Studio #4: Time Response

The objective of this studio is to reinforce material covered in class on time response of first-order and second-order systems.

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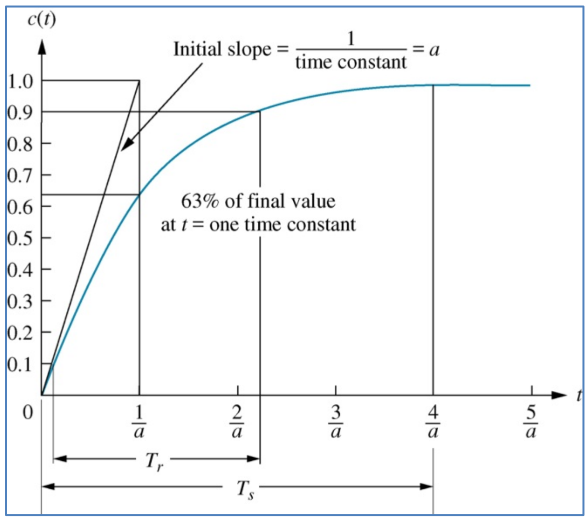
1. Recall that concepts learnt for first and second order systems in class below:

   First-Order Systems $G(s) = \frac{a}{s+a}$



The specifications are defined for the unit step input.

$$c(t) = \mathcal{L}^{-1}\left[\frac{a}{s(s+a)}\right] = (1 - e^{-at})u(t)$$

Table 1 Characteristics of first-order systems

Time constant	$\tau = \frac{1}{a}$
Rise time	$T_r = \frac{2.2}{a} = 2.2\tau$
Settling time	$T_s = \frac{4}{a} = 4\tau$

2. Transient Response Specifications of Underdamped Second-Order Systems
   Consider the transfer function of a standard second-order system

$$G(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

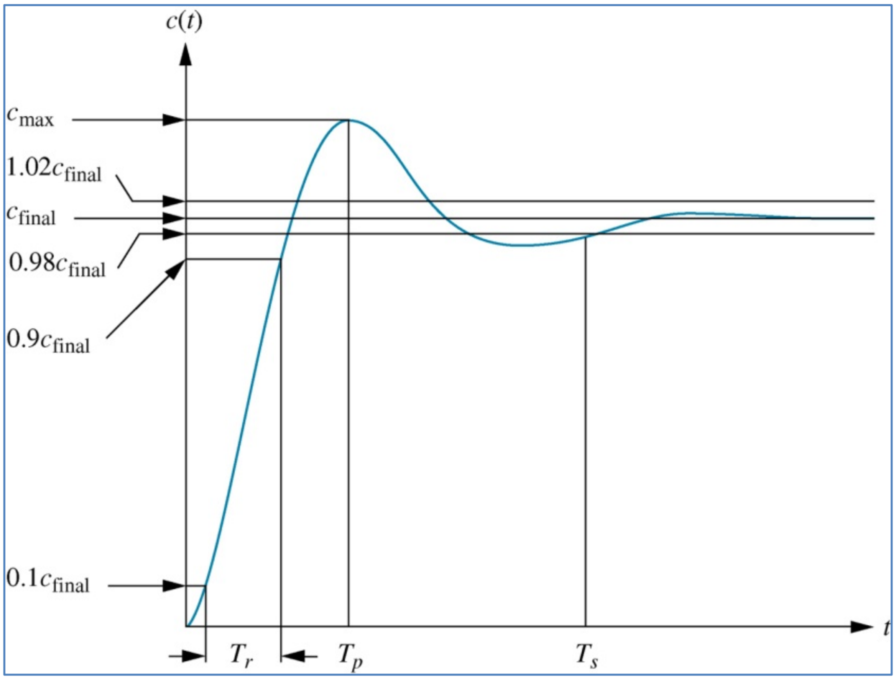


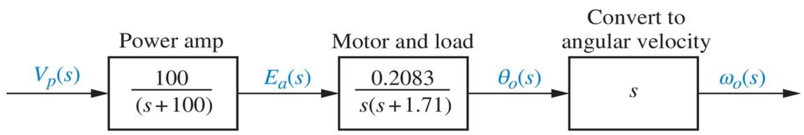
Figure 1. Typical Time response of an underdamped second-order system

The specifications are defined for the unit step input. Consider the under-damped response:

