Aircraft Mechanics II

(Course Code: AE 305/305M/717)

Department of Aerospace Engineering
Indian Institute of Technology Bombay

Instructor: Shashi Ranjan Kumar

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Practice Questions

TA: Jinay Patel

1. Consider the Northrop F-5 fighter airplane, which has a wing area of 15.8 m^2. The wing is generating 80,000 N of lift. For a flight velocity of 400 kmph at standard sea level,
   (a) Calculate the lift coefficient. *(**Ans.** : $C_L = 0.6626$)*
   (b) Given the wingspan (= 7.78 m), calculate the induced drag coefficient and the induced drag. Assume Oswald efficiency factor (e) = 0.8, *(**Ans.** : $C_{D,i} = 0.0466$)*
2. Consider a flying wing (such as the Northrop YB-49 of the early 1950s) with a wing area of 206 m^2, an aspect ratio of 10, a span effectiveness factor of 0.95, and an NACA 4412 airfoil. The weight of the airplane is 7.5×10^5 N. If the density altitude is 3 km and the flight velocity is 100 m/s, calculate the total drag on the aircraft. (Assume, at the density altitude of 3 km, $\rho_\infty = 0.909$ kg/m^3 and also assume that the profile drag coefficient for NACA 4412 is 0.006). *(**Ans.** : $D = 2.53 \times 10^4$ N)*
3. Consider a twin-jet attack aircraft. The airplane has the following characteristics: wing area (S) = 47 m^2, aspect ratio (AR) = 6.5, Oswald efficiency factor (e) = 0.87, weight (W) = 103,047 N, and zero-lift drag coefficient = 0.032. The airplane is equipped with two jet engines with 40,298 N of static thrust each at sea level.
   (a) Calculate the maximum velocity and the maximum rate of climb at sea level and at 5-km altitude. (Assume the engine thrust varies directly with free-stream density.) *(**Ans.** : $V_{max} = 295.38,\ 294$ m/s and $(R/C)_{max} = 85.7,\ 43.8$ m/s)*
   (b) The sea-level corner velocity is 400 kmph and the maximum lift coefficient with no flap deflection is 1.2. Calculate the minimum turn radius and maximum turn rate at sea level.
4. The Boeing 777 has a wing planform area of 428 m^2. Assuming a take-off weight of 22,50,800 N and a take-off velocity of 258 km/hr, calculate the lift coefficient at take-off for standard sea level conditions ($\rho_\infty = 1.2250$ kg/m^3). *(**Ans.** : $C_L = 1.6719$)*
5. Consider an airplane having a weight of 38,220 N, wing area of 27.3 m^2 and aspect ratio of 7.5. The Oswald efficiency factor for this airplane is 0.9 and the parasite drag coefficient is $C_{D0} = 0.03$. Calculate the thrust required to fly at a velocity of 350 km/h at :
   (a) standard sea level *(**Ans.** : $T_R = 5179$ N)*
   (b) an altitude of 4.5 km *(**Ans.** : $T_R = 3711$ N)*

6. For a given wing body combination, the aerodynamic center lies 0.03 chord length ahead of the center of gravity. The moment coefficient about the center of gravity is 0.0050, and the lift coefficient is 0.50. Calculate the moment coefficient about the aerodynamic center. *(**Ans.** : $C_{M_{ac}} = -0.01$)*

7. Consider a model of a wing-body shape mounted in a wind tunnel. The flow conditions in the test section are standard sea-level properties with a velocity of 100 m/s. The wing area and chord are 1.5 m^2 and 0.45 m, respectively. Using the wind tunnel force and moment-measuring balance, the moment about the center of gravity when the lift is zero is found to be -12.4 N $\cdot$ m. When the model is pitched to another angle of attack, the lift and moment about the center of gravity are measured to be 3675 N and 20.67 N $\cdot$ m, respectively. Calculate the value of the moment coefficient about the aerodynamic center and the location of the aerodynamic center. *(**Ans.** : -0.003; 0.02 or 2 % of the chord length ahead of the CG)*

8. Consider the wing-body model in Problem 7 above. Assume that a horizontal tail with no elevator is added to this model. The distance from the airplane's center of gravity to the tail's aerodynamic center is 1.0 m. The area of the tail is 0.4 m^2, and the tail-setting angle is 2.0°. The lift slope of the tail is 0.12 per degree. From experimental measurement, $\varepsilon_0 = 0$ and $\partial\varepsilon/\partial\alpha = 0.42$.

   (a) If the absolute angle of attack of the model is 5° and the lift at this angle of attack is 4134 N, calculate the moment about the center of gravity. *(**Ans.** : -364Nm)*

   (b) Calculate the neutral point and static margin if h = 0.26. *(**Ans.** : $h_n = 0.70$, static margin = 0.44)*

9. The elevator control force to trim a particular airplane at a speed of 154 m/s is zero. Using the following data estimate the force required to change the trim speed to 159 m/s. Assume that $C_{L_{\delta_e}}$ is sufficiently small that $C_{L_{\delta_e}} = 0$ can be used in the expression for control force.

