

**Sample Question paper and hints for solution\***

**AE 1301 Flight dynamics**

**B.E./B.Tech Degree examination,**

**November / December 2006.**

**Anna University.**

Time : 3 hours

Maximum:100 marks

Answer ALL questions

Part A- (10 x 2 = 20 marks)

1. What causes induced drag?

**[ For answer see section 3.2.14 (Flight dynamics-I) ].**

2. Plot the variation of power available with flight speed for a propeller powered airplane and indicate the effect of altitude on the curve.

**[For answer see “Variation of THP with flight velocity” in section 4.2.11 along with sections 4.2.2, 4.2.3 and 4.2.6 (Flight dynamics- I) ].**

3. Define service and absolute ceiling.

**[ For answer see section 6.7 “Absolute ceiling and service ceiling”( Flight Dynamics-I) ]**

4. What are the conditions for maximum endurance of a jet powered airplane?

**[ For answer see section 7.4.3 “Discussion of Breguet formulae” (Flight Dynamics-I) ].**

5. Define neutral point.

**[ For answer see section 2.9 “Stick-fixed neutral point” (Flight dynamics-II) ].**

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\* The hints are given in bold letters.

6. What is the criterion for static longitudinal stability?

**[ For answer see “Criterion for longitudinal static stability” in section 2.1.4 (Flight dynamics-II) ].**

7. What is meant by dihedral effect?

**[ For answer see section 6.2 “Static stability of motion about x-axis – dihedral effect” (Flight dynamics-II) ].**

8. Differentiate between yaw and sideslip angle.

**[ For answer see section 5.2.1 “Sideslip and yaw” (Flight dynamics II) ].**

9. Graphically represents a system which is statistically stable but dynamically unstable.

**[ For answer see section 1.3.3 “Static stability and dynamic stability” and Fig.1.6 (Flight dynamics-II) ].**

10. What is spiral divergence?

**[ For answer see section 9.5 “Response indicated by roots of ... Dutch roll” (Flight dynamics-II) ].**

### **Part - B - (5 x 16 = 80 marks)**

11a) An aircraft weighing 2,50,000 N has a wing area of 80 m<sup>2</sup> and its drag equation is  $C_D = 0.016 + 0.04 C_L^2$ . Calculate (i) minimum thrust required ( $T_{min}$ ) (ii) minimum power required ( $P_{min}$ ) for straight and level flight and the corresponding true air speeds ( $V_{md}$  &  $V_{mp}$ ) at sea level and at an altitude where  $(\sigma)^{1/2} = 0.58$ . Assume sea level air density to be 1.226 kg/m<sup>3</sup>.

**[ This problem is similar to example 5.1 of Flight dynamics I. The answers are: At sea level :  $T_{min} = 12648.2$  N,  $V_{md} = 89.78$  m/s or 323.2 kmph,**

**$P_{min} = 996.5$  kW,  $V_{mp} = 68.22$  m/s or 245.6 kmph.**

**At altitude where  $(\sigma)^{1/2} = 0.58$ :  $T_{min} = 12648.2$  N**

**$V_{md} = 154.79$  m/s or 557.3 kmph,  $P_{min} = 1718.1$  kW,  $V_{mp} = 117.62$  m/s or 423.4 kmph ].**

Or

b) While flying straight and level at sea level at a speed of 100 m/s, the pilot causes his aircraft to enter a horizontal, correctly banked circle of 1100m radius while maintaining the same angle of incidence, the engine thrust being altered as necessary. Without altering either the incidence or the engine thrust, the pilot then brings the aircraft out of the turn and allows it to climb. Estimate the rate of climb if, at the angle of incidence, L/D ratio is 9.

**[Solution to this problem is presented at the end of this section].**

12 (a) Write short notes on:

(i) International standard atmosphere.

**[ For answer see sections 2.3 and 2.4 (Flight dynamics-I) ].**

(ii) Various types of drag of an airplane.

**[ Answer: the various types of drags are skin friction drag, pressure drag, profile drag, induced drag, wave drag and parasite drag. See sections 3.2.2, 3.2.14 , 3.3.2 and 3.6 ( Flight dynamics- I) ].**

Or

(b) Write short notes on:

i)V-n diagram.

**[ For answer see section 9.4.3 “V-n diagram” (Flight dynamics- I) ].**

(ii) Methods to minimize airplane drag.

