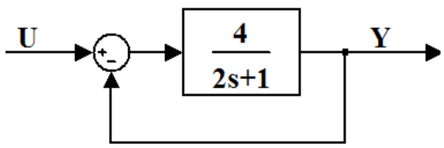
NAME _________________________

ESE406 - SPRING 2014 – Final EXAM

CLOSED NOTES & CLOSED BOOK : NO CALCULATORS

- Choose the one best answer for each question by *circling the letter*.
- A correct answer is worth 3 points.
- No answer is worth 1 points.
- An incorrect answer is worth 0 points. Random guessing will lower your grade, on average.
- You must work completely independently.



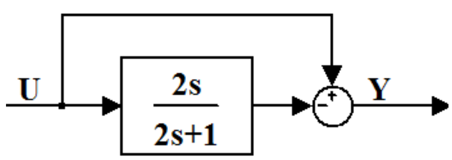
1. The transfer function corresponding to the above block diagram is…

A. $\dfrac{Y(s)}{U(s)} = \dfrac{2}{s+2.5}$

B. $\dfrac{Y(s)}{U(s)} = \dfrac{6s}{s+4}$

C. $\dfrac{Y(s)}{U(s)} = \dfrac{-2s+3}{2s+1.5}$

D. None of the above.



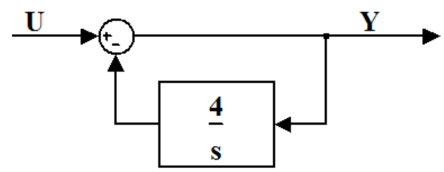
2. The transfer function corresponding to the above block diagram is…

A. $\dfrac{Y(s)}{U(s)} = \dfrac{2}{s}$

B. $\dfrac{Y(s)}{U(s)} = \dfrac{1}{s+2}$

C. $\dfrac{Y(s)}{U(s)} = \dfrac{1}{2s+1}$

D. None of the above.



3. The transfer function corresponding to the above block diagram is…

A. $\dfrac{Y(s)}{U(s)} = \dfrac{s-4}{s}$

B. $\dfrac{Y(s)}{U(s)} = \dfrac{s}{s+4}$

C. $\dfrac{Y(s)}{U(s)} = \dfrac{s-4}{s^2+4}$

D. None of the above.

4. The complex number $(1+j)+\sqrt{2}e^{j3\pi/4}$ is equal to…

A. $2+2j$

B. $-\sqrt{2}$

C. $j\sqrt{2}$

D. $2j$

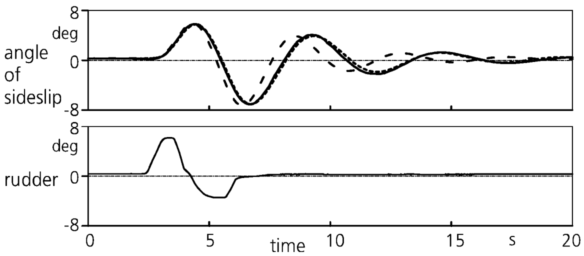
5. Which of the following is equal to $\dfrac{2-2j}{2+2j}$?

A. $e^{-j\pi/2}$

B. $1-j$

C. $2\sqrt{2}e^{j\pi/4}$

D. None of the Above



6. The figure above[1] shows the sideslip response (top graph) of a Transall C-160 aircraft to a pilot rudder input (bottom graph). The graph includes flight data (solid line) and a linear model (dashed line). (Ignore the dotted line which is very nearly on top of the solid line.) Which of the following is the MOST ACCURATE inference about the stability of the system?

   A. The system is unstable without active stabilization by the pilot.
   B. The system is stable but lightly damped.
   C. The system is highly damped, most likely with 2 poles on the negative real axis.
   D. We can only judge stability from unit step inputs, not strange pilot inputs like this one.

7. Which of the following is the MOST ACCURATE inference about the differences between the model and the data?

   A. The model *over*-estimates the frequency of the poles that are clearly visible in the response.
   B. The model *under*-estimates the frequency of the poles that are clearly visible in the response.
   C. The model *over*-estimates the steady-state gain of the transfer function.
   D. The model *under*-estimates the steady-state gain of the transfer function.