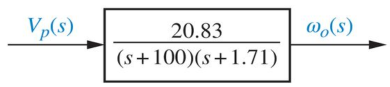
$$c(t) = \mathcal{L}^{-1}\left[\frac{\omega_n^2}{s(s^2 + 2\zeta\omega_n s + \omega_n^2)}\right] = 1 - e^{-\zeta\omega_n t}\left(\cos\omega_d t + \frac{\zeta}{\sqrt{1-\zeta^2}}\sin\omega_d t\right)$$

Peak time, T_p	$T_p = \frac{\pi}{\omega_d} = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$
% Overshoot, %OS	$\%OS = 100e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$
Settling time, T_s	$T_s \approx \frac{4}{\sigma_d} = \frac{4}{\zeta\omega_n}$
Rise time, T_r	Graphical Assessment (Figure 4.16)

3. **Antenna Control System:** Recall that the forward transfer function for the antenna azimuth position control system is given as



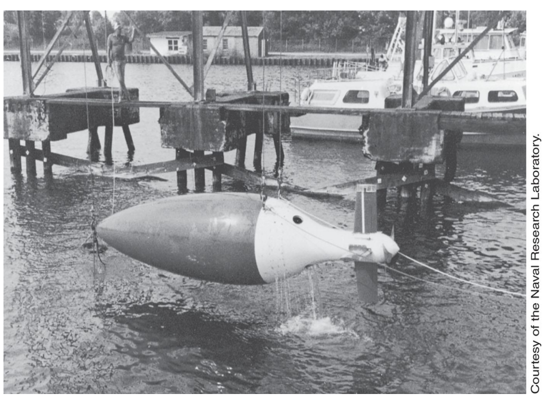
(*a*)

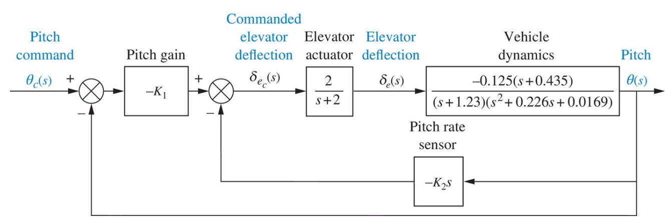


(*b*)

The TA will now compute the natural frequency, damping ratio, percentage overshoot, and settling time for the open-loop response. Using a step response in Matlab as computed in Studio 1, these values will be verified.

4. **Unmanned Free-Swimming Submersible Vehicle (UFSS) - Open Loop Pitch Response:**





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An UFSS and its corresponding pitch control system is shown in the figure above. The time response of the vehicle dynamics that relates the pitch angle output to the elevator deflection input is studied now. The TA will now:

a) Discuss the time response specifications using only second order poles.
b) Compute the pitch time response using both hand calculations and Matlab.
c) Analyze the effect of the additional pole and zero in the system and judge whether the second order response can be approximated for the system.

Exercises

Each student shall complete the exercise below and get their work checked off by the TA.

For Remote Students and Students who do not finish within studio session:

Compile your Matlab/Simulink code and the outputs of Exercises 1 and 2, as described below, in a word file and name it LastNameFirstNameStudio4.docx and upload to Canvas.

For Exercise 1: the time response output and the various performance specifications

For Exercise 2: the computation of the normalized transfer functions and the and the step response plots for both the "control" and "hot-tail" cases.

Exercise 1. For the UFSS system studied in Part 4, use Matlab/Simulink to compute the unit step open-loop response of the transfer function between pitch angle output to the elevator deflection input. Then using the plot, compute the percentage overshoot, rise time, peak time, settling time and compare them with the theoretical predictions. Show these values on the plot as well.

Exercise 2. (Nise, 7th Edition) Several factors affect the working of the kidneys. The figure below shows how a step change in arterial flow pressure affects renal blood flow in rats. In the "*hot tail"* part of the experiment, peripheral thermal receptor stimulation is achieved by inserting the rat's tail in heated water. The vertical lines indicate variations between different test subjects. It has been argued and asserted in the literature that the *"control"* and *"hot tail"* responses are identical except their steady state values.

a) Using the figure below, obtain the normalized ($c_{final} = 1$) transfer function for both responses.
b) Use Matlab to prove or disprove the assertion about the "control" and "hot-tail" responses.