**[ Answer : (a) Parasite drag is minimized by smooth surface finish, low thickness ratio airfoil for wing, high slenderness ratio for fuselage and smooth fillets at wing-fuselage junction.**

**(b) Wave drag is reduced by low thickness ratio airfoil and wing sweep.**

**(c) Induced drag is reduced by increasing aspect ratio.**

**See also section 5.8 (Flight dynamics- I) ].**

13 (a) Discuss briefly the following:

(i) Aerodynamic balancing of control surfaces.

**[ For answer see section 6.11.1 “Aerodynamic balancing” and sections 6.11.2 , 6.11.3 and 6.11.4 (Flight dynamics-II) ].**

(ii) Determination of neutral point and maneuver point ( $x_{mp}$ ) from flight test.

**[ For answers see section 2.13 “Determination of stick-fixed neutral point from flight tests” and section 4.10 “Remark on determination of  $x_{mp}$  and  $x'_{mp}$  from flight test” (Flight dynamics- II) ].**

Or

(b) Discuss in detail the power effects on static longitudinal stability for a jet powered airplane.

**[ For answer see section 2.6 “Contribution of power plant to  $C_{m_{cg}}$  and  $C_{m_{\alpha}}$  ” (Flight dynamics- II) ].**

14 (a) Discuss in detail the contribution of various components of the airplane to static directional stability.

**[ For answers see sections 5.3 to 5.6 for contributions of wing , fuselage , power and vertical tail to  $C_{n\beta}$  (Flight dynamics-II) ].**

Or

(b) Discuss briefly the following:

(i) Basic requirements of the rudder.

**[ For answer see section 5.8 “Directional control” (Flight dynamics-II) ].**

(ii) Aileron reversal

**[For answer see section 6.10.1 “Roll control” (Flight dynamics- II) ].**

(iii) Adverse yaw.

**[For answer see “Adverse yaw” under section 5.8.1 (Flight dynamics- II) ].**

15 (a) discuss the following:

(i) Phugoid motion.

**[For answer see section 8.9 “Modes of longitudinal motion– short period oscillation (SPO) and long period oscillation (LPO) / phugoid” (Flight dynamics- II) ].**

(ii) Stability derivatives in longitudinal dynamics.

**[ For answer see sections 7.8.2 and 7.10 to 7.16 “Estimation of stability derivatives” (Flight dynamics- II) ].**

Or

(b) Discuss in detail autorotation and spin and procedure for recovery from these situations.

[ For answer see section 10.2 “Stability after stall” (Flight dynamics- II) ].

**Solution to question 11(b):**

Question : While flying straight and level at sea level at a speed of 100 m/s, the pilot causes his aircraft to enter a horizontal , correctly banked circle of 1100m radius while maintaining the same angle of incidence, the engine thrust being altered as necessary. Without altering either the incidence or the engine thrust, the pilot then brings the aircraft out of the turn and allows it to climb. Estimate the rate of climb if, at the angle of incidence, L/D ratio is 9.

**Solution :**

This is a solved problem in Ref.1.7 chapter 13. However, the solution needs careful understanding of the question. The solution is presented in a manner consistent with material in chapters 5, 6 and 9 of Flight dynamics- I. The question states that, initially the airplane is flying at some velocity  $V_0$  in steady level flight at sea level at an angle of attack  $\alpha_0$  at which the lift drag ratio (L/D) is prescribed to be 9. Then the pilot causes the airplane to go into a steady level coordinated turn of radius ( $r = 1100\text{m}$ ). The angle of attack in turning flight is kept same as that in the level flight ( $\alpha_0$ ). Now, in a turn the lift has to be more than the weight of the airplane and to generate the extra lift, at the same angle of attack, the airplane must fly at higher flight velocity and would require more thrust. Let the flight velocity and thrust in turning flight be denoted by  $V_t$  and  $T_t$ . The prescribed radius of turn decides the angle of bank ( $\phi$ ), the flight speed required ( $V_t$ ) and the thrust ( $T_t$ ). With this increased level of thrust ( $T_t$ ) the pilot causes the airplane to climb keeping the angle of attack again same ( $\alpha_0$ ). The airplane would now climb at some angle of climb ( $\gamma$ ) and some resultant velocity ( $V_{Rc}$ ). The values of thrust ( $T_t$ ) and the angle of attack ( $\alpha_0$ ) will decide  $V_{Rc}$ . Knowing these the desired rate of climb can be calculated. The thrust ( $T_t$ ) in turn can be obtained as follows.