Table 2 Eigenvalues with outer and inner feedback loops closed

$-0.0006 \pm 0.0140i$	Phugoid
$-2.0107 \pm 1.9866i$	Pitch attitude
$-1.9925 \pm 2.0038i$	Roll attitude
$-4.0000 + 0.0000i$	Yaw rate
$-4.0000 + 0.0000i$	Vertical velocity

8. The table above[2] shows the locations in the complex plane of the closed-loop poles[3] of a helicopter. Which of the following is the MOST ACCURATE about the *yaw rate* pole?

   A. It is neutrally stable because the imaginary part is 0.
   B. It has a damping ratio of about $\zeta = 0.25$.
   C. It is first-order with a time constant of about $\tau = 0.25$ seconds.
   D. It is oscillatory with a period of about $P = 0.25$ seconds.

9. Which pole has a damping ratio $\zeta < 0.1$?

   A. Phugoid
   B. Pitch Attitude
   C. Roll Attitude
   D. Vertical Velocity

10. The same paper includes the following transfer function, which it says "represents the actuator dynamics":

$$\frac{\delta}{\delta_c} = \frac{30^2}{s^2 + 2(0.707)30s + 30^2}$$

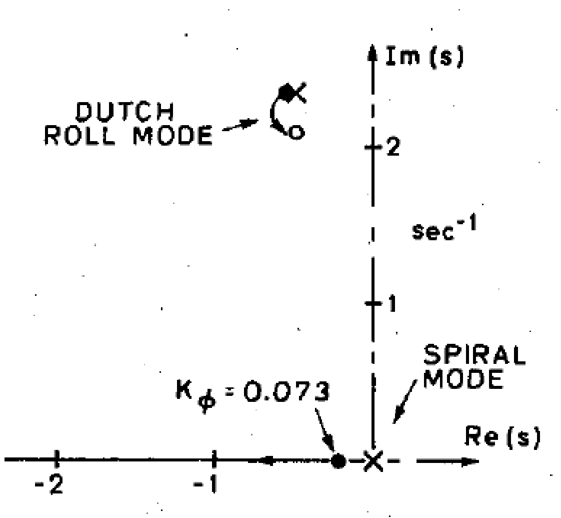
   At about what frequency on a bode plot would this transfer function have a phase of -90 degrees?

   A. $\omega \approx 21$ rad/sec
   B. $\omega \approx 30$ rad/sec
   C. $\omega \approx 900$ rad/sec
   D. This transfer function never has phase equal to -90 degrees.

[1] "Aerodynamic Modeling and System Identification from Flight Data—Recent Applications at DLR," *Journal of Aircraft*, 41:4, 2004.

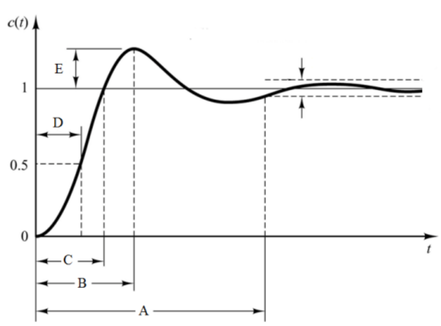
[2] "Design of Flight Control Systems to Meet Rotorcraft Handling Qualities Specifications," *Journal of Guidance, Control and Dynamics*, 16:1, 1993.

[3] Poles are called "eigenvalues" in the table because the paper is using modern control design techniques.



11. The figure above[4] shows the root locus varying the feedback gain K_ϕ. The solid dot (•) shows the pole locations for $K_\phi = 0.073$. Which of the following is the MOST ACCURATE inference about the effects of increasing the value of K_ϕ beyond 0.073?

    A. Larger values of K_ϕ eventually cause the "Dutch Roll Mode" to become unstable.
    B. Larger values of K_ϕ cause the damping ratio of the "Dutch Roll Mode" to approach 1.0.
    C. Larger values of K_ϕ cause the "Spiral Mode" to have a smaller time constant.
    D. Larger values of K_ϕ cause the damping ratio of the "Spiral Mode" to approach 0.1.



12. In the space below, write the letter from the figure above that MOST ACCURATELY represents the *settling time* of a step response.

