AMME3500_AMME8501_AMME9501 Final Exam

ⓘ This is a preview of the published version of the quiz.

Started: May 19 at 21:57

Quiz Instructions

This exam consists of three sections:

- **Section 1 multiple choice questions,**
- **Section 2 written answer question, and**
- **Section 3 analysis questions.**

You will have 130 minutes to complete the exam, including 10 minutes reading time.

This is an open book exam: you may refer to any of your course notes or textbooks during the exam. You may use a programmable calculator or MATLAB (if desired) for calculations.

You must complete this exam yourself without any assistance provided by any other person, including classmates.

You will need to produce hand-written working for questions 17 to 21 following the instructions at the end of each of those problems which may be made on pen and paper during the exam. You will need to scan or photograph this working and submit it via the Canvas assignment link (https://canvas.sydney.edu.au/courses/41981/assignments/375389) provided within 30 minutes of completing the exam.

Failure to provide hand-written working for these questions will result in an automatic zero mark for these questions, regardless of answers entered in Canvas.

Section 1: Mutiple Choice Questions

Questions 1 to 10 are multiple choice questions. Click to select the most appropriate answer.

You do NOT need to provide any additional working for these questions at the end of the exam.

Question 1 1 pts

Consider the following second-order system

$$\ddot{x} + 7\dot{x} + 12x = 6\,.$$

The poles of the system are

- 4 and 3
- -4 and -3
- -4 and 3
- -3 and 4

Question 2

1 pts

For the following second-order system

$$\ddot{x} - 3\dot{x} - 2x = u$$

which statement of the following is true?

- It is possible to obtain a stable closed-loop system by a PD control $u = -k_p x - k_d \dot{x}$.
- The system is open-loop stable.
- It is possible to obtain a stable closed-loop system by a proportional feedback control $u = -k_p x$.
- It is NOT possible to for the closed-loop system to have an overshoot at 2% by a PD controller $u = -k_p x - k_d \dot{x}$.
- It is NOT possible to place the closed-loop poles at -1 and -10 by a PD controller $u = -k_p x - k_d \dot{x}$.

Question 3

1 pts

Consider the second-order system

$$\ddot{x} + 4\dot{x} + 6x = 0.$$

Write down a state space representation of this system.

- ○ $\dot{x} = \begin{pmatrix} 0 & -6 \\ -4 & 1 \end{pmatrix} x$
- ○ $\dot{x} = \begin{pmatrix} 0 & 1 \\ -6 & -4 \end{pmatrix} x$
- ○ $\dot{x} = \begin{pmatrix} 0 & -4 \\ 1 & -6 \end{pmatrix} x$
- ○ $\dot{x} = \begin{pmatrix} 0 & 1 \\ -12 & -7 \end{pmatrix} x$
- ○ $\dot{x} = \begin{pmatrix} 0 & 1 \\ -4 & -6 \end{pmatrix} x$

Question 4

1 pts

Consider the second-order system

$$\ddot{x} + 8\dot{x} + 6x = u.$$

Is the system reachable?

- ○ No, controllability matrix $\begin{pmatrix} 0 & 1 \\ -6 & -8 \end{pmatrix}$ is not full rank
- ○ Yes, controllability matrix $\begin{pmatrix} 0 & 1 \\ -8 & -6 \end{pmatrix}$ is full rank
- ○ No, controllability matrix $\begin{pmatrix} 0 & 1 \\ 1 & -8 \end{pmatrix}$ is not full rank
- ○ Yes, controllability matrix $\begin{pmatrix} 0 & 1 \\ 1 & -8 \end{pmatrix}$ is full rank

○ Yes, controllability matrix $\begin{pmatrix} 0 & 1 \\ -6 & -8 \end{pmatrix}$ is full rank

Question 5

1 pts

Consider the first-order dynamical system

$$\dot{x} + 3x = u.$$

where x is the system state and u is the control input.

If $u(t) = e^{-t}$ is the unit step function, and $x(0) = 1$, derive the response of $x(t)$.

