AERO4600 Automatic Flight Control Systems

Assignment 3, 2024

Report page limit: 30 pages

This assignment builds on the analyses performed in Assignments 1 and 2. The objective is to design a complete autopilot, investigate the stability and performance of the control system, and study the change in response of the aircraft to gust inputs.

You are to work in separate **groups**. Each group will consider either longitudinal- or lateral-directional problems. You are to decide amongst yourselves how to divide the work equitably and clearly state the work allocation on the first page of the report.

- Group 1, 3, 5, 7 should complete the Longitudinal System tasks;
- Group 2, 4, 6 should complete the Lateral-directional System tasks.

Ensure that you illustrate your control loop topologies and explain how you have formulated your closed-loop transfer functions *in zero-pole-gain form*.

Use the aircraft parameters and initial conditions based on the following table.

Group	aircraft parameter	initial condition
1, 2	ICs_aircraft2_75Kts_CG1	LoadFlightData_aircraft2_75kts_CG1
3, 4	ICs_aircraft2_75Kts_CG2	LoadFlightData_aircraft2_75kts_CG2
5, 6	ICs_aircraft2_180Kts_CG1	LoadFlightData_aircraft2_180kts_CG1
7	ICs_aircraft2_180Kts_CG2	LoadFlightData_aircraft2_180kts_CG2

Submit your report in *pdf* and associated codes in *zip* to canvas.

Longitudinal System (For Group 1, 3, 5, 7)

Objective: You are set the task of designing the control laws for the aircraft. The objective is to develop a **vertical speed** autopilot with **auto-throttle** that will make the aircraft track a specified vertical speed by using the elevator actuator while regulating airspeed with throttle.

1. (2) Determine $G_{\delta_e}^{v_s}$, and explain whether the design of an autopilot using elevator to directly control vertical speed is easy or not (based on root locus or Bode plot).

2. (4) Design a pitch rate autopilot which controls the pitch rate q using the elevator. Aim to satisfy a command bandwidth ω_c (-3dB point) of about 2 to 10 rad/s. Design for a noise bandwidth of 20 rad/s. Plot the pitch rate step responses, which should have a settling time (to within 2% of the final value) of around 3 s.

3. (5) Design a vertical speed guidance loop that incorporates the pitch rate controller as an inner loop. The guidance loop should use a compensator in the forward leg of the loop to convert vertical speed error into a pitch rate command. As part of your design process, you should assess the following:

   (a) Draw the complete loop topology.

   (b) Show the aircraft response to a commanded 500 ft/min vertical speed command step input. The vertical speed step response should be designed for a rise time of about 3 s and to settle within about 10 s (closed loop bandwidth of about .5 to 2 rad/s).

   (c) Show the pitch rate responses.

   (d) Show the control (elevator) activity in response to the vertical speed command step input.

4. (8) Design an *auto-throttle* control system. This loop will convert airspeed error into a throttle command. The design procedure is similar to Question 3. As part of your design process, you should consider and/or assess the following:

   (a) Draw the complete MIMO system loop topology, noting that the airspeed and vertical speed loops are cross-coupled.

   (b) Design the loop to the same specifications as Question 3.

   (c) Show the primary control effects ($G_{u_{c_{CL}}}^{u}(s)$ and $G_{v_{s_{c_{CL}}}}^{v_s}(s)$) and compare them to the design responses obtained with only the vertical speed control loop operating. (Why is the throttle now effective in making airspeed changes?)

   (d) Show the cross-coupling effects ($G_{u_{c_{CL}}}^{v_s}(s)$ and $G_{v_{s_{c_{CL}}}}^{u}(s)$) and compare them to the responses obtained with only the vertical speed control loop operating.

   (e) Assess the elevator and throttle activity in response to a vertical speed command step input and an airspeed command step input.

   (f) Assess the effectiveness of the auto-throttle in managing the airspeed when the vertical speed controller is inactive (with and without the pitch rate controller operating).

For your final Design ...

5. (5) Implement the control and guidance laws in the 6DOF nonlinear simulation by representing your controllers as a state space system. Verify that the theoretical responses are realisable in the time domain by generating time history plots and comparing them to relevant theoretical responses from the previous questions. What differences do you notice in the total aircraft response?

6. (3) Simulate the gust effects in the time domain and numerically assess the effectiveness of the closed loop in rejecting gusts.

7. (3) Discuss what would happen if a large vertical speed was commanded? How could this be dealt with when implementing the control system? Demonstrate your approach in the nonlinear simulation.

Lateral-directional System (For Group 2, 4, 6)

Objective: You are set the task of designing the control laws for the aircraft. The objective is to develop a **heading-hold** autopilot that will make the aircraft seek and track a specified heading (*Yaw angle*) by using the aileron actuator.

1. (2) Determine $G^{\psi}_{\delta_a}$, and explain whether the design of an autopilot using aileron to directly control heading is easy or not (based on root locus or Bode plot).

2. (4) Design a bank angle autopilot (wing-leveller) which controls bank angle using aileron. You can expect to require a crossover frequency (command bandwidth (-3dB point)) in the region of 2 to 10 rad/s. Design for a noise bandwidth of 20 rad/s. Plot the bank angle step responses, which should have a settling time of around 3 s. Steady-state error should be less than 1%. Ensure that your closed loop system does not command control inputs in excess of $\pm 20°$ in response to a $30°$ bank angle step input.

3. (5) Design a heading hold guidance loop that incorporates the wing-levelling autopilot. The guidance loop should use a compensator in the forward leg of the loop to convert heading (*Yaw angle*) error ($\Delta\Psi$) into a bank angle command (ϕ_c). As part of your design process, you should assess and consider the following:

   (a) Illustrate the control loop topology.

   (b) Show the aircraft response to a commanded 30 degree heading change (step input). The heading step response should be designed to settle within 10 s,

   (c) Show the bank angle responses,

   (d) Show the aileron control activity in response to the heading command step input.

4.(8) Design a classical yaw damper $\delta_r = K\frac{s}{s+a}r$ to improve the Dutch Roll dynamics.

   (a) Draw the complete MIMO loop topology, noting that the bank angle control and yaw damper loops are cross-coupled.

   (b) Re-evaluate the plant dynamics taking the yaw damper system into account. The bank angle compensator should be re-designed for this plant.

   (c) Reassess the viability of designing a heading angle controller directly with aileron as in Question 1 (with yaw damper) and via the method of Questions 2 and 3 (with yaw damper).

   (d) Re-design the bank angle control and heading loops to the same specifications as in Questions 2 and 3.

   (e) Show the primary control effects ($G^{\phi}_{\phi_{c_{CL}}}(s)$ and $G^{\psi}_{\psi_{c_{CL}}}(s)$) and compare them to the design responses obtained without the yaw damper loop operating.

   (f) Show the cross-coupling effects $G^{r}_{\phi_{c_{CL}}}(s)$) and $G^{r}_{\psi_{c_{CL}}}(s)$) and compare them to the design responses obtained without the yaw damper loop operating.

For your final Design ...

5. (5) Implement the control and guidance laws in the 6DOF nonlinear simulation by representing your controllers as a state space system. Verify that the theoretical responses are realisable in the time domain by generating time history plots and comparing them to relevant theoretical responses from the previous questions. What differences do you notice in the total aircraft response?

6. (3) Simulate the gust effects in the time domain and numerically assess the effectiveness of the closed loop in rejecting gusts?

7. (3) Discuss what would happen if a large heading change is commanded? How could this be dealt with when implementing the control system?