_____

$$\frac{d}{dt}x = \begin{bmatrix} -0.02 & 0.005 & 2.4 & -32 \\ -0.14 & 0.44 & -1.3 & -30 \\ 0 & 0.018 & -1.6 & 1.2 \\ 0 & 0 & 1 & 0 \end{bmatrix} x + \begin{bmatrix} 0.14 & -0.12 \\ 0.36 & -8.6 \\ 0.35 & 0.009 \\ 0 & 0 \end{bmatrix} u$$

$$y = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 57.3 \end{bmatrix} x.$$

13. The equations above are part of an example presented in a seminal paper on Modern Control[5]. Which of the following is LEAST ACCURATE about these equations?

    A. The equations express a state-space model.
    B. There are 2 control inputs in the model.
    C. In the notation we used in class, the state output matrix is $C = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 57.3 \end{bmatrix}$.
    D. Because the last row of the B matrix contains only zeros, control cannot affect the 4th state so the system is uncontrollable.

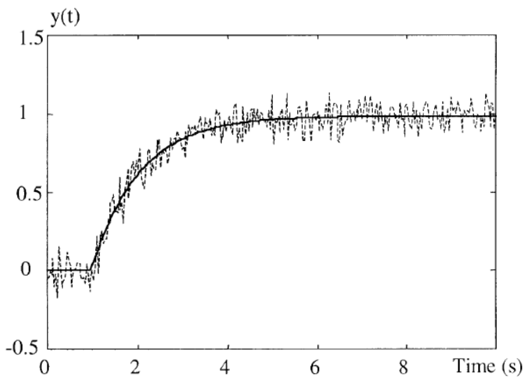
14. Which of the following is MOST CORRECT about lag compensation?

    A. It has the form $\dfrac{s+z}{s+p}$ with $z > p$.
    B. It is used to decrease the phase at high frequency to improve noise rejection.
    C. The name "lag compensator" comes from the observation that the magnitude of the frequency response plot of a lag compensator is less than unity (0dB).
    D. All of the above.

No Questions about Tesla Roadster!

[4] "New Concepts in Control Theory, 1959-1984," *Journal of Guidance, Control, and Dynamics*, 1985.

[5] "Multivariable Feedback Design: Concepts for a Classical / Modern Synthesis," *IEEE Transactions Automatic Control*, 1981.



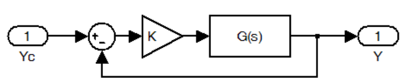
15. The figure above[6] shows the response of a system to a unit step input. NOTE: The step is applied at $t=0$, NOT $t=1$. The dashed line is the measured response, which includes noise. The solid line is a model. Which of the following transfer functions is MOST LIKELY to be the equation for the model transfer function?

    A. $G(s)=\dfrac{e^{-s}}{s+1}$

    B. $G(s)=\dfrac{e^{-s}}{s}$

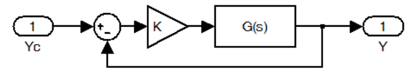
    C. $G(s)=\dfrac{1}{s^2+1}$

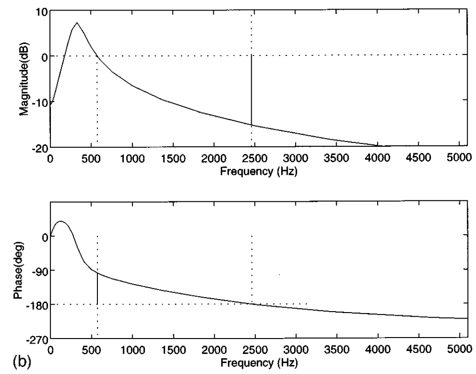
    D. $G(s)=\dfrac{s}{s+1}$



16. If the plant of the previous problem is included in the closed-loop proportional-gain system shown above, which of the following is MOST ACCURATE about the closed-loop stability?

    A. The system is stable for all $K>0$.
    B. The system is unstable for all $K>0$.
    C. The system is stable only for $K>K_{MIN}>0$.
    D. The system is unstable only for $K>K_{MAX}>0$.





