UNIVERSITY OF NOTRE DAME
Aerospace and Mechanical Engineering

AME 437: Control Systems Engineering
Exam 1

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February 27, 2002

NAME: ______________________________

- You have 50 minutes to complete this exam.
- This is an open book exam. You may consult the course text, your class notes, your own homework sets and any documents provided on the course homepage such as homework solutions, tables, *etc.*
- There are 5 questions, each worth 20 points.
- Your grade on this exam will constitute 25% of your total grade for the course. *Show your work* if you want to receive partial credit for any problem.
- Answer each question in the space provided on each page or on pages 3, 5 and 11 which are intentionally left blank. If you need more space, use the back of the pages or use additional sheets of paper as necessary.
- Do not start or turn the page until instructed to do so.

The burden of the lecture is just to emphasize the fact that it is impossible to explain honestly the beauty of the laws of nature in a way that people can feel, without their having some deep understanding of mathematics. I am sorry, but this seems to be the case.

— Richard Feynman, *The Character of Physical Law.*

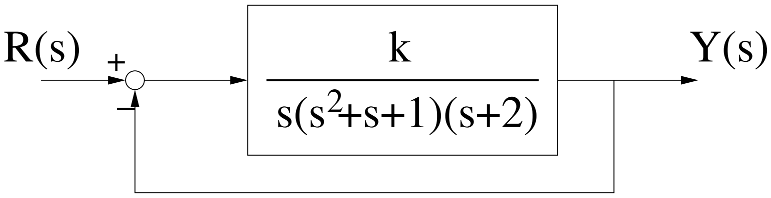

Figure 1. Block diagram for Problem 1.

1. It is now 2004, and you work for the Q-Branch of the British Secret Service. In your fight against the Special Executive for Counterintelligence, Terrorism, Revenge and Extortion (SPECTRE) your first assignment is to work on the control system for the Illudium PU-36 Explosive Space Modulator. In particular, Q has asked you to find the values of k, if any, for which the transfer function, $\frac{Y(s)}{R(s)}$ for the unity feedback system illustrated in Figure 1 stable.

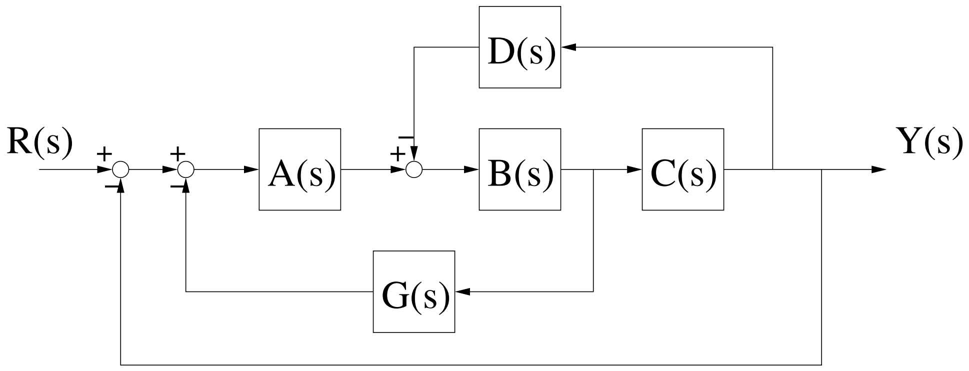

Figure 2. Block diagram for Problem 2.

2. A block diagram of the internal control mechanism for the latest version of the wristwatch produced by Q-Branch that contains a miniature howitzer is illustrated in Figure 2. Find the transfer function from the input to output, *i.e.*, find $\frac{Y(s)}{R(s)}$.

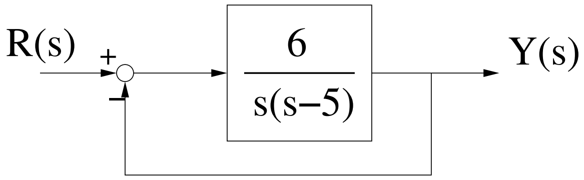

Figure 3. Block diagram for Problem 3.

3. The control loop for the ejection seat in the Aston Martin DB5 "customized" by Q-Branch is illustrated in Figure 3. What is the "final value" of $y(t)$, *i.e.*, what is $\lim_{t\to\infty} y(t)$ if the reference value is a step input, *i.e.*, $R(s) = \frac{1}{s}$?