○ $x(t) = \frac{2}{3}e^{-3t} + \frac{1}{3}e^{-t}$

○ $x(t) = -\frac{1}{3}e^{-3t} + \frac{4}{3}e^{-t}$

○ $x(t) = \frac{4}{3}e^{-3t} - \frac{1}{3}e^{-t}$

○ $x(t) = \frac{2}{3}e^{-3t} + \frac{2}{3}e^{-t} - \frac{1}{3}$

○ $x(t) = \frac{1}{2}e^{-3t} + \frac{1}{2}e^{-t}$

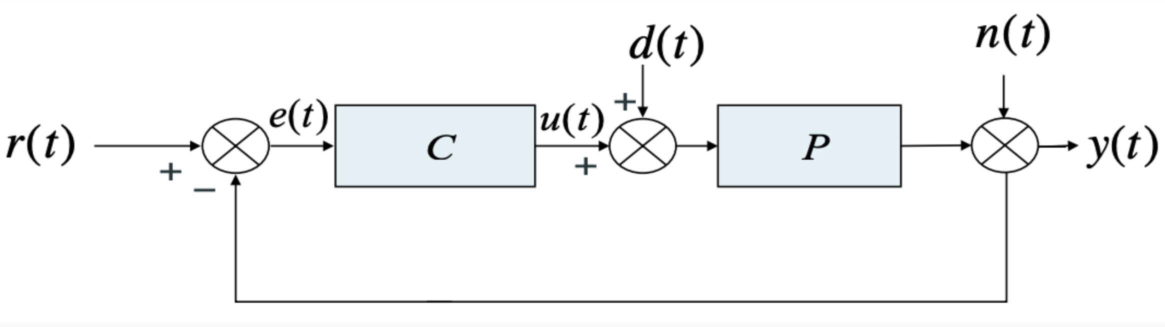
Question 6

1 pts

Assume that a second-order system has the transfer function

$$P(s) = \frac{1}{s^2+3s+5}.$$

Suppose we are using PI control, where $C(s) = 1 + \frac{2}{s}$, for the system below.



What is the closed-loop transfer function from r to y?

- ○ $G_{CL} = \frac{s+2}{s^3+3s^2+6s}$
- ○ $G_{CL} = \frac{s+2}{s^3+3s^2+s+2}$
- ○ $G_{CL} = \frac{s+2}{s^3+3s^2+6s+2}$
- ○ $G_{CL} = \frac{s+2}{s^3+3s^2+6s+3}$

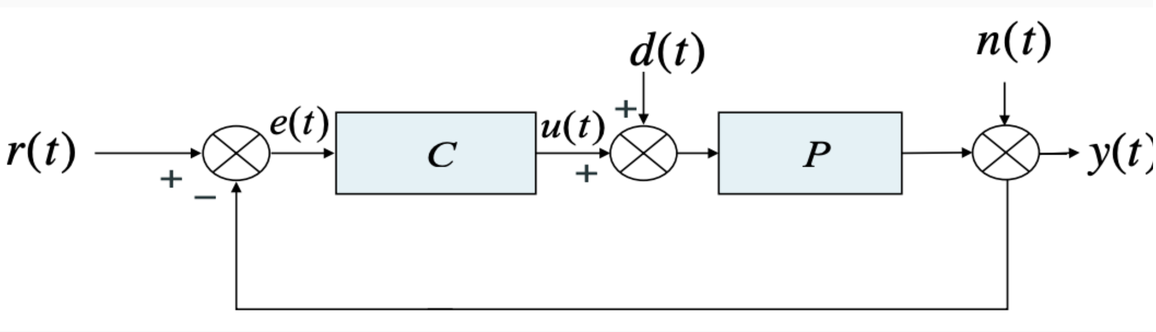
Question 7

1 pts

Assume that a second-order system has the transfer function

$$P(s) = \frac{2}{s^2+2s+3}.$$

Suppose we are using PI control, where $C(s) = k_p + k_i \frac{1}{s}$ for the system below.



What is the loop transfer function?

- $L(s) = \frac{2(k_p s^2 + k_i s)}{s^2+2s+3}$
- $L(s) = \frac{2(k_p s + k_i)}{s(s^2+2s+3)}$
- $L(s) = \frac{k_p s + k_i}{s(s+2+3)}$
- $L(s) = \frac{k_p s + k_i}{2s(s^3+2s^2+3s)}$