17. The figure above[7] shows the bode plot of $KG(s)$ for the feedback system shown at top. Notice that the frequencies are in Hz, instead of our usual rad/sec, and the scaling on the frequency axis is linear. Which of the following is MOST ACCURATE about this system?

    A. The closed-loop system is stable.
    B. The closed-loop system is unstable.
    C. The stability of the closed-loop system depends on the input frequency.
    D. The stability of the closed-loop system depends on the initial conditions.

18. Continuing with the system of the previous problem, how much would the gain, K, need to be changed so that the system reaches neutral stability?

    A. The gain would have to be increased by about a factor of 5.
    B. The gain would have to be increased by about a factor of 2.
    C. The gain would have to be decreased by about a factor of 2.
    D. The gain would have to be decreased by about a factor of 5.

19. If the gain change of the previous problem were implemented, at what frequency would the neutrally stable oscillations occur?

    A. 575 Hz
    B. 2460 Hz
    C. 4000 Hz
    D. The instability would be a divergence, not an oscillation.

[6] "Robust identification of first-order plus dead-time model from step response", *Control Engineering Practice*, 1999. Systems such as these are very common in heating and air conditioning applications. It isn't cheating if you get a hint about the right answer from the title of this paper.

[7] "Implementation of an active headset by using the H-Infinity robust control theory", *Journal of the Acoustic Society of America*, 102:4, 1999.

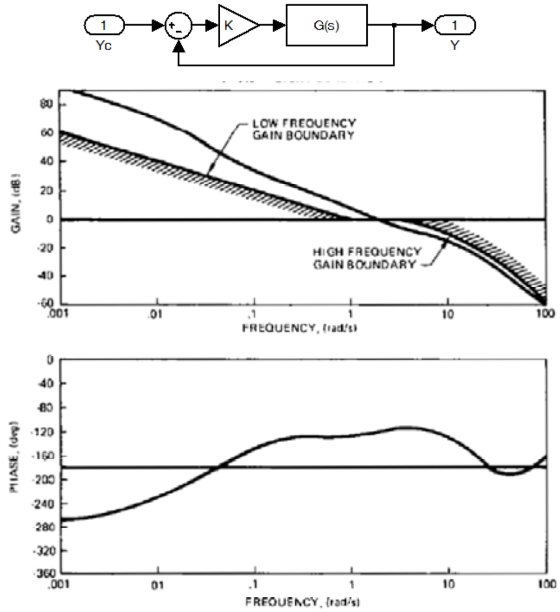


Fig. 22. Elevator open-loop frequency response for LQR design.

20. The figure above[8] shows the bode plot of $KG(s)$ for the system shown at top. The phase margin is...

    A. ...about 20 degrees.
    B. ...about 60 degrees.
    C. ...about 120 degrees.
    D. ...negative, because the system is unstable.

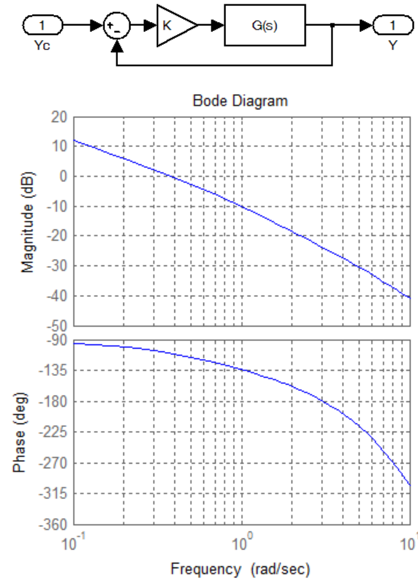
21. In the previous problem, which of the following is a REASONABLE justification for the "low frequency gain boundary" in the bode plot?

    A. Good tracking performance.
    B. Good disturbance suppression.
    C. Both of the above.
    D. Neither of the above.

22. Which of the following is a REASONABLE justification for the "high frequency gain boundary" in the bode plot?

    A. Good noise rejection.
    B. Good stability robustness (there might be dynamics out there that we don't know about so we don't want to risk having high gain).
    C. Both of the above.
    D. Neither of the above.

[8] "Application of Modern Synthesis to Aircraft Control: Three Case Studies", *IEEE Transactions on Automatic Control*, 1986. Surprise! Another airplane control system!



