CUED - Engineering Tripos Part IIA 2022-2023 **Module Laboratory Report**

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Feedback to the student

☐ **See also comments in the text**

		Very good	**Good**	Needs improvmt
C O N T E N T	**Completeness, quantity of content:** Has the report covered all aspects of the lab? Has the analysis been carried out thoroughly?			
	Correctness, quality of content Is the data correct? Is the analysis of the data correct? Are the conclusions correct?			
	Depth of understanding, quality of discussion Does the report show a good technical understanding? Have all the relevant conclusions been drawn?			
	Comments:			
P R E S E N T A T I O N	**Attention to detail, typesetting and typographical errors** Is the report free of typographical errors? Are the figures/tables/references presented professionally?			
	Comments:			

Raw report mark	**/ 5**
Penalty for lateness	

The weighting of comments is not intended to be equal, and the relative importance of criteria may vary between modules. A good report should attract 4 marks.

1 mark / week or part week.
Please refer to the online information regarding our extension policy.

Marker: Date:

Worksheet values

2. Simplified aircraft model. Transfer function $= Y(s) = \dfrac{10}{s^2 + 10s}$

num = [0, 0, 10]   den = [1, 10, 0]

Controller transfer function $= ke^{-sD}$

$k = \dfrac{3}{5} \quad D = 0.5\text{s}$

Phase margin $= 69° = 1.2$rad

Amount of extra time delay which can be tolerated

$$\Rightarrow \omega D = 1.2,\ \omega = 0.583\ D = 2.066\text{s}.$$

2.1 PIO. Period of oscillation (observed) = 2.65s
Period of oscillation (theoretical) = 3.93s

2.2 Sinusoidal disturbances. maximum stabilising gain =

$$\text{Gain at 0.66 Hz} = 9.03\ \text{dB} \qquad \text{Phase at 0.66 Hz} = -223°$$

Transfer function from d to y.

$$\text{Open loop} = L(s) = K(s)G(s) \qquad \text{Closed loop} = \frac{K(s)G(s)}{1 + K(s)G(s)}$$

2.3. Fastest pole. T = 0.5

3. Autopilot. Proportional gain $K_c = 17.4$
Period of oscillation $T_c = 17.4$
3.1 Transfer function of PID controller $= \dfrac{k_p T_i T_d s^2 + k_p T_i s + K_p}{T_i s}$

$$\text{PID constants: } K_p = 10.44 \ \ T_i = 1.06 \ \ T_d = 0.266$$
$$\text{Final value of } T_d = 0.317$$

3. Final choice of **??** = 0.17

Report

1. Nyquist diagram for plant and controller from Bode diagram

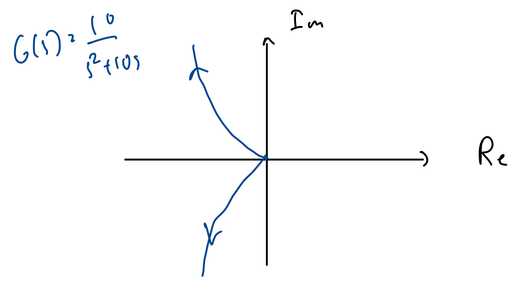

Figure 1: z-plane or s-plane contour for Nyquist diagram (state which)

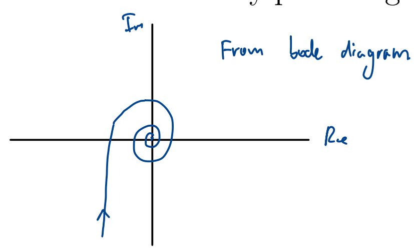

Figure 2: Nyquist diagram

2. Are you using any integral action? Give a brief explanation.

   Answer: From fig. 7, we can see that even though the steady state error is close to 0, there is an offset in the controller output. Looking at a general output for a PID system:

$$u(t) = K_p \left(e(t) + \frac{1}{T_i} \int_0^t e(\tau) \, \mathrm{d}\tau + T_d \frac{\mathrm{d}e(t)}{\mathrm{d}t} \right),$$

   we can conclude that there is integral action as our steady state error $e(t)$ is zero but our output is non-zero.