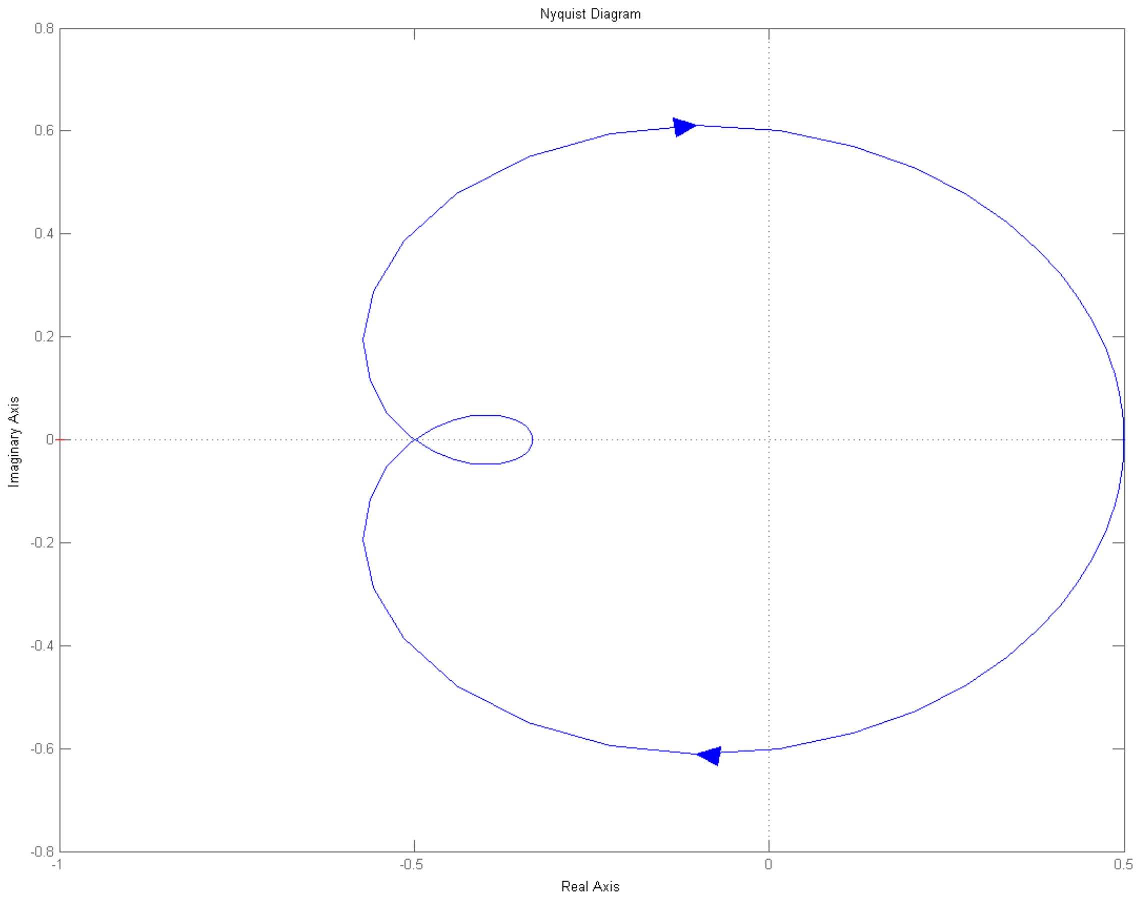
Question 8

1 pts

The Nyquist plot for the plant

$$G(s) = \frac{s^2-5s-4}{2(s^2+5s+6)}$$

(with gain $K = 1$) is given below.



The plant is placed in a unity feedback loop. Which statements of the following are true?

- [ ] The closed-loop system is unstable.
- [ ] The closed-loop system is stable.
- [ ] The gain margin of the system is around 20.
- [ ] The gain margin of the system is around 2.

Question 9

1 pts

Let a transfer function be $G(s) = \frac{5}{6s+8}$. Let an input $u(t) = \cos(t)$ enter the transfer function. Note that $\arccos\frac{4}{5} \approx \frac{\pi}{5}$, $\arcsin\frac{4}{5} \approx \frac{3\pi}{10}$. The steady-state system output is close to

- [ ] $\cos(t - \frac{3\pi}{10})$
- [ ] $0.5\cos(t - \frac{\pi}{5})$
- [ ] $\cos(t - \frac{\pi}{5})$
- [ ] $0.5\cos(t - \frac{3\pi}{10})$

Question 10

1 pts

For the first-order dynamical system

$$\dot{x} + 3x = 4u,$$

we know that $x(t)$ approaches 8 when t tends to infinity. Then what is the value of u?

- ○ 1.5
- ○ 4
- ○ 1
- ○ 6

Section 2: Written Answer Questions

Questions 11 to 16 are written answer questions. Provide your answers using the textboxes provided. You may use text-based short hand notations to describe any equations or other symbols or formulas used as part of your explanations.

You do NOT need to provide any additional working for these questions at the end of the exam.