23. The figure above shows the bode plot of $G(s)$ for the system shown at top. If $K = 3$, the phase margin is about...

    A. ... 130 degrees.
    B. ...80 degrees.
    C. ...50 degrees.
    D. ...not determined by the information in the figure.

24. For $K = 3$, how much additional time delay in $G(s)$ will result in neutral stability?

    A. About 0.1 seconds.
    B. About 0.2 seconds.
    C. About 0.5 seconds.
    D. About 1.0 seconds.

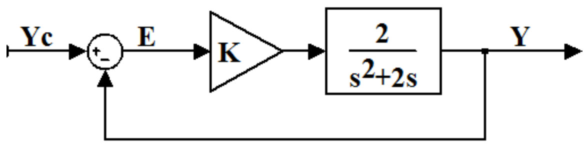
25. For $K = 3$, the steady-state response to a unit step input will be...

    A. ... 1 (perfect tracking).
    B. ... about 0.7.
    C. ... 0.25.
    D. ... 0.

26. If the proportional feedback were replaced by derivative feedback and the derivative gain were increased to the point of neutral stability, at what frequency would the oscillations occur?

    A. The instability would be divergent, not oscillatory.
    B. About 3 rad/sec.
    C. About 8 rad/sec.
    D. The system could not be made unstable by use of derivative feedback alone.

All of the problems in this column refer to the following block diagram:



27. Which of the following statements is MOST ACCURATE about the closed-loop stability of this system?

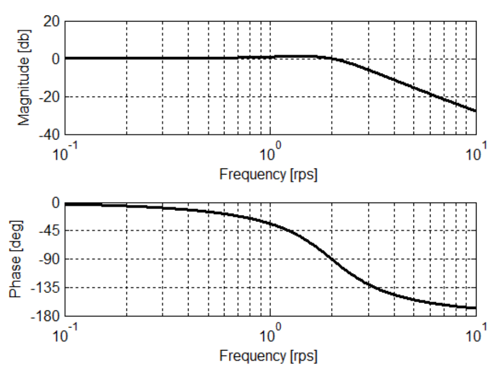
    A. The system will be stable only if $K \geq 4$.
    B. The system will be stable for all $K > 0$.
    C. The system will be unstable for all $K > 0$.
    D. The system will be unstable only if $K \geq 4$.

28. If we choose $K = 8$, what is the closed-loop damping ratio?

    A. $\zeta = -0.25$ (unstable)
    B. $\zeta = 0.25$
    C. $\zeta = 0.5$
    D. $\zeta > 1$ (two real poles)

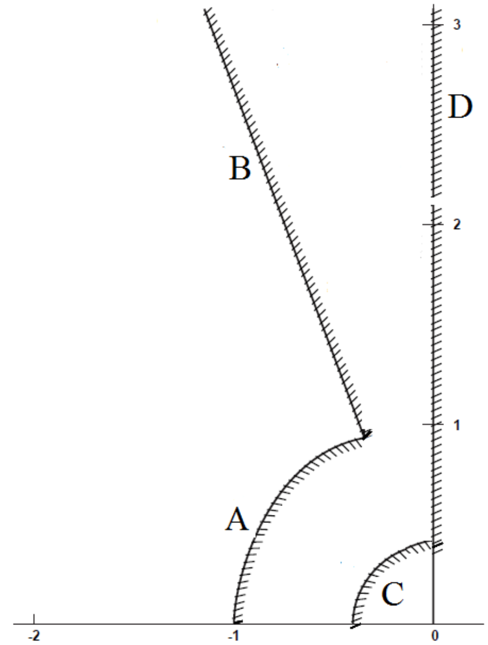
29. For approximately what value of K will the phase margin be 45 degrees?

    A. No $K > 0$ gives phase margin of 45 deg.
    B. $K \approx 1$
    C. $K \approx 3$
    D. $K \approx 12$



30. For what K does the figure above show the *closed-loop* frequency response, $\dfrac{Y}{Y_C}$?

    A. No $K > 0$ gives this closed-loop response.
    B. $K \approx 1$
    C. $K \approx 2$
    D. $K \approx 8$



31. The figure above shows some of the boundaries for pole locations that give various "Levels" of desirable response in a helicopter[9]. Which boundary corresponds to a minimum damping ratio, $\zeta > 0.35$?

