

## 16.333 Homework Assignment #2

Please include all code used to solve these problems.

1. Date of Lindbergh's famous flight? When was the first solo flight across the Pacific?
2. Sketch-plot versus time the Euler angles for the various maneuvers starting at  $\Phi = \Theta = \Psi = 0$  at  $t = 0$ .:
  - (a) Half an inside loop followed by a snap roll at the top (Immelmann turn).
  - (b) outside loop
  - (c) coordinated turn (constant vehicle speed)
3. Consider a jet transport at 40,000 ft with the data given below:
  - (a) Find the short period and phugoid roots. Be careful with the dimensionalization of these coefficients (see Reid, page 119, 207). Compare the phugoid frequencies with Lanchester's approximation.
  - (b) Plot the phugoid response and the short period time response (i.e., find initial conditions that excite each of these modes separately).
  - (c) Graph the equivalent response plots in Figs. 6-8, 6-10, 6-12, and 6-13. Are the results similar?

### Basic aircraft data

Mach	M=0.62	Nominal speed	U <sub>0</sub> = 600 [ft/s]
Density	$\rho = 5.85 \times 10^{-4}$ [slug/ft <sup>3</sup> ]	Tail distance	$l_t/c = 2.89$
Wing area	S=2400 [ft <sup>2</sup> ]	Wing chord	c=20.2 [ft]
Mass	m=5800 [slug]	Moment of inertia	$I_{YY} = 2.62 \times 10^6$ [slug ft <sup>2</sup> ]
Body pitch angle	$\Theta_0 = 0^\circ$		

### Basic Aerodynamic data

Non – dimensional	→ Dimensional
$C_{X_u} = -0.088$	→ $X_u = \frac{SQ}{U_0} C_{X_u}$
$C_{X_\alpha} = 0.392$	→ $X_w = \frac{SQ}{U_0} C_{X_\alpha}$
$C_{Z_u} = -1.48$	→ ?
$C_{Z_\alpha} = -4.46$	→ $Z_w = \frac{SQ}{U_0} C_{Z_\alpha}$
$C_{Z_{\dot{\alpha}}} = -1.13$	→ $Z_{\dot{w}} = \frac{SQ}{U_0} \left( \frac{c}{2U_0} \right) C_{Z_{\dot{\alpha}}}$
$C_{Z_q} = -3.94$	→ $Z_q = SQ \frac{c}{2U_0} C_{Z_q}$
$C_{M_u} = 0$	→ $M_u = \frac{SQc}{U_0} C_{M_u}$
$C_{M_\alpha} = -0.619$	→ $M_w = \frac{SQc}{U_0} C_{M_\alpha}$
$C_{M_{\dot{\alpha}}} = -3.27$	→ ?
$C_{M_q} = -11.4$	→ $M_q = SQc \frac{c}{2U_0} C_{M_q}$
$C_{Z_{\delta_e}} = -0.246$	→ $Z_{\delta_e} = SQ C_{Z_{\delta_e}}$
$C_{M_{\delta_e}} = -0.710$	→ $M_{\delta_e} = SQc C_{M_{\delta_e}}$

4. For the general aviation Navion, find the trim angle of attack ( $\alpha_{\text{trim}}$ ) and elevator deflection ( $\delta_{e_{\text{trim}}}$ ) for the flight condition discussed in class. Note that from Nelson page 400 we have that  $C_{L_{\delta_e}} = 0.355$  and  $C_{M_{\delta_e}} = -0.923$ . How do these trim values change if the tail incidence angle is changed to  $-3^\circ$ ?
5. An aircraft has instruments that continuously record  $P$ ,  $Q$ ,  $R$ . Assuming that the initial flight conditions are known, develop a Simulink block diagram that can be used to calculate  $\Theta$ ,  $\Phi$ , and  $\Psi$  for future time. Plot the angles as a function of time that result when  $P(t) = 0.01$  rad/sec,  $Q(t) = -0.01$  rad/sec,  $R(t) = 0.01$  rad/sec starting from zero initial conditions.
6. The equations of motion for a spinning missile can be approximated as follows:
  - Center-of-mass moves in a straight line through inertial space ( $V_{cm}$  is constant).
  - There is a constant rolling velocity  $P_0$ .
  - The quantities  $\Theta$ ,  $\Psi$ ,  $Q$ , and  $R$  are always small enough to permit linearization.
  - The X-force equation and the rolling-moment equation may be assumed automatically satisfied by proper deflections of the control surfaces.
  - The pitching moment,  $M$ , and yaw-moment  $N$  consist mainly of moments, proportional to  $W$  and  $V$  respectively which tend to restore the X-axis parallelism with the flight direction.

Under these approximations, show how  $Q$  and  $R$  can be eliminated from the remaining four equations of motion.

- (a) With  $U$  approximately constant, show how the last two equations become:

$$\ddot{W} + [(\omega_y/P_0)^2 - I_1] W + (1 + I_1)\dot{V} = 0$$

$$-(1 + I_2)\dot{W} + \ddot{V} + [(\omega_z/P_0)^2 - I_2] V = 0$$

where  $(\dot{\phantom{x}}) = \frac{d}{d\tau}$ , and  $\tau = P_0 t$ ,  $I_1 = (I_{zz} - I_{xx})/I_{yy} > 0$ ,  $I_2 = (I_{yy} - I_{xx})/I_{zz} > 0$ ,  $I_{xz} \approx 0$ , and  $\omega_y$  is the natural frequency of the pitching oscillation in the absence of rolling (with the restoring moment,  $M$ ), and  $\omega_z$  is the natural frequency of the yawing oscillation in the absence of rolling (with the restoring moment,  $N$ ).

- (b) Find the characteristic equation for this system, and identify the ranges of the parameters  $I_1$ ,  $I_2$ ,  $\omega_y/P_0$ , and  $\omega_z/P_0$  where the spinning systems is stable or unstable.
7. Discuss the main points in the paper by McRuer. In particular, answer the following questions:
    - (a) What was the biggest change in aeronautics from 1956 onwards?
    - (b) Who was Byron, and what did he contribute?
    - (c) What was the primary reason for the gap in the tools used by the theoretician and the tinkerers? And what role did the YB49 serve in reducing this gap? (This gap is still very large!)
    - (d) Why was the flight of *Robert C. Lee* so remarkable?