Question 11

3 pts

Describe the benefits and limitations of PID control as opposed to state-feedback control for feedback systems.

Specifically, based on your experiences in designing controllers for the cruise control in Design Project 1 and for the crane control in Simulink Lab 4, explain the respective advantages of PID and state-feedback control, and their suitable systems.

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Question 12

3 pts

(1) Describe the purpose and meaning of observability and observer for a dynamical system, respectively.

(2) Describe the relationship between observability and observers. You may use examples to help explain your points.

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Question 13

4 pts

(1) Explain the significance of sensitivity functions in terms of plant uncertainty.

(2) Explain how the sensitivity function and complementary sensitivity function impose limitations to the performance of feedback controllers in the presence of disturbances and noises.

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Question 14

4 pts

Explain the significance of the separation principle:

(1) The separation principle applies to what systems?

(2) What is the meaning and implication of the separation principle?

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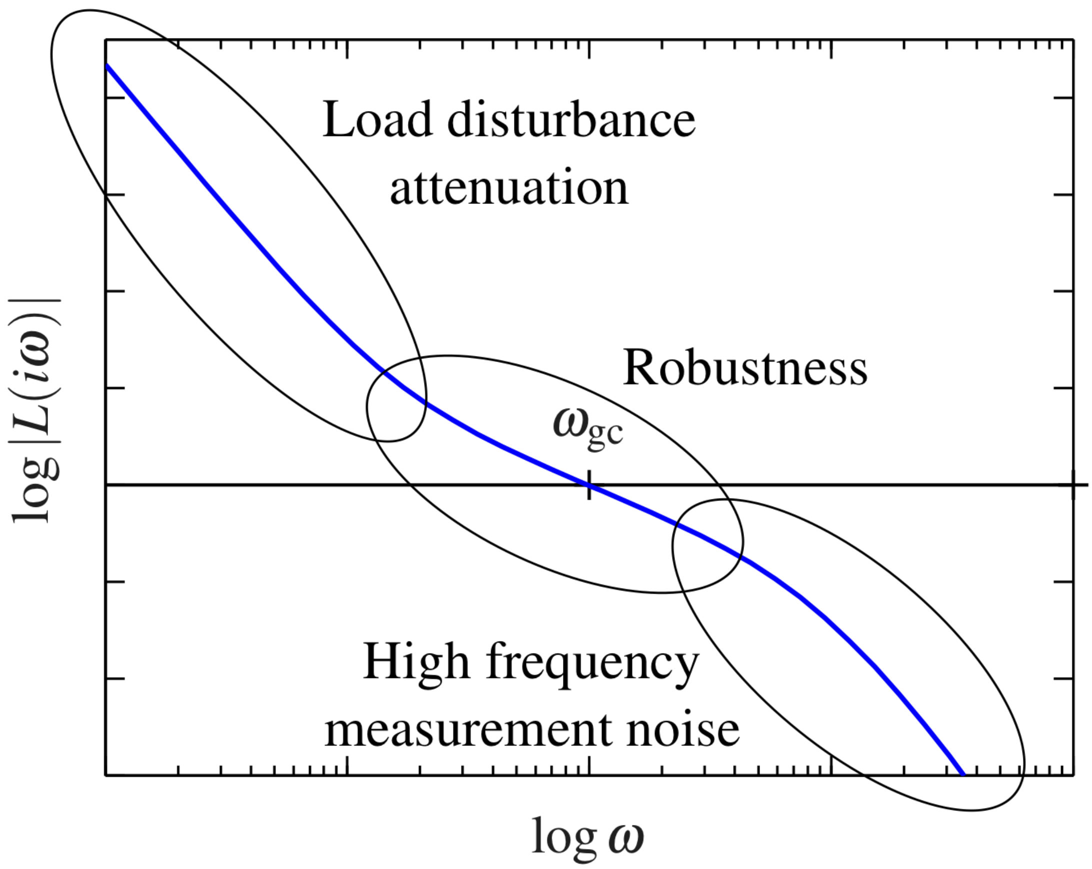
Question 15

6 pts

Describe the motivation and the procedure of loop shaping for the frequency-domain design of feedback controllers. Clearly highlight the implied points from the figure below. In particular, address the following questions in your answer:

(1) WHY do we carry out loop shaping?

(2) HOW do we carry out loop shaping?