    A. Boundary A
    B. Boundary B
    C. Boundary C
    D. Boundary D

32. Which boundary in the figure above corresponds to a minimum natural frequency of $\omega_n \geq 0.4$ rad/sec?

    A. Boundary A
    B. Boundary B
    C. Boundary C
    D. Boundary D

33. Which boundary in the figure above corresponds to the requirement that the system be stable?

    A. Boundary A
    B. Boundary B
    C. Boundary C
    D. Boundary D

[9] *ADS-33E-PRF*, Figure 23, Lateral-Directional oscillatory requirements.

34. Which of the following is LEAST ACCURATE concerning LQR design?

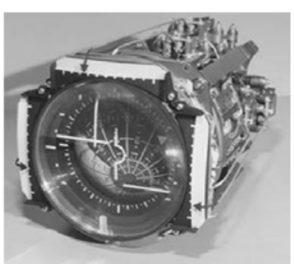
A. "LQR" stands for linear quadratic regulator.
B. LQR is based on minimizing
$$J = \int_0^\infty \left(x^T Q x + u^T R u \right) dt .$$
C. The solution to the LQR minimization problem is proportional state feedback of the form $u = -Kx$, where K is computed from the solution of the Algebraic Riccati equation.
D. LQR is especially useful because it can always be applied to a state-space system, even if (A, B) is not controllable.

35. What are the eigenvalues of the matrix $A = \begin{bmatrix} 0 & 1 \\ -25 & -6 \end{bmatrix}$?

A. $\lambda = -6, -5$
B. $\lambda = -3 \pm 4j$
C. $\lambda = -6 \pm 5j$
D. None of the above.

36. Is the system matrix pair $A = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}$ and $B = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$ controllable?

A. Yes.
B. No.
C. We need initial conditions to determine controllability.
D. We need the C matrix to determine controllability.



37. The attitude gyro used in the Apollo space program, shown above, measures the orientation of the spacecraft and is an example of what type of system element?

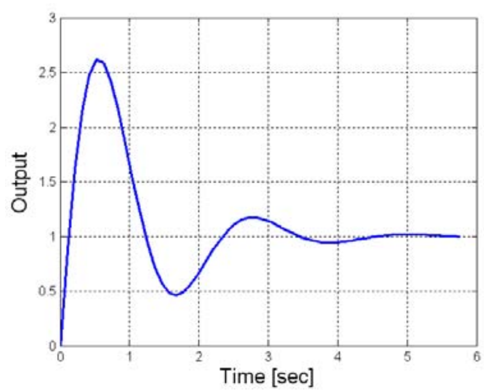
A. Actuator
B. Sensor
C. Notch Filter
D. None of the Above

38. Which of the following is LEAST CORRECT concerning the linear estimator / observer $\dot{\hat{\underline{x}}} = A\hat{\underline{x}} + B\underline{u} + L\left(y - C\hat{\underline{x}}\right)$?

A. If (A, C) is observable, the gain matrix L can be used to place the closed-loop eigenvalues of the estimator arbitrarily.
B. The output of the estimator can be used in a proportional state-feedback design to achieve the same closed-loop eigenvalues as would be obtained with feedback of the state itself (Separation Principle).
C. It has the advantage of being a "static observer" so that it adds no new dynamics to the controller.
D. It requires knowledge of the plant control input, $\underline{u}$.

39. A "Lyapunov Function" is...

A. ...used the demonstrate the stability of a nonlinear dynamic system without having the solve the ODEs.
B. ...a static nonlinear input-output process that is used to stabilize a linear dynamic system empirically, without any analysis.
C. ...a method of scoring two points in basketball without getting the ball through the hoop.
D. All of the above.



40. Which of the following transfer functions is the BEST match to the unit step response shown above?

A. $\dfrac{9}{s^2 + 9}$
B. $\dfrac{9s + 9}{s^2 + 2s + 9}$
C. $\dfrac{9s}{s^2 + 2s + 9}$
D. $\dfrac{9}{s^2 + 9s + 9}$