Indian Institute of Space Science and Technology

AE614/AE457 - Flight Dynamics and Control

May 9, 2025

End Semester

(Open Notes Exam)

Duration: 180 min **Maximum marks: 100**

- Please provide clear steps and expressions for the problems. Steps carry mark.
- State any assumptions you make and justify them.
- **Only hand-written notes are allowed. No photocopies or books allowed.**

1. Using the equations of motion in wind axis system (refer set of equations 1) for the longitudinal dynamics, derive the small perturbation equations for all the state equations. The equilibrium conditions are as follow: $V_0 \neq 0$, $\alpha_0 \neq 0$, $\gamma_0 = 0$, $q_0 = 0$. Assume linear aerodynamic model for the Lift, Drag and Moment with respect to V, α and q. [20]

$$
\begin{aligned}
m\dot{V} &= T\cos\alpha - D - mg\sin\gamma \\
mV\dot{\alpha} &= mVq - T\sin\alpha - L + mg\cos\gamma \\
I_y\dot{q} &= M \\
\dot{\gamma} &= q - \dot{\alpha} \\
\dot{X}_E &= V\cos\gamma \\
\dot{Z}_E &= -V\sin\gamma
\end{aligned}
\tag{1}
$$

2. Using the equations of phugoid mode, derive the transfer function for speed control with throttle position(δ_T) as controller. The throttle control contribution to the phugoid equation is characterised by the equation 2, with $\frac{\partial T_X}{\partial \delta_T} = 1100$, $\frac{\partial T_Z}{\partial \delta_T} = 150$. The throttle control, δ_T, is between 0 and 1, 0 being at idle position and 1 being at full throttle position. The aircraft details are provided in the annex. [20]

$$
\text{X force due to throttle, } \Delta X = \frac{\partial T_X}{\partial \delta_T}\delta_T, \qquad \text{Z force due to throttle, } \Delta Z = \frac{\partial T_Z}{\partial \delta_T}\delta_T \tag{2}
$$

3. An aircraft model is tested in the wind tunnel for dynamic response with constrained to move only about the z-axis i.e, pure yawing moment (figure 1). Note that for the given configuration $\psi = -\beta$. Use the values provided in the second page. Design a feedback PI controller for heading angle (ψ) to achieve the settling time of 4s and maximum peak of 15%. using pure yaw equation, with rudder as control. [25]

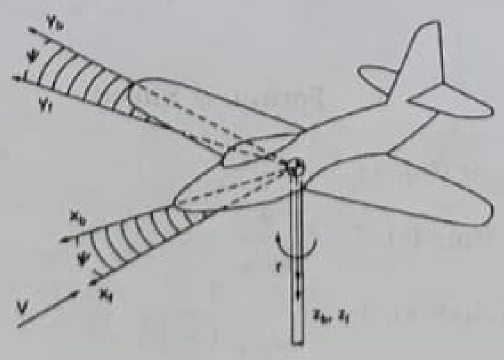

Figure 1

4. It has been decided to have either one of the following two configurations, for an UAV design. [15]

   1. A canard stabilizer and a wing,
   2. A wing and a horizontal stabilizer.

   The canard stabilizer is a smaller wing-like lifting surface placed ahead of the wing. Both canard and horizontal stabilizers have flap acting as elevator which can be used to control the aircraft. Compare the longitudinal dynamics of both the configurations from the flight dynamics and control perspective and suggest one of the two options, with proper justifications, to proceed for design. The designed UAV will be used for ***surveillance and reconnaissance missions during natural disasters from high altitudes.***

5. Please choose the correct answer and give proper detailed justification for your choice. **No justification, no marks.**
   (a) As the altitude increases roll mode becomes more quicker. (True/False) [5]
   (b) An aircraft having stable spiral mode implies smaller lateral stability. (True/False) [5]
   (c) An aerodynamically efficient glider is marginally stable in longitudinal dynamics. (True/False) [5]
   (d) The proportional feedback controller reduces the steady state error of short period mode dynamics. (True/False) [5]

Aircraft details

Aircraft Information

(a) *Geometric and Inertial Parameters*

Mean Aerodynamic Chord, $\bar{c}$	$1.211\ m$
Wing Span, b	$10.47\ m$
Wing Area, S	$12.47\ m^2$
Mass, m	$750\ kg$
Moment of Inertia, I_{xx}	$873\ kg-m^2$
Moment of Inertia, I_{yy}	$907\ kg-m^2$
Moment of Inertia, I_{zz}	$1680\ kg-m^2$
Moment of Inertia, I_{xz}	$1144\ kg-m^2$
Engine Thrust, T	$1136\ N$
Trim speed, V_∞	$55\ m/s$

(b) *Aerodynamic Derivatives*

$C_{D_0} = 0.036$	$C_{L_0} = 0.365$	$C_{m_0} = 0.05$
$C_{D_\alpha} = 0.061$	$C_{L_\alpha} = 4.98$	$C_{m_\alpha} = -0.59$
$e = 0.8$	$C_{L_q} = 27.3$	$C_{m_q} = -9.3$
$C_{L_{\delta_e}} = 0.26$	$C_{L_{\dot{\alpha}}} = 8.3$	$C_{m_{\dot{\alpha}}} = -4.3$
$C_{D_{\delta_e}} = 0.026$	$C_{L_{\delta_e}} = 0.26$	$C_{m_{\delta_e}} = -1.008$
$C_{Y_0} = -0.013$	$C_{l_0} = 0.0015$	$C_{n_0} = 0.001$
$C_{Y_\beta} = -0.431$	$C_{l_\beta} = -0.051$	$C_{n_\beta} = 0.071$
$C_{Y_p} = 0.269$	$C_{l_p} = -0.251$	$C_{n_p} = -0.045$
$C_{Y_r} = 0.433$	$C_{l_r} = 0.36$	$C_{n_r} = -0.091$
$C_{Y_{\delta_r}} = 0.15$	$C_{l_{\delta_r}} = 0.005$	$C_{n_{\delta_r}} = -0.049$
$C_{Y_{\delta_a}} = 0$	$C_{l_{\delta_a}} = -0.153$	$C_{n_{\delta_a}} = 0$

Formulae Sheet

$$\text{Maximum overshoot (\%)},\ M_p = e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}}$$

$$\text{Settling Time (s)},\ T_s = \frac{4}{\zeta\omega_n}$$

$$\text{Time Period (s)},\ T_P = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$$

$$\text{Stead State Error},\ e(\infty) = \lim_{s\to 0}[sE(s)],\ \text{where } E(s) = Y_d(s) - Y(s)$$