3. Explain the oscillation of the feedback loop. How does your observed period of oscillation compare to the theoretical prediction? Can you give a rough guideline to the control designer to make PIO less likely?

   Answer: From the bode plot, when the gain is very close to 0 dB, the phase is very close to $-180°$ which means that the system is marginally stable. This result in an oscillatory response.

   The theoretical prediction is $T = \dfrac{2\pi}{\omega}$ where $\omega \approx 1.6$ rad/s from the bode plot. Therefore, $T \approx 3.93$s. The actual T measured from the graph is $T = (4 - 1.35) = 2.65s$. This is not closed to theoretical value but this is more likely due to the badly plotted graph from the plane being hard to control with PIO than the theory being wrong.

   To prevent PIO from occurring, the system should be asymptomatically stable. To do this, we can reduce the gain of the controller to allow the phase at 0 dB to be greater than $-180°$

4. Are you able to reduce the error (with the use of feedback compared to open loop)?

   Answer: No, it was hard to reduce the error.

5. Nyquist diagram of unstable aircraft and explanation of stability.

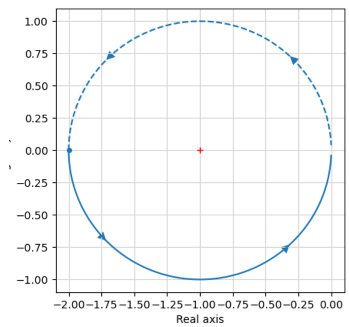

Figure 3: Nyquist diagram of $G_2(s)$

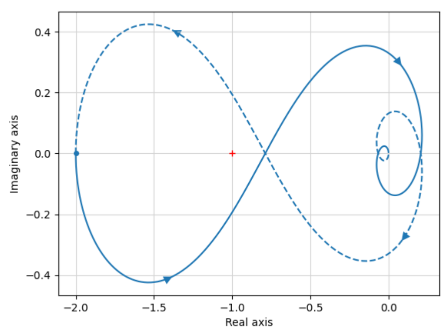

Figure 4: Nyquist diagram with small time delay

   Answer: From the lectures, the Nyquist stability criterion states that: "The closed loop system is stable if and only if the number of encirclement of $1/K$ equals the number of open loop unstable poles."

   As there is one unstable pole, from the Nyquist diagram, we need 1 encirclement of the point $-1/K$ and therefore $1/K < 2$ or in other words $K > 0.5$.

6. Explain you reasoning for your bound.

   Answer: The lowest number that can replace **??** in the code is ≈ 0.17. This value gave a very negligible steady state error (within ± 0.002 which is relatively small and is negligible) and was picked as the bound.

Graphs and Plots

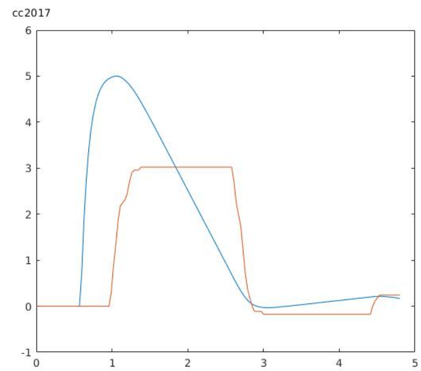

Figure 5: Typical response to an impulse of weight 5

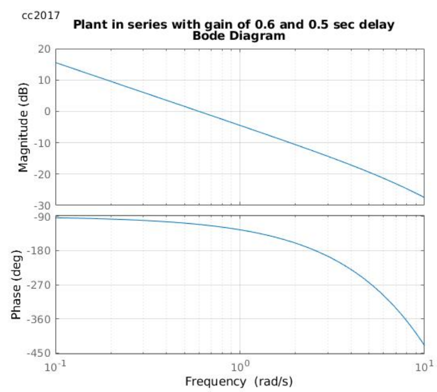

Figure 6: Bode diagram for the open loop K(s)G(s)