   Geometric Data : Elevator gearing, $G = 1.18°/cm$, Elevator area aft of hinge line, $S_e = 3.72$ m^2, Mean elevator chord, $\bar{c}_e = 0.61$ m, $\bar{V}_H = 0.56$, CG location,$h = 0.38$, Wing loading, $w = 2,395$ Pa

   Aerodynamic Data : Elevator hinge moment coefficient $\dfrac{\partial C_{h_e}}{\partial \delta_e} = -0.005/\text{deg}$, $a_e = 0.025/\text{deg}$, Neutral point elevator free, $h'_n = 0.45$

   *(**Ans.** : $P = -18.95$ N forward push on control)*

10. Calculate the variation of the control force per g with altitude from the following data. Ignore propulsion effects.

    Geometric Data : Weight, $W = 222,500$ N, Wing area, $S = 87.10$ m^2, Wing mean aerodynamic chord, $\bar{c} = 3.90$ m, $\bar{l}_t = 9.71$ m, Tail area, $S_t = 21.4$ m^2, $S_e = 6.62$ m^2, Mean elevator chord, $\bar{c}_e = 0.674$ m, $G = 98.4°/\text{m}$

Aerodynamic Data : $a = 0.088/\text{deg}$, $a_e = 0.044/\text{deg}$, $a_t = 0.064/\text{deg}$, $b_o = 0$, $b_1 = -0.17/\text{rad}$, $b_2 = -0.48/\text{rad}$, $C_{h_{e_q}} = -0.846$, $C_{L_q} = 0$, $C_{m_q} = -22.9$, $(h - h_n) = -0.10$, $\frac{\partial \epsilon}{\partial \alpha} = 0.30$, $\delta_t = 0$

*(**Ans.** : $Q = 205.313 + 509.913\ \rho\ N$)*

11. Consider a frame F_1 and a frame F_2 denoted by $\{i_1, j_1, k_1\}$ and $\{i_2, j_2, k_2\}$ unit vectors, respectively. Suppose the frame, F_1, is rotated in the order $\{Z - Y' - X''\}$ where Z, Y' and X'' represent the axes after successive rotations by angles ψ, θ, ϕ, respectively. The resultant composite rotation matrix is given by the direction cosine matrix C_1^2 such as,

$$C_1^2 = \begin{bmatrix} 0.8999 & -0.4323 & 0.0578 \\ 0.4322 & 0.8665 & -0.2496 \\ 0.0578 & 0.24958 & 0.9666 \end{bmatrix}$$

Find the Euler angles for such a transformation. *(**Ans.** : $\theta = -3.3135°$, $\psi = -25.6590°$, $\phi = -14.7889°$)*

12. Consider a rotation about an axis defined by $(1, -1, 1)$ through an angle of $\frac{2\pi}{3}$. Obtain the quaternion to perform this rotation. Compute the effect of rotation on the basis vector $\boldsymbol{k} = (0, 0, 1)$.

*(**Ans.** : Rotation quaternion $[Q] = 0.5 + 0.5\hat{\boldsymbol{i}} - 0.5\hat{\boldsymbol{j}} + 0.5\hat{\boldsymbol{k}}$; Rotated basis vector : $-\hat{j}$)*

13. Consider a rotation of a vector, using quaternion, about an axis defined by the vector $(1, 0, 1)$ through an angle of $2\pi/3$.

    (a) Obtain the quaternion Q to perform this rotation. *(**Ans.** : $[Q] = 0.5 + 0.6124\hat{i} + 0.6124\hat{k}$)*

    (b) Compute the effect of rotation on the basis vector $\mathbf{j} = (0, 1, 0)$. *(**Ans.** :$-0.6124\ \hat{i} - 0.5\ \hat{j} + 0.6124\ \hat{k}$)*

    (c) Find the coordinates of above vector in the new frame if we rotate the coordinate frame itself about the same axis and angle while keeping the vector constant? *(**Ans.** : $0.6124\ \hat{i} - 0.5\ \hat{j} - 0.6124\ \hat{k}$)*

14. An airplane is flying at sea level at a minimum drag speed $V^* = 60$ m/s in cruise conditions. Given the zero lift drag coefficient $C_{D0} = 0.015$ and aspect ratio $AR = 7$ and Oswald efficient factor $e = 0.95$, estimate the phugoid mode frequency and damping. *(**Ans.** : $f = 0.03679$ Hz, $\zeta = 0.037$)*

15. For an aircraft, at some instant of time the system matrix is given as,

$$A = \begin{bmatrix} -0.0212 & 0.06864 & 0 & -32.71 \\ -0.2229 & -0.5839 & 262.472 & 0 \\ 0.0001 & -0.0018 & -0.5015 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Question 15 continues on the next page…

(a) Determine the modes of longitudinal dynamics with the help of eigenvalues of A.
*(**Ans.** : $\lambda_{1,2} = -0.5515 + -i\,0.6880$ - Shortperiod; $\lambda_{3,4} = -0.00178 + -i\,0.1339$ - Phugoid)*

(b) Calculate the damping coefficients, undamped natural frequencies and time periods of different modes using eigen values of A calculated in part (a).

*(**Ans.** : $\zeta_{sp} = 0.6255$; $\zeta_{ph} = 0.0133$; $\omega_{n_{sp}} = 0.882/sec$; $\omega_{n_{ph}} = 0.134/sec$; $T_{sp} = 9.13\ sec$; $T_{ph} = 46.9\ sec$.)*