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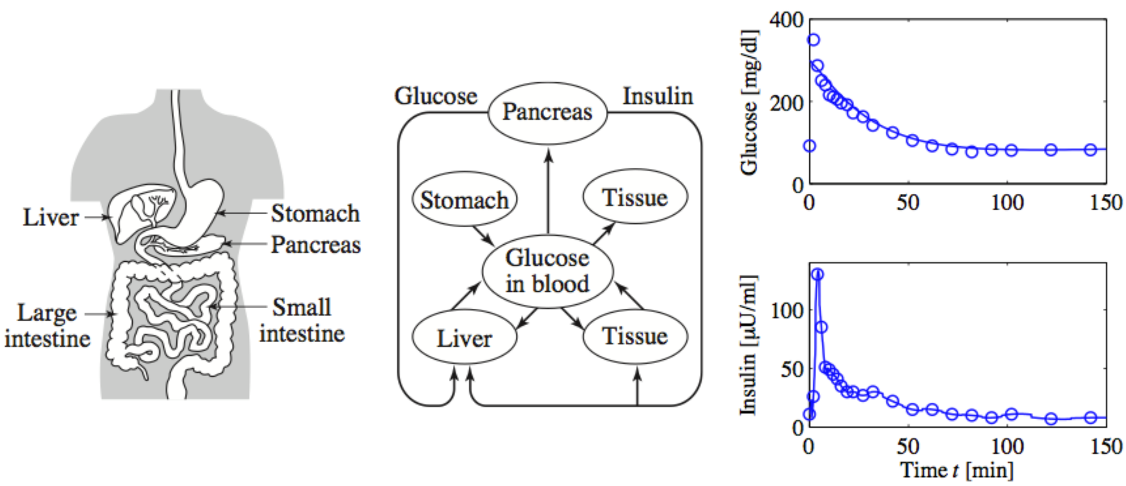
Question 16

10 pts

Insulin/Glucose dynamics are of fundamental importance for us to understand and develop a treatment for diabetes.



Let $y(t)$ be the blood glucose concentration ($\mathrm{mg/dL}$), and $u(t)$ be the intraperitoneal insulin ($\mathrm{U/h}$). Then from clinical data, the continuous transfer function from u to y is

$$G(s) = \frac{-12000(TDI)^{-1}}{(247s+1)(17s+1)^2}$$

where TDI is a positive constant representing the total daily insulin dose of the patient.

(1) Assume $y(t)$ starts from $y(0) = 0$. Describe the main features that we can expect from the response of $y(t)$ when $u(t)$ is a unit step input.

(2) Explain how these features stated in (1) have resulted from the transfer function.

(3) Now assume $y(t)$ starts from $y(0) = 10$ and $u(t) = \cos(0.5t)$. Describe

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Section 3: Analysis Problems

Questions 17 to 21 are analysis problems involving numerical calculation. Enter your final answer in the input boxes provided and make sure to follow instructions.

You will need to produce hand written working, following the instructions at the end of each question.

At the completion of the quiz, you will have 30 minutes to scan/photograph and submit your working for these questions. Failure to provide handwritten working for these questions will result in an automatic zero mark for these questions, regardless of answers entered in Canvas.

Question 17

10 pts

Consider the second-order system $\dot{x} = Ax + Bu$ with

$$A = \begin{pmatrix} 0 & 2 \\ 3 & -1 \end{pmatrix}, \qquad B = \begin{pmatrix} 3 \\ 2 \end{pmatrix}.$$

Design a state feedback controller $u = -Kx = -[k_1 \ \ k_2]x$ so that the closed-loop system has poles placed at $-2 + j$ and $-2 - j$.

Provide your answer for k_1 and k_2 as integers.

$k_1 =$ $\qquad$ $k_2 =$

In your hand written working, include the following explanations and steps:

(1) Can the closed-loop poles be placed at any given positions, and why?

(2) Explain the purpose for each step of your design, and present the key analytical working for each step.

Question 18

10 pts

Consider again the second-order system $\dot{x} = Ax + Bu$ with

$$A = \begin{pmatrix} 0 & 2 \\ 3 & -1 \end{pmatrix}, \qquad B = \begin{pmatrix} 3 \\ 2 \end{pmatrix}.$$

Now suppose the system has an output $y = Cx$ with $C = [1 \ \ 0]$. Design an observer

$$\frac{d\hat{x}}{dt} = A\hat{x} + Bu + L(y - C\hat{x})$$

with

$$L = \begin{pmatrix} l_1 \\ l_2 \end{pmatrix},$$

so that the error dynamics $\dot{\tilde{x}} = (A - LC)\tilde{x}$ have poles placed at $-2 + j$ and $-2 - j$. Provide your answer for l_1 and l_2 as integers.