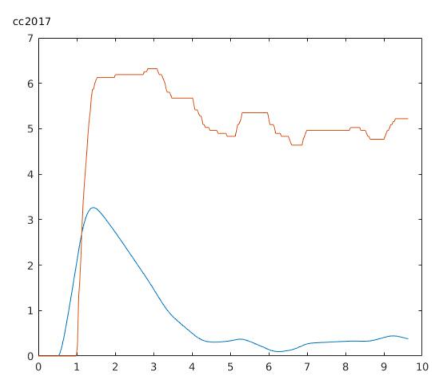

Figure 7: Typical response for a step disturbance of magnitude 5

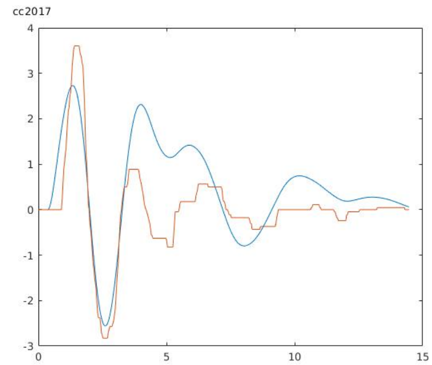

Figure 8: Typical response of pilot induced oscillation

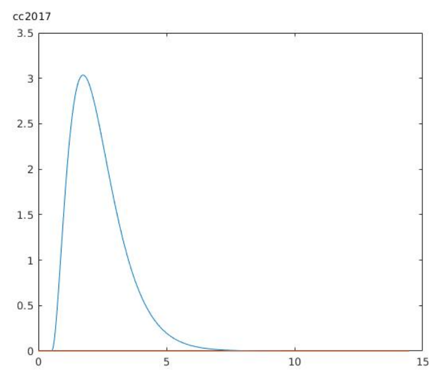

Figure 9: Response with no controller input

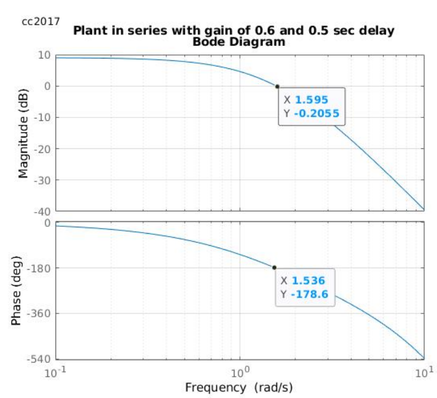

Figure 10: Bode diagram of pilot induced oscillation

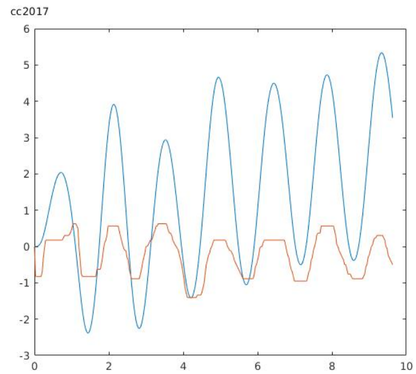

Figure 11: Typical response to a sinusoidal disturbance of magnitude 1 and frequency 0.66 Hz

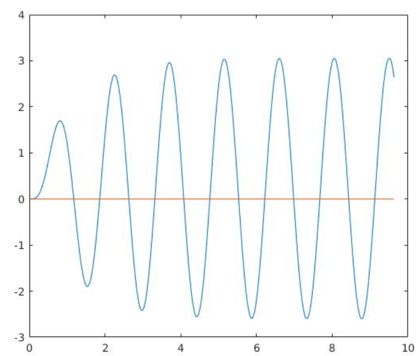

Figure 12: Response to a sinusoidal disturbance of magnitude 1 and frequency 0.66 Hz with no controller input