From Eq.(9.11) of Flight dynamics- I, in a turn :

$$r = \frac{V^2}{g \tan \phi}$$

Let,

$$L_0 = \text{Lift in level flight} = W = 1/2 \rho V_0^2 S C_{L0}$$

$$L_t = \text{Lift in turning flight} = W / \cos \phi = W \sec \phi$$

$C_{L0}$  = Lift coefficient in level flight corresponding to  $\alpha_0$ .

$$L_t = 1/2 \rho V_t^2 S C_{L0} = W \sec \phi = 1/2 \rho V_0^2 S C_{L0} \sec \phi$$

Hence for a turn at  $\alpha_0$  or  $C_{L0}$ , the velocity  $V_t$  is given by:

$$V_t^2 = V_0^2 \sec \phi \quad \text{or} \quad V_t = V_0 (\sec \phi)^{1/2}$$

$$\text{Now, } r = \frac{V_t^2}{g \tan \phi}, \text{ or } \tan \phi = \frac{V_0^2}{g r} \sec \phi \quad \text{or} \quad \sin \phi = \frac{V_0^2}{g r}$$

Noting  $V_0 = 100 \text{ m/s}$ ,  $r = 1100 \text{ m}$ .

$$\sin \phi = (100)^2 / (9.81 \times 1100) = 0.927 \quad \text{or} \quad \phi = 67.9^\circ.$$

Consequently,  $\sec \phi = 2.666$

$$V_t = (2.666)^{1/2} V_0$$

Since,  $\alpha_0$  is same,  $C_D$  is same in both level flight and turn. However,  $V_t$  is  $(2.666)^{1/2} V_0$ . Hence, the thrust required in turn ( $T_t$ ), in terms of that in level flight thrust ( $T_0$ ) is :

$$T_t = T_0 (V_t/V_0)^2 = 2.666 T_0.$$

As per the question, the thrust setting in the climb is same as that in the turning flight i.e.  $2.666 T_0$ . The angle of attack in climb is also  $\alpha_0$ .

In a steady climb at angle  $\gamma$ , the equations of motion are :

$$T_c = D_c + W \sin \gamma$$

$$L_c = W \cos \gamma$$

where  $T_c$  = thrust in climb =  $T_t = 2.666 T_0$ ,  $D_c$  = drag in climb and

$L_c$  = lift in climb

$$\text{Now, } L_c = W \cos \gamma = 1/2 \rho V_0^2 S C_{L0} \cos \gamma$$

$$\text{But } L_c \text{ is also equal to } 1/2 \rho V_{RC}^2 S C_{L0}$$

$$\text{Hence, } V_{RC} = V_0 (\cos \gamma)^{1/2}$$

Noting that, the angle of attack in climb is same as that in level flight gives:

$$L_c / D_c = L_0 / D_0 \text{ or } \left( \frac{D_c}{D_0} \right) = \frac{L_c}{L_0} = \cos \gamma$$

$$\begin{aligned} \text{Now, } T_c &= D_c + W \sin \gamma = D_c \left\{ 1 + \frac{W}{D_c} \sin \gamma \right\} = D_0 \cos \gamma \left( 1 + \frac{W}{D_0 \cos \gamma} \sin \gamma \right) \\ &= D_0 \cos \gamma \left( 1 + \frac{L_0}{D_0} \tan \gamma \right) \end{aligned}$$

But , in this case  $L_0 / D_0 = \text{lift drag ratio} = 9$ . Since,  $D_0 = T_0$ ,

$$\frac{T_c}{T_0} = \left( 1 + \frac{L_0}{D_0} \tan \gamma \right) \cos \gamma = \cos \gamma + \frac{L_0}{D_0} \sin \gamma$$

$$\text{Now, } \frac{T_c}{T_0} = \frac{T_t}{T_0} = 2.666$$

Consequently,

$$2.666 = \cos \gamma + 9 \sin \gamma$$

$$\text{Or } (2.666 - \cos \gamma)^2 = 81 (1 - \cos^2 \gamma)$$

$$\text{Or } \cos \gamma = 0.982 \text{ or } -0.92$$

Ignoring the second value,

$$\cos \gamma = 0.982. \text{ Hence, } \sin \gamma = 0.187$$

$$\text{Consequently, } V_{Rc} = V_0 \sqrt{\cos \gamma} = 100 \sqrt{0.982} = 99.1 \text{ m/s}$$

$$\text{Rate of climb} = R/C = V_{Rc} \sin \gamma = 99.1 \times 0.187 = 18.5 \text{ m/s} = 1110 \text{ m/min.}$$