$l_1 =$ [ ] $l_2 =$ [ ]

In your hand written working, include the following explanations and steps:

(1) Can the poles of the error dynamics be placed at any given positions, and why?

(2) Explain the purpose for each step of your design, and present the key analytical working for each step.

Question 19 10 pts

The Nyquist diagram for the transfer function

$$G(s) = \frac{-2s^2+16s+4}{2(s^2+8s+4)}$$

goes through the point $(2, 0)$. Find one value of s in $G(s)$ that corresponds to this point $(2, 0)$. Provide your answer as a complex number in the form of real and imaginary parts (provide only the integer values)

$s =$ [ ] $+$ [ ] j

In your hand written working, include the following explanations and steps:

(1) Explain what the point $(2, 0)$ stands for in the Nyquist diagram of the transfer function.

(2) Write down the key working of each step for calculating the above answer you provided.

(3) Could there be another point on the real axis that the Nyquist diagram of $G(s)$ passes through, and why?

Question 20 15 pts

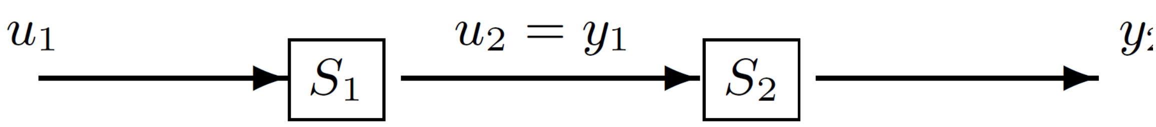
Consider the following two single-input single-output subsystems:

$$S_1 : \begin{cases} \dot{x}_1 = A_1 x_1 + B_1 u_1 \\ y_1 = C_1 x_1 \end{cases} \qquad S_2 : \begin{cases} \dot{x}_2 = A_2 x_2 + B_2 u_2 \\ y_2 = C_2 x_2 \end{cases}$$

where

$$A_1 = \begin{bmatrix} 0 & 2 \\ 3 & -1 \end{bmatrix}, \quad B_1 = \begin{bmatrix} 3 \\ 2 \end{bmatrix}, \quad C_1 = \begin{bmatrix} 2 & 1 \end{bmatrix},$$
$$A_2 = 4, \qquad B_2 = -2, \qquad C_2 = 1.$$

The two systems are cascaded forming an overall system S, as shown in the following block diagram.



Calculate the transfer function $G(s)$ from u_1 to y_2 of the system S. Provide the components of your answer as integers for the numerator and denominator of G.

Numerator of $G(s) =$ s^3+ s^2+ $s+$

Denominator of $G(s) =$ s^3+ s^2+ $s+$

In your hand written working, include the following explanations and steps:

(1) Derive the transfer function from u_1 to y_2 for the system S as a formula in terms of $A_1, B_1, C_1, A_2, B_2, C_2$. Show key steps of working.

(2) Write down your working in deriving the transfer function that you provided.

(3) The system S has input u_1 and output y_2. Explain whether the system is observable and why.

Question 21

15 pts

A simplified aircraft model relating airspeed $v\,(t)$ m/s with thrust $T\,(t)$ N at cruising altitude is

$$m\dot{v} + F(v) = T$$

where m is the mass of the aircraft, and the aerodynamic drag experienced by the aircraft at this altitude is

$$F(v) = 0.45v^2\ .$$

Suppose $m = 27000$ kg, $v_0 = 250$ m/s. Then we may find an appropriate value T_0 for the thrust T under which we may linearise the aircraft model in the form of

$$m\dot{\delta}_v + a\delta_v = \delta_T.$$

Here $\delta_v = v - v_0$ and $\delta_T = T - T_0$. Provide the integer part of the coefficient a .

$a =$ ______ .

In your hand written working, include the following explanations and steps:

(1) Show how the value of T_0 is calculated, and explain the reasoning behind your calculation.

(2) Show the key working in deriving the value of a that you provided.

(3) Suppose there is disturbance and the actual linearised model of the system dynamics is

$$m\dot{\delta}_v + a\delta_v = \delta_T + d.$$

If you design a controller that should be able to have δ_v tracking any constant reference r with zero steady-state error, what controller would you choose?

Present a controller and explain why zero steady-state error is achieved.

END of EXAM.

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