively, for Problems 1 and 2.

Good luck!!!