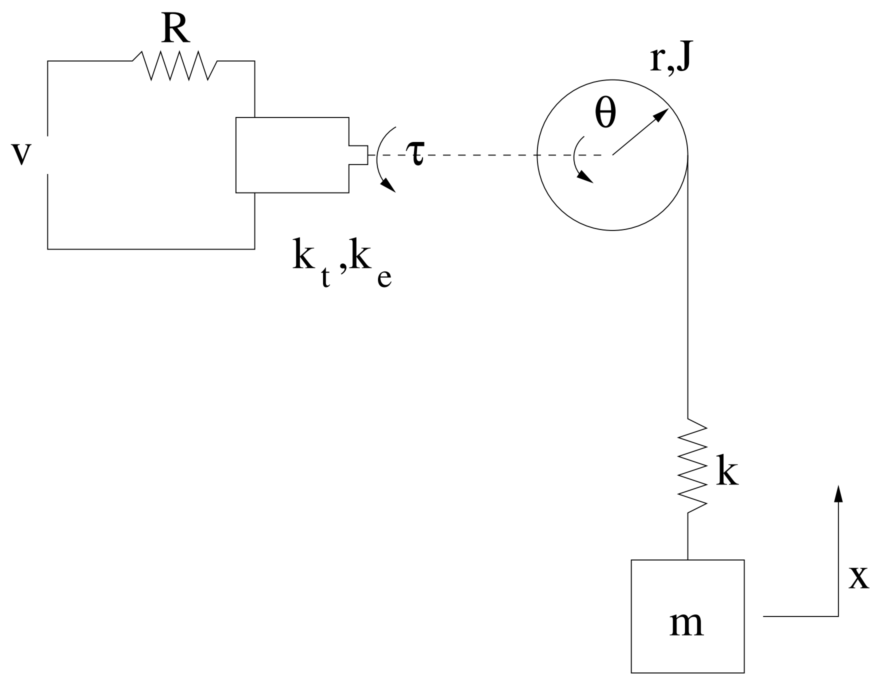

Figure 4. Automated briefcase locking and trigger mechanism.

4. Q-Branch is designing a briefcase that will explode if not opened in a vertical position. A critical component of the locking/trigger mechanism for the briefcase in its horizontal position is illustrated in Figure 4. A voltage source, v, drives a d.c. motor with torque constant, K_t and electric constant, K_e by an electrical circuit with resistance, R. The motor produces a torque, τ, and is attached to a pulley with moment of inertia, J, radius, r and angular position, θ. Assume the signs of τ and θ are such that a positive torque produces a positive $\ddot{\theta}$. A cord is wrapped around the pulley in such a manner that if $\dot{\theta}$ is positive, the cord is wound "up." The cord is elastic, which is modeled with a spring with spring constant, k. At the end of the cord is a mass, with mass, m and position, x.

(a) Derive the equations of motion for this system.

(b) Describe in one or two sentences, how you would compute the transfer function from the voltage to the mass position, $\frac{X(s)}{V(s)}$. Do not actually compute $\frac{X(s)}{V(s)}$, it is too messy and would take too long!

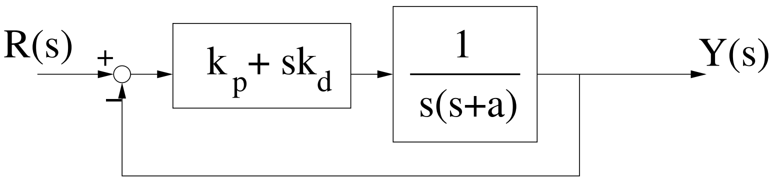

Figure 5. Block diagram for Problem 5.

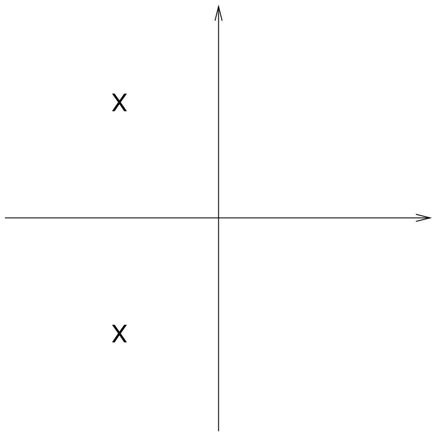

Figure 6. Pole locations for missile launcher.

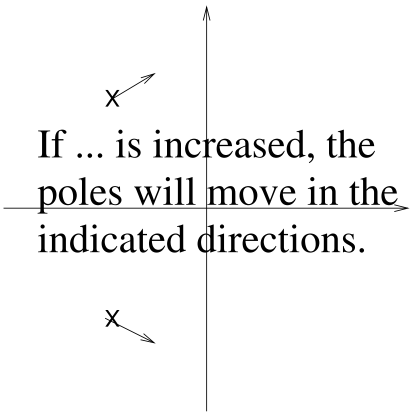

Figure 7. How increasing ... will change the pole locations.

5. The block diagram describing the guidance system for the missile launcher for the Aston Martin DB5 is illustrated in Figure 5 and the poles of the transfer function for specified values of k_p, k_d and a are illustrated in Figure 6.

   (a) In the manner illustrated in Figure 7, on Figure 6 clearly indicate in which direction the poles will move if k_p is increased.

   (b) Will increasing k_p increase or decrease the rise time?

   (c) In the manner illustrated in Figure 7, on Figure 6 clearly indicate in which direction the poles will move if k_d is increased.

   (d) Will increasing k_d increase or decrease the percentage overshoot?