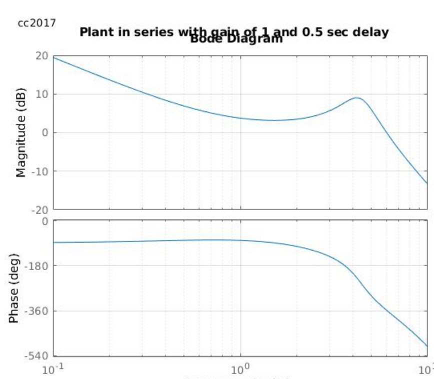

Figure 13: Full bode diagram

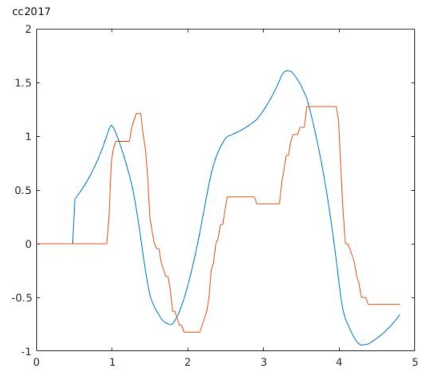

Figure 14: Typical response for unstable aircraft

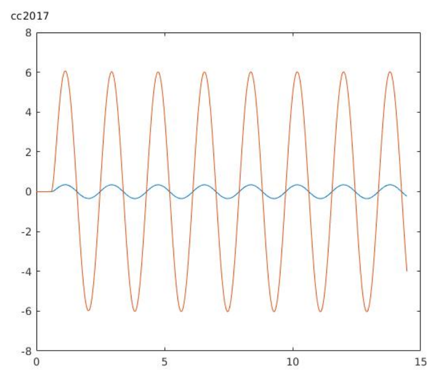

Figure 15: Oscillatory autopilot response

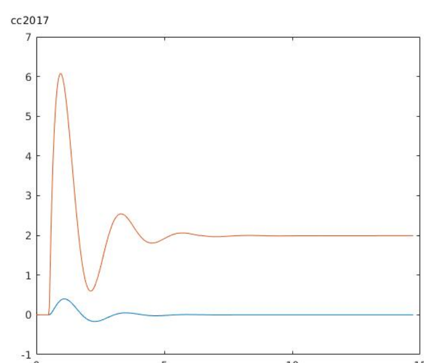

Figure 16: Response for PID controller

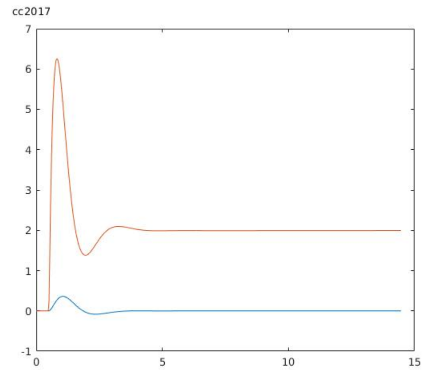

Figure 17: Response for PID controller with increased derivative gain

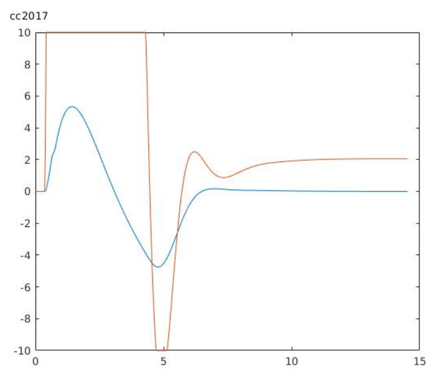

Figure 18: Integrator wind-up without modification

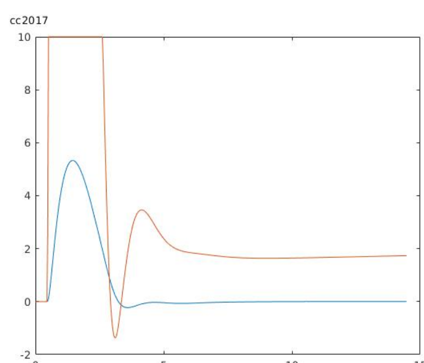

Figure 19: Integrator wind-up with modification